1. Differential Reflectivity (ZDR)

Instructor Notes: This lesson covers the differential reflectivity (or ZDR).

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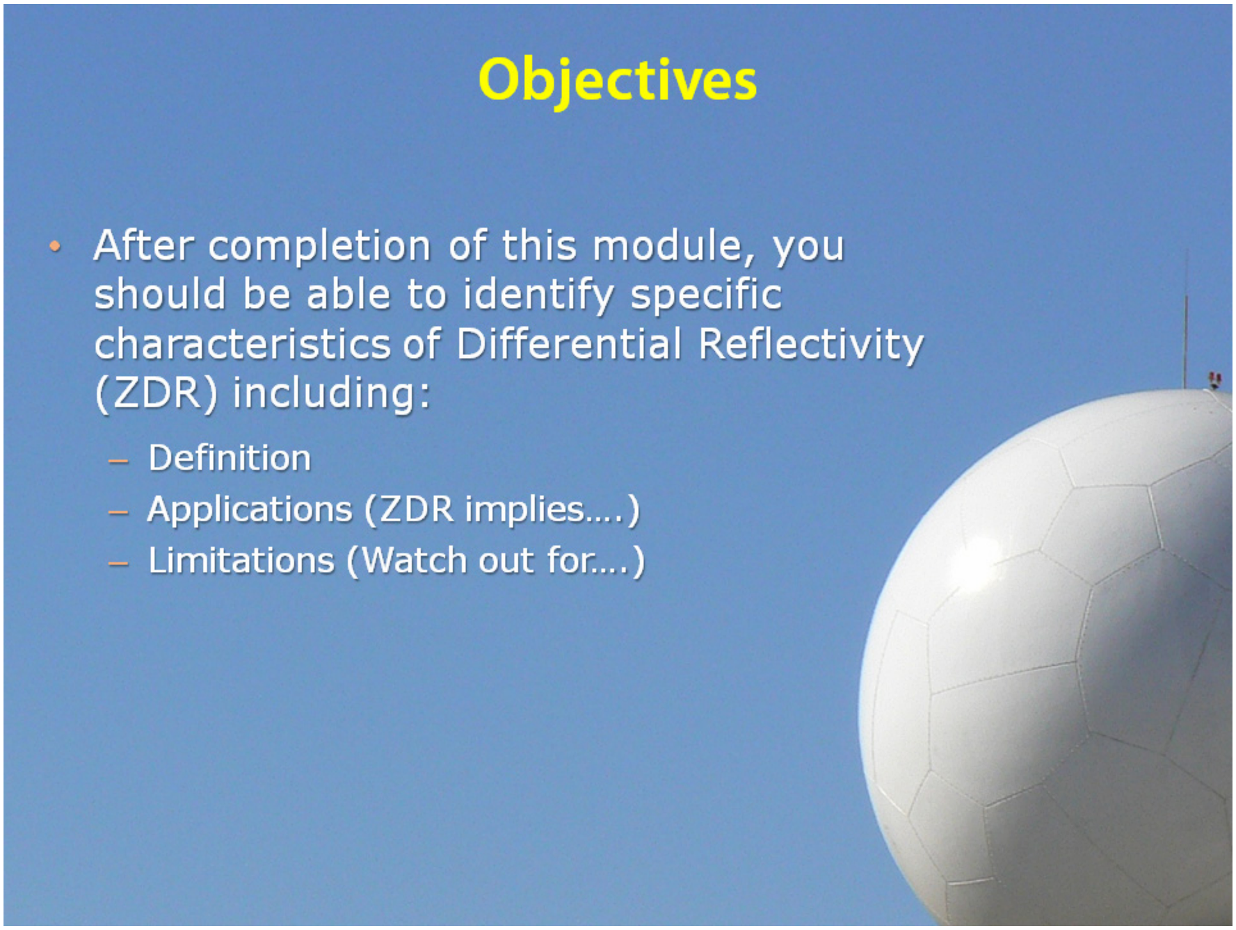


2. Objectives

Instructor Notes: After completing this module, you should be able to define ZDR and recognize situations where ZDR can be useful operationally and when ZDR might be suspect.

Student Notes:

Differential Reflectivity (ZDR)

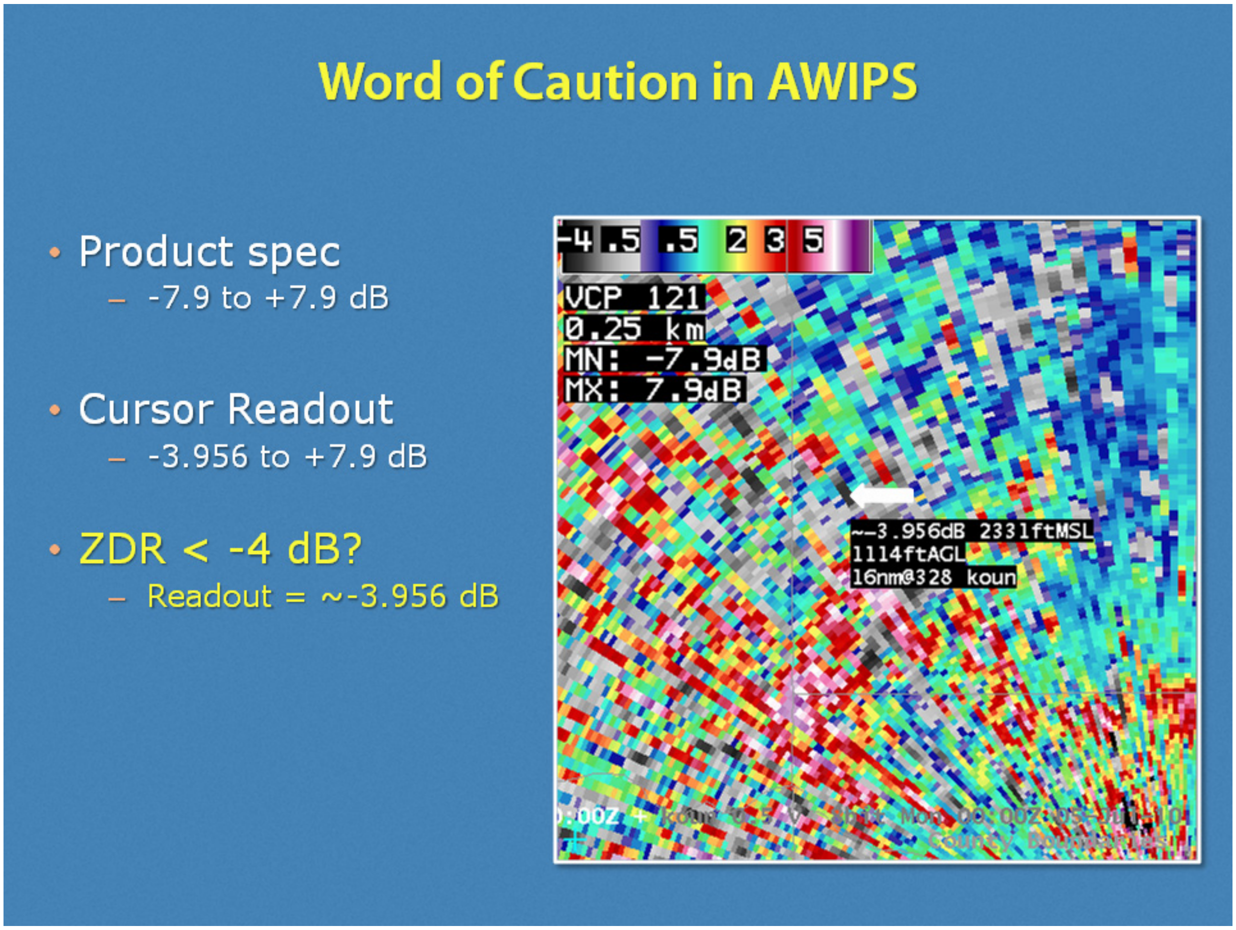
Definition	Possible Range of Values	Units	Abbreviated Name
Measure of the log of the ratio of the horizontal to vertical power returns	-7.9 to +7.9	Decibels (dB)	ZDR

$$ZDR = 10\log_{10}\left(\frac{Z_h}{Z_v}\right)$$

3. Differential Reflectivity (ZDR)

Instructor Notes: Differential reflectivity is a measure of the log of the ratio of the horizontal to vertical power returns in a pulse volume, which can also be thought of as the log of the ratio of the horizontal reflectivity to vertical reflectivity in linear units, not dBZ units. Its values range from -7.9 to +7.9 in units of decibels (dB). In AWIPS, the RPG, GR Analyst, and in research papers you'll see it abbreviated as "ZDR".

Student Notes:



4. Word of Caution in AWIPS

Instructor Notes: On the last slide, I mentioned that the product is able to determine values from -7.9 to +7.9 dB. However, is AWIPS, when values dip below -3.956 dB, cursor readout will not show the actual product value, it will show a ~-3.956. This will most likely not inhibit physical interpretation as most meteorological values very rarely become largely negative. We just wanted you to be aware of this discrepancy.

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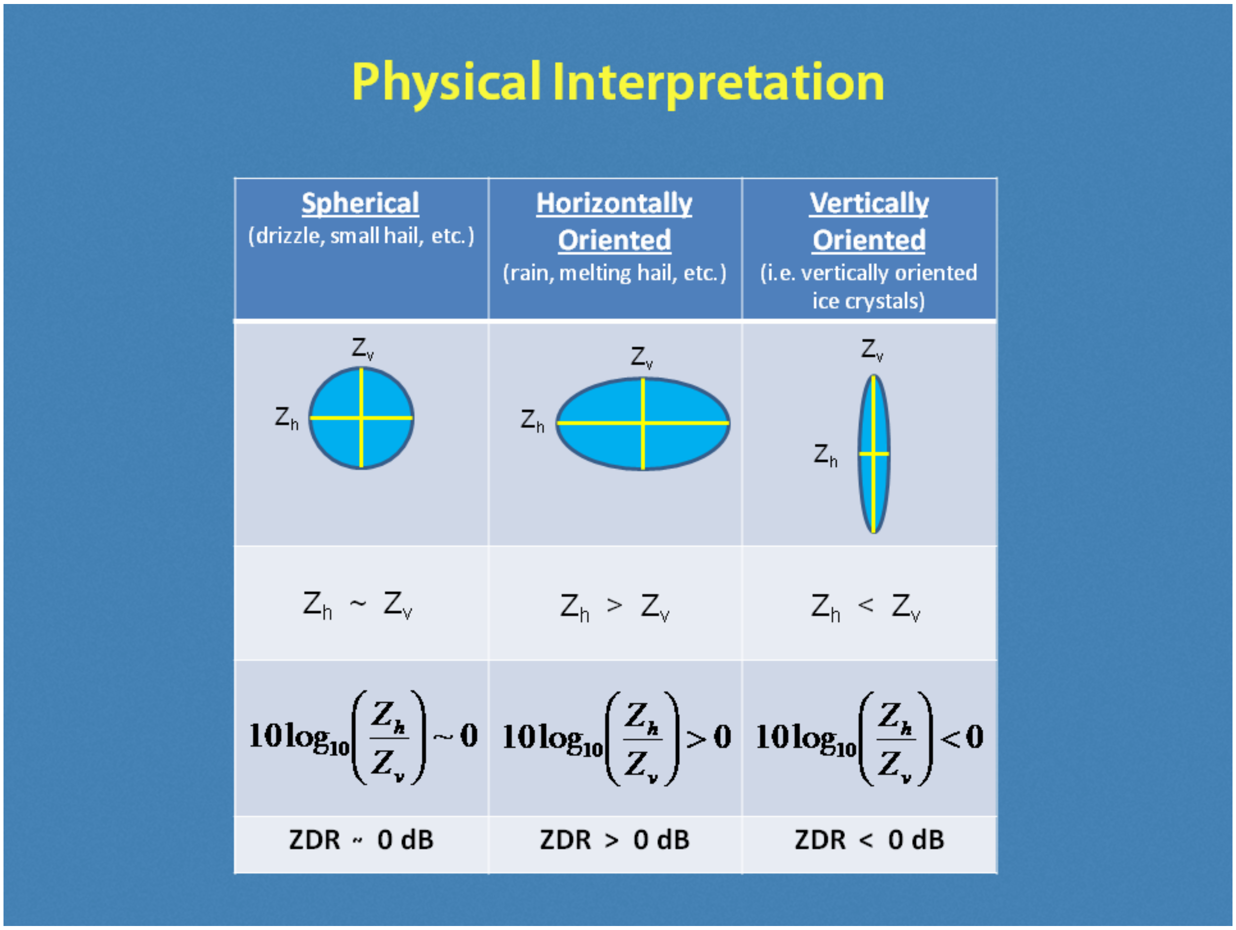
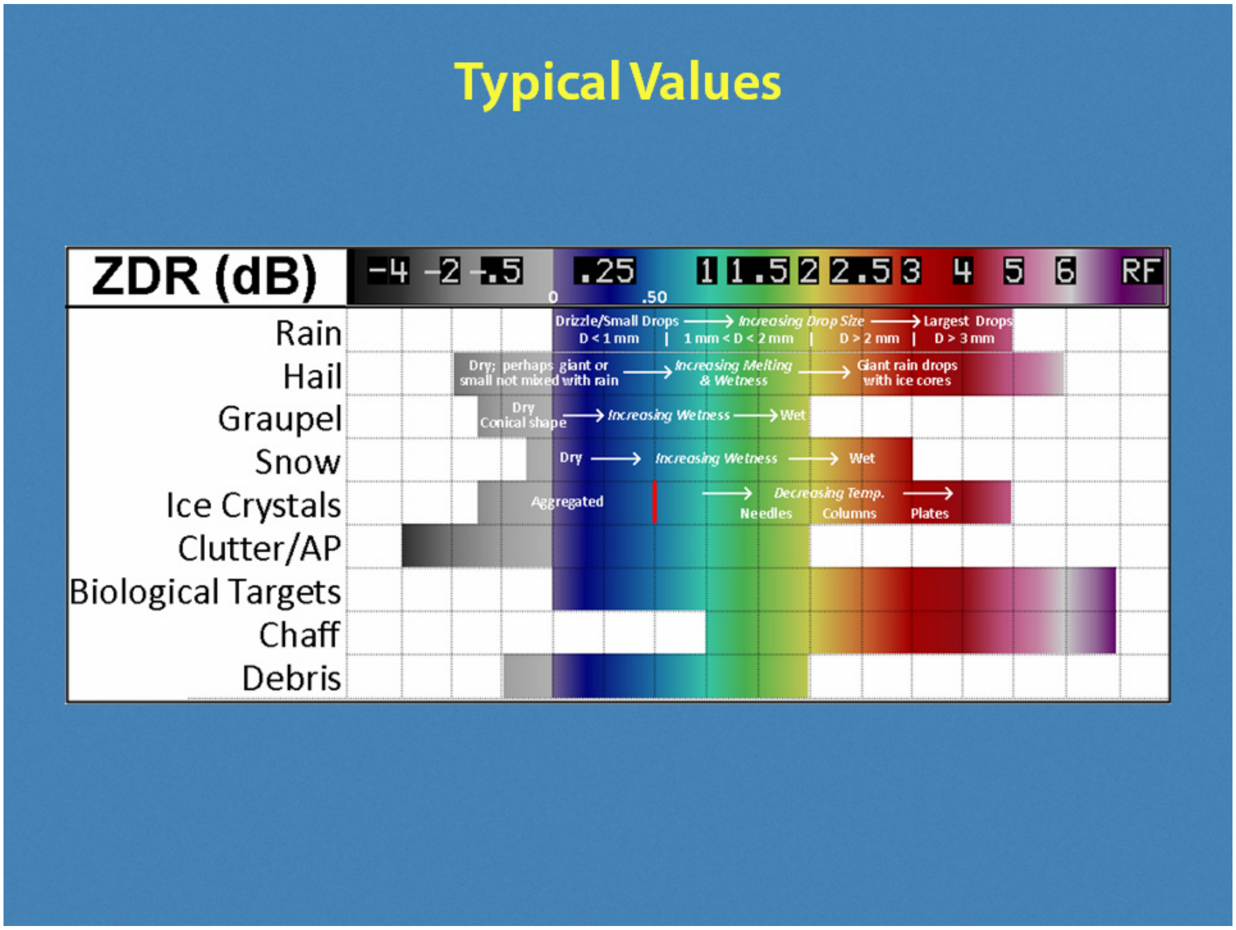


5. Physical Interpretation

Instructor Notes: This chart summarizes the general physical interpretation of differential reflectivity. For spherical hydrometeors such as drizzle drops, the reflectivity for both the horizontal and vertical dimensions of the hydrometeors are approximately equal. This leads to a ratio of horizontal to vertical reflectivities of approximately 1, and the log of this ratio is therefore approximately zero, which means ZDR is approximately 0 dB. The same logic can be applied for the horizontally and vertically oriented hydrometeor cases seen here. Horizontally oriented hydrometeors such as rain drops will have positive ZDRs, and ZDR will increase with increasing hydrometeor size. Vertically oriented hydrometeors such as vertically oriented ice crystals in a high electric field will have negative ZDRs.

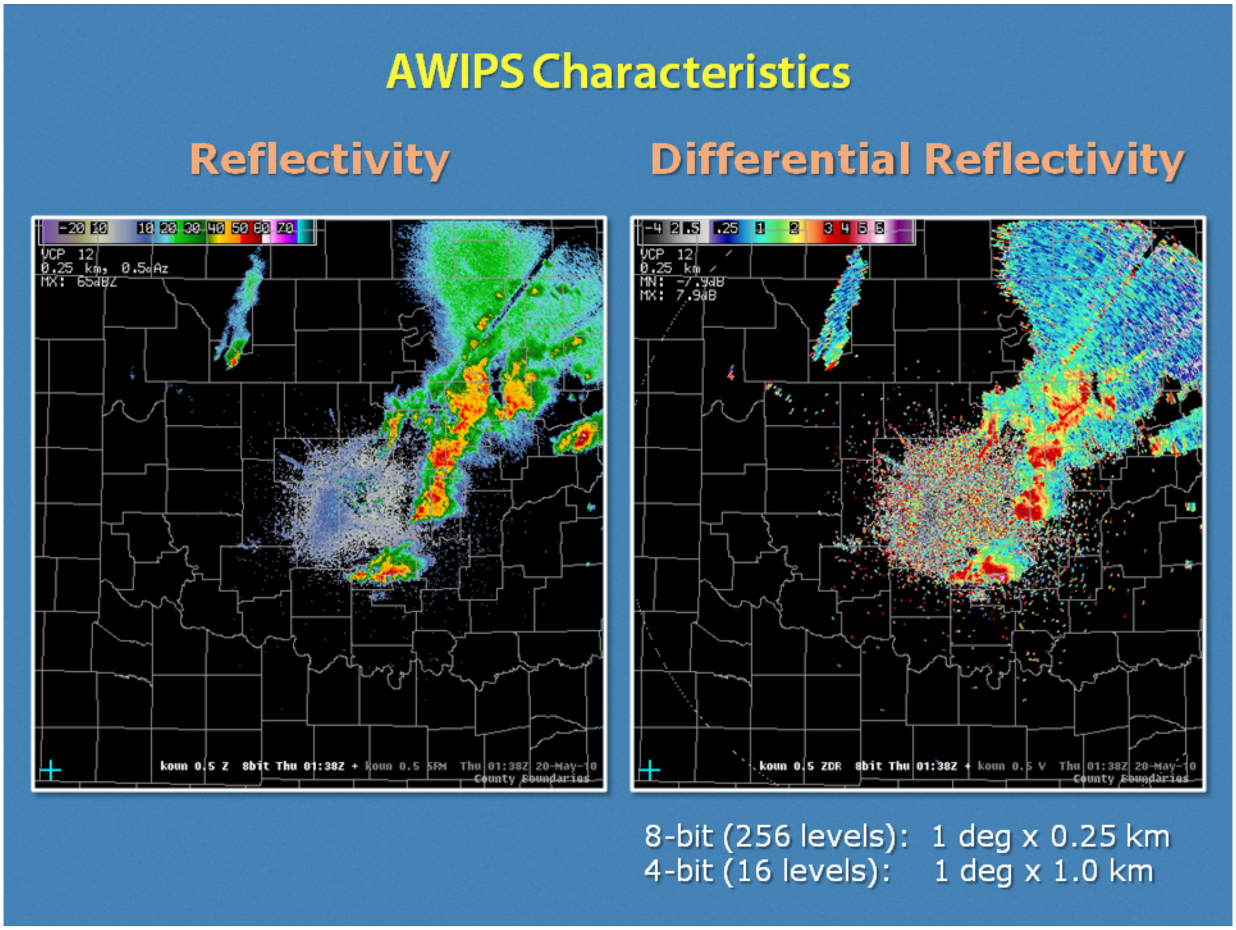
Student Notes:



6. Typical Values

Instructor Notes: Here is a chart of the typical values for ZDR given an echo type listed on the left. This chart is also available with the training aid off the Tools menu on your WES for the dual-pol exercises. Note that there is not as clear of a break between the meteorological and non-meteorological targets as was the case with correlation coefficient (CC). Please take a moment and get a feel for the typical values of the listed echo types. Advance the slide when ready.

Student Notes:



7. AWIPS Characteristics

Instructor Notes: The image on the right is what the ZDR product looks like in AWIPS. A reflectivity image is shown on the left for reference. ZDR will be available in two resolutions: 1) 8-bit at 1 degree x 0.25 km resolution and 2) 4-bit at 1 degree x 1.0 km resolution. ZDR products are available at these resolutions on all elevation angles.

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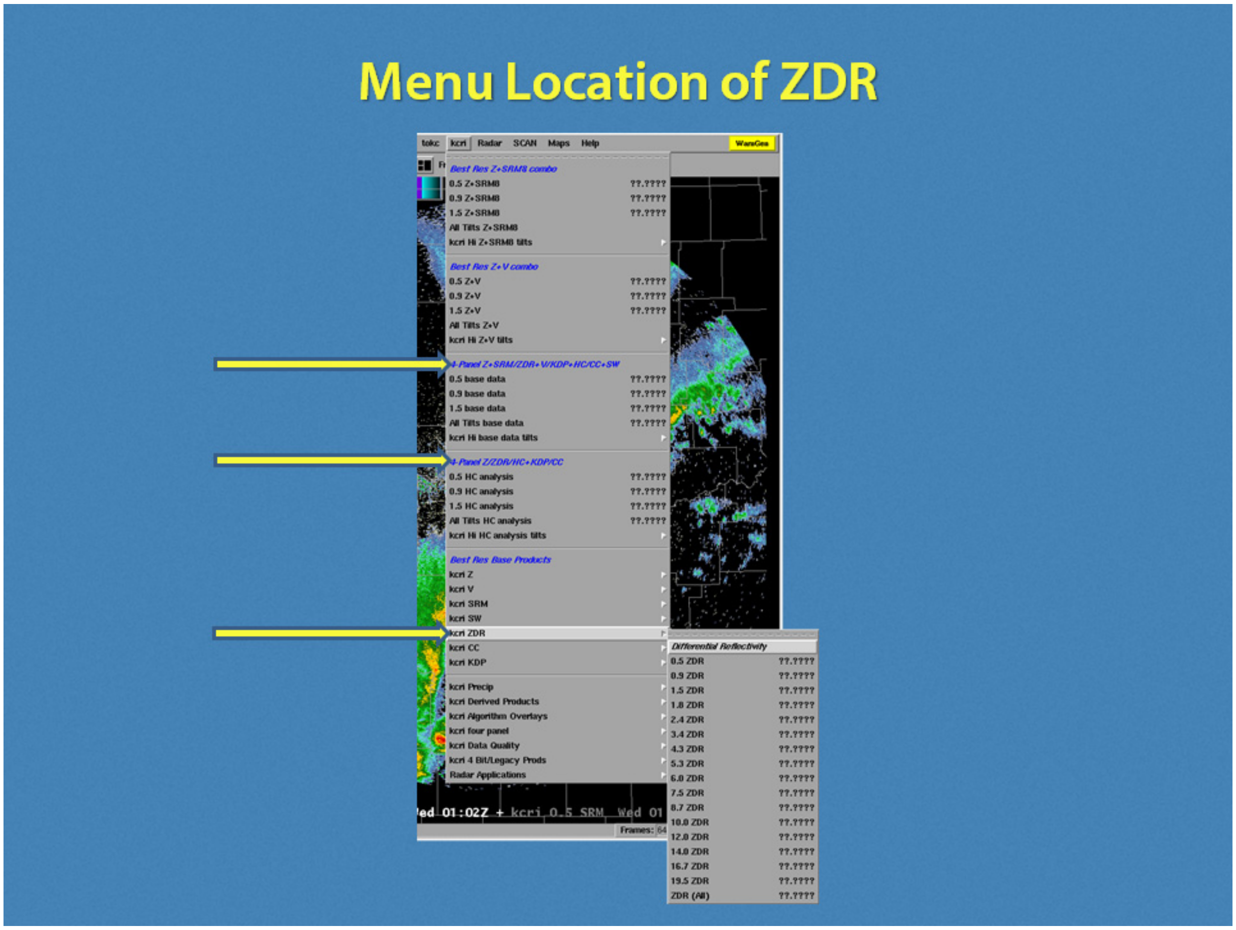


8. Menu Location of ZDR

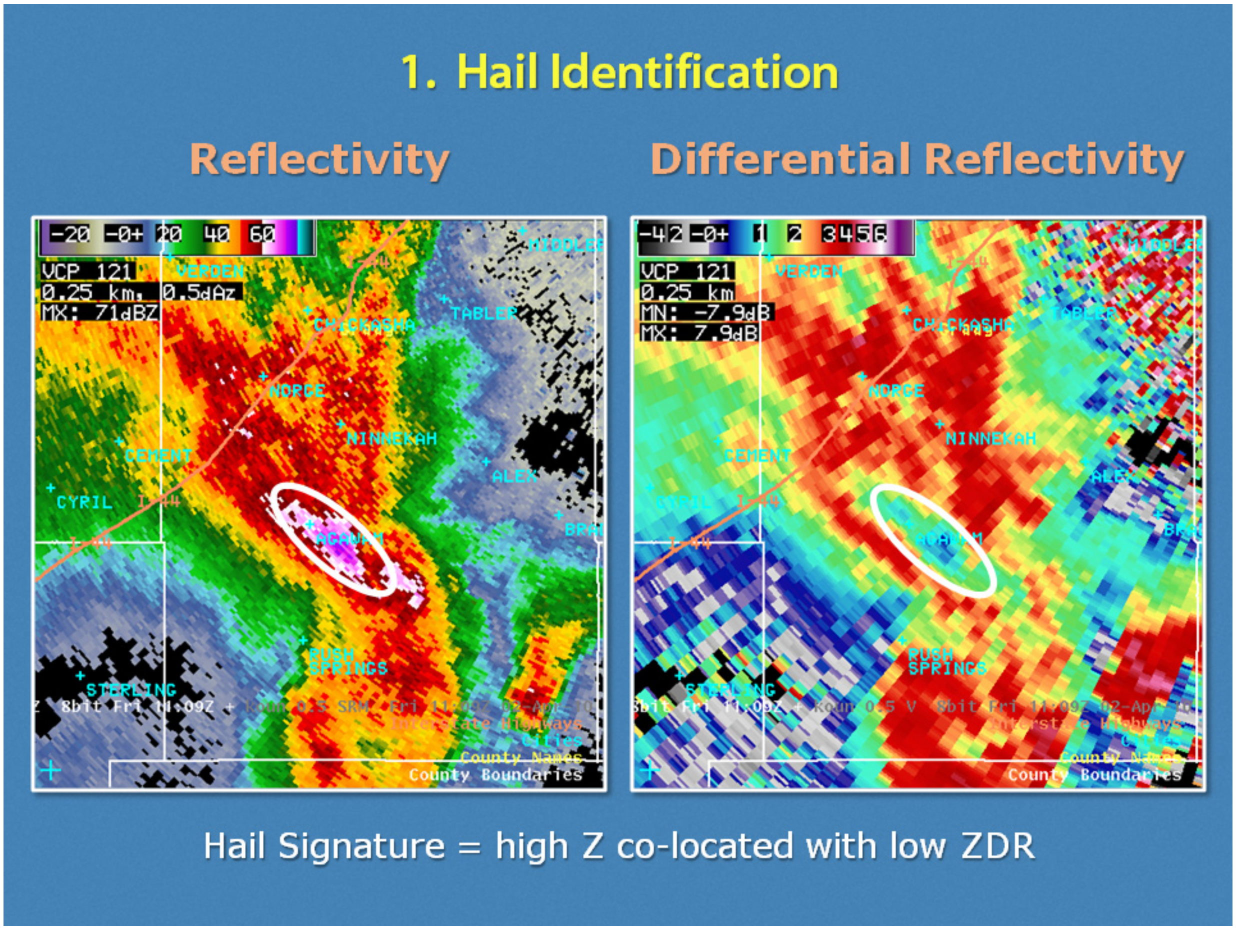
Instructor Notes: Once your local radar is upgraded, you will be able to find the individual ZDR products for each elevation angle inside your dedicated radar's drop-down menu here. ZDR is also available in 4-panel layouts tailor-made for panel-combo rotate dual-pol radar analyses.

Student Notes:

9. Operational Applications

Instructor Notes: The next few slides will briefly show you a high level overview of how to apply ZDR operationally.

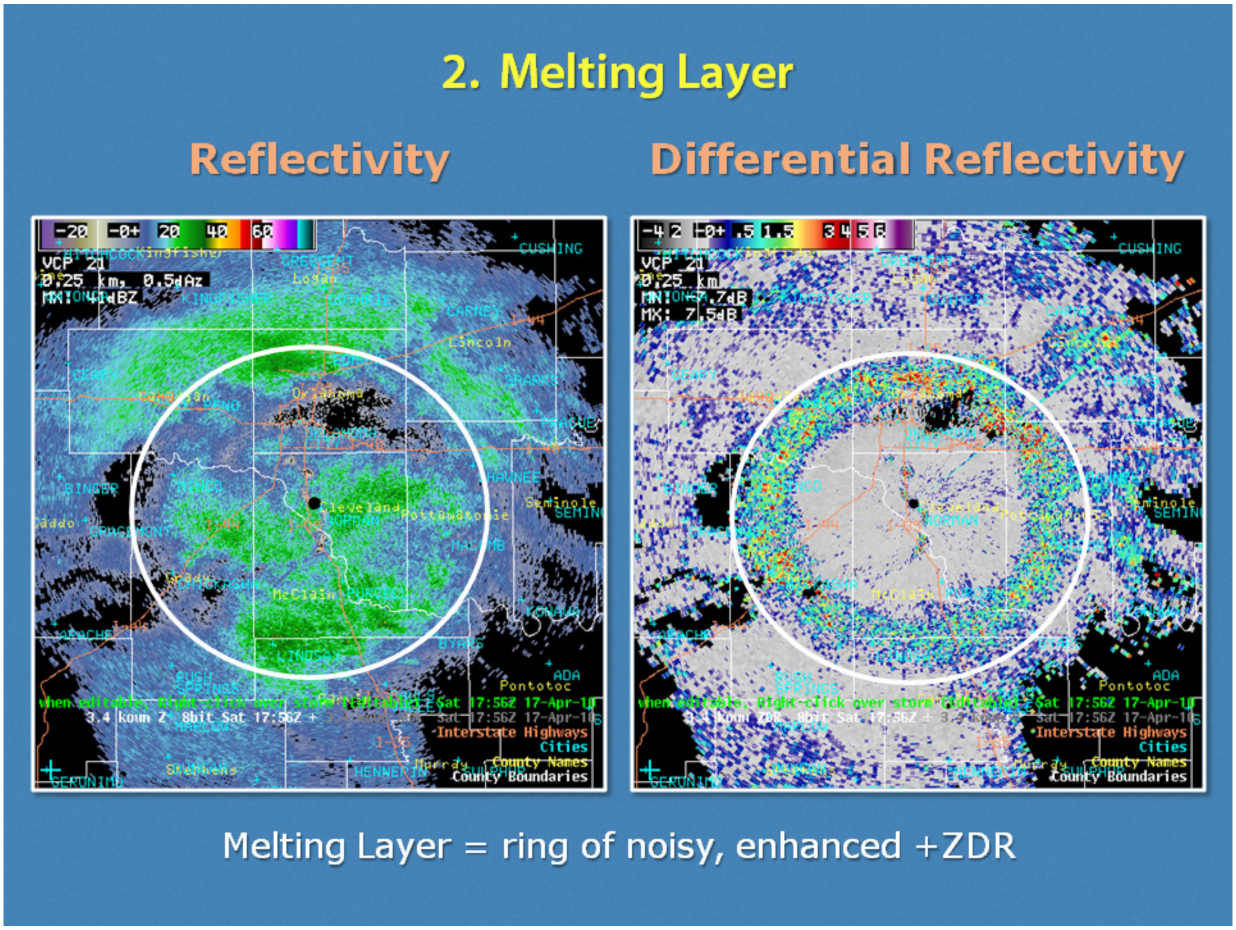
Student Notes:



10. 1. Hail Identification

Instructor Notes: Here is a classic example of hail identification using ZDR. If we focus on the reflectivity core (noted by the white oval) we see high reflectivity values greater than 60 dBZ. Given the high reflectivity, we would suspect hail, and looking at the ZDR product on the right, we are more confident of hail because ZDR values are less than 1 dB and much lower relative to surrounding areas. High reflectivity with low ZDR (near 0 dB and at times even negative) is a classic hail signature.

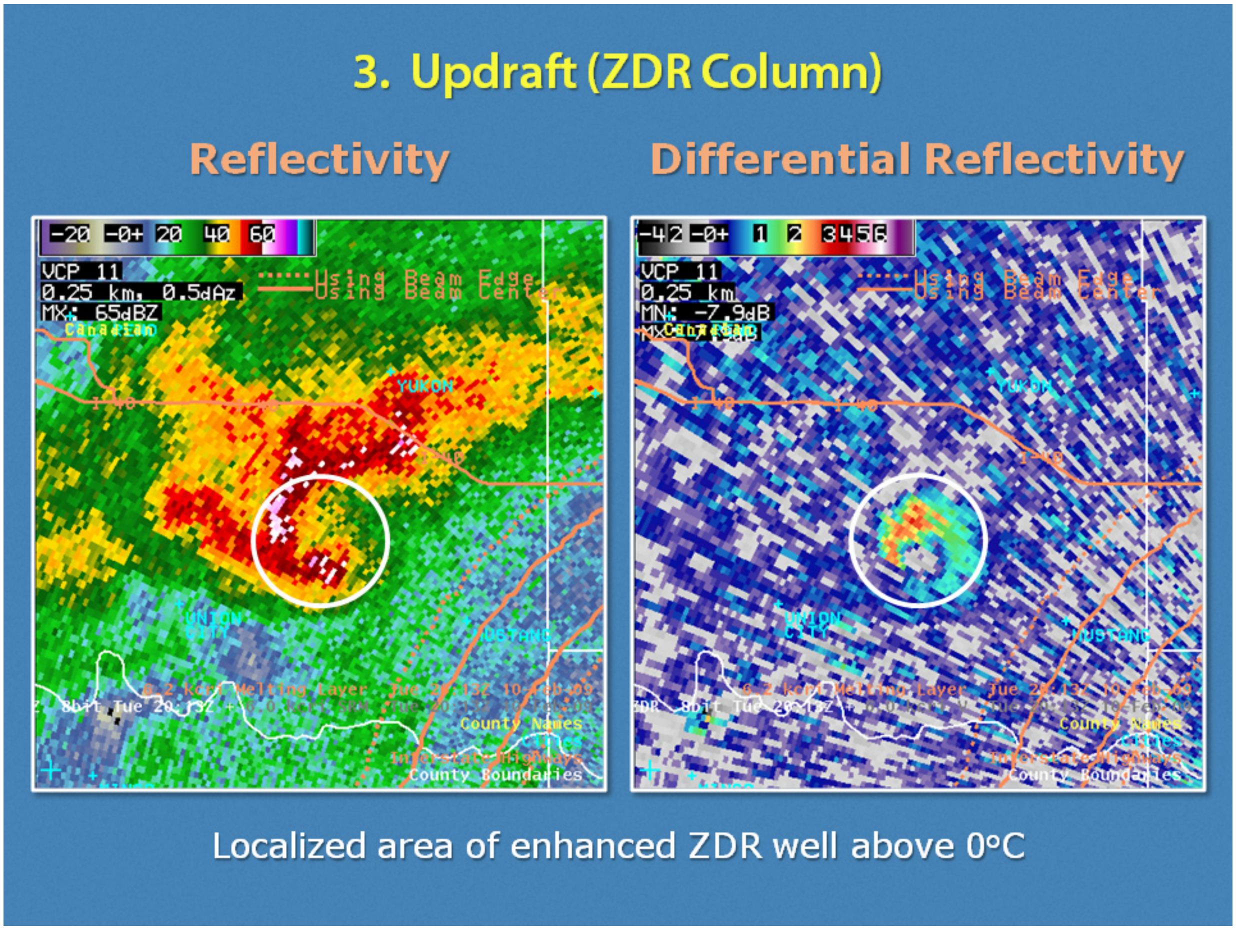
Student Notes:



11. 2. Melting Layer

Instructor Notes: Here is an example of what the melting layer will look like in ZDR. This is from the 3.4 degree tilt of the KOUN dual-pol radar during a stratiform rain event. Note in the reflectivity image on the left that there is not a pronounced ring of high reflectivity typically associated with the bright band (melting layer), but looking at ZDR we see a ring of higher (and noisier) ZDR. As snow and ice crystals begin to melt, they increase in density and also increase in horizontal dimension, both of which will lead to an increase in ZDR.

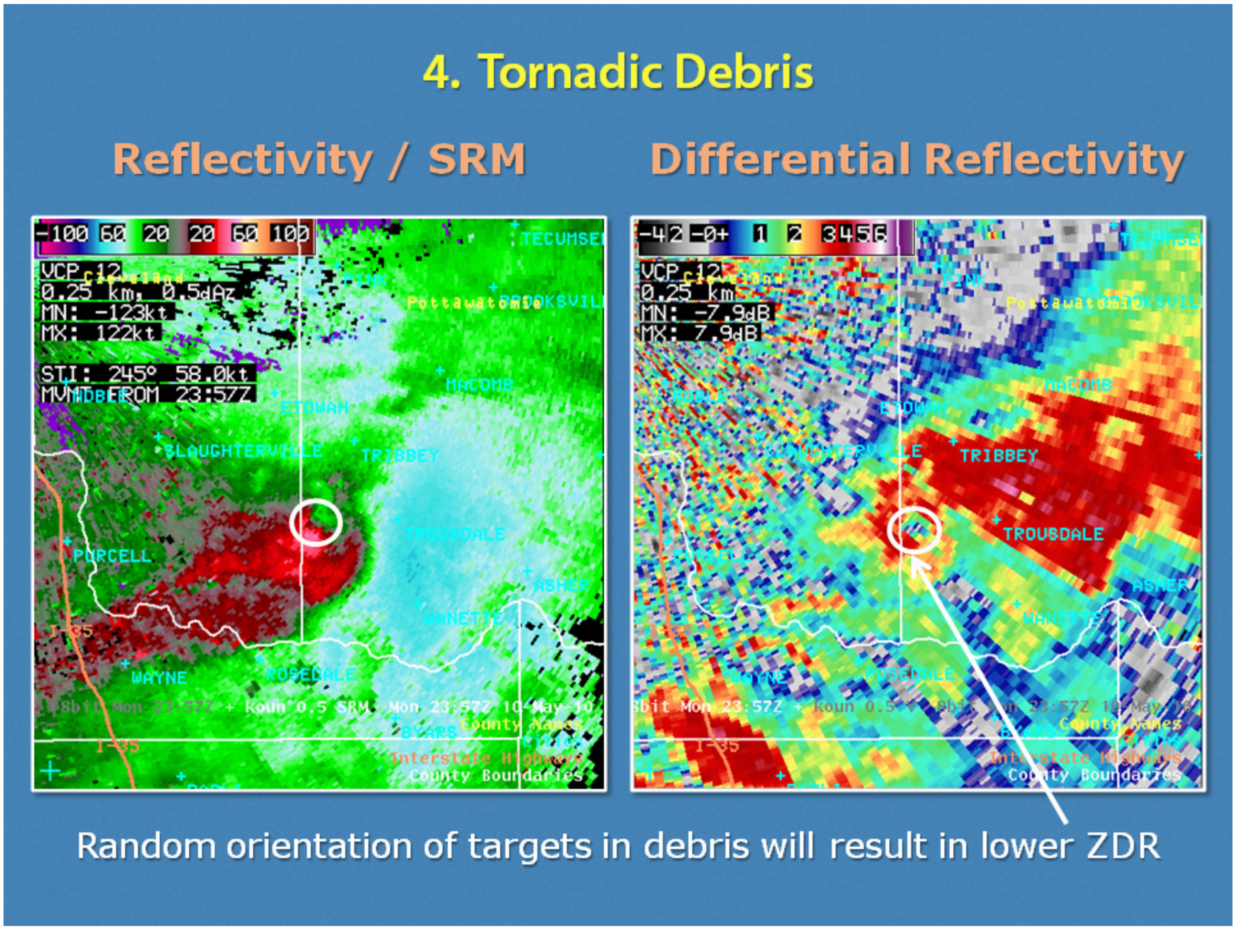
Student Notes:



12. 3. Updraft (ZDR Column)

Instructor Notes: When intense updrafts develop, if enough liquid water is present within them, this liquid water will be lofted well above the environmental 0 Celsius level. This will result in an area of locally enhanced ZDR within an updraft. Here is an example from 10 February 2009 at 2013 UTC in Central Oklahoma. The melting layer height for this day was roughly 10,500 feet and we are looking at 15,700 feet. Looking at reflectivity, we see a supercell with an inflow notch and hook echo denoted by the white circle. The location of the inflow notch should be roughly the location of the updraft. If we look at ZDR, we see a localized area of enhanced ZDR (> 2 dB) in the inflow notch, or inferred updraft region. So, we can confidently say this is where updraft is located with this storm and that hail production is a certainty given the presence of liquid several thousands of feet above 0 celsius level.

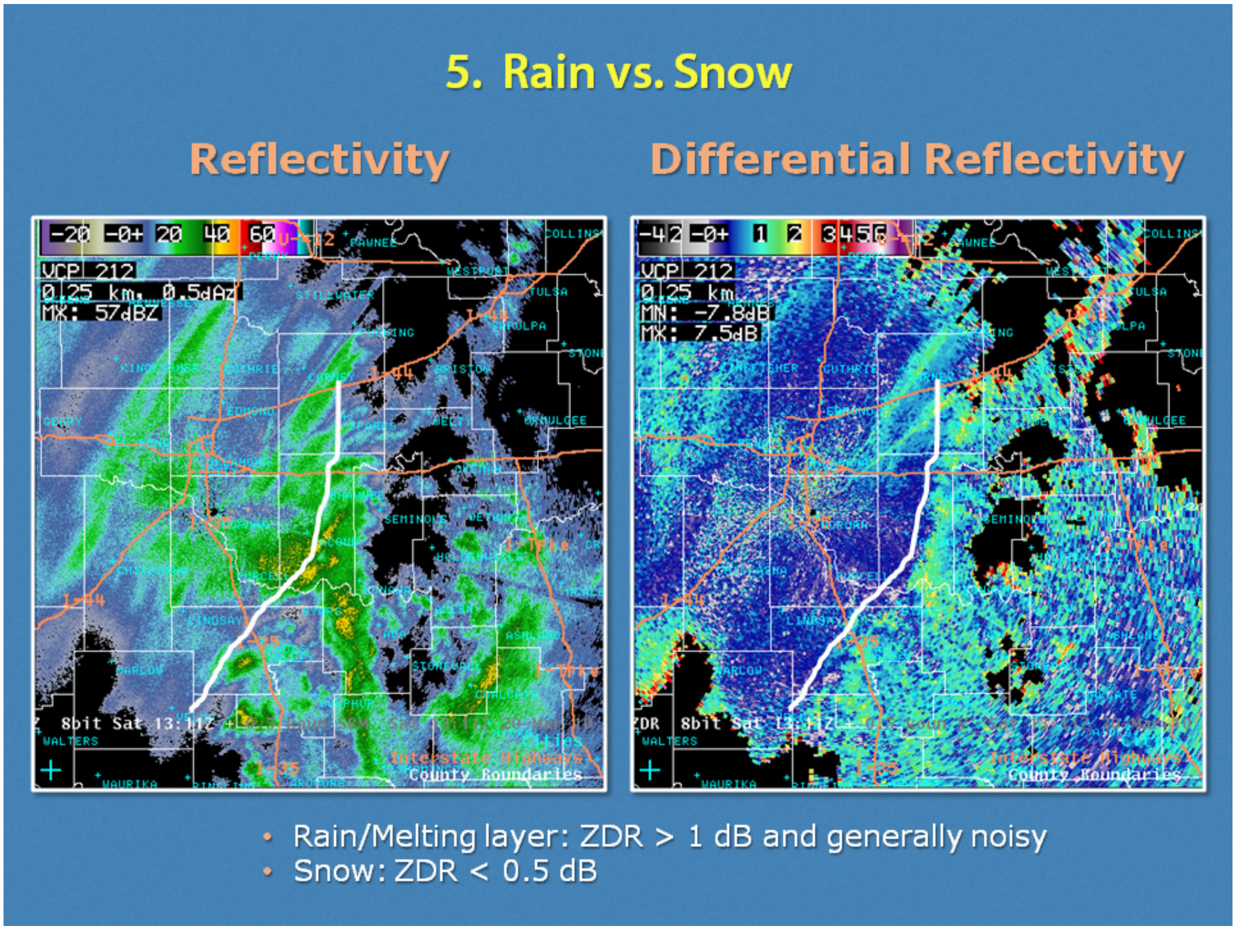
Student Notes:



13. 4. Tornadic Debris

Instructor Notes: Here is an example of how ZDR can be used to detect debris being lofted by a tornado. On the left is an SRM image which indicates gate-to-gate shear. In ZDR, we see a localized area of depressed ZDR values collocated with the velocity couplet which is near the tip of the hook echo (not shown). These depressed ZDR values are caused by lofted debris from a tornado causing damage. The debris has random orientation which causes the ZDR to be lower than surrounding areas.

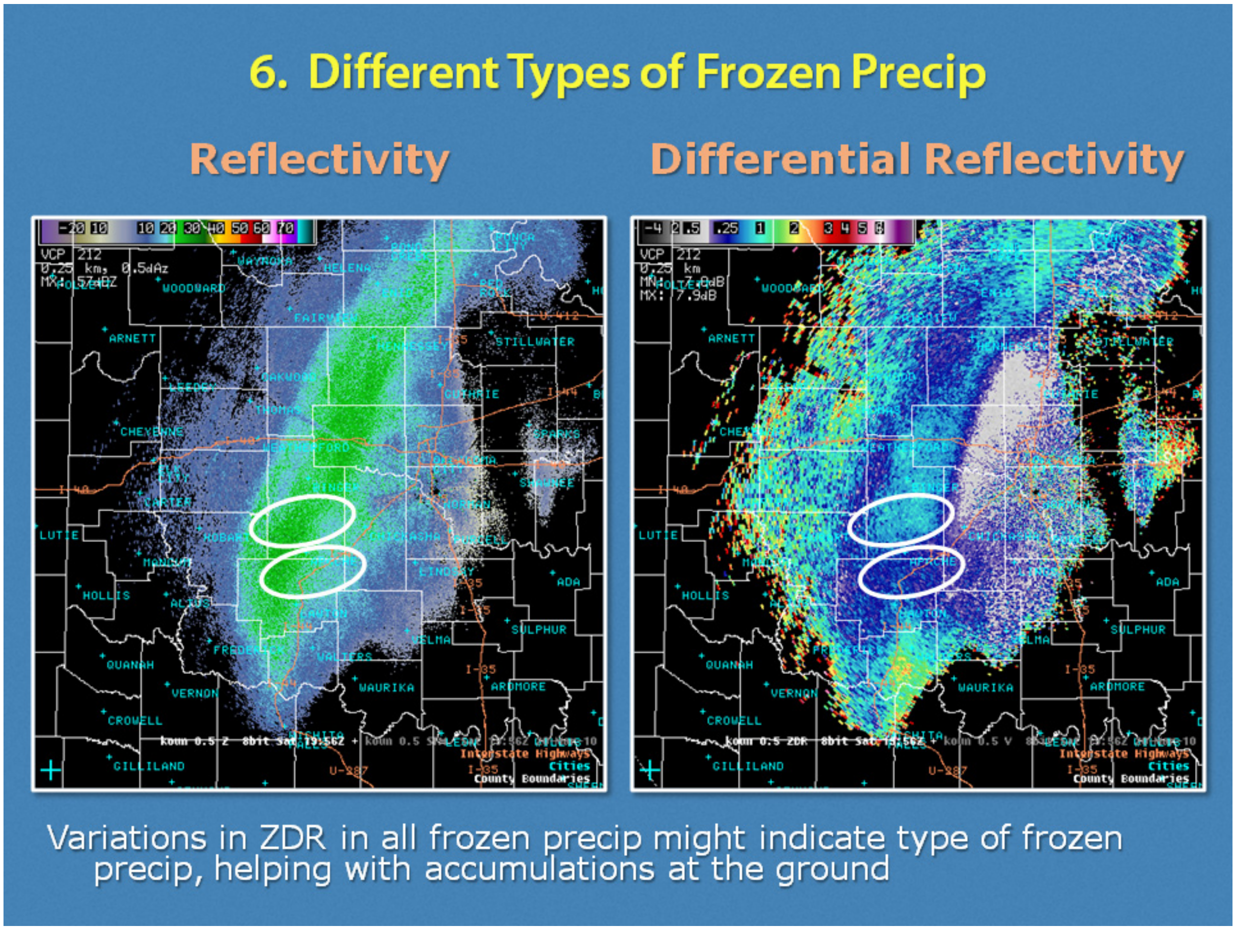
Student Notes:



14. 5. Rain vs. Snow

Instructor Notes: Here is an example where at the surface, rain was occurring east of this white line and snow was occurring west of it. The reflectivity field shows some subtle differences which might indicate a change from rain to snow, but it is more obvious in the ZDR field. ZDR values in rain are typically greater than 1 dB, while ZDR values in snow are typically less than 0.5 dB (exceptions in melting/wet snow) . Keep in mind how far off the ground the radar beam is, and always check surface obs if available to help verify what you are seeing on radar.

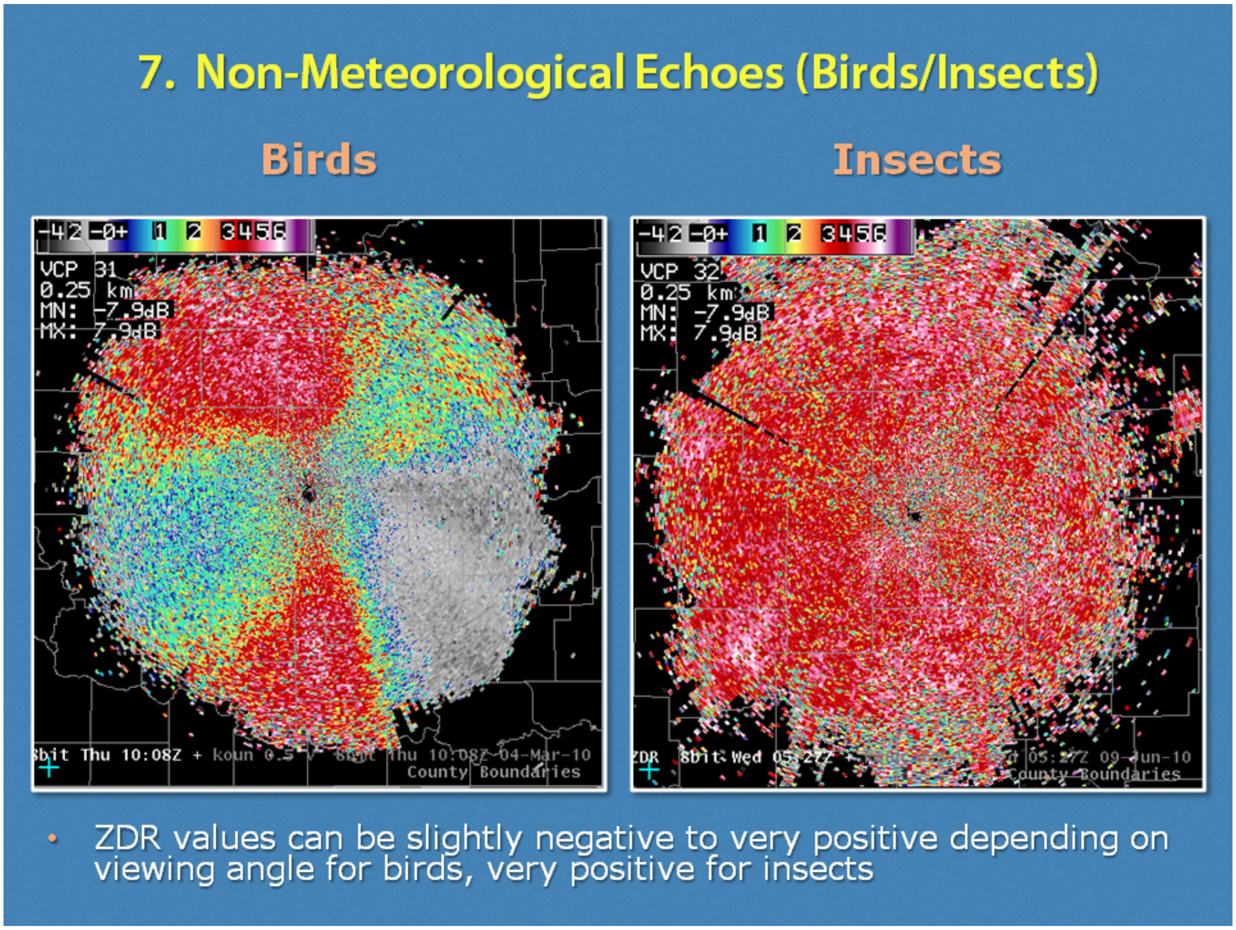
Student Notes:



15. 6. Different Types of Frozen Precip

Instructor Notes: Here is an example of a possible application of ZDR when all frozen precipitation is present. Typically ice particles (such as snow) will have low ZDR (< 0.5 dB) due to their low density nature. However, when higher density ice particles (needles, etc.) form and become oriented either horizontally or vertically, the ZDR will change. Horizontally oriented, high-density particles like plates, columns, or needles, will exhibit high ZDR (> 1 dB) and vertically oriented, high-density particles will exhibit negative ZDR values. Therefore, ZDR in all frozen precipitation might help determine the type of ice crystals that are falling and could possibly help with accumulation estimation. In this example a NNE to SSW band of frozen precipitation is over SW Oklahoma, and ZDR values are in the 0.2 to 0.3 dB range along the southern end of the band. However to the north, ZDR values are approaching 1 dB. The reflectivity in both regions are fairly similar. Most likely there are differences in the type of ice particles falling in these two regions, and it could be affecting the amount of snow fall at the ground. Though it's understood that the type of snow is different in these two ovals, much more research is needed to determine how that affects snow accumulation.

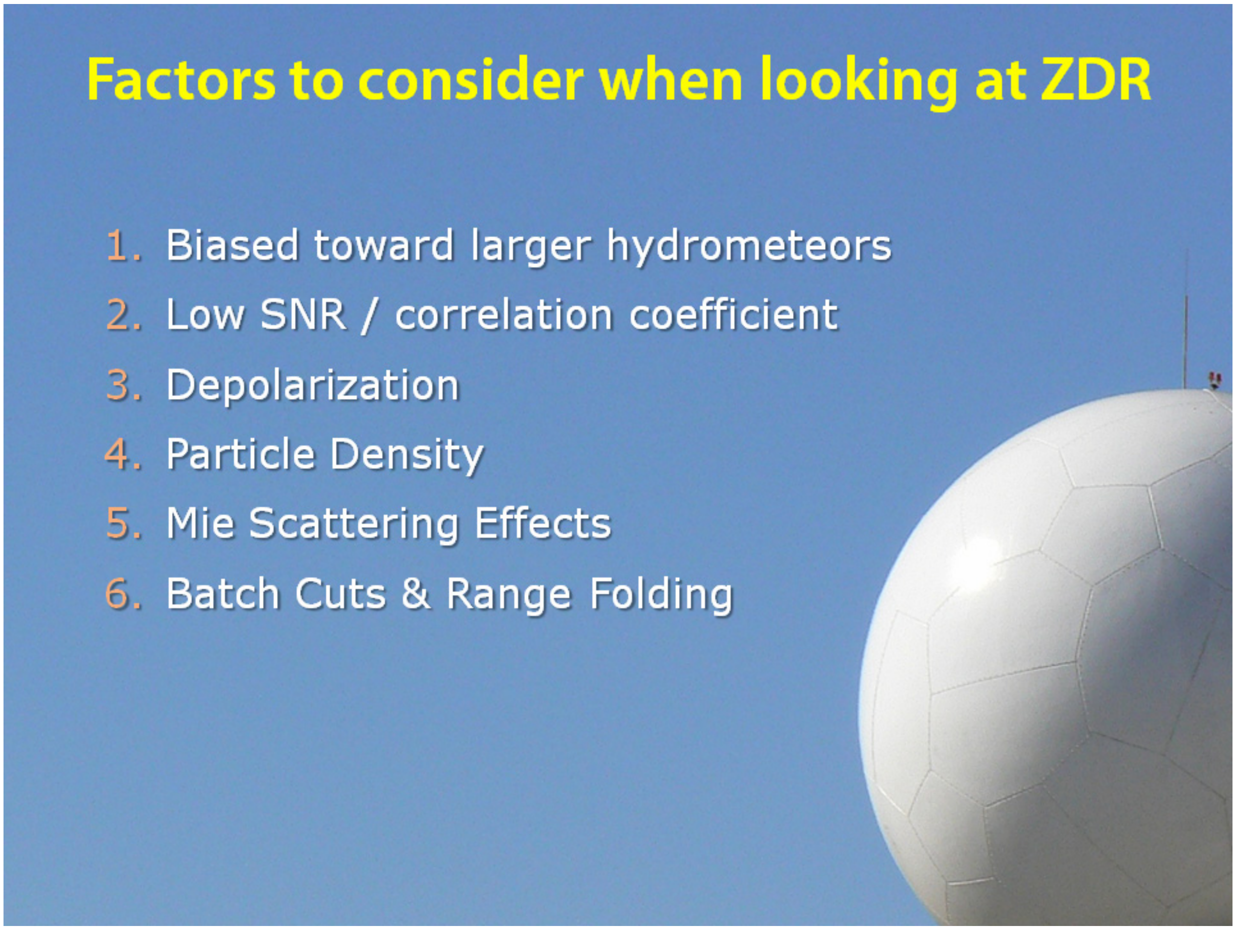
Student Notes:



16. 7. Non-Meteorological Echoes (Birds/Insects)

Instructor Notes: Birds and insects will have distinct ZDR signatures. According to previous studies, birds will have ZDR values that are slightly less than insects. Values for birds can be anywhere from slightly negative (-2 to -3 dB) to substantially positive (+6 or +7 dB) mostly depending on the viewing angle and Mie scattering effects. For insects, ZDR typically is positive and will range from +1 to greater than +7.9 dB. For insects, ZDR values also depend on viewing angle, but not so much on Mie scattering because they are smaller than most birds. Finally, birds are most prominent at night whereas insects are most prominent during the day, though both do co-exist quite often. Knowing your local bird/insect population and habits will help in interpretation. Here are two examples, one of birds (on the left) and one of insects (on the right). The reflectivity images (not shown) appear very similar. However, when looking at the ZDR images, we see distinct differences. In the bird image, the ZDR has a corridor of large, positive ZDR from the south to the north/northwest of the radar which follows the ambient low-level flow. The radar is most likely viewing the birds head-on. The negative values to the west and east of the radar are most likely a result of viewing angle of the birds and Mie scattering. In contrast, the insects image shows very high ZDR in all directions from the radar revealing little information on the orientation of the insects.

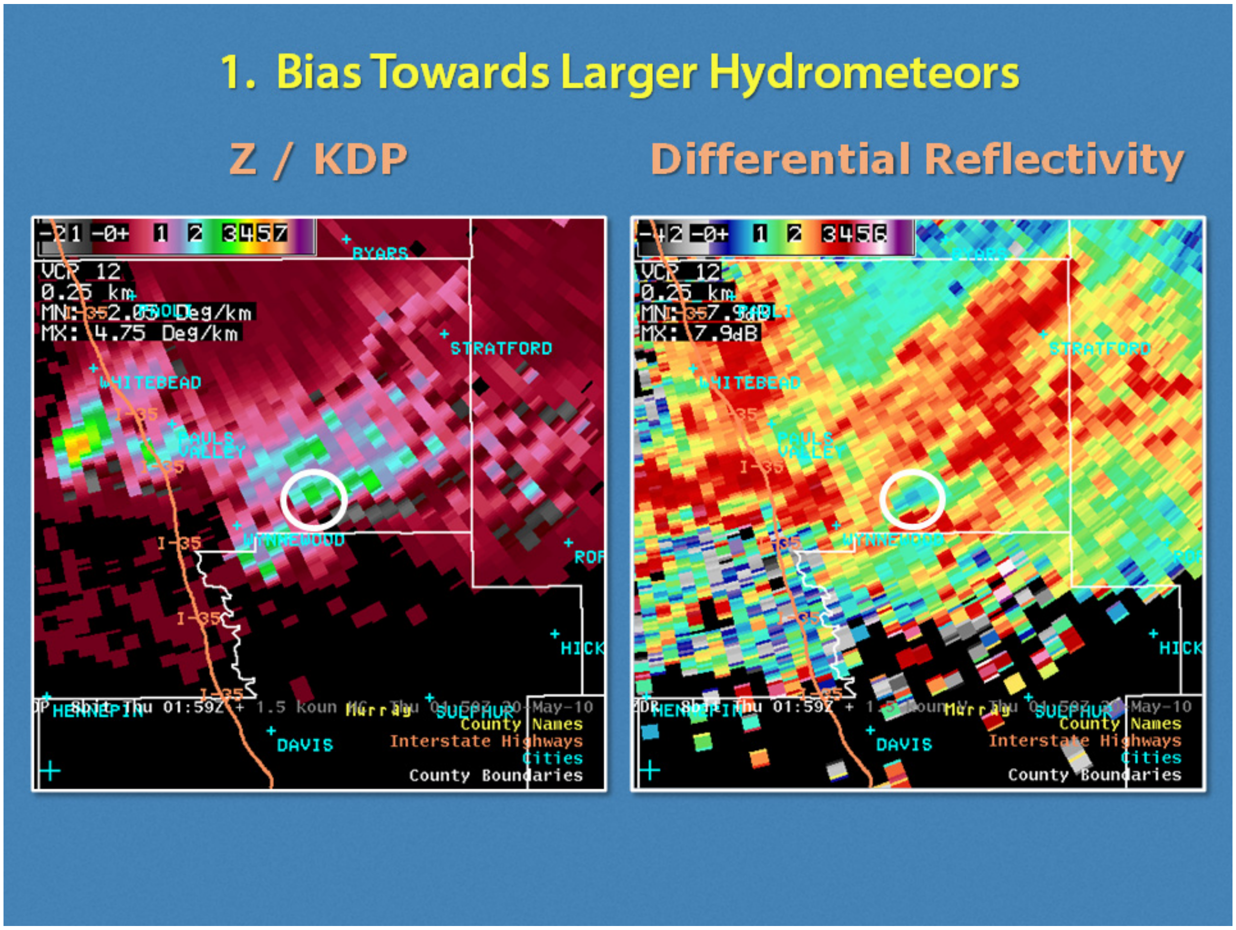
Student Notes:



17. Factors to consider when looking at ZDR

Instructor Notes: As with any radar product, there are factors that will affect the quality of ZDR. I will present the currently known issues concerning the quality of ZDR and show some examples.

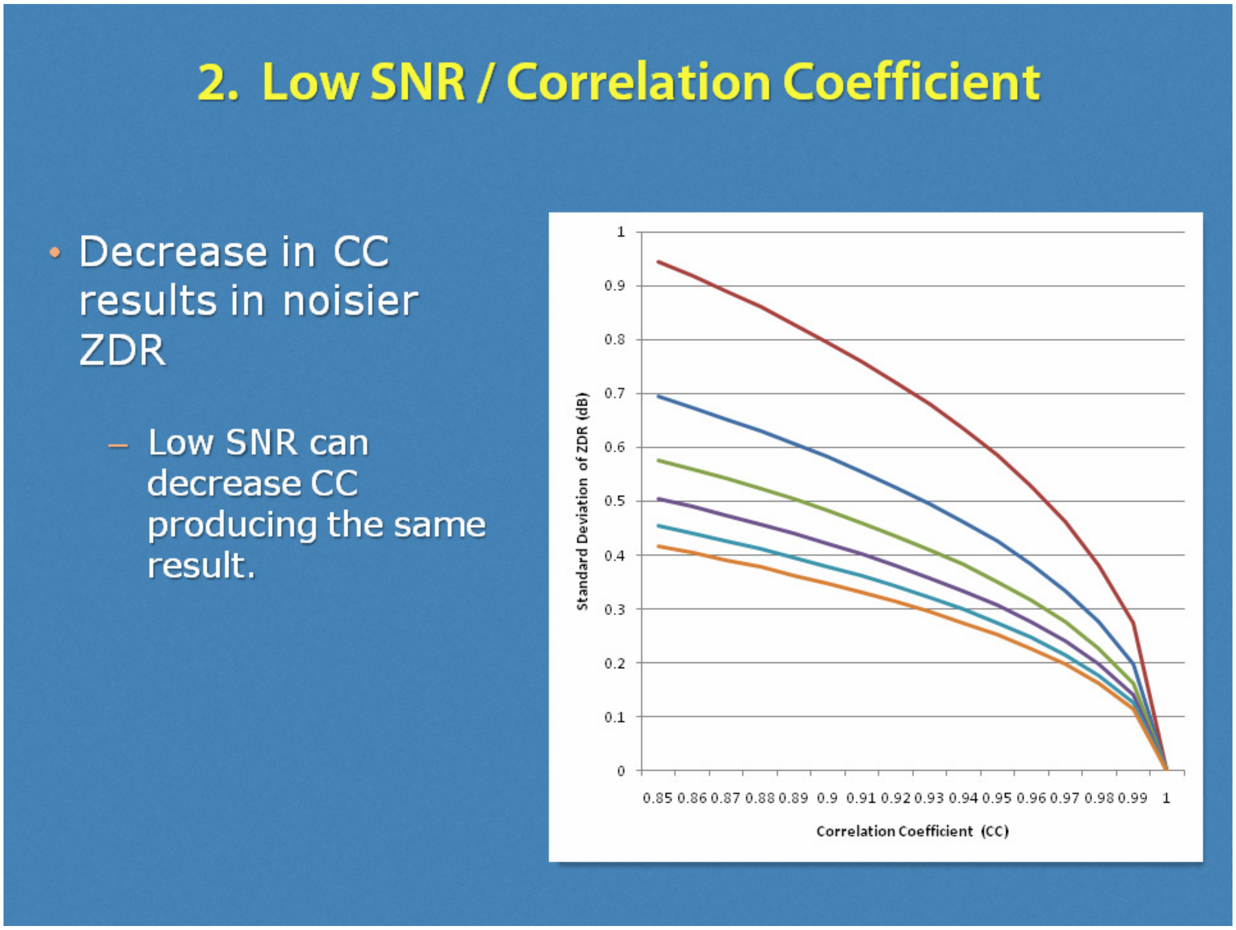
Student Notes:



18. 1. Bias Towards Larger Hydrometeors

Instructor Notes: Here is an example where the larger hydrometeors in the pulse volume are biasing the ZDR toward their lower intrinsic values. Reflectivity values in this region (not shown) are upward of 65 to 70 dBZ, indicating hail is probably present. Upon inspection of ZDR, we see values of approximately or slightly less than 1 dB. Recall though, in pure hail, we would expect to see near 0 dB ZDR, and in pure rain we would expect to see upwards of 2 or 3 dB ZDR for higher Z. So most likely what we are seeing here is a mixture of hail and rain. This is confirmed by the KDP values of almost 3 deg/km. (We'll discuss KDP in another module). However, since the hail is most likely larger than the rain in this region, the ZDR is being biased toward the lower values intrinsic for pure hail.

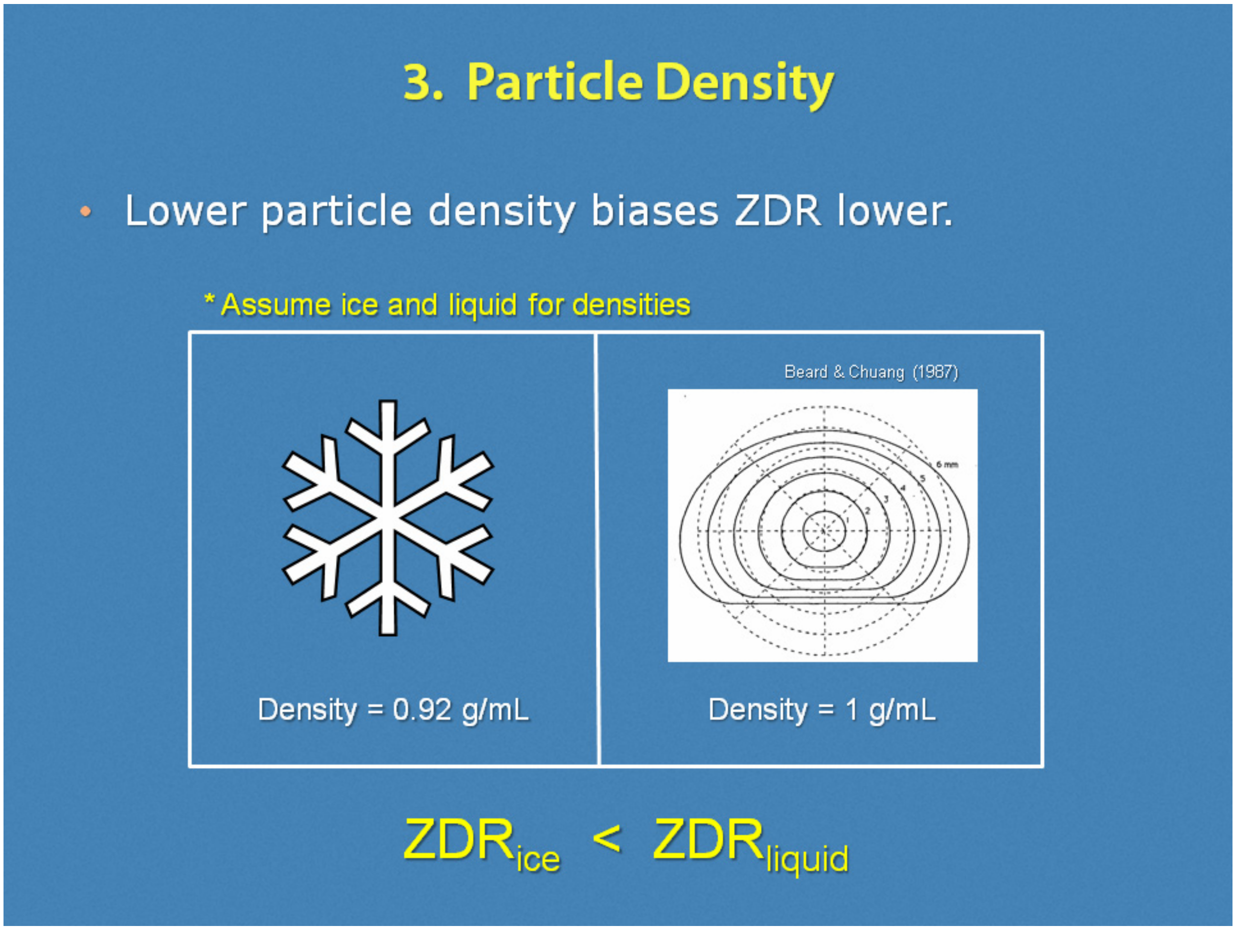
Student Notes:



19. 2. Low SNR / Correlation Coefficient

Instructor Notes: According to Bringi & Chandrasekar (2001), the estimate of ZDR becomes less and less trustworthy as the correlation coefficient drops. This will be evident by a noisier appearance in the ZDR field. The graph here, adapted from the data from Bringi & Chandrasekar (2001), primarily shows that significant error in ZDR become quite large (> 0.4 dB) for CC as high as 0.9! Each curve represents a constant normalized spectrum width. The top curves represent lower normalized spectrum width and bottom curves represent higher normalized spectrum widths. And this is for a radar with the number of samples at 128. For the WSR-88D network, the number of samples typically is around 20 or 30, so the error in ZDR will be worse. Bottom line, be more suspicious of ZDR values in areas with CC less than 0.9.

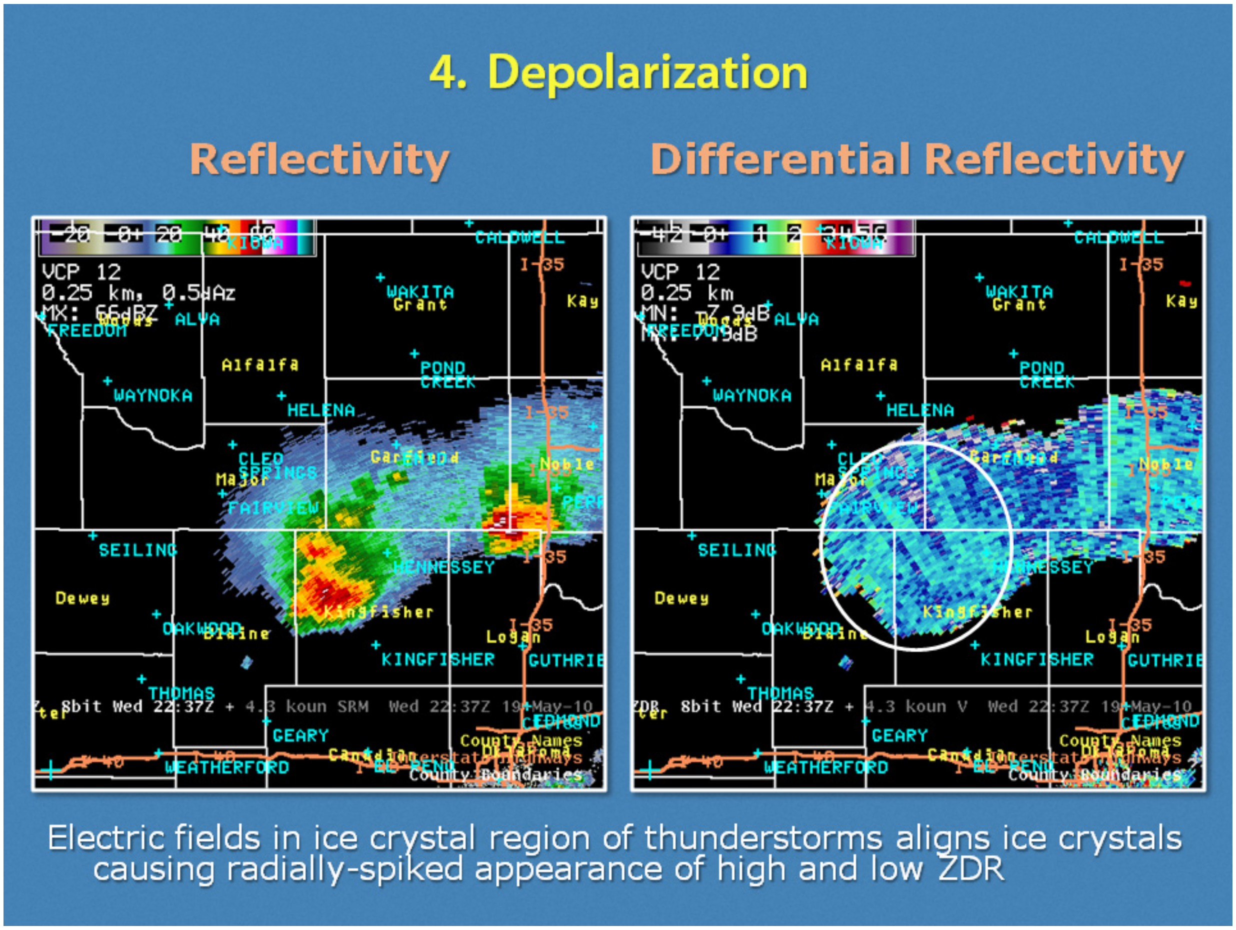
Student Notes:



20. 3. Particle Density

Instructor Notes: The lower the particle density, the lower the ZDR. For example, if there is ice with a density of 0.92 g/mL as shown here, and there are raindrops of the same size and concentration but a density of 1 g/mL, the ZDR of the ice will be lower than the ZDR of the rain just because the density of the ice is lower. In operations this will be noted by a general decrease in ZDR when the targets are ice (aggregated snow or ice crystals such as dendrites (low density)) rather than liquid (rain). NOTE: High density ice particles (needles) that are horizontally oriented can have significantly positive ZDR.

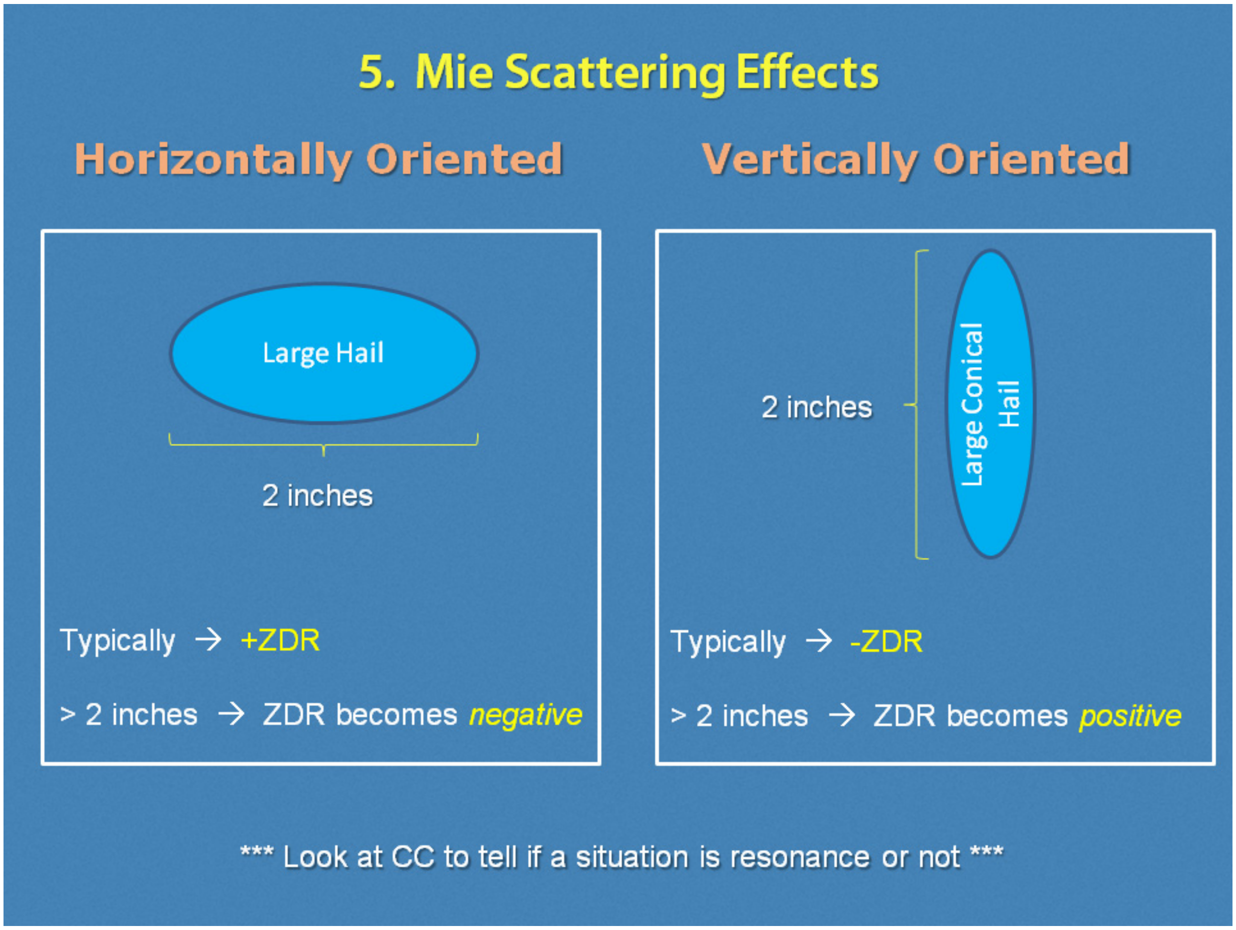
Student Notes:



21. 4. Depolarization

Instructor Notes: Sometimes a pulse will be scattered back towards the radar in its opposite polarization. For example, the horizontally oriented portion of the transmitted pulse may get reflected back to the radar oriented in the vertical. This switch in polarization in the returned power is referred to as depolarization. Depolarization only affects ZDR and shows up as radial spikes of high and/or low ZDR based on the type of depolarization in the ice crystal regions of highly electrified thunderstorms. You will mainly find this feature in the anvil regions which typically can be seen in the upper tilts. Here is an example of depolarization that occurred in a supercell thunderstorms on 19 May 2010 in north central Oklahoma. This is the 4.0 degree tilt at 2237 Z. Note the alternating radials of positive and negative ZDR here.

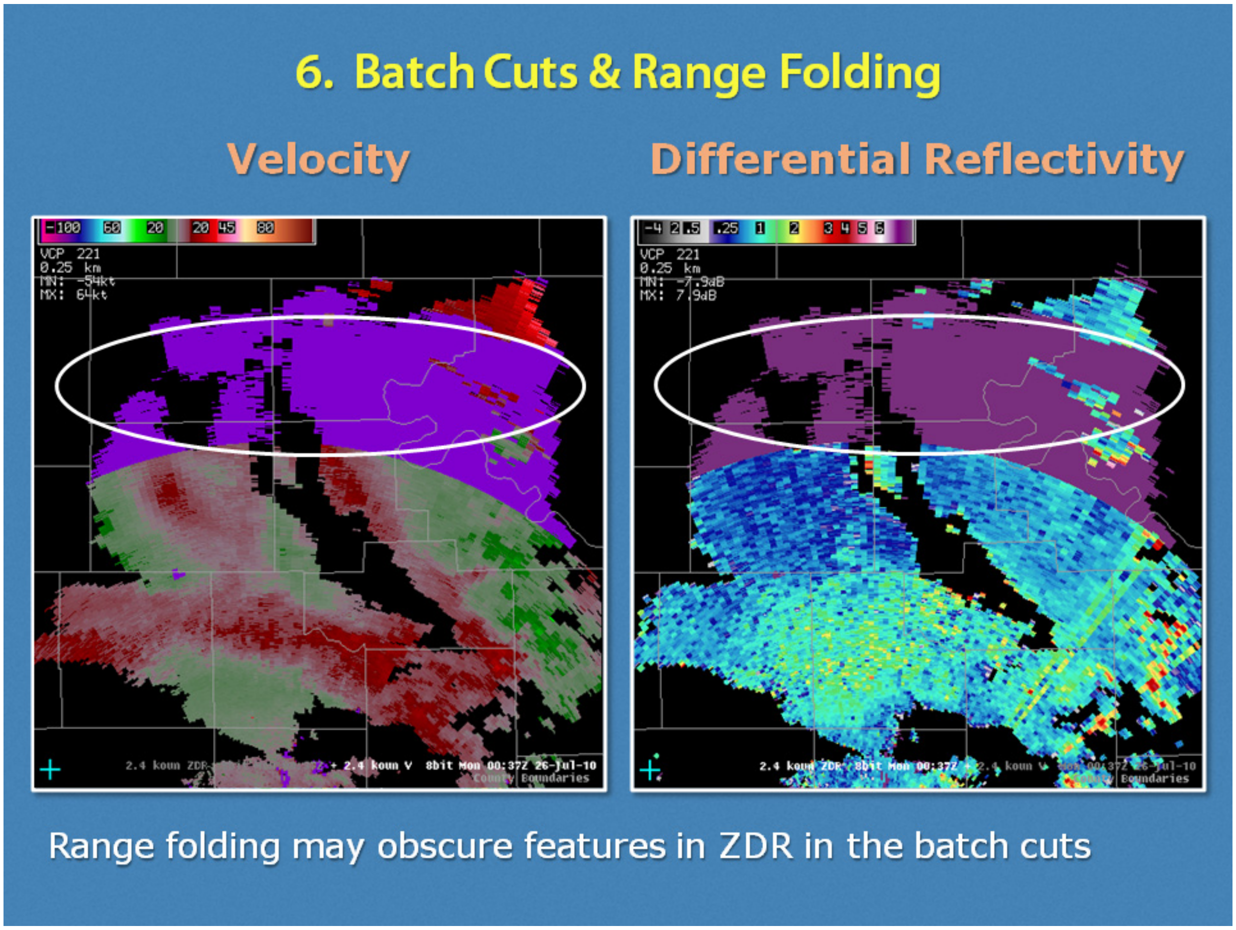
Student Notes:



22. 5. Mie Scattering Effects

Instructor Notes: As particle sizes approach approximately 2 inches in diameter, ZDR can switch signs due to Mie scattering effects. Take for instance, a horizontally oriented hail stone. Typically, it will have a positive ZDR. However, if it's diameter is larger than 2 inches, it will appear on radar to have a negative ZDR due to Mie scattering effects. In operations, keep this in mind when viewing hail producing storms. For example, a strong reflectivity core with negative ZDR may not indicate vertically oriented hail. It may actually be indicating very large horizontally oriented hail. The opposite is also true. Vertically oriented particles can switch signs around 2 inches in diameter. To tell if a particular bin is experiencing Mie scattering effects or not, look at CC. CC for non-Mie scattering (or Rayleigh scattering which is for particles ~ 1.5 inches or less) should be higher (> 0.93) whereas for Mie scattering (~ 2.5 inches or greater), the CC should be lower (< 0.9).

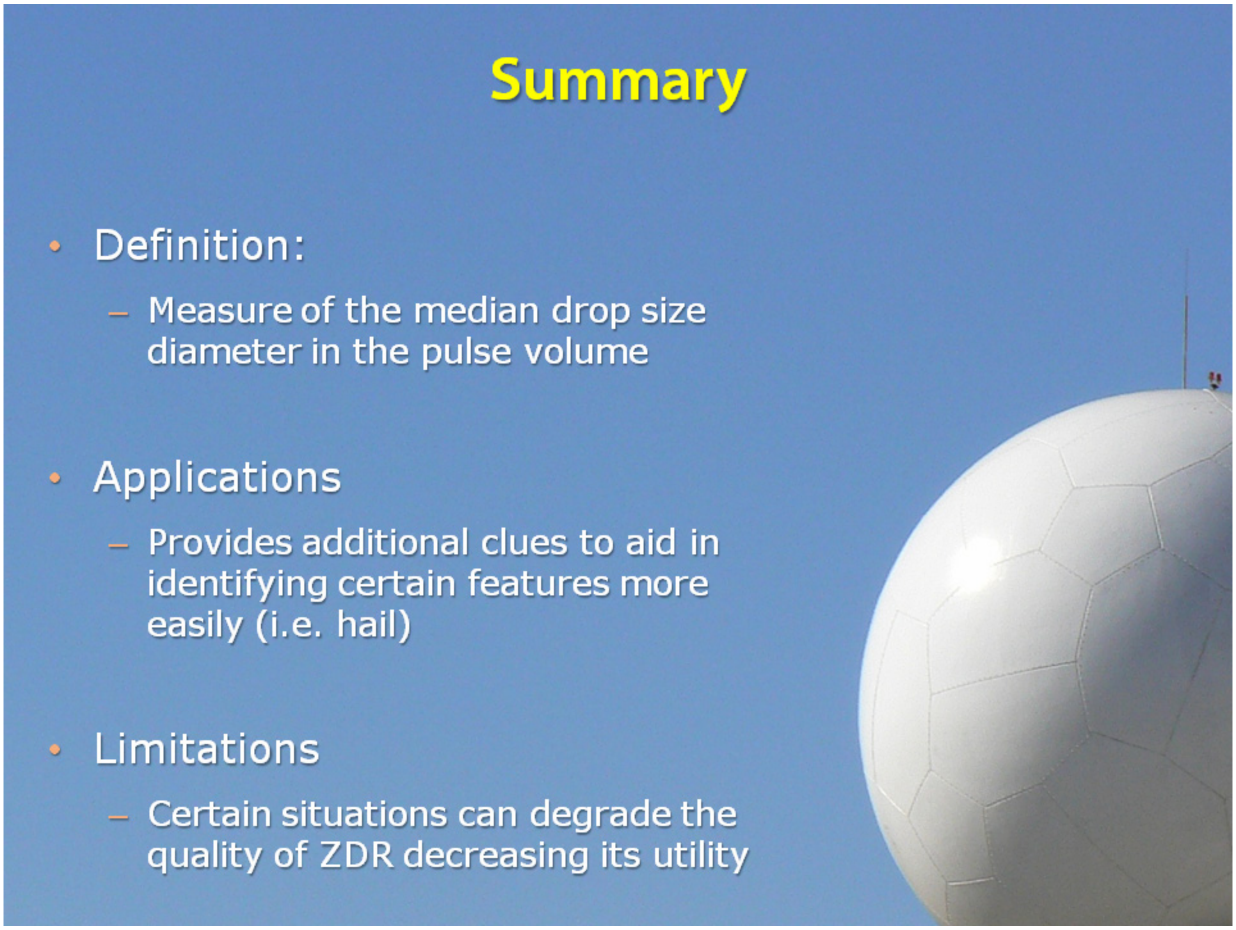
Student Notes:



23. 6. Batch Cuts & Range Folding

Instructor Notes: The last limitation with ZDR that we'll look at is that in the batch cuts, range folding may obscure some signatures in ZDR. Here is an example from 26 July 2010 at 0037 UTC from the 2.4 degree elevation scan. Note that where there is range folding in the velocity, there is also range folding in ZDR.

Student Notes:



24. Summary

Instructor Notes: In summary, we have learned that differential reflectivity is a measure of the median drop size diameter inside a radar pulse volume. We have also learned when ZDR can be used in operations to help make decisions, and in what situations the quality of ZDR is degraded.

Student Notes:

25. Conclusion

Instructor Notes: This concludes the lesson on ZDR, and thanks for your attention. If you have any questions, you can send an email to the dual polarization operations course help list (dualpol_list@wdtb.noaa.gov).

Student Notes: