1. Optimizing Learning

Instructor Notes: This Instructional Component is designed to inform AWOC participants about the learning techniques employed during the course. All of this and more has been shared with training facilitators at each office, however it is important that student participants also be aware of what we're trying to accomplish and how we hope to do it.

Student Notes:

Optimizing Learning

Advanced Warning Operations Course
IC Core 1
Warning Decision Training Branch

2. Learning Objectives

Instructor Notes: To that end, we'll spend some time on what the education field has identified as ways in which adults learn. We'll discuss how we go about evaluating that learning. Finally, some time will be spent on how learning in general is accomplished in simulations, and in particular, using a technique called Collaborative Development of Expertise.

Student Notes:

Learning Objectives

1. Become familiar with the way learning in AWOC is facilitated by:
   - Understanding adult learning strategies
   - Identifying the levels of evaluation
   - Identifying how the Collaborative Development of Expertise applies to simulations

3. Overview

Instructor Notes: This lesson will take about 30-40 minutes and will discuss adult learning strategies and importance of evaluation in accomplishing learning. We'll also spend some time looking at 2 types of simulations, Virtual Reality and Interval-based, and how we incorporate these simulations in AWOC. The simulations which are a part of the AWOC course can be run as designed by your local facilitator, or they can be modified to address local office needs.

Student Notes:

Overview

1. Adult learning strategies
   - Importance of evaluation
2. Effective simulations using Collaborative Development of Expertise (CDE)
   - Example 1: *Virtual Reality* simulation using the Observation and Assessment Record (OAR)
   - Example 2: *Interval–based* simulation using the Situation Awareness Decision Requirements Tool (SADRT)

4. 1. Adult Learning Strategies

Instructor Notes: Learning is about change. The whole reason for training, instruction, and education (all unique and distinct approaches to learning) is to enable people to learn. In AWOC, WDTB instructors, through local facilitators, will be trying to change people by transforming learners in ways that are desirable for both them and for the NWS. So, AWOC is concerned with training the human learner, not just transmitting information. To understand the human learner we start with discussing how we learn - through senses, filters, and memory (see Stolovitch and Keeps, 2003). Remember the human learner has multiple senses (sight, hearing, etc.) each with uniquely different processing capabilities. How we filter the stimuli that continually bombards us depends on our ability to process information. Research suggests that most people can hold only 5-9 items at a time in short-term memory. The size of the items depends on prior knowledge of the learner. For training and learning purposes, it is important to create meaningful chunks that condense several pieces into one. That facilitates perception, learning , and retention. For example, the four cardinal points of a compass are north (N) , east (E), west (W), and south (S) (four items to store in memory). But, if you remember the acronym , NEWS, you only have one item to store in memory. By creating a single chunk, you can reduce the short-term memory load. Long-term memory (for example, thinking about a favorite toy you played with as a child, or that radar topic back in 88D class) depends upon how distinct and unique that memory is. There is virtually limitless storage

space in the long-term memory warehouse. Retrieving the information is the harder part; that depends on how it has been organized to the learner's ability and experience levels.

Student Notes:

1. Adult Learning Strategies

- Short-term memory
  - Time and capacity (10-15 sec and gone if unused)
  - 5 to 9 "chunks" of information can be accommodated at a time
- Long-term memory
  - Capacity is limitless
  - Problem is retrieval

5. Types of Knowledge

Instructor Notes: The brain processes outside information for learning. That information is transformed into two types of knowledge, declarative and procedural. Declarative knowledge, which has evolved in humans to the highest level in any species, allows us to name, explain, and talk about things. Procedural knowledge, on the other hand, enables us to act and perform tasks. Unlike declarative knowledge, which is almost exclusively restricted to humans, procedural knowledge is available to all animals. Human learning suggests we process the two types quite differently. Think about trying to name the number of windows in your house. You probably mentally walk around the rooms in your house and count the number of windows before you just say the number. Thus, to learn someone effectively (from this training course, for example), we need to be able to modify the instruction to help us best learn the knowledge. By the way, experts in general have a very hard time converting declarative knowledge into procedural for novice learners. It is also hard for learners to process declarative instructions into procedural. That's why in this course, we have facilitators who are there to help learners perform the training objectives and make the whole process easier.

Student Notes:

Types of Knowledge

- Declarative
  - Knowledge that allows us to name, explain, and talk about matters
- Procedural
  - Knowledge that enables us to act and do things

6. Key Ingredients for Learning

Instructor Notes: Cognitive psychology research suggests that 3 major factors influence how much and how well we learn: ability, prior knowledge, and motivation. General ability to learn varies depending on our genes, but it can be built up, like muscles. Prior knowledge is important as we build upon what we already know and have used. Motivation is also important.

Student Notes:

Key Ingredients for Learning

- Ability
  - What we are born with
- Prior knowledge
  - Helps us to acquire additional knowledge faster
- Motivation
  - Affected by value, confidence, and mood

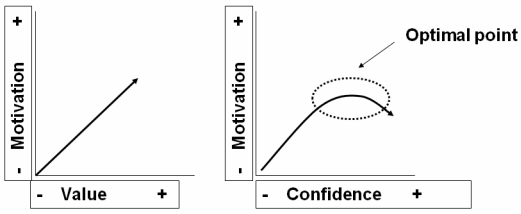
7. Motivation

Instructor Notes: Research (see Stolovitch and Keeps, 2003) and common sense show there is a strong correlation of value to motivation. The left-hand graph illustrates this. In the right-hand graph, the data shows that if the learner feels “this is so easy, I don’t even need to try,” motivation plummets. The optimal point of motivation is where the learner has enough confidence to feel he/she can succeed, but not so much that the incentive to learn declines. Most of us are motivated by challenges (the high point on the curve) and security (“if I work at it I know I can succeed”). As far as mood goes (graph not shown), motivation is directly related. A positive learning/work environment tends to

improve a person's mood and hence, his or her motivation. But, a frivolous or manic mood might have unpredictable effects on motivation. As trainers and learners, we can influence all the factors for learning (ability, prior knowledge, and motivation) in a positive way (good news!).

Student Notes:

Motivation



Overconfidence can lead to a decline in motivation

8. Key Adult Learning Principles

Instructor Notes: Lots of research in this area. These principles are from Malcolm Knowles , a leader in the field of adult education. We will discuss each of these.

Student Notes:

Key Adult Learning Principles

- Readiness
- Experience
- Autonomy
- Action

Malcolm Knowles (1913-1997)

9. Readiness

Instructor Notes: To preclude wasted effort in training , and to make sure learning is receivable, the research is clear that the training , instruction, or education must be for the learners. The focus must be on the learner's needs not on facilitator's or organization's needs.

Student Notes:

Readiness

- Training (learning) can be effective in "opening an adult's mind" to receive knowledge by:
  - Solves a problem or avoids one for them
  - Provides an opportunity or increased status
  - Includes professional or personal growth

10. Experience

Instructor Notes: The experience principle is that the more you factor the experience of the learners into the design and delivery of training, the more effective the learning outcome. A lot of this consideration applies to the primary trainer, or facilitator.

Student Notes:

Experience

- A critical part of learning
- Must be factored into design and delivery
- If considered, makes learning outcomes much more effective

11. Autonomy

Instructor Notes: Adults learn best if they take charge of their learning.They need all these attributes to succeed. Most examples of good training include many elements of learner autonomy.

Student Notes:

Autonomy

- Adult learners want to make their own decisions
- Adult learners want to be treated as independent, capable individuals
- Adult learners need opportunities to participate and contribute to training/learning activities

12. Action

Instructor Notes: In training (and learning), application is very important. There needs to be an action mindset with all training activities. If a great lecture or online module is developed but there is no way forecasters can go back and apply what is taught operationally, then any interest in that subject is quickly forgotten. That is why simulations are usually rated as the highest things on workshop evaluations, because the lessons learned in simulations can be easily practiced back on the job.

Student Notes:

Action

- If learners can't put the concepts taught in the classroom (or in distance) into action back on the job, their interest and learning decrease
  - Evaluations from Winter Weather and Severe Weather WDM Workshops have shown this to be the case

13. Training Approaches and Learning Activities

Instructor Notes: The bottom line on adult learning principles is that training can be a waste of time , for all involved, if it doesn't work. If the focus of the training is on the learners – their needs and characteristics, the chances of success skyrocket. There are lots of innovative training approaches and many, many learning activities that have been shown to be successful with adults. The four types , according to Clark (1998) are: receptive, directive, guided discovery, and exploratory. Which one works best with a trainee depends upon the individual characteristics of the learner. Receptive is most

used, but least effective. Directive learning provides trainer and organization with the greatest control. The side effects are decreased learner activities and more narrow, transfer of learning potential.

Student Notes:

Training Approaches and Learning Activities

1. Receptive
   - Water hose approach
   - To be used sparingly
2. Directive
   - Follow me approach
   - Well suited for learners with little experience with the learning content

14. Training Approaches and Learning Activities

Instructor Notes: These are from Table 5-1 of Stolovitch and Keeps (2003) book. To summarize, all types are different ways of approaching training. All have a place in training, but the receptive approach is the most frequently used method, and it should be the least often employed. It is telling, not training. Guided Discovery is excellent, balanced training approach for encouraging learner initiative under safe conditions. Learning results are usually stronger and more fluid (can be transferred to a broad range of situations).

Student Notes:

Training Approaches and Learning Activities

3. Guided Discovery
   - Shared control
   - Case-based
   - Similar to some types of WES simulations
   - Can require more time

15. Training Approaches and Learning Activities

Instructor Notes: Exploratory learning is powerful for sophisticated, capable learners. It allows for greater individualization and personalization of learning. However, it requires

sufficient resources, decreases trainer control, and is unpredictable in terms of specific outcomes.

Student Notes:

Training Approaches and Learning Activities

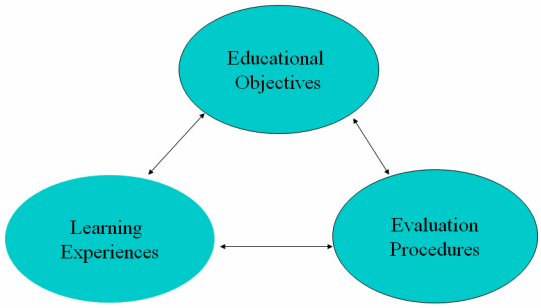
4. Exploratory
   - Self-initiated learning
   - Provides maximum freedom for learner
   - Requires highly self-motivated learner
   - Low control; learner can get lost

16. Evaluation

Instructor Notes: Graphical representation (from Hopkins, 1998) of the three interacting components of the educational process. Evaluation is needed in training to determine the extent of learning the knowledge or skills (level 2). Measurement of performance of newly acquired skills is a type of level 3 evaluation.

Student Notes:

Evaluation



Hopkins, (1998)

17. Evaluation – The 4 Levels

Instructor Notes: The 4 levels of evaluation were initially defined from Kirkpatrick (1959). In addition, some training practitioners refer to a 5th level , Return on Investment (ROI), developed in the 90s as business human resource divisions determined the need to measure monetary effects of training investments. In the AWOC, we will be evaluating at the first 3 levels. Evaluation of training at level 1 typically is about perceptions and has little else to offer trainers (Hodges, 2002). Level 2 evaluation is used to determine the

extent that the trainee was able to meet the learning objectives. The evaluation tool , usually an objective based test, measures the extent to which the trainees acquired the knowledge or skills specified in the training program (or course). The purpose for Level 3 evaluation is to determine the extent to which the training program (or course) has met its performance objectives (we have these for each instructional component in AWOC). Level 3 evaluation in AWOC will help WDTB and others determine the extent to which forecasters have been able to apply or transfer the knowledge gained or skills acquired , to the job. Note there are often factors external to the training course design and implementation, and learner actions, that enable or disable successful outcomes in a level 3 evaluation. Some of these factors include inadequate office time/support from management to compete training, and poor facilitator (coaching) support. The purpose for level 4 (often called impact evaluation) is to determine the degree to which the training program has met its business objectives, or goals. These expectations are often determined by stakeholders (those who have a vested interest in the program) and could include measuring output increases, cost savings, timesaving, and quality improvement (Phillips, 1997). The evaluator may conduct an ROI analysis as part of this evaluation.

Student Notes:

Evaluation – The 4 Levels

- Level 1 – Reaction *(student evaluations)*
- Level 2 – Learning *(testing)*
- Level 3 – Performance/Behavior *(performance in exercises, simulations, or on the job)*
- Level 4 – Results (organizational or business impacts)
- *Level 5 – Return on Investment (ROI)*

18. 2. Simulations in AWOC: Collaborative Development of Expertise (CDE)

Instructor Notes: AWOC simulations will facilitate learning via a technique called Collaborative Development of Expertise. As the name implies, the goal is to develop expertise (refer to IC Core 3, Lesson 1 for more on expertise), and do so by forming a trainer-trainee partnership. The important element of simulations run in this fashion is the exchange of ideas which takes place between trainer and trainee. The simulations can be very focused, maybe not something you are as familiar with. It involves having focused objectives when going through simulations and evaluating their outcome. This is different than just experiencing a data case. Much of the information presented here results from work done by Klein Associates to tailor CDE techniques for simulations in AWOC.

Student Notes:

2. Simulations in AWOC: Collaborative Development of Expertise (CDE)

- With CDE, transfer of expertise builds on:
  - Setting the right learning climate
  - Defining roles and responsibilities
  - Developing a trainer-trainee learning partnership
- Provides a means of Level III evaluation
- Goal is to advance expertise and critical thinking skills through discussion

19. CDE Development

Instructor Notes: CDE was something developed for the Navy to use during cross-oceanic travel. Simulations were fit into whatever time period was available for the trainee…sometimes a couple hours but sometimes just 20 minutes here and there. Other domains have since been able to apply this concept. The result takes an On-the-Job Training type process which is heavily focused around mentoring.

Student Notes:

CDE Development

- CDE was originally developed for the Navy
- Other domains studied to develop this concept:
  - Music tutors
  - NICU nurses
  - A photo finishing retail organization
  - Army National Guard units
  - Navy Air Defense Coordinators
- Result was an On-the-Job Training process for trainer/trainee *team*

20. CDE strategies given to the trainer

Instructor Notes: The strategies given to the trainer in doing simulations (and by the way, anyone with expertise in one area or another can be a trainer in that area) are listed here. These strategies all involve sharing knowledge and expertise. They try to get at reasoning, not just action.

Student Notes:

CDE strategies given to the trainer

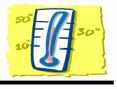
1. ASK OPEN-ENDED QUESTIONS
   - What should you say when you hear X?
   - Why did you…? What just happened?
   - What is the most important thing on your screen right now?
2. TELL
   - When the signature changes like this you should…
   - When X happens then you should be saying…
3. PASS ON YOUR EXPERIENCE
   - When I was in a similar situation, I did…
   - I've seen X before…
4. GIVE FEEDBACK
   - If this is an X type of plane here, what is this?
   - What should you do next?
5. OFFER PROMPTS
   - First I want you to concentrate on learning X.
   - When X is happening, I want you to be looking at Y.

21. Setting the right climate

Instructor Notes: In any learning environment it is very important for the learner to know everything is fair game. Think of the best learning you've been able to do in your life. It has more than likely been in a situation in which it was ok to ask questions and make mistakes. In those environments, you feel free to ask long standing questions about stuff you were "suppose to have learned' long ago but never really grasped, and as time went on, the opportunity to ask without feeling stupid never really presented itself.

Student Notes:

Setting the right climate

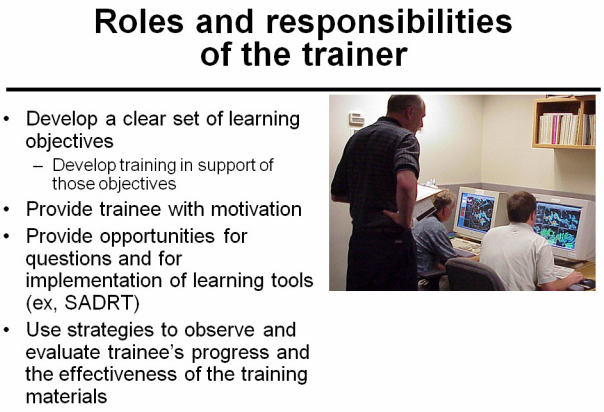


- Spend time on setting up an open and safe learning environment:
  - safe to admit lack of knowledge
  - safe to voice confusion
  - safe to talk to superior about those things without repercussions
  - there are no dumb questions

22. Roles and responsibilities of the trainer

Instructor Notes: Motivation, not cheerleading, is what we're after. Motivation in this context is meant to show the trainee why they should put forward the effort. Students should have an expectation of the learning effort needed. The effort should pay off with a better understanding of the task, which can lead to better decision making and performance results.

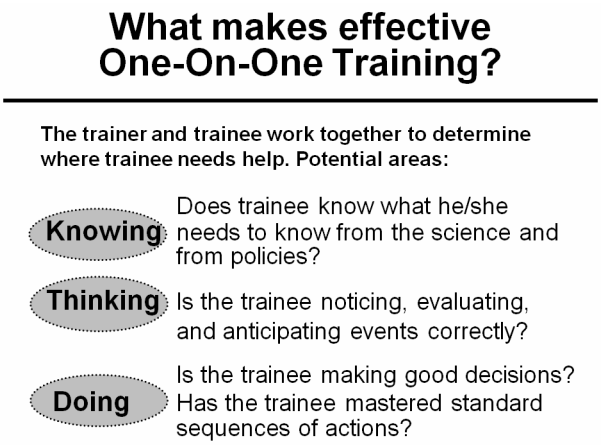
Student Notes:



23. What makes effective One-On-One Training?

Instructor Notes: Research has shown that some of the most effective learning is accomplished with one-on-one training where the trainer and trainee work together as a team. The trainer's job is to guide and interject. They should be checking to make sure that the trainee knows everything they need to before the training begins. They should also make some assessment as to what the trainee is "thinking". This is not easy to do but can be helped by discussion or by using evaluation tools. Finally the trainer should look at the actions and see if they make sense based on what the trainee has shared so far.

Student Notes:



24. CDE: A trainer-trainee partnershipTraining strategies for the trainer

Instructor Notes: These are some of the questions that a trainer could ask to solicit feedback in the "knowing" category. Of course, these would be tailored to the individuals particular domain and simulation.

Student Notes:

CDE: A trainer-trainee partnership
Training strategies for the *trainer*

1. Ask questions about facts
   What is that X?
   What did Y tell you?
2. Summarize what you know
   In accordance with our standard procedures you need to…
3. Identify reference material
   You seem to be having trouble with X, go study Y.

25. CDE: A trainer-trainee partnershipTraining strategies for the trainer

Instructor Notes: Questions which try to get into a trainee's thinking process usually involve getting at the reasoning behind decisions or actions.

Student Notes:

CDE: A trainer-trainee partnership
Training strategies for the *trainer*

1. Direct trainee's attention
   Did you notice X here?
   Make sure you watch X because…
2. Ask for trainee's SA
   At point X in the scenario, what did you think was going on?
   What's the big picture at the moment?
3. Ask trainee to explain why/why not
   Why did you do X then?
   Why did you decide not to say Y?

26. CDE: A trainer-trainee partnershipTraining strategies for the trainer

Instructor Notes: They may also go beyond current actions to get at a higher order of thinking such as contemplating possibilities, sort of thinking ahead.

Student Notes:

CDE: A trainer-trainee partnership
Training strategies for the *trainer*

4. Identify potential problems
   Given X, what could go wrong in the next two minutes?
   What is your biggest concern at the moment?
5. Ask hypothetical questions
   If X moves to point Y, what will you need to do?
6. Use examples, analogues, and stories
   When I was at X, a similar problem occurred and it turned out like….

27. CDE: A trainer-trainee partnershipTraining strategies for the trainer

Instructor Notes: This is the action step. Knowing background information is one thing. Thinking about what it means is the next. Actually doing an action as a result is the final step. You will find in later instructional components that the Know, Think, and Do steps can be related very well to the three levels of situation awareness (IC Core 2 Lesson 1: perception, comprehension and projection).

Student Notes:

CDE: A trainer-trainee partnership
Training strategies for the *trainer*

1. Guide trainee through task verbally as they do task
   So next, what do you need to do?
2. Explain the right way and the wrong way to do things
   When you want to get information from X, you need to say Y
   If you attend to channel X at Y time, then you are going to get Z information which isn't what you want
3. Break material into smaller pieces
   Right now just listen to channel X. What do you hear?
   Now listen to channel Y. What do you hear?

28. Roles and Responsibilities of the Trainee

Instructor Notes: This is what really sets this training apart from other training approaches is that the trainee is being assigned an active role in the process, with rules of engagement but also strategies (tools) to gain the required knowledge and skill.

Student Notes:

Roles and Responsibilities of the Trainee

- Active participant in training, not passive receiver of information but stakeholder in his/her own progress
- Receives rules of engagement and strategies to be active participant

29. CDE: A trainer-trainee partnershipLearning strategies for the trainee

Instructor Notes: Here's is what the trainee is expected to contribute in a simulation using CDE strategies. It mainly involves discussion and asking questions when you don't know what to do or why something should be done.

Student Notes:

CDE: A trainer-trainee partnership
Learning strategies for the trainee

1. **Clarify expectations**
   What are the goals for this training session?
   What should i focus on during the scenario?
2. **Discuss with trainer what could go wrong**
   What should I be worrying about?
3. **State when you need help**
   I understood part X, but not Y. Could you explain?
   I feel like i'm starting to lose track of the big picture.
4. **Ask again when you are confused by trainer's explanation**
   What's the key difference between X and Y?
5. **Ask for other examples**
   So, are there other times when X happens?

30. CDE: A trainer-trainee partnershipLearning strategies for the trainee

Instructor Notes: It is fair game to get into the thinking process of the trainer. Discuss possible actions. Discuss why or why not one course of action might work out better than another.

Student Notes:

CDE: A trainer-trainee partnership
Learning strategies for the trainee

6. **Request feedback**
   Was that the best way to express X?
   Should i have passed on that information?
7. **Ask trainer questions about his/her thinking?**
   When x was happening, what were you noticing the most?
   What would you have done in x situation?
8. **Discuss with trainer if you took x action, what are the likely consequences**
   If I do X, what is likely to happen? Why?
   When x happened, how should i have known that y
   Was going to happen?
9. **If unsure, clarify what you should do next**
   I'm not sure what to do next. What should I do?
10. **Ask for resources to learn off-line**
   I'm having some trouble with X, what do you recommend that I do or read?

31. What does this look likein action?

Instructor Notes: So using the simulation as a mechanism to assess learning, the trainer can see if knowledge can be applied correctly.

Student Notes:

What does this look like in action?

- Trainer needs to know that trainee is actually gaining the knowledge and skills
- Confirm that the training simulation is an effective tool in teaching the desired skills

32. Example 1: Virtual Reality Simulation

Instructor Notes: We have identified 2 types of simulations that we will provide with AWOC, each with a different way of operating and a different goal. The first is a "Virtual Reality" Simulation. In this type of simulation, the flow of the data mimics that in real time. The trainee goes through tasks as they would in real life. During this simulation, the trainer will note the process used by the trainee. They can do this on a form called an "Observation and Assessment Record" (OAR). They are making notes on here to use in the debrief. You can see a copy of this form on the next slide. After the exercise, the trainee fills out a self-evaluation OAR. Then both the trainer and trainee discuss their findings and their perspectives.

Student Notes:

Example 1: Virtual Reality Simulation

1. Prebrief of exercise
   - Establish goals of simulation
2. Training exercise
   - Trainer fills out OAR form during simulation
3. One-on-one debrief
   - Trainee fills out self-evaluation (OAR) form
   - Then trainee and trainer discuss perspectives
4. Team debrief (optional)

33. Observation and Assessment Record (OAR)Trainer Form –Filled out during event

Instructor Notes: This is the form the trainer would fill out as the event is worked. These categories and subcategories can be tailored to fit the office focus, the student need, or the simulation itself.

Student Notes:

Observation and Assessment Record (OAR)
Trainer Form **–Filled out during event**

Challenges	Examples of what trainee is doing: Good	Examples of what trainee is doing: Other
Science		
- Understanding/Applying Conceptual model		
- Discriminating severity		
Technology		
-Use of Applications (WARNGEN, FFMP, SCAN, procedures, etc.)		
-Use of data sets		
Human Factors		
- Getting/Maintaining SA	.	
- Managing workload		
- Threat communication to public		
- Managing sectors/boundaries		
Follow up actions:		

34. OAR Form - Trainer, example

Instructor Notes: An example of the kind of stuff a trainer might fill out during an event.

Student Notes:

OAR Form - Trainer, example

Trainee LinQ **Observation and Assessment Record (OAR)** Date 6/10/04 Trainer Joe

Trainer Form

Challenges	Examples of what trainee is doing: Good	Examples of what trainee is doing: Other
Science		
- Understanding/Applying Conceptual model	Caught on to the potential for supercells. Recognized cyclic nature as seen in radar data	Did not consider nature of training echoes and potential impact on FF
- Discriminating severity	Good job with tornado threat	Large A report – failed to correlate with TBSS
Technology		
-Use of Applications (WARNGEN, FFMP, SCAN, procedures, etc)	Good use of ALLTILTS feature, 4panels	Warning sent with bad motions. Difficult to keep warnings straight with orientation of etms
-Use of data sets	Noted boundary interactions in mesonet data near tornadic storm	Not accessing other radars very often. Not looking at precip data
Human Factors		
- Getting/Maintaining SA	Initially very well with regard to tornado threat.	Needed additional radar data on storms in south part of CWA (hvl 1). No monitoring of FF threat (hvl 2).
- Managing workload	Did well early on.	Needed to ask for help with unexpected reports came in.
- Threat communication to public	Communicated tornado threat well. Kept steady stream of SVS's	Disregarded large hail report – didn't see radar support.
- Managing sectors/topology		A difficult situation…needed better coordination for

35. OAR FormTrainee Form - Filled out after event

Instructor Notes: This is the form the trainee fills out at the end of the simulation.

Student Notes:

OAR Form

***Trainee Form* - Filled out after event**

Challenges	How are I doing? Great	OK	Shaky	Clueless	Specific Examples from Scenario
Science					
- Understanding/Applying Conceptual model					
- Discriminating severity					
Technology					
-Use of Applications (WARNGEN, FFMP, SCAN, procedures, etc)					
-Use of data sets					
Human Factors					
- Getting/Maintaining SA					
- Managing workload					
- Threat communication to public					
- Managing sectors/topology					
What would you do different next time? (Filled out with trainer after debrief)					
Follow up actions you'd like to take:					

36. OAR – Trainee Form, example

Instructor Notes: A sample of the type of things a trainee might fill out. You get to assess yourself in the same areas as the trainer did. Sometimes we can be our own worst critic and we've actually done better than we think. On the other hand, sometimes we can think we're doing well but really we are totally unaware of just how bad things have gotten. Comparing this form with the similar one from the trainer can be very revealing. Generally, both parties learn something during the ensuing discussion. This effort can point to areas which need attention. This might be help with the understanding of a conceptual model. Or it might be some work with the software (using WARNGEN, for ex). It could also show very effective strategies used by the learner which had not been considered by the trainer. It really is a two-way street.

Student Notes:

OAR – Trainee Form, example

Trainee Liz O **Scenario Debrief Worksheet** Date 6/10/04 Trainer Bill

Trainee Form

Challenges	How did I do? Great	OK	Shaky	Clueless	Specific Examples from Scenario
Science					
- Understanding/Applying Conceptual model	X				Expected a long duration cyclic supercell and kept warnings on storm
- Discriminating severity			X		Hail size in warnings over southern sections was different than reports
Technology					
-Use of Applications (WARNGEN, FFMP, SCAN, procedures, etc)		X			Handled WARNGEN but sent out some bad motions. Alltilts used extensively and showed good rotation in tornadic storms.
-Use of data sets			X		Didn't look at other radars very often. Didn't check precip til report came in
Human Factors					
- Getting/Maintaining SA		X			SA would have been improved by alternate radar view (shd have done earlier). Report of ff a total surprise. Good job in tornado threat.
- Managing workload			X		Wasn't able to investigate storms in south part of CWA very well (too busy)
- Threat communication to public		X			Tornado threat communicated but hail size not correlated (see above). Missed ff.
- Managing sectors/topology				X	Total mess trying to coordinate boxes with adjacent sector

What would you do different next time? (Filled out with trainer after debrief). Sectorize differently (or more quickly change sectors if not working). Look more often at alternate radars (would have shown TBSS and might have included higher hail size in warning). Always include FF monitoring in routine, even if not expected (farm out if too busy)

Follow up actions you'd like to take: Work on developing some procedures to help with other radar views. Develop ff monitoring

37. Example 2: Interval-based Simulation

Instructor Notes: The second type of simulation we've provided in AWOC is an "Interval-Based" simulation. This is a very different type of simulation and unlike the Virtual Reality simulation, we are not trying to totally duplicate the real world. The goals can be extremely focused on very specific learning objectives. That may feel counter-intuitive for some but the goal is to take something which was taught, and see if it can be practiced. In this type, the simulation will run as normal for a period of time, and then be "paused". The trainee will answer a series of questions. The questions are on the form (slide 40) and attempt to assess the trainee's Situation Awareness, hence the "Situation Awareness Decision Requirements Table" (SADRT) form.

Student Notes:

Example 2: Interval-based Simulation

1. Prebrief of exercise
   - Establish goals of simulation
2. Training exercise includes stop times where:
   - Trainee fills out SADRT form
   - Trainer has "ideal" solution
3. One-on-one debrief
   - Trainee and trainer perspectives
   - Discuss differences and similarities in forms
4. Simulation continued until next stop time

38. Interval-based simulation using SADRT

Instructor Notes: This is some background on the use of the SADRT form. This form is modified to fit the domain in which the simulation is occurring. The goal is to get "inside" the trainee's head and look at their process and reasoning. FYI - This tool was originally developed for use by those in nuclear power plants during simulations of not-so-routine

events. It was then modified and is used in real-time critical events by the shift leader who gets input from the entire operational team. This gives him/her a quick status of events based on everyone's perceptions…a sort of 1 minute SA time-out to make sure nothing is being missed!

Student Notes:

Interval-based simulation using SADRT

Situation Awareness Decision Requirements Tool:
A tool to assess SA during a simulation exercise

- Based on over 12 years of research in assessing SA and the decision process with:
  - U.S. Marine Corps
  - Nuclear Power Plants
  - Hospital Emergency Rooms and ICUs
  - AWACS Weapons Directors
- Used to:
  - Chart and document progress
  - Assess the impact of training materials

39. How SADRT is used in simulations

Instructor Notes: In using the SADRT during simulations, the simulation will be paused at points unknown to the trainee. The trainee will take 1-2 minutes to quickly fill this out, mainly jotting things to prompt their memory, while keeping in mind the objectives of the simulation. The trainer on the other hand, has an "idealized" answer key…one which would reflect "perfect" SA. It's not that anyone expects you to always have perfect SA (this is very difficult for lots of reasons). It's just to see and compare. Trainer and trainee then discuss their respective "solutions" and take a few minutes to see why their answers are different. Some strategies or areas on which to focus might be discussed. The process here is to develop critical thinking skills through the discussion. After 5-10 minutes, the simulation is resumed. The trainee almost always feels more in control after going through the process at the first stop time. As many stops as are needed can be included in this simulation. Generally, the stop times have been associated with key decision points in the simulation. At the end, the trainer and trainee can again look at areas which are being done well, and areas which can benefit from additional resources or training.

Student Notes:

How SADRT is used in simulations

1. Discuss objectives of the simulation
   - Very pointed and focused (not the scope of a live event)
   - Looking at how the trainee maintains SA re objectives
   - Goal is to advance critical thinking skills via discussions
2. Begin running simulation
3. Simulation stopped at various points.
   - Trainee fills out SADRT (trainer has a "completed" version based on their knowledge of the events and objectives)
4. Trainer and trainer review SADRT
   - What are similarities?
   - What are differences? Why?
   - Were objectives addressed? Why or why not?
   - Things to consider when simulation resumes
5. Resume simulation

40. SADRTFilled out by trainee at stop times

Instructor Notes: The questions are fairly generic, as opposed to filling out a "check list" of items. SA is what is in your head at any moment in time, what your awareness level is. Fill this out keeping in mind the specific objectives of this simulation.

Student Notes:

SADRT
Filled out by trainee at stop times

Stop Time:

Assessments so far?
What watches/warnings if any do you have out?
What are you worried about now?
What data is most important right now?
What data or information do you need that you're not getting? Are there any system status issues?
What is this situation going to look like in (...)hours/minutes?
What will be your next action?

41. SADRT…an example

Instructor Notes: Here's the kind of stuff you might have in a filled out SADRT at a stop time. Of course, you wouldn't be stopping to make a word document and would likely just jot down notes and abbreviations.

Student Notes:

SADRT…an example

Type of information we are looking for…a sample "answer sheet" for stop 1,2

Stop Time: 18:30z

Events/Assessments so far? Squall line developing with isolated storms (showing supercell characteristics) out ahead. Very saturated ground and potential training echoes.
What watches/warnings if any do you have out? Flash flood watch; Svr tstm.
What are you worried about now? Training echoes; Storms moving into area with few spotters. Concerned about high winds in developing bows. Area of rf masking parts of the line. Line configuration makes it hard to sectorize (potential warnings overlapping or being lost). Workload is becoming an issue – difficult to do good base data analysis on all storms.
What data is most important right now? Radar ref, hi-res v and srm. Mesonet data may show storms moving into more conducive environment.
What data or information do you need that you=re not getting? Are there any system status issues? Spotter reports. Low-level velocity data at far end of squall line. Not getting any radar data from KXXX.
What is this situation going to look like in 1 hour? Could have additional isolated storms develop. May have large scale damaging wind event underway. May also have ff threat near metro area.
What will be your next action? Notify law enforcement/Ham operators of need for reports in remote areas. Experiment with PRF changes. Get someone to do updated mesoanalysis. Probably need to redistribute workload and see who is available to come in and help. Order pizza.

42. Review

Instructor Notes:

Student Notes:

Review

- There are important considerations for adult learning
- Several levels of evaluation are important in order to detect real learning
- It is critical to establish a safe learning environment for the trainee
- There must be clear learning objectives upon which the training medium is based
- A learning partnership is critical to the CDE method of developing expertise via simulations

43. Contact Information

Instructor Notes:

Student Notes:

Contact Information

- For questions on this IC
  - Contact your SOO
  - awoccore_list@wdtb.noaa.gov

44. References

Instructor Notes:

Student Notes:

References

Clarke, R.C., 1998: Building Expertise: cognitive methods for training and performance improvement. International Society for Performance Improvement, Washington D.C.

Hahn, Bianka B. , D.W. Klinger, Klein Associates. Advanced Warning Operations: Collaborative Development of Expertise Workshop (Work funded by OCWWS, Warning Decision Training Branch) 2004.

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45. References

Instructor Notes:

Student Notes:

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1. Situation Awareness and Decision Making in a Warning Environment

Instructor Notes: Welcome to IC Core 2, Situation Awareness and Decision Making in a Warning Environment!

Student Notes:

Situation Awareness and Decision Making in a Warning Environment

Advanced Warning Operations Course
IC Core 2
Warning Decision Training Branch

2. Overview

Instructor Notes: Situation Awareness and Decision Making in a Warning Environment is divided into 5 lessons, each of which is a separate on-line module. There is one exam for all 5 lessons of IC Core 2.

Student Notes:

Overview

- Lesson 1: The Warning Process and the Role of Intuition
- Lesson 2: Individual Situation Awareness (SA)
- Lesson 3: Team Situation Awareness (SA)
- Lesson 4: SA Demons: The Enemies of Situation Awareness
- Lesson 5: Maintaining SA by Managing the Unexpected

3. Learning Objectives

Instructor Notes: Here are the Learning Objectives for IC Core 2. The objectives that apply to each lesson will be repeated at the beginning of each lesson. The Learning Objectives will be tested when you take the on-line exam for IC Core 2.

Student Notes:

Learning Objectives

1. Identify conditions favoring analytical and intuitive decision making styles.
2. Identify definitions, examples and failures of the three levels of Situation Awareness (SA).
3. Identify factors that can impact getting and maintaining individual SA.
4. Identify factors that can impact getting and maintaining team SA.
5. Identify the SA demons and how they can inhibit SA.

4. Learning Objectives

Instructor Notes: Here are the remaining Learning Objectives for IC Core 2. The objectives that apply to each lesson will be repeated at the beginning of each lesson and will be tested using a single on-line exam for IC Core 2.

Student Notes:

Learning Objectives

6. Identify the two practices that can help facilitate a prompt response to unexpected events.
7. Identify the attributes of the operating environment of a Highly Reliable Organization.
8. Identify the 5 characteristics of a Highly Reliable Organization.
9. State the impact of overconfidence on responding to the unexpected.

5. Performance Objectives

Instructor Notes: The Performance Objectives for IC Core 2 apply during this course as well as after completion. Though they are not tested formally, questions related to these Performance Objectives will be posed during the course simulations.

Student Notes:

Performance Objectives

1. Using specific data examples, identify the three levels of SA and how they are contributing to your warning decisions, while working:
   a) WES simulations, and
   b) Warning events.
2. As part of post-event analysis, determine the role that SA (good or bad) at the three levels played in the warning decisions that were made.

6. Situation Awareness and Decision Making in a Warning Environment

Instructor Notes: Lesson 1 will focus on the elements of the Warning Process, which includes both meteorological and non-meteorological factors. There is also a section on analytical and intuitive decision making, and the role of intuition in the warning "domain".

Student Notes:

Situation Awareness and Decision Making in a Warning Environment

Advanced Warning Operations Course
IC Core 2
Lesson 1: The Warning Process and the Role of Intuition
Warning Decision Training Branch

7. Lesson 1: The Warning Process and the Role of Intuition

Instructor Notes: Lesson 1: The Warning Process The Learning Objective associated with this lesson addresses analytical and intuitive decision making.

Student Notes:

Lesson 1: The Warning Process and the Role of Intuition

Learning Objective:

- Identify conditions favoring analytical and intuitive decision making styles.

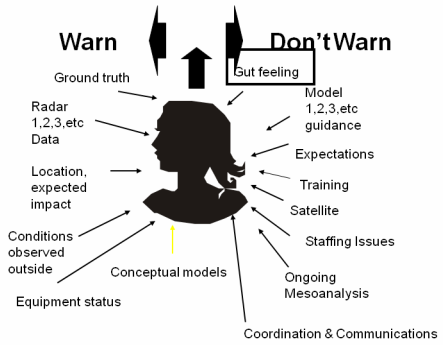
"We dance round in a ring and suppose, but the secret sits in the middle and knows."
Robert Frost

8. Information Processing in a Warning Environment

Instructor Notes: There are so many different types of information that must be processed to make a warning decision. Using each of these data sources effectively is difficult, since the strengths and limitations of each data set must be well understood. Also, the update times of the various data sources vary, which requires mental tracking. This lesson will take a particular look at the contribution of "gut feeling", which is your intuition.

Student Notes:

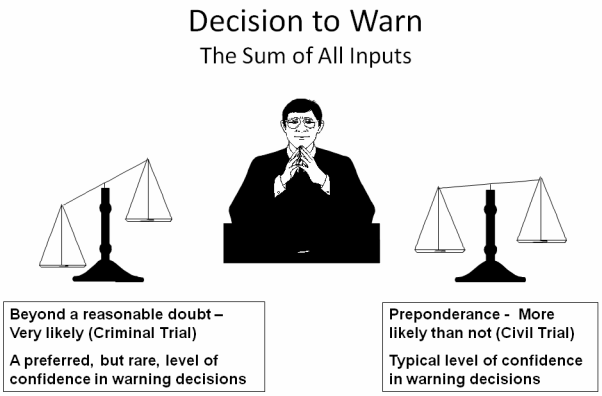
Information Processing in a Warning Environment



9. Decision to Warn, The Sum of All Inputs

Instructor Notes: "Beyond a reasonable doubt" is a level of certainty that is very rare in warning decisions. We would like to operate at that level, but most often, a warning is issued because the "preponderance of the evidence" supports it. If you find yourself delaying making a warning decision by waiting for a higher level of certainty, think about this concept. Perhaps you are waiting for a level of certainty that is not going to exist.

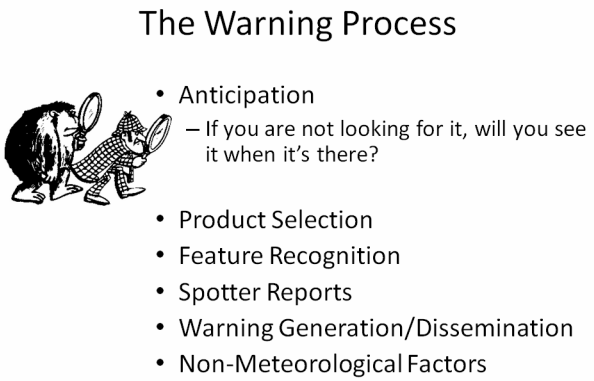
Student Notes:



10. The Warning Process

Instructor Notes: Among these elements of the warning process, we will first focus on Anticipation. Anticipation is based on your threat assessment, which is hopefully an ongoing process. Threat assessment and monitoring the mesoscale environment creates your expectations. Those expectations affect the data cues that you will be looking for. An example would be an expectation of large hail leading you to look for hail spikes in the radar base data.

Student Notes:

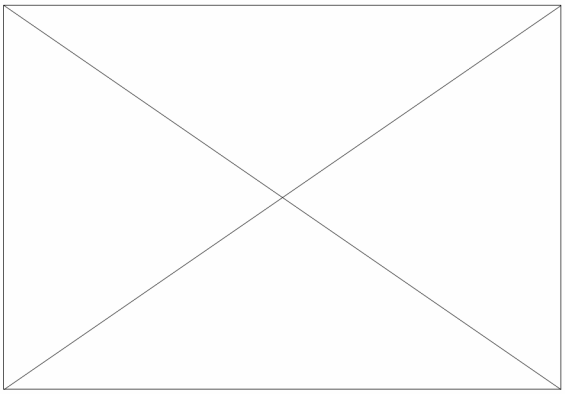


11. Before You See Radar Data…

Instructor Notes: This animation depicts the "tipping of the scales" of a warning decision before looking at radar data. The climatology, synoptic, and mesoscale factors all affect the warning decision. In this case, the scales are moderately tipped in favor of a warning. You can replay the movie if you wish.

Student Notes:

Before You See Radar Data…

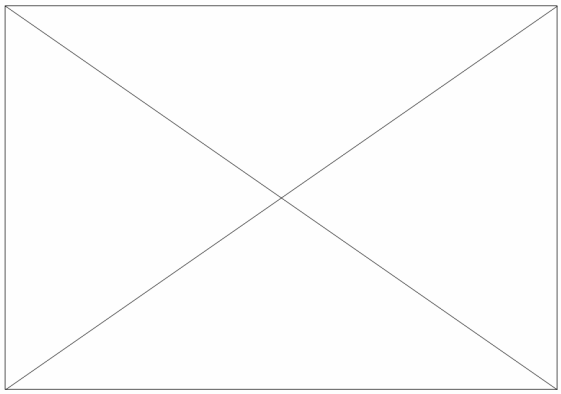


12. Before You See Radar Data…

Instructor Notes: This animation depicts a different “tipping of the scales” of a warning decision, where the scales are strongly tipped in favor of a warning. Consider looking at the same radar data given the conditions of the previous slide vs. the conditions of this slide. How might your expectations impact your decision to warn? Or impact how intensely you may interrogate radar data looking for signatures?

Student Notes:

Before You See Radar Data…



13. The Warning Process

Instructor Notes: There are many challenges here: choosing products appropriate for the anticipated threat, recognizing a significant feature when you see it, knowing which spotter reports to rely on, and conveying the threat through language in products issued. Then there are numerous factors that have nothing to do with meteorology…

Student Notes:

The Warning Process

- Anticipation
- Product Selection
- Feature Recognition
  - Aha! The intuitive response
- Spotter Reports
- Warning Generation/Dissemination
- Non-Meteorological Factors

14. Non-Meteorological Factors

Instructor Notes: Your work environment is known as a "domain" by those who study decision making. The WFO domain is a particularly complex one, especially during a warning event. There are things that can be done to mitigate some of the potential chaos, which will be presented later in Core 2 and in other parts of the AWOC Core track.

Student Notes:

Non-Meteorological Factors

- The complex "domain" of the forecast office
  - Staffing experience, availability, workload, stress, fatigue…
  - Volume of calls
    - Incoming and outgoing
  - Equipment problems
  - Concerns/pressure about office performance
  - Communication and coordination

15. Cognitive Load, A Limited Resource

Instructor Notes: The total mental activity for working a task is called cognitive load. This involves cognitive work done at the conscious and sub-conscious level. These concepts will be explored later in IC Core 2. The key thing to remember is that no matter how skilled a human may be, cognitive activities are in total a limited resource. Intuition is an important part of cognitive load and will be discussed in the next few slides. One of the ways to learn to use intuition effectively is to understand that it may be experienced as either a conscious thought or an emotion (gut feeling).

Student Notes:

Cognitive Load
A Limited Resource

- Warning forecaster's processing involves…
  - Attention and working memory (short term)
    - Conscious activities
  - Long term memory and intuition
    - May be conscious or sub-conscious
- *Your intuitive response (gut feeling) may be a conscious memory or a feeling*

I've seen this before!

Something's not right here

16. Decision Making Involves both Intuition and Analysis

Instructor Notes: Our decisions are always processed with some combination of analysis and intuition….this is not an either/or relationship. Some environments are more favorable to the different decision making approaches. For examples, buying a car is (hopefully) going to be largely an analytical decision, while deciding to get out of a burning building is (hopefully) largely an intuitive decision.

Student Notes:

Decision Making Involves both Intuition and Analysis

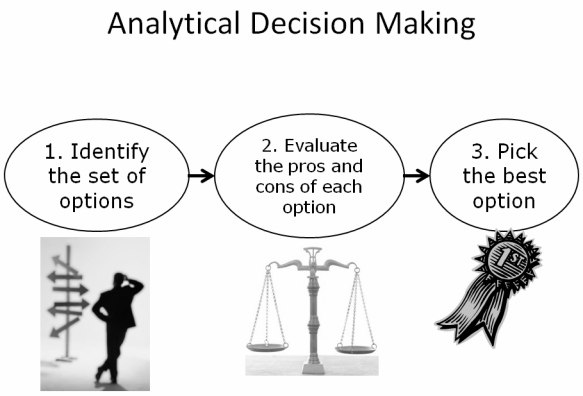
- Some conditions more favorable for analytical vs. intuitive decision making
- Use intuition to buy a car?
  - Hope not!

- Do a thorough analysis of options before leaving a burning building?
  - Hope not!

17. Analytical Decision Making

Instructor Notes: The process of analytical decision making has the following steps. We begin by identifying the available options. Then the pros and cons of each option are evaluated. Based on the those pros and cons, the best option is determined.

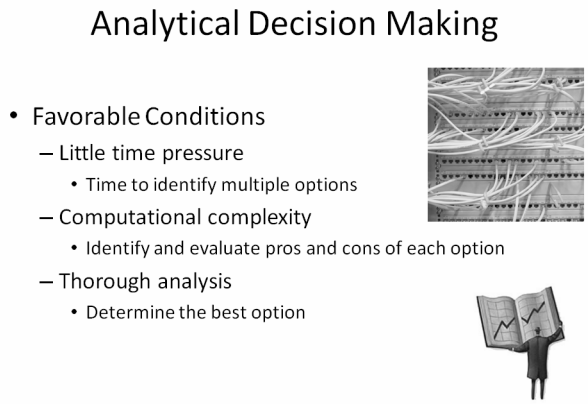
Student Notes:



18. Analytical Decision Making

Instructor Notes: Given the analytical process, the most favorable conditions start with environments that do not have significant time pressure. There is time to identify multiple options. Identifying and evaluating the pros and cons of each option is the next step, which also requires time and computations, sometimes rather complex ones. A thorough analysis process results in finding the best option.

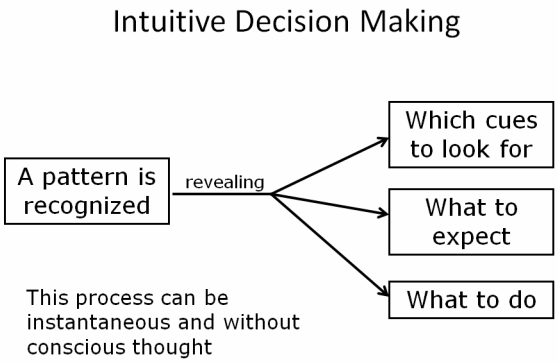
Student Notes:



19. Intuitive Decision Making

Instructor Notes: Intuitive decision is usually triggered by pattern recognition of some sort. The data cue that triggers your intuition reveals the next steps to take, such as which additional data to look for, formulating your expectations and how to respond. This process is usually a conscious one. As you gain more expertise, it can also be nearly instantaneous and the next steps occur without conscious thought (at least initially!).

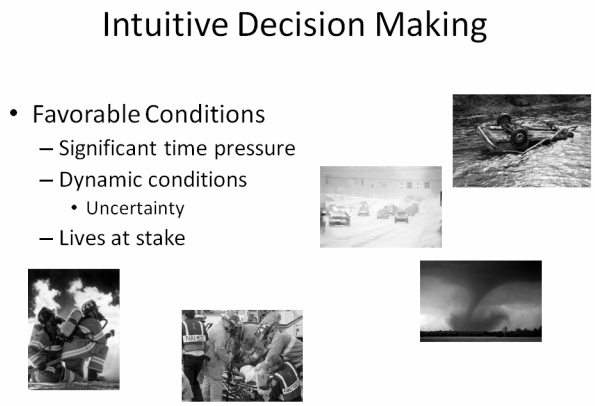
Student Notes:



20. Intuitive Decision Making

Instructor Notes: The favorable conditions for intuitive decision making are much different. There is significant time pressure in these environments. Things are happening quickly and there is a lot of uncertainty…it is a dynamic situation. Frequently, lives are at stake.

Student Notes:



21. The Role of Intuition

Instructor Notes: Gary Klein is a psychologist who has studied decision makers in their environments. He has written about the importance of the use of intuition among experts in dynamic environments. Intuition comes from experience, but that is not the same as expertise. Intuition is your experience speaking to you, but using it effectively involves expertise. An intuitive response may be a conscious thought or just a feeling. Experts have learned to respect that response and use it as a prompt to take the next step.

Student Notes:

The Role of Intuition

- "Your intuitions are not accidental. They reflect your experience." Gary Klein

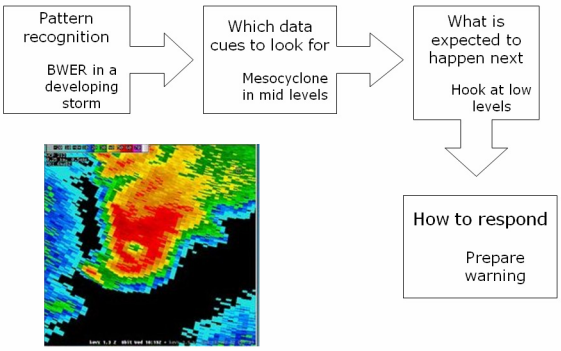
- Experience ≠ expertise
  - Intuition is the voice of your experience
  - Using it effectively is expertise
- Your intuition responds (a thought or a feeling) to data cues, prompting your next step

22. Experts in Dynamic Domains Often Use Their Intuition

Instructor Notes: The expert warning forecaster has many things in common with experts in other dynamic domains that use both their intuition and their analysis to make decisions. Recognizing a significant pattern can occur consciously (aha! I know what this is and I know what to do) or sub-consciously (a feeling that this is significant). There may be additional data cues to look for and decisions to make. The point here is that the intuitive response can be the beginning of a process that leads to a warning decision.

Student Notes:

Experts in Dynamic Domains Often Use Their Intuition



23. The Role of Intuition

Instructor Notes: The "aha" intuitive response happens when the data do fit a known pattern…"it makes sense". The remaining steps follow quickly. If additional information is needed, you know what you are looking for. You also know what you are going to do. The other possibility is that the data do not fit a pattern…"it doesn't make sense". This

often involves stepping back and doing some re-evaluating. In each case, the expert knows what to do following the intuitive response.

Student Notes:

The Role of Intuition

Two different types of intuitive responses:

The data cues *fit* a pattern
"It makes sense":
- I've seen this before
- I know what it means
- I know what to look for
- I know what to do

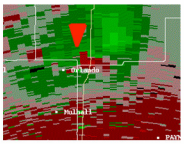
The data cues *do not fit* a pattern
"It doesn't make sense":
- There is something missing here
- Something doesn't seem right
- Step back and re-evaluate

24. "It Just Didn't Look Right"

Instructor Notes: In this event, the forecaster was concerned about the algorithm detections, but the signatures in the radar base data conflicted with the TDA results and the environment was not favorable for tornadoes. The sense that something wasn't right led him to seek additional data cues and maintain the warning status as Severe Thunderstorm.

Student Notes:

"It Just Didn't Look Right"

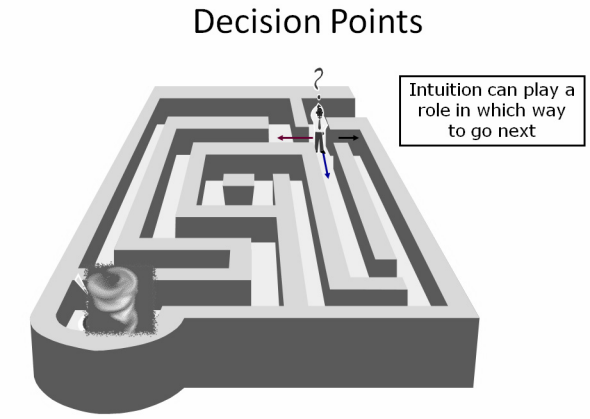


- TDA detections behind gust front
  - No vertical continuity of rotation in SRM
- Severe Thunderstorm warning; environment not favorable for tornadoes
- Reports of wind damage; cause ambiguous
- Readied Tornado Warning pending better ground truth or more convincing radar signatures
- No tornado; wind damage due to gust front

25. Decision Points

Instructor Notes: The decision making for a warning event can be represented by a maze. The intuitive response often leads to the next step…with additional data cues to look for or perhaps going directly to issuing a warning. When examining your warning decision making, consider the role of intuition.

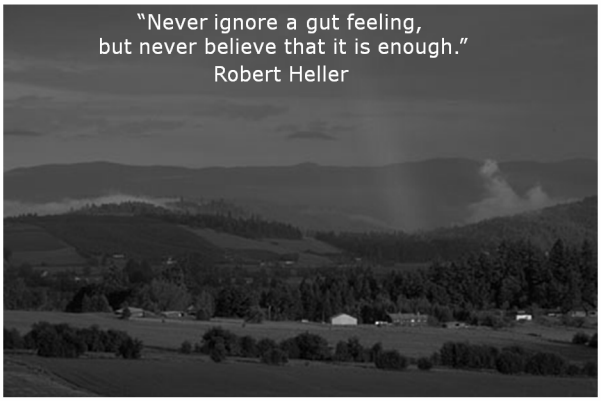
Student Notes:



26. Final Quote

Instructor Notes: Intuition can be a powerful tool, but it is not the only tool. It is just a part of the process of analyzing the radar base data, assessing the near storm environment and assimilating reports.

Student Notes:



27. Situation Awareness and Decision Making in a Warning Environment

Instructor Notes: This concludes Lesson 1: The Warning Process and the Role of Intuition. There are four remaining lessons for IC Core 2.

Student Notes:

Situation Awareness and Decision Making in a Warning Environment

Advanced Warning Operations Course
IC Core 2
Lesson 1: The Warning Process and the Role of Intuition
Warning Decision Training Branch

28. Questions?

Instructor Notes: If you have questions about the material from IC Core 2, first check with your AWOC facilitator (most likely your SOO). If your AWOC facilitator cannot answer your question, please send an email to awoccore_list@wdtb.noaa.gov.

Student Notes:

Questions?

1. Check with your AWOC facilitator (most often the SOO)
2. Send your question to awoccore_list@wdtb.noaa.gov

1. Situation Awareness and Decision Making in a Warning Environment

Instructor Notes: Lesson 2 will focus on the Situation Awareness (SA) of an individual. This lesson will take a look at the three different levels of SA, as well as examples of failures at each level.

Student Notes:

Situation Awareness and Decision Making in a Warning Environment

Advanced Warning Operations Course
IC Core 2
Lesson 2: Individual SA
Warning Decision Training Branch

2. Lesson 2: Individual SA

Instructor Notes: The Learning Objectives for Lesson 2 apply to the definitions, examples, and failures of each of the three levels of SA. The objectives also address factors that can impact getting and maintaining SA. The Learning Objectives will be tested when you take the on-line exam for IC Core 2.

Student Notes:

Lesson 2: Individual SA

Learning Objectives
- Identify definitions, examples and failures of the three levels of SA.
- Identify factors that can impact getting and maintaining individual SA.

"To see, to hear, means nothing. To recognize (or not to recognize) means everything."
Andre Breton

3. Lesson 2: Individual SA

Instructor Notes: The Performance Objectives for Lesson 2 apply during this course as well as after completion. Though they are not tested formally, questions related to these Performance Objectives will be posed during the course simulations. Developing SA in the "domain" of the warning environment is a skill that evolves over time and is an important asset in making sound warning decisions.

Student Notes:

Lesson 2: Individual SA

Performance Objectives

1. Using specific data examples, identify the three levels of SA and how they are contributing to your warning decisions, while working:
   a) WES simulations, and
   b) Warning events.
2. As part of post-event analysis, determine the role that SA (good or bad) at the three levels played in the warning decisions that were made.

4. Situation Awareness: The Ability to Maintain the Big Picture

Instructor Notes: Looks like one of the individuals is lacking SA in this domain…

Student Notes:

Situation Awareness: The Ability to Maintain the Big Picture

5. SA Helps You Anticipate

Instructor Notes: SA supports your expectations. It also supports the process of shifting expectations during an event.

Student Notes:

SA Helps You Anticipate

6. What SA is Not

Instructor Notes: SA is not something that you are born with. The ability to acquire SA is learned, and SA must be acquired for each domain. You already have SA in many domains in your life…for example, driving a car.

Student Notes:

What SA is Not

"Howdy. My name is John. I am 40 years old and live in the USA.

I was born with brown hair, green eyes, and situation awareness."

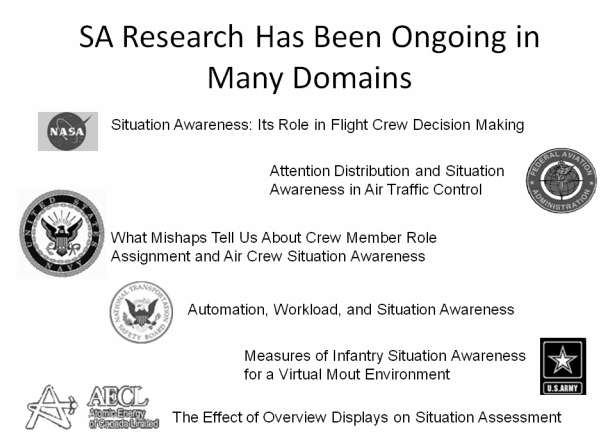
SA is *not* an inherent ability. It is *acquired* for different domains, such as driving a car

7. SA Research Has Been Ongoing in Many Domains

Instructor Notes: SA has been studied for many years in other domains. Here are examples of research papers from NASA, the FAA and others. There are many things in the NWS warning environment that are common to the military, aviation, emergency

medicine, nuclear power, and other domains. All require decision making in high stress environments with significant uncertainty, time pressure and lives are often at stake.

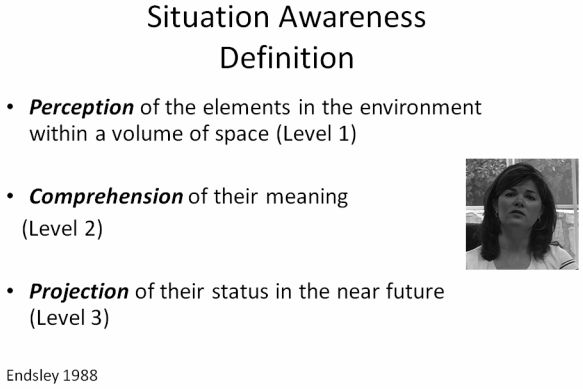
Student Notes:



8. Situation Awareness, Definition

Instructor Notes: There are three levels of SA, as defined by Mica Endsley. Each level will be examined separately. Notice that none of these definitions involves making a decision! SA forms the framework for making decisions.

Student Notes:



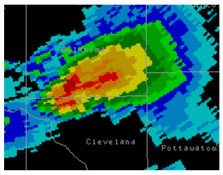
9. Situation Awareness, Level 1

Instructor Notes: Level 1 SA involves simply seeing the relevant data in the domain. Since there is such an enormous volume of data available in the warning environment, success with level 1 SA requires looking at what is most appropriate. However, the most pertinent data may be unavailable, masked by system design or it may require a great deal of effort to find.

Student Notes:

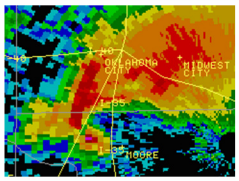
Situation Awareness
Level 1

- ***Perception*** of the elements in the environment within a volume of space (Level 1)



Is this what your decision is based on?

Same time…different radar



Or did you see this as well?

10. Situation Awareness, Level 2

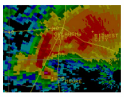
Instructor Notes: Level 2 SA involves your ability to comprehend the data and recognize patterns. In this example, you may understand the significance of a hook echo (and were able to see it in the data – level 1). The added significance of the high dBZ value in the tip of the hook is also (hopefully) comprehended. The radar beam is reflecting back from debris which has been lofted into the circulation.

Student Notes:

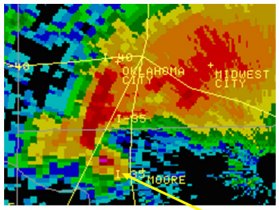
Situation Awareness
Level 2

- ***Comprehension*** of their meaning (Level 2)

Perceive



Did you *see* this?



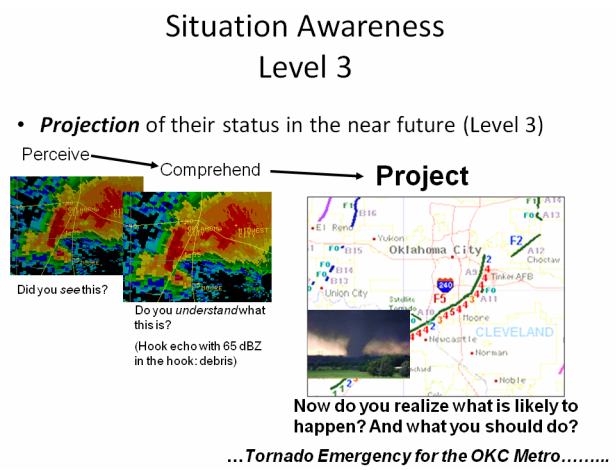
Now that you've seen this, do you *understand* what this is?

Hook echo with 65 dBZ in the hook ⟶ ***debris***

11. Situation Awareness, Level 3

Instructor Notes: Level 3 SA involves mentally projecting this feature forward in time and understanding the associated consequences. With level 3 achieved, the decision on what to do next is usually straightforward. Note that attaining the three levels of SA is not the same as making a decision.

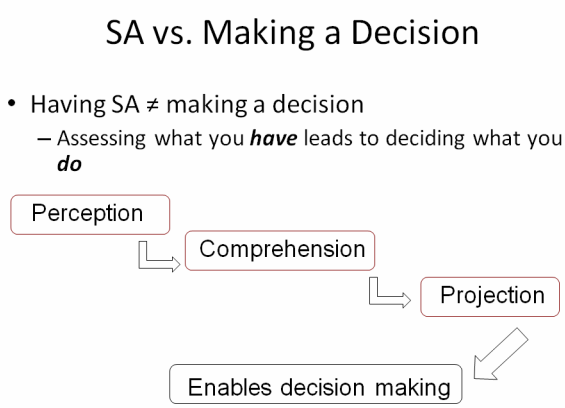
Student Notes:



12. SA vs. Making a Decision

Instructor Notes: Though there are three levels of SA, none of these levels involves making a decision. Once all three levels of SA are achieved, the decision directly follows. SA provides the framework for making a decision.

Student Notes:



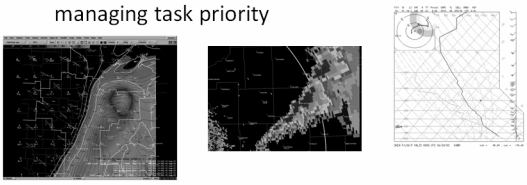
13. Attaining and Maintaining Individual SA

Instructor Notes: SA can be enhanced if the domain is designed to support human attention, which is a limited resource. Our attention manages multiple data streams, as well as their relative priority. Attention must also function to screen out information that is not relevant. Irrelevant information is essentially noise, whether it is visual or audible. It is important that the domain (systems and people) does not overly tax human attention, and appropriate design can support attention.

Student Notes:

Attaining and Maintaining Individual SA

- Attention
  - Switching among multiple data streams and managing task priority



  - Screen out the "noise" (audio and video)
  - Domain can be designed to support attention

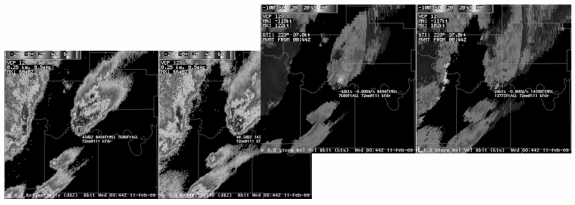
14. Attaining and Maintaining Individual SA

Instructor Notes: Another limited resource is working memory, where the data chunks found by our attention are stored. Working memory can support a limited number of these data chunks. We need enough of these data chunks to identify patterns in the data. Pattern recognition is critical for comprehension of the data. Hopefully, your working memory has enough chunks of relevant data to recognize relevant patterns!

Student Notes:

Attaining and Maintaining Individual SA

- Working memory (short term)
  - Processes and holds data in chunks
  - Supports a limited number of data chunks
  - Need enough data chunks for identifiable patterns



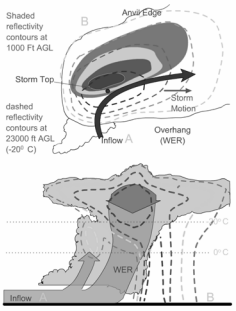
15. Attaining and Maintaining Individual SA

Instructor Notes: You don't go around all the time thinking about HP supercells, but patterns associated with them reside in long term memory. This is where a number of conceptual models for severe weather would be stored. The conceptual model provides the necessary connections among the chunks of data in working memory. Accessing a conceptual model from long term memory during an event may not be conscious, but that feeling of "I've seen this before" means something!

Student Notes:

Attaining and Maintaining Individual SA

- Long term memory
  - Conceptual models
  - Recognition of ***meaningful*** patterns
    - Conceptual models make the connections among the data chunks



16. Attaining and Maintaining Individual SA

Instructor Notes: Workload has a significant impact on SA, and it can be made manageable. Automation has increased so much in many domains. It can decrease workload for routine tasks, However, it can increase workload for significant or unexpected events. You'll be hearing a lot about unexpected events in the AWOC Core track modules. The good news is that many aspects of workload are controllable.

Student Notes:

Attaining and Maintaining Individual SA

- Attention and memory are limited resources
  - Significantly impacted by workload
- Automation can
  - Decrease workload for routine tasks
  - Increase workload for significant or unexpected events

- *Many aspects of workload are controllable*

17. SA and Workload

Instructor Notes: We'll start with low SA and high workload. This means you don't know what's going on and you're working too hard to find out. In aviation, this is known as "flying behind the plane". The next possibility is that you have high SA, but you are working too hard to maintain it. This is dangerous because it is not sustainable! How about low SA and low workload? You don't know what's going on and you aren't trying to find out. Maybe you're in "that doesn't happen here" mode? The goal is to maintain high SA with a low workload . This doesn't mean that you are bored, but that the information

flow is manageable. If you aren't operating in the high SA, low workload area, find out why and fix it! More about how to do that later.

Student Notes:

SA and Workload

	Low Situation Awareness	High Situation Awareness
High Workload	Don't know anything, but am trying way too hard to find out	Do know plenty, but at great effort (can't keep this up for long!)
Low Workload	Don't know anything, don't want to know...	Do know, and it comes steadily *If you are not operating here, find out why and fix it!*

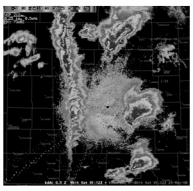
18. SA and Workload

Instructor Notes: Why is workload so important? Appropriate storm interrogation requires proactive analysis of the radar base data. Sectorizing can ensure that each warning forecaster has a manageable number of storms to interrogate.

Student Notes:

SA and Workload

- Warning decisions require all three levels of SA
  - ***Perception*** of relevant data, ***Comprehension*** of patterns, and ***Projection*** to the near future
- Maintaining SA requires:
  - Proactive radar ***base data*** interrogation
  - Keeping number of storms for ***each*** forecaster ***manageable***

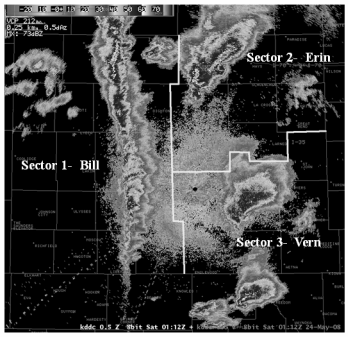


19. Sectorizing and SA

Instructor Notes: Sectorizing can have great benefits. In this example, there are three sectors, based on geography. The workload is divided such that each individual can maintain higher SA. The challenge with sectorizing is the need for an overall coordinator, providing oversight and "event level" SA. Storms may need to be passed from one sector to the next or sectors redefined. A designated warning coordinator can oversee this process and ensure that the event overall is managed.

Student Notes:

Sectorizing and SA



Advantages

- Divide the workload
- Focus on base data
- Maintain higher SA

Disadvantages

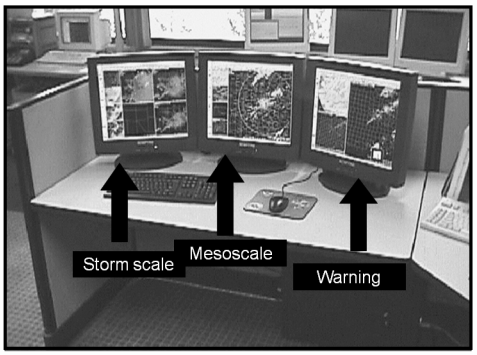
- Coordination becomes a challenge and must be managed

20. Workstation Configuration

Instructor Notes: Workstations can also be configured to support your SA. There are many possible configurations. In this example, two monitors are set up for storm scale and mesoscale analysis, respectively. The third monitor is set up to process warnings.

Student Notes:

Workstation Configuration Can Maximize SA by Decreasing Workload



21. SA and Workload, One Final Comment

Instructor Notes: A recommendation from one of the WDM IV workshop field presenters! During a largely successful event, one thing that wasn't expected was a visit from the media. Having an extra person available for the unknowns can make a huge difference, and keeping that extra person available is the coordinator's decision. Though the warning coordinator may be able to do short interviews, his/her SA may be lost if too much time is spent away from maintaining the big picture.

Student Notes:

SA and Workload

One Final Comment

"Keep an extra person* available for the one thing that you did not plan to happen...ie…the media showing up at our building wanting to do interviews while warnings were being issued."

WDM IV Workshop Field Presentations

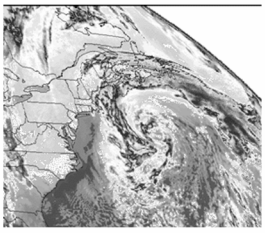
*that "extra person" is ***not*** the warning coordinator!

22. Failures in Situation Awareness

Instructor Notes: There are many different ways that each of the three levels of SA might fail. Denial is only one of the possibilities, but it was a factor in the loss of the Andrea Gail.

Student Notes:

Failures in Situation Awareness



"When you're in the denial business…it's hard to know when to stop."

Sebastian Junger, The Perfect Storm

23. Level 1 Failure: What May Prevent Perceiving Data

Instructor Notes: Level 1 SA is all about seeing the most relevant data. An important example for warning operations would be the masking of radar data by range folding. This problem can often be mitigated by changing the VCP, or editing the Doppler PRF, but workload may get in the way. Sometimes relevant data gets overlooked because it is embedded in too much irrelevant data. An example might be loading multiple AWIPS procedures that aren't really personalized for you. Inexperience may mean that you don't yet know what is the most relevant. Distractions and a high workload can negatively impact any of these contributors.

Student Notes:

Level 1 Failure: What May Prevent Perceiving Data

- Most relevant data not available or obscured
  - Sometimes human intervention can correct this
- Data presented in too much detail
  - Must extract useful information from the glut
- User doesn't know what is relevant
- Distractions, workload

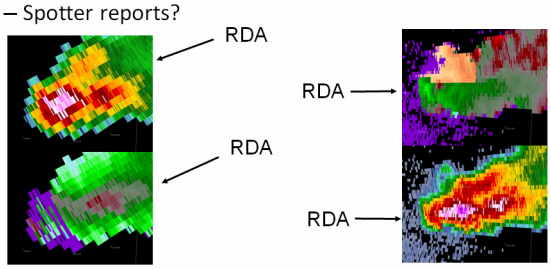
24. Level 1 Failure: What May Prevent Perceiving Data

Instructor Notes: In this example, there is a storm viewed from two different radars, but there are data quality problems with the velocity products. From one viewing angle (left side of slide) part of the storm is embedded in range folding, while the other viewing angle (right side of slide) has a velocity dealiasing failure. These data uncertainties can cause a level 1 SA failure with respect to the radar data. Hopefully, alternatives exist, such as changing the VCP or the PRF, or having good spotter information.

Student Notes:

Level 1 Failure: What May Prevent Perceiving Data

- Most relevant data not available or obscured
  - Radar sampling issues; VCP or PRF change?
  - Spotter reports?



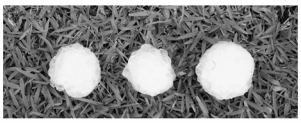
25. Failure in Level 1 SA, NWS Example

Instructor Notes: Here's an NWS example of a level 1 failure, drawn from a Root Cause Analysis exercise, which you will get to do as part of Core 3. This event was a missed hail event. The most relevant data was at the mid and high levels, but it was missed because they were only looking at the lowest four elevations. This "failure to seek" was based on a poor mental model, which drove expectations, which drove the data choices. More about the impacts of poor mental models later….

Student Notes:

Failure in Level 1 SA
NWS Example

- Negative lead time on storm with large hail
- Based on (not so good) expectations:
  - Only looking at lowest 4 elevations, instead of All Tilts
- Missed 100 kt storm top divergence



AWOC Core 3 RCA

26. Failure in Level 1 SA, NWS Example

Instructor Notes: Other NWS examples presented in IC Core 2 are drawn from service assessments or presentations from field representatives at WDTB workshops. In this case, a tornado developed from a storm that was in an area of range folding. Perhaps the staff was unfamiliar with the procedure to change the PRF, weren't sure about an alternate VCP or just didn't have time to do either. Since the storm was at long range, perhaps looking at an adjacent radar would have been helpful. The workload was over-whelming, likely contributing a great deal to the lost perception of the significance of this storm. Additional staff and/or sectorization may have mitigated the workload impact.

Student Notes:

Failure in Level 1 SA
NWS Example

- ***Contributors*** to an unwarned tornado
  - Feature masked by range folding
    - PRF not changed
    - Different VCP?
  - Storm at long range
    - Sampling limitations not well understood?
    - Data from other radars available?
  - Workload overwhelming
    - Sectorizing? Need additional staff?

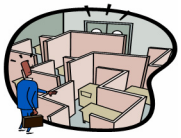
27. Level 2 Failure: What May Prevent Comprehending Data

Instructor Notes: In the warning environment, level 2 SA requires comprehension of multiple data streams (radar images, spotter reports, near storm environment data) to support the pattern recognition and build the connection to the conceptual model. If the

relevant data are seen but not understood, level 2 SA with respect to a conceptual model may be lost. Lack of experience can limit comprehension, even if the data are readily available. Distractions and a workload that is too high can also compromise level 2 SA.

Student Notes:

Level 2 Failure: What May Prevent Comprehending Data



- Inability to connect data chunks to a known conceptual model
  - Multiple data streams often needed
- Lack of a relevant conceptual model
- Lack of experience
- Distractions, workload

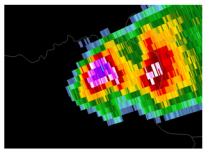
28. Level 2 Failure: What May Prevent Comprehending Data

Instructor Notes: In this example, the view from radar A depicts a storm with very high dBZs in its core, which would make hail a suspected threat. However, the view of the same storm from an adjacent radar reveals a 3 body scatter spike. If you understand what that means, your level 2 SA on this storm now includes the likelihood of very large hail. The 3 body scatter spike adds significant additional information, if you understand what it means.

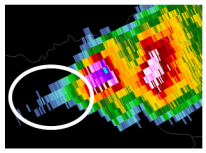
Student Notes:

Level 2 Failure: What May Prevent Comprehending Data

- Storm from radar A with very high dBZs: hail suspected as a threat



- Storm from radar B: Do you know what the appendage ***means***?



3 body scatter spike, which implies ***very large*** hail

29. Failure in Level 2 SA, NWS Example

Instructor Notes: In this NWS example from an AWOC RCA, the conceptual model of a flash flood was “not used”. Since the threat was thought to be minimal, the data chunks were not being put together. The other contributors were an overwhelming workload and a lack of experience.

Student Notes:

Failure in Level 2 SA
NWS Example

- Unwarned flash flood
- Conceptual model of flash flood “not used”
  - Threat assumed to be minimal
- Distracted by overwhelming severe weather workload
- Lack of experience

AWOC Core 3 RCA

30. Failure in Level 2 SA, NWS Example

Instructor Notes: In this event, a storm had previously produced a tornado, but a delayed report of the tornado was not relayed to the warning forecaster in real time. Additionally, the ability of the warning forecaster to interrogate the storm was compromised by inadequate RPS lists. The conceptual model of this tornadic supercell might have been better understood if the tornado report was passed on and the storm had been more thoroughly interrrogated.

Student Notes:

Failure in Level 2 SA
NWS Example

- ***Contributors*** to an unwarned tornado
  - Conceptual model of tornadic supercell not well understood
  - Report of previous tornado with storm not relayed to warning forecaster
  - 3D storm analysis incomplete
    - Inadequate RPS lists

31. Level 3 Failure: What May Prevent Correctly Projecting Data

Instructor Notes: Level 3 SA requires a thorough understanding of conceptual models, sufficient to predict future threats. So lack of experience or lack of a relevant conceptual model (or both) greatly impact level 3 SA. The data streams used in warning decisions all have strengths and limitations, which must be understood. A storm's expected future behavior may be incorrect or inconclusive due to data limitations. The combination of limitations from radar and near storm environment may result in projections that are in conflict or in error. The storm's impact must also be projected, such as passing through populated areas or crowded outdoor events.

Student Notes:

Level 3 Failure: What May Prevent Correctly Projecting Data

- Limited understanding of conceptual model
- Inability to deal with conflicting storm expectations due to data limitations
  - Radar sampling
  - Near storm environment analysis

- Limited experience
  - Knowledge of local area
  - Population centers, outdoor events
- Distractions, workload

32. Level 3 Failure: What May Prevent Correctly Projecting Data

Instructor Notes: Conceptual models must be familiar for both Level 2 and 3 SA. In this example, a storm has previously produced a tornado. Now the radar data shows a lowering top, lower max reflectivity and a weakening circulation. The near storm environment is not significantly different, so the question to ask is how does this behavior fit the model of a tornadic supercell?

Student Notes:

Level 3 Failure: What May Prevent Correctly Projecting Data

- Conceptual models must be familiar enough to
  - Be understood from the data (Level 2 SA)
  - Know what to expect in the near future (Level 3 SA)
- Example: Storm has produced a tornado but now
  - Max reflectivity decreases and top has lowered
  - Circulation has weakened
  - Near storm environment not significantly different
- How does this behavior fit with the conceptual model of a tornadic supercell?

33. Failure in Level 3 SA, NWS Example

Instructor Notes: In this example, the radar features were assumed to mean that the storm was weakening and the warning was allowed to expire. The cyclic nature of tornadic supercells was not sufficiently understood, thus not projected. This level 3 failure resulted in a reactive tornado warning with little lead time.

Student Notes:

Failure in Level 3 SA
NWS Example

- Supercell has previously produced a tornado, but radar features less significant
  - Conclusion: storm is weakening
  - Decision: warning allowed to expire
  - Result: new warning issued with no lead time when tornado redevelops

- Cyclic nature of tornadic supercells not well understood?
  - Near storm environment: has storm moved to an area where weakening makes sense?

34. Three Levels of SA, NWS Example

Instructor Notes: As an exercise, take a look at this excerpt from a regional weather discussion. Identify the different levels of SA represented in the phrases. Statements of perceived data represent level 1. Statements of the meaning of the data represent level 2, and statements projecting the consequences of that meaning represent level 3.

Student Notes:

Three Levels of SA
NWS Example

THE EASTERN MOST STORM IN XXXX COUNTY SHOWING CHANGES WHICH MAY SIGNAL THE BEGINNING OF SURFACE BASED SEVERE STORMS. THE HIGHEST REFLECTIVITIES WITH THIS ECHO DEVELOPED AT HIGHER ALTITUDE THAN IN THE EARLIER STORMS. SINCE THIS CELL IS RAPIDLY MOVING ACROSS THE INSTABILITY GRADIENT INTO THE AXIS OF HIGHER CAPE VALUES...IT IS REASONABLE TO EXPECT A TREND TOWARD STRONGER CELLS. WE EXPECT THE LOWER LCLS IN THE INSTABILITY AXIS TO RESULT IN LOWER CLOUD BASES AND A TENDENCY TOWARD STRONGER LOW LEVEL ROTATION GIVEN SUFFICIENT MID-LEVEL MESOCYCLONES. WILL MONITOR SRM AT MULTIPLE LEVELS IN EACH STORM TO DETECT ROTATION DEVELOPMENT.

Level 1: Perception
Level 2: Comprehension
Level 3: Projection

35. Three Levels of SA, NWS Example

Instructor Notes:

Student Notes:

Three Levels of SA
NWS Example

THE EASTERN MOST STORM IN XXXX COUNTY SHOWING CHANGES WHICH MAY SIGNAL THE BEGINNING OF SURFACE BASED SEVERE STORMS. THE HIGHEST REFLECTIVITIES WITH THIS ECHO DEVELOPED AT HIGHER ALTITUDE THAN IN THE EARLIER STORMS. SINCE THIS CELL IS RAPIDLY MOVING ACROSS THE INSTABILITY GRADIENT INTO THE AXIS OF HIGHER CAPE VALUES...IT IS REASONABLE TO EXPECT A TREND TOWARD STRONGER CELLS. WE EXPECT THE LOWER LCLS IN THE INSTABILITY AXIS TO RESULT IN LOWER CLOUD BASES AND A TENDENCY TOWARD STRONGER LOW LEVEL ROTATION GIVEN SUFFICIENT MID-LEVEL MESOCYCLONES. WILL MONITOR SRM AT MULTIPLE LEVELS IN EACH STORM TO DETECT ROTATION DEVELOPMENT.

Level 1: Perception
Level 2: Comprehension
Level 3: Projection

36. SA Summary

Instructor Notes: In summary, SA is the ability to build and maintain the big picture, which supports your ability to make sound warning decisions. There are several controllable factors, such as workload, which can support your ability to have good SA. Developing the ability to have good SA in the warning environment in the future is dependent on understanding how these controllable factors come together.

Student Notes:

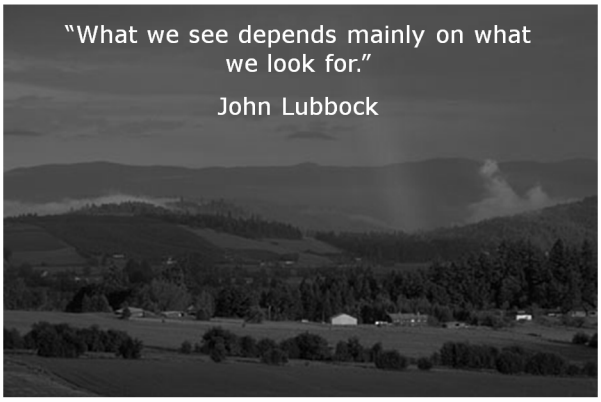
SA Summary

- SA is the ability to step out, construct and maintain the big picture
- Controllable factors aid your ability to have it and keep it
- Understanding how these factors come together affects your ability to manage SA better in the future

37. Final Quote

Instructor Notes: John Lubbock reminds us that what we perceive is often limited to what we are looking for.

Student Notes:



38. Situation Awareness and Decision Making in a Warning Environment

Instructor Notes: This concludes Lesson 2: Individual SA. There are three remaining lessons for IC Core 2.

Student Notes:

Situation Awareness and Decision Making in a Warning Environment

Advanced Warning Operations Course
IC Core 2
Lesson 2: Individual SA
Warning Decision Training Branch

39. Questions?

Instructor Notes: If you have questions about the material from IC Core 2, first check with your AWOC facilitator (most likely your SOO). If your AWOC facilitator cannot answer your question, please send an email to awoccore_list@wdtb.noaa.gov.

Student Notes:

Questions?

1. Check with your AWOC facilitator (most often the SOO)
2. Send your question to awoccore_list@wdtb.noaa.gov

1. Situation Awareness and Decision Making in a Warning Environment

Instructor Notes: Lesson 3 will focus on the Situation Awareness (SA) of teams. The "teams" in this lesson are not limited to the forecast office staff. For example, another team would be the entire group comprised of the forecast office, the media, and emergency managers, who are all part of the warning effort.

Student Notes:

Situation Awareness and Decision Making in a Warning Environment

Advanced Warning Operations Course
IC Core 2
Lesson 3: Team SA
Warning Decision Training Branch

2. Lesson 3: Team SA

Instructor Notes: The Learning Objective for Lesson 3 applies to factors that affect getting and maintaining team SA. The Learning Objectives will be tested when you take the on-line exam for IC Core 2.

Student Notes:

Lesson 3: Team SA

Learning Objective:

- Identify factors that can impact getting and maintaining team SA.

"When in danger, when in doubt, run in circles, scream and shout"
John Helpling

3. Lesson 3: Team SA

Instructor Notes: The Performance Objectives for Lesson 3 apply during this course as well as after completion. Though they are not tested formally, questions related to these Performance Objectives will be posed during the course simulations. Developing SA in the "domain" of the warning environment is a skill that evolves over time and is an important asset in making sound warning decisions.

Student Notes:

Lesson 3: Team SA

Performance Objectives

1. Using specific data examples, identify the three levels of SA and how they are contributing to your warning decisions, while working:
   a) WES simulations, and
   b) Warning events.
2. As part of post-event analysis, determine the role that SA (good or bad) at the three levels played in the warning decisions that were made.

4. Team SA, A Shared Understanding

Instructor Notes: This photo was taken at a forecast office during a significant warning event. There are eight people working in this one area and others working elsewhere. The potential for communications chaos is very high and there are a number of important questions to consider about managing this environment.

Student Notes:

Team SA

A Shared Understanding

5. Apollo 13 and Team SA

Instructor Notes: The Apollo 13 mission is an interesting example of a shift in team SA. This large team of controllers had to build their SA sufficiently to shift the goal from mission completion to getting the astronauts back alive. Imagine the reluctance to abandon the mission, but lengthy resistance would have caused delays that might have prevented the return of the astronauts.

Student Notes:

Apollo 13 and Team SA

6. Flight 1549: Landing on the Hudson River

Instructor Notes: A recent example of a significant shift in team SA is the successful landing of Flight 1549 on the Hudson river in January of 2009. Captain Sully had to sacrifice the goal of saving both the plane and passengers in order to change his goal to simply saving the passengers. Once that shift occurred, the crew shifted with him and knew what to do.

Student Notes:

Flight 1549: Landing on the Hudson River

- This team had a clearly defined leader
  - some teams don't
- Sully had to "goal sacrifice", shifting
  - from saving the plane + passengers
  - to saving just the passengers
- Crew members shifted with him and knew what to do

Time: Year in Pictures 2009 / Steven Day / AP

7. Are Team Decisions Inherently Better?

Instructor Notes: Team SA has its own challenges. Team decisions are not necessarily better. There are a number of things that can derail team SA, such as inability to resolve conflicts, poor communication, status and cultural differences.

Student Notes:

Are Team Decisions Inherently Better?

- ***Nope***
- Differing views can paralyze a team
- Teams may have collective errors
- Communication among team members may be faulty
- Status and cultural differences may have impacts

8. Team SA Definition

Instructor Notes: The definition of team SA addresses the construction of SA for each individual, with information shared among team members, building team SA. The quote from ASRS shows that the impact is significant when only one member of a team loses their SA. ASRS is the Aviation Safety Reporting System, a web site provided by NASA where pilots and crew members can report incidents anonymously. This database is also used by human factors researchers.

Student Notes:

Team SA Definition

"The active construction of a situation partly shared and partly distributed between two or more agents, from which one can anticipate important states in the near future." Salas et al 1995

- Team SA is the result of each individual's SA
- If one individual loses SA, it can affect that of the group

"40% of reported incidents in the ASRS data base occurred when ***only one*** crew member had a problem with SA."

http://asrs.arc.nasa.gov

9. Loss of Team SA, NWS Example

Instructor Notes: Here's a case of an unwarned flash flood. Each of the individuals had some knowledge, but it was not communicated. One person had been monitoring for flash flooding earlier, changed to another task, but did not delegate to someone else. Members of the team noted the heavy rain at different times, but nothing further was done. Most importantly, no one was formally assigned the task.

Student Notes:

Loss of Team SA
NWS Example

- Unwarned flash flood
  - Each individual had awareness of heavy rain and/or flood potential
    - Each person knew one piece of the threat
  - Nobody assigned to monitor for flash flooding
    - Duties among staff not well communicated
    - No one seeking ground truth

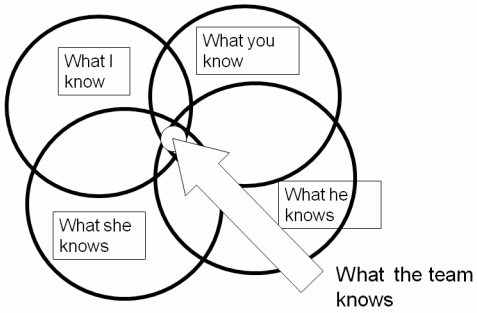
AWOC Core 3 RCA

10. Team SA

Instructor Notes: The subset of information that all team members need to know can be quite small. Each team member will likely have a vast amount of individual knowledge, but only a portion of it needs to be shared. In the previous example, just keeping track of who is monitoring for flash flooding may have been sufficient for "what the team knows" and might have been enough for a warning.

Student Notes:

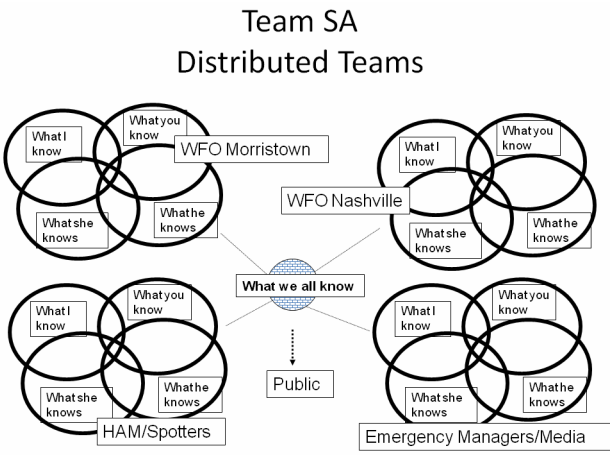
Team SA



11. Team SA, Distributed Teams

Instructor Notes: The warning process involves many teams, both internal and external to the NWS office. In addition to the NWS offices, HAMs/spotters, Emergency Managers, and the media are all members of the distributed team involved in the warning process. The better the communications among these groups, as well as a clear understanding of roles and responsibilities, the better the chance for good decision making and public service during severe weather events.

Student Notes:



12. Distributed Teams and NWSChat

Instructor Notes: NWSChat has a unique role in the distributed teams of the warning process. It improves the flow of information between the NWS and its core partners. It allows FOs to monitor upstream impacts. Most importantly, it has the potential to build relationships and trust. The goals of the NWS and its core partners are ultimately the same, and NWSChat supports the sharing of these goals.

Student Notes:

Distributed Teams and NWSChat

- Improves flow of information to/from FOs and core partners
  - Media/EMs have faster & easier access to FO products
- Tool for FOs to monitor upstream impacts
- Potential to build relationships and trust
  - Enhance shared goals of NWS and its core partners

13. Distributed Teams – SA Shift, NWS Example

Instructor Notes: In this example, the fact that a PDS Tornado Watch had been issued had shifted the SA of the spotters toward rotation and tornadoes. Radar was indicating intense supercells, but rotation signatures on radar were minimal. No tornado warnings were issued, only severe thunderstorm. The forecast office was expecting hail reports and not getting them until a spotter reported “debris” at a distance. The NWS used amateur radio to communicate to the spotters that the tornado potential was low at that time and that hail seemed to be the threat. Not long after, hail reports began coming in as the spotters shifted their SA.

Student Notes:

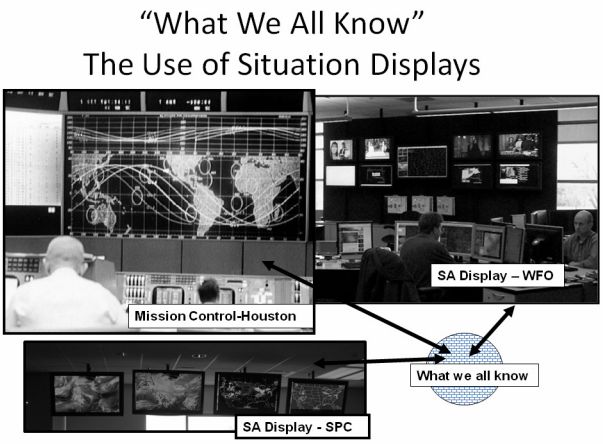
Distributed Teams – SA Shift
NWS Example

- PDS Tornado watch; spotters looking for tornadoes
- Radar shows intense non-tornadic supercells
  - SVR warnings, no TORs
- One spotter reports “debris” at distance
  - Actually large hail
- NWS message to spotters through amateur radio
  - Not seeing tornado potential on radar
- Spotters shift SA and hail reports increase

14. “What We All Know” The Use of Situation Displays

Instructor Notes: SA displays have been used in other domains for many years and new technologies support more robust designs. Mission Control in Houston may be the best known example of a large SA display. Many forecast offices have SA displays to support warning operations.

Student Notes:



15. Team SA and Leadership

Instructor Notes: Leadership can strongly affect team SA and performance…favorably or unfavorably! Leadership is most important in creating an environment where roles and responsibilities are well defined, understood and the role of each individual is valued and respected. Leadership sets the tone for communications among staff members. Good leadership can also minimize "face threat", which is a sometimes dangerous hindrance to communication. At all times, the most junior member of the staff should feel comfortable pointing out potential errors to the most senior member of the staff. If not, there's a chance that critical information may not be communicated.

Student Notes:

16. Team SA and Leadership

Instructor Notes: "Face Threat" inhibits communication, sometimes tragically. Self-awareness on the part of senior person is just as important as assertiveness on the part of the journeyman. Good leadership provides an environment where communication between superiors and subordinates flows freely.

Student Notes:

Team SA and Leadership

- Leadership and Face Threat
  - In aviation, face threat often cited in failures of first officers in monitoring/challenging the captain's decisions

17. Team SA and Leadership

Instructor Notes: The successful landing and evacuation of Flight 1549 was achieved due to the leadership of Captain Sully, which included his ability to communicate only what was needed to the crew. He also had confidence in their ability to do what they had been trained to do. His verbal and non-verbal communication conveyed that confidence.

Student Notes:

Team SA and Leadership

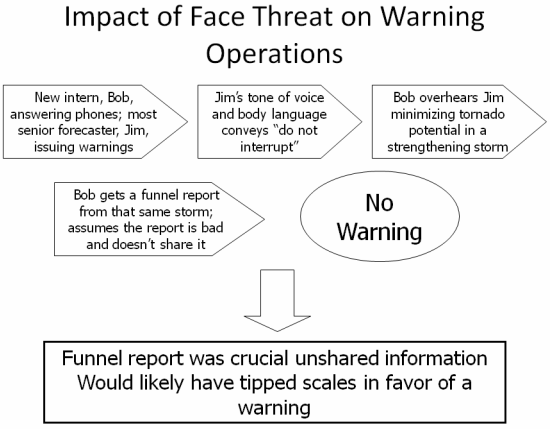
- Flight 1549: clear leadership, no face threat
  - "My aircraft"
    - Sully takes control; co-pilot Jeff knows what to do
      - "Jeff seemed to be equally on task." "Without me asking, he began to call out to me the altitude above the surface and the airspeed. It was awful and beautiful at the same time."
  - "This is the captain. Brace for impact"
    - Flight Attendants know what to do
      - "I knew that if I could deliver the aircraft to the surface intact…their direction and professionalism would be keys to our survival, and I had faith in them."

Time: Year in Pictures 2009 / Steven Day / AP

18. Impact of Face Threat on Warning Operations

Instructor Notes: This situation is based on a real event. "Bob" is the new intern, answering the phones. "Jim" is the lead forecaster, but his verbal and non-verbal messages deliver the message that he doesn't want to be bothered and that a strengthening storm isn't likely to produce a tornado. When Bob gets a report of a funnel, he is reluctant to share it (can you blame him?) and decides it must be invalid. The result is an unwarned tornado.

Student Notes:



19. Leadership, Not Limited to Management

Instructor Notes: This type of leadership is not limited to management. It is about contributing to the team rather than directing the team and everyone has the potential to do that. A rigid hierarchy is not needed to allow a team to perform well, with each individual contributing to the communications, planning, etc.

Student Notes:

Leadership

Not Limited to Management

- Leadership is ***contributing*** to team; not ***directing*** the team
  - ***Everyone*** can contribute leadership
  - Teams do ***not*** need rigid hierarchy to perform well
  - ***Everyone*** can contribute to communications, planning and adaptability (coming up…)

20. Team SA and Communications

Instructor Notes: Even in the absence of face threat, communications can suffer. Once again, roles and responsibilities need to be well defined and understood by all. Assumptions need to be avoided, so ask questions as needed for clarity. Do not share irrelevant information, which will vary from event to event.

Student Notes:

Team SA and Communications

- Communications
  - *Roles & responsibilities well defined, understood and respected*
  - Seek clarity, avoid assumptions, focus on ***most relevant*** content
  - Minimize "distracter" information
    - Flight 1549 descending very rapidly
    - Patrick (controller) ignored protocol
      - Did not ask basic questions
      - Asked Sully what he wanted instead of directing him

21. Lesson in Communications From an Experienced Pilot…

Instructor Notes: This example is a personal story from an experienced commercial pilot, Air Force Reserve Guard unit commander, and trainer. His message is to always be on guard for error and to always listen to everyone on your crew.

Student Notes:

Lesson in Communications
From an Experienced Pilot…

- Family vacation…turn attention to my wife and the map in her lap…youngest son makes the call: "Daddy, the trees!" We're off the road…I spin the wheel to the left…we're back on the road. I'm a very humble man.
- Lesson 1: Each of us, regardless of time, experience, qualification, rank or position, can ***still do stupid things***. Be humble.
- Lesson 2: A "fledgling" member of my crew makes the call. Listen to ***everyone***. Look beyond age, experience, rank and qualifications.

J.S.T. Ragman

22. FO Team SA Internal Communications

Instructor Notes: Here are examples of internal communications within a forecast office, both good and bad. The gaps are examples of crucial pieces of information that were not passed to the right person…the warning forecaster needs to know in real time if a particular storm has previously produced a tornado. Another gap is one staff member telling an EM that a storm is expected to weaken and not sharing this conversation with the warning forecaster who was working that storm. An example of good connections is the presence of a warning coordinator and all staff members having clearly defined roles and responsibilities.

Student Notes:

FO Team SA
Internal Communications

- Gaps
  - Report of previous tornado sent to WFO, but not passed to warning forecaster
  - Call from EM…told storm was expected to weaken; call was not logged or discussed with others…storm intensified

- Connections
  - Warning coordinator, teams of warning forecasters, roles & responsibilities for each individual well defined and understood

23. FO Team SA External Communications

Instructor Notes: Here are examples of external communications, both good and bad, between the forecast office and the media and emergency managers (EMs). One of the gaps results from not having adequate staff for the event, resulting in no SVSs or LSRs being issued. These products provide a valuable service to the media and EMs, and hampered the performance of these external partners. In another case, an EM talked to a WFO staff member and was told that a storm is expected to weaken. When the storm intensified and a warning was issued for that county, the EM was not notified in advance. Good external communications involve direct connections between the NWS and core partners. Use of strong language in warnings and statements helps to convey a particularly high threat.

Student Notes:

FO Team SA
External Communications

- Gaps
  - Not enough staff to handle workload, SVSs and LSRs not issued
  - EM told storm expected to weaken, though it intensified; EM not contacted before warning issued for his county

- Connections
  - NWSChat provides direct communications between the NWS and its core partners

24. Team SA and Planning

Instructor Notes: Pre-planning can make a significant difference during warning operations. Successful office performance often results from well defined responsibilities for each individual, as well as a coordinator to oversee workload and to deal with the inevita-

ble surprises. The quote is from a service assessment of a widespread but successful event. Each staff member was better able to focus on their particular duties because they knew that all necessary operations were accounted for.

Student Notes:

Team SA and Planning

- Preparation, Planning
  - *Roles & responsibilities well defined, understood and respected*
    - "predefined severe weather shift duties…allowed the staff to focus on specific duties with knowledge that all necessary tasks were being completed…minimized duplication of effort and maximized warning and communications performance."
  - Prepare yourself, be aware of yourself and others, have a plan

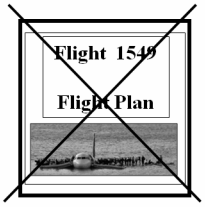
25. Team SA and Adaptability

Instructor Notes: There is no single "plan" for severe weather operations. Since the warning environment is so dynamic, adaptability is essential. It may be necessary to call in more staff, adjust warning sectors, and adjust roles and responsibilities, as needed. Adaptability allows for a more proactive approach to warning operations, instead of reactive.

Student Notes:

Team SA and Adaptability

- Adaptability
  - If the plan isn't working, change the plan!
  - Strive for a pro-active mode, instead of reactive
  - Be mindful of the potential need to "goal sacrifice"



26. Team SA and "Warning Coordinator"

Instructor Notes: The warning coordinator has to maintain his or her own SA, which is "event level". The warning coordinator does not know details such as storm scale structures, which is the focus of the warning forecaster's individual SA. The warning coordina-

tor manages team SA by monitoring staffing and workload, as well as monitoring the office's overall message to the customer.

Student Notes:

Team SA and "Warning Coordinator"

- ***Not*** a "catch all" person for unassigned tasks
- Maintains "event level" SA
  - Oversees end-to-end office operations
  - Doesn't know details such as storm scale structures
- Monitors staffing and workload
- Gages the office's message to the customer
  - Flow of products
  - Wording of products
- Ensure actions are documented

27. Team SA Summary

Instructor Notes: In summary, team SA requires team members to maintain their individual SA and contribute to the group SA. There are several controllable factors, such as well defined roles and responsibilities, effective communications, planning, adaptability, and managing staff workload.

Student Notes:

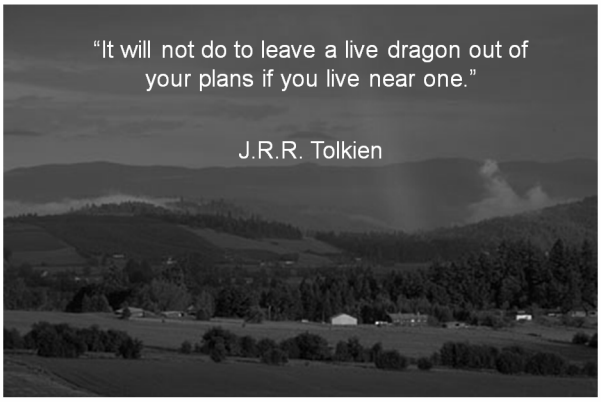
Team SA Summary

- Team SA requires all to maintain individual SA and contribute to group SA
- Several ***controllable*** factors can impact the team's ability to have it and keep it
  - Roles & responsibilities defined, understood, and respected
  - Effective communications: No face threat!
  - Pro-active planning and adaptability
  - Having adequate staff available and managing workload supports all of the above!

28. Final Quote

Instructor Notes: A final word from J.R.R. Tolkien. Since we have a live dragon living nearby, it's best to plan for it!

Student Notes:



29. Situation Awareness and Decision Making in a Warning Environment

Instructor Notes: This concludes Lesson 3: Team SA. There are two remaining lessons for AWOC Core 2.

Student Notes:

Situation Awareness and Decision Making in a Warning Environment

Advanced Warning Operations Course
IC Core 2
Lesson 3: Team SA
Warning Decision Training Branch

30. Questions?

Instructor Notes: If you have questions about the material from AWOC Core 2, first check with your AWOC facilitator (most likely your SOO). If your AWOC facilitator cannot answer your question, please send an email to awoccore_list@wdtb.noaa.gov.

Student Notes:

Questions?

1. Check with your AWOC facilitator (most often the SOO)
2. Send your question to awoccore_list@wdtb.noaa.gov

1. Situation Awareness and Decision Making in a Warning Environment

Instructor Notes: Lesson 4 will focus on the SA Demons, which are the enemies of Situation Awareness.

Student Notes:

Situation Awareness and Decision Making in a Warning Environment

Advanced Warning Operations Course
IC Core 2
Lesson 4: SA Demons: The Enemies of Situation Awareness
Warning Decision Training Branch

2. Lesson 4: SA Demons: The Enemies of SA

Instructor Notes: The Learning Objective for Lesson 4 applies to the SA demons, identifying them as well as how they can inhibit SA.

Student Notes:

Lesson 4: SA Demons: The Enemies of SA

Learning Objective

- Identify the SA demons and how they can inhibit SA.

"There is nothing so likely to produce peace as to be well prepared to meet the enemy."
George Washington

3. Lesson 4: SA Demons: The Enemies of SA

Instructor Notes: The Performance Objective for Lesson 4 applies to post event analysis during this course as well as after completion. Though they are not tested formally, understanding SA demons and their impact as part of post event analysis will improve your ability to build and maintain good SA in future events.

Student Notes:

Lesson 4: SA Demons: The Enemies of SA

Performance Objective

1. As part of post-event analysis, determine the role that SA (good or bad) at the three levels played in the warning decisions that were made.

4. SA Demons Overview

Instructor Notes: Summarizing the previous lessons of Core 2, getting and maintaining good SA is dependent on how humans perform in the complex domain of the warning environment. SA Demons are elements to look for in this environment.

Student Notes:

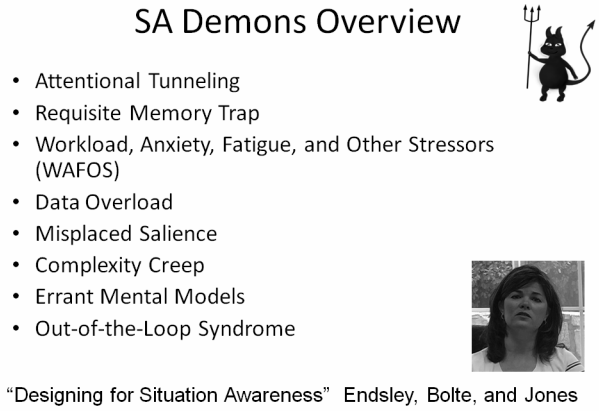
SA Demons Overview

- Attaining and maintaining good SA is a function of
  - Human performance and processing
  - The complex "domain" of the forecast office during a warning event
- SA Demons are factors that inhibit SA

5. SA Demons Overview

Instructor Notes: There are eight different SA demons, each of which will be defined and examples provided. The concept of SA demons comes from a book by Mica Endsley, "Designing for Situation Awareness".

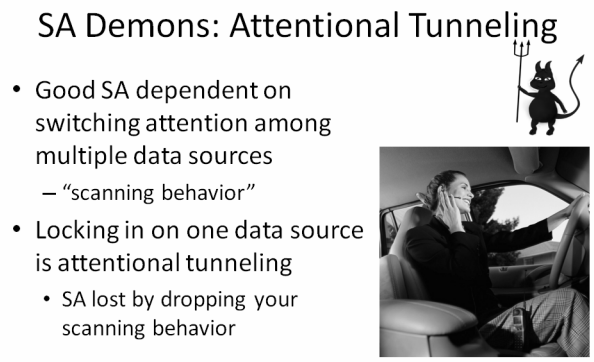
Student Notes:



6. SA Demons: Attentional Tunneling

Instructor Notes: In most domains, good SA requires regularly switching your attention among multiple data streams, also known as scanning behavior. In highly dynamic domains like warning operations, the number of data sources is very high and their relative importance changes. Attentional tunneling is becoming overly fixed on certain data sources to the exclusion of others, which means losing your scanning behavior. A sometimes tragic example from everyday life is making calls on a cell phone while driving. Losing your SA on the driving task for even a few moments can sometimes have terrible consequences.

Student Notes:

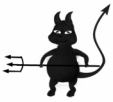


7. Attentional Tunneling, NWS Example

Instructor Notes: In this example, the day's expectations were for a low probability of thunderstorms. Thunderstorms did develop in the midst of some equipment problems. The warning forecaster was part of the group working the problem. Since his attention was tunneled toward the equipment, he missed a BWER in a particularly strong thunderstorm. The storm did produce a damaging tornado.

Student Notes:

Attentional Tunneling
NWS Example



- Expectations are low for thunderstorms
- Warning forecaster busy working equipment problems
  - Doesn't notice BWER in strong developing thunderstorm
  - Unwarned tornado

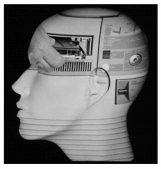
- Attentional tunneling on equipment caused loss of SA on developing convection

8. SA Demons: Requisite Memory Trap

Instructor Notes: Working or short term memory is the part of our cognitive load that "caches" chunks of data. Good SA (level 2) is dependent on holding sufficient data chunks to apply a conceptual model. Research has shown that working memory can be better developed, but is still a limited resource. Technology that is designed in a way that requires significant memory just for operating the system erodes working memory.

Student Notes:

SA Demons: Requisite Memory Trap



- Working memory holds chunks of data to support SA (level 2)
  - Limited resource for anyone!
- When system requires lots of memory just to use it...
  - Does not support data interpretation
  - "System" can be technology or how humans interact based on organizational structure

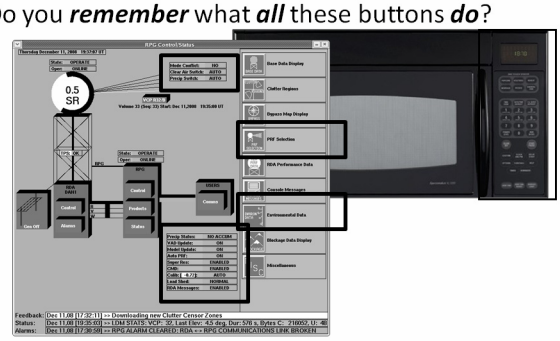
9. SA Demons: Requisite Memory Trap

Instructor Notes: Systems that require "getting out the manual" for operations beyond the baseline are common in everyday life. Most microwave ovens have a myriad of features that aren't used because the design requires too much memory. With the WSR-88D, there are many tasks that will optimize radar performance, but are difficult to do during warning operations.

Student Notes:

SA Demons: Requisite Memory Trap

- Do you ***remember*** what ***all*** these buttons ***do***?



10. SA Demons: Requisite Memory Trap

Instructor Notes: Anticipation of events and setting parameters before the event begins can partially mitigate this demon. This is particularly important for tasks that require too much memory to be done on the fly. Examples include adjustments to AWIPS procedures, RPS lists, considering potential VCPs, and radar algorithm parameter changes, such as the Z-R relationship.

Student Notes:

SA Demons:
Requisite Memory Trap

- Mitigations:
  - Pre-event anticipation & preparation
    - Radar optimization
      - Potential VCPs
      - Algorithm parameter changes
  - AWIPS configuration
    - Adjust/create procedures
  - Adequate staffing to address the unexpected

11. SA Demons: Workload, Anxiety, Fatigue, and Other Stressors

Instructor Notes: Workload, Anxiety, Fatigue, and Other Stressors (WAFOS) are human conditions common to dynamic domains. WAFOS is likely to be a significant issue in warning operations and should be monitored and adjusted as best possible. Humans usually assume that they can “keep on going” despite stressful circumstances. The warning coordinator can often identify someone who needs a break well before the individual would know. For example, during a historic tornado event, one of the warning

forecasters, “Joe”, was working a supercell with a large tornado that passed through his neighborhood. Phone communications were down and Joe could not reach his family. Joe did not ask if he could leave to check on his family…the warning coordinator told him to go. It took awhile for Joe to find out, but his family survived despite significant structural damage.

Student Notes:

SA Demons: Workload, Anxiety, Fatigue, and Other Stressors

- Stress & anxiety ***likely*** issues in warning environment
  - Lives are at stake (sometimes office staff and/or family members)
  - Shift work and chaotic environment
  - Humans often misjudge their own ability to cope

- WAFOS reduces a person’s ability to process information

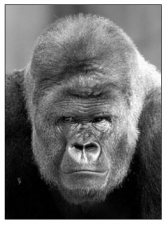
12. SA Demons: Workload, Anxiety, Fatigue, and Other Stressors

Instructor Notes: There are non-meteorological factors that affect WAFOS as well, taxing attention and working memory. Ambiguous roles and responsibilities and poor communication among team members will worsen the “distraction” that WAFOS provides. Face threat is a particularly damaging hindrance to team communication, and all staff must be aware of the potential for face threat to get in the way.

Student Notes:

SA Demons: Workload, Anxiety, Fatigue, and Other Stressors

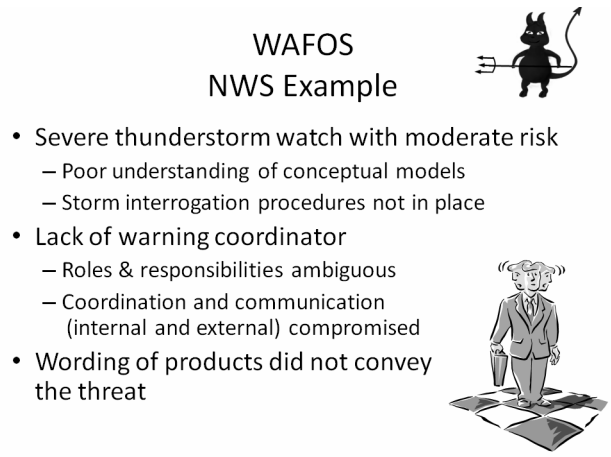
- WAFOS worsened by
  - Ambiguous roles& responsibilities
  - Poor communications among team members
  - Face Threat



13. WAFOS, NWS Example

Instructor Notes: This example resulted in significant hail and wind damage in some unwarned counties. A number of factors came together to raise the WAFOS to the point of hindering storm recognition, internal and external communications and conveying the severity of the threat.

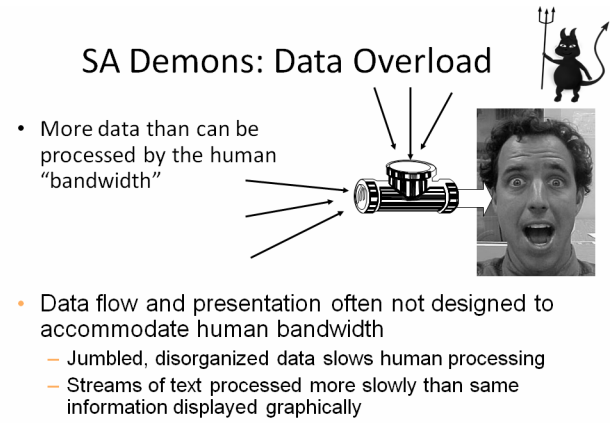
Student Notes:



14. SA Demons: Data Overload

Instructor Notes: Data Overload is a frequently cited problem in our culture. In warning operations, it can significantly inhibit good SA. Humans have a limited bandwidth, yet systems (technology and communications) are often not designed to accommodate this limitation.

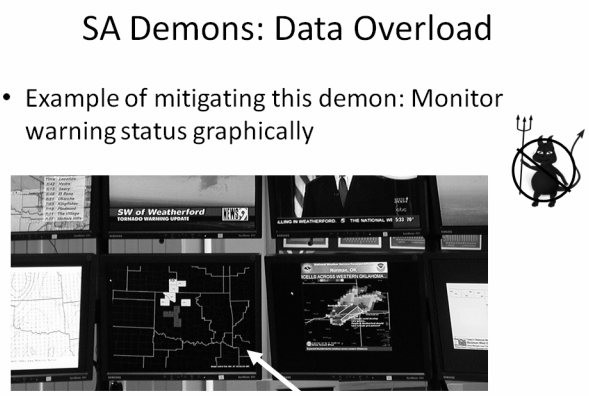
Student Notes:



15. SA Demons: Data Overload

Instructor Notes: One example of mitigating this demon is to graphically display current warnings and the number of minutes remaining for each warning. In this example, it is part of an overall situation awareness display.

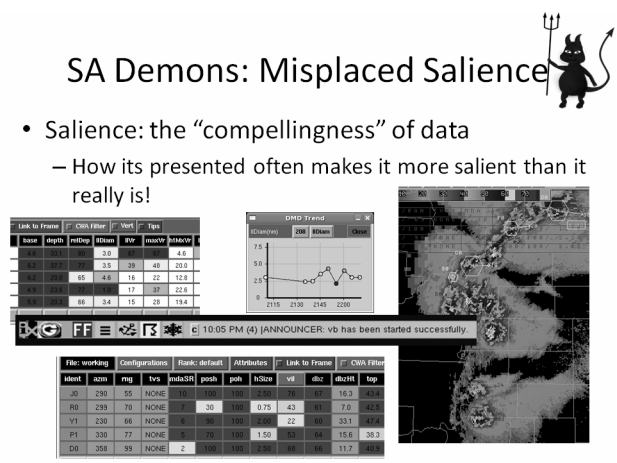
Student Notes:



16. SA Demons: Misplaced Salience

Instructor Notes: You are probably all too familiar with red boxes and banners and the associated audio alarms. It is often left to the operator to investigate and determine which of these alarms is actually relevant. Misplaced salience with these alarms is a typical example.

Student Notes:



17. SA Demons: Misplaced Salience

Instructor Notes: A more subtle example is misplaced salience on the lack of information. We humans tend to assume that the absence of information means that the phe-

nomena doesn't exist. For example, a lack of spotter reports from a storm is often interpreted to mean that the storm isn't producing hail or strong winds.

Student Notes:

SA Demons: Misplaced Salience

- Data given greater salience because ***it isn't there***
  - Lack of information (we humans tend to think) means the phenomena doesn't exist
  - May be "missing" due to sampling limitations

18. Misplaced Salience, NWS Example

Instructor Notes: In this example, there was a supercell that had previously produced a tornado. The office staff wanted to improve their warning statistics, and were looking hard for clues from the environmental data. Surface boundaries were not seen in the data and assumed not to be there, reducing the tornadic potential. Though the radar showed a strong mesocyclone, spotter reports were not available, which was interpreted to mean that the storm was not tornadic. In both cases, the lack of data was interpreted to mean that the phenomena was not there. The radar signatures and storm history were given too little salience, and the storm produced an unwarned tornado.

Student Notes:

Misplaced Salience
NWS Example

- Supercell had previously produced a tornado
- Desire to improve office performance metrics
  - Looking for surface boundaries to enhance tornadic potential, but not seen in data
- Strong meso on radar, but no information below radar horizon: spotter reports "missing"

- Radar signatures and storm history given low salience

19. Misplaced Salience, NWS Example

Instructor Notes: This was a case of a missed flash flood, mainly due to the lack of ground truth. This occurred in a county where the officials are usually very pro-active, but not this time.

Student Notes:

Misplaced Salience
NWS Example

- Missed flash flood event
  - Ground truth arrived too late
  - Officials in affected county usually very pro-active, but not heard from for this event
  - Tendency to think no report = nothing happening
    - This assumption may not even be a conscious one!

AWOC Core 3 RCA

20. SA Demons: Complexity Creep

Instructor Notes: Complexity creep is a long term problem with many science and technology driven organizations and has an impact on all three levels of SA. Training is typically proposed as the solution to this problem, though often by those who aren't going to produce the training or those who will complete it!

Student Notes:

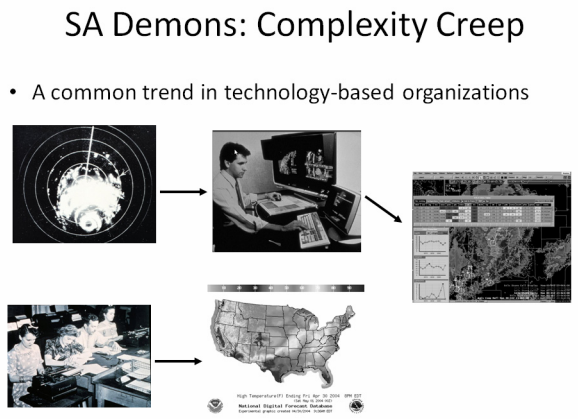
SA Demons:
Complexity Creep

- Slows down perception of information (level 1)
- Primarily undermines understanding (level 2) and projection (level 3)
- Additional training is often proposed as the solution to this problem….

21. SA Demons: Complexity Creep

Instructor Notes: Complexity creep is a common trend in technology-based organizations. Here are a couple of trends in the NWS in the past several decades.

Student Notes:



22. SA Demons: Errant Mental Models

Instructor Notes: Errant mental models can have an impact in different ways. Though the appropriate conceptual model may have been anticipated, an incomplete understanding of that model may hinder comprehension and projection (level 2 and 3 SA). If the wrong model is anticipated, the data may be incorrectly interpreted. Humans have a tendency to explain away cues in the data that conflict with the mental model that they have selected. An extreme example is an underlying assumption that "tornadoes don't happen here". The following slides have a couple of examples of conflicting data that is "explained away".

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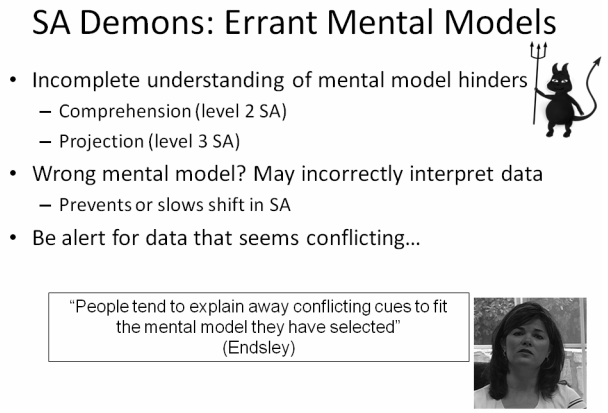


23. Errant Mental Model, NWS Example

Instructor Notes: In this example, the primary threat expected is small hail and strong winds. No hail is reported, yet high radar rainfall estimates are assumed to be hail contaminated. There's not much gage data, but no-one sought additional ground truth. The storms were over an area of new urban development and detention ponds were expected to be sufficient for runoff. The mental model of hail and winds was used to explain away the potentially important cues of high radar rainfall estimates over areas of new urban development.

Student Notes:

Errant Mental Model
NWS Example

- Expectation: marginally severe storms with small hail, strong winds
- No hail reported; high radar rainfall estimates assumed to be hail contaminated
  - Storms missing gages; did not seek other ground truth
- Storms over area of new urban development
  - Detention ponds and other design elements assumed to be sufficient for runoff
- ***Result: flash flooding in small basin areas***

24. Errant Mental Model, NWS Example

Instructor Notes: This unwarned flash flood event came from an AWOC Core 3 RCA. The mental model of the team was based on the expectation of severe weather, but not flash flooding. The workload was distributed to address the severe weather threat and the team was very focused on that task. Unfortunately, public reports of localized flooding were "trivialized". This is an example of the human tendency to "explain away conflicting cues", when what is really needed is a shift in the mental model.

Student Notes:

Errant Mental Model
NWS Example

- Unwarned flash flood event
  - Severe weather believed to be dominant threat
  - Workload resources committed to severe weather monitoring/warnings
  - Initial public reports of localized flooding are "trivialized"

AWOC Core 3 RCA

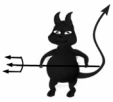
25. SA Demons: Out-of-the-Loop Syndrome

Instructor Notes: In many domains, much of the "routine" work that humans do forms the foundation of their skills. Automation of routine tasks is sometimes a good thing, but there is risk. In some cases, an attempt to minimize human error has sometimes resulted in automating as much as possible of the routine tasks, leaving the human to intervene only when there is a problem. This approach can result in a loss of the skills that are built and maintained by doing the routine tasks. It also may not allow the human enough time to respond, even when they know what to do.

Student Notes:

SA Demons:
Out-of-the-Loop Syndrome

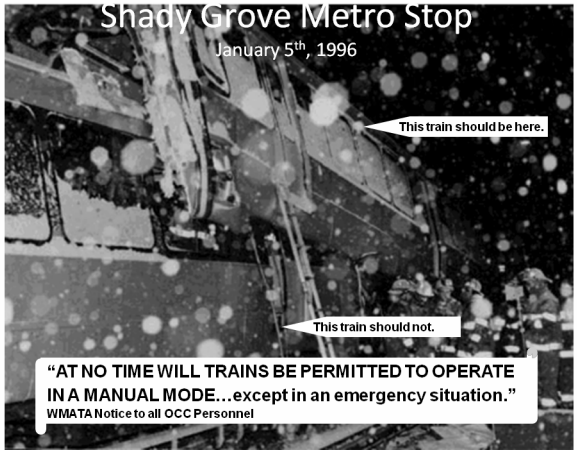
- Automated systems that don't involve the human until there is a problem
- Assumption is automating routine tasks will minimize "human error"
  - Sometimes true, but other times…
- Automation does not eliminate error
  - Changes the types of errors that are made



26. Shady Grove Metro Stop, January 5th, 1996

Instructor Notes: Under the assumption that letting the computers run the trains would minimize wear on parts, train operators were not allowed to run the trains manually, unless there was an emergency. This policy impairs an operator's ability to assess a problem, react quickly, and be sufficiently skilled to react effectively. Automation resulted in a train traveling too fast for the snowy conditions. The operator was unable to react quickly enough to avoid this accident, which unfortunately killed him.

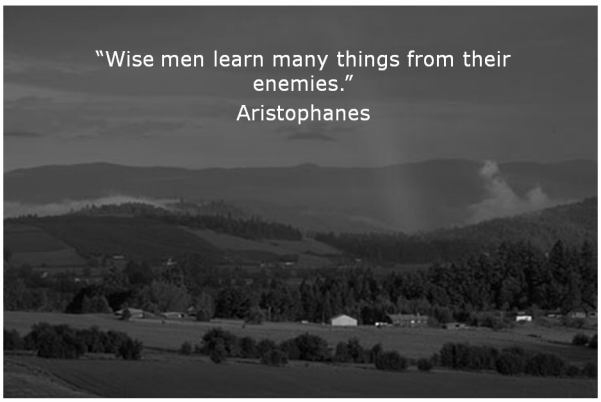
Student Notes:



27. Final Quote

Instructor Notes: Aristophanes says it best…

Student Notes:



28. Questions?

Instructor Notes: If you have questions about the material from IC Core 2, first check with your AWOC facilitator (most likely your SOO). If your AWOC facilitator cannot answer your question, please send an email to awoccore_list@wdtb.noaa.gov.

Student Notes:

Questions?

1. Check with your AWOC facilitator (most often the SOO)
2. Send your question to awoccore_list@wdtb.noaa.gov

29. References for IC Core 2

Instructor Notes:

Student Notes:

References for IC Core 2

Toward a Theory of Situation Awareness in Dynamic Systems; M. Endsley, 1995, Human Factors and Ergonomics Society

Design and Evaluation for Situation Awareness Enhancement. M.R. Endsley, 1988: Proceedings of the Human Factors Society, 32nd annual meeting, Santa Monica, CA

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Designing for Situation Awareness, M. Endsley, B. Bolte, and D. Jones; Taylor & Francis

30. References

Instructor Notes:

Student Notes:

References

Guidelines for Situation Awareness Training: C. Prince, NAWCTSD/UCF/FAA Partnership for Aviation Training

Defensive Driving. Wait, Make That Defensive Flying; J. S. T. Ragman, Flying Safety, May 2002

1998 Railroad Accident Report Collision of Washington Metropolitan Area Transit Authority Train T-111 with Standing Train at Shady Grove Passenger Station, Gaithersburg, Maryland January 6, 1996, NTSB

Sources of Power: How People Make Decisions, G. Klein; MIT Press

Intuition at Work, G. Klein; Doubleday

31. References

Instructor Notes:

Student Notes:

References

- Highest Duty, My Search for What Really Matters; C. Sullenberger, J. Zaslow; HarperCollins

1. Situation Awareness and Decision Making in a Warning Environment

Instructor Notes: This lesson will look at how we can maintain situation awareness at one of the most challenging of times – when the unexpected happens.

Student Notes:

Situation Awareness and Decision Making in a Warning Environment

Advanced Warning Operations Course
IC Core 2
Lesson 5: Maintaining SA by Managing the Unexpected
Warning Decision Training Branch

2. Overview

Instructor Notes: One of the most difficult times for us to maintain situation awareness is when we are faced with an unfolding event that is not what we were expecting. This is associated with an element of surprise which for many can be uncomfortable. You have gone from a sense of understanding what is about to happen to being blindsided. This problem of surprise can manifest itself in many ways, which we will look at. Other disciplines are faced with some of the same issues. A subset of these disciplines are referred to as High Reliability Organizations. We'll look at what that means and how these organizations function in a way to help mitigate the unexpected. Finally, we'll take a look at how overconfidence plays a role in your ability to respond to unexpected events.

Student Notes:

Overview

- What are the challenges with unexpected events?
- The problem of surprise
- Learning from High Reliability Organizations
  - What are they
  - What makes them HROs?
  - Improving SA by becoming an HRO
- Overconfidence Assessment

3. Objectives

Instructor Notes: Here are the specific objectives we will address in this module: Identify the two practices that can help facilitate a prompt response to unexpected events. Identify the attributes of the operating environment of a Highly Reliable Organization. Identify the 5 characteristics of a Highly Reliable Organization. State the impact of overconfidence on responding to the unexpected.

Student Notes:

Objectives

1. Identify the two practices that can help facilitate a prompt response to unexpected events.
2. Identify the attributes of the operating environment of a Highly Reliable Organization.
3. Identify the 5 characteristics of a Highly Reliable Organization.
4. State the impact of overconfidence on responding to the unexpected.

4. Challenges with the UnexpectedImpact on SA

Instructor Notes: Here is why we can have such a challenge when something unexpected happens. As we formulate our understanding regarding what is likely to unfold, we've developed the 3 levels of SA (assess, comprehend, project). When the unexpected happens we first have to notice (update level 1), then we have to understand what that means (level 2). The next step is to take corrective action based on what we see as the likely outcome (level 3). That is assuming that we know what action to take and that we take it in a timely fashion.

Student Notes:

Challenges with the Unexpected

Impact on SA

- Must update expectations
  - *Update SA (assess, comprehend)*
  - *Does this fit any Conceptual Model?*
- Must be willing to take action
  - *Update SA(comprehend, project)*
  - *Do you know what action to take?*
  - *Are you equipped to take that action?*
  - *Do you have to convince others?*
- Narrow window for effective action

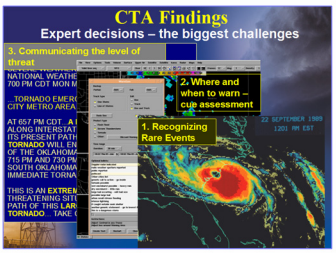
5. Challenges with the UnexpectedWhat experts say

Instructor Notes: The Cognitive Task Analysis the NWS undertook with expert warning forecasters cited rare events as one of the biggest challenges. This might mean a rare even in general or an event that is rare in your location. This is one of the reasons forecasters can benefit for routine simulations as a way to experience something that is not routinely provided for you in the course of your job. Sometimes you have a rare event that you are able to anticipate…at least to some degree. Much more challenging is a rare event that is not in your list of possibilities. Finally, you might face a rare event that you certainly know about, but you certainly didn't expect it today. All of these bring challenges in training, expectation, and implimentation.

Student Notes:

Challenges with the Unexpected

What experts say



- NWS experts list rare events as one of the biggest challenges
- Rare could mean
  - Rare and expected
  - Rare and unexpected
  - Not so rare, but still unexpected

From Core 3, Lesson 1

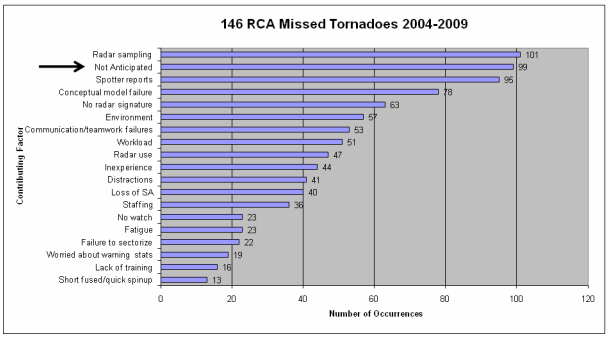
6. Slide 6

Instructor Notes: Here is an example of how a lack of expectation can have an impact on an outcome. This chart represents data from Root Cause Analysis done by students as part of AWOC Core 3. This process attempts to reveal factors, and their relationships, which contribute, in this case, to missed tornado events. In the best estimate of the people involved in these 146 missed tornado events, the fact that the event was "Not Anticipated" appeared 99 times. In the cases with these missed tornado events, the fact that the event was not expected contributed to a slow or non-response by the decision maker.

Student Notes:

Challenges with the Unexpected

From AWOC Root Cause Analysis



7. So what's wrong with being surprised?

Instructor Notes: There is a reason we are resistant to surprise. It immediately puts us in unfamiliar territory where we may not know what the proper response is. This can be associated with a feeling of "unpleasantness" that we quickly want to dismiss. For some, that may mean resistance to letting go of what they thought they knew (the current forecast) or going into denial by explaining away data to the contrary. If you are the forecaster, in this example, who has put out a forecast of benign weather, what do you do when significant storm quickly develops and begins doing damage? If you can't let go of your expectations (which are now erroneous) it can cause you to lose precious minutes in formulating a response.

Student Notes:

So what's wrong with being surprised?

- Surprise is "unpleasant"
- We may feel resistance to letting go of what we thought we knew

8. Types of SurprisesBolt from the Blue

Instructor Notes: There are all kinds of surprises. With the "Bolt from the Blue", the event unfolding was not in your experience, training, or maybe even your imagination. In the world of weather, this might mean that what is happening is not to be found (yet) in the literature. In other words, there is no conceptual model for what is unfolding and

therefore, what actions one might need to take. Nature may be providing hints, but you don't recognize them.

Student Notes:

Types of Surprises
Bolt from the Blue

- No expectations
- No conceptual model
- No "hint"

9. Types of SurprisesBolt from the Blue

Instructor Notes: One example of a "bolt from the blue" might be the events of 9/11. At 8am on that day, the United States was considered in a "State of Deep Peace" with "No threats assessed against our country." The belief at the time implied that if there were to be a threat, it would come from across the ocean, hence radars were on the coast pointed outward. There was not a conceptual model which outlined what was about to happen. Yet, within an hour of the events starting to unfold, a complete ground stop had been ordered (that had never happened before), and permissions were granted for Air Force fighter jets to shoot down a commercial US airplane. Unthinkable the day before! In this case, we saw the birth of a new conceptual model that future learners will have the benefit of knowing about.

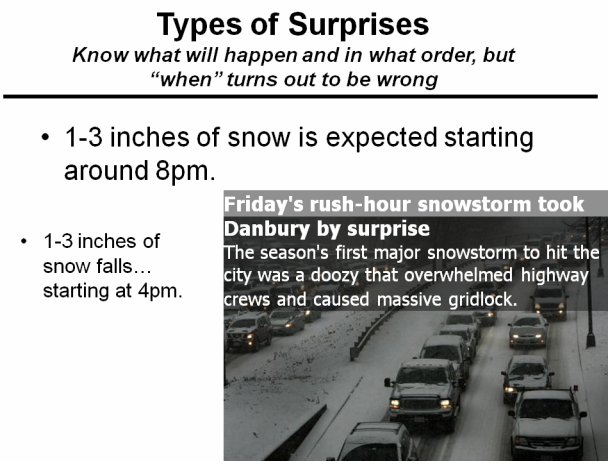
Student Notes:

Types of Surprises
Bolt from the Blue

10. Slide 10

Instructor Notes: Other types of surprises are a little more subtle. Perhaps this is a day when you feel confident about what is going to happen and in what order, but your assessment of “when” turns out to be wrong. A perfect forecast of rain changing to snow with 1-3 inches accumulating is all for naught when the rain changes to snow not at 8pm as expected, but at 4pm at the start of rush hour. Event is the same but the start time is a little different and the impacts, in this case, just increased from moderate to significant.

Student Notes:



11. Slide 11

Instructor Notes: Or in this case where you are expecting the event, but the duration of it is a surprise. A couple hours of freezing drizzle at 10 pm might not do too much. But your expectation that temperatures would warm slightly causing the freezing part to cease and desist, does not seem to be happening. Hour after hour, you are still expecting temperatures to warm, but they never do. Next thing you know that tree outside your window starts losing branches with accumulating ice. Your minor impact event, with some traffic implications for a couple hours, has gradually become a major ice storm with traffic and power implications. All for a couple of degrees. In this case, the event unfolded very gradually, which can mean you have more time to respond, but may make it harder to realize it’s happening.

Student Notes:

Types of Surprises

Event is expected; duration is wrong

- Freezing Drizzle forecast
- 24 hours of it is not

12. Slide 12

Instructor Notes: For events that you actually are expecting, you can still get caught off guard when they turn into something extreme. On this day, a High Risk of severe weather was expected with hail likely and some isolated tornadoes. Sounds like a typical severe weather day in the Plains. What wasn't expected was an event of historical magnitude which would capture national attention, and impact communities and staff for years to come. Actions that went with the high end event (not expected with a 'typical' event) included capturing data real-time, planning for the onslaught of national media, reworking the schedule.

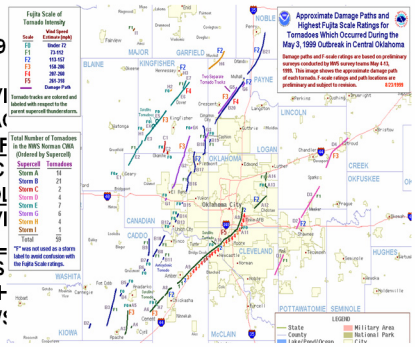
Student Notes:

Types of Surprises

Event is evident, magnitude is wrong

Outlook from 349

STORM RELATIVI
THIS EVENING A
THE DRY LINE AF
ENHANCE HELIC
LINE. THUS...ISOL
WITH THE ACTIVI
THREAT BEING L
18Z RUN SHOWS
J/KG ACROSS TH
300 AND 400 M2/S

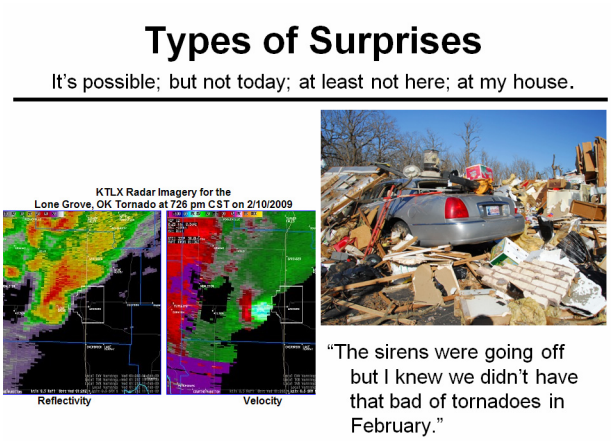


13. Types of SurprisesIt's possible; but not today; at least not here; at my house.

Instructor Notes: Surprises may also happen with our public users. And it may be a surprise to us that it's a surprise to them. In this case, forecasters are on top of the event. But at the receiving end, the user is still surprised by what is unfolding as is revealed in

their stating, “The sirens were going off but I knew we didn’t have that bad of tornadoes in February.” Social scientists can do more to help us shed light on how best to communicate rare events to a public that is already fighting an uphill battle in thinking they personally are ever at risk.

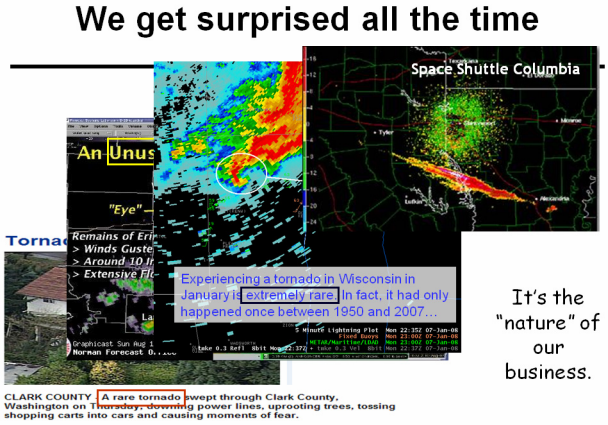
Student Notes:



14. We get surprised all the time

Instructor Notes: In reality, the business of forecasting weather is fraught with unexpected events. Whether it’s a tornado in the Pacific Northwest, tropical storm intensifying in the plains, a tornado with snow cover in the upper midwest, or the demise of the space shuttle, we should learn to expect the unexpected. It’s the nature of our business.

Student Notes:



15. ExpectationsCan be a way to combat surprises

Instructor Notes: Forming expectations can be way to combat surprises. Having expectations that turn out to be valid can shorten the time it takes to respond with the correct actions. In surveys done with NWS forecasters, having a good understanding of the environment, which is important in forming valid expectations, is the number one key

to a successful warning event. In contrast, having expectations that turn out to be invalid can lengthen the time it takes to undergo proper action. This is because we tend to assume all our expectations are valid and all are decisions are correct. Because of that, there is the tendency to only accept cues that support our belief, and explain away, minimize, or ignore cues to the contrary. This is referred to as confirmation bias. It's what can happen once we make up our mind, whether it is about the forecast, our political choices, or our favorite sports team. All of that denial uses up valuable time which should be put to updating our SA and as a result, our actions.

Student Notes:

Expectations

Can be a way to combat surprises

- Valid expectations shorten time to action
  - NWS forecasters: understanding environment is #1 key to successful warning event , however
- Invalid expectations can lengthen time to action
  - We assume our expectations are valid!
  - We tend accept supporting cues
  - We tend to explain away/ignore conflicting cues (Confirmation Bias)

16. What's wrong with this woman?

Instructor Notes: This young woman is in charge of a big meeting about to get underway. She's briefing all the organizers. "I believe we've thought of everything unexpected," she proudly states. So what's wrong with her statement? There's nothing wrong with imagining what could surprise you and being ready for it. That's actually a good use of your time. Her problem appeared when she decided they had all possibilities covered. Once you do that, you stop looking for evidence to the contrary. You get complacent. She's no longer being proactive, she's going into an overconfidence abyss. And she's taking everyone else with her. She must be stopped!

Student Notes:

What's wrong with this woman?

17. How are you able to respond to surprises?

Instructor Notes: There are a couple of things you can do to help yourself notice and then respond to the unexpected. The first, and perhaps the most difficult, is changing your mindset. It's important to be aware of confirmation bias and constantly be on guard against it. When you allow for a range of possibilities, not just the one you've settled on, you are halfway there. Next you must be physically able to detect cues that may tell you something different is afoot. Let's say a family member may need a ride to work from you, although chances are low. You say, "OK – just call me." Then you don't ensure you have our cell phone. You've altered the mindset, but you haven't made yourself available to the data. You need access to the data, and then you have to have a car to take the proper action! In order to have a chance at responding to unexpected events, you need to do both of these. This is what Highly Reliable Organizations do.

Student Notes:

How are you able to respond to surprises?

1. Mental - Overcome Mindset
   - Allow other possibilities to exist
2. Physical - Position Yourself
   - Be able to detect cues when they sprout
   - Be empowered to act on them when you see them

This is what Highly Reliable Organizations do!

18. Highly Reliable Organizations (HROs)

Instructor Notes: Highly Reliable Organizations (HROs) are far from perfect. They are defined by how they co-exist with all the variables in their environment. First, they work

in an environment that is complex, unstable, and to varying degrees, unknowable and unpredictable. This is not because they are lazy, but rather due to the nature of their environment. Next, because of this they have at any point in time, an incomplete understanding of their own "system". A very important thing occurs when they accept these facts. It allows for the possibility of something unexpected. This then helps them have a mitigation plan (because then know it will be needed at some point). If they can't mitigate the event, they then will attempt to contain it (damage control). In spite of all this, sometimes all will fail. In that case, they will focus on resilience. The ability to be resilient is critical to learning and moving forward.

Student Notes:

Highly Reliable Organizations (HROs)

- Encounter unexpected events often because:
  - Environment is complex, unstable, unknowable, unpredictable
  - Have an incomplete understanding of their own "system"
    - Not always sure what they will face
- They accept these facts so
  - Big effort on mitigation (in addition to prevention)
  - When that fails, put effort into containment
  - When that fails, focus on resilience

19. Some HRO Environments

Instructor Notes: With this in mind, here are potentially some examples of organizations that can function as Highly Reliable Organizations. They all represent domains that are complex, uncertain, and every changing. What is needed now is how individuals respond within those domains.

Student Notes:

Some HRO Environments

20. Characteristics of HROs

Instructor Notes: Based on work done by Weick and Sutcliff, here are some of the attributes that can determine if you are a highly reliable organization. They are Preoccupied with Failure They practice a Sensitivity to Operations They have a Commitment to Resilience They exhibit a Deference to Expertise Proper use of Mindfulness/Mindlessness We'll talk a little about what is meant by each of these.

Student Notes:

Characteristics of HROs

1. They are Preoccupied with Failure
2. They practice a Sensitivity to Operations
3. They have a Commitment to Resilience
4. They exhibit a Deference to Expertise
5. Proper use of Mindfulness/Mindlessness

21. 1. They are Preoccupied with Failure

Instructor Notes: HROs are preoccupied with failure. While this sounds like something negative, it's a characteristic that keeps them grounded. Success (especially recent success) can make an individual or organization complacent. The minute we decide we have it all figured out, we stop look for places to improve. One of the ways to improve is the freedom to acknowledge errors. That is actually the first step in improving. Instead of someone who make an error being chastised, they are looked at as being willing to help the organization as a whole improve. There is not a stigma attached. They also know the difference between being lucky and being good. We've all made the right decision for the wrong reason. We can either pat ourselves on the back and think "Wow! I'm good!", or think, "That was close!", and do nothing. Or we can say, "We were lucky this time; next time that may not be the case." As this SOO, quoted after experiencing a very successful event, admonished the staff, "We're still just one missed event away from a warning disaster."

Student Notes:

1. They are Preoccupied with Failure

- Success doesn't result in gloating
  - *Aware that success breeds complacency*
- Encourage reporting of errors
- Consider near misses as failures
  - *We were lucky, not good.*

"We're still just one missed event away from a warning disaster." *NWS SOO*

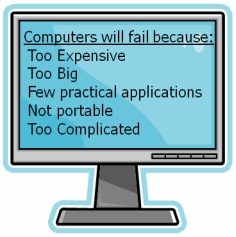
22. Preoccupation with FailurePre-Mortem*

Instructor Notes: One way a preoccupation with failure can produce benefits is by practicing a "pre-mortem". This technique developed by Klein Associates uses mental simulation to identify key vulnerabilities in a plan. It's a way to first admit your expectations might be imperfect, and then identify and be on the lookout for information which illustrates that. Imagine a pre-mortem years ago that PC developers might have done musing about why this invention might fail. Watching for and or mitigating things on this list will help you be more successful. A pre-mortem of sorts which is based on your expectations will help you identify the indicators that you might see if your expectations are going south.

Student Notes:

Preoccupation with Failure
Pre*-Mortem

A method which uses mental simulation to identify key vulnerabilities in a plan.



What are the indicators I will see if my expectations are going bad?

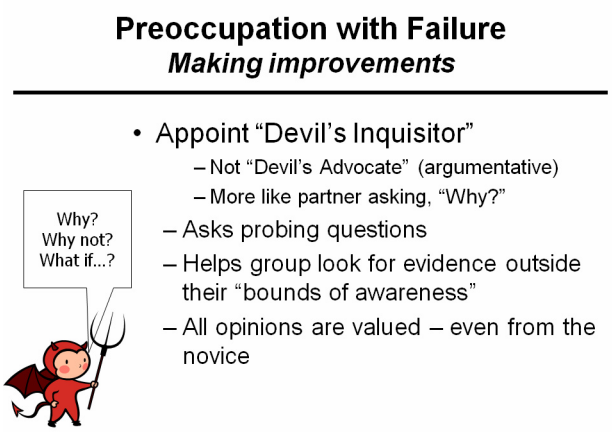
* Klein Associates

23. Preoccupation with FailureMaking improvements

Instructor Notes: Another strategy you can employ is that of a Devils' Inquisitor. This is not the same as a devils advocate who plays an argumentative role, but more like a partner who is on the lookout for problems. When someone has the role, questioning is no longer threatening. Pointing out inconsistencies is not an accusation of inadequacy. He

or she can help the group look for evidence that is outside their “bounds of awareness”, because that’s what you want them to do. This helps to mitigate the so called “Group Think” process where everyone goes down the same flawed road together. A devil’s inquisitor works when all opinions are valued, even those from the novice. This role can be assigned to one person, or if you’re really good, can be assigned to all.

Student Notes:



24. Slide 24

Instructor Notes: Another way to make improvements can be borrowed from aviation protocol which now includes Crew Resource Management (CRM) findings. With CRM, the crew works together, with the assumption that any member of the crew, not just the pilot, can offer valued insight. This acknowledges that even those with lots of experience can make mistakes. Anyone can have a perspective that can offer valuable information. This can come in spite of age, experience, rank or qualifications. Someone outside looking in may see things that would be explained had they more information or experience. But sometimes they might offer a splash of cold water to wake you up to possibilities. Ultimately, humility is what enables this to work. In the words of this SOO, “In some ways, experience may have hurt in this case…but the Met Intern didn't care that it was January. He saw upper 50s dewpoints and tremendous shear, and was excited about severe weather.”

Student Notes:

Preoccupation with Failure

Making improvements – Aviation findings with CRM

- Even when you have a lot of experience, you can still make mistakes
- Listen to everyone
- Look beyond age, experience, rank, qualifications
- Humility is good

"In some ways, experience may have hurt in this case...but the Met Intern didn't care that it was January. He saw upper 50s dewpoints and tremendous shear, and was excited about severe weather." NWS SOO

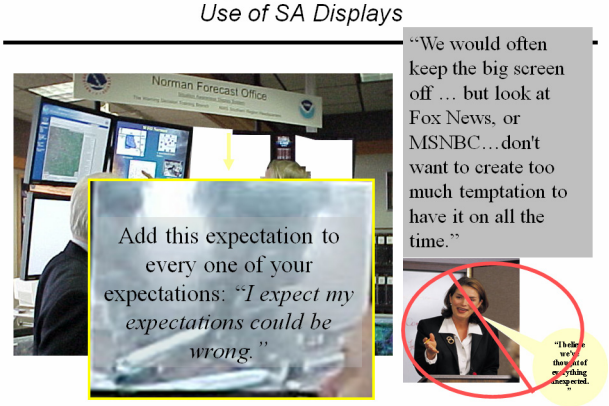
25. Preoccupation with FailureUse of SA Displays

Instructor Notes: The way you configure your SA display can offer a way to head failure off. Perhaps you only have certain things on display when your are expecting certain kinds of weather. If in this case, you weren't expecting weather so you turned off the TV feeds to keep down "distractions", you would have missed the news story showing a train derailment due to river flooding at a compromised bridge. The resulting toxic spill into the river will shortly be something you are involved when you ultimately get notified of this event. Populating your SA Display in such a way that you can catch surprises, or things you are not expecting, is one way to physically set yourself up for success. You've done that by adding this expectation to every one of your expectations: "I expect my expectations could be wrong." It's one way to make sure this woman doesn't show up!

Student Notes:

Preoccupation with Failure

Use of SA Displays



26. 2. They have a Sensitivity to Operations

Instructor Notes: A sensitivity to operations means an organization prioritizes and responds to factors that are affecting operations. You are on the lookout for "latent conditions", or those conditions that are sitting around every day waiting to combine with

other factors to result in a disaster. Root Cause Analysis helps to reveal these latent conditions (more about both of these in Core 3, Lesson 3: Learning from Post Mortems). Some examples of latent conditions that might need addressing before they show up to negatively impact an event include: not wearing seatbelts, budget cuts, a culture of silence, personnel turn over, belief systems, and personality conflicts.

Student Notes:

2. They have a Sensitivity to Operations

Important to Identify Latent Conditions that may have impacts

- Budget Cuts
- Culture of Silence
- Personnel Turn Over
- Belief Systems (tornadoes don't happen here)
- Personality Conflicts

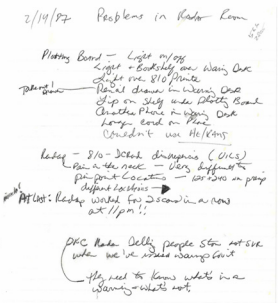
27. Sensitivity to OperationsMaking improvements

Instructor Notes: When sensitivity to operations is a priority, management immerses in real-time information. They treat operations as gold by assuring they have it gets undivided and thorough attention. Taking steps to support operational SA is critical. This chicken scratch example is the result of management requesting help to understand what worked and want didn't during a severe weather event the day before. While crude, the resulting list of things which impeded operations provided valuable information to the management team which allowed them to address each concern within 24 hours of the event. That is showing a sensitivity to operations.

Student Notes:

Sensitivity to Operations
Making improvements

- Management immerses in real-time information
- Operations are gold
  - Operations get undivided and widespread attention
  - Support Operational SA



28. 3. They have a Commitment to Resilience

Instructor Notes: Next , HROs will have a Commitment to Resilience. This is critical because, as stated before, the world of formulating weather expectations is imperfect. Stuff happens. Knowing that and accepting that, you can be willing to quickly relocate resources to where they are needed most. In addition,the ability to creatively improvise can mean the difference between failure and success. Think of how important that was with the flight of Apollo 13 as they tried to figure out amongst other things, how to make a square peg fit into a round hole.

Student Notes:

3. They have a Commitment to Resilience

- Stuff happens
- Relocate resources at will
- Encourage improvisation

"Mission control devised a way to attach the CM canisters to the LM system by using plastic bags, cardboard and tape, all materials carried on board."
- NASA

Apollo 13 crew after their "successful failure."

29. ResilienceMaking improvements

Instructor Notes: In practice, one can improve resilience by encouraging 'conceptual slack'. That means you have a culture and environment which allows teams to express opinions openly. Questioning is acceptable and that is because there is respect in the interaction. You don't have to agree, but you do have to respect. In training, resilience can be beefed up by allowing the training environment to be imperfect. If things fail, practice recovery. Insert problems and surprises into the situation. It can allow one to strengthen their ability to cope with disturbances. Finally, be prepared to take action on what is happening before you understand why. While it would help to know why things are going south, it should not be a prerequsite for taking action. You may not ever fully understand what went wrong and why, but you can take action to mitigate the impacts.

Student Notes:

Resilience
Making improvements

- Encourage "conceptual slack"
  - Divergence in team and opinions
  - Willingness to question
  - Respectful interaction
- Training
  - Allow things to fall apart – practice recovery
  - Develop capability to cope with disturbance
- Actions
  - Take action on what before you fully understand why
    - Maybe you'll never understand why

30. 4. They practice a Deference to Expertise

Instructor Notes: HROs will practice a Deference to Expertise. This means they respect expertise, wherever it is found. They understand the value of the system, but are willing to bypass it when necessary. Instead of the senior person being the source of all answers, the question essentially migrates around looking for the expertise.

Student Notes:

4. They practice a Deference to Expertise

- Bypass system when necessary
- Decisions "migrate" around looking for the expert

31. Deference to ExpertiseMaking improvements

Instructor Notes: One way to accomplish this is to practice "coordinate" leadership. This means that anyone can be the leader in the area in which they have the expertise. This might mean the MIC defers to the FIC during the severe weather shift, who for a particular problem, defers to the intern who had just been trained on this piece of software. This may seem obvious to some, however, this is not a given in everyone's cultural experience. The quote from this MIC indicates the office philosophy when the staff is empowered to use their judgment and experience to the best of their ability. Of course, the MIC will need to back that up!

Student Notes:

Deference to Expertise
Making improvements

- Practice "Coordinate" leadership
  - Shifting leadership role to person who has the answers to problem at hand

MIC Defers To FIC

FIC Defers Intern

Intern most familiar with this application

"Operational staff should be empowered to respond to situations based on their judgment and experience."
NWS MIC

32. 5. Proper use of Mindfulness and Mindlessness

Instructor Notes: Mindlessness sounds like a bad thing, but it has its place. To do routine activities without having to spend time thinking about them conserves resources. One example you probably do a lot is using cruise control in your car. It saves gas and allows your foot to rest. This works so longs as status quo conditions exist. The challenge will be when the status quo is busted. For cruise control, you come across debris in the road, or an unexpected detour, or freezing drizzle starts to fall. Conditions are no longer homogeneous. At that point you are required to intervene. If you haven't noticed that things have changed, or haven't been involved in the process until change occurs, you may have a hard time knowing what intervention is required. As Capt. Sullenberger can attest, while the automation helps in lull periods, it requires more out of you in unique or high demand situations. This is because there is often a lot more to monitor, sort through, and make sense of when something unusual is unfolding.

Student Notes:

5. Proper use of *Mindful*ness and *Mindless*ness

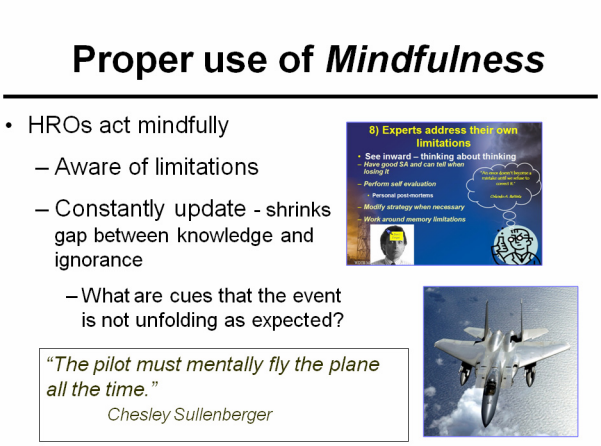
- Mindlessness benefits
  - Conserves resources
  - Cruise control
    - Gas saver
    - Foot saver
- Assumes status quo
  - Conditions rarely stay homogeneous
- Intervention required
  - Did you notice that things are no longer status quo?

"Automation decreases workload in lull periods; automation increases workload in unique or high demand situations. " *Chesley Sullenberger*

33. Proper use of Mindfulness

Instructor Notes: HROs know when to be mindful. They start by being aware of their limitations. This is a trait of experts universally (discussed in Core 3). One of the ways to do this is to constantly update your understanding. By doing this you may be more able to recognize surprising cues closer to when they occur. To quote Capt. Sullenberger, “The pilot must mentally fly the plane all the time.” This means you are engaged and vigilant even when you’re on auto pilot.

Student Notes:



34. How to improve Mindfulness

Instructor Notes: One of the ways to promote mindfulness is with feedback on behaviors which are applauded and those which are not. One of the biggest boulders to overcome for some people is to ask for help. This can lead to being understaffed, overworked, loss of SA and the consequences which result. Recognize when you or the team are falling behind and ask for help. Management needs to support that decision as the right decision, not a sign of weakness. Next, we can get by sometimes when we operate on our own without the input of others. Eventually though, it will likely come back to haunt us. Supporting an attitude of including viewpoints and questions, even when they are from new or inexperienced voices, is a practice that will promote mindfulness. This practice takes more than words in order to provide an environment in which all can speak up. It takes action and follow Finally, when we start to let success go to are heads, we are in trouble. Eventually we might think, hey, I am really really good at this, in fact, maybe I’m perfect! Then who shows up again? She does! In any event we do well, there is always some area in which we can improve.

Student Notes:

How to improve Mindfulness

- Approval for behaviors that support mindfulness
  - Asking for help
  - Soliciting "lower ranking" input
  - Not letting success go to your head
    - Remember: Success breeds complacency

35. Improving mindfulness…cont

Instructor Notes: One of the best ways to support behaviors which promote mindfulness is in modeling the behavior. So often people are afraid to admit mistakes. We are human, we operate in an imperfect environment – mistakes and misjudgments will be made. When someone at the top admits mistakes, it makes others feel free to do so. Some theories of learning indicate that errors from critical events are what allow learning to take place. Knowing we are not perfect opens the door for others to question without offending. It essentially wipes out face threat. By asking anyone who is aware of a potentially harmful latent condition to speak up, we can all feel like we are on one team and essentially have each other's backs.

Student Notes:

Improving mindfulness…cont

- Support behaviors which promote mindfulness
  - Admit mistakes
    "In some theories of learning, errors form the critical events that allow learning to take place."
  - I'm not perfect; you can question me
  - Are you aware of a potentially harmful latent condition? Please…speak up!

36. Slide 36

Instructor Notes: The last way we'll discuss in improving mindfulness is in addressing overconfidence. There is nothing wrong with being confident, that is what allows us to move forward. It is when we are overconfident that we have problems. Problems which arrive from overconfidence are that it may keep you from: Collecting key information

(since you already know it all) Learning from mistakes, since you won't make them often (or make them again) Most people over estimate what they know, in trivia as well as in their own field. To illustrate this point, we will do a little self test on Overconfidence.

Student Notes:

How to improve mindfulness

- If overconfident, may not
  - Collect key information
  - Learn from mistakes
- Most people over estimate what they know
  - In trivia as well as in their own field
  - Try Self-Test

37. Take Overconfidence Assessment

Instructor Notes: At this point, stop and take no more than 3 or 4 minutes to go through the overconfidence assessment. Your goal is not to "know" the answer, because odds are you don't. Try to bracket the answer with a range of values. If you make the interval too narrow, you are overestimating what you know. Too large, and you are underestimating. When you look at your completed assessment, you should be 90% confident that the correct answer lies within the range you chose. When finished, go on to next slide.

Student Notes:

Take Overconfidence Assessment

- Take "assessment"
- Spend no more than 3 or 4 minutes.
- Bracket the answer within a range.
- When done advance to next slide.

38. Over Confidence AssessmentQuestions

Instructor Notes: The answers aren't in this handout, but you'll find them in the presentation. Note: if you feel the need to go off and research these before filling our you're answers, you kind of missing the point! So don't do it!

Student Notes:

Over Confidence Assessment Questions

Self-Test of Overconfidence

For each of the following ten items, provide a low and high guess such that you are 90 percent sure the correct answer falls between the two. Your challenge is to be neither too narrow (i.e. overconfident) nor too wide (i.e. underconfident). In otherwords, the point of this is not to see how much trivia you know, but for you to successfully capture the correct answer in your range of uncertainty. If you meet this challenge, you should miss only 1.

	90% Confidence Range Low	High
1. Martin Luther King's age at death	____	____
2. Length of the Nile River	____	____
3. Number of countries that are members of OPEC	____	____
4. Number of books in the Old Testament	____	____
5. Diameter of the moon in miles	____	____
6. Weight of an empty Boeing 747 in pounds	____	____
7. Year in which Wolfgang Amadeus Mozart was born	____	____
8. Gestation period (in days) of an Asian elephant	____	____
9. Air distance from London to Tokyo	____	____
10. Deepest (known) point in the oceans (in feet)	____	____

Decision Traps (1989)

39. Overconfidence Assessment

Instructor Notes: This pop quiz was NOT to see how much trivia you know, but to see if you are aware of the "bounds of your knowledge". Less than 1% of all people miss 0 or 1. Most managers miss between 4 and 7. That is, they think their knowledge is better than it is. Amazingly, percentages change little with job-specific questions. This type of overconfidence affects organizations as a whole when 1) people don't seek information because they think they already know, which leads to 2) decisions being made with less than optimum knowledge. This applies to decisions at all levels of an organization, and frankly, in all aspects of your life. When this overconfidence is strong, it contributes to the confirmation bias, where we once again, notice information that matches our beliefs and ignore or minimize the rest. The lesson of this is that which helps experts be experts and HROs become HROs: Having strengths is important. Admitting you have limitations and knowing them is equally important.

Student Notes:

Overconfidence Assessment

- Less than 1% of people miss 0 or 1
- Most managers miss 4-7
  - They think their knowledge is better than it is
- Percentages change little with job-specific questions
- Affects organizations as a whole
- Overconfidence and confirmation bias are related

Having strengths is important. Knowing your limitations is equally important.

40. Summary

Instructor Notes: To summarize the key things which will help you respond to unexpected events: Admit unexpected things will happen Knowing this, the two practices that will help you are to have the proper mindset of acceptance and then position yourself to pick up on the queues of an unfolding unexpected event Highly Reliable Organizations work in very complex changing, uncertain environments. They practice characteristics which help them respond and recover from unexpected events. These characteristics include Preoccupation with Failure Sensitivity to Operations Commitment to Resilience Deference to Expertise Proper use of Mindfulness/Mindlessness Knowing your strengths and limitations will help you address the problems of overconfidence and seek additional help and information when needed.

Student Notes:

Summary

- Unexpected things will happen
- Mindset and Positioning are two practices to help pick up these
- HROs work in complex, changing, uncertain environments
- HROs have practices which help respond / recover from unexpected events
- Know your strengths/limitations: address overconfidence

41. One more surpriseIt's possible; never actually expect it

Instructor Notes: Here's one last look at how a particular surprise was handled in real time. It's the kind of surprise that is in the realm of possibility, but you never really expect it.

Student Notes:

One more surprise

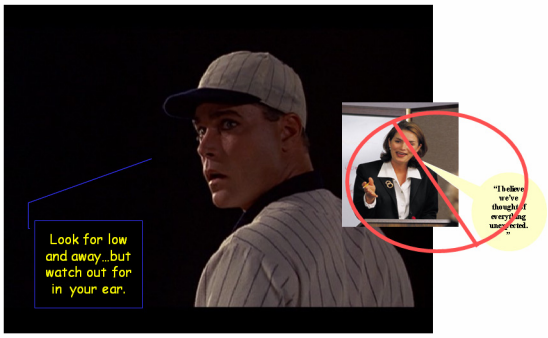
It's possible; never actually expect it

42. Your Mantra?

Instructor Notes: What should your mantra be? If you've ever seen the moving Field of Dreams, you'll recall Shoeless Joe Jackson's advice to the rookie Moonlight Graham as he stepped up to take his 3rd pitch, not knowing what to expect. Joe's advice, "Look for low and away…but watch out for in your ear." In other words, have expectations, just watch out for nature's curve ball! It's the best way to get rid of this woman for good!

Student Notes:

Your Mantra?



From "Field of Dreams" Universal Studios

43. For Additional Help

Instructor Notes: For additional help check with your AWOC facilitator or send your questions to awoccore_list@wdtb.noaa.gov. When you are ready, go to the LMS and take the test for AWOC Core 2, Lessons 1-5.

Student Notes:

For Additional Help

1. Check with your AWOC facilitator (most often the SOO)
2. Send your question to awoccore_list@wdtb.noaa.gov

44. Resources/References

Instructor Notes:

Student Notes:

Resources/References

- Managing the Unexpected. Karl E. Weick, Kathleen M. Sutcliff
- Intuition at Work. Gary Klein
- Decisions Without Blinders. Max H. Bazerman and Dolly Chugh. Harvard Business Review January 2006
- We Learn from our Mistakes – Don't We? Addie Johnson. Ergonomics in Design Spring 2004
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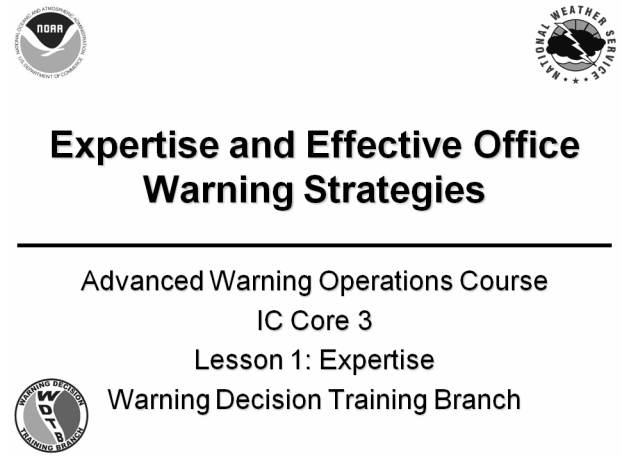
- AWOC RCAs 2005-2010
- WDM1 Survey Results 1997-98
- Managing the Risks or Organizational Accidents. Ken Hammond
- Highest Duty. Capt. Chesley Sullenberger
- Human Error. James Reason
- Decision Traps: Ten Barriers to Decision-making and How to Overcome Them. J. Edward Russo and Paul J.H. Shoemaker
- Who is Watching You? "J.T. Ragman" Flying Safety June 1999
- Defensive Driving. Wait, make that Defensive Flying. "J.T. Ragman" Flying Safety May 2002
- Anatomy of an Effective Warning: Event anticipation, data integration, feature recognition. Quoetone and Huckabee. WAF January 1995 Dallas, TX.
- Warning Decision Making: The Relative Roles of Conceptual Models, Technology, Strategy, and Forecaster Expertise on May 3rd, 1999, Andra, Quoetone, Bunting, 2002: Weather and Forecasting: Vol. 17, No. 3
- Cognitive Task Analysis of the Warning Forecaster Position. Klein et al,

1. Expertise and Effective Office Warning Strategies

Instructor Notes: IC Core 3 will begin with a discussion of Expertise. It will be important to understand what we mean by this term in order to appreciate its value throughout the remainder of this IC.

Student Notes:



2. Lesson 1:Expertise

Instructor Notes: See if you can recognize who these folks are. They all have something in common in that each is associated with a level of expert knowledge or performance in their domain. Whether your area is medicine, baseball, world affairs, pushing the aviation envelope, mitigating human suffering, or issuing warnings, there is a process by which you develop that skill.

Student Notes:

3. Learning Objectives

Instructor Notes: The learning objectives for this lesson are testable. They are: 1) Identify the difference between routine and adaptive experts and novices. 2) Identify the characteristics of an adaptive expert. 3) Describe how interactions with automation can hinder expertise. 4) Identify ways in which expertise is developed.

Student Notes:

Learning Objectives

1. Identify the differences between routine experts, adaptive experts, and novices
2. Identify the characteristics of an adaptive expert
3. Describe how interactions with automation can hinder expertise
4. Identify ways in which expertise is developed

4. ExpertiseOverview

Instructor Notes: During the next 30 minutes, we'll discuss at least some definitions of what constitutes an expert. We'll demonstrate why that expertise is so valuable to an organization. Automation is neither good nor bad. It just is. They way in which it is designed or the way it is applied in operations however can either foster or inhibit the development of expertise. Finally we'll look at what you can do to develop expertise in the area of warning operations. As we go through this talk, think of people you know in your domain, or in other domains with which you interact, and see where you think they fall in these descriptions.

Student Notes:

Expertise
Overview

1. What is an expert?
2. What is the value of an expert?
3. What can be the impacts of interactions with automation?
4. What do experts do to acquire and maintain expertise?

5. What is an Expert?

Instructor Notes: We all are novices at many things. I personally am a novice at judging how much air in a tire is too much (since when are tires not suppose to be “round” anymore?). Novices tend to live in the moment. They don’t easily make connections and the options they produce for action are limited. Next we have a routine expert. These people are great. They can swoop in and fix what’s wrong instantly; they can quote regulations. They only run into trouble when the situation takes on a unique appearance; looks out of the ordinary. Then their very strict processes don’t provide unique answers. What we are going to discuss for the remainder of this session is the adaptive expert. Their understanding goes deep. You probably really feel good working a stressful event in the company of this type of expert.

Student Notes:

6. Experience vs Expertise

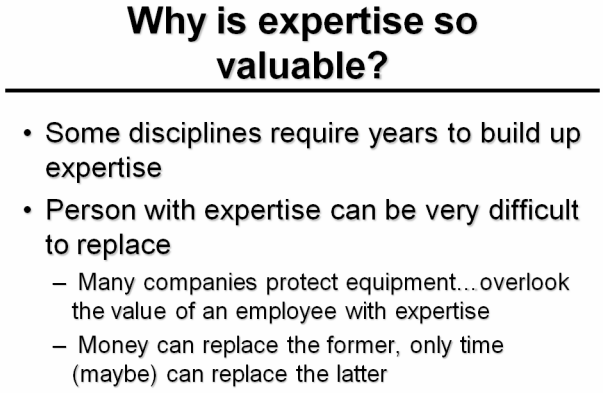
Instructor Notes: First we should stress that experience alone does not guarantee one develops expertise. This guy is fast but is he really good? Perhaps he’s good at being fast but that’s about it. This person in a forecast office may always get the products out on time but their content leaves something to be desired. What you do with each experience is more important in developing expertise than just having that experience.

Student Notes:

7. Why is expertise so valuable?

Instructor Notes: Why do we care about expertise? One reason is that it often takes time to grow and it can therefore be difficult to replace. Many organizations have made the mistake of saving money (in the short run) but investing in equipment but not in investing in the development of their employees.

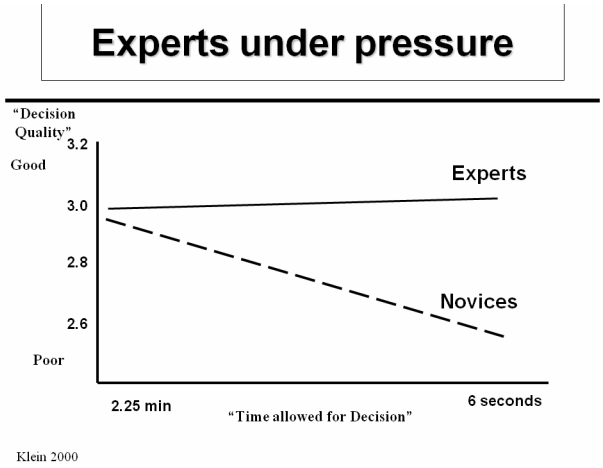
Student Notes:



8. Experts under pressure

Instructor Notes: Experts really shine when the pressure gets turned up. This study showed that the quality of decisions (as seen on the y axis), tends to remain the same as the time for that decision (on the x axis) is shortened…at least for the experts. The novice on the other hand succumbs to pressure and the quality of their decision making deteriorates.

Student Notes:



9. What do experts do so well that others don't?

Instructor Notes: So what do experts do so well that others don't? We'll take a look at each of these characteristics. Keep in mind how you might rate yourself using this criteria.

Student Notes:

What do experts do so well that others don't?

1. Recognize patterns
2. Detect anomalies
3. Keep the big picture (SA)
4. Understand the way things work
5. Observe opportunities, able to improvise
6. Relate past, present, and future events
7. Pick up on very subtle differences
8. Address their own limitations

10. Experts recognize patternsThe ability to see patterns gives us SA

Instructor Notes: Experts recognize patterns. With loads of data dumped on us continually, seeing a pattern, and seeing it quickly, is what can make all the difference. For fireground commanders, it's behavior of smoke in a burning building. It's connecting what looks like unrelated information to form a picture of what's happening. For a warning forecaster it's putting together a spotter report with a radar signature that tells you there's a high likelihood for a tornado. This relating cause and effect helps the development of SA.

Student Notes:

1) Experts recognize patterns

The ability to see patterns gives us SA

- Fireground commanders
  - Look at burning building and can infer what's happening inside. They relate cause and effect by connecting the dots.

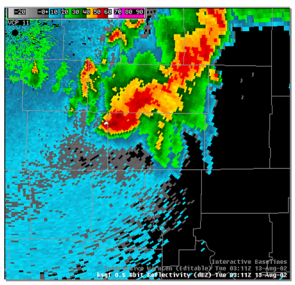
11. Patterns are seen in the raw data

Instructor Notes: Most experts in the warning environment recognize those patterns using base data. That may mean hi-res velocity and reflectivity data, or mesonet observations, or upper air analysis, or live TV video. They get to the data which has gone through the least amount of processing.

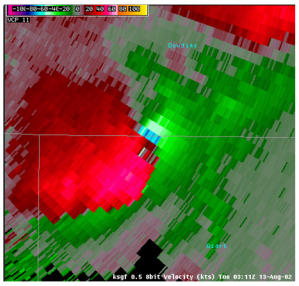
Student Notes:

Patterns are seen in the raw data

- Look at raw data when possible



DZ – 8 Bit Reflectivity

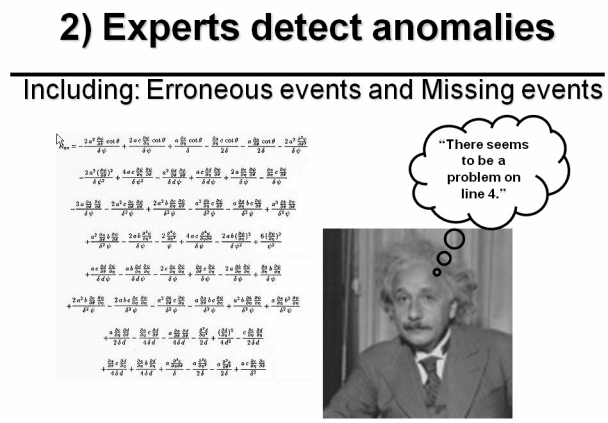


DV – 8 Bit Velocity

12. 2) Experts detect anomalies

Instructor Notes: One of the hardest things to do is detect things which are "just not right" or things which are missing. Albert sees the problem here, but I don't. He should, he wrote this equation. For warning operations, it might be a messed up surface observation which is impacting local analysis. Or it might be the lack of acknowledgement from a TV station regarding a warning you just issued (maybe it didn't go out?).

Student Notes:



13. 3) Experts keep the big picture

Instructor Notes: Experts often keep good SA. They tend to focus their energy on the important cues and filter out the rest. How do they know what's important? More on that later. They are able to weigh options and judge consequences of each. By contrast, the novice may actually suffer "paralysis by analysis". It's the never ending "one more volume scan" syndrome in which the novice hopes all uncertainty will vanish and the decision will be obvious. Experts are able to make decisions even when the picture is somewhat fuzzy (which it usually is).

Student Notes:

14. 4) Experts understand the way things work

Instructor Notes: Experts are aware of how and why things and processes are designed. This includes the need for communication and coordination. They have a good sense when to trust equipment and when not. They know when to go with a known practice, and when to deviate. In the 9/11 Commission report, the General violated "protocol" because he believed it was called for in this case.

Student Notes:

4) Experts understand the way things work

- Can see inside events and objects
- Know how tasks are supposed to be done
  - *Also know when to do them differently*

> "General Arnold instructed Col. Marr to 'go ahead and scramble the airplanes, and we'd get permission later.'"
>
> 9/11 Commission report Staff Statement #17 regarding the first notification of hijacking of AA 11.

- Know how teams coordinate
- Know strengths and limitations of equipment

15. 5) Experts observe opportunities, able to improvise

Instructor Notes: When data sources conflict, experts are often able to resolve the differences. Their deeper level of understanding also allows them see when expectations are not being met before it's too late. This helps them more readily "let go" of a previous expectation when it is clearly no longer valid. While the discussion here is regarding the earlier than expected stratus deck, it may also involve a strong rotational signature developing on a day where "no severe weather" is expected.

Student Notes:

5) Experts observe opportunities, able to improvise

- Have learned not to rely too heavily on guidance
  - Can generate explanations and predictions which are inconsistent with data

16. 6) Experts relate past, present, and future events

Instructor Notes: Experts quickly, and usually without being aware of it, make the connections between what has occurred, what is occurring, and therefore what is most likely in the future. They mentally simulate possibilities and outcomes and take action based on the result which gives the first good workable solution. They tend to look at a problem

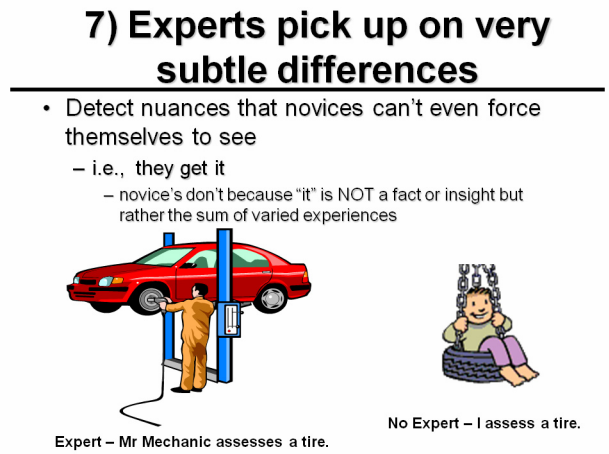
from more than one angle, allowing them to see more than one possible explanation for what is occurring.

Student Notes:

17. 7) Experts pick up on very subtle differences

Instructor Notes: Experts can pick up on subtle differences. The sum of their experiences has come together in a way to make this easier. Novices have not been assessing the same things and have not developed the same sensitivity.

Student Notes:



18. 8) Experts address their own limitations

Instructor Notes: Nobody's perfect, including experts. What allows someone to gain expertise is knowing this fact and constantly making an effort fill in the knowledge gaps. We all make mistakes. We grow in our expertise if we understand why and how a mistake was made. Experts will accept their limitations and work around them. They will be uncomfortable with a situation that doesn't work out as expected and will look at the reasons why. This knowledge will then be available to them the next time they are faced with a complex decision. This is how they get the most out of every experience.

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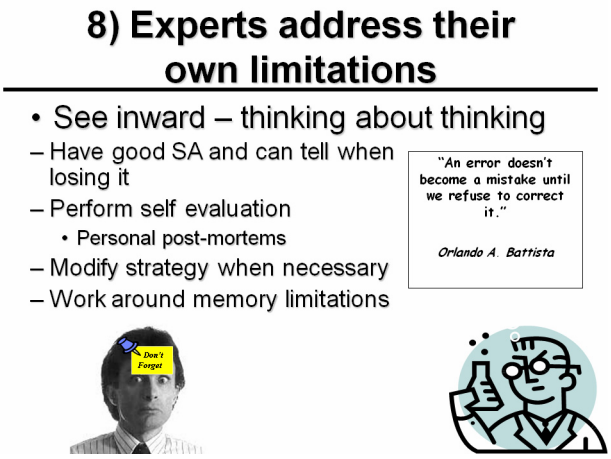


19. When and why you want experts

Instructor Notes: Experts are especially beneficial when a crisis erupts and, as is often the case, resolving it means dealing with fast paced decisions in an environment where data is not necessarily all pointing at the same answer. In this case from an NTSB file, one of the most important things this expert pilot did was ask for help when the workload became overwhelming. The group never did resolve the cause of the crisis, but still managed to work through the uncertainty and overcome the consequences of the initial problem before a catastrophe resulted.

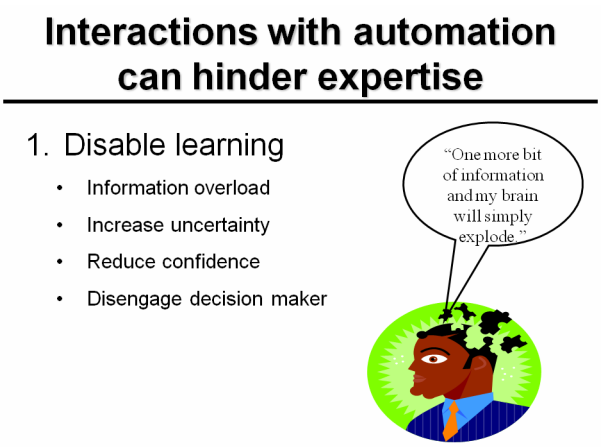
Student Notes:

20. Interactions with automation can hinder expertise

Instructor Notes: So we have looked at the characteristics of an expert, let's look at what can keep them from using that expertise, or what can hinder the novice from attaining it. When automation is inserted into the process without considering the user, it has the potential to "disable learning". If the automation has the characteristics listed here, it can have an affect on learning and application in real time. No doubt you have felt the impact of all these things at one time or another. Simply adding more and more informa-

tion is not always the answer. Is it better to have 2 sources which suggest 2 possibilities or 10 sources which suggest 10 possibilities? Neither! On the other hand, more and better information which helps us reduce uncertainty and increase confidence in our understanding of the threats is another story.

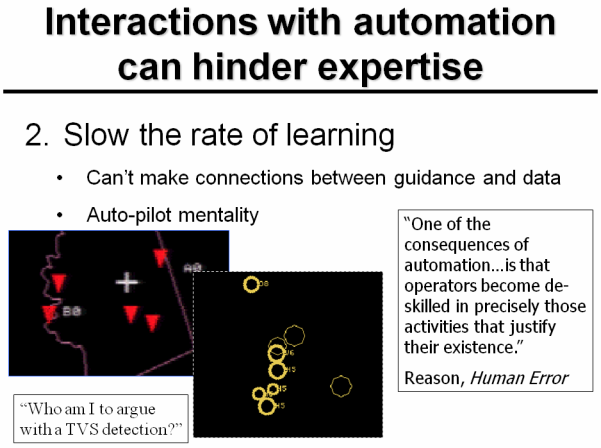
Student Notes:



21. Interactions with automation can hinder expertise

Instructor Notes: When the automation does not provide a means for the user to evaluate its validity, it can actually reduce the decision makers confidence it what they believe is happening, and may even cause them to disengage. This quote from James Reason is pretty telling. When we get to the point of saying we can't argue with the automation, we are implying we are no longer needed in this process. And with perfect automation that may be true. Until then, we need to be able to add value to the decision by using our expertise and incorporating the automation properly.

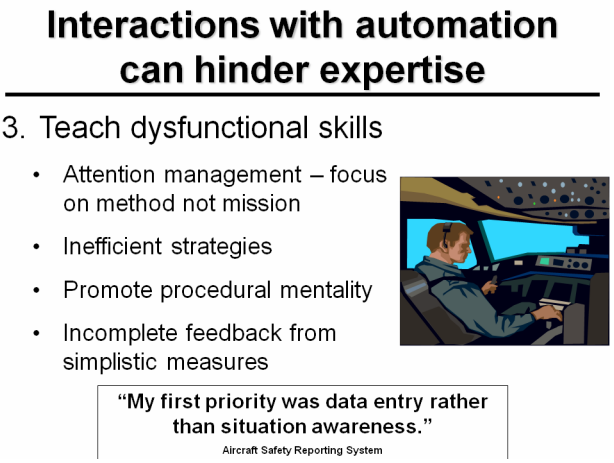
Student Notes:



22. Interactions with automation can hinder expertise

Instructor Notes: Sometimes automation can be so labor and attention intensive that we lose track of the process we are trying to accomplish. We don't get to tap into our expertise. The pilot quoted here is lost in the process of working the automation, so much so that he's losing SA. Another problem can arise if the feedback you get indicating whether you succeeded or not is not really representative of your skill, or one's idea of what success really means. Remember our guy who could shoot 10 arrows in 10 seconds? That was easy to measure but did it really measure what was important? Unfortunately, that simplistic measurement can get fed back into the system and ultimately be what we end up training for…in the previous case, not accuracy but speed.

Student Notes:



23. How to Retain/Develop Expertise

Instructor Notes: So what do we do? The process by which we assess, understand, and evaluate our decisions is very important. Automation, operations, and training which support the efforts to develop skills in pattern recognition and aid in constructing conceptual models are important. These efforts should also focus on making unusual and rare occurrences more recognizable. Routines are important…they save time. New routines need to be developed when skills or software or mission change. The routine you may have had 15 years ago (not you youngin's) has had to change considerably, as will the one you likely use 5 years from now. One of the best practices you can do is challenge your expectations, both during and after an event. Look at why they are not working out, or did not come to pass.

Student Notes:

How to Retain/Develop Expertise

- Support efforts to develop
  - Perceptual skills and pattern recognition
  - Construct conceptual models
  - Sense of typicality, ability to spot anomalies
  - Routines and workarounds
  - Form expectations, and learn why they did or did not pan out

24. How to Retain/Develop Expertise

Instructor Notes: One of the best ways to develop expertise is in simulations. Just as having experience doesn't guarantee you have expertise, going through a simulation won't either. It has to be pointed toward some goal which can be rather simple (get very comfortable with WARNGEN) or more complex (recognize MARC signatures). One thing that is common to all simulations is the process of evaluating reasoning, not just outcomes.

Student Notes:

How to Retain/Develop Expertise

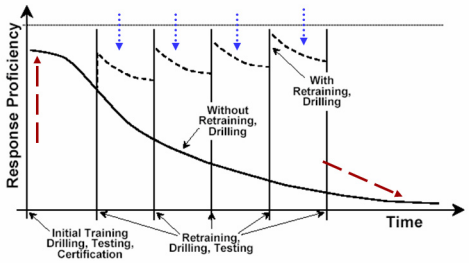
- Simulations
  - 25 hours of *well done* simulations can achieve the same effect as 2 years of experience (or much more)
  - Simulate as many of the "real" parts as possible
    - Including personnel interactions, time, stress, resource allocations, "bogus" data
  - Interject problems
  - Critique reasoning, not just outcomes

25. Simulations…once is not enough

Instructor Notes: This study revealed how proficiency was impacted by initial training (dashed arrow) and how it went to pot with time. Like watering a seed when you plant it, and then neglecting it and expecting it to grow without any further nourishment. However, with continued refresher training (dotted arrows), proficiency remains at a much higher level and can even improve. This is especially important when the event for which you're training is relatively rare (nature doesn't routinely offer chances to keep up skills otherwise).

Student Notes:

Simulations…once is not enough



*Based on: "Human Error Evaluation and Human Reliability Analysis"; B. J. Bell; American Institute of Chemical Engineers

26. How to Retain/Develop Expertise…cont

Instructor Notes: Asking "why?' is a great practice. It's how most of us learned at a very young age (hopefully, the answer you get when asking that question after a warning event is still not "because I said so."). Post-mortems are key to advancing knowledge and critical thinking. Looking at the raw data, something the Air Force refers to as "owning the data" also helps cement understanding and assists in solidifying conceptual models. Forming opinions based on objective analysis, and then looking at automated guidance helps avoid what researchers call the "automation bias". Studies have shown that decision makers are more likely to come to the "automated" solution if they look at the automated solution BEFORE forming their own opinion. In that case, they are less likely to resolve differences in what the automation says versus what their original opinion might have been.

Student Notes:

How to Retain/Develop Expertise…cont

- Post-mortems
  - Ask Why? Why? Why? and Why not?
- Look at raw data when possible
  - Stay as close to the "truth" when possible
  - Form opinions with this first then look to automated input (avoid automation bias)

27. Summary

Instructor Notes: A summary of the meaning and value of expertise.

Student Notes:

Summary

1. Experts are those that have a deep comprehension of the situation
2. They are extremely valuable to an organization, especially when problems are unique and constrained by time.
3. Automation, if not developed or integrated correctly, can hamper one's ability to gain or apply expertise.
4. Experiencing simulations, doing personal post-mortems, and resolving "why", are ways in which you can gain expertise.

28. Questions?

Instructor Notes:

Student Notes:

Questions?

1. Check with your AWOC facilitator (most often the SOO)

2. Send your questions to awoccore_list@wdtb.noaa.gov

29. References

Instructor Notes:

Student Notes:

References

Aviation Safety Network, http://aviation-safety.net/index.shtml

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Klein, Gary. (2000) *Sources of Power: How People Make Decisions*, Cambridge MA: MIT Press.

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Wood, David D., Johannesen, L., Cook, R., Sarter, N., *Behind Human Error: Cognitive Systems, Computers and Hindsight* (SOAR December 1994, from the Crew Systems Ergonomics Information Analysis Center). Wright-Patterson AFB, Columbus OH.

1. Expertise and Effective Office Warning Strategies

Instructor Notes: Continuing through the Expertise and Effective Office Warning Strategies instructional component, we will now look at a Cognitive Task Analysis of the warning process.

Student Notes:

Expertise and Effective Office Warning Strategies

Advanced Warning Operations Course
IC Core 3
Lesson 2: Cognitive Task Analysis
Warning Decision Training Branch

2. Lesson 2:Cognitive Task Analysis of expert warning forecasters

Instructor Notes: This lesson will share result of a CTA which was recently conducted using NWS expert warning forecasters.

Student Notes:

Lesson 2:
Cognitive Task Analysis of expert warning forecasters

What does expertise look like in NWS warning operations?

COGNITIVE TASK ANALYSIS OF THE WARNING FORECASTER TASK
Final Report
Order No. RA1330-02-SE-0280

Prepared by:
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Prepared for:
The National Weather Service
Office of Climate, Water, and Weather Services
Norman, OK 73071
December 31, 2002

3. Overview

Instructor Notes: We'll discuss what we mean by the term Cognitive Task Analysis, or CTA, and the process by which it was conducted. We will also look at the findings from

this study. These findings help us get a good picture of what an expert does and thinks as he or she encounters a severe weather event.

Student Notes:

Overview

1. What is a CTA
   - Process
2. CTA of NWS warning forecaster task: Findings
   - General approach to the weather
   - Use of technology
   - Developing mental models
   - Use of unusual cases
   - Working in teams
   - Relating with the public
   - Expert decisions

4. Learning Objectives

Instructor Notes: The learning objectives, which are testable, involve defining a CTA, and identifying the results of this particular CTA.

Student Notes:

Learning Objectives

1. Define a cognitive task analysis
2. Identify the results of the NWS CTA on expert warning forecasters

5. What is a CTA?

Instructor Notes: Did you ever work with someone who was about to retire and think, “Man we need to clone him before he leaves!”. Well a CTA tries to see what the characteristics of that “clone” might involve, at least in the area of interest. In this context, a CTA is defined as a study of the mental processes needed to perform a task proficiently. While a “task analysis” looks at the job tasks which are done to accomplish a goal, the CTA focuses on the thinking processes and reasoning of the person doing the task. Not just what they do, but how they come to the decisions they come to. A CTA can be done on anyone, but if you are attempting to capture and grow expertise, it is important to do this

with those who are considered experts. Findings from a CTA can help design research needs and guide training efforts in the direction of fostering, in our case, warning expertise. The results can also be used to direct hardware and software design to assist the expert in using their expertise, instead of working against them.

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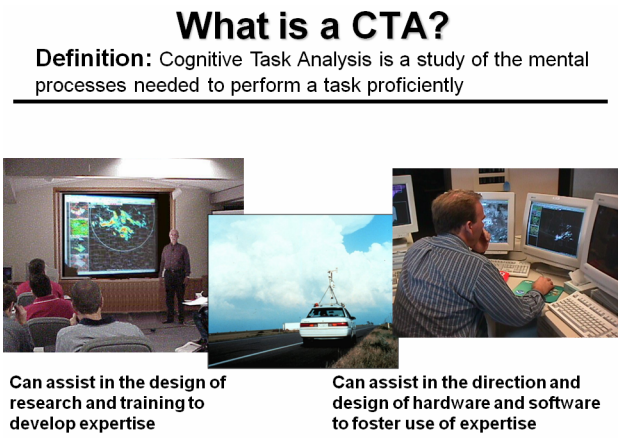

6. CTA Process

Instructor Notes: For the NWS CTA, Klein Associates, an organization which does human factors research with other high-stress, pressured domains (Army command and control, Aircraft carrier flight control) was commissioned to conduct a CTA on NWS warning forecasters. They interviewed 6 recognized warning forecast experts, each of which had between 12 and 20 years of experience in offices which covered all aspects of weather across the U.S. In addition, one novice was interviewed, the results of which were used as a control. The process involved interviews of actual events worked by each of the experts, rather than hypothetical situations. In other words, the CTA was focused around what these experts did, not what they might do. Many of you looking at this are probably considered experts, or know someone who is. The findings here will likely NOT be any surprise to you and in fact may describe you!

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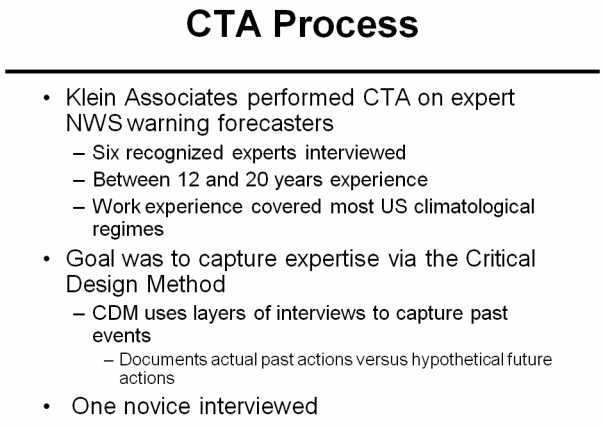

7. CTA Findings

Instructor Notes: The CTA produced several findings. First was the way that the experts approached weather in general. None considered weather an “8 to 5” job. They were on a lower level of “watch” when off duty but on watch nonetheless. What this means is that they are constantly in a learning, observing mode. The field of weather affords that opportunity more so than other domains. Experts will take advantage of this. By the time they go on duty, they’ve already formulated some expectations about what is in store for them that day. However, experts will frequently reassess expectations which helps prevent them from locking in on their initial assessment.

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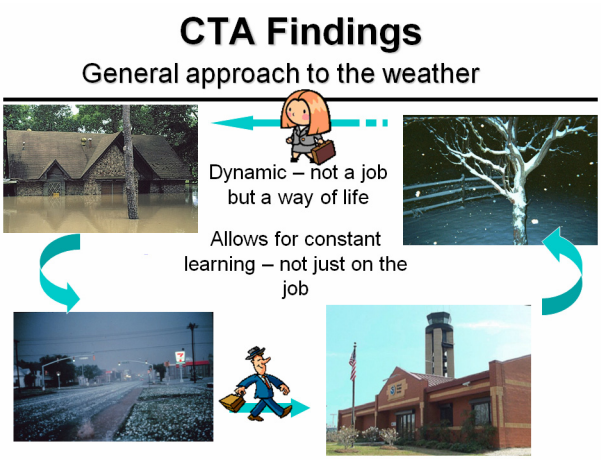

8. Slide 8

Instructor Notes: The second finding involved the use of technology. As you all know, the warning environment is technologically rich, and getting richer every day! This requires experts to have a strong understanding of the domain in which they are immersed and a constant effort to properly use the technology to the best outcome.

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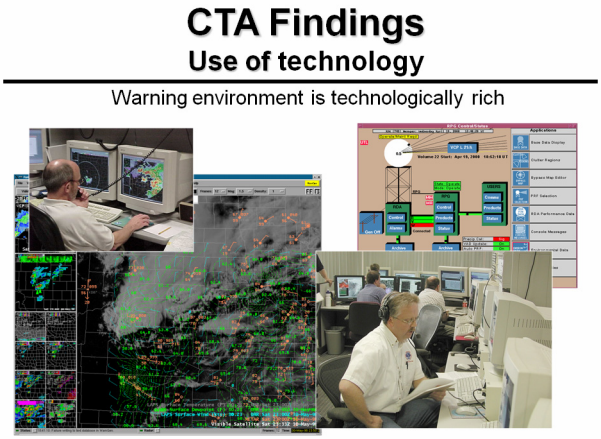

9. The scientific warning process

Instructor Notes: One of the ways experts do this is with a grounded warning process. This process is built around detailed and frequent base data analysis, the assimilation of ground truth, and considerations for the impacts of a representative mesoscale analysis. These things help illuminate conceptual models which help bring order and expectation out of the mountains of available data. The warning decision comes from this process, with the use of algorithms as a safety net to help catch things that slip through the cracks. The experts were aware however that this safety net has “holes” and therefore to rely on algorithms as a “first line of defense” is dangerous.

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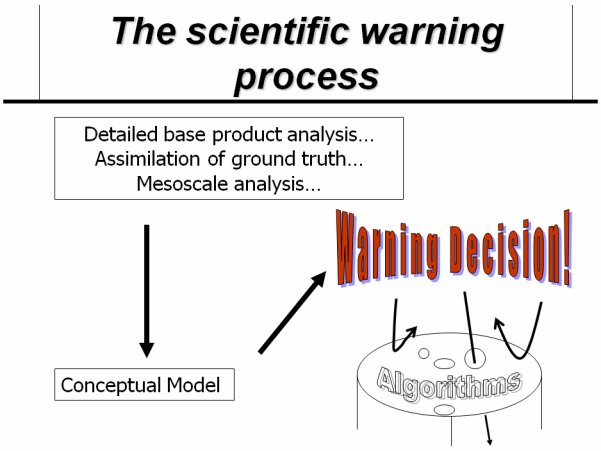

10. Experts put a high value on Base Data

Instructor Notes: All the experts interviewed here put a high value on base data analysis. They have developed numerous procedures and methodologies to make this analysis as quick and easy as possible. Their reasoning primarily comes from the base data being the closest data one has to the “truth”, with each step of processing thereafter having the potential of introducing additional levels of uncertainty. Since these experts are very aware of conceptual models, they are able to use the base data to recognize and validate those models. The challenges of base data analysis for these experts is the workload it places on individuals. However, most placed a high priority of ensuring staffing to support this effort.

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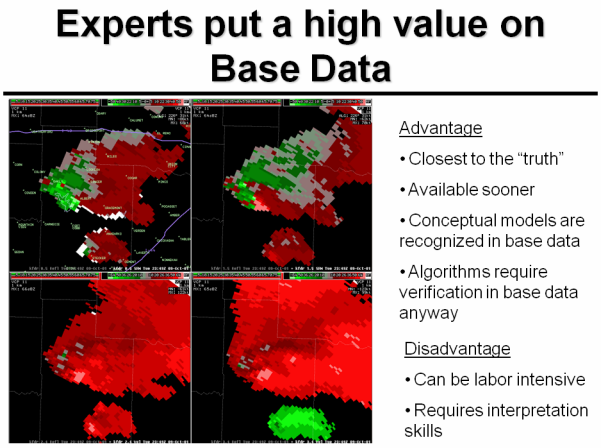

11. Use of Decision Aides

Instructor Notes: Decision aides, which may or may not use the output of algorithms, were also used to support expert warning forecasters. The experts found value in those outputs which were easily traceable to their base data inputs. This ability allowed them to develop confidence and reduce uncertainty. Outputs which added value above and beyond what was readily detectable in the base data were used more often. However, outputs which were difficult to verify or validate were considerably less likely to be used. On the other hand, novices are more likely to use decision aids without questioning their validity.

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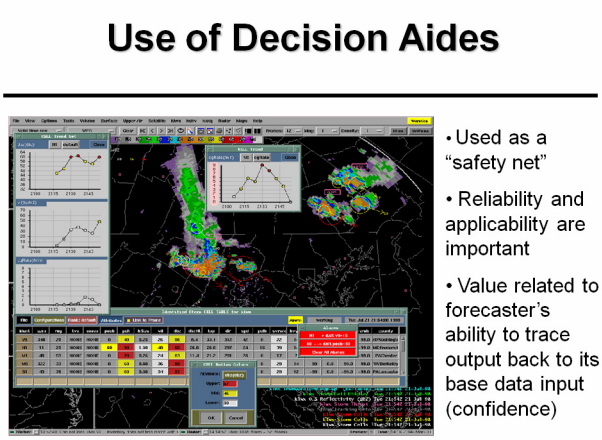

12. Basis for Warning Decision

Instructor Notes: For the expert warning forecasters, all data gets weighed against all other data, and in the context in which it is received. All data sources rarely point to an "obvious" answer. In addition, no one piece of data (except on extremely rare occasions) is ever enough to base a decision upon. The expertise comes in deciding on which side

of the scale inputs reside and how much weight each carries with it. The context in which the event is occurring is always being considered.

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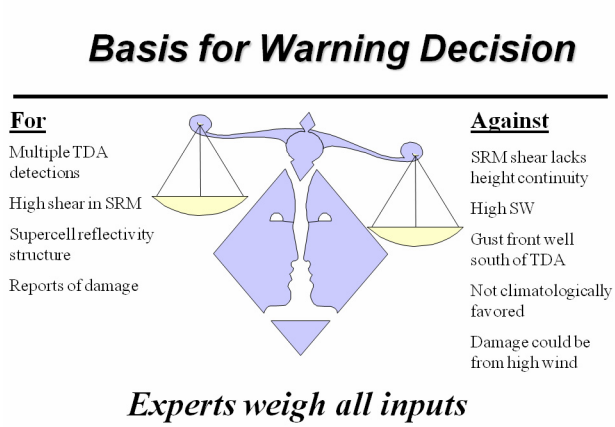

13. Slide 13

Instructor Notes: The CTA found that expert warning forecasters are very familiar with mental and conceptual models. This begins taking shape during the expectation phase before echoes appear on the radar screen. It was important for these forecasters to not get locked in on any particular threat, but rather consider a range of threat possibilities, each with an associated likelihood. This helps focus effort on the biggest threats and ensure resources are arranged to support that effort. At the same time, it was necessary to prevent tunnel vision ("flash flooding is not a threat today") which can contribute to the likelihood of low probability or rare events going undiagnosed. In addition, the experts were aware that oftentimes the signatures will not fit the "textbook" classics, but that they can still be good enough.

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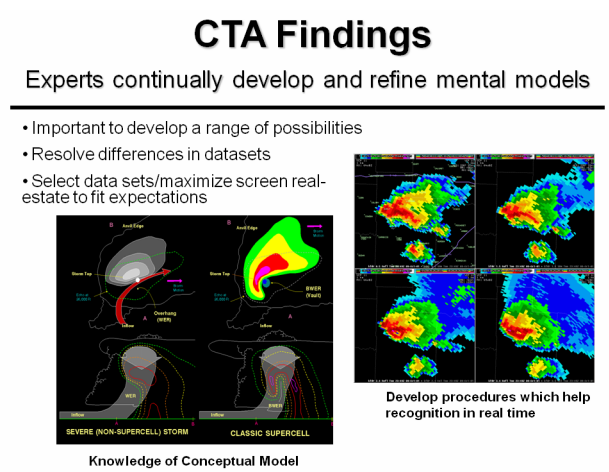
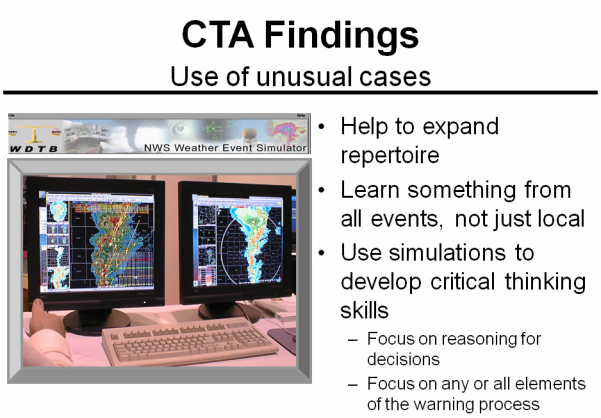


14. Slide 14

Instructor Notes: The experts were very prone to looking at numerous events in hindsight. This included events from other areas, even other countries, and events which, even though they were not common to their particular locale, were in the realm of possibilities. The benefit of doing this was to expand exposure and possibilities, as well as develop critical thinking skills. They viewed simulations as a challenge and sought to get the most out of any event they experienced.

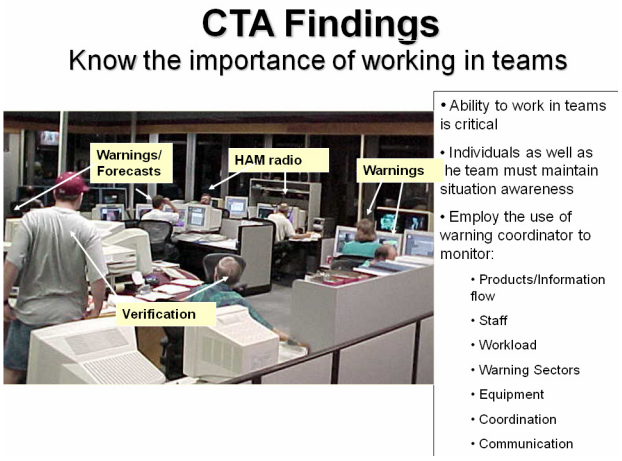
Student Notes:



15. Slide 15

Instructor Notes: The teamwork focus of the experts interviewed was a common theme. They considered success and failures as belonging to the office and the NWS, not just the person composing the warning. Each team member has a responsibility for communication and coordination as well as situation awareness. They valued the role of each member of the team, regardless of their experience level. The experts endorsed the use of a warning coordinator to help ensure nothing gets overlooked and that the message the office is sending is understood be each team member.

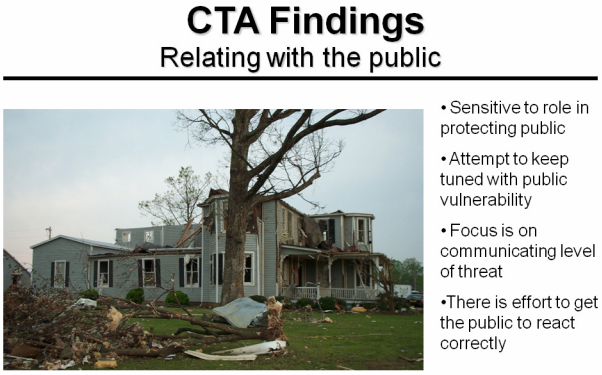
Student Notes:



16. Slide 16

Instructor Notes: The experts viewed issuing warnings as a social action which was based on a scientific decision. They were very focused on their relationship with the public and public vulnerabilities at any point in time. They did not view their job as just issuing a warning, but rather making attempts to elicit the best public response to ensure safety. A focus on a constant and consistent communication of the threat, both from sources within the office and with outside partners, was a critical piece of the job.

Student Notes:

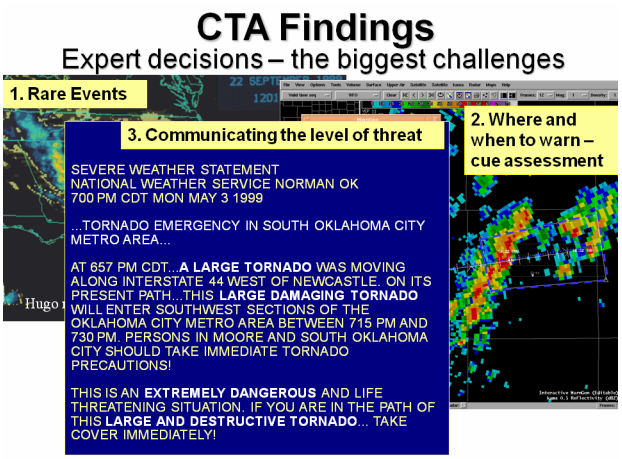


17. Slide 17

Instructor Notes: The biggest and most important challenge that the forecasters interviewed found in their jobs was the ability to rise to the occasion when the “big event” presented itself. It was believed that this was where the NWS needed to meet and even exceed all expectations. They tended to look at all events as having that potential, knowing that it is often not known ahead of time which event will be the one that defines your reputation or that of your office or the agency. Their belief was that seeing and properly reacting to these catastrophic events as they are unfolding (correctly assessing the rele-

vant cues) is the biggest challenge one is faced with in the forecast and warning environment. The importance of categorizing the threat once it is realized in words which convey not only its magnitude but its certainty was thought to be imperative.

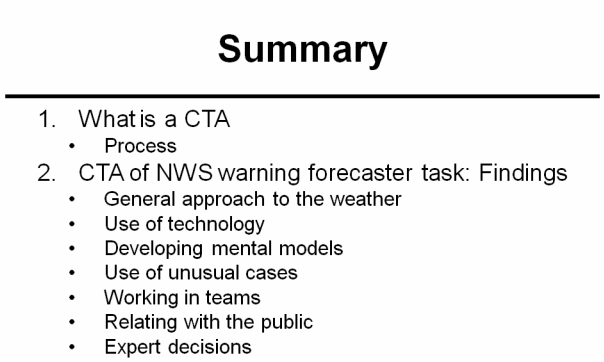
Student Notes:



18. Summary

Instructor Notes:

Student Notes:



19. Questions?

Instructor Notes:

Student Notes:

Questions?

1. Check with your AWOC facilitator (most often the SOO)

2. Send your questions to awoccore_list@wdtb.noaa.gov

20. References

Instructor Notes:

Student Notes:

References

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1. Expertise and Effective Office Warning Strategies

Instructor Notes: Lesson 3 of IC Core 3 deals with the use of post-mortems as a means to gain expertise as well as a means of gaining insight into to warning operations and decision-making, both for the individual and for the agency.

Student Notes:

Expertise and Effective Office Warning Strategies

Advanced Warning Operations Course
IC Core 3
Lesson 3: Learning From Post-Mortems
Warning Decision Training Branch

2. Lesson 3:Learning from Post-Mortems

Instructor Notes: Most often when you work an event which has a bad outcome, you have a desire not to go through that again. By the same token, an event which flows smoothly can offer just as much insight as to effective strategies. Post-mortems should be considered for both situations. The Fed-Ex plane which caught fire on approach to Memphis is an example of an event one would not like to see repeated.

Student Notes:

Lesson 3:
Learning from Post-Mortems

3. Brought to you by…

Instructor Notes:

Student Notes:

Brought to you by…

Liz Quoetone

Jami Boettcher

4. Learning Objectives

Instructor Notes: The learning objectives for this lesson are testable and have to do with the benefits of a post-mortem and why you would want to do one in the first place. However, just going through the motions doesn't mean you will reap all the benefits. The post-mortem must avoid certain pitfalls. In addition, having a database constructed of post-mortems from numerous events and offices can reveal systemic issues (both good and bad). We will look at the term "human error" and discuss its meaning and relevance. We will also discuss some of the challenges with assessing decision making in real-time, while already knowing the outcome (outcome and hindsight biases). Finally we'll discuss a means of going in deeper by using a root cause analysis approach.

Student Notes:

Learning Objectives

1. Identify the potential benefits of a post-mortem analysis
2. Identify characteristics of ineffective post-mortems
3. Identify the value of having a post-mortem database
4. State what is meant by human error
5. State the impact of the hindsight and outcome biases on performing post-mortems
6. Explain the value and meaning of a root cause analysis

5. Performance Objectives

Instructor Notes: This lesson will also include two performance objectives in the form of exercises. The first will be do root cause analysis on a couple of small case studies. The second will be to use the root cause method to look at one warning or forecast decision in which you were actually involved.

Student Notes:

Performance Objectives

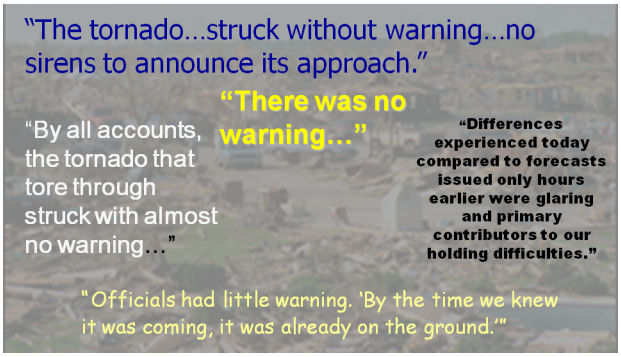
1. Using the examples provided, do a simple Root Cause Analysis on the 2 events described.
2. Using root cause structure, perform an analysis on one particular warning or forecast decision you made or were involved in.

6. What you don't want to read in tomorrow's paper…

Instructor Notes: Anyone who's worked a significant weather event has seen headlines the next day which may or may not reflect the service provided, but nonetheless are extremely troublesome. In some cases, the office would have been hard pressed to get a better outcome. In others, actions before and during the event show room for improvement. An honest post-mortem will help us know where improvement can be made, whether it is in understanding the science, better technology, or human factors related issues.

Student Notes:

What you *don't* want to read in tomorrow's paper…



7. Finding out what happened What do other disciplines do?

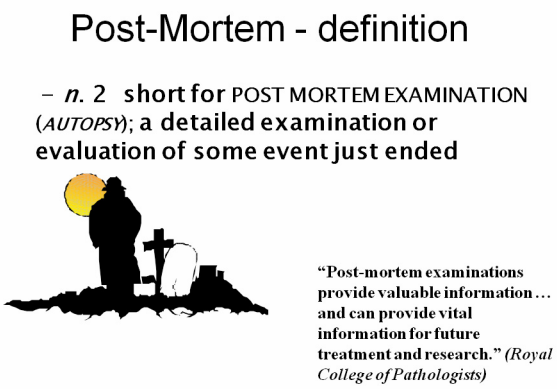
Instructor Notes: As you see here, many domains conduct post-mortems using many different strategies and formats.

Student Notes:

8. Post-Mortem - definition

Instructor Notes: The official definition of a post-mortem is an examination of an event that has just ended. No mention of whether that event had a good or bad outcome. Post-mortems can not only tell us about the past but can help point us in the direction of needed research, technology, policy, or procedures.

Student Notes:



9. Value of Post-mortems: a. Tie to expertise

Instructor Notes: One of the most important benefits of a post-mortem is that it ties with the development of expertise. This slide from lesson 1 shows that this is one of the crucial methods that experts use to develop and maintain their expertise. It has not always been a formal look at an event, but enough so that the cause, effect, and actions are understood, and therefore, can provide feedback about current needs or future actions.

Student Notes:

1. Value of Post-mortems:
   a. Tie to expertise

Experts grow in their expertise by doing lots of post-mortems

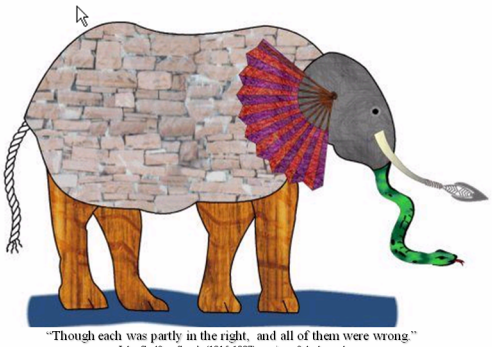
From IC Core 3 – Lesson 1: Expertise

10. Value of Post-mortems: b. include any perspectives

Instructor Notes: A good post-mortem will include many perspectives. In the old legend depicted here, each person had a hold of a different part of the elephant, and each then described an elephant based on the part they had in their hand. “An elephant is like a rope”, said the guy holding the tail. “An elephant is like a snake”, said the guy with the trunk. In reality, the elephant was like none of these individually, but all of these collectively. Your perspective of what happened in an event may be totally different than that of the gal working the other desk. Together, your perspectives give a more complete picture of what really happened.

Student Notes:

1. Value of Post-mortems:
b. include any perspectives



“Though each was partly in the right, and all of them were wrong.”
John Godfrey Saxe's (1816-1887) version of the legend

11. Traditional post-mortems have not been multi-disciplinary

Instructor Notes: Unfortunately, traditional post-mortems have usually only included the perspective of one domain, which results in a solution originating in that domain. A

post-mortem which involves research, operations, and something representing the users will take more effort but may be the key to solving outstanding issues. This quote from Dr. Mileti represents a desire to expand the problem solvers. A more recent effort at integrating many perspectives in problem solving comes from the WAS*IS initiative which led to the SSWIM Program, started by Dr. Eve Gruntfest. This approach integrates social science into meteorological research and practice when looking for solutions to problems.

Student Notes:

12. Value of Post-mortems: c. assist all levels of an organization

Instructor Notes: A post-mortem can offer insight for any level of an organization. For the individual, he or she can see in what areas they are strong and in what areas they need help, whether it be practice with a new software tool, additional understanding in the science, or a better comprehension of how the operational strategies employed by the office are meant to be. Local management can see what is working and what is actually impinging on forecasters ability to do the job, including office policies (official and unofficial), roles and responsibilities or way in which workload is distributed. The agency can see if the same issues are occurring at several sites and look at policies and procedures which are contributing to these issues.

Student Notes:

13. Value of Post-mortems: d. Help pinpoint what's wrong...

Instructor Notes: There is nothing worse than having a negative experience and then going on to the next event without knowing why it was so negative. If you can't figure out what went wrong, how will you be able do learn and perhaps prevent it in the future? "Tornado struck without warning" is not enough information, just like "some sort of error" is not enough information.

Student Notes:

14. Value of Post-mortems: …and leave alone what's right. Implementing a fix without understanding the problem

Instructor Notes: A consequence of not understanding the problem is an increased likelihood of repeating it. A consequence of misunderstanding the problem can be implementing solutions which are irrelevant. In this case, an increasing number of runway

incursions was attributed to pilots not being able to see the markings on the runway. So the solution was to paint wider markings. When the mishaps continued to occur, a second and more thorough look found out that runway markings weren't the issue at all. Implementing a solution before understanding the problem in this case was a waste of time and money, and more importantly, didn't help prevent future mishaps.

Student Notes:

1. Value of Post-mortems:
…and leave alone what's right.

Implementing a fix without understanding the problem

Problem: FAA records showed runway incursions on the increase.

Solution: Paint wider stripes at intersections so pilots can see them.

Results: Runway incursions continued to increase.

Upon further review: Turns out most incursions had been caused by miscommunications or failure to follow protocol...not by pilots failing to see intersection lines!

15. Value of a post-mortem…Not the blame game!

Instructor Notes: One of the BIG obstacles to doing post-mortems is the perception that the effort is designed to place blame. If that is true, then most of those involved will expend their energies to ensure the amount of blame they take on is minimal. And who could "blame" them? Research has shown, and your experience probably tells you, that once people suspect the process is all about punishing the "guilty", then the process is hosed. Part of that may stem from historic efforts which only look at cases where the outcome was bad. It's a compelling reason to look at all cases. Another problem has been in the failure to recognize that there are numerous contributors to outcomes, good and bad, at all levels. To affect real change, we must consider all levels, and consider how the entire process came together during the event.

Student Notes:

Value of a post-mortem…*Not the blame game!*

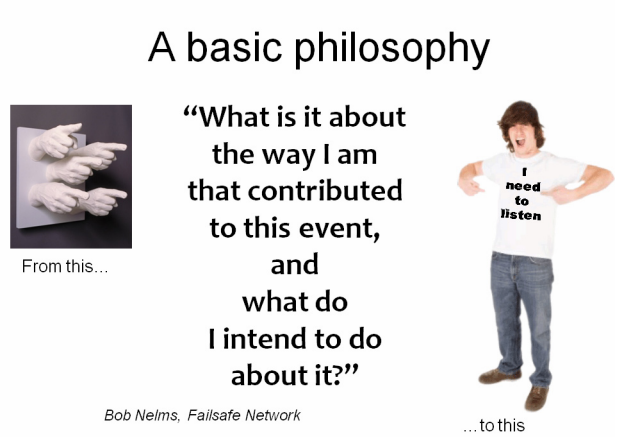
"We have learned the futility of trying to *understand* when people are afraid of *blame*."

* B. Nelms, FAILSAFE Network

16. A basic philosophy

Instructor Notes: The need to fingerpoint and place blame on someone who can take the fall is counterproductive. Much more beneficial is to see how each of us contributed to some outcome in our own way.

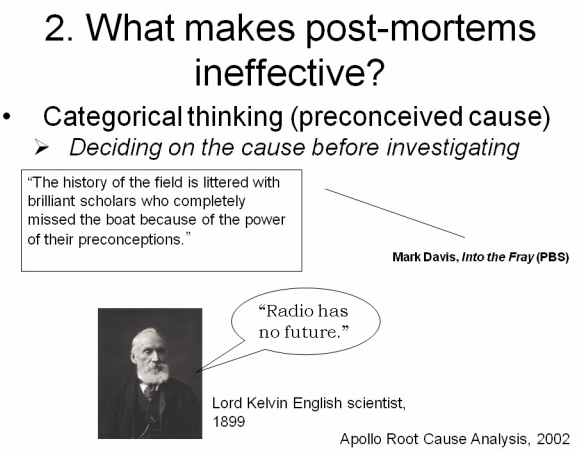
Student Notes:



17. What makes post-mortems ineffective?

Instructor Notes: When we go into an event with a strong perception as to the cause, it can result in missing important information. Sort of like when you decide that tornadoes aren't going to happen today and you therefore never check for velocity couplets. It's like having blinders on. The more open minded you can be when reviewing an event, the more likely you are to discover things you hadn't anticipated. As Mr. Davis says, the power of one's preconceptions can cause us to totally miss the boat. No doubt Lord Kelvin would like to have had the opportunity to take this statement back!

Student Notes:



18. What makes post-mortems ineffective

Instructor Notes: The one who goes into an event with a "favored solution" in mind will no doubt find what they are looking for…somehow. There can be all kinds of reasons for this approach, most of which are left for your imagination, but the end result can be that real and meaningful cause and effect are left out, and therefore not addressed in the solution. The article from Moorhead et al in Human Relations points to the dangers. Finally, it's important to not just get facts but get "stories". Some of the most important information can be gleaned when people recount events. One of the things that gets left out with just the facts is how pieces of information fit together…their causal relationships.

Student Notes:

2. What makes post-mortems ineffective

- Solution oriented (preconceived *solution*)
  - "Favorite solution" mindset
    - *Work in "preferred" solution than to understand the cause*

"The leaders had a preferred solution and engaged in behaviors designed to promote it rather than critically appraise alternatives."

Moorhead, et al., **Group decision fiascoes continue: Space shuttle Challenger and a revised groupthink framework**. *Human Relations*,44

- Causal relationships are unknown
  - Fact finding does not reveal cause and effect

Apollo Root Cause Analysis, 2002

19. What we learn depends on how we conduct the post-mortems

Instructor Notes: The bottom line is that what you get out of a post-mortem depends on your attitude going in and the process by which you conduct it. In the final report regarding the Columbia Accident, it was noted that with both the Challenger and Columbia, problems were accepted without a full understanding of the risks associated with those problems. Some had mistaken being very lucky for being very good.

Student Notes:

What we learn depends on how we conduct the post-mortems

20. Challenges in performing post-mortems

Instructor Notes: So let's look at some of the challenges we face when doing a post-mortem. They involve how we measure success in the first place, how we define and account for human error, and the effect of biases. Col Scott probably said it best when he said, "What you see depends on where you sit." This is certainly the case as an event unfolds (whether 9/11 or a significant weather event), as well as in looking at an event after the fact.

Student Notes:

3. Challenges in performing post-mortems

a. Measuring success

b. Human error

c. Hindsight bias

d. Outcome bias

"What you see depends on where you sit."

Col. Alan Scott (ret) First Air Force, regarding the events as they unfolded on 9/11

21. a. Measuring success Which Office Performed Better?

Instructor Notes: Let's look at how success may have been measured for these offices. The statistics are fairly close with Office A showing slightly better numbers. Based on these measures of success, which office did a better job? Which office would you rather be? Is there more information you would like to know before you decide this? If so, what are some of the questions you'd like to have answered?

Student Notes:

a. Measuring success

Which Office Performed Better?

	Office A	Office B
POD	80	70
FAR	70	80
Ave. Lead Time	10	10
Total Fatalities	2	2

22. To learn, you must go deeper

Instructor Notes: If you do seek more information, you are on the right track. These numbers tell some of the story but not the whole story. Other issues were involved.

Student Notes:

To learn, you must go deeper

	Office A	Office B
POD	80	70
FAR	70	80
Ave. Lead Time	10	10
Total Fatalities	2	2

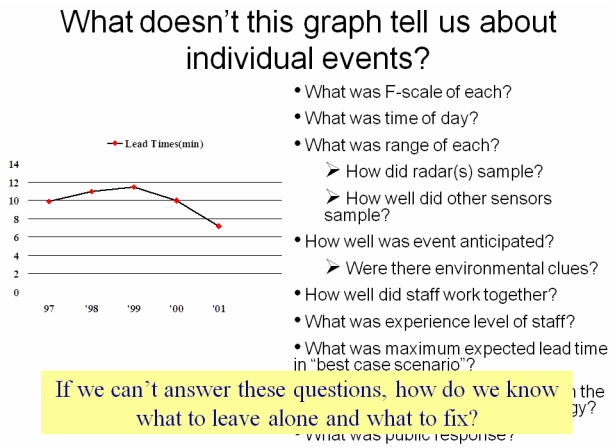
In the eyes of the customer….Office B was a hero. Office A got nothing but grief. Why?

There was more to the story than just these statistics (there usually is).

23. What doesn't this graph tell us about individual events?

Instructor Notes: Here are just some of the details which might be useful when trying to decide what performance was really like. Answering these questions may help us know if the event was handled well or if there is room for improvement, and if so where? These and other questions you and your co-workers might have should be included in a routine part of a post-mortem.

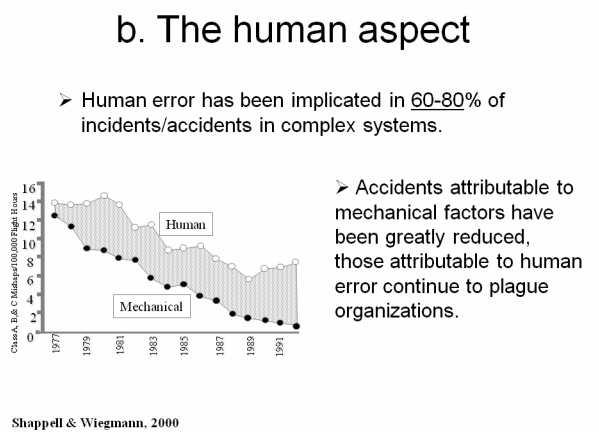
Student Notes:



24. b. The human aspect

Instructor Notes: Human error has been implicated in 60-80% of incidents/accidents in complex, high technology systems. These systems include aviation, nuclear power, oil, medical, rail, and marine transport industries. Weather forecasting also occurs in a complex environment. Although the overall rate of many industrial and transportation accidents has declined steadily during the past 20 years, reductions in human error-related accidents have not paralleled those related to mechanical/environmental factors. The tendency after seeing this is to think that humans are becoming more and more of the problem. Is that really what is happening? What are some other explanations?

Student Notes:



25. Some possible explanations

Instructor Notes: In Shappell and Wiegmann's studies, it is revealed that as technology continues to expand in scope and coverage, the need to include the human user in the design is not always (or even often) considered. Technology which does not consider how a human operates, especially an expert, is not going to have good results when fielded. It is also a possibility that the person using the technology will have an overconfi-

dence in its ability to perform a function. This may result from never having seen the technology “fail” (perhaps too few cases), or from not having much expertise in the area (must rely on technology as I don’t know any better). Finally, it is likely that we are not getting routine feedback on the human-system interactions. That feedback is not only necessary during design but after implementation.

Student Notes:

Some possible explanations

- Systems induce human error
  - Don’t account for human need to understand the state
- “Fail safe” measures lead to higher risk behavior
  - Stop lights
  - The “unsinkable” Titanic
  - Algorithms/ decision aid tools
    - Easy to forget that the safety net has holes!
- Not getting good feedback on human-system interactions

26. What is human error?Complex systems and human error

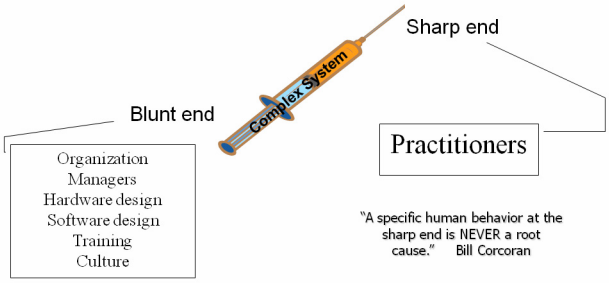
Instructor Notes: There are lots of definitions of “human error” all of which seem to point to the action taking place at the “sharp end of the stick”. This is where the practitioner takes everything which has gone into the process up to this point and makes a yes/no, warn/no warn, shoot/don’t shoot etc., decision. While that may be the easiest thing to do, it is extremely simplistic and does not account for all the components present in a complex system. Bill Corcoran who studies events and their causes for a living, points out that the behavior of the human is not the start of everything, but rather the result.

Student Notes:

What is human error?

Complex systems and human error

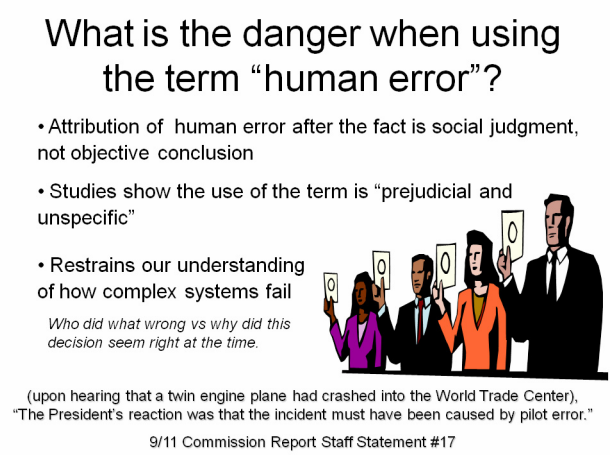
Things attributed to human error occur at the “sharp” end of the complex system



27. What is the danger when using the term “human error”?

Instructor Notes: Far from being a compelling diagnosis, citing human error has often been used to direct blame. In reality, it is not an objective assessment and may actually keep an investigation from going any further. A “Heads will roll!” mentality. There is something in assigning “human error” which implies that nothing is really wrong, except the person making the decision.

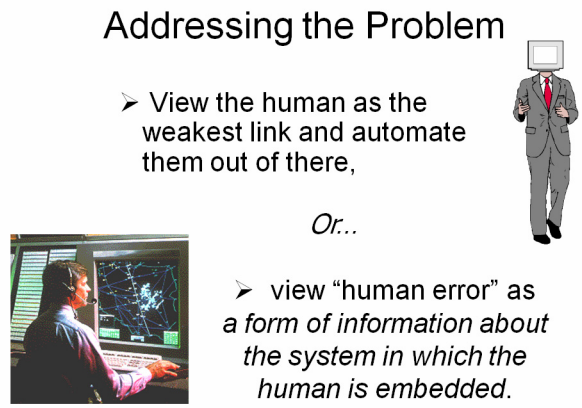
Student Notes:



28. Addressing the Problem

Instructor Notes: So to address the problem one can take a couple of stances. Decide the human is really the problem and ramp up the automation to replace them. This might have one set of implications when the task is wrapping bon-bons in candy wrappers, but an entirely different implication when the human in the loop is there to add expertise and employ critical thinking. Another solution might be to look at the way the human and automation interact and view “errors” as a form of information about that interaction.

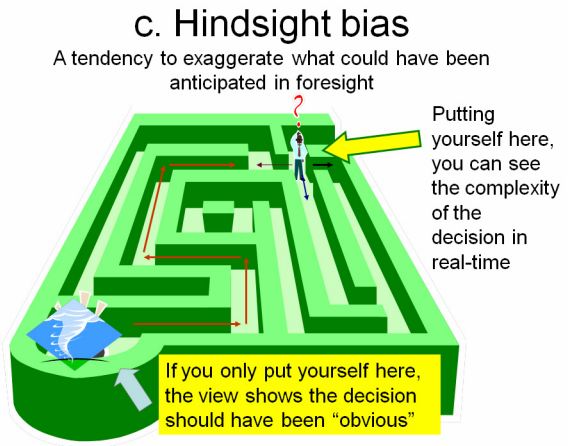
Student Notes:



29. c. Hindsight bias A tendency to exaggerate what could have been anticipated in foresight

Instructor Notes: What are some other dangers when doing post-mortems? Have you ever seen a bad outcome and wonder “just what was the guy thinking?” or thought “Anybody should have been able to see that!” Well that may be how you feel, and it may even be true, but apparently it didn’t happen in this case and the question is “why”? To really understand how we got from a to b, it is important to leave behind what you know happened, and put yourself in the position of the decision maker and see what they saw at that time. This helps avoid the “hindsight bias” which is a tendency to exaggerate what could have been anticipated in foresight. We see lots of issues regarding this in the 9/11 discussions. Look at the options which were available to the decision maker at the time and see how they got to where they went. That’s where the real understanding of the process and the potential solutions lie. If you only set yourself at the end of the event and look backwards, you won’t have the same view. The best way to work a maze is by starting at the end and going back to the beginning…there is only one way to go and it is obvious. But that tells you nothing about how it was possible for the events to unfold as they did.

Student Notes:

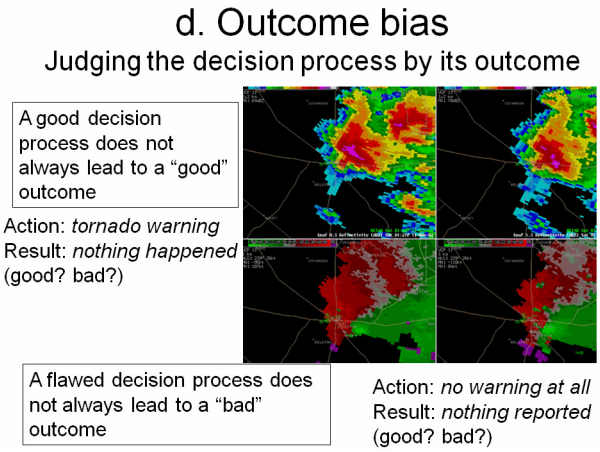


30. d. Outcome bias Judging the decision process by its outcome

Instructor Notes: Another bias to be aware of is the “outcome bias”. In this instance we tend to judge the process by the outcome. Good outcome…must have been good process. Bad outcome…must have been bad process. Not necessarily. In the first example, a tornado warning was issued and no verification was received. Was it a good or bad decision process based on what you see here? Although verification stats show a check in the FAR column, do you feel the warning justified based. Strong rotation at more than one slice at a location with a pendant and inflow notch are certainly in the tornado potential category. Maybe no one was there to witness it, or maybe it just didn’t happen. Know-

ing the limitations of the science and technology as well a need for adequate lead time, perhaps this was the best decision. In the second example, no warning was issued and nothing was reported. Was it a good or bad decision process based on what you see here? True it went down in the books as a good non-warning decision but that could have been attributable to other things, not to mention one of which was nobody in the vicinity. While you might could argue the tornado potential with this, are there indicators that at least large hail is occurring?

Student Notes:



31. Getting past the outcome bias How about evaluating the process?

Instructor Notes: So it is important to do the best we can with what we have and what we understand. Ultimately when assessing the process, you want it to be sound and based in a good understanding of the science and technology with consideration to the context of the event itself including the public you serve. You'd want the action repeatable. The process is in our control, but the outcome is not. Dr. Hammond captures the dilemma when he discusses the effects of irreducible uncertainty. At any moment in time there is some degree of uncertainty and if you are not able to reduce it by adding data or adding understanding, you must make decisions based on the information available at the time, imperfect as it can be.

Student Notes:

Getting past the outcome bias

How about evaluating the process?

A good decision-making process accounts for:

- the current state of the science
- strengths and limitations of the technology
- human factors

Uncertainties in all areas means outcomes will not always be perfect

"Irreducible uncertainty is accompanied by inevitable error which results in unavoidable injustice." Kenneth Hammond

32. Overcoming biases To affect outcomes, evaluate the process

Instructor Notes: One set of questions you might ask of yourself after an event is whether or not you would do the same thing next time? Maybe ask some co-workers or someone you'd consider an expert. If all agree, then you probably have a good process and the issues may have resided in the uncertainties of the data sets or technology we have. Or it could have been a conscious decision to err on the side of caution due to an unacceptable risk you perceived for those in the path. If others might have done something else, look at their reasoning and discuss. Maybe you haven't thought of all aspects, or maybe they haven't thought of yours. Regardless, it's an opportunity to grow in knowledge and advance your critical thinking skills.

Student Notes:

Overcoming biases

To affect outcomes, evaluate the process

Ask,

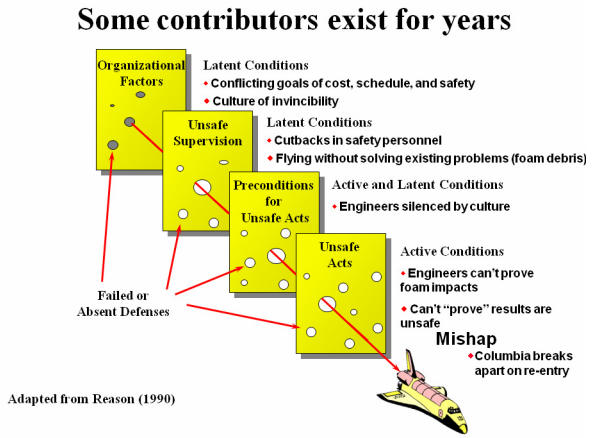
- "What would you do next time given the same set of circumstances?"
- "What would your co-workers do?"
- "What would an expert do?"

- If the answer is "the same thing", solution probably doesn't lie with the decision process.
- If the answer is "something different", investigate the reasoning for alternate courses of action.

33. Some contributors exist for years

Instructor Notes: Another example can be gleaned from the final report on the Columbia mishap. This takes into account the “latent” conditions which are in place at the time of the incident. Latent conditions can go unaddressed for long periods of time for numerous reasons, but one of the more common is the effort it takes to resolve, especially if nothing “bad” has resulted so far. Numerous latent conditions, many still in place after the Challenger investigation, were cited as contributors to the Columbia accident. Ultimately you want to identify these “holes” or absent defenses and plug them up before they contribute to a larger disaster.

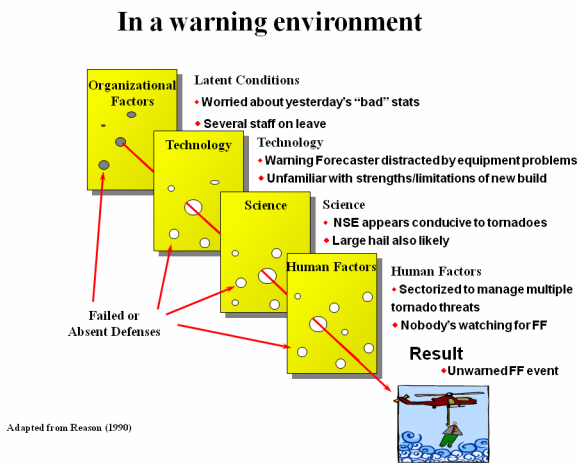
Student Notes:



34. In a warning environment

Instructor Notes: How about in warning operations? There may be organizational issues in place either nationally or locally every day which are not in and of themselves bad. However when put with other contributors, they can facilitate a bad outcome. In this example, the “slices of swiss cheese” are organizational factors, technology, science, and human factors with the “holes” in each representing factors or in some cases contributors to the outcome.

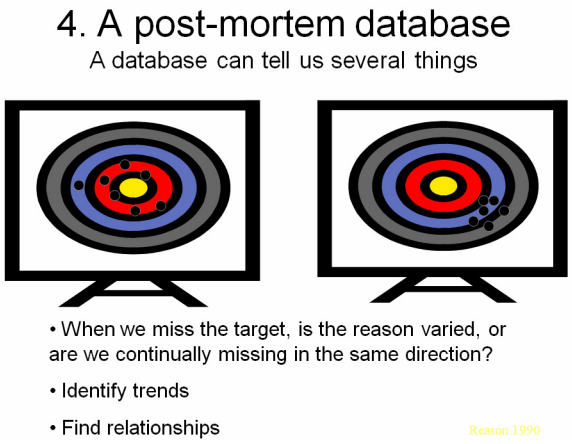
Student Notes:



35. A post-mortem database A database can tell us several things

Instructor Notes: Next we want to look at another motivation for doing post-mortems which is producing a database. When we no longer have just a few in depth assessments, but rather a large population of events, much can be revealed. We can see if most contributors to bad outcomes all fall in the same area, or if they vary by office or region or time of year. We can compare meaningful statistics over time to see if more or less outcomes are being affected by technology-based contributors, or if workload for instance, is becoming more and more of a factor. We can answer those questions about sampling issues or time of day and see if there is a relationship between these occurrences and our ability to get lead time.

Student Notes:

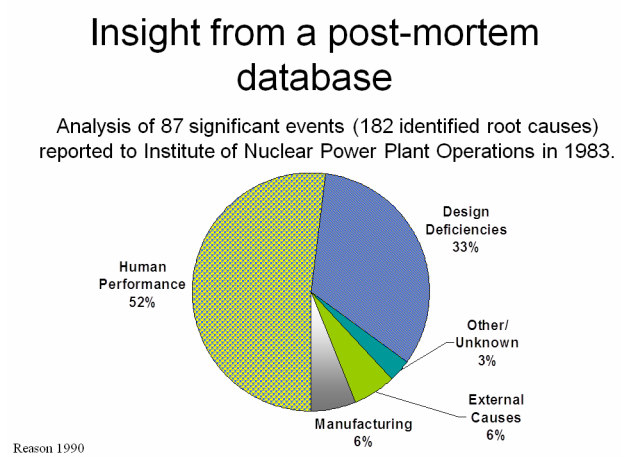


36. Insight from a post-mortem database

Instructor Notes: Here is an example of a database of Nuclear Power Plant operations in 1983. By having a database, it was readily apparent what categories were showing up

in what numbers. Human performance (and hopefully we now have a better understanding what we mean by that) was the leading category. Design deficiencies followed that. This can be helpful (after digging a little deeper of course) when trying to adjust problem solving resources.

Student Notes:



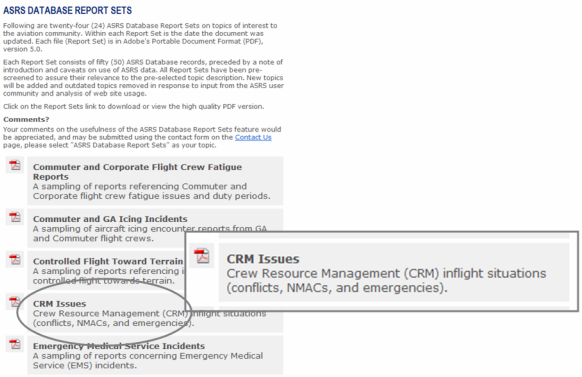
37. Example of a post-mortem database Aircraft Safety Reporting System (ASRS)

Instructor Notes: Another example of the use and construction of a database can be seen in the Aircraft Safety Reporting System (ASRS). This came about when it was felt that valuable information and critical lessons were being lost because flight crews had no avenue to express concerns (below the NTSB investigation level) without fear of retribution. This website is used for flight crews who want to anonymously report safety issues which occur during the course of a flight. None of these would be under the guise of a full-blown NTSB investigation, but most have resulted in a near miss of some disaster. The information flow via this vehicle is two-way. The arrows indicate both where a report can be generated, and where database information can be extracted. In this example we see a list of categories under which the issues reported fall into. In particular we will look at the “Crew Resource Management (CRM)” Issues.

Student Notes:

Example of a post-mortem database

Aircraft Safety Reporting System (ASRS)

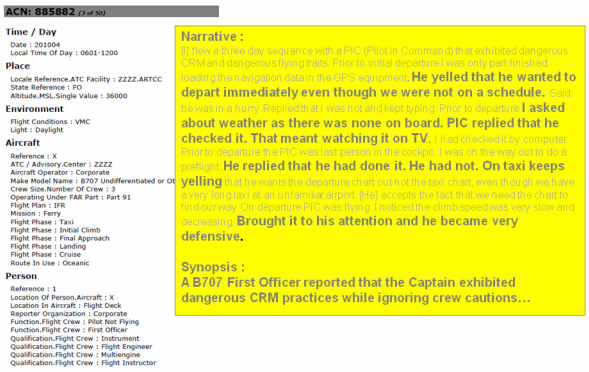


38. ASRS Sample Entry

Instructor Notes: By selecting on this we see several entries, one of which we have displayed. We see the “just the facts ma’am” type of stuff on the left (all of which has been stripped of pilot/plane identification), and the narrative which accompanied this on the right. You can see why this incident report has fallen into the crew interaction category and how big of a potential disaster this person felt they had. There is a boatload of information in this which if we waited for the actual disaster to occur before studying, we might not have seen before the next time it occurred and did result in disaster. Think of times where you’ve had near misses, the “right thing for the wrong reason” type of situation and imagine how beneficial it would be to study that type of situation as well.

Student Notes:

ASRS Sample Entry



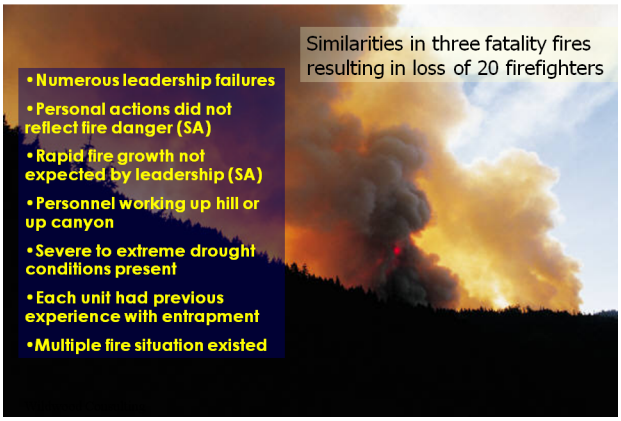
39. Firefighting post-mortem database

Instructor Notes: Here is a look at a limited number of wildfires, in particular those which resulted in fatalities amongst firefighters. In this case, we see what all the events had in common. All revealed because a database of incidents were looked at. By the

way, your experiences in the warning environment may have something in common with those facing decision makers in the fire fighting world.

Student Notes:

Firefighting post-mortem database



40. Naval Safety Center database entries

Instructor Notes: Another database, this time the Naval safety Center database. This information must first be illuminated, via a post-mortem type of process, before it can be gathered and used for local and agency purposes. Once again, while many of these entries are domain specific, many could apply to any domain.

Student Notes:

Naval Safety Center database entries

Compensation For Wind Conditions Inadequate
Distance Misjudged
Flare Delayed
Ground Loop/Swerve Intentional
Remedial Action Delayed
VFR Flight Into IMP Initiated
Visual Lookout Not Maintained
Compensation for Wind Conditions Impr
Directional Control Not Maintained
Diverted Attention
Ice/Frost Removal From Aircraft Inadequ
IFR Procedure Improper
Aircraft Control Not Possible
Stall Inadvertent
Inadequate Visual Lookout
Lack of Familiarity With Aircraft
Lack of Total Experience in Type of A

Lowering of Flaps Performed
VFR Flight Into IMC Inadvertent
Aborted Takeoff Performed
Communications Not Understood
Emergency Procedure Not Followed
Inadequate Weather Evaluation
Procedure Inadequate
VFR Flight into IMC Continued
Emergency Procedure Not Performed
Lack of Familiarity with Geographic Area
Maintenance, Adjustment Improper
Monitoring Inadequate
Remedial Action Not Possible
Visual/Aural Perception
Preflight Planning/Preparation Inadequate
Aircraft Handling Improper
Crew/Group Coordination Inadequate

A database rich with contributing factors can provide enormous insights

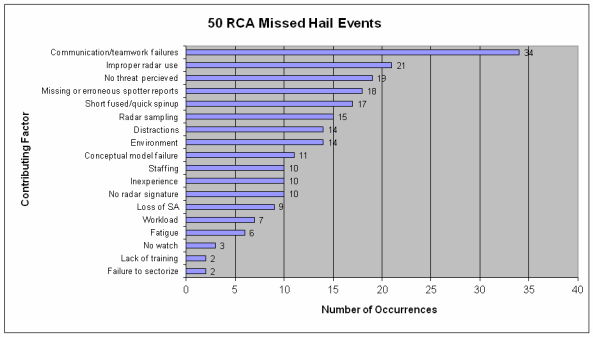
41. NWS Example What factors contributed to 50 missed hail events?

Instructor Notes: An example closer to home shows how we are beginning to use an NWS database to see what factors have contributed to certain events. In this example, Root Cause Analysis done by AWOC students (something you'll be doing soon!) shows that in 50 missed hail events, numerous factors contributed. In this case, communication and teamwork failures showed up as a contributor 34 times in these 50 missed events.

Student Notes:

NWS Example

What factors contributed to 50 missed hail events?



42. Methods of performing effective post-mortems

Instructor Notes: In this last section we'll look at post-mortems which are done in the NWS and suggest some additional possibilities. There currently is a variety of ways in which we examine events, varying considerably by region and by office. Next we'll look at a method of going in deeper to particular forecast or warning decisions.

Student Notes:

5. Methods of performing effective post-mortems

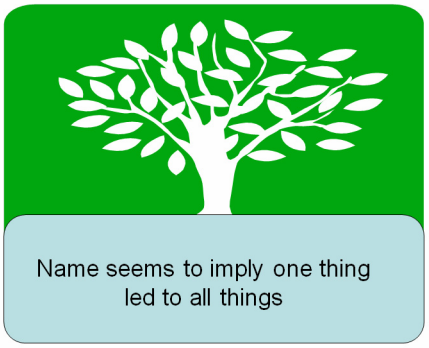
- National
  - Service Assessments
- Regional
  - Sig Ops, For the Record, etc.
- Local
  - Varies
  - Some very detailed, performed regularly
  - Some brief, occasional

43. Root cause?

Instructor Notes: That further investigation might take the form of a root cause analysis. While the term "root cause" implies there's one thing at the bottom of it all, it really is not the case. In fact, nothing could be further from the truth. Every "cause" has causes of its own.

Student Notes:

Root cause?

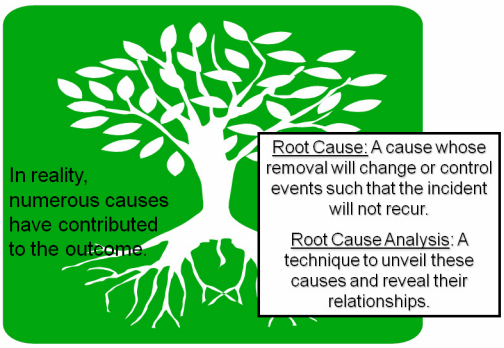


44. Root cause?

Instructor Notes: When doing a root cause process, one uncovers numerous “roots” each with numerous “offshoots” which have all contributed to an outcome. While the definition of Root Cause Analysis is wide and varied, depending on where you ask, the one listed here seems to fit our needs.

Student Notes:

Root cause?



45. What is the value of finding the root causes?

Instructor Notes: So why find the root causes? Just as with the “swiss cheese” model of “latent” factors, the root causes of most incidents are present long before the thing happened. For example, organizational factors don’t instantly appear at the time of an incident or a disaster, they pare present long before.

Student Notes:

What is the value of finding the root causes?

"...most of the root causes of a serious accident in complex technologies are present within the system long before the obvious accident ..."

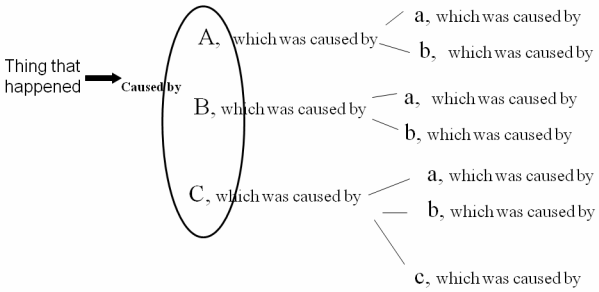
Reason *Human Error*

46. One example of how a root cause analysis works

Instructor Notes: The ways in which you can do a root cause seem to be numerous. Lots of schools of thought exist on how and when these should come about. There are a host of vendors and sites which offer root cause training. Some require travel, while others can be done on line. If you are interested, some resources which point to further training can be found at the end of this presentation. One example is presented here but this is certainly not the only way, or maybe even the best way to do the process. But it is one we'll use in our simplistic example. For this analysis, the "thing that happened" (either good or bad) is what you start with. You ask "why" did this happen or state, "this was caused by" and then get at least 2 contributors to that, listed here as A,B,and C. In this method, A, B, and C must all have occurred together. If you take A away, no problem. If you take C away, no problem. All must have occurred together. Then each of these has a list of contributors, and so on. This process will end when: You get enough information to work solutions You run out of time The "branch" your going down is cost or time prohibitive or out of your control We'll look at some actual examples shortly.

Student Notes:

One example of how a root cause analysis works



Apollo Root Cause Analysis

The further back you go, the more you will unveil latent causes.

47. Let's look at one event

Instructor Notes: For comparison's sake, here's an event which had a negative outcome. This is how it might look in a write-up which captures the facts of the event. In this case, there was no tornado warning for a county in which deaths occurred. We'll do a RCA on that particular event.

Student Notes:

Let's look at one event

Severe weather outbreak early in the fall season with a considerable number of storms to manage.

Example 1 Event Summary

Deaths: 3

Injuries: 10

Damage: 400K

Outlook: Slight risk of Svr

Watches: Tornado Watch issued at 1830z

Warnings: 5 tornado, 25 severe, 2 flash flood. Average lead time 8 min. on tornadoes, 15 min. for severe, 45 minutes on flash flood. No lead time for county in which deaths occurred.

Service: Tor warning for storm in upstream county. Warning re-issued when report arrived.

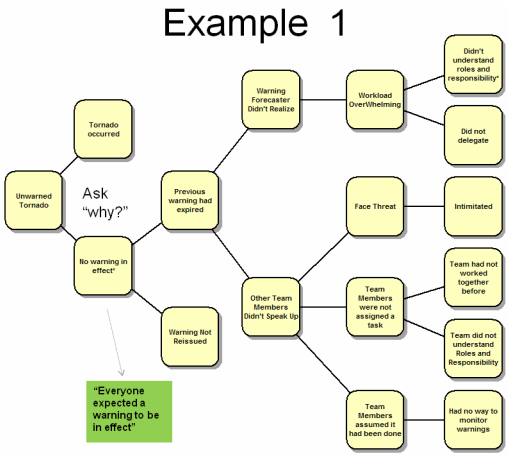
Systems: Functioning properly

Response: Covered initially by local media. Damage survey team sent.

48. Example 1

Instructor Notes: So we start with the "unwarned tornado". The two things which had to occur together for this to be an issue are: Tornado occurred AND no warning in effect. Change either of those and your outcome is different. As some information on the side, we see that there was an expectation by the team in this event that a warning was needed. Hmmm…so why didn't it happen? Of the two causes, "tornado occurred" and "No warning in effect", we will choose to focus on the "no warning in effect branch". If this was a science based focus, we might choose to go down the "tornado occurred" branch and see what clues the science holds (especially useful when there was no expectation of tornado possibility), no doubt leading to some research. With each factor…we ask "why?" in order to determine what comes next. You can see the various contributors to the question as to why no warning was in effect. Included here are inputs from all team members which ultimately point to several factors, some technological, and several involving communication and roles and responsibilities. It is easy to see how this warning fell through the cracks with this in place.

Student Notes:

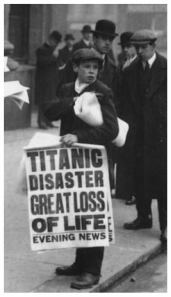


49. RCA – What to investigate: April 14, 1912

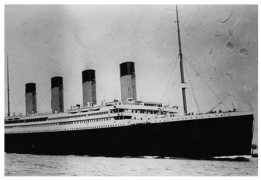
Instructor Notes: Sometime you have to stop and see what exactly it is you want to investigate. Do you want to know why the ship sank?

Student Notes:

RCA – What to investigate:
April 14, 1912



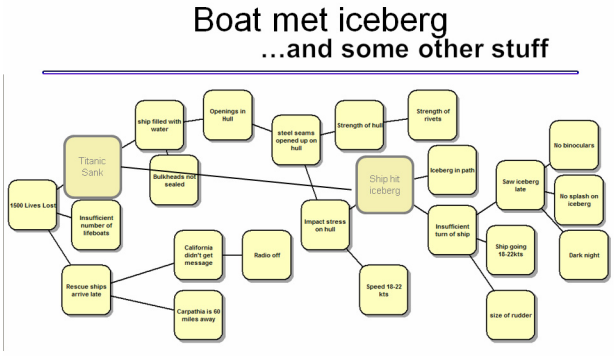
- Ship sank
- Hit iceberg



50. Boat met iceberg

Instructor Notes: The answer to that is as simple or as complex as you like. Obviously, the more detail you can discover, the more opportunities you have to intervene. You may also want to, at least in this case, ask why people died. Certainly ships have sunk where no one died. That would open up your RCA to account for many other facets. Changing any factor you see listed in an RCA would change the outcome. The more detailed your RCA is, the more opportunities you have to see what interventions are the most doable.

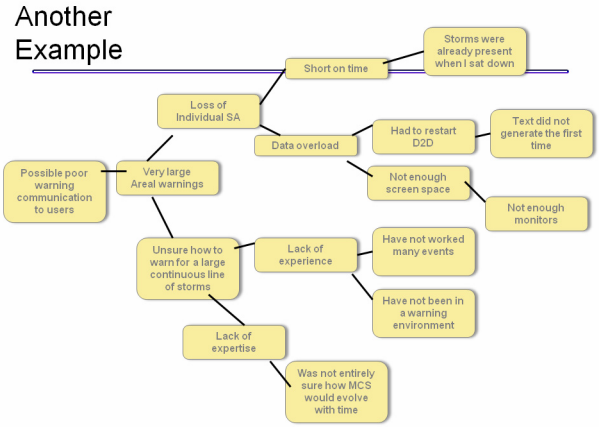
Student Notes:



51. Another Example

Instructor Notes: Here's another example. Remember to ask "Why?" or state "This was caused by…" before going on to the next box.

Student Notes:

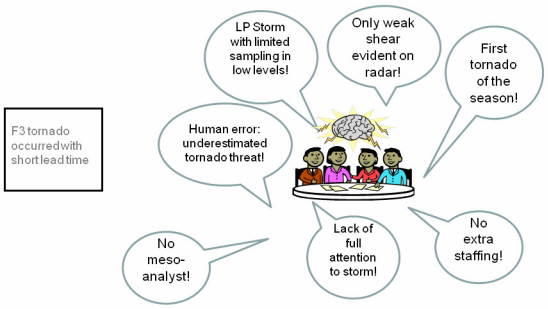


52. Group RCA

Instructor Notes: Everyone will have a perception about what "the problem is". In most cases, their perception is right, just incomplete. Much like the earlier example of the description of the elephant. The purpose of the RCA is to validate these perceptions with evidence and then locate them in the proper chain of events.

Student Notes:

Group RCA – "I'll tell you what <u>the</u> problem was!"



YES! And also……..

53. RCA Good Practice – Ask the hard question

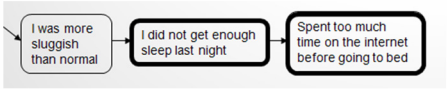
Instructor Notes: One of the most challenging yet beneficial practices in doing root cause analysis is to take a close look at our own actions. While it's tempting to limit your sights on what everyone else did wrong, it is far more revealing and more productive to look at what you could have done differently, afterall, you can change your behavior far more easily than you can change others. In this example, the RCA author tied a delay in product issuances to their own behavior the day before.

Student Notes:

RCA Good Practice – Ask the hard question

"To address this mistake we must use root-cause analysis. I'll begin by saying it's not my fault."

Always look at your role, afterall YOU have control over YOU



54. When to do an RCA

Instructor Notes: When should you do a root cause analysis? More schools of thought on that, whether it be event driven, or a function of resources, etc. It will take some time. Maybe your office, or you personally, want to develop some guidelines. Generally, use it any time you want to find casual relationships. Not just the facts, but how everything fit together. Pick one warning outcome or decision. Look at events that went well, and also look at "near misses". As Corcoran states, if all you look at is big events, you will soon have another big one to investigate.

Student Notes:

When to do an RCA

- Find causal relationships
  - Judge impact of event
  - Consider "near misses"
- Consider events which went well
  - Model good processes
  - Reveal luck (versus skill)

"Organizations that only do good investigations on big ones soon have a big one to investigate."

*Dr. Bill Corcoran, **Nuclear Safety Review Concepts Corporation***

55. Learning Objectives

Instructor Notes: We've restated the objectives here.

Student Notes:

Learning Objectives

1. Identify the potential benefits of a post-mortem analysis
2. Identify characteristics of ineffective post-mortems
3. Identify the value of having a post-mortem database
4. Define what is meant by human error
5. State the impact of the hindsight and outcome biases on performing post-mortems
6. Explain the value and meaning of a root cause analysis

56. Performance Objectives

Instructor Notes: The performance objectives will take the form of exercises which are outlined on the following slides.

Student Notes:

Performance Objectives

1. Using the examples provided, do a simple Root Cause Analysis on the events described.
2. Using root cause structure, perform an analysis on one particular warning or forecast decision you made or were involved in.

57. AWOC CORE 3 Assignment 1

Instructor Notes: Try your hand at this easy RCA. Fred is on midnight shifts. His last one is tonight. During the day, instead of sleeping, Fred went to a fishing tournament at a lake 150 miles away. Fred loves fishing. Because Fred never checks the oil in his car, car trouble on the way home delayed his arrival back to 11pm. Fred then laid down for “just a few minutes” setting his alarm for 11:30pm. A storm knocked out power and Fred’s alarm clock didn’t go off. He woke up when the his office called at 12:15am to see where he was. Hint: Start with “Fred is Late to Work” When finished, upload your file to the LMS to receive one possible solution to this.

Student Notes:

6. AWOC CORE 3 Assignment 1

Assignment 1: (Easy and Generic) Using the case provided, do a simple Root Cause Analysis. Submit your answer through the LMS in order to see one possible solution.

58. Assignment 2

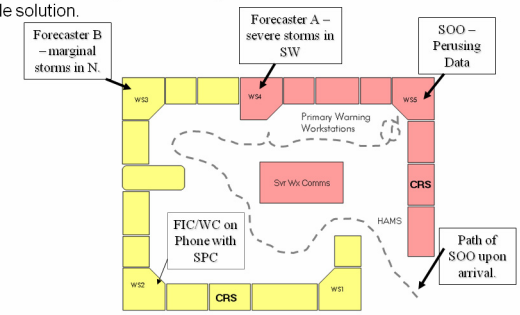
Instructor Notes: Do a Root Cause Analysis on the following event: A low end to moderate severe weather event is in progress at WFO WOW. The Forecaster –in-Charge acting as the Warning Coordinator (WC) has sectorized warning operations to give Forecaster A several storms in the Southwest part of the CWA. Forecaster A is experienced but tends to work in isolation. The WC tells Forecaster B to monitor a small cluster of

storms over the Northern part of the CWA. These are not severe but may produce some marginal hail and flash flooding. Forecaster B, who has just completed 88D training is relatively new to the office. The WC mentions that they might need some help if things continue to develop. He then calls SPC for a discussion regarding expectations. Meanwhile, the SOO drops by the office to check the weather before he heads out of town. He passes by the WC, makes eye contact, sees he's on the phone and walks on. The SOO then saunters by everyone else, noticing they have their hands full so he sits at an open workstation and peruses the data. He spends time interrogating the radar data including a newly developed storm over the Southeast part of the CWA (he doesn't realize it's newly developed). This new storm intensifies. The SOO comments out loud at how impressive it now looks. Forecaster A says "Uh-huh." Forecaster B thinks it looks severe and audibly concurs. Forecaster B is glad the SOO has come in to help but is wondering why the SOO isn't issuing a warning. Being new to severe weather and the office, Forecaster B assumes the SOO knows best. The SOO assumes there's a warning out but can't find evidence of it. Forecaster A is busy fighting with WarnGen. The WC gets off the phone in time to get a report of golfball hail associated with the new storm which has no warning on it. All four forecasters look at each other with dismay. Hint: Start with "Unwarned hail event" When finished, upload your file to the LMS to receive one possible solution to this.

Student Notes:

Assignment 2

Assignment 2: (More challenging, weather specific). Using the case provided, do a Root Cause Analysis. Submit your answer in order to see one possible solution.



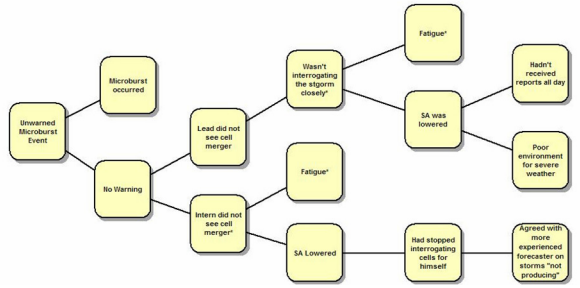
59. Assignment 3

Instructor Notes: In this assignment, you are asked to do a RCA on some warning event or decision. Missed event, event you hit, good lead time, negative lead time, false alarm, scope not anticipated, etc.

Student Notes:

Assignment 3

Assignment 3: (Your case). Using root cause analysis, analyze a specific warning (or forecast) decision or outcome in which your were involved. You can work as a team. Optional: Share with your SOO or office. (all submissions confidential)

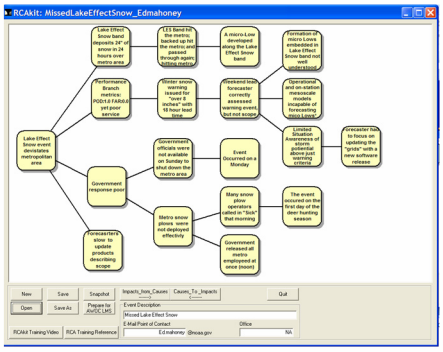


60. RCA Toolkit

Instructor Notes: You'll be using an online RCA Toolkit in order to submit your RCAs. We'll have a special website for you to go to in order to enter the data on your RCA. We'll provide you the link and instruction on how to do this in your teletraining session.

Student Notes:

RCA Toolkit



61. Questions? Email: awoccore_list@wdtb.noaa.gov

Instructor Notes:

Student Notes:

Questions?

Email: awoccore_list@wdtb.noaa.gov

1. Check with your AWOC facilitator (most often the SOO)

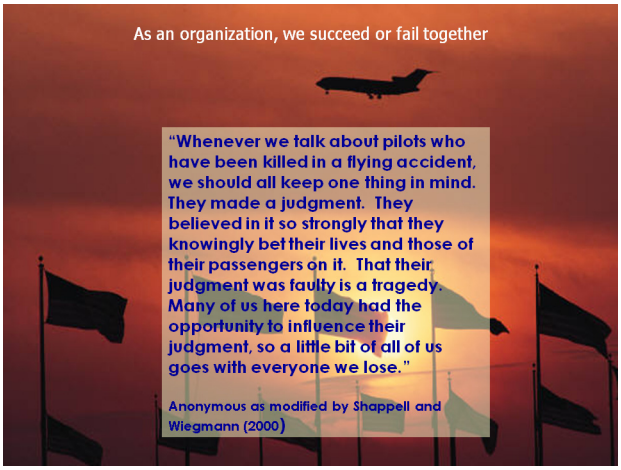
2. Send your questions to awoccore_list@wdtb.noaa.gov

Submit RCAs with the assignment in the AWOC Core Development Plan

62. As an Organization...

Instructor Notes: Finally, when doing post-mortems it's important to keep in mind that most people are doing there best. No one intends to work an event that has a bad outcome. We are all part of the same agency (especially as far as the public sees) and what any office does reflects on me, whether it be a local office or an office at region or headquarters. We are all part of the same team and we can either support each other in that or not. This quote from Shappell and Wiegmann illustrates the belief in an aviation environment.

Student Notes:



63. References

Instructor Notes:

Student Notes:

References

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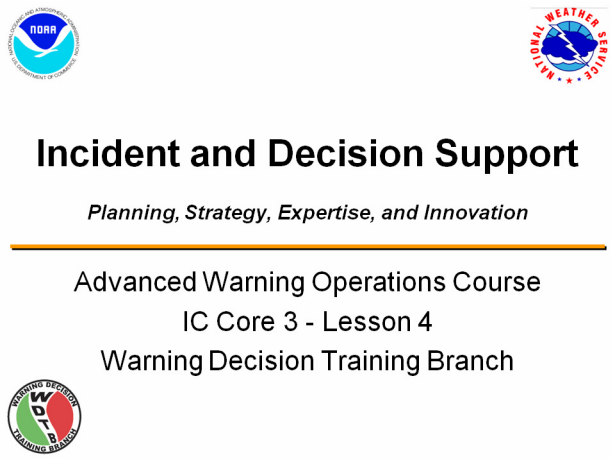
1. Incident and Decision SupportPlanning, Strategy, Expertise, and Innovation

Instructor Notes: Welcome to Incident and Decision Support. This lesson is brought to you by David Andra (SOO, WFO Norman) and Bill Bunting (MIC, WFO Fort Worth).

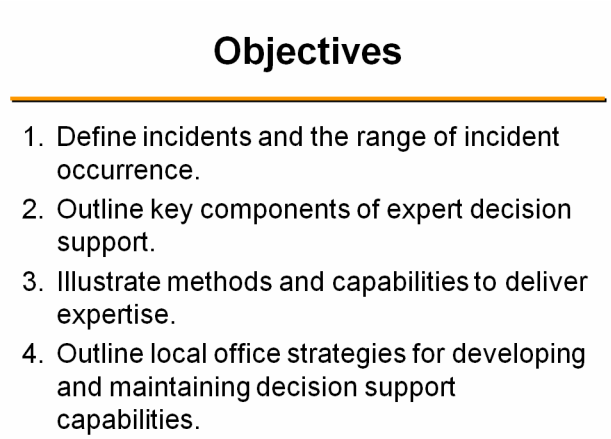
Student Notes:



2. Objectives

Instructor Notes: This lesson has four objectives.

Student Notes:



3. Why Do We Care?

Instructor Notes: You may wonder, “Why the emphasis on incident and decision support?” The fact is that the NWS can play an important support role in disasters and other situations where decision-makers need detailed weather information. Since 9-11, our role has expanded at an ever-increasing rate.

Student Notes:

Why Do We Care?

- *The ability of you and your office to identify and manage incidents and decision support has far-reaching consequences personally and to the agency.*

4. NWS Future Direction - Improving forecaster-provided interpretive services for decision makers.- Jack Hayes, NWS Director

Instructor Notes: NWS Director Jack Hayes recently articulated his vision for the future when he called for improved forecaster-provided interpretive services for decision makers.

Student Notes:

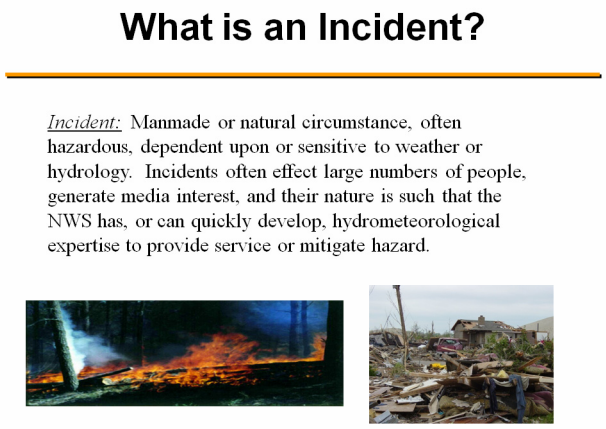
NWS Future Direction - Improving forecaster-provided interpretive services for decision makers.

- ***Jack Hayes, NWS Director***

5. What is an Incident?

Instructor Notes: Before we go to far, it's important to define what we mean by the term "incident." In this definition we find the term has a broad meaning that encompasses both natural and manmade events – virtually any hydrologic or weather-sensitive circumstance where we can help mitigate the hazard and help leaders make informed decisions.

Student Notes:



6. A Range of IncidentsShort Duration, Localized

Instructor Notes: Incidents come in many shapes, sizes, and durations. Coping with and understanding the vast range of possibilities is one of the main challenges in effective incident support. In this slide we see “incidents” that include localized very dense fog that can cause major impacts to surface and air travel, flash flooding that may sweep cars from roadways, and a violent tornado. At this end of the range incidents may be only be important over a small part of a county with durations as short as a few minutes.

Student Notes:

7. A Range of IncidentsNational Importance

Instructor Notes: At the opposite end of the scale lie catastrophic events that impacts millions of people, last for weeks or months, span states, cost billions of dollars, and captivate national media interest. He we find things like the Columbia accident, the 9-11 terrorist attacks, and major hurricanes.

Student Notes:

8. A Range of IncidentsEverything In the Middle

Instructor Notes: Most of the time the events involving your office will be somewhere in the middle. Here, a snow storm, flooding in a small town, and a derailment fall into the middle ground. Even though these events occur frequently, they can still be deadly and cause substantial damage.

Student Notes:

9. A Range of IncidentsPlanned vs. Unplanned

Instructor Notes: In addition to variations in space and size, incidents may also be categorized as planned and unplanned. Obviously events like the flash flood are not planned. However, contrast that to support provided to federal, state, and local law enforcement for events like the Superbowl. Planning for managing security and logistics begins months or even years in advance!

Student Notes:

A Range of Incidents
Planned vs. Unplanned

10. What is Decision Support?

Instructor Notes: We spoke about the definition of "incident," but what about "decision support?" Decision support is about conveying relevant information to those tasked with making decisions effecting others. Here, we define the key components of decision support as: "Specific, mission-based, situational information, including our expert interpretation and explanation, provided in formats and language our customers understand."

Student Notes:

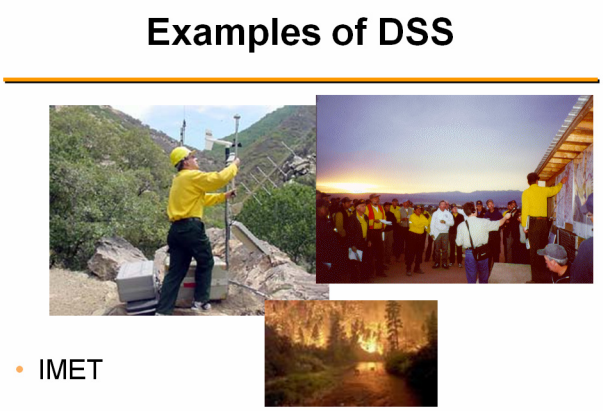
What is Decision Support?

Decision Support: Specific, mission-based, situational information, including our expert interpretation and explanation, provided in formats and language our customers understand.

11. Examples of DSS

Instructor Notes: The IMET program is probably one of the first examples we think of when discussing decision support services. This is a form of on-site decision support.

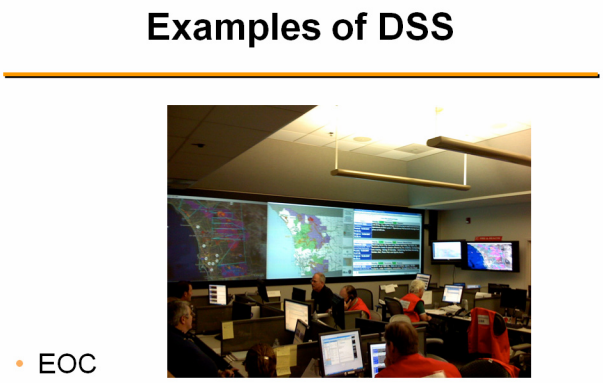
Student Notes:



12. Examples of DSS

Instructor Notes: We may also provide decision support through our presence in a state or local emergency operations center. While our role in decision support services at a fire scene is fairly well defined, our services in the EOC may be for disaster recovery efforts, as the Norman office did following the Murrah Building bombing. We may be called upon to provide support during an approaching hurricane, flood, or even to support a preparedness exercise.

Student Notes:



13. Examples of DSS

Instructor Notes: Here NWS forecasters use laptops to access web-based information and provide interpretation for those supporting Super Bowl security.

Student Notes:

Examples of DSS

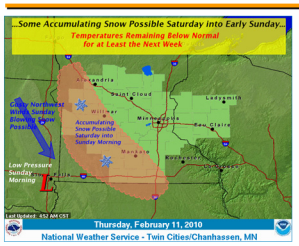
- Sporting events – Super Bowl

14. Examples of DSS

Instructor Notes: The ever-growing capabilities of the internet provide a fertile area for development of decision support services. Here are just a few examples. For the first time we can now provide narrated, graphical briefings such as this example from Little Rock. Or, specialized information for planned incidents like the 2010 Winter Olympics. Many government agencies use GIS to integrate geospatial data sets to support decision making. Expect GIS formats for weather data to be another web-based growth area for DSS.

Student Notes:

Examples of DSS



- Web

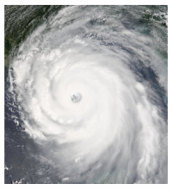
15. Essential to understand needs of decision makers

Instructor Notes: We must work to understand our customers needs and decision points if we are to provide the best support. For example, in coastal areas what thresholds or decision points determine when, where, and how an evacuation takes place for an approaching hurricane.

Student Notes:

Essential to understand needs of decision makers

- What are their key decision points?



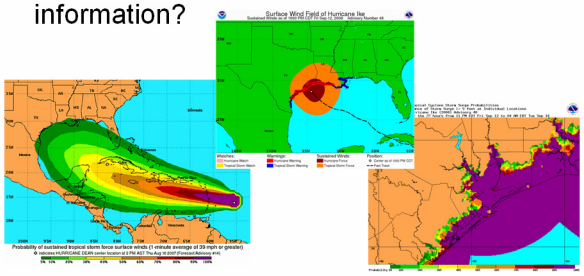
16. Essential to understand needs of decision makers

Instructor Notes: Continuing with the hurricane example, how do they use uncertainty or probabilistic information? Can you help with the interpretation?

Student Notes:

Essential to understand needs of decision makers

- How do they use uncertainty or probabilistic information?



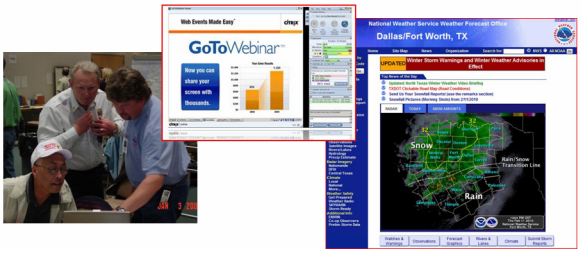
17. Essential to understand needs of decision makers

Instructor Notes: How we deliver our expertise depends on our customers. Some will require on-site support, others will utilize our web page alone, while others may utilize a conference call or webinar.

Student Notes:

Essential to understand needs of decision makers

- What are the preferred methods for delivering our expertise?



18. Situational AwarenessHow do you…

Instructor Notes: In other words, how do you get and maintain that "complete mastery of your environment" as described by Captain Sullenberger. Ask yourself these questions. How do you - become aware of an incident? - quickly assess the scope and impacts? - develop a plan and respond? We'll see these questions again at the end of this lesson.

Student Notes:

Situational Awareness
How do you…

- Become aware of an incident?
- Quickly assess the scope and impacts?
- Develop a plan and respond?

19. Situational AwarenessTechnology

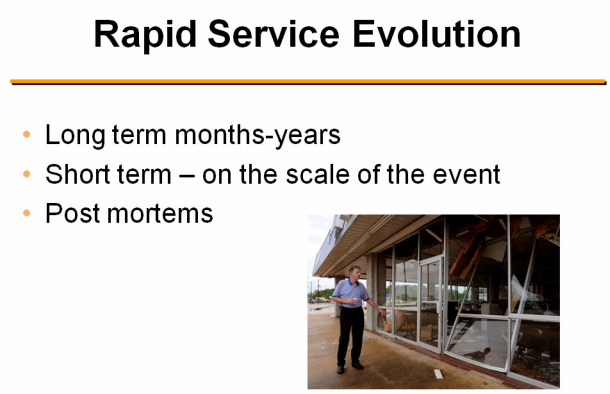
Instructor Notes: Situation awareness-related technology could be virtually any technology that helps to understand and manage information. It may take the form of multi-monitor displays that integrate weather information, media coverage, and status of important systems. Amateur radios, web cams, cell phone cameras, web based scanner services that allow you to monitor emergency radio traffic, devices that allow you to stream media coverage (video and audio) from remote parts of your CWA are other examples.

Student Notes:

20. Rapid Service Evolution

Instructor Notes: The ability to respond to an incident or event develops over a period of time based on a detailed understanding of decision maker information needs and on the development of methods of communicating that information. Service evolution that evolves over months and years can be viewed as strategic in nature, and is continually refined based on advances in science and technology and feedback from past events. Tactical service evolution can be viewed as adjustments to decision support services that are made during the course of an incident or event. Experience from past events suggests that local office guidance on incident decision support should be flexible in nature and allow for operational staff to respond to changing circumstances.

Student Notes:



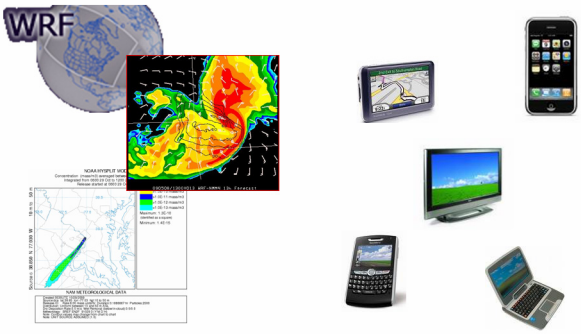
21. Potential role of technology in service delivery

Instructor Notes: Changing technology, especially the spread of broadband communications, is allowing us to reach and interact with our customers in ways we would not have imagined even a few years ago. Meanwhile, new capabilities are evolving within

the NWS to produce mesoscale forecasts and help quantify uncertainty through ensembling.

Student Notes:

Potential role of technology in service delivery



22. Potential role of technology in service delivery

Instructor Notes: An area of rapid growth is that of social media and other technologies that link people. Just how the NWS will fit in and benefit remains unclear. What is apparent, is that such networks have the ability to reach vast numbers of people very quickly and in ways they are accustomed. For now, keep an open mind, consider the possibilities, and be ready to learn new ways to provide decision support services.

Student Notes:

Potential role of technology in service delivery

skype

facebook

twitter

23. Additional Resources

Instructor Notes: There are many training opportunities that will better prepare operational staff for incident support. FEMA and COMET courses can be taken at times that are convenient for the student. Tabletop and full-scale exercises with local communities and their emergency personnel are typically scheduled throughout the year, and give NWS staff the chance to interact with local decision makers in a realistic decision support

environment. At the same time, exercise participants can be introduced to a range of NWS support services that goes beyond traditional hazardous weather products.

Student Notes:

Additional Resources

- FEMA Incident Command Courses
- FEMA IS-700.a: National Incident Management Sys.
- Cameo/Aloha Training
- HySplit Training
- COMET NWS Support During HAZMAT Incidents
- Media interview training
- Participation in local tabletop/full-scale exercises
- Effective briefing training
- Leadership training

24. Closing Thought

Instructor Notes: In conclusion, this proverb underscores the importance of your ability to recognize the potential importance of any incident and the willingness to act accordingly.

Student Notes:

Closing Thought

The reputation of a thousand years may be determined by the conduct of a single hour.

-- Japanese Proverb

25. Assignment

Instructor Notes: The assignment for this lesson is to go to the LMS and submit your answers to the following questions (you may need to have discussions with co-workers before completing this): In my office, how do I/We: Become aware of an incident? Quickly assess the scope and impacts? Develop a plan and respond? Your answer will be submitted using the “Assignment” tab in the LMS for this lesson.

Student Notes:

Assignment

- Submit answers to the following via the LMS

In my office, how do I/we

1. Become aware of an incident?
2. Quickly assess the scope and impacts?
3. Develop a plan and respond?

26. Questions

Instructor Notes:

Student Notes:

Questions

For questions, contact your training officer or send an email to:

awoccore_list@wdtb.noaa.gov

1. Data Quality

Instructor Notes:

Student Notes:

Radar Sampling Issues

Warning Decision Training Branch

2. Learning Objectives

Instructor Notes: It may be challenging to remain aware of the fact that radar is not a perfect sampling tool. The considerations listed here will impact (to varying degrees) the quality and quantity of the radar data depicted on your display. Unfortunately, most of these impacts are not always apparent by simply looking at the data. You (the user) must do the work of keeping these in mind and assessing as best you can when the data you are depicting are not telling the whole story, which in reality, is all the time!

Student Notes:

Learning Objectives

Describe the impacts of each of the following on radar data depiction:

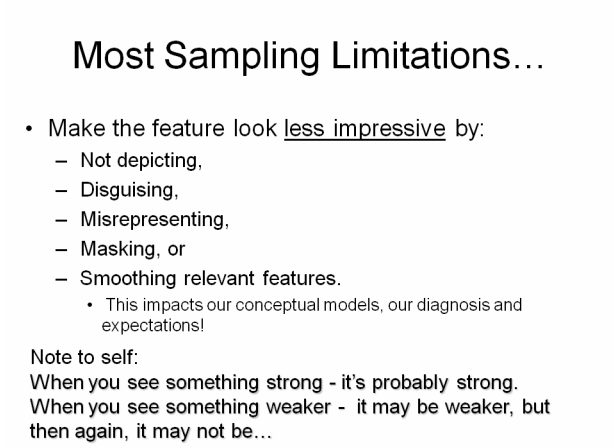
1. Aspect Ratio
2. Radar Estimated Heights
3. Radar Horizon
4. Scan Strategy
5. Beam Blockage
6. Viewing Angle
7. Beam Sampling
8. Data Resolution

Each of these will impact your available radars differently.

3. Most Sampling Limitations…

Instructor Notes: With a few exceptions, most sampling limitations make storms features appear weaker or broader or located somewhere else. A prudent assumption would be that what is really there is at least as strong or stronger than what you see.

Student Notes:

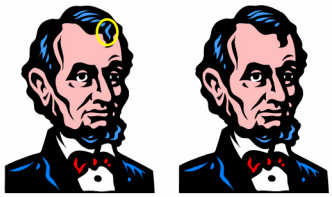


4. Learning Objectives

Instructor Notes: Sometimes recognizing sampling limitations can be like trying to imagine the difference between what you see and what you would see under the best conditions. In other words, you know what you should be seeing, and you recognize that for whatever reasons, you are not seeing it. In our example here, we look at a picture of Abe Lincoln. If we know what Abe should look like under the best conditions, we can hopefully recognize what's missing in this depiction. We have a mental picture (the newly arriving image on the left) of what he should look like so we noticed that the highlight (yellow circle) was missing. This recognition is hard enough to do with the conceptual and compromised images next to each other! Imagine trying to notice something that's missing when you only have the compromised image to see. This is what you are trying to do with radar data all the time: recognize what's missing. This absent data is an example of a "negative cue".

Student Notes:

Learning Objectives



What is wrong with this picture?

A conceptually "sampled" Abe is now available for comparison.

Assumptions:

- You know what Abe is suppose to look like (conceptual model)
- You can tell what's missing

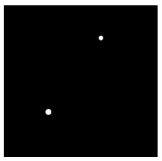
5. Being aware of negative cues

Instructor Notes: A negative cue: Like when a bunch of adults are talking, with their kids playing in the next room. Someone then asks, "Why is it so quiet in there?!" The lack of noise coming from the next room is a significant 'negative cue' which causes you to investigate further. Sherlock Holmes solved a crime with a negative cue. The lack of a dog barking during the time of a neighborhood crime inferred to him that the criminal was known in the neighborhood. The missing sound of a dog barking was a negative cue.

Student Notes:

Being aware of *negative cues*

- Negative cues (clues) are those cues (clues) made relevant by their *absence*
  - Recognizing these is doable, yet challenging, for experts
  - This is extremely difficult for novices
- Warning decisions are based on cues; but actions which may lead to them can be based on *negative* cues



6. What's a negative cue in the warning world?

Instructor Notes: Let's look at some negative cues in the warning world. When a storm moves into a major metro area (1), would you normally expect your public line to ring, and would you notice if it didn't? What would be some possible explanations? Items 2 and 3 fall in the "if a warning is issued and nobody knows about it is it still issued?" category. How would you notice? What might be the cause(s)? For 4, it might be that no warning was issued, or it went the road of #2 and 3. For 5, you might know about cases where warnings have been withheld because the "storm's just not intensifying", while

other warnings have been re-issued for storms that appear nearly “stationary”….all because the data were not updating. It has happened. Do you always pay attention to the time on products? How about the “blank spot” (6) where a surface ob should be? Or that blank position on the ob where the precip type should be? For 7, it gets a little tricky when you try to make sure something doesn’t make it through the cracks in your team effort at severe weather warnings. A rare and dramatic looking radar image would most surely cause someone (the warning forecaster?) to holler, “Wow look at this!” or some such, wouldn’t it? What if that didn’t happen, and the warning you might think would come, doesn’t? Did they see it? Did they recognize it? Did they type up a warning and forget to send? Did the storm develop in a “dead area” between assigned sectors? The last three are directly related to imperfect depictions of radar data. In 8, low (green VILs) can be a result of sampling errors which happen when the storms move quickly during the time it takes for a volume scan. For 9, does “no mesocyclone apparent” mean one isn’t there? Nope. At further ranges this could be especially a problem with aspect ratio. Further the mesocyclone can appear to shrink or even disappear at certain stages of tornadic development. For 10, impacts of beam width, range, and gaps in elevation angles can cause the business end of a storm to be totally overlooked by the radar. These negative cues require you to know what’s “normal” and proactively check-in to see when normal is not happening, and then investigate why.

Student Notes:

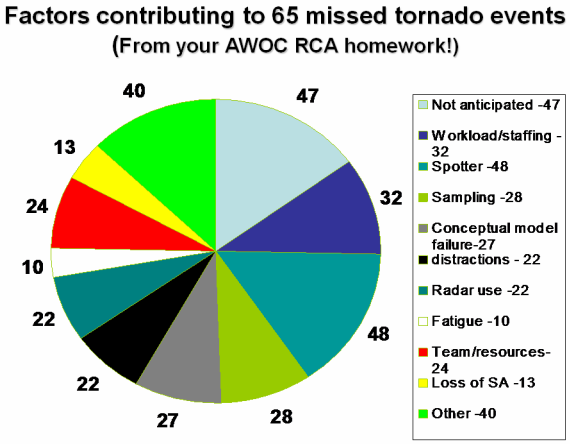
What’s a negative cue in the warning world?

1. Major storm moves into metro and public *phone doesn’t ring*
2. *Warning doesn’t broadcast* on NWR
3. *Tornado warning doesn’t show up* on TV
4. *Warning does not come* from neighboring office
5. Time on radar data *stops updating*
6. *Blank spot* where a surface ob should be
7. Warning forecaster *doesn’t “gasp”* at sight of 120kt TVS signature (and *no warning follows*)
8. *“Green” VILs* in an intense fast moving squall line
9. R suggests supercell but *no mesocyclone apparent* in V
10. Portion of a *storm is not sampled*

7. Slide 7

Instructor Notes: Here are some factors which contributed to 65 missed tornado events. This comes from Root Cause Analysis studies done for AWOC (See Core 3, Lesson 3). For example, in 47 of the 65 events, a contributing factor was that the event was “not anticipated.” Let’s look at the impact of Sampling and Radar use on the next slide.

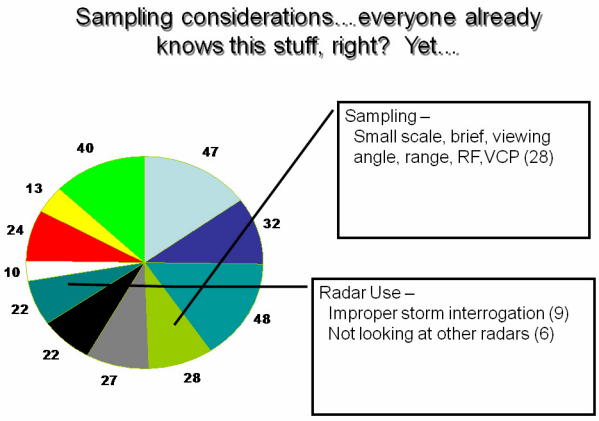
Student Notes:



8. Slide 8

Instructor Notes: In 28 of the 65 missed events, sampling limitations such as aspect ratio, viewing angle, range etc contributed to the forecasters inability to recognize the threat. In 22 of the events, improper use of the radar, which could be failure to look at the relevant products or elevation angles (altitudes) contributed. It might also have been failure to look at other radar views of the storm in question. In these cases, the storm probably looked less threatening to the decision maker than it really was.

Student Notes:

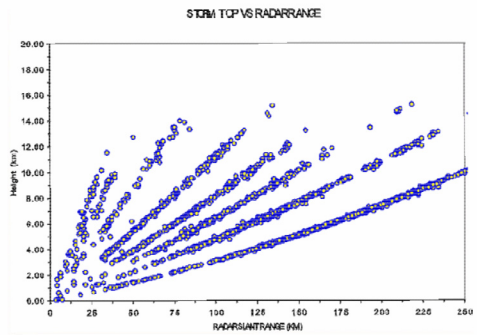


9. Radar Height Estimation

Instructor Notes: When radars sample the atmosphere, they do so with fixed elevation cuts. These plots represent storm tops which the radar has measured over a period of time. Why do they line up in relatively straight lines? Is that how nature made them? Hardly. You might recall that the only height we have is that of the beam centerline of each elevation cut. Therefore, anything sampled in that beam will be assumed to be close to the height of the beam centerline, which is really what is being depicted here.

Student Notes:

Radar Height Estimation

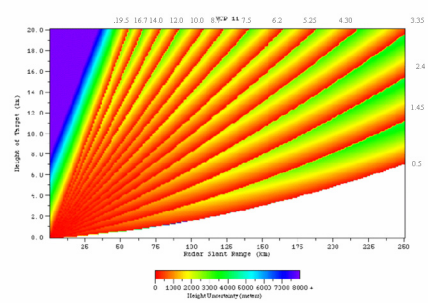


10. Uncertainty in Radar Heights

Instructor Notes: The uncertainty associated with storm-top height measurement is illustrated here. This shows the uncertainty (in meters) between the WSR-88D determined heights of a target and the actual heights for VCP 11. If the storm top is centered precisely on the beam center line (base of the red shaded region for each elevation angle) then the uncertainty is minimized (or is 0). This same uncertainty is also applicable to all other radar-based height measurements (e.g., height of the maximum reflectivity, echo top, echo base, etc.). For example at the 100-km (54 nm) range from the radar, the uncertainty between the radar-observed storm top and the actual storm top height can be greater than 9kft for very tall storms (those above 33kft).

Student Notes:

Uncertainty in Radar Heights



11. Uncertainty in Radar Heights

Instructor Notes: With all this uncertainty it can be seen that radar is not a precise tool when it comes to measuring heights. Impacts of beamwidth, beam filling, limited samples with range, gaps, atmospheric refractivity, and the cone of silence can depict heights in a poor fashion. When algorithm output (or your use of that output), assumes more preci-

sion than exists, problems can occur. This can happen with base data, EET, VIL, VIL Density, estimated height of any reflectivity value, HI, M, TVS, VAD, VWP, etc. When using radar and all its products, the user must keep this limitation in mind and not place an inordinate amount of value on any one piece of data.

Student Notes:

Uncertainty in Radar Heights

- Radar often measures heights poorly. Why?
  - beamwidth and beam filling,
  - fewer beams with range,
  - gaps between beams,
  - variable atmospheric refractivity,
  - cone of silence, etc.
- Things to consider:
  - How does height uncertainty affect algorithm output where height is a factor?
  - Implied precision and accuracy can be misleading, especially at further ranges or where VCP gaps occur.

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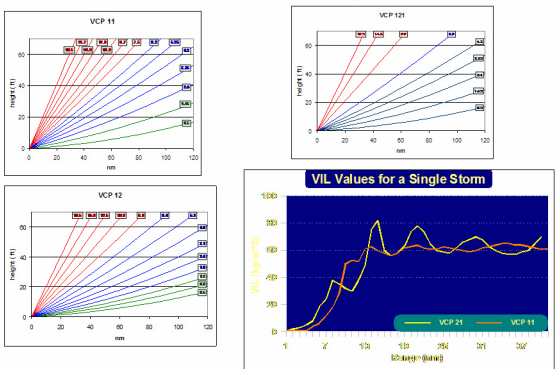
12. Scan strategy determines which parts of the storm will be sampled…or not

Instructor Notes: Storms will look different purely because of the scan strategy employed. Derived products such as VIL, CZ, ET, and others will all be impacted by the use of different scan strategies. Base data interpretation is also impacted. In general, the more elevation cuts available, the less impact scan strategy will have on the output, and the more meaningful will be the information obtained.

Student Notes:

Scan strategy determines which parts of the storm will be sampled…or not

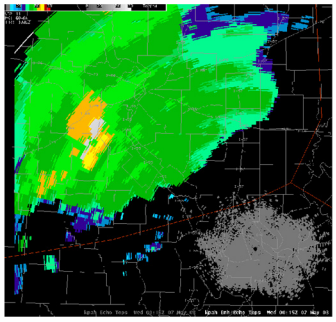


13. Scan strategy impacts – A radar negative cue reminder

Instructor Notes: Rather than have to remember that data around the radar is compromised, this product provides that information. This “graying” out of data tries to provide a measure of the uncertainty involved with the data you see. It is a reminder that the Echo Tops you would have seen plotted in this area would not have been trustworthy due to the effects of the cone of silence (a limitation of using scan strategies). This is analogous to the areas of uncertain velocities being labeled as “range folded”, thereby eliminating the possibility of misinterpretation.

Student Notes:

Scan strategy impacts –
A radar negative cue reminder



Gray area surrounding the RDA in the EET product is where echo is “topped” by radar at 19.5 degrees.

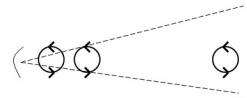
14. Aspect Ratio and Radar Horizon

Instructor Notes: With aspect ratio, you must know the approximate dimensions of your feature in order to determine the extent of the sampling impacts. Large storm? Mini supercell? In general, the closer and bigger a storm is, the better it is represented on radar. Smaller features are more significantly impacted when they are further away from the radar. In some cases, a feature of interest may be contained entirely in one beam width. With velocity, this will often cause the feature to be eliminated altogether. (Note: Rotational velocities of storms at further ranges may be lower than you would expect to be associated with significant rotation). The impacts of radar horizon are too dependant on the type of feature being sampled, You may entirely overshoot what would have been significant cues to threat assessment in some storms, especially lower topped convection. In addition, storms will appear to change with range simply due to the effects of radar horizon. Recall that at close ranges, storms can be sampled at 1kft or less at 0.5 degrees. At far ranges (>100nm) the 0.5 degree cut is sampling between 9kft and 21kft.. Thus a storm moving outward along the 0.5 degree slice will appear to change simply due to the changes in the part of the storm being sampled as well as beamwidth. Again the impact of both of these sampling limitations most often will be that storms appear weaker than they really are.

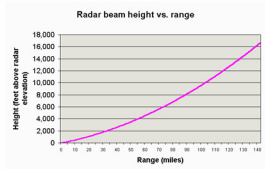
Student Notes:

Aspect Ratio and Radar Horizon

Aspect Ratio
Consideration: The size of the feature compared to size of the beam determines how it is resolved/depicted.



Radar Horizon
Consideration: The part of the storm you see at 0.5 degree changes due to effects of radar horizon/earth's curvature.

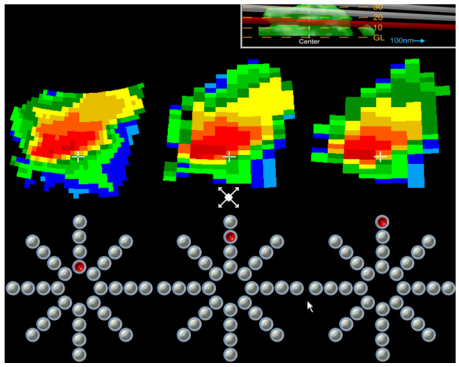


15. Aspect Ratio and Radar HorizonChange size, shape, intensity of features

Instructor Notes: Three views of the same storm, each changing only by range. The storm is assumed to be at the center of the grid of potential radar positions. Thus, we have a view of the storm from a radar 25 miles to the north (left) and the same storm as view from a radar 75 miles to the north (center). The image on the right is the view from a radar 100 miles north of the storm. The storm's change in appearance is due to both aspect ratio and radar horizon effects. Thus, from left to right, the pixels get bigger (beam is larger) and the height being sampled is higher.

Student Notes:

Aspect Ratio and Radar Horizon
Change size, shape, intensity of features



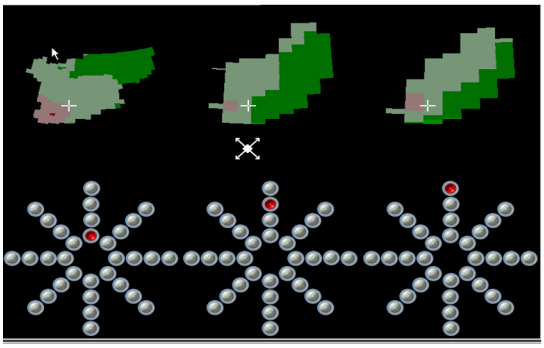
Note: Storm is assumed to be in center of each grid with radar location the red "dot"

16. Slide 16

Instructor Notes: Same thing only with velocities. Our beam is getting bigger in the images from left to right and we are sampling different altitudes.

Student Notes:

Aspect Ratio and Radar Horizon
Change size, shape, intensity of features

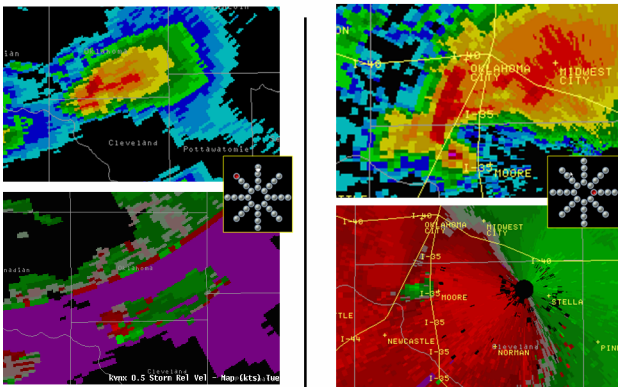


17. Aspect ratio/Radar horizonFar Close

Instructor Notes: View on the left of both Reflectivity and Storm Relative Velocity is 0.5 degrees, but at 12Kft. View on the right is at 0.5 degrees but at around 1Kft (keeping in mind the height uncertainty). Are you always looking at multiple views from various radars to account for these sampling impacts?

Student Notes:

Aspect ratio/Radar horizon
Far Close



18. Where is the feature, really?Radar indicated location of circulation is less accurate at longer ranges (partially due to radar horizon)

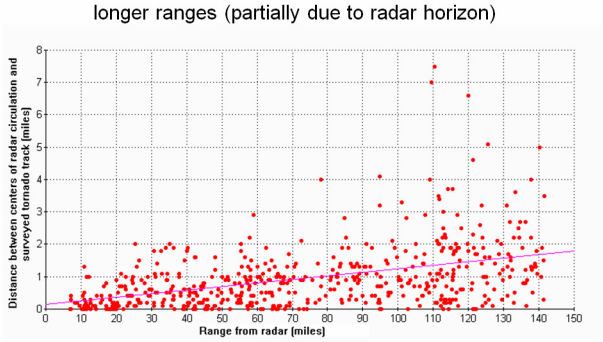
Instructor Notes: In this image, the difference between the radar indicated circulation center and the damage path is plotted with range. The distance between the indicated feature and the actual feature increases the farther away you are from the radar (i.e. the higher you get above the ground). Many times this will be the case when the circulation tilts with height. This is helpful information when deciding where the actual threat is in a warning, and also in deciding where to go to conduct damage surveys (will likely not be

exactly where the center is indicated at further ranges). When wording a warning even though detail is desirable, caution must be exercised in just how much detail should be used in stating specific locations and cities affected.

Student Notes:

Where is the feature, really?

Radar indicated location of circulation is less accurate at longer ranges (partially due to radar horizon)



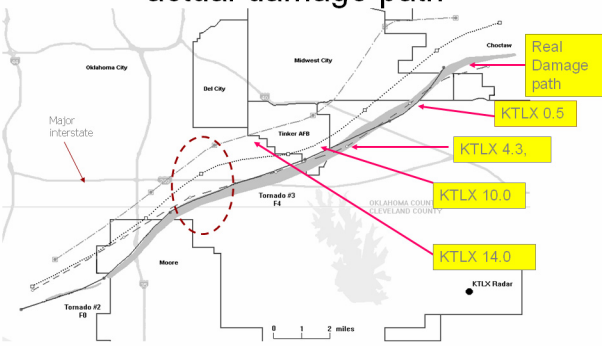
From Speheger and Smith 2006

19. Indicated circulation centers versus actual damage path

Instructor Notes: The location of the circulation center varies at different altitudes (i.e. different elevation slices). This variability would also be what you see if you are looking from different radars, each perhaps sampling the storm at 0.5 degree but at different ranges and therefore different heights. Storm tilt with height is also a major factor. This has an impact when using street level background maps when your depiction is at different altitudes. For example, in the area enclosed by the red dashed line, the tornado is either a couple miles south or a couple miles north of the interstate, depending on the depiction you have in front of you (i.e. which altitude you have sampled). Think about a severe weather statement you are writing at this stage and the tornado location you would use.

Student Notes:

Indicated circulation centers versus actual damage path



3ft – 20kft

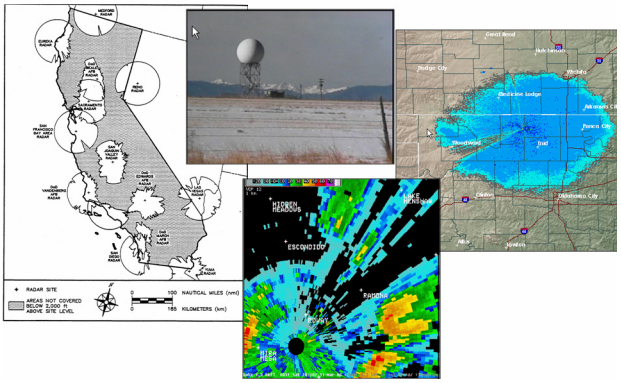
From Speheger and Smith 2006 (5/8/2003)

20. Beam Blockage

Instructor Notes: Pretty obvious that you are susceptible to beam blockage when you see mountains out the window. Still, to what degree the blockage affects your data may be challenging to discern. Other blockage can be caused by nearby buildings, or towers, wind generator farms, or as in the case here (example on the far right), a stand of trees on a ridgeline.

Student Notes:

Beam Blockage

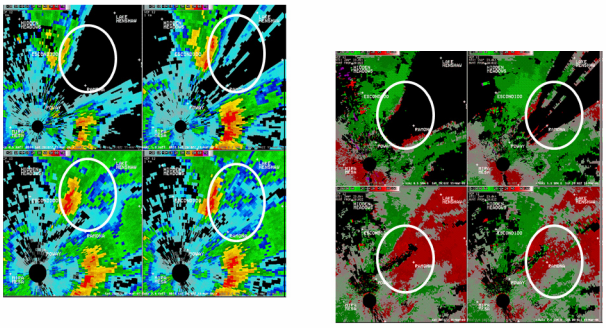


21. Beam Blockage 3/11/06 1945z

Instructor Notes: Where is the data suspect due to beam blockage in these images? The circles indicate the general area when the beam blockage will have the biggest impact. That blockage will be more significant on the lowest elevation cuts, but will have at least partial impact in the higher cuts. As the storm just northeast of the RDA moves east, it will move into this area. Much of the data will become compromised, especially at the lower 2 cuts. It can be hard to remember these impact are about to insert themselves, and knowing to what degree is an even bigger challenge, especially when not all data is blocked. A tornado is about to occur with this storm.

Student Notes:

Beam Blockage 3/11/06 1945z



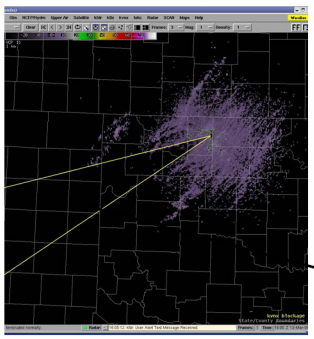
22. Beam blockage overlayNegative cue reminder…

Instructor Notes: The cue serves to say “don’t trust data in this area”. Close in you have the break in the clear air return to indicate where beam blockage is an issue. Would you be as aware if the radar was sampling data considerably further out?

Student Notes:

Beam blockage overlay

Negative cue reminder…



Forecaster developed cue - AWIPS overlay to indicate area partially blocked by trees on hillside

The message: Don’t completely trust data in this area!

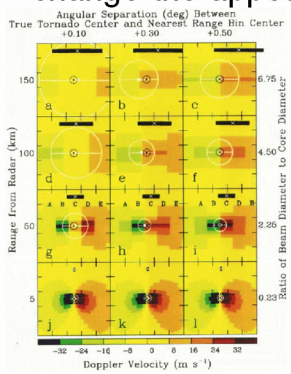
23. Beam Sampling: How does it change the appearance of echoes?

Instructor Notes: While you can sometimes imply the impacts of some sampling limitations, with beam sampling, it is almost impossible to do so. This is especially true with changes that occur from volume scan to volume scan and slice to slice at constant range. Many a circulation has appeared to weaken via this process causing misinterpretation by the forecaster. In this depiction, each row is at the same range, but the circulation appears differently based on changes in azimuthal sampling, i.e. the location of the beam relative to the actual circulation center. Beam placement is random. At further ranges (top most rows in the graphic) this change is more dramatic because there are

fewer (and larger) beams sampling the feature. Look at the row at 100km from the radar. The couplet depicted in this row appears to vary from a weak circulation (left) to a decent mesocyclone (right). Remember the feature is not changing…only the sampling of the feature from volume scan to volume scan (and even elevation slice to slice). Being aware of this sampling impact should cue you to not rely too heavily on computed rotational velocities or shear values, especially if they appear to weaken drastically.

Student Notes:

Beam Sampling: How does it change the appearance of echoes?



Discrete azimuthal sampling may or may not coincide with the peak rotational velocities in the vortex. Result: Strength and location of vortex will seem to vary.

Actual feature

Depicted feature

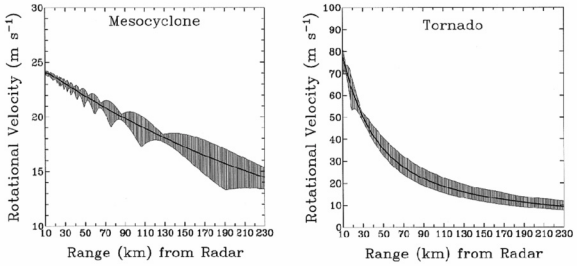
Wood and Brown 1997

24. Beam sampling and range combine to alter Meso/ TVS strength depiction

Instructor Notes: This graphic shows how rotational velocities can appear to change (mostly weaken) as the distance to the feature increases. The feature is not changing, just the appearance on radar. All strength changes inside the envelope are due to random changes in sampling.

Student Notes:

Beam sampling and range combine to alter Meso/TVS strength depiction



Actual strength is constant!

Wood and Brown 1997

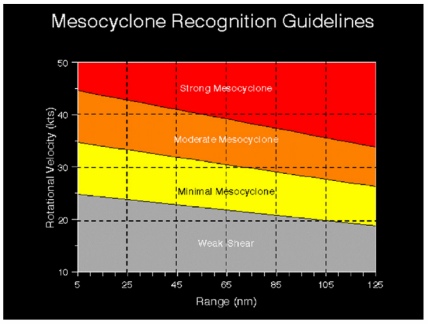
25. How strong is the feature, really?We relax guidelines at further ranges because of sampling, aspect ratio

Instructor Notes: Here is another tool that the user devised to help remind decision makers of the uncertainty of radar data at farther ranges. But even this tool needs changing as actual circulation size changes (e.g. for mini-supercells).

Student Notes:

How strong is the feature, really?

We relax guidelines at further ranges because of sampling, aspect ratio



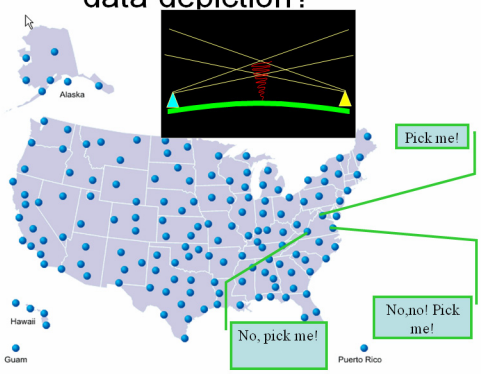
This is a forecaster - generated *negative cue* reminder: Objects on radar may be stronger than they appear! (especially at longer ranges)

26. How does the viewing angle impact data depiction?

Instructor Notes: Choosing which radar will give you the best picture can be a challenge. This is especially true when the differences are caused by the radar viewing angle. Normally the radar nearest the feature in question is the best, but not always! Viewing angle impacts may change that radar selection.

Student Notes:

How does the viewing angle impact data depiction?

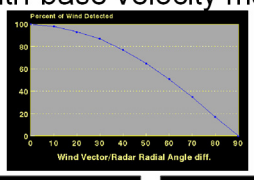


27. Viewing angle is everything when dealing with base velocity magnitude

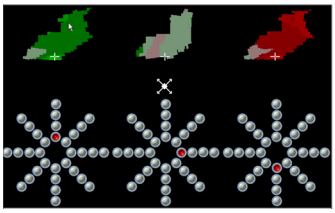
Instructor Notes: Recall that if the wind is blowing down the radial, you measure all of it. If it's blowing perpendicular to the radial, you measure none of it. Usually it's somewhere in between. The bottom left image shows the same radial velocity data when viewed from 3 radars, one north of the echo, one east of the echo, and one south of the echo (the echo is assumed to be in the middle of the "grid" of radars). The image on the right shows the actual flow field superimposed on the last depiction.

Student Notes:

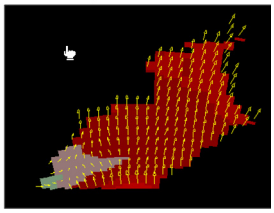
Viewing angle is everything when dealing with base velocity magnitude



Depicted velocities



Actual flow field

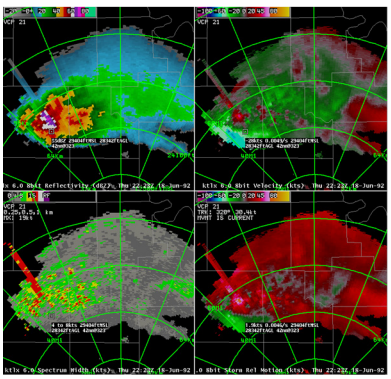


28. Viewing angle and the TBSS

Instructor Notes: TBSS, caused by the presence of large hail, shows up as weak echo down radial from the high reflectivity core. Weak or negative velocities show up on the base velocity along with very high spectrum widths. Since there is little additional echo on the downrange side of the storm in this example, the TBSS shows up very well with this viewing angle.

Student Notes:

Viewing angle and the TBSS



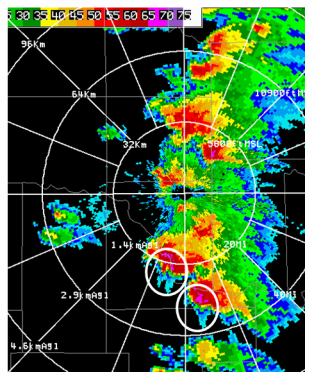
The viewing angle from any radar may make the TBSS signature easier or harder to see.

29. Viewing angle and the TBSS

Instructor Notes: We can still see this TBSS in this example, although not as well as in the last. However, in this case, the weak or slightly negative velocities associated with the TBSS are overlaid on the part of the storm where we would expect mesocyclone signatures. The resulting display will be a mixture of velocities from the two signatures. This will change the appearance of the mesocyclone, and perhaps what you conclude about it. This can even disrupt the velocity field as detected by the radar to the extent that both the forecaster and the algorithm fail to identify the circulation.

Student Notes:

Viewing angle and the TBSS



Here the TBSS signature overlays the right flank of storm where very little intervening echo exists.

Result:
Great for TBSS viewing!

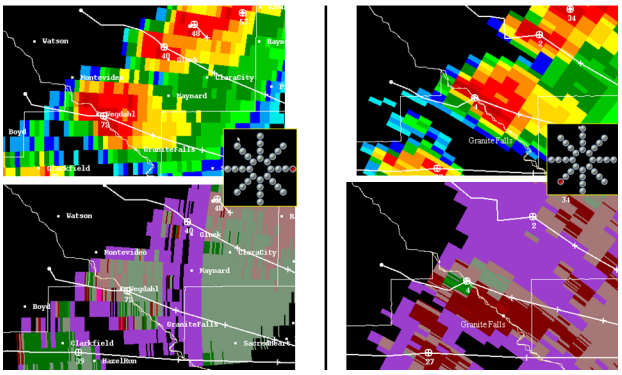
Bad for mesocyclone viewing!

30. What are impacts of viewing angle when radars are at about the same range?

Instructor Notes: You'd think that radars at the approximate same range would show the same thing, right? Often however this is not the case. The storm here is viewed from a radar 100 miles to the east (left image) and a radar 100 miles to the southwest (right). Differences in the two are caused by several things including the presence and location of RF data (a function of PRF selection, range, and intervening echo). Keep in mind that the circulation is likely not axisymmetric which may be contributing as well. While this illustration concerns mesocyclone recognition, the same impact is present when viewing microbursts or downbursts near the radar.

Student Notes:

What are impacts of viewing angle when radars are at about the same range?

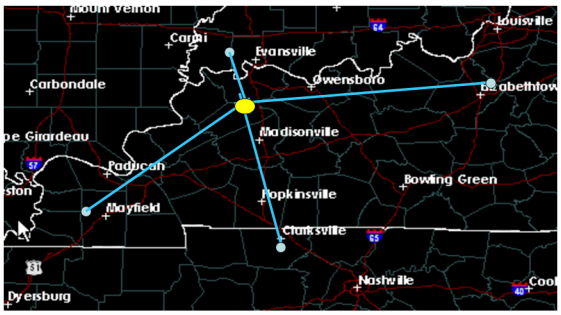


31. Culmination of Sampling Issues

Instructor Notes: Let's look at one storm as viewed from 4 different radars.

Student Notes:

Culmination of Sampling Issues

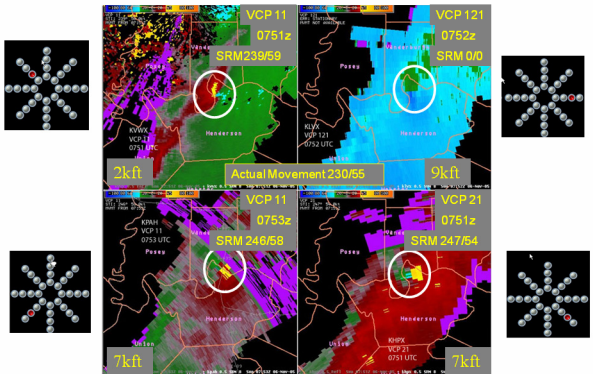


32. What is contributing to variations?(0.5 degree SRM for KVWX, KLVX,KPAH, KHPX)

Instructor Notes: Each of the velocity images is from a different radar. For reference, the image is assumed to be in the middle of each of the grid of "potential radars", with each of the grid points representing radar sites at 25, 50 , 75 and 100 nm from the storm. So in the upper left image, the radar viewing the storm is to the northwest about 50 miles looking at the storm to its southeast. You can see that the storm is sampled at about 2Kft. Here are the locations, and sampling altitudes, of the other 3 views. Take a moment and look at these images and ponder if you will why they look different from each other. Some hints as to possible contributors to these differences will be appearing on this image. When you think you know all the impacts, go to the next slide.

Student Notes:

What is contributing to variations?
(0.5 degree SRM for KVWX, KLVX, KPAH, KHPX)



33. What's contributing to the variations?

Instructor Notes: Here are at least some of the contributors to the variations in the images you see. Each of these impacts will vary with each radar. How do you know which perspective to believe? The variations or limitations listed here will not create, in almost every case, a stronger or more pronounced feature than is actually the case. Therefore, prudence would dictate that you use of the most impressive depiction. In order to do that, you had to make sure you saw all of these views!

Student Notes:

What's contributing to the variations?

- Beam sampling
- VCPs (11/121/11/21)
- Radar horizon
- Aspect ratio
- Viewing angle
- Storm height (2kft, 7kft, 9kft)
- Storm speed
- Storm tilt
- Differences in storm motion on SRM
- Differences in product times (:51, :52, :53, 51)
- Others?

Who to believe?

Prudence says the radar with the most impressive depiction!

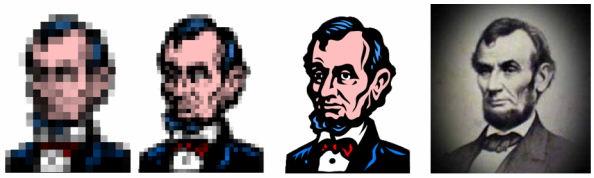
34. Data resolution and its impact on feature recognition

Instructor Notes: Our ability to resolve features, especially small features, is also a function of the data resolution. With help once again from Abe, we are able to depict how improved data resolution helps us get closer and closer to the real thing. Obviously, we can't resolve the actual feature at this point in time, but we can get close enough to help identify the signature. The next few slides will discuss the changes you can expect to see

simply based on the changes in data resolution. Keep in mind that these changes will be further impacted by the sampling limitations already mentioned.

Student Notes:

Data resolution and its impact on feature recognition



Someone. Resolution: .54nm

Abe-like. Resolution: .27nm

Abe. Resolution: .13 nm (The best we can do now.)

Abe. Close up spotter view.

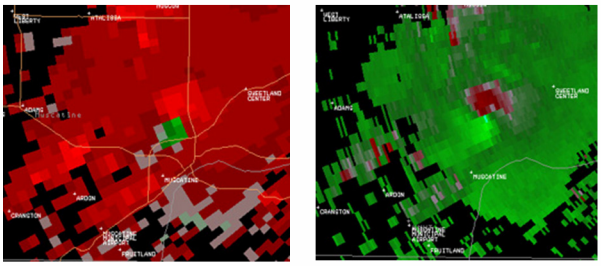
35. Data Resolution Alters appearance and location of features

Instructor Notes: Higher resolution data accounts for other differences in data depiction. In this case we have the low res versus hi res WSR-88D data. Where you place the center of the circulation is a function of data resolution. In virtually every case the higher resolution product is most desirable.

Student Notes:

Data Resolution

Alters appearance and location of features



1 degree x .54nm

1 degree x .13nm

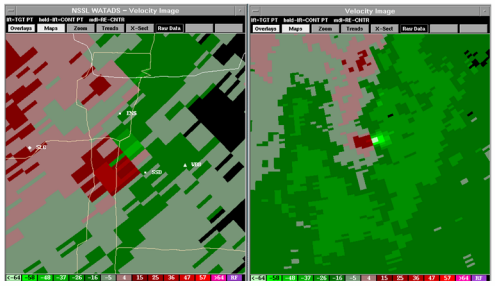
36. Slide 36

Instructor Notes: In this example, the Salt Lake City WSR-88D is at a greater distance to metropolitan Salt Lake City than the TDWR. The WSR-88D also is located at a higher altitude. Therefore the WSR-88D 0.5 degree beam is higher above the city than the TDWR 0.5 degree elevation beam. This plus the difference in data resolution accounts for a different depiction.

Student Notes:

Data Resolution

Alters appearance and location of features



WSR-88D TDWR

Salt Lake City Tornado, Aug 11, 1999

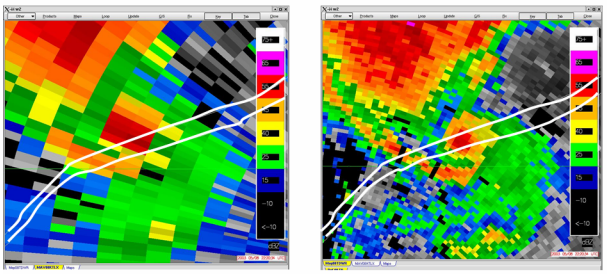
37. Slide 37

Instructor Notes: WSR-88D and TDWR images from May 8, 2003 tornado. The highly reflective “debris ball” is noticeable on both images, but the better resolution of the TDWR allows for much greater detail. Question: Are there challenges with seeing all this detail? In the TDWR depiction, the debris ball is located within the damage path (white lines), where as in the WSR-88D depiction, the debris ball is along and to the north of the path.

Student Notes:

Data Resolution

Alters appearance and location of features

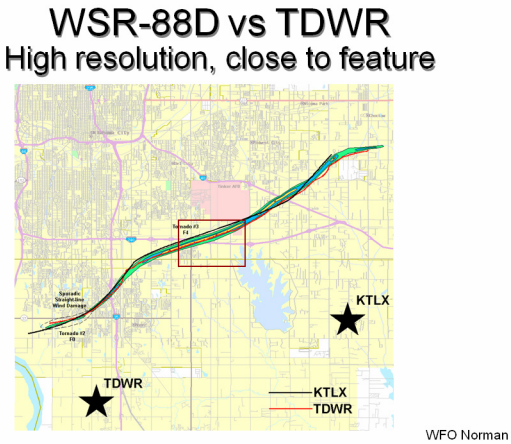


WSR-88D May 8, 2003 SE OKC Tornado TDWR

38. WSR-88D vs TDWRHigh resolution, close to feature

Instructor Notes: In this case, both radars are close to the tornado, especially where it is at its strongest. We’ll take a look at the differences we see here from radars at about the same distance, but using different resolutions.

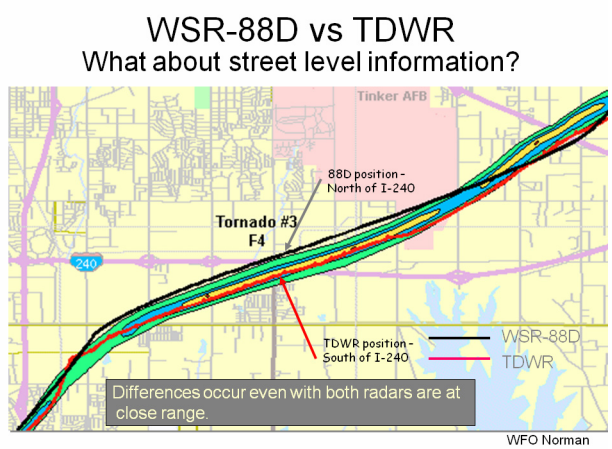
Student Notes:



39. WSR-88D vs TDWRWhat about street level information?

Instructor Notes: This image is similar to the one we showed in slide 20. But in this image, instead of having positions that vary because of a depiction of different altitudes bythesameradar,thesedifferingpositionsareduetotwodifferentradarviews.
In this image, the light green is F0 and F1 damage, the light blue is F2 damage, and the yellow is F3 damage. The black line is the circulation center as indicated by the WSR-88D. The red line is the circulation center of the TDWR. Even at these close ranges, there are differences in the TDWR depiction of the circulation center and the WSR-88D depiction. The differences are likely due to variations in radar resolution and slight differences in altitudes sampled, even with both at close range. At one point in time, the 88D has the circulation center north of I-240, while the TDWR has it south of I-240 (the same problem we saw on slide 20 where we were sampling the circulation at different altitudes. This leads to the same dilema: With such variability in the high resolution data close in, how can or should you incorporate street-level information in your statements and warnings?

Student Notes:



40. Summary

Instructor Notes: To summarize, sampling considerations will always impact the look of the radar data. The question we can not always easily answer is how, and to what degree. That often means we have to be proactive in detecting negative cues which often come in the form of missing data or data which seems good but is actually highly compromised. One way to help minimize the impacts these limitations have on our decisions is to ensure we look at multiple radar views. One of the best way to do this is by having procedures which compare radar views…then all you have to do is remember to use them! Your mission now is to come up with other ways you (or your office) can address these issues operationally.

Student Notes:

Summary

- Sampling considerations always impact the look of radar data
  - The question is how and to what degree?
- This means we have to overcome the subtlety of negative cues by being proactive with data interrogation.
- Looking at multiple radars may help insure that no one radar's sampling limitations overly skew data interpretation and resulting warning decisions.
- Question for you: What's the best way to incorporate this practice into your storm interrogation methodology?

41. Thanks for your attention!

Instructor Notes:

Student Notes:

Thanks for your attention!

References

- On the Imprecision of Radar Signature Locations and Storm Path Forecasts, Douglas A. Speheger and Richard D. Smith, NOAA/NWS Forecast Office (submitted for publication Jan 2006, NWA Digest)
- Effects of Radar Sampling on Single-Doppler Velocity Signatures of Mesocyclones and Tornadoes, Vincent T. Wood, Rodger A. Brown; Weather and Forecasting: Vol. 12, No. 4, pp. 928–938.
- Sources of Power: How People Make Decisions; Gary Klein, 1998
- Uncertainties in WSR-88D Measurements and Their Impacts On Monitoring Thunderstorm Life Cycles, K.W. Howard, J. J. Gourley and R. A. Maddox; Weather and Forecasting: Volume 12, No. 1, pp. 166 -174.

- Cases/data provided by Jim Purpura, MIC San Diego, Pat Spoden, SOO, Paducah, Rich Naistat, SOO Minneapolis, Dave Andra, SOO Norman, Larry Dunn, Former SOO Salt Lake City

1. Introduction

Instructor Notes: Welcome to this short module on mitigating potential errors in spotter reports. This lesson, which lasts approximately 20 minutes, discusses how NWS offices receive spotter reports, the groups of people who submit reports, and some simple ideas on mitigating common errors that can sneak into reports. My name is Andy Wood, and I will be presenting this material.

Student Notes:

Conveying Warnings and Public Response

Mitigating Potential Errors in Spotter Reports

Warning Decision Training Branch

2. Learning & Performance Objectives

Instructor Notes: There are three learning objectives and one performance objective for this lesson. Please take a few moments to review these objectives before proceeding to the next slide.

Student Notes:

Learning & Performance Objectives

Learning Objectives

1. Identify the sources of storm reports (i.e., how they are received and from whom) along with their strengths and weaknesses
2. List some of the common reasons storm reports are erroneous
3. Identify the methods discussed to mitigate erroneous reports in warning operations

Performance Objective

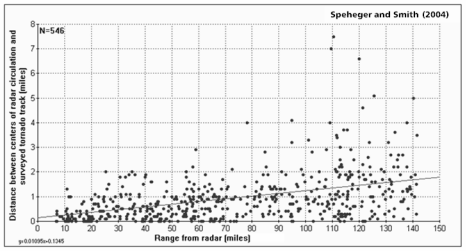
1. Demonstrate the ability to mitigate erroneous spotter reports in warning operations

3. Spotter Reports: Vital Ground Truth Data

Instructor Notes: Anyone even slightly familiar with NWS warning operations knows that spotter reports are important. While all observational data have value, radar data and spotter reports are heavily weighted during warning operations. Radar data, with all of its benefits, do have some significant limitations. For example, the graphic shown is from a study comparing radar circulation locations to tornado damage. The pink line indicates that the further a tornado is from the radar, the greater the error present in the radar observed location (Speheger and Smith, 2004). Spotters are the forecasters eyes and ears in the field and help overcome some of radar data's limitations. On one hand, they provide ground truth data as critical as any mechanical sensor. On the other hand, they are people communicating their observations. To make the most of this vital data, NWS staff must use their meteorological knowledge and people skills to quality control these data just as you would from any other "sensor".

Student Notes:

Spotter Reports: Vital Ground Truth Data



- Radar and spotters crucial in warning ops
- Radar data have limitations
- Spotters help overcome those limitations

4. How You Receive Reports Is Important

Instructor Notes: Before we discuss the individuals who provide you with spotter reports, let's talk for a moment about the ways you receive these reports. After all, how you receive the information can be just as important as from whom you receive it. When spotter information comes into your office, many times a spotter has contacted your office. E-spotter is one of many tools that would be used by spotters to send in a report. TV reports of severe weather or damage are another method. Both of these communication tools are initiated by the spotter and push information into the forecast office. While these "push" technologies are helpful for forecasters, these tools don't always provide you with the information you need, or want. When a forecast office has to solicit reports from spotters, it requires more effort to get the information. However, if you "pull" the specific information into the office this way, you are more likely to get the information you are looking for. The more common tools forecasters use to contact spotters (such as Ham radio and phones) also have the benefit of being two-way forms of communication. In other words, they are both push and pull tools. When you contact someone over the

phone or ham radio, it's easier to have a conversation, ask follow-up questions, and clarify what it is they are observing. During warning operations, you'll ideally want to achieve a balance between the benefits of both "push" and "pull" technologies to receive pertinent storm information in as efficient a manner as possible.

Student Notes:

5. Recent, Significant Technology Changes

Instructor Notes: There are many ways that your office can receive spotter information. Some methods have been around a while, such as TV, phone calls, and Ham Radio. Other methods, such as on-line reporting, is newer. There are two relatively recent technology changes that may have, or may already have had, an impact on your warning operations. Starting in 2009, nearly all NWS forecast offices will be using NWSChat as a collaboration tool to exchange mission critical significant weather information. This tool has both chat and instant messaging capabilities, allowing for quick information exchanges between NWS, media, and emergency response personnel. While NWSChat was not necessarily designed to receive spotter reports, you will inevitably receive some through this medium. If your office has not used chat software extensively in the past, expect to receive some reports via this tool in the future. Another relatively new resource is the on-line Spotter Network. This community provides on-line access to real-time spotter locations, movement, and information. This information is accessible through a variety of software applications (e.g., GRLevel, Google Earth, and RSS feeds). In some cases, these spotters will stream their storm video live (or nearly live) on-line so that you can see what they are seeing. While this network is most dense in the Central Plains, there are members of this community scattered throughout the lower 48 states.

Student Notes:

Spotter Reports: Recent Technology Changes That May Impact Operations

NWSChat

- Tool for conveying significant weather info
- You may receive some spotter reports via chats

Spotternetwork.org

- Real-time web access to spotter location, movement, & reports
- Some spotters post streaming storm video live

6. Spotter Reports: Network Composition

Instructor Notes: In many ways, the spotters in your county warning area are just like any other surface observing network. Of course, unlike other surface data sources, spotter networks are composed of observers with a variety of experience and skill levels. These different observers fall into four general categories: Local spotters (including emergency managers and public safety personnel) trained by the NWS; Other "experienced" spotters, including storm chasers, researchers, and other weather enthusiasts in the area due to the severe weather potential; Various media (i.e., TV and radio) personnel reporting on severe weather and its impacts; and The general public. On the next slide, you will see a breakdown of the pros and cons of observations provided by these different groups.

Student Notes:

Spotter Reports: Network Composition

7. Sources of Spotter Reports

Instructor Notes:

Student Notes:

8. Poor Observations

Instructor Notes: We've discussed how you receive reports and the people that provide them. Now let's discuss some of the common sources of errors, starting with poor observations. Poor observations can result from either honest mistakes, a lack weather knowledge, or other reasons. In some cases, these errors result from spotters who don't know what they are looking at, or for, when severe weather is occurring. Not knowing where to look, or what to look for, can result in missing the important details. Other reports are poor because clearly observing the phenomenon is not possible. Remote, rain-wrapped, and nocturnal tornadoes are examples of this problem. Smoke plumes, smoke stacks, or even grain silos in the vicinity of a storm can confuse a spotter about what they are really seeing.

Student Notes:

Possible Spotter Report Significant Errors: Poor Observations

- Result from:
  - Honest mistakes
  - Lack of weather knowledge
  - Other reasons
- Conditions for observing phenomenon less than ideal
  - Remote, rain-wrapped, or nocturnal tornadoes
  - Distant objects can be mistaken for tornadoes

9. Poor Communication

Instructor Notes: Communication problems can also introduce errors into spotter reports. As with poor observations, almost anyone can make these mistakes. The biggest problems result from reports that are relayed through an intermediary. Reports that go through multiple parties before getting to the NWS are only as good as the weakest communicator in the chain. As a result, I refer to this problem as "Chain" error. It's human nature for us to paraphrase, especially when we are busy and repeating information constantly. Anyone can make this mistake. If you ever played the game "Operator", you know what I'm talking about. Location error is another possible communication problem. When spotters report a location, is that location where they are or where they observed (or think) the phenomenon is occurring? This problem is more likely when a spotter reports weather at a distance (e.g., tornado) and less likely when a spotter reports damage or an in situ measurement (e.g., hail measured with a ruler). However, e in these latter cases, location errors are possible. When a spotter provides their location and the phenomenon's location, this information can get swapped somewhere down the line. Time errors occur in a similar fashion to location errors. In haste (either the spotters or the forecasters), the occurrence time of delayed reports may occasionally be omitted.

In these cases, either the time the call was received or the time of an adjacent report may be recorded instead.

Student Notes:

Possible Spotter Report Significant Errors: Poor Communication

- "Chain" error
  - The more people in the chain, the greater chance of error
  - Direct communication clearer
- Location swapping
- Time swapping

10. How Many Significant Errors Are There?

Instructor Notes: While the errors discussed here are not all-inclusive, they can result in the more common storm report problems. So lets ask the question you are probably thinking at this point: How many spotter reports have significant errors? The honest answer is we don't know. As a result of conversations with multiple WFOs, the minimum rate of significant reporting errors is somewhere around 10%. However, the research on this subject has been limited. One study, Witt et. al (1998), indicated the number could be as high as 30% in areas of the country that regularly experience severe weather.

Student Notes:

Possible Spotter Report Significant Errors: Just How Many Are There?

Hail Reports (in CSV format)

Time	Size	Location	County	State	Lat	Lon	Comments
1230	75	WARREN	BRADLEY	AR	3361	9207	(LZK)
1322	100	MARSHALL	HARRISON	TX	3254	9435	HAIL FELL JUST SOUTH OF THE HARRISON COUNTY AIRPORT ALONG HWY 31 JUST NORTH OF INTERSTATE 20. (SHV)
1409	88	SHREVEPORT	CADDO	LA	3247	9380	TV STATION REPORT IN DOWNTOWN SHREVEPORT (SHV)
1613	75	COLFAX	GRANT	LA	3152	9271	(SHV)
1615	88	HORNBECK	VERNON	LA	3133	9340	REPORTED BY VALLEY ELECTRIC. (LCH)
1705	75	DEVILLE	RAPIDES	LA	3135	9216	(LCH)
1725	75	JONESVILLE	CATAHOULA	LA	3162	9183	(JAN)
1750	100	HATHAWAY	JEFFERSON DAVIS	LA	3035	9267	(LCH)
1751	88	3 NSW DUPONT	AVOYELLES	LA	3092	9199	HIGH WINDS ALSO REPORTED (LCH)
1809	88	SIMMESPORT	AVOYELLES	LA	3098	9181	(LCH)

- It's difficult to know for sure
- Conservative estimate: at least 10%
- Witt et. Al (1998): ~30% in common severe weather areas

11. Quiz Question #1

Instructor Notes:

Student Notes:

12. Problem #1: Observing Nocturnal Tornadoes

Instructor Notes: Now let's discuss some common situations where spotter problems may arise. Regardless of a spotter's experience level, it's difficult to identify cloud features at night. Many well-meaning folks have interpreted low-hanging scud cloud as a rapidly rotating wall cloud, funnel, or even a tornado. Educating spotters eliminates these problems during the day, but there's usually not enough light to consistently see the features in nocturnal storms. Many times, the best source of light will be from lightning. Power flash reports can also help identify the location of a tornado. However, some spotters tend to think the power flashes are definitive proof of a tornado. Unfortunately, power flashes, or arcing lines, can occur in strong straight line winds, or even strong inflow winds.

Student Notes:

Common Spotter Problem #1:
Observing Nocturnal Tornadoes

- Cloud features misidentified by some
- Problem magnified at night
- Lightning often best light source
- Power flashes ⇒ tornado

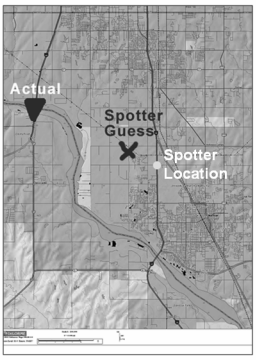
13. Problem #2: Distance to Tornado Location

Instructor Notes: Regardless of time of day, people have a difficult time gauging their distance from storm features. Even experienced spotters will use some sort of correction of their estimate based on their personal knowledge. Objects at a distance, especially those in the sky, appear closer than they actually are when there are no reference features to provide context. When a spotter provides an estimate of a tornado location several miles from their location, expect the estimate to have some error. In these cases, it can be helpful to know a spotter's location. If you have multiple wall or funnel cloud reports observed from a distance, then the spotter locations (along with the direction they are looking) can help you triangulate the location.

Student Notes:

Common Spotter Problem #2:
Distance to Tornado Location

- Difficult to gauge distance
- Lack of reference points
- Actual distance double (or more) of estimate



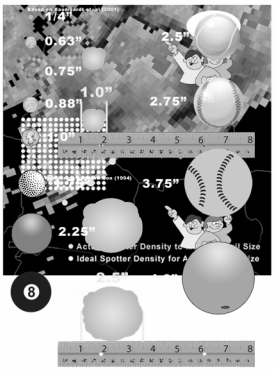
14. Problem #3: Accurate Hail Sizes

Instructor Notes: Spotter reports of hail size have several potential issues. For starters, your spotter density will usually be less than ideal to accurately measure hail size in a thunderstorm (which is approximately one observer per square mile; Changnon, 1968). Time and location errors for hail can occur frequently, up to one-third of the time in some cases (Witt et al. 1998). Recent efforts, such as the SHAVE project, have attempted to better measure and verify hail sizes in some areas of the country, but it's difficult to know if this error rate has improved significantly over the last decade. Errors related to hail size are often a result of spotters not measuring the stone size with a ruler (or similar measuring tool). Lacking an objective measurement, a study conducted through the NWS LaCrosse, WI office (Baumgardt et al., 2001) found that spotters tend to underestimate the size of hail smaller than golf balls. At larger sizes, the bias is less significant, but the size estimates vary greatly. A study by Herzog and Morrison (1994) found that there may be substantial bias towards larger hail stones in Storm Data. While these conclusions don't agree completely, one can conclude that it's easier to get significant overestimates on large hail vs. small hail. In a follow up study, the NWS LaCrosse, WI office (Baumgardt et al., 2002) found that spotters are more accurate identifying hail size compared to an object (e.g., egg, golf ball) if they don't have a ruler. While this process can cause hail reports to cluster at certain object sizes, including golf ball and baseball (Edwards and Thompson, 1998), the reports are more accurate than trying to estimate the size in inches.

Student Notes:

Common Spotter Problem #3:
Accurate Hail Sizes

- Spotters density
- Significant time & location errors
- Spotters underestimate small hail
- Positive size bias possible for large hail
- Without ruler, spotters most accurate comparing hail size to objects

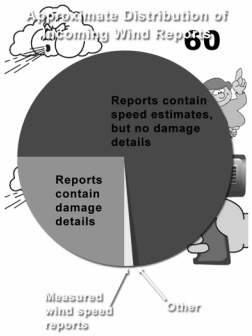


15. Problem #4: Lack of T-Storm Wind Damage

Instructor Notes: Strong winds from thunderstorms are often the most common severe weather threat reported. Unfortunately, wind speed estimates from these storms are very susceptible to error. While spotters do their best, they tend to overestimate wind speeds (LaDue, 2003). This issue is most significant for storms with marginally severe or sub-severe thunderstorm winds. Unlike speed estimates, damage reports result in an objective impact. Unfortunately, wind damage is either not well reported (or well documented) at WFOs. From a small sample of severe weather events, we found that reports in phone logs generally contained an indication of wind damage in only 1 in 5 reports. Similarly, the climatological record of thunderstorm winds lack detailed records of damage for ¾ of reports (Weiss and Vescio, 1996). While these numbers have likely improved somewhat in recent years, a lack of damage details is still a concern. When damage is reported, it's often tree damage. Using due diligence, you can often determine the level of tree damage in first hand reports. While warning operations are time sensitive situations, do your best to document the details of the report. When working an event with numerous reports, you are likely to forget, or confuse, the details of a specific report in a few minutes.

Student Notes:

Common Spotter Problem #4:
Lack of Wind Speed Damage Details



- Thunderstorm wind reports:
  - Most common, prone to error
  - Speed estimates often overestimated
- Significant for marginally severe, sub-severe storms
- Wind damage more objective, but poorly reported/recorded
- Record damage report details ASAP

16. Problem #5: Different Kinds of Snow Obs

Instructor Notes: And now for a problem you might not have thought about being in this lesson. In several forecasts offices, especially those prone to convective snow events with strong intensities, there are two different types of snow measurements that they receive. These snow measurements can be classified as either climatological or real-time. The difference between the two is in the timing of the observations (NOAA, 1997). Climatological snowfall observations, are taken anywhere from once a day to every 6 hours. These reports should include new snowfall, snow depth, and liquid equivalent and are added to the climatological record of snowfall. Real-time snowfall observations are taken more frequently, usually on the order of once every 1-6 hours. Real-time observations provide the warning forecaster more precise information on snow intensity and event duration. Real-time observations, because they are so frequent, don't allow new snow enough time to settle. The resulting measurement will overestimate snow accumulations when they are compared to climatological observations. If you utilize real-time snowfall measurements, you should educate your local media to avoid comparing real-time and climatological snow totals. If significant deviations occur between your official totals and those in media reports, public confusion (and a few angry phone calls) may result.

Student Notes:

Common Spotter Problem #5:
Climatological vs. Real-time Snowfall Obs

- An issue in WFOs that often experience convective snow events
- Timing of observations is key difference
- Climate obs:
  - Every 6 hrs to 1/day
  - Included in local climate record
- Real-time obs:
  - Every 1-6 hrs
  - Help determine snow intensity & event duration
- When compared, real-time obs will overestimate snow totals

Real-Time Observations

Location	Time	Amount
Circleville	7:00 AM	1"
Circleville	8:00 AM	0.5"
Circleville	9:00 AM	2.0"
Circleville	11:00 AM	3.3"

Climatological Observations

Location	Time	Amount
Circleville	6:00 AM	5.1"
Circleville	12:00 PM	1.1"
Circleville	6:00 PM	0.3"
Circleville	12:00 AM	0.0"

17. Quiz Question #2

Instructor Notes:

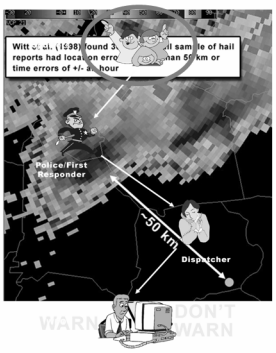
Student Notes:

18. Some Simple Mitigation Steps to Try

Instructor Notes: Now let's move on to some simple mitigation steps you can take in your office. For starters, maintain good Situation Awareness (SA). You likely cannot quality control every spotter report as it comes into your office. With good SA, most reports with significant problems will be obvious right away. If you suspect a report is suspicious, use radar and other data to match the report to what you are observing. This step can be conducted in real-time, regardless of how the information was received. Location or timing errors can be identified best through this data comparison. During post-event analysis, we recommend you compare all of your reports (not just suspicious ones) to radar data. Whether or not a report seems suspicious, note whether the report is direct from the source or relayed through someone else. During a significant event, even experts at relaying information from others may get confused, mix up information, and misread report locations and times. Knowing which reports are 2nd hand can come in handy at a later time during the event if a question arises. Lastly, indicate clearly a reports source in your office notes. Report quality will vary based on both who made the report and where they live. Where NWS-trained spotters are plentiful, they will report on events 80% of the time or more. In areas where spotters are sparse, the chances are closer to 30% (Baumgardt, 2004). Following these steps will not catch every bad report, but the results you get.

Student Notes:

Mitigation Efforts:
Some Simple Steps You Can Take



- Maintain good SA
- Use radar, other data to verify report location & timing
- Indicate in records whether reports 1st or 2nd hand
- Take the time to clearly indicate a reports source

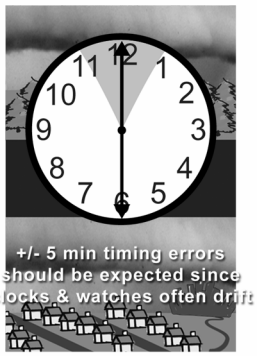
19. Some Questions to Ask Yourself?

Instructor Notes: Here are some other questions to ask yourself (or the spotter): Are they seeing the phenomenon, or are they experiencing the event? Seeing a tornado is one thing, but having your home damaged or destroyed by one is another. Our eyes can be deceived much easier by events at a distance than by more material evidence nearby (such as physical damage). Is there only one report? A single, uncorroborated report is more likely to cause decision-making problems in your office. To put this issue into perspective, one out of six tornadoes reported during the May 3rd tornado outbreak in Oklahoma and Kansas had only a single report (Speheger et al., 2001). While it's nice to

have multiple reports of a single event, it's not always possible. Are there any non-meteorological factors at play? Highly populated areas are more likely to have people experience impacts than sparsely populated spots. Good spotter reports in rural areas are very valuable during significant events because there are fewer of them. What time do you have? A report may appear inaccurate because the spotter's time is inaccurate. For fast moving storms, deviations of five minutes or so can be significant. The clocks in our house probably deviate by that much…maybe even more! When comparing reports to radar data, your accuracy is limited to a 4-6 minute window. Some devices, like cell phones, regularly synchronize their time with a standard clock. Comparing these reports to suspicious ones in the same vicinity may help identify poor times in reports.

Student Notes:

Mitigation Efforts:
Some Questions to Ask Yourself?



- Is the spotter seeing or experiencing the event?
- Is there only one report?
- Are there any non-meteorological factors at play?
- What time do you have?

20. Summary

Instructor Notes: The quality of information we receive from spotters depends significantly on the observation source. The data source depends on both the person who made the report and how you receive that information. Any single report can be good or poor. Over the long haul, reports should trend toward the generalizations presented here. To assist in your future error mitigation efforts, several common situations were presented as examples. Several simple mitigations steps were provided, including some basic questions to ponder when analyzing spotter reports that you receive. Your office may have some local policies as well to help mitigate impacts of erroneous reports. Now is as good time a time as any to review your local policies to make sure you understand them. After all, poor spotter information is a single destination, but there are many ways to get there.

Student Notes:

In Summary: Mitigating Potential Errors in Spotter Reports

- Data quality varies depending on source
  - NWS trained spotters
  - Other experienced spotters
  - Media
  - General public
- Several situations where reports can go bad were presented
  - Observing nocturnal tornadoes
  - Tornado locations
  - Accurate hail sizes
  - Lack of wind damage details
  - Climatological vs. real-time snow observations
- Basic QC steps helps mitigate most common problems
  - Good SA
  - Use radar & other data to verify times and locations
  - Record report source & whether information is 1st or 2nd hand

21. Questions???

Instructor Notes: If (after going through this lesson) you have any questions, first ask your SOO. Your SOO is your local facilitator and should be able to help answer many questions. If you need additional info beyond what your SOO provided, send an e-mail to the address on the slide. This e-mail address connects you with all the instructors involved with this IC. Thanks for your time and good luck on the exam!

Student Notes:

Questions???

If you have any questions about this lesson:

1. First ask your SOO (or local facilitator)
2. If you need additional help, send an e-mail to **awocccore_list@wdtb.noaa.gov** (Instructors group – answers will be CC'd to the SOO and considered for the FAQ page)

Take test ASAP after completing all lessons in this IC

1. Conveying Warnings and Public Response

Instructor Notes: Welcome to this lesson on the warning response process. This lesson, which should last about 20 minutes, addresses the general social-psychological process that people go through from the time a warning is first heard to the time people respond. My name is Dale Morris and I am joined in this lesson by Chris Spannagle.

Student Notes:

Conveying Warnings and Public Response

The Warning Response Process

Warning Decision Training Branch

2. What response do you want?

Instructor Notes: What things can a warning forecaster do to get the desired response from the public? A man in the path of an F5 tornado actually crawled into a sewer to escape injury. During this same event, others left safe shelter to go to a highway overpass. Later this same day, patients in a rural hospital were moved into a hallway after communication between the hospital and their local emergency manager. Their rooms eventually were filled with tornado debris, but the patients sustained only minor cuts and scratches. The hospital eventually was condemned and torn down. In Missouri, emergency managers were able to move road crews out of the way of an F4 tornado. What happened in these situations, and what did NWS forecasters do to elicit these responses? Objective metrics like FAR, POD, and Lead Time only partially measure the success of a warning event.

Student Notes:

What response do you want?

- May 3, 1999
  - Man crawls into sewer
  - People left shelter and went to a highway overpass
  - Hospital patients moved into hallway before rooms filled with debris
- May 4-10, 2003 – Missouri Emergency Management: *"There were no surprises."*
- Is success in a warning event defined by FAR, POD, and Lead Time?

3. Overview

Instructor Notes: Although there is not a lot of research linking warnings and behavioral response, much of the research that does exist shows that there is a process that takes place between hearing the warning and reacting. Programs like WAS*IS, (Weather and Society Integrated Studies) are helping to answer questions related to the end-to-end warning process. New research is trying to get a glimpse into what people were thinking during certain responses to warnings and other environmental stimuli (like deciding to drive through a flooded roadway).Depending on how the warning is crafted, the sender of the warning message can impact the actions of the receiver. Therefore, it is important for forecasters that issue warnings to understand the process people generally go through prior to responding to the warning message.

Student Notes:

Overview

- What is the social-psychological process that people go through from the time a first warning is heard to the time people respond?
- What factors influence the response?

"Understanding human behavior is at least as hard as understanding and predicting the atmosphere."
- Dr. Eve Gruntfest
Director Social Science Woven in Meteorology (SSWIM) Program
University of Oklahoma

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4. Learning Objectives

Instructor Notes: This lesson has three objectives.

Student Notes:

Learning Objectives

1. Identify the common process between a person hearing the initial warning and responding.
2. Identify the most common sources of warning information.
3. Identify methods forecasters can use to impact the actions of warning recipients.

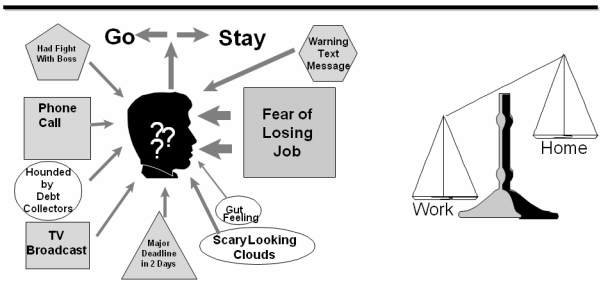
5. Inputs into a Warning Response

Instructor Notes: You may have seen a graphic similar to this relating to how forecasters weigh the sum of all inputs in making a warning decision. In an analogous way, individual people probably weigh various factors when they make decisions. A weather warning may be one piece of information that may be seemingly logically and rationally over-ruled by other competing thoughts and emotions. For instance, consider someone who is at home and is about to leave for work and has received a weather warning message via TV, a telephone call and a text message. However, this person also has had tension on the job because of a looming work deadline and an argument with the boss. Add to that other personal issues like debt collectors or child care or medical expenses, and the pressure to go to work for fear of losing the job may overpower the weather warning. Of course, one important factor that may be excluded from this decision-making process is that the job doesn't matter if the worker dies trying to get to work!

Student Notes:

Inputs into a Warning Response

Do Weather Warnings Outweigh Need To Go To Work?

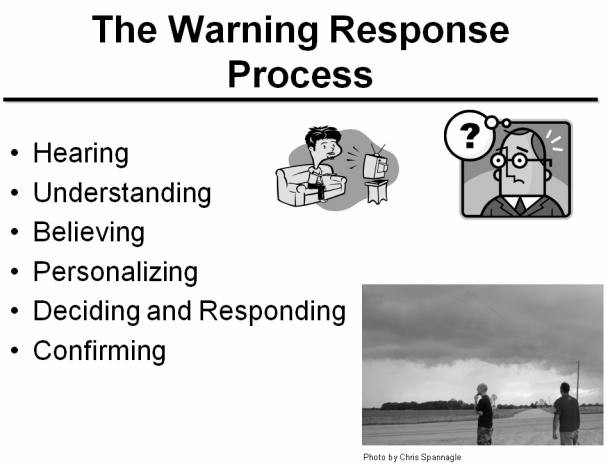


For someone at a particular time, ignoring a warning to go to work may be a perfectly rational decision.

6. The Warning Response Process

Instructor Notes: People don't just hear a warning and immediately take action. There is a process that takes place between hearing the warning and reacting. That process can take only a few seconds or several minutes. People go through a more or less sequential process in which they consider various aspects of the decision confronting them before acting. The sequence may not be the same for every person, and each stage is not necessary for a response to occur. Importantly, the behavioral outcomes of the public are impacted by both the sender (issuing the warning), the receiver (those hearing the warning), and other intermediate factors.

Student Notes:



7. Hearing

Instructor Notes: It can't be assumed that just because a warning is broadcast that people will hear it. Most people receive NWS warnings over the television. NWS forecasters must partner closely with the local media to ensure the warnings are transmitted accurately and in a timely fashion. NWS Directive 10-1801 specifically addresses this aspect, encouraging the media to participate in drills to test all aspects of the integrated warning system.

Student Notes:

The Warning Response Process

- Hearing
  - Most people get warnings via TV
    - Interpretation (or misinterpretation?)
    - Presentation
  - Time of day
    - Less likely to hear at 3AM

8. Hearing: Community Preparedness

Instructor Notes: The level of community preparedness also plays a large role in the warning response process. NWS offices can and should help to increase community preparedness. In fact, NWS Directive 10-1801 states that “NWS offices should conduct training sessions for hazards community members so they know how to use our services and how to integrate them into their decision processes.” Another way to increase community preparedness is through the Storm Ready program. Storm Ready is a program aimed at preparing cities, counties, towns and universities across the nation with the communication and safety tools necessary to save lives and property. This program has several requirements in order to be certified as Storm Ready: Establish a 24-hour warning point and operations center Create a system to monitor local weather conditions Have the ability to receive severe weather forecasts and warnings and alert the public through multiple methods Promote the significance of public readiness through community seminars Develop a formal hazardous weather plan, which includes training severe weather spotters and holding exercises

Student Notes:

The Warning Response Process

- Community Preparedness
  - Sirens
  - Alert System
  - StormReady

StormReady

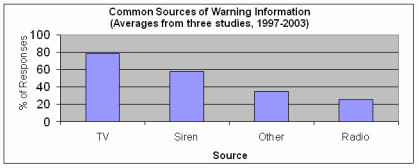
9. Hearing: Sources of Information

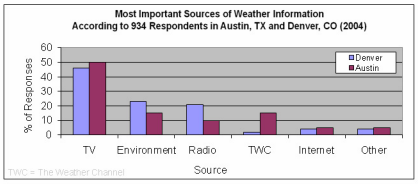
Instructor Notes: Recent studies show that TV is both the most common source of warning information and considered to be the most important source of weather information. The top figure shows common sources of weather information obtained from three separate studies which took place between 1997 and 2003. These three studies consisted of a study by Hammer and Schmidlin in 2002 with 190 people affected by the May 3rd 1999 Oklahoma City tornado. Another by Balluz et al. questioned 146 participants affected by tornadoes in Clark and Saline counties in Arkansas on March 1, 1997. A third study, consisted of 129 respondents affected by tornadoes in parts of Kansas, Missouri and Tennessee on May 4th, 2003. The figure clearly shows that television and sirens are by far the most common ways people obtain warning information. The bottom figure shows rankings of what people considered to be the most important source of weather information according to a 2004 study by Hayden et al. which took place in Austin, TX and Denver, CO. This study again shows that TV is considered to be the most important source of weather information, with environmental clues and AM/FM radio ranked second and third.

Student Notes:

The Warning Response Process

Past studies on ways the public receives warning and weather information.

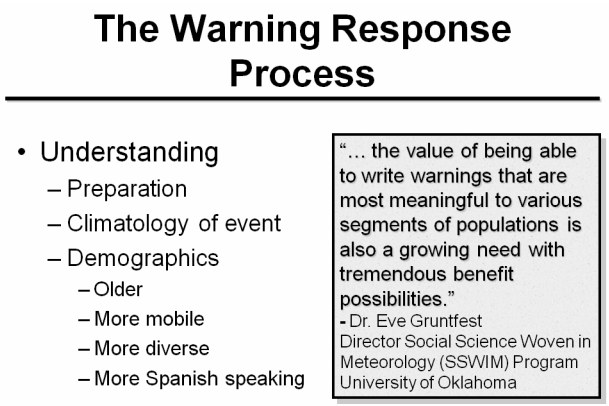




10. Understanding

Instructor Notes: After hearing the warning, the listener must understand the warning. The capability of the public to understand the warning has a lot to do with preparation. It is not just the duty of the Warning Coordination Meteorologist to educate and prepare the public. This is a huge task, the job is never done, and the entire NWS organization needs to help. The public's understanding is also impacted by the climatology of the event. For instance, the public's understanding of a severe thunderstorm warning is better in areas where severe thunderstorms are more common. Finally, it is probably incorrect to think of a single monolithic "public". In fact, there are many publics. Demographics play into understanding. In 2000, one in eight Americans was over age 65. By 2030 one in five Americans will be 65 or older. The increasing Spanish speaking population especially in the South Central and Southwestern U.S. also is an issue in understanding warnings.

Student Notes:



11. Believing

Instructor Notes: The warning may be heard and understood, but is it believed? Recent findings show that public reliance on "official" warnings from traditional sources may be shifting to more private and informal sources. (Baker 1995; Dow and Cutter, 1998; Drabek, 2001). People use new, previously unavailable sources of information and weigh several factors in their decisions about whether, how, and when to react to hazardous conditions. The classic referenced case is the "cry wolf" syndrome. Most studies have not found evidence of a direct link between previous false alarms and the credibility of warnings. However, one recent study by Simmons and Sutter has found an increased likelihood of fatalities in areas that previously have had a higher incidence of false alarms for tornado warnings. Nevertheless, this is a complicated issue because areas with more warnings probably have more tornadoes and thus more injuries or deaths. In their work, Simmons and Sutter did recognize there is a tradeoff between our detection and warning capabilities and false alarms. For another perspective on the false-alarm issue, a very limited sample of interviews were conducted as part of a recent NWS service assessment. According to the assessment, "Many of those interviewed, including EMs and other public officials, mentioned that they have been under numerous tornado watches and warnings where 'nothing happens.'" Believability can be influenced by many factors associated with the method and contents of the warning. Later portions of this presentation will focus on how the warning forecaster can influence believability.

Student Notes:

The Warning Response Process

- Believing
  - Shift away from belief in "official" warnings
  - Public weighs several factors prior to deciding whether to react
    - Perceived susceptibility
    - Appraised severity of threat
    - Belief in positive outcome from response

Does the "cry wolf" syndrome have a major impact on believability?

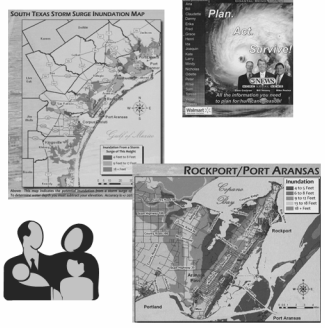
12. Personalizing

Instructor Notes: People think of warnings in personal terms—what are the risks for themselves and family? The perception of risk is an important step in responding to a warning. If they feel "it can't happen to me", they may well ignore a warning. The ability of the public to personalize the threat is to some degree set prior to the warning event. If an area has recently been hit by severe weather, the public will be much more likely to personalize the threat than people in an area that has not been threatened for several years. Through various outreach and public education efforts, the NWS can influence how people perceive risk and their vulnerability to hazardous weather. As one example, all four WFOs that serve the Texas coast (the Lake Charles, Houston, Corpus Christi and Brownsville offices) have partnered with the State of Texas, local media and emergency managers, the American Red Cross, a non-profit organization, and a major retailer to produce and distribute 1.1 million full-color 32 page Hurricane Guides in English and Spanish. One of the sections in the guide includes regional and local storm surge inundation maps which can help local residents assess their vulnerability to storm surge. The next slide contains a video that provides an example from a broadcast media perspective of a viewer personalizing a tornado warning .

Student Notes:

The Warning Response Process

- Personalizing
  - Level of community interaction
  - Family composition
  - Length of residency
  - Emergency risk perception
    - Prior experience
    - Perceived proximity
    - Observation



13. Personalizing Example

Instructor Notes: For some time, the KSN WeatherLab in Wichita was co-located at a children's science center. We were right there doing all of our broadcasting including severe weather coverage in front of the public. So one day, we have a tornado warning for downtown Wichita. The children's museum staff did their job. They executed their safety plans. They got on the PA system and informed everybody they needed to evacuate to the shelters in the other part of the complex. Pretty soon, there's nobody here. We're still doing our coverage. All of a sudden, here comes this dad and his couple of kids just kind of walking around the corner. They sit down in the bleachers and proceed to watch. And I'm talking about the tornado warning and how everybody in downtown Wichita should be in shelter. They're not moving. So I said, "Everyone at Exploration Place should be in shelters, should follow the severe weather safety plan because we have a tornado warning." Nothing. They didn't move. So finally, I actually kind of had to stop my broadcast, and I looked right at this guy, and I said, "Sir, I'm talking to you. There's a tornado warning for downtown Wichita. You need to move to shelter." And this is what I saw. "Ohhh!". And the guy jumps up, grabs his kids, and tears out of there to go to the shelter. Now, I've never forgotten that moment because, in that moment, I was able to actually see the process that is taking place for people at home. I see him kind of going from the "Oh, isn't this interesting" to "Oh my! That's really possibly could be really affecting me, and oh my gosh, I had better do something about it!" And it just reinforces the fact that this is a process and that we have to help people at home get through that process of recognizing that there's a threat, personalizing the threat, and then taking action to protect their families.

Student Notes:

The Warning Response Process

- Personalizing: Example from a broadcast media perspective

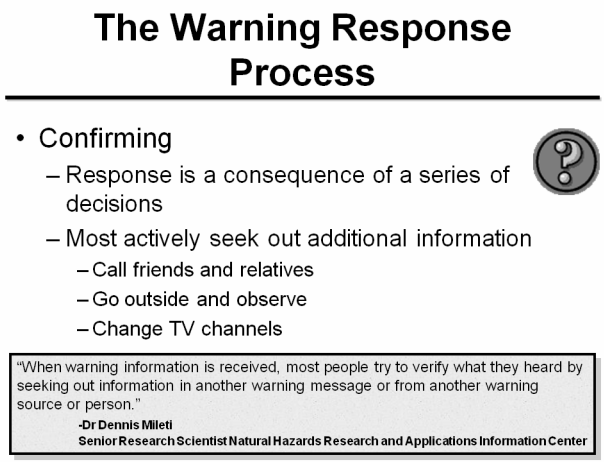
Dave Freeman
Chief Meteorologist
KSNW-TV, Wichita, KS

14. Confirming

Instructor Notes: People are information hungry following the receipt of warnings. This can mean turning the TV to another station, checking with a neighbor, friend or family member, or going outside to look at the sky. There is a need for a continuous flow of information. Even statements that repeat previously available information can help con-

firm the threat. That confirmation helps people better understand warnings, believe them, personalize the risk, and make response decisions. Because people confirm warnings and receive information from multiple intermediate sources, it is critically important that the continuous flow of information from various media sources as well as various state, local, and federal government officials contains consistent messages.

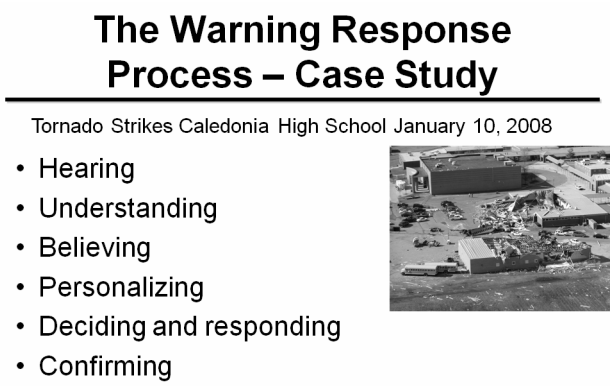
Student Notes:



15. Case Study: Caledonia High School

Instructor Notes: Here is a recent example of a warning response process lifted from the pages of the March 2008 NOAA World Newsletter. Understanding the behavioral aspects of the warning response process can help shape better warnings leading to a better outcome. In this case, an EF3 tornado heavily damaged a school complex in Caledonia, MS, on January 10, 2008, but a timely warning, a NOAA Weather Radio receiver, a prepared principal, and several phone calls from the county EM kept as many as 2140 students and employees from harm.

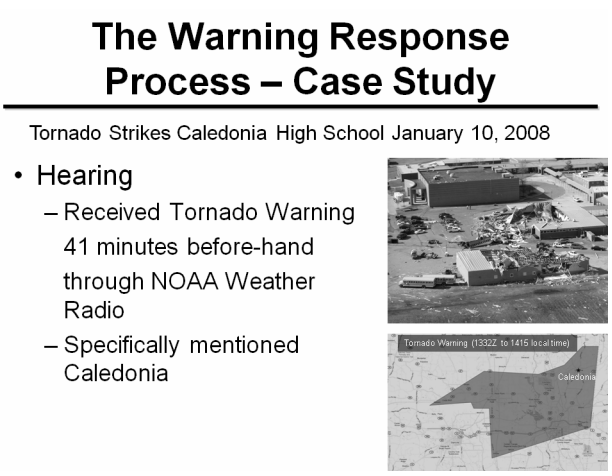
Student Notes:



16. Case Study: Hearing

Instructor Notes: In this case, the hearing aspect was from NOAA Weather Radio and a warning that specifically mentioned the city of Caledonia (shown by the blue star in the warning image). Studies have shown that less than five percent of the population receive warnings from NOAA Weather Radio with most receiving warnings from TV and radio. Most of the nation's workforce do not have access to TV and radio at work. The local office led by the WCM can target workplaces to educate management at those sites of the cost benefit of a weather radio.

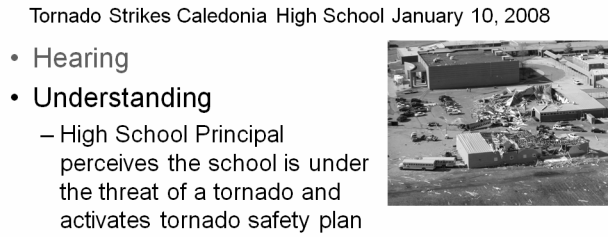
Student Notes:



17. Case Study: Understanding

Instructor Notes: Experience and training made understanding of the warning nearly instantaneous at the Caledonia school complex. A tornado warning activated the schools' tornado safety plan, sending students and employees to their designated shelters.

Student Notes:



18. Case Study: Believing

Instructor Notes: In this case, the principal concluded it was time to take shelter within seconds of hearing the Tornado Warning was issued. The strong wording in the tornado warning, stating that the storm was capable of producing strong to violent tornadoes and that this was an extremely dangerous and life threatening situation, also helped to impart the seriousness of the situation and lead the principal to the conclusion that the threat was real.

Student Notes:

The Warning Response Process – Case Study

Tornado Strikes Caledonia High School January 10, 2008

- Hearing
- Understanding
- Believing
  - Heard tornado sirens activate
  - Placed students in gym locker room and another interior room

19. Case Study: Personalizing

Instructor Notes: Caledonia is located in Lowndes County, MS which has been certified as a Storm Ready community. As part of the certification process, the school participated in state-wide tornado drills, severe weather awareness week and received several severe weather safety presentations. These experiences resulted in the development of a strong safety plan, clearly marked shelter locations and receipt of a NOAA Weather Radio.

Student Notes:

The Warning Response Process – Case Study

Tornado Strikes Caledonia High School January 10, 2008

- Hearing
- Understanding
- Believing
- Personalizing
  - Storm Ready
  - Safety presentations to students
  - Appropriate shelter locations identified and marked
  - School had participated in state-wide tornado drill

20. Case Study: Deciding & Responding

Instructor Notes: The decision to seek shelter is not made upon hearing a warning. Studies have shown that a warning must be understood, believed, personalized, and confirmed before a decision is made to respond. In this case, a lead-time of 41 minutes allowed for the principal to move students and employees from nominally safe areas to safer areas of the main building on campus.

Student Notes:

The Warning Response Process – Case Study

Tornado Strikes Caledonia High School January 10, 2008

- Hearing
- Understanding
- Believing
- Personalizing
- Deciding and responding
  - Due to long lead-time moved students to safer areas
  - Accounted for all students and employees after event and surveyed property

21. Case Study: Confirming

Instructor Notes: The receipt of the tornado warning through NOAA Weather Radio, sirens and television sent all students and employees to their designated shelters. Two phone calls from the county emergency manager further confirmed the threat and allowed for everyone to be moved to safer shelters. The final confirmation, in this case, was when the tornado struck the school complex.

Student Notes:

The Warning Response Process – Case Study

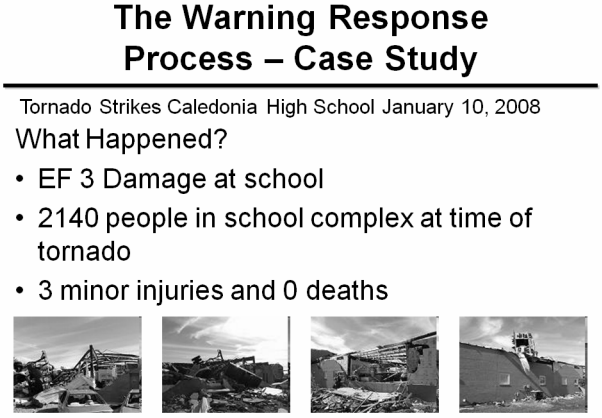
Tornado Strikes Caledonia High School January 10, 2008

- Hearing
- Understanding
- Believing
- Personalizing
- Deciding and responding
- Confirming
  - Received two personal phone calls from county EM
  - Gymnasium and adjacent building severely damaged
  - School bus tossed onto roof of gymnasium

22. The Warning Response Process – Case Study

Instructor Notes: So what happened with this event? An EF3 tornado struck the city of Caledonia and more specifically the Caledonia High School complex at about 2:13PM CST which is roughly 41 minutes after the first tornado warning was issued. Damage at the school complex consisted of the almost total destruction of a gymnasium in which some students were initially sheltered. A school bus was thrown onto the roof of a Vocational Tech building located adjacent to the gymnasium where other students had initially been sheltered. Cars and other school buses were flipped over and the football press box and concession stands were destroyed. At the time the tornado struck, approximately 2140 students and employees were on the campus: none were killed and there were only three minor injuries. Elsewhere around town, numerous trees were snapped and uprooted, many homes sustained roof damage and/or collapsed walls.

Student Notes:

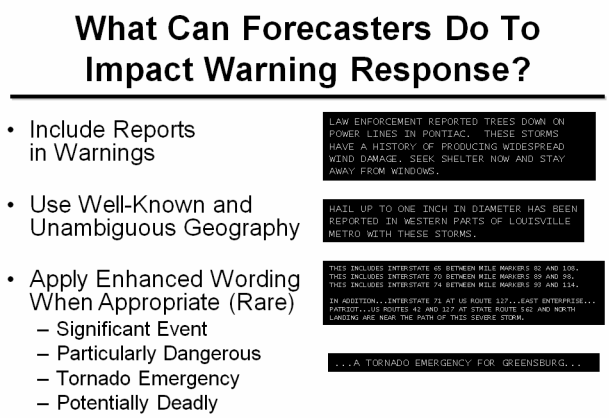


23. What Can Forecasters Do To Impact Warning Response?

Instructor Notes: What can warning forecasters do to influence the warning response? Including actual and credible reports with the source of the report in the warning text can increase the believability of the warning. Using well known and unambiguous geography helps the personalization process. The automated geographic specification of county sections in storm-based warnings can seem ambiguous and not clear to some residents. For example, individuals may not realize they are in northern Washington County, but they may know they are north of Highway 15. Finally, in rare situations, applying enhanced wording in warnings can draw attention to the most significant of events. For example, specific policy guidance is available in Directive 10-511 about using “tornado emergency”: In exceedingly rare situations, when a severe threat to human life and catastrophic damage from a tornado is imminent or ongoing, the forecaster may insert the headline "...TORNADO EMERGENCY FOR [GEOGRAPHIC AREA]...". Additionally, in such a situation, this headline should only be used when reliable sources confirm a tor-

nado, or there is clear radar evidence of the existence of a damaging tornado such as the observation of debris.

Student Notes:



24. Quiz

Instructor Notes:

Student Notes:

25. Summary

Instructor Notes: In summary, a warning forecaster's understanding of the behavioral warning response process can result in a positive response by the public. Also, knowing that most people receive warning information through intermediate sources (such as broadcast media or other government officials) means that partnerships should be worked out well in advance of an event to ensure message consistency. Finally, specific wording in warnings and follow-up statements can help people to believe and personalize the warnings.

Student Notes:

Summary
The Warning Response Process

- Hearing
  - Intermediate sources (TV)
- Understanding
- Believing
  - Actual reports
- Personalizing
  - Unambiguous Geography
  - Enhanced Wording
- Deciding and responding
- Confirming

26. End of Lesson

Instructor Notes: You have completed this lesson on The Warning Response Process. For more information you can consult the list of references attached to this presentation. You can access these references by clicking on the “Attachments” button at the top right of this presentation window.Please complete the remaining lesson in this Instructional Component before attempting the test required for completion. The test should be taken as soon as possible after completing all of the lessons. If you have any questions about this lesson, first ask your SOO. Your SOO is your local facilitator. If you need additional help, please send an e-mail to the address listed on the slide. Thank you for your time and good luck on the exam!

Student Notes:

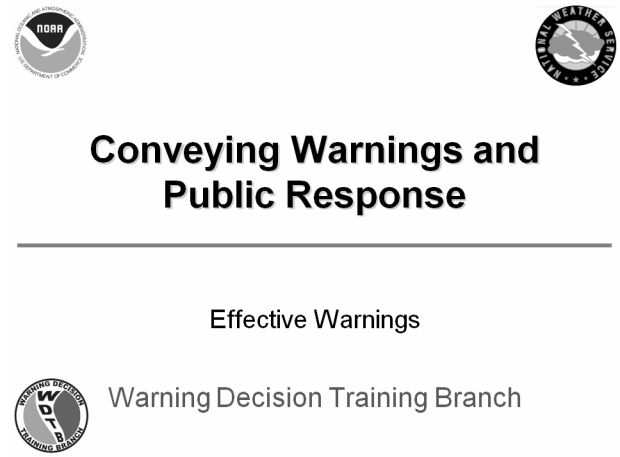
End of Lesson

Questions about this lesson
“The Warning Response Process”?
E-mail: awoccore_list@wdtb.noaa.gov

1. Conveying Warnings and Public Response

Instructor Notes: Welcome to this lesson on effective warnings. This lesson, which last approximately 20 minutes, focuses on how to issue effective warnings. The lead instructor for this presentation is John Ferree.

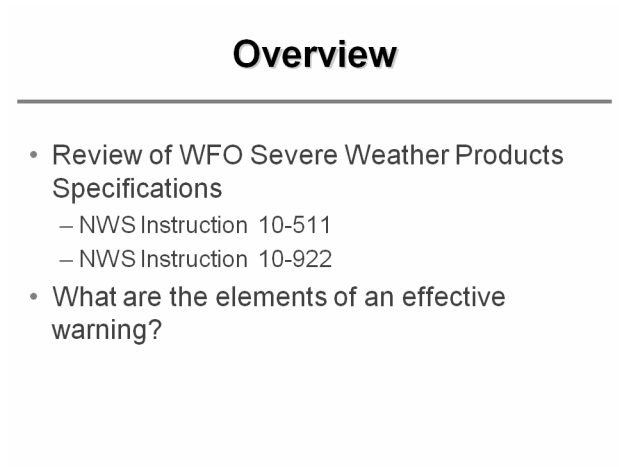
Student Notes:



2. Overview

Instructor Notes: In this lesson we will first review the NWS "official" product specifications. Many of the elements of an effective warning are built into the product specifications. We will then discuss the elements of an effective warning, and discover ways to deliver effective warnings.

Student Notes:



3. Performance Objectives

Instructor Notes: There is one performance objective for this lesson. This performance objectives is a statement of the behaviors that participants will be able to demonstrate both in the simulations and on the job.

Student Notes:

Performance Objectives

1. Demonstrate the ability to apply the five characteristics of an effective warning:
   - Specificity,
   - Consistency,
   - Certainty,
   - Clarity, and
   - Accuracy.

4. Learning Objectives

Instructor Notes: There are only three objectives to this lesson.

Student Notes:

Learning Objectives

1. According to NWS Instruction 10-511, be able to identify specifications of WFO Severe Weather Products.
2. Be able to name five characteristics of an effective warning.
3. Be able to identify effectively worded warning phrases.

5. NWS Instruction 10-511 Highlights

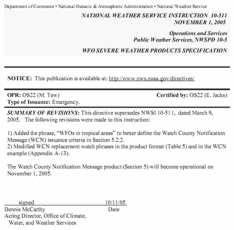
Instructor Notes: A quick review of NWS Instruction 10-511 will be our starting point for a discussion of effective warnings. The focus here is on Severe Thunderstorm Warnings, Tornado Warnings, and Severe Weather Statements. Watch County Notification Message is available in other training sessions (not in AWOC).

Student Notes:

NWS Instruction 10-511 Highlights

http://www.weather.gov/directives/sym/pd01005011curr.pdf

- Severe Thunderstorm Warning (SVR)
- Tornado Warning (TOR)
- Severe Weather Statement (SVS)
- Watch County Notification Message (WCN)



Department of Commerce • National Oceanic & Atmospheric Administration • National Weather Service

NATIONAL WEATHER SERVICE INSTRUCTION 10-511
NOVEMBER 1, 2005

Operations and Services
Public Weather Services, NWSPD 10-5

WFO SEVERE WEATHER PRODUCTS SPECIFICATION

NOTICE: This publication is available at: http://www.nws.noaa.gov/directives/

OPR: OS22 (M. Taw) **Certified by:** OS22 (E. Jacks)
Type of Issuance: Emergency.

SUMMARY OF REVISIONS: This directive supersedes NWSI 10-511, dated March 9, 2005. The following revisions were made to this instruction:

1) Added the phrase, "WFOs in tropical areas" to better define the Watch County Notification Message (WCN) issuance criteria in Section 5.2.2.
2) Modified WCN replacement watch phrases in the product format (Table 5) and in the WCN example (Appendix A-13).

The Watch County Notification Message product (Section 5) will become operational on November 1, 2005.

signed 10/11/05
Dennis McCarthy Date
Acting Director, Office of Climate,
Water, and Weather Services

6. 10-511 Highlights: Severe T-Storm Warnings

Instructor Notes: Some of the highlights from the instruction on Severe Thunderstorm Warnings.

Student Notes:

NWS Instruction 10-511 Highlights

http://www.weather.gov/directives/sym/pd01005011curr.pdf

- Severe Thunderstorm Warning (SVR)
  - Gust of 50 kts (58 mph) and/or
  - Hail size criterion has changed to 1 inch (quarter) diameter or larger
  - Valid times should be **30 to 60** minutes
  - If Tornado Watch, include possibility of tornadoes
  - Should **not** combine with Flash Flood Warnings

7. 10-511 Highlights: Tornado Warnings

Instructor Notes: Highlights from the instruction on Tornado Warnings.

Student Notes:

NWS Instruction 10-511 Highlights

http://www.weather.gov/directives/sym/pd01005011curr.pdf
Starting page 7

- Tornado Warning (TOR)
  - Tornado
  - Valid times should be **15 to 45** minutes

8. 10-511 Highlights: SVR & TOR Guidelines

Instructor Notes: Instructions common to both Severe Thunderstorm Warnings and Tornado Warnings.

Student Notes:

NWS Instruction 10-511 Highlights

http://www.weather.gov/directives/sym/pd01005011curr.pdf
Starting page 4

- SVR and TOR
  - Should use nine part directions (I.e. northeast, east central, etc.) to identify portions of counties
  - Moves over coastal water -> Special Marine Warning
  - Keep bullets brief
  - Include call to action statements
    - May discontinue during widespread severe weather outbreaks
  - May use mileage markers of major highways as reference points

9. 10-511 Highlights: Severe Weather Statements

Instructor Notes: Highlights from the instruction on Severe Weather Statements.

Student Notes:

NWS Instruction 10-511 Highlights

http://www.weather.gov/directives/sym/pd01005011curr.pdf
See page 10

- Severe Weather Statement (SVS)
  - Include updated location
  - Include reports
  - Portions canceled or expired
  - **At least once** during valid time
  - Notify of expiration or erroneous counties
  - Include call to action statements if suspended in warnings

10. NWS Instruction 10-922 Highlights

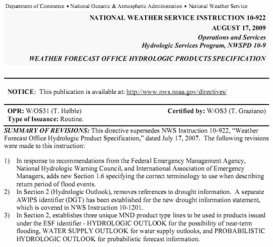
Instructor Notes: Flash Flood Warning product specification is in NWS Instruction 10-922. The focus here is on Flash Flood Warnings and Statements. Refer to the instruction (link is in the subtitle) for information on the other WFO Hydrologic Products.

Student Notes:

NWS Instruction 10-922 Highlights

http://www.nws.noaa.gov/directives/sym/pd01009022curr.pdf

- Hydrologic Outlook (ESF)
- Flood Watch (FFA)
- **Flash Flood Warning (FFW)**
- **Flash Flood Statement (FFS)**
- Flood Warning (FLW)
- Flood Statement (FLS)
- Hydrolometeorological Coordination Message (HCM)
- RVS, RVA, RVD, RRx, Hyx, AHPS



Department of Commerce • National Oceanic & Atmospheric Administration • National Weather Service

NATIONAL WEATHER SERVICE INSTRUCTION 10-922
AUGUST 17, 2009
Operations and Services
Hydrologic Services Program, NWSPD 10-9

WEATHER FORECAST OFFICE HYDROLOGIC PRODUCTS SPECIFICATION

NOTICE: This publication is available at: http://www.nws.noaa.gov/directives/

OPR: W/OS31 (T. Hebble) **Certified by:** W/OS3 (T. Graziano)
Type of Issuance: Routine.

SUMMARY OF REVISIONS: This directive supersedes NWS Instruction 10-922, "Weather Forecast Office Hydrologic Product Specification," dated July 17, 2007. The following revisions were made to this instruction:

1) In response to recommendations from the Federal Emergency Management Agency, National Hydrologic Warning Council, and International Association of Emergency Managers, adds new Section 1.6 specifying the correct terminology to use when describing return period of flood events.
2) In Section 2 (Hydrologic Outlook), removes references to drought information. A separate AWIPS identifier (DGT) has been established for the new drought information statement, which is covered in NWS Instruction 10-1201.
3) In Section 2, establishes three unique MND product type lines to be used in products issued under the ESF identifier - HYDROLOGIC OUTLOOK for the possibility of near-term flooding, WATER SUPPLY OUTLOOK for water supply outlooks, and PROBABILISTIC HYDROLOGIC OUTLOOK for probabilistic forecast information.

11. 10-922 Highlights: Flas Flood Warnings

Instructor Notes: A flash flood warning will be issued when: Flash flooding is reported; Precipitation capable of causing flash flooding is indicated by radar, rain gages, and/or satellite; Local flash flood monitoring and prediction tools indicate flash flooding is likely; The effective time of a pre-existing warning changes; The geographical area covered by a pre-existing flash flood warning increases; A dam or levee fails; A sudden failure of a naturally-caused stream obstruction (including debris slide, avalanche, or ice jam) is imminent or occurring; or Small basin hydrologic models indicate flash flooding for specific locations along small streams.

Student Notes:

NWS Instruction 10-922 Highlights

http://www.nws.noaa.gov/directives/sym/pd01009022curr.pdf
See page 30

- Flash Flood Warning (FFW)
  - *"Short-term events which require immediate action to protect lives and property"*
    - Dangerous small stream or urban flooding
    - Dam or levee failures
  - Valid Time. *"… until flooding (requiring immediate actions to protect lives and property) is expected to end"*

12. 10-922 Highlights: Flash Flood Statements

Instructor Notes: Flash Flood Statements should include the latest information on the current flash flood warning products. Focus on useful information that will help customers and partners direct mitigation activities where waters continue to present a danger to lives and property.

Student Notes:

NWS Instruction 10-922 Highlights

http://www.nws.noaa.gov/directives/sym/pd01009022curr.pdf
See page 34

- Flash Flood Statement (FFS)
  - Supplemental information on current flash flood warning products
    - Updated observations
    - Impact information
  - Announce cancellation or expiration of a flash flood warning
    - Expires within 10 minutes of warning expiration

13. What Is An Effective Warning?

Instructor Notes: First we learned that you as the sender of information can impact public response. We then quickly reviewed the "requirements" for a thunderstorm warning. Now we will look at how you can issue effective warnings.

Student Notes:

What Is An Effective Warning?

- Effective = Having an effect; producing a result
- Effective warnings…
  - Are accurate and timely
  - Are composed to highlight the threat and expected impacts
  - Are aimed at those most at risk

14. Use Technology to Help…

Instructor Notes: Technology, such as AWIPS and Warngen, can help in the warning process, but the forecaster still has to make the warning decision and issue warnings and statements that meet the needs of the users.

Student Notes:

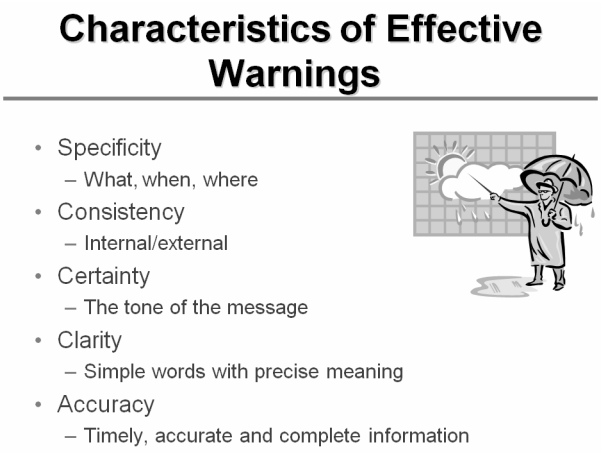
Use Technology to Help…

- AWIPS/Warngen
  - Issue warnings faster
  - Be sure technology does not mean good quality information is lost
  - It's still the forecaster's job to
    - Interpret radar/other information
    - Make the warning decision
    - Relay useful information via warnings and statements

15. Characteristics of Effective Warnings

Instructor Notes: Recall that the behavioral outcomes of the public in a warning situation are impacted by both the sender (issuing the warning) and receiver (those hearing the warning) factors. Severe weather warnings that include these five characteristics will have the best chance for a positive outcome.

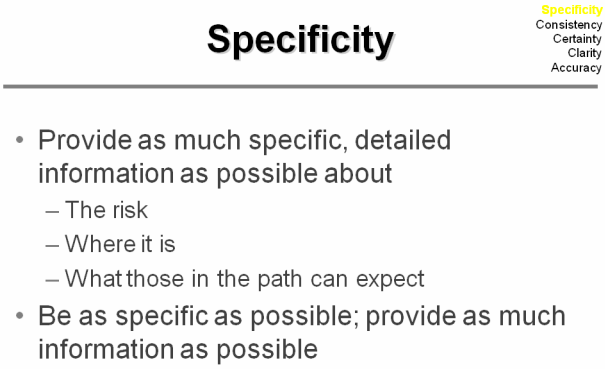
Student Notes:



16. Specificity

Instructor Notes: Although the what, when, and where is a requirement in a severe weather warning, the warning forecaster has latitude in the specificity of the warning. There are many occasions when specificity cannot be high. Include what you know in the warning message, be as specific as possible without exceeding the capabilities of the science and technology. An example of specificity comes from estimating a reasonable forecast of maximum winds in a warning. Some offices have worked with their EM community to blow sirens if expected winds exceed 65kts.

Student Notes:



17. Specificity: Highlight the Threat

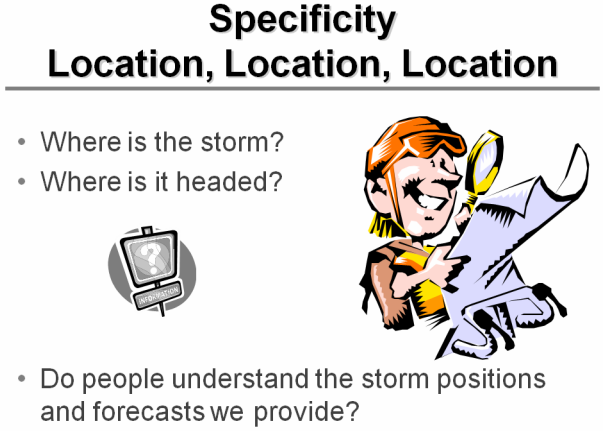
Instructor Notes: Be as specific as possible about the threat.

Student Notes:

18. Specificity: Location, Location, Location

Instructor Notes:

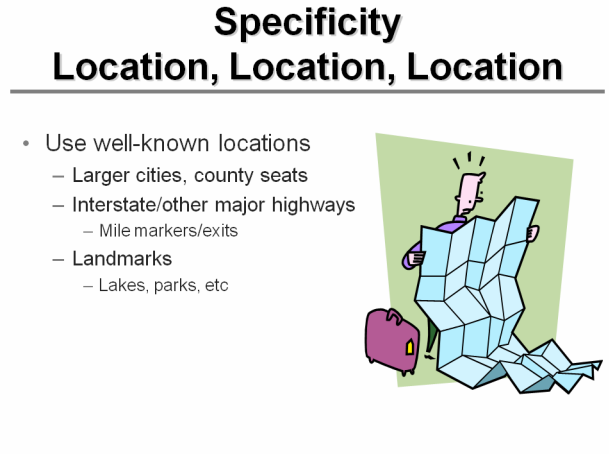
Student Notes:



19. Specificity: Use Well-Known Locations

Instructor Notes:

Student Notes:



20. Specificity: Help Travelers & Geographically Challenged

Instructor Notes:

Student Notes:

21. Specificity

Instructor Notes: Here are three example of actual statements in warnings. With each statement, what are potential outcomes? Are these the desired outcomes?

Student Notes:

Specificity

- "… THE MAIN THREAT WITH THIS STORM IS DIME TO NICKLE SIZE HAIL. THE HAIL MAY CAUSE SOME VEHICLE OR ROOF DAMAGE. STRONG AND GUSTY WINDS UP TO 50 MPH CAN ALSO BE EXPECTED."
- "…THIS TORNADO WILL CROSS INTERSTATE 135 NEAR THE MEADOWS MALL…"
- "PEOPLE TRAVELING EAST ON INTERSTATE 40 BETWEEN EXITS 270 AND 275 SHOULD EXIT AND FIND SUBSTANTIAL SHELTER …IF POSSIBLE. GOLFBALL SIZE HAIL IS LIKELY WITH THIS STORM."

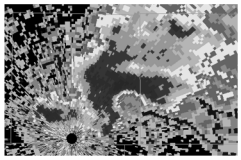
22. Pathcasts

Instructor Notes: Pathcasts were intended to provide valuable information to users on where the tornado is expected to be during the course of a warning. However, its precision can easily be misused in providing users a false sense of security about where the tornado is expected to be. The science is not that good in forecasting specific locations and times that a tornado will be in the warning polygon.

Student Notes:

Pathcasts

- WarnGen makes it easy
  - BUT!!
    - Are we that good???
    - Are we exceeding our abilities???



23. Pathcasting Cautions: Too Much Detail?

Instructor Notes:

Student Notes:

Pathcasting Cautions

- Too much detail?
  - * THE TORNADO WILL BE NEAR
    HUTCHENS ELEMENTARY SCHOOL BY 715 AM
    MAGNOLIA GROVE GOLF COURSE BY 725 AM
    LOTT AND COLEMAN DAIRY ROADS BY 730 AM
  - * SEVERE THUNDERSTORM WILL BE NEAR
    GREEN HILLS MALL AT 1220 PM
    VILLAGE MALL AT 1220 PM
    ONE HUNDRED OAKS MALL AT 1225 PM
    HARDING MALL AT 1225 PM
    HICKORY HOLLOW MALL AT 1225 PM

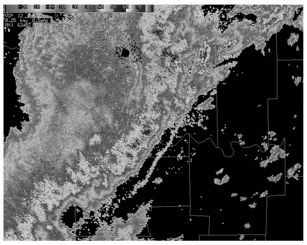
24. Pathcasting Cautions: What Are You Tracking?

Instructor Notes: WHAT are you tracking? Gust front Leading edge of precipitation High reflectivity gradient High reflectivity cores

Student Notes:

Pathcasting Cautions

- WHAT are you tracking?
  - Gust front
  - Leading edge of precipitation
  - High reflectivity gradient
  - High reflectivity cores



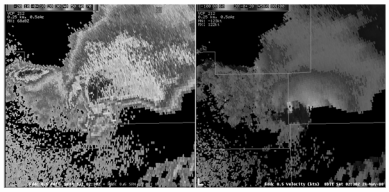
25. Pathcasting Cautions: What Are You Tracking?

Instructor Notes: Another example is to make sure you track where the best possible location of where the tornado is and not the midlevel mesocyclone

Student Notes:

Pathcasting Cautions

- WHAT are you tracking?
  - Tornado location
  - Mesocyclone
  - Leading edge of precipitation
  - Large hail core
  - Gust front



26. Pathcasting Cautions: Technological Limitations

Instructor Notes: Another caution of pathcasting is to not forget the limitations of your radar. Don't forget that the resolution of the radar and height of the beam increase as you get farther from the radar. There are map background inaccuracies. Cities are depicted as a point but don't forget that they have geographical extent. Algorithms are time-lagged.

Student Notes:

Pathcasting Cautions

- Technological Limitations
  - Radar resolution and range
  - Background map inaccuracies
  - Large and/or irregularly shaped cities
  - Radar algorithm time differential

27. Pathcasting Cautions: Meteorological Concerns

Instructor Notes: Meteorological concerns impact pathcasting including Erratic storm motion – speed/direction Storm interactions – splits, mergers Mesocyclone uncertainties Multiple threats from a single storm Tracking tornado arrival time may expose people in the path to large hail, damaging winds, flooding rains

Student Notes:

Pathcasting Cautions

- Meteorological Concerns
  - Erratic storm motion – speed/direction
  - Storm interactions – splits, mergers
  - Mesocyclone uncertainties
  - Multiple threats from a single storm
    - Tracking tornado arrival time may expose people in the path to large hail, damaging winds, flooding rains

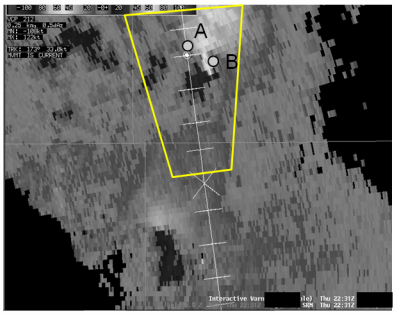
28. Pathcast Cautions: An Example

Instructor Notes: Here is an example of why depending on pathcasts can lead to poor service. In this hypothetical example, there is a mesocyclone intensifying from 2212-2217 UTC that prompts you to issue a tornado warning outlined by the yellow polygon. Warngen allows you to track the track of the vortex, and that provides the basis for the general direction of the polygon. Consider towns A and B within the polygon. Notice that town A is directly on the extrapolated track and so it becomes mentioned in the pathcast. Five minutes into the warning, the vortex is close to the pathcast and all seems well. However by 2226 UTC (10 minutes in), the vortex has veered well to the right of your pathcast and is beginning to slow down more than you previously thought. And by 19 minutes into your warning, town B is seeing a tornado on its doorstep despite it not being mentioned in the pathcast. Yet town B is still well inside the tornado warning polygon. These implications are why the Mother's day 2008 tornado outbreak service assessment stressed that pathcasts should not be emphasized because such previous emphasis caused a dangerous over-reliance on pathcasts.

Student Notes:

Pathcast Cautions: An Example

- An hypothetical example
- Town A is in the pathcast

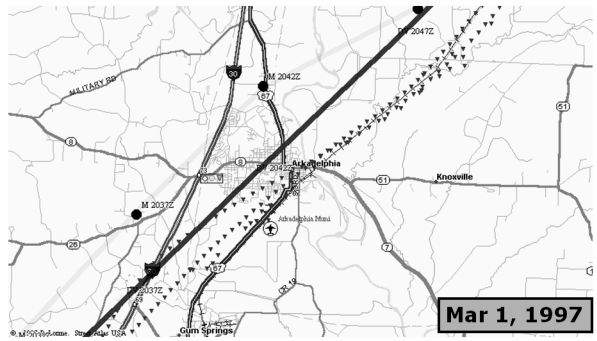


29. The Dangers of False Precision

Instructor Notes: Here is a comparison of tracks from the Mesocyclone algorithm (yellow), TVS algorithm (red), actual tornado (red triangles). The radar circulation signature may be some distance from where the tornado is occurring. This becomes an even greater problem using a linear extrapolation pathcast since the track will usually be non-linear. Reference: Correlation Between Tornado Damage Paths and WSR-88D Signatures, and Resulting Implications for the use of Pathcasts in Tornado Warnings Steven Piltz and Richard Smith: NWS, Tulsa OK

Student Notes:

The Dangers of False Precision



30. Making Pathcasts More Effective (realistic)

Instructor Notes: If you are compelled to use pathcasts, here are some suggestions on pathcasts. Only forecast short distance ahead in initial warning with frequent updates Use range of arrival times based on storm type/threat/motion Simply mention towns in path for the valid period of the warning – more precise updates via the SVS

Student Notes:

Making Pathcasts More Effective (realistic)

- Only forecast short distance ahead in initial warning with frequent updates
- Use range of arrival times based on storm type/threat/motion
- Simply mention towns in path for the valid period of the warning – more precise updates via the SVS

31. awoccore4lesson3resp1

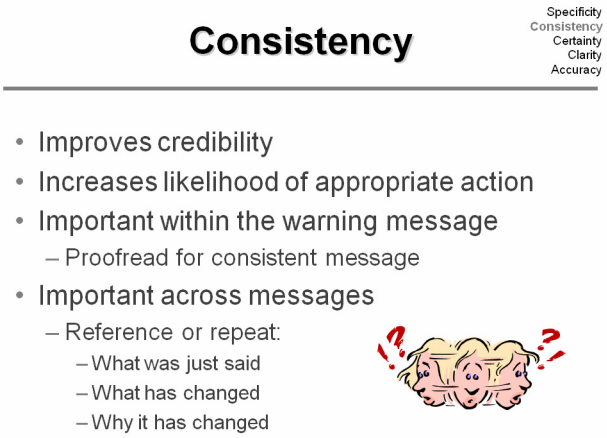
Instructor Notes:

Student Notes:

32. Consistency

Instructor Notes: A consistent message is important in establishing the credibility of the message. Often different warning forecasters are writing warnings and statements, and sometimes neighboring offices will be writing statements about the same storm. Frequent communication within the office and between neighboring offices is necessary to ensure a consistent message. Use of the “Call-To-Action” statements in Warngen can sometime result in an inconsistent message within an individual warning or statement. A quick proofread of the warning prior to issuance can help keep the message consistent. Keep the flow from message to message consistent by referencing or repeating previous statements.

Student Notes:



33. Consistency: Example #1

Instructor Notes: The intent might have been to indicate that the hail is in a different location than the tornado. This problem is the confused public may go outside to put the car in the garage as a tornado hits. Call to action statements that are not consistent with the body of the warning happens more than we would like. Proofreading your warning for consistency of message before issuing may help.

Student Notes:

Consistency

TORNADO WARNING
NATIONAL WEATHER SERVICE ~~~
448 PM ~~~
—

* AT 443 PM EDT NATIONAL WEATHER SERVICE DOPPLER RADAR INDICATED A DEVELOPING TORNADO 9 MILES NORTH OF ~~~ AIRPORT. MOVING SOUTH AT 10 MPH.

* SOME LOCATIONS NEAR THE PATH OF THE STORM THROUGH 515 PM EDT...
~~~ AIRPORT AND ~~~...

VERY LARGE HAIL IS POSSIBLE WITH THE PARENT THUNDERSTORM. IF YOU ARE IN THE PATH OF THE STORM...PUT YOUR CAR IN A GARAGE.

34. Consistency: Example #2

Instructor Notes: And another example of where call-to-action statements in Warngen can cause problems in consistency of the message.

Student Notes:

Consistency

AT 903 AM CDT…AMATEUR RADIO WEATHER SPOTTERS REPORTED A BRIEF TORNADO TOUCHDOWN 8 MILES NORTH OF AKINS.

THIS IS AN EXTREMELY DANGEROUS AND LIFE THREATENING SITUATION. IF YOU ARE IN THE PATH OF THIS LARGE AND DESTRUCTIVE TORNADO…TAKE COVER IMMEDIATELY.

35. Consistency: Example #3

Instructor Notes: Another example of where call-to-action statements in Warngen can cause problems in consistency of the message.
~~~

Student Notes:

Consistency

AT 1234 PM EST...SEVERE THUNDERSTORM WITH STRONG ROTATION OVER SOUTH CENTRAL TAYLOR COUNTY...MOVING NORTHEAST AT 35 MPH...THIS DANGEROUS STORM COULD PRODUCE A TORNADO AT ANY TIME.

* OTHER LOCATIONS IN THE PATH OF THIS STORM INCLUDE …SPRINGFIELD

CONFIRMED REPORT FROM SPOTTER OF TORNADO 10 MILES SOUTHWEST OF ANYTOWN AT 1239 PM EST.

36. Certainty

Instructor Notes: A warning message should be stated with certainty even in circumstances in which there is ambiguity associated with the hazard's impact. "Hedging" terms tend to spur the listener into "inaction" rather than action. Using terms which indicate action or development can fill the gap in listener's minds between "nothing's happening" to "it's too late now".

Student Notes:

Certainty

Specificity
Consistency
Certainty
Clarity
Accuracy

"When faced with uncertainty we frequently base our commitments to particular action on factors other than the facts."
- Dr. Roger Pielke Jr.
Director CIRES Center for Science and Technology Policy Research

- State with certainty, even when there is ambiguity associated with the hazard's impact
- Avoid hedging terms (possibly, may, could…)

37. Certainty: Examples

Instructor Notes: Even though the impacts in all of these situations are uncertain, these statements have included a degree of certainty that would tend to spur the listener to action.

Student Notes:

Certainty

- …DOPPLER RADAR INDICATED A SEVERE THUNDERSTORM CAPABLE OF PRODUCING A TORNADO. THE MOST DANGEROUS PORTION OF THE STORM WAS LOCATED 4 MILES EAST OF…
- …AT 812 PM CDT…NATIONAL WEATHER SERVICE METEOROLOGISTS INDICATED A RAPIDLY INTENSIFYING SEVERE THUNDERSTORM CAPABLE OF PRODUCING A TORNADO. THE MOST DANGEROUS PORTION OF THE STORM WAS LOCATED…
- …A BRIEF TOUCHDOWN OF A TORNADO WAS REPORTED 5 MILES NORTH OF BEETOWN. THE TORNADO HAS LIFTED BUT IS EXPECTED TO REDEVELOP AT ANY TIME…

38. Clarity

Instructor Notes:

Student Notes:

Clarity

Specificity
Consistency
Certainty
Clarity
Accuracy

- Warnings MUST be worded in simple language that can be understood
  - Tailored to your area
  - Avoid technical jargon
- Focus Call-To-Action statements
  - Impacts expected with THIS storm
  - Quick, targeted safety information
  - General statements about complicated subject
  - Focus on the MAIN threat
    - Can't give every possible safety rule

39. Call to Action Statements (Page 1)

Instructor Notes: Clarity is especially important in "Call To Action" statements. Keep it simple!

Student Notes:

Call to Action Statements

- TAKE COVER NOW. MOVE TO AN INTERIOR ROOM ON THE LOWEST FLOOR OF A STURDY BUILDING. AVOID WINDOWS. IF IN A MOBILE HOME…A VEHICLE OR OUTDOORS...MOVE TO THE CLOSEST SUBSTANTIAL SHELTER AND PROTECT YOURSELF FROM FLYING DEBRIS.
- HEAVY RAINFALL MAY HIDE THIS TORNADO. DO NOT WAIT TO SEE OR HEAR THE TORNADO. TAKE COVER NOW.
- TORNADOES ARE DIFFICULT TO SEE AND CONFIRM AT NIGHT. TAKE COVER NOW.

40. Call to Action Statements (Page 2)

Instructor Notes: More examples of simply worded “Call-To-Action” statements.

Student Notes:

Call to Action Statements

- MOTORISTS SHOULD NOT TAKE SHELTER UNDER HIGHWAY OVERPASSES. AS A LAST RESORT...EITHER PARK YOUR VEHICLE AND STAY PUT…OR ABANDON YOUR VEHICLE AND LIE DOWN IN A LOW LYING AREA.
- For a "Tornado Emergency",
  - TO REPEAT…A LARGE…EXTREMELY DANGEROUS…AND POTENTIALLY DEADLY TORNADO IS ON THE GROUND. TO PROTECT YOUR LIFE…TAKE COVER NOW.
- A TORNADO WATCH IS ALSO IN EFFECT. TORNADOES CAN DEVELOP SUDDENLY FROM SEVERE THUNDERSTORMS.

41. Clarity?

Instructor Notes: What is wrong with each of these statements?

Student Notes:

Clarity?

- SPOTTERS REPORT AN INCIPIENT TORNADO
- REPORTS HAVE BEEN RECEIVED THAT THE PARENT THUNDERSTORM PRODUCED TWO TORNADO FUNNELS
- THIS STORM HAS HAD A HISTORY OF PRODUCING A BRIEF TORNADO TOUCHDOWN
- A THUNDERSTORM NEAR THE TOWN OF OROVILLE REPORTED LARGE HAIL
- NUMEROUS REPORTS OF TORNADOES WERE REPORTED

42. Accuracy

Instructor Notes:

Student Notes:

Accuracy

Specificity
Consistency
Certainty
Clarity
Accuracy

- Timely, accurate and complete information
- Simple typos, spelling, incorrect locations
- Header errors
  - e.g., SVR under SVS header

43. Accuracy: Examples

Instructor Notes:

Student Notes:

Accuracy

- AT 301 PM CST...DOPPLER WEATHER RADAR INDICATED A SEVERE THUNDERSTORM 162 MILES NORTH OF SALEM OR 155 MILES NORTH OF MOKO... MOVING NORTHEAST AT 40 MPH.
- HAIL UP TO 10 INCHES IN DIAMETER HAS BEEN REPORTED WITH THIS STORM
- THIS IS A VIOLENT THUNDERSTORM PRODUCING HUGH HAIL!

44. Characteristics of Effective Warnings

Instructor Notes:

Student Notes:

Characteristics of Effective Warnings

- Specificity
  - Where, when, what
- Consistency
  - Internal/external
- Certainty
  - The tone of the message
- Clarity
  - Simple words with precise meaning
- Accuracy
  - Timely, accurate and complete information

45. AWOC-core4-lesson3-quiz2

Instructor Notes:

Student Notes:

46. References (Page 1)

Instructor Notes:

Student Notes:

References

- The Role of Effective Communications in the Warning Process
  - Richard Smith, WDM III Workshop Presentation
- Communication of Emergency Public Warnings: A Social Science Perspective and State of the Art Assessment
  - Mileti and Sorensen, Aug 1990
- Correlation Between Tornado Damage Paths and WSR-88D Signatures, and Resulting Implications for the use of Pathcasts in Tornado Warnings
  - Steven Piltz and Richard Smith: NWS, Tulsa OK

47. References (Page 2)

Instructor Notes:

Student Notes:

References

- Toward Improved Understanding of Warnings for Short Fuse Weather Events
  - Eve Gruntfest, March 2002
- Factors Related to Flood Warning Response
  - Denis S. Mileti, Nov 1996
- NWS Instruction 10-511 WFO Severe Weather Products Specification, November 2005
- NWS Instruction 10-922 WFO Hydrologic Products Specification, August 2009

48. End of Lesson

Instructor Notes: You have completed this lesson on Effective Warnings. Please complete the remaining lessons in this Instructional Component before attempting the test required for completion. The test should be taken as soon as possible after completing all of the lessons. If you have any questions about this lesson, first ask your training facilitator. If you need additional help, please send an e-mail to the address listed on the slide. Thank you for your time and good luck on the exam!

Student Notes:

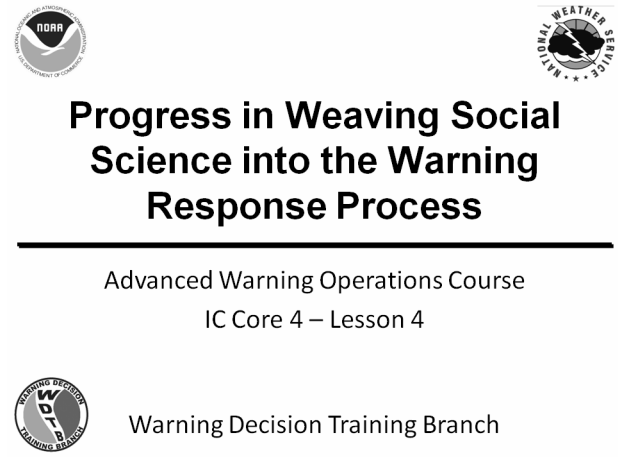
End of Lesson

Questions about this lesson
"Effective Warnings"?
E-mail: awoccore_list@wdtb.noaa.gov

1. Progress in Weaving Social Science into the Warning Response Process

Instructor Notes: I am extremely pleased that this presentation is included in the course. I welcome comments and questions, and I hope to hear from students regularly. This lesson was first included in the AWOC course years ago and has now been updated to account for the numerous changes and great progress that has been made in integrating social science into the warning process.

Student Notes:



2. Objectives

Instructor Notes: There are now many social science research projects that have studied warnings. Economists (e.g. Dan Sutter Kevin Simmons, Jeff Lazo and David Letson), sociologists (e.g. Betty Morrow, Walt Peacock, Nikki Dash) and others are helping us understand how to communicate uncertainty, what sources of information people want, and how to improve response but the number of social science studies is still much smaller than the number of physical science studies. This means we are still spending more money on research to understand the atmosphere than we are on research to understand how to improve warning response. There are some efforts that are working hard to integrate social science into meteorology. Two of them SSWIM (Social Science Woven into Meteorology) and WAS*IS (Weather and Society * Integrated Studies) are briefly described in this presentation. The questions included as part of this presentation are general questions that we all need to address if we are going to reduce losses from hazardous weather.

Student Notes:

Objectives

- Identify findings from recent National Science Foundation social science research
- Describe SSWIM and its mission
- Describe WAS*IS and its mission
- Identify ten questions to consider when relating meteorology with society

3. My Role – Applied Geographer

Instructor Notes: Please let me know if you have case studies to share of user surveys or other collaborations between social and physical scientists. Also, please let me know if I can help with the development of questionnaires or surveys. I have been working as an “add on” social scientist since the 1976 Big Thompson flash flood in Colorado. It’s so rewarding that now so many people are joining in the collaborations to address the physical and social science of warnings.

Student Notes:

My Role – Applied Geographer

- Social scientist in world of engineers and physical scientists
- Research flash flood and warning systems
- Over 30 years as “socio-hydro-meteorologist”
- Inventor of WAS*IS movement

4. The Big Thompson Flood in Colorado - July 31, 1976

Instructor Notes: My master’s thesis was a study of what people did the night of the flood. What actions lead to survival or non survival. My research was the first study that clearly showed that cars cannot outrace flash floods. People who drove or who stayed in their homes were more likely to die than those who climbed to safety. The road sign in this slide was developed following my research and is placed in many canyon entrances in Colorado and elsewhere to encourage drivers to abandon their cars and climb to higher ground when faced with rising water.

Student Notes:

5. National Science Foundation Social Science Research

Instructor Notes: Few studies have evaluated how people respond to warnings. I hoped my National Science Foundation study would be able to give the National Weather Service enough specific suggestions for how to improve warnings. We had two large case studies: Austin, TX and Denver, CO but we found that there is "no one size fits all" answer to how Americans perceive flash flood and tornado risks. There are many differences between how Austin folks perceive flash floods compared with Denver folks and then there are many variations based on how old people are, what their jobs are, and other demographic factors. We did find that people did not think there was a problem with over-warning.

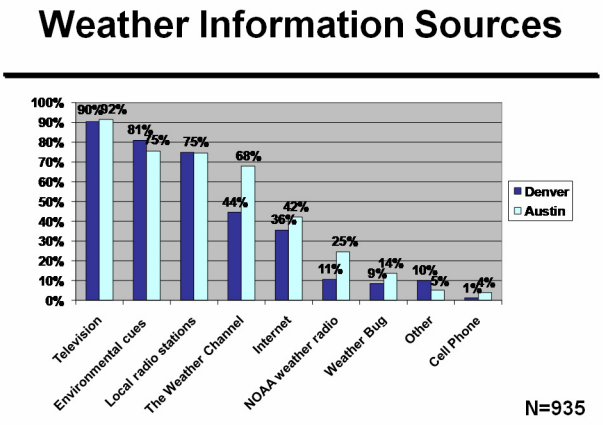
Student Notes:

6. Weather Information Sources

Instructor Notes: When we completed this study in 2005 and 2006 most people reported getting their weather information from television. Now, in 2011, many more peo-

ple would report getting their information from the Internet or from their cell phone. However, remember that television broadcast meteorologists are playing a tremendous role in getting the warning information out to the public.

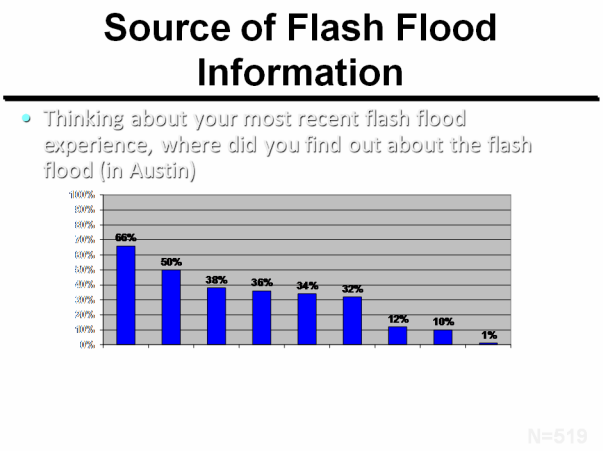
Student Notes:



7. Source of Flash Flood Information

Instructor Notes: Austin has had many serious flash floods in the past decade. Austinites use local television for their warnings (as of 2006). A couple of interesting points: 1) Austin has a 24 hour station that shows weather and radar and many people rely on this station for their information; and 2) there were some promotions arranged between the supermarkets and the weather radio company (Midland) and 10% of the people used the NOAA Weather Radio for their flash flood warning notification.

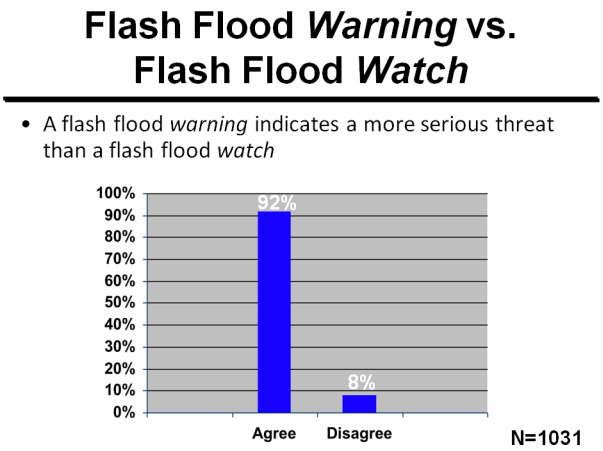
Student Notes:



8. Flash Flood Warning vs. Flash Flood Watch

Instructor Notes: Our study showed that people know the difference between a watch and a warning.

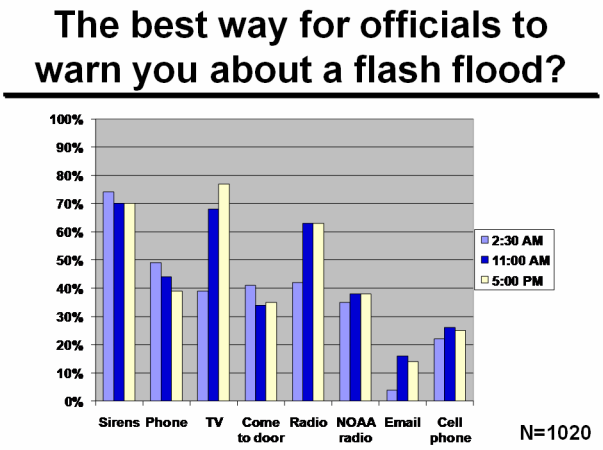
Student Notes:



9. The best way for officials to warn you about a flash flood?

Instructor Notes: This question aimed to recognize that the NWS and emergency managers may need to use different strategies to reach people at different times of the day. People said they liked sirens but there is a divided expert opinion regarding the effectiveness of sirens since so many people live in sprawling cities, sirens cannot be heard indoors over air conditioning or other indoor noises, and for other reasons.

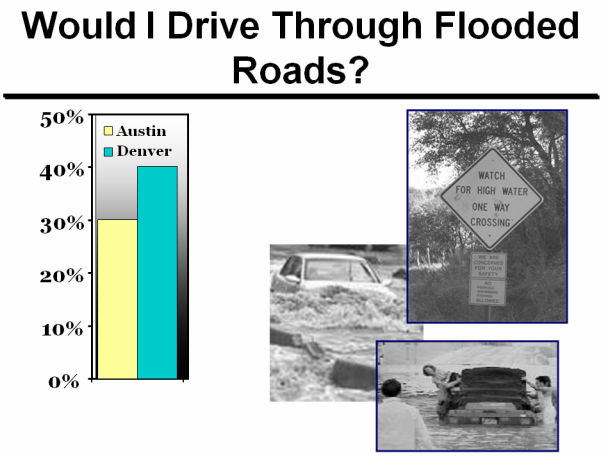
Student Notes:



10. Would I Drive Through Flooded Roads?

Instructor Notes: Is this good or bad news? How can we evaluate changes in behavior? The key here is to have baseline data and then try a new public education project to see if the data change – can public education change peoples' perceptions and their behavior? We need much more research on the effectiveness of these programs. Even the "Turn Around Don't Drown" project has not been evaluated to see if and how it makes a difference.

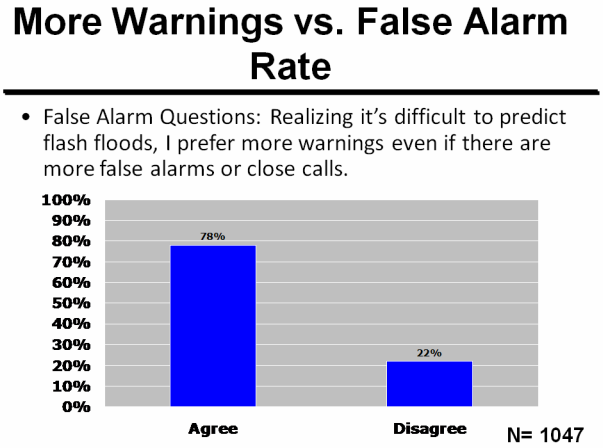
Student Notes:



11. More Warnings vs. False Alarm Rate

Instructor Notes: Moving on to the second question "Realizing it's difficult to predict flash floods, I prefer more warnings even if there are more false alarms or close calls" The difference between Austin and Denver residents was not statistically significant. Majority of respondents, 78%, agreed they would rather have more warnings with the possibility of more false alarms. This highlights that our hypothesis, based on the conventional wisdom, that over-warning is a problem – is not right.

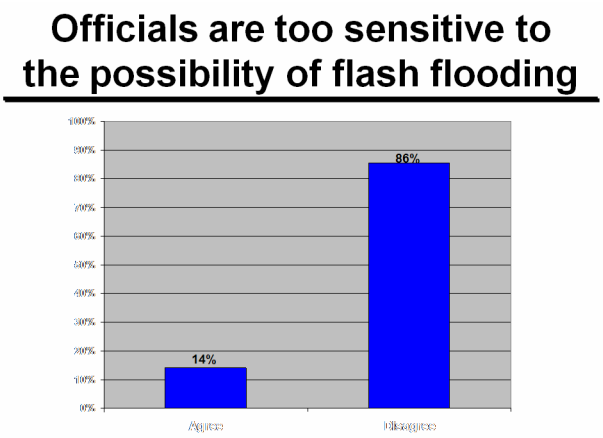
Student Notes:



12. Officials are too sensitive to the possibility of flash flooding

Instructor Notes: The difference between Austin and Denver residents was not statistically significant. We can see that the large majority of respondents, 85%, disagreed that officials are too sensitive to the possibility of flash flooding. Again, people are not that concerned about over-warning.

Student Notes:



13. Recent Research Findings

Instructor Notes: As I said earlier we hoped we would be able to generalize from our research and provide NWS with clear guidance as to how to best warn and what messages were best to use. However, we found that there is a large variability between people in harm's way. People need different information depending on where they are, what their responsibilities are, how old they are, their access to resources (including cars and money for hotel rooms) and so now I strongly advocate for research on why people behave as they do rather than their perceptions. We need to look at what people do and then find out what motivates them to take constructive timely action and what keeps them from doing the right thing with the limited time they have.

Student Notes:

14. What We Know About Warnings – Public Response Components

Instructor Notes: This slide reinforces that the warning process is not a stimulus/response quick interaction. All of these processes listed above must occur before people

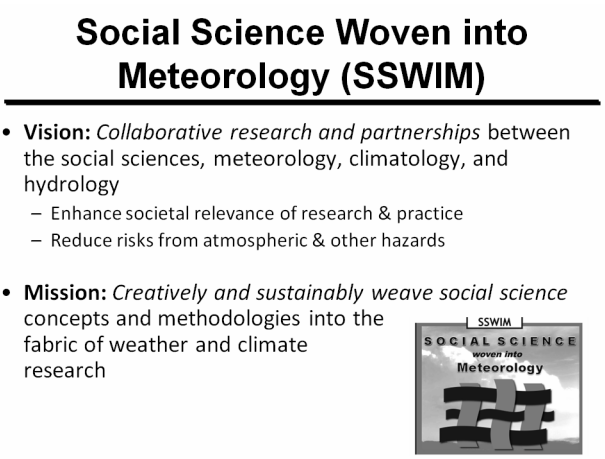
are motivated to take mitigating behavior. We tend to focus on the people we lose. Most people do take appropriate action to reduce their vulnerability. Let's study the success stories.

Student Notes:

15. Slide 15

Instructor Notes: SSWIM began in 2008 as a collaborative effort funded by University of Oklahoma and NOAA at the National Weather Center. It is an exciting new growing initiative.

Student Notes:



16. Objectives of SSWIM

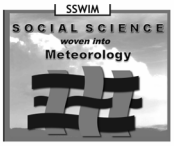
Instructor Notes: Being in the National Weather Center means SSWIM has the advantage of being co-located with the Storm Prediction Center, the OU School of Meteorology, the Warning Decision Training Branch, the Hazardous Weather Testbed, the National Severe Storms Lab and many other groups dedicated to improving meteorological research and practice. Social scientists must be willing to work on day-to-day practical/operational R2O problems with meteorologists, but meteorologists must also be

willing to allow social scientists to define problems that are identified by work with stakeholders and end users.

Student Notes:

Objectives of SSWIM

- Innovative research and capacity building
  - By increasing the appreciation of the value of *qualitative as well as quantitative approaches* including archival, ethnographic & participatory methods
  - Through partnerships with public, private, and academic sectors, including students, practitioners and policymakers *across the spectrum of stakeholders*



17. SSWIM's Three Goals

Instructor Notes: SSWIM has three main goals. As of 2010-2011 we are working closely with the Hazardous Weather Testbed, the Storm Prediction Center and the NOAA Global Systems Division in Boulder to learn how emergency managers, school administrators and others use weather forecasts and how to bring them directly into the process of the development of new software and tools.

Student Notes:

SSWIM's Three Goals

- To *weave* social science into the activities of the National Weather Center and elsewhere
- To *build* a reputation as a center of social science research and practice in weather and climate work
- To *revolutionize* the research to operations equation so it's no longer top-down and all partners play equal roles –

18. SSWIM Members (10/2010)

Instructor Notes: I'm the SSWIM Director and then we have four early career leaders on the SSWIM team. Their expertise is shown in the slide.

Student Notes:

SSWIM Members (10/2010)

- Dr. Heather Lazrus – Deputy Director
  - Perceptions of Climate Change and Governance of Vulnerability in Tuvalu
  - Research with NOAA Fisheries on policy and environmental changes
- Jen Spinney – Ethnographer
  - How emergency managers and broadcasters use weather forecasts
- Amy Nichols and Stephanie Hoekstra
  - Masters Degree Students in Geography, part of Warn on Forecast and Hazardous Weather Testbed projects

19. Social Science Currently Woven into Meteorology

Instructor Notes: These are some of the projects that SSWIM have been collaborating with.

Student Notes:

Social Science Currently Woven into Meteorology

- National Weather Service Training
  - Updating course lectures
  - Incorporated into all NWS orientation classes
- Warn-on-Forecasting
- Developing ways to integrate social science into the Storm Prediction Center
- Added to SHAVE studies for hail and flash floods

20. Slide 20

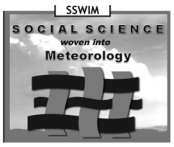
Instructor Notes: We hope you will contact use about how we can engage with you on research and evaluation. The challenges and obstacles are enormous but 2011 is a year for great progress.

Student Notes:

SSWIM Summary

- The go-to group for social science in meteorology inside and outside the National Weather Center
- Growing footprint in meteorology, climatology, and hydrology

- SSWIM has a global identity as leader in a new movement… We have a firm platform with high visibility



21. Weather and Society * Integrated Studies (WAS*IS)

Instructor Notes: WAS*IS is a movement that began at the National Center for Atmospheric Research and as of 2011 has 300 official WAS*Isers who have been through the workshops in Boulder, Puerto Rico, Australia, or Norman. The National Weather Service Integrated Hazard Team meetings have been productive spin-offs of WAS*IS. The IWT's workshops include broadcast meteorologists, emergency managers, and NWS folks who discuss issues of local and regional concern. Workshops have been held in Kansas City, Cedar Rapids, Springfield, MO, Wichita, Omaha and elsewhere. The movement is continuing to grow and develop.

Student Notes:

Weather and Society * Integrated Studies (WAS*IS)

"I want to do work that integrates meteorology and societal impacts BUT…
- I don't know how, and…
- I don't know anyone else who does this kind of work"

WAS*IS Vision

- To change the weather enterprise by comprehensively and sustainably integrating social science into meteorological and hydrological research and practice

22. WAS*IS Mission

Instructor Notes: For more information on WAS*IS consult the website www.sip.ucar.edu/wasis and consider joining the Societal Impact Program's electronic discussion board to learn more and interact with others about current warning and response issues.

Student Notes:

WAS*IS Mission

1. Build an interdisciplinary community of practitioners, researchers and stakeholders *dedicated to the integration of meteorology and hydrology and social science*
2. Provide opportunities to learn and examine ideas, methods, and examples related to integrated weather-society work

23. Movement from WAS to IS

Instructor Notes: Many WAS*Isers are finding that their passion for integrating social science and physical science has helped them with job and grant opportunities.

Student Notes:

Movement from WAS to IS

- Originated with two-part workshop in Boulder, CO (Nov '05 and Mar '06) – now more than 250 WAS*ISers
- Inspired numerous Integrated Warning Team Meetings
- Teaching – New course offerings in Weather & Society
- Research
  - Journal publications
  - Presentations at professional meetings

24. Notable WAS*IS Contributors

Instructor Notes: Each of the WAS*Isers has found a niche for this exciting new collaborative work. These four people are leading examples who have advanced their careers based on the recognition that social science and meteorology together are a greater combination than the sum of their parts.

Student Notes:

Notable WAS*IS Contributors

1. Daniel Nietfeld – Scientific Operations Officer at National Weather Service Forecast Office - Omaha
2. Cedar League - Collaborative Adaptive Sensing of the Atmosphere (CASA)
3. Julie Demuth – Completing Ph.D. in Communication at Colorado State University
4. Rachel Riley – Completed inter-disciplinary Master's Degree at U. of Oklahoma asking broadcasters about new weather technologies

Clark County Regional Flood Control District

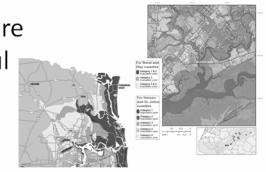
25. Ten Issues to Keep in Mind

Instructor Notes: So many fundamental questions are still unanswered in comprehensive consistent ways. With the emphasis on GIS and satellite imagery its essential that we develop new software and tools in meaningful ways that address actual needs expressed by stakeholders and that we not get too carried away with the elegance of the graphics. Much more work needs to be done to improve on the ground communication during and immediately following events. Even with the new social media it's easy for many people to be left out of the loop.

Student Notes:

Ten Issues to Keep in Mind

1. Fancy graphical images are everywhere… How useful are they to the public?



2. How can we assure robust communication on many levels? Where were maps and GIS, even telephones right after Hurricane Katrina?

26. Ten Issues to Keep in Mind

Instructor Notes: We are now working on the Warn-on-Forecast project that will significantly extend current lead times. How will people (emergency managers, hospital administrators, school coaches, business owners, and others) use this time to be better prepared and reduce their vulnerability? The housing point is that recent studies show that most people do not die in tornadoes because they have no warning or not enough time. They are stuck in mobile homes where there is no safe place to escape the storm.

As far as acceptable levels of risk– New York City faced its 6th worst snowstorm on December 26, 2010. The warnings were excellent but city officials chose to wait until after the storm and then they faced numerous grave challenges to getting the city back up and running. They did not move into snow emergency mode before the blizzard hit. Also, they do not have the resources on hand to deal with such a large and rare storm. Should they? This question is also being seriously faced when levees in New Orleans and elsewhere are being rebuilt. How safe is safe enough?

Student Notes:

Ten Issues to Keep in Mind

3. Is there a BEST lead-time? Forecasts are often very good but people die – *housing or transportation more important than forecast accuracy*
4. What are acceptable levels of risk?

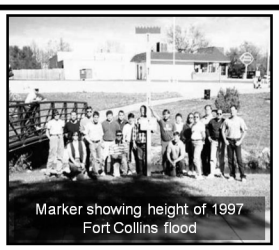
27. Ten Issues to Keep in Mind

Instructor Notes: Research shows that forecasters are not likely to experience a rare event during their forecasting career. How can the best decisions be made acknowledging the uncertainty that thunderstorms, flash floods and other weather hazards present? As stated before we need to recognize that we will still lose people even if warnings are perfect. We need to be able to more easily recognize all the people we have saved by providing excellent forecasts, outlooks, watches and warnings. Most people are doing the right thing but we rarely learn from their experiences!

Student Notes:

Ten Issues to Keep in Mind

5. How do we address nuisance events versus catastrophic events?
6. How do we measure warning success? If 28 people die in Texas or France or if 1,000 people die in Bangladesh, were the warnings successful?



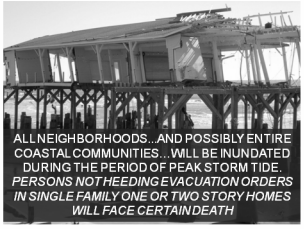
28. Ten Issues to Keep in Mind

Instructor Notes: We continue to believe that once we get the right, accurate, well crafted messages out then we will no longer have any fatalities. Good information is only one part of this equation. Recent flash flood research shows that drivers knew they were crossing deadly low water crossings and that there were flash flood warnings in effect but they felt they HAD to go to work and so they were unwilling to postpone or cancel their trips. So, there are now examples of employers (e.g. Lower Colorado River Authority in Austin, TX) who allow employees to call in and delay their arrival at work if weather is hazardous. We need to see more of this! Calls to action are used in extreme circumstances. How effective are they? Morss and Hayden looked at the Calls to Action as part of the Galveston warnings for Hurricane Ike and the 45 people they talked to provided intriguing feedback. We need to find out what actions people are taking as a result of the Calls to Action.

Student Notes:

Ten Issues to Keep in Mind

7. How do we change "public education" paradigm?
   - Having the right message is one piece of the puzzle to change behaviors



8. What should be the policy regarding NWS "Calls-to-Action?"

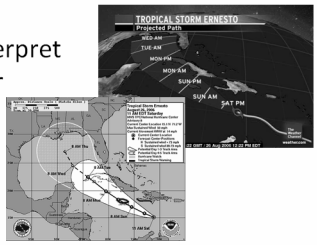
29. Ten Issues to Keep in Mind

Instructor Notes: A lot of social science research is now addressing ways to better convey different levels of uncertainty. But, remember that the information about the weather that people receive is only one element in a complex decision making context that includes many other factors.

Student Notes:

Ten Issues to Keep in Mind

9. Were "Calls-to-Action" too strong or not strong enough? How can we motivate people to evacuate who need to evacuate?
10. How do people interpret probabilities and/or uncertainties?



30. Forecasting accuracy is improving but…

Instructor Notes: We are making great strides in bringing lessons from social science research into warning practice. The next few years should provide leaps in how we forecast effectively (as measured by the stakeholders). Much work needs to be done but we are on our way.

Student Notes:

Forecasting accuracy is improving but…

We need more than more accurate information to save lives and reduce losses

We need to understand why people behave as they do

31. Summary

Instructor Notes: Thanks for your attention and I look forward to any questions and comments you have. EveGruntfest@yahoo.com is the best email address to use.

Student Notes:

Summary

- Understand findings from NSF social science research
- SSWIM and WAS*IS
  - Applying social sciences to meteorology and hydrology
  - Create better understanding of human behavior and perceptions
- Ten questions to keep in mind when relating meteorology with society

32. References

Instructor Notes:

Student Notes:

References

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- Schultz, D., E. Gruntfest, M. Hayden, C. Benight, S. Drobot, & L. Barnes 2010. Decision Making by Austin, Texas, Residents in Hypothetical Tornado Scenarios *Weather, Climate, and Society* 2 (3) 249-254

33. End of Lesson

Instructor Notes: You have completed this lesson on The Warning Response Process. Please complete the remaining lesson in this Instructional Component before attempting the test required for completion. The test should be taken as soon as possible after completing all of the lessons. If you have any questions about this lesson, first ask your SOO. Your SOO is your local facilitator. If you need additional help, please send an e-mail to the address listed on the slide. Thank you for your time and good luck on the exam! National Oceanic & Atmospheric Administration OU Vice President for Research NOAA National Severe Storms Laboratory Cooperative Institute for Mesoscale Meteorological Studies OU College of Atmospheric and Geographic Sciences OU Center for Spatial Analysis

Student Notes:

End of Lesson

Questions about this lesson
E-mail: egruntfest@ou.edu

1. Conceptual Models for Origins and Evolutions of Convective Storms

Instructor Notes: The title for this instructional component (IC) is Conceptual Models for Origins and Evolutions of Convective Storms. This is the first IC in the AWOC Severe Track. Lesson 1 will introduce the IC and then describe conceptual models for supercell tornadic storms.

Student Notes:

Conceptual Models for Origins and Evolutions of Convective Storms

Advanced Warning Operations Course
IC Severe 1
Lesson 1: Supercell Tornadic Storms
Warning Decision Training Branch

2. AWOC Severe Track Training Components

Instructor Notes: The entire Severe Track is divided up into 4 ICs. IC 1 is on conceptual models of storms. This instruction forms the foundation for how we visualize and come to understand important processes in convective storms.

Student Notes:

AWOC Severe Track Training Components

- IC 1 – Conceptual Models
- IC 2 – Threat Assessment
- IC 3 – Storm Interrogation Strategies
- IC 4 – Application and Review

3. IC1 Performance Objective

Instructor Notes: Performance objectives provide precise, measurable statements of the behaviors that training participants will be able to demonstrate on the job. They often specify the condition under which the behaviors will be demonstrated as well as the criteria for acceptable performance. The performance objective for this entire IC is that the trainee will demonstrate ability to incorporate the knowledge of conceptual models to help describe convective storm structure and evolution.

Student Notes:

IC1 Performance Objective

- The trainee will demonstrate ability to incorporate the knowledge of conceptual models to help describe convective storm structure and evolution.

4. IC1 Lesson Plan

Instructor Notes: The instruction for IC1 is broken up into 3 lessons, with the following topics in each lesson: Tornadic supercell storms Hail storms Flash flooding (meteorological and hydrological effects) Individual learning objectives are designed into each Lesson and the IC test is on the objectives.

Student Notes:

IC1 Lesson Plan

Lesson 1: Supercell tornadic storms

Lesson 2: Hail storms

Lesson 3: Flash flooding

5. IC1 Learning Objectives

Instructor Notes: These are the learning objectives for lesson 1. There will be a test on the learning objectives for this IC.

Student Notes:

IC1 Learning Objectives

Lesson 1 : Supercell tornadic storms

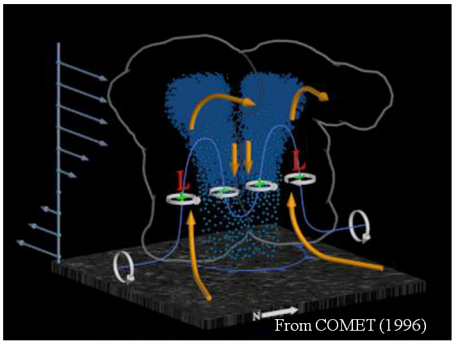
1. Identify the role of shear on supercell structure and evolution.
2. Determine supercell motion using the ID method.
3. Explain the role of baroclinic generation of vorticity.
4. Identify some characteristics of favorable boundaries for supercell tornado development.
5. Describe the role of the rear-flank downdraft for tornado development.
6. Explain the primary buoyancy effects in supercell storm development.
7. Identify the fundamental conceptual model of a supercell.
8. Identify some considerations regarding cyclic tornado evolution.

6. Role of Deep Shear (non-linear dynamic forces)

Instructor Notes: The interaction of the updraft with an environment characterized by strong vertical shear of the horizontal wind permits some storms to develop nonhydrostatic vertical pressure gradients that can be as influential in developing updrafts as the buoyancy effects (Weisman and Klemp 1984). The midlevel rotation arises from a couple of dynamical forces at play. The end result is the tilting of horizontal vorticity into the updraft. The mid-level low pressure centers on the updrafts result from the pressure gradient forcing arising to help counter-balance the centrifugal force. Where updraft is strongest (at midlevels) the vertical vortices are most intense. With the dynamic pressure at its lowest aloft, an enhanced vertical pressure gradient force promotes the development of new updrafts within the centers of rotation. Greatest tilting of horizontal vorticity occurs to the right and left of the shear vector. Development of rotation in mid levels and the updraft also occurs right and left of shear vector. Precipitation develops in the middle of widening updraft which acts to split the updraft into two parts. Similar upward dynamic forcing leads to equally strong splitting supercells. Once the supercell is deviating off the hodograph, it experiences streamwise vorticity and storm-relative helicity in its inflow layer. Tilting of the streamwise vorticity into the updraft immediately produces vertical vorticity well correlated with the updraft. RKW theory also explains another internal dynamic force which affects supercell morphology.

Student Notes:

Role of Deep Shear
(non-linear dynamic forces)

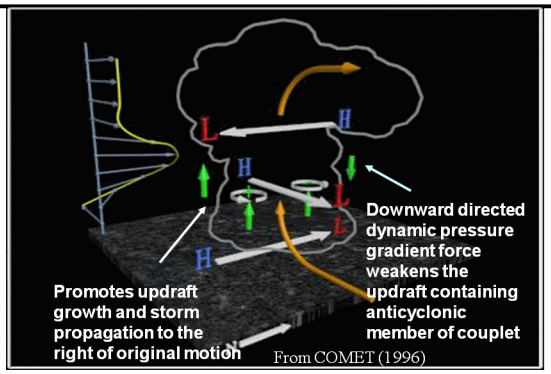


7. Role of Deep Shear (linear theory)

Instructor Notes: There are also linear forces arising from an updraft interacting with the sheared flow. Note the high-to-low pressure gradient developing across the updraft in the direction of the local shear vector at each level. The shear vectors are veering with height thus high pressure is produced on upshear side (west), low pressure on down-shear side (east). This reinforces the storm inflow. With a clockwise curved-hodograph, there is an upward directed pressure gradient force that causes new updraft development and therefore, storm propagation to the right of its original motion. Meanwhile, the left side of the updraft would experience a downward directed PGF which would tend to weaken or even destroy the anticyclonic member of the rotation couplet. In summary, shear affects supercell propagation, which is a result of: 1) linear shear processes-dynamic low forming on the right (left) sides of an updraft relative to the shear vector promoting right (left) propagation vector, and 2) curved shear processes-dynamic (high) low pressure forms on the up (down) shear sides of an updraft. The changing shear vector creates upward pressure gradient force and new updraft right of the original updraft with respect to the mean shear vector.

Student Notes:

Role of Deep Shear
(linear theory)



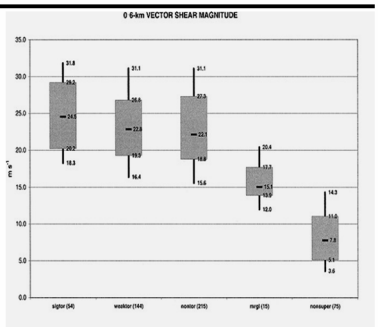
8. Role of Deep Shear

Instructor Notes: The complete reference is R.L. Thompson, R. Edwards, J. A. Hart, K. L. Elmore, and P. Markowski, (2003): Close proximity soundings obtained from the Rapid Update Cycle. Deep shear produces rotation that is in the updrafts of supercells. When there is 15 m/s or greater shear from 0 to 6 km, you get rotation that arises from dynamic pressure forces in storms. This study indicates bulk shear (surface to 6 km AGL) has limited utility in distinguishing between supercells that produce significant tornadoes and those that do not (also see Rasmussen and Blanchard, 1998). Operationally, lower-bound thresholds of bulk shear (0 to 6 km) of 15-20 m/s and mean shear values around .001 s-1 can be used as a first approximation to help determine potential supercell environments. Note: additional factors (e.g., buoyancy distributions, mesoscale variations, etc.), should be considered as well because they can significantly modulate the character of severe storm environments. Rasmussen and Blanchard (1998)found that mean shear in the lowest 4 km AGL was able to distinguish (to a degree) between supercells that produced significant tornadoes and those that only produced large hail. Recent and ongoing research has focused on mean shear in the lowest kilometer above the ground and have found even more distinguishing signals Other research such as Craven et al. (2002) and Markowski et al. (2002) using proximity soundings have found that the 0-1 km layer shear is the primary distinguishing kinematic parameter that separates supercells that produce significant tornadoes from those that do not. Also, see Markowski et al. (2002) study of RUC model proximity soundings which showed a statistically significant difference in the lowest 1 km layer. Observations of mature derecho environments (Evans and Doswell, 2001) suggested that bulk shear in the lowest 2 km was predominately greater than 15 m/s when combined with high CAPE.

Student Notes:

Role of Deep Shear

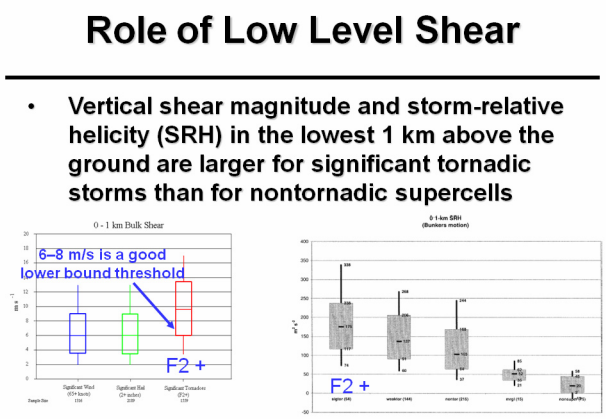
- **Lower-bound thresholds of 0-6 km bulk shear of 15-20 m/s can be used as a first approximation for potential supercell environments**



9. Role of Low Level Shear

Instructor Notes: Stronger low-level shear appears to be associated with a higher frequency of significant (F2 rating or higher) tornado events. The most important results from Craven et al. (2002) were in discriminating between significant hail/wind events and significant tornadoes. The low-level shear parameter, 0-1 km AGL bulk shear, indicated more than a quartile offset between significant tornadoes (F2 or larger) and significant hailstorms (2” diameter hail or larger). Most F2 and larger tornadoes occur with bulk shear above 10 m/s. Lower threshold is likely a bit lower than 10 m/s, around 6 to 8 m/s. Much like the lower threshold that has been established for deep layer shear and supercell development (i.e. 20 m s-1 ; Weisman and Klemp 1982; Davies and Johns 1993; Rasmussen and Blanchard 1998; Bunkers et al. 2000; and Craven (2000), it appears that 6-8 m/s (12-16 kts) may be used as a lower threshold for significant tornado events. These results are consistent with Edwards and Thompson (2000), who found a substantial difference between the mean 0-1 km SRH for supercells with significant tornadoes versus supercells with either weak or no tornadoes observed. A limitation of these results is that supercells may exert an influence on low-level shear and buoyancy profiles up to 30 km away from the storm, effectively altering what had been the pre-storm environment. Apparent storm impacts on local environments have been documented during formal field experiments (e.g., Markowski et al. 1998), and have been observed by storm chasers across the Great Plains of the United States since the 1970s. Note that in interpreting and applying these results, an observed value does not always result in the preferred frequency category. In other words, a weaker than F2 tornado could result even if you see values of shear or SRH in the “significant” TOR category.

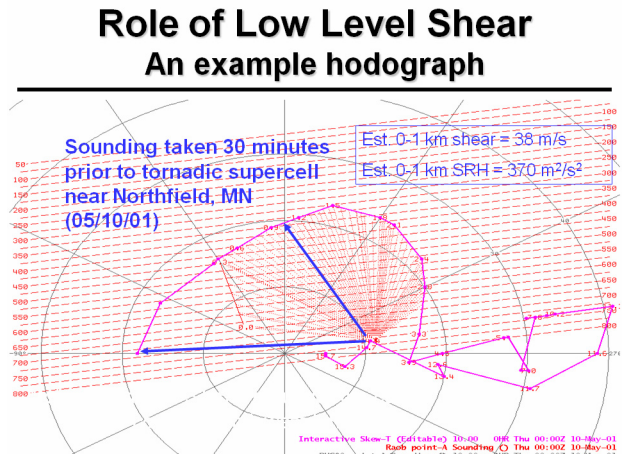
Student Notes:



10. Role of Low Level Shear An example hodograph

Instructor Notes: This is a example proximity hodograph from the 10 May 2001 Northfield, MN F2 tornadic storm. Likely the sounding exhibits influences directly from the storm, since it was taken less than an hour from touchdown time and less than 30 miles from the tornado itself.

Student Notes:



11. Role of Low Level Shear

Instructor Notes: Low-level shear is related to updraft persistence and the likelihood of tornado formation. What sort of updraft are we talking about? In order for the tornado-genesis process to occur, the updraft must process near-ground, SRH-rich air. This happens when the updraft extends below the region of buoyant ascent toward the ground, a result of vertical pressure gradient forces related to the interaction of the updraft with lower-tropospheric shear. Further, because tornadoes form beneath the updraft, the low-level ascent should not be shallowly sloped as it often is when the storm is associated with a vigorous gust front. Sheared updrafts can persist at levels where there is no parcel buoyancy, and it is the low-level processing of inflow that brings low-level SRH into the updraft. Supercell storms are more likely than other storm types to produce tornadoes largely because they have relatively long updraft persistence. Updraft persistence is related most strongly to shear through the lowest one-half of the troposphere (because this forces low-level lifting as just mentioned), as well as a combination of precipitation distribution and low-level humidity. The latter two factors are important in controlling the nature and vigor of the pool of evaporatively cooled air that may or may not form beneath the storm. Vigorous low-level cold pools beneath the updraft are detrimental to tornado formation. If the near-ground air is relatively dry, lesser precipitation falling around the updraft could produce a vigorous cold pool. On the other hand, if the near-ground air is nearly saturated, cooling will be weak even if there is a lot of precipitation around the updraft (Rasmussen, 2002).

Student Notes:

Role of Low Level Shear

- Updrafts in strong low-level shear can persist at levels where there is no parcel buoyancy.
- Low-level inflow brings low-level SRH into the updraft.

12. Role of Shear

Instructor Notes: The other parameter that distinguishes significant tornadoes from non-significant ones is low level humidity (LCL heights).

Student Notes:

Role of Shear

- Sufficient vertical shear (through a deep layer) produces mid level rotation in storms.
- Interaction of updraft with vertically sheared environment permits some storms to develop nonhydrostatic vertical pressure gradients and enhanced vertical motions.
- Low level shear (e.g., 0-1 km AGL) is the primary distinguishing kinematic parameter that separates supercells that produce significant tornadoes from those that do not.

13. Forecasting Supercell Motion

Instructor Notes: The Bunkers ID method is vastly superior to old supercell storm motion methods such as 30R75. That method didn't work for storms moving in all quadrants. You can plot supercell storm motion using ID method in AWIPS Volume Browser.

Student Notes:

Forecasting Supercell Motion

- The Internal Dynamics (ID) method (Bunkers et al., 2000) incorporates the process by which the updraft interacts with vertical shear to cause deviant motion in supercells.
- Can be used to calculate storm motion for cyclonic and anticyclonic rotating storms resulting from a storm split

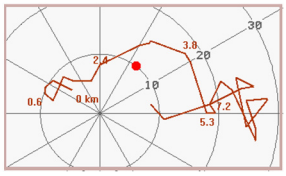
14. Estimating Supercell Motion

Instructor Notes: Just follow the directions, or use BUFKIT. Note, there have been several observations where actual supercell motion was much different than what the ID method suggested. Interaction with other storms, boundaries, topographic effects, etc. All of these may affect the motion.

Student Notes:

Estimating Supercell Motion

- The Internal Dynamics (ID) method
  - Plot the 0-6 km mean wind
  - Draw the 0-6 km shear vector
  - Draw a line orthogonal to the shear vector through the mean wind
  - Plot the left (right) moving storm 7.5 m/s to the left (right) of the mean wind along the orthogonal line.



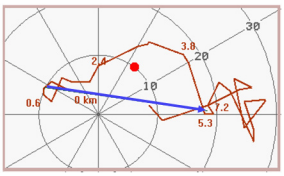
15. Estimating Supercell Motion

Instructor Notes:

Student Notes:

Estimating Supercell Motion

- The Internal Dynamics (ID) method
  - Plot the 0-6 km mean wind
  - Draw the 0-6 km shear vector
  - Draw a line orthogonal to the shear vector through the mean wind
  - Plot the left (right) moving storm 7.5 m/s to the left (right) of the mean wind along the orthogonal line.



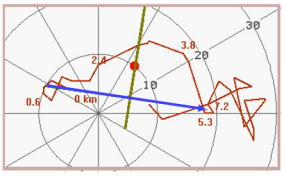
16. Estimating Supercell Motion

Instructor Notes:

Student Notes:

Estimating Supercell Motion

- The Internal Dynamics (ID) method
  - Plot the 0-6 km mean wind
  - Draw the 0-6 km shear vector
  - Draw a line orthogonal to the shear vector through the mean wind
  - Plot the left (right) moving storm 7.5 m/s to the left (right) of the mean wind along the orthogonal line.



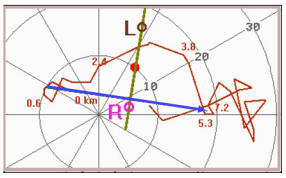
17. Estimating Supercell Motion

Instructor Notes: For more information see http://meted.ucar.edu/convectn/ic411/

Student Notes:

Estimating Supercell Motion

- The Internal Dynamics (ID) method
  - Plot the 0-6 km mean wind
  - Draw the 0-6 km shear vector
  - Draw a line orthogonal to the shear vector through the mean wind
  - Plot the left (right) moving storm 7.5 m/s to the left (right) of the mean wind along the orthogonal line.



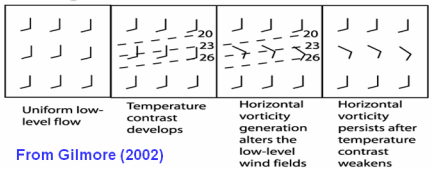
18. Role of Baroclinic Generation of Vorticity

Instructor Notes: These findings are from VORTEX results and illustrate how difficult it is to analyze horizontal vorticity fields on the mesoscale. They could be all over the place when there are multiple boundaries such as outflow boundaries.

Student Notes:

Role of Baroclinic Generation of Vorticity

- The buoyancy gradient enhances streamwise vorticity and SRH.
  - Note 1: Augmented horizontal vorticity from the forward flank region is usually not enough to produce tornadoes.
  - Note 2: Augmented horizontal vorticity remains long after thermal gradient weakens.



From Gilmore (2002)

19. Effects of Low Level Shear (vorticity stretched into updraft)

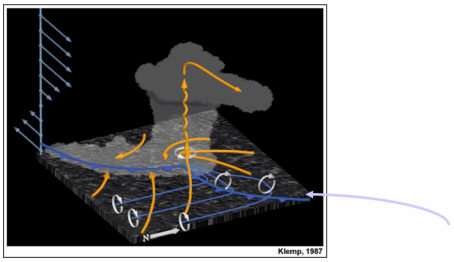
Instructor Notes: From COMET's (Convective Storm Matrix, 1996), the generation of low-level rotation is a result of the processes described so far. This 3-D figure depicts a classic supercell in its mature phase. The near-surface vortex lines (in blue) represent the environmental vorticity bending toward the storm's updraft in the baroclinic zone of the forward flank downdraft. This diagram, based on simulations in the mid to late 80s, indicates the baroclinic generation of horizontal vorticity in the FFD region. Once vorticity enters the updraft, it is stretched vertically to create much stronger low-level rotation. This process can be an important contributor to low-level storm rotation, which previously

was thought led directly to tornadogenesis. However, VORTEX results in the mid-90s and more recent storm scale numerical simulations suggested that augmented horizontal vorticity from the FFD is usually insufficient for tornadogenesis. In moist low-level conditions, there might not be a discernible FFD (thus no baroclinicity). The tornadic scale stretching is thought to come from the RFD (more later). Horizontal vorticity enhancements are necessary for low-level mesocyclogenesis, which appears to precede tornadogenesis if additional key supercell structures develop (e.g., the RFD). Only in cases where large-scale low-level horizontal vorticity is already very high (e.g., 0–3-km mean horizontal vorticity of 1 × 10 2 s 1 or greater or storm-relative helicity of 500 m2 s 2 or greater) or deep-layer shear is very strong (e.g., 50 m s 1 in the lowest 10 km AGL), can forward flank baroclinity alone provide sufficient augmentation of the horizontal vorticity associated with the large-scale mean shear for tornadogenesis to occur. Other sources for streamwise vorticity that may become stretched into the updraft originate from behind the cold front boundary (aka RFD). More on this next.

Student Notes:

Effects of Low Level Shear

(vorticity stretched into updraft)



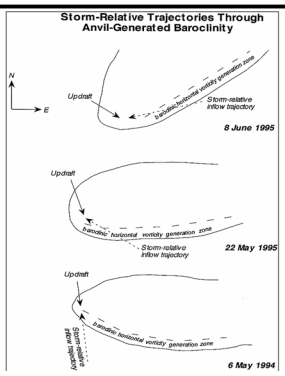
20. Anvil Shadow Effects

Instructor Notes: Due to low-level temperature gradients along the edges of anvil shadows, a baroclinic zone develops. Residence time in the baroclinic zone, estimated by analyzing storm-relative winds from proximity sounding hodos were shown to produce horizontal vorticity (~ 10 –2 s –1) that can be acquired by updraft inflow parcels. Schematic representation of the storm-relative trajectories through the anvil-generated baroclinic zones on 8 June 1995, 22 May 1995, and 6 May 1994. (from Rasmussen et al., 1998) In the first two cases, not only does the vorticity generated contain a greater streamwise component, but the parcel residence times in the baroclinity are longer.

Student Notes:

Anvil Shadow Effects

- Storm anvils can promote baroclinic generation of vorticity (mostly streamwise) and longer parcel times in the zone.

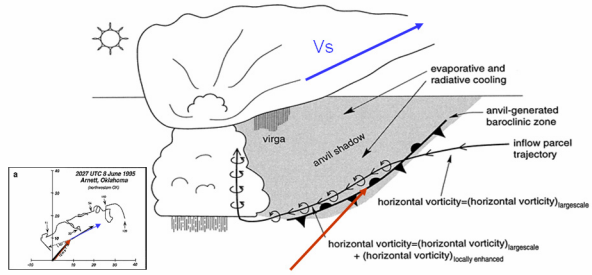


21. Anvil-Generated Baroclinity

Instructor Notes: This is a conceptual model by Markowski et al. (1998) showing enhancement of low-level horizontal vorticity by an anvil-generated baroclinic zone. The amount of horizontal vorticity generated is a function of baroclinity and parcel residence time in the baroclinic zone. Residence time is a function of both storm-relative inflow speed and crossing angle with respect to the baroclinity. Horizontal vorticity will be mostly streamwise if the crossing angle of the storm relative near-surface inflow with respect to the anvil zone is very small (~ 0). The estimated max. parcel residence time was 73 min to ~ 2 hrs. for the 3 cases examined. Their research of proximity hodographs in baroclinic regions revealed that: to maximize horizontal vorticity generation in the near-ground inflow, the head of the storm motion vector should lie close to the line drawn from the heads of the 0–500-m mean wind vector and the wind vector near the equilibrium level. This assumes that the baroclinic zone is aligned closely with the anvil edge. Horizontal vorticity generated with a streamwise component can serve to enhance the storm-relative helicity already present in the environment due to the low-level vertical shear. SRH has been shown to be the source for net updraft rotation in supercells. Thus, the observations of anvil-generated baroclinity may have implications for the origin or enhancement of updraft rotation in thunderstorms.

Student Notes:

Anvil-Generated Baroclinity

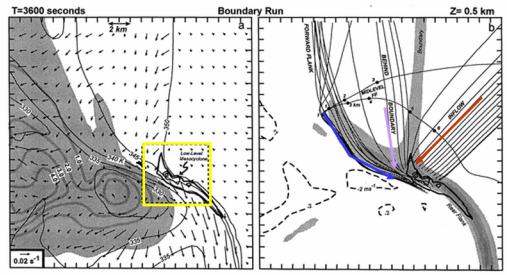


22. Sources of Streamwise Vorticity

Instructor Notes: From Atkins et al. (1999), the low-level storm structure (0.5 km AGL) at 3600s for the boundary simulation. (a) Rainwater mixing ratio greater than 0.1 g kg−1 is shaded gray. The gray contours are rainwater mixing ratio starting at 1.0 g kg−1. Thin black lines are θe (K). Thick black lines are vertical vorticity with contours starting at 0.01 s−1 and a contour interval of 0.01 s−1. The vector field is horizontal vorticity. (b) Positive and negative vertical velocities are gray shades and thick dashed lines, respectively. The contour and shade interval is 2 m s−1 and the 0 m s−1 contour is not plotted. Thin solid lines are the projection of the 3D trajectory locations. Numbers at the black dots on the midlevel trajectories are the height of the parcel (AGL). Thick solid lines are vertical vorticity, contoured as in (a). Parcels from behind the boundary and forward-flank regions had acquired streamwise horizontal vorticity, which was then tilted and stretched by the storm's updraft. The preexisting boundary provides an important additional source region of parcels at low levels that have acquired solenoidally generated streamwise vorticity. These results support the hypothesis put forth by Wicker (1996) that low-level streamwise vorticity enhances low-level mesocyclogenesis and confirm the discussion by Markowski et al. (1998) and Rasmussen et al. (2000) that horizontal vorticity generated at low levels along boundaries is an important vorticity source for low-level mesocyclones. Vertical vorticity along the preexisting boundary augments low-level mesocyclogenesis.

Student Notes:

Sources of Streamwise Vorticity



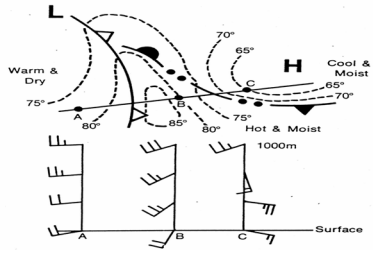
23. Characteristics of Boundaries that Enhance Supercell Tornadoes

Instructor Notes: Boundaries can promote enhanced horizontal vorticity and storm relative helicity on the immediate cool side. Through tilting and stretching processes, boundaries help produce enhanced vertical vorticity - important vorticity source for low-level mesocyclogenesis. This graphic shows the important mesoscale modifications to thermodynamic and kinematic (esp. in low levels) fields in the vicinity of boundaries (from Maddox et al., 1980). Intense horizontal stretching occurs in the storm inflow, as parcels accelerate toward the updraft. We'll look at some important findings from VORTEX as the importance of boundaries in our conceptual models of supercell storms.

Student Notes:

Characteristics of Boundaries that Enhance Supercell Tornadoes

- Boundaries can promote enhanced horizontal vorticity and storm relative helicity on the immediate cool side.
- Thus, boundaries are an important source for vertical vorticity.

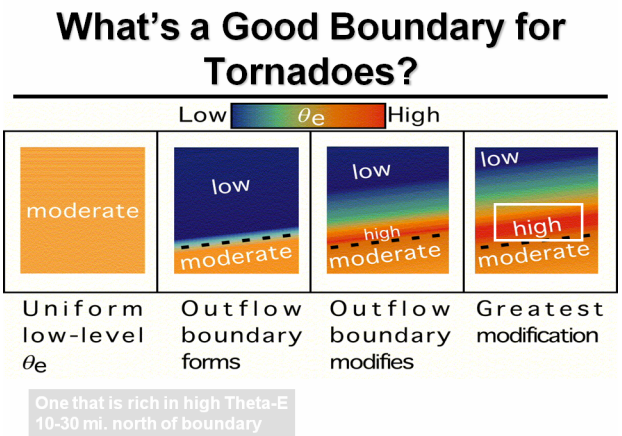


24. What's a Good Boundary for Tornadoes?

Instructor Notes: The answer is one that is rich in high equivalent potential temperature, just north of a boundary. In this location is enhanced SRH, which can remain long after the temperature gradient weakens. Through surface data, esp. mesonet, you can

observe gradients of Theta-E in the vicinity of boundaries. Boundaries that have shallow cold air, there is sufficient MLCAPE on the cold side, and the vertical pressure gradient generated by an updraft in low-level shear remains strong, would be a “good” boundary. The more shallow the boundary, the further into the cold air the tornado potential would exist. Based on the VORTEX findings (and the types of boundaries they researched), the greatest tornado potential probably was located from around 10 km on the warm side to roughly 30 km into the cold air. Boundary layer moisture, as measured on the mesoscale, also has direct correlation to tornado development WRT considerations of the Rear Flank Downdraft (RFD) and associated buoyancy characteristics of the storm scale. Note that a main point here is that the enhanced SRH can be around long after the temperature gradient weakens. Also, note that actual forecasts of SRH increases would be quite difficult. This is because the parcel residence time is most important.

Student Notes:



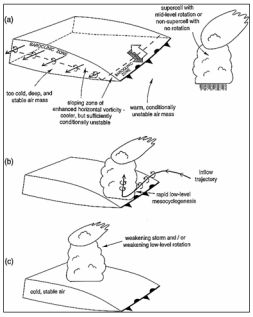
25. Low Level Tilting & Stretching Process

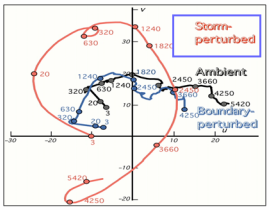
Instructor Notes: Horizontal vorticity is readily stretched horizontally by storm-induced accelerations to the flow, and then tilted into, and stretched by the storm updraft. SRH in inflow region of storm is not likely the same as in pre-storm environment, due to low-level inflow acceleration. Vorticity that is initially mainly horizontal can contribute to quasi-vertical vortices such as supercell mesocyclones through reorientation and stretching. Horizontal vorticity that is streamwise (i.e., vorticity and storm-relative velocity vectors parallel) produces net updraft rotation (Davies-Jones 1984) upon tilting. It is worthwhile to note that the tilting of crosswise horizontal vorticity (horizontal vorticity and velocity vectors perpendicular) also produces vertical vorticity. In the case of purely crosswise horizontal vorticity, integration of vertical vorticity over an entire updraft yields no net rotation; however, a pair of vortices, one cyclonic and the other anticyclonic, will result. SRH is also critical. You’d like to see a large, looping hodo in the lowest 1 km because this means that the vector of the horizontal vorticity generated is directed across the buoyancy gradient (along the buoyancy isopleths). Therefore, for a wide range of typical storm motion, the generation of horizontal vorticity due to buoyancy gradients will increase SRH to the degree that the flow is also along the buoyancy (temperature) isopleths. Key point: Horizontal vorticity generated at low levels along boundaries is an

important vorticity source for low-level mesocyclones. Vertical vorticity along boundaries augments low-level mesocyclogenesis by producing enhanced streamwise vorticity. Boundaries contain low-level horizontal vorticity due to generation of solenoidal effects from buoyancy gradients. Because of large accelerations in storm inflow, the baroclinically generated horizontal vorticity can be amplified by horizontal stretching (Brooks et al. 1993) even prior to reaching the updraft itself. A vigorous updraft, such as those that occur in environments with strong deep shear and sufficient convective available potential energy, can readily tilt and stretch the low-level horizontal vorticity present with the boundary (Weisman and Klemp 1982; Klemp and Rotunno 1983) if the updraft draws air from beneath the boundary interface. The black curve ("ambient" warm sector) in the figure to the right is the hodograph from the LBB special sounding at 2315 UTC. The blue curve is the hodograph from the special sounding at 2248 UTC near Lockney, TX that was 15 km toward the cool side of the pre-existing outflow boundary.

Student Notes:

Low Level Tilting & Stretching Process



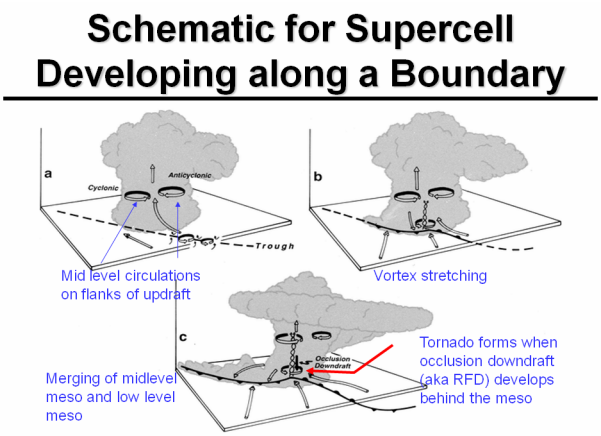


Sounding	Time	0-1 km SRH
Ambient	2315	205 $m^2 s^{-2}$
Boundary	2248	405 $m^2 s^{-2}$
Storm	**0100**	**>1000 $m^2 s^{-2}$**

26. Schematic for Supercell Developing along a Boundary

Instructor Notes: A schematic model summarizing the life cycle of the Garden City storm. (from Wakimoto et al., 1997) Cylindrical arrows depict the storm-relative flow. The location of the low-level and midlevel vorticity centers is shown by the ribbon arrows. The synoptic-scale trough is shown by the black dashed line. The rear-and forward-flank gust fronts are indicated by the frontal symbols. The occlusion downdraft, also known as the rear-flank downdraft (RFD), is shown by the black arrow. Pre-existing synoptic wind shift line, possibly interacting with HCRs helped to produce low-level updraft maxima/ vorticity stretching along the boundary. Interaction of supercell mesocyclone and one of these vorticity maxima was associated with tornadogenesis. This data from the Garden City, KS tornado in 16 May 1997. The occlusion downdraft or RFD in the mesocyclone leads to a highly curved band of vorticity maxima reminiscent of the multiple vortex phenomenon in a tornado. One of these maxima develops into the Garden City tornado.

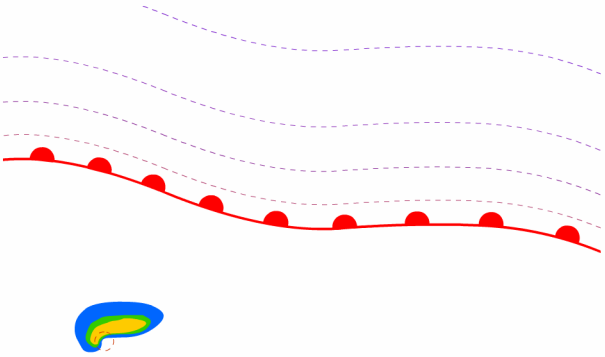
Student Notes:



27. Slide 27

Instructor Notes: The animated flash graphic on this slide will help illustrate some of these key environmental considerations with boundaries and supercell tornadoes. Boundaries that have shallow cold air, there is sufficient MLCAPE on the cold side, and the vertical pressure gradient generated by an updraft in low-level shear remains strong, would be a “good” boundary. Based on the VORTEX findings, the greatest tornado potential probably is located between no more than 10 km into the warm air to roughly 30 km into the cold air.

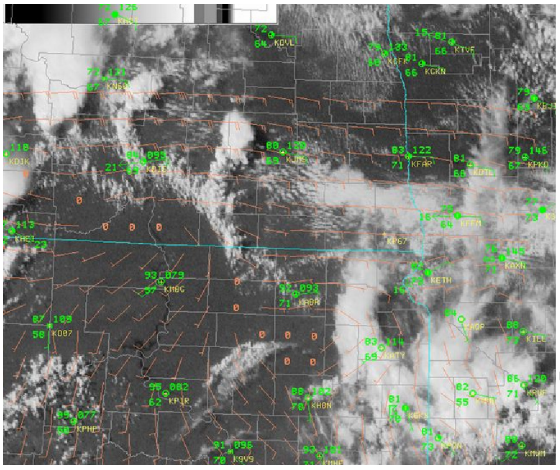
Student Notes:



28. Slide 28

Instructor Notes: This is D2D imagery from 23 June 2002 near Aberdeen, SD.

Student Notes:



Play

Pause

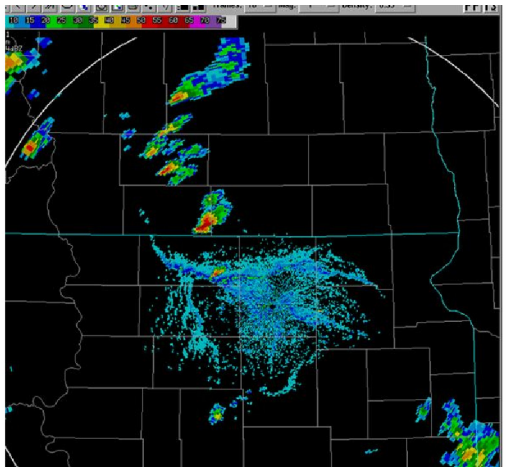
Step Forward

Step Backward

29. Slide 29

Instructor Notes: This is the 0.5 degree reflectivity data. Note 4 distinct boundaries. The one furthest north is the one which is the focus for storms.

Student Notes:



Play

Pause

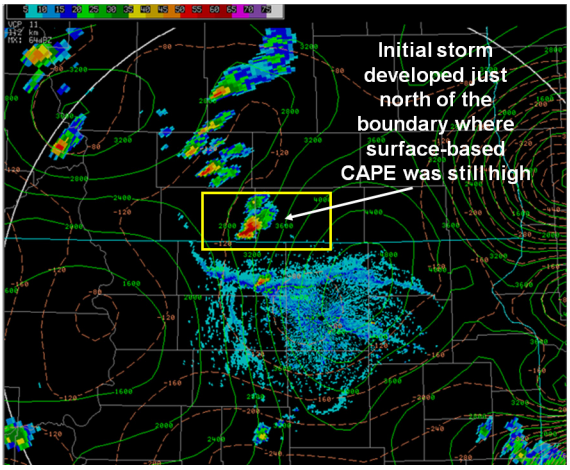
Step Forward

Step Backward

30. Real Life Boundary Example

Instructor Notes: Analyzed CAPE and CIN (Surface based) from the 22z LAPS analysis.

Student Notes:



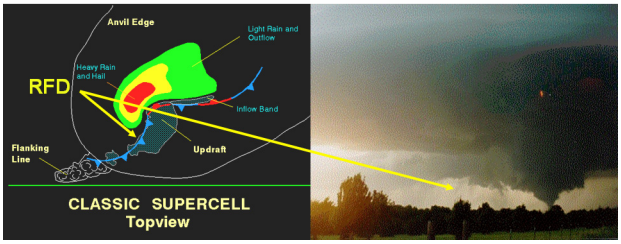
31. The Role of the RFD

Instructor Notes: Most supercells (tornadic and nontornadic ones) have circulations extending to the ground embedded in the outflow. Some supercells have “cold” (relative to inflow air) RFD’s that keep the tornado cyclone from concentrating into a tornado, and that spread a great distance.

Student Notes:

The Role of the RFD

- Important factor in tornadogenesis process for supercells

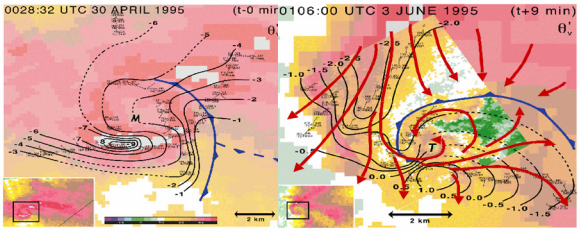


32. The Role of the RFD

Instructor Notes: Paul Markowski (2002) analyzed a large number of project VORTEX cases and found a strong correlation between Rear Flank Downdraft (RFD) potential virtual temperature deficit and the likelihood of a significant tornado (F2 or greater). Analysis in the figures show contours of ?v departure from the pre-storm environment as sampled by mobile mesonet probe. Radar reflectivity is overlain, either from mobile radar or the nearest WSR-88D.

Student Notes:

The Role of the RFD

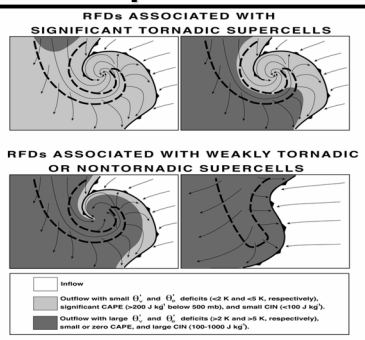


33. RFDs Associated with Tornadic Supercells

Instructor Notes: More from Markowski et al. (2002), this is a composite diagram illustrating the general characteristics of RFDs associated with supercells that produce "significant" (e.g., F2 or stronger, or F0–F1 persisting >5 min) tornadoes vs RFDs associated with nontornadic supercells or those that produce weak, brief tornadoes. The thick, dashed contour is the outline of the hook echo, and thin, solid arrows represent idealized streamlines. In the bottom two depictions, the illustration on the left was representative of 11 of 12 tornadogenesis failures, while the illustration on the right depicts an evolution that was observed in only one nontornadic case.

Student Notes:

RFDs Associated with Tornadic Supercells



34. Role of RFD

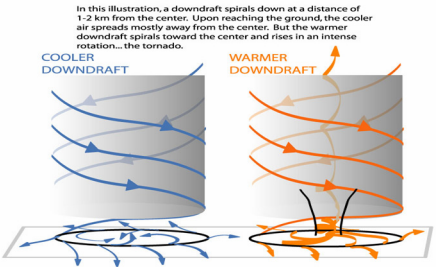
Instructor Notes: (Note: There is a neat flash graphic on this slide.) Most supercells (tornadic and not) have circulations extending to the ground embedded in the outflow. Some supercells have cold RFDs that keep the tornado cyclone from concentrating into a tornado, and that spread a great distance. To elaborate on this concept, one of the most exciting findings of VORTEX and its successors was that rear-flank downdrafts in

tornadic supercells seem to have a very unusual character compared to non-tornadic supercells and thunderstorm downdrafts in general. This finding comes from the Ph.D. dissertation research of Paul Markowski and collaborators. By examining mobile mesonet observations from beneath about 18 tornadic and 12 non-tornadic mesocyclones, the following was found: tornado cyclones~2-3 km diameter vortices… extended to the ground in all but one of the storms. The sample is biased towards storms that appeared to have good tornado potential, but suggests that mesocyclones that fail to produce tornadoes do not fail, in general, because of an “undercutting” by outflow. The notion of “outflow dominated” supercells may be much overused, and it is possible that many supercells have vortices extending to the ground embedded in the outflow below the updraft. In tornado cyclones that produce tornadoes, the RFD reaches the ground with more CAPE, less CIN, larger equivalent potential, wet bulb potential, and virtual potential temperature than in tornado cyclones that do not produce tornadoes.

Student Notes:

Role of RFD

- Warm RFDs promote tornadoes; cold RFDs discourage them



35. RFD Characteristics Related to Tornado Occurrence

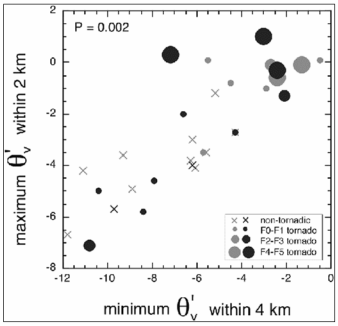
Instructor Notes: These observations were taken by mobile mesonets within RFDs. These results suggest that unstable RFDs implied plenty of CAPE available to aid vortex stretching. To account for sampling errors, the maximum and minimum θv’ for each RFD is plotted on two axis. Researchers speculate that the following description summarizes why buoyancy may be important in an RFD. The RFD is known to descend in an annular, or semi-annular region roughly centered on the axis of maximum low-level rotation. i.e., it descends around the developing vortex. (The degree to which the RFD is driven by thermodynamic/microphysical forcing, and/or dynamic forcing through vertical pressure forces, remains to be resolved.) Upon reaching the ground, some of the RFD air flows toward the axis, and some flows away from the annular region and thus away from the vortex. It appears that the vigor of the down-in-up flow vs. the down-out flow is related to the buoyancy present in the RFD air. If it is relatively buoyant, more air flows toward the axis with subsequent convergence and stretching leading to tornado formation. In this illustration the cool downdraft spirals down at a distance of 2-3km from the center. Upon

reaching the ground, the downdraft spreads mostly away from the center. But the warmer updraft spirals toward the center, and rises in an intense rotation, the tornado. Future research in this area will likely center on understanding what governs the thermodynamic character of the RFD. Rasmussen and others' hunches are that the RFD is strongly related to both low-level humidity, and the sizes and types of precipitation particles comprising the hook-echo, or rear-side supercell precipitation cascade. A further complication is the degree of entrainment of dry environmental air, if present.

Student Notes:

RFD Characteristics Related to Tornado Occurrence

- Evidence builds that unstable RFDs favor more significant supercell tornadoes



36. Humid Boundary Layer

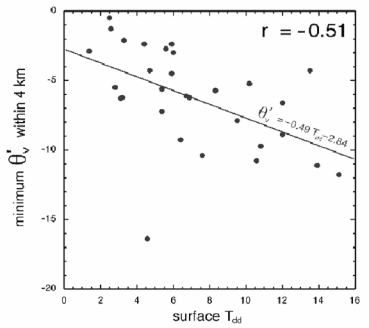
Instructor Notes: RFD buoyancy was compared to the best performing environmental parameter. Tdd was the highest correlated parameter to minimum Theta-V (the RFD proxy). In fact, equivalent potential temperature in tornadic circulations is about the same as the supercell inflow, while in non-tornadic circulations it is colder. Note that all three potential temperatures are correlated with each other. These are very significant findings in our effort to understand and forecast tornadogenesis. Unfortunately, when Markowski examined proximity soundings to all of these events, there were only very weak signals at best. The one environmental measurable that was reasonably well correlated with RFD character and with tornado production was the surface dewpoint depression in the airmass the storm was moving through. This is completely consistent with the strongest predictor found in the 1992 climatological study of Rasmussen and Blanchard: LCL height. From a forecasting perspective, large low-level humidity (i.e., small dewpoint depressions, low LCLs) in the presence of sufficient CAPE is a red flag that the threat of significant tornadoes is enhanced. Note that it is a rare occurrence in the atmosphere to have small dewpoint depressions and still have CIN small enough, and CAPE large enough, for supercells. It is much more common to have humid low-level conditions in which CIN is large and CAPE is small or nonexistent. Also note that humidity is higher on the cool side mesoscale outflow boundaries, where SRH is enhances as discussed previously. This means that boundaries may play a role in tornado production beyond the enhancement of SRH. The situation of tornado threat in relatively drier low-level environments is much more complicated and will require additional research into the conditions in which the RFD can reach the surface with sufficient CAPE and reduced CIN for tor-

nado formation. Right now, we think that a dry environment means that the precipitation in the hook echo must be “just right” to prevent too much evaporation, while a humid environment affords much more latitude in the amount/type of precipitation in the RFD. In a nutshell, some air goes toward the axis and some flows away.

Student Notes:

Humid Boundary Layer

- Of all major environmental parameters, surface dewpoint depressions are most related to RFD buoyancy
- Still a bit of uncertainty

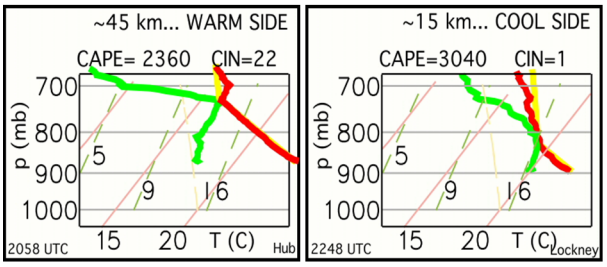


37. RFD Related to LCL Height Related to Boundary Layer RH

Instructor Notes: Just as ?T can enhance SRH, cold/dry outflow can be modified to cool/moist outflow. These soundings were taken on 2 June 95, one of the VORTEX days. Note the difference in LCL height, surface based CAPE and CIN. The most low-level CAPE and least CIN is .7 km north of boundary. This “moisture pooling” N of fronts (low LCLs) is the mode for tornadoes in the N Central Plains (Johns et al. 2000). Johns et al. (2000, Severe Storms Conference) found that intense tornadoes most often occurred to the cool side of stationary or warm fronts (46 years of cases from 1953-1999, N Central Great Plains of the US) where LCL heights were low and moisture pooling was occurring. In contrast, LCL heights in the warm sector were most always higher and tornadoes were rare.

Student Notes:

RFD Related to LCL Height Related to Boundary Layer RH



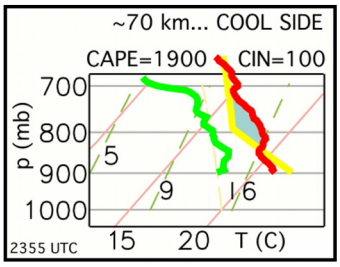
38. Special RFD: Enhancing Boundary Layer RH

Instructor Notes: Note there is some low-level CAPE, but more CIN deep in the cold air.

Student Notes:

Special RFD : Enhancing Boundary Layer RH

- Further north of the boundary, however, the moisture was not modified as much.
- It is no wonder that all tornadoes occurred within 40 km of the boundary!



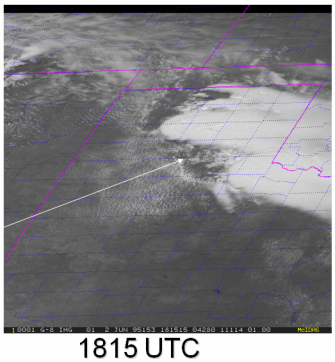
39. Special RFD: Enhancing Boundary Layer RH

Instructor Notes: This is the area where severe thunderstorms erupted.

Student Notes:

Special RFD: Enhancing Boundary Layer RH

- Early convection created cold /dry outflow boundary
- The outflow modified with time to become cool & moist
- Increased moisture ⇒ Lower LCL, larger CAPE, smaller Tdd



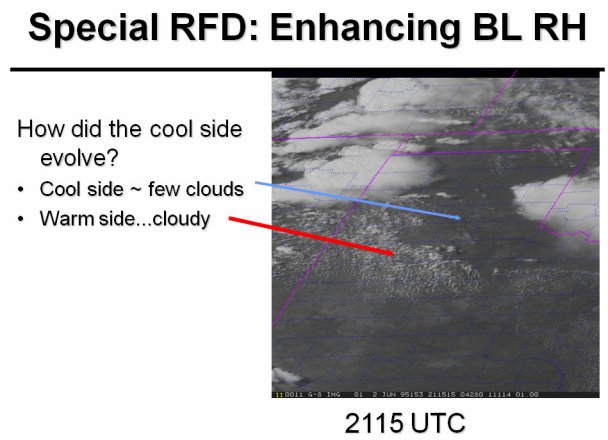
1815 UTC

40. Special RFD: Enhancing BL RH

Instructor Notes: Note that this proposed evolution is different from how the warm sector would be expected to mix-out moisture during the day (as shown by McGinley in “Nowcasting Mesoscale Phenomena”, Chap 8 of the Mesoscale Meteorology and Forecasting book edited by P.S. Ray.(1986). See pg. 667 of that book. McGinley does not treat the special case of airmass modification. Assuming equal insulation and vegetation on both sides of boundary, moisture could be boosted on the cool side due to: 1)

Enhanced moisture fluxes owing to stronger surface winds, 2) “Trapping” of surface-based thermals in the internal boundary layer (BL) due to stability above, 3) Detraining of thermals in lower BL via stronger shear, and 4) Rotor circulation. Moisture is lost on the warm side due to thermals reaching their LCL - (boundary layer convective rolls) and deeper boundary layer mixing.

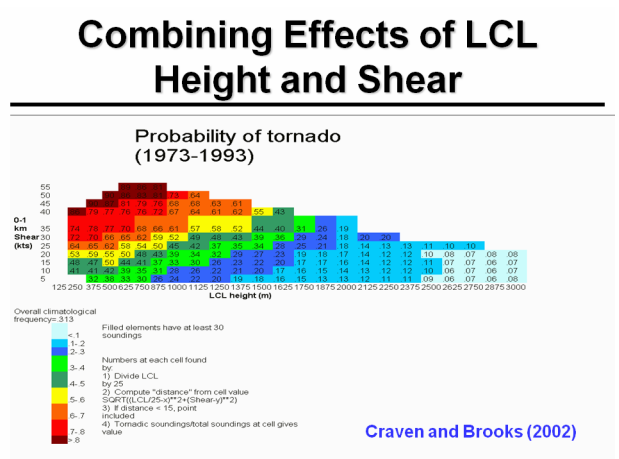
Student Notes:



41. Combining Effects of LCL Height and Shear

Instructor Notes: This chart, from Craven and Brooks (2002) shows a smoothed probability of a tornado as a function of LCL height (m) and 0-1 km shear. The data was obtained from observed 1800 LST soundings on the condition that CAPE was present. The results are based on 20 yrs. of climatological data. The graph indicates the following relationship: tornado likelihood greatly increases as 0-1 km shear increases AND LCL height decreases. Other parameters that take into account low-level CAPE and shear are EHI, VGP, and the Significant Tornado Parameter (STP). See SPC’s Mesoanalysis page for more details (http://www.spc.noaa.gov/exper/mesoanalysis/s3/index2.html) on STP.

Student Notes:



42. Unanswered Questions

Instructor Notes: Future research such as VORTEX 2 may help to explore answers to these questions.

Student Notes:

Unanswered Questions

- Failure modes
- Tornado scale affects (how & why do tornadoes form?)
- In-observables
- What are the roles of entrainment and microphysics in determining the thermodynamic character of the RFD?

43. Buoyancy Effects

Instructor Notes: Research has shown that low-level CAPE and or corresponding low-level CIN may have relevance to tornado production. More CAPE in the lowest levels (and thus lower LCF heights) above the ground suggests stronger potential for large low-level vertical accelerations and enhanced low-level mesocyclone intensification, and thus increasing likelihood of tornadoes in supercells. In a recent study, Davies (2004) showed than stronger tornadoes (≥F2) tended to have more MLCAPE, less MLCIN, and lower MLLFC heights than weaker tornadoes and non-tornadic supercell storms. Simulations of storms with small CAPE (~ 800) squashed into the lowest 5 km indicate that pressure gradient forcing from rotation in mid levels is the primary force for accelerations below 500 mb. Above 500 mb, buoyancy forcing becomes more important (Wicker and Cantrell, 1994). Low-level buoyancy is also related to LCL/LFC heights (RFD characteristics).

Student Notes:

Buoyancy Effects

- Buoyancy can help stretch the vortex associated with supercells
  - Especially when CAPE is compressed into lower levels (note: pressure gradient forcing from shear is still major acceleration factor below 500 mb)
- Related to CIN, LCL height , and LFC height
- Mean layer lifting process most representative in proximity soundings

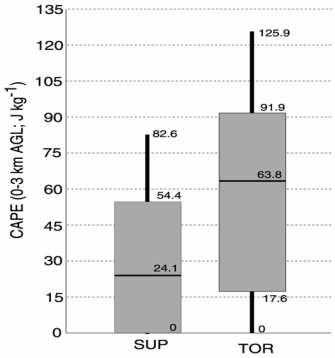
44. Buoyancy Effects

Instructor Notes: From Rasmussen and Blanchard (1998), and Rasmussen (2003) research have shown that low-level CAPE may have relevance to tornado production. More CAPE in the lowest levels above the ground suggests stronger potential for large low-level accelerations and enhanced low-level mesocyclone intensification. LCL height and MLCIN are likely better indicators for low level vortex stretching potential. Also, boundaries could provide pre-existing vertical vorticity even without strong low-level buoyancy.

Student Notes:

Buoyancy Effects

- Increases stretching
- Larger for significant tornadic supercells
- Lots of overlap



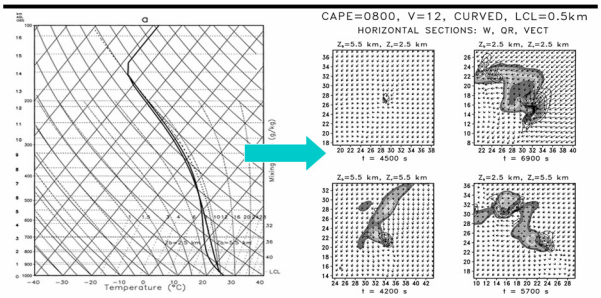
45. Buoyancy Effects

Instructor Notes: McCaul and Weisman's study (2001) showed that there are variations in buoyancy that need to be available in storms with given amounts of shear. They found that the effect of the buoyancy profile shape on convection is quite strong for small bulk CAPE, where the buoyancy profile is susceptible to specification in a wide variety of ways, but gradually weakens as CAPE assumes larger and larger values. Also, they found that increases in the low-level lapse rate tended to produce both stronger updraft

rotation and colder surface outflows, and more rapid storm cell propagation relative to the low-level ambient wind, at least for the cases where supercells were found. In this figure, they have maps of simulated updraft velocity w at z = 1.71 km (contoured at 2 m s−1 intervals), rainwater mixing ratio qr at z = 0.127 km (shaded starting at 0.5, 1.0, 2.0, 3.0, and 4.0 g kg−1 values), and horizontal storm-relative wind vectors (every other vector removed) at z = 0.127 km for a simulation with 800 j/kg of CAPE and a curved hodograph with 12 m/s of shear. Coordinates relative to the full simulation domain are marked at 2-km intervals along the sides of the plots. Vectors are scaled so that a length of 1 km on the plots corresponds to a wind speed of 12.5 m s−1. All plots are taken from the second hour of the simulated storms at selected times (see markings beneath each panel) deemed representative of mature storm structure.

Student Notes:

Buoyancy Effects



- When buoyancy and shear are concentrated in the lowest levels of the lower troposphere (e.g., tropical land falling systems), updrafts can be intense and long-lasting (from McCaul and Weisman, 2001).

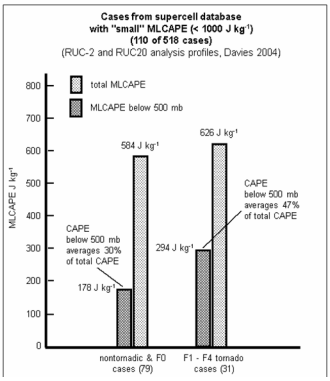
46. MLCAPE Distributions

Instructor Notes: This is from Jon Davies' study of 110 RUC-2 and RUC20 soundings.

Student Notes:

MLCAPE Distributions

- Tornadic storms in small CAPE settings with moderate to strong shear are associated with CAPE that is mostly below the midlevels of the atmosphere (Davies, 2004)

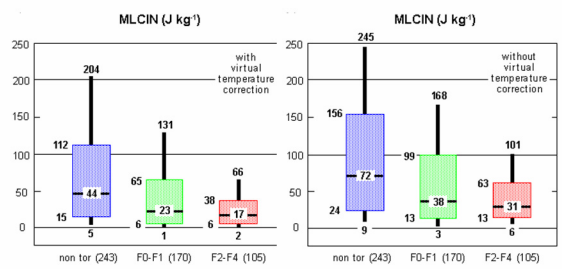


47. Role of Negative Buoyancy

Instructor Notes: In another recent study, Davies (2004) showed than stronger tornadoes (≥F2) tended to have more MLCAPE, less MLCIN, and lower MLLFC heights than weaker tornadoes and non-tornadic supercell storms. Tornadoes are considered less likely to occur with “elevated” supercells found in storm environments where the only instability is from parcels that originate well above the surface (Rasmussen and Blanchard 1998) and Grant (1995). Elevated convection as defined by Colman (1990) has no surface-based convective available potential energy (CAPE, Moncrief and Miller 1976). But many thunderstorm environments have significant surface-based CAPE present above a deep layer of convective inhibition (CIN, Colby 1984), signified by a large area of negative buoyancy below the positive CAPE area on a thermodynamic diagram. Therefore, a distinction can be made between thunderstorm settings that have no surface-based CAPE, with positive CAPE associated only with lifted parcels from well above the surface and thunderstorm settings that involve positive surface-based CAPE located above a large layer of surface-based CIN associated with a relatively high level of free convection (LFC). From a physical standpoint, an environment with large CIN and associated high LFC heights may inhibit low-level parcel ascent and stretching near the ground, reducing likelihood of tornadoes. It is also possible that tornadogenesis may in part be related to rapid upward acceleration and stretching within the layer containing largest helicity. If CAPE is not positive and large within the same layer where SRH is large (e.g., CAPE located above and vertically “disconnected” from a layer of large SRH), then tornado development may become less likely.

Student Notes:

Role of Negative Buoyancy



From Davies (2004)

48. Conceptual Models of Supercells

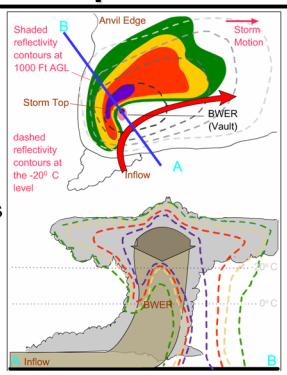
Instructor Notes: There will be more of this in IC3, but the main things to note conceptually are: tight low-level reflectivity gradients, the displacement of low level echo core, storm top slightly displaced on low level inflow side over the Bounded Weak Echo Region (BWER), pendent or hook echo on right, rear storm flank. Features are caused

by the interaction of the rotating updraft in a sheared environment. Not all radar features are present in supercells.

Student Notes:

Conceptual Models of Supercells

- Classic features identified from radar and visual observations

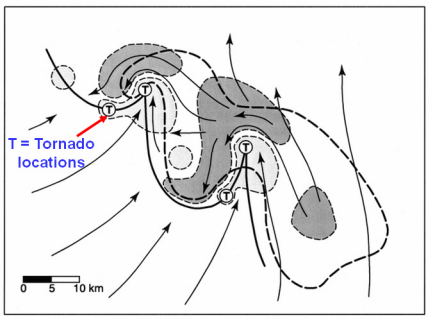


49. Supercell model hybrids

Instructor Notes: Conceptual model of the mature Newcastle–Graham storm complex in the lowest 1 km, as inferred from the Doppler analyses and derived from classical conceptual models described in the text (from Ziegler et al., 2001). Heavy solid curves are mesoscale cold fronts, heavy dashed contour denotes the precipitation shield, thin black arrows are airflow streamlines, and light and dark shading denote updraft and downdrafts areas, respectively. The circled “T” symbols indicate possible tornado locations. Supercell character, albeit rapidly evolving, was present prior to the Newcastle tornado. Mid-level mesocyclone developed through stretching. Subsequent low-level intensification through stretching; source of weak vertical vorticity not clear but parcels came from rainy area to the east. This data was from Newcastle, TX tornado from 29 May 1994.

Student Notes:

Supercell model hybrids



From Ziegler et al. (2001)

50. Cyclic Tornado Process

Instructor Notes: See the flash graphic on slide 52 that shows the cyclic process for tornadogenesis. Subsequent tornadogenesis in a cyclic storm is typically observed to be somewhat faster than from the initial storm, but often these tornadoes can last the longest and be the largest.

Student Notes:

Cyclic Tornado Process

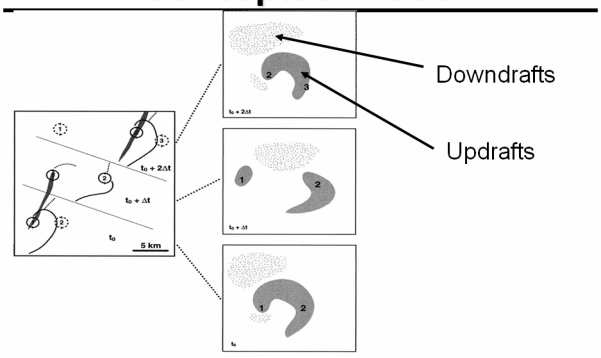
- Occurs after RFD with a mature supercell surges forward and enhances convergence along leading edge
- Locally enhanced convergence promotes updraft and increases tilting of horizontal vorticity
- New supercell forms on head of RFD surge while “old” storm continues to left of initial storm track

51. Cyclic Tornadogenesis Conceptual Model

Instructor Notes: From Dowell and Bluestein (2002). Circles and thick lines indicate vortices and wind shifts, respectively. Tornado tracks are shaded. (right) Shading indicates updraft, and the spotted pattern indicates downdraft. The time between successive tornadoes (2Δt) is 20 min.

Student Notes:

Cyclic Tornadogenesis Conceptual Model

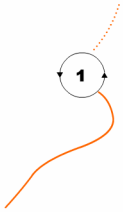


52. Slide 52

Instructor Notes:

Student Notes:

Adapted from Dowell and Bluestein (2004)



53. Summary

Instructor Notes:

Student Notes:

Summary

- Review the 8 objectives on identification of various aspects of supercell conceptual models.

54. References

Instructor Notes: Please see the reference page for AWOC Severe Track IC1 at http://wdtb.noaa.gov/courses/awoc/index.html

Student Notes:

References

- See the reference page

1. Conceptual Models for Origins and Evolutions of Convective Storms

Instructor Notes: The title for the instructional component is “Conceptual Models for Origins and Evolutions of Convective Storms. This is lesson 2 of the first instructional component (IC 1) in the AWOC Severe Track. Lesson 2 is on the conceptual models and important concepts regarding hail storms.

Student Notes:

Conceptual Models for Origins and Evolutions of Convective Storms

Advanced Warning Operations Course
IC Severe 1
Lesson 2: Hail Storms
Warning Decision Training Branch

2. Lesson 2 Learning Objectives

Instructor Notes: The first 4 learning objectives for this lesson on hail and hailstorms.

Student Notes:

Lesson 2 Learning Objectives

1. Determine the role of shear and midlevel rotation on updraft strength.
2. Determine the roles of buoyancy and steep lapse rates in hail growth zone.
3. Identify the effects of melting.
4. Identify favorable hail growth trajectories.

3. Lesson 2 Learning Objectives

Instructor Notes: Learning Objectives 5-7.

Student Notes:

Lesson 2 Learning Objectives

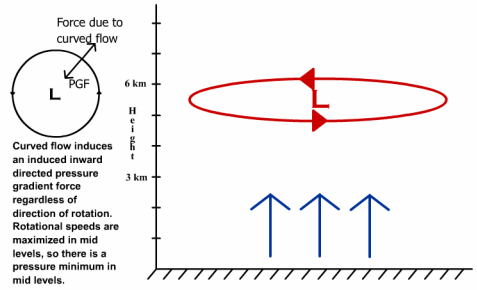
5. Identify favorable hail embryo source regions in convective storms.
6. Identify favorable soundings for surface based updraft hail and elevated updraft hail.
7. Identify characteristics of the hybrid Multicell-Supercell Hailstorm.

4. 1. Role of Shear and midlevel rotation on updraft strength

Instructor Notes: As seen in IC Severe 1 lesson 1 on supercells, wind shear produces horizontal vorticity that can tilted into the vertical within strong updrafts. Vertical vorticity is associated with mid-level rotation, and many times rotation is strongest in the mid-levels of a storm. Regardless of the direction of spin of the rotation, whether cyclonic or anti-cyclonic, there is going to be a centrifugal force associated with the rotation. The stronger the rotation, the stronger the centrifugal force. To keep the forces balanced, an opposing pressure gradient force must be present. Again, both cyclonic and anti-cyclonic rotations will have an inward directed pressure gradient force, in turn leading to a dynamically induced low pressure in the center of the circulation. Low pressure in mid-levels lead to an upward directed pressure gradient force below the circulation, and thus stronger vertical motion. It has been shown mathematically that the dynamically induced (via mid-level rotation) contribution towards total updraft velocity can be as large as the contribution due to buoyancy. With regards to hail, stronger updrafts have the ability to support larger hail stones, thus the presence of mid-level rotation can signal stronger updrafts within a storm, and thus a higher threat of severe hail with all other environmental factors being equal. Key Point: A storm exhibiting mid-level rotation is more likely to contain severe hail than one without rotation in identical environments and with all else being equal. This is because mid-level rotation can enhance updraft strength due to a dynamically induced vertical pressure gradient force.

Student Notes:

1. Role of Shear and midlevel rotation on updraft strength



5. 2. Buoyancy and steep lapse rates in hail growth zones

Instructor Notes: Steeper lapse rates aloft increases the overall instability of the atmosphere. Greater instability allows for more buoyant parcels of air if enough lift is present to overcome any cap that may be in place. Intuitively, more buoyant air (and thus lapse rates) within the –10 to –30 ^{o}C layer, corresponding to the maximum hail growth zone, would mean stronger updrafts in the growth zone. All other factors being equal, larger stones would have the ability be suspended longer in the prime growth zones, thus growing even larger. To date, no studies have been done to verify the usefulness of this concept…currently it is just a conceptual picture of an ingredient for simplified hail growth trajectories. Key Point: Steep lapse rates in the hail growth zone (–10 and –30 ^{o}C) leading to the potential for higher instability and thus strong updrafts are favorable to support large hail.

Student Notes:

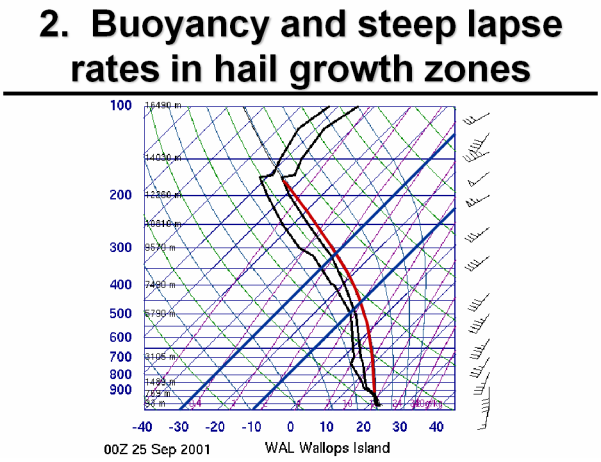
2. Buoyancy and steep lapse rates in hail growth zones

- Most studies have found that the most significant hail growth occurs in the -10 to -30°C layer
- Higher CAPE in the -10 to -30°C layer could mean larger hail
- Important to have steep lapse rates in the hail growth zone

6. 2. Buoyancy and steep lapse rates in hail growth zones

Instructor Notes: This is a sounding from Wallop's Island, VA. Thin CAPE profile from a tropical environment. Lapse rates in the -10 to -30 layer are weak. Surface based CAPE is over 1000 J/kg but stretched through a large depth. Consequently, even with great shear and CAPE, there was absolutely no hail to report on this day with weak lapse rates and CAPE in the hail growth zone.

Student Notes:

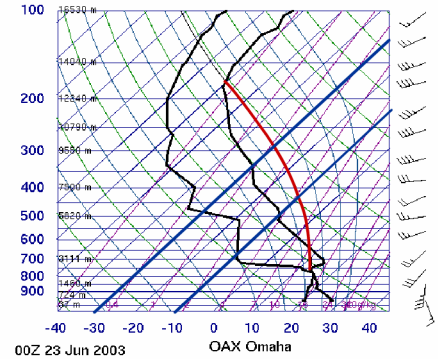


7. 2. Buoyancy and steep lapse rates in hail growth zones

Instructor Notes: This is a sounding from Omaha, NE. This CAPE profile is thick. There quite a bit of surface based CAPE, and much of it is in the -10 to -30C layer. The lapse rates, thus CAPE, are significant in the hail growth zone. Supercells containing baseball to american football sized hail pounded southern Nebraska. One storm produces the world record for hail diameter, over 7 inches.

Student Notes:

2. Buoyancy and steep lapse rates in hail growth zones



8. 3. Melting Affects

Instructor Notes: Melting affects hail most significantly affects smaller hail sizes as they fall through the 0oC level. All other factors being equal, small hail will melt proportionately more than large hail for 2 reasons: 1. larger hail has a higher terminal velocity and spends much less time in the melting layer before reaching the surface and 2. surface area is related to the radius of the hailstone, squared, while volume of rainwater loss is related to the cube of the radius. Thus, smaller hailstones will have a proportionately larger surface area exposed to melting conditions than larger stones, and thus proportionately melt faster than larger stones as well. Certain atmospheric conditions favor more rapid melting as well, with the amount of melting always dependent on the initial size of the hailstone. Conditions within the melting layer that favor melting are relative humidity (higher RH promotes greater melting and/or the presence of liquid drops falling with the hail), temperature profile (higher freezing level and warmer temps favor greater melting). Low relative humidity allows for a delay in the onset of melting by providing favorable conditions for the hailstone surface to remain dry. In melting layers with 50% or less relative humidity, melting has been found to proceed when the stone reaches air with +5 ^{o}C, obviously diminishing the amount of time the hail falls through the melting layer. Additionally, low RH hinders melting even if the stone is coated in water, since the layer of water is more likely to evaporate off the surface, cooling both the hail stone and the surrounding environment, further slowing the melting process. Having a warmer temperature profile intuitively results in more rapid melting, as heat transfer from the atmosphere to the hailstone is larger in a warmer environment. Another factor not mentioned above deals with hailstone ice density. Low density hail (common on the high plains), typically with graupel cores, melts much more effectively than high density hail. It is also strongly size dependent, but it is very important to note that low density hail is easily the most important factor when dealing with melting. The problem is that we currently have absolutely no way of knowing if low density hail exists in a storm, nor what proportion of the total hailfall consists of low-density stones. Finally, microphysical differences between the makeup of all the stones in a hailfall can also influence melting, although these differences have not been studied nor can they be measured at this time. Some of

these differences are shape of the hailstone, hailstone size spectrum within a particular hailfall, and direct influences of surface hailstone heat transfer, among others. Key Point: Smaller hail melts proportionately more than larger hail because of differences in surface area and terminal falls speeds. Thus, hail that is large in-cloud will remain large at the surface. Relative humidity, temperature profile, and hailstone density all play important roles in the amount of melting a stone undergoes falling through the melting layer.

Student Notes:

3. Melting Affects

- Large hail melts proportionately less than smaller hail in identical environments because:
  1. Large hail falls faster
  2. Surface Area vs. Volume

	Surface Area	Volume
1 inch hail	3.1 in^2	0.52 in^3
3 inch hail	28.3 in^2	14.1 in^3

→ 6-1 ratio for 1 inch hail, 2-1 ratio for 3 inch hail

9. 3. Melting Effects

Instructor Notes:

Student Notes:

3. Melting Effects

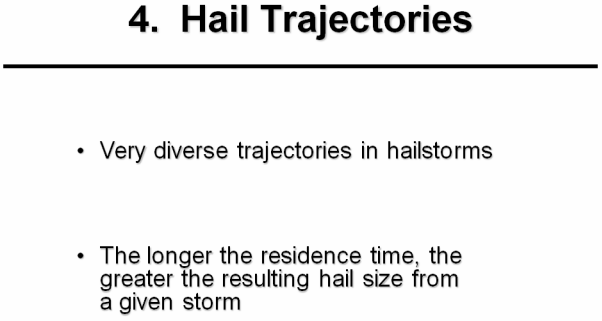
Manually advance the slide when you are finished viewing the hail melting flash graphic

10. 4. Hail Trajectories

Instructor Notes: Hail trajectories have been found to be extremely diverse within convective storms. The diversity of the trajectories becomes even more complicated when the size of the storm and the strength of the updraft/wind shear increases. A single trip up an updraft in a pulse storm can grow a hailstone up to about golfball size (Knight and

Knight 2001), and the updraft necessarily has to have an ideal vertical velocity profile such that the hail stone spends as much time as possible in the updraft. An updraft too weak won't allow a sizable stone to grow, and an updraft too strong will eject the hail embryo too quickly before significant growth can occur. Hail larger than about golfball in size can be produced with some form of recycling trajectories within a storm or complex of storms. Recycling can occur with multicelled convection where an older updraft produces hail that falls into or near the base of a newer updraft. Supercell convection allows for numerous recycling trajectories, but the bulk of the trajectory studies to date have found relatively simple paths through or around the main updraft, and nearly all of the growth occurs within a fairly narrow altitude and temperature range (-10 to -30oC). The largest hail tends to originate from embryos that find themselves on the southwest side of the large updraft. Upon entering the updraft these particles are then able to experience the longest growth time by traversing the full length of the updraft's long dimension (Foote 1984). The importance of any hailstone trajectory lies in the amount of time the hailstone resides in an updraft, and this time period is referred to as "residence time". As residence time increases, so does the possibility for growth of large hail within a convective updraft. Residence time is increased when: The hailstone's terminal velocity is nearly balanced by an updraft, the updraft width is substantial, and storm relative flow across and through the updraft isn't too strong. Key Point: A wide variety of trajectories exist that can produce large hail. The important concept is residence time within the updraft, the longer the residence time, the larger the hail. Wide updrafts and larger embryos lead to the largest hail sizes.

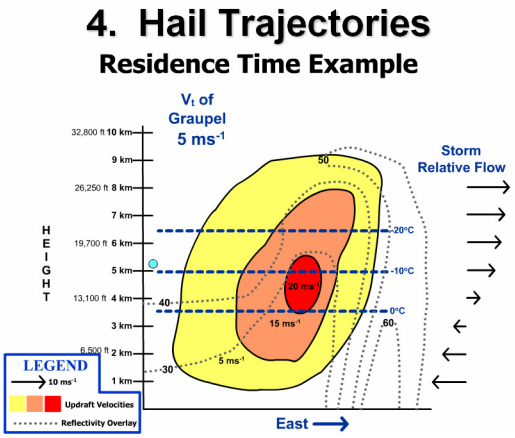
Student Notes:



11. 4. Hail Trajectories

Instructor Notes:

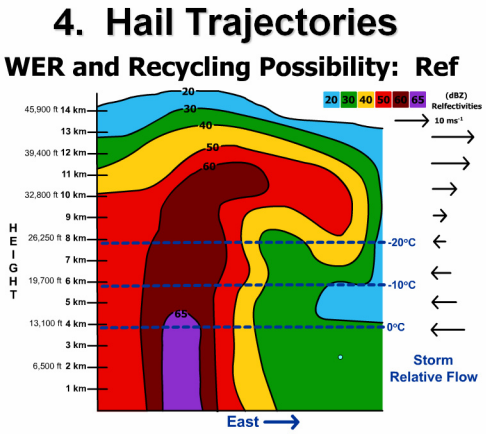
Student Notes:



12. 4. Hail Trajectories

Instructor Notes:

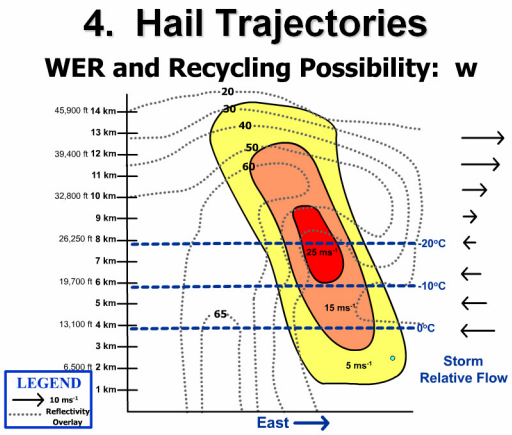
Student Notes:



13. 4. Hail Trajectories

Instructor Notes:

Student Notes:



14. 5. Favorable Embryo Source Regions

Instructor Notes: The main issue about hail embryo origins is how embryos arrive within the updraft (Knight and Knight 2001). There is no real distinction between an embryo and small hailstone, thus some of the principles involved in transport are covered in other objectives. A remarkable finding regarding hailstone embryos is that many analyses of hailstone collections from significant hailstorms from all over the world reveal mixtures of types of embryos. The importance of this is that either embryo delivery into strong updrafts straddles the freezing level or embryo sources are typically diverse: or both could be true. If embryos sources straddled the freezing level then frozen drops and graupel particles would equally be likely as embryos. Though embryo sources are very diverse, there are 3 important sources of hail embryos within convective storms. The first is within developing cumulus towers on the flanks of parent storms or within newer updrafts within multi-celled convection. The embryos grow within the developing updraft early in the lifecycle when updraft velocities are ideally not so strong that all liquid water is advected too quickly vertically before significant growth can occur. Of course this mechanism works in single celled “pulse storms”, where embryos grow in a developing updraft, then as they are advected vertically, they grow such that their Vt increases at about the same rate that the updraft velocities increase, thereby significantly increasing residence time in the updraft growth zone. These storms, given the right environmental conditions and ideal updraft velocities, can produce over 1.00 inch diameter hail from the initial embryo. The second favorable source of hail embryos is near stagnation points in the mid-levels of a convective storm with an intense updraft. The updraft is necessarily intense so that mid-level storm relative flow does not significantly penetrate the updraft nor significantly tilt the updraft. A stagnation point arises when the strong updraft is an obstacle to the mid-level flow, resulting in a dynamically induced high pressure on the upwind side of the updraft and a region of little to no horizontal flow where the mid-level flow splits and is diverted around the updraft. Realize that the updraft is porous, i.e. it isn’t a “rigid” obstacle to the low, it diverts a certain percentage of the mid-level flow, but some of the flow enters and mixes with the updraft. This region is important for embryo growth because it is on the edges of the main updraft in which the embryos can stay with the storm long enough to grow. A third favorable source of hail embryos is from drops

shed from growing or melting hail above or below the 0oC level. This source assumes hail is already present in the storm. Hailstones that are greater than 9 mm in diameter have been found to shed liquid drops during either melting or wet growth processes. These shed drops then can become hail embryos if they are lofted above freezing in an updraft. The majority of hailstones within a severe thunderstorm that contain frozen drop embryos are likely to be formed through this process. Key Point: Understand that where embryos come from is relatively unimportant, but what is important is where (and if) they are input into the updraft. Know three important areas for embryo growth: stagnation points in the mid-levels of an updraft, within growing cumulus towers on the flanks of the parent storm or within multi-celled convection, and from drop shedding. Additionally, all 3 sources may be working within a given convective storm at the same time.

Student Notes:

5. Favorable Embryo Source Regions

- 2 primary sources, 1 secondary source

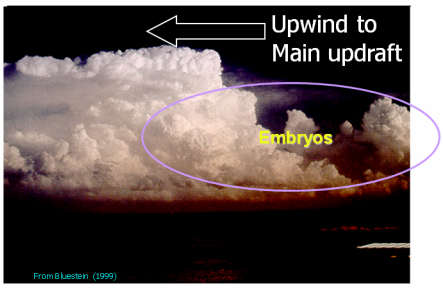
1. Nearby growing CBs, flanking lines
2. Stagnation points
3. Shed drops from growing/melting hail
   → secondary source since hail already in storm

15. 5. Favorable Embryo Source Regions

Instructor Notes: Source region #1: growing cumulus towers or flanking lines

Student Notes:

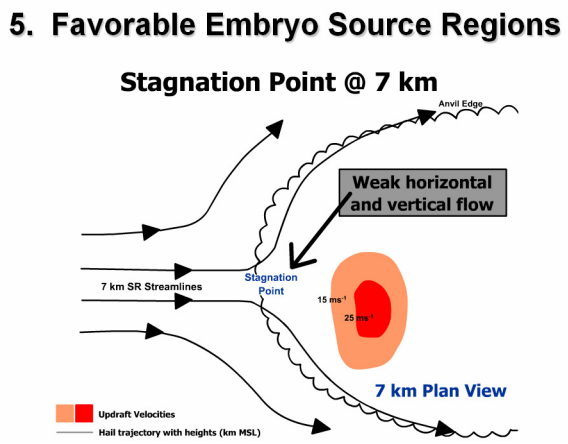
5. Favorable Embryo Source Regions



16. 5. Favorable Embryo Source Regions

Instructor Notes: Source region #2: stagnation points: very weak horizontal flow (and vertical flow), thus allowing depositional/collection growth for embryos, typically graupel

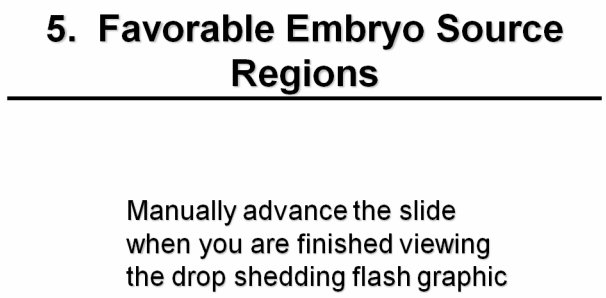
Student Notes:



17. 5. Favorable Embryo Source Regions

Instructor Notes: Source region #3: shed drops, which is a secondary source. This animation will demonstrate a hail in wet growth regime and how drops are shed from the ice core.

Student Notes:



18. 6. Hail Soundings

Instructor Notes: The link on this slide takes you to an optional website containing a wide variety of real soundings from hail cases. You can test your knowledge of favorable hail parameters based on one sounding to diagnose the threat of severe hail. In some cases, because of the unrepresentativeness of the sounding, this is difficult. The website

is a good exercise to show just how diverse environments are that may produce severe hail. Key Point: Look for strong CAPE of any kind (ML, SB, Elevated, MU, etc), good deep layer wind shear, lapse rates aloft. Much like for supercell and tornado environmental assessment, but without any low level shear and LCL/LFC considerations.

Student Notes:

6. Hail Soundings

- 20 soundings are available for optional review, from all across the country (AK, HI included) with all types of shear/CAPE profiles:

Hail Soundings

19. The "Hail Monster"

Instructor Notes: Hybrid multicell/supercell hailstorms produce not only unusually large hail in high quantities, but the hailswaths containing the large hail cover an extraordinarily large region, leading to destruction over a large area. These storms are characterized with intense gust fronts on their rear flank, and very deep zones of convergence along the leading edge of the rear and forward flank gust fronts. These storms tend to move fast, to the right of the mean wind, and persist for several hours. They are typically non-tornadic or very weakly tornadic, both in strength and amount of time. The huge region of deep, moist convergence along the rear flank allows for a very wide region of updraft, not necessarily one single updraft, but likely many updrafts which collectively form a wide region of rising motion. Very broad updrafts have already been discussed in this lesson as allowing a high amount of residence time for hail to grow. The deep and broad convergence zone accounts for the sheer size of the hail cores. Hybrid hailstorms typically have very high Z all along south, west, and north sides of the mesocyclone.

Student Notes:

7. The "Hail Monster"

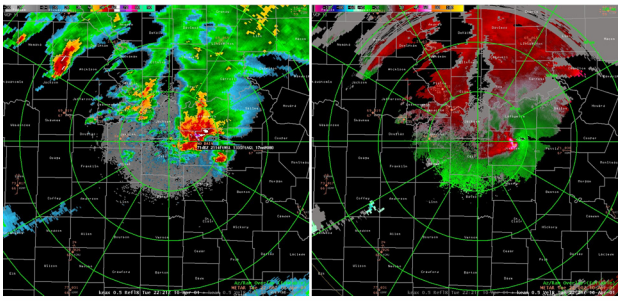
- Nelson (1987) studied hybrid multicell-supercell storms that dropped not only enormous hail, but the enormous hail covered a large area and persisted for several hours
- Characterized by a Deep Convergence Zone (Lemon & Parker 1996), huge reflectivity cores along the southern flank and forward flank, few if any tornadoes, tremendous straight line winds

20. The "Hail Monster"

Instructor Notes: April 10, 2001 Supercell that tracked all the way across Missouri, turned out to be the costliest hailstorm in US history. Notice the tremendous size of the reflectivity cores on NW of the inflow notch and to the south, typical of these hybrid multi-supercellular hailstorms. True to form, this storm produced only a few very weak, brief tornadoes, but golfball to baseball size hail across entire counties occurred, with very high amounts of this large hail.

Student Notes:

7. The "Hail Monster"



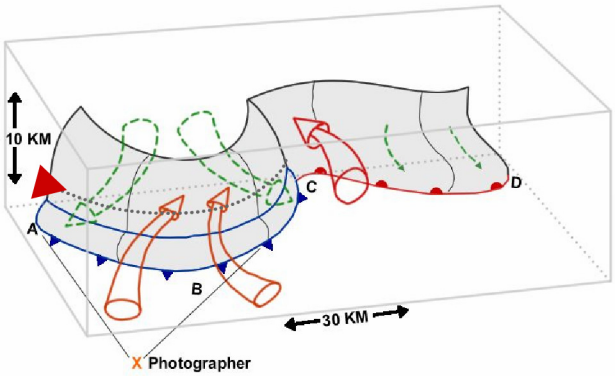
21. The "Hail Monster"

Instructor Notes: The X marks the approximate location of the photographer in the following image. This image is adapted and updated from an original image first published in Lemon and Parker (1996). The supercell updraft is located from B to C with a BWER, and the storm summit is in the vicinity of B. Arrows indicate storm relative flow; dashed arrows indicate, in perspective, flow behind the DCZ surface. Storm motion is directly at you. The most intense and deep portions of the DCZ are found nearly coincident with the strong reflectivity gradients bordering the WER and BWER. In terms of hail growth, the

DCZ has been found to shield the updraft from the destructive entrainment of environmental air. In the Lahoma Storm in August 1991, the DCZ passage signaled the greatest wind threat and within 2-5 minutes, the greatest hail threat.

Student Notes:

7. The “Hail Monster”



22. The “Hail Monster”

Instructor Notes: This is a picture of an approaching DCZ, from the Cashion, Oklahoma storm June 18, 1992.

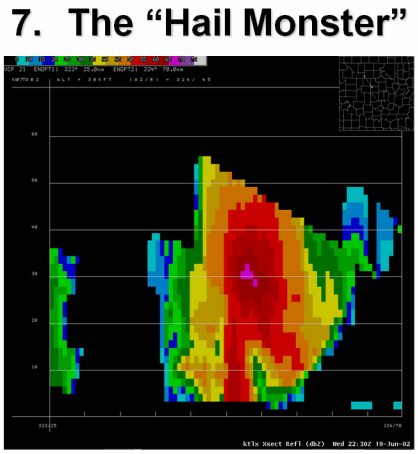
Student Notes:

7. The “Hail Monster”

23. The “Hail Monster”

Instructor Notes:

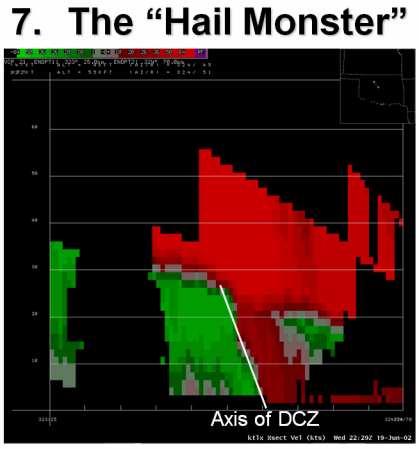
Student Notes:



24. The “Hail Monster”

Instructor Notes:

Student Notes:



25. Hail Ingredients Summary

Instructor Notes: Summary of ingredients for large hail and large amounts of hail

Student Notes:

Hail Ingredients Summary

Large Hail:

Microphysics	Kinematics
High supercooled LWC	Light SR flow through updraft
Wet growth in mixed phase region	Large contiguous updraft, 20-40 m/s
Low density growth	Optimal trajectories
Large embryos	Favorable horizontal updraft gradients

Large *Amounts* of Hail:

Microphysics	Kinematics
High embryo concentration	Large contiguous updraft, 20-40 m/s
Ample supercooled LWC	Flow that injects embryos across a broad updraft front

26. Lesson 2 Summary

Instructor Notes:

Student Notes:

Lesson 2 Summary

- Review the 7 objectives on aspects of hail and hailstorms

27. Lesson 2 References

Instructor Notes: Link to PDF document with all the references for IC Severe 1, Lesson 3 on hailstorms: http://www.wdtb.noaa.gov/courses/awoc/ICSvr1/lesson2refs.pdf

Student Notes:

Lesson 2 References

- Our website has a full list available:

CLICK HERE FOR HAIL REFERENCES

1. Conceptual Models for Origins and Evolutions of Convective Storms

Instructor Notes: The title for the instructional component is “Conceptual Models for Origins and Evolutions of Convective Storms. This is lesson 3 of the first instructional component in the AWOC Severe Track. Lesson 3 will be on conceptual models for flash flooding, both meteorological and hydrological factors.

Student Notes:

Conceptual Models for Origins and Evolutions of Convective Storms

Advanced Warning Operations Course
IC Severe 1
Lesson 3: Flash Flooding
Warning Decision Training Branch

2. Lesson 3 Learning Objectives

Instructor Notes: Learning Objectives 1-3 for Lesson 3 on Flash Flooding. 6 total learning objectives.

Student Notes:

Lesson 3 Learning Objectives

1. Identify meteorological conceptual models concerning heavy rainfall
2. Identify hydrological ingredients favorable for flash flooding
3. Identify the possible watershed responses to excessive rainfall and problems with flash flood guidance

3. Lesson 3 Learning Objectives

Instructor Notes: 4-6

Student Notes:

Lesson 3 Learning Objectives

4. Identify the primary parameters that help determine precipitation efficiency
5. Identify characteristics of the flash flood potential in supercells
6. Identify the effects of advection and propagation and their significance to flash flooding

4. 1. Meteorological Conceptual Models

Instructor Notes: Maddox FF events is a review and will not be covered in AWOC. The point is that each type deals with a low-level boundary of some type, increased moisture/ instability, and relative movements of convective elements whether they are training or nearly stationary Junker et al. studies MCSs from the midwest during the great flood of'93. He found differences in MCSs that produced extreme rainfall and those that were "ordinary", and those differences will be discussed next.

Student Notes:

1. Meteorological Conceptual Models

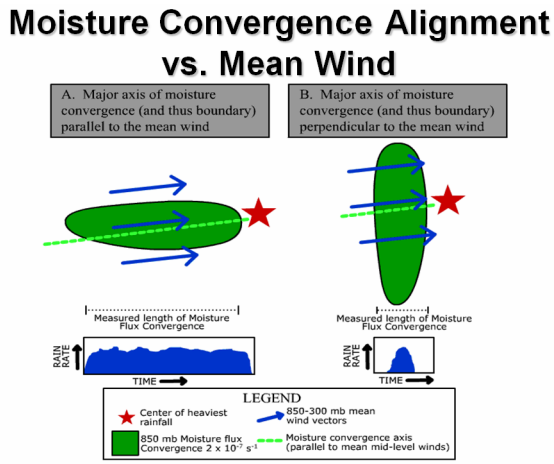
- Maddox (1979): 4 flash flood types from a meteorological standpoint
- More recent work (Junker et al. 1999) has focused on moisture fields and the location of surface boundaries

5. Moisture Convergence Alignment vs. Mean Wind

Instructor Notes: Obviously case A led to extreme rainfall events in the Junker (1999) study, while case B led to must less extreme rainfall A larger scale of forcing and a longer

duration of intense rainfall are possible when a long axis of moisture flux convergence coincides with the mean wind.

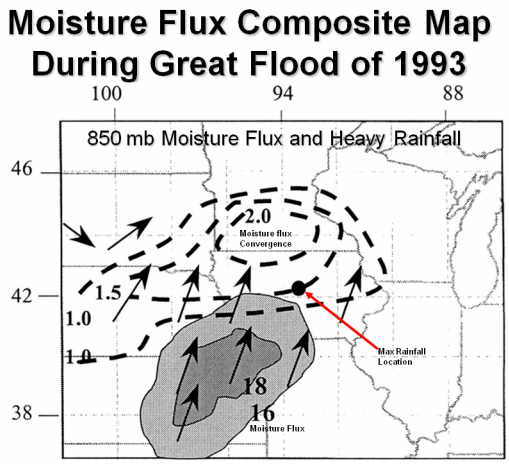
Student Notes:



6. Moisture Flux Composite Map During Great Flood of 1993

Instructor Notes: From Junker et al. (1999), in a study of Midwest MCS's during Flood of 1993. This is a composite map of 850 mb moisture flux and moisture flux convergence and it's relation to location of maximum rainfall This favors upstream cell development, where forcing and instability remain strong, then track downstream with the mean flow. The low-level boundary focuses new cell development This is a good setup for backward propagating MCSs

Student Notes:

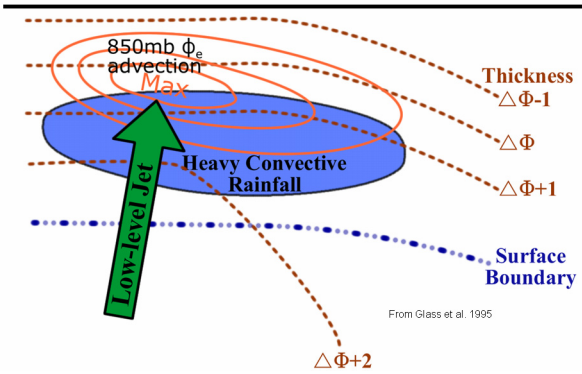


7. Boundary Configuration for Heavy Rainfall

Instructor Notes: From Glass et al. 1995 This is the proposed conceptual model of heavy convective rainfall north of an E-W oriented boundary. In the blue region of heavy convective rainfall, cell repeatedly develop and organize into small cores of heavy rainfall convection, then move downstream with the 850-300 mb cloud layer shear

Student Notes:

Boundary Configuration for Heavy Rainfall



8. 1. Meteorological Conceptual Models: Ingredients Review

Instructor Notes:

Student Notes:

1. Meteorological Conceptual Models: Ingredients Review

1. DMC (especially at night)
2. High moisture content (relative to normals) through a deep layer
3. Weak to moderate mid-level shear
4. Winds veer considerably with height (LLJ vs mid-level flow)
5. Large-scale forcing weak or negligible

9. 1. Meteorological Conceptual Models: Review cont'd

Instructor Notes:

Student Notes:

1. Meteorological Conceptual Models: Review cont'd

6. LLJ moisture supply and focus for the convection: determines rainfall scale
7. Winds aloft parallel to low-level stationary boundary
8. Cells "training"
9. Upstream mesoscale wave moving into a long wave ridge

10. 2. Hydrologic Ingredients

Instructor Notes: These conditions should be known as best as possible before any heavy rainfall begins. Hydrologic ingredients are every bit as important to flash flooding as meteorological ingredients. We'll examine each one briefly.

Student Notes:

2. Hydrologic Ingredients

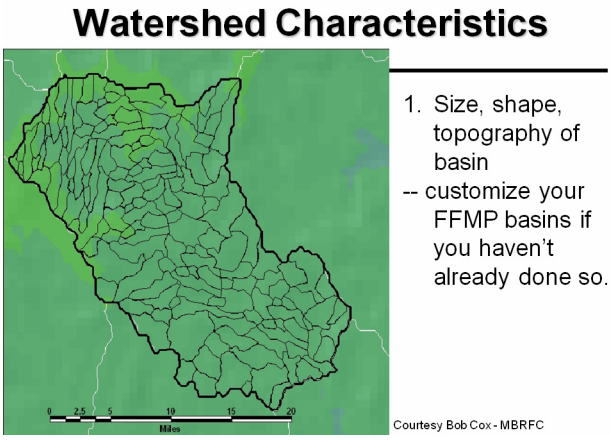
- Given an amount of rainfall and duration, 5 Flash Flood Threat Factors:

1. Size, shape, topography of basin
2. Size, shape, condition of stream channel
3. Infiltration capacity and saturation of soil
4. Vegetation and Land Use
5. Season

11. Watershed Characteristics

Instructor Notes: The majority of flash floods occur in very small basins, mainly because the scale of the heaviest rainfall is also quite small.

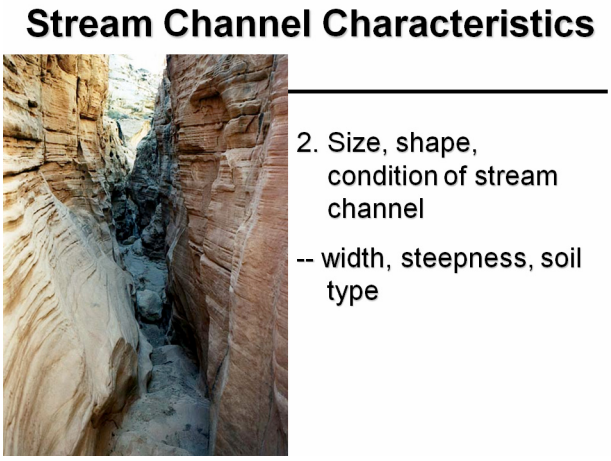
Student Notes:



12. Stream Channel Characteristics

Instructor Notes: Steep terrain, soil type (such as rock), and narrow channels are all conducive to flash floods, meaning far less rainfall can produce significant flash flooding in basins with such characteristics. The above is from Crack Canyon in Southeast Utah: probably a worst case scenario for stream channel condition and propensity for flash flooding

Student Notes:



13. Soil Type and Condition

Instructor Notes: Soils that are heavily clay have a low infiltration capacity and thus more prone to runoff. Rocky soils likewise are prone to high levels of runoff. By the same token, soils that are saturated from previous rainfall are prone to high levels of runoff.

Student Notes:

Soil Type and Condition

3. Infiltration capacity and saturation of the soil

- Doswell et al. (1996) present a case of 180 mm (7 inches) rainfall in less than a day in Iowa Sep 1989, with only minor flooding
  - → Tail end of 2-year drought, soil could handle precipitation
  - → Soil type (infiltration) and saturation (soil moisture) differences can make the difference in any event

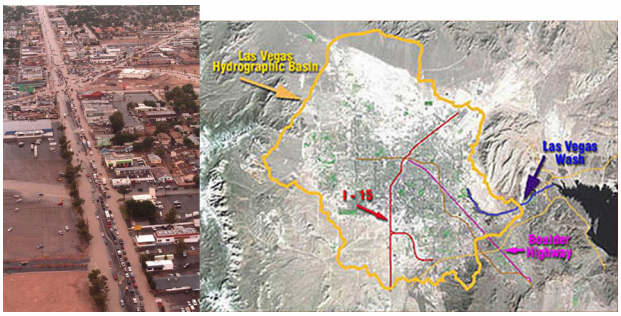
14. Vegetation and Land Use

Instructor Notes: Vegetation intercepts rainfall, inhibits surface runoff, allowing more time for infiltration Las Vegas is one of the worst cities for flash flooding because the soil surrounding the city has very poor infiltration with next to no vegetation: thus nearly all rainfall is converted to runoff. Add to the fact that all the natural washes within the city are now paved over with city streets and the problem is exacerbated. Cities in general are very flash flood prone with all the concrete and poorly constructed drainage systems

Student Notes:

Vegetation and Land Use

4. Vegetation and Land Use



15. Season

Instructor Notes: Dormant vegetation leads to less rainfall interception, less evapo-transpiration (soil moisture high to begin with)

Student Notes:

Season

5. Season

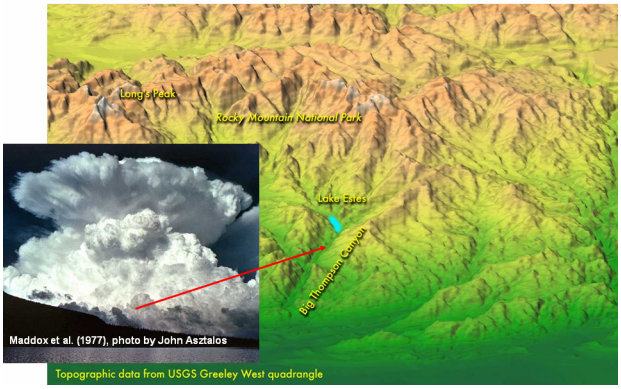
- Mainly impacts surface runoff potential
  - → Vegetation growth stage
  - → Lower temperatures, higher viscosity and lower infiltration
  - → Frozen ground worst case

16. 3. Watershed Response

Instructor Notes: We've discussed the meteorological and hydrological ingredients for flash flooding. Now let's look at what happens when heavy rainfall occurs across a watershed. What is the response of the watershed to the rainfall and how can we measure this response? The above is the Big Thompson Storm and topo map

Student Notes:

3. Watershed Response

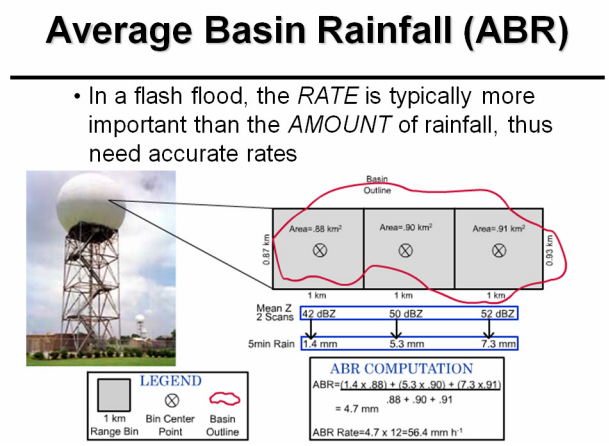


17. Average Basin Rainfall (ABR)

Instructor Notes: 4 inches of rain in 4 hours is much different than 4 inches in one hour for a basin The gray area is with very high rate AND small amount, meaning a very quick burst of heavy rainfall. That's tougher to gage FF threat. Size of watershed and extent of heaviest rainfall important How ABR is computed: Reflectivity (Z) of each radar 1 km polar bin is converted to a 5 minute rainfall amount, then multiplied by the area of each bin to get a rainwater volume per bin Only the rainfall volumes of each bin that have a center point falling within the watershed are summed Summed rainfall volumes are divided by the total area of all used radar bins in the watershed to determine ABR: a total

precip for 5 minutes across the basin ABR rate is calculated by multiplying the calculated 5 minute ABR by 12 (hourly rate)

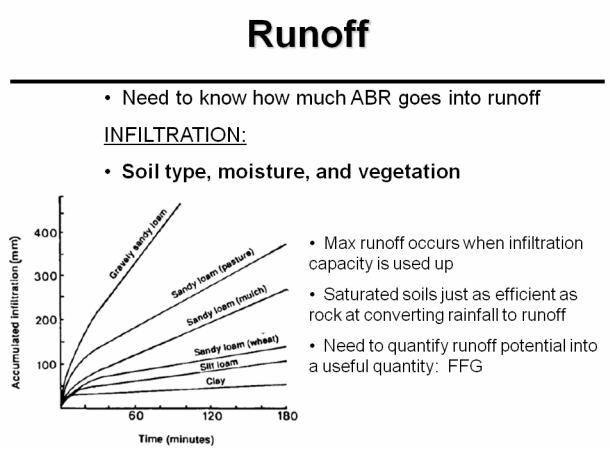
Student Notes:



18. Runoff

Instructor Notes: A small portion of ABR may be lost due to evaporation, transpiration, and depression storage, but compared to the ABR rate related to flash flood producing rainfall, these losses are minimal

Student Notes:



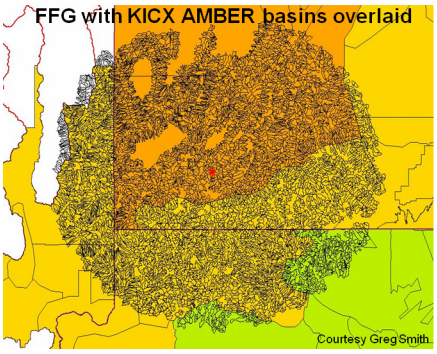
19. Flash Flood Guidance

Instructor Notes: FFG updated twice a day in most other areas Terrain, soil and other basin characteristics vary widely within many counties across America, especially the Western U.S. No consistency on how to compute FFG from RFC to RFC It is painfully obvious that actual FFG for each basin varies widely within each CWA zone Many flash floods quicker than 1 hour as well, i.e. some flash floods can occur in 15 minutes of heavy rainfall What constitutes a significant flash flood? ? Slot canyons can cause serious problems with just 30-50 cfs flow during a flash flood: different thresholds to floods

and FFG doesn't address this. Tying thresholds to "bankful" not always a meaningful statistic FFG works best during an extended period of dry weather, worst with multiple rainfall events during previous 24-48 hours

Student Notes:

Flash Flood Guidance



- FFG updated once a day by CWA zones for Colorado River basin RFC
- Diversity of basins in each zone

20. Topography and Rainfall Intensity

Instructor Notes: Topography and rainfall intensity seem to be most important to gauge the watershed response to rainfall.

Student Notes:

Topography and Rainfall Intensity

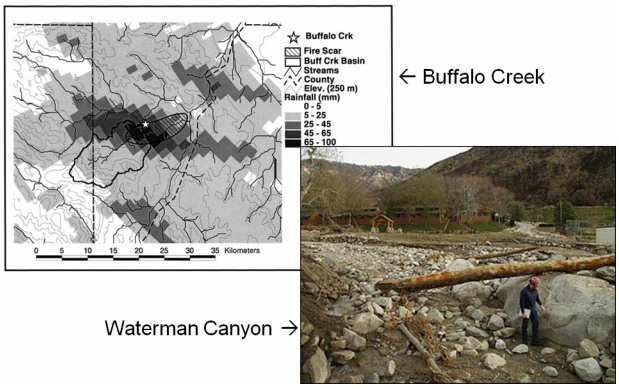
- Topography: The steeper the slope, the quicker surface runoff reaches the stream, with rapid stream response, and a higher crest
- Intensity: gentle slopes can still see significant flash flooding if rainfall intensity is exceptional

21. Burn Scars

Instructor Notes: All rainfall converted to runoff in burn areas, and the problem is especially severe in steeper terrain Buffalo Creek: 2 injuries but substantial structural/road damage in the area Fei et al. 2001 also showed though numerical simulation that the burn area was actually preferred location for convection due to enhanced insolation Lytle Creek killed 15 after 2 days of moderate/heavy rains over a recent burn area led to tremendous flash flooding

Student Notes:

Burn Scars

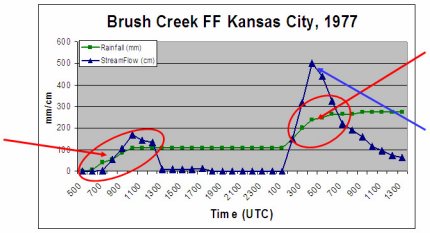


22. Antecedent Precipitation

Instructor Notes: 2 distinct periods of intense rainfall separated by 12 hours, claimed 25 lives in Kansas City. First rainfall saturated the soil, while the second rainfall went entirely into runoff, producing disastrous flash flooding. Much more will be discussed about the importance of antecedent precipitation and how FFG may not be representative in IC Severe 3 in the lesson on Flash Flood Guidance Modification by Bob Davis of the PBZ office.

Student Notes:

Antecedent Precipitation



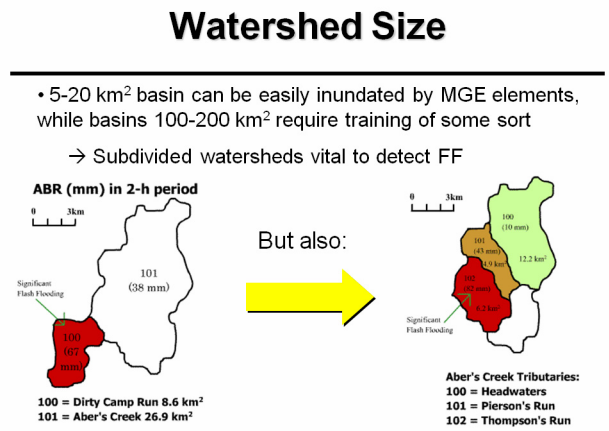
Moral: Soil moisture/saturation strongly influences surface runoff. Antecedent precipitation important to account for, and many times FFG doesn't capture it

23. Watershed Size

Instructor Notes: These basins are 38-44 km from KPBZ, and color equates to flash flood threat, with red meaning significant. MGE=mesoscale gamma elements, pretty much individual heavy rain cores make up this scale of phenomena Evening of July 1, 1997 The image on the left clearly shows the threat in Dirty Camp run, which did in fact verify after greater than 2 inches fell in 2 hours. Aber's Creek in the left doesn't appear to have much of a threat since just 1.25 inches fell in 2 hours…until you subdivide it further

into smaller tributaries it is clear Thompson's run is at high risk, and indeed significant flash flooding occurred in that small basin

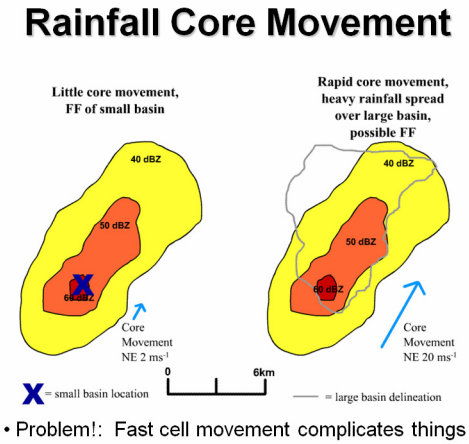
Student Notes:



24. Rainfall Core Movement

Instructor Notes: On the left, with little core movement, typically ONLY small basins are under a flash flood threat since the footprint of the heaviest rainfall occurs in a very small areas. However, on the right, with very fast storm movement, the rainfall footprint is spread out, such that a basin of any size could be in danger of flash flooding depending on several factors. Fast cell movement is problematic: not obvious where flash flooding will occur if at all, and fast movement means strongly sheared environment and thus a forecaster may be more concerned with other forms of severe weather With training, fast individual cell movement can lead to flash flooding with repeated development over the same areas

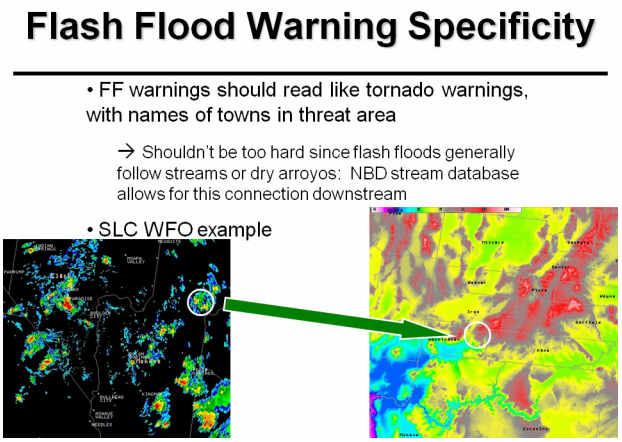
Student Notes:



25. Flash Flood Warning Specificity

Instructor Notes: Zion National Park. No rainfall in the Narrows Section, just upstream. Issued a flash flood warning for the Narrows that saved 40 lives. SLC WFO used topo image and radar to determine where the heaviest rain was falling If storms move slowly along the downstream direction of the stream, flash flooding can be enhanced FFMP in OB6 will have basin trace capabilities such that you can decipher where downstream basins may be affected

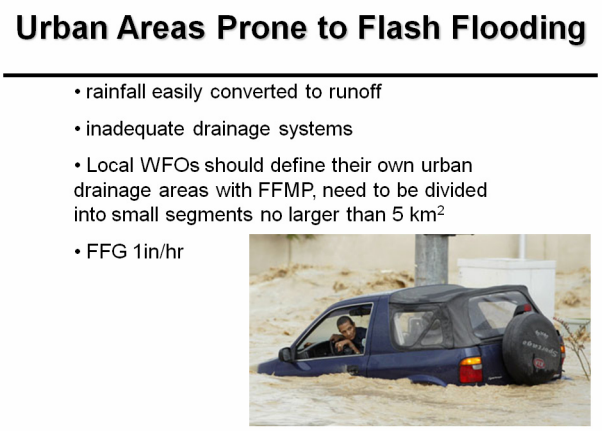
Student Notes:



26. Urban Areas Prone to Flash Flooding

Instructor Notes: PBZ has found that setting FFG at 1in/hr for all urban areas has worked well and is consistent with past events. Other WFOs should examine their areas for past events to see how much rainfall in a hour is required to initiation urban flooding. Forced FFG GUI is how you can permanently change flash flood guidance for urban drainages.

Student Notes:



27. 4. Precipitation Efficiency

Instructor Notes: Entrainment significant when: RH decreases anywhere, but especially below cloud base. Also with very strong wind shear entrainment will be enhanced as updrafts are more tilted Entrainment of dry air reduces PE because it introduces unsaturated air into the convection, which in turn promotes evaporation Very strong updrafts eject condensate out of the top before they can grow into precipitation size, leading to decreased PE. You'd really like to see "thin CAPE" profiles Key Point: A deep warm cloud layer, high RH all levels but especially below LCL, low vertical wind shear, all increase precipitation efficiency. Narrow and/or very strong updrafts decrease precipitation efficiency. Highly efficient rain production is achieved through warm rain processes. It should be kept in mind that with supercellular convection and convection west of the Rockies precipitation efficiency is not important to flash flooding.

Student Notes:

4. Precipitation Efficiency

Decreases:
- → updraft strengthens, narrows
- → excessive evaporation
- → strong wind shear

Increases:
- → high RH everywhere, especially below LCL
- → "Warm rain" processes

• Neither PE nor entrainment can be observed operationally, only *inferred*

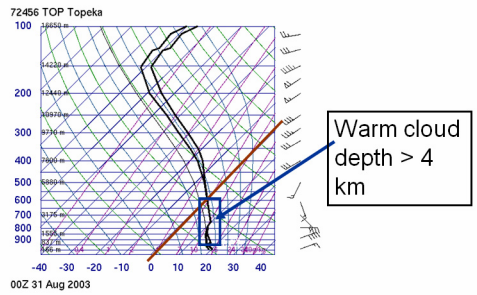
28. Sounding with High PE Potential

Instructor Notes: To maximize the effectiveness of warm rain processes, a deep "warm cloud" layer should be present. You can see these layers on soundings as the vertical distance between the LCL and where the moist adiabat from the LCL intersects the 0oC isotherm. Depths greater than 3 km are considered to be "deep" warm cloud layers, but in tropical environments exceptionally deep layers should be 4 km or greater. Residence time in the updraft above freezing is maximized with weak to moderate updrafts within a warm cloud depth, allowing for larger drops and thus more collision/coalescence. Also evident on this sounding is high RH at all levels, relatively weak vertical wind shear (although directional shear excellent)

Student Notes:

Sounding with High PE Potential

- deep warm cloud layer, RH, CAPE, shear



29. 5. Supercell Flash Flooding

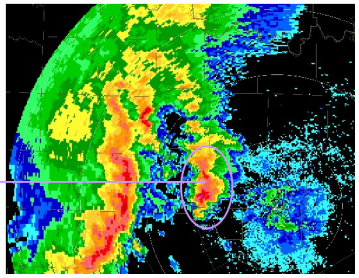
Instructor Notes: There are advantages and disadvantages to flash flood potential in supercells. Loaded gun sounding, isolated nature and very strong updrafts all are detrimental to flash flooding threat. However, very moist low level inflow and possibly speed of movement are both contributing factors to flash flooding. The single most important consideration for supercells is their movement. They are capable of producing tremendous rainfall rates, a key to flash flooding, but if they are not moving slowly, flash flooding becomes less likely. HP supercells are important to the flash flood threat, more so than classic and certainly more than LP types. HPs tend to be larger and move slower than other supercell types. Training supercells can also pose a high flash flooding threat. Though supercells are traditionally associated with low precipitation efficiency, this can be balanced, especially in HPs, by tremendous moisture inflow into the storm, as is shown in the following slides. Key Point: Flash floods can occur with supercells, especially if HP in nature and if slow moving and/or training.

Student Notes:

5. Supercell Flash Flooding

- Significant low-level moisture inflow (+)
- "Loaded Gun Sounding" (-)
- Strong updrafts (-)
- Isolated (-)
- Movement Speed (+/-)

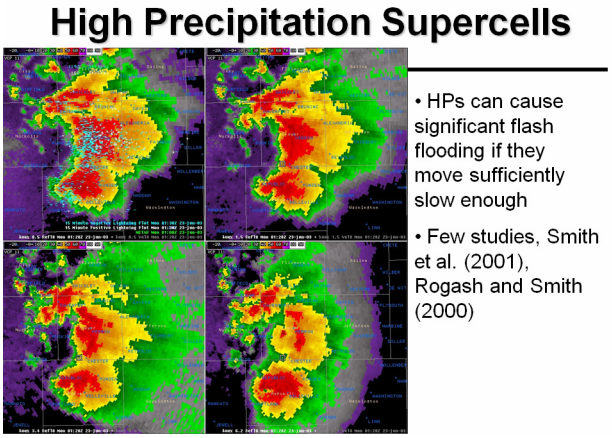
→ HP's



30. High Precipitation Supercells

Instructor Notes: Smith et al. (2001) study: There is currently no forecast methodology for HP's, and very little are known about them. We know that they move slower and are more efficient precipitation producers HP's have unusually large precipitation cores, which are exceptionally intense Contain some of the highest/richest moisture inflow of any known convective element

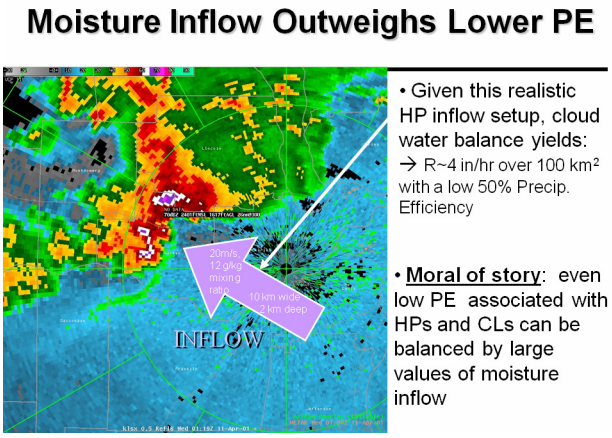
Student Notes:



31. Moisture Inflow Outweighs Lower PE

Instructor Notes: This is the key to supercell flash flooding: understanding why supercells are such a threat despite poor precipitation efficiencies and at times swift movement. This is because of their tremendous moisture inflow, PE is essentially meaningless. These are actual calculations from May 5, 1995 HP over DFW from Smith et al. (2001), although the above image is from an HP that hammered the STL metro in April 2001, with hail and flash flooding LP supercells cannot produce flash flooding

Student Notes:



32. 6. Cell "Movement"

Instructor Notes: Flash flooding can occur when these two effects cancel each other out leading to very little net movement of heavy rain cores. The previous lesson (lesson 4) dealt with the modified Corfidi (2003) technique. Backbuilding or backward propagating convection (where advection and propagation cancel each other) are most important to flash flooding. Techniques on how to determine which process will be prevalent or if they cancel each other out will be discussed in Severe IC 2: Mesoanalysis

Student Notes:

6. Cell "Movement"

- Movement takes into account effects of:

1. Advection
   → cells travel with mean wind in cloud layer, easy to measure
2. Propagation
   → cell movement from the development and dissipation of individual cells, very hard to determine but usually related to moisture flux and instability axes

33. IC SVR1-Lesson 3: Summary

Instructor Notes:

Student Notes:

IC SVR1-Lesson 3: Summary

- Review the 6 objectives on Flash Flooding on slides 2 and 3

34. Lesson 3 References

Instructor Notes: Link to PDF document with all the references for IC Severe 1, Lesson 3 on flash flooding: http://www.wdtb.noaa.gov/courses/awoc/ICSvr1/lesson5refs.pdf

Student Notes:

Lesson 3 References

- Our website has a full list available:

CLICK HERE FOR FLASH FLOOD REFERENCES

1. Threat Assessment

Instructor Notes: The title for this Instructional Component (IC) is “Threat Assessment.” This is the 2nd instructional component for the AWOC Severe Track. Lesson 1 in this IC is on outlook and short-term assessment of hazards.

Student Notes:

Threat Assessment

Advanced Warning Operations Course
IC Severe 2
Lesson 1
Outlook and Short-Term Assessment
Warning Decision Training Branch

2. AWOC Severe Track Training Components

Instructor Notes: This IC (one of 4 in Severe Track) is devoted to environmental threat assessment. There are 3 lessons in this IC. The IC will address the process for evaluating the threat for severe weather hazards (hail, high winds, flash flooding, and tornadoes). Background for this training is from PCUs 3 and 4 in the Severe Convection Forecasting and Warning PDS. See http://www.nwstc.noaa.gov/nwstrn/d.ntp/meteor/svrpds.html.

Student Notes:

AWOC Severe Track Training Components

IC 1 – Conceptual Models
IC 2 – Threat Assessment
IC 3 – Storm Interrogation Strategies
IC 4 – Application and Review

3. IC2 Performance Objective

Instructor Notes: The performance objective (the desired trainee behavior from training) for this IC is to demonstrate the ability to monitor the mesoscale environment to anticipate and identify storm types, storm evolutions, and hazardous severe weather threats to support severe weather warning methodologies. This would include some of the following: Demonstrating ability to coordinate with SPC and adjacent WFOs on watch decisions (for ex. watch extensions and cancellations) Demonstrate the ability to utilize full suite of products to issue short-term forecasts of convection. Demonstrate ability to monitor mesoscale conditions (including near-storm environment) and provide input to warning decisions based on that data.

Student Notes:

IC2 Performance Objective

- Demonstrate processes for continuous evaluation of hazardous weather threats (tornadoes, damaging winds, hail, and flash floods) to support effective warning methodologies.

4. IC2 Outline

Instructor Notes: These are 3 lessons in this IC. Lesson 1 is on outlook and short-term assessment, Lesson 2 on lifting mechanisms, and Lesson 3 on threat assessment of Quasi-Linear Convective Systems (QLCS).

Student Notes:

IC2 Outline

Lesson 1: Outlook and Short-term Assessment

Lesson 2: Lifting Mechanisms

Lesson 3: Threat Assessment of QLCS

5. Lesson 1 Learning Objectives

Instructor Notes: These are the learning objectives for lesson 1. The test will cover all objectives from all three lessons in the IC.

Student Notes:

Lesson 1 Learning Objectives

1. Identify purposes of threat assessment
2. Identify key job tasks for threat assessment for 0 to 24 hour time period
3. Identify 3 key job tasks for threat assessment in the 0 to 6 hour time period

6. Purpose for Threat Assessment

Instructor Notes: Threat assessment (TA) is an important part of an effective warning methodology. It is important in determining the tone of awareness for the subsequent event. This step enables the severe weather warning team to begin to focus on specific threat areas and specific storms within the CWA (how to initially sectorize the CWA for severe weather operations). By assessing the spatial and temporal evolution of the mesoscale convective environment, forecasters can improve their decision making skills because they can acquire an increasing knowledge of the perceived level of threat for each storm. Threat assessment is a continuous process, not a one-time action. Thus, many of the key job task skills presented here are applicable throughout the entire severe weather event, especially during warning mode, because forecasters often lose their situational awareness of the environment once warnings commence. The assessment of potential hazards influences what radar products you might look at and how you will look at them, which is related to interrogation strategies (one of the steps in a warning methodology). One way to think about this is that there is a range of possibilities for all severe weather. After the synoptic and mesoscale assessment, you have narrowed down your expectations. When storms develop and you detect them on radar, you then compare that data to the mental images that have been processed in your brain. Even though the initial expectations provide an important working framework for subsequent warning sequences, individual and collective expectations must be re-evaluated during the event. This is another vital part of warning methodologies.

Student Notes:

Purpose for Threat Assessment

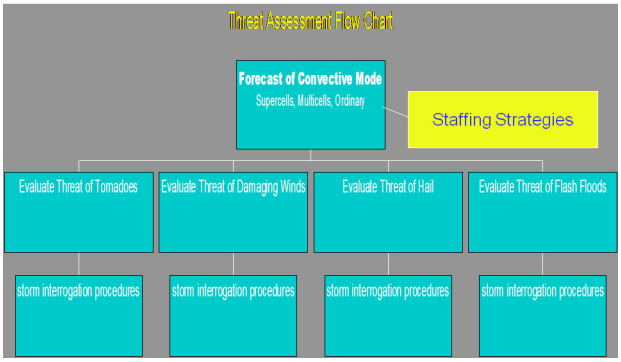
- TA determines what products/procedures will be used in warnings
- TA is a key factor in establishing mental models for the entire event
- TA sets the tone for severe awareness (anticipation factor) in local office and user community

7. Links to Storm Interrogation

Instructor Notes: Environmental threat assessment influences subsequent actions in a warning methodology. There is an initial assessment of convective storm mode (super-cells, multicells, or ordinary convection), then an evaluation of specific hazards. These threats for each storm help determine interrogation procedures.

Student Notes:

Links to Storm Interrogation



8. Threat Assessment Outlook Phase (0 – 24 hr)

Instructor Notes: An important aspect of threat assessment is comparing observations to known patterns. The role of climatology is important in recognizing relative seasonal threats. As you analyze large scale features and make the forecast for potential severe weather, it is important to not get caught up in evolution of model details, but try to target relative threats from the potential convective storm types. The evaluation of the quality of model fields, especially at 24 hrs, is an important factor in conducting threat assessment. Strong synoptically-forced events are often much better handled by the models than events where the synoptic forcing is weak and/or mesoscale is the critical aspect for the environment. Another important task in this phases is knowing how the model handles

convection and the results of the convection on other fields. Methodically, the process includes analyzing fields of shear, available potential buoyancy, potential storm/system movement, and all potential lifting mechanisms. These would help you define the highest threat areas within the CWA. Hourly model forecast soundings can help you to predict convective storm mode and evolution. Coordinate your forecasts with the SPC outlooks, mesoscale discussions and watches.

Student Notes:

Threat Assessment
Outlook Phase (0 – 24 hr)

- Applies climatology and pattern recognition
- Includes synoptic/mesoscale analysis
- Evaluation of model signals and parameter output (forecast fields/soundings)
- Evaluate accuracy of model fields (impacts of convection)

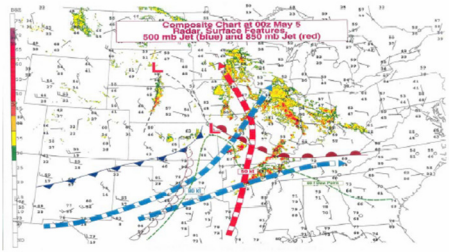
9. Pattern Recognition Ex. 1

Instructor Notes: It is important to compare synoptic patterns to analog events.

Student Notes:

Pattern Recognition Ex. 1

Does this …



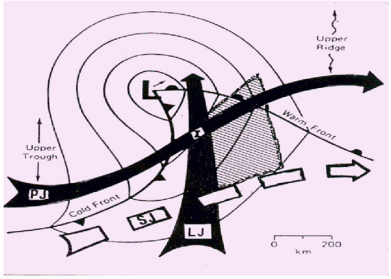
10. Pattern Recognition Ex. 1

Instructor Notes: This is a pattern well known to severe storm forecasters (see http://www.nwstc.noaa.gov/METEOR/SynPat/synpat_main_frm.htm).

Student Notes:

Pattern Recognition Ex. 1

Look like this?



Classic Tornado Outbreak Pattern (from Newton, 1967)

11. Pattern Recognition Ex. 1

Instructor Notes: For more details on the May 4, 2003 tornado outbreak, which was a well forecast event, see http://www.noaanews.noaa.gov/stories/s1136.htm.

Student Notes:

Pattern Recognition Ex. 1

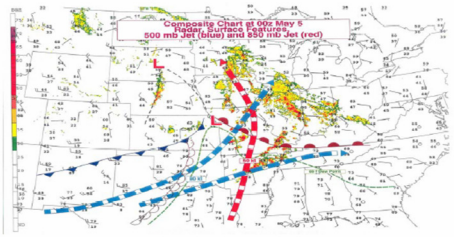


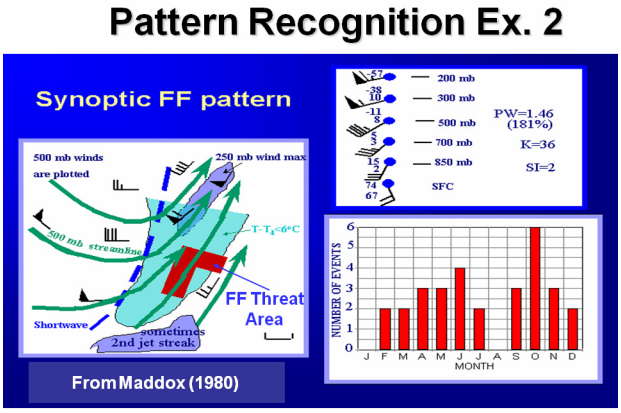
Figure 2. Composite Radar Reflectivity, Surface Fronts, 500 millibar and 850 millibar jet streams at 0000 UTC, (7:00 p.m. CDT May 4, 2003) May 5, 2003. Courtesy of SPC.

From NOAA/NWS Service Assessment of May 4-10, 2003 Tornado Outbreak

12. Pattern Recognition Ex. 2

Instructor Notes: Another pattern to recognize, this one for heavy rain/flash floods events from Maddox (1980).

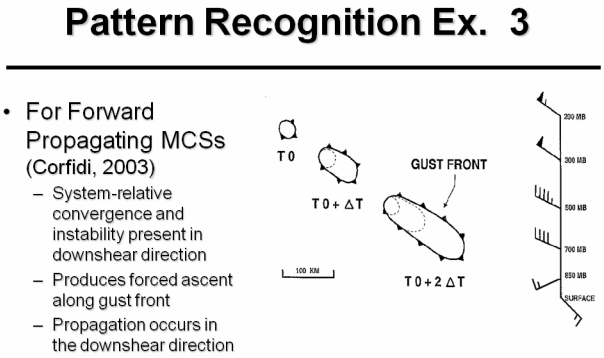
Student Notes:



13. Pattern Recognition Ex. 3

Instructor Notes: This one is for forward-propagating MCSs (Corfidi, 2003).

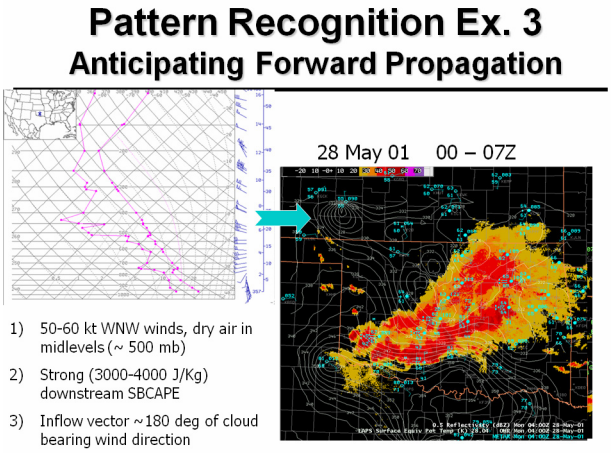
Student Notes:



14. Pattern Recognition Ex. 3 Anticipating Forward Propagation

Instructor Notes: There are 3 ingredients for forecasting the potential a downstream (or forward) propagating MCS motion based on Corfidi (2003): Relatively dry conditions in midlevel and/or in the subcloud layer (to increase tendency to produce strong convective-scale downdrafts) Storm-relative inflow strongest on the periphery of the cold pool (portions of gust front oriented parallel to the mean wind vector) Surface-based instability is present downshear.

Student Notes:



15. Evaluating Model Signals and Parameter Output

Instructor Notes: Establishing confidence in the model solutions involves several components that include, but are not limited to, these factors: Knowledge of the model characteristics (fundamentals, strengths and weaknesses) Knowledge of the role of precipitation, cloud and convective parameterization schemes Knowledge of post-processing of model data Knowledge of model physics Knowledge of model data assimilation and initialization problems For example, model convective precip. can affect the model precip forecast and models soil moisture availability, which will affect evaporation and subsequent boundary-layer dewpoints and CAPE. Incorrect timing, placement, and amount of model precip can cause errors in the model forecast variables, even if they are treated in a consistent, physically realistic manner. Model soundings are affected where model convection occurs, and these effects are advected downstream. For more information on model precipitation and cloud parameterization issues, visit the COMET NWP web site at http://meted.ucar.edu/nwp/pcu1/ic3/index.htm.

Student Notes:

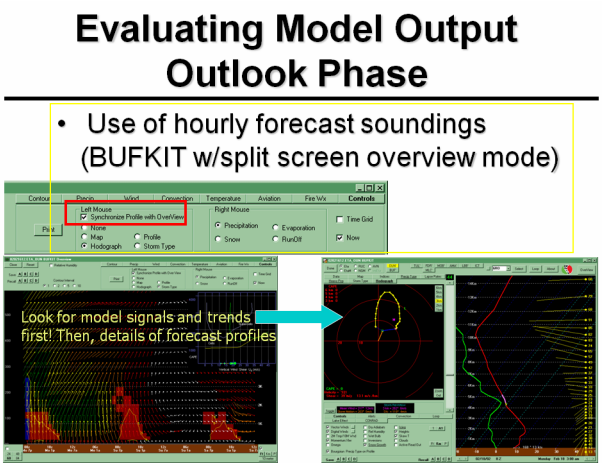
Evaluating Model Signals and Parameter Output

- Once confidence in model solution is established:
  - Evaluate output (from plan view plots and forecast profiles)
  - Verify threat assessment

16. Evaluating Model Output Outlook Phase

Instructor Notes: With the split screen mode and synchronized profile with overview option on BUFKIT, one can more easily analyze model signals and process single forecast profile output (See http://wdtb.noaa.gov/resources/projects/BUFKIT/index.html) for the latest version of BUKIT.

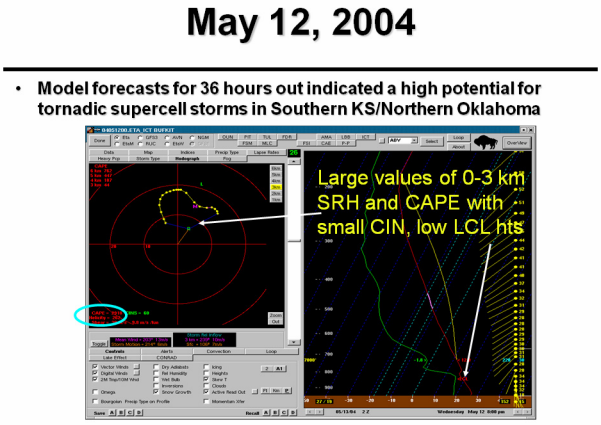
Student Notes:



17. May 12, 2004

Instructor Notes: Note this is a 36 hr forecast!

Student Notes:

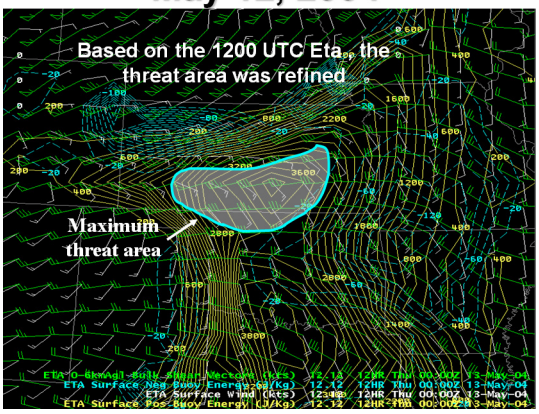


18. May 12, 2004

Instructor Notes: The 12z Eta was suggesting a high potential for tornadic supercells in Southern KS by 00z

Student Notes:

May 12, 2004

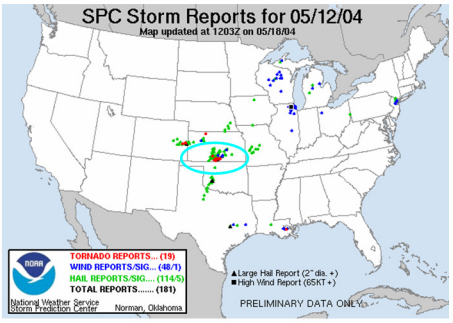


19. May 12 Results

Instructor Notes: Reports were concentrated in south central KS where the models were showing the highest threat would be.

Student Notes:

May 12 Results



20. Threat Assessment Short-Term Forecast Phase (0 to 6 hrs)3 Key Job Tasks

Instructor Notes: Proper threat assessment on the mesoscale adds accuracy to the initial convective outlook process. The analysis of mesoscale data helps to determine when and where convection will develop, and, on some occasions, may yield clues to the probability of a specific hazard occurring. Since thunderstorms are a function of the environment within which it forms, if we can understand that environment, we have an advantage when it comes to accurately warning before events occur (i.e. increasing lead times). Thus, with environmental recognition of parameters we achieve heightened awareness of threats (for significant tornado events for example). The goals of these efforts are improved warning service. This phase is difficult because of the level of effort

that must be made to ensure the assessment is thorough. It is also difficult because of the level of uncertainties in the data sets used in the analyses. How can forecasters provide useful information in a short-term threat assessment which supports the ongoing warning methodology? There are several ways. We will discuss briefly all 4 key tasks shown here. It is important to note that time and data quality are big factors in this process. How good are the objective analyses (OA) of thermodynamic and kinematic fields that are displayed on AWIPS? Are there observations to support the analysis? Important questions to ask as this component is performed in the warning methodology. Try to improve your local OA by getting more observations into the analysis. As time approaches the expected severe event, you will typically be analyzing mesoscale features using observed data and high-resolution models. Remember, this information will help you determine how you will interrogate these storms and can have a very strong influence effect on how you weigh radar and other information in the eventual warning decision.

Student Notes:

Threat Assessment
Short-Term Forecast Phase (0 to 6 hrs)
3 Key Job Tasks

1. Analyze mesoscale environment to determine changes that may affect model and public forecasts
2. Determine representativeness of environmental data
3. Provide warning forecasters with continuous decision inputs of environmental data

21. Short-Term Assessment (0-6 hr) “Nowcasting”

Instructor Notes: Many of these cases have been developed into good training cases and are available from the Convective PDS web site at http://www.nwstc.noaa.gov/nwstrn/d.ntp/meteor/svrpds.html.

Student Notes:

Short-Term Assessment (0-6 hr) "Nowcasting"

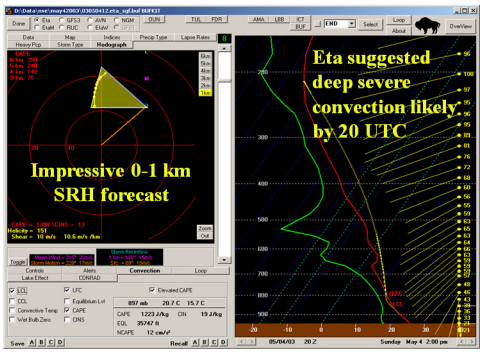
- Determine mesoscale (or storm-induced) changes to current forecast
  - July 2, 1997 (Lower Michigan tornado outbreak)
  - April 21, 2001 (Hoisington, KS tornado)
  - May 31,1998 (NY tornado outbreak)
  - Check the WES Case Library

22. May 4, 2003 12z Eta

Instructor Notes: This is an example of short-term threat assessment. Based on the model forecasts, both the low-level CAPE (0-3 km CAPE = 76) and Shear (0-1 km SRH = 151 m2/s2) were very favorable for significant tornadic development. LCL height = 3137 ft (957 m) AGK, LFC = 4916 ft (1500 m) AGL. The model signals were indicating increasing probability for tornadic supercells. But, could observations tell us even more?

Student Notes:

May 4, 2003 12z Eta



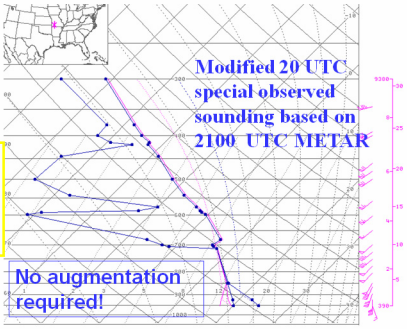
23. May 4, 2003 20z - Observed

Instructor Notes: Much more impressive parameters from observed sounding (no storm influences either!). This mesoscale sounding indicated that conditions were already extremely high in terms of tornado potential, and that most storms that developed were going to be tornadic once they developed – and they did.

Student Notes:

May 4, 2003 20z - Observed

- Turned out the moisture was even deeper than Eta forecasted and surface dew points 2-3 deg F higher.
- LCL ht = 2100 ft (640 m)
- CIN ~ 6 J/kg
- SBCAPE ~ 3068 J/kg
- SRH (0-3km) = 522 m2/s2

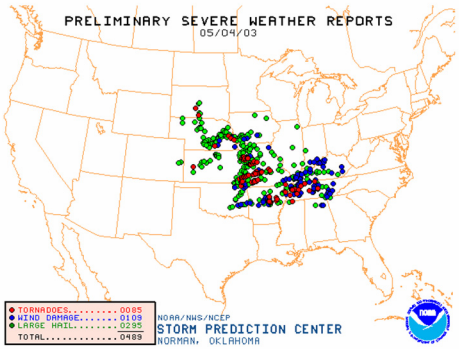


24. May 4, 2003 Results

Instructor Notes:

Student Notes:

May 4, 2003 Results



25. Short-Term Assessment (0-6 hr) “Nowcasting”

Instructor Notes: It is important to QC environment data because using “bad” data can be an impediment to effective warning methodologies. Misinterpreted or inappropriate data can mislead the warning team. Most staffing strategies recommend a dedicated threat assessment forecaster, due to this reason.

Student Notes:

Short-Term Assessment (0-6 hr) "Nowcasting"

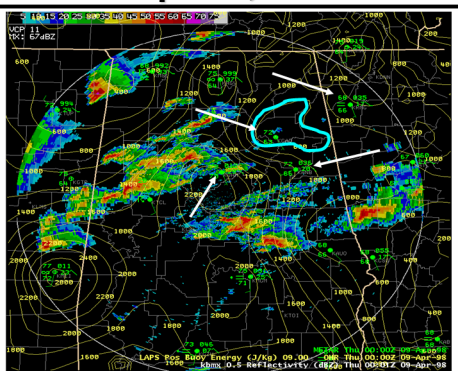
- Important to evaluate the representativeness of the data
  - How to "quality control" the model analysis
  - How to anticipate how convection will modify its environment

26. QC-ing Model Forecast April 8, 1998

Instructor Notes: Look at this area in northeast AL. How does the CAPE analysis compare to the observations?

Student Notes:

QC-ing Model Forecast April 8, 1998

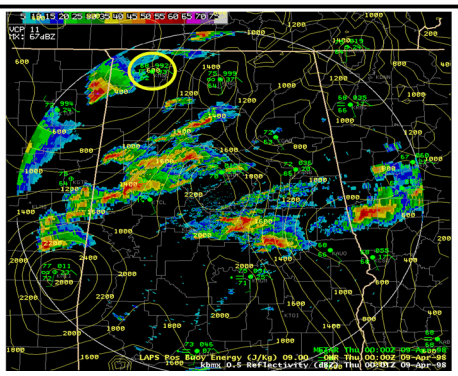


27. April 8, 1998

Instructor Notes: Look at this area in northwest AL. How has CAPE LAPS analysis been affected by the 00z ob at MSL?

Student Notes:

April 8, 1998



28. QC-ing Model Forecast

Instructor Notes: Check out this WES case at http://www.wdtb.noaa.gov/resources/docs/simulationguide/

Student Notes:

QC-ing Model Forecast

- LAPS and RUC often show spurious signals in CAPE fields
- April 8 ,1998 WES case is a good case to evaluate the “goodness” of the LAPS analysis from 22-01 UTC

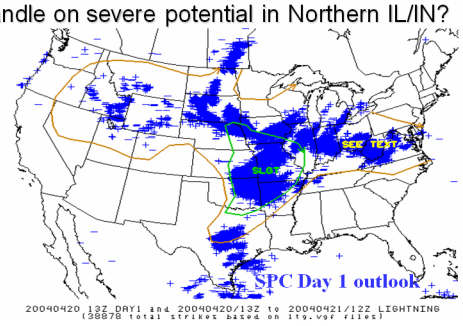
29. Evaluating Representativeness of Model Data – 4/20/04

Instructor Notes: No risk of severe in northern IL/IN. Let’s see what happened.

Student Notes:

Evaluating Representativeness of Model Data – 4/20/04

- Did the models and current forecasts have a good handle on severe potential in Northern IL/IN?

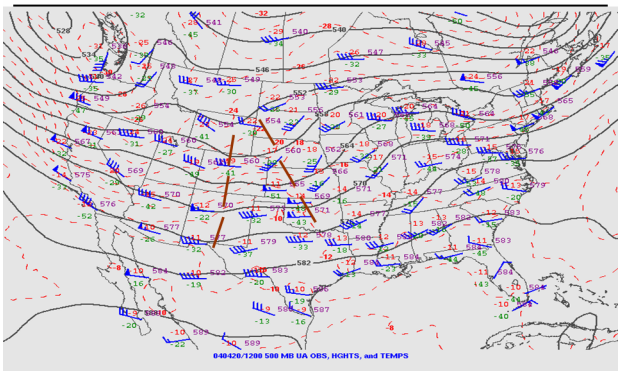


30. Evaluating Representativeness of Model Data – 4/20/04

Instructor Notes: Satellite trends – large scale pattern indicating broad scale lift across central plains into the Ohio Valley (from distinct shortwave troughs).

Student Notes:

Evaluating Representativeness of Model Data – 4/20/04

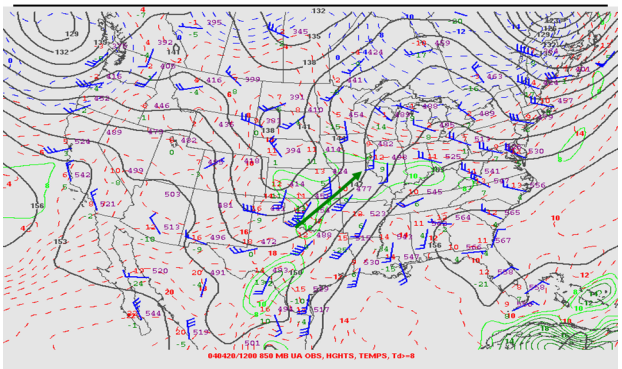


31. Evaluating Representativeness of Model Data – 4/20/04

Instructor Notes: Strong H85 moisture advecting northward into Mid Ms Valley

Student Notes:

Evaluating Representativeness of Model Data – 4/20/04



32. 4/20/04 WV Loop

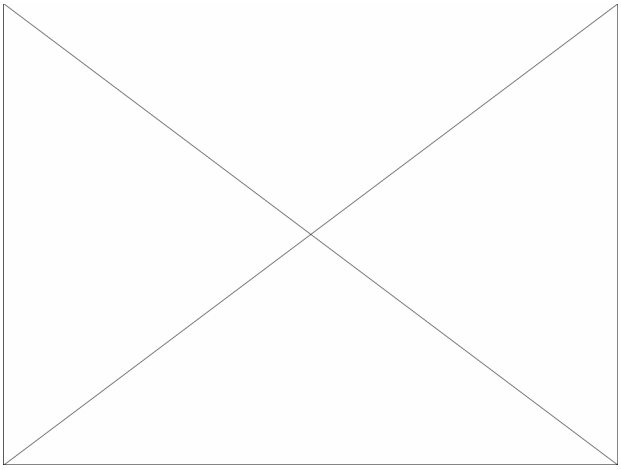
Instructor Notes: There are flash loops showing the satellite imagery.

Student Notes:

33. 4/20/04 Vis Loop

Instructor Notes: There are flash loops showing the satellite imagery.

Student Notes:

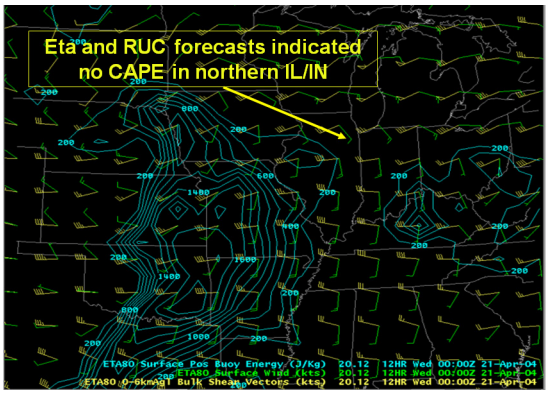


34. 4/20/04 data

Instructor Notes:

Student Notes:

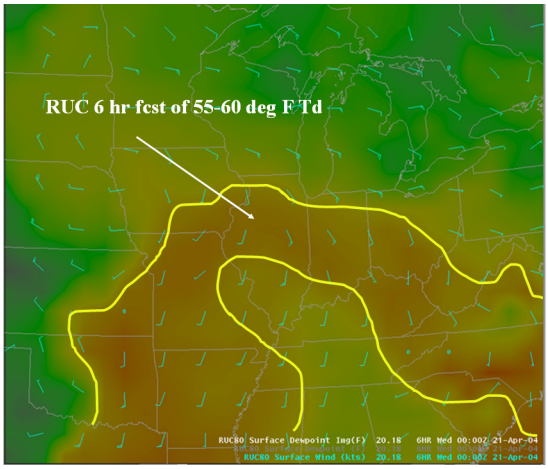
4/20/04 data



35. 4/20/04 data

Instructor Notes: RUC dewpoint temps from 13z to 03z had forecast 60 deg F dewpoints increasing northward into central IL, but that was 5-6 deg less than what was indicated on Metars from 20-23z. Note the animation of RUC model surface dewpoints

Student Notes:



36. RUC Data

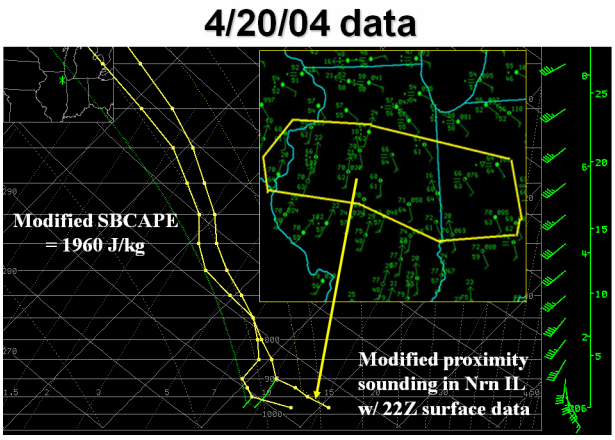
Instructor Notes: There are flash loops showing the satellite imagery.

Student Notes:

37. 4/20/04 data

Instructor Notes: Low-level moisture was (Td > 60deg F) were starting to pool in this region.

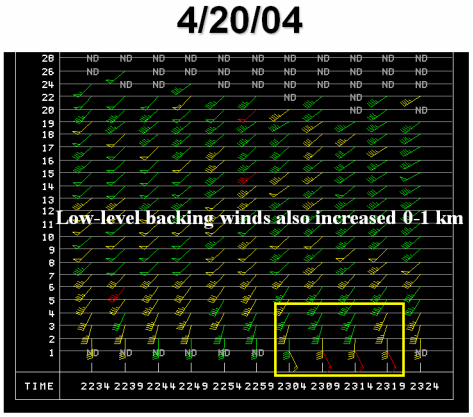
Student Notes:



38. 4/20/04

Instructor Notes:

Student Notes:

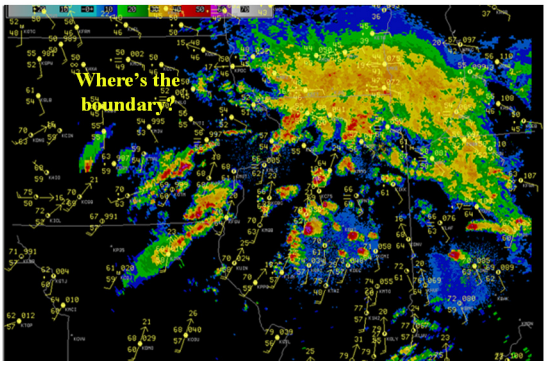


39. 4/20/04

Instructor Notes: Play loop for evolution. Threat assessment helped forecasters see that the models were way underplaying the low level buoyancy and shear in northern IL/ IN. The RUC was too cold and dry. By the way, interesting supercell initiation along what? (i.e. No boundary)

Student Notes:

4/20/04



40. Short-Term Threat Assessment Key Tasks

Instructor Notes: These are some more tasks in general threat assessment, this time in the short-term and in some instances, nowcast phase. We will discuss most of these in the next lesson.

Student Notes:

Short-Term Threat Assessment
Key Tasks

- Evaluating mesoscale environment to determine
  - Location of significant lifting mechanisms and associated character of lift
  - Location & timing of severe development
  - Likelihood and intensity of specific hazard (tornadoes, flash flooding, etc.)
  - Evolution of threat (especially movement)

41. Lesson 1 Summary

Instructor Notes:

Student Notes:

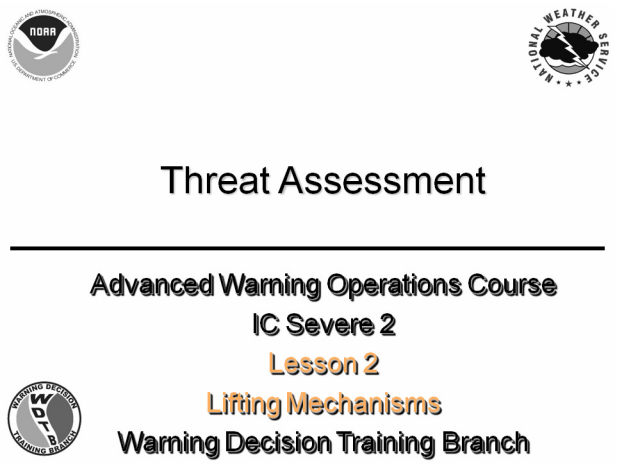
Lesson 1 Summary

- Threat assessment is a key component in a warning methodology
  - Helps determine storm interrogation procedures
- Involves analyzing mesoscale environment
- Evaluating the "quality" of the environmental data (esp. models)

1. Threat Assessment

Instructor Notes: The title for this instructional component is “Threat Assessment.” This is the 2nd instructional component for the AWOC Severe Track. This is lesson 2 on lifting mechanisms.

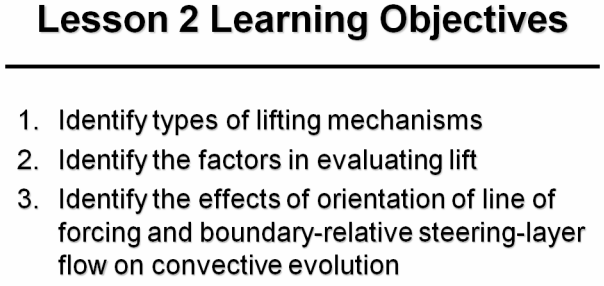
Student Notes:



2. Lesson 2 Learning Objectives

Instructor Notes: The detection and analysis of lifting mechanisms are crucial components in short-term threat assessment. We will describe types of lifting mechanisms, how to evaluate lift, and look at the details of the lift as it relates to boundary orientation.

Student Notes:



3. Lifting Mechanisms

Instructor Notes: All lifting mechanisms are not created equal. Boundaries with the greatest persistent convergence would have the highest potential for initiating convection given all other parameters being equal. But it is difficult to define persistence based on

our limitations of the observing network. Often what may seem to be convergence could be a bad wind observation, or minor fluctuations in the reported winds. Persistence adds credibility that something is real there. So here are some cautions to evaluating the strength of boundaries WRT convergence: Most boundaries converge air on scales too small for even mesonetworks to resolve (Crook 1996). Strength of convergence doesn't always mean deep convergence. A boundary may have strong convergence down low and be capped well below the LFC. This is a problem especially when the LFC is high and/or if there's a significant capping layer below it. Drylines are notorious for exhibiting strong surface convergence and yet shallow circulations. One thing to remember is that when looking at the vertical continuity equation, the vertical velocity at some level depends on the integrated values of convergence/divergence below. Vertical velocity is highest at the level of non-divergence where convergence resides below and divergence above. In most cases, the deeper the convergence, the higher the level of maximum vertical velocity will occur.

Student Notes:

Lifting Mechanisms

- Evaluation of lift involves 5 factors:
  - Type
  - Scale (intensity)
  - Duration
  - Details of lift (what is being lifted, how sounding will modify)
  - Orientation (Boundary relative flow, shear vector orientation with respect to boundary, cold pool shear balance)

4. Types of Lift

Instructor Notes: There are many types of lifting mechanisms, low-level boundaries being the most common. Depending on the scale, observable boundary attributes are location, density gradients, low-level convergence and ascending air. Density gradients produce direct mesoscale ascent, so that's why we analyze direct observables such as T, Td, q, P, and θ (actually θv is the best for density). Convergence can be estimated by calculating differential velocity across the width of the boundary (See http://www.nssl.noaa.gov/istpds/icu92/icu922web/ic922.html for more details). Ascending air, W, can be estimated by integrating values of convergence with height. Notes from other training on boundaries: Estimating one-dimensional convergence assumes a uniform airflow on either side. In other words, a front with no undulations or intersections with other boundaries. Convergence will be higher at intersections, mergers, collisions with other sources of ascent. Convergence is scale dependent. Data from METARs and mesonets will underestimate convergence in boundaries by 2 to 3 orders of magnitude. Model analysis will underestimate convergence similarly. All operational model resolutions are too poor to capture the true width of a boundary. Also, stormscale boundaries are typically

unobserved by models. Typical boundaries are 3-10 km wide. Actual convergence will be occurring on these scales. Convergence will be higher at boundary intersections with other boundaries, circulations, rolls. Two dimensional convergence with boundary intersections becomes important since winds vary both along and normal to the boundary axis. Surface convergence may not always mean deep convergence/ascent. A capped atmosphere may limit the depth of even strong surface convergence. Therefore, the deeper the convergence zone relative to the LFC, the more likely initiation will occur. Refer to the Boundary Analysis Session (http://www.cira.colostate.edu/ramm/visit/boundaries1/title.asp) regarding some strategies to estimate boundary depth.

Student Notes:

Types of Lift

- Boundaries
  - Evaluate strength by analyzing density gradient at surface and aloft (θ, T, Td, and P)
  - Evaluate convergence by analyzing moisture divergence
  - Best lift when coupled with jets

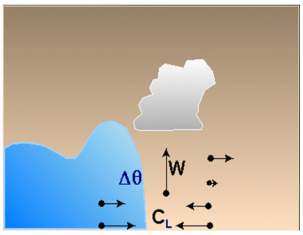
5. Observable Boundary Attributes

Instructor Notes: When analyzing boundaries as a potential lifting mechanism, try to evaluate the following: Location and movement Density gradients (which creates a thermally direct circulation and ascent on the least dense side of a boundary) Low-level convergence (typically strongest near the surface) Ascending air, W (even if you have convergence at the surface, it doesn't necessarily imply ascent). It has to be integrated values of convergence with height (decreasing convergence with height for example). Visual manifestation of moist W is cumulus clouds.

Student Notes:

Observable Boundary Attributes

- Location and movement
- Density gradient, $\Delta\theta$
  - Except for troughs and HCRs
- Low-level convergence, C_L
  - Change with height
- Observing ascending air, W



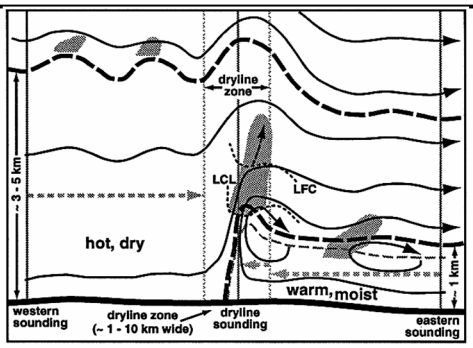
All of these are important when assessing lift

6. Lifting Along the Dryline

Instructor Notes: Moist boundary layer air parcels must be lifted to their LCL and LFC prior to leaving the mesoscale updraft to form deep convection. Cloud formation is predicted when the vertical mesoscale moisture flux predominates below the LCL, and deep convection is predicted if strong mesoscale lifting is deeper than the LFC. A modification of proximity soundings to account for mesoscale lift, the across-dryline differences of environmental thermal stratification, and westerly wind shear effects can improve the diagnosis of the mesoscale dryline environment and the prediction of convective initiation at the dryline (Ziegler and Rasmussen, 1998).

Student Notes:

Lifting Along the Dryline



From Ziegler and Rasmussen (1998)

7. Types of Lift

Instructor Notes: In addition to boundaries, there are other lifting mechanisms like these shown here, which produce synoptic scale ascent. Most of these types of lifting can support the development of convection.

Student Notes:

Types of Lift

- Lower branch of indirect circulation
  - Enhances θ_e transport, low-level jet, convergence
- Upper divergence
  - From jet streaks, large scale ascent from Q-vector divergence
  - May be important to monitor when near-surface layer convergence is weak

8. Types of Lift

Instructor Notes: The diagnosis of frontogenesis will result in a diagnosis of the forcing for vertical motion on the frontal scale. Ascent occurs on the warm side of a maximum of frontogenesis and on the cold side of a region of frontolysis (Schultz, 2001)

Student Notes:

Types of Lift

- Frontogenesis
  - Analyze incremental layers from 700 to 500 mb determined from AWIPS cross section drawn perpendicular to the temperature gradient
- Isentropic lift
  - Related to warm air advection and potential elevated convection if sufficient MUCAPE present

9. Elevated Convection and Frontogenesis

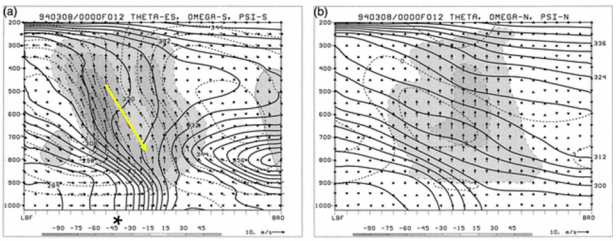
Instructor Notes: If sufficient instability is available aloft, then severe elevated convection can result.

Student Notes:

Elevated Convection and Frontogenesis

circulation **within** plane of cross section
(i.e., frontal circulation)

circulation **normal** to plane of cross section
(i.e., synoptic-scale circulation)



Vertical motion: shaded
Theta-Es: solid lines

Vertical motion: shaded
Theta: solid lines

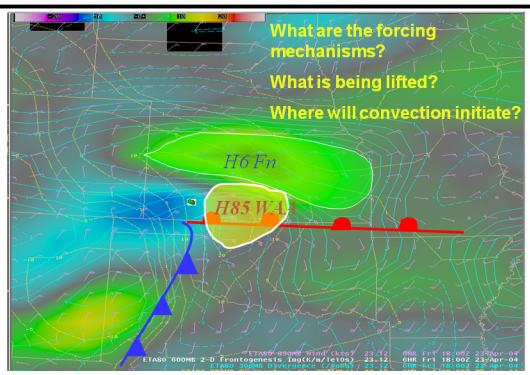
From Schultz (2001)

10. Combo of Lifting Example4/23/04

Instructor Notes: There were multiple contributions to upward motion indicated by the Eta across KS; all the convection which occurred, including the severe thunderstorm complex which developed and moved across KS during the morning hours was not surface based.

Student Notes:

Combo of Lifting Example 4/23/04

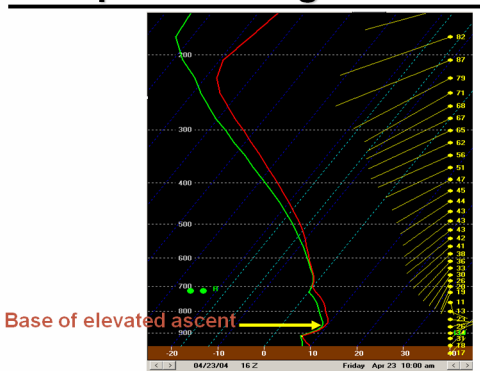


11. Sounding Showing Elevated parcel lifting necessary

Instructor Notes: Note the level of parcel maximum parcel lift is at around 850 mb.

Student Notes:

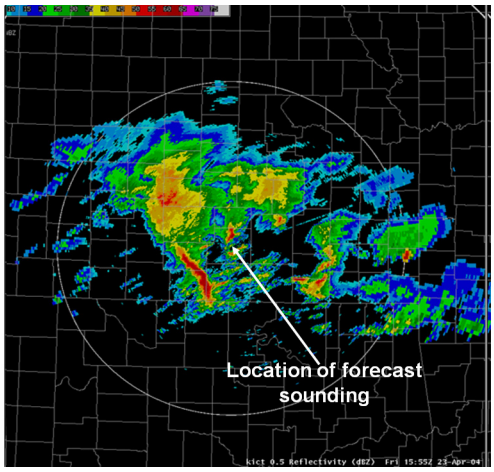
Sounding Showing Elevated parcel lifting necessary



12. Radar Loop of 4/23/04

Instructor Notes: After this slide, you will see a flash movie showing the radar reflectivity evolution at 0.5 deg from the morning of April 23, 2004.

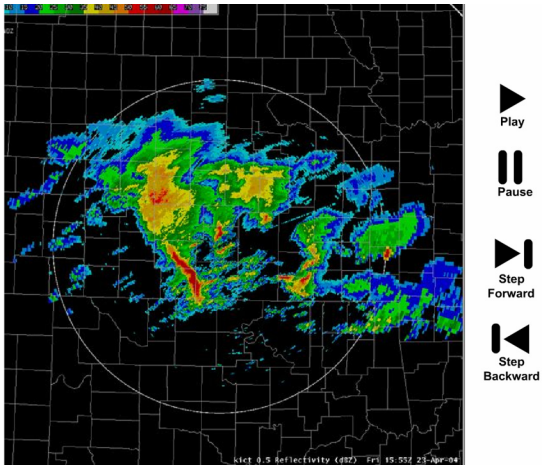
Student Notes:



13. Slide 13

Instructor Notes:

Student Notes:



14. Types of Lift

Instructor Notes: We'll take a look at lifting from differential heating.

Student Notes:

Types of Lift

- Differential heating
- Upslope winds

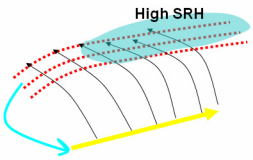
15. Differential Heating

Instructor Notes: Pressure rises near the top of the boundary layer over the warmer air mass. This leads to divergence aloft and surface pressure falls within the warm sector. The adjacent cooler air subsequently flows toward the area of lowered pressure, and a direct circulation (warm air rising, cold air sinking) results. The increase gradient produces a solenoidal circulation, which, depending on amount of CAPE/CIN and external lifting mechanisms, can initiate severe convection. Example at right is from 14 June 2001 (Wolf, AMS SLS conf.)

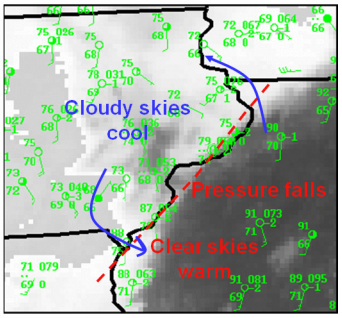
Student Notes:

Differential Heating

- Over time differential ground heating will produce a solenoidal circulation



- Thermal gradient can also act to back low-level flow and increase near-ground SRH



From Wolf (2002)

16. Upslope Lifting

Instructor Notes: This is obviously an important consideration where there are significant changes in topography and wind flow.

Student Notes:

Upslope Lifting

- Terrain effects can aid boundary layer low-level jet characteristics
- Also, flow effects due to topography
- http://meted.ucar.edu/mesoprim/flowtopo/

17. Duration of Lift

Instructor Notes: In the DMX derecho event of 29 June 98, there were 3.6 mb/hr pressure falls in central IA for 3-4 hours prior to line intensifying and mesolow development. One of the results was increased low level winds into the leading edge of the line, which increased vertical shear and updraft strength for storms which developed along the leading edge (some spawned tornadoes and 100 mph+ winds).

Student Notes:

Duration of Lift

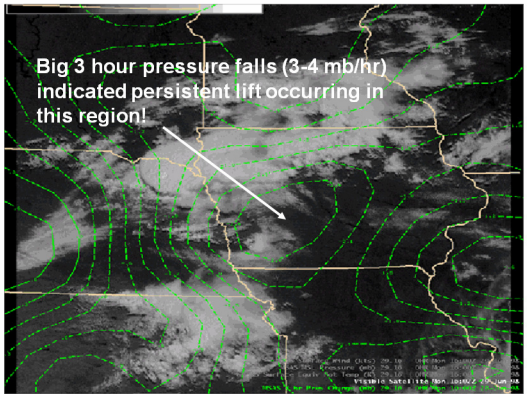
- Surface pressure falls
  - 2 and 3 hour falls with continuity (often fall/rise couplets)
  - Location of fronts and movement of meso-lows by analyzing isallobaric pattern

18. DMX 6/29/98

Instructor Notes: This event was analyzed in the DMX 29 June 1998 WES case.

Student Notes:

DMX 6/29/98

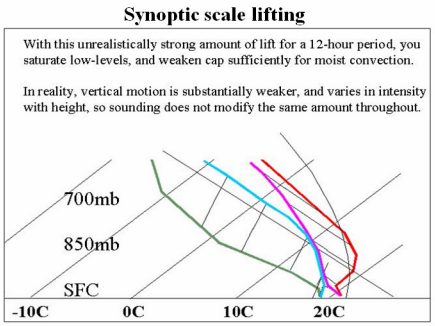


19. Details of Lift

Instructor Notes: This is for synoptic scale layer lifting, which over a period time (0-12 hours) can act to significantly destabilize the atmospheric profile. This development of instability due to vertical motion on the large scale can contribute to convective development, but the instability alone provides inadequate mesoscale lifting for severe thunderstorms.

Student Notes:

Details of Lift

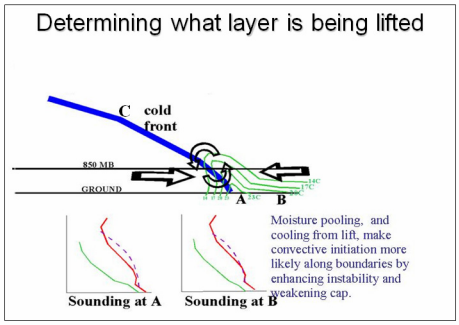


20. Details of Lift

Instructor Notes: Use a surface based parcel along boundaries, a mixed layer parcel in warm sector, and a most unstable parcel north of a parcel (when instability is not rooted in boundary layer). Graphics courtesy of Pete Wolf (ICT).

Student Notes:

Details of Lift



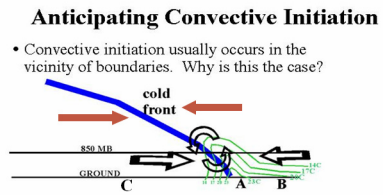
21. Details of Lift

Instructor Notes: This sounding would be back in the colder air.

Student Notes:

Details of Lift

- Now, let's look at a sounding at Point C

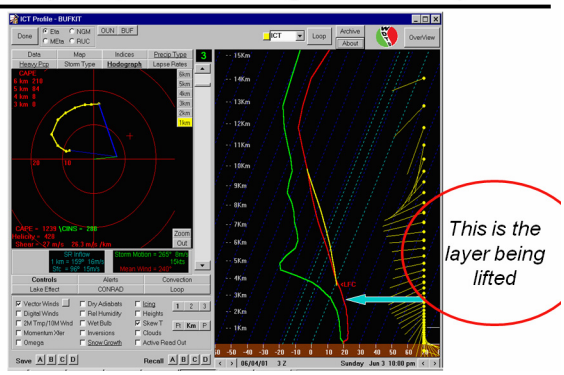


22. Elevated Convection (sample sounding at Point C)

Instructor Notes: Look at lifting forces in the 2-4 km layer (6.5 – 13.1 kft) (800-625 mb), not surface to 850mb. That's why Warm Air advection centered around 850 mb is often a good correlation to lifting forces for elevated severe convection. Important to assess convergence (theta-E convergence in 850-700 mb) and boundary relative flow. Also, frontogenesis in a 50-100 mb layer below the bottom level of positive buoyancy.

Student Notes:

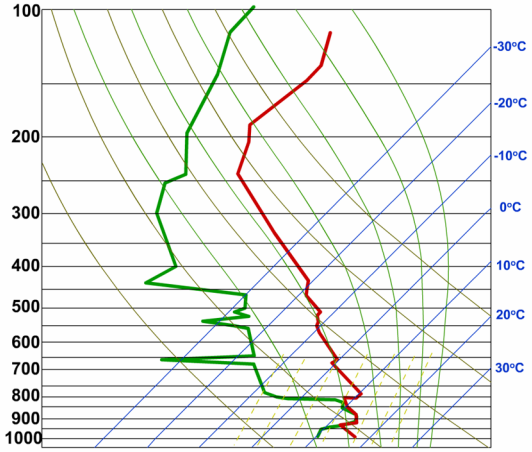
Elevated Convection
(sample sounding at Point C)



23. Slide 23

Instructor Notes: If you lift the parcel from 878 mb, you get the most CAPE. This sounding was a proximity sounding for the big hailstorm that hit Dallas-Ft. Worth area. For elevated convection, use the most unstable parcel (MUCAPE in SPC plots). Be aware of the limitations; it can overestimate the degree of instability and erode the cap too early before convection develops. Sometimes, it is better to use a lower mean layer for surface based convection. There is an animation showing the effects of adjusting lifting parcel level with this sounding.

Student Notes:



24. Orientation of Lift

Instructor Notes: In addition to evaluating the individual details of parcels for lifting, we should look at the characteristics of lift associated with boundaries in terms of how strong and deep the lifting will be. Based on observations by Wilson and Megenhardt (1997), boundaries in FL were most active if cell motion -boundary motion was ~ 5 m/s. Before storms, the 2 - 4 km mean wind = cell motion. Several observational studies including this one sampled the mean flow in a 2-4 km layer and found the boundaries were most convectively active when the boundary-normal flow was less than 5 m/s. The 2-4 km layer was chosen since it correlated best with new storm motion. Boundary-relative flows greater than 5 m/s exhibited less storm activity and those storms that did form on the boundary would quickly be left behind in less stable air and dissipate. Note: This study was done during a field project around Cape Kennedy during the summer. Therefore the storms were mostly driven by surface-based phenomenon and there were small amounts of shear. Whether these findings can apply to stronger synoptically forced situations still remains a question worthy of testing at any of your locations. Also note that not all storms will dissipate if the boundary-relative 2-4 km flow is high. Convection can persist or even thrive well after they leave the original boundary if there is still sufficient uncapped instability.

Student Notes:

Orientation of Lift

- There are some additional factors to consider when evaluating how strong (and deep) the lift will be:
  - Boundary-relative flow (low-levels and steering layer)
  - Boundary-orthogonal shear (RKW Theory)

25. Boundary-Relative Flow Considerations

Instructor Notes: Results of simulations (Bluestein and Weisman, 2000) suggest that when the deep-layer shear is normal to the line of forcing, isolated, cyclonically (anticyclonically) rotating, right-moving (left-moving) supercells develop at the end of the line to the right (left) of the deep-layer shear. A squall line having embedded, but distinct, intense cells develops in between. The squall line develops after neighboring right- and left-moving cells collide. The cells in the squall line have some supercellular characteristics, but the updrafts at midlevels are not very well correlated with vertical vorticity.

Student Notes:

Boundary-Relative Flow Considerations

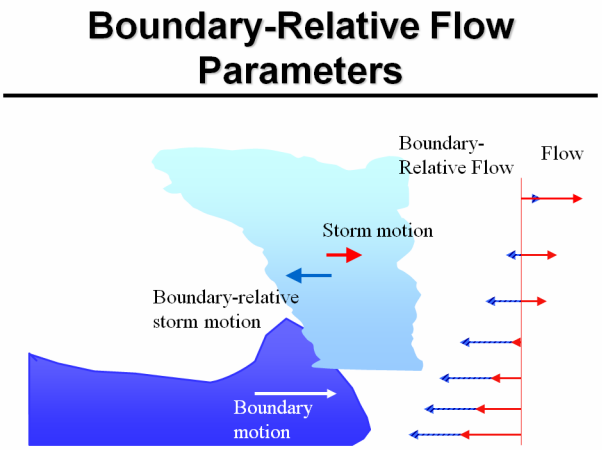
- Weak (0-5 m/s) boundary-relative (steering-layer) flow increases convective cell coverage
- Orientation of line of forcing can be as important as CAPE and shear in determining type of outbreak
  - Orientation WRT shear & wind vector
  - Boundary-relative supercell motion

26. Boundary-Relative Flow Parameters

Instructor Notes: Graphic courtesy of Jim LaDue. These are theories that apply to density current boundaries: A boundary-relative headwind (tailwind) increases (decreases) the depth of the ascending air column. Based on numerical modeling of an outflow boundary, the boundary height increases when a boundary moves into a headwind. Boundaries with a headwind move more slowly than those with a tailwind. (From Liu and Moncrieff, 1996 MWR, 124, pp 2282.) From these theoretical and numerical experi-

ments, the ascending air column will be deeper for boundaries experiencing a significant headwind than for those following into a tailwind. It stands to reason that low-level convergence with headwind (tailwind) boundaries is higher (lower).

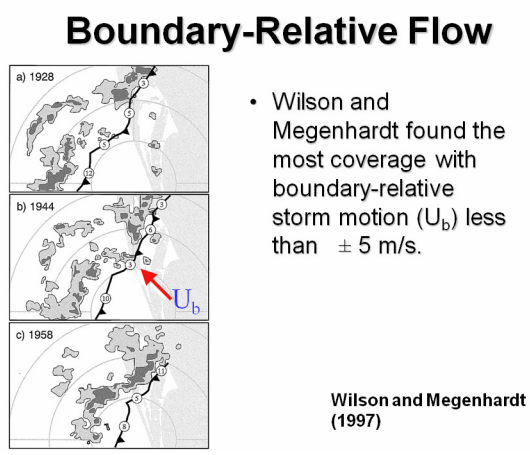
Student Notes:



27. Boundary-Relative Flow

Instructor Notes: Wilson and Megenhardt (1997) found the most coverage with boundary-relative storm motion (Ub) less than ± 5 m/s. These storms occurred in weakly sheared environments.

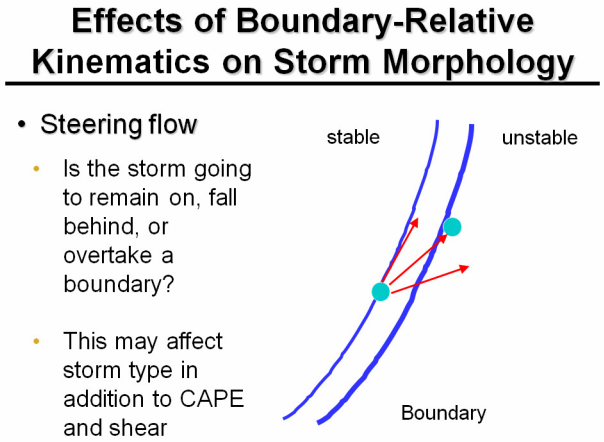
Student Notes:



28. Effects of Boundary-Relative Kinematics on Storm Morphology

Instructor Notes: Based on boundary-relative considerations, the northward moving storm has the lowest boundary-relative flow which allows parcels to ride along the boundary and reach its LFC the fastest, thus maximizing lifting potential.

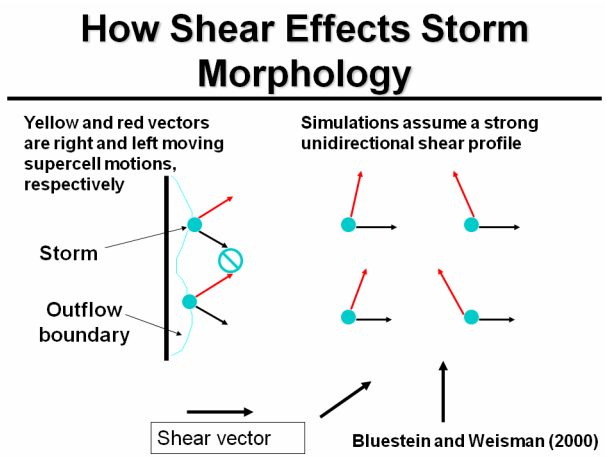
Student Notes:



29. How Shear Effects Storm Morphology

Instructor Notes: This is based on numerical simulation of storms (Bluestein and Weisman, 2000) where they looked at various orientations of the vertical shear vector with respect to the lines of forcing. The left-most example is of a shear vector oriented at a 90 deg. angle to the boundary. In this case, the right-mover will collide with the left-mover. In the middle situation, the shear vector is at a 45 deg. angle to the boundary. With the exception of the northernmost storm, the left-moving members will move across the outflow bndry generated by the right-moving neighbor to the north, and weaken, while the right movers will move away from the boundary and may not collide with their neighbors. The last case (far right) is where the shear vector is oriented parallel to the boundary. In this scenario, the left movers will move behind the boundary, while the right movers will slowly move ahead of the boundary. However, since there is also a component of storm motion parallel to bndry, the right movers might be able to catch up to the outflow bndrys generated by the adjacent right movers along the line, and weaken. Thus, boundary-orthogonal shear (component of the shear vector normal to the boundary orientation) affects the motion of storms and thus, how long updrafts will stay on the boundary. The shear vector is drawn perpendicular to the gust front (thin lines), with right (yellow vectors) and left (red vectors) supercell storm motions based on Bunker's et al. (1999) method.

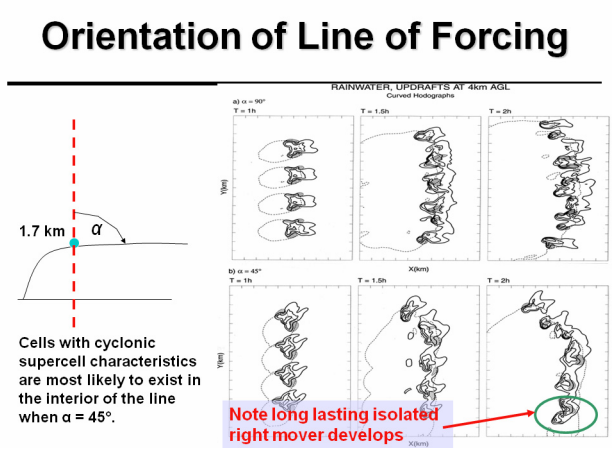
Student Notes:



30. Orientation of Line of Forcing

Instructor Notes: From Bluestein and Weisman (2000), simulated fields for a line simulation, at 1, 1.5, and 2 h, of liquid-water mixing ratio (thick contours at 1, 4, and 8 g kg−1) and vertical velocity (shaded region in excess of 8 m s−1) at 4 km for the modified sounding and curved hodograph. Tick marks are spaced 10 km apart. Gust front at 0.25 km depicted by dashed line (perturbation temperature at 0.25 km, with respect to ambient environment, of −1°C). This simulation was for when alpha (angle between shear vector above 1.7 km AGL and line of forcing) was = 90 deg. In reality, this would be for a westerly shear and a north-south boundary.

Student Notes:



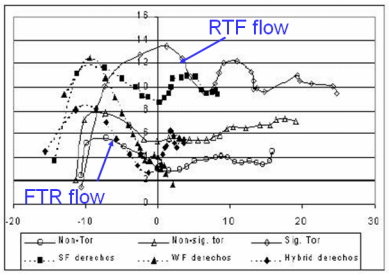
31. Storm-Relative Winds Effect Mode of Convection

Instructor Notes: When storm-relative winds are examined (as in this figure from Evans and Doswell, 2002) it is apparent that the derechoes yield the strongest inflow in the lowest 1 km. In addition, weakly forced events develop and persist in environments with deep storm relative inflow (front-to-rear flow) from the surface through 8-9 km. In contrast, the supercell data set reveals pronounced rear-to-front flow above 2-3 km,

especially the significantly tornadic events. This is really evident above 4 km, where only the supercells indicate rear-to-front storm-relative flow increasing through 10 km. These results were consistent with other studies that found the distribution of hydrometeors and precipitation largely due to the mid- and upper-level wind fields relative to the storms.

Student Notes:

Storm-Relative Winds Effect Mode of Convection



From Evans and Doswell (2002)

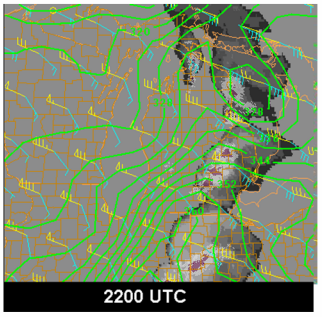
32. Boundary-Relative Flow 7/2/97– Michigan Tornadoes

Instructor Notes:

Student Notes:

Boundary-Relative Flow
7/2/97– Michigan Tornadoes

- Strong synoptic forcing and favorable CAPE/shear for tornadic supercells
- Boundary-relative flow in mid to upper levels was rear-to-front



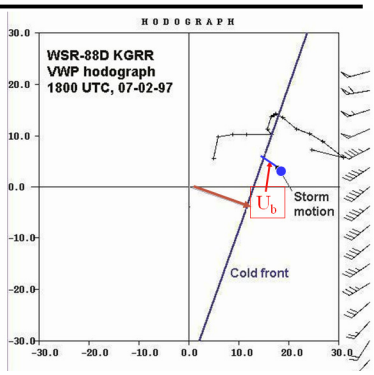
33. 7/2/97 Michigan Tornadoes

Instructor Notes: The blue dot is the storm motion vector. Boundary relative flow is the blue vector (~ 280 deg, 5 m/s).

Student Notes:

7/2/97 Michigan Tornadoes

- VWP hodograph shows observed storm motion pulling ahead of front

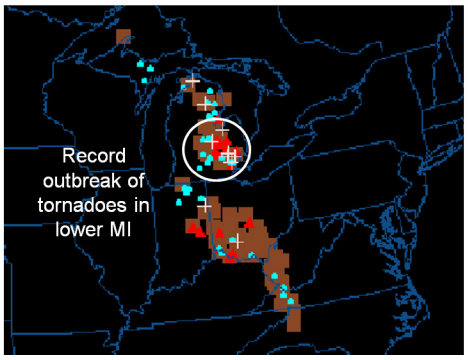


34. 7/2/97 Storm Summary

Instructor Notes: Severe weather reports from 1200 to 2300 UCT 02 July 1997. Small blue square-like symbols are hail >= 0.75 inches in diameter, red triangles are tornadoes, large brown squares are wind damage, white crosses are reported wind gusts >= 50 knots. See http://www.wdtb.noaa.gov/resources/cases/jul02case/torcase.htm for more information on this event.

Student Notes:

7/2/97 Storm Summary



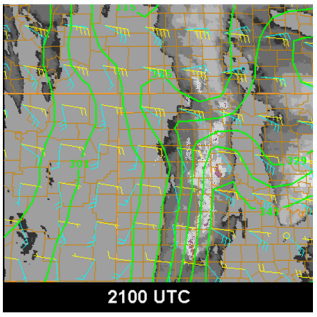
35. May 5, 1995 – TX PH Tornado Null Case

Instructor Notes:

Student Notes:

May 5, 1995 – TX PH Tornado Null Case

- As in 7/2/97 case, shear and buoyancy were in range of supercell tornadoes
- However, boundary-relative upper level flow was front-to-rear



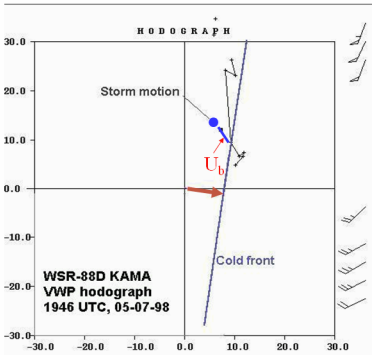
36. May 05, 1995 – TX PH tornado null case

Instructor Notes: Same color convention as previous example.

Student Notes:

May 05, 1995 – TX PH tornado null case

- VWP hodograph shows observed storm motion falling behind front



37. Visualizing Boundary-Relative Flow/Shear

Instructor Notes: The best way to view orientations of line of forcing and shear is through a hodograph like what is available on BUFKIT.

Student Notes:

Visualizing Boundary-Relative Flow/Shear

- Line of forcing can be viewed as another axis on a hodograph
- Winds and shear can be interpreted with respect to the line of forcing
- The line of forcing can be displayed with the BUFKIT hodograph

38. Visualizing in BUFKIT

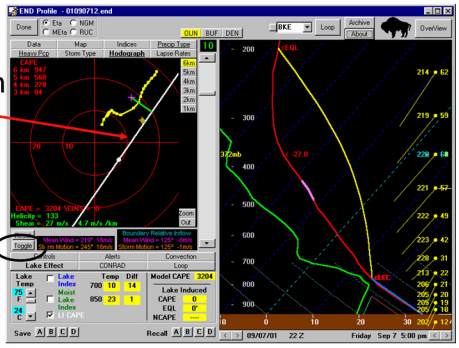
Instructor Notes: This hodograph is from a Eta forecast profile at Enid, OK.

Student Notes:

Visualizing in BUFKIT

- Boundary Orientation

Use the toggle button to go from hodograph display to B-R coordinates



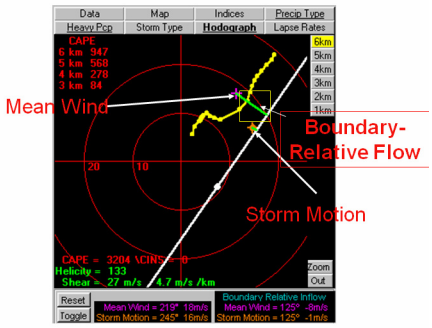
39. Visualizing in BUFKIT

Instructor Notes: This shows storms falling behind the boundary due to BRF considerations. On BUFKIT, the green vector is the Boundary-relative flow vector.

Student Notes:

Visualizing in BUFKIT

- 10 hr Eta forecast for END
- Storms forecast to fall behind boundary



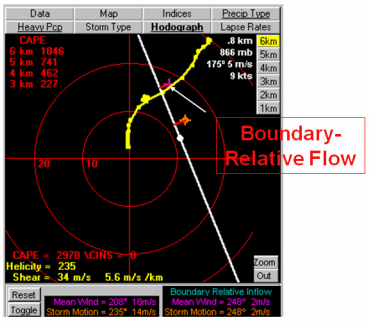
40. Visualizing in BUFKIT

Instructor Notes: This forecast shows storms staying out ahead of the boundary in the warmer air.

Student Notes:

Visualizing in BUFKIT

- 10 hr Eta forecast for ICT
- Storms forecast to stay just ahead of boundary



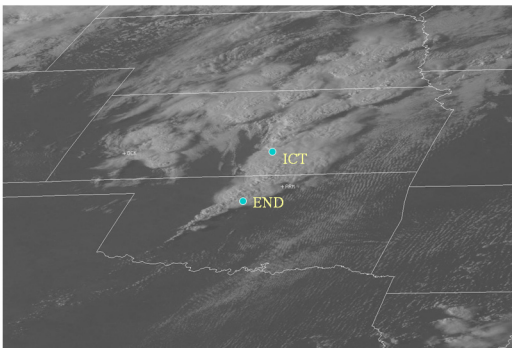
41. Sept 07, 2001 case

Instructor Notes:

Student Notes:

Sept 07, 2001 case

GOES-8
2200 UTC



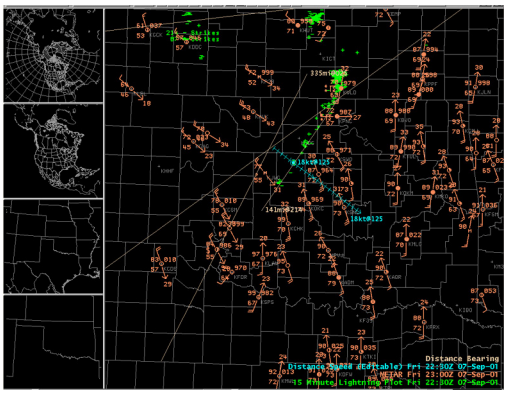
42. Sept 07, 2001 case

Instructor Notes:

Student Notes:

Sept 07, 2001 case

2230 UTC
LTGCG
and
Metars
with frontal
motion
near END



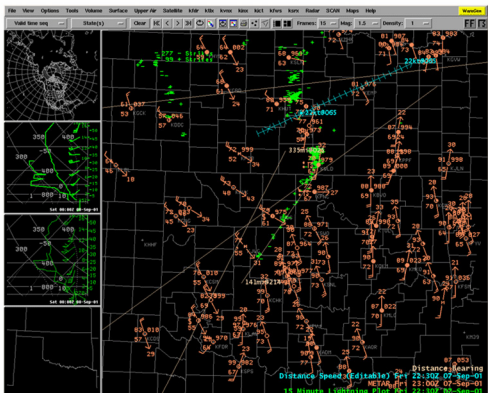
43. Sept 07, 2001 case

Instructor Notes:

Student Notes:

Sept 07, 2001 case

2230 UTC LTGCG and Metars with frontal motion near END



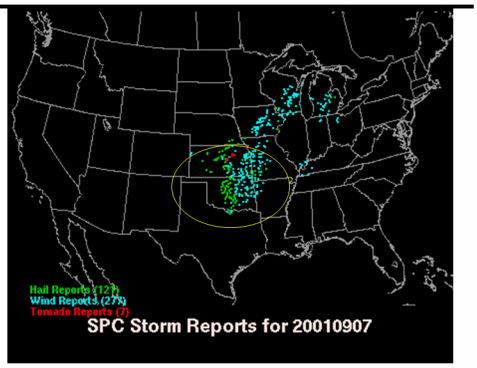
44. Sept 07, 2001 case

Instructor Notes: Boundary orientation relative to mean wind and shear appeared to influence convective mode, another consideration to lifting characteristics and your threat assessment.

Student Notes:

Sept 07, 2001 case

Only tornadoes occurred in KS. Rest of the line consisted of severe hail and wind.



45. Depth of Ascent Zone

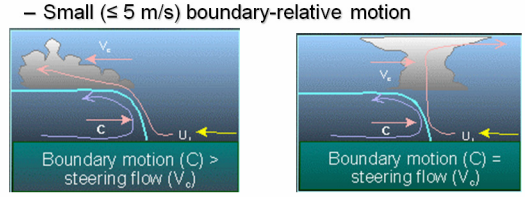
Instructor Notes: This theory is based on Rotunno, Klemp, and Weisman (RKW) numerical simulation studies from the 80s and early 90s. It is based on horizontal vorticity arguments. The key to maximizing residence time of a parcel in the ascent zone is to ensure it reaches the LFC. (See http://meted.ucar.edu/mesoprim/shear/frameset.htm). These theories apply to density current boundaries. Density current boundaries include strong fronts, seabreeze boundaries and outflow boundaries. Deepest ascent occurs when boundary orthogonal environmental shear balances cold pool vorticity (Rotunno et al. 1988), or when the boundary speed (C) cancels out positive shear magnitude (UL). C/UL ~ 1. When the boundary-normal (or orthogonal) component of the shear is oriented forward away from the cold side of the boundary (positive shear) and it has the same

magnitude as the forward speed of the boundary, the conditions are optimal for the strongest, most vertically oriented ascent zone. That is C/ Delta UL ~ 1. This is graphically shown in the right side schematic. What often occurs is shown in the left side figure where the shear vector is directed front to rear of the boundary (negative shear). In that case, no balance occurs in C/ UL and the ascent zone becomes much shallower. When a boundary does not have any density current characteristics, the shear considerations do not apply in the sense in which they were presented. In some sense shear is still important since boundary-normal shear can be too strong potentially ripping apart an ascending zone of air before it can reach the LFC. There is another way to look at the potential depth of an ascent zone. Given an ascending air column reaching toward the LFC, what kind of flow aloft will favor the ascending air column to remain over the boundary for the longest time? And what kind of flow aloft should be considered useful? These are important questions. Some of this was covered in lesson 2 of this IC.

Student Notes:

Depth of Ascent Zone

- Key is to maximize residence time of parcel in ascent zone to ensure parcel reaches the LFC
  - Related to deep layer shear but also could be any boundary
  - Small (≤ 5 m/s) boundary-relative motion



Destructive to lifting **Promotes deeper lifting**

46. Determining Depth of Ascent Zone: 3 main factors

Instructor Notes: This is a summary of topics covered related to determining the ascent zone.

Student Notes:

Determining Depth of Ascent Zone : 3 main factors

1. Maximize low-level headwinds
   - Applies to density current boundaries
   - Not necessarily strong convergence
2. Boundary-orthogonal shear
   - For isolated storms (eg. supercells), like to see rear-to-front flow from 2-3 km through 10 km equal to boundary motion
3. Boundary-orthogonal mean flow
   - For isolated storms, best if this value is ≤ 5 m/s

47. Summary Lesson 2

Instructor Notes:

Student Notes:

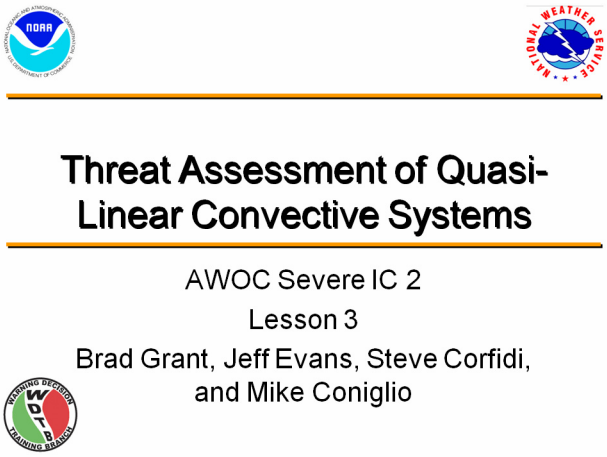
Summary Lesson 2

- Factors in assessing lift
  - Boundary-relative flow, shear/cold pool relationships
- Types of lifting
  - Synoptic or mesoscale
- Orientation of lines of forcing
  - Can affect intensity and longevity of storms

1. Threat Assessment of Quasi-Linear Convective Systems

Instructor Notes: Welcome to a brand new lesson in the AWOC Severe Track. This lesson is on environmental threat assessment of Quasi-Linear Convective Systems (or QLCS). It is Lesson 3 of Instructional Component 2 in the AWOC Severe Track. My name is Brad Grant, Team Leader of the Warning Decision Training Branch. I will be narrating this lesson along with the other meteorologists listed on this slide, who have been the primary content collaborators for this lesson.

Student Notes:



2. Rationale

Instructor Notes: So, why do we need to learn about QLCS Events? The answer is that many long-lived multicell convective systems have a propensity to take lives and damage property with high winds, hail, and tornadoes. Damage often occurs over a broad swath encompassing multiple county warning areas. Danger to public in these situation is obvious and often more extreme, impact-wise, than a single tornado storm. Challenges for a warning forecaster on the threat assessment level include: Recognition of the intensity of these type of events Determination of duration and movement, and Determination of all the threats associated with these type of events. In this lesson, which is a companion to the storm interrogation module in IC Severe 3 on recognition and detection of QLCS storm-scale features, we are going to treat many of these challenges associated with forecasting QLCS events.

Student Notes:

Rationale

Why Learn about QLCS events?

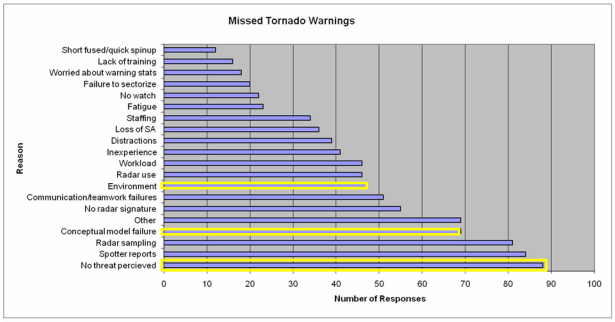
1. Intensity
2. Duration
3. Multi-threat Potential

3. What is the Link to Warnings?

Instructor Notes: When individual forecasters analyze the root cause for missed tornado events, like this chart from AWOC Core (2004-05), one of the reasons frequently cited for missing events is the lack of a perceived threat. This can be a result of a number of things, including aspects of environmental analysis , or a failure of a conceptual model. In the case of QLCS events, the ability to use a correct conceptual model to recognize threats typically associated with the events is a big part of successful threat assessment.

Student Notes:

What is the Link to Warnings?

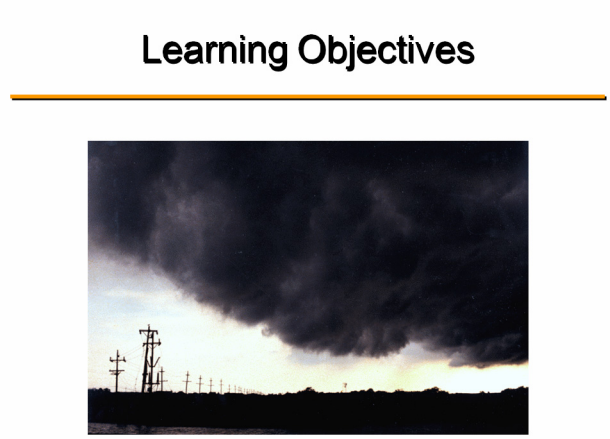


4. Learning Objectives

Instructor Notes: For this lesson on threat assessment of QLCS events, we have identified 6 learning objectives, as listed in the speaker notes: Identify some of the key features found in conceptual models of QLCS events. Identify the types of QLCS events that produce the most intense impacts. Identify parameters for evaluating the severity of QLCS events. Identify discrimination capabilities of parameters used in forecasting

QLCS events. Identify patterns/parameters that affect longevity of a QLCS. Determine motion of a QLCS (both forward propagating and backward).

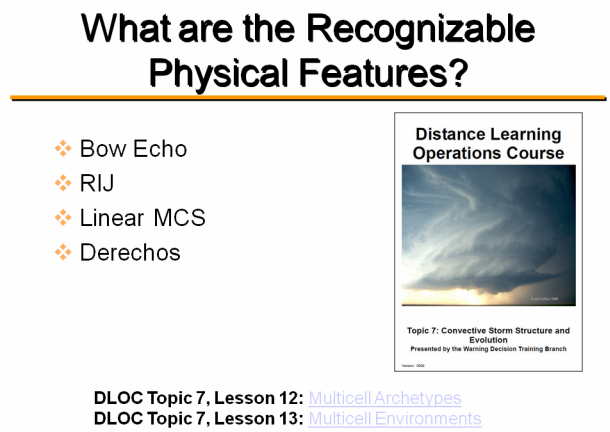
Student Notes:



5. What are the Recognizable Physical Features?

Instructor Notes: An understanding of the primary features and associated physical processes of some of the well-accepted conceptual models of long-lived multicell convective systems is essential to evaluating QLCS environmental threats. Most of the physical features listed here have been identified in various conceptual models. Well-known radar features like the Bow Echo and Rear Inflow Jet have been described in previous training lessons such as DLOC Topic 7 Lessons 12 and 13. If you haven't taken these modules in a while, it would be worth your time as these features are discussed in more detail.

Student Notes:



6. Conceptual Model #1

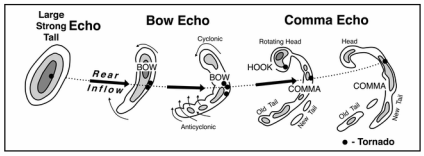
Instructor Notes: Conceptual models of quasi-linear convective systems span several years. One of the earliest models was Fujita (1978), who defined the evolutionary stages

of convective development from conventional radar signatures as in the image shown on this slide. There was an initial large, strong echo which developed into a bow echo with cyclonic and anticyclonic rotation , and then into a comma shaped echo. The bulging portion of the line of echoes was termed a “bow echo” , which he said was produced by thunderstorm downburst winds. Fujita also noted cyclonic and anticyclonic circulations at the ends of the bowing segments. Later bow echo researchers such as Weisman (1993) referred to these counter rotating circulations as “bookend vortices.” This early conceptual model fit well with other models on squall line type bow echoes and presented that the bow echo bulge was associated with a strong rear-inflow jet. There was also important work conducted on discriminating the location of tornadoes with bow echoes (black dots in this figure).

Student Notes:

Conceptual Model #1

The Bow Echo



Based on Fujita (1978)… from Wakimoto et al. (2006)

7. Conceptual Model #2

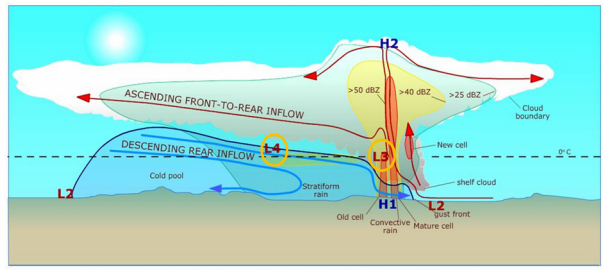
Instructor Notes: Smull and Houze, as well as other researchers, examined a number of squall lines using radar data and concluded that the bulge and associated concavity seen in Fujita’s bow echo was directly related to the rear-inflow jet. How did the RIJ form the bow echo? By doing two things: 1) advecting part of the squall line forward and 2) entraining dry air into the rear flank which then erodes the back side of the echo through evaporation of hydrometeors. They developed a complex conceptual model of a mature squall line within a Mesoscale Convective System (or MCS) that included a large anvil and a cold pool that modulated the pressure field from the surface to upper levels. The development of the RIJ was attributed to midlevel, mesoscale areas of low pressure (labeled L3 & L4). The RIJ transported strong buoyant ambient air to the anvil. The mesolow “L3”, formed immediately behind the leading line convection, was a hydrostatically-induced negative pressure perturbation that develops under up- shear tilted warm convective updrafts and above the attendant cooled downdrafts. Midlevel mesolow “L4” forms in the stratiform region in between the warm buoyant air which gets pulled rearward past the cool, dry descending air flow. Note that there are can be significant differences in the evolution of multicell systems based on the strength of the cold pool, ambient shear, and attendant RIJ. But one thing appeared to be clear, the RIJ could push descending air all the way to the front of the leading line in the most extreme, long lasting

situations. As more details emerged from examining the thermodynamic structure within a mature mesoscale convective system containing a squall line, the focus in research switched to numerical simulations and the role of the cold pool and ambient shear.

Student Notes:

Conceptual Model #2

The Rear-Inflow Jet (RIJ)



Modified from Smull and Houze (1985)

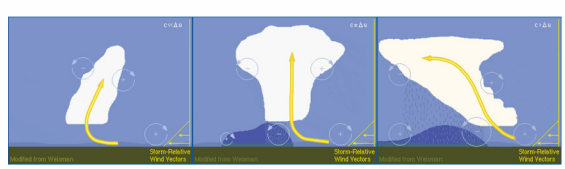
8. Conceptual Model #3

Instructor Notes: Modeling studies by Weisman suggested that shear in the lowest 2.5 km and the strength of the cold pool controlled the orientation of the rear-inflow jet . A typical transition shows ideally what takes from an initial surface based convective element to a multicell. Discrete multicellular convection initiates from forcing, and slowly generates a cold pool that builds in strength over time. Multicell forcing may be dominated by either external forcing or updraft induced dynamic pressure gradients. Eventually the cold pool may take control of the multicell including both the initial forcing and its embedded updraft forcing. How long it takes for the cold pool to dominate matters depends on how strong the cold pool becomes compared to the vertical wind shear and the strength and orientation of the initial forcing.

Student Notes:

Conceptual Model #3

Role of Cold Pool and Shear



Initial convection and weak cold pool

Cold pool forms and balances with inflow shear

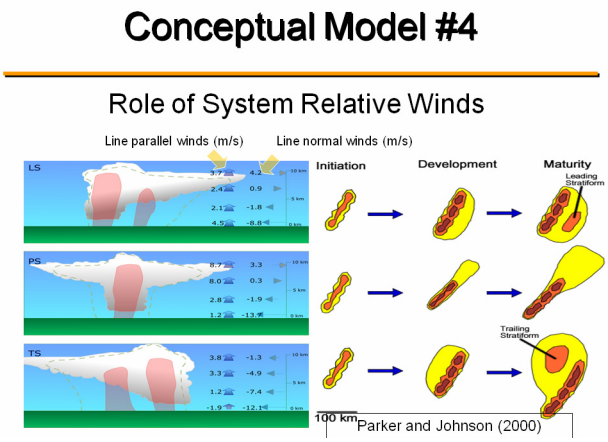
Cold pool grows to dominated the multicell

From Weisman (1992)

9. Conceptual Model #4

Instructor Notes: One of the most recent conceptual models of MCS and how they develop are from Parker and Johnson (2000). Although MCSs develop a number of ways, typical mature systems contain convective and stratiform precipitation regions. The eventual MCS type is determined to a large extent by the environmental conditions in which it develops and the strength of the system cold pool. Parker and Johnson studied numerous MCSs and determined the distribution of hydrometeors and stratiform precipitation shapes were largely a result of mean storm-relative winds. The speed and direction of the environmental mid- and upper-level winds relative to system motion affect the resulting evolution of the MCS. According to their studies, Parker and Johnson (2000) found MCS squall lines evolve into three major archetypes (shown in their modified figure from top to bottom): 1) Leading Stratiform, 2) Parallel Stratiform, and 3) Trailing Stratiform. The main distinction arose from storm-relative flow fields. For more details on these three multicell archetypes, please refer back to Lesson 12 of DLOC Topic 7. More recent conceptual models of QLCS events, especially on the storm scale, will be presented in parts of AWOC IC Severe 3: Storm Interrogations.

Student Notes:

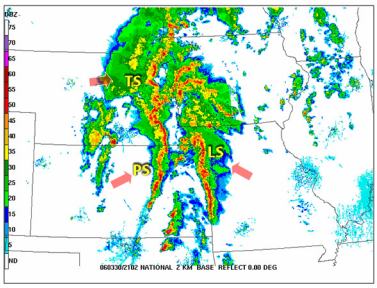


10. Linear MCS Archetypes Examples

Instructor Notes: This figure shows an example of all three archetypes occurring simultaneously ahead of an ejecting strong upper-level shortwave trough. Each MCS formed from a different boundary. The TS formed on a stationary front north of the surface low, the PS formed on a dryline, and the LS formed on what may have been a residual outflow boundary with the cooler air to the east (French and Parker, 2006).

Student Notes:

Linear MCS Archetypes Examples

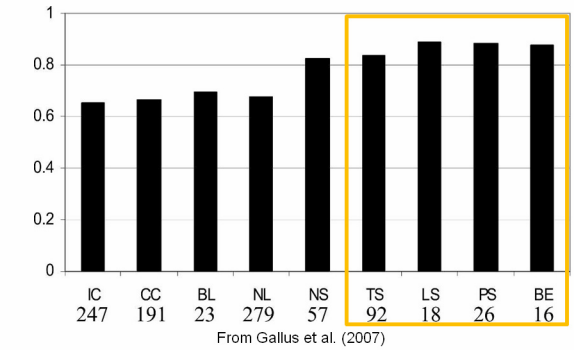


11. Threats from Various Types

Instructor Notes: While we can to some degree distinguish (after the fact) environments and radar morphologies of resulting QLCS events, an important point is that ALL types can produce severe weather . This graph from a study by Gallus et al. shows the percentage of storms with at least one severe report (not including flooding), organized by morphology. The morphology TS, LS, and PS are similar to Parker and Johnson's notation. BE is for Bow Echoes. The numbers of events of each type are shown beneath the morphology codes.

Student Notes:

Threats from Various Types



12. Can We Discriminate Intensity of QLCS Events?

Instructor Notes: To identify the types of QLCSs that produce the most intense impacts, you must evaluate forcing, shear (at low, mid- and upper-levels), CAPE, especially in the region supporting updraft parcels, and especially, the potential for downwind cell propagation.

Student Notes:

Can We Discriminate Intensity of QLCS Events?

- Evaluation of:
  - Forcing
  - Shear (System-Relative Flow at multiple layers)
  - CAPE
  - Downwind cell propagation

13. Role of Forcing and Orientation

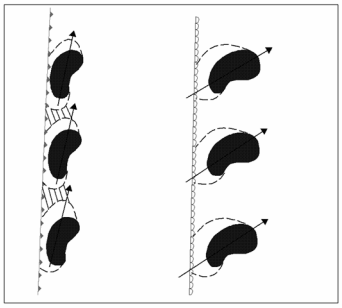
Instructor Notes: Large multicells are more apt to exhibit a linear nature to them reflecting the elongated lifting that commonly occurs along external forcing mechanisms (e.g., fronts), and internally generated cold pool boundaries. Fronts offer a linear nature to forcing, however multicells may not merge into a long line if the forcing is weak. If the deep layer shear is largely boundary-parallel (such as the left-most evolutions) individual cold pools may more easily merge, reinforce the front, and enhance upscale growth into a long line. In terms of forcing, the next image is a similar depiction showing the initiation of storms in two different flow regimes relative to a boundary. The dark arrows represent the mean cloud-layer wind and shear vector orientations, the shading represents precipitation regions, the dotted lines are convective outflow and the hatched areas indicate where new development is likely as convective outflows merge (from Dial and Racy, 2009). Once again, the most intense QLCSs likely develop from the orientation shown on the left. Note that both of these results are most relevant in situations along well defined, linear boundaries and most appropriate during the developing stages of the QLCS.

Student Notes:

Role of Forcing and Orientation

Need deep-layer shear that's mostly boundary-parallel

Most relevant for
- Linear boundaries
- Developing stages

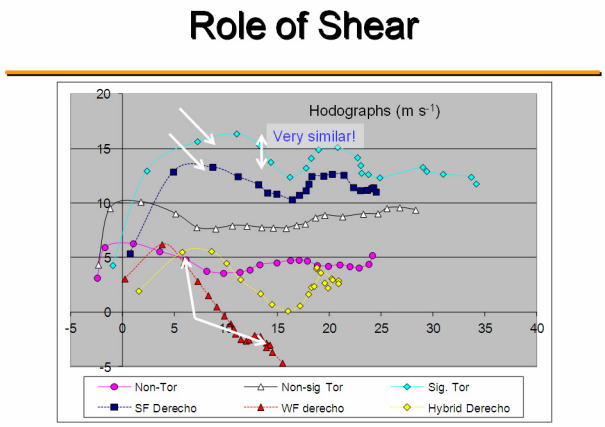


Dial and Racy (2009)

14. Role of Shear

Instructor Notes: This plot of composite hodographs from Evans and Doswell (2002) illustrates differences in mean wind profiles associated with derechos (dashed lines) and discrete supercells (solid lines). The hodographs were created from proximity soundings near 65 derechos, stratified by synoptic-scale forcing strength, and 100 supercells divided into: non-tornadic, F0-F1 tornadoes, and those producing F2 or greater tornadoes. The differences in these mean hodographs indicate that shear plays a very important role in helping determine the organization potential and any ensuing severe threats. The SF derechos (dark blue dashed line) occur in stronger flow and shear than the other derecho categories, while the WF Derechos (red dashed line) commonly occur in weaker shear environments. In addition, the mean WF derecho hodographs indicate weaker and more uniform nwly flow at mid and upper levels. In comparison, the significant tornadic supercells (lt. blue solid line) have much longer hodographs and more substantial low and deep layer shear. However, it important to note the similarities between the SF derecho and tornadic supercells mean wind profiles. In fact, the SF derecho average falls well within the range of shear magnitudes and hodograph structure associated with discrete supercells producing significant supercells! Shear, though a necessary ingredient, will not provide ample forecasting clues regarding the impending mode of expected thunderstorms. It is very important to consider the nature of initiation and storm motion/ speed relative to the initiating boundary when dealing with events in strong synoptic-scale forcing.

Student Notes:



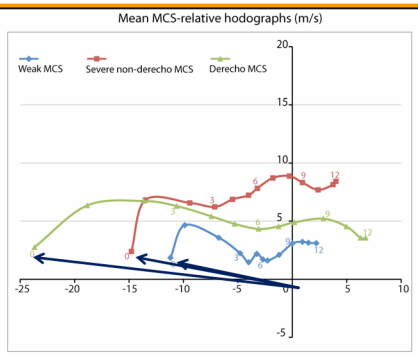
15. Can We Discriminate Intensity of Events?

Instructor Notes: To address the question of distinguishing run-of-the-mill MCSs from high-end events, the figure shown is a graphic of mean MCS-relative hodographs from a proximity sounding data set of 55 weak MCSs (shown in blue), 78 severe but non-derecho MCSs (show in red), and 51 derecho MCSs (shown in light green) that were taken in the downshear environment during the developing stages of the systems. This analysis is based on the data set described in Cohen et al. (2007) in W&F. The mean

hodograph clearly shows that shear becomes more stretched and straight-line along the x-axis (MCS-motion) as you go from the weak MCSs to the derecho MCSs (the colored numbers along the hodographs are kilometers Above Ground Level (AGL)). You can also see the huge increase in low-level storm-relative inflow for the derecho MCSs.

Student Notes:

Can We Discriminate Intensity of Events?



16. Role of CAPE

Instructor Notes: The role of convective instability is multifaceted. Not only is sufficient CAPE necessary to maintain intense updrafts along the leading edge of the cold pool, but the larger the CAPE the more intense the updrafts and resultant supply of moisture and energy to the overall MCS. This in turn increases the subsequent downdrafts and strengthens or at least maintains the cold pool momentum. If CAPE weakens or the out-flow surges into an environment of little or no CAPE and/or significant convective inhibi-tion, then the convective system would quickly lose its energy source and diminish-sometimes quite quickly.

Student Notes:

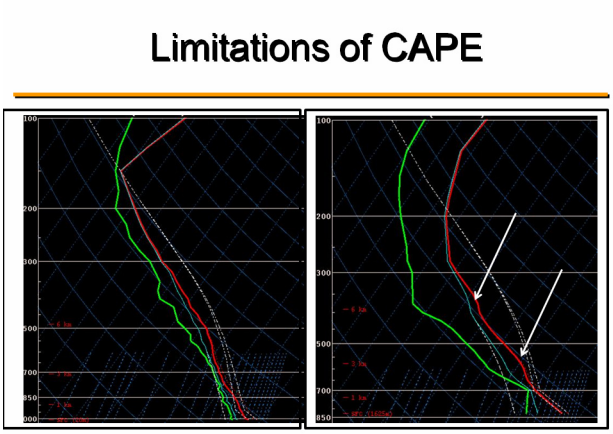
Role of CAPE

- **Necessary to maintain updrafts along leading edge**
- **Increases downdrafts and maintains cold pool momentum**

17. Limitations of CAPE

Instructor Notes: There are a couple of caveats of using CAPE. CAPE alone can be misleading, and is most relevant when used in combination with environmental lapse rates or lifted-indices. For instance, one can derive equal amounts of CAPE from a deep, moist sounding (shown on the left) and a more typical mid-latitude Spring-like sounding shown on the right. However, the steep lapse rates in the second sounding would be expected to support greater vertical motion within the ensuing updraft and stronger/colder downdrafts. In addition CAPE is very dependent on the lifted parcel choice. Craven et al. 2002 found that lifting a 100-mb mixed parcel was most representative of cloud heights near peak heating.

Student Notes:



18. Other Factors Related to QLCS Maintenance

Instructor Notes: To anticipate high-end QLCS events, it is important to identify environments that are conducive to rapid, downwind cell propagation near an existing thunderstorm or a group of storms. "Downwind cell propagation" is simply the development of new thunderstorms on the downwind side of existing convection. Environments that foster rapid downwind propagation are those that allow incipient convective systems to continuously redevelop --- and potentially grow upscale. Such systems are more likely to produce large-scale bow echoes, MCVs, and severe weather. Although many factors ultimately govern the rate and location of new cell development relative to existing storms, downwind propagation is especially encouraged by the presence of the following:

Student Notes:

Other Factors Related to QLCS Maintenance

- **Rapid downwind cell propagation**
  - **Increases system likelihood of:**
    - Large Bow Echoes
    - MCVs
    - Severe Weather

19. Other Factors Related to QLCS Maintenance

Instructor Notes: (1) Rich boundary layer moisture --- Moisture-rich air fosters new storm development by lowering the LCL and enhancing precipitation drag (2) Steep low-level lapse rates --- Steep lapse rates enhance both CAPE and downward momentum transfer (3) Minimal Convective Inhibition or CIN --- The potential for storm initiation is maximized when CIN is low (4) Fast cloud-layer flow --- Fast flow increases gust front speed by strengthening storm outflow; fast flow also fosters the development of embedded supercells and their associated severe threats (5) Deeply unidirectional flow --- Unidirectional flow encourages elongation of the system cold pool in a preferred direction, thereby enhancing storm-relative inflow in that direction (6) Slightly-backed near-surface winds relative to the mean flow --- Backed low-level winds enhance storm-relative inflow and the rate of downwind cell development

Student Notes:

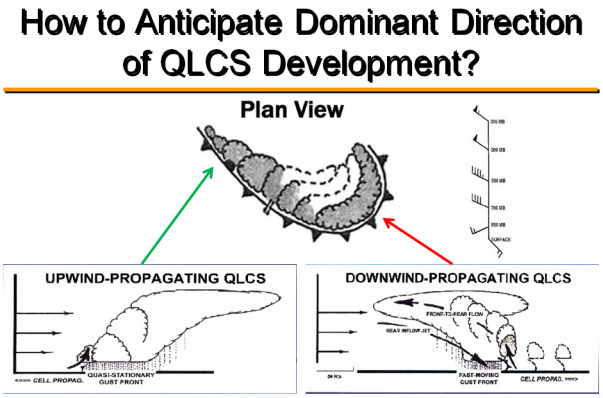
Other Factors Related to QLCS Maintenance

- Factors encouraging downwind propagation
  - Rich BL moisture
  - Steep low-level lapse rates
  - Minimal CIN
  - Fast cloud-layer flow
  - Deep unidirectional flow
  - Slightly backed near-surface winds relative to the mean flow

20. How to Anticipate Dominant Direction of QLCS Development?

Instructor Notes: The previous slide noted that unidirectional flow encourages elongation of convective system cold pools along the direction of the mean flow. As a cold pool elongates, a portion of its associated gust front necessarily becomes oriented perpendicular to the flow, while the other part comes to lie parallel to it. This process is shown schematically for unidirectional northwest flow in the plan view at the top of the slide. Recurring production of storm outflow along the part of a gust front oriented perpendicular to the mean wind --- and downward momentum transfer --- cause that part of the gust front to move steadily downwind with time. This is shown on the right side of the plan view in the slide. In contrast, the flow-parallel portion of the boundary moves very slowly or not at all, as shown on left side of the plan view. The orientation of the gust front relative to the mean flow is important in determining the direction of cell propagation and, therefore, the type of MCS that will be most favored along it.

Student Notes:



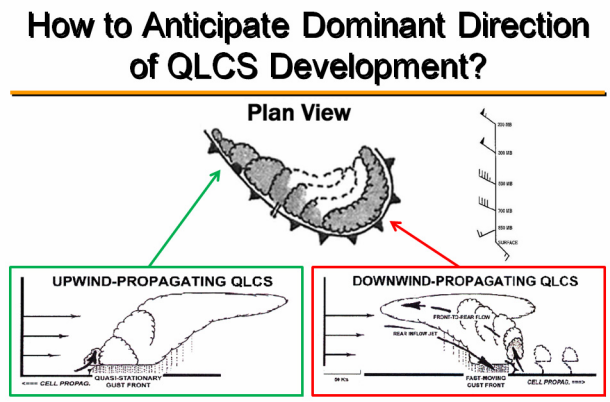
Corfidi (2005)

21. How to Anticipate Dominant Direction of QLCS Development?

Instructor Notes: If low-level convergence and the thermodynamic environment are favorable for new cell development along the flow-parallel portion of the gust front, a back-building or regenerative MCS is likely to develop, as shown in the lower left inset of the slide. Such convective systems are best known for their ability to produce excessive rainfall as storms "train" or move repeatedly along the stationary boundary. But if sufficient cloud-layer shear is present, embedded supercells and LEWPs (line echo wave patterns) may yield damaging winds and tornadoes, especially when the moisture content is great. If convergence and instability are favorable for storm development along the flow-perpendicular part of the gust front, a downwind-developing or "forward-propagating" MCS is likely to form, as seen in the lower right inset. Because new storm development occurs in the direction of the mean wind, the convective system can move faster

than the mean flow. Such systems may evolve into a bow echo or derecho-producing MCS if the rate of forward propagation is great --- and this condition persists.

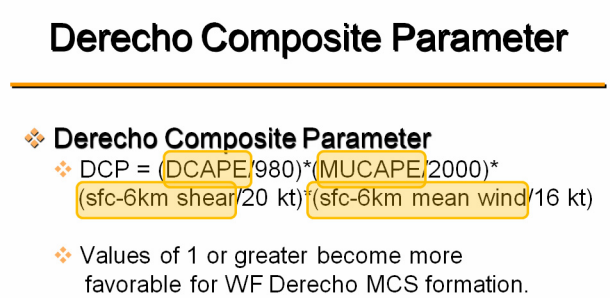
Student Notes:



22. Derecho Composite Parameter

Instructor Notes: As forecasters attempt to differentiate between typical warm season, non-severe MCS development versus a forward-propagating/accelerating-Derecho MCS, SPC developed a parameter that is based on 113 Derecho soundings from ED01. This parameter examines four primary mechanisms discussed previously for MCS forward propagation development: 1) DCAPE, used as a proxy for cold pool strength and/or strong downdraft production, 2) MUCAPE- was used as a proxy for the ability to sustain strong storms along the leading edge of the gust front, 3) Surface to 6 km shear, used to account for potential of organization , and 4) Surface to 6 km mean wind to account for favorable ambient flow to elongate the cold pool in a favored downshear direction. Similar to other composite indices developed at the SPC, a value of 1 or greater becomes favorable for a weak forcing Derecho development. Each of these parameters was 'normalized' by mean values developed from the ED01 proximity sounding dataset. DCP = (DCAPE/980)*(MUCAPE/2000)*(sfc-6 shear/20 kt)*(sfc-6 km mean wind/16 kt)

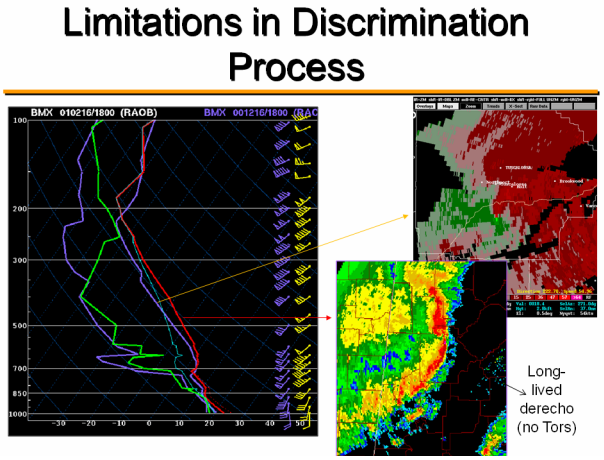
Student Notes:



23. Limitations in Discrimination Process

Instructor Notes: As mentioned in earlier slides, there are many limitations to discriminating what mode storms will develop and evolve into, and what specific severe threats will ensue. This is especially true when dealing with very dynamic events associated with strong large scale ascent and pronounced low and deep layer shear- which are typical from Fall into late Spring. Despite very favorable wind profiles for discrete tornadic supercells, limited thermodynamic support and/or the nature of initiation may force storms to evolve in the form of a fast moving QLCS. For instance in cases where capping remains strong in the warm sector, development may remain tied to a fast moving surface boundary. Also, many times the mean storm motion vector is not sufficient in magnitude and/or direction to move updrafts away from the initiating feature. The images shown here are an example of how similar environments can produce distinctly different thunderstorm modes and severe weather. These are two proximity soundings: 1) near the F4 tornado which struck Tuscaloosa, AL on Dec. 16th, 2000 (in purple), and 2) near the long-lived derecho MCS which produced widespread wind damage and one fatality (but no tornadoes) as it swept across central AL on Feb 16th, 2001 (red/green and yellow wind barbs).

Student Notes:



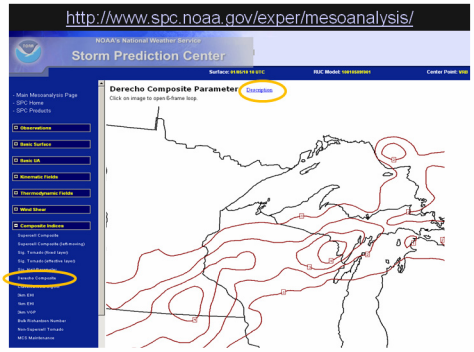
24. Operational Uses

Instructor Notes: The mesoscale analysis page from the Storm Prediction Center can be found at the URL shown above, and has been developed to aid forecasters assess the severe threats evolving over the next 0-3 hrs. The SPC runs a 2-pass Barnes surface objective analysis around 5 min after each hour, using the latest RUC forecast as a first guess. Next, the surface data is merged with the latest RUC forecast upper-air data to represent a 3-dimensional current objective analysis. Finally, each grid point is post-processed with a sounding analysis routine called NSHARP to calculate many technical fields related to severe storms. The parameters are organized under their primary uses on the left hand of the page under the yellow headers. In the case displayed here, the

‘Composite indices’ sub-menu is expanded to display the available fields. A description of each field is available near the top center of each page for each of the parameters.

Student Notes:

Operational Uses



25. Revisiting the Key Points

Instructor Notes: To revisit some of the key points made in the lesson: QLCS events can be described as intense, multi-hazard events that are based on many conceptual models with recognizable features such as rear-inflow jets, bow echoes, linear MCSs, and derecho producing windstorms. The recognition of these features are typically made by evaluating the following parameters , which have been shown to play important roles in helping determine severity and duration: Forcing - look for deep layer shear that’s mostly boundary-parallel, Shear - longer straighter hodographs favor the QLCS derecho producing windstorm types, but, the pattern can be similar to supercells. You need to carefully consider the nature of the convective initiation and the storm motion relative to the forcing to help evaluate the role of this factor for each event.

Student Notes:

Revisiting the Key Points

1. Forcing
   - Look for deep shear parallel to boundary
2. Shear
   - Longer, straighter hodographs favor the QLCS derecho producing windstorm types, but... pattern can be similar to supercells

26. Revisiting the Key Points

Instructor Notes: Key Point 3) CAPE- A multifaceted, necessary parameter related to strength of updrafts along the leading edge of the cold pool and strength of subsequent downdrafts. CAPE helps quantify intensity of updraft, and how the system is provided a supply of moisture and energy . Note that computed amounts of CAPE can be misleading when trying to use this variable as a discrimination variable for convective mode.

Student Notes:

Revisiting the Key Points

3. CAPE
   - Updraft strength
   - Cold Pool momentum
   - Amounts can be misleading

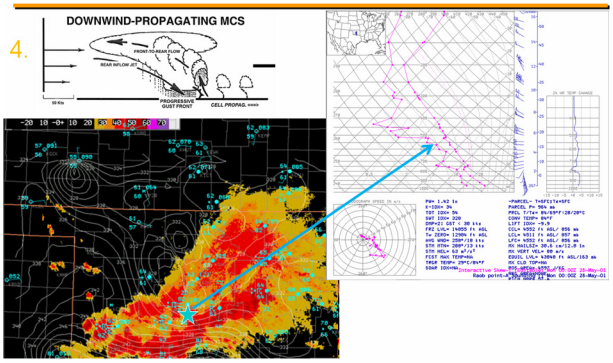
27. Revisiting the Key Points

Instructor Notes: And finally, the 4th Key point: Downwind propagating MCS. Remember that the development of rapid, downwind cell propagation is tantamount to estimating QLCS intensity. Factors such as rich, boundary-level moisture, steep, low-level lapse rates, minimal CIN, fast, cloud-layer flow, deep, unidirectional flow, and slightly backed near-surface winds relative to the mean flow are ALL factors that favor the development of this situation. The example shown is from forward propagating MCS from May 28, 2001 in Oklahoma.

Student Notes:

Revisiting the Key Points

4.



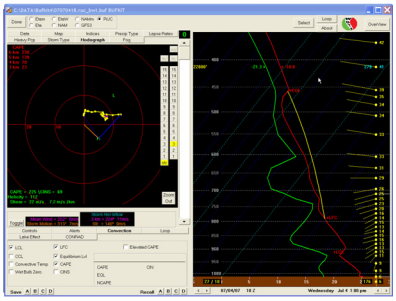
28. Revisiting the Key Points

Instructor Notes: Finally, the SPC has several parameters to help you discriminate if QLCS –type of events are the most intense and long-lasting. You should use these to help assess threats associated with QLCS events. And remember, there are limitations in our science of forecasting convective mode and eventual evolution, as well as determining specific threats due the fact that these parameters don't always tell the full story. Use of the SPC Mesoanalysis Page (http://www.spc.noaa.gov/exper/mesoanalysis/) as well as Model Forecast Sounding applications like BUFKIT are some of our best forecasting tools to assess subtle changes in the mesoscale environment which can influence modality changes.

Student Notes:

Revisiting the Key Points

- Maintenance
- Limitations



29. Contact Information

Instructor Notes:

Student Notes:

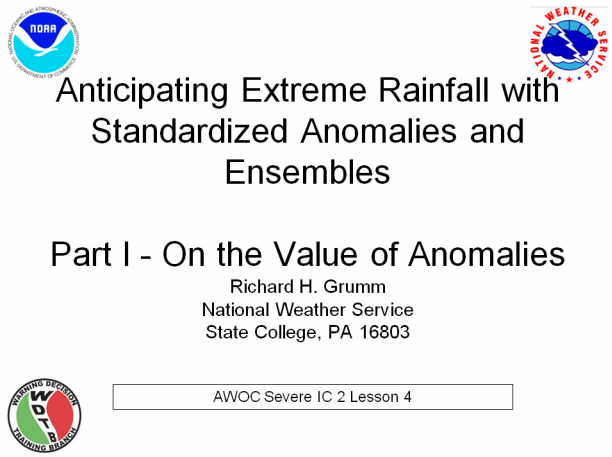
Contact Information

- awocsevere_list@wdtb.noaa.gov
  - Questions on any AWOC Severe lesson
- bradford.n.grant@noaa.gov
  - 405-325-2997
  - Questions on this lesson

1. Anticipating Extreme Rainfall with Standardized Anomalies and Ensembles Part I - On the Value of Anomalies

Instructor Notes: Hello, and welcome to the module on Recognizing High Impact Hydro Events. The first part of this module is on anticipating extreme rainfall with standardized anomalies and ensembles. In this part I will specifically talk about anomalies. I'm Richard Grumm, and I'm the SOO at the National Weather Service Forecast Office in State College, PA.

Student Notes:



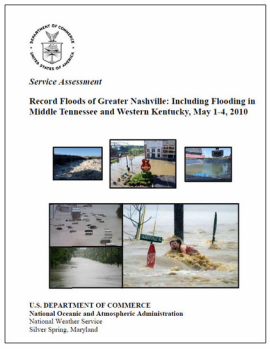
2. Motivation

Instructor Notes: This training evolved out of the Service Assessments of the Southeast US Floods and the Nashville Floods of 1-4 May 2010 and is related to several other significant flood events over the past few years. Our goal here is to aid in recognizing the potential of high end events using standardized anomalies to improve situational awareness. Improved Situational awareness should help users of our forecasts make better decisions and aid us in improving our products and services.

Student Notes:

Motivation

- Service Assessment of flood events
  - Southeast US Flood 19-23 Sept 2009
  - Nashville Floods 1-4 May 2010


Service Assessment

Record Floods of Greater Nashville: Including Flooding in Middle Tennessee and Western Kentucky, May 1-4, 2010

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
Silver Spring, Maryland

3. Objectives

Instructor Notes: These are our primary objectives: Never under estimate the value of knowing antecedent conditions prior to any rainfall event. Standardized anomalies often provide strong signals in the larger scale flooding events and may aid in distinguishing meteorological significant events from ordinary events. There are limits to standardized anomalies, especially with more mesoscale events. Finally, and in a separate lesson we will apply these concepts to models and ensembles. You will be amazed how one cannot distinguish an observed anomaly from a forecast anomaly!

Student Notes:

Objectives

- Understand the role of antecedent conditions in flood events
- Understand how standardized anomalies aid in identifying the potential for heavy rain and flooding
- Understand the limits of standardized anomalies in the forecast process and in heavy rainfall events
- Understand how standardized anomalies and ensembles can provide confidence in forecasting flood events

4. Role of Antecedent Conditions

Instructor Notes: It is very important before the onset of a heavy rain event to know the antecedent conditions. During prolonged periods of dry weather we all know rivers and streams have low flows and can generally handle more water. During wet conditions flows are often higher to begin with so the response can be faster and less rainfall may be required to produce flooding. Terrain and land use and changes in land use can play a

significant role here too. Cold season events add the problems with ice and water in the snow pack!

Student Notes:

Role of Antecedent Conditions

Moorhead, Minnesota
Images courtesy of Minnesota Public Radio, Photos/Nathaniel Minor

5. Antecedent Conditions Impact Response to Heavy Rainfall

Instructor Notes: This simple list shows some historic events. Hurricane Connie primed the pump to put Diane in the record books despite similar rainfall amounts from both systems. The January 1996 snowmelt floods were associated with about a top 20 rainfall event for the month of January. Despite this it is one of the top 1 to 3 flood events of record at many sites in the Mid-Atlantic and northeastern US. And the historic Pakistani floods of 2010 were triggered by a single event which was actually the 4th heavy rainfall event in about 21 days. Many historic events involved a significant pattern and ideal antecedent conditions for a disaster.

Student Notes:

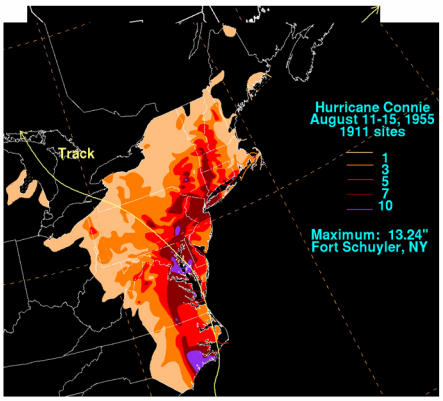
Antecedent Conditions Impact Response to Heavy Rainfall

- 1955: 11-15 August Hurricane Connie and Hurricane Diane 15-19 August 1955
  - Both produced heavy rainfall
  - Diane produced record floods
- January 1996: Snow melt floods
  - Warmth produced snowmelt with 3-5 inches of rain
  - Record floods
- Pakistan July 2010
  - Four successive heavy rainfall events
  - 4th one was devastating in late July

6. Connie and Diane Rainfall

Instructor Notes: Here is the rainfall for Connie and Diane, two tropical cyclones, flooding the heart-land. Hard to believe Connie produced so little flooding.

Student Notes:



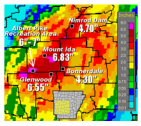
7. Standardized Anomalies

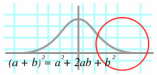
Instructor Notes: Standardized anomalies can be used to identify the pattern or “finger print” of extreme weather events. They can be used with re-analysis data to learn from past events or with forecast data to aid in predicting potential events. The anomalies put known patterns into context. Distinguishing a significant event from a more typical event. The method is not perfect and will often be of limited value in more mesoscale forced events. Additionally, there are limits of predictability and the higher the forecast uncertainty, more difficult it is to use anomalies at longer ranges. A key point too is that these data are not truly Gaussian. Thus, it is hard to make clean estimates of the return periods but rather the potential for an extreme end event.

Student Notes:

Standardized Anomalies

- Used in pattern recognition
- Predicting potential events
- Limited value for “mesoscale” events
- Events are not normally distributed





8. Phase Space of Heavy Rainfall: A Spectrum of Events

Instructor Notes: You should be familiar with the basic patterns associated with heavy rainfall. I keep the original Maddox paper at the ready! We will use these terms associated with these patterns in this lesson but we will not review the patterns. All of the known patterns are not clean and compartmentalized. The true phase space is a spectrum of events and these events can transition and interact the key is the wind and moisture fields. The names tell it all . Tropical cyclones interactions produce either a Synoptic pattern or a Frontal pattern. Predecessor Rainfall Events (PRE) can occur ahead of TC and change antecedent conditions before TC rainfall arrives! Frontal systems can turn into Synoptic-like patterns which caused the significant New England floods of March 2010.

Student Notes:

Phase Space of Heavy Rainfall:
A Spectrum of Events

- Tropical Synoptic
- Tropical Frontal
  - *May get Predecessor Rainfall Events (PRE) then full TC-front interaction.*
  - *PRE changes antecedent conditions*
- Frontal transitions to TC-hybrids
- Frontal (Synoptic) can transition to Synoptic (Frontal)

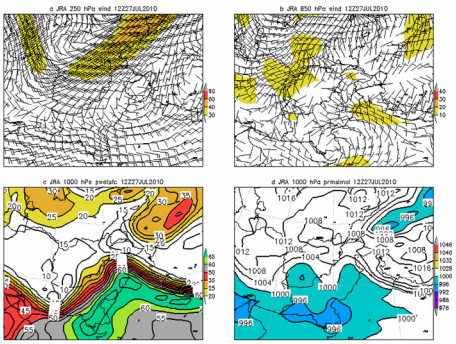
9. Easterly Flow High PW Pakistan July 2010 with wet antecedent conditions

Instructor Notes: This looks like a frontal pattern over India and Pakistan. As the pattern fades to the pattern with the anomalies, see how the anomalies add context. The mint-green PW over 60 mm is a 4-5 standard deviation PW anomaly. And those 850 mb easterlies are well above normal too!

Student Notes:

Easterly Flow High PW

Pakistan July 2010 with wet antecedent conditions

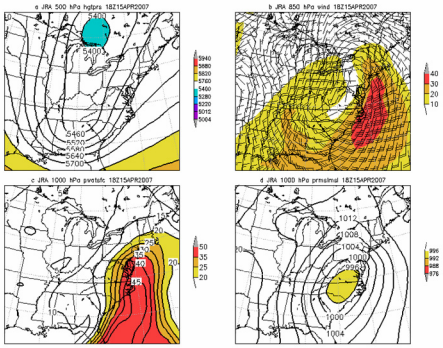


10. Features of a Maddox Synoptic Event

Instructor Notes: This rare event...which was top-5 rainfall in the Mid-Atlantic region occurred in April 2007. The 30-40kt 850 mb jet is 4 sigma above normal event and the 40-45 PW are a 3 sigma above normal event. The anomalies aid in pattern recognition and seeing above normal values in key parameters associated with heavy rainfall.

Student Notes:

Features of a Maddox Synoptic Event

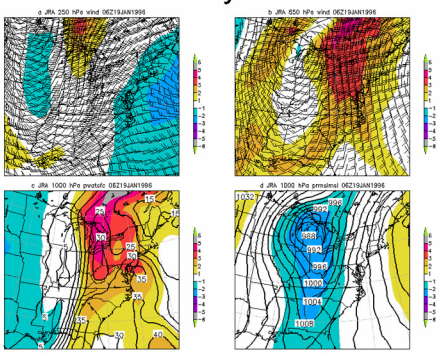


11. Synoptic-Snow Melt January 1996

Instructor Notes: Another great pattern, clearly a Maddox Synoptic event...produced 2-4 inches of rain in January 1996. A good rain event but not a record maker. But, the record snow pack released a lot of water in the surge of warm air before the rainfall creating an historic flood event. Fade to anomalies and see how anomalies work well but in conjunction with knowing the antecedent conditions can work even better!

Student Notes:

Synoptic-Snow Melt
January 1996



12. Anomalies Pattern Recognition and Context

Instructor Notes: The overall pattern provides the event type and the anomalies provide context. We want a method to distinguish an ordinary from an extraordinary event. The right pattern with big anomalies can aid in distinguishing between an ordinary and an extraordinary event. In and of themselves, anomalies do not provide the confidence information that ensembles and probabilities accomplish and this is covered in a separate lecture (Part II). We have a method where we can help distinguish significant events and high impact events.

Student Notes:

Anomalies Pattern Recognition and Context

- Pattern provides event type
- Anomalies provide context
- Distinguishes Ordinary from Extraordinary
- Not Confidence Information

13. Western US Pattern Atmospheric River 14 October 2009

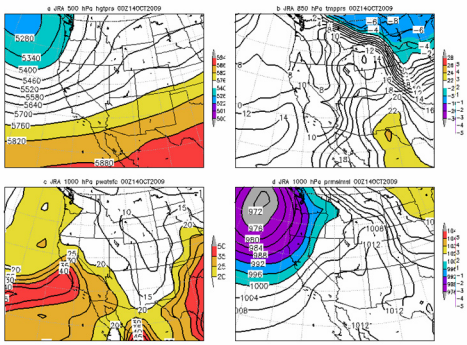
Instructor Notes: Note the high heights to the south and east indicating a strong ridge and the low heights to the northwest...the trough. The strong flow between these two systems produces the high PW surge seen in the lower left panel. Western US events are often well defined by PW plumes or atmospheric “rivers” into the terrain of the west-

ern US. As we fade from the pattern to the pattern with the anomalies the PW anomaly simply jumps out of the page at you! This was an incredible event from many perspectives. But the anomalies provided context.

Student Notes:

Western US Pattern

Atmospheric River 14 October 2009



14. Moisture Plume Strong Trough and Ridge

Instructor Notes: This loop shows the evolution of this impressive and historic storm from a pattern and anomaly perspective. Watch the evolution of the strong PW plume, the deep trough and strong winds into the western United States. Not to mention the anomalous surface cyclone.

Student Notes:

Moisture Plume

Strong Trough and Ridge

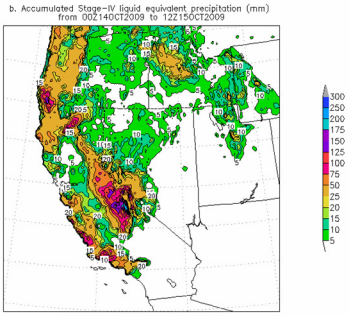
A separate window should appear containing a flash animation...

15. Rainfall over 250 mm in Mountains

Instructor Notes: And here is the rainfall. Other parameters with this event could include wind damage, severe weather, and record low pressure. It was an amazing event. The Western Region of the NWS did exceptionally well predicting this event using anomalies produced at Salt Lake City Office. Randy Graham is the WR and AR expert on anomalies and how to employ them to forecast record events.

Student Notes:

Rainfall over 250 mm
in Mountains



16. There is a Spectrum of Flood Events and Types

Instructor Notes: Take a minute to read this slide. The key point is… There is a spectrum of flood events and event types out there. Standardized anomalies can aid in identifying them and provide a context with which we can better predict high end weather events.

Student Notes:

There is a Spectrum of Flood
Events and Types

- We know about identifiable patterns associated with floods. We understand the patterns and features of big flood events.
- But the atmospheric phase space, like the climate and the model phase space is more complex.
- Anomalies provide a context.

17. Synoptic-Tropical Hybrid Never Underestimate the Power of Ridges

Instructor Notes: Here is another historic rain and flood event. We changed projection to see over the Atlantic for the trough-ridge interaction. It is always advantageous to know the pattern both up and down stream. The flow about anticyclones is often a key player in evolving PW plumes. Atmospheric rivers or moisture plumes come about ridges. As stated in Bodner et al (2011), many heavy rainfall events involve an anomalous upstream trough and an anomalous downstream ridge. The big picture is critical, the old Snellman funnel is always of value before you drill down.

Student Notes:

Synoptic-Tropical Hybrid
Never Underestimate the Power of Ridges

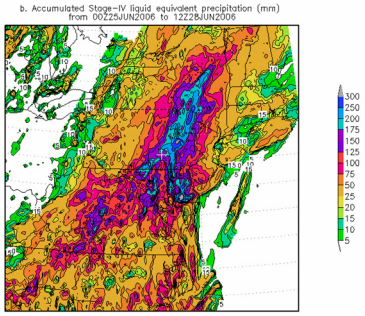
A separate window should appear containing
a flash animation…

18. Pattern of Heavy Rainfall Multi-day Event Persistent Pattern

Instructor Notes: The pattern from the previous slide produced a record multi-day rain event and significant flooding. Note how focused the axis of heavy rainfall was.

Student Notes:

Pattern of Heavy Rainfall
Multi-day Event Persistent Pattern

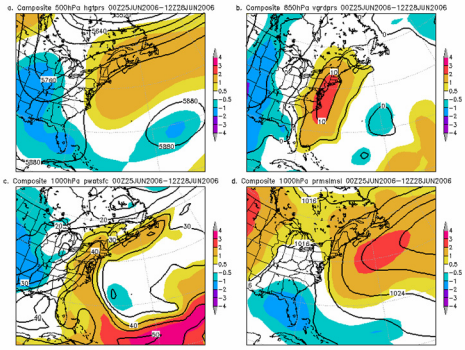


19. Persistent Anomalous Pattern

Instructor Notes: For long duration events, it is useful to look at the pattern and anomalies for periods of 12,24 and sometimes 72 hours. It is important to know if you are facing a long duration event. This image shows the pattern and anomalies over 3.5 days. This long duration pattern shows the strong subtropical connection of the moisture plume. We need forecast tools like this!

Student Notes:

Persistent Anomalous Pattern



20. The Simple Anomaly Context

Instructor Notes: Take a minute to read this slide… Okay ten seconds was all you needed. Surges of high PW air with strong southerly flow typically produce many of the high end rain events. Easterly wind events can also produce heavy rainfall. Moisture and strong low-level winds are critical. The larger the anomalies, the higher potential for a record or near record event. This implies the value of moisture flux in association with heavy rainfall events.

Student Notes:

The Simple Anomaly Context

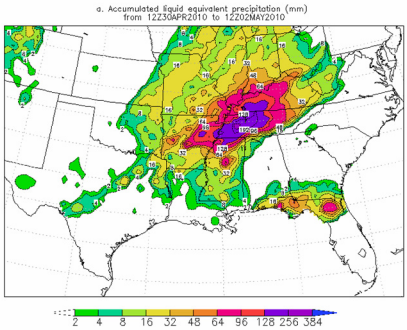
Pattern	Event Type	Anomalies
Moisture plumes ("Atmospheric Rivers")	High end heavy rain	2 to 4σ PW
Strong poleward flow	Synoptic	3-5σ v-wind
Strong easterly flow	TC or Frontal	3-5σ u-wind
Simplistically high moisture/High wind	Big rainfall	2 to 4σ Moisture Flux

21. Nashville Flood May 2010

Instructor Notes: Now we will look at the historic Nashville flood rainfall pattern over 48 hours. This was an impressive and enduring rainfall event over the Mid Mississippi Valley.

Student Notes:

Nashville Flood May 2010



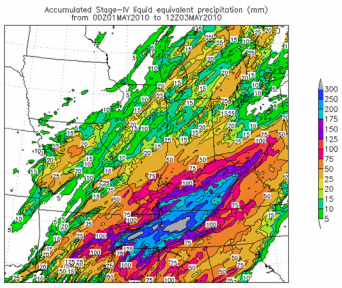
22. Nashville Flood Stage-IV data

Instructor Notes: Here is a zoomed view of the rainfall. Those blue colors show over 250 mm or 10 inches of rainfall. And those grays, like my hair, show over 300 mm or 12 inches of rainfall. This was an impressive rainfall event.

Student Notes:

Nashville Flood Stage-IV data

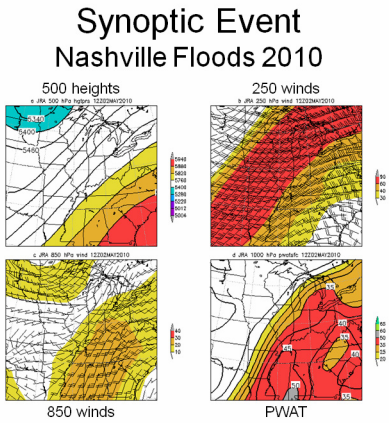
- Multi-day rainfall
- Note Southwest to Northeast rainfall
- Over 300 mm (> 12 in) over key basins



23. Synoptic Event Nashville Floods 2010

Instructor Notes: Here is the pattern over the region defined by the 500 heights, 250 winds, 850 winds and precipitable water. As we fade to the anomalies... The anomalies of this event provide context of the known heavy rainfall pattern. We will look a bit more at this…..

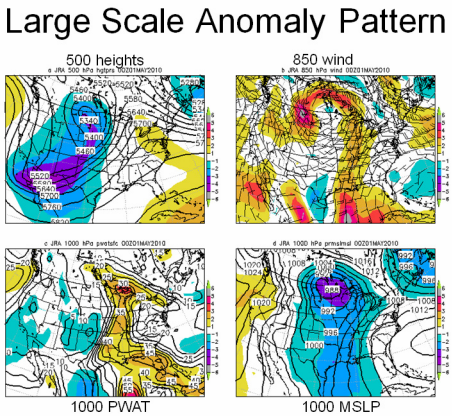
Student Notes:



24. Large Scale Anomaly Pattern

Instructor Notes: Watch the evolution of the large scale pattern over the United States during the event. Note the evolution of the deep trough to the west and the strong ridge to the east. This impacts both the low-level winds and surge of high PW air. Once we know the large scale pattern we can drill down to the local scale.

Student Notes:



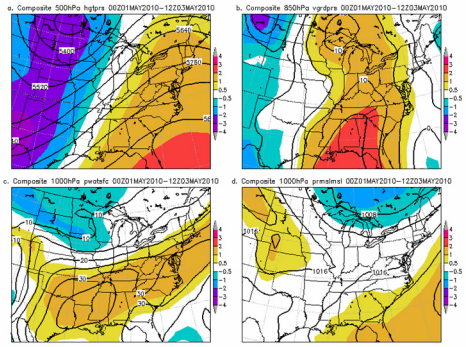
25. Composite Anomalies Persistent pattern for heavy rainfall

Instructor Notes: This is the composite pattern from the data used on the previous slide during the heavy rainfall associated with the Nashville flood. Not the persistent plume of moisture and winds into the region over the 2.5 day long period. Beware of persistent or lingering anomalies in patterns associated with heavy rainfall. They tend to be associated with many record or near record events.

Student Notes:

Composite Anomalies

Persistent pattern for heavy rainfall



26. 6-Hour Evolution of Anomaly Pattern

Instructor Notes: The composite showed the persistence of the pattern. This loop shows the evolution of the pattern in 6-hour time steps. The ridge over the Atlantic strengthened, the PW plume surged south-to-north several times, and there were surges of strong south-southwest winds into the Mid-Mississippi Valley. An ideal set up lasting for several days.

Student Notes:

6-Hour Evolution of Anomaly Pattern

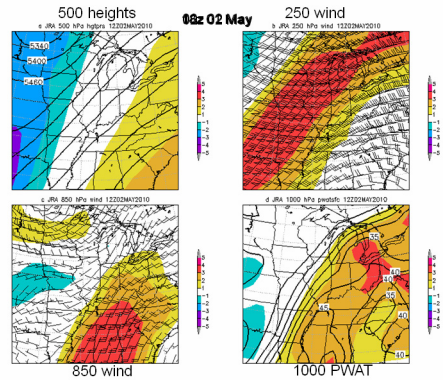
A separate window should appear containing a flash animation…

27. Regional Anomaly Evolutions

Instructor Notes: This slide shows the evolution of the pattern in slower time steps. Play the slide over to visualize the PW plume or the strong low-level jet. The key is the multiple surges and persistence of anomalous conditions over the Mid-Mississippi Valley.

Student Notes:

Regional Anomaly Evolutions



28. Forecast Methodology

Instructor Notes: Our examples and experiences suggest a simple forecast method. 1. Know the large scale set up. 2. Then focus on the regional scale. Know the large scale pattern and sources of moisture. The pattern matters (Bodner et al 2011 is a good read with references to other good papers). Drill down and find the region likely most highly impacted by the pattern. Finally, the model QPF and ensemble QPF probabilities can be of great value. The key point so far is Anomalies and Patterns can aid in identifying climatologically and meteorological significant events and help us distinguish between ordinary and meteorologically significant events .

Student Notes:

The Key Point

Anomalies and Patterns can aid in identifying climatologically and meteorological significant events and help us distinguish between ordinary and extraordinary events.

29. Anomaly Summary

Instructor Notes: We are almost to the goal line.. We showed re-analysis data here to reconstruct the pattern and the anomalies. All of these concepts apply to forecast output too! The same concepts apply to single model forecasts from the GFS and NAM and ensemble output. You can use re-analysis data to reconstruct historic events in your

region. Building your expertise! The ensembles provide probabilities and the all important confidence information. More on ensembles follows in the next module.

Student Notes:

Anomaly Summary

- Reanalysis of anomalies and patterns
  - Up to now shown with re-analysis data
  - Same concepts apply to model and ensemble data
- Ensembles, anomalies and patterns
  - Allow base anomalies and probabilities of exceeding thresholds
  - Contain uncertainty information
  - Probability of exceeding rain can be used with high confidence pattern (more on this next)

30. Summary

Instructor Notes: Hopefully this module reinforced your knowledge on the patterns associated with heavy rainfall and the value of knowing the antecedent conditions prior to the onset a high impact weather event. Anomalies are a powerful tool in providing quick pattern recognition and putting that pattern into context. All of these concepts can and should be used in forecasting. They should aid in helping you better identify and provide more confidence in predicting future HIW flood and heavy rainfall events in your not to distant future. Thanks!

Student Notes:

Summary

- Never underestimate the role of antecedent conditions
- Make good use of standardized anomalies aid when forecasting HIWE's
- Using standardized anomalies and ensembles can provide confidence in forecasting flood events
  - Patterns and probabilities are the keys to success!

31. Acknowledgements

Instructor Notes:

Student Notes:

Acknowledgements

- Randy Graham Western Region for collaboration on cases and events
- WDTB staff for assistance in this module and providing the opportunity to include Brad Grant and Steve Martinaitis
- The Pennsylvania State University data access

32. References

Instructor Notes:

Student Notes:

References

Bodner, M.J., N.W Junker, R.H. Grumm and R.S Schumacher 2011: Comparison of Atmospheric Circulation Patterns during the 2008 and 1993 Historic Midwest floods. Accepted NWA Digest March 2011.

Junker, N.W., R.H. Grumm, R.H. Hart, L.F Bosart, K.M. Bell, and F.J. Pereira, 2008: Use of normalized anomaly fields to anticipate extreme rainfall in the mountains of northern California. *Wea. Forecasting*, **23**,336-356.

--------, M.J. Brennan, F. Pereira, M.J. Bodner, and R.H. Grumm, 2009: Assessing the Potential for Rare Precipitation Events with Standardized Anomalies and Ensemble Guidance at the Hydrometeorological Prediction Center. *Bull. Amer. Meteor. Soc.*, **90**, 445–453.

Maddox,R.A., C.F Chappell, and L.R. Hoxit. 1979: Synoptic and meso-alpha aspects of flash flood events. *Bull. Amer. Meteor. Soc.*, **60,** 115-123.

33. Want to learn more or questions

Instructor Notes: If you have any questions, please contact Richard Grumm using the email address provided.

Student Notes:

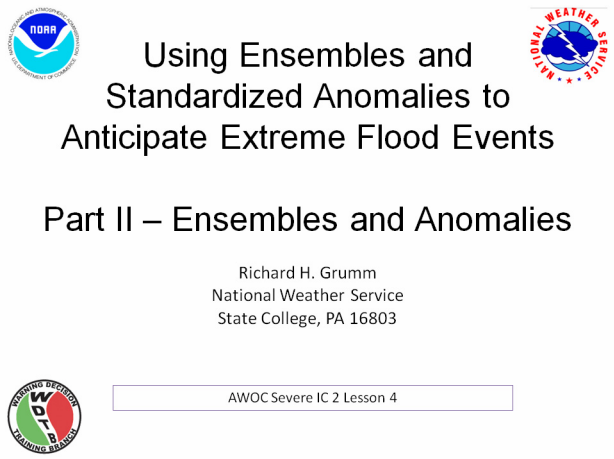
Want to learn more or questions

- We can help you do case studies if YOU want to learn more...
- Or Questions?
- Contact: Richard Grumm@noaa.gov

1. Using Ensembles and Standardized Anomalies to Anticipate Extreme Flood Events Part II – Ensembles and Anomalies

Instructor Notes: Hello! I am Richard Grumm, the SOO at the NWS office in State College, PA. Welcome back! This is part-II of the module on recognizing High Impact hydro events. Our goal is to use ensembles and standardized anomalies to anticipate extreme rainfall events.

Student Notes:



2. Overview/Motivation

Instructor Notes: Ensembles will provide us with confidence information and good probabilistic information, such as the probability of exceeding 1,2 or 4 inches in a specified period of time. They can provide spread and uncertainty with regards to storm tracks and intensity of features of interest and could be used for more issues. The anomalies can be computed from models and ensembles to gage the potential significance of the event type being predicted. We could use EPS guidance to produce probabilities of anomalies and the persistence of anomalous features. We cannot cover all of this here over the next 30 minutes!

Student Notes:

Overview/Motivation

- Ensembles provide **confidence information**
  - Probability of exceeding 1,2, or 4 inches in time
  - Spread and Uncertainty
- Anomalies
  - Potential significance of the event type

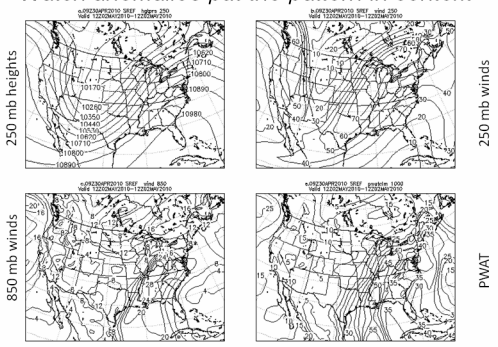
3. 12Z 02 May 2010 SREF Pattern Forecast from 09Z 30 April 2010

Instructor Notes: This image is the SREF ensemble mean pattern over the United States valid at 12Z 02 May 2010. Interesting pattern but if we apply the anomalies the features of note jump out at us. The upstream trough and down stream ridge along with the strong jet between these systems and the low-level jet and the associated plume of high PW air into the Mid-Mississippi Valley. Now we can see a classic heavy rainfall pattern and one associated with significant anomalies.

Student Notes:

12Z 02 May 2010 SREF Pattern Forecast
from 09Z 30 April 2010

Watch anomalies put the pattern in context



4. Anomalies and Patterns

Instructor Notes: The anomalies and the known patterns aid in distinguishing an ordinary from a potentially extraordinary event. A known pattern with large anomalies may provide confidence in the potential for a high impact event. Ensembles add the confidence information related to predictability. Ensembles provide things we often use like

the probability of exceeding 2, 3, or 4 inches of QPF. They can show spread and areas of high and low predictability.

Student Notes:

Anomalies and Patterns

How are these related?

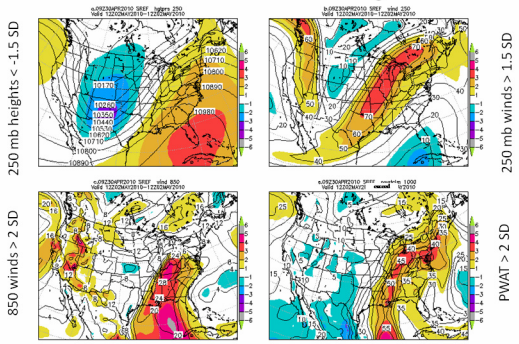
- **Anomalies** and the known **Patterns** distinguish an ordinary from an extraordinary event
- Known **pattern** + large **anomaly** provide confidence in predicting **high impact events**
- Ensembles add the **confidence information** related to probability of exceeding a certain QPF

5. Ensembles can provide confidence and predictability of the pattern while providing context

Instructor Notes: The first image shows the pattern with the anomalies. A pattern often associated with heavy rainfall. The fade in image shows the probability of key anomalies as forecast by the SREF. We have confidence in the anomalous trough and the +2 sigma 850 hPa low-level jet and +2 sigma PW plume. We could also derive images for the probability of exceeding 50 mm of PW or 25 kts of wind at 850 hPa. Ensembles provide confidence in the pattern and thus the predictability of the system.

Student Notes:

Ensembles Provide Confidence and Predictability of the Pattern while Providing Context



6. Ensembles and Anomalies

Instructor Notes: This slide is a summary of the points on the previous slide. Take a minute to read the key points. The ensembles can provide us with confidence and the anomalies with the context of the event type.

Student Notes:

Ensembles and Anomalies

- Ensembles provide confidence in the pattern
  - Deep trough and ridge with moisture plume or Atmospheric River in the PW field with strong low-level winds
  - A well known large scale signal for heavy rainfall
- Anomalies provide context
  - Known pattern with high probability of above normal PW and winds
  - An event that could be bigger then most heavy rain events of this type

7. A Word on Confidence vs. Uncertainty

Instructor Notes: And now a word about confidence.... Uncertainty is a word used as a scientific term. The general public often confuses it with knowing or not knowing. Thus, outside of our community we should always refer to how confident we are in the forecast or the potential outcome. We want users to know if we have high or low confidence in our forecasts and not perceive us as being unsure. So be mindful of highly uncertain and low probability forecasts especially at longer ranges as these forecasts typically change. Finally, uncertainty is a reason to act not a reason not to act.

Student Notes:

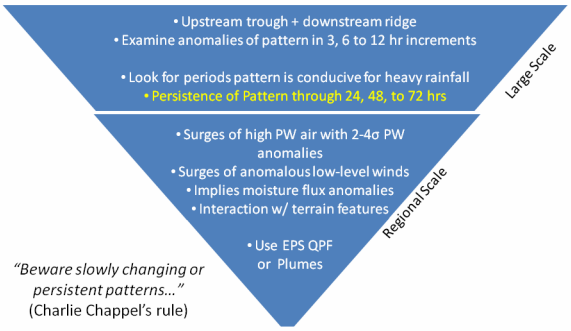
Uncertainty is a reason to ACT not a reason NOT to act

8. Forecast Funnel Considerations

Instructor Notes: Whenever making a forecast...always start from the large scale and work your way down. Heavy rain events, Bodner 2011 again, often have an upstream trough and a downstream ridge. This opens the United States up to subtropical moisture plumes and can enhance the upper and thus low-level jet. Beware slowly changing or persistent patterns as Charlie Chappell's rule states... It rains the most where it rains the hardest the longest...often applies in these conditions. Forecasts of patterns and anomalies over 12,24 and 48 hours can be of value for enduring events. Drill down to the more regional scale to refine your forecast. Surges of high PW and strong low-level winds can focus heavy rainfall and interact with known terrain features. Moisture flux as well as PW and winds may help along with QPFs especially ensemble probabilities of QPF or Plume Diagrams showing the QPF PDF.

Student Notes:

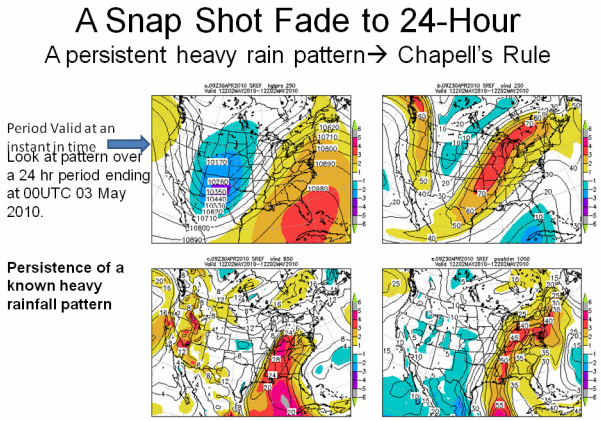
Forecast Funnel Considerations



9. A Snap Shot Fade to 24-Hour

Instructor Notes: The traditional way to view forecast data is at an instant in time as in this image. It shows the strong pattern often associated with heavy rainfall and explained earlier. The second image shows the pattern and anomalies as forecast over the 24 hour period. This implies that the pattern was enduring and lasting somewhat ensuring a prolonged period of rainfall. Images of 12, 24, 48 and even 72 hours could be value in enduring rainfall and heat events.

Student Notes:



10. High Impact Weather Forecast Methodology ? Heavy rainfall

Instructor Notes: Below is a simple method to predict heavy rainfall. 1. Start with the large scale pattern. 2. Move downscale. 3. Know the antecedent conditions. Put the larger scale pattern into context to be aware of persistent patterns and features with large anomalies. Move down scale to tie in the more regional sensible weather. Probabilities might include: Quantitative precipitation such as exceeding 2 and 4 inches in 12 or 24 hours CAPE exceeding 1200 JKg-1 or PW exceeding 2 inches or +2 sigma. Your high impact weather problem dictates key probabilities to focus on. Anomalies may aid in confidently predicting a high end rainfall events. Finally, always checked antecedent conditions. Recent rainfall may have lowered amount of rain requried to get flooding or flash flooding.

Student Notes:

High Impact Weather Forecast Methodology → Heavy rainfall

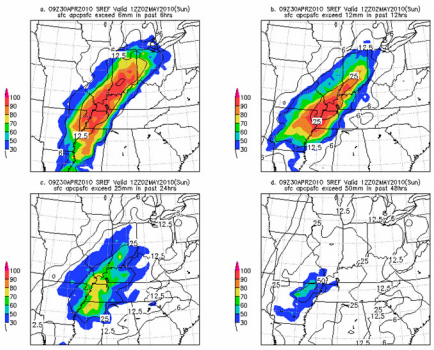
1. Large scale pattern and the context
   - Key fields and strength of the field (anomalies)
   - Probabilities or spread (predictability)
   - Know the pattern and potential context
2. Regional scale ties in sensible weather (more effort & time)
   - Probabilities of high impact variables (QPFs>4, CAPE>1200 J/kg, or PW > 2" or > 2σ)
   - Anomalies and persistence tie in confidence
3. Antecedent conditions matter

11. Where it rains, when it rains, and how much it rains…

Instructor Notes: Where it rains, when it rains, and how much it rains...is critical decision making information.... Example of high probability of rainfall four panel format: 6 mm (~0.25 in) 6 hours where its raining 12 mm (~0.5 in) 12 hours of recent moderate rainfall 25 mm (1 in) 24 hours of area large rainfall 50 mm (2 in) 48 hours of heavy rainfall We need to know confidence where it will rain and when it will rain and relate this to an established favorable large scale pattern.

Student Notes:

Where it rains, when it rains, and how much it rains…



12. Previous QPFs Show Heavy Rainfall Potential

Instructor Notes: The previous slide's QPFs showed the heavy rainfall potential. They showed a high probability of rainfall in the mid-Mississippi valley. We could probably use other thresholds. We need reinforcing regional data. The pattern and the key parameters conducive to heavy rainfall… were they present? The anomalies may help add context for the potential of a significant event. Ensembles could also add confidence in the pattern. There are things we do not know. We don't know the internal QPF of the model ensembles. It would be interesting to know what the 80% or 90% or a record rainfall event is in the SREF, GEFS, or NAM. Do you have a "feel" for these in your area?

Student Notes:

QPFs Show Heavy Rainfall Potential

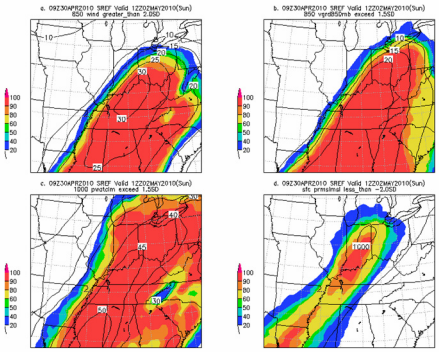
- High probability of heavy rainfall in Mid-Miss Valley
- We need reinforcing regional data
  - Pattern and key parameters conducive for heavy rainfall?
  - Anomalies for context (significant event)
  - Ensembles aid confidence in the pattern
- Things we do not know
  - Internal system QPF climatology
  - What is a 80, 90% or record rainfall in the SREF, GEFS, NAM?
    - Do you have a "feel" for these?

13. Rainfall and heavy rainfall from high Probability Anomalous Pattern

Instructor Notes: This SREF images show the pattern of some key fields associated with heavy rainfall using the ensemble mean. The probabilities show the confidence based on the 21-SREF members of a strong 850 hPa LLJ using the wind and the v-winds along with the PW and MSLP. The persistent high PW plume with the low-level jet is a known signature for heavy rainfall. The next slide shows how this evolves…..

Student Notes:

Rainfall and Heavy Rainfall From High Probability Anomalous Pattern



14. Pattern with large anomalies and high probability persisted for hours

Instructor Notes: This loop shows the surge of a high PW with about 100% chance of PW being in excess of 1.5 sigma above normal into the MMV and Ohio Valleys over a pro-longed period of time. This PW surge is accompanied by a strong LLJ at 850 hPa.

Student Notes:

Pattern with Large Anomalies and High Probability Persisted for Hours

A separate window should appear containing a flash animation...

15. Persistent surges high PW air and strong low-level winds

Instructor Notes: Our loop showed high confidence, based on probabilities, of a persistent plume of above normal PW into the Mid-Mississippi Valley. The loop showed a persistent and strong low-level jet into the same region Here the anomalies were displayed in probabilistic form, giving us confidence in the predictability of the pattern. We tied in anomalies for context and ensembles for predictability and thus confidence in the forecasts.

Student Notes:

Persistent Surges High PW air and Strong Low-level Winds

- Large scale pattern showed common event type
  - Anomalous trough-ridge and persistent plume of above normal PW into Mid-Miss Valley
  - Persistent, strong LLJ
- Anomalies for context and ensembles for confidence
  - Some reinforcing data (GFS/GEFS/NAM)

16. Estimate Rainfall (Verification)

Instructor Notes: Now we will look at what happened... We will see where it rained and how much over the period. Then we will look at the pattern from an independent data set. The pattern match was rather good.

Student Notes:

Estimated Rainfall (Verification)

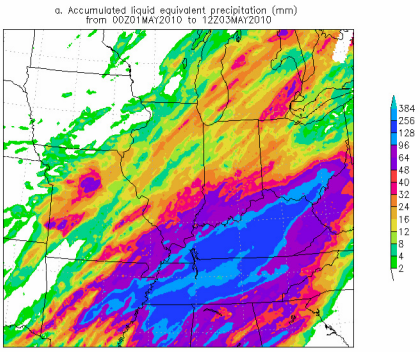
- Stage-IV Data Used
  - Extremely heavy rainfall over Mid-Miss Valley
    - Focus over TN and KY
  - Axis of rainfall maximum
    - Matched well with the PW plume and LLJ
- JRA Loop (Pattern Verification)
  - 1.25 x 1.25 degree reanalysis data
  - Shows the features which the models and EPS correctly, synoptic sense, predicted

17. QPE - Where it Rained

Instructor Notes: Stage-IV rainfall for the period from 0000 UTC 1 May through 1200 UTC 3 May 2010 is shown. These data show the extreme rainfall...in this gridded data set... over TN and KY. Dark blues are up to 256 mm or 10 inches of rainfall. The purple 48 mm about 2 inches covers most of the MMV and Ohio Valleys.

Student Notes:

QPE - Where it Rained



18. Verifying Pattern - Zoomed in View

Instructor Notes: This is a loop of the JRA 1.25 x 1.25 degree data. It shows our moisture plume and strong LLJ as predicted by the NCEP SREF. Note the SREF at 32km resolution is much finer than the JRA. But these data independently show we got the pattern right.

Student Notes:

Verifying Pattern - Zoomed in View

Independent Japanese data used to verify pattern

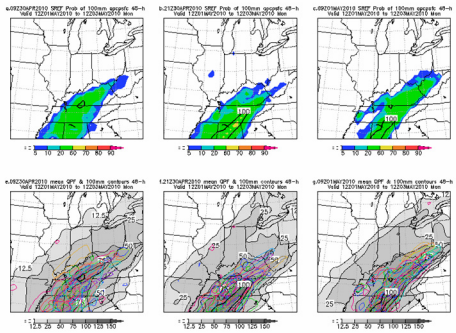
A separate window should appear containing a flash animation…

19. SREF Probability of 2,3, and 4 inches

Instructor Notes: Here we included 3 runs of the SREF to show the probability of over 50 mm or 2 inches of rainfall. All forecasts are valid ending at 12Z 03 May 2010. The lower panel shows the mean QPF and each member 2 inch contour. The key point is our pattern with persistent anomalies was causing the 21-member SREF to predict a large area of high QPF. We will now look at 75 mm or 3 inches… and 100 mm or 4 inches of QPF. We get positive feed back from the SREF probabilities of heavy rain in a pattern conducive for heavy rainfall and a pattern with significant anomalies.

Student Notes:

SREF Probability of 2,3, and 4 inches

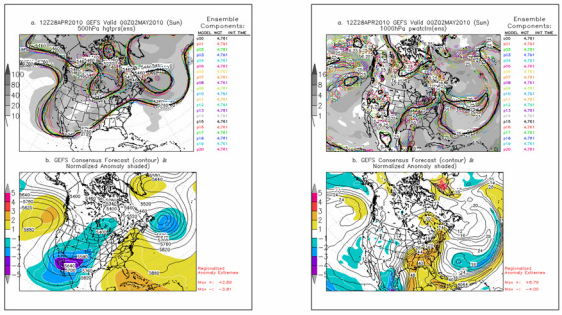


20. Supporting Data

Instructor Notes: So, the SREF predicted heavy rain and showed pattern we associated with heavy rain. Now we will look at the GEFS and its component model the GFS. Do forecasts from these systems corroborate the pattern and QPF potential? A Funnel approach for pattern recognition and a tie back into model and ensemble system QPFs will aid in confidently predicting heavy rainfall.

Student Notes:

Let's Look at Supporting Data



Do forecasts from the GEFS/GFS corroborate the pattern and QPF potential?

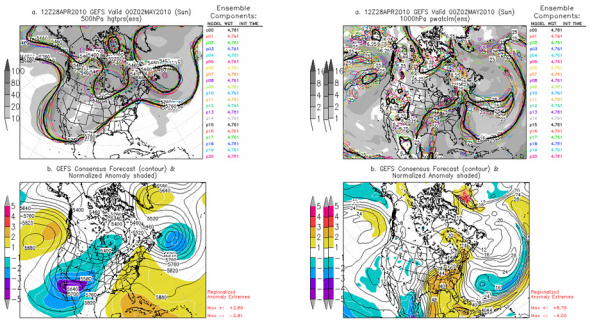
21. GEFS 500 and PW forecasts Established heavy rainfall pattern

Instructor Notes: GEFS forecasts of the large scale 500 mb heights on the left..and PW pattern...right...are included to provide uncertainty information. We can zoom in and see closer to our threat area how this pattern looks... and finally zoom in over the Ohio Valley where the rain will hit the proverbial road. Similar to the SREF....these data show high confidence in the pattern in the GEFS and a surge of high PW air into the MMV!

Student Notes:

GEFS 500 and PW forecasts

Established heavy rainfall pattern → funnel down

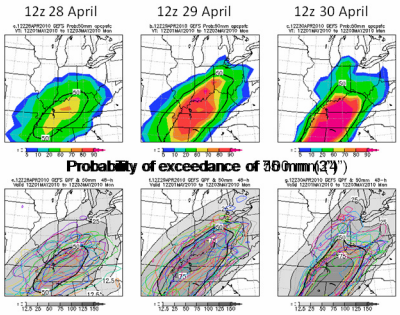


22. Tie in Patterns and Probabilities

Instructor Notes: Using the same concept we used from the SREF we will look at 3 GEFS forecasts of QPF.... The resulting GEFS QPF probabilities show significant rainfall in the region our pattern would imply it would be. Patterns tie in the QPF probabilities. We showed the pattern for one cycle but here show 3 GEFS runs and their QPFs for critical thresholds.

Student Notes:

Tie in Patterns and Probabilities



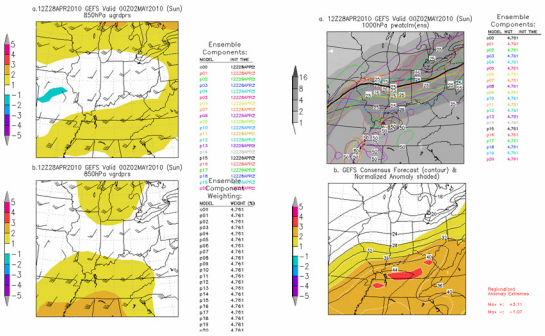
- 3 GEFS 48 hr QPF Forecasts
- 24 hours apart
- Patterns tie in QPF probabilities

23. Successive Forecast High high PW air and strong low-level winds

Instructor Notes: We will now look at the regional pattern of 850 winds and PW anomalies from the GEFS. Similar to the SREF the GEFS too had the strong winds and the high PW anomalies with high confidence in the region of higher PW and PW anomalies.

Student Notes:

Successive Forecast High PW Anomalies



24. Ensembles and Heavy Rainfall Events

Instructor Notes: From a forecast perspective the ensembles provide both the confidence in the pattern and the context when viewed with anomalies. The probabilities of the higher end QPF and the pattern add to the confidence. Of course, probabilities of big anomalies are also of great value in this process. NCEP is working on a new 1981 to 2010 climatology and products showing exceedance of key thresholds from the GEFS and NAEFS.

Student Notes:

Ensembles and Heavy Rainfall Events: Interim Summary

- Provide confidence in the pattern
  - High or low uncertainty
- Anomalies put the pattern into context
  - Strong LLJ, trough, ridge, PW plume
- Probabilities of higher end QPF and pattern add to the confidence
- Probabilities of big anomalies are also valuable

25. Deterministic High Resolution Models

Instructor Notes: Deterministic models are very useful at all ranges and more so at shorter ranges. They are of higher resolution than our ensemble forecast systems and we need to take advantage of this. They typically show larger anomalies at longer ranges especially when there is high uncertainty as there is no averaging. The impacts of averaging often limit high and lower end values in EFS data relative to the single model.

Student Notes:

Deterministic High Resolution Models: What Do They Add?

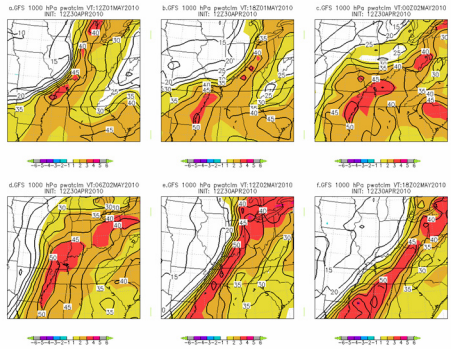
- Higher resolution
  - Aid in predicting the potential for higher end events
  - Extremely useful at shorter ranges
- Larger anomalies
  - One model and averaging uncertainty information is lost
  - Finer scale than our EFS and climatology

26. GFS Regional Pattern and Anomalies with QPF

Instructor Notes: These data show GFS forecasts initialized at 12Z 30 April 2010 in 6-hour increments beginning at 12Z 01 May 2010. The GFS like the SREF and GEFS shows the surge of high PW air with large anomalies in the six periods shown. The winds in the ~27km GFS are nearly 5 sigma above normal at times. This produces large moisture flux anomalies. And thus heavy rainfall in the GFS at the forecast intervals shown.

Student Notes:

GFS Regional Pattern and Anomalies with QPF

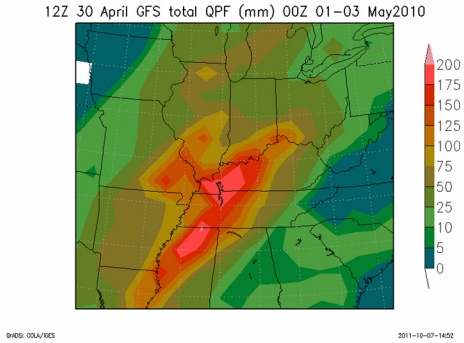


27. GFS Total Accumulated QPF

Instructor Notes: And here is the total QPF produced by the GFS! Not surprisingly the GFS puts out quite a lot of QPF, over 200 mm in places a bit too far to the west relative to observed though verification is not shown here.

Student Notes:

GFS Total Accumulated QPF

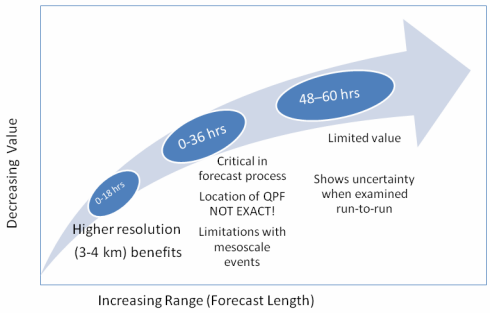


28. Deterministic High Resolution Models

Instructor Notes: This slide sums up so key aspects of our higher resolution models. Take a minute to read this slide. Only comparing them run-to-run can one see the uncertainty. But higher resolution pays off at shorter ranges and they are critical in our forecast process in the 0-36 hour period if you realize and accept the fact that the location of the QPF will not be EXACT! Resolution pays of in the 0-18 hour period We need higher resolution for QPF! Now some practical limits...

Student Notes:

Deterministic High Resolution Models: Interim Summary



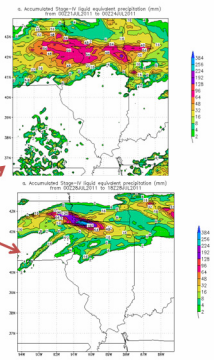
29. Large Scale Successes but Mesoscale Issues

Instructor Notes: Our example thus far was a strongly forced larger scale event. We did not go into the details of the meteorology. The Nashville event had lots of convection and mesoscale rainfall issues. A list of some strongly forced and relatively successful flood events is provided. Now we briefly look at some mesoscale events with weaker synoptic forcing and signals. These events produced heavy rainfall, but due to the more local scale forcing, the convective nature were not so predictable. It happens.

Student Notes:

Large Scale Successes but Mesoscale Issues

- Large scale successes
  - Patterns for heavy rainfall
    - Pakistani Floods July 2010
    - East Coast Floods
      - March 2010
      - With TC Irene and Lee
    - Mid-Miss Valley Floods April-May 2010
- Mesoscale limitations
  - Chicago 21 Jul 2011
  - Iowa - Illinois 28 Jul 2011
  - Many more hard to anticipate events

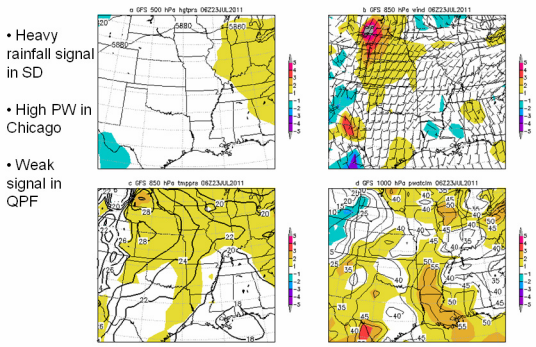


30. GFS Heavy Signal Rainfall

Instructor Notes: These data are not as descript as the Nashville case and there was not a lot of rain forecast over the Chicago area. Yes, the heavy rain was there and Chicago set a new 24-hour rainfall record, in a few hours at that. These forecasts are not that impressive for Chicago. We still need to know this and we still need to deal with this.

Student Notes:

Mesoscale Limitations Event #1
21 July 2011 Chicago Flood

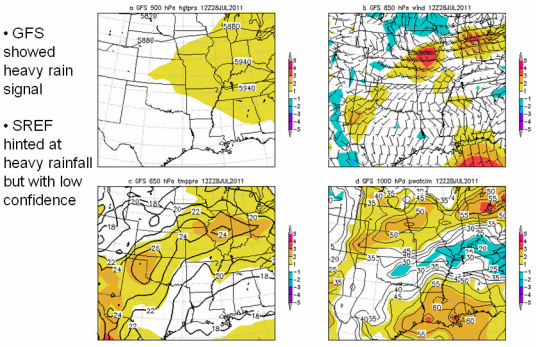


31. GFS shows heavy rain signal SREF hints Heavy rainfall but low confidence

Instructor Notes: Another mesocale rainfall and flood event. This time over western IL and IA. This event had some stronger signals relative to the Chicago event but was still not well predicted. Mesoscale systems are still tough. Perhaps in some cases 3-4km models and storm scale ensembles will help at times. These events require high Situational Awareness and monitoring in the short-term.

Student Notes:

Mesoscale Limitations Event #2
28 July 2011 Iowa-Illinois



32. Limitations

Instructor Notes: The method we showed is for pattern recognition and works well for the larger scale and strongly forced events. It has its limits...related to the limits of predictability. Mesoscale forced events are tough nuts to crack. As high resolution models and storm scale ensembles develop we may get a little better at these events. View this Problem as hard to deal with and a form job security as long as your are situationally aware and vigilant!

Student Notes:

Limitations

- Method is good for pattern recognition
-
- Larger scale events with strong signal
  - Well predicted but not the exacting details and
  - Not the exact region errors of ~100km are typical
- Mesoscale events (Chicago example)
  - Pattern may look generally good
  - NWP has limited ability to predict locally heavy rainfall
  - *Predictability is a hurdle we can never clear*
  - Storm scale models & ensembles may help 0-12 hours

33. Review

Instructor Notes: This lecture was all about Patterns and Probabilities aiding in better anticipating HIWEs. We need to tie the confidence information in our EFS with the anomaly information. If we can recognize a pattern, tie in the anomalies and then the probabilities, in this case of heavy rainfall, we can more confidently anticipate high end rainfall and thus flood events. Internal model climatologies would be of value. What is a record rain event in 12, 24 or 48 hours in the GEFS, SREF, GFS or NAM? We may never solve the more subtle mesoscale events….

Student Notes:

Review

- Tie in the **confidence information** in our EFS with the **anomaly information**
- Once patterns are recognized, leverage Anomaly information and then the probabilities
  - Put known patterns into context→ Identify HIWE!
  - Provide some information on predictability
- Future??
  - Need internal model climatologies
  - What is a record rain event in 12, 24, or 48 hrs in the models?
  - Solving Mesoscale Events?

34. References

Instructor Notes: These are all available from the WDTB Recognizing High Impact Hydro Events course webpage.

Student Notes:

References

Bodner, M.J., N.W Junker, R.H. Grumm and R.S Schumacher 2011: Comparison of Atmospheric Circulation Patterns during the 2008 and 1993 Historic Midwest floods. Accepted NWA Digest March 2011.

Junker, N.W., R.H. Grumm,R.H. Hart, L.F Bosart, K.M. Bell, and F.J. Pereira, 2008: Use of normalized anomaly fields to anticipate extreme rainfall in the mountains of northern California.*Wea. Forecasting,* **23**,336-356.

--------, M.J. Brennan, F. Pereira, M.J. Bodner, and R.H. Grumm, 2009: Assessing the Potential for Rare Precipitation Events with Standardized Anomalies and Ensemble Guidance at the Hydrometeorological Prediction Center. *Bull. Amer. Meteor. Soc.*, **90**, 445–453.

Maddox,R.A., C.F Chappell, and L.R. Hoxit. 1979: Synoptic and meso-alpha aspects of flash flood events. *Bull. Amer. Meteor. Soc.*, **60,** 115-123.

35. Want to Learn More or Have Questions?

Instructor Notes: If you have any questions, please contact Richard Grumm using the email address provided.

Student Notes:

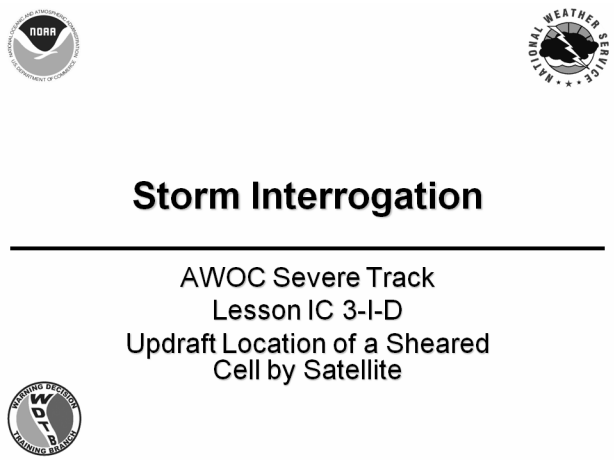
Want to Learn More or Have Questions?

- We can help you do case studies if YOU want to learn more
- Questions?
  - Contact: Richard.Grumm@noaa.gov

1. Storm Interrogation

Instructor Notes: Storm Interrogation, Updraft location of a sheared cell by satellite This lesson is 17 slides long and should take 20 minutes to complete.

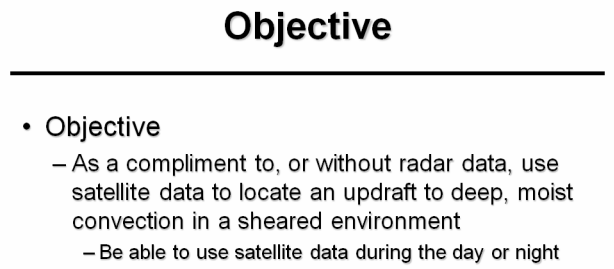
Student Notes:



2. Objective

Instructor Notes: This lesson looks at how to interpret storm top brightness temperature information from GOES to locate the storm top in an environment with significant vertical wind shear. This process may seem straightforward if there is a unique relationship between storm height and brightness temperature. However, that is often not the case. We will look at how you can locate a storm top even if cloud height and brightness temperature are not co-located.

Student Notes:



3. Motivation

Instructor Notes: Why do you want to use satellite to locate a storm top? Satellite data can compliment radar in cases where the radar data are poor in quality or you just need some confirming piece of evidence as to the location of a storm. More likely than not, poor radar data, or even lack of radar data provides a strong incentive to use satellite data as a backup.

Student Notes:

Motivation

- Motivation
  - Uncertain radar presentation of storm structure requires interpretation from independent sources
  - No radar data available
  - No spotters
  - No web cams

4. Sheared Storm Updraft Location via Satellite

Instructor Notes: In this lesson, we will assume that the upper-level updraft is near the location of an overshooting top that is depicted well in visible imagery. As we mentioned before, the cloud top summit and the brightness temperature minimum can be occasionally displaced from each other, especially in sheared storm environments.

Student Notes:

Sheared Storm Updraft Location via Satellite

- Locating updraft summits with GOES 0.6 and 10.7 μm data
  - Assume that the updraft location is at the summit of an overshooting storm top
  - Most of the time, cloud height and brightness temperature are related
  - However, not always, and this complicates locating the updraft summit

5. Brightness Temperature in Relation to Storm Top Height

Instructor Notes: Research has theorized three possible contributions for why brightness temperature and storm top summits may be uncorrelated. There could be a plume of elevated cirrus over and downwind of the storm top. If the temperature at the elevated cirrus is warmer than the storm top summit, as may be the case in an inversion, then the storm top may appear warm. The storm top summit may be too small to be adequately resolved. The most likely scenario is that the storm summit cloud boundary contains strong mixing resulting in the cloud edge taking on the properties of the environment around it, including its temperature. Let's examine the bottom two possibilities in more detail

Student Notes:

Brightness Temperature in Relation to Storm Top Height

- Brightness temperature can be uncorrelated from storm top height because
  - Elevated cirrus over storm top
  - **Resolution of IR imagery**
  - **Mixing warm air above the tropopause**

6. IR Resolution Issues

Instructor Notes: Most overshooting storm tops are large enough to be resolved even by the GOES IR imager. But a significant minority of storm tops may be too small for detection compared to the surrounding anvil brightness temperature. The result is that the anvil brightness temperature may be lower than the storm summit, since the anvil is a large, relatively flat expanse much larger than the Instantaneous Field Of View or IFOV from the GOES satellite. In order to properly resolve any overshooting top, the GOES IR imagery will need to decrease this size of its IFOV to about 1 km. This requirement will be met by the time GOES-R is launched within the next several years. The 2X4 km IFOV at nadir refers to the point directly below the satellite. If you want to figure out the resolution for any area of your choice, consider reviewing the lesson on satellite data quality in the section on data quality in AWOC. We show you a simple method to determine the satellite resolution anywhere within view of a GOES satellite.

Student Notes:

IR Resolution Issues

- IR Resolution
  - 2 X 4 km Instantaneous Field of View (IFOV) at nadir is too large to resolve small overshooting tops.
  - Downwind anvil T_b may be lower than at updraft summit.

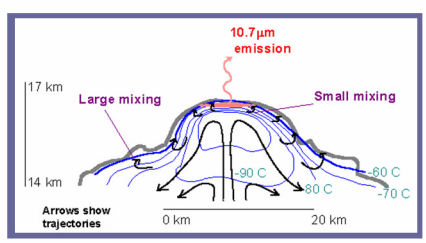
7. Updraft Dome Mixing

Instructor Notes: The most likely explanation for decorrelating storm top height and brightness temperature involves mixing the edges of the overshooting top with the relatively warm environmental air. Note that the 10.7 ?m radiation is emitted mostly right at the cloud top edge in the region of thermal gradient between the extremely cold undiluted updraft air and the environment. The stronger the mixing along this edge, the more diluted the temperature gradient, and the more likely the thermal IR emissions are closer to that of the environment. Now imagine that the overshooting top is penetrating into a thermal inversion. It is quite conceivable that the mixing may cause the cloud edge to actually warm with height. Let's go on and explore the thermal inversion some more.

Student Notes:

Updraft Dome Mixing

- Mixing along the top of the updraft dome mixes environmental air with cloud air



8. Temperature Profiles Above the EL

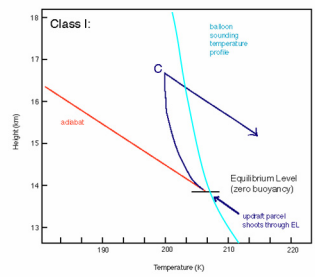
Instructor Notes: The figure to the right shows the temperature vs. height track of a theoretical air parcel marked as a blue curve as it passes above its equilibrium level, reaches its maximum altitude and descends. In this case, the temperature lapse rate is still positive (temperature decreasing with height) across the equilibrium level as shown

by the cyan line. Therefore, as the parcel continues its slowed ascent, the parcel cools. The rate of cooling decreases as mixing commences with the environment but temperature still cools with height until it reaches its maximum altitude located at “C”. This is the case where the overshooting top and brightness temperature minimum are co-located.

Student Notes:

Temperature Profiles Above the EL

- If the temperature keeps falling above the EL, the brightness temperature (T_b) minima and cloud top height are correlated



Based on one-dimensional model runs by Adler and Mack (1986)

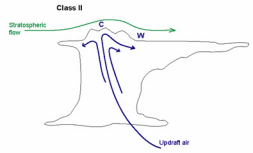
9. Example of EL Below Tropopause

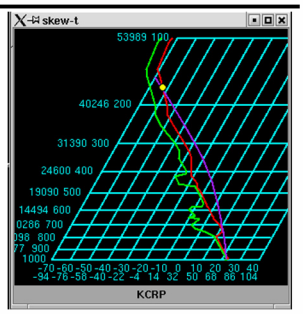
Instructor Notes: Here is a case from South Texas from a cool season severe weather event with supercells. The nearby Corpus Christi sounding showed that the equilibrium level is below the tropopause and positive lapse rates exist above it. This environment suggests that we stand a good chance of picking out the storm top location at its cold point “C”. Any warm wakes “W” may lie downwind of the storm top.

Student Notes:

Example of EL Below Tropopause

- The EL is below the tropopause
- This means good correlation most likely between updraft summit and T_b minimum





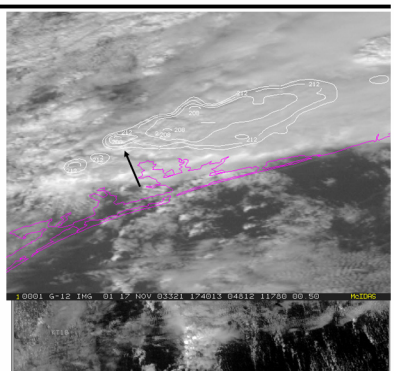
10. Vis vs. IR Satellite for Updraft Summit

Instructor Notes: Comparing the visible imagery with the IR, we see that the brightness temperature minima just northwest of the black arrow is right where the brightest cumuliform cloud top shows up in the visible imagery.

Student Notes:

Vis vs. IR Satellite for Updraft Summit

- The EL is below the tropopause
- This means good correlation most likely between updraft summit and T_b minimum



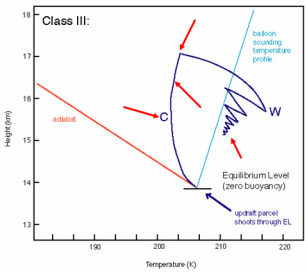
11. EL in an Inversion

Instructor Notes: When the EL is in an inversion, mixing causes the cloud top to actually start warming with height. This causes a displacement between the highest cloud and the coldest temperature. The cold spot is displaced upwind of the highest point. The cloud sinks downwind of the highest point warming nearly adiabatically until it settles to a level closer to the environmental EL.

Student Notes:

EL in an Inversion

- If the temperature rises above the EL, the brightness temperature (Tb) minimum and cloud top height become displaced



Based on one-dimensional model runs by Adler and Mack (1986)

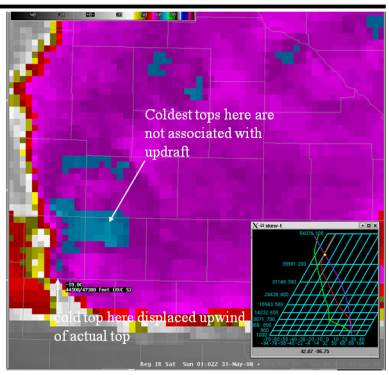
12. Displaced Cold Top Example

Instructor Notes: The Spencer, SD tornadic storm on 31 May 1998 exhibited a typical upwind displacement of the coldest tops. In fact, the overshooting top was warmer than the rest of the anvil. The coldest top visible here is actually a collision of two anvils between two storms and has nothing to do with updraft.

Student Notes:

Displaced Cold Top Example

- Displaced cold top example
- Cold T_b top is displaced upwind of physical top
- or little relation between T_b and cloud height



13. Test Your Knowledge

Instructor Notes:

Student Notes:

14. Interim Summary

Instructor Notes: To summarize, if the EL is in a positive lapse rate, the Tb minimum is well correlated with cloud height. Once the EL becomes embedded in a neutral or inverted lapse rate, the cloud actually begins to warm with height creating features such as the warm wake, the enhanced-V, and decorrelating the relationship between Tb and cloud height.

Student Notes:

Interim Summary

- If the EL is in a positive or neutral lapse rate, the T_b minimum is located over the updraft summit
- If the EL is in an inversion, the updraft summit may lie between the T_b minimum and the warm wake
- You may compare to visible imagery during the day

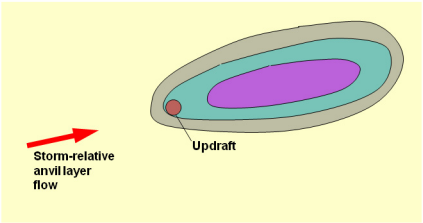
15. Updraft Summit in Small Storms

Instructor Notes: Small overshooting tops from small storms may be completely unresolved by GOES. Or a storm struggling in high wind shear will have no overshooting top. The result is an anvil whose lowest Tb is in the flat anvil well downwind from the updraft. In these cases, the updraft will be at the extreme upwind location of the cold anvil.

Student Notes:

Updraft Summit in Small Storms

- For small storms, the updraft summit will be at upwind edge or point



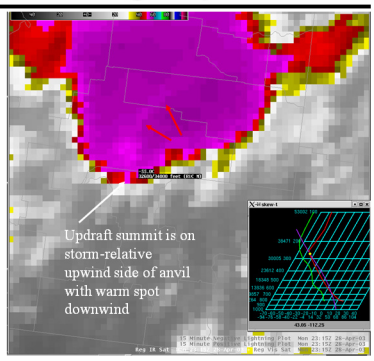
16. Example of Unresolved Overshooting Top

Instructor Notes: On 28 April 2003, a supercell southwest of Pocatello, ID exhibited a very small overshooting top that was unresolved by the GOES satellite. However, there is a warm wake since the EL is in a near isothermal layer. Both of these factors contribute to difficulty in finding the updraft summit by satellite. Two things help to make an educated guess as to where the updraft is located: Look to the upwind wide of the anvil with respect to the storm-relative anvil-layer flow. Upwind of the warm wake.

Student Notes:

Example of Unresolved Overshooting Top

- Resolution problems
- 28 Apr 2003 - PIH
- Small updraft overshooting top in visible is lost in IR



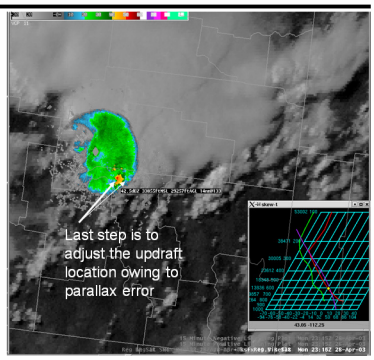
17. Radar/Satellite Overlay

Instructor Notes: Overlaying the high level reflectivity core shows good agreement between satellite educated guess and the radar observed location of the upper-level updraft. Note the parallax correction.

Student Notes:

Radar/Satellite Overlay

- Resolution problems
- 28 Apr 2003 - PIH
- Small updraft overshooting top in visible is lost in IR



18. Summary: Sheared Updraft Detection by Satellite

Instructor Notes: When there are positive lapse rates above the EL, there is good agreement between updraft summit height and IR Tb. When the lapse rates become negative (inversion), the Tb minimum gets displaced upwind. In some cases, there might not be a Tb minimum. Small overshooting tops are likely to be unresolved by satellite and therefore, you need to look at the upwind side of the anvil relative to the storm-relative anvil layer flow.

Student Notes:

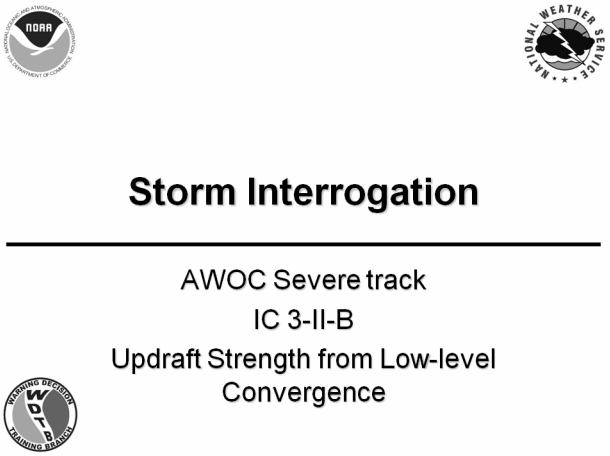
Summary: Sheared Updraft Detection by Satellite

- Positive lapse rate above EL
  - Updraft summit height and IR brightness temperature well related
- Negative lapse rate above EL (inversion)
  - Updraft summit height and IR brightness temperature may **not** be well related
- Small overshooting tops will be poorly resolved by 4km GOES IR
- Parallax correction needed

1. Storm Interrogation

Instructor Notes: slide 1: AWOC Severe Track. IC3-II-B Storm Interrogation - Updraft Strength from Low-level Convergence. This lesson covers detecting and estimating the effects that low-level convergence has on updraft strength. There are 17 slides in this lesson and it should take about 20 minutes to finish.

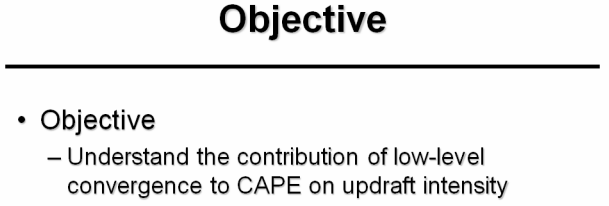
Student Notes:



2. Objective

Instructor Notes: At the end of this presentation, you should understand the contribution of low-level convergence to CAPE on updraft intensity. You may not be able to provide specific values on how strong an updraft is likely to be, but you will have gained an appreciation in how updraft strength can be significantly enhanced beyond what the theoretical CAPE can provide in certain situations.

Student Notes:



3. Updraft Strength: Low-level Convergence

Instructor Notes: Consider this example of dual-Doppler derived velocities of a colliding gustfront visualized in this cross-section taken from Mahoney (1988). A gustfront 1 km deep colliding at a combined speed of 13 m/s can produce an updraft of similar strength at 3 km AGL. Cloud physics and storm electrification research (See papers by Zipser and Marwitz) suggest storm electrification begins when updrafts exceed 5m/s. Without any CAPE, we could've initiated lightning had the atmosphere been cold enough to produce graupel. This is not the case since this updraft forcing is too shallow to extend into cold enough air, however it does show that if this low-level forcing were to occur under a developing towering cumulus, the extra boost would give this cumulus a much greater initial updraft strength than a neighboring cumulus away from this forcing.

Student Notes:

Updraft Strength: Low-level Convergence

- Consider this
  - Example of updraft strength after gustfront collision.
  - Strong enough to create hail and split charges if cold enough
  - From Mahoney, 1988

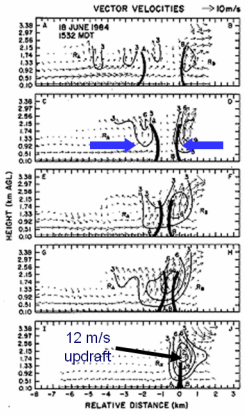


FIG. 9. Vertical cross sections of the ground-relative vector velocities. The grey, thick lines are the estimated frontal locations, and the dark, thin contours are updraft velocities in m s^{-1}. The circulation centers are marked R_A and R_B for fronts A and B, respectively.

4. Low-level Convergence Parameters

Instructor Notes: Several considerations need to be accounted for to determine how much of an initial boost to buoyancy convergence provide. The magnitude of convergence is obvious since stronger updrafts result from stronger convergence. However, I could have a situation where an adjacent gustfront may be weaker in convergence magnitude but it's forcing deeper convergence. The second consideration, convergence depth, is equally important to magnitude when the final updraft speed is concerned. Finally, when an air parcel responds to the forcing that has created the convergence, it starts to accelerate as long as that forcing is there. If the forcing is removed, the final vertical velocity of that parcel will have failed to reach its full potential. One thing to remember is that convergence is not a forcing mechanism, but is a result of a forcing mechanism. Something forces the convergence, and likewise the vertical velocity. This has implications in the following scenarios.

Student Notes:

Low-level Convergence Parameters

- Convergence parameters to affect updraft magnitude
  - magnitude
  - depth
  - residence time of DMC over convergence

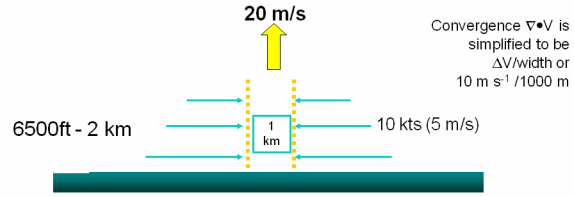
5. Calculate Updraft Strength from Low-level Convergence

Instructor Notes: I will show a few examples of changing the convergence depth and magnitude across a boundary. For the vertical velocity that arises out of the convergence, I estimate using a greatly simplified continuity equation in order to see the results more clearly. I mentioned before that convergence is not a forcing, it is just a diagnostic. What forced the convergence and its vertical motion field may be from a thermal gradient, or density gradient like you see across a gust front. In this scenario, I have a 2km deep boundary where the average flow toward the center interface is 10 kts. That means my velocity difference is 20 kts (10m/s). The boundary is roughly 2 km wide. First, I estimate the mean convergence across the width of that convergence by dividing the velocity difference by the width of the boundary (all in meters and seconds). Then I multiply my convergence by the depth of the mean convergence (2000 m). My answer comes out to 10 m/s at 2 km altitude. The boundary may be a bit deep but it's also a bit wider than a real boundary. Most fine lines are 2 km wide or less.

Student Notes:

Calculate Updraft Strength from Low-level Convergence

Assuming a steady state convergence
Depth: ΔZ = 2 km
Boundary width = 1 km (one .54 nm range gate)
Mean convergence over 1 km: $\nabla \bullet V = 10 ms^{-1} / 1000m = .01\ s^{-1}$
Updraft strength at 2 km W = $(\nabla \bullet V)\ \Delta Z = .01 s^{-1} * 2000m$ = **20 m/s**



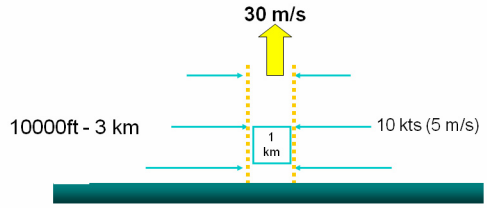
6. Deeper, More Narrow Boundary

Instructor Notes: If I change my boundary depth to something deeper, maybe a deep convergence zone along a squall line gust front, my final vertical velocity at the top of my convergence (3 km) is 15 m/s, certainly strong enough to generate hail if the air temperature was cold enough.

Student Notes:

Deeper, More Narrow Boundary

Assuming a steady state convergence
Depth: ΔZ = 3 km
Boundary width = 1 km (one .54 nm range gate)
Mean convergence over 1 km: $\nabla \bullet V$ = 10ms^{-1} / 1000m = .01 s^{-1}
Updraft strength at 3 km W = ($\nabla \bullet V$) ΔZ = .01s^{-1} *3000m = **30 m/s**



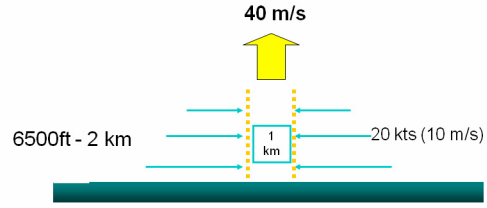
7. Double the Strength of the Inflow

Instructor Notes: Going back to my 2 km deep boundary, now I double my inflow. Now I get a 20 m/s updraft at 2 km, that's double my previous 2 km deep boundary after doubling the inflow. This may be a realistic squall line gust front which is moving at 40 kts. Remember, these are for illustrative purposes only. There are a lot of factors that may work against realizing these updraft numbers including the residence time of any parcel in the zone of convergence, entrainment, etc.

Student Notes:

Double the Strength of the Inflow

Assuming a steady state convergence
Depth: ΔZ = 2 km
Boundary width = 1 km (one .54 nm range gate)
Mean convergence over 1 km: $\nabla \bullet V$ = 20ms^{-1} / 1000m = .02 s^{-1}
Updraft strength at 2 km W = ($\nabla \bullet V$) ΔZ = .02s^{-1} *2000m = **40 m/s**



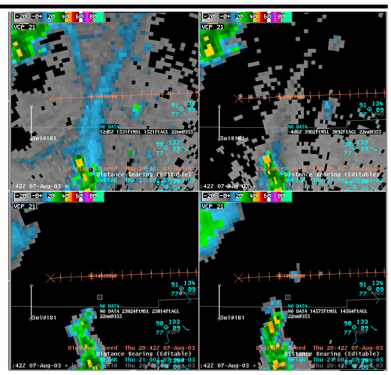
8. Case #1: Boundary Collision

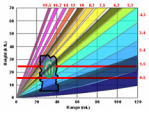
Instructor Notes: Here's an example from Florida of a boundary collision from 07 August 2003 near Palm Beach, FL. I tracked the motion of these two boundaries with the distance speed tool in AWIPS to get a combined collision speed of 18 kts. Looking at my 4-panel, I'm having trouble observing the boundaries above the 1.5° elevation slice, so I may have a good idea on the depth of the gust fronts. But what is the convergence?

Student Notes:

Case #1: Boundary Collision

- 07 August 2003, Palm Beach, FL
- Two boundaries about to collide
- Collision speed 18 kts





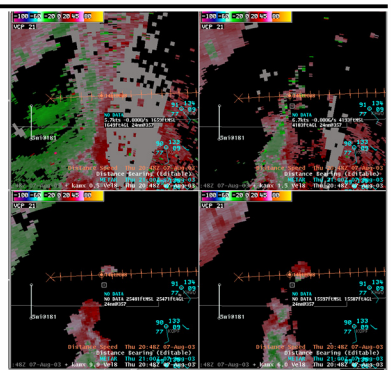
9. Case #1: Velocity 4-panel

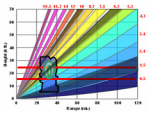
Instructor Notes: Looking at the velocity, I have a problem. The velocities are weak, probably because the winds in either cold pool are mostly tangential. I cannot use the velocity data to come up with an estimate on convergence.

Student Notes:

Case #1: Velocity 4-panel

- 07 August 2003, Miami
- Velocity is of limited use here owing to the angle of collision
- Flow is mostly tangential

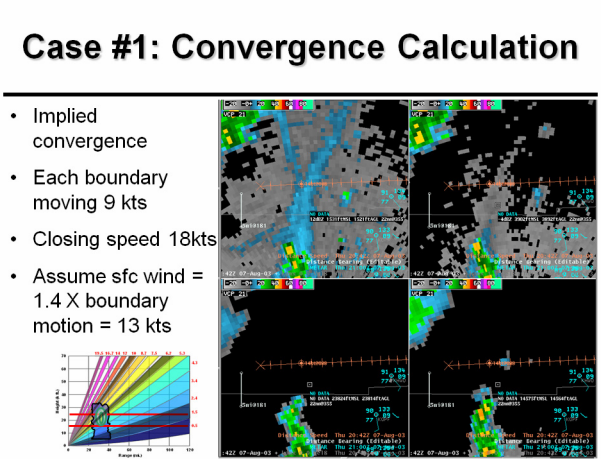




10. Case #1: Convergence Calculation

Instructor Notes: We will have to imply convergence based on an estimate of the winds behind each boundary. The closing speed of each boundary is roughly 18kts. Mahoney (1988) found that surface 10m winds behind a gust front was roughly 1.4 times that of the boundary motion after sampling a large number of boundaries. Apply that here to each boundary motion of 9 kts and we have winds roughly 13 kts in each boundary. After collision, the combined differential velocity may be 26 kts. Note that the relation between boundary speed and maximum wind speed behind the boundary assumes a relatively calm pre-boundary environment. This relation works for this case. This relation needs to be revised for strong low-level wind events.

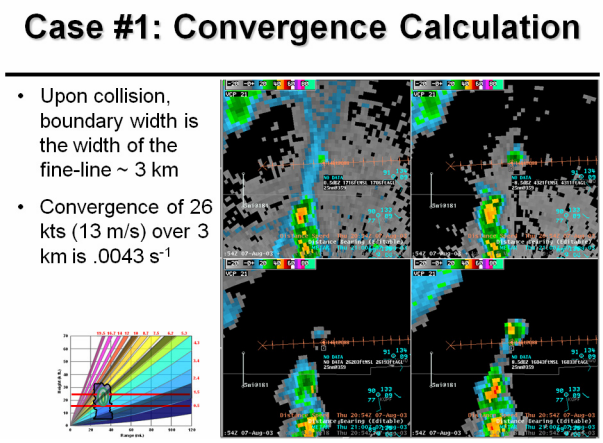
Student Notes:



11. Case #1: Convergence Calculation

Instructor Notes: Radar observed the fine-line after collision to be around 3 km wide. Dividing 13 m/s (26 kts) by the width of the fine-line in meters gives me a convergence of 0.004/s. This is going to be the maximum convergence near ground level. That convergence should be weaker going up in altitude. But let's keep this convergence for the lowest 1 km above the ground.

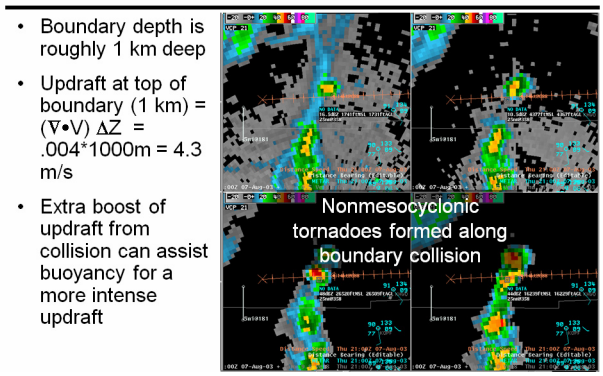
Student Notes:



12. Case #1: Updraft Boost Estimation

Instructor Notes: By the simplified continuity principle, multiply the convergence by its depth of 1 km and we get an updraft speed of 4.3 m/s at the top of the boundary. A developing towering cumulus is likely and initiation will be strongly forced compared to a other developing convection from most other initiation mechanisms this day. As can be seen, convective cells rapidly developed along and after the collision.

Student Notes:



13. Case #1: Summary

Instructor Notes: To summarize this event, the boundary collision may have added up to 8 kts of vertical velocity to the base of the convective updrafts. In addition, large plumes of moisture have been advected upward to produce a much stronger base for buoyancy to continue the initiation process. The result was a more intense set of thunderstorm updrafts than the initial storms that created the original cold pool boundaries in the first place. There are some caveats to everything. First, the convective layer steering flow must be such as to minimize boundary-relative storm motion in order to generate the strongest, deepest updraft possible. Deep layer shear should be optimally balanced with

the motion of the gust front to generate a deep overturning convective current. In this event, shear was not a consideration in the environment, storm motion was small, and the updraft generated by the boundary collision was likely upright and deep.

Student Notes:

Case #1: Summary

- Convergence adds vertical velocity to the peak updraft expected from buoyancy alone
- Convergence depth and magnitude modulate the strength of the updraft
- Caveats
  - Updraft must reside over convergence to realize its vertical velocity
  - That means boundary-relative storm motion needs to be small

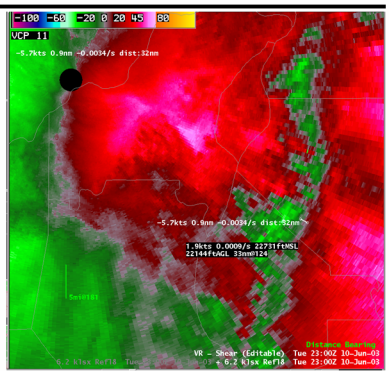
14. Case #2: Deep Convergence from a Sustained Severe Storm

Instructor Notes: Here is a case of a severe quasi-linear multicell event with a deep convergence boundary along the gust front. The gust front motion was nearly 50 kts resulting in some very strong convergence. Since velocity is likely mostly radial here, I use the VR-shear tool to estimate convergence across the width of the convergence zone, roughly 1.5 km. The actual zone was probably even narrower than that. This convergence was maintained through the lowest 3 km (10kft). This may be an overestimate because multiplying this convergence through the lowest 3 km resulted in an updraft of nearly 30 m/s at 3 km. Whether or not this is actually the case, the updraft generated here is nearly an order of magnitude higher than the Florida boundary collision case. Imagine this kind of boundary even in a situation where the linear system runs low on CAPE. One could easily imagine this system maintaining itself on its low-level convergence for longer than expected.

Student Notes:

Case #2: Deep Convergence from a Sustained Severe Storm

- Convergence of .01 s^{-1} in a 3 km deep layer
- Followed by weaker divergence above 3 km
- Yields updraft of **~30 m/s** at 3km
- ~**25 m/s** at 4.7 km



15. Test Your Knowledge

Instructor Notes:

Student Notes:

16. Case #2: Summary

Instructor Notes: Summarizing, this boundary moving at 50 kts resulted in some incredible convergence, especially considering that the ground-relative low-level inflow was out of the southeast. This convergence was also deep (3 km) and the matching vertical velocity was calculated at 30 m/s at 3 km. The convective layer storm motion allowed the deep updraft to maintain its footing close to the vertical velocity generated by the convergence zone and the result was a deep overturning updraft capable of generating all the features associated with a high end severe squall line including tornadoes, severe low-level winds and excessive rainfall rates. Very large hail was not something found in this event for many reasons. One of them may be that squall line updrafts tend to flatten out at lower altitudes than for more isolated modes of convection in similar environments.

Student Notes:

Case #2: Summary

- Updraft strength profile is maximized due to
  - Strong convergence (ΔV>50 kts over a few km)
  - Deep convergence (>3 km or 10 kft)
  - Low boundary-relative storm motion
    - Storm matching cold pool speed

17. Summary: Distant Storms

Instructor Notes: Estimating low-level convergence from distant, persistent convective modes is a bit more problematic and relies on circumstantial evidence. Let's assume a cluster or supercell is moving along at a speed and has a large, intense core. As long as you can say this event has an intense gust front capable of forcing the storm-relative low-level inflow upward through convergence, you could use the forward motion of the storm and estimate its convergence as it moves into the low-level inflow. Be careful, it is hard to say what the storm-relative winds within the cold pool are when all you know is the storm motion.

Student Notes:

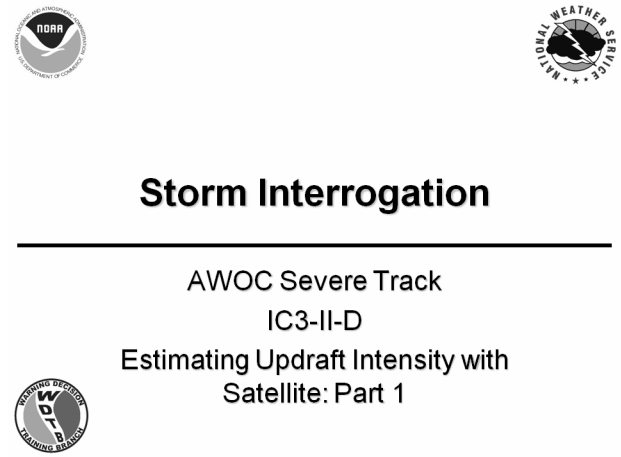
Summary: Distant Storms

- Estimating low-level convergence for distant persistent storms
  - Use the storm motion and calculate storm-relative low-level inflow
  - Storms with large, intense, persistent core are likely to have strong enough gust fronts to 'block' the storm-relative inflow providing strong convergence

1. Storm Interrogation

Instructor Notes: This presentation is Severe Track IC 3 storm Interrogation - Estimating updraft intensity by satellite - part 1. This presentation is 23 slides long and should take 20 minutes to complete.

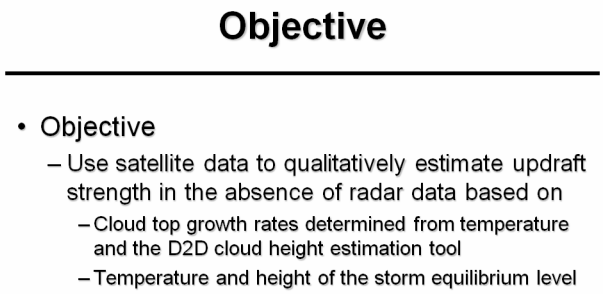
Student Notes:



2. Objective

Instructor Notes: As a motivation for this lesson, there have been times when offices are stripped of radar data for various reasons. Satellite data can provide a useful backup, or as a tool of confirmation. The objective of this lesson is to qualitatively estimate updraft strength from satellite based on two major parameters that you have the capability to evaluate The cloud top growth rate in terms of time trends of cloud top temperature and height. Temperature and height of the storm Equilibrium Level (EL) Both of these parameters, you can evaluate for yourself using the D2D cloud height estimation tool. We will discuss this more later in this lesson.

Student Notes:



3. Methods to Estimate Updraft Intensity with Satellite

Instructor Notes: There are many methods for evaluating storm intensity from satellite: Cloud top cooling rates prior to anvilgenesis. Cloud top cooling rates after anvilgenesis. Now we are talking about the cooling rate of the overshooting top Cloud top growth rate using the cloud height tool in AWIPS. This technique simply converts cloud top temperature to height. Otherwise, the physical basis remains the same as 1 and 2. Anvil equilibrium level temperature and/or height. In many ways, this technique is better to use than cloud top growth rates

Student Notes:

Methods to Estimate Updraft Intensity with Satellite

- Possible methods
  - Cloud Top Temp (CTT) cooling rates pre-anvilgenesis
  - CTT cooling rates post-anvilgenesis
  - Cloud top growth rate using the cloud height tool in AWIPS
  - Anvil equilibrium level temperature/height

4. Prerequisite

Instructor Notes: I mentioned that the D2D cloud top height tool is used in evaluating some of these techniques. This tool was developed by the Aviation Weather Center to help forecasters write convective sigmets around the world. Now that this technique is available to all, this tool should help you out in convective forecasting. The VISIT program has developed a training session for the general use of this tool at http://www.cira.colostate.edu/ramm/visit/cldhgt.html. The session is generic in the use of this tool. Here we provide some specific potential applications.

Student Notes:

Prerequisite

- Recommended Prerequisite
  - Be familiar with the Interactive cloud height algorithm in D2D
  - Training is available at
    - http://www.cira.colostate.edu/ramm/visit/cldhgt.html

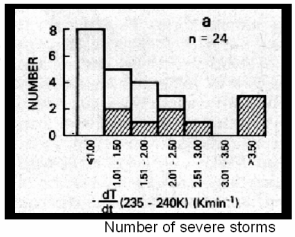
5. CTT Cooling Rate Pre-anvil

Instructor Notes: Satellite-based severe thunderstorm analysis research peaked in the mid 1980's prior to the advent of the WSR-88D because of the incentive to provide more information than the old radar system could provide. Some of the results from that time are still relevant today but there are caveats since we are now talking about higher resolution satellite imagery. Nevertheless, I present some of the techniques devised then in our current framework. Adler et al 1985 approached discriminating severe from non-severe storms using the cloud top cooling rate determined from rapid scan GOES imagery. After several severe storm outbreaks, they found a fairly good relationship between cooling rate and eventual severe weather reports. This bar chart shows the maximum cooling rate found in a storm before it had a chance to produce an anvil. Note that the storms that went on to produce severe weather (gray shaded bars) tend to dominate when the cooling rates exceeded 2 degrees/minute. This only corresponds to a 4 m/s updraft. Poor resolution was blamed for the low values. GOES IR imagers before the advent of GOES 8 had a 4X8 km field of view at nadir (below the satellite). Now we have routine 2X4km imagery. Today's cooling rates are higher as a result and so this graph's purpose is to highlight the relationship, rather than specific thresholds.

Student Notes:

CTT Cooling Rate Pre-anvil

- Note that cooling rates are >2° K/min for most severe storms based on limited samples
  - Prior to anvilgenesis
  - 2° K/min corresponds to only 4 m/s of updraft



Number of severe storms are shaded.

From Adler et. Al 1985

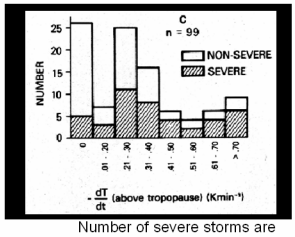
6. CTT Cooling Rate Post-anvil

Instructor Notes: As the storm creates an anvil, and the overshooting top begins to extend above it, the cooling rate typically slows down. Following updraft surges also have slower cooling rates. The reason is that the overshooting top growth is in a region of negative buoyancy. Adler et al 1985 reflects this with much smaller cooling rates. Instead of 2 deg/min, now we are talking 0.4 deg/min as a strong severe/nonsevere thunderstorm discriminator. Again, these cooling rates reflect the maximum cooling rate found in the overshooting top prior to the severe report. Another word of caution, their database was limited to major spring severe storm outbreaks with strong vertical wind shear. We will look at multiple events as examples later.

Student Notes:

CTT Cooling Rate Post-anvil

- After anvilgenesis, overshooting top cooling rates are much smaller.
- If the cooling rates > 0.4° K/min severe storms were more likely in this dataset.



Number of severe storms are shaded.

Sampled from typical mid-western severe events

From Adler et. Al 1985

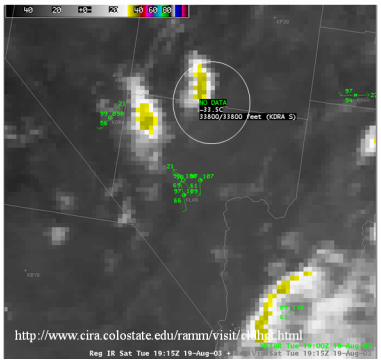
7. Cloud Top Cooling Rates Las Vegas Event (Storm A)

Instructor Notes: This storm is embedded in a monsoon environment with a shortwave trough moving northwest through AZ. It is generating off some high terrain north of LAS. GOES-10 is in normal scan mode and the D2D cloud height algorithm is basing the cloud top height on the KDRA sounding at 12 UTC. It may be a bit on the dry side but should be fairly relevant when trending the cloud height and temperature. Right away, notice the 6 deg temperature drop in the overshooting top in 15 minutes. This is the pre-anvil growth stage of this storm. See http://www.cira.colostate.edu/ramm/visit/cldhgt.html for the training on the AWIPS cloud height algorithm.

Student Notes:

Cloud Top Cooling Rates
Las Vegas Event (Storm A)

- Initiation in pre-anvil stage north of LSV (Storm A)
- Use the cloud height algorithm to track cooling rate and cloud top growth



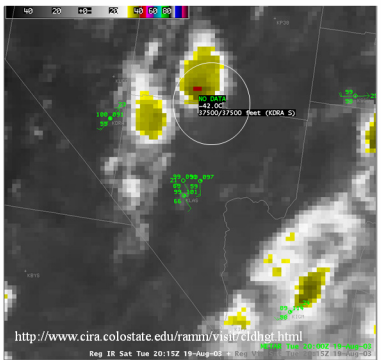
8. Storm A Post-anvil Stage

Instructor Notes: In these three frames of this loop, this storm is now creating an anvil and any growth rate during this part of the storm growth can only be compared to the growth rates of storms after their respective anvils have formed.

Student Notes:

Storm A Post-anvil Stage

- post-anvil stage north of LSV (Storm A)
- Use the cloud height algorithm to track cooling rate and cloud top growth

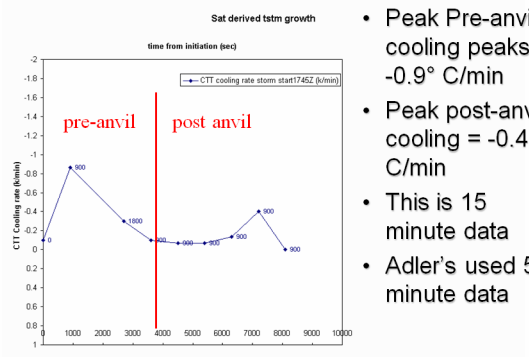


9. Cloud Top Cooling Rates Plotted for Storm A

Instructor Notes: Time trends of temperature were taken of this storm from first cumulus to reveal this graph. Note there are large temporal gaps in the imagery which tend to overlook rapid growth spurts (see between 1000 and 2500 seconds). Still, the maximum temperature rate of –0.9 K/sec occurs in the first stages of the towering cumulus. After anvilgenesis the peak cooling occurs as a subsequent updraft surge cools the overshooting top by 0.4 K/sec at 7200 seconds after initiation. These rates are small compared to Adler's work. Adler et. al 1985 used 5 minute data, and if we had access to such, we would get higher rates. However, our higher resolution imagery should be expected to produce higher rates than Adler et. al 1985. Do the competing differences cancel each other? We don't know.

Student Notes:

Cloud Top Cooling Rates Plotted for Storm A



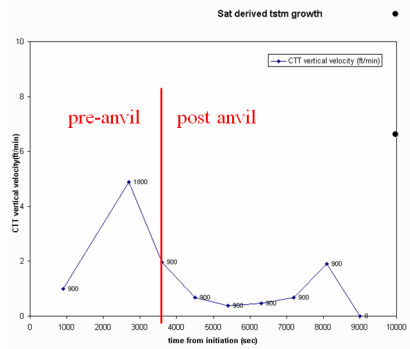
- Peak Pre-anvil cooling peaks at -0.9° C/min
- Peak post-anvil cooling = -0.4 C/min
- This is 15 minute data
- Adler's used 5 minute data

10. Cloud Top Vertical Velocity Plotted for Storm A

Instructor Notes: Converting temperature rate to growth rate of storm top height gives us maximum vertical motions of 5 (2) mph for the pre- (post) anvil stage respectively. To create this graph, I simply read off the maximum cloud height found nearby the cursor using the D2D cloud height algorithm (see the altitude on the right in the cursor readout) These results agree with Adler's results very nicely. We'll compare this storm with another one that formed closer to Las Vegas.

Student Notes:

Cloud Top Vertical Velocity Plotted for Storm A

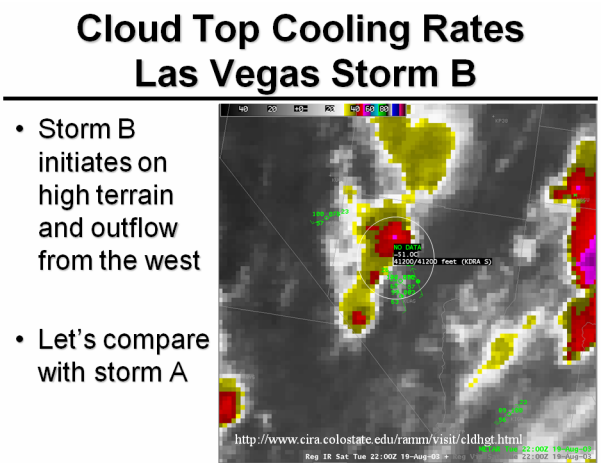


- Peak Pre-anvil cloud top vertical velocity = 5 mph
- Peak post-anvil cloud top vertical velocity = 2 mph

11. Cloud Top Cooling Rates Las Vegas Storm B

Instructor Notes: Storm B initiates on the high terrain northwest of the city's northern Suburbs near an implied outflow boundary (inside the white circle). Now we have RSO operations going on GOES-10. I cannot emphasize enough the importance of having RSO imagery should you try any of these techniques. Note the cloud tops are taller with this storm. There are two separate updraft surges within this multicell. This loop shows only the first surge, mostly prior to anvil production.

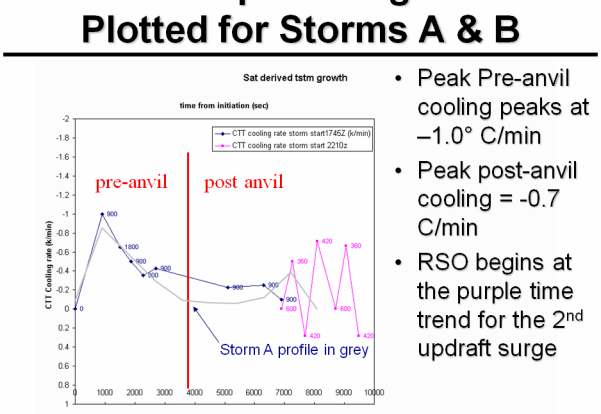
Student Notes:



12. Cloud Top Cooling Rates Plotted for Storms A & B

Instructor Notes: This graph compares storm A and storm B, where the storm A profile is grey. Both have also been set so that the timeline is time from initiation for both storms. Note that both of them exhibit rapid growth but storm B is a little more rapid than storm A, given the same image frequency. Storm B continues to show the same or more rapid cooling through its pre-anvil stage. During the post-anvil stage, the overshooting top is also more rapid than storm A. A second updraft surge, shown in purple, exhibits wild fluctuations in cooling rate but that the highest values are higher than with storm A.

Student Notes:



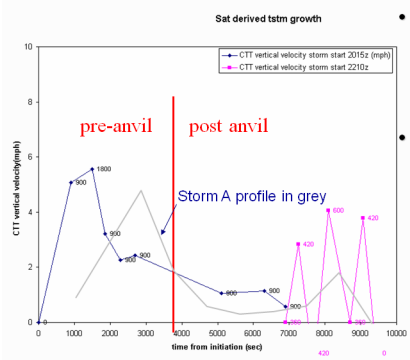
13. Cloud Top Vertical Velocity Plotted for Storms A & B

Instructor Notes: Similarly, using the AWIPS cloud height estimator, peak updraft speeds are up to 5.7 (4) mph prior to (after) anvilgenesis. Actual updrafts are much higher given: that the satellite field of view is larger than individual updraft pulses, that the IR imager only senses cloud edge in the zone of mixing, and not parcel core temper-

ature After anvilgenesis, updraft strength converts mainly to anvil-level divergence owing to adverse buoyancy gradients Therefore 5.7 mph, or 501 ft/min is a significant number in the towering cumulus stage, and 4 mph or 352 ft/min is quite big.

Student Notes:

Cloud Top Vertical Velocity Plotted for Storms A & B



- Peak Pre-anvil cloud top vertical velocity = 5.7 mph
- Peak post-anvil cloud top vertical velocity = 4 mph for secondary pulse (purple)

14. Interim Summary: Las Vegas Storms

Instructor Notes: Storm B went on to produce 70 mph winds and 1” hail. No reports came in for Storm A, although I caution that storm A originated over relatively unpopulated territory and there may have been unreported severe weather at the surface. Note that we used the peak cooling rates prior and after anvilgenesis for the lifetime of a particular single or multicell event. Remember that cooling rates pre- and post-anvil are distinct and should be treated separately.

Student Notes:

Interim Summary: Las Vegas Storms

- Storm B produced 1.25” hail and 70mph winds over LSV
- Storm A had no reported severe weather
  - Low population density
- The peak cloud top cooling and ascent rate for the storm should be used
- Different criteria before and after storm produces an anvil

15. Interim Summary: Cloud Top Cooling Rates

Instructor Notes: There are real problems using this technique, the worst of them is the uncertain image time interval. Cooling rates can be more a function of image frequency than anything real. The optimal frequency should be 30 seconds, which the GOES satel-

lites have done under research operations. Probably the best way to assess cooling rate is to compare cooling rates between storms in a similar environment. The next satellite-based updraft intensity technique may help a bit to account for image frequency problems.

Student Notes:

Interim Summary: Cloud Top Cooling Rates

- Cooling rates are dependent on image temporal frequency
  - Faster scans usually result in higher growth rates
  - Really need 30 second scanning to capture individual updraft growth spurts
- Best to make relative comparisons
- Another technique next

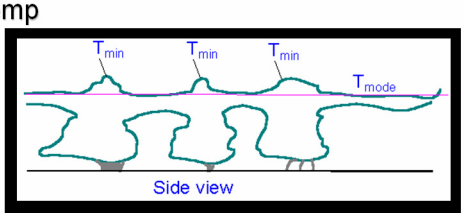
16. Anvil Equilibrium Temperatures

Instructor Notes: When a thunderstorm updraft does reach its own equilibrium level (EL), anvil material spreads out to form a relatively flat region around the updraft overshooting top. This flat region is relatively large, larger than the field of view of the GOES imagery, and therefore, its temperature is easily resolved by the imager. Quantitatively, the mode of the brightness temperature reveals the flat region of the anvil.

Student Notes:

Anvil Equilibrium Temperatures

- Each convective cell has its own equilibrium level height which is visualized on satellite data as relatively flat areas of anvil.
- Represented by the mode of the brightness temp



17. Anvil Equilibrium Temperatures

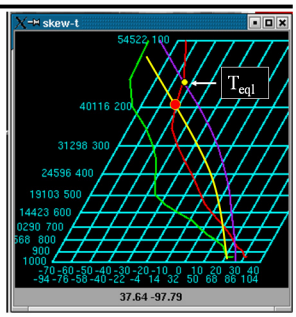
Instructor Notes: Every convective cell has its own equilibrium level, quite distinct from what your RAOB or model sounding may tell you. There are a million reasons for this to happen, the most frequent may have to do with dry air entrainment in updraft parcels.

Another reason may be that the parcel originated at a level or incorporated air at different levels than the chosen method of deriving the theoretical parcel. As a forecaster, you can sample the brightness temperature of areas that appear flat around the overshooting domes. The equilibrium level brightness temperature can be theoretically converted to the updraft parcel ?e for the storm by looking on the sounding for satellite EL at a the given temperature and following the moist adiabat down to the surface. Then comparing ?e based off the satellite EL to that of a representative sounding should provide an impression as to how close to the sounding ?e the storm in question realized. A storm that is utilizing all of the potential ?e shown in the sounding should have an EL brightness temperature close to the EL temperature in the sounding (purple curve with yellow EL). Storms experiencing loss of updraft ?e through dry air entrainment, or a different level or parcel origin should show a warmer EL brightness temperature than the sounding suggests (yellow curve with red EL). In theory, this technique appears straightforward but there are complications as follows: 1. The comparison environmental sounding is not representative of the NSE 2. Storm anvils modify the upper-level temperature environment and change your sounding. Anvils warm the environment at their bottoms and cool the environment at the top. Large contiguous anvils push the tropopause upward and cool it down so that subsequent updrafts are able to reach cooler brightness temperatures without necessarily being more intense. 3. An inversion at the EL may complicate the relationship between cloud height and brightness temperature. As stronger updraft pulses create a higher EL, the brightness temperature may not change or even show warmer values. Overall, this technique should be better than attempting to find the height of an overshooting top and comparing that to the sounding. The reason is that resolution, and cloud edge mixing prevents one from deriving an accurate, or even close to accurate, storm top height based on satellite. Even 1 km imager data will not solve the cloud edge mixing problem to get a picture of the parcel core temperature. This technique works best for: isolated convection growing in an undisturbed environment, that is an environment without prior anvil, Good environmental data, EL lapse rate still positive (no isothermal layers or inversions)

Student Notes:

Anvil Equilibrium Temperatures

- The standard parcel theta-E (purple) gives an equilibrium temperature (T_{eql}) of -55° C
- However, if the storm is entraining dry air, or is elevated, the actual theta-E realized (yellow) may give a warmer T_{eql}



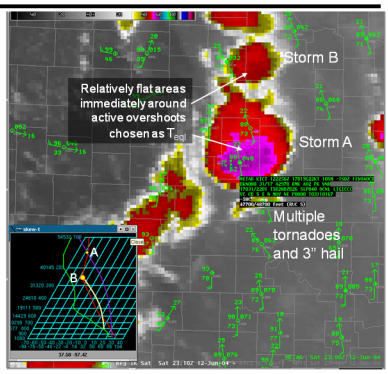
18. T_{eql} Example #1

Instructor Notes: A good example of the application of this technique is to examine storm behavior in a comparative sense. On 12 June 2004, two storms in Kansas formed along a dryline. Given similar surface dewpoints, storm B looks relatively anemic vs. Storm A. Investigating the areas of relatively flat brightness temperature around the overshooting gives me an idea that the two storms have highly different EL temperatures. Storm A appears to be realizing all the SBCAPE found in the RUC model data in its proximity (see “RUC” in the AWIPS cloud height cursor readout). Storm B appears to be grossly under utilizing the SBCAPE available to it, and therefore realizes a much smaller ?e. Storm B eventually dissipated while A went on to produce all sorts of severe weather.

Student Notes:

T_{eql} Example #1

- 12 June 2004
- Storm A appears to be realizing all available SBCAPE
- Storm B is **not** realizing the available SBCAPE



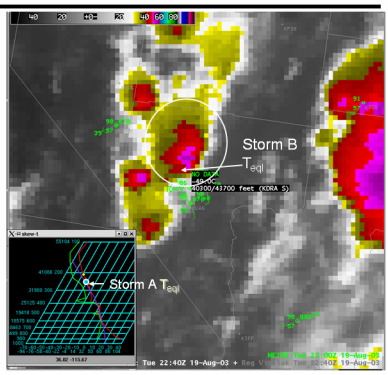
19. T_{eql} Example #2

Instructor Notes: Going back to the LSV example, storm B is the storm that struck LSV with hail, strong winds, and flooding. Note that Storm A has a much lower EL temperature than Storm B. It is likely that Storm B is accessing higher ?e air from the Colorado River Valley than Storm A. Or Storm A never realized the low-level ?e air available to it. Either way, storm A likely has a weaker updraft than B. http://www.cira.colostate.edu/ramm/visit/cldhgt.html

Student Notes:

T_{eql} Example #2

- Back to LSV
- Storm B T_{eql} is colder than Storm A.
- Storm B is likely accessing higher theta-E air from near LSV



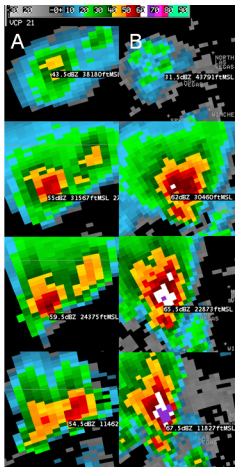
20. T_{eql} Example #2 Radar

Instructor Notes: We can add evidence to the conclusion by noting that Storm B (right column) has a much stronger core with higher reflectivities.

Student Notes:

T_{eql} Example #2 Radar

- Compare the storm A (left) and B (right) to note the relatively larger and more intense core that corresponds to the higher anvil equilibrium level



21. Test Your Knowledge

Instructor Notes:

Student Notes:

22. Interim Summary: Anvil T_{eql}

Instructor Notes: To summarize, assessing the satellite based EL temperature can give you clues as to the ?e in the updraft column, and therefore how well the storm is utilizing the ?e found in its environment. Use this technique to assess relative updraft strengths between adjacent storms. But be careful. The storm anvil should be exposed to undisturbed environment free of pre-existing anvils. Equilibrium temperatures may also lose their relation to anvil height where isothermal layers or inversions exist across the EL.

Student Notes:

Interim Summary: Anvil T_{eql}

- Strengths –
  - Allows you to approximate the theta-E the updraft is realizing.
  - Relative strengths between storms
- Limitations
  - Required anvil exposure to undisturbed environment
    - Storm complexes push the equilibrium level higher
  - T_{eql} and height ambiguity in isothermal layers and inversions at the equilibrium level

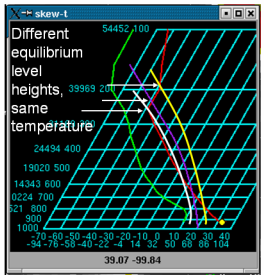
23. Interim Summary contd: Anvil T_{eql}

Instructor Notes: This is an example of the EL temperature and height ambiguity in an isothermal layer. All three parcel ?e profiles give out the same EL temperature. I'm sure the updraft strengths would not be the same, however.

Student Notes:

Interim Summary contd: Anvil T_{eql}

- Limitations: T_{eql} and height ambiguity contd.
  - Isothermal layer on right may result in ambiguity of equilibrium level height



24. Other Satellite-based Severe Convection Training Materials

Instructor Notes: Here are some extra satellite-based training sessions that address severe storms detection. There is another session centered on a case that illustrates the supporting role of satellite data while interrogating storm structure.

Student Notes:

Other Satellite-based Severe Convection Training Materials

- Enhanced-V's and what they mean
  - http://www.cira.colostate.edu/ramm/visit/ev.html
- More on how Enhanced-Vs are formed:
  - http://www.nssl.noaa.gov/istpds/icu624/
- Interpreting Rapid Scan Operations data
  - http://www.cira.colostate.edu/ramm/visit/rso3.html
  - http://www.cira.colostate.edu/ramm/visit/newrso.html

1. Storm Interrogation

Instructor Notes: Storm Interrogation: Estimating Updraft Intensity with Satellite – Part 2 This session is a follow up to part 1 of estimating updraft intensity with satellite data. It is short with 11 slides and should take 15 minutes to complete. There is no “Test Your Knowledge” quiz with this lesson.

Student Notes:

Storm Interrogation

AWOC Severe Track

IC3-II-E

Estimating Updraft Intensity with Satellite: Part 2

2. Objective

Instructor Notes: This objective uses a case to highlight how the following signatures can be used to assist radar in estimating updraft strength and severe storm potential. We will mention: Overshooting top characteristics, enhanced-V signatures, anvil shape vs. storm-relative anvil-layer flow, and Anvil top temperatures. We will also look at the radar presentation of this storm and some near storm environmental information.

Student Notes:

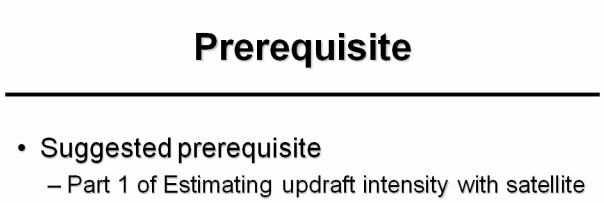
Objective

- Objective
  - Utilize the following satellite signatures to assist radar in estimating updraft strength and severe storm potential
    - overshooting top characteristics,
    - presence of an enhanced-V,
    - anvil shape vs. storm-relative anvil-layer flow,
    - and anvil top temperatures.

3. Prerequisite

Instructor Notes: This is a follow up to part 1 of estimating satellite updraft intensity. Because of this, many satellite-based signatures will be mentioned but not explained in any detail. If there is anything that confuses you, refer to part 1 of this session.

Student Notes:



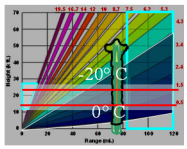
4. Example Case

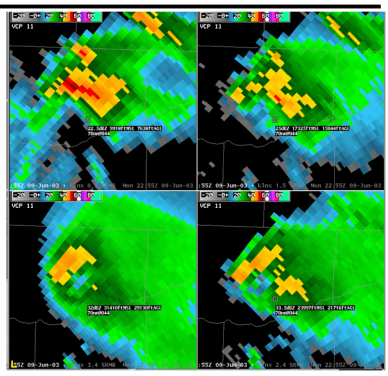
Instructor Notes: This is a developing storm in northern Nebraska on 09 June 2003. It just recently formed ahead of a dryline bulge near or just south of a warm front. A fairly significant 500mb short-wave trough is coming in from the west and SPC has a MDT risk out for the area. The three frames of this loop show what appears to be a supercell structure with a low-level sharp concave reflectivity gradient, and what appears to be a BWER at 2.4° and 3.4° in elevation, or 21 to 25 kft AGL. However, the surrounding reflectivity is extremely weak at high altitudes. The only reflectivities > 60 dBZ are located at the lowest slice, well below the freezing level. Is this echo hole a true BWER, one with intense updraft or is it a gap between two cells? What is this cell capable of doing? Would you issue a warning based on this data alone? Let's take a look at some more information.

Student Notes:

Example Case

- Northern Nebraska
- Is this updraft severe enough to put out a warning?
- If so, what kind of weather do you expect?

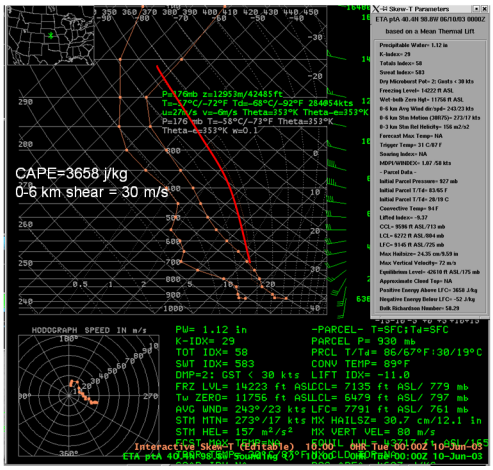




5. ETA Proximity Sounding

Instructor Notes: Since this storm is not near any RAOB sounding, I chose to pick an ETA analysis sounding at 00 UTC. During the actual event, this would've been impossible but a RUC or LAPS sounding showed a similar sounding profile to this one. This sounding shows strong 0-6 km shear of 30 m/s, more than enough for supercells. Steep lapse rates and high CAPE means any storm could go severe quickly and be supercellular in nature. The environment supports the radar structure to be more supercellular than two components of a multicell. But how to explain the low reflectivities?

Student Notes:



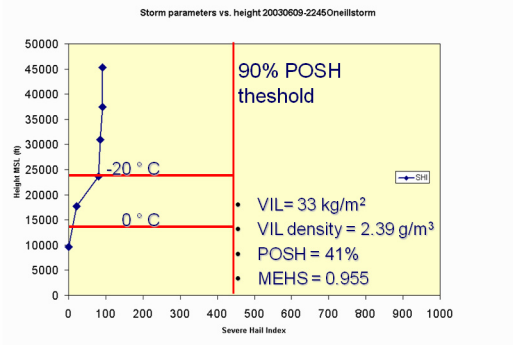
6. Reflectivity Based Vertical Profiles: 2245 UTC

Instructor Notes: If I take the vertical reflectivity profile for this event, and apply the HDA/VIL tool discussed in the lesson on updraft intensity and reflectivity core heights, I see a slowly decreasing profile of reflectivities, especially where it is needed to increase the Severe Hail Index (SHI). VIL reaches only 33 kg/m2, VIL density is only 2.39 g/m3, and SHI is far less than what's needed for a Probability Of Severe Hail (POSH) of 90% (it is only 41%). The Maximum Expected Hail Size (MEHS) seems a bit high given this pro-

file but it is barely over severe limits. Both VIL and VIL Density are far below any minimum threshold discussed in the literature for a warning. The reflectivity profile does not support any warning, and hasn't in all three volume scans.

Student Notes:

Reflectivity Based Vertical Profiles: 2245 UTC



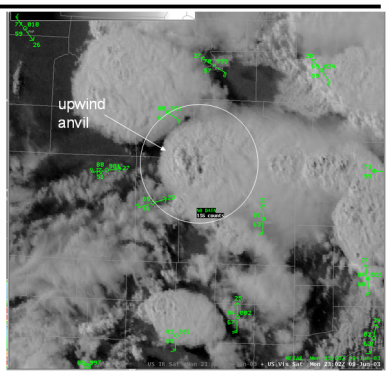
7. Visible Satellite Imagery: 2245 & 2300 UTC

Instructor Notes: The GOES-12 visible imagery shows a well defined overshooting top with a long anvil downwind and yet, significant upwind anvil growth. The Storm Relative anvil layer flow is about 20 m/s which is in the range to support classic supercells according to Rasmussen and Blanchard (1998). The presence of upwind anvil growth and the classic oval shaped anvil in the face of 20 m/s SR anvil layer flow supports the shape and morphology of the radar structure implying a severe updraft.

Student Notes:

Visible Satellite Imagery: 2245 & 2300 UTC

- Strong overshooting top clearly visible
- SR anvil layer flow ~ 20 m/s
- But upwind anvil growth evident

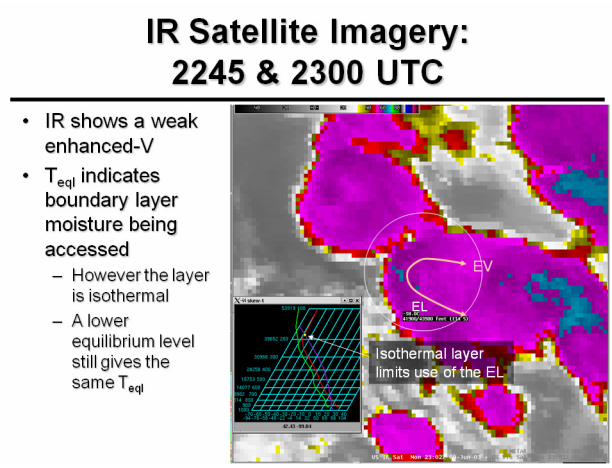


8. IR Satellite Imagery: 2245 & 2300 UTC

Instructor Notes: The GOES-12 IR imagery indicates that the brightness temperature EL based on the AWIPS cloud height tool is about where the ETA analysis expects it to be. However, note that there is an isothermal lapse rate across the EL. This means that a

fairly broad range anvil EL heights may give similar brightness temperatures. We will not use the EL method here. However, the presence of a weak Enhanced-V and a cold overshooting top supports the visible imagery and the radar reflectivity shape that this storm is a supercell.

Student Notes:



9. Summary of Available Data for a Warning Decision

Instructor Notes: To summarize, the radar showed weak overall reflectivities. The HDA and techniques using the vertical reflectivity profile of this storm fail to indicate the potential for severe weather. The presence of a WER is suggested but the classic definition of a WER is one that is overlaid by an intense echo overhang. This is not a classic WER and the same logic applies to the BWER presented here. The GOES 12 IR/VIS data support the argument that the WER and BWER are legitimate indicators of a severe updraft, even if they are not surrounded by high reflectivities aloft. The enhanced-V indicates the presence of a strong, persistent updraft in a sheared environment. Evidence of an overshooting top and upwind anvil growth against 40 kts of SR anvil layer flow both add additional support for a severe updraft. The storm appears to be a supercell with a strong updraft. This is not a high end updraft capable of creating baseball hail but it appears at least strong enough to support golfball hail. The lack of intense reflectivities suggest an LP supercell in appearance and probably has difficulty in developing any kind of severe downdraft. I will go for golfballs in this storm and they are likely to be widely scattered otherwise high reflectivities would show up throughout the storm.

Student Notes:

Summary of Available Data for a Warning Decision

- Radar
  - Weak reflectivities
  - Evidence of BWER and WER but no marginal echo overhang reflectivities
- Satellite
  - Evidence of Enhanced-V
  - Strong overshooting top
  - Upwind anvil growth against 20 m/s SR anvil layer flow
- Decision?

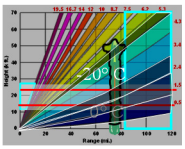
10. SRM Velocity Data for this Event

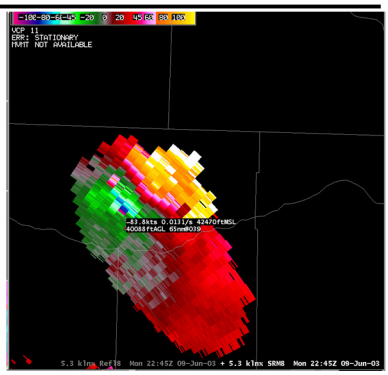
Instructor Notes: I purposely kept the velocity from entering into our analysis until now. But upon showing it, this storm clearly has a classic midlevel mesocyclone and intense updraft summit divergence of nearly 160 kts. This only adds evidence and confidence that this updraft is significantly strong. At 2300 UTC, golfball hail was observed by storm chasers from a supercell with visually LP appearance.

Student Notes:

SRM Velocity Data for this Event

- This velocity all-tilts scan should help
- What is your decision?





11. Summary

Instructor Notes: This is a low precipitation supercell that has a higher severe hail potential than any VIL or HDA products can estimate. There is a BWER and the proper shape of a supercell but the criteria that the BWER must be surrounded and capped by high reflectivities not being met might cast a bit of doubt about the structure indicating a severe updraft. However, the presence of an enhanced-V, large overshooting top, and the velocity structure showing a strong mesocyclone and storm top divergence adds credibility to the fact that this storm's updraft is very strong.

Student Notes:

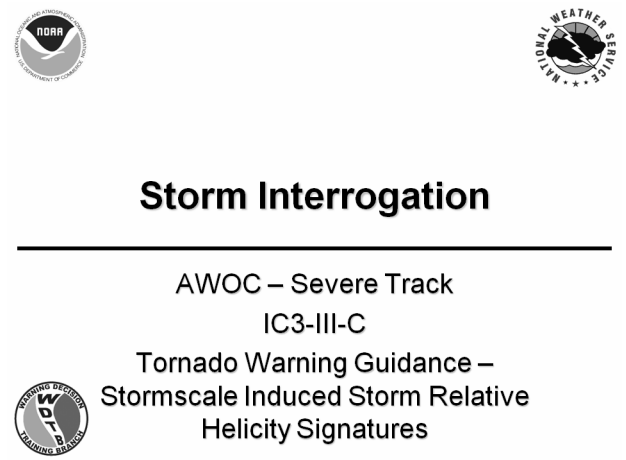
Summary

- Low Precipitation supercell
- Severe hail potential higher than weak reflectivities suggest
- Structure analysis along with impressive satellite appearance suggests greater severe potential than the hail algorithm suggests

1. Storm Interrogation

Instructor Notes: Storm Interrogation – Tornado Warning Guidance – Stormscale Induced Storm Relative Helicity Signatures This lesson is relatively short, only 11 pages long. It should take 10 to 11 minutes to complete.

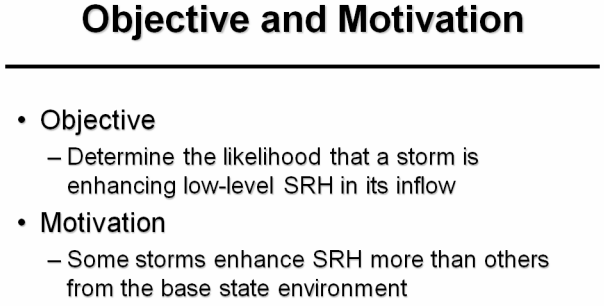
Student Notes:



2. Objective and Motivation

Instructor Notes: The objective of this lesson is to provide you considerations on how a potentially tornadic supercell may enhance Storm-Relative Helicities (SRH) in its storms-cale environment. These considerations are based on results from recent project VOR-TEX experiments and other studies. It is important to know which storms enhance SRH more than others due to factors that you cannot detect on the mesoscales. Some storms may modify their local environment more than others and it is important to deter-mine which ones may do so.

Student Notes:



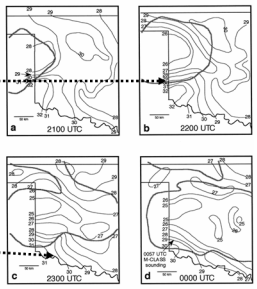
3. Anvil-induced Baroclinity

Instructor Notes: Anvil shading induced baroclinicity is a phenomenon that was proposed by Markowski 1998 after examining several cases, some going back to the early 1980's to several events from project VORTEX including the June 08, 1995 tornado outbreak in the Texas Panhandle. In these cases, Markowski noted significant surface temperature drops induced by the loss of solar insolation under the forward anvils of supercells. The June 08 case shown above is an analysis of surface temperatures from the Oklahoma mesonet. Note the significant temperature gradient forming under the southern anvil edge. After a scale analysis of horizontal vorticity production resulting from this temperature gradient, Markowski found that mesocyclonic vorticities can develop in as little as 20 minutes for air parcels residing in this anvil shadow induced temperature gradient. Two features are needed to support evidence of horizontal vorticity production by anvil shading: The low-level inflow needs to be roughly parallel to the anvil-layer SR flow so that the low level flow parallels the anvil edge. Solar insolation must be significant surrounding the anvil to set up the relative cooling under the anvil.

Student Notes:

Anvil-induced Baroclinity

- Cooling along south anvil edge results from shadow. Baroclinity results leading to horizontal vorticity.
- Strongest 1 km SRH enhancement may occur when low-level inflow parallels anvil edge.
- Need sunlit ground right of anvil.



Markowski, MWR 1998, pg2924

4. Anvil-induced Baroclinity Example

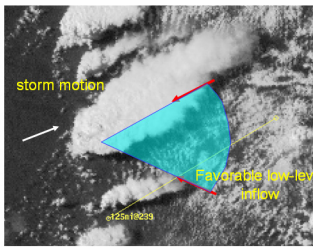
Instructor Notes: This event, occurring on May 6, 2001 in Southern Oklahoma shows an anvil that may be a good candidate for anvil-induced horizontal vorticity production. The anvil layer SR flow and storm motion are nearly parallel. Low-level inflow is nearly opposite to the anvil layer SR flow. The anvil shadow edge should remain relatively fixed. Low-level air parcels acquire increasing horizontal vorticity in the anvil edge-induced thermal gradient the longer they remained in that region. Markowski found that 20 minutes residence time was sufficient to generate mesocyclonic horizontal vorticity of .01 s-1. The depth of shadow-induced cooling was found to be less than 200 m deep. However, the shallow layer shear is also the greatest tornado/non-tornado discriminator for mesocyclonic tornadoes. Perhaps there is some forecasting value to looking for anvil-induced enhancements to 0-1km SRH but the evidence to date is weak. This is certainly

a parameter not to depend on to make your tornado warning decision. But if the situation presents itself favorably, you may want to take note.

Student Notes:

Anvil-induced Baroclinity Example

- Prefer low-level inflow to be nearly parallel to anvil-level SR flow.
- Anvil-induced baroclinicity is not a well documented mechanism for enhancing SRH.



5. Forward Flank Downdraft Gust Fronts?

Instructor Notes: Forward flank downdraft gust fronts have long been recognized as a potential source of enhanced SRH through buoyancy gradient induced horizontal vorticity formation. Numerous stormscale numerical modeling studies continue to support the production of low-level mesocyclogenesis through tilting of forward flank gust front horizontal vorticity. This mechanism had failed to show up for most VORTEX project cases in 1994 to 1995, and also during most subsequent cases that were sampled by mobile mesonets. Clearly the necessity of a forward flank gust front for tornado production was shown not to be true in general. However, do not ignore the presence of a forward flank gust front when one does materialize. There have been several documented events with marginal low-level pre-storm shear that likely were enhanced by the production of a forward flank gustfront and resultant horizontal vorticity.

Student Notes:

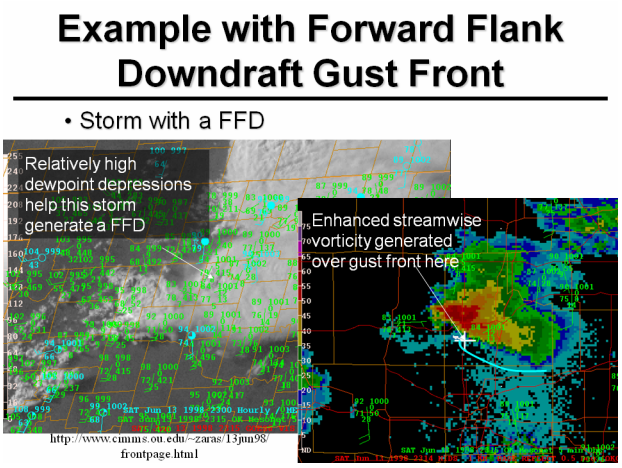
Forward Flank Downdraft Gust Fronts?

- Theory supports FFDs enhancing 1 km SRH and tornadogenesis through numerical analysis.
- VORTEX (1994-2000) observations unable to observe FFDs in most tornadic supercells.
- The role of FFDs in enhancing SRH and tornadogenesis may help in some cases but is not a necessary condition.

6. Example with Forward Flank Downdraft Gust Front

Instructor Notes: Low-level Forward Flank Downdrafts (FFD) and gustfronts are favored in environments with evaporational cooling potential from sufficiently large near surface dewpoint depressions. This event on 13 June 1998 is a strong candidate for this kind of event. On this day, there was strong deep layer shear and very large CAPEs. Dewpoint depressions averaged between 15 and 20° C. Note 0.5 ° radar scan overlaid by mesonet data for the same time shows one mesonet with a northeast wind on the south side of the forward flank core. Horizontal vorticity, and SRH are likely to be enhanced in this region just south of the core upon which the updraft ingests this to assist in low-level mesocyclogenesis. Shortly after this image, an F1 tornado formed and lasted about 10 minutes.

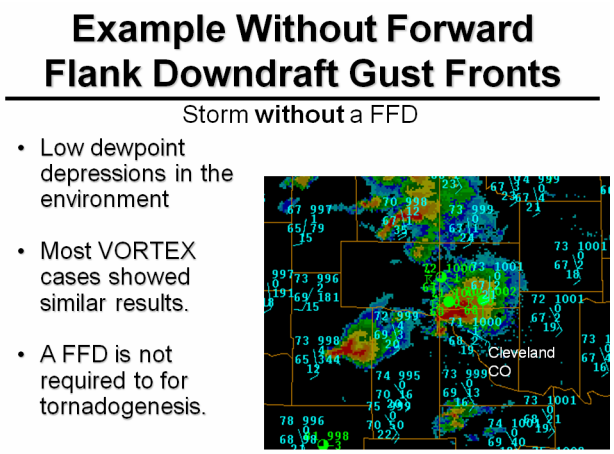
Student Notes:



7. Example Without Forward Flank Downdraft Gust Fronts

Instructor Notes: If an environment with 15 to 20 °C dewpoint depressions can generate a FFD gustfront, then an environment with a nearly saturated boundary layer may inhibit FFD formation. May 3, 1999 provided a classic example. Here, dewpoint depressions were on the order of a few degrees. There was much weaker evidence of a significant FFD gustfront across the south edge of the forward flank core in northern Cleveland County. Despite the lack of well defined FFD boundaries, this day produced exceptionally long tracked, violent tornadoes. Many of the VORTEX cases had similar environments.

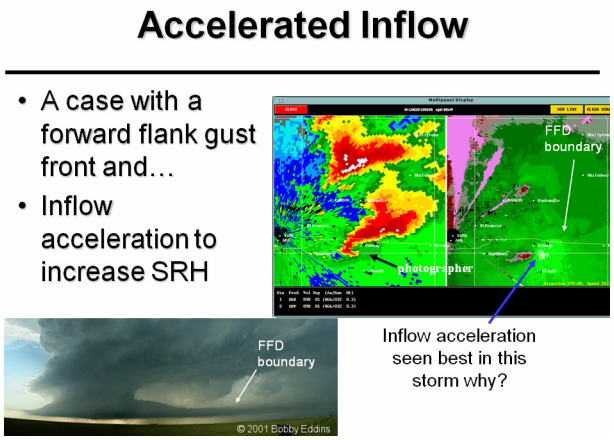
Student Notes:



8. Accelerated Inflow

Instructor Notes: Mesocyclones, by virtue of their enhanced vertical pressure gradients, often assist buoyancy in generating a strong updraft, and consequently, enhanced inflow. Enhancing inflow speeds also enhances SRH given the same embedded streamwise vorticity. The southern supercell shows very obvious enhanced inflow while the northern one does not. I will let you speculate as to why that is the case. This event which occurred on 29 May 2001 east of Amarillo, TX produced several tornadoes, but only from the northern supercell. Note that a FFD boundary shows up in the velocity product in the southern storm. This boundary is likely to reside along the inflow cloud band observed in the photograph.

Student Notes:

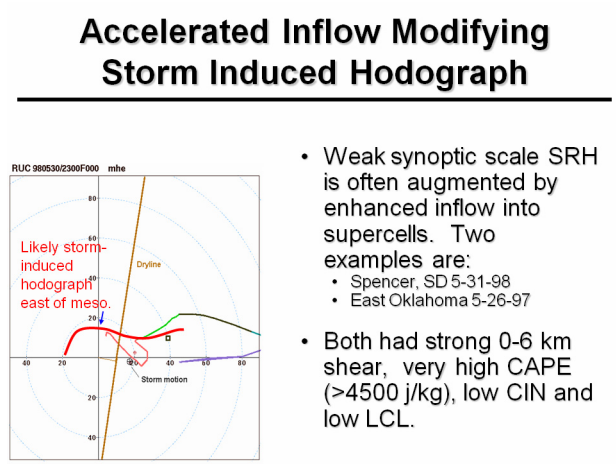


9. Accelerated Inflow Modifying Storm Induced Hodograph

Instructor Notes: Accelerated inflow is often not just a shallow feature, and seems to increase in strength as the deep layer shear increases. Observations from the field also

suggest that supercells utilizing very high CAPE (>4500 j/kg) appear to have significantly stronger inflows than weaker CAPE storms. The hodograph on the left was taken from the RUC model sounding east of the Spencer, SD tornadic storm on 30 May 1998. Environmental low-level flow was almost nonexistent. However, there was extreme CAPE and very strong 0-6 km shear (50 kts). Spotters just ahead of the supercell reported inflow of at least 20 kts. Using a little artistic license, the hodograph has been modified in the lowest 6 km based on their observations and a small numerical study by Weisman et. al (2000).

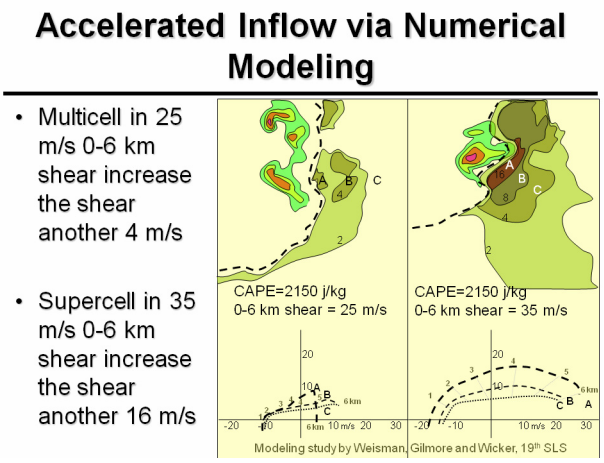
Student Notes:



10. Accelerated Inflow via Numerical Modeling

Instructor Notes: Weisman et. al (2000) ran several experiments where the pre-storm environmental 0-6 km shear was changed, and then the 0-6 km shear was analyzed during the lifecycle of the modeled convection. Their experiments show a large increase in storm-induced shear, with shear values increasing with decreasing distance from the storm (see sounding points C to B to A) on the right hand side. The earth colored shaded regions ahead of the reflectivity core of the storm show where the storm has affected the 0-6 km shear fields. Some of the shear is induced by accelerated low-level inflow, while some is induced by accelerated midlevel flow on the south and southeast sides of the mesocyclone. Lowering the pre-storm shear produces nonsupercell storms and lower enhancements to the storm proximity shear (see the left side).

Student Notes:



11. Choices

Instructor Notes:

Student Notes:

12. Summary: Low-level SRH Enhancement

Instructor Notes: Low-level SRH enhancement can be detected close to the radar in the form of forward flank outflow boundaries, and storm-induced inflow acceleration. Far from the radar, your information content goes down and the need for inference and intuition go up. FFD boundaries are most likely to become prominent when supercells produce long forward flank cores and there are adequately high dewpoint depressions in the boundary layer. Another, less tested consideration, is the anvil baroclinity. Look for this where the anvil extends ahead of the anticipated storm motion and there is strong solar insolation outside the anvil shadow.

Student Notes:

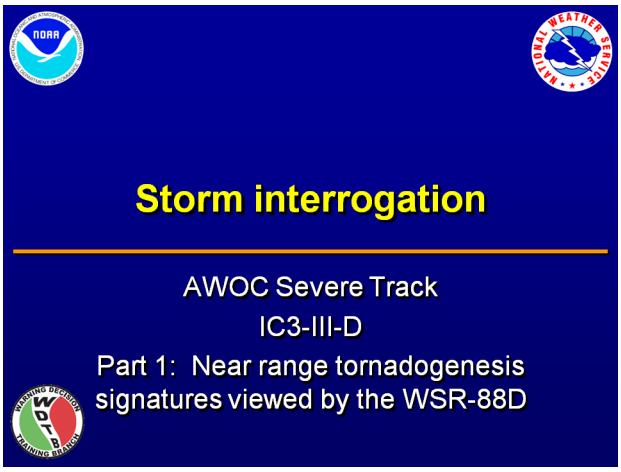
Summary: Low-level SRH Enhancement

- Close to radar, can detect
  - Forward flank outflow boundaries in velocity
  - Storm-induced inflow acceleration in velocity
- Far from the radar, must infer
  - FFD boundary right of the reflectivity core
  - Adequately high dewpoint depressions
- Anvil baroclinicity
  - Anvil must extend ahead of anticipated storm motion
  - Adequate solar heating right of anvil edge

1. Storm interrogation

Instructor Notes: Welcome to the AWOC Severe Track Part 1: Near range tornadogenesis signatures viewed by the WSR-88D This lesson is 18 slides long and should take 20-25 minutes to complete. Part 2 of this duo examines near range tornadogenesis by the TDWR

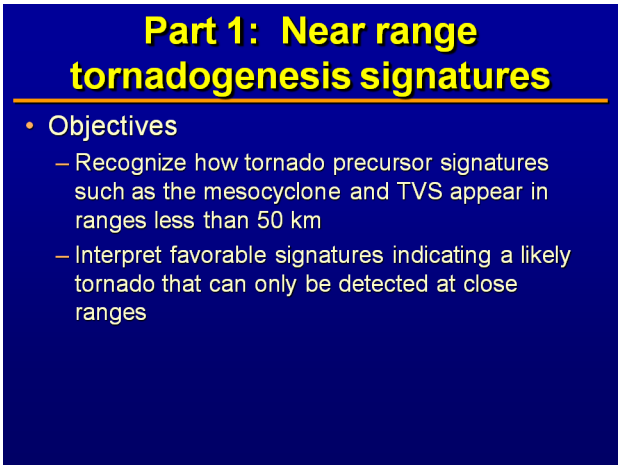
Student Notes:



2. Part 1: Near range tornadogenesis signatures

Instructor Notes: The appearances of the classic mesocyclone and TVS are quite different when these features become large relative to the beam width. As we will see, the TVS may not represent the entire tornado cyclone, but perhaps an increasingly small part of it. The mesocyclone may not even look like a coherent rotational structure when smaller velocity structures within can be resolved. On the other hand, it is these close ranges where radar data becomes by far the most useful tool because of the extreme detail it can portray. There are two objectives in Part 1: Recognize how tornado precursor signatures such as the mesocyclone and TVS appear in ranges less than 50 km Interpret tornado signatures that can only be detected at close ranges.

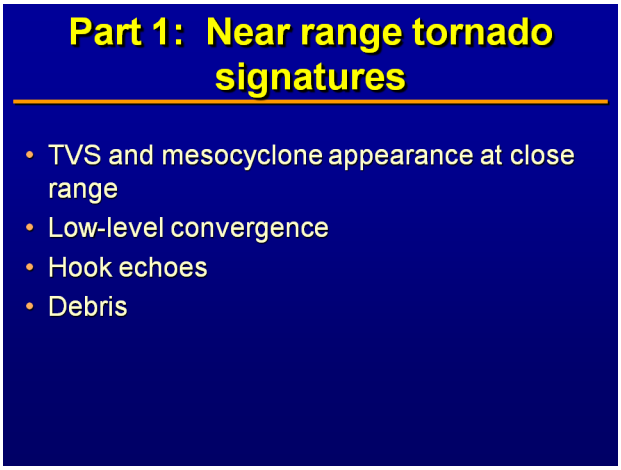
Student Notes:



3. Part 1: Near range tornado signatures

Instructor Notes: This lesson, using two cases that represent a growing number of documented close range tornadic events to radars, will show the appearances of a TVS and mesocyclone at close range, low-level convergence signatures, the finescale appearance of hook echoes, and debris signatures.

Student Notes:

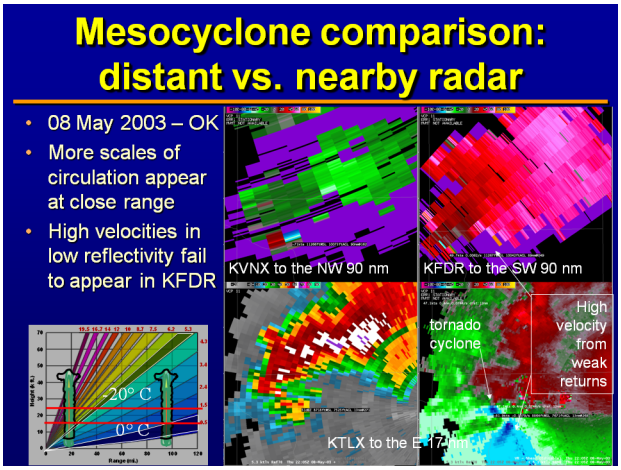


4. Mesocyclone comparison: distant vs. nearby radar

Instructor Notes: This case on May 8, 2003 resulted in an F4 tornado that struck Moore, OK and was observed at close ranges by KTLX WSR-88D, a nearby TDWR, and the experimental radars at NSSL and the ROC. All the radars observed the entire lifecycle of the tornado less than 15 miles in range. To start off, we show the appearance of this mesocyclone at approximately 10 kft AGL from two radars of different viewing angles but 90 nm away to that of KTLX, only 17 nm away just before the start of the tornado at 2205 UTC. To the northwest, KVNX lucks out and manages to sample the tornado cyclone with an almost 0.5° offset angle (See IC3-III-A) resulting in a gate to gate signature that easily is strong enough to be called a TVS if it has vertical continuity. None of

the strong flow around the storms right flank can be detected because of weak returned energy. KFDR, 90 nm southwest, suffers from range folding problems in the area of the mesocyclone for the same reason. Other volume scan times show better resolved strong outbounds on the right flank of the storm and KFDR is well positioned to see the flow around the right side of the mesocyclone; some gates show > 100 kts of outbounds. KFDR is barely able to resolve the gate to gate tornado cyclone signature. KTLX, 17 miles away, and with an elevation in the center of the 0.5° slices of the other radars, is close enough to resolve the low reflectivity, high velocity signature on the storms right flank. This is often visualized as rapid horizontal motion in the cloud bands to the right of the visual storm updraft at midlevels and comprises part of the mesocyclone as viewed from more distant radars. These high inbounds are nearly completely separate from the occluded portion of the mesocyclone (or tornado cyclone) within the hook echo and inside the rear flank downdraft. Note that the tornado cyclone does not show the maximum velocities in this circulation in adjacent gates at this elevation angle. There is a 90 kt gate to gate velocity difference, but higher velocities exist at greater ranges from the tornado cyclone center. Sometimes a circulation may not even show up as a TVS at these ranges and yet be very tornadic.

Student Notes:

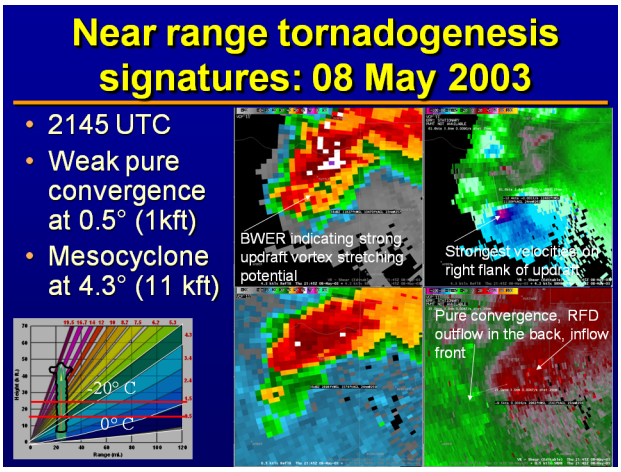


5. Near range tornadogenesis signatures: 08 May 2003

Instructor Notes: The environment on this day was very supportive of tornadoes, low LCLs, 0-1 km wind shear exceeding 25 kts, CAPE on the order of 4000 j/kg, no CIN and a strong dryline west. A PDS tornado watch is in effect and any supercell in the stage of development shown above is likely to have high tornado potential. We'll take a walk through of common signatures at near range leading up to the tornado. We'll start at 2145 UTC, about 20 minutes before tornado time. Two slices are displayed, the lowest slice at 1 kft AGL, and the other at 11 kft AGL. As the storm approaches the radar, I will change elevations to keep sampling the storm between 8 and 11 kft for the upper slice. Several precursor signals are coming together for tornadogenesis. The higher reflectivity slice shows evidence of a strong midlevel updraft signified by a BWER. Strong velocities appear on the right flank of the storm updraft comprise a well developed mesocyclone, more evidence that air is accelerating strongly upward between the surface and 10 kft.

Also at 10 kft, there are areas of separate inbounds and convergence which may indicate an RFD. Near surface velocities show almost pure speed convergence. But that convergence is under a mesocyclone further indicating some stretching potential is there for any near surface vorticity in the vicinity. At this time, there is no significant RFD outflow surge and low-level convergence is fairly weak. Given the elevated convergence, an RFD outflow surge may seem likely.

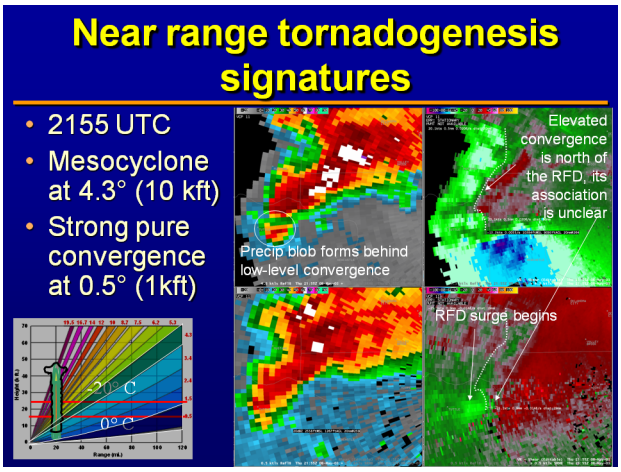
Student Notes:



6. Near range tornadogenesis signatures

Instructor Notes: At 2155 UTC, 5 minutes later, the low-level velocity shows the RFD outflow surge may indeed be underway. Convergence at its nose ramps up considerably. But note there is no rotation. Above the RFD surge, note the inbounds and midlevel convergence increases a little behind the low-level convergence (accounting for system motion before the radar scans at 10 kft AGL) and is marked by the dotted white boundary. An area of precipitation forming above and behind the low-level RFD surge a feature that has been observed before prior to tornadogenesis and may have some relationship that has not been identified yet. We often call this a Descending Reflectivity Core (DRC).

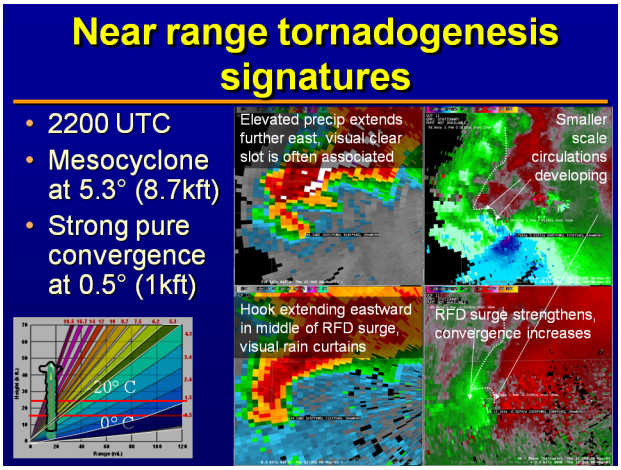
Student Notes:



7. Near range tornadogenesis signatures

Instructor Notes: At 2200 UTC, the elevated precipitation blob connects with the low-levels to form the beginning of a hook echo. The part of the hook about to curl to the east lies in the middle to south part of the RFD surge. Strong convergence begins to broaden north to south just ahead of the hook echo. Note that the inflow into this convergence (visualized as outbound low-level velocities) increases too. At 8.7 kft AGL, small scale circulations begin to develop, nearly overhead of the low-level convergence. Developing rotation above strengthening low-level convergence, all underneath a strong echo overhang (not shown) signifies stronger and more immediate mesocyclonic tornado precursor signals.

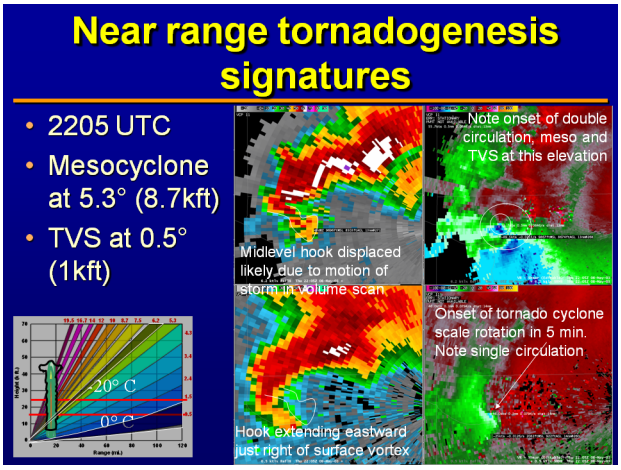
Student Notes:



8. Near range tornadogenesis signatures

Instructor Notes: At 2205 UTC, the southern of the two circulations at 8.7 kft AGL consolidates and links with the rapid onset of circulation at the lowest level. This is tornadogenesis underway. The hook echo extends further east embedded on the strengthening RFD surge, now right of the circulation, now a tornado cyclone. Note that the radar must complete many scans before adequately sampling the low- and midlevels of this storm. Meanwhile the circulation is progressing eastward causing an artificial tilt of all features in the direction of storm motion.

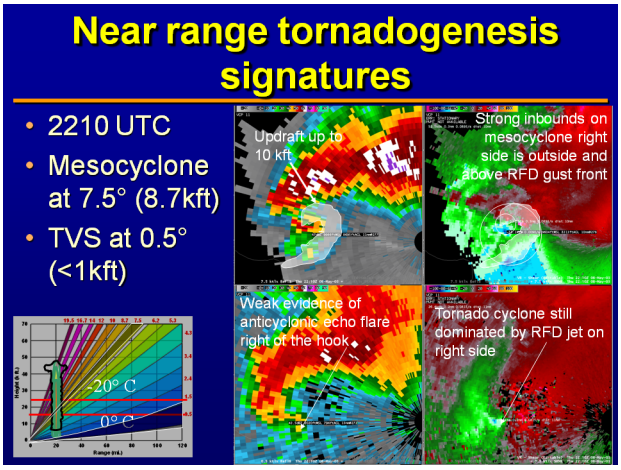
Student Notes:



9. Near range tornadogenesis signatures

Instructor Notes: The tornado cyclone is still dominated by an RFD jet on its right side. At 8.7 kft AGL, note that the tornado cyclone (inner circle) still has the maximum inbound/outbound velocities away from the center. A TVS is present after noting the gate-to-gate shear of adequate magnitude. Some tornado cyclones at this range fail to show a TVS. The larger mesocyclone is still evident at 8.7 kft as a separate circulation from the tornado cyclone. Visually, the tornado cyclone is mostly RFD outflow swirling toward the cyclone center. The RFD air contains the hook echo. Part of that hook may be falling out of a deep dry slot carved out of the updraft (white shaded comma shaped region), which in turn, conforms roughly to the RFD gust front boundary. Thus the updraft becomes more horse shoe shaped. Not all updrafts will undergo this shape transformation to a horse shoe, but most will while low-level mesocyclogenesis commences. One other interesting effect of the RFD surge is that an area of anticyclonic vorticity can accumulate on the right side of the surge. If the radar is close enough and the anticyclonic circulation is large enough, you may see it visualized in the reflectivity data as an anticyclonic flare echo. What you are seeing is likely a reflection of baroclinic vorticity forming at the nose of the RFD in the form of arches, the south side of the vortex arch is anticyclonic, the north side, cyclonic. Sometimes this sheet of anticyclonic vorticity coincides with the tail part of the updraft over the trailing gust front and anticyclonic tornadogenesis may be the result

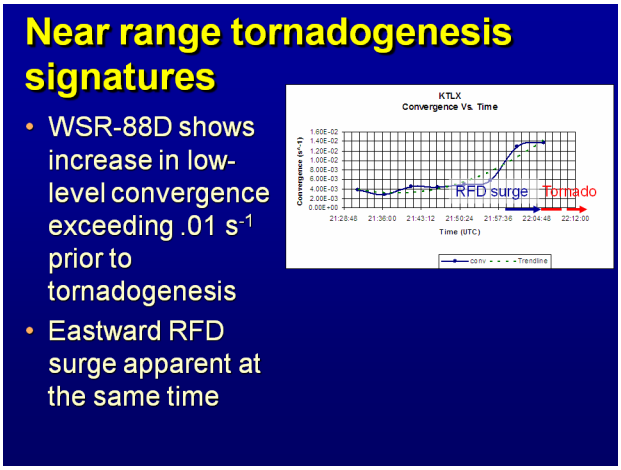
Student Notes:



10. Near range tornadogenesis signatures

Instructor Notes: The RFD surge in combination with increasing storm-relative low-level inflow increases convergence rapidly just before tornadogenesis. Low-level convergence values rise above .01 s-1 across a one km baseline. There is perhaps a 1 to 10 minute leadtime before tornadogenesis in this case.

Student Notes:

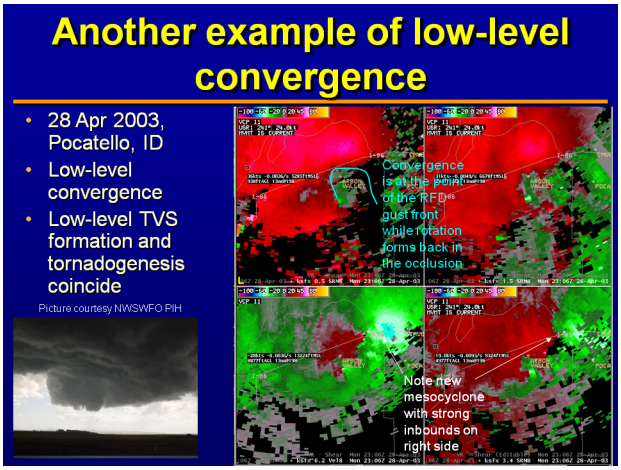


11. Another example of low-level convergence

Instructor Notes: A close range tornadogenesis event occurred just south of Pocatello, ID on 28 April 2003. This time, the radar was left of the storm track, whereas on 08 May 2003, the radar was to its right. The different viewing angle precludes viewing the full strength of the RFD surge; it is directed more to the east instead of straight at the radar. At 2256 UTC, the RFD gust front is evident as a horse shoe shaped region of convergence turning to shear on the left side. Given the ground clutter on the lowest slice, the convergence appears a little better at the 1.5° slice. The larger mesocyclone appears best at 10 kft AGL at 2256 UTC with more pure convergence below in the lowest two slices. A tornado cyclone also forms at 10 kft AGL over the left side of the RFD horse-

shoe shaped gust front. The next scan at 2301 UTC shows the tornado cyclone extending to ground level and tornadogenesis commenced.

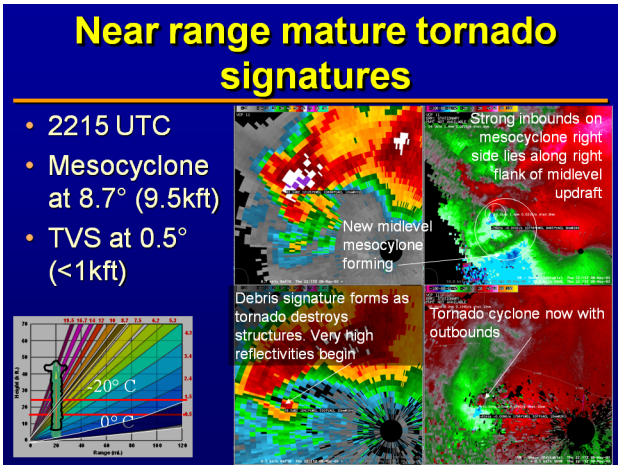
Student Notes:



12. Near range mature tornado signatures

Instructor Notes: Going back to the 08 May 2003 tornado, we now look at some mature tornado signatures that show up only at near ranges. The lowest velocity scan now shows a more symmetrical tornado cyclone, although the RFD inbounds still provide some asymmetry to the circulation. The RFD shows strong connection to the downdraft and outflow from the forward flank region of the storm's core. The tornado cyclone and larger mesocyclone still appear as separate circulations at 10 kft AGL. Note, however that on the right flank of the midlevel mesocyclone, a separate area of enhanced inbounds increase in strength that indicates the development of localized updraft rotation and the beginnings of a new separate mesocyclone. Perhaps the most notable signature is the existence of a small area of strong reflectivities at the tip of the hook echo in the lowest scan. This small area of reflectivity appears just as the tornado destroys structures near I-35 in Moore. The reflectivity "ball" is the signature that the radar is detecting debris. The follow up session to this shows another region of even more intense reflectivities viewed by the TDWR.

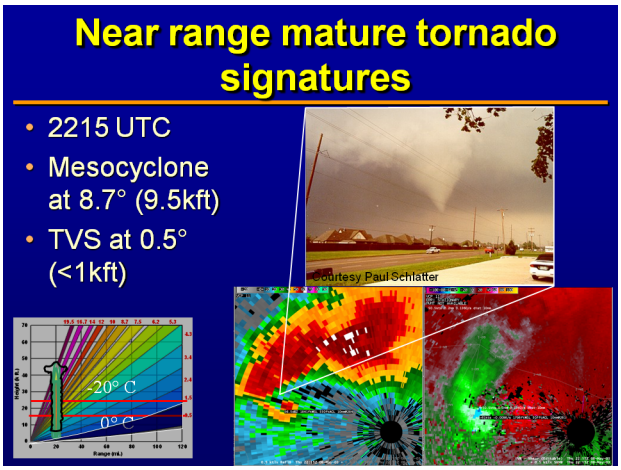
Student Notes:



13. Near range mature tornado signatures

Instructor Notes: As observed from the ground to the northwest, and a couple minutes before the radar image, the tornado is beginning to loft debris several hundred feet into the air. At 16 miles range, large debris at this altitude is enough to be detected by the radar. Again, the debris needs to be large to present a significant radar cross-section. Dust particles alone are not enough to provide reflectivities that exceed normal reflectivities associated with the hook echo and other natural scatterers (e.g., insects).

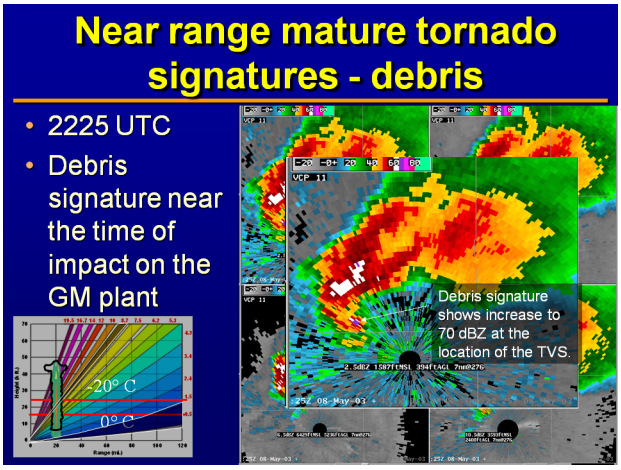
Student Notes:



14. Near range mature tornado signatures - debris

Instructor Notes: At 2225 UTC, the tornado impacted the General Motors plant in Southeast Oklahoma City resulting in a significant upward surge in debris.

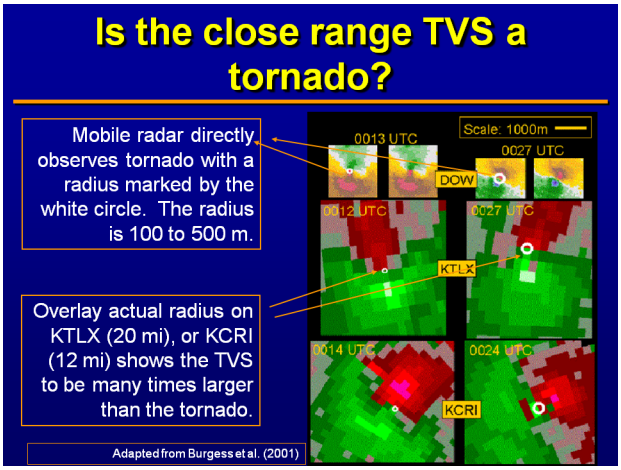
Student Notes:



15. Is the close range TVS a tornado?

Instructor Notes: A question often arises as to whether the tornado core can be adequately sampled by the WSR-88D at close ranges. On May 3, 1999, the Doppler On Wheels (DOW) sampled a large tornado within a few km range. The small velocity couplet signature from the DOW that can be seen at two different times, 0013 UTC and 0027 was the tornado core. Its radius was chosen as the radius of maximum winds found around the tornado center. Superimposing the white circle at 0013 UTC, marking the tornado diameter on the WSR-88D from KTLX (20 miles range), and the test bed WSR-88D, KCRI (12 miles range), you can see that the tornado core is still far smaller than the individual gate sizes from both radars. Even when the radar was closer (16 miles from KTLX, 8 miles from KCRI) the tornado core diameter is still too small for the two radars to resolve it. Adequate tornado sampling requires about 4 azimuthal gates across the core. Other factors also hinder adequate velocity sampling of the tornado: The tornado offset angle from the beam centerline is too small, or a single range gate is sampling both sides of the tornado. Most of the returned power to the radar comes from relatively slow moving debris. You don't see the velocity spectra, only the velocity from which the radar detects the greatest returned power.

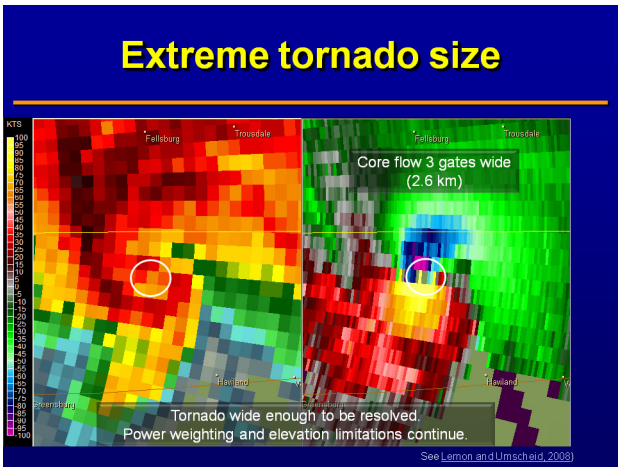
Student Notes:



16. Extreme tornado size

Instructor Notes: So far in this lesson we've shown you that large tornadoes are not resolvable by the WSR-88D because of the gate to tornado size ratio is not large enough. However, since this lesson was first introduced, we've seen a couple events where the tornadoes were large enough to call our first assumption into question. Featured here is the Trousdale tornado from 0325 UTC, 05 May 2007. The inbound/outbound velocity maxima in this image are approximately 105 and 118 kts respectively. These velocities are certainly in the tornadic range, even with the limitations of the power weighting. The width of the damage track corresponds to a tornado width > 2.6 km though the core flow of this tornado was estimated to be close to 2.6 km. That's wide enough for the WSR-88D to sample this core with three azimuthally adjacent scans. We are very close to resolving the tornado here even at a range of 38 nm. See the paper by Lemon and Umscheid by clicking on the link in the lower right for a more detailed discussion on this event.

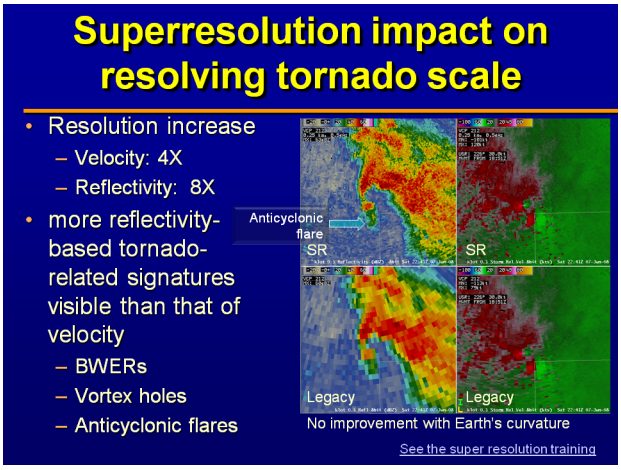
Student Notes:



17. Superresolution impact on resolving tornado scale

Instructor Notes: The recent addition of super-resolution data adds the ability to detect features associated with tornadoes at greater ranges. This is especially true with reflectivity data where you're now able to view the individual 0.13 nm range gates. As a result, you are now more likely to see features associated with tornadoes such as vortex holes, and anticyclonic flares in hook echoes. The top reflectivity image shows an anticyclonically-shaped hook echo appendage much more clearly than the legacy resolution product on the bottom. While the main features in the SRM show up in both images, the velocity difference is a little larger in the SR product. Superresolution data is extremely useful in resolving features scanned by the radar such as tornado cyclones and vortex holes. However, you still have the range limitations of detecting certain features such as low-level convergence. For more information on super resolution data, I refer you to our training linkable in the lower right.

Student Notes:



18. Choices

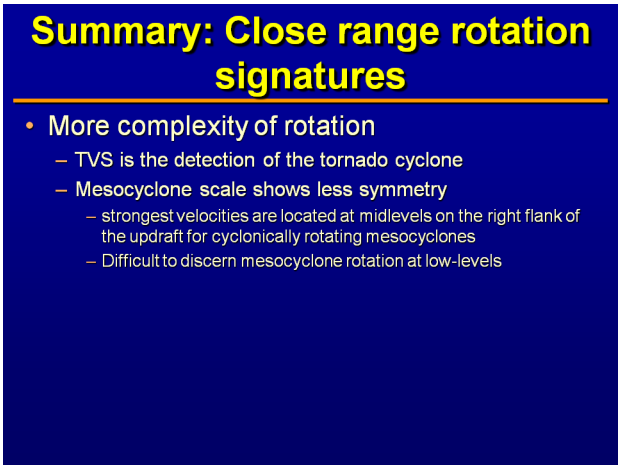
Instructor Notes:

Student Notes:

19. Summary: Close range rotation signatures

Instructor Notes: To summarize, close range rotation signatures are more complex in scales. At close ranges, the TVS is the manifestation of the tornado cyclone. The meso-cyclone does not appear as symmetric as before, with most of the strong velocities dis-placed to the right side of the updraft for cyclonically rotating storms. At low-levels, the mesocyclone may not appear at all.

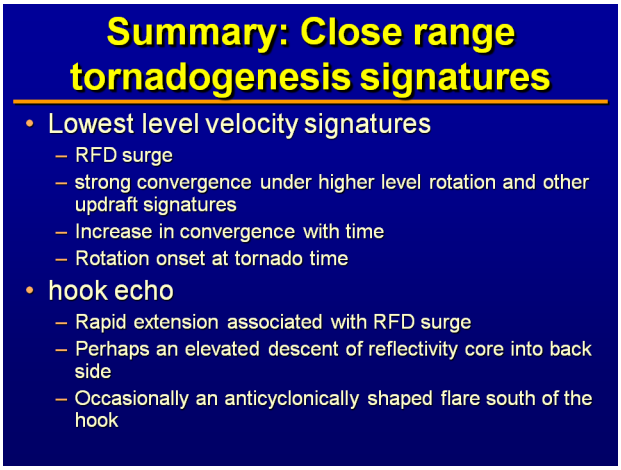
Student Notes:



20. Summary: Close range tornadogenesis signatures

Instructor Notes: Remember that these signatures apply best to mesocyclone induced tornadoes. Tornadogenesis signatures appear at low-levels as the RFD begins to develop. Convergence increases dramatically at low-levels and should appear under a midlevel mesocyclone and other strong updraft signatures. Only immediately before tornado formation is there any appearance of a tornado cyclone at low-levels. The convergence signature gives you on the order of 5 to 10 minutes of lead time. The onset of an intense tornado cyclone may only appear within a minute of tornadogenesis. The hook echo may appear to extend in length and definition as the RFD develops. More recent research work has suggested that a descending ‘blob’ of reflectivity on the back side of the storm may contribute to RFD genesis. As the RFD matures and begins to develop low-level rotation, an anticyclonic flare echo may be detected right of the main hook echo. Anticyclonic tornadoes are most likely if this anticyclonic flare coincides with the gust front underneath strong updraft.

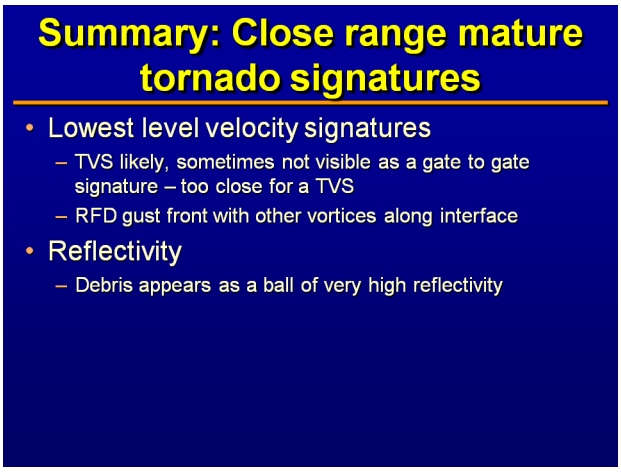
Student Notes:



21. Summary: Close range mature tornado signatures

Instructor Notes: Close range radar signatures of a mature tornado include good sampling of the tornado cyclone. Sometimes, the sampling is such that no gate to gate TVS strength signature appears in the tornado cyclone. The RFD gust front appears well defined, and there may be other vortices appearing along its interface. If the tornado is ejecting large debris (e.g., tree branches, building parts), a reflectivity debris ball may appear as a small region of very high reflectivities extending upward several thousand feet or more.

Student Notes:



1. Storm interrogation

Instructor Notes: Welcome to the AWOC Severe Track ICsvr3: Part 2, Near range tornadogenesis signatures viewed by the TDWR This part follows part 1 of near range tornadogenesis signatures by the WSR-88D. It is approximately 13 slides long and should take about 10 minutes to complete.

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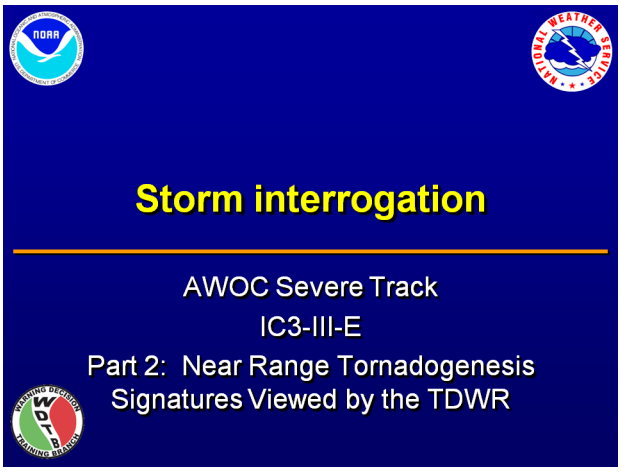
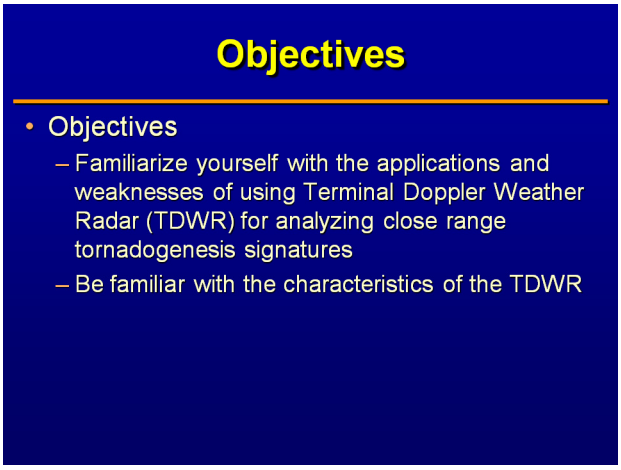


2. Objectives

Instructor Notes: As objectives, you should familiarize yourself with the applications and weaknesses of using the TDWR for analyzing close range tornadogenesis signatures. The same applications and weaknesses should apply to the interrogation of many meteorological features. This lesson will also help you become more familiar with the characteristics of the TDWR. At this point, development is underway to send TDWR data to WFOs on an operational basis. Thus for any site that has a TDWR in your CWA, this lesson will have more relevance to you.

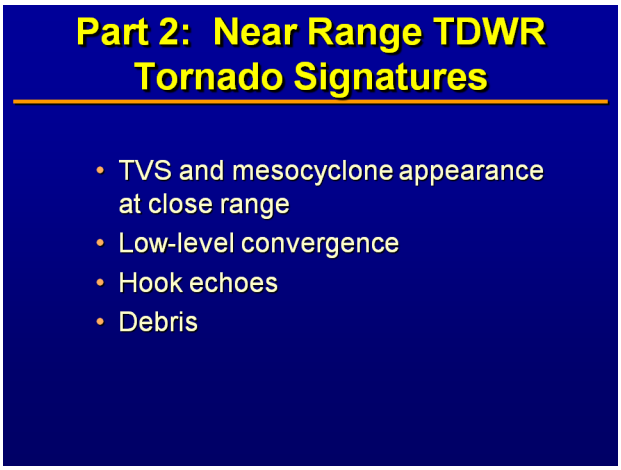
Student Notes:



3. Part 2: Near Range TDWR Tornado Signatures

Instructor Notes: We will look at the similar events as with part 1, a close range mesocyclonic tornado formation case in Norman, OK, and a nonmesocyclonic case from Salt Lake City, UT. You will see how TVS signatures and mesocyclones appear in the TDWR, how low-level convergence signatures appear, how hook echoes become more complicated, and at the sensitivity of the TDWR to debris signatures.

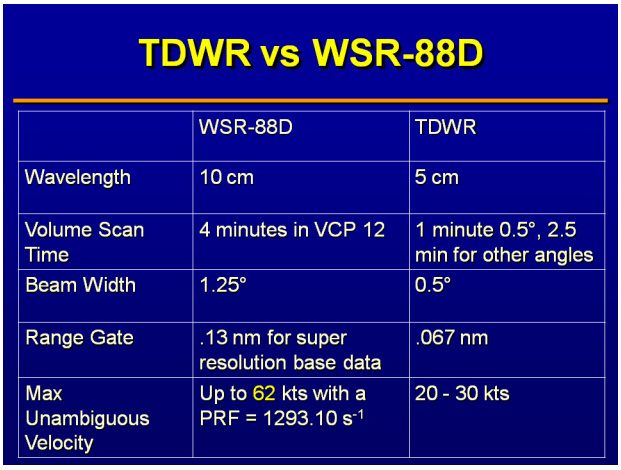
Student Notes:



4. TDWR vs WSR-88D

Instructor Notes: The TDWR operates at 5 cm and is more susceptible to attenuation in heavy precipitation. However, this wavelength is more conducive to detecting most nonprecipitating echoes such as insects. One of the TDWR volume scan strategies allows for one minute sampling at the 0.5° angle while sampling other elevation angles on a 2.5 minute basis. The real advantage comes with the 1 minute sampling when a storm is undergoing tornadogenesis. The beam width of the TDWR is half that of the WSR-88D. Add a shorter range gate due to a faster PRF, and the TDWR delivers much higher resolution, 4 times more data than a single range gate from the WSR-88D. The tradeoff is that the maximum unambiguous velocity (from here on, Vmax) is a lot lower for the TDWR. Examples will show the effects on real information coming next.

Student Notes:

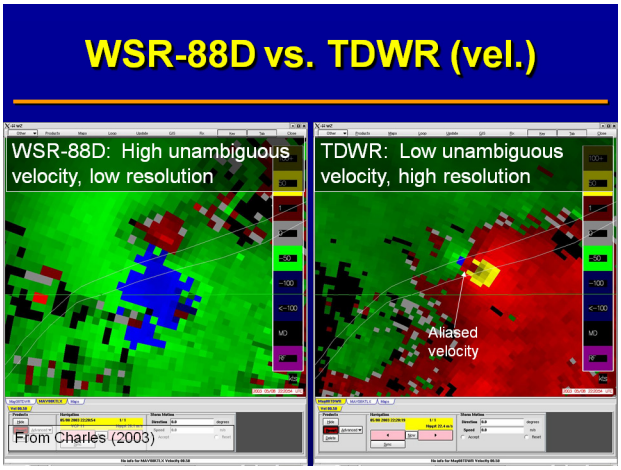


	WSR-88D	TDWR
Wavelength	10 cm	5 cm
Volume Scan Time	4 minutes in VCP 12	1 minute 0.5°, 2.5 min for other angles
Beam Width	1.25°	0.5°
Range Gate	.13 nm for super resolution base data	.067 nm
Max Unambiguous Velocity	Up to 62 kts with a PRF = 1293.10 s^{-1}	20 - 30 kts

5. WSR-88D vs. TDWR (vel.)

Instructor Notes: Here are two views of a mature tornado cyclone at 8 miles the radar. The WSR-88D, left adequately samples the high velocities associated with the right flank of the tornado cyclone but washes out the tight velocity couplet that should be there given that the tornado is in its mature stage. The resolution of the TDWR produces a much tighter velocity couplet on the same order of size as the damage track being produced by the tornado (within the area bounded by the thin white perimeter). But notice that some aliased velocities exist near the circulation center, just on its left side. Much of the May 08, 2003 results are from a paper by Mike Charles (2003) while working with the NWS OUN as a summer student in the Research Experiences for Undergraduates (REU) program and with Dave Andra, Dan Miller, and Mike Foster serving as mentors.

Student Notes:

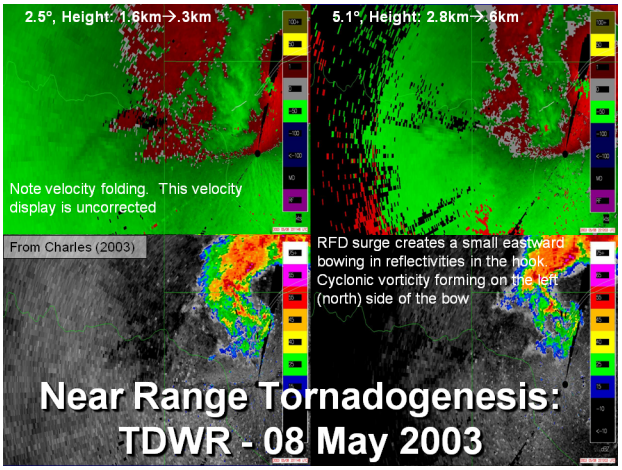


6. Near Range Tornadogenesis: TDWR - 08 May 2003

Instructor Notes: Displayed here is a 4 panel image of the 2.5°, and 5.1° velocity and reflectivity slices as the supercell is about to generate its first tornado. Each scan is roughly 3 minutes apart starting at 2141 UTC. The 2.5° slice ranges from 1.6 km AGL at

the beginning to 0.3km AGL at the end of the loop. The 5.1° slice starts from 2.8 km to 0.6 km in a similar way. The first few times show the strong inbounds south of the developing hook echo, and above 1.6 km AGL. The inbounds are folded once to outbounds and then again to inbounds again in the 5.1° slice from 2141 to 2148 UTC. At 2150 UTC, the 5.1° slice shows strong convergence on the back side of the hook echo. These velocities are folded over to outbounds. This is the elevated convergence of air flowing into the RFD, possibly visually manifesting itself as the “waterfall” of clouds on the back side of the updraft as long as the precipitation is not too dense. At 2156 UTC, the storm approaches enough that both slices samples well below cloud base where the RFD is mostly outflow. Again, the outflow winds exceed Vmax and are folded to outbounds. Convergence is much stronger along the nose of the gust front. At 2202 UTC, the RFD outflow is curling to the north ahead of the supercell updraft core causing an area of strong outbounds northwest of the radar. These outbounds exceed Vmax and are folded to appear as inbounds. Note at the same time in the 5.1° slice southwest of the hook echo, the strong inbounds of the midlevel mesocyclone. Also at the same time, the hook echo appears to gain some anticyclonic curvature just south of the strong RFD surge. At 2205 UTC and after, the strong tornado cyclone is apparent as a couplet of inbounds and outbounds, both sides with velocity folding. The tornado track begins at this time, visible on the map in a thin white perimeter. The hook echo has an inflection point, where it changes shape from cyclonic to anticyclonic at the tornado location. The shape of the hook echo deforms in this case as a result of the RFD surge. Anticyclonic vorticity is found to right of the tornado track. Sometimes, this deformation may appear as a small scale bow with a cyclonic, anticyclonic vortex pair.

Student Notes:

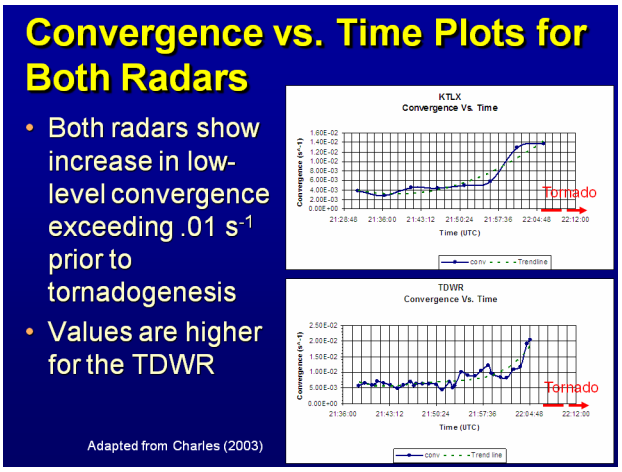


7. Convergence vs. Time Plots for Both Radars

Instructor Notes: An analysis of maximum convergence found at the lowest elevation from both radars show increasing values before first tornado. The improved TDWR temporal resolution results in more noise and sharper increases in the RFD convergence. Note that both show rapid increase in convergence less than 5 minutes before tornado time. Note that the trend line in the WSR-88D shows a false picture of slowly increasing convergence. Unfortunately, you only see the convergence represented by the data

points and thus the WSR-88D gives you less lead time to convergence increase than the TDWR. The TDWR maximum convergence exceeds .02 s-1, a third higher than that of the WSR-88D.

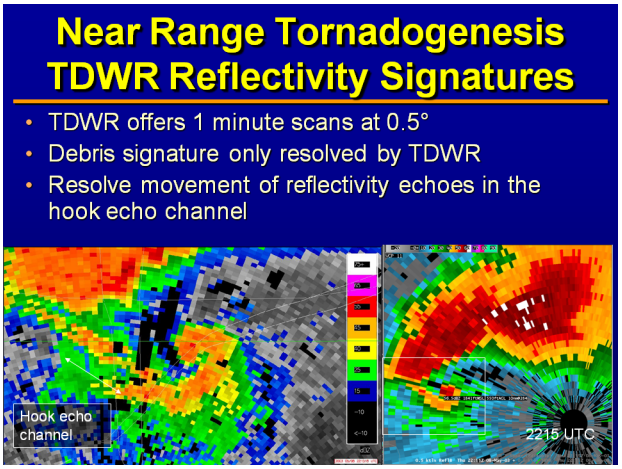
Student Notes:



8. Near Range Tornadogenesis TDWR Reflectivity Signatures

Instructor Notes: The one minute resolution of the TDWR is just about enough to track individual reflectivity patterns northwest to southeast along the hook echo channel. As this loop proceeds, the onset of the debris signature in the TDWR occurs right as the damage track begins. The WSR-88D cannot detect it as early. During the event, forecasters, and ham radio operators were able to relay minute by minute positions of the tornado as it plowed through Moore and South Oklahoma city. This level of communication helped emergency responders at a level not done before.

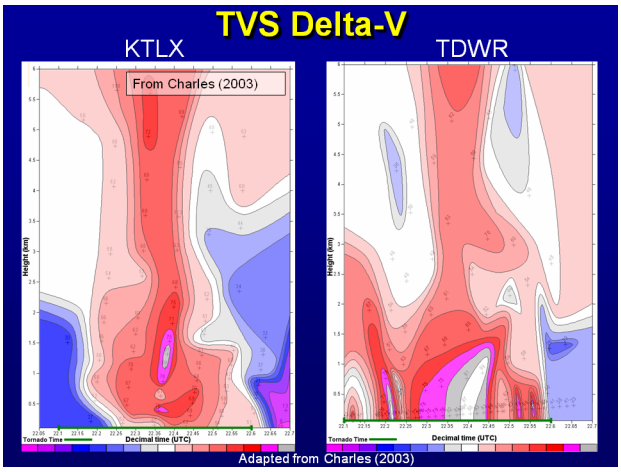
Student Notes:



9. TVS Delta-V

Instructor Notes: The TDWR should provide stronger values of velocity difference in the TVS signature than the WSR-88D. Stronger may not be necessarily better when assessing tornado potential since just about all TVSs may appear stronger with finer resolution. However, the chance for early detection of a tornadic circulation is much greater with the TDWR. Given the better temporal resolution, the structure of the time/height trends show more detail. In either case, both KTLX and the TDWR clearly show the TVS signature strengthen during the mature stages of the tornado.

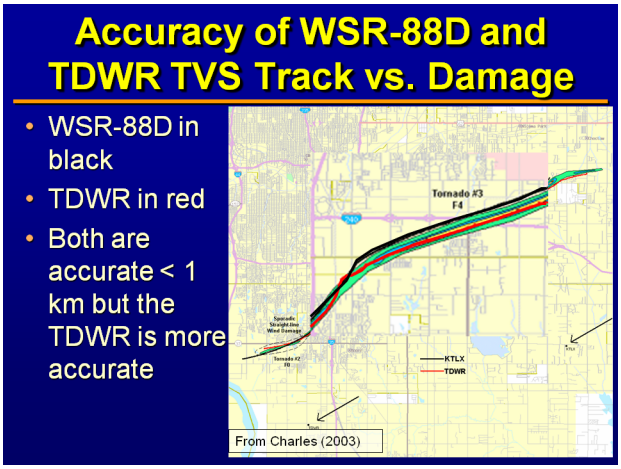
Student Notes:



10. Accuracy of WSR-88D and TDWR TVS Track vs. Damage

Instructor Notes: Finer resolution does mean finer accuracy in positioning the tornado with the TDWR. Upon zooming in on the F-scale contour damage map, the lowest slice circulation center of the WSR-88D (black line) is a quarter mile off from the axis of worst damage. The TDWR track (red line) is just about dead center on the damage.

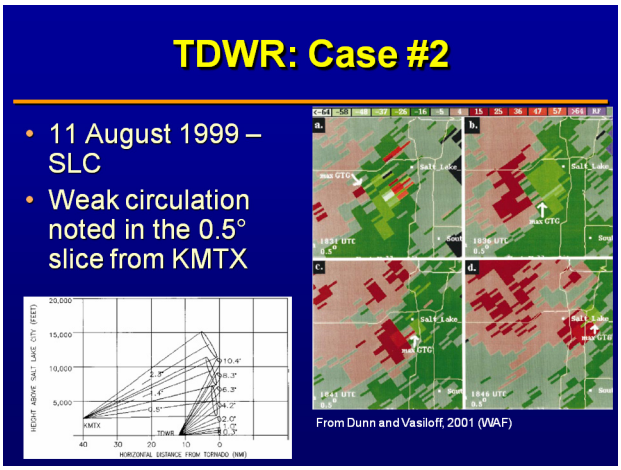
Student Notes:



11. TDWR: Case #2

Instructor Notes: Another case has been published in Weather And Forecasting by Larry Dunn and Steve Vasiloff where the TDWR data were compared to the WSR-88D for the Salt Lake City tornado. The differences in distance between these two radars is much greater, with the TDWR in close proximity to the damage track. The fine resolution and number of beams below the 0.5° slice of the KMTX WSR-88D make the TDWR there indispensable for analyzing small features in the Salt Lake Valley. The tornadic storm here barely showed any gate to gate signature, labeled as “max GTG” with the storm as it scoured a damage path through downtown.

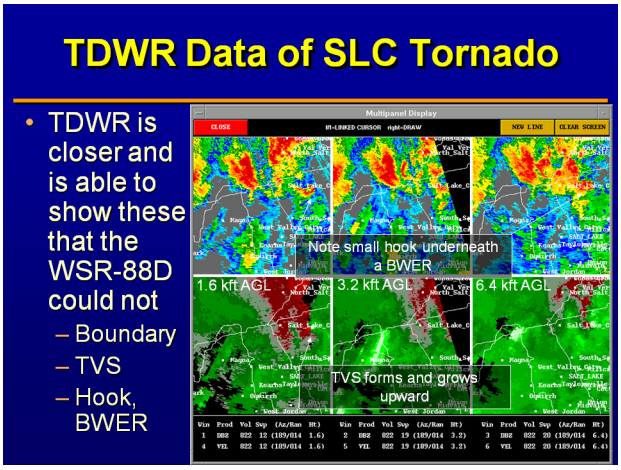
Student Notes:



12. TDWR Data of SLC Tornado

Instructor Notes: The TDWR data, only 14 km (8nm) in range, and with numerous low slices below the lowest slice of KMTX, shows an accurate evolution of this tornado as a near surface-based vortex extending upward into the storm near 1840 UTC. A small hook echo feature and even a BWER forms around the vortex at the end of the loop. This TDWR did not have a one minute lowest slice sampling period but with its proximity, provided high quality information on the tornado vortex.

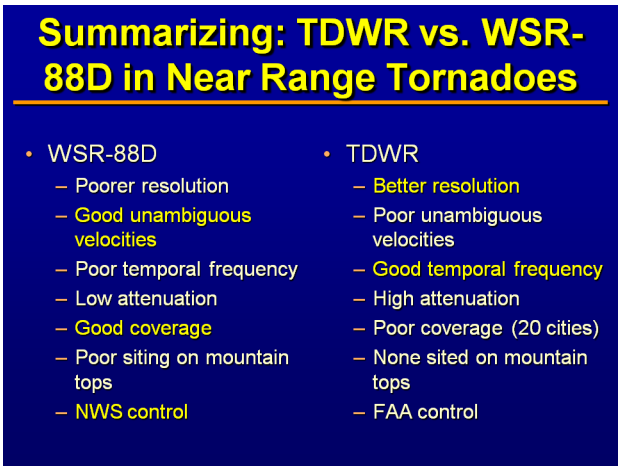
Student Notes:



13. Summarizing: TDWR vs. WSR-88D in Near Range Tornadoes

Instructor Notes: The TDWR offers you excellent resolution and temporal frequency. However, given other factors favoring the WSR-88D, the TDWR will serve as an enhancement to the current network, and certainly not a replacement. Note the strengths of each radar are colored in yellow. The WSR-88D's advantages lie in its coverage, and high unambiguous velocities. Vmax, and it is under NWS control. The TDWR's strengths are its better spatial and temporal resolution.

Student Notes:



1. Supercell Collapse Phase

Instructor Notes: Hi, my name is Les Lemon and I would like to welcome you to this instructional training component dealing with the supercell storm collapse phase.

Student Notes:

Supercell Collapse Phase

Warning Decision Training Branch
2010

2. Training Objectives

Instructor Notes: At the conclusion of this module and without aids the student will be able to define the supercell collapse phase, identify its characteristics, identify the variations of the collapse phase, and to identify the significance of the supercell collapse. Finally, the student will be able to identify the importance of the supercell collapse to warning decision making and to the warning forecaster.

Student Notes:

Training Objectives

- Define the Supercell Collapse Phase
- Identify Collapse Phase Characteristics
- Identify Variations in the Collapse Phase
- Identify its Significance
- Identify Importance of Collapse Phase Recognition to the Warning Decision

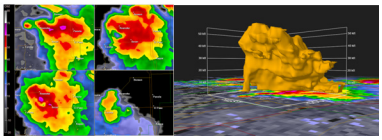
3. Supercell Collapse Phase

Instructor Notes: Here we will see that the supercell collapse phase, associated with mesocyclone occlusion, is characterized by a relatively 'rapid' reflectivity echo weakening and loss of the reflectivity supercell storm structure. We will see that during tornadogenesis all or part of the supercell updraft is disrupted and the storm can become multicellular and non-severe, reorganize as a mature supercell, or die. Sometimes the process affects only a portion of the updraft, at other times it disrupts the entire storm updraft. As the collapse proceeds the warning forecaster must pay careful attention to the velocity character or he/she can be mislead into thinking the storm is weakening and may no longer be a threat when, in fact, the tornado is just beginning or is ongoing. It is important to understand that not every tornadic supercell undergoes this collapse phase. But the purpose of this module is to alert the warning forecaster to this antithetical situation.

Student Notes:

Supercell Collapse Phase

- **Supercell Collapse Phase:**
  - A rapid echo weakening & loss of reflectivity supercell storm structure
  - Updraft disrupted in part or whole
  - Velocity character is key
  - Not all supercells collapse



4. Early Work on Collapse

Instructor Notes: While Browning (1965) made the first observations hinting at the collapse phase (rapid hail size decrease, hook echo 'wrap up') it wasn't until Burgess (1974) that additional observations more strongly suggested a collapse phase. Here low-level (white) echo is seen as compared to mid-level echo overhang, (black). As a series of five tornadoes and a damaging wind swath began at 1700 CST the low-level hook echo was seen to "wrap-up" with echo top above (1700 – 1720). By the last damaging wind and tornado were occurring at 1740 the overhang had vanished; the Doppler radar mesocyclone was engulfed in strong echo (heavy rain and some hail) and the declining echo top above. The echo top and BWER collapse are illustrated here as the severe weather was occurring. Burgess termed this the collapse phase for obvious reasons. Following collapse, the storm was non-severe and a member of a squall line.

Student Notes:

Early Work on Collapse

- 19 April 1972

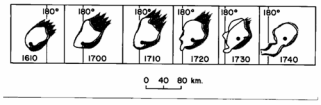
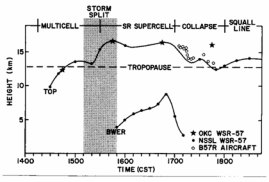


Fig. 10. Outlines of low and mid-level echo from the WSR-57. Shading indicates overhang. Anvil regions have been omitted. Dark dot is the position of echo top.



From Burgess 1974

Fig. 11a. Graph of echo and BWER top with respect to time. Shading indicates the time of storm split.

5. Early Work on Collapse

Instructor Notes: Arguably, the most thoroughly documented tornadic storm at the time, the Union City, OK storm inflicted F5 tornadic damage near the small hamlet on 24 May, 1973. In a comprehensive report it was shown that as the echo top and BWER B both collapsed surface tornadogenesis commenced (1536 CST). The tornado continued on as it enlarged and intensified. Simultaneously the echo overhang (dense stippling) descended around the occluding mesocyclone and tornado (star) as both migrated toward the rear of the storm. Doppler velocity data indicated that during the initial stages of reflectivity collapse the mesocyclone intensified and decreased in diameter and a TVS developed. The TVS developed aloft within the mesocyclone at 1517 CST and descended reaching the surface at 1536 CST. As the tornado weakened the mesocyclone broadened, decreased in vertical depth, and also weakened. Similar to the 19 April storm, at the conclusion of the collapse phase the Union City storm had again become a non-severe, multicellular storm and part of a squall line.

Student Notes:

Early Work on Collapse

- 24 May 1973

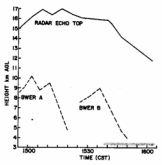


Fig. F.2 Graph of Union City storm top and maximum height of bounded weak echo regions A and B as a function of time. Tornado duration on the ground indicated by stippled bar. From Lemon and Burgess (Chapter 8).

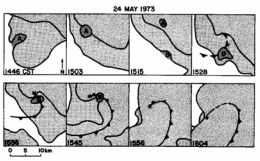


Fig. 8.7 Supercell right flank changes with time (extracted from Fig. 8.3). Star represents surface tornado location.

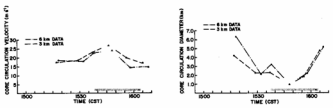


Fig. F.1 Core circulation tangential velocity and diameter at two heights above ground as a function of time. Velocity and diameter values obtained at about 1547 are from the TVS gates and are therefore considerable under and over estimates, respectively. Tornado duration on the ground indicated by stippled bar. From Lemon and Burgess (Chapter 8).

6. Early Work on Collapse

Instructor Notes: This 18 June storm was a very large supercell propagating slowly into the mean wind. Note that following BWER collapse and during tornado production the storm summit began a slow but fluctuating decline until the storm became a non-severe multicellular storm. The second study here again documented a general decline in reflectivity structure and weakening while the mesocyclone amplified and occluded while tornadoes occurred. Even though not shown here, the depth of the high reflectivity diminished and VIL declined. This storm also became multicellular and non-severe.

Student Notes:

Early Work on Collapse

- 18 June 1973 & 8 June 1974

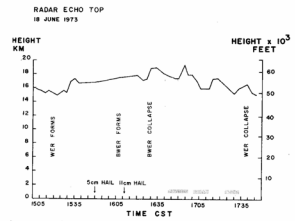


Figure 5. Graph of storm P echo top as a function of time. Tornado duration on ground is indicated by the stippled bars. Other echo and surface weather is included as indicated.

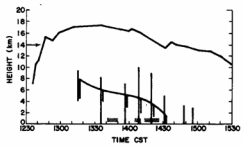


Figure 4. Vertical changes of supercell echo top (upper trace) and BWER top (lower trace) with respect to time. Vertical line pairs at tilt sequence times indicate vortex extent (left vertical line) and BWER extent (right vertical line). After 1431, only vortex extent shown. Tornado times are hatched and horizontal arrow gives tropopause height.

7. Supercell Collapse Phase: Reflectivity Characteristics

Instructor Notes: To summarize previous studies, during tornadogenesis and in some cases as the tornado increases in size and strength, the supercell collapse phase is revealed in reflectivity data by a rapid loss of supercell storm structure. In other words, the hook echo is seen to “wrap up” and disappear as the BWER and echo top descends and as the WER collapses downward. Overall, the echo top lowers, reflectivity weakens and the depth of the higher reflectivity diminishes as does VIL. These earlier studies found that this process is symptomatic of substantial updraft weakening leading to weakening of the entire storm. In fact, in the earlier studies, most of these collapsed storms became non-severe and multicellular as they were absorbed into squall lines. However, as we shall see later, only a portion of the supercell updraft may be affected.

Student Notes:

Supercell Collapse Phase: Reflectivity Characteristics

During Tornadogenesis & as tornado increased:

1. **Rapid loss of reflectivity supercell storm structure –**
   a. **Hook Echo "wraps up", Bounded Weak Echo Region (BWER) fills with echo & disappears, Weak Echo Region (WER) disappears**
2. **Overall Storm Reflectivity Weakens**
   b. **Echo top lowers, reflectivity weakens, high reflectivity depth diminishes, VIL diminishes; all indicate updraft weakening**
3. **May involve entire storm updraft or only a portion**

8. Supercell Collapse Phase: Velocity Characteristics

Instructor Notes: As the reflectivity structure of the collapsing supercell is diminishing the velocity characteristics are undergoing amplification. The mesocyclone shear/rotational velocity increases typically in lower levels. Contemporaneously the circulation may decrease in diameter and its depth increase. With the amplification of the mesocyclone, a TVS may develop and become detectable within the mesocyclone aloft and/or in low-levels. The overall reflectivity weakening may well be associated with RFD strengthening, surface gust front occlusions, and cutoff of low-level inflow.

Student Notes:

Supercell Collapse Phase: Velocity Characteristics

- **As reflectivity structure weakens supercell velocity structures amplify**
  a. **Mesocyclone shear/rotational velocity increases near surface**
  b. **Mesocyclone diameter may decrease**
  c. **Mesocyclone depth often increase**
  d. **TVS often develops aloft and/or near surface**
  e. **RFD gust front occludes cutting off inflow**

9. Supercell Collapse Phase: An Example – The Electra Storm

Instructor Notes: Here we will examine a supercell storm that occurred near Electra, TX on April 7th 2008. This photo was taken looking west toward the slowly rotating wall cloud from under the rain-free updraft base at about 21:50 CST. The wall cloud is the location of the updraft core and is tapping very moist contact layer air having originated in

the precipitation cascade and forward flank downdraft region. A few thousand feet above this cloud base a tornadic vortex was descending toward the surface.

Student Notes:

Supercell Collapse Phase:
An Example – The Electra Storm

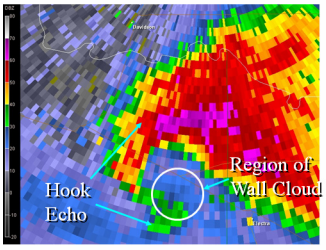
10. Supercell Collapse Phase: An Example – The Electra Storm

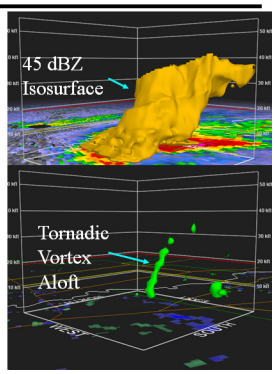
Instructor Notes: Just before the previous photo, the 0.5 degrees reflectivity echo of the mature isolated supercell is seen only 14 miles south of the KFDR radar as the storm moves east-southeast at 20 kts. It exhibits a well defined hook echo bounding the inflow notch to the west. The area where the wall cloud is located is in indicated here. The wall cloud itself is within but much smaller than this circle. Using GR2Analyst software we can see the large 3-dimensional 45 dBZ echo region surrounded the BWER. Because of the proximity of the storm to the radar, the upper surface of this echo is truncated by the cone of silence but very likely extends upward to a height greater than 45 kft. Using the GR2Analyst velocity processing algorithm we can also see the TVS aloft above the hook echo end and wall cloud. Note the TVS extend from a relatively short distance above the surface upward to near 30 kft.

Student Notes:

Supercell Collapse Phase:
An Example – The Electra Storm

- 4/7/2008 21:47 CST
  Near KFDR WSR-88D

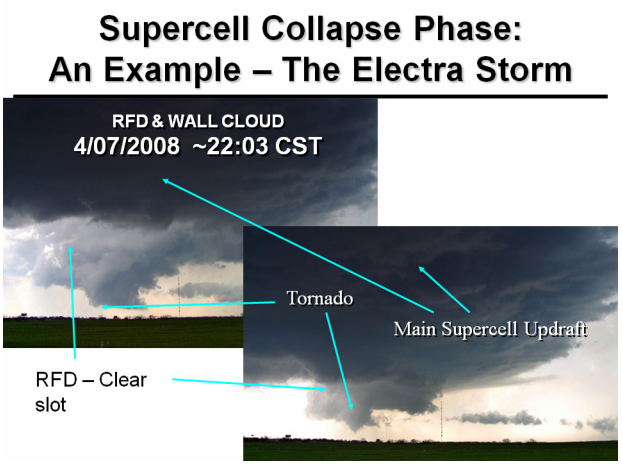




11. Supercell Collapse Phase: An Example – The Electra Storm

Instructor Notes: Again, looking west about 12 to 15 minutes later the dark, rain-free, cloud base of the primary supercell updraft is little changed but the wall cloud has now shifted back near the western edge of the primary updraft and the "clear slot" of the rear flank downdraft is seen rotating from the west and south around to east side of the wall cloud. And now, while the condensation funnel of the tornado is not in contract with the surface the vortex itself is and has been for about the last 4 minutes. Thus, the tornado is underway at this time.

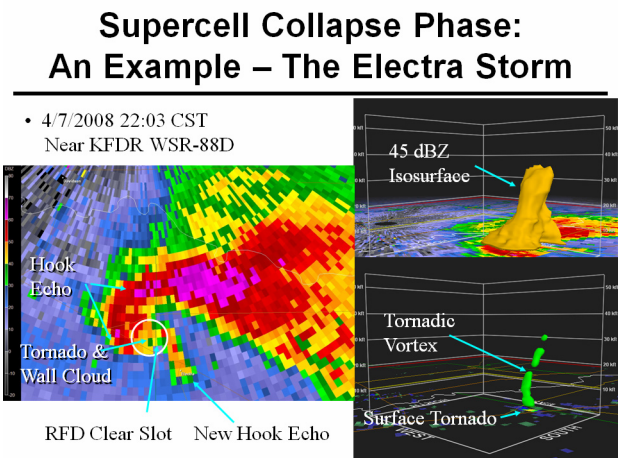
Student Notes:



12. Supercell Collapse Phase: An Example – The Electra Storm

Instructor Notes: At the same time as the previous visual cloud appearance, the low-level reflectivity echo is seen here. The shank of the previous hook echo has pulled back northward and eastward from its previous storm-relative position. The wall cloud and tornado, just shown, is located within the encircled area and the wrapping clear-slot here. Aloft the old BWER has filled with echo while a new BWER is developing along with a new low-level hook echo here. There has occurred a substantial decrease in the hook and tornado associated 45 dBZ echo and the top of that portion of the supercell has fallen substantially to about 35 kft. We can see here that the surface tornado and TVS aloft still extends upward to about 30 kft as it moves northward at 15 kts.

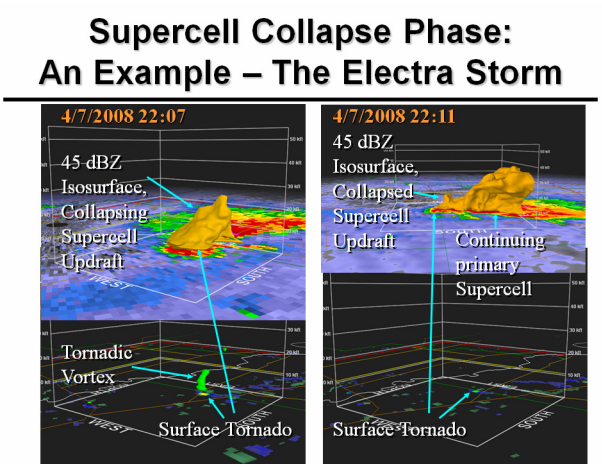
Student Notes:



13. Supercell Collapse Phase: An Example – The Electra Storm

Instructor Notes: Just one volume scan later the 45 dBZ isosurface associated with the collapsing tornadic updraft is seen here. The TVS has also decreased in vertical depth to ~ 17 kft but the tornadic surface vortex is still present. Finally, by the 22:11 volume scan what is left of the original supercell updraft is shown here. It is a very small region of 45 dBZ extending upward to perhaps 12 kft! All that remains of the tornado is a rapidly weakening surface vortex with small vertical extension. Note the perspective has changed here so we can see to the rejuvenated primary supercell updraft and structure with overhang and BWER (just beneath storm summit). The supercell continued moving east-southeast with slow weakening for the next 40 minutes but without additional torna-does.

Student Notes:



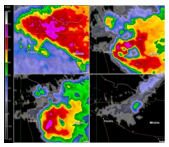
14. Electra Storm Summary

Instructor Notes: In this case study we began with an archetype large mature supercell storm, mesocyclone, hook echo, Weak Echo Region, and Bounded Weak Echo Region. A Tornadic Vortex Signature or TVS develops aloft within the mesocyclone as the collapse begins, signaled by a filling BWER and weakening portion of the supercell updraft. The hook echo, in a storm relative fashion, moves northward. As the collapse proceeds, visually a clear slot is seen to develop and encircle the developing tornado and wall cloud which has now shifted, storm relative, to the west and north of the primary supercell updraft cloud base. As this is occurring visually, on radar the TVS aloft lowers toward the surface as the updraft portion shrinks. That tornado persists at or very near the surface for 12 to 15 minutes before dissipating. A new hook echo has developed and the original but rejuvenated supercell updraft continues moving east-southeast but without further tornadoes.

Student Notes:

Electra Storm Summary

- Large, mature supercell storm, hook echo, WER, and BWER exist.
- Tornadic vortex develops aloft, collapse begins, BWER begins to fill, updraft portion weakens, moves N with hook echo.
- Dry slot develops, updraft shrinks further, tornadic vortex lowers to surface.
- Tornado & updraft dissipates.
- New hook echo, original supercell continues, no further tornadoes.



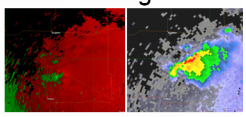
15. Supercell Collapse - Operational Impact?

Instructor Notes: What is the supercell collapse impact on operational applications? The warning forecaster must be careful not to be mislead by the supercell reflectivity structural weakening. During such, tornadogenesis may be taking place or an existing tornado may be continuing or even enlarge and strengthen. The warning forecaster must be vigilant to continue a tornado warning unless and until both reflectivity and the velocity storm characteristics weaken. The collapse may disrupt and weaken the entire storm updraft or it may affect only a portion of the updraft as with the Electra storm. During supercell updraft collapse, storm spotter reports are especially important. This is especially true because the mesocyclone and TVS (if detected) often have reduced vertical depth.

Student Notes:

Supercell Collapse - Operational Impact?

- Threat continues despite supercell reflectivity structural weakening.
- Tornadogenesis often as supercell weakens.
- Continue warning unless ***both reflectivity*** & ***velocity*** features disappear.
- Can affect entire or part of storm & updraft
- Spotter reports especially critical during weakening indicators.



16. Supercell Collapse Phase

Instructor Notes: We have examined an aspect of some supercells called the collapse phase. The warning forecaster must be alert to the fact that not all supercells seem to exhibit this phase but some do and when it occurs the forecaster may me mislead. Should you have any questions, please contact Les Lemon at Les.Lemon@noaa.gov

Student Notes:

Supercell Collapse Phase

- We have examined an aspect of some supercells called the collapse phase. The warning forecaster must be alert to the fact that not all supercells seem to exhibit this phase but some do and when it happens the forecaster may me mislead.
- Should you have any questions, please contact Les Lemon at Les.Lemon@noaa.gov

17. REFERENCES

Instructor Notes: Here are a number of references should you wish to pursue the subject further.

Student Notes:

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- Brown, R. A., D. W. Burgess, and K. C. Crawford, 1973: Twin tornado cyclones within a severe thunderstorm: Single Doppler radar observations. ***Weatherwise*, 26**, 83-71.
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1. Storm Interrogation

Instructor Notes:

Student Notes:

Storm Interrogation

AWOC Severe Track
ICSvr 3
Three Body Scatter Spike
by Les Lemon and Jim LaDue

2. Objective

Instructor Notes: The objective of this lesson is to understand what causes a three body scatter spike, what it signifies, and how it may contaminate velocity data

Student Notes:

Objective

Objective:

- Understand what causes a three body scatter spike, what it signifies, and how it may contaminate velocity data

3. Three Body Scatter Spike

Instructor Notes: The Three Body Scatter Spike is a feature, like many others, that is not all-inclusive: If the signature is in the data, it is nearly a guarantee of severe hail, but with many severe hail storms it is not visible Many times this feature is masked by ‘real’ reflectivity behind the main core. A “disclaimer” that may be applied to ANY radar based signature.

Student Notes:

Three Body Scatter Spike

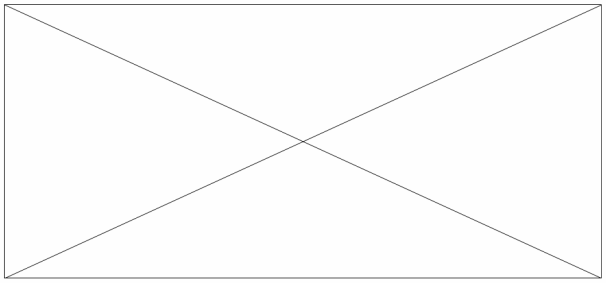
- A feature, like many others, that is not all-inclusive: If the signature is in the data, it is nearly a guarantee of severe hail, but with many severe hail storms it is not visible
  - Can be masked by "real" reflectivity behind the main core

4. Animation of the formation of a TBSS

Instructor Notes: Step by step process 1. radar pulse from radar to hail core 2. strongly reflecting large, wet hydrometeors are encountered, and scatter the signal in all directions, including downward 3. The trees, earth, and vegetation reflect the energy diffusely 4. reflected energy illuminates the hail core once more 5. the reflected energy from the ground has been found to drop off as r-3 (r is the distance the energy travels from the ground to the hail core) 6. for a second time, the large, wet hydrometeors scatter the energy, but this time a significant amount of the ground reflected energy is backscattered and received by the radar 7. the radar "sees" this entire event as occurring along the same radial, and due to the longer traversed paths of the triple reflected signals, the spike appears at a range downradial from the hail core 8. The hail spike begins down the radial at a distance exactly equal to the height of the hail core above the ground 9. Note that each successive range gate along the hail spike will have progressively lower reflectivities because of the r-3 decrease of power with distance from the scatterers 10. 1st gate of the hail spike will have maximum reflectivities

Student Notes:

Animation of the formation of a TBSS



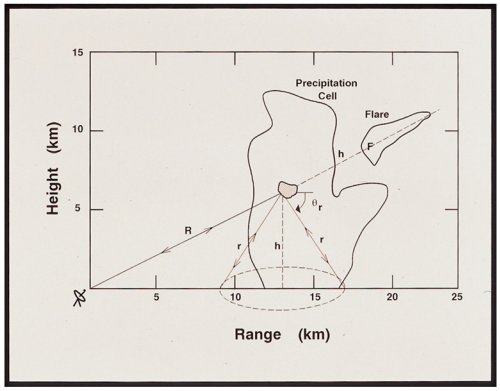
- If visible, it is the most robust indicator of severe hail

5. Graphical Depiction

Instructor Notes: You get a range of possible reflection regions from the ground back to the hail stone, such that a “cone” of possible reflection areas are possible. This is precisely why the flare extends for various lengths down radial, as the reflection along dotted line h is both quickest and strongest (again, returned power falls off as R^3). Power returned from the edges of the cone takes longer and is weaker, thus the flare extends further downradial and decreases intensity the further down radial you look.

Student Notes:

Graphical Depiction



6. Summary of How TBSS Forms

Instructor Notes: The factors affecting the strength of the hail spike is important to comprehend. Extremely wet hail, in very high quantities, even though it could be “small”, can produce a hail spike. Most storms with large hail or large quantities of small hail likely produce hail spikes, it’s just that typically the precipitation core is too broad or there are other storms down radial such that the hail spike is not visible.

Student Notes:

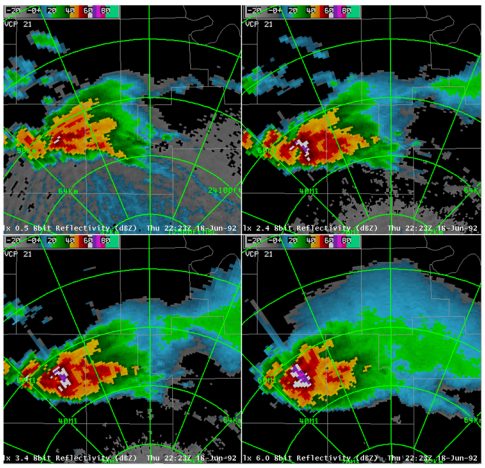
Summary of How TBSS Forms

- position of hail spike along the radial is proportional to core altitude above the surface
  - → Precisely why it is seen primarily at higher altitudes in the storm
- strength of hail spike proportional to: hail size, **concentration**, **wetness**, and vertical extent of core
- must be no precipitation behind core along radial

7. Slide 7

Instructor Notes: 4 panel reflectivity. Hail spike shows up on tilts 2.4 degrees and above, but not at 0.5 degrees TBSS begins at a range from the radar that is the range to the hail core plus the twice the height above the ground the beam hits the core. AT 0.5 degrees the core is closest to the ground, and thus the TBSS begins very near the back side of the hail core, and the reflectivities are so low in the hail spike that the actual reflectivities from the northwest portion of the storm “drown” them out Rapid hail stone growth occurs aloft in mid-levels, in wet growth making them highly reflective, and at 6 degrees the core is hit at 33 kft, thus the TBSS is much longer and extends a long distance down radial behind the core.

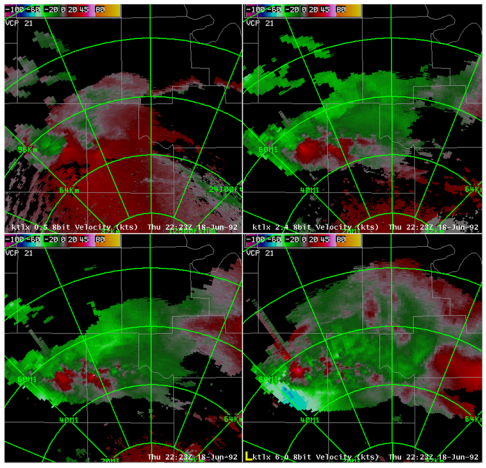
Student Notes:



8. Slide 8

Instructor Notes: 4 panel velocity: Velocities are typically low in the TBSS At each range gate you are combining both horizontal and vertical air motions, and hail is normally falling relative to the ground Thus, velocities are low negative velocities within the TBSS, but you are combining returns at each range gate withint TBSS from multiple areas within the hail core, both horizontal and vertical motions. Velocities themselves are meaningless, but generally low and negative.

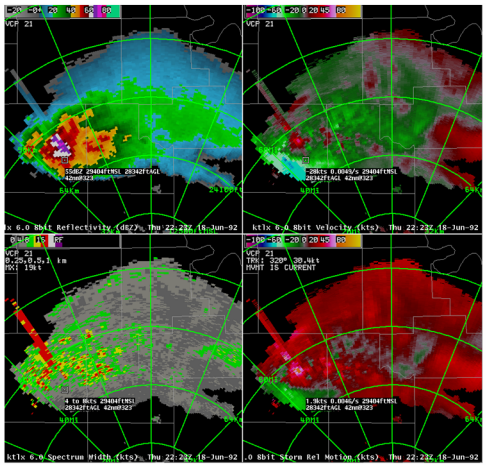
Student Notes:



9. Slide 9

Instructor Notes: 6 degree Z (top left), V (top right), SW (lower left), and SRM (lower right) Horizontal region in Velocity away from radar in the hail region itself that is out-bound, then another region further down radial of the core that is also outbound: this is created by the TBSS, velocity contamination and is an unfortunate result of TBSS SW has very high values within the TBSS: each location along the TBSS is a combination of several different motions both horizontally and vertically from multiple locations within the hail core. The spectrum is very broad as as result and is very near white noise along the TBSS. SW can help identify TBSSs. TBSS means you have a serious core, but just because you don't see it doesn't mean the storm cannot produce very large hail. It is a "sufficient condition" for knowing large hail exists in the storm, but it not a "necessary condition". TBSS is not an algorithm, if you see it, you should be confident that large hail is occurring with the storm. Does that mean you would expect a 100% chance of large hail from the storm. No, there is no always and never in this science, however your skill should be high in your warnings.

Student Notes:

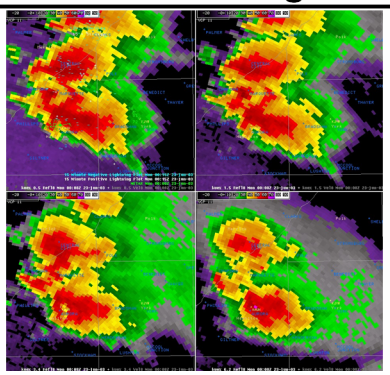


10. June 22, 2003 Aurora:Record Breaking Hail

Instructor Notes: No hail spike with this storm at any time, although it would be very hard to see due to the precip behind the main core. Also notice the lack of really high reflectivities.

Student Notes:

June 22, 2003 Aurora: Record Breaking Hail



11. April 23, 2004 Supercell near ICT

Instructor Notes: Examine this loop of reflectivity from a mid-morning supercell in southern Kansas. The hail spikes are very small, and could be mistaken for an appendage on the southern flanks of the storm. Always investigate velocity (and SW if available) and zoom far in on any potential hail spikes to verify their presence.

Student Notes:

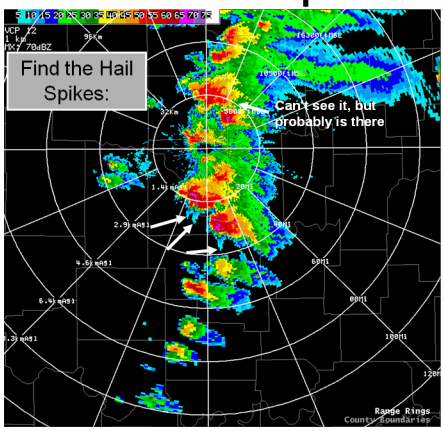
12. TBSS Example

Instructor Notes: It is your job to find the hail spike in this image. Golfball to baseball hail was reported with these storms, although around this time just 1-1.5 inch hail falling

out of any one storm. The storm entering Logan county “should” have a hail spike but the spike is obscured due to echoes all around behind the main core. I would point this out.

Student Notes:

TBSS Example



13. Subtle TBSS

Instructor Notes:

Student Notes:

Subtle TBSS

14. Test Your Knowledge

Instructor Notes:

Student Notes:

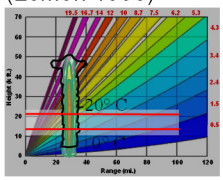
15. TBSS: Summary

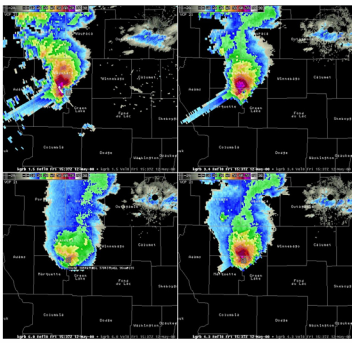
Instructor Notes: Another important point Lemon brings up in his paper is the additional threat of severe winds. With large hail and/or large quantities of wet hail, downburst potential is very high due to precipitation drag, and thus storms with hail spikes ALSO are likely to contain severe damaging winds, as is the case with this storm. A recent local study by Matt Bunkers (SOO at Rapid City) found ~90% POD for severe hail. Recent talks with Les Lemon in light of several new examples of non-severe hail with hail spike has caused some rethinking about the TBSS. The majority of the cases with hail spikes that do not have severe hail typically have extremely high amounts of small hail, or in some instances, no hail reaches the ground at all. But again, TBSSs without severe hail are believed to be fairly rare and should warrant a warning each time.

Student Notes:

TBSS: Summary

- "storms producing the artifact, will or are now, *with absolute certainty*, producing very large hail" (Lemon 1998)

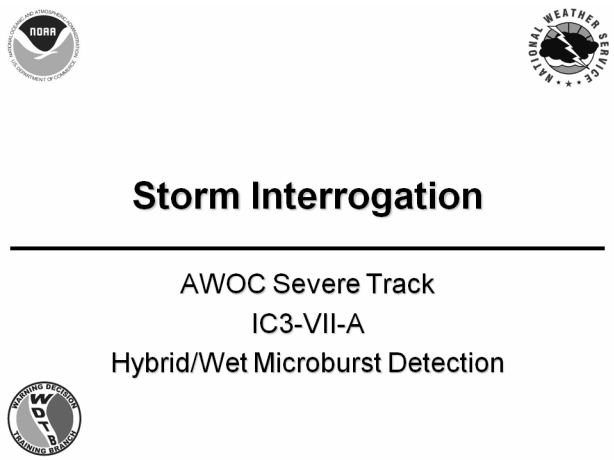




1. Storm Interrogation

Instructor Notes: Welcome to the AWOC Severe Track IC3-VII-A Hybrid/wet microburst detection This session is 20 slides long and may take 20 to 25 minutes to complete.

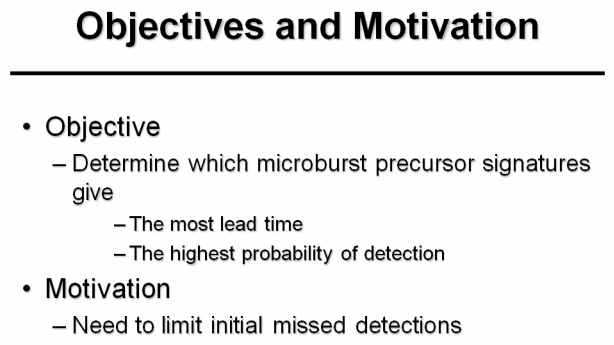
Student Notes:



2. Objectives and Motivation

Instructor Notes: The one objective of this lesson is to show which stormscale precursor signatures give you the most lead time and the highest probability of detection of wet and hybrid microbursts. The motivation for this session is to limit missed detections of the first microburst producing storm of the day and then increase the leadtime of all following microburst events. We will limit ourselves to mostly stormscale signatures within the context of the environmental sounding.

Student Notes:



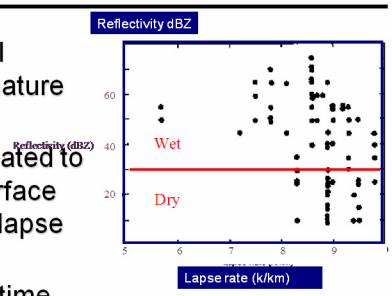
3. Environmental Considerations

Instructor Notes: The first step in improving leadtime is recognizing the favorable microburst environment. Srivastava 1985 plotted the surface to cloud base lapse rates versus the microburst reflectivity at 500m AGL for a population of low shear pulse storm microburst events. He found that no microburst events occurred with a lapse rate less than 5.5° K/km and most microbursts prefer greater than 7° K/km. Note that dry microbursts (microbursts with almost no surface precipitation) require a nearly dry adiabatic layer. All these microbursts were sampled during the JAWS project which took place east of Denver.

Student Notes:

Environmental Considerations

- Environmental precursor signature
- Microburst occurrence related to near storm surface to cloud base lapse rate
- Greatest lead time



Wet microbursts imply significant precipitation (>.01") associated. Srivastava (1985)

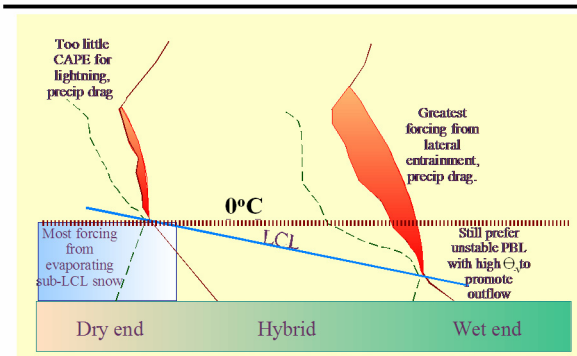
4. Differences in Microburst Environments

Instructor Notes: Microburst environments range the full spectrum with one end being dry, and the other wet. Dry end microburst environments carry very little CAPE (< 500 j/kg), and extremely deep, mixed boundary layers with LCLs near the freezing level and greater than 13 kft AGL. In this case, both temperature and height coordinates are important. Height coordinates are important because the higher the LCL, the more room for an accelerating downdraft to reach severe speeds, and DCAPE is larger. Temperature coordinates of the LCL are important only whether the LCL is higher or lower than the freezing level. If the LCL is higher, frozen hydrometeors become exposed to the sub-cloud air and you suddenly can add the latent heat of melting liquid to evaporation and increase the negative buoyancy of the downdraft. The downdraft forcing is almost entirely below the LCL and there is no significant precipitation loading. Maximum storm reflectivities are less than 35 dBZ in many cases. Wet end microbursts feature significant CAPE and low LCL heights. These events feature large DCAPEs when midlevel dry air is present to act as a source of evaporational cooling when precipitation becomes mixes with the environmental air. The high CAPEs create intense reflectivities, and therefore, significant precipitation loading potential. Precipitation loading for reflectivities exceeding 60 dBZ becomes as important as evaporational cooling. Look for wet microburst environments when there is a large ?e difference between the surface-based updraft parcel, and the

mid-levels (3-6 km AGL). If you expect storms with 60 dBZ cores, precipitation loading becomes a big factor to consider. Most downdraft forcing occurs by lateral dry air entrainment in the mid-levels, and very little comes from below the surface-based LCL. Surface based convection is highly favored for microbursts since you don't want significant surface-based CIN. Many environments favoring microbursts may have a little bit of both dry and wet microburst characteristics. Environments where significant CAPE resides above high LCLs (above 1500 m), allow for microburst forcing by lateral and sub-cloud evaporational cooling. While ?e differences are easy to calculate when assessing wet microburst potential, DCAPE is a quantity that accounts for both lateral and sub-cloud negative buoyant forcing for downdrafts and is therefore a more adaptable parameter to use. The starting level to choose where the downdraft should begin is a tough one but we'll try to estimate that in the upcoming cases.

Student Notes:

Differences in Microburst Environments



5. Wet Microburst Case #1

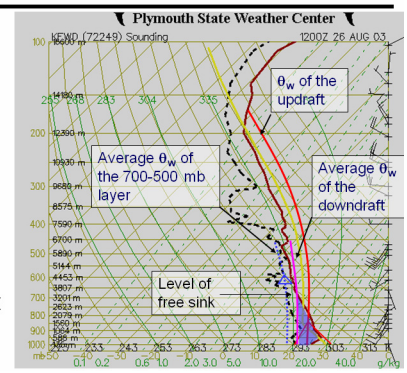
Instructor Notes: On 26 August 2003, the Dallas area is in the middle of a fairly active summertime convective period. You've probably seen this case presented before in the hail storm interrogation and in the sessions on locating pulse storm updrafts. The morning sounding modified for the afternoon temperature/dewpoint combination shows significant CAPE but somewhat marginal source of dry air, except for a layer that is typically too high to consider as a downdraft initiation level (400 mb). This sounding is not a classic high end microburst environment. Let's calculate what shape the DCAPE may look like. We'll assume that the downdraft air will have a mix of temperature and dewpoint between the updraft air parcel and the environment. As long as that's a safe assumption, we can visualize DCAPE as following: First, we find a representative ?w for the environment around the mid-levels, say about 630 mb. The ?w can be found at mid-levels by launching the environmental air parcel using the temperature and dewpoint at that level and raising it to its LCL. Note the little blue triangle, the left vertex being the dewpoint at 630 mb, the right vertex being the temperature, the top vertex being the LCL. The point at the LCL is the ?w at that level. I highlighted that ?w as a dotted blue curve. Then I launch the surface-based, or mixed layer parcel from the ground up and call it the updraft ?w visualized as the solid red curve. The mixed layer downdraft parcel should be some-

where in the middle, and I chose the magenta ?w curve as the curve the downdraft will follow. The negatively buoyant area for the downdraft is anywhere the downdraft temperature is lower than the environment. Note that there is a small layer just below my downdraft initiation level where the downdraft air is positively buoyant, and then it reaches the Level of Free Sink (LFS) where the downdraft is unobstructed from accelerating. The LFS is exactly analogous to the LFC for updrafts.

Student Notes:

Wet Microburst Case #1

- The orange parcel is the best estimate for the afternoon Θ_w.
- Blue dotted parcel is the average Θ_w of the 700-500 mb environment
- Purple parcel is the best guess downdraft Θ_w
- Blue shaded area is the estimated DCAPE area



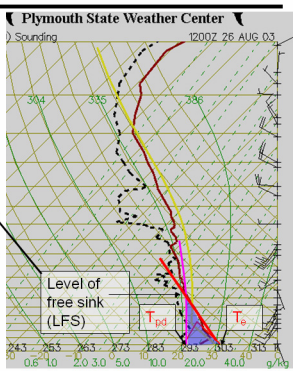
6. Computing DCAPE for Case #1

Instructor Notes: The DCAPE can actually be estimated by taking the afternoon surface temperature minus your theoretical temperature of the downdraft at the surface, dividing it by the environmental surface temperature and multiplying by the depth of the layer from the surface to the LFS (meters), multiply again by gravity (9.81) and divide by 2 since we're calculating the area of a triangle, not a parallelogram. DCAPE =1/2 g((Te – Tpd)/ Te)?Z I estimate the environmental Te to be 304 K, The downdraft Tpd is about 297 K, ?Z is the distance from the LFS down to the surface and I will put in 3300 m. Entering in those numbers, I get this: DCAPE=1/2[9.81((304-297)/304)3300] ? 372 m2/s2 If an updraft has a hard time realizing all of its theoretical CAPE, a downdraft will practically never realize its full DCAPE. In order for my theoretical Tpd to be fully realized, my downdraft would have to be saturated. In other words, saturated descent would be required for my downdraft to follow the downdraft ?w all the way to the surface. Observations show that downdrafts are almost never saturated. Therefore, we have to be realistic and perhaps cut the DCAPE by a factor of 2. But let's use the 384 m2/s2 to compare with later cases. As an additional task, we can take the DCAPE and estimate the maximum potential downdraft velocity from evaporational cooling mechanisms. Maximum W=(2DCAPE)1/2 = (2*372)1/2 = 27 m/s But if only half the theoretical DCAPE is realized, then Maximum W = (2*186)1/2 = 19 m/s This downdraft strength is not likely to be very severe. However, we haven't considered: The precipitation loading factor to overall downdraft intensity. This will add further downward forcing to the evaporational cooling for which we calculated DCAPE. Potential changes in the environment

Student Notes:

Computing DCAPE for Case #1

- Estimating DCAPE
- Find these
  - Surface environment temperature (T_e)
  - Expected downdraft surface temp (T_{pd})
  - Depth of negatively buoyant air $\Delta Z_{(LFS\ to\ sfc)}$
- DCAPE ≅ ½ $g((T_e-T_{pd})/T_e)\,\Delta Z_{(LFS\ to\ sfc)}$
- DCAPE ≅ ½ 9.81((304-297/304)3300m
- DCAPE ≅ 372 m^2/s^2
- Maximum W ≅ $(2*DCAPE)^{1/2}$ ≅ $(2*372)^{1/2}$ ≅ 27 m/s
- Downdrafts almost never realize the theoretical DCAPE because they are unsaturated



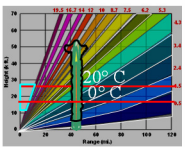
7. Case #1: KFWS Reflectivity

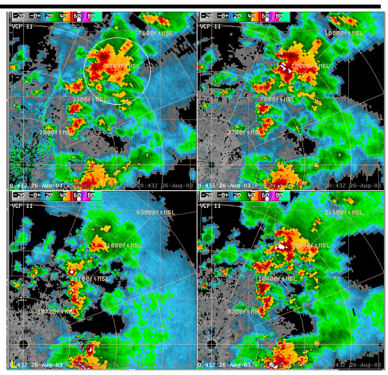
Instructor Notes: The multicell storm in question is inside the white circle. You may notice that the multicell is propagating down an outflow boundary merger with new cells forming on the southwest side of the complex. Strong reflectivities > 60 dBZ extend up to 21 kft in the storm just prior to 2043 UTC, the last frame of the loop.

Student Notes:

Case #1: KFWS Reflectivity

- Low shear multicell initiating on colliding boundaries





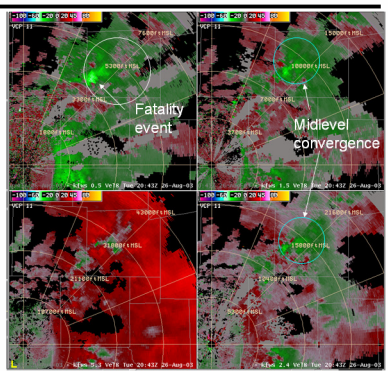
8. Case #1: KFWS Velocity

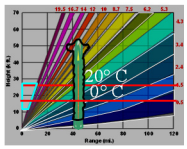
Instructor Notes: Note in the 4 panel velocity loop, the onset of strong midlevel convergence at 9000' AGL to above 15800' AGL just prior to the strong inbounds seen in the lowest slice (upper left). Weak midlevel convergence exists before with greater lead time to the surface downburst. The strong winds at the surface were likely in existence for some time before it impacted the home construction site where the fatality existed.

Student Notes:

Case #1: KFWS Velocity

- Well defined midlevel convergence forms



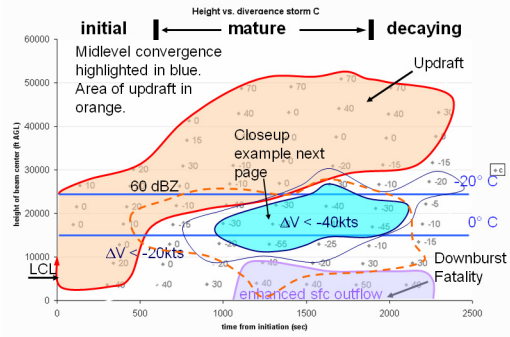


9. Time-height Velocity Plot

Instructor Notes: I sampled the maximum reflectivity for each level of the storm, using new cells if they developed so close to the older ones that they were all one contiguous heavy reflectivity area. The first time height plot is of reflectivity. The next time height plot is the maximum velocity difference found within the bounds of the heavy reflectivity core. At the lowest slice (5 kft AGL), there was strong convergence, mostly ahead of the precipitation core while divergence was found inside the core. I chose the divergence. At mid-levels, I found strong negative velocity differences (convergence) in the core while divergence existed to some extent on either side. Midlevel convergence patterns are often complicated, sometimes the convergence axis being on the core edge. Perhaps that is not unexpected because of the complex nature of the cores themselves, and therefore, downdraft forcing mechanisms. The downdraft initiates, and the midlevel convergence follows. Note that the midlevel convergence followed 5 – 10 minutes after the onset of > 60 dBZ reflectivities in the 0 to -20° C layer. Strong midlevel convergence < -40 kts appeared only 5 minutes before the onset of strong inbounds and divergence in the 0.5° elevation slice (4500' AGL). It was to be another 15 minutes before the fatality event. Several downburst surges probably occurred in this time span.

Student Notes:

Time-height Velocity Plot



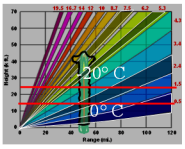
10. Midlevel Convergence

Instructor Notes: This example shows very well the midlevel convergence at 14.8 kft AGL and near the freezing level right within the intense reflectivity core. Updraft is likely above this level but the midlevel convergence is likely a response to the downdraft already underway and beginning to show up as a divergence field at the surface. At this distance, the divergence at 4390' is nowhere nearly as strong as it would be had the radar sampled the lowest few hundred feet above ground.

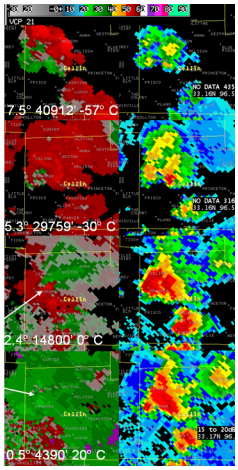
Student Notes:

Midlevel Convergence

- Midlevel convergence is well detected here
- Damaging winds are quite possible here though the first report is 20 minutes later



Midlevel convergence maximum above lower level divergence... Downdraft underway



11. Lead Times for Signatures from Case #1

Instructor Notes: In this example, the 55 dBZ then 60 dBZ core appeared in the layer where we would expect initial downdraft formation, somewhere near the freezing level and just above. Downdraft forcing is likely occurring at lower levels too. Anywhere with midlevel convergence in reflectivity core, downdraft forcing is possible. The best leadtime is the onset of the strong core aloft, followed by the weak midlevel convergence, and finally, strong convergence (?V<-30 kts).

Student Notes:

Lead Times for Signatures from Case #1

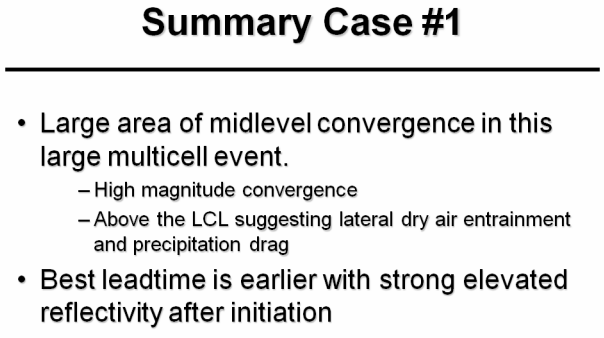
Precursor signatures in order of occurrence

Strong, large initial core, 55 dBZ 20 to 25 kft AGL (0 to –20 C) level:	leadtime = 10 – 15 min
Descent of high reflectivity's (>50 dBZ) to the surface:	leadtime = 5-10 min
Onset of midlevel 30kt convergence 12 – 20 kft AGL (0 to –10 C) level:	leadtime = 0-5 minutes

12. Summary Case #1

Instructor Notes: This event also had a large area of midlevel convergence. The convergence was strong and above the LCL suggesting that wet microburst processes were occurring, that is lateral dry air entrainment and precipitation drag. Waiting till the onset of strong midlevel convergence before considering a warning will not give you any leadtime. But there will probably be a pretty low probability of a false alarm.

Student Notes:



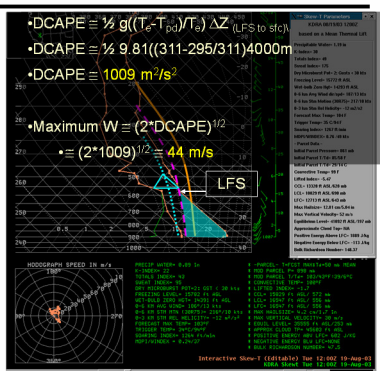
13. Case#2: 19 Aug 2003 Las Vegas

Instructor Notes: Now we go to the 19 August Las Vegas storm of 2003. All sorts of severe weather occurred on this day, including high winds. Low-level monsoon moisture entered into the valley after this sounding was taken allowing for high CAPEs. The hot surface temperatures made sure that the LCL was high and that plenty of negative buoyancy would be available below. Following the same method of visualizing the potential DCAPE area, launching a midlevel air parcel (note the cyan triangle) helps to estimate the midlevel ?w. Remember that there is a lot of flexibility as to what midlevel parcel height to choose for the ?w. 2. Next, choosing a representative parcel at the surface gives us the updraft parcel ?w in the orange curve. 3. Then the magenta dashed line represents an average of the two ?w curves and that becomes our downdraft ?w. 4. The DCAPE area occupies everywhere the downdraft ?w is colder than the environmental temperature, I estimate the surface environmental temperature Te to be 311 K, The downdraft surface temperature is about 295 K, the starting point of my downdraft is 4000 meters above ground. Entering in those numbers, I get this: DCAPE ? 9.81((311-295)/311)4000/2 ? 1009 m2/s2 This value is larger than the Dallas event. Add big CAPE precipitation loading potential and the downburst potential is quite high. Maximum theoretical W = (2*DCAPE)1/2 = 44 m/s Again, this is likely overestimating the potential some but the purpose here is to show the numbers are larger than for the Dallas microburst event.

Student Notes:

Case#2: 19 Aug 2003 Las Vegas

- 19 Aug 2003
- Large CAPE implies big precip loading
- Larger DCAPE than with FWD
  - 1009 m^2/s^2
- Both combine to increase threat of downbursts



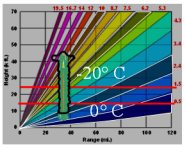
14. KESX Z and V

Instructor Notes: This vertical 8 panel shows that the storm has a strong elevated reflectivity core > 60 dBZ up to 28 kft AGL. But the midlevel convergence is not well defined. In fact, it appears that the midlevel convergence here is weaker than with the Dallas case.

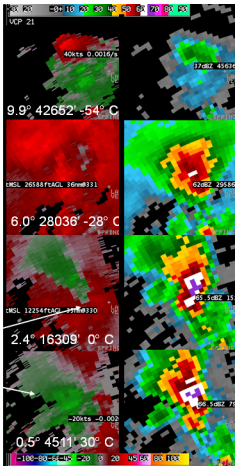
Student Notes:

KESX Z and V

- KESX 4-panel display
- Case with small midlevel convergence
- Axis of midlevel convergence likely downradial



Midlevel maximized near 0° C level... Outflow at surface too shallow for adequate detection

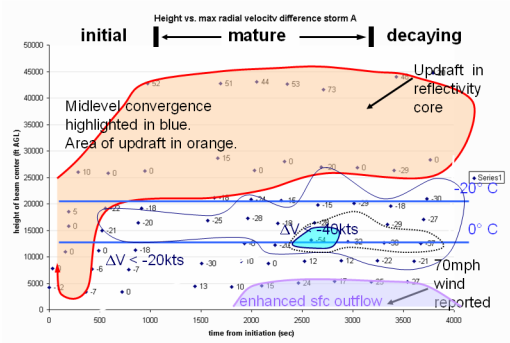


15. Time-height Reflectivity/Velocity

Instructor Notes: I was still able to find several gates with < -40 kts of midlevel velocity difference. But for the most part, the midlevel convergence was narrow and fairly weak. The updraft appeared strong on radar throughout this event, with two main cells making sure some strong updraft was always present. Enhanced low-level divergence appeared about 15 minutes before the 70 mph wind was reported. Strong winds were likely occurring well before the wind report.

Student Notes:

Time-height Reflectivity/Velocity



16. Lead Times for Signatures from Case #2

Instructor Notes: The best leadtime was the onset of a large initial core > 55 dBZ above 20 kft AGL. The descent of the high reflectivity core would give you about 15 minutes leadtime The onset of –30 kt velocity difference at 12 – 20 kft would have given you nearly 0 leadtime to the onset of low-level divergence.

Student Notes:

Lead Times for Signatures from Case #2

Precursor signatures in order of occurrence

Strong, large initial core, 55 dBZ 20 to 25 kft AGL (0 to –20 C) level:	leadtime = >15 min
Descent of high reflectivity's (>50 dBZ) to the surface:	leadtime = 15 min
Onset of midlevel 30kt convergence 12 – 20 kft AGL (0 to –10 C) level:	leadtime = 0 minutes

17. Summary Case #2

Instructor Notes: This may be speculative but the axis of inflow into the downdraft at mid-levels was possibly oriented in a way that prevented the radar from detecting it. Note that the long axis of the core is down radial. If the axis of convergence followed a similar orientation, then the inflow into the downdraft could be mostly tangential and hard to detect. The strength of the core above the freezing level in conjunction with the environment should give you an idea that strong downburst would be likely once that core descended to ground.

Student Notes:

Summary Case #2

- Midlevel convergence is actually weaker except for one volume slice – no leadtime
  - Inflow into midlevel convergence may have been mostly tangential
- But larger DCAPE and stronger reflectivity core than Ft. Worth event suggests bigger potential for damaging downburst

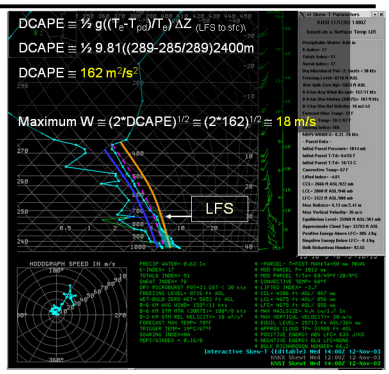
18. Case #3: 12 Nov 2003 LAX

Instructor Notes: Contrast the Las Vegas and Dallas events with a cool season, low topped event. There is actually a fair amount of dry air and low ?w air in the midlevels. CAPE is low only because the equilibrium level is low. Buoyancy or CAPE density is high relative to the total CAPE. Putting the numbers in, DCAPE ? ½ g((Te-Tpd)/Te) ?Z (LFS to sfc)\ DCAPE ? ½ 9.81((289-285/289)2400m DCAPE ? 162 m2/s2 Maximum W ? (2*DCAPE)1/2 ? (2*162)1/2 ? 18 m/s These numbers are small compared to the other two cases. Unless there is an exception, or precipitation loading is a big factor, or other downdraft forcing mechanisms are at work (e.g., Rear Flank Downdraft), then we don't expect severe downdrafts in this environment.

Student Notes:

Case #3: 12 Nov 2003 LAX

- Smaller CAPE, but high buoyancy (orange parcel)
- Small DCAPE (cyan shaded region)



19. KSOX Z and V

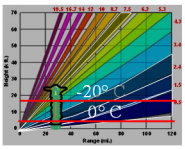
Instructor Notes: This cell does have a midlevel convergence axis and a downdraft is being generated. The differential velocity across the convergence is weak, perhaps 25 to 30 kts. Reflectivities are high and precipitation could be a factor. However, several parameters work against a severe downdraft in this case: Depth of the negative buoy-

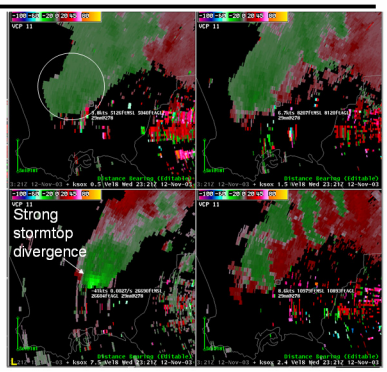
ancy is small and DCAPE is small Weak midlevel convergence supports the idea that downdraft may not be strong. Precipitation loading is there but the depth of its forcing is small too. Lack of very strong horizontal environmental flow means no vertical mixing of horizontal momentum. The last point is something not typically considered, however weak shear pulse convection can occur in strong wind environments. They do produce severe surface winds without strong downdrafts.

Student Notes:

KSOX Z and V

- Midlevel convergence (ΔV) peaks at -30 kts at 2.4° (10 kft, -4° C)





20. Summary Case #3

Instructor Notes: No severe winds were reported with the Los Angeles hail storm. The midlevel convergence appears well sampled with the axis perpendicular to the radials. But the values were weaker than for the other two cases. The depth of the convection was smaller too resulting in less room for downward acceleration of air to achieve high velocities. There was no other downdraft forcing besides precipitation loading and that is even limited by the shallow depth of the high reflectivities. This is the kind of environment and storm structure in which severe winds are not expected. No severe wind reports had been received from this storm.

Student Notes:

Summary Case #3

- CAPE = 800 j/kg, DCAPE much smaller than first two cases
- > 60 dBZ core implying precipitation loading is significant but depth is small
- Midlevel convergence –30 kts compared to –54 kts for FTW case and –40 kts LSV case
  - Likely well sampled midlevel convergence based on orientation of its axis
- No severe wind reports

21. Choices

Instructor Notes:

Student Notes:

22. Summary: Hybrid/Wet Microbursts

Instructor Notes: In summary, I present a table of microburst precursor signatures ordered with respect to the lead time each one offers. The environment makes up for the most lead time but individual storm behavior precludes using the environment as a sole warning tool for every storm and thus the FAR is potentially high. The best set of parameters to view in conjunction with the environment is to watch for the storms with rapid initiation capable of sending high reflectivities to greater altitudes than other adjacent storm. The descent of the high reflectivity core results in lower lead time but is usually when a warning is sent out since the descending core occurs rather rapidly. It is usually when the reflectivity core descends that the onset of midlevel convergence occurs. Don't wait for the midlevel convergence to reach some large value since large values of midlevel convergence and the period of strongest outflow occur nearly simultaneously. In this session, I have not mentioned situations of weak shear convection embedded in strong horizontal winds. There have been many events where even weak showers have been able to initiate downdrafts bringing the high horizontal winds to the surface. I encourage the use of DCAPE more than other parameters, because it accounts for downdraft forcing by lateral and sub cloud base dry air entrainment for a wider variety of situations. The method shown in this lesson is something that can be applied relatively quickly on the day of an expected event. There are some caveats to its use. Note that it assumes a constant lapse rate of environmental temperature from the surface to the level of free sink. In many cases, the bumps and wiggles in the vertical temperature profile tend to cancel each other out. Sometimes they don't. DCAPE is best applied for isolated convection either in weak or significant vertical wind shear. DCAPE becomes less relevant when you are faced with an organized multicell cold pool or in situations of weak convection embedded in strong horizontal winds.

Student Notes:

Summary: Hybrid/Wet Microbursts

Precursor signatures

Signature	FAR	Leadtime
1 Large enough CAPE to produce significant precipitation loading	high	Day 1
2 Significant DCAPE – evaporational cooling	high	Day 1
3 Strong initiation with high reflectivities (see updraft strength sessions)	med	15 min
4 Descent of high reflectivity core	med	5-10 min
5 Onset of midlevel convergence	med	0-10 min
6 Midlevel convergence (ΔV) > 50 kts	low	0 - 5 min

1. Storm Interrogation

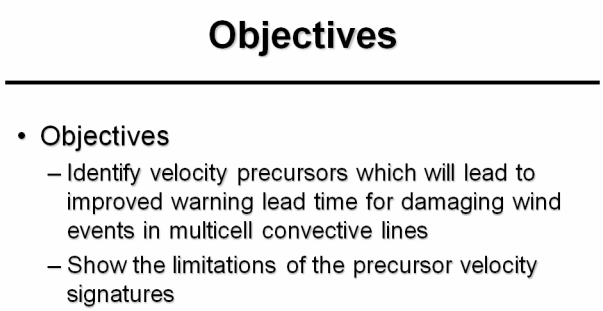
Instructor Notes: Welcome to the AWOC Severe Track IC3-VII-B Convergent Signatures prior to Organized Convective Wind Events The content of this lesson has been produced by Gary Schmocker of NWS WFO St. Louis, MO The lesson is about 8 slides long and should take 10 minutes to complete.

Student Notes:

2. Objectives

Instructor Notes: Objectives: Identify velocity precursors which will lead to improved warning lead time to damaging wind events in multicell convective lines Show the limitations of the precursor velocity signatures

Student Notes:



3. Convergent Signatures in Multicell Convective Wind Events

Instructor Notes: Przybylinski et al. 1995 noted strong Mid-Altitude Radial Convergence (MARC) along the forward flank of convective lines before they began to “bow out”. We are using the WSR-88D to survey a component of the squall line’s sloping updraft/downdraft currents along the forward flank of the MCS during the intensifying stage.The region of strong outbound velocities signifies a component of the storm’s updraft current and FTR flow (with respect to approaching storm west or upstream of radar) The region of strong inbound velocities represent the component of the storm’s downdraft current or early stages of the mesoscale Rear Inflow Jet (RIJ).

Student Notes:

Convergent Signatures in Multicell Convective Wind Events

- Przybylinski et al. 1995 noted strong Mid-Altitude Radial Convergence (MARC) along the forward flank of convective lines before they began to “bow out”
- When the intensifying MCS is upstream
  - strong outbounds indicate updraft
  - strong inbound velocities indicate downdrafts & origins of the mesoscale RIJ

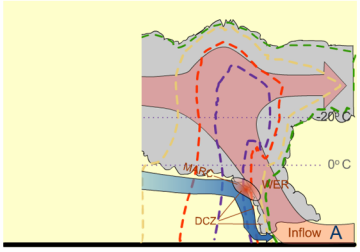
4. MARC Signature in a Mature MCS

Instructor Notes: The MARC signature represents the convergence of two air streams, the developing Rear Inflow Jet (RIJ) and the leading convective updraft. The RIJ in a severe Mesoscale Convective System (MCS) forms on the upshear side immediately behind the tall convective towers and develops rearward with time. The MARC manifests itself as a persistent localized zone of radial convergence as viewed by radar. It is typically embedded in a longer region of background convergence and resides in the forward flank of the intense convective line echoes.

Student Notes:

MARC Signature in a Mature MCS

- Persistent, localized, and strong radial convergence
- In larger background of convergence
- In forward flank of intense convective line echoes



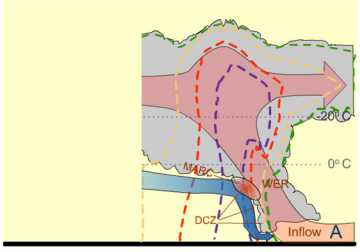
5. MARC Characteristics

Instructor Notes: The length of a typical MARC signature is approximately less than 15 km long by 7 km or less wide. There can be nearly gate to gate radial velocity differences that can exceed 25 m/s (50 kt). If you detect 25 m/s or more of velocity difference, expect an increased threat of severe surface winds. You can calculate actual convergence, either by using the Vr shear tool, or by visual inspection by taking the near gate to gate radial velocity difference and dividing by the distance of the baseline. You should see values ranging up to .025 s-1 or more for severe MARC signatures. These convergence values were taken within a 7 km baseline. Remember that you want to pick a consistent baseline if you use the Vr shear tool.

Student Notes:

MARC Characteristics

- Length < 15 km
- Width < 7 km
- Nearly gate to gate strong velocity gradient
- $\Delta V \geq 25$ m/s increases potential for severe surface wind



Actual convergence ranges from .0056 to .025 s^{-1} within a 7 km baseline

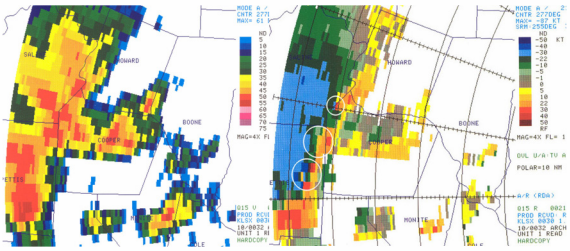
6. An Example MARC

Instructor Notes: This example shows three MARC signatures, each one roughly in a localized enhanced reflectivity core, and about 15 kft AGL. Note that the velocity difference in these MARCs exceed 50 kts. All three MARCs are embedded in a contiguous convergent zone along the axis of the convective line.

Student Notes:

An Example MARC

- White circles indicate three enhanced convergent signatures embedded in longer region of convergence

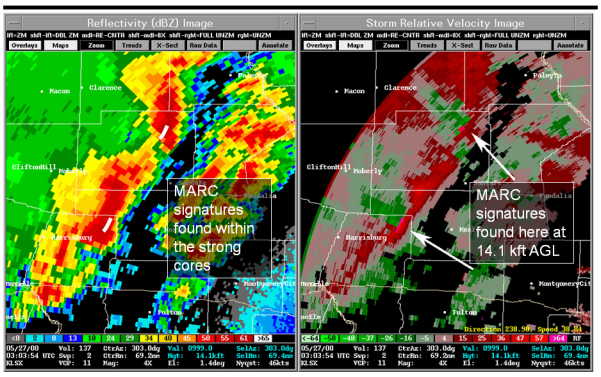


7. MARC Example: 27 May 2000

Instructor Notes: Another example here shows two MARC signatures in eastern Missouri on 27 May 2000. The radar beam is 14 kft AGL and in a good elevation to see this signature. Each MARC shows nearly 50 kts of gate-to-gate velocity differences with increasing range, a sign of intense convergence. Also note that each MARC signature is embedded in the most intense cores in this display. In some ways, it appears that the MARC signature in an MCS (or a Quasi Linear Convective System, QLCS), is similar in appearance to mid-level convergent signatures found in single cell pulse convection. Both of them occur in intense midlevel cores and are precursor signatures to severe surface winds. The difference lies in the fact that the MARC signatures in an organized event are embedded along a sloping interface between a long-lasting updraft sheet and the rear inflow associated with the RIJ and cold pool. This sloping interface is able to keep its configuration over a long period of time, much longer than the time it takes for individual air parcels to traverse its length, on either side. The pulse storm midlevel convergence and downdraft result in a spreading outflow, quickly resulting in the demise of the original cell. Here, the MARC signature often marks the genesis of a bow echo, and in fact, the localized downburst activity helps to initiate the bow echo. Many times the worst wind damage may occur before a bow echo has formed.

Student Notes:

MARC Example: 27 May 2000



8. Test Your Knowledge

Instructor Notes:

Student Notes:

9. Summary: MARC Signature

Instructor Notes: To summarize, look for velocity differences > 25 m/s in a small region, typically 15 by 7 km and embedded in a larger convergent region at midlevels The MARC signatures occur prior to the formation of bows, line-end vortices and low-level vortices within the intense deep reflectivity core. Look to the midlevels, approximately 4 – 5 km AG for the MARC signature. One final note, if the radials of your radar are roughly parallel to the line axis, you will have a difficult time detecting the MARC signature since most of the air flow is tangential and not radial.

Student Notes:

Summary: MARC Signature

1. Look for $\Delta V \geq 25$ m/s in a small region (typically 15 by 7 km) embedded in larger scale convergence
2. Usually prior to formation of bows, line end vortices, low-level vortices within intense, deep reflectivity core
3. Found at midlevels of 4 – 5 km (13-16.5 kft)
4. Difficult to discern when line is parallel to the radials

10. Summary: MARC Signature (contd)

Instructor Notes: Finally, the environment in which a MARC signature leads to severe surface winds, the optimal situation for severe surface winds in the vicinity of a MARC is one in which the pre-storm CIN is low and there is no shallow stable layer. However, there are a minority of events where severe winds have been observed in elevated MCSs where the stable layer can reach 2 km, even a bit more.

Student Notes:

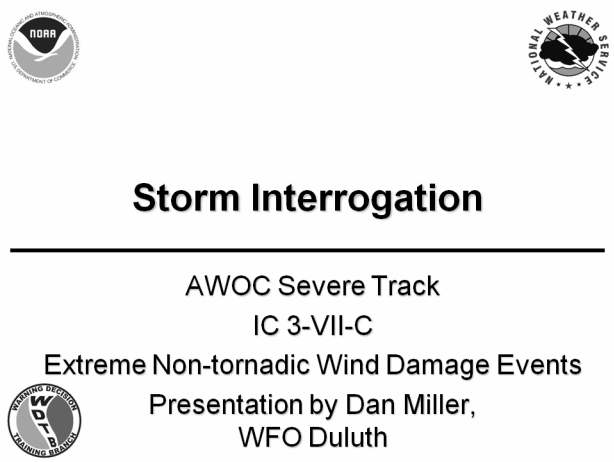
Summary: MARC Signature (contd)

5. Environment favors these events in regions where surface-based CIN is not large
   - Downdrafts have increasing difficulty penetrating to the surface if cool, stable layer exceeds 2 km
   - Damaging wind potential thus mitigated in areas deep in the cool side of a polar front or outflow boundary

1. Storm Interrogation

Instructor Notes: AWOC Severe Track IC 3-VII-C, presented by Dan Miller, SOO at Duluth.

Student Notes:



2. Extreme Non-Tornadic Wind Damage Events

Instructor Notes: Study of Extreme Non-Tornadic Wind Damage Events, or XDW events, began about 5 years ago and was motivated initially by a simple desire to document an event on 1 July 1997 in central Minnesota. After looking at that event in detail, and with level 2 WSR-88D data, it became apparent that the conceptual model of high-end non-tornadic wind events needed scrutiny, because many of these events do not fit well into the bow echo conceptual model very well when high resolution radar data is examined. The initial phase of the study was focused on derecho producing MCSs that resulted in exceptionally severe non-tornadic winds and/or wind damage. It should be emphasized that considerable effort was made to distinguish these events from “ordinary” derecho events, in that these events are a sub-set of derecho events, characterized by widespread forest blowdowns or wind damage areas that include observed damage of high-end F1 or greater intensity and/or peak measured wind gusts roughly 80 knots or greater. Two SLS conference papers has been published to date on this topic, and those publications are listed at the bottom of this slide.

Student Notes:

Extreme Non-Tornadic Wind Damage Events

XDW – eXtreme Damaging Wind

Characterized by one or more of:

- Widespread forest blowdowns
- Observed damage of ≥ high-end F1 intensity
- Peak measured wind gusts ≥ 80kt

A Detailed Look at Extreme Wind Damage in Derecho Events
D.J. Miller and R.H. Johns, 2000 SLS Conference

Observations of the 27 May 2001 High-End Derecho Event in Oklahoma
D.J. Miller, D.L. Andra, J.S. Evans and R.H. Johns, 2002 SLS Conference

3. Objectives

Instructor Notes: Objectives Identify volumetric radar characteristics of extreme non-tornadic wind producing supercells within derecho producing MCSs. Understand storms-cale mechanisms for the production of extreme winds Understand suggested operational philosophies during warning operations

Student Notes:

Objectives

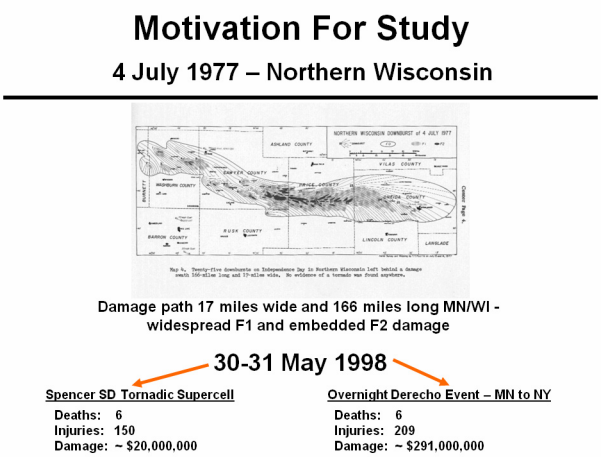
- Objectives
  1. Identify volumetric radar characteristics of extreme non-tornadic wind producing supercells within derecho producing MCSs.
  2. Understand stormscale mechanisms for the production of extreme winds
  3. Understand suggested operational philosophies during warning operations

4. Motivation For Study

Instructor Notes: Additional motivations for further study are numerous. First, these events are the non-tornadic equivalent to tornado outbreaks, and although a qualitative study has not been done to date, it is quite likely that a disproportionate amount of the injuries, deaths, and damage from non-tornadic winds each year are due to XDW events. Second, many XDW events produce widespread damage areas that include consider-able areas of equivalent F1 damage, and some include quite sizeable areas of F2 equiv-alent damage. The figure at the top of this slide (from one of Dr. Fujita's publications) is an extreme example from 4 July 1977. The damage path is 166 miles long, and up to 17 miles wide, extending across parts of 6 counties in northern Wisconsin, and includes

widespread F1 damage (in the dark gray shading), and considerable areas of F2 damage (in the black shading.) Winds in this event were estimated at 100-120 mph winds with gusts up to 135 mph. One eyewitness account from this event stated that the intense wind continued for 20 minutes and was accompanied by large hail. Third, many XDW events produce just as much, if not more, dollars in damages than tornadoes, and injury/deaths can be comparable. For example, a major severe weather outbreak occurred on 30-31 May 1998 from the northern plains states eastward into much of the Great Lakes region. An F4 tornado struck the tiny town of Spencer, SD during the afternoon of the 30th, killing 6, injuring 150, causing $20 million in damage, and destroying over half of the town. Consequently, media converged on the town and provided several days of coverage. 6 years later, many remember the Spencer, SD tornado. However, what most DO NOT remember about this event is the very intense derecho event occurred during the overnight hours following the Spencer, SD tornado. This XDW event from the evening of the 30th, through the morning of the 31st, affected areas from central Minnesota, eastward across Wisconsin, Lake Michigan, Lower Michigan, extreme northern Ohio, Lake Erie, and far western New York State, resulting in 6 fatalities, 209 injuries, and $291 million in damage. The winds also resulted in a 4 foot seiche on Lake Michigan, that was the primary factor in the sinking of a ship in port on the eastern shore of the lake. It is only a matter of time before an event like this affects a major metro area, perhaps during rush hour, that could result in event greater loss of life and property. There is much improvement that can be done with respect to forecasting and warning for these events, and increased situation awareness to these events is the primary goal of this module.

Student Notes:



5. Extreme Non-Tornadic Wind Damage Events

Instructor Notes: To drive home the point, this slide shows a now somewhat-famous video taken during an XDW event in the Pakwash forest of northwest Ontario, Canada on 18 July 1991. Incidentally, this video was taken on the edge of a large forest blowdown area. Damage in the center of the blowdown path was described as considerably more severe than at the location where the video was taken. The entire video is about 15 minute long, and shows three separate pulses of extreme winds, within a period of sus-

tained winds ~50-60 mph. There was no hail in this video, but in some XDW events, particularly ones that involve supercells, the intense wind can be accompanied by golfball to baseball size hail. As an interesting aside, note the time stamp on the video (which is accurate) – 1051 AM CDT.

Student Notes:

Extreme Non-Tornadic Wind Damage Events

Pakwash Forest Blowdown Event
18 July 1991 - Northwest Ontario, Canada

6. What Convective Elements Are Associated with XDW Events?

Instructor Notes: In investigating XDW events, it quickly became obvious that the best way to look at them was to define an XDW event, and then work backward to the radar data and 4-D storm structure evolution. So, what storm-scale convective elements are associated with XDW events? Many (most?) of these events are produced by forward propagating MCSs, and therefore are, by definition, part of a derecho event. As one might expect according to the widely held conceptual model (from Johns and Hirt, 1987, and many other papers) some events are produced by serial or progressive bow echoes. However, some of the forward propagating MCSs involved exhibit very complex 4-D reflectivity/velocity structure evolution, and involve circulations on the storm-scale. For the purpose of this presentation, we will focus on the MCSs that contain embedded supercell storm structures. A summary of events that have been studied in full or in part are listed on the slide.

Student Notes:

What Convective Elements Are Associated with XDW Events?

Non-Supercell (Serial or Progressive Bow Echo)
15 July 1995 – Upstate New York
30-31 May 1998 – Minnesota to New York

Hybrid (Line Mesovortex/Supercell structure)
30-31 May 1998 – Minnesota to New York
4 July 1999 – Northern Minnesota
22 July 2003 – Western Tennessee (Memphis event)
4 March 2004 – Texas/Oklahoma

Supercell (MCS with embedded supercells)
3-4 May 1989 Texas/Oklahoma
1 July 1997 – Central Minnesota
29 June 1998 – Central Iowa
27 May 2001 – Oklahoma
26 August 2002 – Western Kansas

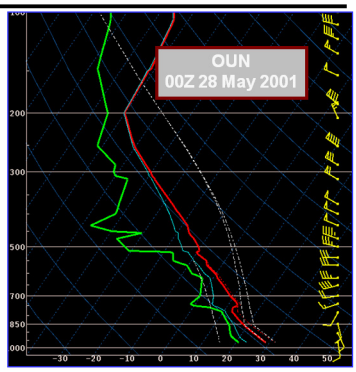
7. 27 May 2001 - Oklahoma

Instructor Notes: The first case example we will look at occurred on 27 May 2001 in Oklahoma. This slide and the next provide a brief overview of the larger-scale environment that supported this MCS. The thermodynamic profile was characterized by very strong instability (surface-based CAPE approaching 5000 j/kg), and rich tropical moisture in the low levels (surface dewpoints in the low 70s F.) Also of note is the relatively low LCL height at 858 mb, which is roughly 2,500 meters AGL.

Student Notes:

27 May 2001 - Oklahoma

SBCAPE 4874 j/kg
MLCAPE 3279 j/kg
CIN 0 j/kg
LI -11
WBZ 11653 ft
700-500 LR 7.6 deg/km
LCL 858 mb



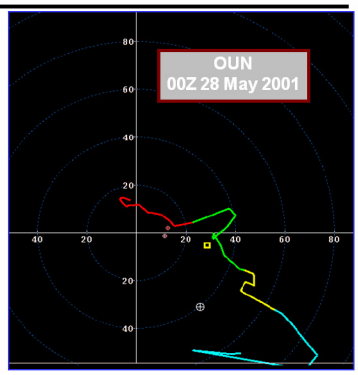
8. 27 May 2001 - Oklahoma

Instructor Notes: The wind shear profile, when viewed in combination with the thermodynamic profile as seen on the previous slide, reveals an environment that would easily support supercell thunderstorms, with surface to 6 km wind shear of 60 kts (30 m/s), and BRN shear of 67 m2/s2.

Student Notes:

27 May 2001 - Oklahoma

Sfc-6km shear	30 m/s
Sfc-3km SRH	264m^2/s^2
BRN	47
BRN Shear	67m^2/s^2
LFC-EL wind	280/30kt
Storm motion	320/40kt

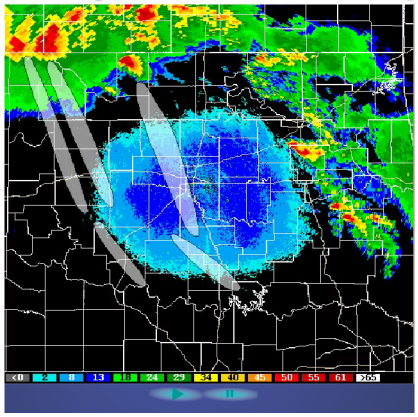


9. 27 May 2001 Radar Loop

Instructor Notes: This XDW event was produced by a forward propagating MCS that evolved from several discrete supercells over southwest Kansas. The annotated areas on the radar loop are corridors of XDW that were produced by this MCS (corridors were derived from a combination of Oklahoma mesonet peak winds, damage reports, and damage surveys conducted by local emergency managers.) Radar data viewed at this scale, suggests that this was a rapidly moving and large-scale bow echo. However, if one studies the loop carefully, individual storm elements can be identified, that coincide with the corridors of XDW. These elements are supercells embedded within the MCSs, and we will examine the storm structure in detail on the next several slides.

Student Notes:

27 May 2001 Radar Loop

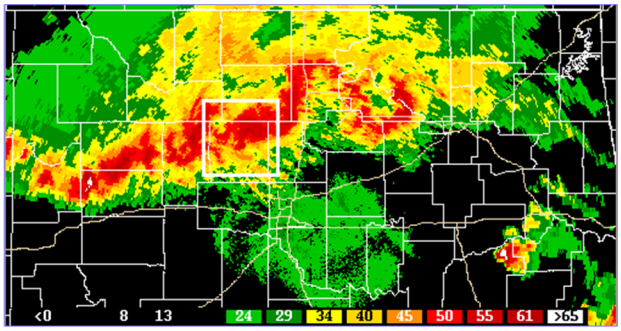


10. State-Scale Radar Data 0210 UTC

Instructor Notes: The image on this slide is a state-scale reflectivity image from the central Oklahoma Twin Lakes WSR-88D (KTLX) at 0210 UTC 28 May 2001. Again, viewed at this scale, the MCS at first glance appears to be a large-scale bow echo. However, on the next slide we will zoom in on the area within the white square.

Student Notes:

State-Scale Radar Data
0210 UTC

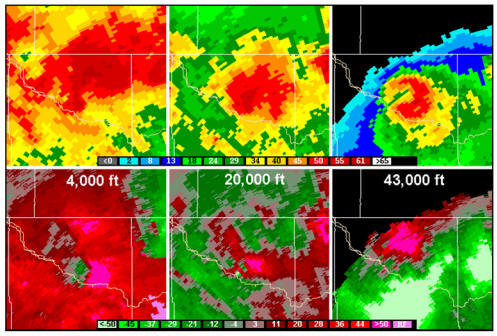


11. Volumetric Radar Data

Instructor Notes: Here is the volumetric reflectivity/velocity data from the white box on the previous slide at 0210 UTC. Reflectivity (top) and velocity (bottom) data are shown at roughly 4,000 ft agl (left), 20,000 ft agl (center) and 43,000 ft agl (right), which should provide a representative view of the storm at low, mid and high levels, respectively. The reflectivity core is strong and very deep, with 55+ dBz echo evident up to at least 43,000 ft, with significant mid and upper level overhang to the inflow (south) side of the storm. A rather large and high reflectivity hook echo is also evident in the low levels. Velocity data at low levels clearly indicates a cyclonically convergent mesocyclone that is displaced slightly to the lower reflectivities on the inflow flank. In the mid levels, a strong mesocyclone is evident (although there are velocity dealiasing errors in the radial inflow velocities), that is co-located with the high reflectivity core. At high levels, strong anti-cyclonic divergence is indicated near the storm summit. The combination of these reflectivity and velocity signatures is exceptionally consistent with the conceptual model of radar-observed supercell storm structure, and indicates a mature (likely Hp-type) supercell embedded within the MCS. The location just on the upshear flank of the low-level mesocyclone was directly associated with a long-tracked XDW corridor.

Student Notes:

Volumetric Radar Data



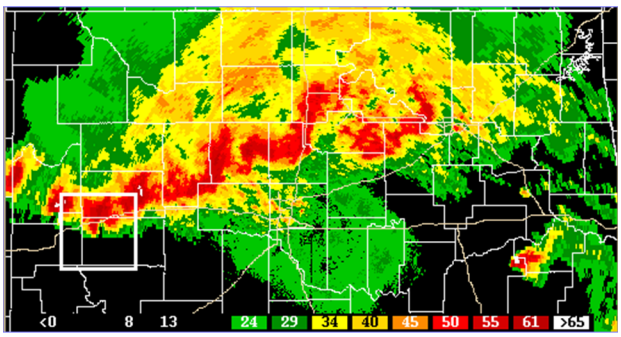
AZ/RAN – 326°/51 nm

12. State-Scale Radar Data 0230 UTC

Instructor Notes: At 0230 UTC, we will zoom in and examine an area farther to the west in the quasi-linear MCS. On the next slide, we will look at volumetric reflectivity data from the area highlighted in the white box.

Student Notes:

State-Scale Radar Data
0230 UTC

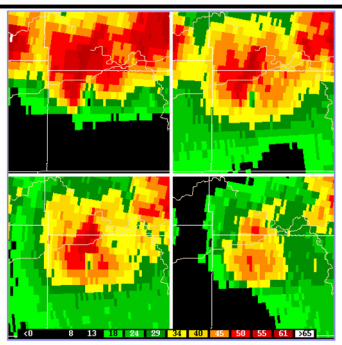


13. Volumetric Radar Data

Instructor Notes: Radial velocity data at this location was range-folded. However, the volumetric reflectivity data reveals a lot. We are somewhat limited in sampling the lower levels of the storm at a range of 93 miles, but at 10,000 ft agl, an notch on the inflow side and a well-defined hook echo are clearly evident. At 20,000 and 30,000 ft agl, a very well-defined bounded weak echo region is present, with the storm summit and highest reflectivities at 40,000 ft agl displaced to the inflow side, directly above the inflow notch at low levels. This feature was present for over 30 minutes, and again is clear evidence of a mature, intense and long-lived supercell updraft. This embedded supercell was responsible for another long corridor of XDW over western Oklahoma.

Student Notes:

Volumetric Radar Data



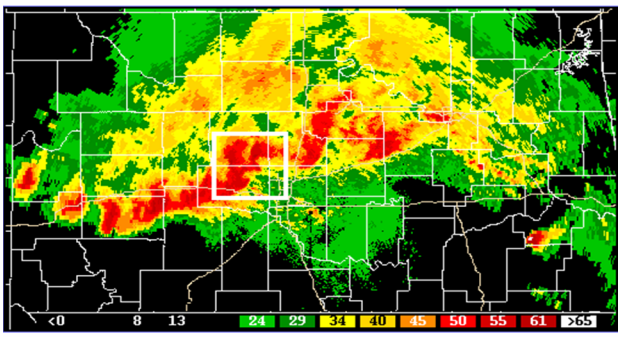
AZ/RAN – 272°/93 nm

14. State-Scale Radar Data0249 UTC

Instructor Notes: Finally, at 0249 UTC, we will zoom in and examine a storm in the MCS immediately to the west of the storm we examined in slides 8 and 9. On the next slide, we will look at volumetric reflectivity data from the area highlighted in the white box.

Student Notes:

State-Scale Radar Data
0249 UTC

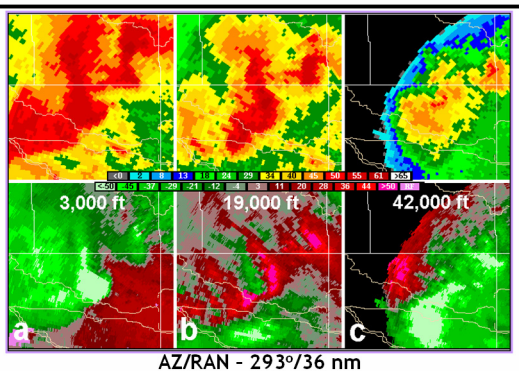


15. Volumetric Radar Data

Instructor Notes: This slide shows volumetric reflectivity/velocity data from the third storm embedded within the MCS at 0249 UTC. This storm was located immediately to the west of the storm that we looked at in slides 8 and 9 at 0210 UTC. Again, reflectivity (top) and velocity (bottom) data are shown at roughly 3,000 ft agl (left), 19,000 ft agl (center) and 42,000 ft agl (right). Very similar signatures are evident. The reflectivity core is strong and very deep, (although the highest reflectivities are a bit more shallow than the 0210 UTC storm we looked at) with 50+ dBz echo evident at 42,000 ft, with significant mid and upper level overhang to the inflow (southeast) side of the storm. A rather large and high reflectivity hook echo is once again clearly evident at 3,000 ft agl. Velocity data at low levels clearly indicates a strong and unbalanced cyclonically convergent mesocyclone coincident with the low level reflectivity hook. The velocity image at 3,000 ft agl above is radial base velocity, and raw data sampling revealed nearly 100 kt inbound velocities at 3,000 ft agl. In mid levels, a mesocyclone is evident, co-located with the high reflectivity core. At high levels, strong anti-cyclonic divergence is indicated near the storm summit. Again, clear indication of a mature (HP-type) supercell embedded within the MCS. As with the other two storms we have looked at, locations just on the upshear flank of the low-level mesocyclone (underneath the location of strong inbound radial velocities) experienced XDW. This storm was responsible for considerable F2 structural damage in the city of El Reno, including taking the roof off of a hospital and city hall.

Student Notes:

Volumetric Radar Data



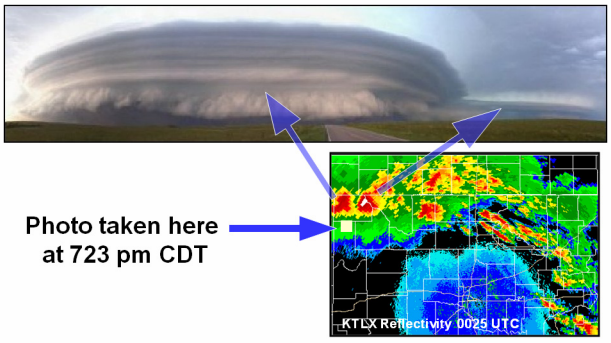
AZ/RAN - 293°/36 nm

16. Relating Visual Appearance to Radar

Instructor Notes: Here is a photograph of the storm complex as it appeared in northwest Oklahoma, just before 730 PM local time (0030 UTC.) At this time, the MCS was still in the process of transitioning from discrete supercells, to a quasi-linear MCS with embedded supercells, but a common gust front and strong surface cold pool had already become established. The photo shows two distinct HP type supercell storms, linked by a common gust front. For comparison, the location of the photo is annotated on the lowest cut reflectivity image in the lower right, with the two arrows pointing to the two storms from their respective radar echoes.

Student Notes:

Relating Visual Appearance to Radar

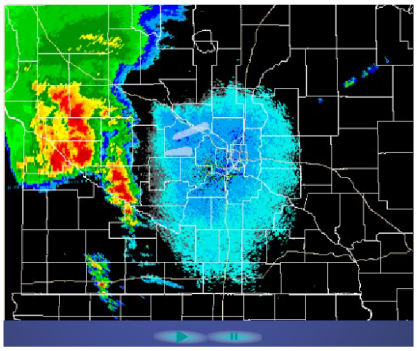


17. 1 July 1997 – Central Minnesota

Instructor Notes: It is also useful to provide an example from another part of the country. This is a 0.5 degree reflectivity loop of the 1 July 1997 MCS that produced an XDW event. The XDW areas are annotated in white on top of the radar loop. Much as in the Oklahoma case we just looked at, the MCS is quasi-linear, and at state-scale appears much as a large-scale bow echo.

Student Notes:

1 July 1997 – Central Minnesota

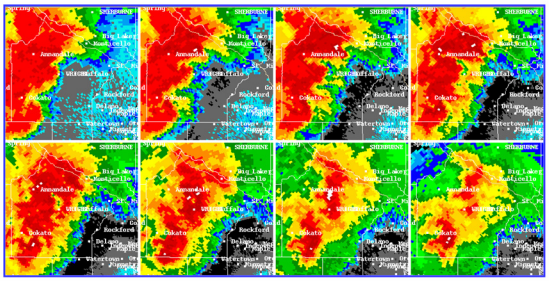


18. Volumetric Radar Data

Instructor Notes: This slide is an enlarged view of the volumetric radar data, zoomed in on Wright County, Minnesota at the time two corridors of XDW were in progress. Nearly identical volumetric reflectivity and velocity signatures are again clearly apparent, with the location of the XDW events placed just on the upshear flank of the low level mesocyclone, coincident with the precipitation filled rear-flank downdraft portion of the HP supercell.

Student Notes:

Volumetric Radar Data



19. Ground-Relative Wind Production Mechanisms

Instructor Notes: So, why do XDW events seem to have a favored storm-relative location of occurrence? Primarily because of the juxtaposition of exceptionally strong storm-scale isallobaric wind accelerations near the surface, the ground relative winds in the near-surface mesocyclone circulation, and precipitation loading and column cooling from hail melt. The primary point is that these events appear to be much more complicated than a simple “downburst,” with a significant contribution to the extreme ground-relative wind speeds coming from storm-scale dynamic forcing.

Student Notes:

Ground-Relative Wind Production Mechanisms

Superposition of
1) Exceptionally strong storm-scale isallobaric accelerations
2) Maximum ground-relative winds within the mesocyclone circulation
3) Precipitation loading and
4) Column cooling due to melting hail

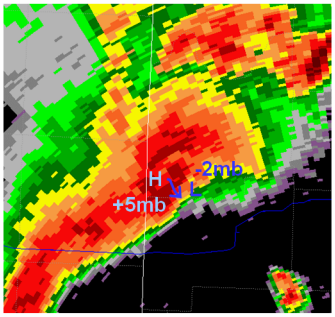
→ Overall message is that warning forecasters need to be keenly aware of an enhanced potential for wind damage (possibly high-end) when circulations are present

20. Pressure Perturbation Example

Instructor Notes: Meteograms from several XDW events indicate that a 5-10 mb pressure perturbation exists between the low under the updraft, and the high underneath the downdraft and cold precipitation core, and radar data suggests that separation of these storm-scale features was generally on the order of 5 to 10 miles. Most of the MCSs examined had forward propagation speeds of greater than 35 kts, and it follows that a very intense storm-scale isallobaric wind acceleration is likely a very strong contributor to the intense wind speeds.

Student Notes:

Pressure Perturbation Example



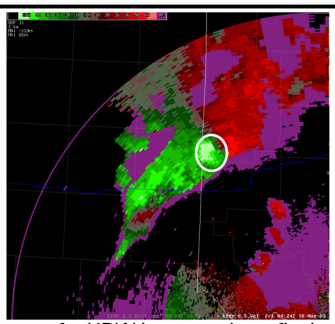
Much more than a simple 'downburst'

21. Location of XDW

Instructor Notes: This annotated velocity image simply shows where this area of the storm is located in the velocity imagery.

Student Notes:

Location of XDW



Most likely area for XDW is on up-shear flank of low-level mesocyclone and in the precip-filled RFD area

22. Unique? Characteristics of XDW Events

Instructor Notes: Much more research needs to be done, including obtaining data from new cases as they occur, to ascertain whether these XDW characteristics are generally the case with all XDW events. However, these characteristics were common in most cases examined thus far.

Student Notes:

Unique? Characteristics of XDW Events

1) Quite long in duration at any one location along the path (10-20 minutes - or longer in extreme supercell/mesovortex events vs. a few minutes or less for bow echoes)
2) Very tight damage gradients along the periphery of XDW area
3) Supercell events have a much higher probability of being accompanied by large hail (> 4cm)

23. Operational Considerations

Instructor Notes: The bullets presented here generally need little additional explanation. All are important things to remember when working an XDW event operationally. AWIPS and other operational procedures should be optimized to maintain maximum situation awareness during the event.

Student Notes:

Operational Considerations

- Supercells *within* a derecho producing MCS can be associated with an enhanced threat for XDW
- In *many* high-end derecho events - the most extreme damage is associated with supercells/mesovotices
- Supercell/Mesovortex XDW events *may* have somewhat different characteristics than "traditional" Bow Echo XDW events
- Events often move/evolve rapidly → timely flow of accurate information becomes *very* challenging
- Even high resolution surface mesonetwork observations may not be dense enough to completely capture storm-scale extreme wind events

24. Forecasting XDW 6-24 Hours Out

Instructor Notes: A few brief comments about forecasting these events. It should be emphasized that a qualitative study of environmental parameters has not been completed yet, primarily because the data set is still too small for results to be statistically significant. With addition of additional cases as they occur, hopefully the data set will reach a critical mass soon. With that said, there are a few general points about forecasting these events that can be stated from anecdotal and observational evidence. First, the fact that most of these events occur in tornado watches, and many in PDS tornado watches, seems to suggest that there is a significant overlap in the large-scale environmental conditions that support both XDW events and significant tornado events (strong instability, strong surface-6 km shear, strong surface-1 km shear, low LCL/LFC heights, etc.) It seems as though event type is highly dependent on convective mode (discrete supercells vs. MCS development.)

Student Notes:

Forecasting XDW 6-24 Hours Out

- Almost all of these events have tornado watches
  - → *many* have PDS tornado watches
- Significant overlap of atmospheric conditions between XDW events and tornado outbreak days
- Event type/evolution seems to be highly dependent on convective mode

25. Tips for AWIPS D2D Display

Instructor Notes: Here are a few tips for AWIPS procedures and conveying information to users in warnings, statements and graphical products.

Student Notes:

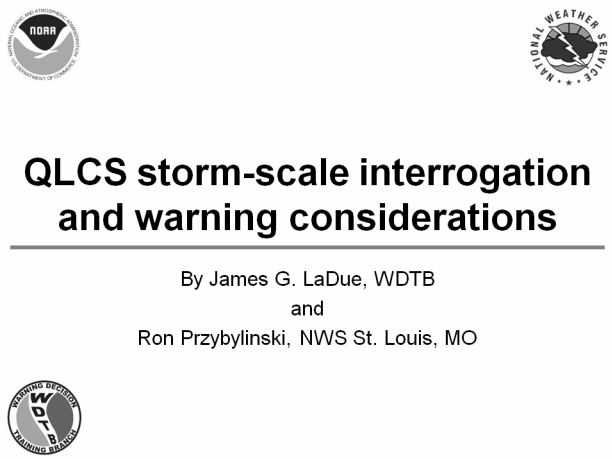
Tips for AWIPS D2D Display

- All tilts, in combination with judiciously constructed 4-panel displays from multiple radars, is exceptionally useful in seeing the 4-D storm structure evolution
- Remember to keep at least one radar panel paired with 8bit base velocity
- Possible to be fairly confident about specifics of enhanced wind damage area in warnings/statements and graphical products

1. QLCS storm-scale interrogation and warning considerations

Instructor Notes: Welcome to the AWOC Severe lesson on QLCS storm-scale interrogation and warning considerations. This lesson is 43 slides long and will probably take 45 minutes to take. Jim LaDue of WDTB and Ron Przybylinski, the SOO at NWS St. Louis, MO, will be your primary instructors.

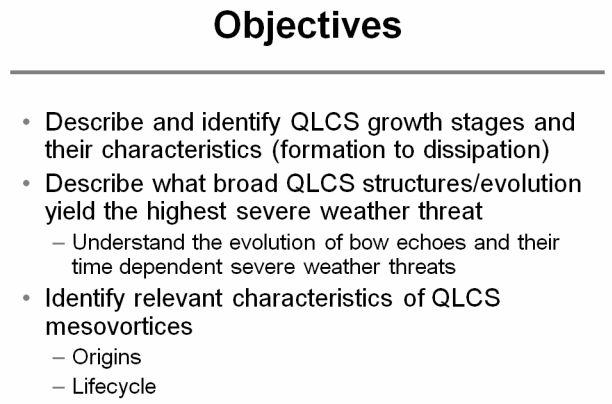
Student Notes:



2. Objectives

Instructor Notes:

Student Notes:



3. Objectives, contd

Instructor Notes:

Student Notes:

Objectives, contd

- Identify QLCS vortex severe wind/tornado precursor signatures
  - Location relative to the QLCS and rear inflow jet
  - Boundary intersections
  - Vortex width, base, height, strength
  - Evolution of precip features
- Understand warning decision making considerations for QLCS events.

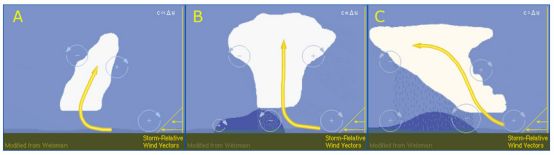
4. Generic Lifecycle of a QLCS

Instructor Notes: This is to answer what stage in a QLCS lifecycle is most likely to produce most severe wind (tornado) potential. We typically evolve convective systems from a point where the updraft is primarily the dominant feature and the cold pool is yet too immature to interact with a the sheared environment. If we were in an environment where deep-layer shear is capable of supporting supercells and severe QLCS events, we would most likely see supercells in this case because the shear dominates the cold pool and the shear would interact primarily with the updrafts. We wouldn't expect to see QLCS-based mesovortices or cold pool-induced severe winds in this stage. As the original small multicells, whether clusters, or a line segment, merge and begin producing an enhanced cold pool, you finally have a period in which it becomes a significant contributor to the morphology of the updrafts. The lifting on the cold pool becomes more aggressive allowing for more widespread updraft formation, and the updraft tilt becomes as much a function of the cold pool as the environmental shear. There's a period in time where the cold pool balances well with the environmental shear allowing for deep, upright updrafts along the gust front. Lifting along the gust front forms the base of the updraft and the balance between the cold pool vorticity and the environmental shear forces that updraft to stand upright. If the shear continues through the deeper layer in the atmosphere, the updraft maintains its upright character and eventually overturns in both forward and backward trajectories forming the anvil. This is the tall echo stage of an impending severe QLCS event where the strongest MARC signatures prevail. Sometimes when bows form, they remain in the tall echo stage if the cold pool and shear remain balanced and deep convective overturning continues in the upper-levels. More likely the updraft depth decreases as the bow forms as the cold pool begins to race ahead. The more severe bows still maintain a deep gustfront with strong slab-like updraft from near surface to 20 kft AGL but then the updraft quickly tilts rearward. When you recognize the tall echo phase, you'd maximize your odds of verifying on a warning with adequate lead time. If the cold pool becomes too dominant, it begins to outrun the deep updraft leading to the gust front outrunning the deep convection. The updrafts often lose their slab-like lifting appearance and begin to breakup into a more cellular appearance. This kind of structure can appear along the edges of a bowing echo because in those

areas, the cold pool dominates the shear. How is that possible? Well, it's really the component of the shear perpendicular to the gust front that's important and gust front bends back along the edges of a bow.

Student Notes:

Generic Lifecycle of a QLCS



Weak cold pool
C/ΔU<1

Matched cold pool
and shear
C/ΔU~1

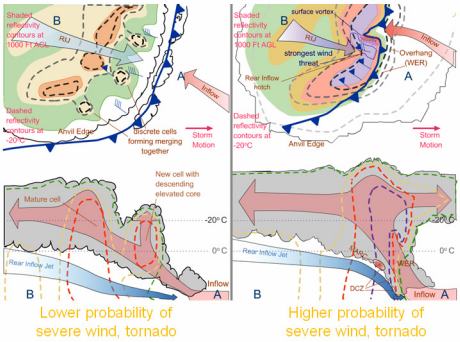
Cold pool
Overpowers shear
C/ΔU>1

5. 3-D QLCS structure

Instructor Notes: The most severe QLCS events typically have and upright updraft with almost slab-like appearance along a deep gust front. The convection is able to remain attached to the gust front and so on radar, you may not actually see a separate fine line from the intense reflectivity cores. A deep convergent zone accompanies the gust front. On some occasions, and after accounting for system motion during volume scanning, you may see a strong echo overhang leading the reflectivity core. Rear inflow notches signify intense RIJ channels. The RIJ remains elevated to descend only immediately behind the convective line. Lightning often precedes the arrival of the line. Mesovortices are common with these structures as there is plenty of deep updraft over their formation regions. The less severe events exhibit more isolated convective cells often displaced well behind the gust front. A separate fineline is often visible ahead of the first reflectivity cores. The gust front is often severely sloped with a shallow leading edge. The RIJ often descends well behind the leading convective cores. Deep, severe mesovortices would be extremely rare with a sloped system like this.

Student Notes:

3-D QLCS structure

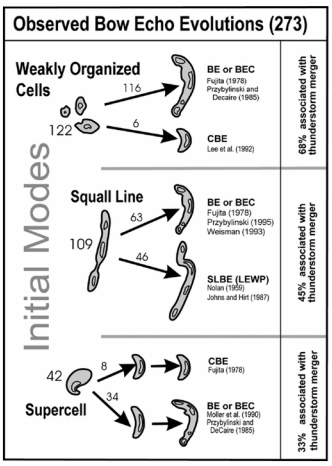


6. Initial convective modes leading to Bow Echoes

Instructor Notes: By the time you see the reflectivity echo of a multicell organize into a bow, it's already too late to issue a warning because the strong outflow has already been on the ground long enough to deform the precipitation shield. So it's useful to understand what kinds of convective structures lead to damaging bows. Here's a study by Klimowski, Hjelmfelt, and Bunkers in 2004 where hundreds of damaging bows were backtracked in time to see what created them. The most common evolution was the merger of small weakly organized multicells that were originally noninteracting. However, they quickly started interacting when one of the individual small multicells merged with another setting off a sequence of rapid cold pool production and subsequent bow. The fastest of the individual small cells or multicells usually corresponded to the motion of the bow. Sometimes the individual small multicells would briefly organize into a line on its way to a bow. Either way, the consolidation of individual cells likely helped create a similar consolidation of cold pools and helped to contribute to intense updraft and subsequent downdraft formation. The second most common evolution of a bow came from a squall line that persisted more than the pre-bow linear structures that we just talked about. In this type of evolution, the squall line is moving east changing relatively little in structure and then a trigger causes a forward surge in the gust front in a confined segment. Most often the trigger is an interaction with a pre-existing boundary or another convective storm. Sometimes the trigger is more subtle and may be manifested as a significant updraft surge somewhere along the line. By the way, the acronym of BE is defined as a classic bow echo whereas BEC is a Bow Echo Complex. The latter is when a bow echo is the primary, but not the only convective structure making up a multicell. The former is when the multicell is completely identified as a bow echo. Finally, a bow echo accompanying others along a line is called a Squall Line Bow Echo (SLBE), and has been also called a Line Echo Wave Pattern (LEWP). The third kind of bow echo evolves from a supercell when the bowing rear flank downdraft ignites strong convection along its gust front, and the mesocyclone begins to morph into a line end vortex, or QLCS vortex. Bow echoes originating from squall lines tended to have the longest lifespan (3.4 hr) vs. 2.9 hr from initial clusters. Bows originating from squall lines seem to be most common in the eastern US.

Student Notes:

Initial convective modes leading to Bow Echoes

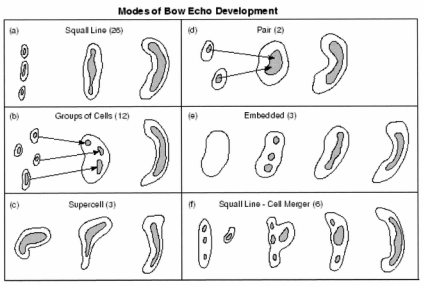


7. Initial convective modes leading to Bow Echoes – cool season

Instructor Notes: Another study by Burke and Schultz also investigated what kinds of convection led to bows, but only for cool season events. They're classification scheme added three new categories including an embedded line development, pairs of cells, and a squall line-cell merger. Like Klimowski et al., most of the bows originated as a linear squall line or a group of isolated cells. They also noted that merging cells or small multi-cells occurred frequently before bow echo genesis. For the cool season, supercells occurred in 43% of the formative and mature stages of bow echoes and 38% of squall-lines had supercells embedded. Nine of their 51 cool season cases were termed long-lived bow echoes (LBE's) that qualified as Derechos too. The number of cases for each storm type are listed in parentheses.

Student Notes:

Initial convective modes leading to Bow Echoes – cool season

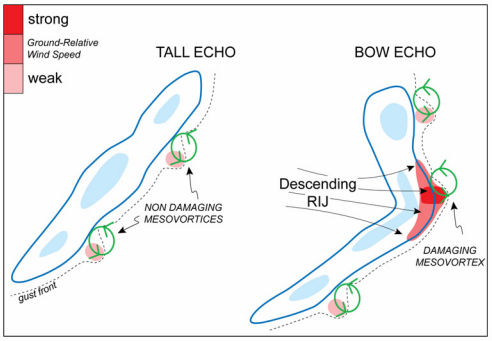


8. Initial stage of a damaging bow echo

Instructor Notes: The initial stage of a bow echo at the onset of severe damaging surface winds is a time when the precipitation area is not bowed at all. An updraft surge typically happens which then yields a severe downdraft. Also at the same time, anvil debris typically spreads rearward of the main convective line with respect to the steering layer flow. This anvil debris acts to initiate the rear inflow jet (RIJ). Assuming you're about to have a severe bow echo, the best time for initial warnings is in the tall echo state when updraft surges occur prior to the onset of the severe downdraft and RIJ. This is when you typically see strong, deep convergence, represented by the MARC (Mid Altitude Radial Convergence), along a segment of the line. Just before the bowing state, the descending RIJ hits the ground and begins to push forward. The most severe mesovortices may form at this time. The most severe surface winds occur when the mesovortex forms near the apex of the RIJ. As the convection morphs into a bow echo, the updraft depth often decreases, and a rear to front dry slot forms. The strong outflow from the RIJ is firmly established and has been on the ground for some time.

Student Notes:

Initial stage of a damaging bow echo



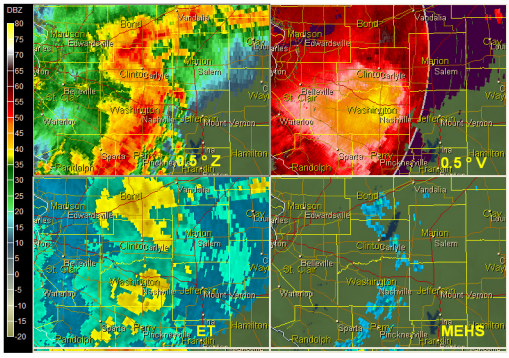
9. An example of a bow echo lifecycle: 10 June 2003 - STL

Instructor Notes: A flash-based looper will popup in a separate window in 10 seconds but first direct your attention to this main articulate slide. I'll wait until you get your bearings. This case of a bow forming shows the first cells at a very updraft-dominant stage. This is the time in which you first see the upscale organization of small multicells slowly consolidate and merge. If the shear is strong enough, then some of these small multicells may be supercells. Echo tops are usually high and the updrafts are deep. Notice the relatively high values of maximum expected hail size (MEHS). Next, the small multicells consolidate and new, strong updrafts begin to produce strong downdrafts. You can see the outflow already surging toward the radar. This is a time when the first warnings would've been out if you deem this event potentially severe, as in this case. In the

next image, this QLCS is still exhibiting tall reflectivity echoes, a sign of deep updrafts. However the RIJ is strong, and there have already been several severe mesovortices to the left of small surges of the gust front that have produced tornadoes and enhanced severe winds. The main precipitation shield has not yet deformed into the classic bow shape but it is about to produce the most severe winds yet. In this image there is the most faint hint of a rear inflow dry notch impinging inward from the west over Belleville, IL. This notch represents the most intense RIJ along this QLCS. The strongest mesovortex of this event forms to the north of the RIJ axis and that is where the most intense wind damage was observed along a belt northeast of Belleville to across the Mid America airport and Scott AFB and then southwest of Clinton, IL. It's clear there's a better association of the intense winds with the mesovortex, and not so much the RIJ axis. The last frame in this loop now shows a classic bow echo appearance though only well after the onset of the most damaging winds and most of the QLCS tornadoes. The echo tops have gone down as well as the MEHS, all indicating a trend toward shallower updrafts. The leading edge of the deep convection is still keeping up with the gust front and this bow echo is still more than just borderline severe. In the flash window loop, step through the frames to see the full evolution. Overlaid on the velocity panel, you'll see a box containing a detailed graphic of wind damage and tornadoes. The white shaded regions show wind damage of F0 (EF0) or greater while the white lines represent tornadoes. The small checkbox brings up the most relevant graphical conceptual model that corresponds to the stage of the QLCS in its lifecycle.

Student Notes:

An example of a bow echo lifecycle: 10 June 2003 - STL



10. Early lifecycle of 4 Jul, 2004 Springfield, MO event

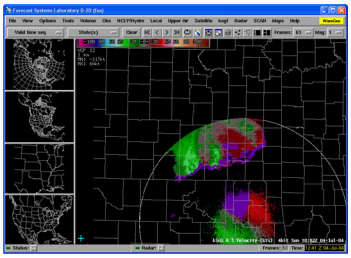
Instructor Notes: This event is an example of a bow echo originating from a multicell cluster. However, you could classify this evolution as an initial squall line since each multicell cluster was aligned on a common gust front. A popup window will appear with Ron Przybylinski, the SOO at WFO St. Louis, discussing the evolution of this severe bow echo from its inception. Ron has written and spoken extensively about QLCS severe weather events. Grab a drink and enjoy Ron's tour of this bow echo evolution. Ron's captions: Looking at reflectivity and storm-relative velocity from 10:02 - 10:24 - 10:37 UTC, you'll find that there was a weak vortex, not really well defined. You may come across

weak circulations during this initial isolated, to cluster phase of a bow echo. Nolan Atkins has documented these events back during BAMEX where we observed weak and short-lived vortices. Now we move forward to 1041 UTC we don't see much rotation but we do see inbounds behind on the backside of this cluster of storms. This is the tall echo stage. We start seeing some cyclonic shear in the midlevels. Mostly hail and high winds can be expected here around 1107 UTC. Moving forward, we see a vortex, now at the leading edge! We mentioned this particular vortex showing up around 11 UTC but now it's showing up nicely. Now the SRM data is showing a vortex in Cherokee county. We move closer in time (to the first tornado) and we see a multiple vortex structure. One to the southwest of Joplin and one to the northwest. It was this second vortex that spawned a tornado in northern Newton county. Note the location of the surface boundary (connecting with the tornadic vortex). We've seen this play a role with many QLCS tornadic events. Going back to reflectivity, we see a nice bowing structure with a rear inflow notch forming (at tornado time). We see multiple rear inflow notches where some lower Theta-E air penetrates into the leading convective line. Going back to SRM data, there's additional wind damage along the apex of the bow and the RIJ but to the south of the tornado. The damage was not so bad north of the tornadic vortex. Most of the wind damage was south and east across Neosho and counties directly downstream of the bow echo.

Student Notes:

Early lifecycleof 4 Jul, 2004
Springfield, MO event

- An example of a bow echo originating from a multicell cluster along a gust front.
- Ron Pryzbylinski will guide you through the evolution of this bow echo up to the first major wind/tornado damage.
- Wait for a popup video in a separate window.
- This video lasts 3.5 minutes



11. Review of the 04 July 2004 evolution

Instructor Notes: The bow started as a multicell cluster on a gust front (a cross between the cluster and squall line origins in Klimowski et al. 2004 and Burke and Schultz, 2004) QLCS vortices were weak in the early stages before the RIJ formed QLCS vortices strengthened here after signatures of the RIJ form (rear inflow notch, inbounds) The leading boundary intersecting the bow was associated with a tornadic mesovortex. The most wind damage was along and north of the RIJ axis to the tornadic mesovortex.

Student Notes:

Review of the 04 July 2004 evolution

- The bow started as a multicell cluster on a gust front
  - (a cross between the cluster and squall line origins in Klimowski et al. 2004 and Burke and Schultz, 2004)
- QLCS vortices were weak in the early stages before the RIJ forms
- QLCS vortices strengthened after signatures of the RIJ formed
  - (rear inflow notch, inbounds)
- The leading boundary intersecting the bow was associated with a tornadic mesovortex.
- The most wind damage was along and north of the RIJ axis to the tornadic mesovortex.

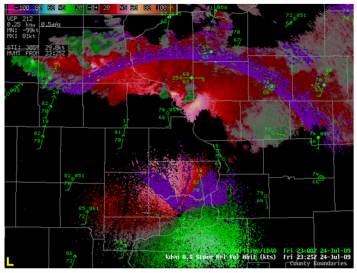
12. Early lifecycle of the 24 July, 2009 DVN QLCS

Instructor Notes: In this case, the bow echo starts off as two interacting supercells. Ron Przybylinski guides you through the evolution. Wait for the popup window and the video lasts two minutes. From Ron's captions: Another form of convective line evolution formed from supercell structures in the Davenport CWA. In this case, there are two supercells with strong mesocyclones positioned east-west. With time, these two supercells weaken in terms of their reflectivity structure though but the eastern one still has strong inflow notch. SRM data doesn't show much but some weak rotation on the eastern storm (near Scales Mound) and another is trying to form with the same storm at the head of the RFD push. As the storms continue moving southeast, and we see the bowing segment (especially with the RFD push) continue to evolve. The bowing segment continues to evolve and become dominant into Carroll county. SRM shows some weak rotation but nothing substantial at this time. Continuing further southeast and the main bow continues while a second bowing segment forms to the west.

Student Notes:

Early lifecycle of the 24 July , 2009 DVN QLCS

- Now here's a bow echo originating from supercells.
- Ron Pryzbylinski will guide you through the early evolution of this bow.
- Wait for a popup video in a separate window.
- This video lasts 2 minutes



13. Review of the 24 July 2009 evolution

Instructor Notes: Two supercells exhibited HP characteristics, each with significant low-level mesocyclones The RFD of the eastern one erupted convection. Given the shape of the RFD gust front, the convection acquired a bow shape with an enhanced RIJ that was the RFD. Many times the primary mesocyclone occludes and drifts rearward

Student Notes:

Review of the 24 July 2009 evolution

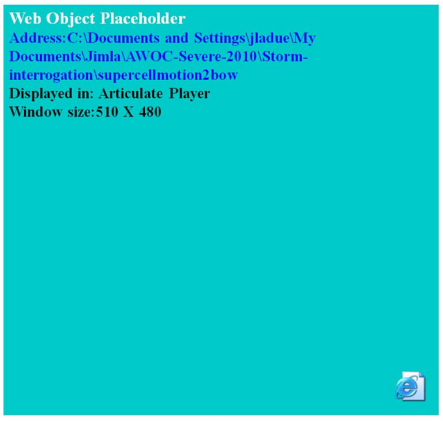
- Two HP supercells, with low-level mesocyclones
- The RFD of the eastern one erupted convection.
- New convection acquired a bow shape with an enhanced RIJ that was the RFD.
- Many times the primary mesocyclone occludes and drifts rearward

14. Supercell to bow echo motion

Instructor Notes: Watch the evolution of this supercell to bow echo as I move this loop using the feature following zoom following the supercell. As the supercells go on, you can see they're moving relatively closely to how I placed my 'drag me to storm' feature. As the supercell turns into a bow echo, you can see that the motion starts moving off to the left (of the distance speed tool). Now I'll move it faster so you can see the evolution in a different way.

Student Notes:

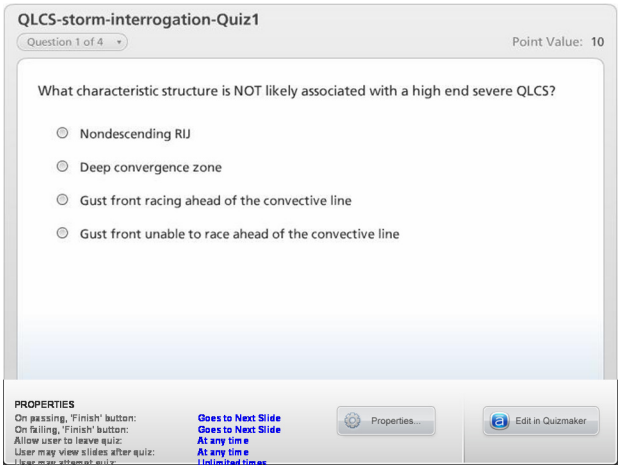
Change in storm motion from supercell to bow echo



15. QLCS-storm-interrogation-Quiz1

Instructor Notes:

Student Notes:

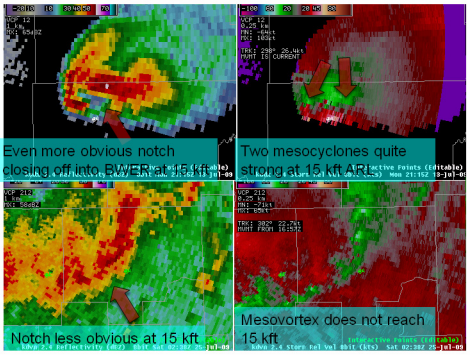


16. QLCS Mesovortex structure, evolution

Instructor Notes: While both the supercell mesocyclone and the QLCS mesovortex exhibit vertical vorticity at least partly colocated with updraft, they are structurally and dynamically different animals. You can see the differences with these two examples. At low-levels, the supercell features an obvious hook echo and broad, concave notch with a sharp reflectivity gradient. There is an occluding low-level mesocyclone, and enhanced inbounds further east signifying strong inflow into the RFD gust front indicating a new mesocyclone may be underway. The QLCS at low-levels shows a less obvious inflow notch and sometimes a rear inflow notch. The mesovortex forms along the gust front, and in this case, that's on the leading edge. At midlevels (15kft AGL), the supercell notch, or WER is closing off into a BWER while the inflow notch on the QLCS is less obvious. There are even more stark differences in SRM. Now you can see the occluded low-level mesocyclone is deep. The new mesocyclone is strongest at this level. Meanwhile, the QLCS mesovortex does not reach this level. The radar is sampling at the top of the gust front. Let me discuss a couple things you should know. First, the terminology, mesocyclone and mesovortex can be somewhat confusing. After all they are both mesovortices. These terms came about from different paths and often there is little coordination or reassessment to see if there would be ensuing confusion amongst the research community. So often it's useful to say supercell mesocyclone or QLCS mesovortex if this helps you to categorize their differing behaviors. Also, there is a term called bookend vortex. The mesovortex, such as this one, is not the kind of vortex that researchers from back to the days of Fujita called a bookend vortex. The bookend vortex refers to the circulation associated with the bow echo comma head and is quite a bit larger than a typical mesovortex. Sometimes mesovortices grow upscale to become bookend vortices.

Student Notes:

QLCS Mesovortex structure, evolution

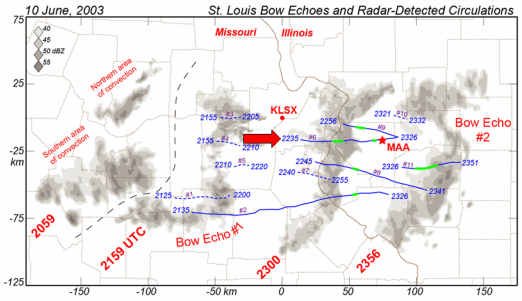


17. QLCS mesovortex structure and evolution: tracks

Instructor Notes: We'll take a closer look at the northern bowing segment for the June 10 case. Notice that the most intense mesovortices form well after the convective echoes congeal together to form a QLCS. We'll take a look at the initiation and evolution of mesovortex #6. If you'd like, please take a look at this case study written up by Atkins et al. 2005 titled "Damaging surface wind mechanism within the 10 June 2003 Saint Louis bow echo during BAMEX" in Monthly Weather Review.

Student Notes:

QLCS mesovortex structure and evolution: tracks



From Atkins et al. (2005)

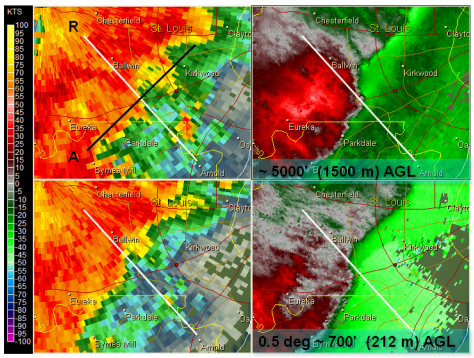
18. A typical severe mesovortex initiation (t=0 min)

Instructor Notes: At 2235 UTC on June 10, 2003, mesovortex #6 was initially tracked. You can see two elevations in this four-panel with SRM on the right, one at 5000' ARL and the other, 700' ARL (lowest elevation scan). Note that the lowest scan shows a gust front that's beginning to become kinked. Notice southwest of the kink, a strong RIJ with outbounds approaching 40 kts. Recall that this SRM display removed about 270 deg at 35 kts already. This mesovortex that's forming doesn't have an obvious maximum and minimum velocity core like you'd expect in a traditional mesocyclone, however there is a

local vorticity maximum that the updraft along the gust front can easily amplify. Let's take a look at two cross-sections, an Azimuthal one to see the mesovortex, and then a Radial one to see the QLCS structure.

Student Notes:

A typical severe mesovortex initiation (t=0 min)

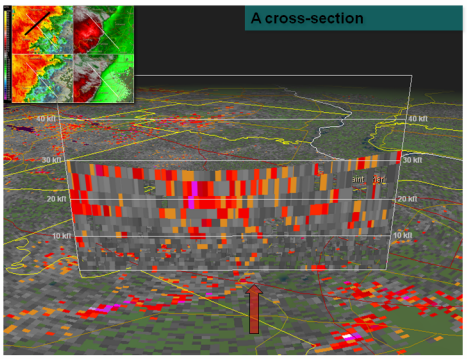


19. Azimuthal Cross-section: mesovortex initiation

Instructor Notes: First, the azimuthal cross-section shows heavy cores overlying a weak echo region. Remember that system motion may have caused an artificial WER. Going to velocity, the cross-section falls from within the protruding gust front then across it into the pre-storm air. The gust front at the kink is nearly vertical for the lowest 10 kft ARL with an abrupt cutoff. This structure is pretty typical and sometimes the mesovortex will be stronger down low. Spectrum width shows a zone of slightly higher values along the gust front interface, and then over the gust front. The high values above may simply be due to turbulence in the convective core.

Student Notes:

Azimuthal Cross-section: mesovortex initiation

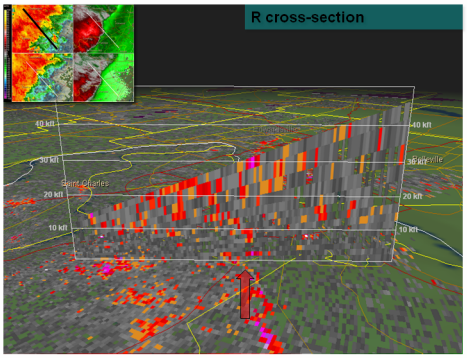


20. Radial Cross-section: mesovortex initiation

Instructor Notes: The Radial reflectivity cross-section shows that what may have been an artificial WER may be partly real since the strong echo overhang extends so far forward. The core is certainly at least led by a wall of high reflectivity gradient that typifies severe QLCSs. The SRM shows an intense nondescending rear inflow jet right up just behind the gust front of 10 kft depth. Note that there is an artificial forward tilt to the gust front due to system motion. Notice that the artificial displacement is not as far as the forward displacement of the intense reflectivity core so we are seeing true intense reflectivity echo overhang. Spectrum width shows again the most turbulence along, and above the gust front with low values in the RIJ core and in the pre-storm inflow. Signs that we will have a severe mesovortex event are already here. They include a nearby association of the intense RIJ with the low-level onset of the mesovortex, and a deep gust front and deep convection coincident with each other.

Student Notes:

Radial Cross-section: mesovortex initiation



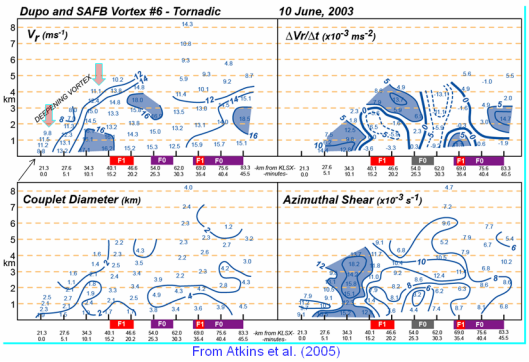
21. QLCS mesovortex structure and evolution: Time height

Instructor Notes: Adding a time-height profile, what you've just seen is marked by the arrow. In the upper-left panel, rotational velocity shows values peaking at 11 m/s (21 kts). But notice that the highest values are just above the lowest scan. This is a frequent behavior where scans above the ground up to 1-2 km have somewhat stronger values than at the lowest scan. So if you're radar is nearby, going up a scan or two may help show a more stout mesovortex. However, the mesovortex is still shallow and not exceeding 1.5 km AGL as documented by Atkins et al. 2005. The following 10 minutes show rapid deepening and strengthening of the vortex as you can see in the time trends of rotational velocity in the upper right. Notice that the azimuthal shear values in the lower right are right in line with any significant supercell mesocyclone (>10X10E-3 per second). Different than a typical mesocyclone, notice the diameter of this mesovortex is quite small, only 2 km (1.2 nm). The mesovortex occasionally peaked above 5 km as it

matured and produced a sequence of tornadoes. Intensification occurred prior to or at least during tornadogenesis, a typical behavior. Also notice the long lifespan of the mesovortex. It would be nice to take warn the initial deepening and intensification of this mesovortex before tornado time but you can also be more comfortable with followup warnings based on its persistence. Let's take a look at this mesovortex at a mature stage just prior to the first tornado.

Student Notes:

QLCS mesovortex structure and evolution: Time height



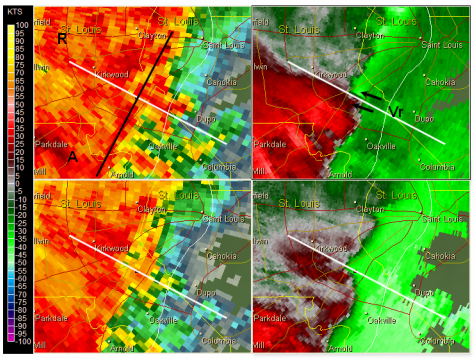
From Atkins et al. (2005)

22. A typical severe mesovortex mature stage (t=15 min)

Instructor Notes: Shifting 10 minutes later, the mesovortex looks much stronger at the 5000' ARL level (top) with now what appears to be at least an isolated velocity minimum (inbound) on the top and even a hint of a core of maximum outbounds south of the center. The lowest scan also shows at least a maximum velocity core and even a hint that an azimuthal gate-to-gate velocity couplet is forming. These values were used to calculate the Vr in the time height trace. In the reflectivity, there's a little confusion in the picture. It appears that strong reflectivity has swallowed the mesovortex. However, there were some convective cells merging with the main line. So look left of the radial cross-section line and you see an S-shaped reflectivity gradient where the inflection point is right on the mesovortex. Also note southwest of the mesovortex you still see evidence of the RIJ in both the SRM and the rear inflow notch. All these are components of a severe mesovortex. Let's look at the cross-sections starting with the azimuthal one (A).

Student Notes:

A typical severe mesovortex mature stage (t=15 min)

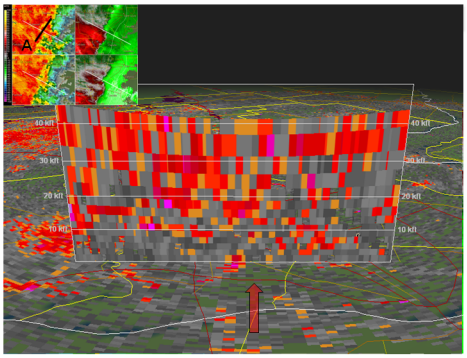


23. Azimuthal Cross-section: mature mesovortex

Instructor Notes: Again the reflectivity pattern looks a little muddy because of the merging cells. The SRM now shows the mesovortex extending to 15 kft (~5 km) ARL. The strongest rotational velocity still is in the lowest part of the mesovortex. This time the spectrum width highlights a bullseye of high values at the low-level mesovortex center.

Student Notes:

Azimuthal Cross-section: mature mesovortex



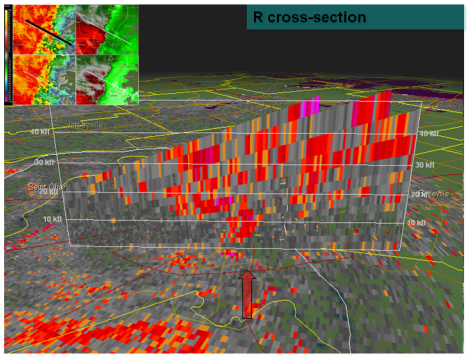
24. Radial Cross-section: mesovortex initiation

Instructor Notes: At 2245 UTC or initiation + 15 minutes, that same overhang is still visible, that is with the main convective line, and even the merging cell. Base velocity shows the RIJ right behind and leading into the south side of the mesovortex. The gust front has deepened behind the mesovortex, almost 15 kft ARL! All the winds in yellow are meeting severe thresholds or more. Notice in the SRM the big convergence down low, the strong rearward flow above the deep gust front and then the anvil layer outflow to the right. This is a pattern typical of a high-end severe QLCS. The SW shows again the vortex bullseye down low and the high values along and above the gust front inter-

face. But the inflow and initial updraft ahead of the gust front are relatively smooth, as is the RIJ core.

Student Notes:

Radial Cross-section: mesovortex initiation



25. Interim summary: severe mesovortex evolution

Instructor Notes: To summarize, we had a nondescending vortex though it may appear weaker down in the lowest layer. The strong RIJ on the right side and behind the mesovortex is a serious precursor of a severe mesovortex. The mesovortex was not a classic Rankine combined archetype. We could see the deepening vortex as it matured and a more classic look as it garnered a min and max velocity. The convection was upright and even featured a WER. Front and rear inflow notches formed. SW was also useful to snag the vortex location as long as you know where to look since there's lots of other high SW centers.

Student Notes:

Interim summary: severe mesovortex evolution

- Nondescending vortex
  - However the vortex may appear weak below 2000' AGL
- Strong RIJ on the right (south) a precursor
- Did not initiate as an ideal Rankine combined vortex
  - Measured Vr from where max and min velocity plateaus
- Upright convection, even a WER
- Front and rear inflow notch
- SW useful when combined with velocity

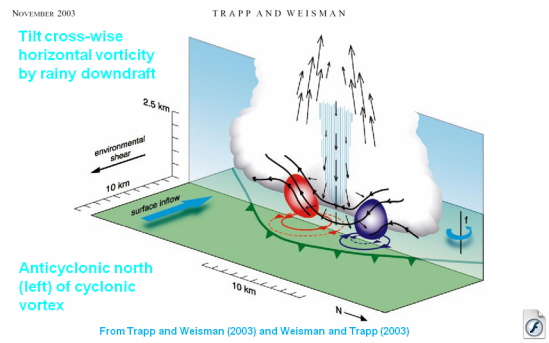
26. Mesovortex formation: Downdraft tilts vortex lines

Instructor Notes: Researchers have been trying to establish how QLCS mesovortices form and as expected there's more than one answer. This result that popped up in a sep-

arate window, featured one of the first theories and it's one that we still consider. That is a localized strong downdraft formed behind the gust front and depressed the vortex lines along the cold pool boundary eventually leading to a couplet. This evolution results in a vortex couplet with the anticyclonic member north or to the left if your pointed in the direction that the QLCS is moving. Not many warning forecasters have seen this kind of vortex couplet but there's evidence in BAMEX that they exist, perhaps mainly in the early stages of a QLCS before the RIJ really has a chance to mature. The anticyclonic member dies off quickly as it fights against Earth's vorticity.

Student Notes:

Mesovortex formation: Downdraft tilts vortex lines

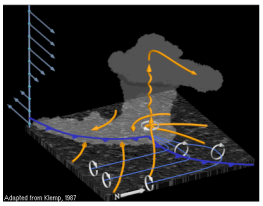


27. Mesovortex formation: Local updraft tilts vortex lines

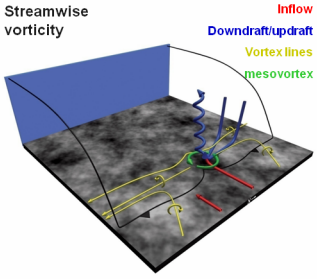
Instructor Notes: More recently, Atkins and Laurent developed more than one theory for mesovortex formation because they saw different evolutions within the QLCS. This one requires a locally intense updraft along the gust front to tilt and stretch streamwise vorticity running down the boundary. The resulting vortex would be of a single sign and not a couplet. A similar theory for mesocyclone formation looks quite similar developed by Rotunno, Klemp, Davies-Jones and others. Instead of a QLCS gust front it's the forward flank gust front that helps. However mesocyclones happily form just tilting environmental streamwise vorticity without needing a forward flank gust front.

Student Notes:

Mesovortex formation: Local updraft tilts vortex lines



Mechanism is similar to low-level mesocyclogenesis within supercells discussed by Rotunno, Klemp, Davies-Jones and others



No couplet forms

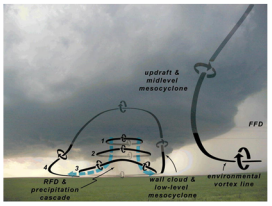
From Atkins and St. Laurent 09b

28. Mesovortex formation: Local updraft tilts vortex lines

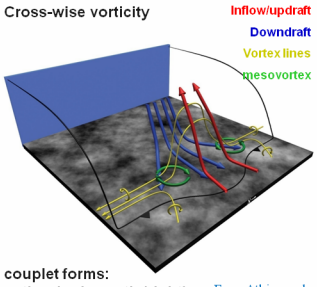
Instructor Notes: This other evolution in mesovortexgensis was found by Atkins and Laurent where instead of an isolated updraft pulling up streamwise vorticity, a local outward bulge in the gust front forms, possibly from the RIJ axis or a local downdraft. A horseshoe vortex arch forms with the cyclonic member on the north side (or left pointing ahead of the QLCS). This couplet is in the opposite sense to what Trapp and Weisman theorized and it's something we see more often, especially during the mature RIJ stage of the QLCS. Notice that this evolution is quite similar to what Markowski et al. 2008 theorized with the formation of a low-level mesocyclone in a supercell. In the supercell case, air from the downdraft descends, creates cross-wise vortex lines around its exterior, in the form of a horseshoe. Some of those vortex lines get entrained into the updraft. Notice that they distinguish those vortex lines from the environmental vortex lines that help create the midlevel mesocyclone.

Student Notes:

Mesovortex formation: Local updraft tilts vortex lines



Mechanism is similar to low-level mesocyclogenesis within supercells discussed by Markowski et al. 2008.



couplet forms: anticyclonic south (right) of cyclonic couplet

From Atkins and St. Laurent 09b

29. Mesovortex formation: Implications

Instructor Notes: So we described downdrafts directly tilting cold pool vortex lines to create a couplet with cyclonic (anticyclonic) member to the right (left). Then we talked about updraft tilting streamwise vortex lines to generate a singular cyclonic vortex, and we discussed the formation of vortex arches to create a couplet with the cyclonic (anticyclonic) member to the left (right). We didn't talk about horizontal shearing instability. Basically here the gust front vertical vorticity gets so large that it breaks down into regularly spaced vortices of the same sign, namely cyclonic. So the difference between this and the local updraft tilting streamwise vorticity is that first, we don't know how that vertical vorticity got there to be rolled up, and the local updraft tilting doesn't produce regularly spaced vortices at the same time. I think you've seen pictures of multiple waterspouts occurring simultaneously. That's a manifestation of shear instability, and the same thing could happen on a QLCS gust front.

Student Notes:

Mesovortex formation: Implications

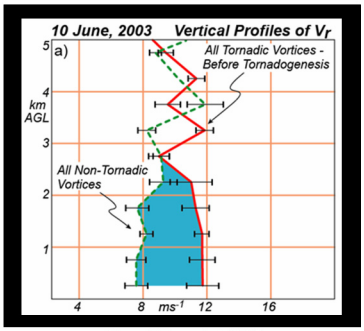
Formation process	Implication (assuming westerly environmental shear)
Downdraft tilting cold pool vortex lines	Couplets: Anticyclonic mesovortex forms north of cyclonic mesovortex
Local updraft tilts streamwise vortex lines	No couplets: Multiple mesovortices irregularly spaced
Local updraft tilts crosswise vortex lines	Couplets: Anticyclonic mesovortex forms south of cyclonic mesovortex
Horizontal shearing instability	No couplets: Multiple mesovortices spaced at regular intervals.

30. QLCS mesovortex tornado precursors – Vr profiles

Instructor Notes: There hasn't been a lot of work done in the field of discriminating tornadic vs. nontornadic QLCS mesovortices but what there is appears to be fairly applicable. The 10 June 2003 case had a clear discrimination between tornadic and nontornadic mesovortices. In this figure the mean rotational velocity of the tornadic mesovortices as a function of height shows how much stronger they were than for the nontornadic mesovortices, especially from 2 km AGL down toward the surface. So at least for this case, the mean Vr for tornadic mesovortices was around 24 kts (12 m/s). There needs to be more work to show how well this discrimination goes for a large sample of cases. However, the take home message is that the tornadic mesovortices are much stronger at low-levels.

Student Notes:

QLCS mesovortex tornado precursors – Vr profiles



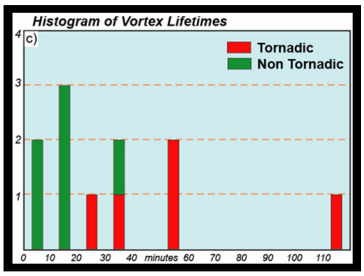
From Atkins et al. 2005

31. QLCS mesovortex tornado precursors: lifespans

Instructor Notes: In terms of longevity, the 10 June 2003 tornadic mesovortices lasted longer than those that were nontornadic. Again, the sample size is somewhat limited but there is evidence that this trend holds true for a larger set of cases too. As a warning forecaster, you don't have time to see if a particular mesovortex is going to last a long time, otherwise you'd have to sacrifice a lot of people before issuing a warning. But you can certainly increase your confidence in your warnings as the mesovortex continues to persist, and especially if its strong and long-lived.

Student Notes:

QLCS mesovortex tornado precursors: lifespans



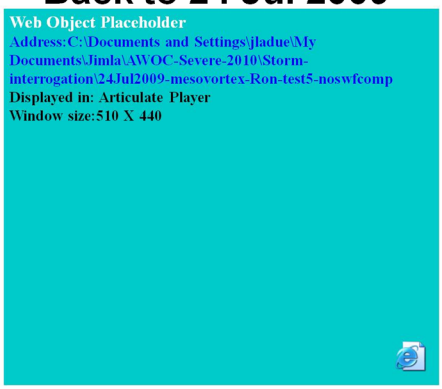
From Atkins et al. 2005

32. Mesovortex evolution: Back to 24 Jul 2009

Instructor Notes: Going back to the 24 July 2009 case, Ron will be walking you through the evolution of a particular mesovortex as he would do in a warning decision making mode. This video lasts about 3 minutes.

Student Notes:

Mesovortex evolution: Back to 24 Jul 2009

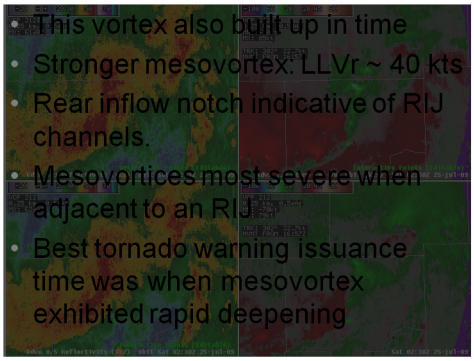


33. Review: 24 July 2009 mesovortex

Instructor Notes: The main message from Ron's discussion is: This vortex also built up in time Stronger mesovortex: LLVr ~ 40 kts Rear inflow notch indicative of RIJ channels. Mesovortices most severe when adjacent to an RIJ Best tornado warning issuance time was when mesovortex exhibited rapid deepening

Student Notes:

Review: 24 July 2009 mesovortex



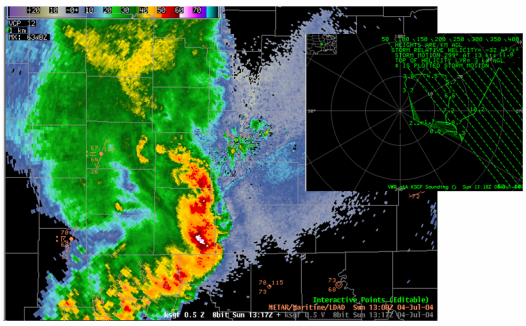
34. Along-line variations: intersecting boundaries

Instructor Notes: As a final major topic, this lesson wouldn't be complete without discussing the impacts of heterogeneity (e.g., boundaries, mergers) on QLCS severity, especially on mesovortex behavior. There's quite a bit of work done on how boundaries and merging instability lines impact QLCSs but rather than recite all the work, let's apply it to this case, 04 July 2004, that we've been going through in this lesson. We already eluded to the presence of a pre-line boundary in this case extending to the southwest creating an intersection. Let's start at 1153 UTC and we'll see how the boundary has impacted the pre-storm environment. There's not much to go on except a couple METAR stations, Joplin and Springfield, and the Springfield WSR-88D VWP. The post boundary

air is important to sample because it'll determine how well the bow can survive on that side. But also equally important is how the boundary-bow intersection plays a role in enhancing mesovortexgenesis. For this page, we'll concentrate on the post-boundary air. I included the SGF raob hodograph at 12 UTC to show that there's a fairly complex shear profile from 0 – 3 km AGL and a general west-northwest bulk wind difference of 30 kts from 0 – 6km AGL. At 1153 UTC, the boundary has just passed Joplin and we can see the temperature hasn't dropped yet. The apex of the bow is directly in line with the boundary. At 1214 UTC, the KSGF wind profile shows a complex vertical wind profile but the VWP is not picking up the lowest level winds. There's perhaps a tendency for a northeasterly 0-3 km shear vector averaging the lowest few hundred meters within the surface and a similar layer around 3 km AGL. At 1240 UTC, the boundary passes over the radar and the surface winds go from southwest to northwest. The vertical shear is still complex. At 1300 UTC, There is a marked increase in southeasterly shear within the boundary layer with northwesterly surface winds and almost southerly 3 km winds. Above 3 km the wind shear reverses to northerly again. This feature persists through the end of the loop. The 0-3km shear is much stronger but in this case may not actually be conducive to enhancing the strength of the line since the predominant component of the shear is line-parallel, even front to rear. Notice that the northern end of the line never extends far beyond the boundary intersection. As far as instability is concerned, the SGF METARs eventually drop from 75 deg F just north of the boundary to 73 deg F an hour later. However the dewpoint remained higher than the pre-boundary air. It's not clear that the instability decreased rapidly north of the boundary but the shear could've had a negative impact on the QLCS survival. Had the shear been oriented from the WSW behind the boundary, the QLCS may have threatened Springfield with potential mesovortices. But most likely for the shear to be oriented from the WSW, the post boundary wind direction would've needed an easterly component, an attribute most commonly associated with a stalling, or even lifting outflow boundary.

Student Notes:

Along-line variations: intersecting boundaries



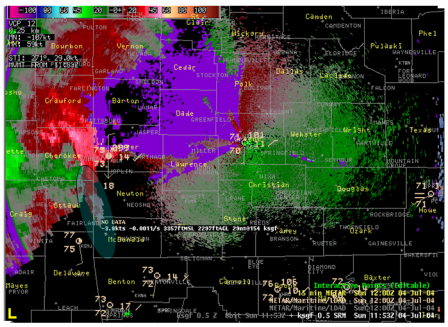
35. Along-line variations: Merging ascent zones

Instructor Notes: If the horizontal shear along and north of the boundary is not conducive for maintaining the QLCS, then perhaps another one or two other sources could

help to increase the threat of a severe mesovortex. One could be the enhanced convergence at the boundary intersection, and another could be the intersection of other convective cells, or the forcing mechanism producing them. In this case, there's a double intersection between an instability line forcing an axis of broken cells and the boundary at the same time. The locally stronger convergence here could easily have locally amplified any vertical vorticity lying along either boundary into a well defined vortex. Lese, 2006 noticed that the mesovortex that coincided with this double intersection resulted in a tornado while an adjacent mesovortex to the south did not. In the next slide, Ron will describe his thought process in warning forecaster mode.

Student Notes:

Along-line variations: Merging ascent zones



36. Along-line variations and mesovortices: 04 Jul 2004

Instructor Notes: Ron will be showing you the evolution of this particular mesovortex and how it relates to the surrounding intersections. Take note of his interrogation of its evolution with time and height too.

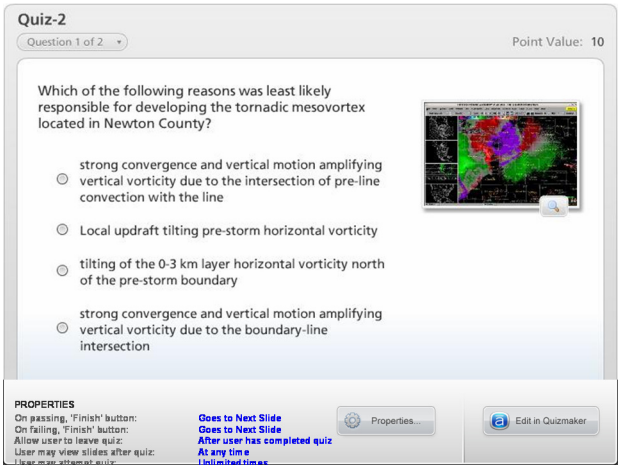
Student Notes:

Along-line variations and mesovortices: 04 Jul 2004

37. Quiz-2

Instructor Notes:

Student Notes:



38. Along-line variations: Interim summary

Instructor Notes: Post-boundary air altered vertical shear, this time possibly in a negative way Boundary intersection likely enhanced convergence to amplify existing vertical vorticity Instability line manifested by merging line of cells created a double intersection with the other intersection and helped the one mesovortex become tornadic

Student Notes:

Along-line variations: Interim summary

- Post-boundary air altered vertical shear, this time possibly in a negative way
- Boundary intersection likely enhanced convergence to amplify existing vertical vorticity
- Instability line manifested by merging line of cells created a double intersection with the other intersection and helped the one mesovortex become tornadic
- See Lese, 2006, and Wheatley and Trapp, 2008.

39. Summary

Instructor Notes: What stages in a QLCS lifecycle are most likely to produce the most severe wind (tornado) potential? During and after formation of the RIJ What kinds of 3-D structure are most related to the most intense severe wind (tornadic) events? Look for deep and steep gust front with a deep convergence zone and attached to a solid wall of

deep convection. What is a common evolution of convection preceding the formation of bows? Merging small multicells and associated cold pools What is the motion of typical bows? Typically with the mean convective layer wind and faster

Student Notes:

Summary

- What stages in a QLCS lifecycle are most likely to produce the most severe wind (tornado) potential?
  - During and after formation of the RIJ
- What kinds of 3-D structure are most related to the most intense severe wind (tornadic) events?
  - Look for deep and steep gust front with a deep convergence zone and attached to a solid wall of deep convection.
- What is a common evolution of convection preceding the formation of bows?
  - Merging small multicells and associated cold pools
- What is the motion of typical bows?
  - Typically with the mean convective layer wind and faster

40. Summary - contd

Instructor Notes: How do mesovortices form? downdraft tilting vortex lines behind gust front, local updraft tilting streamwise vorticity on gust front, updraft tilting cross-wise vorticity over protruding gust front When are mesovortices most likely to become severe (wind and tornado)? After the RIJ forms and moves adjacent to a mesovortex How do I discriminate tornadic from nontornadic mesovortices? Stronger rotational velocity, depth, lifespan, environment When is the best time to issue a warning on a mesovortex? As the mesovortex begins to deepen

Student Notes:

Summary - contd

- How do mesovortices form?
  - downdraft tilting vortex lines behind gust front, local updraft tilting streamwise vorticity on gust front, updraft tilting cross-wise vorticity over protruding gust front
- When are mesovortices most likely to become severe (wind and tornado)?
  - After the RIJ forms and moves adjacent to a mesovortex
- How do I discriminate tornadic from nontornadic mesovortices?
  - Stronger rotational velocity, depth, lifespan, environment
- When is the best time to issue a warning on a mesovortex?
  - As the mesovortex begins to deepen

41. Summary - contd

Instructor Notes: How can a pre-storm boundary enhance mesovortices? Increasing pre-storm vertical shear, enhancing convergence at the intersection point Does a pre-

storm outflow boundary or warm front always enhance mesovortices? No, we need to worry about stability and shear changes as always

Student Notes:

Summary - contd

- How can a pre-storm boundary enhance mesovortices?
  - Increasing pre-storm vertical shear, enhancing convergence at the intersection point
- Does a pre-storm outflow boundary or warm front always enhance mesovortices?
  - No, we need to worry about stability and shear changes as always

42. Credits

Instructor Notes:

Student Notes:

Credits

- Dr. Nolan Atkins, Lyndon State University
- Angela Lese, NWS Louisville, KY
- Ray Wolf, NWS Davenport, IL
- Chris Spannagle, Steve Martinaitius, Veronica Davis, and Brad Grant at WDTB

43. Contact Information

Instructor Notes: Get in touch with us should you have a question or would like to chat about severe weather.

Student Notes:

Contact Information

- awocsevere_list@wdtb.noaa.gov
  - Questions on any AWOC Severe lessons
- NWS-chat
  - wdtbchat chat room
- James G. LaDue
  - James.G.LaDue@noaa.gov
  - 405-325-3004