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Topic: Winter Weather Applications

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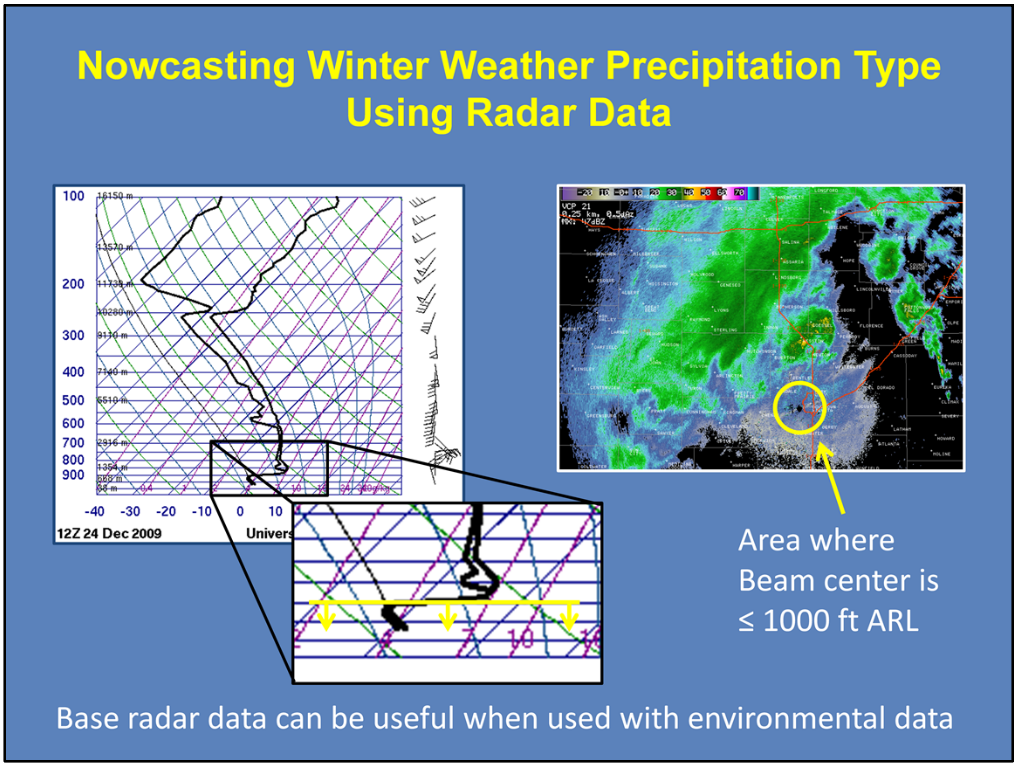
Welcome to this lesson on Winter Weather Precipitation Type Nowcasting. This training is part of the Winter Weather Applications topic in the Radar and Applications Course. Let's get started.

Learning Objectives

1. Identify how base radar data can indicate the presence of a melting layer and/or refreezing layer and their importance in precipitation type nowcasting

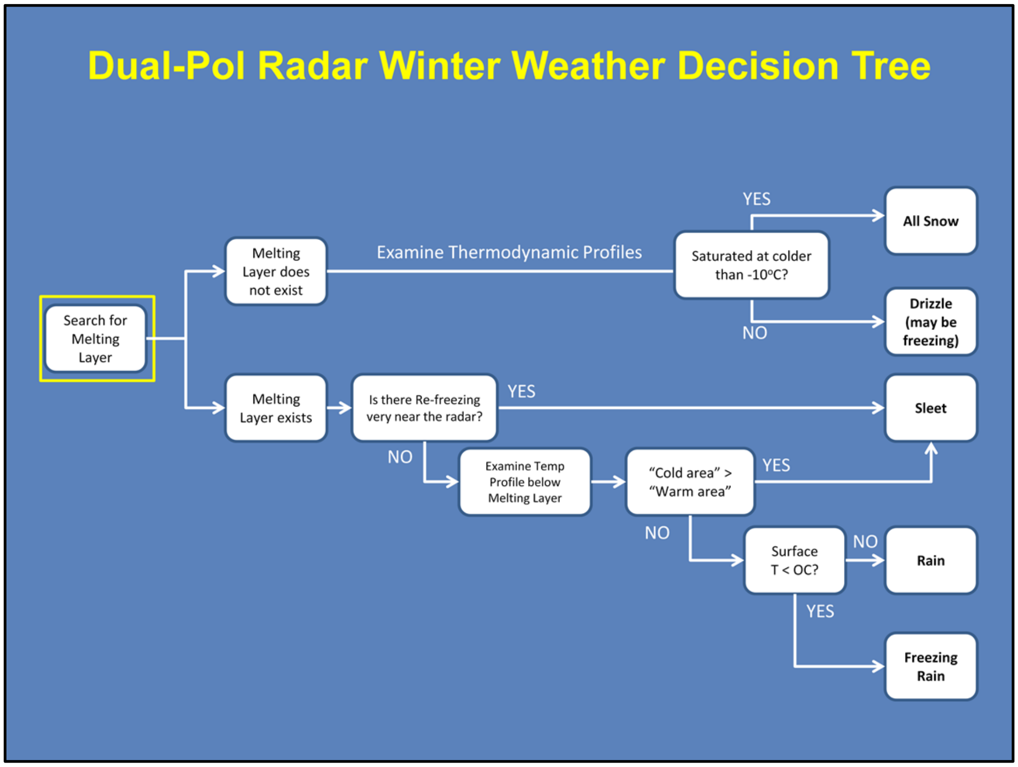
2. Identify the how the following meteorological concepts are important for determining winter precipitation type:
   – Condensation nuclei microphysics
   – Low tropospheric temperature profiles

There are two objectives for this lesson. Please take a few moments to read them over. When you are ready to proceed, advance to the next slide.



Observed winter weather precipitation type at the surface depends upon several factors, with the vertical temperature profile near the surface being particularly critical. As a result, using radar to determine precipitation type is very challenging. On the lowest radar tilt, 0.5 degrees, the center of the radar beam will already be 1000 feet above the radar height at a distance of approximately 10 nm from the radar. So, radar data alone is generally not sufficient to determine precipitation type at the surface.

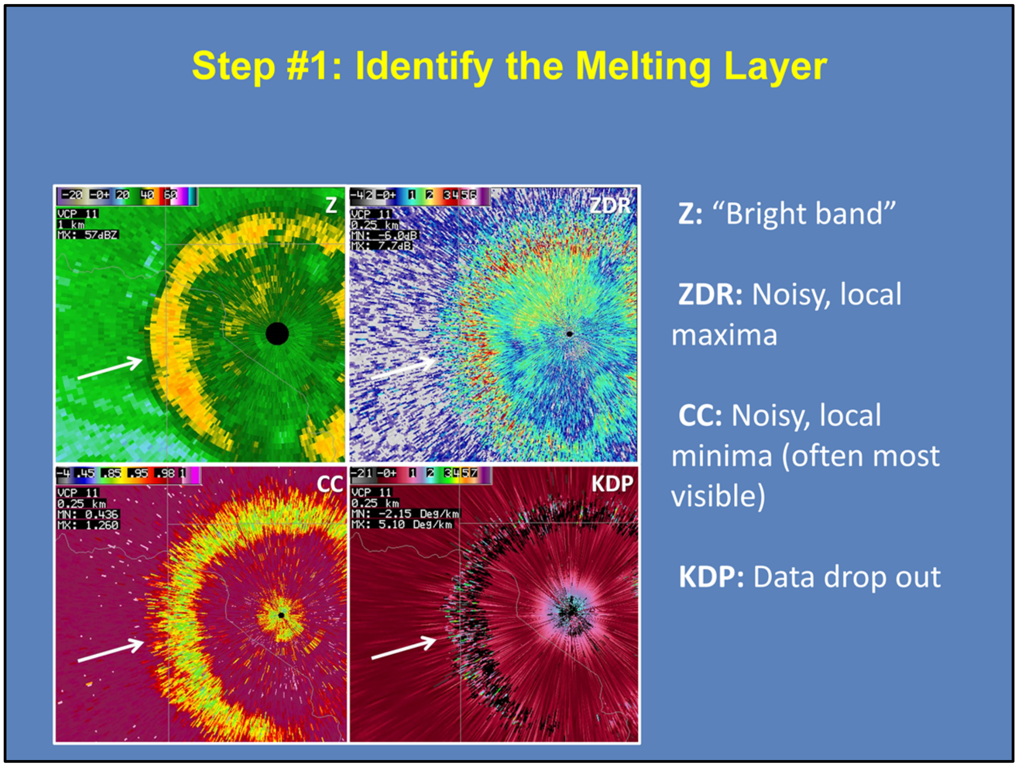
That doesn't mean that base radar data isn't useful for determining precipitation type. Base radar products should be used in conjunction with other available environmental data. Using both radar and environmental data can greatly increase a forecaster's confidence in what precipitation type is occurring at the surface over large areas. Much of the discussion that follows focuses on using Reflectivity and dual-polarization base radar data in conjunction with environmental observations and model forecasts to determine precipitation type at the ground (WDTD, 2011).



To help you, the forecaster, with winter weather nowcasting, we are providing a basic methodology to determine the most likely hydrometeor occurring at the surface. This process involves radar and environmental data used in conjunction with conceptual models from winter weather forecasting.

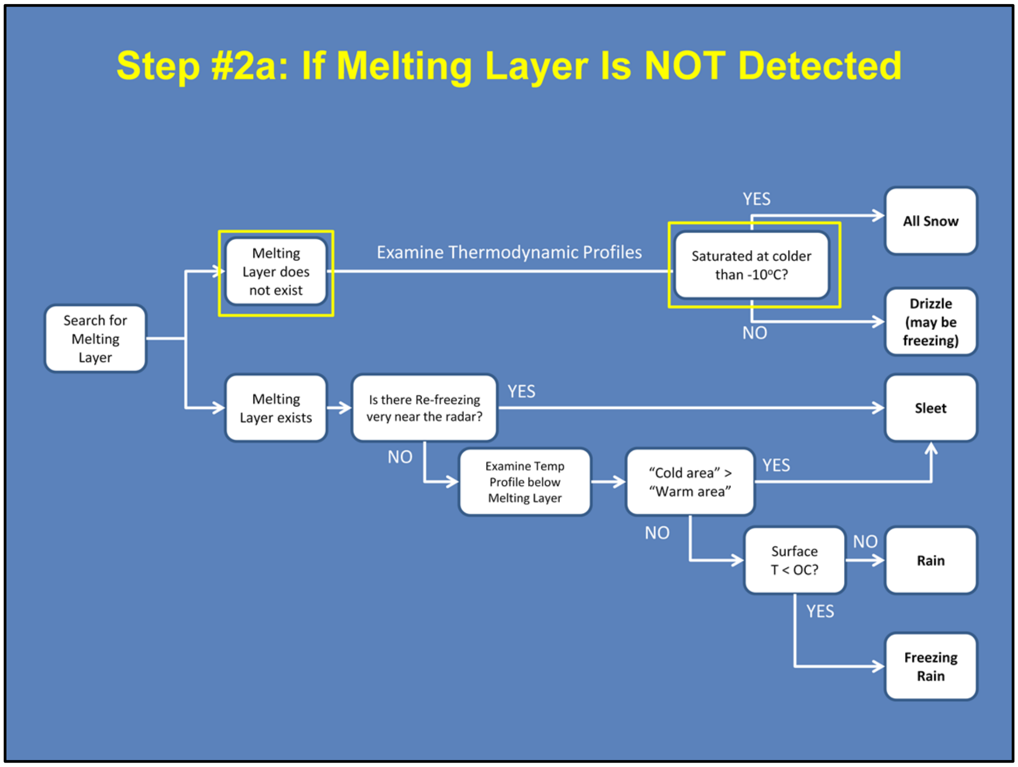
The bulk of this lesson will focus on this methodology. We will try to keep things as simple as possible. As you gain more operational winter weather experience, you will see that there is much more nuance in this process.

With all that said, let's dive in to the first step in the methodology: Searching for a melting layer!



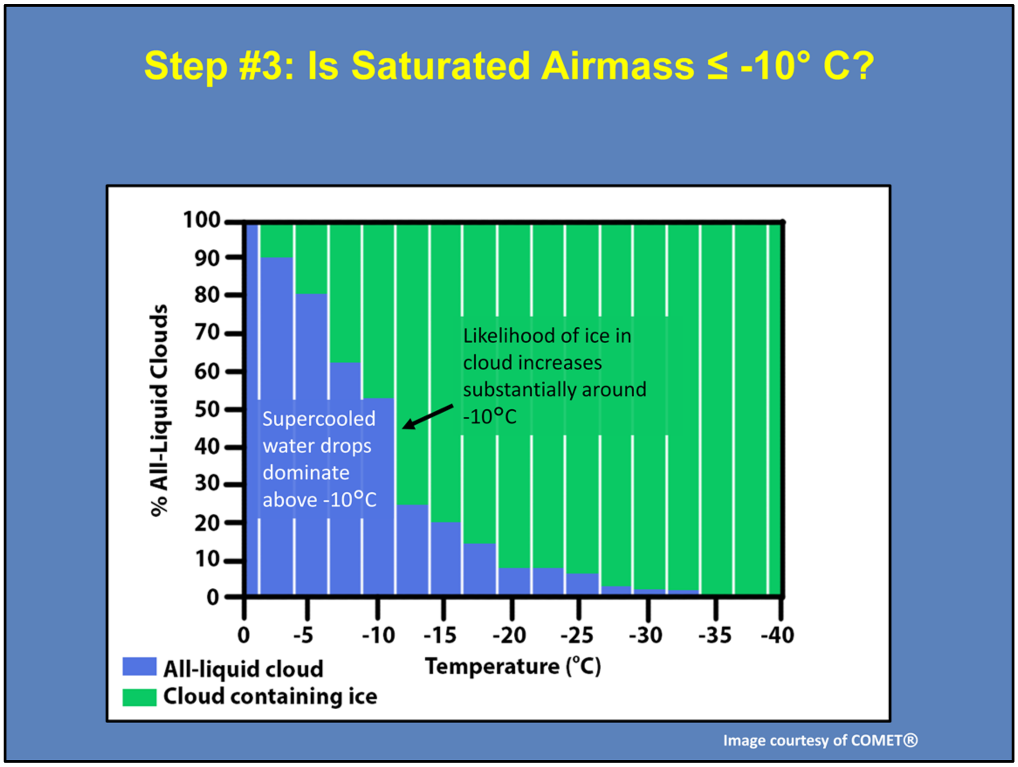
One of the most prominent applications of dual-pol base data in winter weather is the ability to detect a melting layer, when present. The melting layer appears as a "bright band" in Reflectivity (Doviak and Zrnic, 1993). However, this feature can be ambiguous, particularly on lower elevation tilts. The melting layer stands out much more prominently in the dual-pol base data (Sharfenberg and Manross, 2007).

The arrows in the graphics indicate where the melting layer is located in each product. In general, Differential Reflectivity will show a noisy, local maximum in the melting layer as frozen hydrometeors melt and appear to the radar as giant rain drops until they fully melt. Correlation Coefficient, which is often the best product for viewing the melting layer, will show a noisy, local minimum due to the increase in hydrometeor diversity. Lastly, Specific Differential Phase will usually show a data drop out in the melting layer as Correlation Coefficient values often drop below 0.9 in this region.



The next step in the process depends on whether or not you detect a melting layer in the base radar data. If you do not detect a melting layer, it likely means that the environmental temperature profile is completely below freezing. If that is the case, you are limited to two potential precipitation types at the surface: snow or drizzle.

The next couple of slides will discuss how you can differentiate between the two. Before we do, I recommend you double-check your environmental data and make sure the lack of melting layer makes sense. Especially near the surface. The difference between freezing drizzle or liquid drizzle could be a shallow layer (say 100-200 m) of at or above freezing temperatures at the surface.



So why does the next step focus on a saturated air mass at, or colder than, -10 degrees Celsius? The answer involves cloud microphysics and the activation of cloud condensation nuclei (Baumgardt, 2001).

The chart on the slide illustrates it well. Cloud condensation nuclei tend to activate (create hydrometeors) as liquid or ice. Liquid CCN tend to dominate when the minimum saturated air temperatures are between 0 and -10 degrees Celsius. Once those temperatures get to -10 degrees Celsius, it’s about a 50-50 split, with ice dominating when its colder than -10.

As a result, when the saturated air mass creating hydrometeors is warmer than -10 degrees Celsius, you will usually observe drizzle or freezing drizzle at the surface. Which one you get will depend on surface temperatures in that area. When colder, saturated temperatures are present, expect snow.

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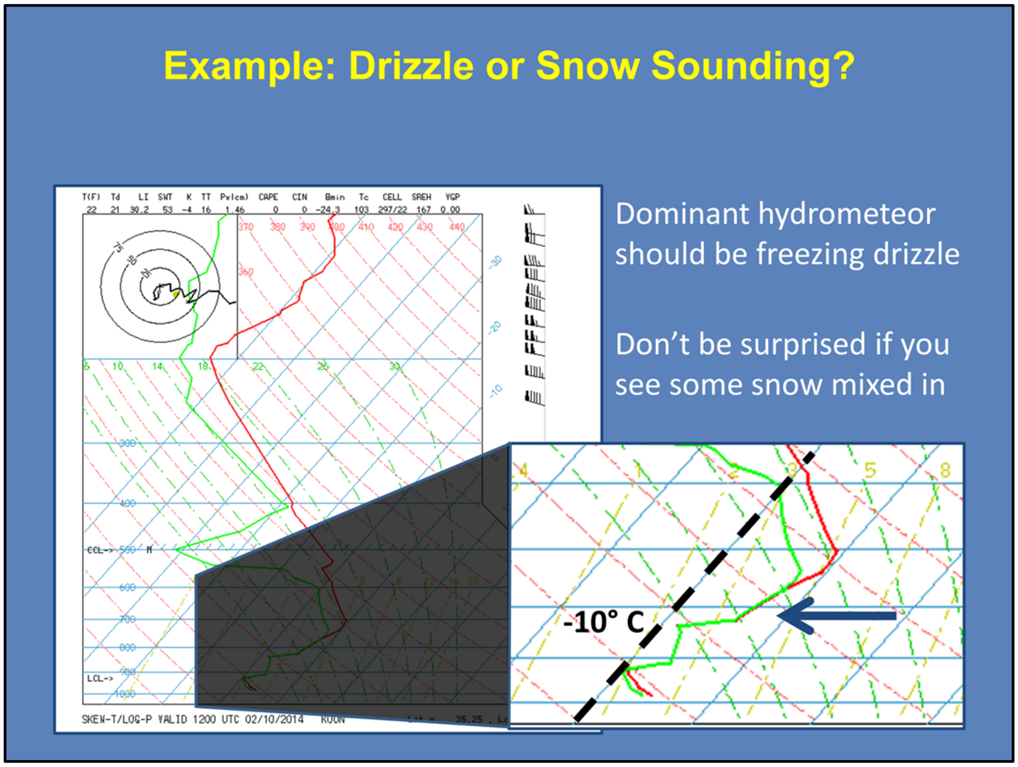

Here is an example sounding to illustrate the decision-making process discussed on the previous slide. This sounding represents a winter air mass that is saturated between 750 mb and the surface. I'll magnify the lower portion of the sounding so you can see the details a little better. The saturated portion of the sounding is between 0° C and -10° C. So, the dominant hydrometeor you would expect from this sounding is freezing drizzle.

Here's an important caveat to remember, especially in a sounding like this where part of the air mass is close to that -10° C threshold. What this process identifies is the dominant hydrometeor. You may see a mixture of snow and freezing drizzle because some ice cloud condensation nuclei have been activated. Those hydrometeors are just in the minority with regards to overall hydrometeor distribution.

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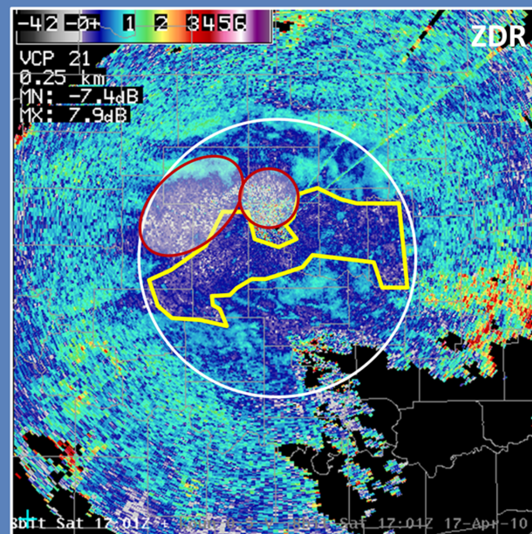
What Will Drizzle Look Like in Base Radar Data?

Very small liquid drops (diameter < 0.5 mm):

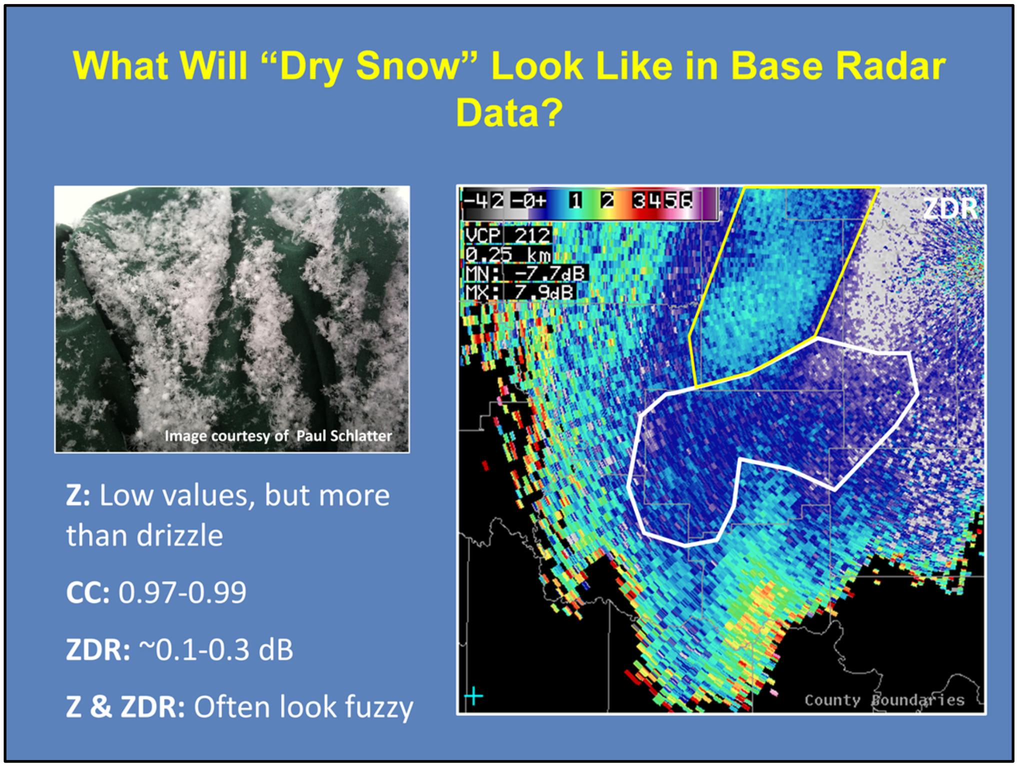
- **Z:** < 20 dBZ
- **CC:** ~ 0.99
- **ZDR:** 0 – 0.2 dB

Spotter confirmation more critical in areas where data quality is poor!



So what might drizzle look like in base radar data? Drizzle drops, by definition, are less than 0.5 mm in diameter. Drops at that diameter appear spherical and fall very slowly. They are associated with low Reflectivity values, generally lower than 20 dBZ. Since drizzle produces such a weak reflectivity signal, expect potentially poor data quality in the dual-pol products, especially at further ranges. If you trust the quality of these products, then expect Correlation Coefficient values to be high, around 0.99. Watchout for areas with CC values above 1.0 in suspected drizzle locations as data quality is poor there. Differential Reflectivity values should be low, between 0 and 0.2 dB. These values would support the generally spherical appearance of small hydrometeors

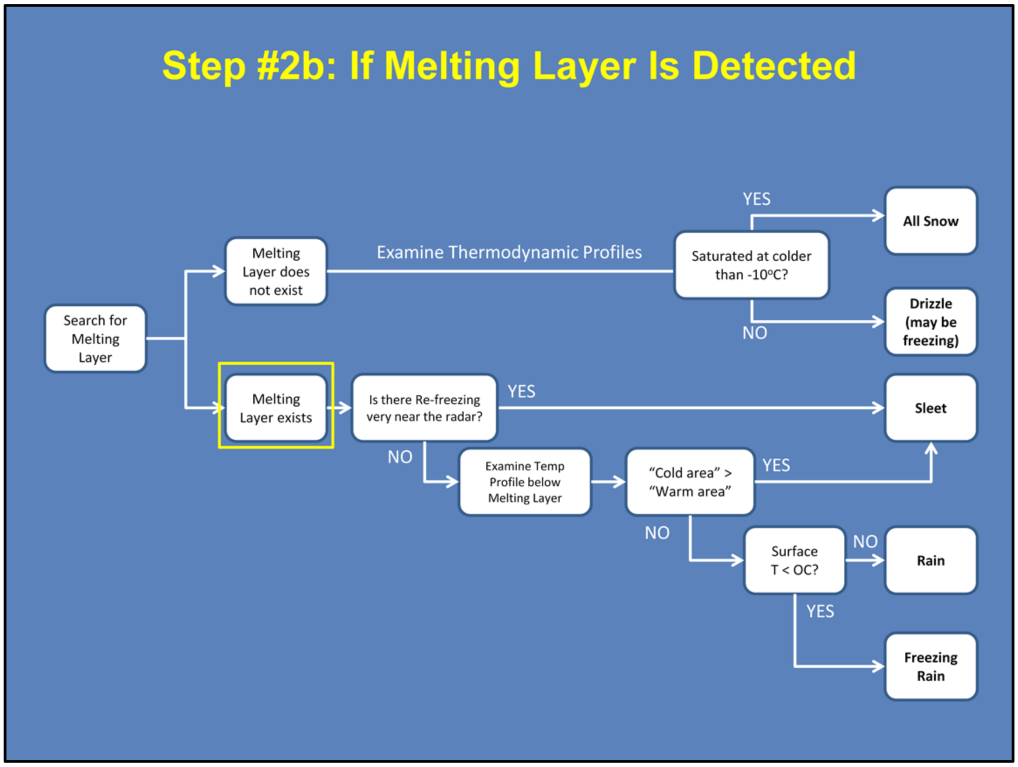
Let’s look at ZDR a little more closely, focusing inside the white circle on the slide. Drizzle was observed at areas inside the yellow polygon at the surface with this event. The slightly higher ZDR values inside the white oval, but outside the yellow polygon were areas of light rain. The areas highlighted in red may have contained drizzle, too. However, the CC values were above 1.0 here. So, we would want some confirmation from observers in this area before we were confident that drizzle was present there.



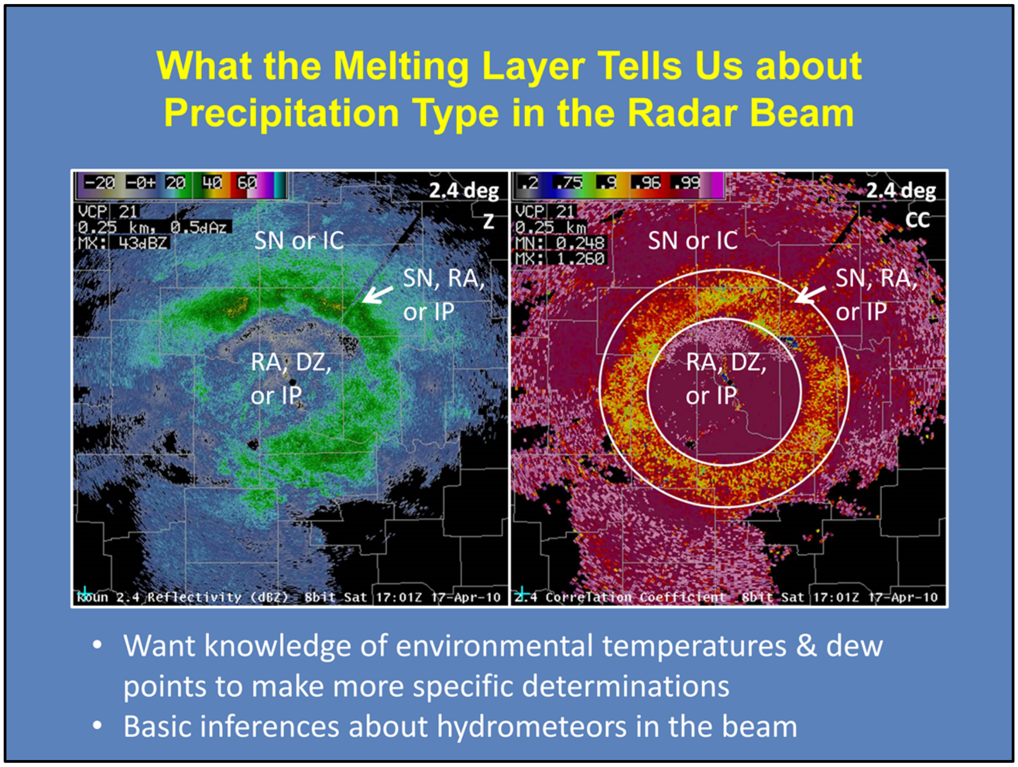
So how does "dry snow", or snow that's not melting, compare to drizzle? Well that will depend on several things, including snow structure, whether the snow crystals are aggregated, and the number of hydrometeors present. This picture shows a variety of pure and aggregated dendrites. You know, the stereotypical snow flake. Dry snow could also include plates, columns, needles and aggregated combinations depending on the environment where the crystals form and fall through.

Dry snow has generally low Reflectivity values, but it can be much higher than drizzle. As high as 40-50 dBZ in extreme cases. Correlation Coefficient values will generally be in the 0.97-0.99 range. So, similar to drizzle but noticeably lower. Likewise, Differential Reflectivity is low, but a touch higher than drizzle. In the 0.1 to 0.3 dB range. Pure crystals can be quite a bit higher than that, like the difference between the yellow polygon and the white polygon.

The last point I would make about snow is in regards to the appearance of the data. Both Reflectivity and Differential Reflectivity will often have a "fuzzy" appearance in areas of dry snow. I know that description is qualitative, but as you look at multiple cases you will get a better understanding of what I'm talking about.



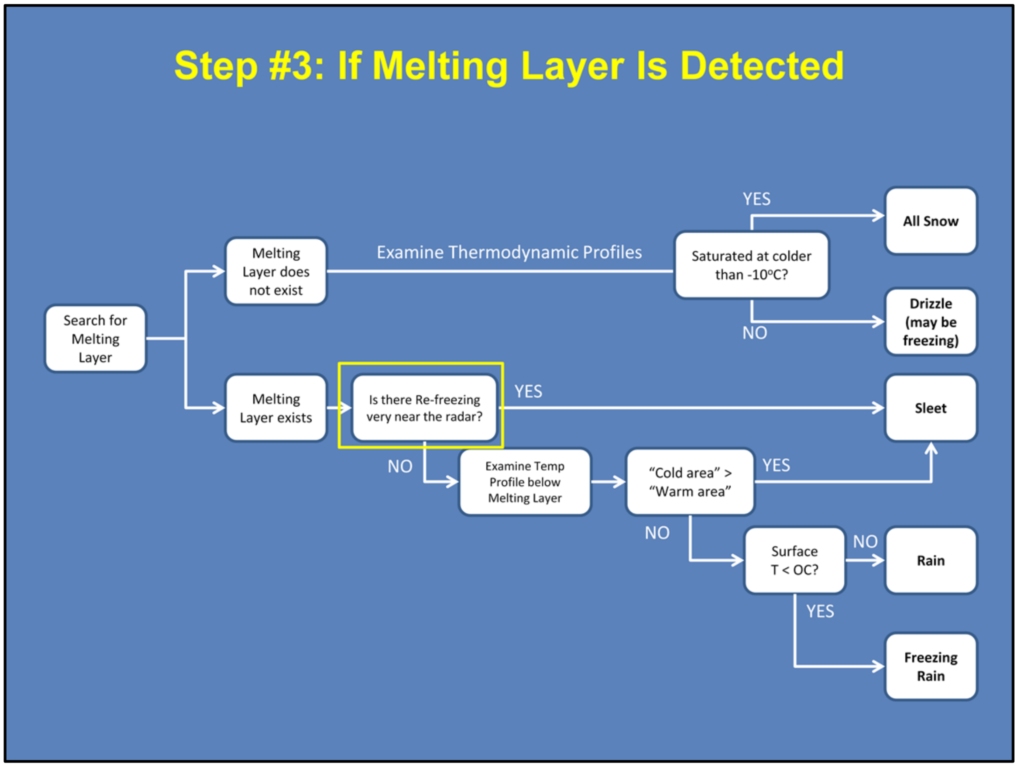
So, those steps cover situations where a melting layer isn't detected. Now let's cover what happens if a melting layer is detected. Before we move on to the next decision-making step, let's discuss what hydrometeors we are detecting in the radar beam (but not necessarily at the ground) when a melting layer is detected.



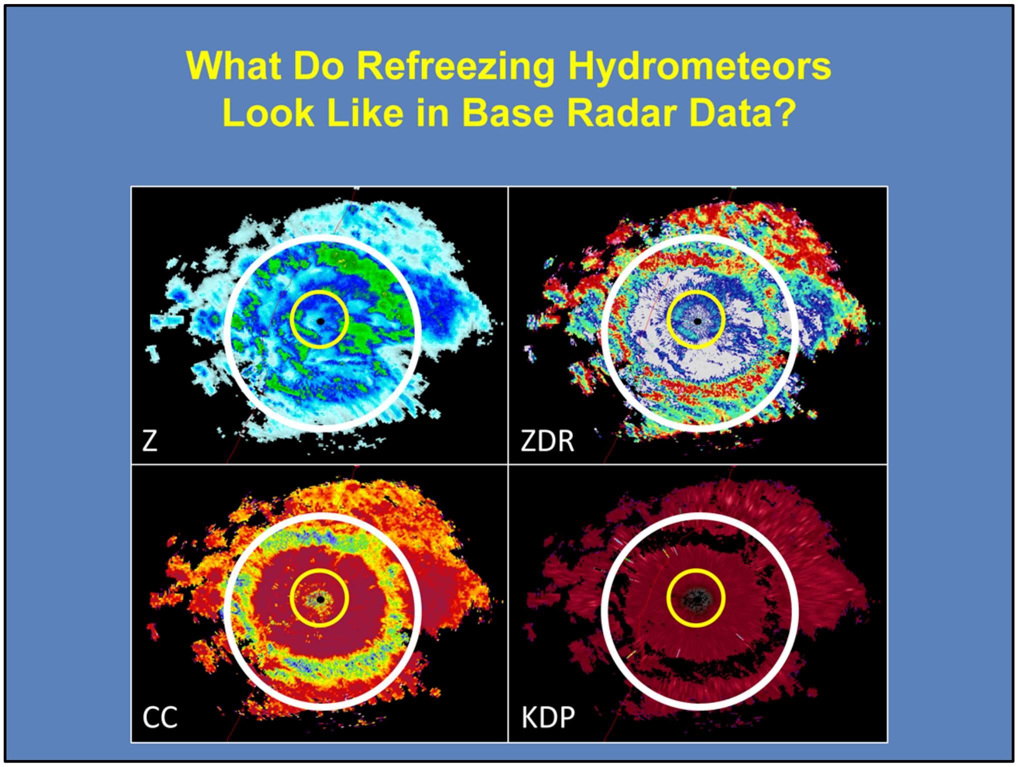
So, when we see a melting layer in the base radar data, what can we really say about the hydrometeors that the radar is detecting. While you always want to have knowledge of the temperature and dew point environmental data, there are some basic generalizations that we can realize from the base data alone.

When a single, well-defined melting layer is apparent in the base data (as in the example shown), we can infer the basic hydrometeor types that are present in the beam. Above the melting layer (or at ranges farther than the melting layer) you should expect some form of frozen hydrometeors. So, snow or ice crystals. Once you get into the melting layer, you will see some form of liquid-frozen mixture. Expect the percentage of liquid hydrometeors to increase as the radar samples towards the bottom of the melting layer. Once you get below the melting layer (or closer to the radar than the melting layer ring), the radar should be sampling some form of liquid hydrometeor. So, rain or drizzle. The one caveat is that you could also be sampling ice pellets or sleet in this area, too.

That sets us up for our next decision point: identifying a refreezing layer in the base data.

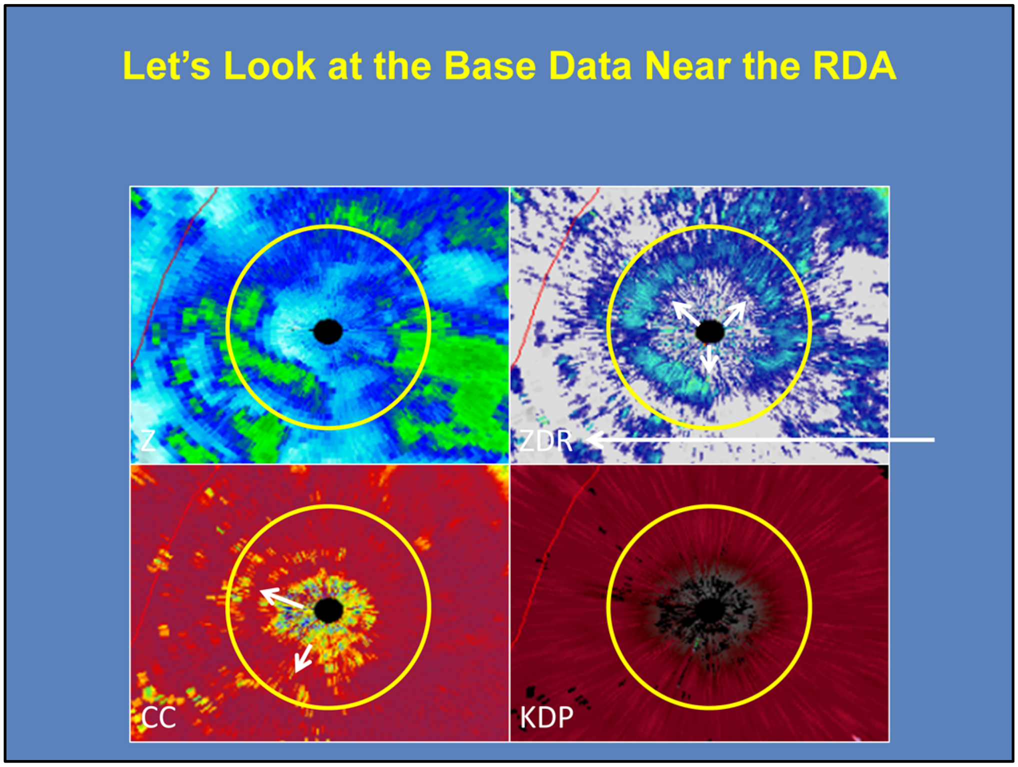


In some circumstances, the base radar data can detect the presence of hydrometeor refreezing near the earth's surface. The next step in our methodology is to check the base data and see if such a signature exists.



So what do refreezing hydrometeors look like in the base radar data? Well, the signature is often subtler than the primary melting layer. It will be easier to explain using an example.

I have a four-panel display on the slide with Reflectivity in the upper left, Differential Reflectivity in the upper right, Correlation Coefficient in the lower left, and Specific Differential Phase in the lower right. All of the products shown were collected at 3.4 degrees. Based on the training you've had so far, you can probably spot the melting layer in the white oval overlay. That signature is straight-forward. I now want to focus your attention on the area in the yellow circle near the radar.



Here are those same graphics, but zoomed in on the yellow circle. The key product to focus in on is Differential Reflectivity. You can see a ring of increased ZDR values almost completely around the radar. The current thinking about why this ring forms relates to how hydrometeors refreeze (Kumjian et al., 2013). The smaller, more circular drops are thought to freeze first. As they freeze, these hydrometeors reflect less energy because their dielectric constant is lower than liquid drops. Therefore, more of the returned power comes from larger drops that tend to have higher differential reflectivity values associated with them.

The other base data products are less functional at detecting a refreezing layer in most cases. Correlation Coefficient is the next best product, where you will usually see a noisy local minimum in values. However, the data field can look very spotty compared to ZDR. Reflectivity values tend to decrease once refreezing begins, leading to a donut-like appearance in values around the RDA. Lastly, KDP provides little assistance at all in identifying refreezing.

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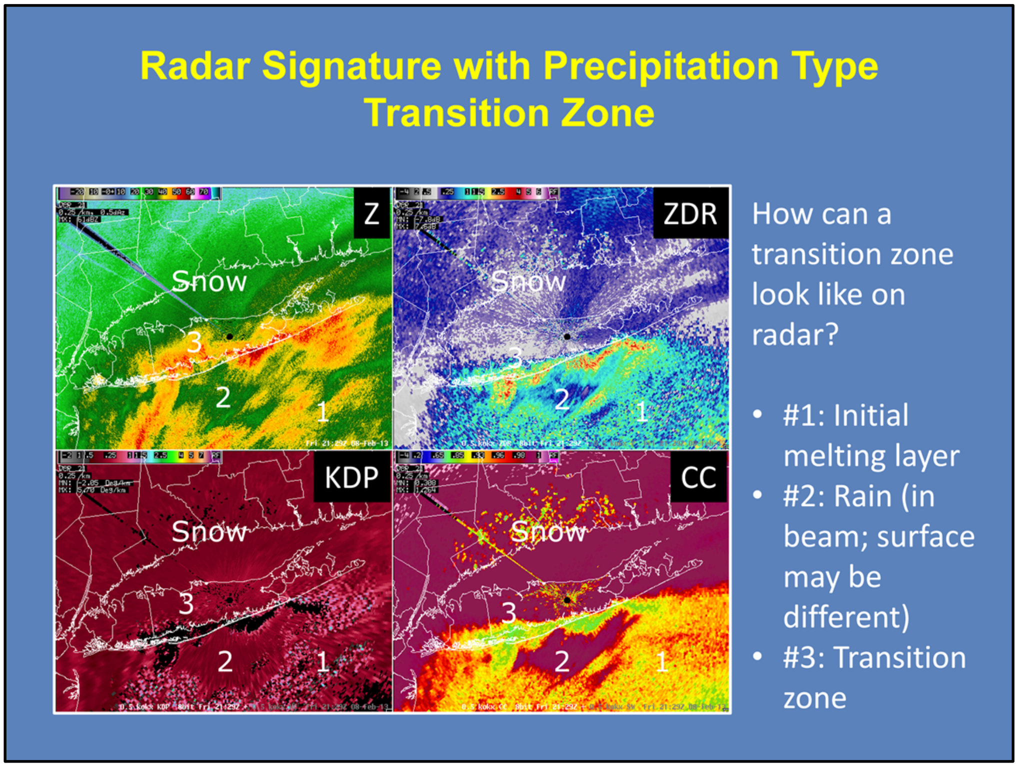

The previous slides present the “classic” refreezing signature. Now lets look at a common, but not so “classic” situation: When ice pellets, or even a narrow transition zone between snow and rain, are located at some distance from the RDA. Let’s show you an example.

The images on the slide show the base data for a nor’easter impacting Long Island with a mixture of winter precipitation. At the RDA and to the north, no melting layer is visible and snow was observed there. Just south of the RDA is a completely different feature. If we look out over the ocean, we see a traditional melting layer aloft with higher Reflectivity, ZDR, and KDP, with lower CC values. Moving inside the melting layer, the parameters change as we would expect inside the melting layer. The hydrometeors sampled by the radar in this area are likely rain, but that may not be what is seen at the surface.

Moving closer to the radar leads to a completely new feature. We see what looks a bright band on steroids! The parameters change just like we would expect in the melting layer, but in a more intense fashion. The maxima/minima are much narrower, too. This feature corresponds to the transition zone between the snow to the north and rain further south. In this narrow transition zone, a mixture of snow and sleet was reported.

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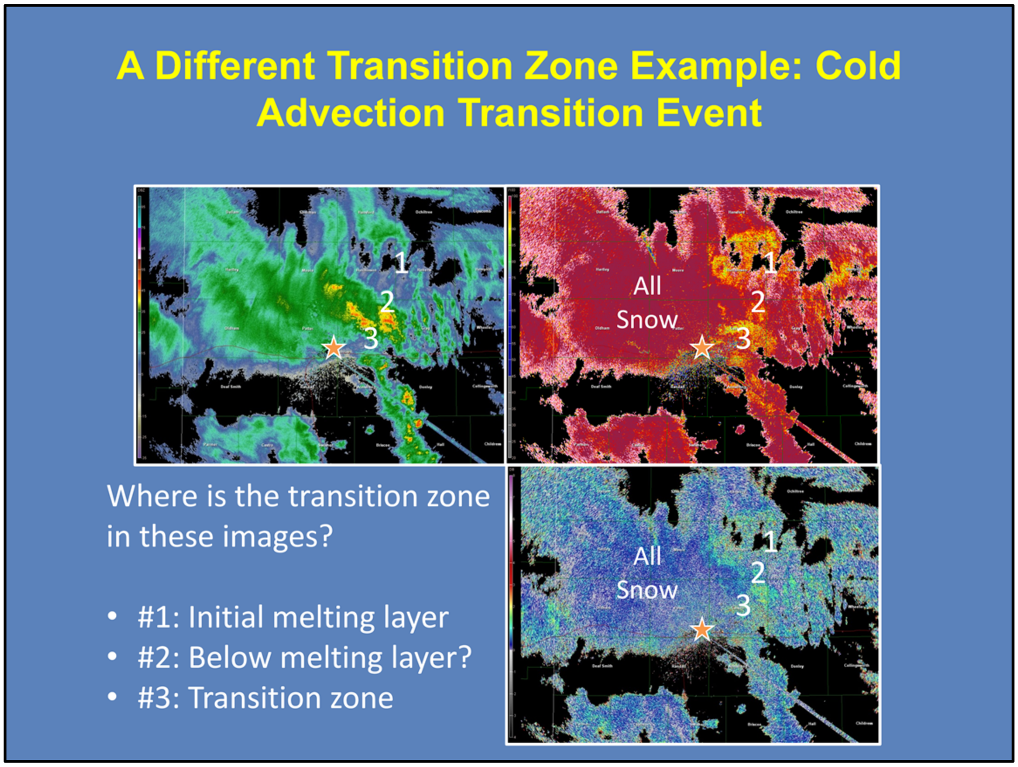
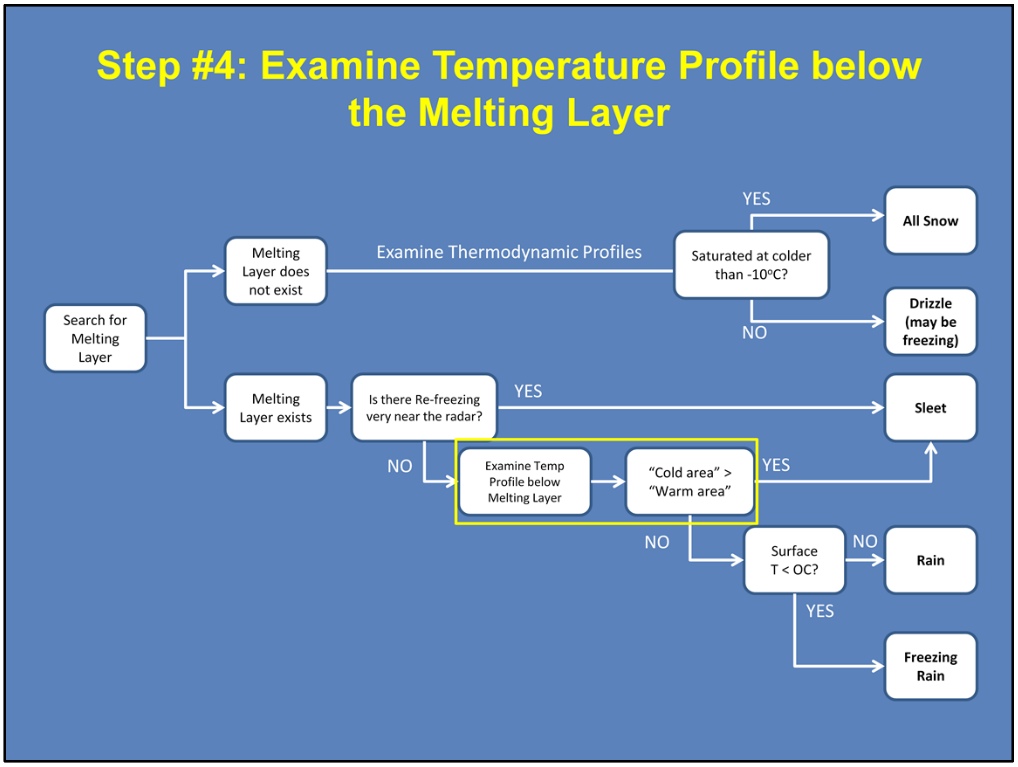
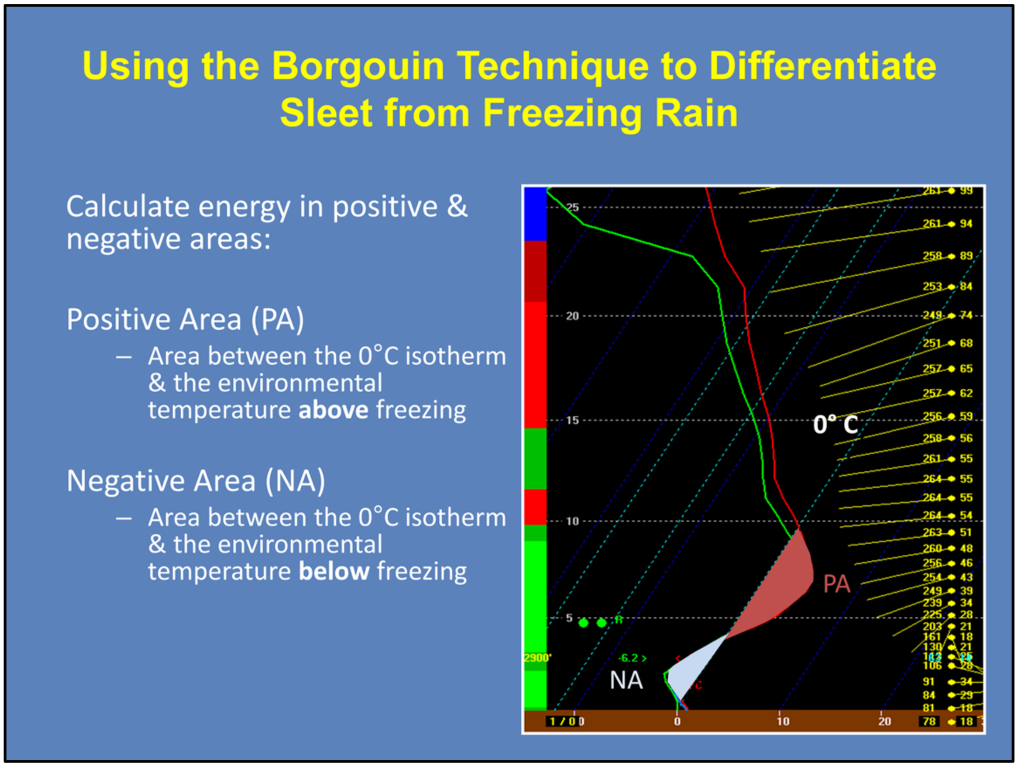


Just so you don't get the idea that identifying transition zones is always easy, here's a different example involving cold advection over the southern high plains. The star on the graphic indicates where the RDA is located. A front is bringing in cold air from left to the right, resulting in a change over from rain to snow from west to east, with a brief period of mixed precip in between.

I'll use the same labels as I did on the previous slide. "1" indicates where the melting layer is aloft. "2" is the area where we expect to see liquid precip in the radar beam. Notice in this example how the Correlation Coefficient and Differential Reflectivity values haven't fully rebounded to what you would normally expect below the melting layer. It's quite possible that the beam never fully samples below the melting layer. In the area of label "3" we see the high Reflectivity and ZDR in the same area as the very low CC values. The transition zone is likely in this area, but it's hard to say with certainty from just the radar data because the precipitation coverage isn't uniform.



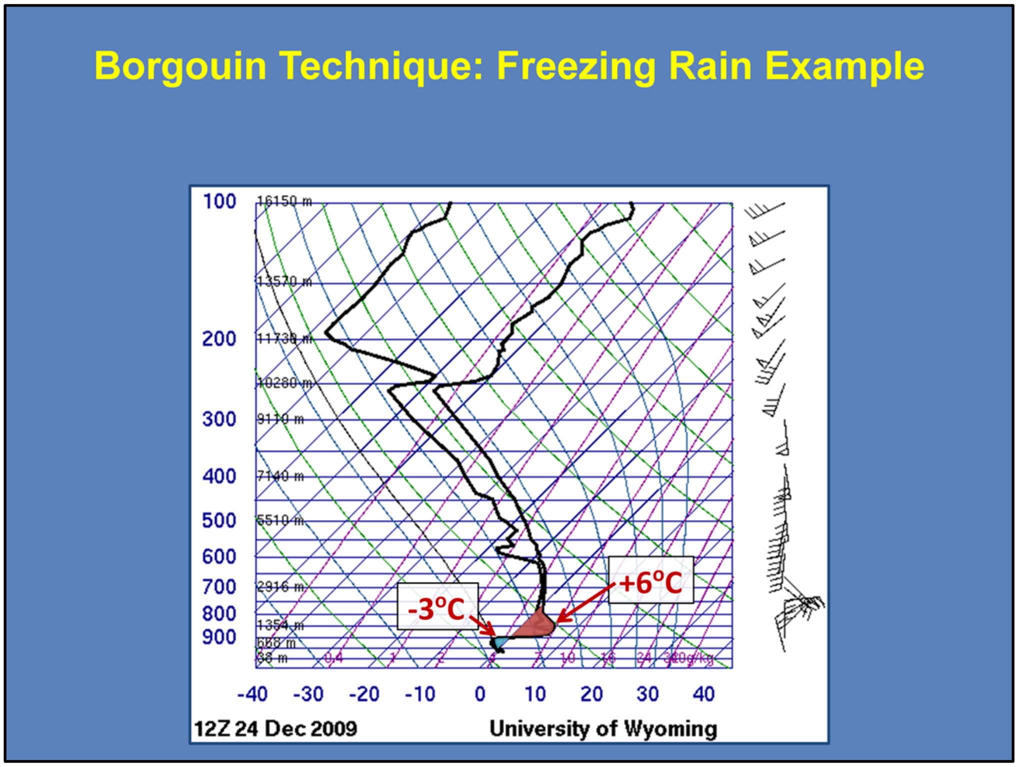
If you can't see a refreezing layer (or even a low-level transition zone) in the radar data, then you will need to look at low-level observed and model soundings to see if sleet is possible.



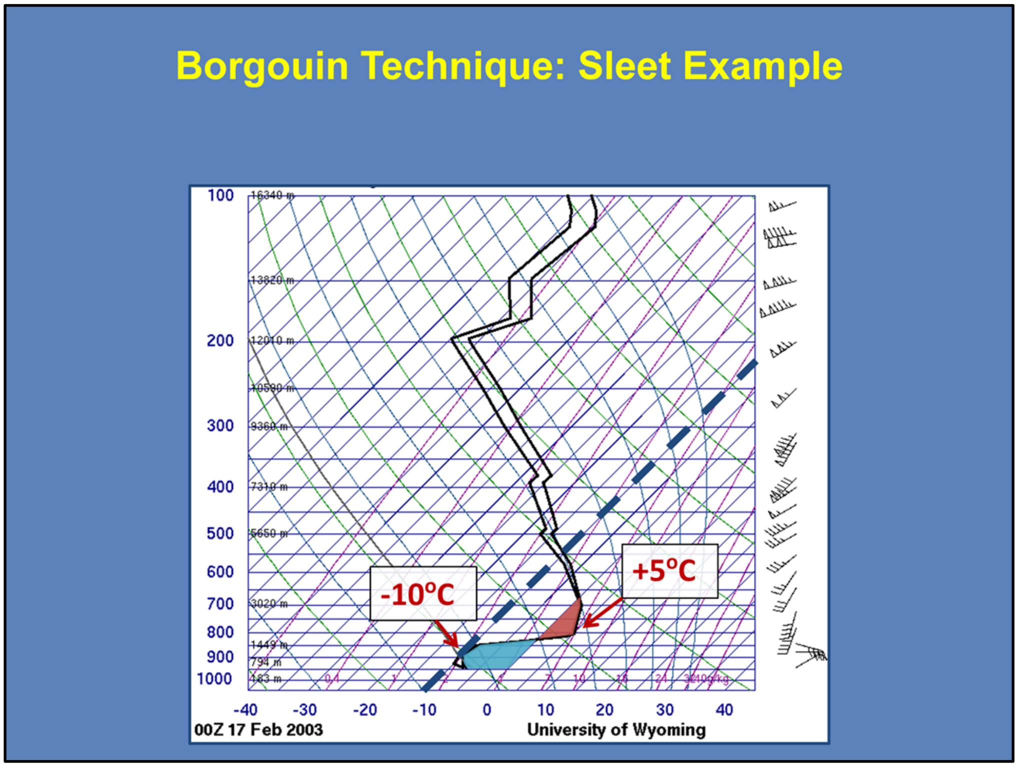
There are multiple techniques that have been published in scientific literature about determining precipitation type. For the purpose of this methodology, we will focus on the Borgouin Technique (Bourgouin, 2000) to identify whether we expect sleet or freezing rain to be observed.

The Borgouin Technique focuses on the amount of energy in positive and negative areas. What are these areas you ask? The positive area is the area between the 0 degree isotherm and the environmental temperature ABOVE freezing. Conversely, the negative area is the area between the same isotherm and the environmental temperature BELOW freezing. Which precipitation type you should expect will depending on the magnitude of these areas relative to each other.

Let’s look at a couple of examples to see how this works.



Here's the first example where we will apply the Borgouin Technique. We'll focus on the portion of the sounding below the highest melting layer. We see the positive area highlighted in red and the negative area highlighted in blue. The positive area is larger than the negative area, which indicates freezing rain should be expected with this sounding.



Here's a second example where will apply the Borgouin Technique. Unlike the previous example, you can see the negative area is much larger than the positive area. This suggests that sleet is likely with this sounding.

One important caveat to remember. Earlier we talked about the cloud condensation nuclei and the importance of -10 degree Celsius. If the saturated air mass in the sounding is completely at or above -10 degrees Celsius, than you should still expect freezing rain even if the negative area is larger than the positive area. If this is the case, then you probably didn't see a melting layer in the base data. Still, you should keep cloud microphysics in mind when analyzing soundings at this point of the methodology as well.

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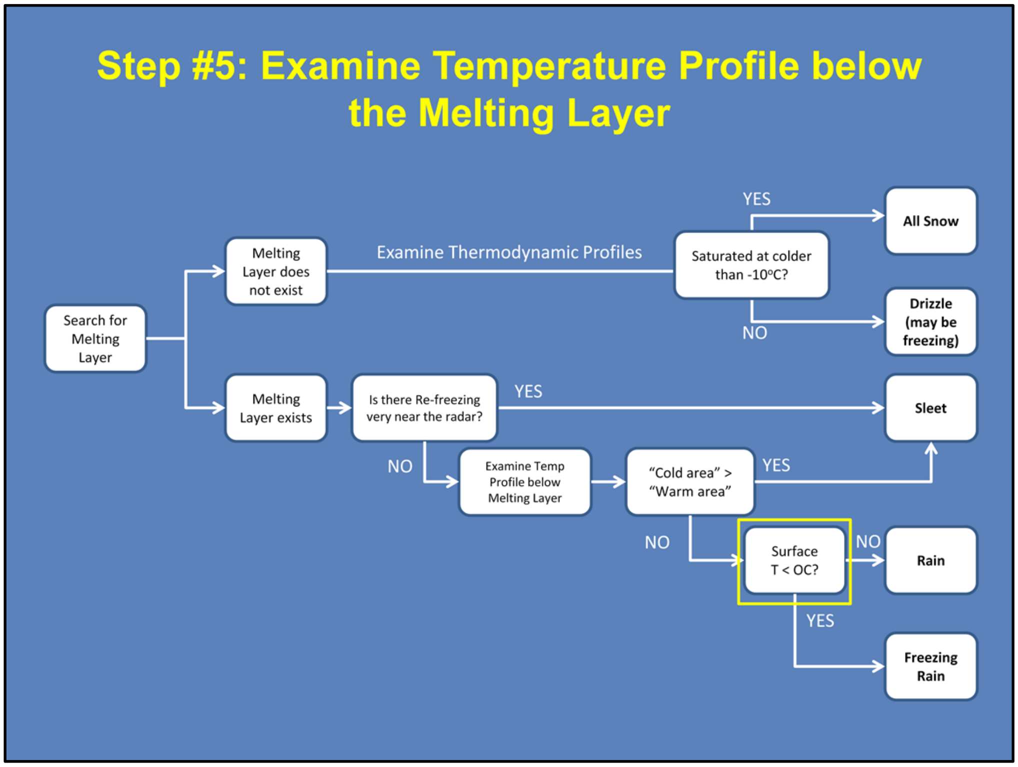

The final step in this methodology is to determine whether you have rain or freezing rain at the surface. To make this determination, you need to look at surface temperatures in the area where precipitation is falling.

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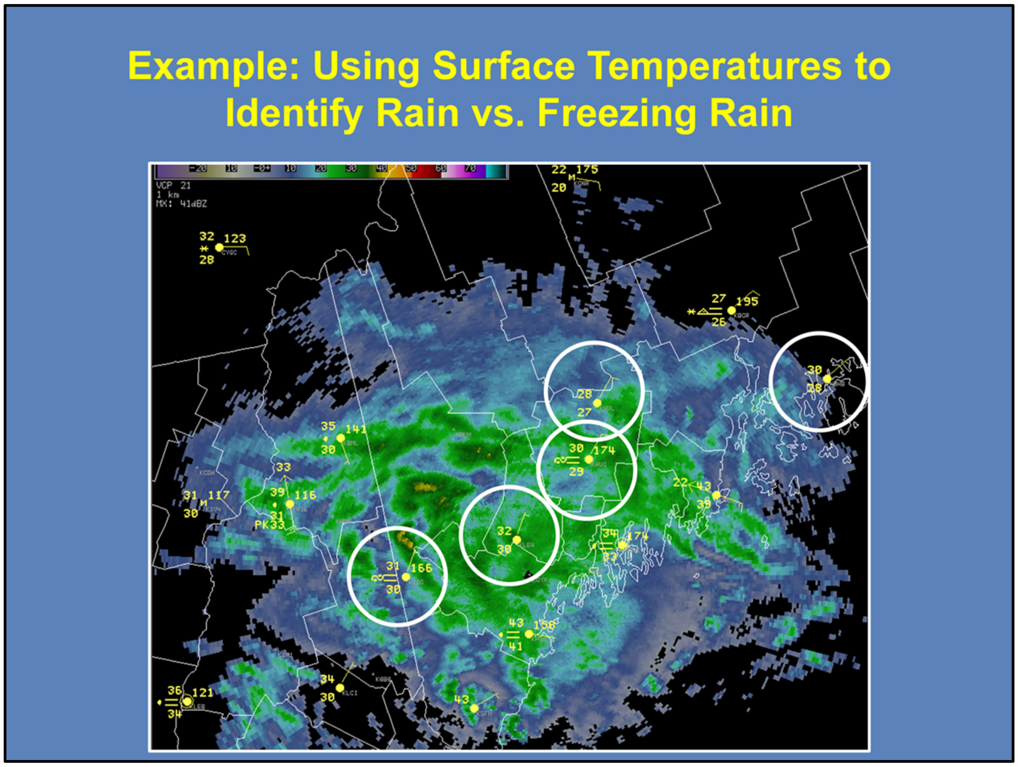
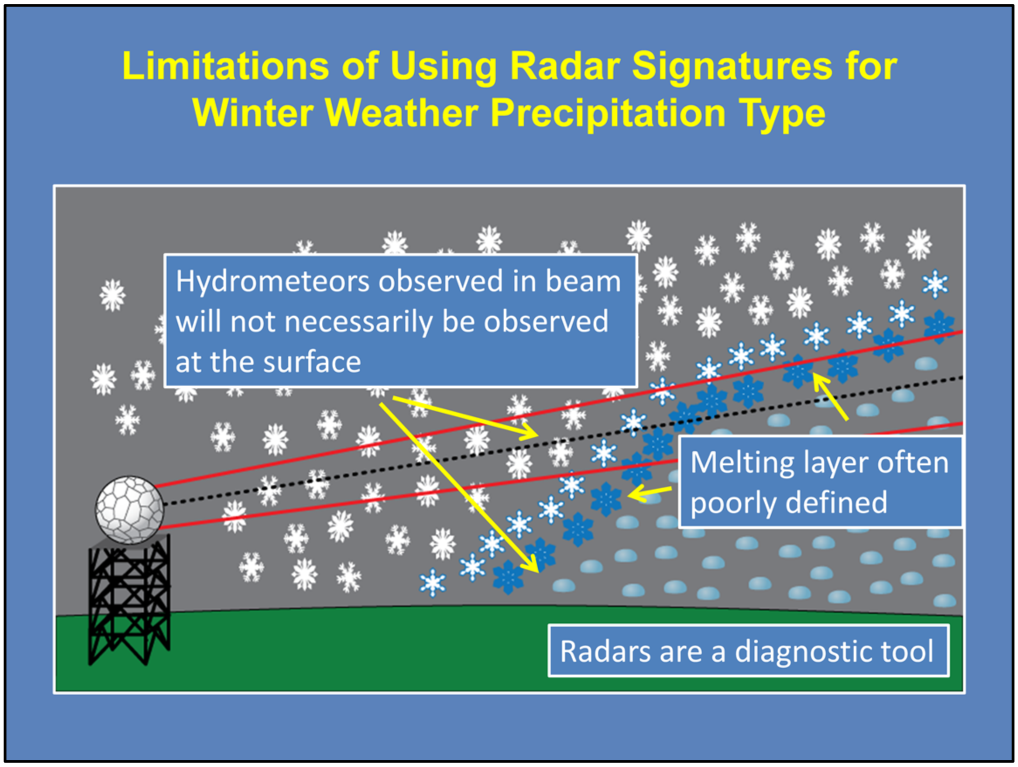


The only way to determine if you are getting freezing rain at the surface is by comparing areas of precipitation with observed surface temperatures. After all, freezing rain is still rain until it comes in contact with a freezing surface.

In the example shown on the slide, we have a broad area of precipitation visible on radar. The surface observations show a range of temperatures from the low 40s Fahrenheit (along the coast to the south) to the low 20s Fahrenheit to the north. In the center of the display, we see four observations in the precip that suggest a broad area of freezing rain is present. It helps that two of the surface observations are reporting freezing rain. However, there are two observations in this same area that are also below freezing. The observations along the coast are all above freezing except way to the east in Bar Harbor. These observations are consistent with shallow cold air damming along the southern side of the Longfellow Mountains in Maine, a classic set up for freezing rain in this area.



While we have covered our methodology to its logical completion, I want to remind you of some basic limitations for using radar data to diagnose precipitation type. The most obvious one for this topic is below beam effects. The hydrometeors detected in the radar beam will not necessarily be the same as what is observed at the surface due to below beam effects. Another limitation to remember is that the melting layer is often not well defined during winter weather events, especially when conditions are changing rapidly or when the 0 degree isotherm is strongly sloped. Lastly, remember that radars are a diagnostic tool. Radars alone cannot be a substitute for a detailed and thorough environmental analysis.

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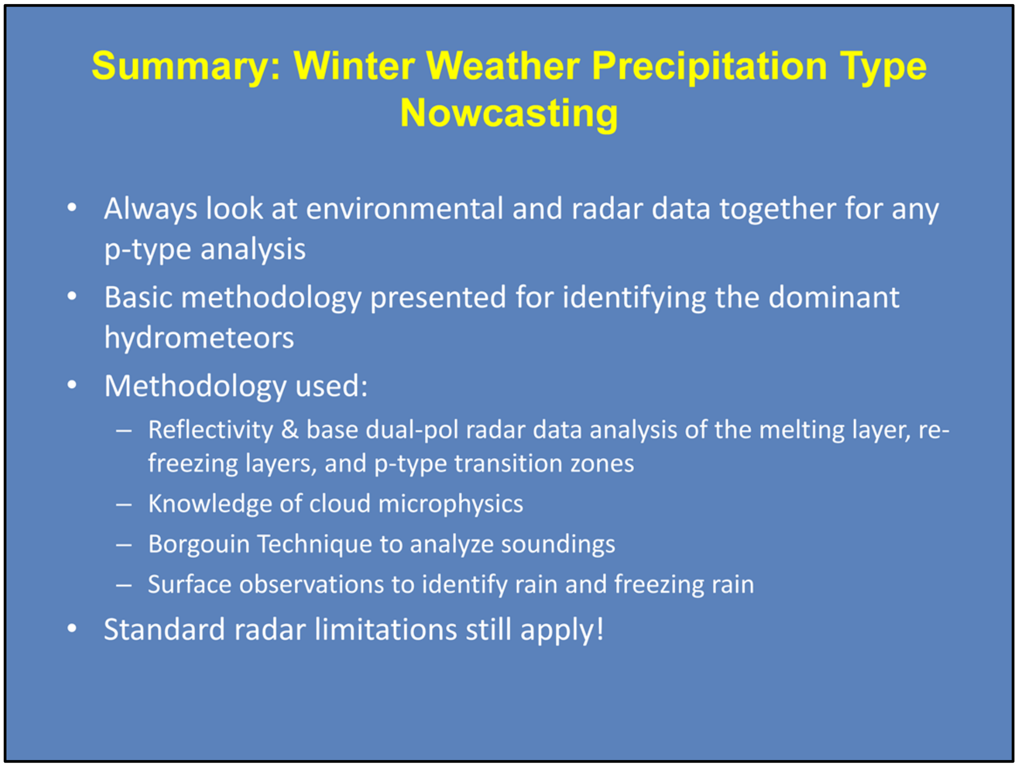

In summary, this lesson discussed how forecasters can use environmental data and radar data together to perform a rudimentary precipitation type analysis. It's important to use these data together as radar data alone will not provide the needed context for a thorough investigation.

I provided a simplistic methodology for determining the dominant hydrometeor in a given area. Remember that more than one hydrometeor type may be present in some circumstances. The methodology focused on four items. First, using Reflectivity and dual-pol base data to identify a melting layer and look for refreezing layers and precipitation type transition zones. Second, having a rudimentary understanding of cloud microphysics to know when liquid or frozen hydrometeors are more likely. Third, using the Borgouin Technique to analyze the portions of a sounding below the melting layer to determine if sleet or freezing rain is more likely at the surface. Lastly, we used surface observations to distinguish areas of rain from freezing rain. Since this methodology relies on radar data, it's important to remember that the standard radar data limitations apply.

The next slide contains the quiz for this lesson. You will need to get a score of 70% or higher to receive completion credit for the lesson.

If you have passed the quiz, then you have successfully completed this lesson. If you have any questions, please contact us using any of the e-mail addresses listed on the bottom of the slide.

Welcome to the winter weather applications lesson on snowfall nowcasting. This lesson should last about 35-40 minutes.

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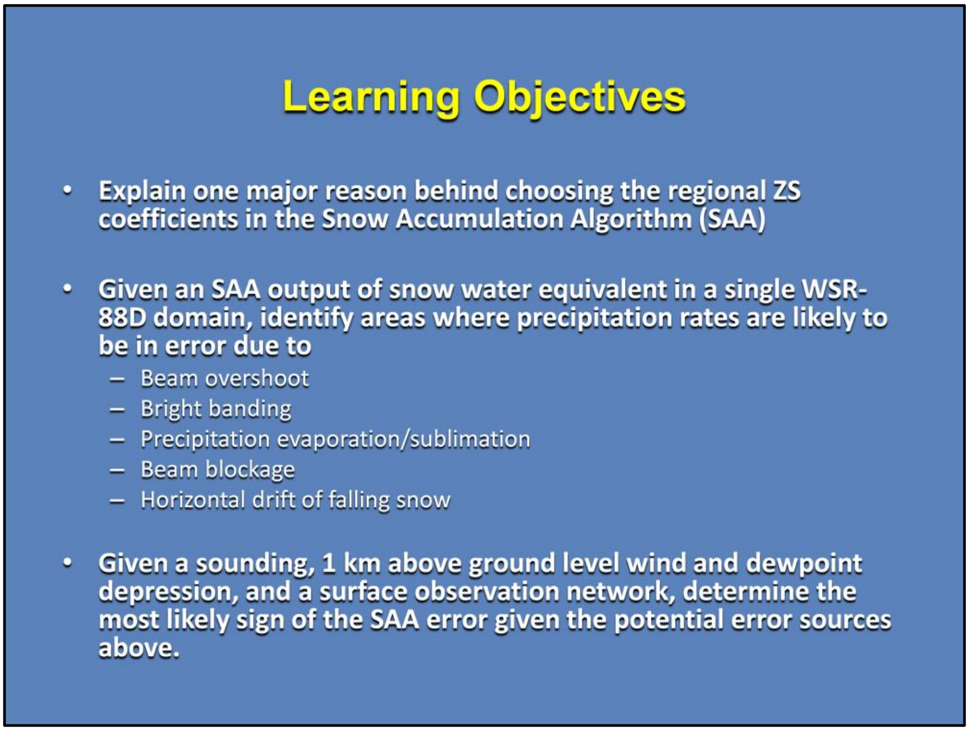

Explain one major reason behind choosing the regional ZS coefficients in the Snow Accumulation Algorithm (SAA)

Given an SAA output of snow water equivalent in a single WSR-88D domain, identify areas where precipitation rates are likely to be in error due to

- Beam overshoot
- Bright banding
- Precipitation evaporation/sublimation
- Beam blockage
- Horizontal drift of falling snow

Given a sounding, 1 km above ground level wind and dewpoint depression, and a surface observation network, determine the most likely sign of the SAA error given the potential error sources above.

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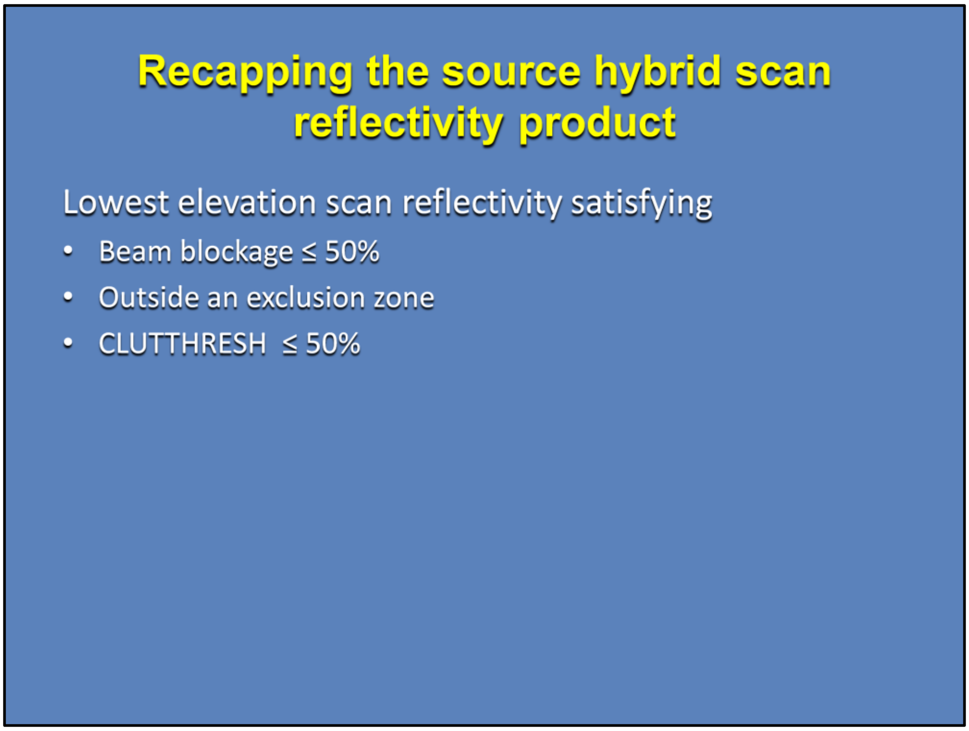

As a review, the snow algorithm depends on the hybrid scan reflectivity product. Recall that this product is generated from the lowest elevation scan reflectivity that satisfies three criteria, less than or equal to 50% beam blockage, outside an exclusion zone, and the clutter threshold less than or equal to 50%.

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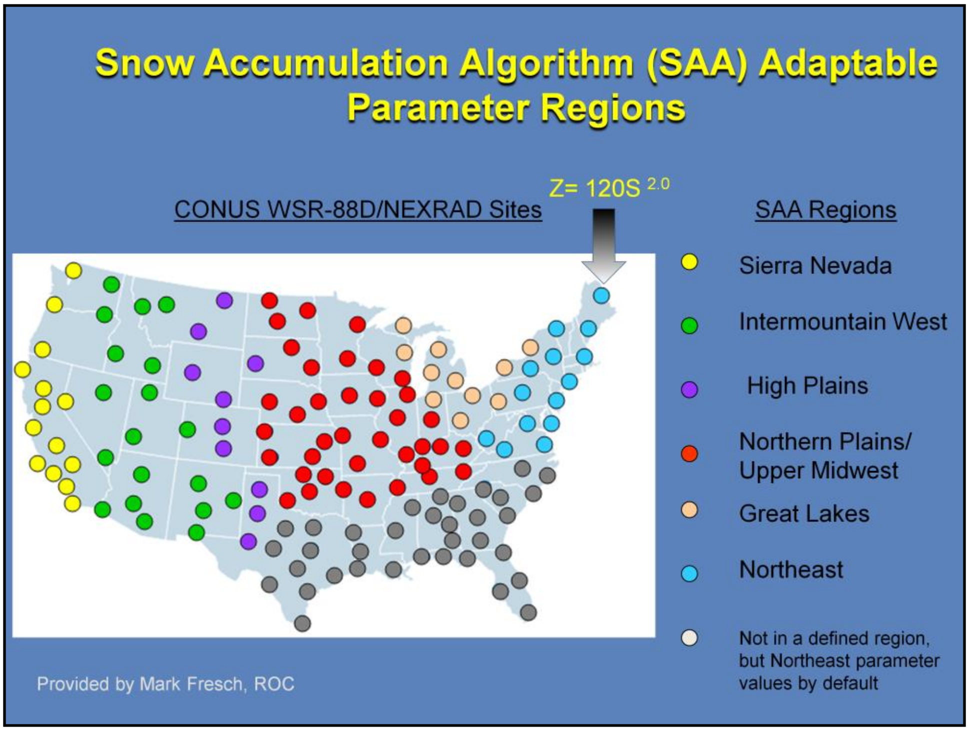
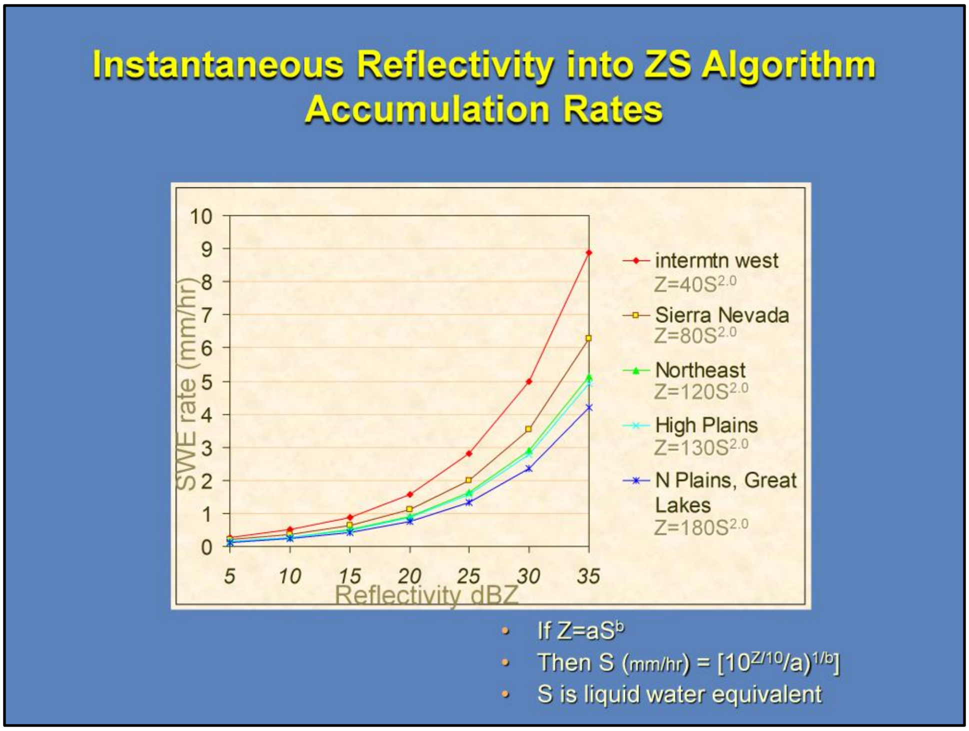


The ZS algorithm, was first deployed in the RPG in 2004. The Bureau of Land Management worked with the NWS to determine the most appropriate ZS algorithm for geographical regions. A representative office in each geographical region was the site of a one or more season's worth of high quality snow spotter data, where spotters not only sample snow depth but liquid equivalent too. After enough data has been collected, Super and Holroyd (1997) fixed the alpha and beta coefficients to one value that represents the minimum error between radar snowfall estimates and ground truth. Adjacent offices are also assigned these same coefficients based on the assumption that similar climatic conditions as the focus office exist, too.



The default output of the ZS algorithm is liquid water equivalent rate in mm/hr. However, the ZS algorithm output will provide accumulated products of both liquid water equivalent and snow depth, both in English units. By the way, the snow depth will be derived using a fixed snow-to-liquid ratio. The ZS algorithm results show an exponential increase in snowfall rates with reflectivity for any region. The default coefficients are fixed over regions, however the weather is not. Variations in many factors can cause deviations from your default ZS algorithm settings.

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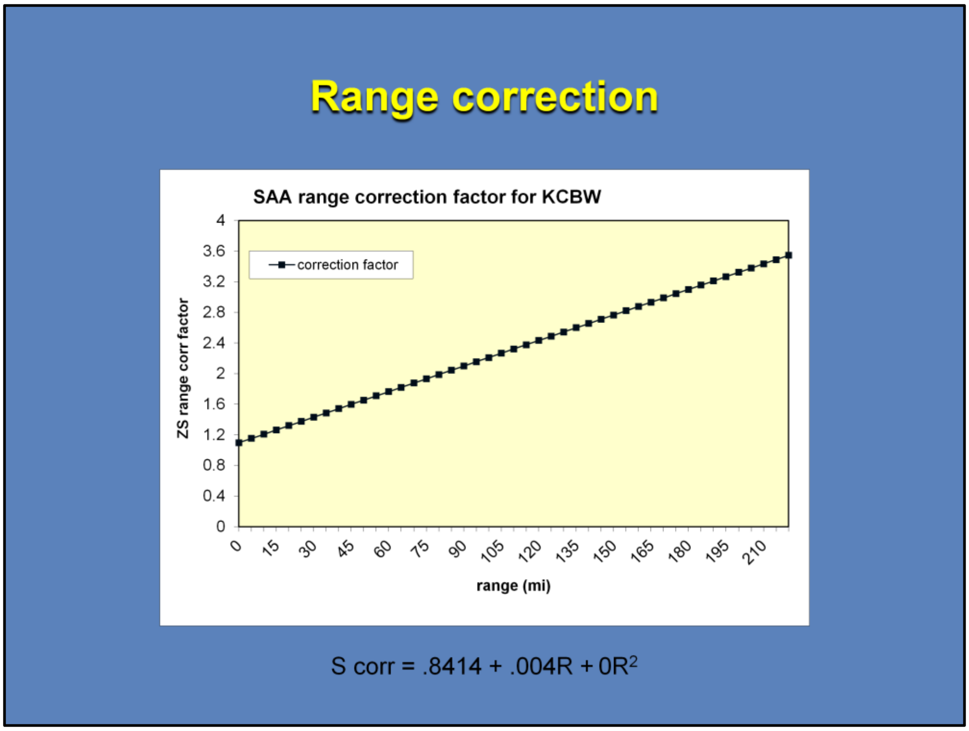

The SAA applies a range correction to the estimates in order to compensate for the most obvious source of error of snow fall estimates. While the correction can use a second order polynomial, the last term is often neglected yielding a linear correction factor ranging from 1 at the radar and increasing to more than 3 at 200 mi. For all practical purposes, this correction is meaningless when the radar beam lifts above all precipitation echoes, which often occurs well short of the maximum theoretical range.

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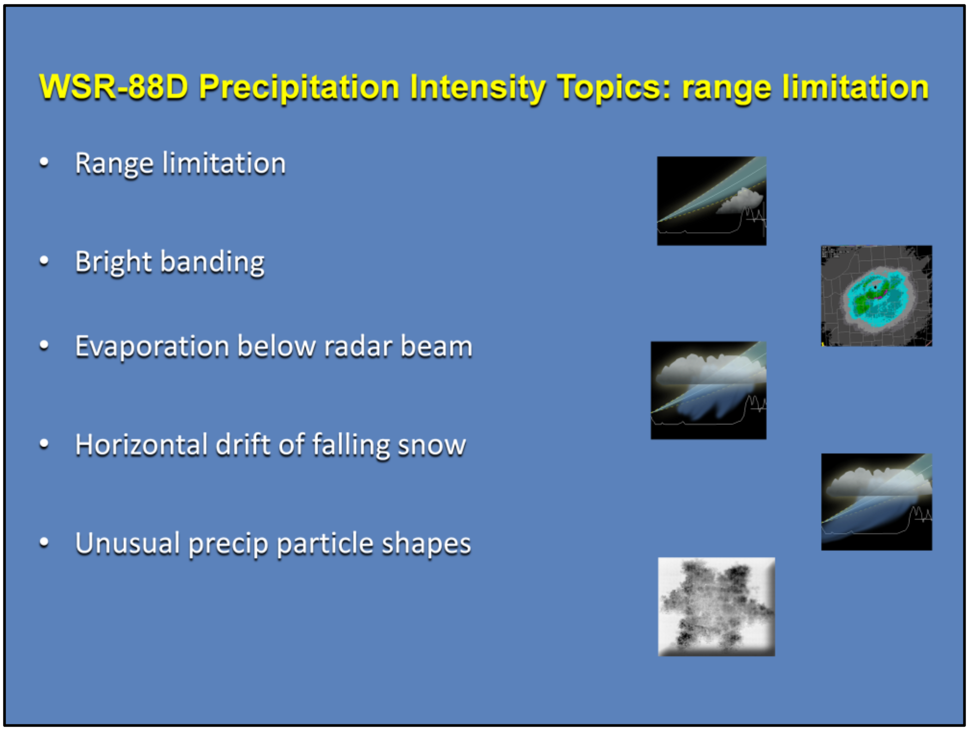
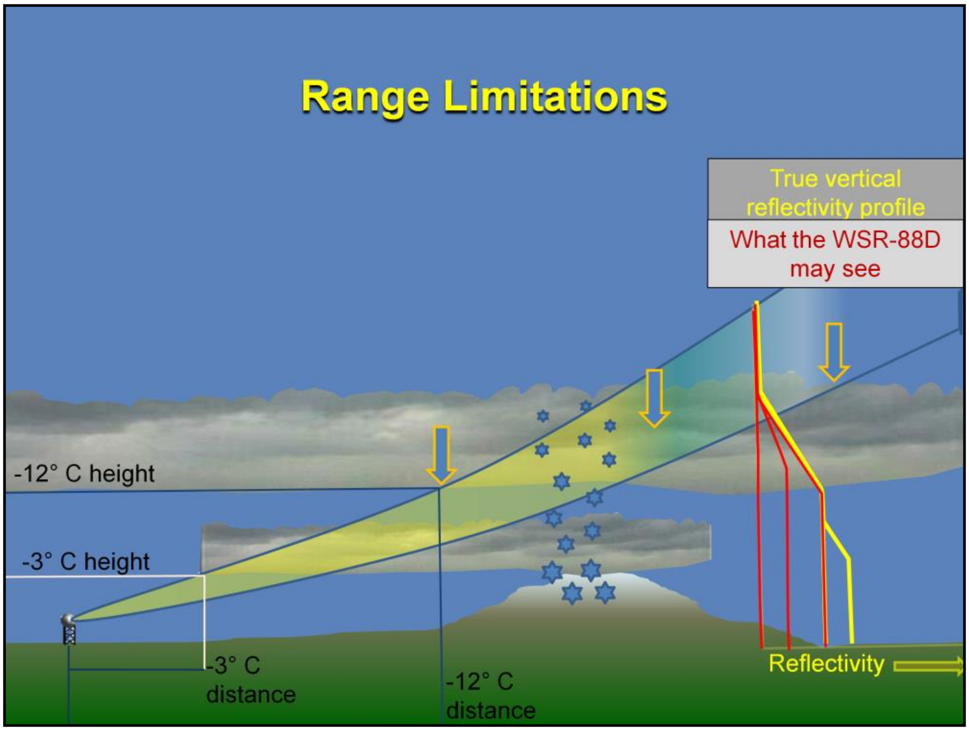


Five considerations adversely affect good precipitation estimates, and especially snowfall. Limited range becomes exacerbated in the winter when cold temperature microphysics routinely occur closer to ground. Bright banding becomes more of an issue as the freezing level is low enough to interfere with the hybrid scan selection. Evaporation below the lowest radar beam increases errors even at short range and magnifies as range increases.

Two more error sources include horizontal drift of falling snow and then unusual precipitation particle shapes. Both I'll explain later.



Assume we have a cloud pictured here actively generating precipitation so precipitation intensity increases going down through the cloud. Then if a radar was pointing up from underneath, the best vertical reflectivity profile shows increasing values as precipitation forms near cloud top and grows as the particles fall through the cloud followed by no growth as the precipitation falls out of the bottom of the cloud. Let's assume the reflectivity profile is the same everywhere under this cloud.

Now a WSR-88D from some distance away will detect all of the precipitation as long as the entire beam is below the precipitation production layer. Reflectivity begins to degrade once the top end of the radar beam climbs above the lowest part of the precipitation production layer because part of the beam is now sampling lower reflectivities. You're guaranteed to lose the signal once the bottom end of the beam departs the precipitation region.

The precipitation generation region is difficult to quantify. One definite zone is the maximum growth layer for dendrites (e.g., the -12 to -18 degrees C layer).

However, the presence of high cloud liquid water content in zones warmer than the dendritic growth layer but still below freezing can contribute significant amounts of riming and needles. In warmer saturated regimes, the collision-coalescence becomes active, too. Even the dendritic production layer can be fairly low in very cold weather, even near ground level. All of these precipitation production zones can be shallow and, therefore, cause reflectivity degradation at close ranges to the radar. As a side bar, orographic precipitation can occur very close to mountain sides. The WSR-88D has an exceedingly difficult time separating ground returns from real precipitation when both occur within a range gate. Clutter filtering can reduce or eliminate precipitation in range bins also containing clutter.

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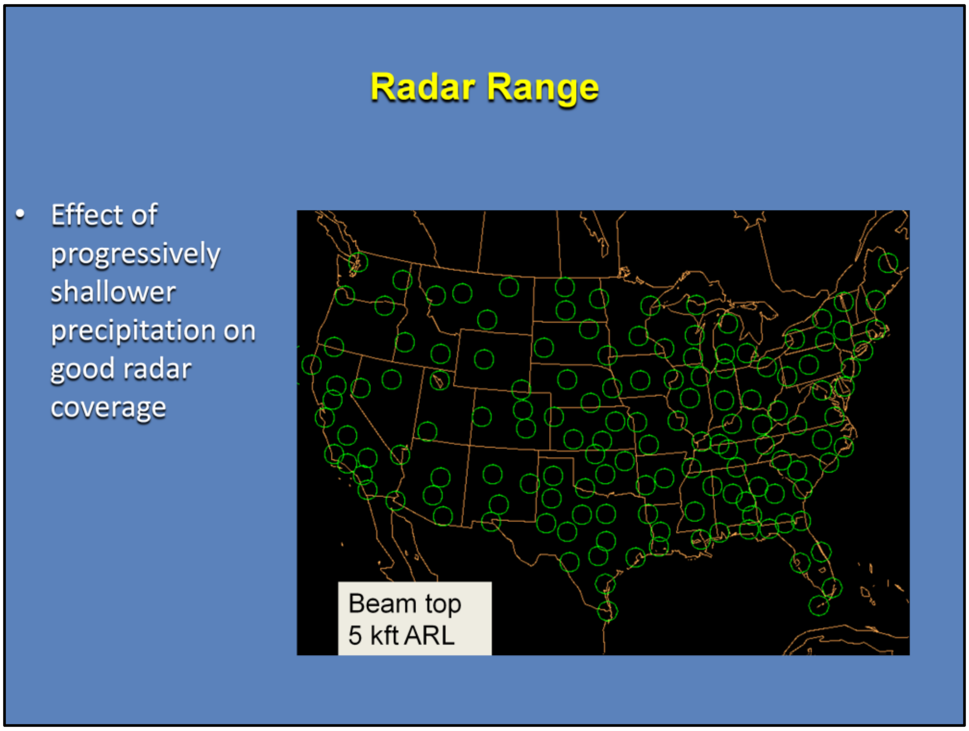

Here is the radar coverage for CONUS given that the dendrite production zone is relatively high, say > 22 kft. ARL. So for example, if there was a warm advection precipitation event where the dendrite production was the only layer producing precipitation, then expect good sampling by radar. Range limitations in this case are not a big problem. Now, the precipitating layer is lowering. Synoptic situations where this is common often occur in TROWALS, or along frontogenesis zones. Range degradation begins at a lower level and gaps in adequate coverage begins. Orographic clouds often hug the sides of mountains which can mean range is extremely limited. Also, in arctic outbreaks, shallow convection can result in significant snowfall rates, even with the precipitating layer at just 5 kft ARL. I have seen cases of power plant plumes and midwestern reservoirs producing significant snowfall whose cloud tops were only 1000’. Radar is extremely limited in its usefulness. Here is the coverage of typical lake effect snow, and precipitating orographic clouds where the precipitating layer is 8.5 kft ARL.

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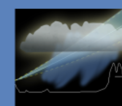
WSR-88D Precipitation Intensity Topics: sub-beam evaporation

- Range limitation
- **Evaporation below radar beam**
- Bright banding
- Horizontal drift of falling snow
- Unusual precip particle shapes



Let’s talk about sub-beam evaporation of precipitation and where it affects radar precipitation estimates.

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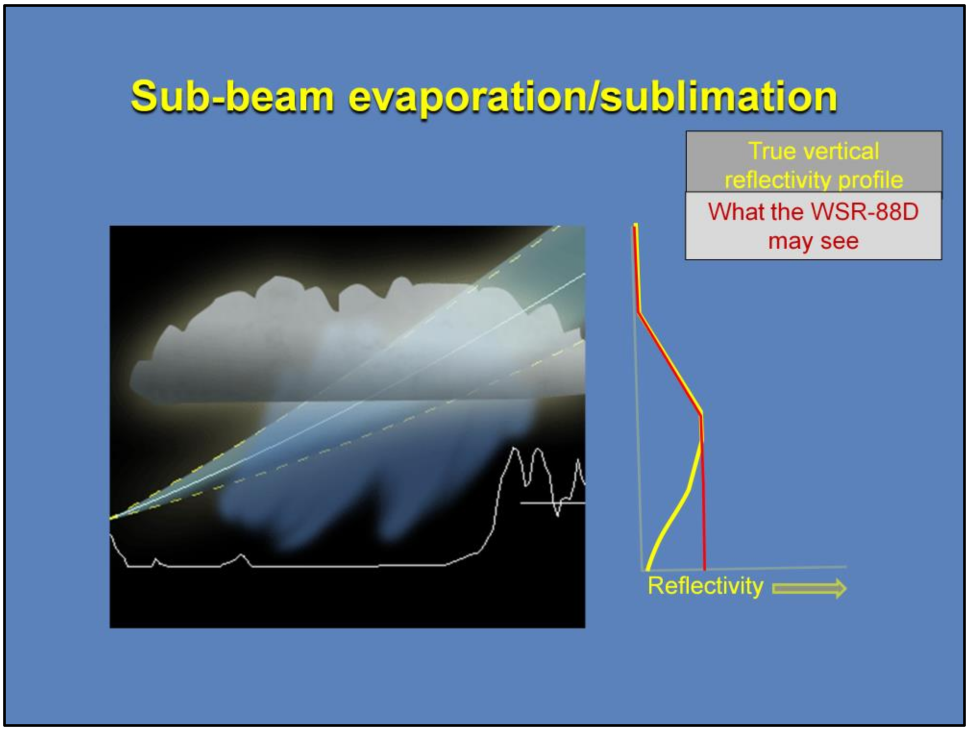

Sub-beam evaporation/sublimation presents the opposite problem for us as this process is often quite shallow and easily missed by radar resulting in precipitation overestimation.

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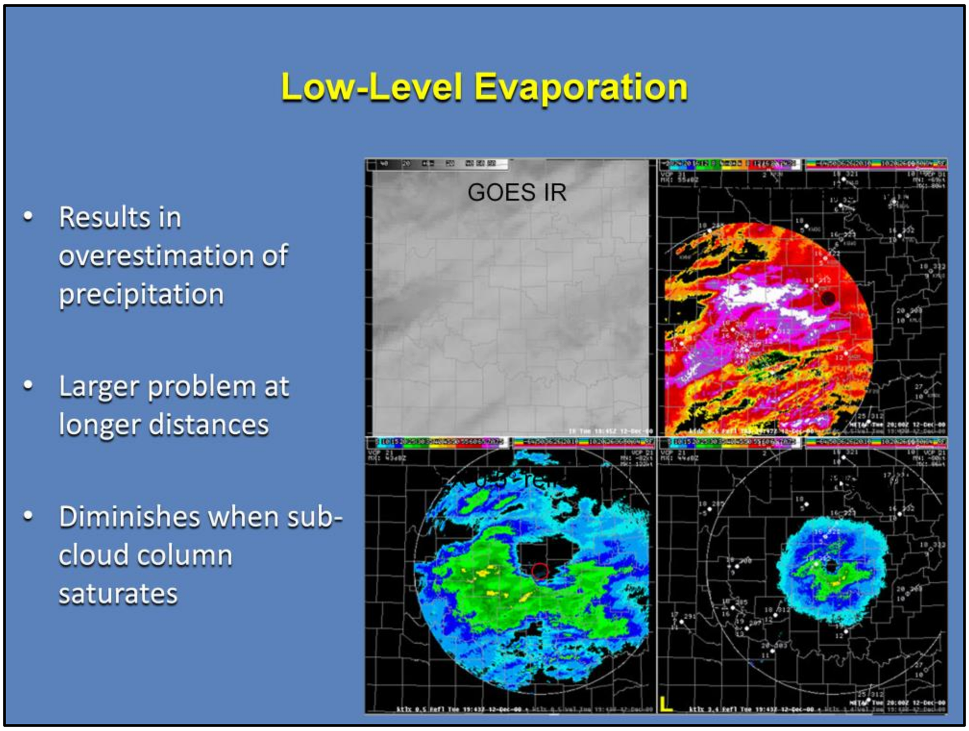

The overestimation problem increases with increasing range from the source radar. The KFDR radar in the upper-right shows precipitation over an area where it is clearly virga, as viewed by the KTLX radar. If the environment saturates below the radar beam, this problem would diminish. The problem is if you don't have a nearby radar, how can you tell where the radar is overestimating precipitation rates. We'll look at reflectivity as a proxy for instantaneous precipitation rate and then look at some cases of hourly rates.

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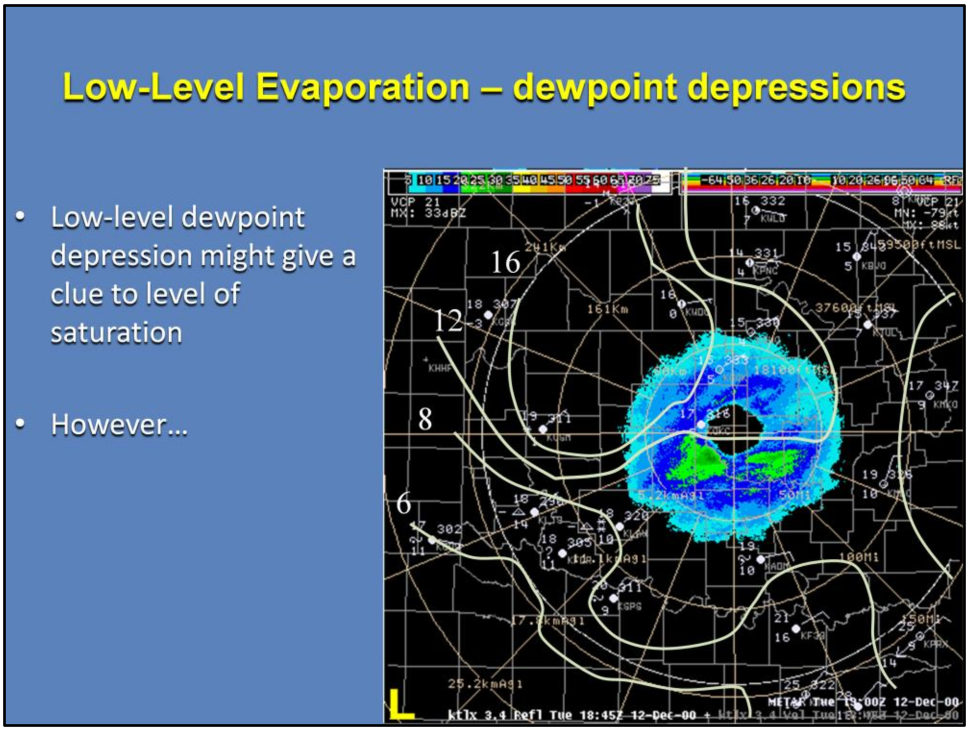

You can clue in on any subsaturated air by observing dewpoint depressions. Remember that these depressions are based on dewpoint, and not frost point. Thus if it’s significantly below freezing, you probably will not see dewpoint depressions less than 5 degrees C.

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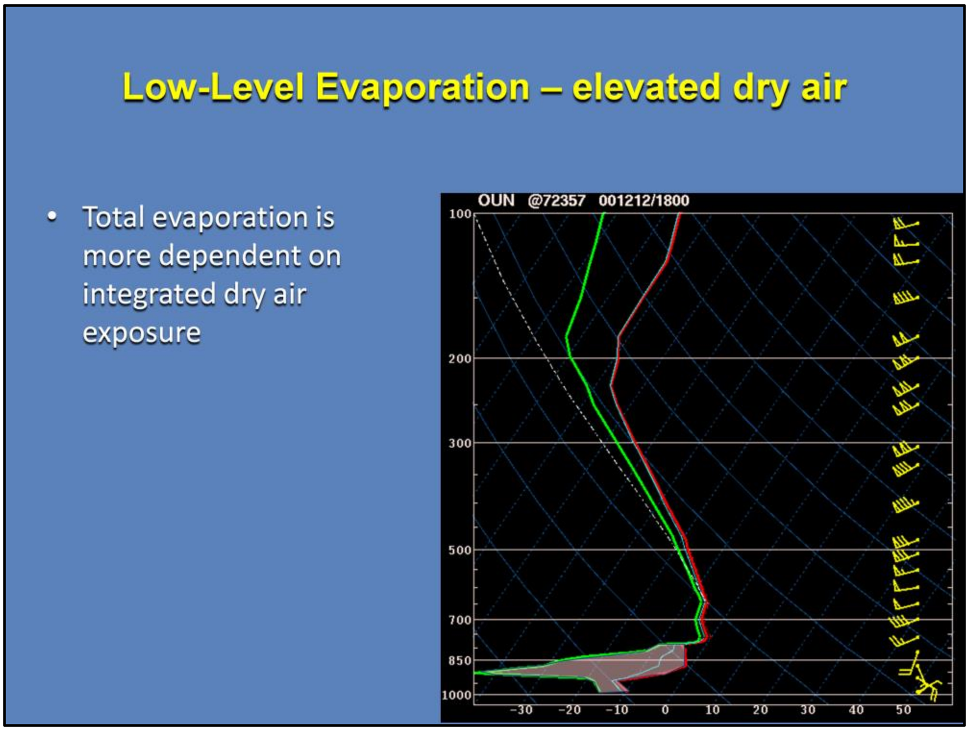

Surface dewpoint depression in the last page was not entirely representative of the amount of total evaporation that a hydrometeor would experience on its way to the surface. It's also a function of the integrated dry air exposure a precipitation hydrometeor experiences along its downward path. We still know that precipitation rate will be overestimated by distant radars.

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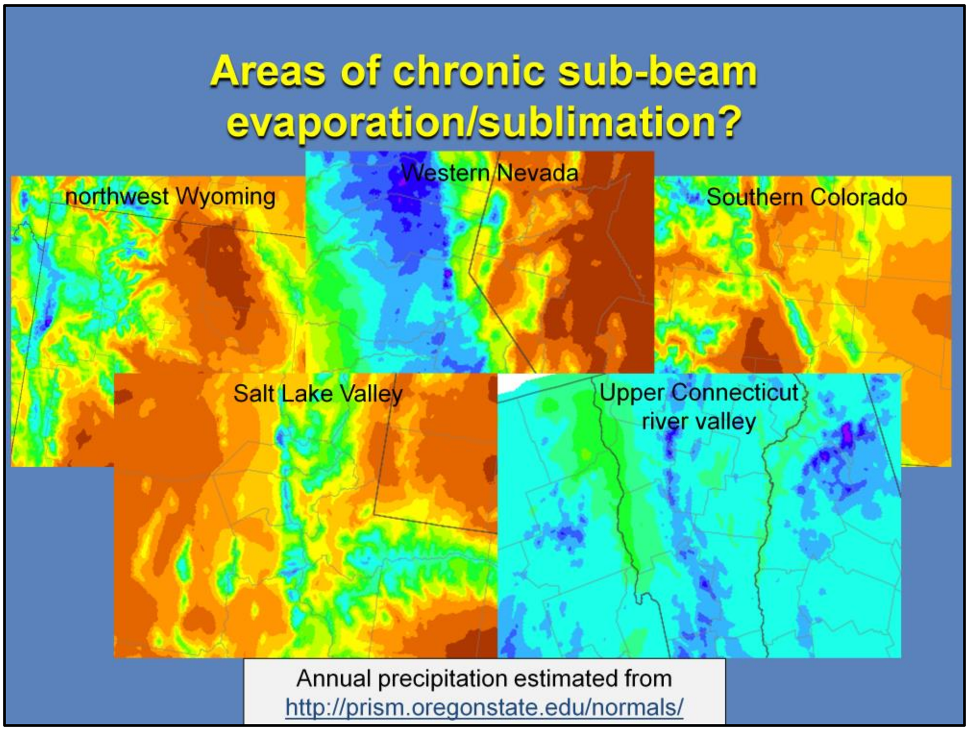

Those areas can quickly saturate as precipitation saturates the whole atmosphere.

Some geographical areas are quite likely to be subjected to chronic sub-beam evaporation, even with a radar nearby. Some areas listed above are examples, however I cannot possibly name all areas where this problem exists. Areas of downslope winds are primarily responsible for evaporating/sublimating precipitation. Since these areas change from one event to another, understanding your local climatology and how observed precipitation relates to your radar's estimates is of utmost importance.

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How to Estimate Where Radar is Missing Evaporating Precipitation

- Subsaturated air under lowest beam
- Downslope and valley locations in most events with topography
- Increasing error with increasing range
- Without a drying process virga will saturate column and reduce this radar-based error.

Anytime there's subsaturated air, precipitation evaporates. And as long as this is occurring underneath the radar beam, you're going to run into potential precipitation overestimates. Downslope and valley locations have the most likelihood for chronic sub-beam evaporation and such errors increase as range increases. Most areas subjected to hours of virga without any compensating process to dry the air will saturate fairly quickly and you'll watch your radar precipitation overestimates disappear fairly quickly from this error source.

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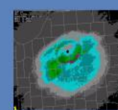
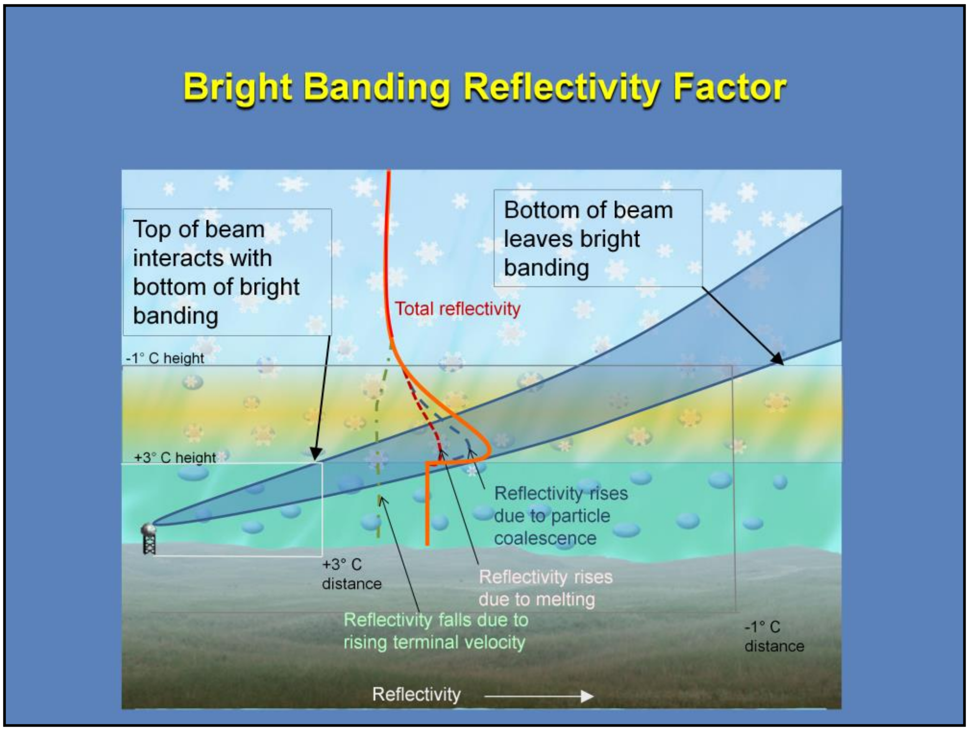
WSR-88D Precip Intensity Topics: bright banding

- Range limitation
- Evaporation below radar beam
- **Bright banding**
- Horizontal drift of falling snow
- Unusual precip particle shapes



Five considerations adversely affect good precipitation estimates, especially snowfall. Limited range becomes exacerbated in the winter when cold temperature microphysics routinely occur closer to ground. Bright banding becomes more of an issue as the freezing level is low enough to interfere with the hybrid scan selection. Evaporation can also occur below the lowest radar beam.



Let's start with a stratiform precipitation region with a melting layer where the starting vertical profile of reflectivity in the snow appears as the red curve where reflectivity increases going to the right.

Breaking down the mechanisms behind the bright band, you see on radar because there is more than one. As snow flakes approach the melting layer, liquid resides longer on their ice surfaces before freezing. The increased water coating helps colliding ice particles to coalesce and snow flakes begin to increase in size. The larger particles increase the reflectivity.

The liquid water coating itself also helps to increase radar reflectivity because the dielectric constant increases as ice changes phase to liquid, especially when melting occurs.

An offset to the increasing reflectivity occurs when the terminal velocity of the precipitation particles increases as melting accelerates. Increasing terminal velocity increases the separation between hydrometeors and lowers the reflectivity.

The combined result is an increase in reflectivity, maximized around +1 to +2 deg C.

Given that the center of a radar beam provides the most emitted energy, the strongest return from the bright-band effect is when the beam center is at these temperatures. But any part of the beam intersecting any part of the melting layer will also be affected.

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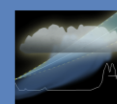
WSR-88D Precipitation Intensity Topics: horizontal drift of falling snow

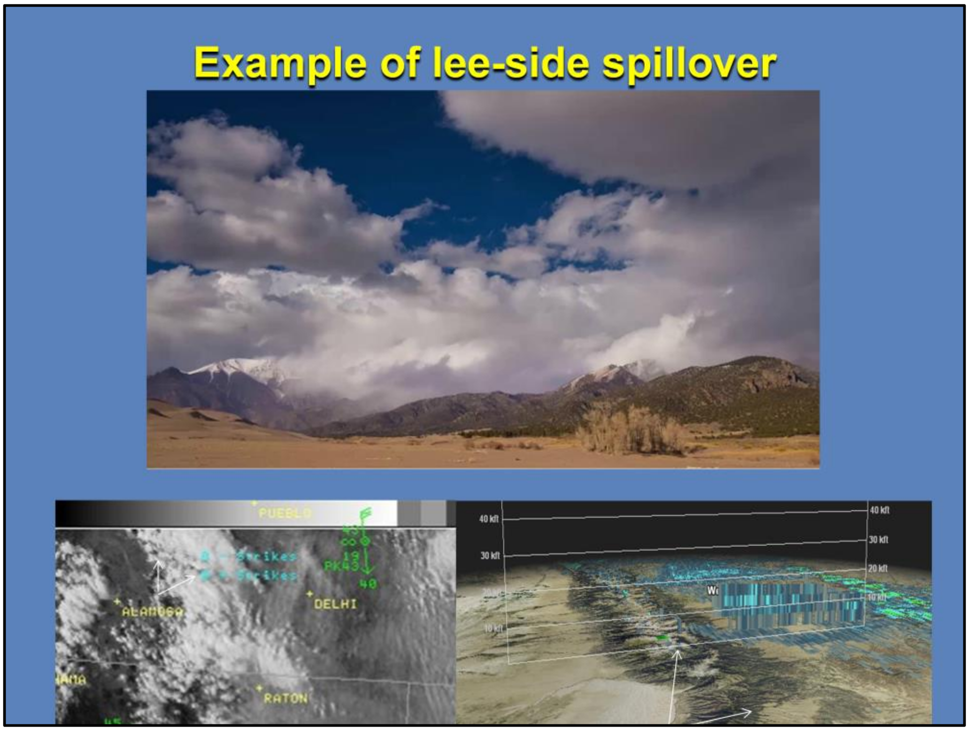
- Range limitation
- Evaporation below radar beam
- Bright banding
- **Horizontal drift of falling snow**
- Unusual precip particle shapes



We will discuss precipitation errors coming from horizontal drift of falling snow.

Snow only falls at about 1 m/s, graupel, perhaps 3-4 m/s. The first case, the precipitation source is moving with the flow but the snow falling out of the base is subjected to horizontal displacement owing to vertical wind shear. Normally this may not be a problem for a radar beam to accurately locate estimates if the precipitation source is widespread. But perhaps some mesoscale snowbands would be displaced if the shear displaces the snow sideways under the beam and relative to the band.

The second case is where the precipitation source is anchored but horizontal winds displace the snow sideways such as with snow spilling over a mountain ridge from the orographic clouds on the windward side.



This time lapse from the Great Sand Dunes National Park shows a classic example of snow spilling over the Sangre De Cristo mountains into the San Luis valley as low-level upslope flow manages to make its way over the terrain into the lee-side. The time lapse is facing north with a field of view represented by the arrows on the satellite image and the reflectivity cross-section from the KPUX WSR-88D. While some of the upslope snow is visible from the KPUX WSR-88D east of the mountains, none of the lee-side spillover is visible to the radar. The spillover extends 2-3 nm downslope from the crest before sublimating.

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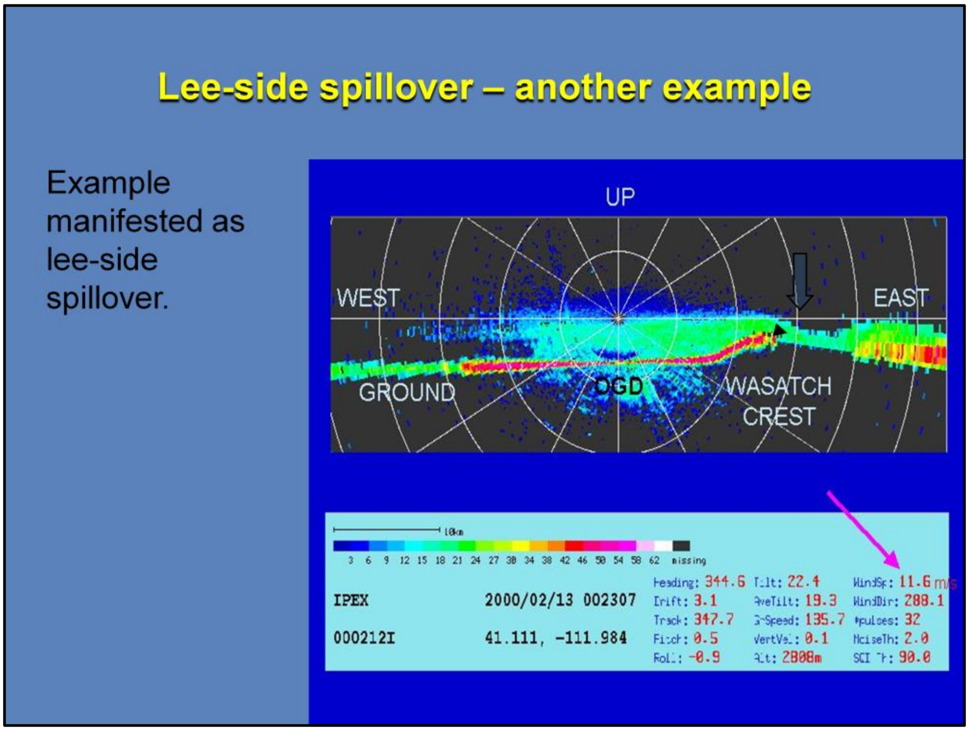

What would lee-side spillover look like if you could see it from radar? illustrated nicely here in this cross section taken from the P3 aircraft tail radar just west of the Wasatch mountains. Snow forming in the upslope drifts down the lee side of the crest for several miles. In this part of the country, the 'spillover' effect is a blessing for ski areas on the east side of the crest.

In other parts of the country, this effect can occur if there is strong wind shear and rapidly moving transverse snowbands. If the location you're monitoring is far enough from the radar when one of these bands pass overhead, you may not have snow fall under the band for quite some time. Fortunately, this is one error source that can be mitigated by knowing the vertical wind profile and the height of the beam. The BLM attempted to implement a correction for horizontal drift of falling snow into the ZS algorithm. The results showed no significant improvement to the algorithm, possibly because other errors were so large.

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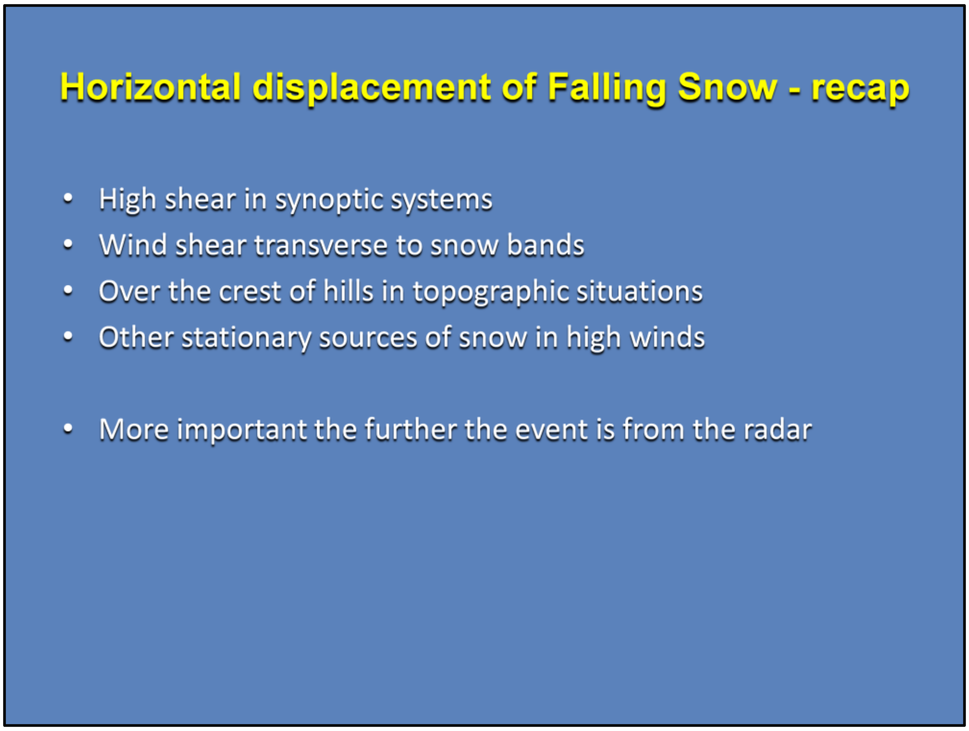
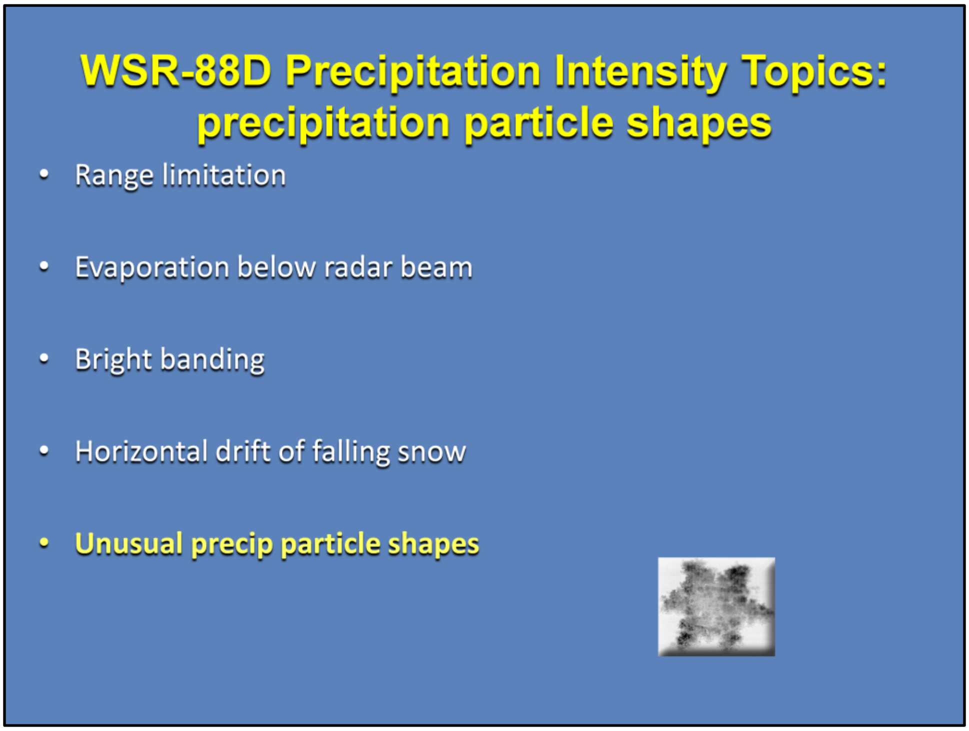


What you want to look for are situations where either you have a situation where rapidly moving bands transverse to the mean flow exist in regions of high vertical wind shear or a stationary snow production source embedded in strong winds such as orographics. The high shear forces the snow to horizontally drift relative to the source of the snow. Lake effect is a stationary source of snow by relative standards but the snow often falls within the axis of the band, just downwind. There are times though at the end of a lake effect band where snow production is nonexistent and all the snow that is falling is simply drifting there from upwind.

Finally, the further you are from the radar, the greater this source of error becomes.



This final error source is probably the most intractable. Precipitation particle shape and size is something we'll talk about next.

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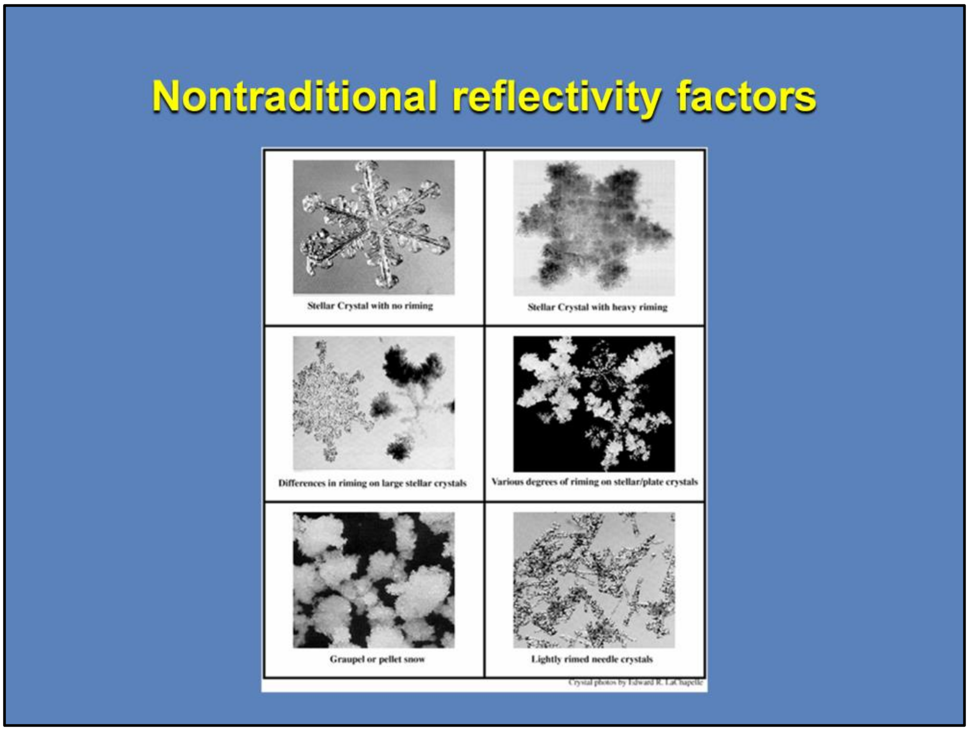

Snow particles come in all sizes, shapes, and densities, ranging from pure dendrites to needles, clusters of each, rimed clusters of each, and eventually, graupel. Given the same true precipitation rate, the diversity of precipitation shapes can cause changes in reflectivity. Some basic precipitation particle shapes can be gleaned from polarimetric radar, however at this time a polarimetric ZS algorithm is not imminent. We will also not consider this potential error sources in this course owing to the number of undetectable considerations that affect precipitation particle shapes beneath the lowest radar scan as well as the lack guidance available in dealing with the potential errors.

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Recap

source	Radar SAA estimate
Bright banding	Overestimate
Overshooting precip formation	Underestimate
Sub-beam evaporation	overestimate
Horizontal precip displacement	Location error
Nontraditional reflectivity factors	Multiple errors

To recap, we have three sources of errors which can be assessed using operational data. Two of them induce precipitation overestimates, bright-banding and sub-beam evaporation/sublimation. Beam overshooting precipitating clouds is the major source of precipitation underestimations. Note that two of the three error sources magnify as range increases, however at a moderate range, errors from sub-beam evaporation can cancel out beam overshooting issues resulting in a fairly accurate ZS estimate – though for the wrong reason.

Horizontal snow displacement more or less affects the location of the precipitation reaching the ground relative to what the radar detects and can come from vertical wind shear below the precip source or precipitation falling laterally from an anchored precipitation source.

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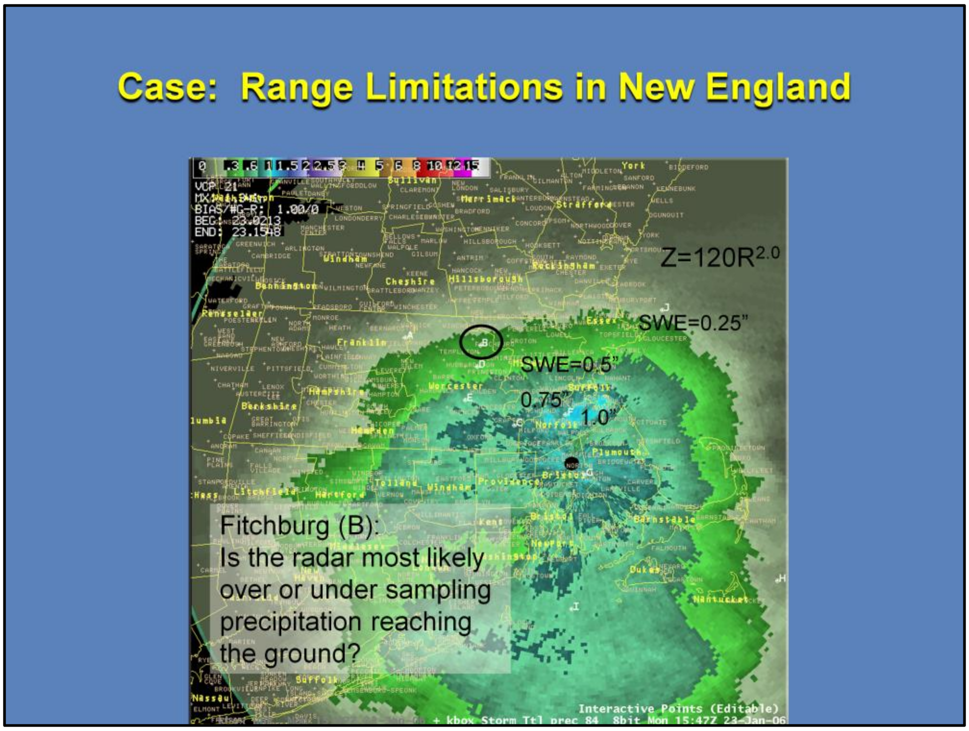

Let's try an example and take a look at how well the radar is estimating precipitation at Fitchburg, MA (in the circle). We ran the ZS algorithm using the default coefficients that exist for the Northeast U.S. and the minimum dBZ set to 10. There is no range correction applied here. Given the criteria I set, do you think the precipitation is likely to be over or underestimated for Fitchburg?

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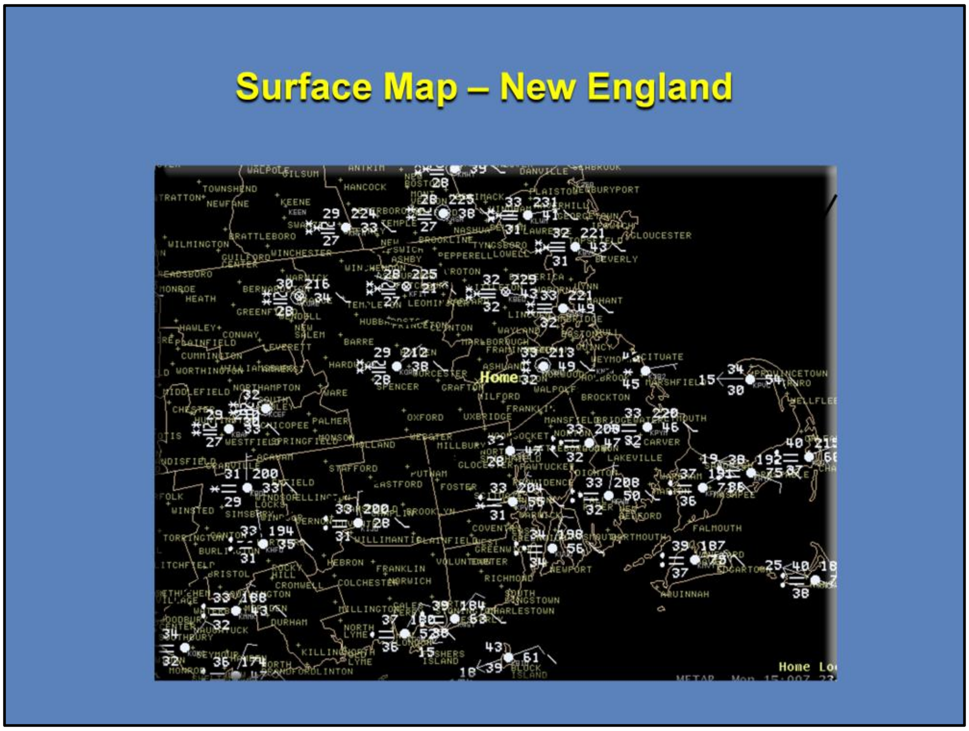

Fitchburg is well north of the rain snow line. The near saturation around the area also corresponds to relatively low cloud bases. Light winds in the area suggest that any bucket gauge should be able to be pretty efficient at capturing falling snow.

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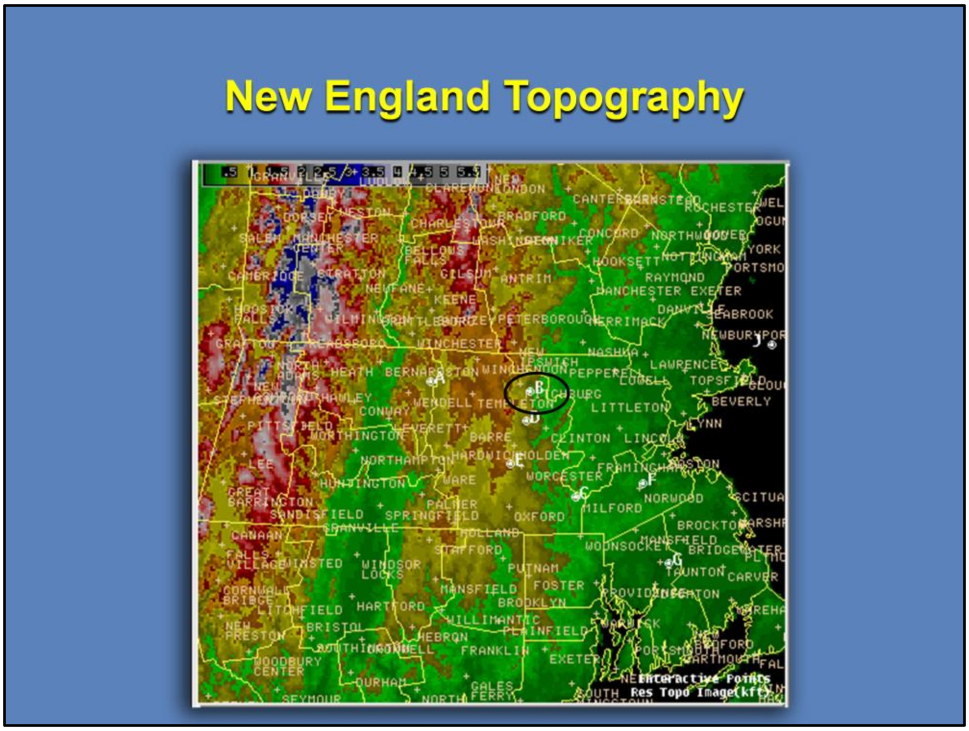
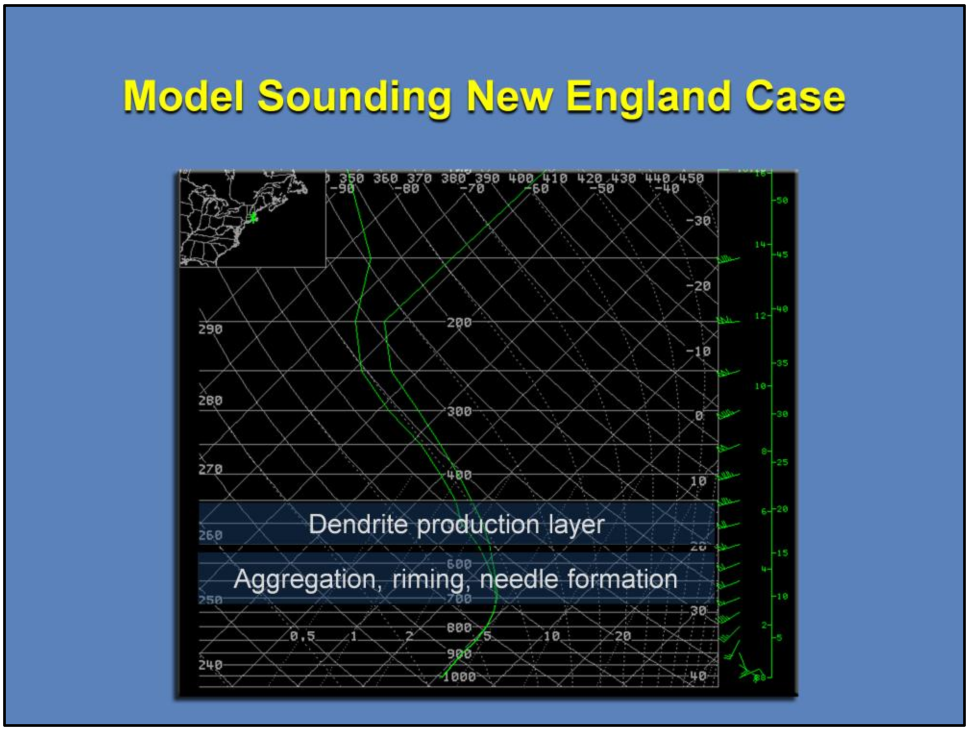


Fitchburg is in an area of relatively high terrain (600’ MSL) and with the light easterly winds, there should be some upslope component to the flow. Upslope flow in subfreezing air means a greater possibility of low-level feeder clouds. Let’s see what the morning sounding on Cape Cod shows. Let’s see what you think about the sounding with the question coming up.



Let’s assume that we need to have the lowest beam entirely below the dendrite production layer. Well, that’s below about 560 mb layer or 15 kft. MSL. But it’s not sufficient to be below just the dendrite production layer. We need to capture ice multiplication, aggregation, riming and needle formation. Most of these processes occur at temperatures colder than -4 degrees C. You’ll need to have the beam top below 10 kft MSL to capture most of those processes. Given the deep saturated layer below, there may still be some additional aggregation as snow flakes become coated with thin films of water and get “sticky”. So, reflectivity may go up a bit more. As a word of caution, thin films of water also increase the dielectric constant; therefore, reflectivity increases with no corresponding increase in actual liquid precipitation rate. Also, this sounding is not quite as far north as Fitchburg so the cold precipitation generation layer may be a little bit lower.

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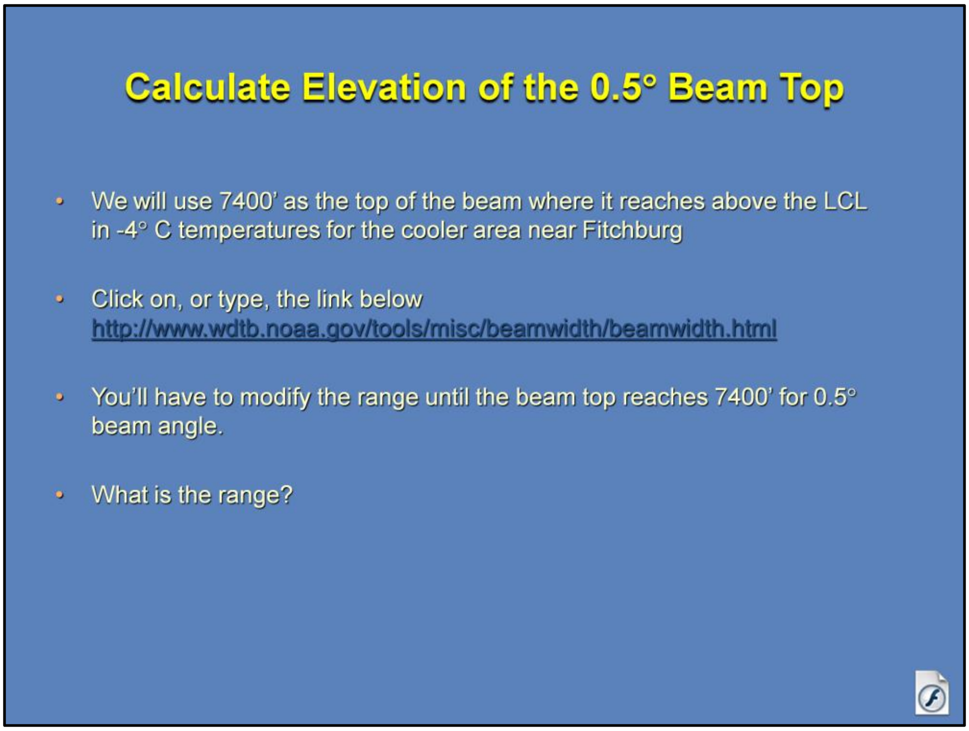
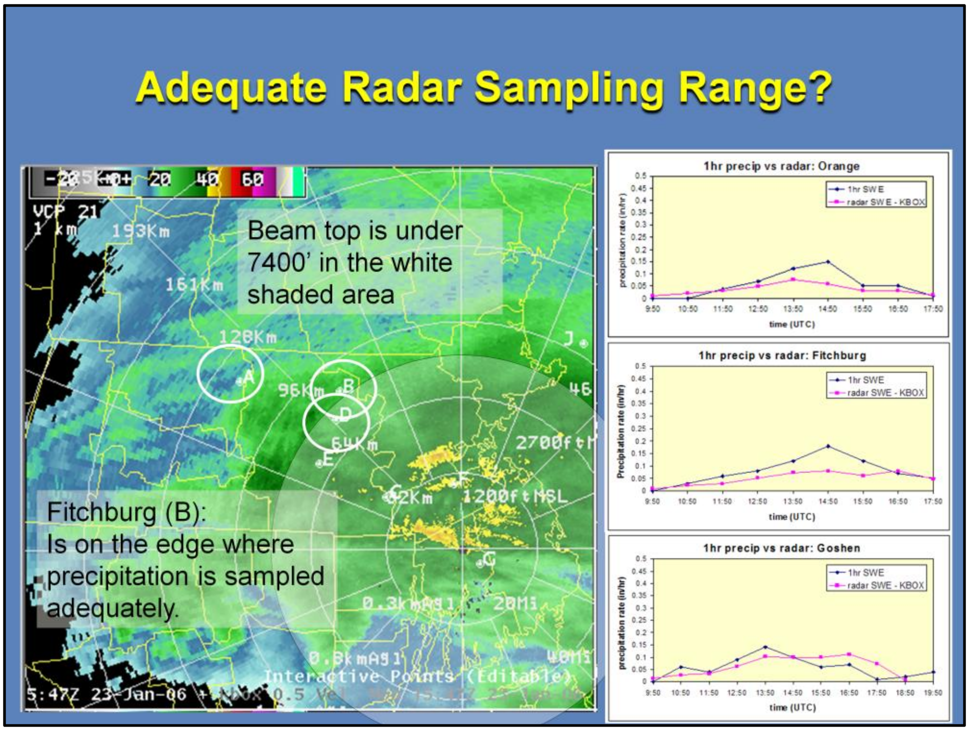


It is difficult to tell where in the sounding precipitation generation ceases and precipitation falls to the ground in its final form and intensity. We do know that below the dendrite production zone, frozen precipitation continues to develop. Even in warmer temperature you still have needle formation, riming and aggregation. We'll take temperatures warmer than -4 to -5 degrees C to be the point where most frozen precipitation growth will have already occurred. The soundings in the previous page show that temperature to be roughly 7400' MSL. We'll take that height and use the beamwidth tool.

You're welcome to click on the beam width calculator below and modify the range until the beam top reaches 7400' for the 0.5 deg angle. What is the range that you find closest to 7400'?



It would be ideal if the beam was hugging the ground and there was no ground interference. Instead, it appears that perhaps we can adequately sample most precipitation if the entire beam remained below 7400' AGL. The white shaded circle satisfying this condition extends out about 53 nm from the radar. The Fitchburg observation is right on the outer edge of good radar sampling. Is 7400' enough or do we need to be lower? As it turns out, the Fitchburg ASOS is reporting higher hourly precipitation rates than the radar using the Z=120S2.0 relationship.

Going to the town of Orange, MA, which is further away, the same problem reveals itself. The radar is underestimating the hourly reports. Going a little closer to the town of Goshen, MA, the comparison is different. The radar is showing better agreement, perhaps even a bit of an overestimate.

If we believe the surface COOP station, then the radar beam is more accurately sampling the precipitation at Goshen than at Fitchburg. That is quite possibly because the beam is extending above some significant precipitation generation as one goes to Fitchburg and points beyond relative to the radar. I could make the argument that the COOP station is underestimating its precipitation and that would be a valid argument. However, I will show later in this lesson that there is nothing indicating that there is enough instrument error to change the conclusions that the radar beam over Fitchburg and beyond is overshooting generating precipitation.

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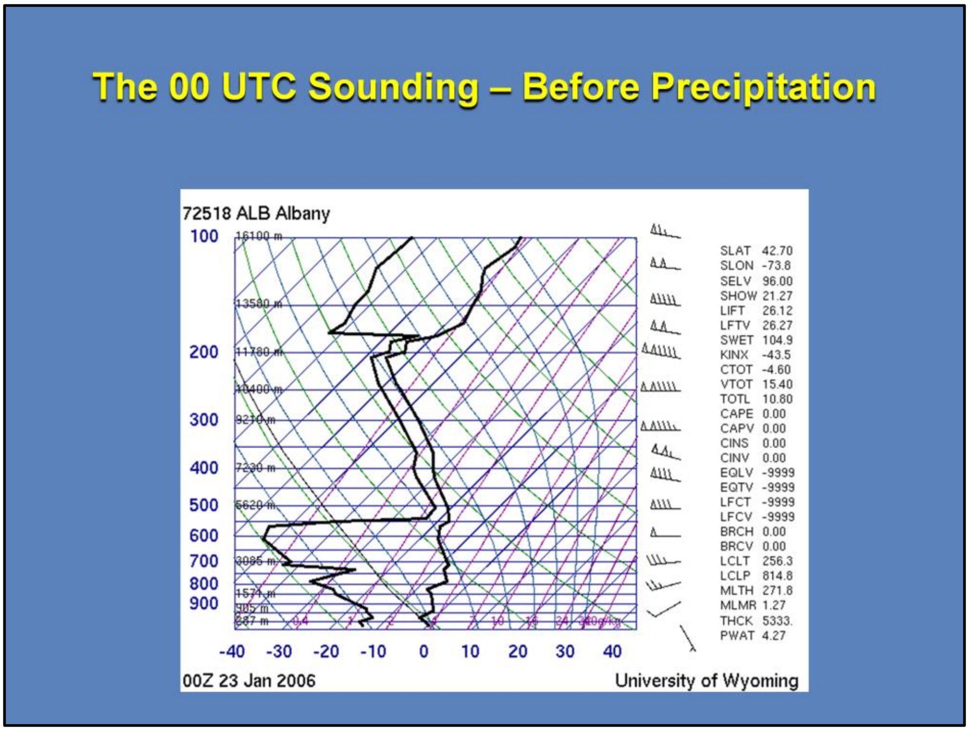

Now let's check out the sub-beam evaporation/sublimation potential. At 00 UTC on the 23rd, the Albany, NY sounding showed a very dry airmass below the midlevel moisture streaming in ahead of a short-wave trough. Let's take a look at the radar 4-panel image next.

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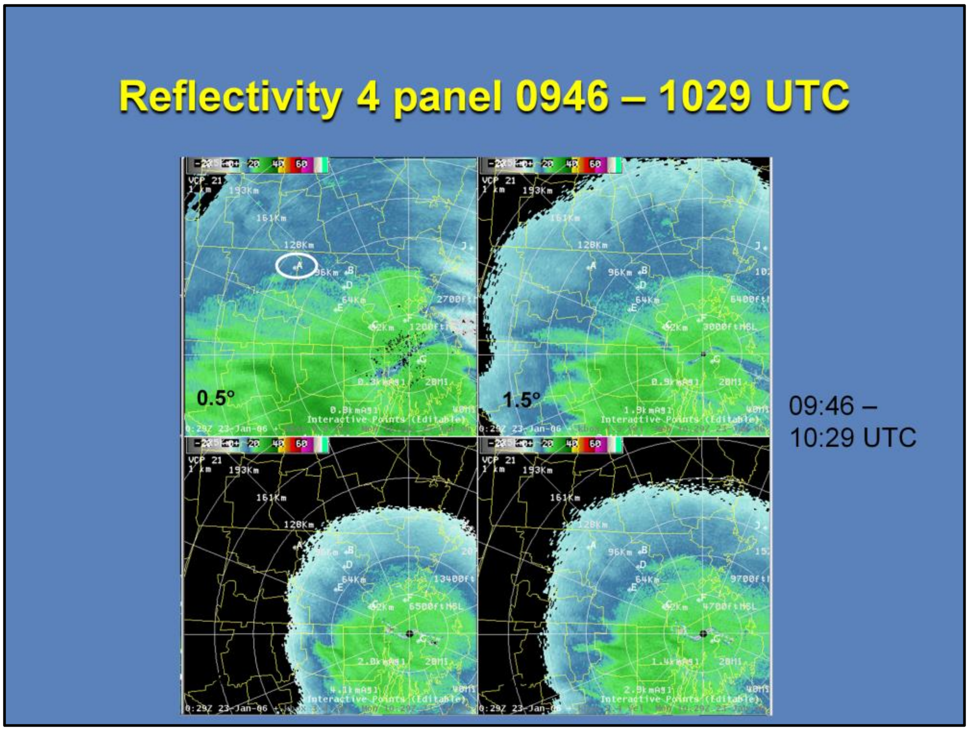
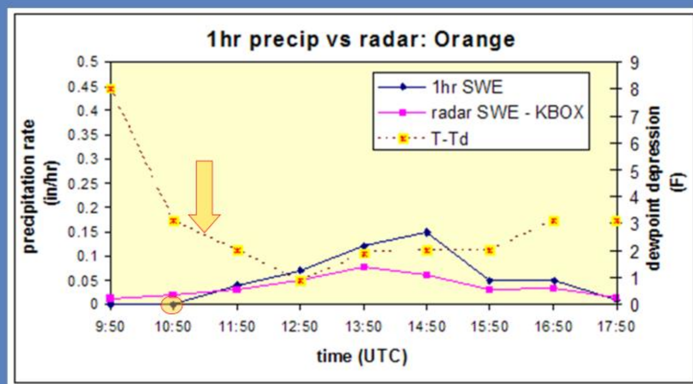


Take a look at this loop and given the previous sounding and the nature of the reflectivity echoes, determine the type of radar-based precipitation error you may observe here. Orange, in the white oval, is reporting a 9 degree dewpoint depression. I'll stop this from going on and allow you to come up with an answer before going on to the next slide.

Orange, MA Precip Rate and Dewpoint Depression meteogram



When you look at the dewpoint depressions, the dewpoint depressions correlate well with the propensity of the KBOX radar to overestimate precipitation rate at Orange. We're using Z=200S2, but we could raise the coefficient to 220 or 230 and I bet that wouldn't help because no precipitation is being recorded at Orange. Even if there was, note how the errors switch signs later on. You'd have to adapt by changing the ZS coefficients again. The error sign flipped as a large flux in moisture from above quickly saturates the air at Orange. I believe this is a common evolution for many sites that are located well away from the nearest radar.

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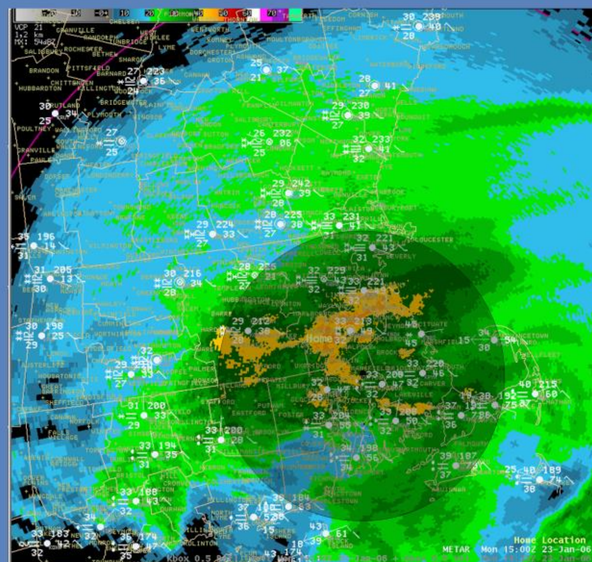
Add Any 1501 UTC Evaporation Errors?



1501 – 1530 UTC

At this time, most everyone’s saturated (at least with respect to ice). I doubt sub-beam evaporation is an issue now. Let’s not include it in our considerations. So we still consider where the radar may overshoot precip outside the white shaded circle.

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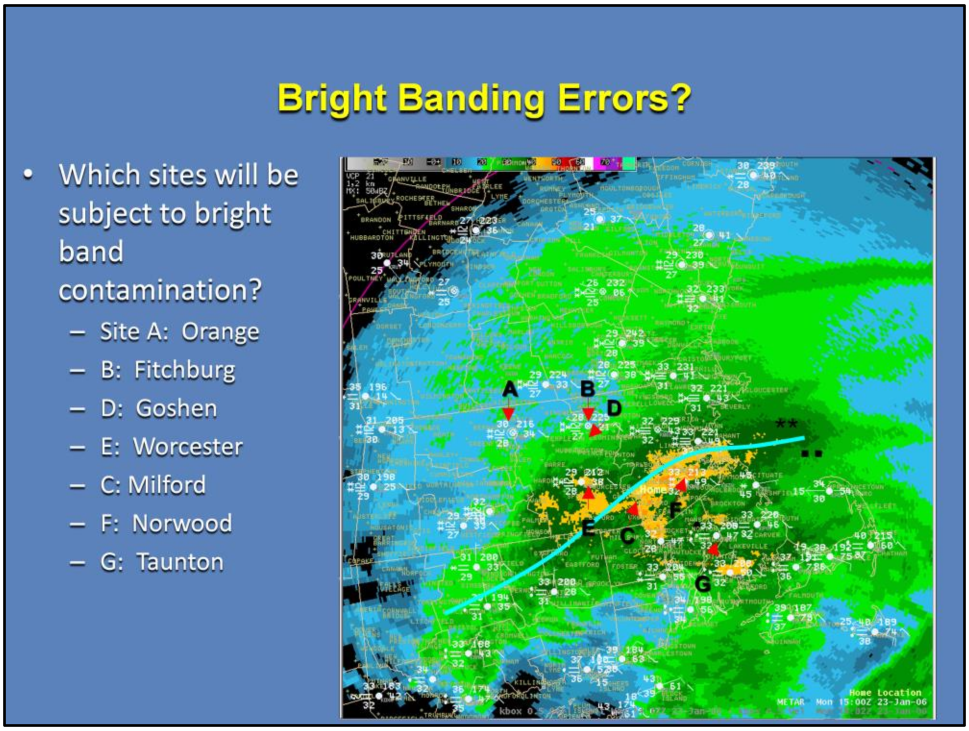

Let’s try out your skill at locating bright band contamination. I have seven sites, some are ASOS, some are COOP sites. I am going to trust these sites as being relatively accurate. Understand that ASOS buckets are heated with poor shielding so some losses may occur due to evaporation and wind. Fortunately the wind is light and temperatures are fairly warm so it won’t take much to melt snow into the bucket. The METARS tell me that the rain/snow line should be along the blue contour. The sites are, Orange, Fitchburg, Goshen, Worcester, Milford, Norwood, and Taunting. We’ll go to a quiz.

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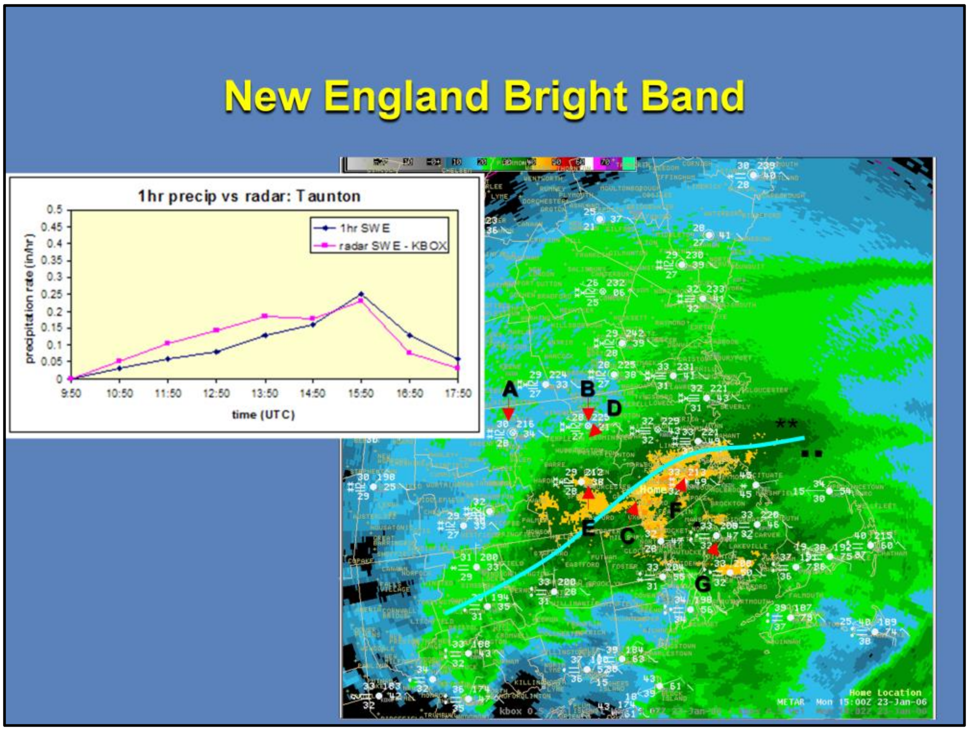

Let's go through the answer to the last question. We start off with Orange (A) and see the problems with underestimation because of overshooting.

The same goes with Fitchburg (B).

When we get to Goshen (D) we see the radar transition from underestimate to overestimation around 15 UTC. It could be either wet snow, sub-beam evaporation, change in precipitation particle shapes, or an error with the gauge. If we just talk about adequate precipitation coverage, it is doubtful there is sub-beam evaporation given the saturated conditions. I suggest that we are looking at wet snow aggregates with a larger than normal reflectivity factor than the liquid equivalent present. In other words, perhaps some bright banding is beginning even though it is all snow.

Going to Worcester (E), shows the same effect and here it is also snow.

Going to Milford (C), and especially Norwood (F), we are looking at large waterlogged flakes with a huge reflectivity cross-section as the melting layer is fully sampled by KBOX.

Finally, the radar is sampling completely melted precipitation at Taunton (G) and there is better agreement there. Note, though, that earlier in the day there is some potential bright banding.

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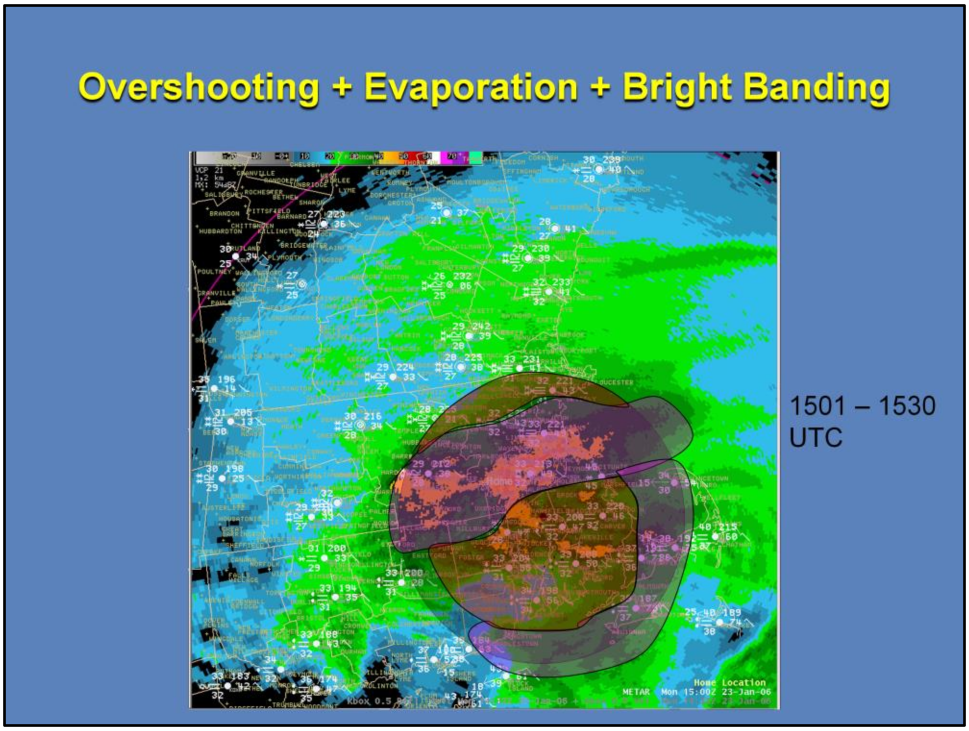

Beam overshooting problems exist outside the white shaded circle. There are likely no significant evaporation errors given the saturation across the radar domain. The most likely areas of bright banding appear in purple. The northern area is where the rain snow line exists at the surface but the errors leach into the wet snow areas to the north. Thus, the only areas of good precipitation sampling most likely exists in the orange areas. The northern orange area is the only area where snowfall is adequately sampled for the 15 UTC time frame.

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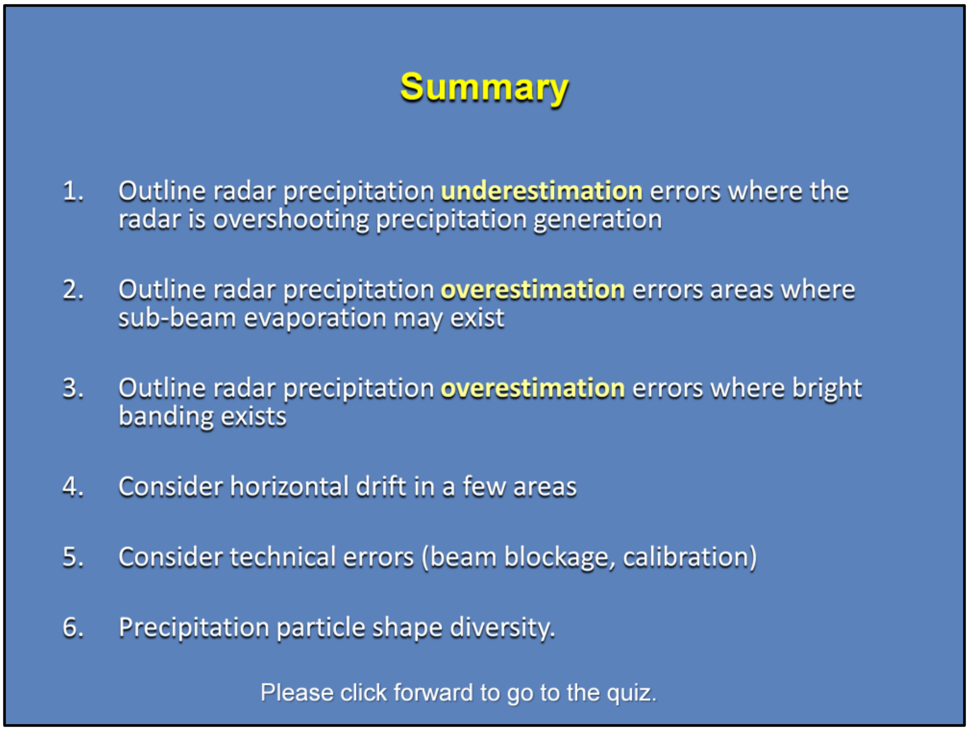
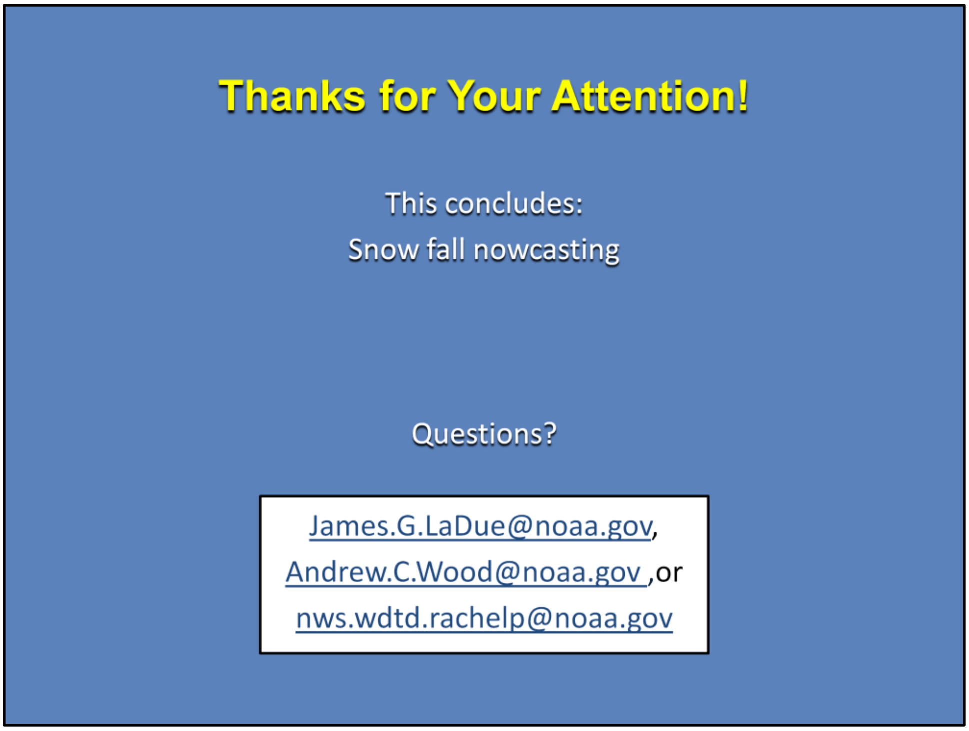


Outline radar precipitation underestimation errors where the radar is overshooting precipitation generation. Outline radar precipitation overestimation errors areas where sub-beam evaporation may exist. Outline radar precipitation overestimation errors where bright banding exists. Consider horizontal drift in a few areas. Consider technical errors (beam blockage, calibration). Precipitation particle shape and density is the final error source that cannot be directly accounted for except when after considering the first 5 errors. If there is a consistent bias in the precipitation where sampling is good, you may consider the ZS algorithm coefficient to be in error because of precipitation particle shape.



If you have passed the quiz, then you have successfully completed this lesson. If you have any questions, please contact us using any of the e-mail addresses listed on the bottom of the slide.