1. Snowfall Forecasting

Instructor Notes: Welcome to IC 6, Lesson 5: Snowfall Forecasting. This is Part 2.

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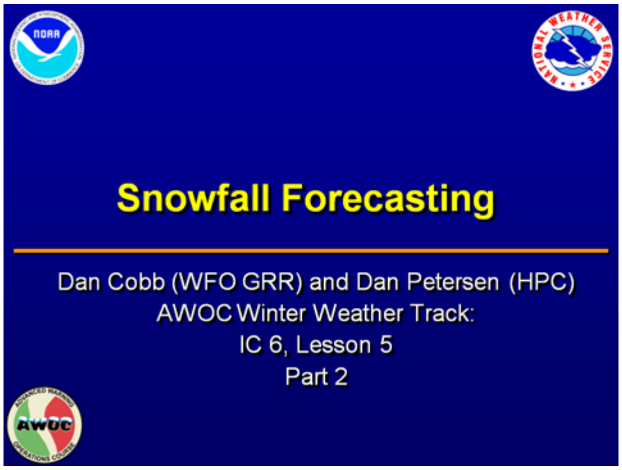

2. What is Contained in this Lesson?

Instructor Notes: As a quick review – the purpose of this less is to learn how to diagnose snow ratio and use it to convert a QPF into a snowfall forecast. In part one, we discussed snow ratio basics, climatology, and snow microphysics. Now in part two, we will cover snow production, conceptual ways to diagnose snow ratio tools, and 2 diagnostic tools for estimating snowfall amounts.

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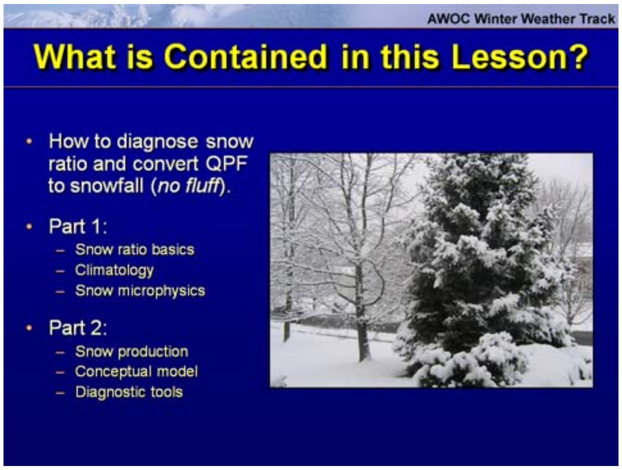

3. Lesson 5 - Outline

Instructor Notes: This is the lesson outline. In part 2 we will cover sections 4-6.

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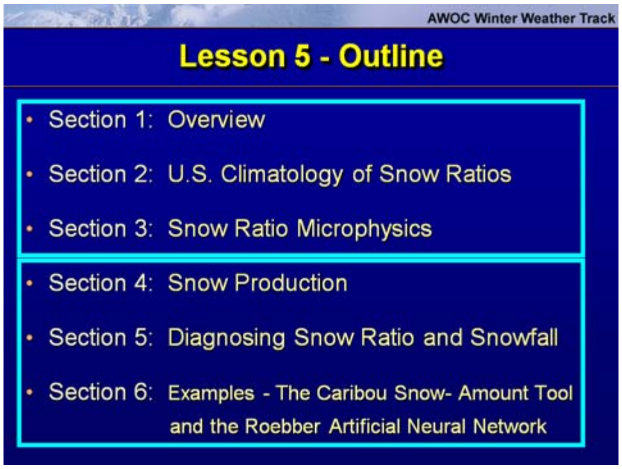

4. Learning Objectives

Instructor Notes: The learning objectives for IC 6 lesson 5 are: Become familiar with climatological variation of snow ratios across the country, Understand how temperature and humidity directly effect the type and density of growing snow crystals, Be able to define the term Dendritic Growth Zone (DGZ), and Explain its relationship to snow crystal growth and snow ratios. Be able to explain the role of vertical motion in producing snow crystals of different densities, and be able to define processes that contribute to compaction.

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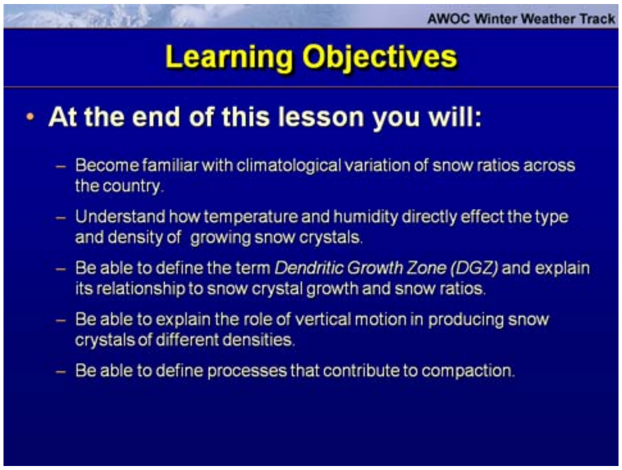

5. Performance Objectives

Instructor Notes: The performance objectives for this lesson are to improve estimates of snow density. You should be able to do this by: Diagnosing the snow ratio category (light, average, heavy) through inspection of NWP profiles of temperature, dewpoint, and vertical motion, Modifying snowfall accumulation rates based on sub-cloud and surface conditions and, Converting NWP forecasts of equivalent liquid precipitation to snowfall. In part 2, we will focus on the 2nd performance objective: Demonstrating how to use two diagnostic tools to assess snow ratio and expected snowfall, the Caribou forecast tool and the UWM Neural Net.

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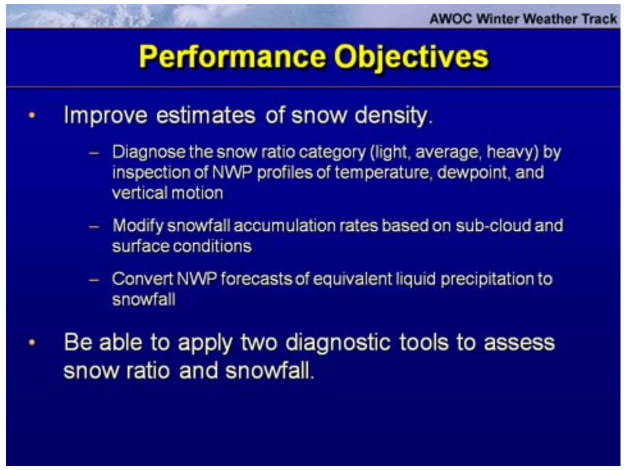

6. Quick Review of Lesson 5: Part 1

Instructor Notes: As a quick warm-up, I want to briefly discuss some highlights of Lesson 5 - Part 1. We defined the forecast problem by showing the potentially large variation in snowfall given an accurate QPF and a sampling of commonly observed snow ratios. A look at some climatologies revealed that light snows are favored away from the coast, at both higher elevations and latitudes, and that there is a distinct seasonality with the denser snows associated with warmer ground temperatures in the fall and higher sun angles in the spring. We learned about the DGZ, where fast growing spatial dendrites are favored at temperatures between -10 and -20C. And that stellar snowflakes are often associated with snow ratios of greater than 25:1. Snowflakes of mixed crystals often lead to average snow ratios, and heavy snows are associated with heavily rimed or partially melted or melting snowflakes.

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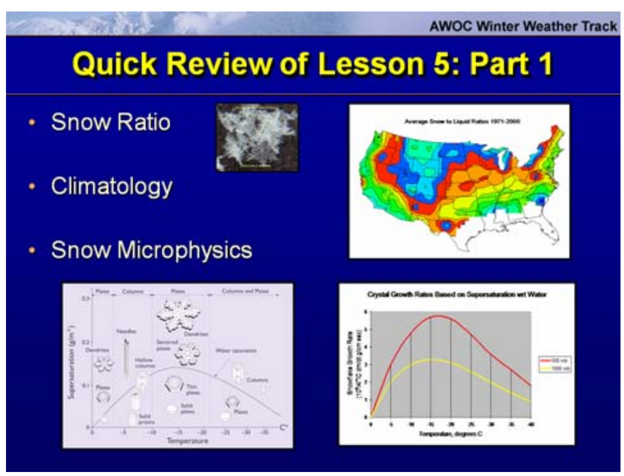
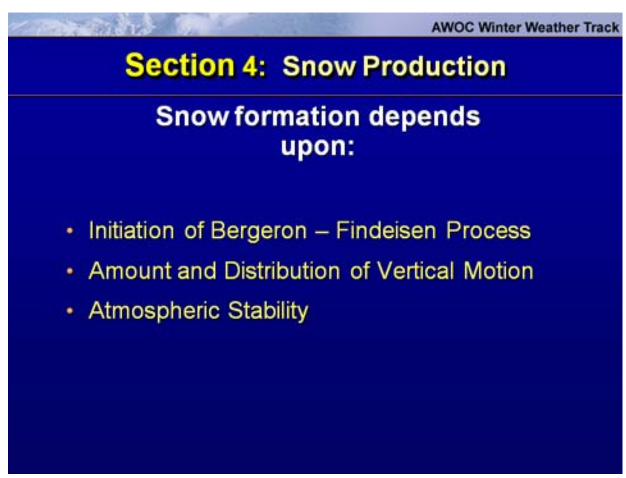


7. Section 4: Snow Production

Instructor Notes: Snowfall production is influenced by the following: initiation of the Bergeron-Findeisen Process, the amount and distribution of vertical motion, and modification by atmospheric stability, which is related to cloud types and their properties. Some miscellaneous notes: 1) Rising air currents cool air to saturation which supports the formation of cloud water droplets or ice crystals (cloud mixing ratio) which then fall out as precipitation. For cold clouds, the layer with greatest vertical motion and secondarily with relatively warmest temperature will produce the greatest cloud mixing ratio. 2) A second potential source of cloud mixing ratio occurs as warm and relatively moist air above the inversion slowly mixes with the cooler air below the inversion producing and maintaining saturation within the inversion layer. 3) Ice crystal formation in mixed phase clouds is a very important process for enhancing formation of precipitation. 4) Optimal precipitation production would be expected to occur when vertical motion maxima is collocated with optimal ice crystal growth rates (i.e. Dendritic or optimal Snow Growth Zone (SGZ) -12 to -18 degree C). 5) Vertical motion influences the observed snow ratio in two critical ways: (a) First, assuming saturated conditions, it is directly related to the rate of precipitation production. (b) Secondly with respect to ice formation, it influences the persistence and the degree to which supersaturation can be maintained in the presence of growing ice crystals. The degree of supersaturation directly influences crystal density through the branching potential of growing ice crystals (Libbrecht 1999). In terms of the Bergeron-Findeisen precipitation process, the SGZ represents a region of increased precipitation efficiency (relative to cold precipitation processes) in which low density crystals are likely to form. This infers that to a first approximation, a persistent vertical motion maxima collocated with the SGZ would be very conducive to producing both high snowfall rates and high ratio dendritic snowfalls. Such a correlation was noted and dubbed the "Cross-Hair Approach" in a study by Waldstriecher (2001). Other studies by Baumgardt et al. (1999) and Dubè et al. (2003) further support such an approach.

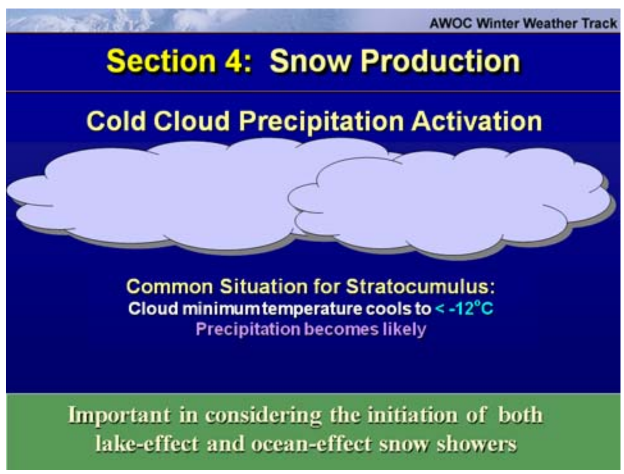
Student Notes:



8. Section 4: Snow Production

Instructor Notes: Let's take a look at a conceptualization of the Bergeron-Findeisen process as it relates to snow production. We'll use as a ball park figure -12 C as our critical temperature for initiation of ice multiplication; of course this temperature will vary depending upon the availability of different ice deposition nuclei. Initially consider the case where cloud temperatures are warmer than -12 C. In this scenario, the cloud is too warm to produce enough ice to initiate snow production. Also, it is too shallow for the collision coalescence process to produce super-cooled drizzle droplets. Now cloud temperatures are below -12 C and the ice multiplication process is fully activated. Additionally, the turbulent nature of the stratocumulus clouds will produce supersaturated conditions leading to rapid growth of dendritic crystals and their aggregation into snowflakes. This example is operationally relevant to the forecast problem of whether lake or marine stratocumulus is likely to produce snow showers. It also helps us to understand why deeper stratocumulus, that are warmer than -12C, can produce freezing drizzle or rain, even without a melting or above freezing layer present in the sounding. Some miscellaneous notes: A presentation "Cloud-Top Temperatures for Precipitating Winter Clouds" at the 2005 Washington DC AMS meeting by Jay Hanna et al indicated, "Snowfall reports tend to exhibit a Gaussian distribution that is skewed heavily towards higher temperatures with a pronounced mode at -16°C. A very sharp drop in the frequency distribution warmer than -12°C is indicative of the depletion of ice nuclei with progressively higher temperatures." This reinforces the findings that the Bergeron Findeisen Process is less effective at producing ice crystal growth at warmer temperatures and occurs most effectively at temperatures starting at -12C down to -18C, due to more ice nuclei being activated at these temperatures.

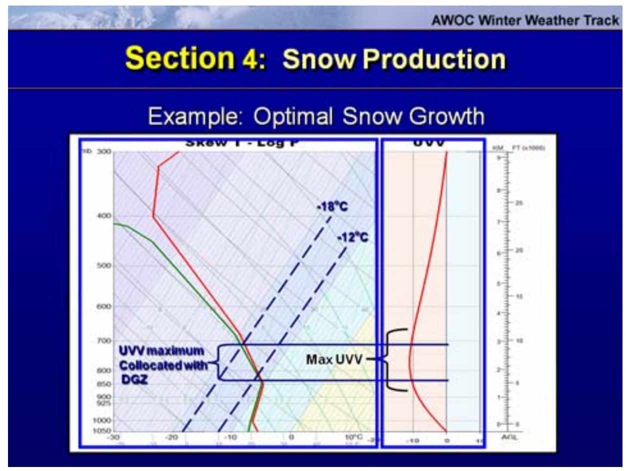
Student Notes:



9. Section 4: Snow Production

Instructor Notes: On this diagram - I want to conceptually illustrate conditions favorable for optimal snow production. This diagram features a sounding on the left using a skewT-logP diagram; the red line depicts temperature and the green line is dewpoint. On the right side, the vertical profile of omega is shown where negative values represent upward vertical motion. On the sounding I am highlighting the -12 and -18 C isotherms to give an idea of where the sounding intersects the core of the DGZ. Now let's highlight the region of highest upward vertical motion. Putting it all together, the region of strongest upward vertical velocities intersects the DGZ. The result is that water vapor is supplied most rapidly to a region where it can be most efficiently converted into snow. The diagnosis of this intersection of the maximum Upward Vertical Motion (UVV) with the DGZ is referred to as the cross-hair approach, which has been used as a conceptual tool for discriminating significant snowfall events.

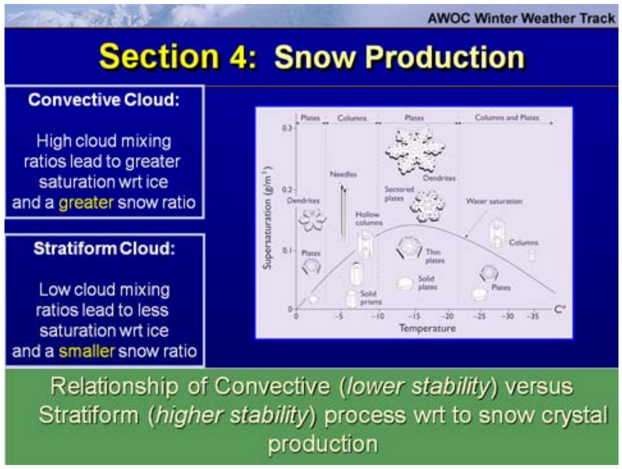
Student Notes:



10. Section 4: Snow Production

Instructor Notes: The last point about snow production pertains to stability. Stability can both inhibit or amplify local vertical motion and mixing … both of which influences growing ice crystals. Remember the ice crystal type morphology diagram where dense crystals grow at marginal degrees of supersaturation while light crystals grow at higher degrees of supersaturation. In the case of low stability or steeper lapse rates, cumuliform clouds are favored which tend to have relatively high water content, and given cloud temperatures below -12C, will tend to produce lighter dendritic crystals and higher snow ratios. However, stratus clouds existing in a stable layer with similar temperatures will contain relatively low water content, and will tend to produce denser crystals (less branching).

Student Notes:



11. Section 5: Diagnosing Snow Ratio and Snowfall

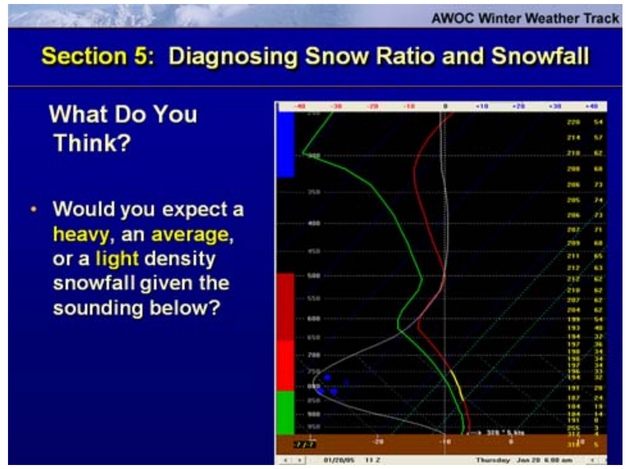
Instructor Notes: Now we'll move on to Section 5 - Diagnosing snow ratio and potential snowfall. In this section, soundings and time-sections from several snow cases will be presented. You'll first be asked to identify the snow ratio class given a representative Bufkit sounding from the event. We'll then step through the diagnosis of the case using a three step top-down approach. The first step is to assess the snow density potential of the cloudy layers. In the second step, one assesses the sub-cloud layer. Finally, in the third step, surface conditions are considered. Together these three steps give us a practical approach to conceptually diagnosing the most likely observed snow ratio.

Student Notes:

12. Section 5: Case 1

Instructor Notes: What-do-You-Think? Given the sounding below – which of the snow ratio classes would be more likely heavy, average, or light? When you're ready - Proceed to the next slide for a discussion.

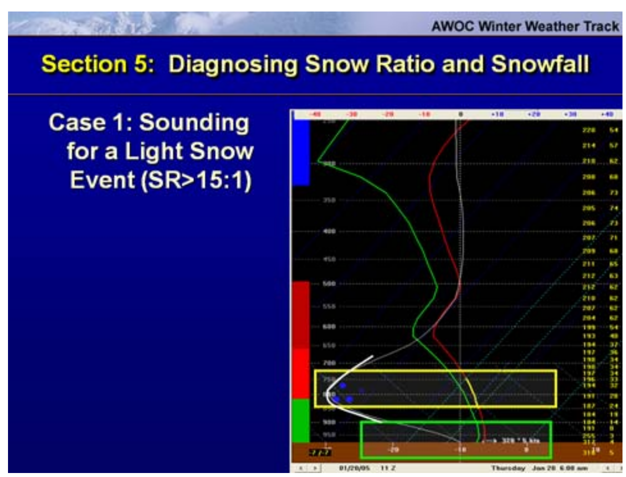
Student Notes:



13. Section 5: Case 1

Instructor Notes: This is a good example of a sounding for a light snow event with SR > 15:1. Step 1) First from a cloud perspective – this sounding features a pronounced cross-hair signature with a nearly 40 microbar/s vertical velocity maxima collocated with the DGZ. Secondly, lapse rates through this region are nearly moist adiabatic indicating the possibility of convection and cumuliform clouds properties. Also, significant riming would not be a big threat … as there is only a shallow cloud layer with temperatures above -10C near the surface and the vertical motion in this layer is quite modest which would limit the production of super-cooled cloud droplets. Step 2 & 3) Cloud bases are low and there is no subsidence indicated below cloud base so sublimation would not be a factor. Additionally, surface temperatures are forecast to be near 20 F, with winds of around only 5 kts and lastly, it is the middle of January, so one would not expect any substantial reduction of snow density due to compaction by melting, wind, or crystal metamorphosis.

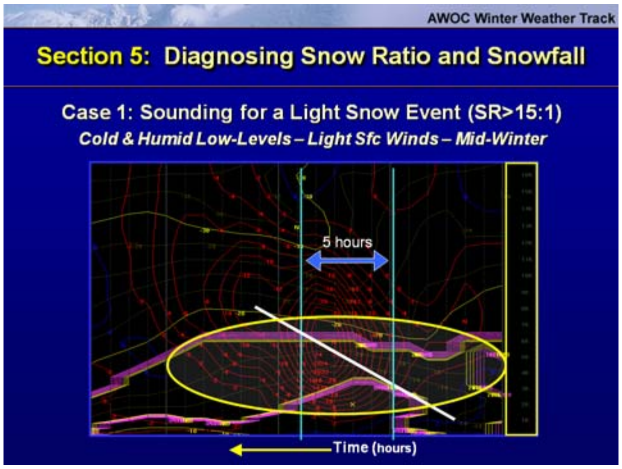
Student Notes:



14. Section 5: Case 1

Instructor Notes: Here is a look at the time-section for the light event case. Time is increasing from right to left (click 1) and on the right side of the time-section altitude is shown in thousands of feet. Temperatures (light beige contours) and vertical velocities (the red and blue contours) are plotted with the DGZ (depicted w/ magenta contours (click 2 – let me highlight this for a moment)). The intersection of the upward vertical velocity max with the DGZ (click 3) lasted about 5 hours (click4) with most of the observed snowfall also occurring within that time window. Snow accumulation rates occasionally exceeded 3 inches per hour during this window.

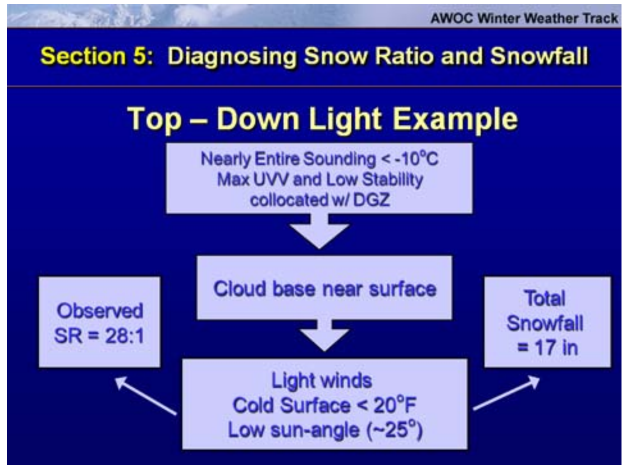
Student Notes:



15. Section 5: Case 1

Instructor Notes: So, once more from the top-down perspective here are the key points: 1) Nearly Entire Sounding < -10C and Max UVV and Low Stability collocated w/ DGZ. 2) Little opportunity for sublimation with low cloud base and vertical motion max. 3) Light winds, Cold Surface < 20F, and Low sun-angle (~25 degrees) afford little chance of rapid surface compaction. 4) Observed SR of 30:1 – one of the fluffiest snows I have ever observed. 5) and with little over a half inch of liquid equivalent – total snowfall was 17 inches!

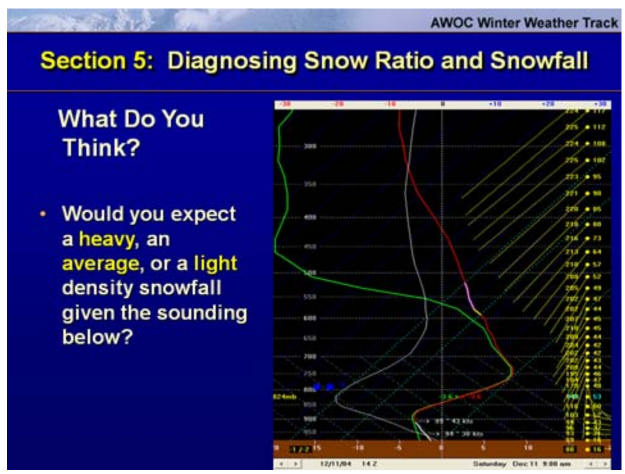
Student Notes:



16. Section 5: Case 2

Instructor Notes: Lets take a look at another event - What-do-You-Think? Given the sounding below – which of the snow ratio classes would be more likely heavy, average, or light? When you're ready, proceed to the next slide for a discussion.

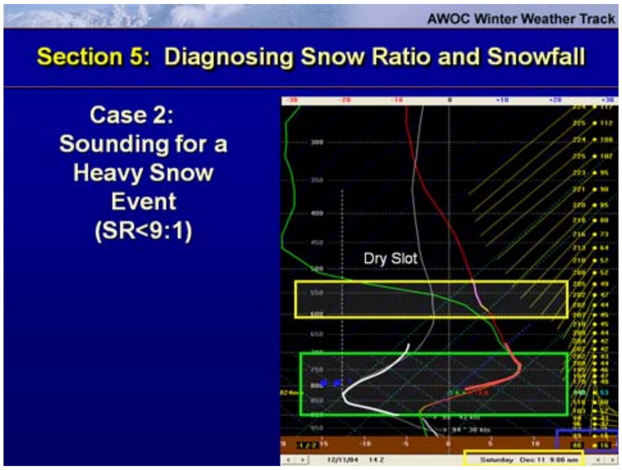
Student Notes:



17. Section 5: Case 2

Instructor Notes: This is a good example of a sounding associated with a heavy snow event with SR < 9:1. 1) In terms of cloud snow production, the pronounced warm nose between 850 and 700 mb, where temperatures range from near 0 to -5 C immediately catches the eye. The maximum region of upward ascent (about 20 microbars/s) closely coincides with the warm nose being just a bit below the tip of the nose itself. This coupling would likely produce copious amounts of supercooled water droplets and a high potential for significant riming. The potential for riming is further increased by the dry air within and above the DGZ. Cloud top temperatures are roughly between -10 and -15C with little upward ascent at those temperatures. So in many ways this sounding is the opposite of the first case. You might also be thinking that in terms of Top-Down Precipitation type thinking - that this sounding is marginal for producing ice and snow at all. The availability of ice nuclei, like sea salt, from the relatively nearby Atlantic Ocean probably tipped the scales in favor of snow for this case. The surface temperature is near 30F, but the sun angle is at one of the lowest points of the year and there was already snow-cover present so this might be a wash. However, winds sustained near 15 kts could be conducive to densification of falling snow.

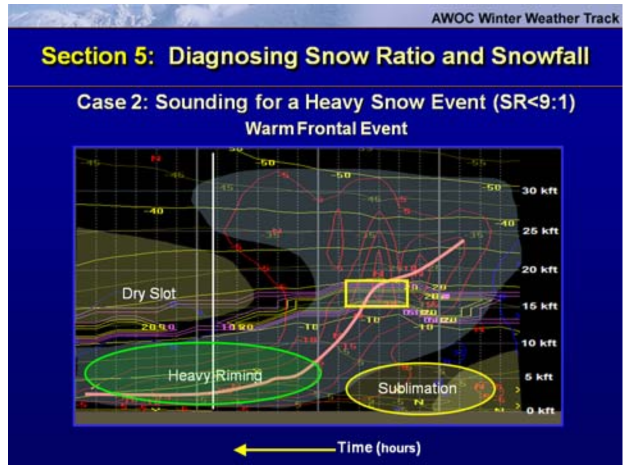
Student Notes:



18. Section 5: Case 2

Instructor Notes: The time-section shows a nice warm-frontal signature (click 1) with the level of maximum ascent lowering with time. I have shaded the cloudy regions in grey and the dry regions in yellow. For reference, the sounding from the last slide was for this hour here (click 2). Early on, there is briefly, a pretty good cross-hair signature between 15 and 20 kft … (click 3) which is pretty high-up. However, below that layer there is dry air, dry air advection associated with a departing sfc high, and some modest downward motion – let me circle that for you…(Click 4) This would be a good set-up for sublimation. Later on, (Click 5) the conditions flipped with the ideal riming conditions at lower levels and dry air aloft. So – overall – there was little opportunity for lighter crystals to form and make it to the surface.

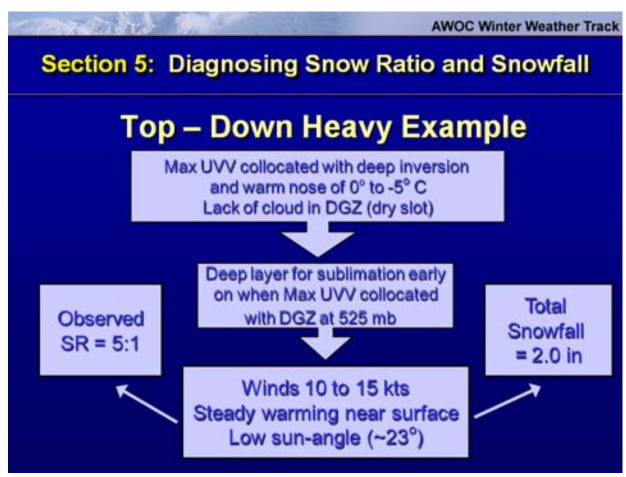
Student Notes:



19. Section 5: Case 2

Instructor Notes: So for case 2 - from the top-down perspective here are the key points: 1) The maximum UVV was collocated with a deep inversion and warm nose of 0 to -5 C for most of event - there was also lack of cloud in DGZ (due to dry slot) over this time. 2) A deep layer for sublimation existed early on when maximum level of ascent was briefly collocated with DGZ at 525 mb. 3) As far as surface compaction there were some winds of 10 to 15 kts. 4) Steady warming occurred near the surface but not above freezing and was coupled with low sun angle of 23 degrees. 5) Observed snow ratio of 5:1 was one of the more dense snowfall I have observed, and in case you were wondering there were trace amounts of sleet in the snow. The sleet pellets occurred towards the end of the occurrence of the cross-hair signature. 6) Like the last case - the liquid equivalent was just over a half inch - but this time total snowfall was only 2 inches! The snow had the consistency of sand and was similar in texture to the man-made snow you might see at a ski area.

Student Notes:



20. Section 5: Case 3

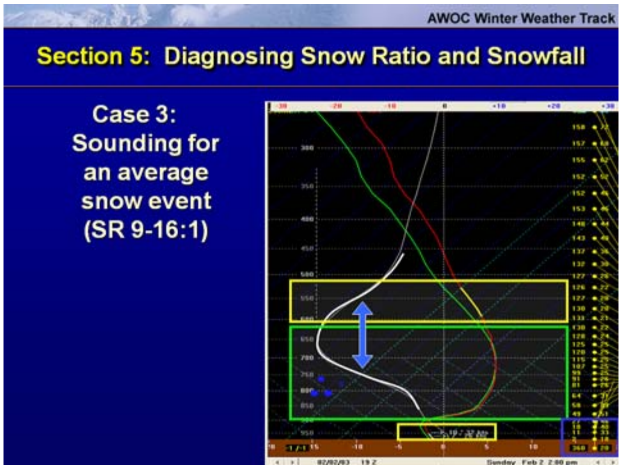
Instructor Notes: Last Event - What-do-You-Think? What are some reasons this might be an example where an average snow ratio class was observed? When you're ready, proceed to the next slide for a discussion.

Student Notes:

21. Section 5: Case 3

Instructor Notes: The first thing that strikes me about this sounding is the depth of the ascent maximum. It's about 250 mb deep with a peak of 25 microbars/s. Secondly, just about half of the ascent maxima lies in the DGZ and the other half overlaps a potential riming layer. The DGZ has steeper lapse rates while the warmer layer below is more stable. Most of the vertical motion in the rime layer is at temperatures between -5 and -10 C which is about 5 degrees colder than in the previous heavy snow example. So, we have indications of both good dendritic growth potential as well as rime potential. I believe what is happening in this example is that the DGZ is providing enough ice to the warmer layer below such that ice-crystal multiplication is helping reduce the amount of liquid cloud droplets thereby reducing the probability of heavy rime icing and a heavy snowfall. There is no chance for sublimation with the sounding saturated to the surface. Again, temperatures are near 30F, but this time it is later in the season, which might enhance the compaction rate. Also, winds are about 20 kt, which would tend to break apart the larger snowflakes into smaller more tightly fitting pieces.

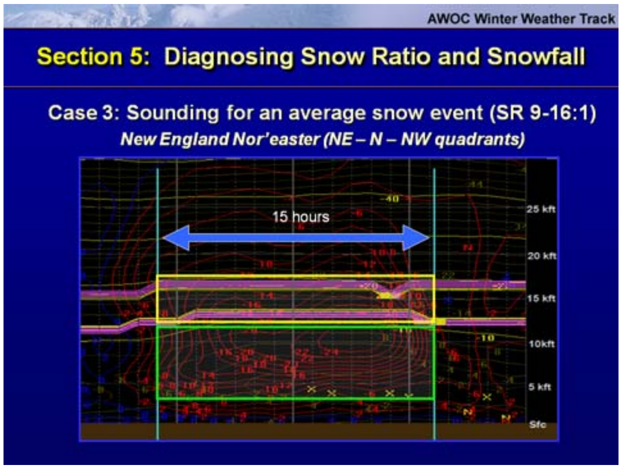
Student Notes:



22. Section 5: Case 3

Instructor Notes: From a time-section one can see that this was a pretty long lasting event (Click 1) at about 15 hours of significant snowfall. Secondly, that the vertical motion maxima was pretty uniform throughout the event in its magnitude and height … (Click 2) saddling the DGZ and the 0 to -10 C thermal layer throughout the storm. Temperature wise, there was modest cooling of the warm nose at 850 mb after the previous 2 pm sounding but otherwise pretty uniform as well. Observed snowflakes varied throughout the event with generally light-moderately rimed aggregates of spatial dendrites and plates. However, at times – large aggregates of spatial dendrites were observed and at other times – small heavily rimed plate were observed.

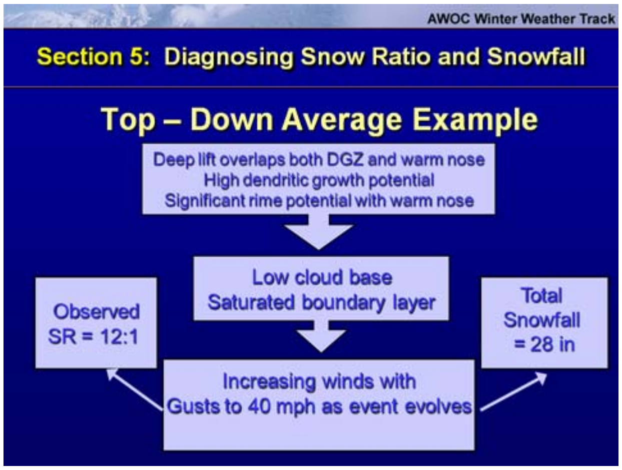
Student Notes:



23. Section 5: Case 3

Instructor Notes: So for the last, Case 3, from the top-down perspective here are the key points: 1) Deep lift overlaps both DGZ and the potential rime layer of 0 to -10 C. 2) Low cloud base negates sublimation potential. 3) Increasing winds w/ gusts to 40 m.p.h. as event evolves. 4) Observed SR of 12:1 which is a bit below climatological expected value of 14:1. 5) Fifteen hour event with just over 2 inches of liquid equivalent resulted in the 3rd largest snow storm recorded in Caribou with Total Snowfall of 28 in.

Student Notes:



24. Quiz

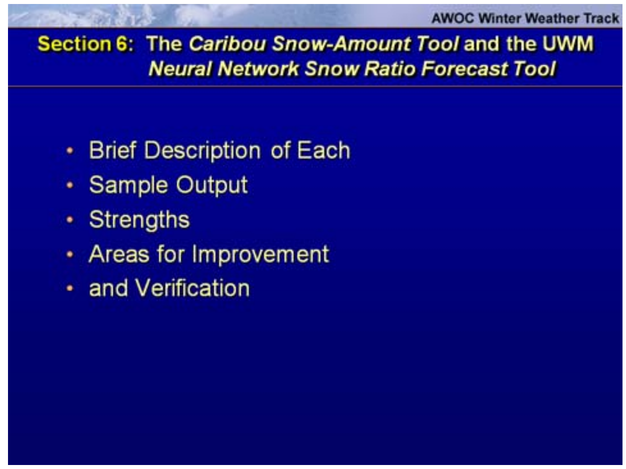
Instructor Notes: Here is an interactive quiz.

Student Notes:

25. Section 6: The Caribou Snow-Amount Tool and the UWM Neural Network Snow Ratio Forecast Tool

Instructor Notes: Now we're going to cover two tools which can be used to assist in the determination of snow to liquid ratios, the Caribou Snow Amount Tool and the UWM Neural Network Snow Ratio Tool. We'll describe each tool and show outputs, strengths, and areas for improvement.

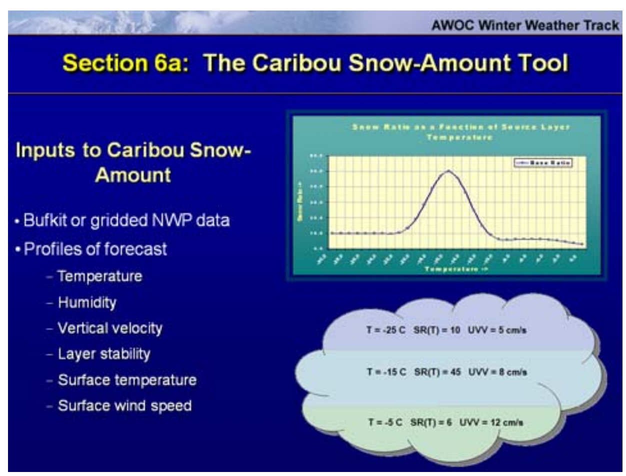
Student Notes:



26. Section 6a: The Caribou Snow-Amount Tool

Instructor Notes: The Caribou snow amount tool predicts snow ratios by reviewing forecast vertical profiles of temperature, humidity, and vertical motion And determining snow ratios over time intervals during each storm. The snow ratios are then multiplied by the QPFs for each interval and summed to yield a storm-total snowfall. The forecast inputs are shown on the left. On the upper right is a graph showing the assigned snow ratios according to the layer temperature. The lower right illustrates how snow ratios are calculated over multiple layers of the sounding, with the final ratio determined using a weighted average. The algorithm takes into account whether the vertical velocity maximum overlays the highest relative humidity and temperatures of the dendritic growth zone, and adjusts for compaction due to surface temperatures and wind.

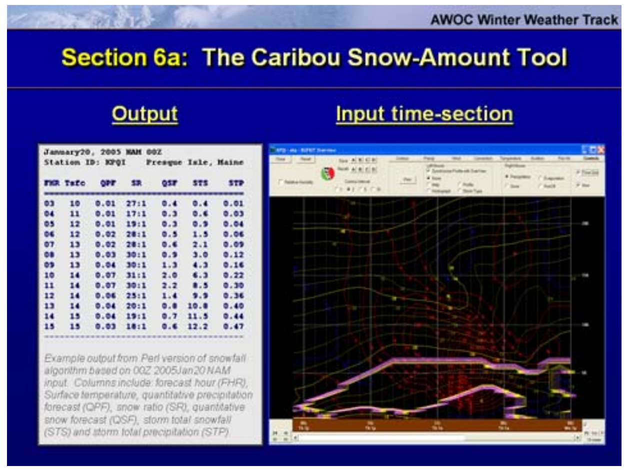
Student Notes:



27. Section 6a: The Caribou Snow-Amount Tool

Instructor Notes: You can see a sample of The Perl version of the Caribou Snow Amount tool on the left. The program uses model soundings from the NAM, GFS, or WorkStation version of the Eta that are processed for use in the BUFKIT software. This version of the program also uses precipitation type logic to improve on its snow ratio and snowfall calculations. BUFKIT sounding data are advantageous because they have the full native model vertical resolution, as well as very high temporal resolution (hourly for the NAM and Workstation Eta, 3-hourly for the GFS), yielding the best estimate of forecast snow ratio and potential snow accumulation at a given point. It also allows a forecaster to evaluate the snow ratio through visual inspection of the model data using the BUFKIT, such as the time section on the right. This GFE "Smart Tool" has the advantage of producing areal distributions of snow ratio and snowfall. This allows the forecaster to deliver more robust gridded forecasts of snowfall.

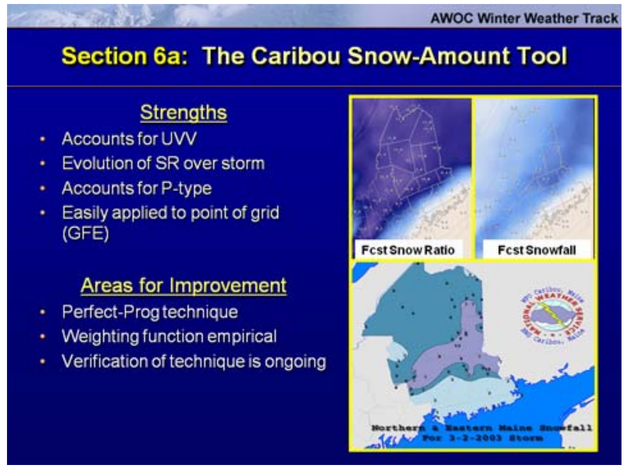
Student Notes:



28. Section 6a: The Caribou Snow-Amount Tool

Instructor Notes: We'll review the algorithm output in the right graphic. The upper left graphic shows output on information on the changes in snow ratio which occur during each event, and the upper right graphic shows output snowfall totals in the Graphical Forecast Editor. The bottom graphic shows observed amounts during an event, which you can compare to those forecast in the upper right panel. The strength of the Caribou snow amount tool is it accounts for the vertical velocity distribution, the evolution of snow ratios as profiles of vertical velocity, temperature, and relative humidity change during an event, and accounts for precipitation type. The areas for improvement would be to conduct a bias adjustment to the model profiles of temperature, relative humidity, vertical velocity, etc. which lead to errors in the algorithm performance. Potential improvements could also come from a study which provides a more robust statistical analysis showing more precisely how vertical velocities impact snow density. A comprehensive verification needs to be looked at to fully validate the utility of the algorithm. The current plan is for algorithm testing to continue.

Student Notes:



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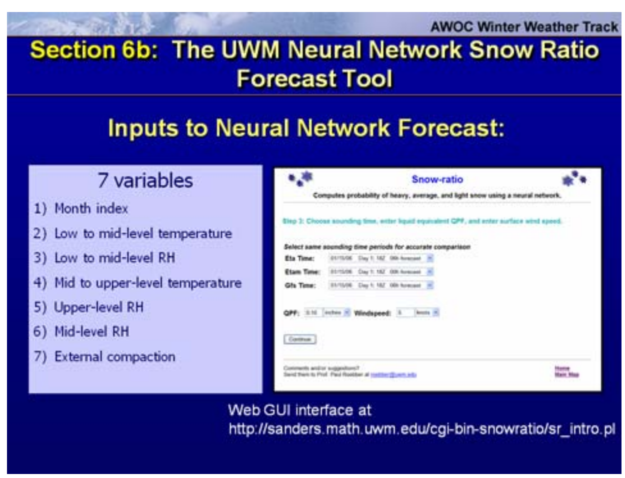
29. Section 6b: The UWM Neural Network Snow Ratio Forecast Tool

Instructor Notes: The neural network ingests model forecast soundings (obtained from the NAM/Eta, the MesoEta and the GFS) and determines the likelihood that the snow will fall into one of three density classes (heavy, with ratios up to 9:1; average, with ratios from 9:1 up to 15:1; light, with ratios exceeding 15:1). The Roebber et al (2003) study indicated the most critical inputs for determining snow ratio are related to the month, temperature, and external compaction, so these are the inputs into the neural network forecasts. (Additional notes: Ten members with different weighting of each variable are run, and the outputs from these runs are then used to determine the probability of snow ratio class for each event. The authors have indicated that the highest probability of each class leads to an increasing probability of an extreme event. If a high probability occurs for the light class (low probabilities for the average and light categories), then the resultant snow ratio would likely be at the higher end of the range of snow ratios, instead of barely above the average range.)

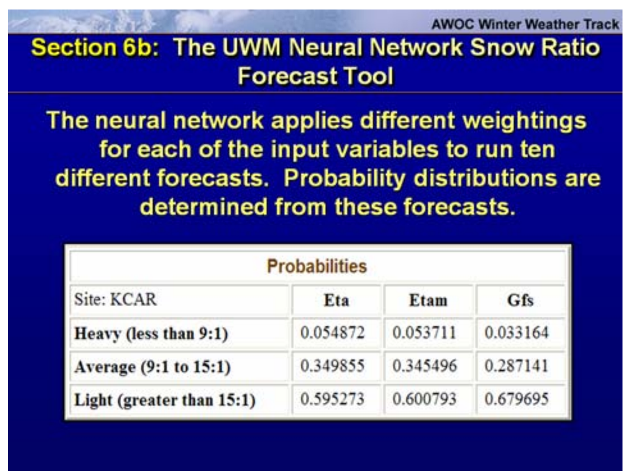
Student Notes:



30. Section 6b: The UWM Neural Network Snow Ratio Forecast Tool

Instructor Notes: The neural network applies different weightings for each of the seven input variables to run ten different forecasts. Probability distributions are determined from these forecasts. The predicted snowfall probabilities are shown for the table below for each range of snow ratio. When the probability in the light category is high (greater than 15:1 snow/liquid equivalent ratio), such as > 67%, then very high snow ratios are likely. When the probability for the heavy snow category is high (less than 9:1 snow/liquid equivalent ratio) then low snow ratios are likely. So the highest probabilities placed in either the light and heavy categories indicate when extreme events are likely. The Roebber web site http://sanders.math.uwm.edu/cgi-bin-snowratio/sr_intro.pl provides more background and specifics of the technique, plus the interface to choose the locations and provide forecast input to receive diagnosed snow to liquid equivalent ratios for each of the categories shown above. See Roebber et al (2003) and Ware et al (2006, accepted for publication in Weather and Forecasting) for background on the data, techniques, and elucidation of the dependence of snow ratio on temperature, month, relative humidity, and compaction due to liquid equivalent precipitation and wind speed.

Student Notes:

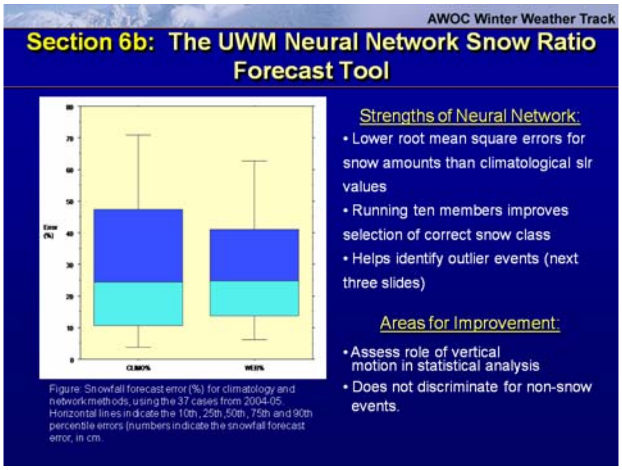


Site: KCAR	Eta	Etam	Gfs
Heavy (less than 9:1)	0.054872	0.053711	0.033164
Average (9:1 to 15:1)	0.349855	0.345496	0.287141
Light (greater than 15:1)	0.595273	0.600793	0.679695

31. Section 6b: The UWM Neural Network Snow Ratio Forecast Tool

Instructor Notes: The neural network forecast results show improvement over climatological snow to liquid ratios (60.4% correct determination of snow category vs. 41.7% for climatology). As you can see in the lower left, there are lower rms errors plus the neural net narrows the range of the most likely snow-liquid ratios (see verification graphic). The neural net weightings were calculated using 1650 events over a large portion of the country, so it is statistically robust. One possible area of improvement would be to see if a neural net could determine the contribution of vertical motion to snow-liquid ratios and factor in forecast vertical velocities. Another area would be to conduct a bias correction for the forecast inputs, temperature and relative humidity inputs, and then use these bias adjusted forecasts as inputs into the algorithm. The neural net also needs to discriminate to not assign a snow ratio if the precipitation type is not forecast to be snow.

Student Notes:



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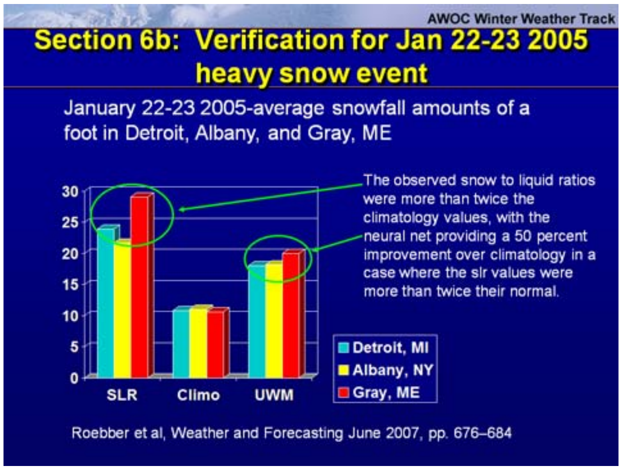
32. Section 6b: Verification for Jan 22-23 2005 heavy snow event

Instructor Notes: Here is a case where the neural net provided a major improvement over using climatological snow to liquid ratios. On the left is the observed snow to liquid ratios for this event, with Detroit shown in blue, Albany in yellow, and Gray ME in red. In the middle is the climatological slr values for all three locations, and on the right is the forecast neural net slr's for this event. While the neural net forecasts were under the observed values, they showed a 50 percent improvement of the climatology slr values. The key benefit of using the neural net is to identify cases of unusually high or low snow to liquid ratios, when climatology has potential to produce the greatest error. This is adapted from table 3 of Real-Time Forecasting of Snowfall Using a Neural Network Paul J. Roebber, Melissa R. Butt, Sarah J. Reinke, and Thomas J. Grafenauer Weather and Forecasting Volume 22, Issue 3 (June 2007) pp. 676–684

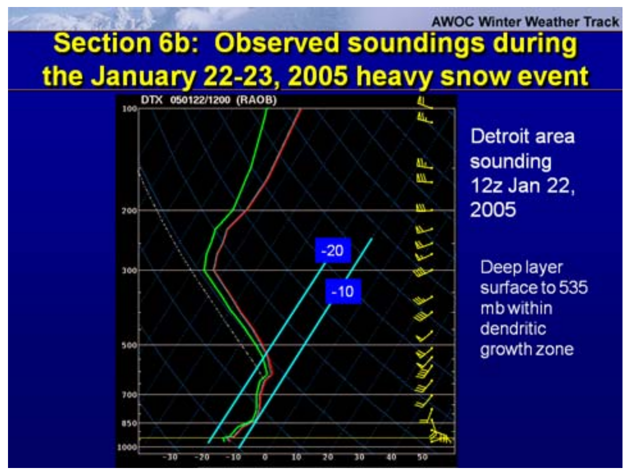
Student Notes:



33. Section 6b: Observed soundings during the January 22-23, 2005 heavy snow event

Instructor Notes: The soundings near the beginning and end of the January 22-23, 2005 event will be shown. Here at the beginning of the event in southeast Michigan in the Detroit area at 12z Jan 22, a deep layer of the sounding was in the dendritic growth zone of -10 to -20C, from the surface to 525 mb. Further, there were no warm layers surface or aloft to cause riming or accretion. On the next slide, we'll see that cooling occurred during the event, remaining under favorable conditions for dendritic growth for an extended period.

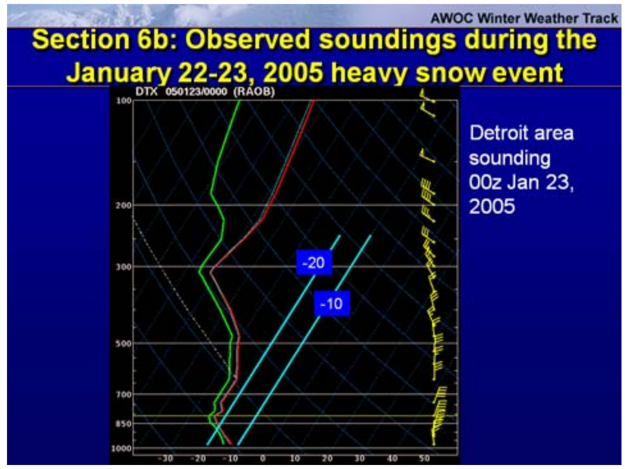
Student Notes:



34. Section 6b: Observed soundings during the January 22-23, 2005 heavy snow event

Instructor Notes: Here in the last few hours of the event, the 00z Jan 23rd sounding shows cooling has occurred to steepen the lower level lapse rates from the surface to 825 mb, with more uniform cooling above 825 mb. The -10 and -20 degree lines are highlighted in light blue or turqoise. The winds have switched above 825 mb to a back-ing, or cold advection profile. Again, there is an absence of warm layers aloft or near the surface to promote riming, accretion, or partial melting of the falling snow.

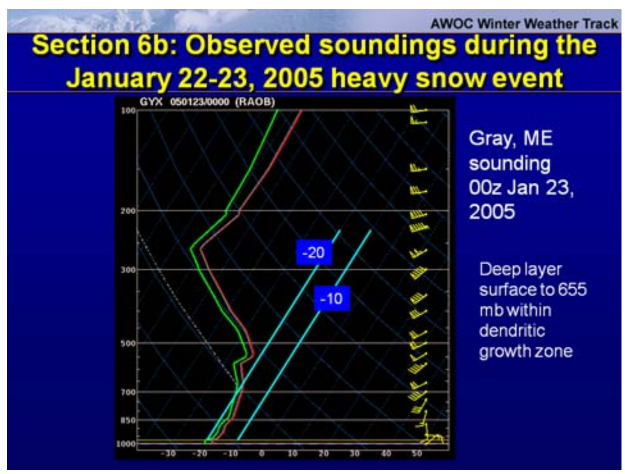
Student Notes:



35. Section 6b: Observed soundings during the January 22-23, 2005 heavy snow event

Instructor Notes: And here on the Gray ME soundings, the temperature profile remain in the favored area for dendritic growth for even a longer period. This is the 00z sounding for January 23, 2005, showing a deep, nearly isothermal profile from the surface to near 700 mb. RH values of 90 percent plus extend through the depth of the soundings from the surface to 400 mb.

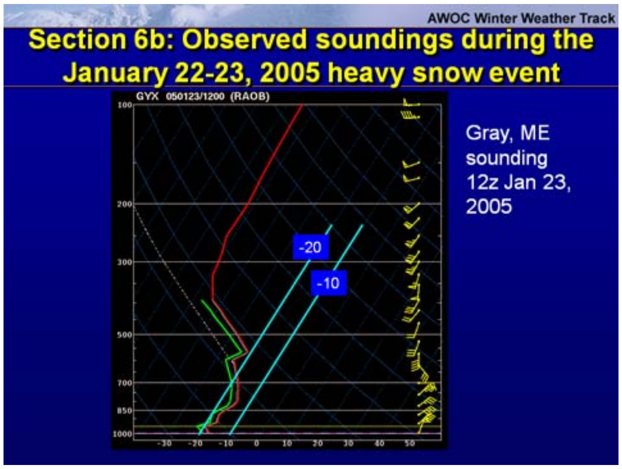
Student Notes:



36. Section 6b: Observed soundings during the January 22-23, 2005 heavy snow event

Instructor Notes: And here, 12 hours later at 12z Jan. 23, there has been little change in the temperature profile, with the low level winds backing as the storms moves off the New England coast, ending the warm advection profile. The continued conditions favorable for dendritic growth are apparent, along with the absence of low level warm layers to minimize aggregation. The event ending before the 00z January 24 sounding was taken.

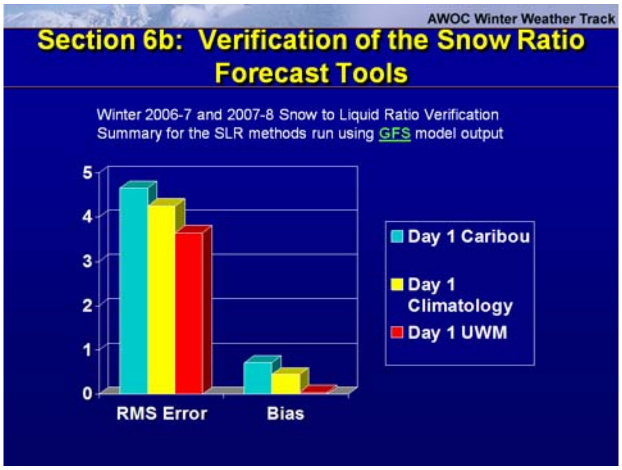
Student Notes:



37. Section 6b: Verification of the Snow Ratio Forecast Tools

Instructor Notes: In this graph, the day one performance of the snow to liquid ratio root mean square errors and the bias of forecasts derived from GFS output are shown. In this case, the bias is the mean of (Forecast-Observed), so a perfect score is zero, and positive values indicate a high forecast bias. Note the current methods show an average error near 4:1, and each has a slightly high bias, with the neural net showing the bias closest to an ideal value. These biases drop to below zero (or have negative biases) on both day two and day three for all methods.

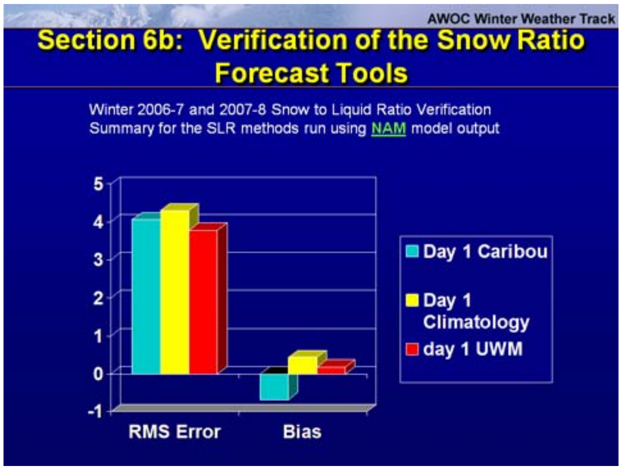
Student Notes:



38. Section 6b: Verification of the Snow Ratio Forecast Tools

Instructor Notes: The climatological snow to liquid ratios show a higher rms error than the other techniques when the methods are run using the NAM model output. The slightly high bias for the caribou method using the gfs output changes to a low bias using the NAM output. This is possibly due to changes in the NAM's vertical velocity profile, which is often weaker through the sounding depth than that in the gfs. Each method's bias continue to decrease on the forecasts for days two and three.

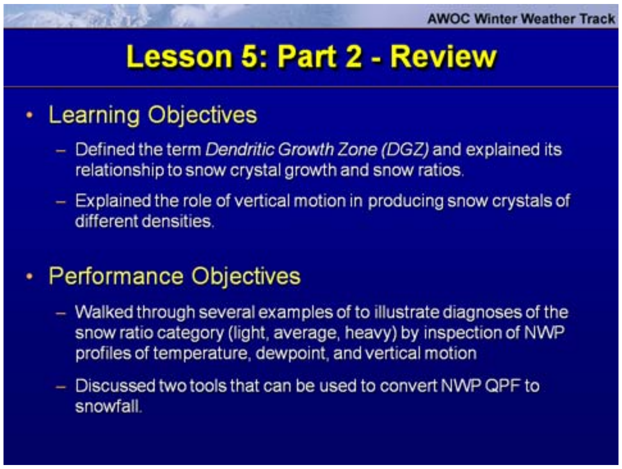
Student Notes:



39. Lesson 5: Part 2 - Review

Instructor Notes: For our learning objectives, We've covered the importance of the dendritic growth zone and the overlap with vertical motions and their implications for snow growth and snow density. For our performance objectives, we applied these concepts by showing how to analyze soundings to determine whether snowfalls will have average, light, or heavy density, and discussed the Caribou and neural net forecast tools which provide calculations of snow density which you can use to determine snowfall accumulations. The sounding analysis and quantitative forecast tools can be combined to provide improved snowfall accumulation forecasts. This concludes the lesson on determining snow ratios-we hope it was interesting and we look forward to receiving your feedback.

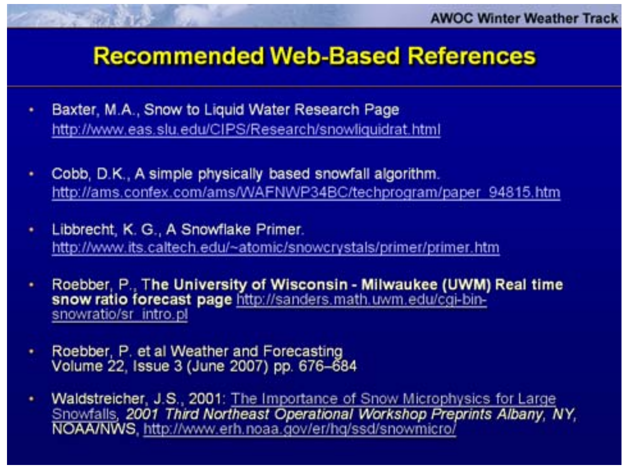
Student Notes:



40. Recommended Web-Based References

Instructor Notes: This is the first of three slides providing the references cited in this lesson.

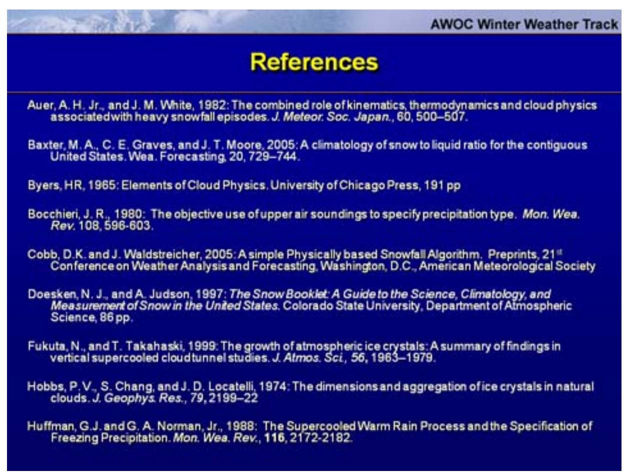
Student Notes:



41. References

Instructor Notes: This is the second of three slides providing the references cited in this lesson.

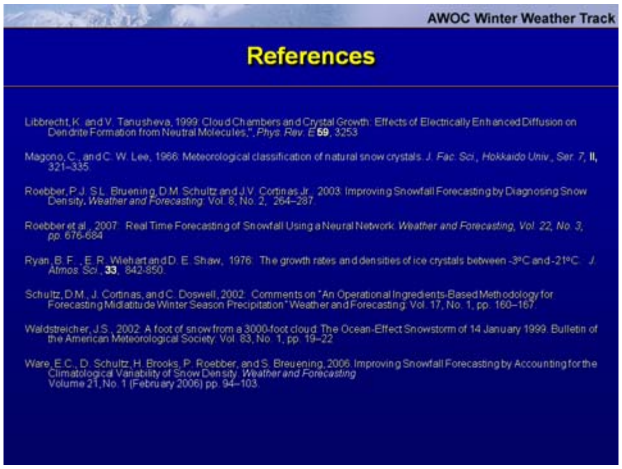
Student Notes:



42. References

Instructor Notes: This is the last of three slides providing the references cited in this lesson.

Student Notes:



43. Questions???

Instructor Notes: After going through this lesson if 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 from what your SOO provided, send an E-mail to the address on the slide. This address sends the message to all the instructors involved with this IC. Our answer will be CC'd to your SOO so that they can answer any similar questions that come up in the future. We may also consider the question and answer for our FAQ page. Thanks for your time and good luck on the exam!"

Student Notes: