Conceptual Models for Origins and Evolutions of Convective Storms

Advanced Warning Operations Course

IC Severe 1

Lesson 5: Flash Flooding

Warning Decision Training Branch

The title for the instructional component is "**Conceptual Models for Origins and Evolutions of Convective Storms** . This is the first instructional component in the AWOC Severe Track. Lesson 5 will be on conceptual models for flash flooding, both meteorological and hydrological factors.

Lesson 5 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

Lesson 5 Learning Objectives

4. Identify the primary parameters that help determine precipitation efficiency

5. Identify characteristics of the flash flood potential in supercells

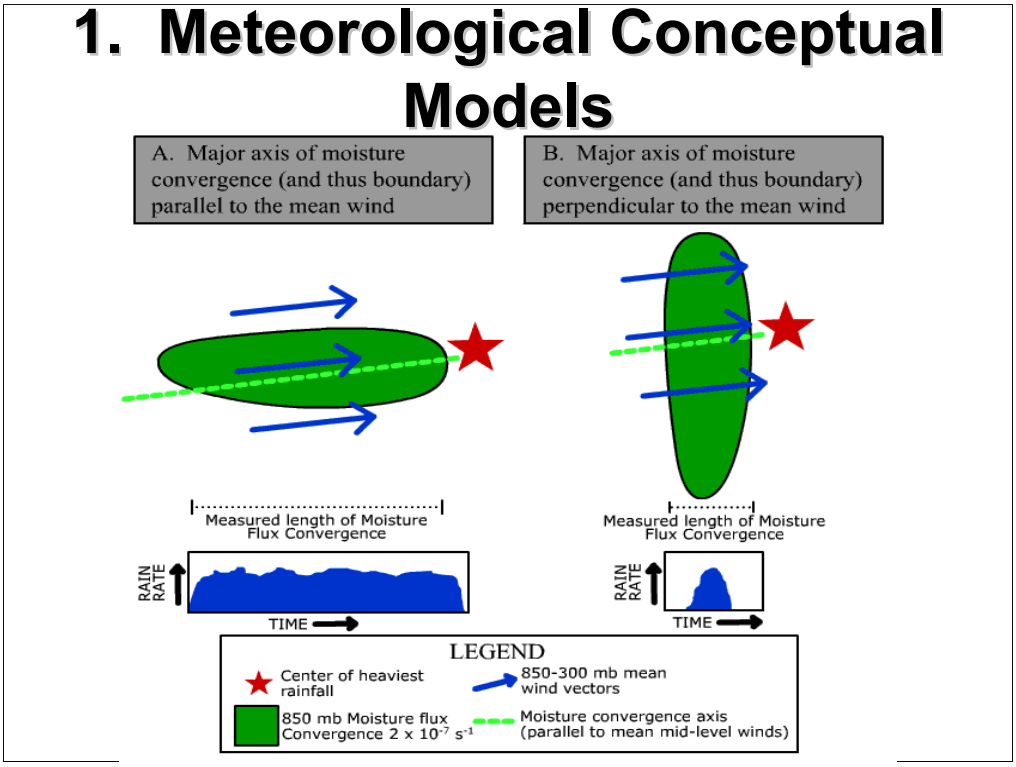
6. Identify the effects of advection and propagation and their significance to flash flooding

1. Meteorological Conceptual Models

- Maddox (1979): 4 flash flood types from a meteorological standpoint
- More recent work (Junker et al. 1999) has focused on the moisture field and location of surface boundary to distinguish the most extreme heavy rainfall events

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

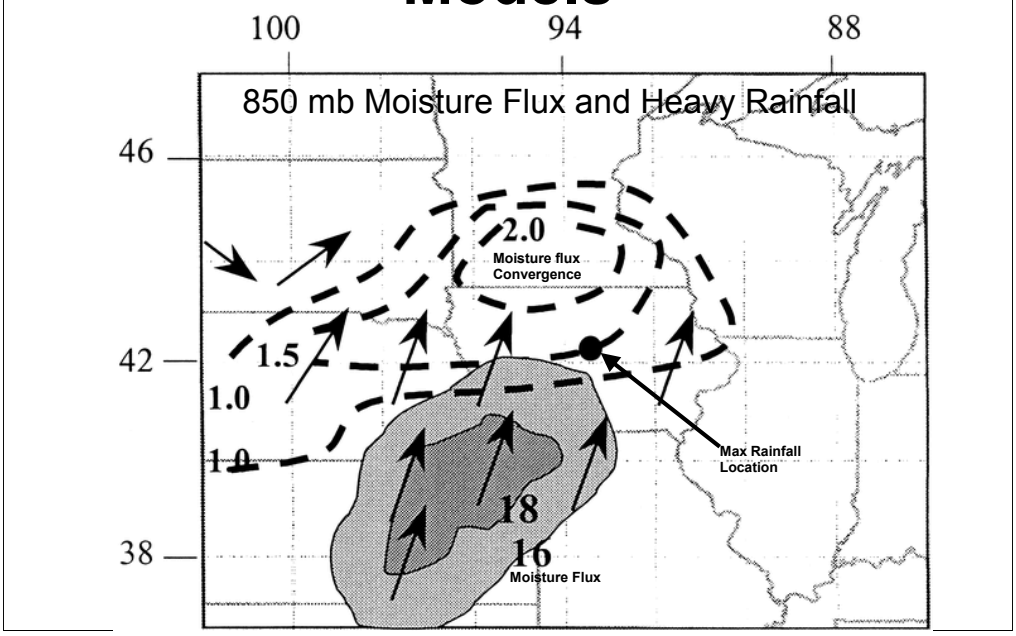
Junkers studied MCSs from the Midwest during the great flood of ’93. He found differences between MCSs that produced extreme rainfall and those that were “ordinary”, and those differences will be discussed here



Obviously case A led to extreme rainfall events in theJunker (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.

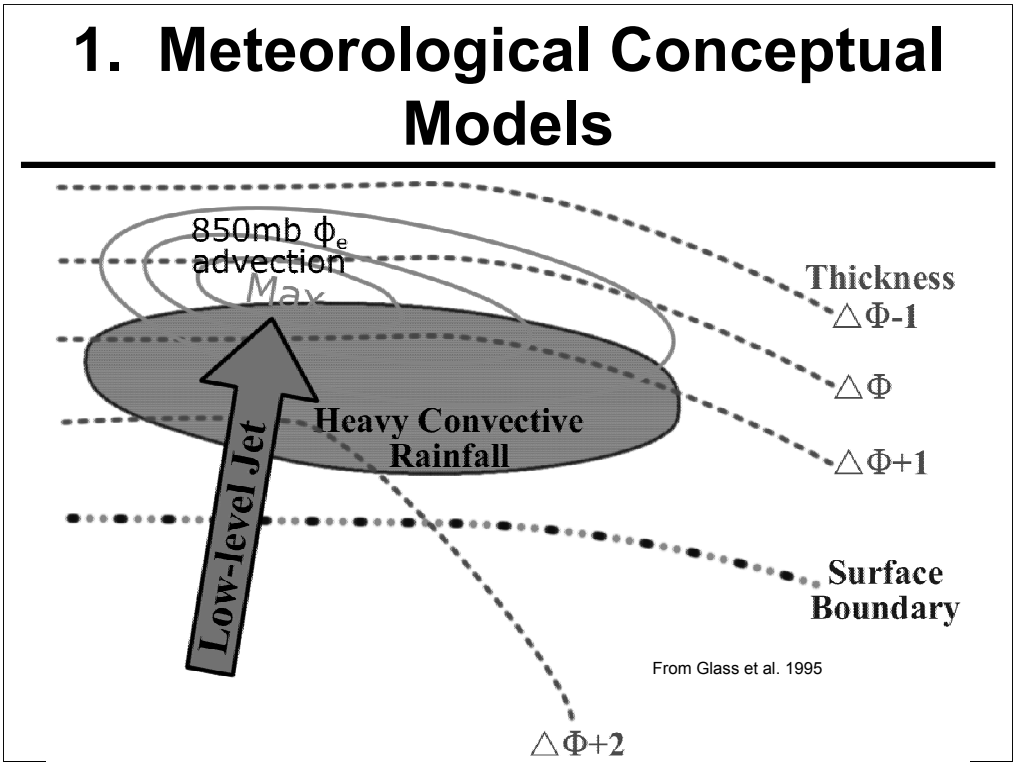
1. Meteorological Conceptual Models



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



•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

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

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

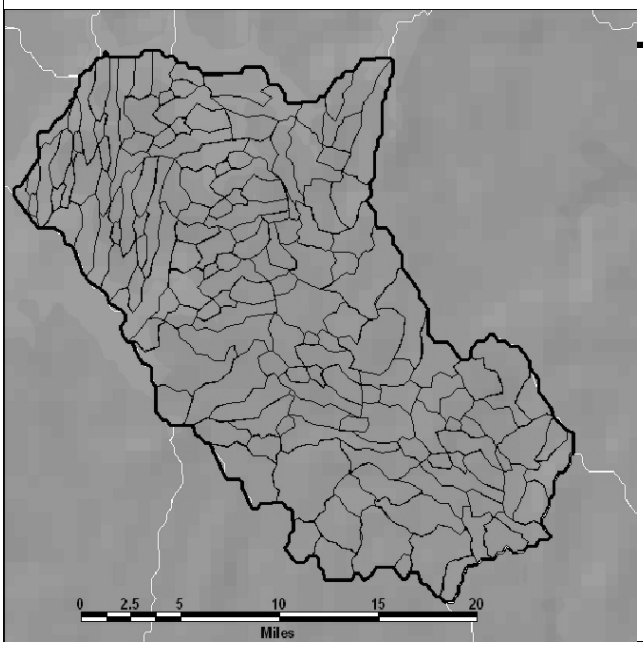
2. Hydrologic Ingredients

- 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

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

Watershed Characteristics



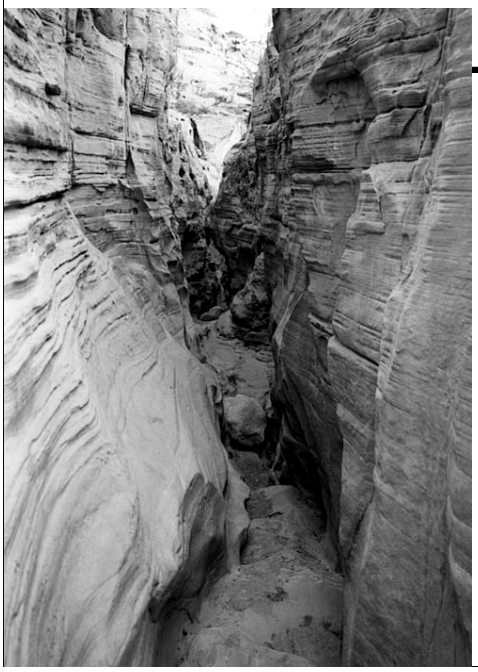
1. Size, shape, topography of basin

-- customize your FFMP basins if you haven't already done so.

Courtesy Bob Cox - MBRFC

The majority of flash floods occur in very small basins, mainly because the scale of the heaviest rainfall is also quite small, thus it is crucial that you have basins defined small enough that flash flooding rainfall will not be too "averaged" too much across the basin.

Stream Channel Characteristics



2. Size, shape, condition of stream channel

-- width, steepness, soil type

Steep terrain, soil type (such as rock), and narrow channels are all conducive to flash floods, meaning far less rainfall can produce siginificant flash flooding in basins with such makeup. The above is from Crack Canyon in Southeast Utah: probably a worst case scenario for stream channel condition and propensity for flash flooding

Soil Type and Condition

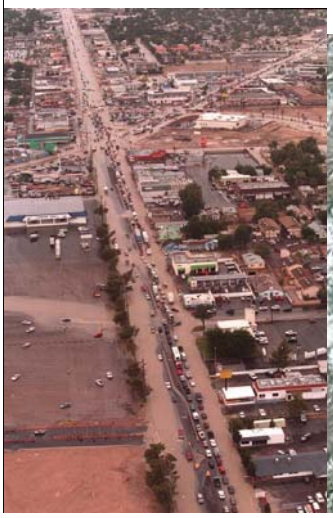
3. Infiltration capacity and saturation of the soil

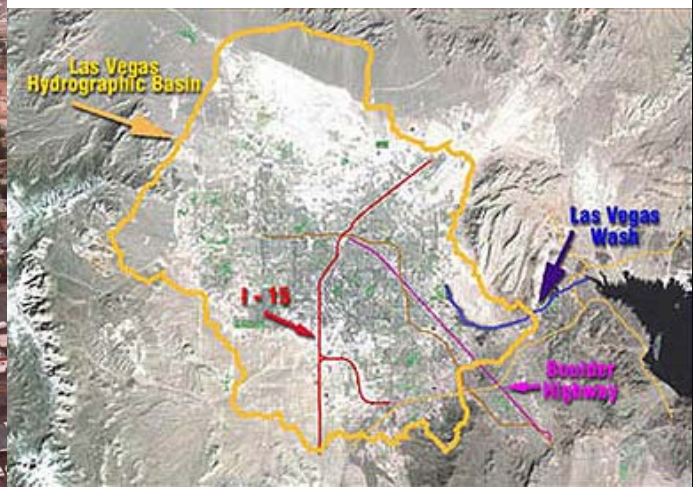
- Doswell et al. (1996) present a case of 180 mm (7 inches) rainfall in less than a day in Iowa Sep 1989, with only minor flooding
  - → Tail end of 2-year drought, soil could handle precipitation
  - → Soil type (infiltration) and saturation (soil moisture) differences can make the difference in any event

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.

Vegetation and Land Use

4. Vegetation and Land Use





Vegetation intercepts rainfall, inhibits surface runoff, allowing more time for infiltration

•Las Vegas is one of the worst areas 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

Season

5. Season

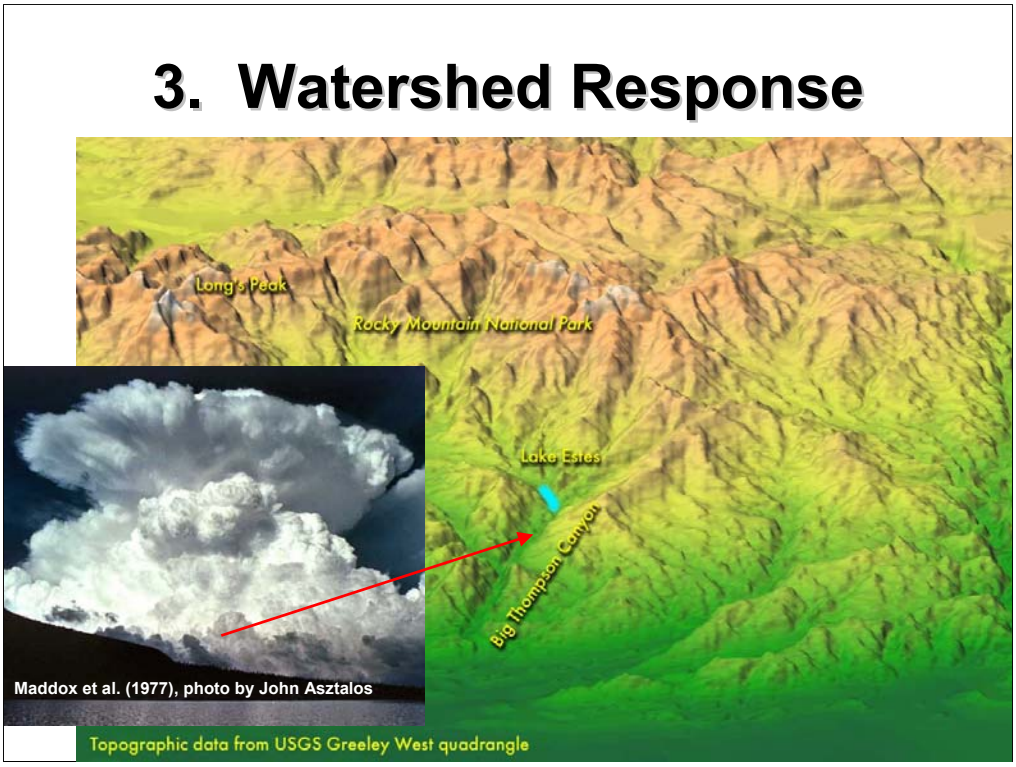
- Mainly impacts surface runoff potential

  → Vegetation growth stage

  → Lower temperatures, higher viscosity and lower infiltration

  → Frozen ground worst case

Dormant vegetation leads to less rainfall interception, less evapotranspiration (soil moisture high to begin with)

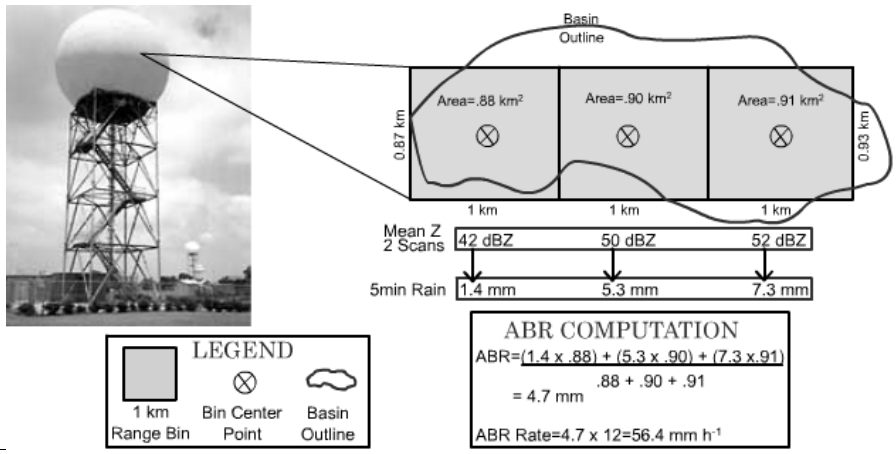


•We've discussed the meteorological and hydrological ingredients for flash flooding. Now let's look at what happens when heavy rainfall occurs across a watershed. What is the response of the watershed to the rainfall and how can we measure this response?

•The above is the Big Thompson Storm and topo map

3. Watershed Response: ABR

- Average Basin Rainfall: In a flash flood, the *RATE* is more important than the *AMOUNT* of rainfall, thus need accurate rates



•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 size of heaviest rainfall important

•How ABR is computed:

1.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

2.Only the rainfall volumes of each bin that have a *center point* falling within the watershed are summed

3.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

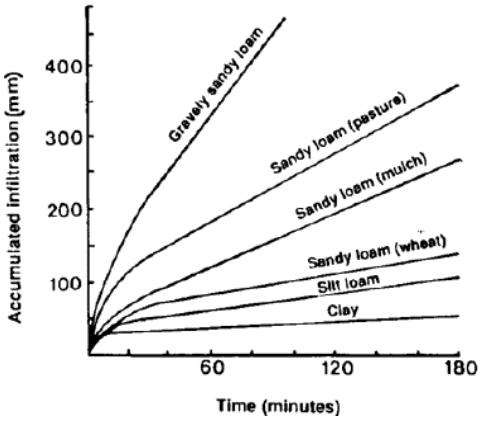
4.ABR *rate* is calculated by multiplying the calculated 5 minute ABR by 12 (hourly rate)

3. Watershed Response: Runoff

- Need to know how much ABR goes into runoff

INFILTRATION:

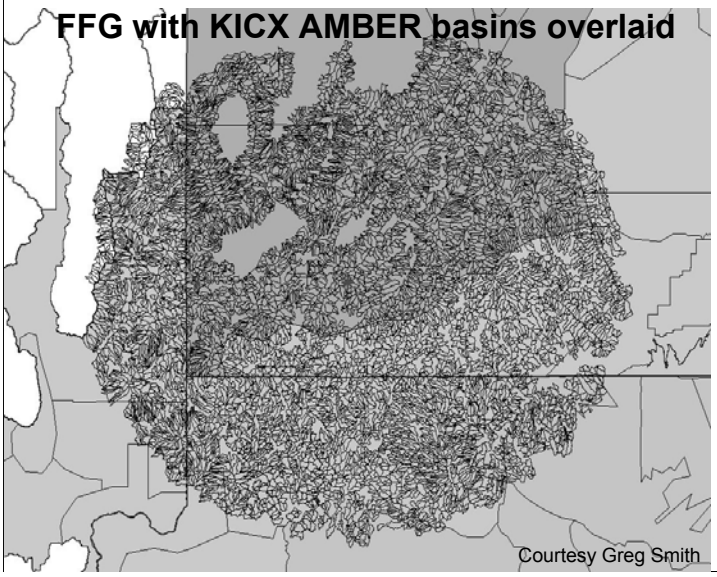
- **Soil type, moisture, and vegetation**



- Max runoff occurs when infiltration capacity is used up
- Saturated soils just as efficient as rock at converting rainfall to runoff
- Need to quantify runoff potential into a useful quantity: FFG

•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

3. Watershed Response: FFG



- FFG updated once a day by CWA zones in the Western U.S., twice per day in other regions
- Diversity of basins in each zone

•Terrain, soil and other basin characteristics vary widely within many counties and forecast zones across America, especially the Western U.S.

•No consistency on how to compute FFG from RFC to RFC

•Twice a day updates isn't frequent enough since antecedent precipitation can play a huge rule in flash flooding.

•Many flash floods quicker than 1 hour as well

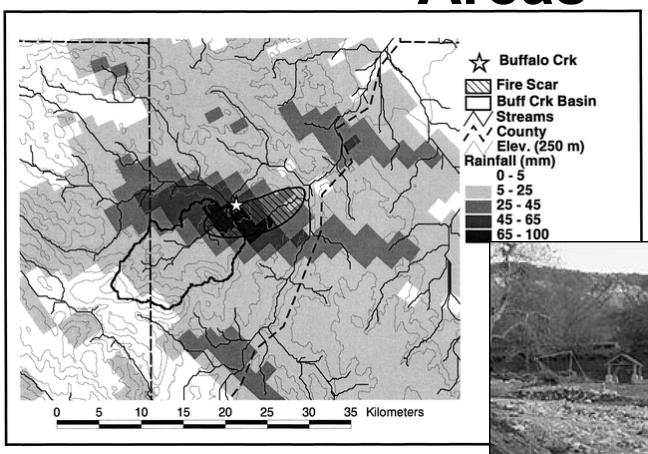
• What constitutes a significant flash flood? → Slot canyons can cause serious problems with just 30-50 cfs flow during a flash flood: different thresholds to floods and FFG doesn't address this. Tying thresholds to "bankful" not always a meaningful statistic

•FFG works best during an extended period of dry weather, worst with multiple rainfall events during previous 24-48 hours

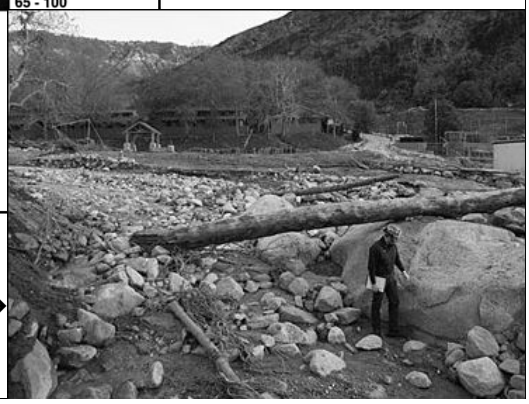
3. Watershed Response: Topography and Intensity

- 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

3. Watershed Response: Burn Areas



← Buffalo Creek



Waterman Canyon →

•All rainfall converted to runoff in burn areas, and the problem is especially severe the steeper the terrain

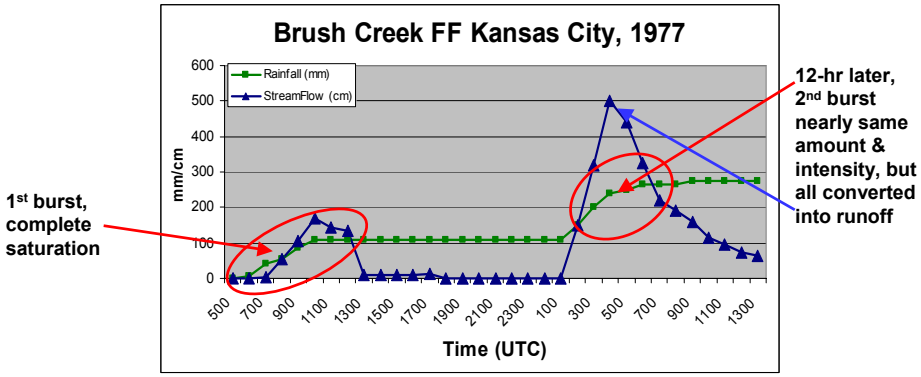
•Both these of these flash floods were a direct result of rainfall falling in a burn scar

•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, which led to tremendous flash flooding

3. Watershed Response: Antecedent Precipitation



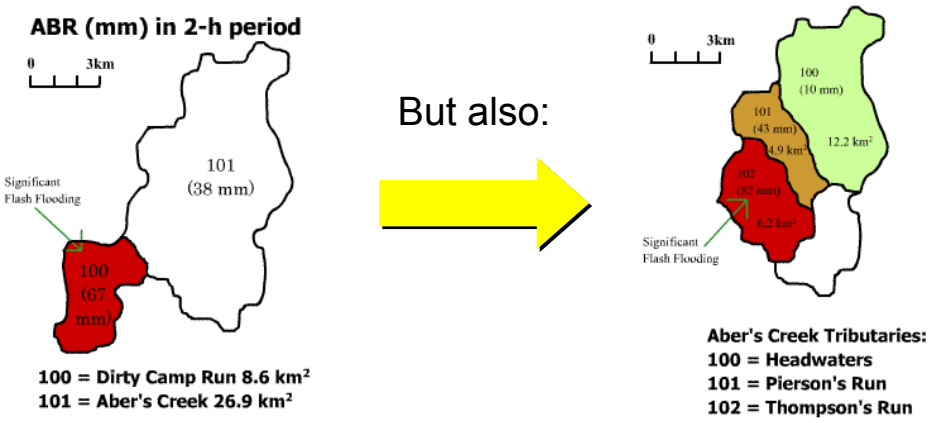
Moral: Soil moisture/saturation strongly influences surface runoff. Antecedent precipitation important to account for, and many times FFG doesn't capture it

•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

3. Watershed Response: Size

- 5-20 km^2 basin can be easily inundated by MGE elements, while basins 100-200 km^2 require training of some sort

→ Subdivided watersheds vital to detect FF



•These basins are 38-44 km from KPBZ

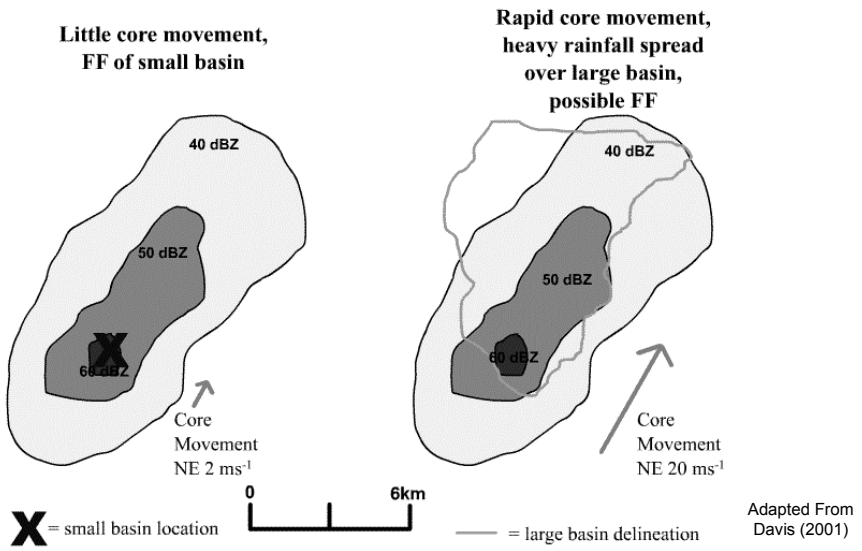
•MGE=mesoscale gamma elements, essentially individual heavy rain cores make up this scale of phenomena

•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…until you subdivide it further into smaller tributaries. On the right, Aber's Creek watershed has a basin (Thompson's Run) at high risk, and indeed significant flash flooding occurred in that small basin

•This example shows the importance of dividing basins into smaller units so that rainfall is averaged over smaller areas.

3. Watershed Response: Rainfall Core Movement



Adapted From Davis (2001)

• Problem!: Fast cell movement complicates things

•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

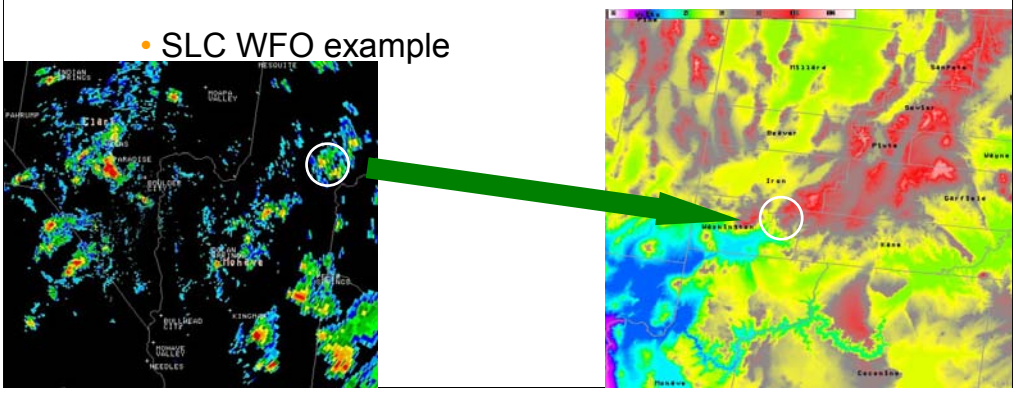
•With training, fast individual cell movement can lead to flash flooding with repeated development over the same areas, and would likely have to be the case with the scenario on the right: training could produce flash flooding in that large basin.

3. Watershed Response

- FF warnings should read like tornado warnings, with names of towns in threat area

  → Shouldn't be too hard since flash floods generally follow streams or dry arroyos: NBD stream database allows for this connection downstream

- SLC WFO example



•Zion National Park. No rainfall in the Narrows Section, but just upstream significant rainfall occurred. SLC 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, then used stream connectivity to determine that the flood waters would enter the Narrows Section

•If storms move slowly along the downstream direction of the stream, flash flooding can be enhanced

•Future FFMP builds will have stream connectivity

3. Watershed Response

- rainfall easily converted to runoff in urban areas
- some cities have inadequate drainage systems
- Local WFOs should define their own urban drainage areas with FFMP, need to be divided into small segments no larger than 5 km^2
- FFG 1in/hr

Many offices across the U.S. have set FFG to 1 in/hr for highly urban areas.

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*

•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

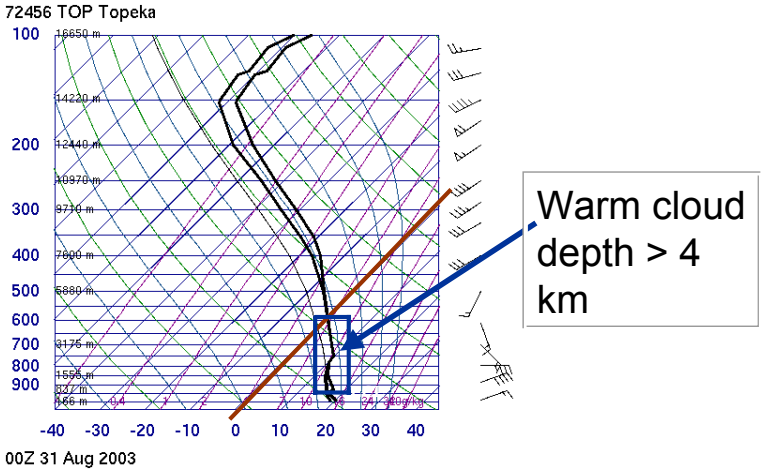
•Entrainment of dry air reduces PE because it introduces unsaturated air into the convection, which in turn promotes evaporation

•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.

4. Precipitation Efficiency

- Infer high PE potential: Example
  → deep warm cloud layer, RH, CAPE, shear



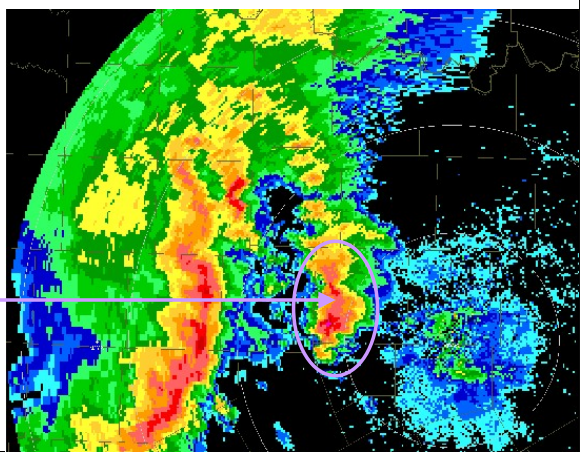
To maximize the effectiveness of warm rain processes, a deep "warm cloud" layer should be present. You can see these layers on soundings as the vertical distance between the LCL and where the moist adiabat from the LCL intersects the 0ºC isotherm. Depths greater than 3 km are considered to be "deep" 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)

5. Supercell Flash Flooding

- Significant low-level moisture inflow (+)
- "Loaded Gun Sounding" (-)
- Strong updrafts (-)
- Isolated (-)
- Movement Speed (+/-)

→ HP's

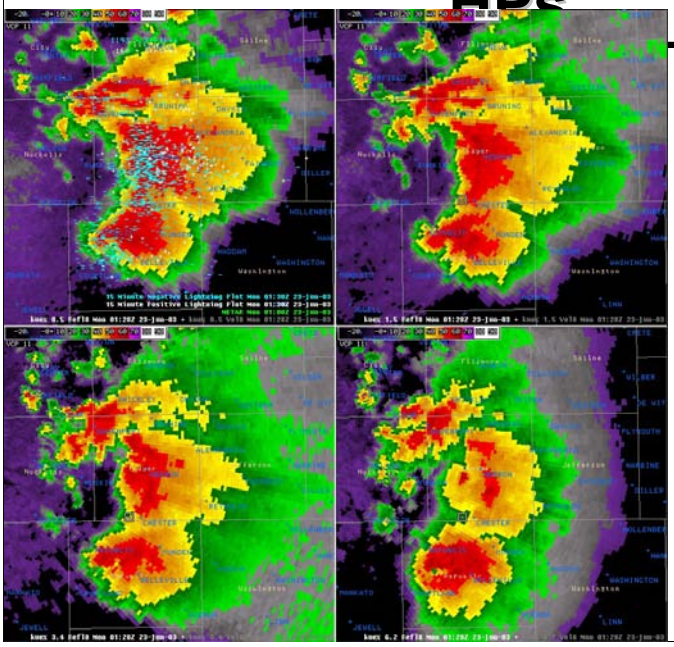


There are advantages and disadvantages to flash flood potential in supecells. Loaded gun sounding, isolated nature and very strong updrafts all are detrimental to flash flooding threat. However, very moist low level inflow and possibly speed of movement are both contributing factors to flash flooding. 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 unlikely.

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 ppt slides.

Key Point: Flash floods can occur with supercells, especially if HP in nature and if slow moving and/or training.

5. Supercell Flash Flooding: HPs

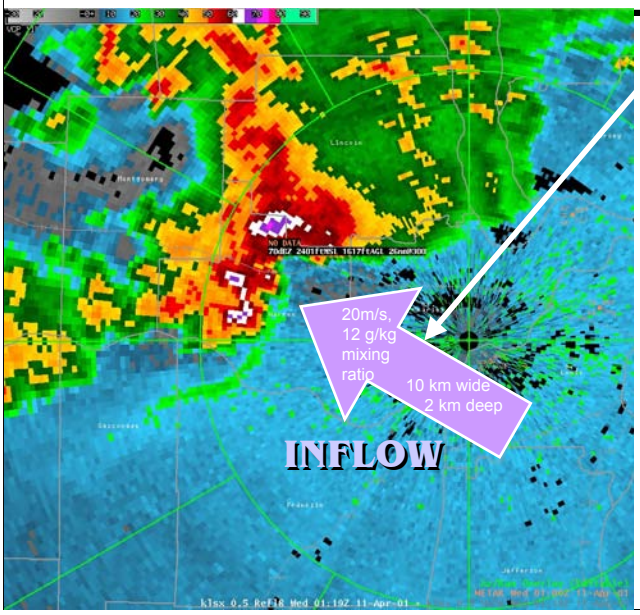


- HPs can cause significant flash flooding if they move sufficiently slow enough
- Limited studies, Smith et al. (2001)

•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

5. Supercell Flash Flooding: Moisture Inflow



- Given this realistic HP inflow setup, cloud water balance yields:
  → R~4 in/hr over 100 km^2 with a low 50% Precip. Efficiency
- **Moral of story**: even low PE associated with HPs and CLs can be balanced by large values of moisture inflow

This is the key to supercell flash flooding: understanding *why* supercells are such a threat despite poor precipitation efficiencies and at times swift movement.

•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.

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

•Flash flooding can occur when these two effects cancel each other out leading to very little net movement of heavy rain cores.

•Back building MCSs are most prone to flash flooding because of "training of inidividual mature cells", which can happen when advection and propagation effects cancel each other out.

Techniques on how to determine which process will be dominant or if they cancel each other out will be discussed in Severe IC 2: Mesoanalysis