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Topic: Principles of Radar

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WSR-88D Fundamentals Part 1: Radar Beam Characteristics

1. Intro to Radar Beam Characteristics

1.1 Welcome

Notes:

Welcome to the Radar & Applications Course (RAC) Principles of Doppler Weather Radar. This lesson is on WSR-88D Fundamentals Part 1: Radar Beam Characteristics. It is presented by the Warning Decision Training Division (WDTD). Let's get started!

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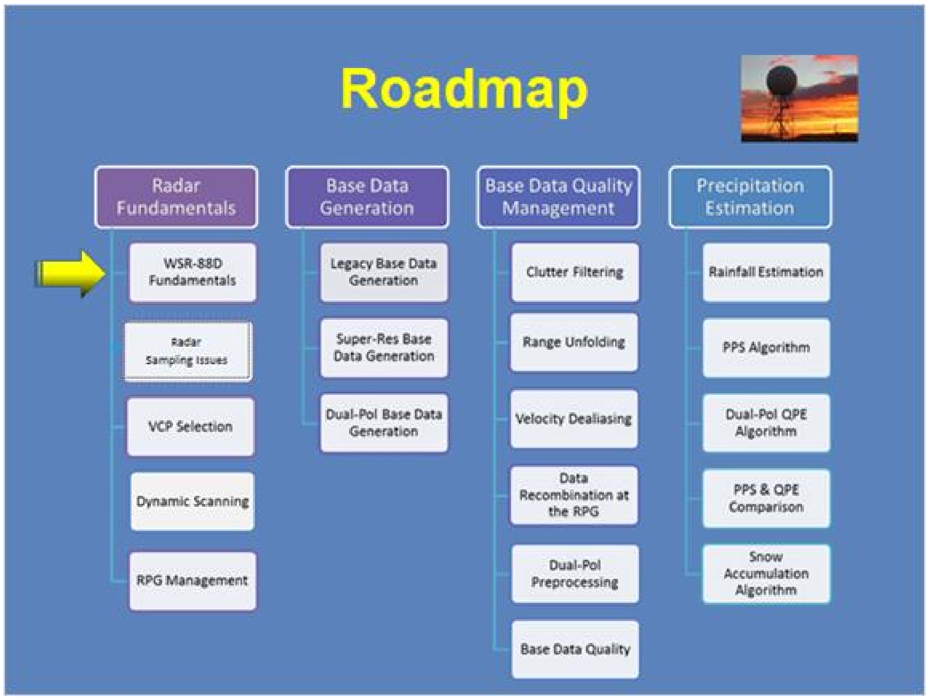
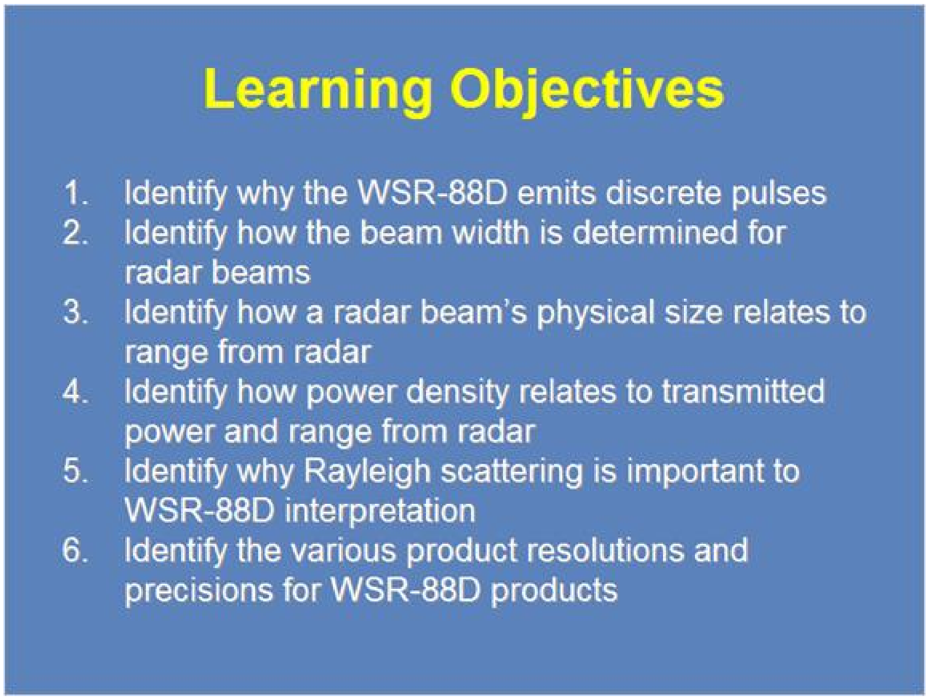
1.2 Roadmap



Notes:

Here is the complete roadmap for the entire "Principles of Doppler Weather Radar" section of RAC. You are currently in the WSR-88D Fundamentals portion of this section, and this portion consists of 5 lessons. Let's keep going!

1.3 Learning Objectives



Notes:

Here are the learning objectives for this lesson. Please take a moment to review these objectives, as the quiz at the end of this lesson is based on these objectives.

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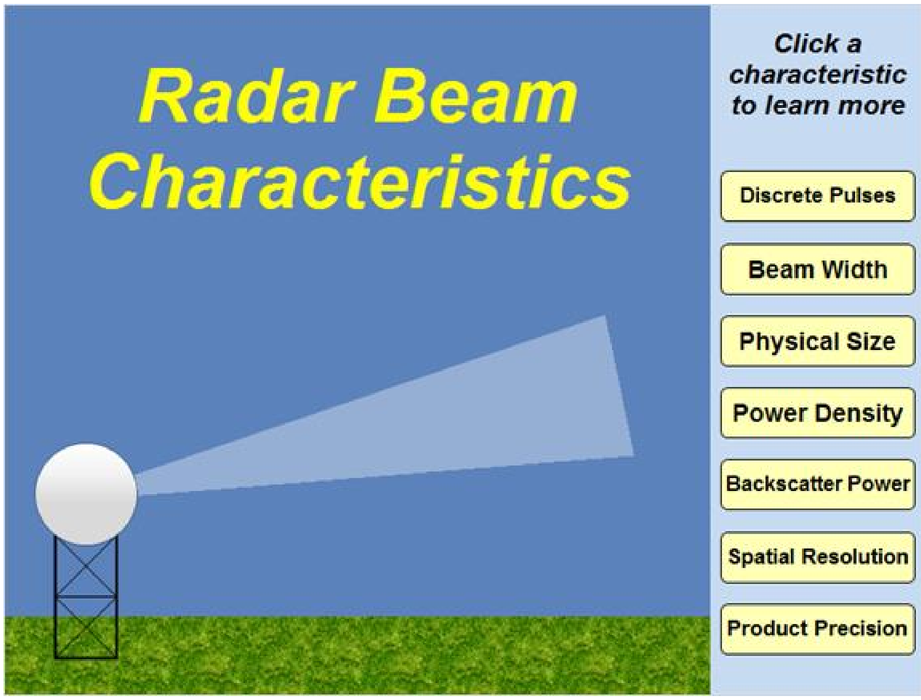
2. Main Radar Graphics

2.1 Radar Beam Characteristics HOME



Notes:

The radar beam has many different characteristics which help determine the information you will see as a warning forecaster. These various characteristics include: discrete pulses, beam width, physical size, power density, backscatter power, spatial resolution, and product resolution. Click on each of these characteristics to learn more. Once you have completed viewing each of these characteristics, you will be ready for the quiz to test your understanding.

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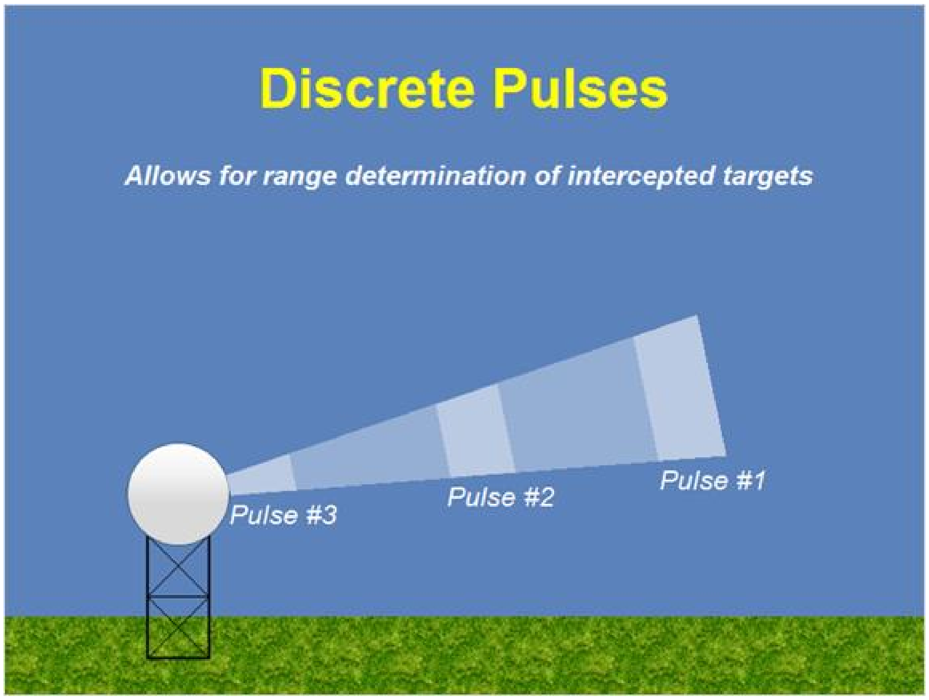
2.2 Discrete Pulses



Notes:

The WSR-88D emits pulses of energy into the atmosphere at pre-defined intervals. This discrete pulse mode allows for the radar signal processor to determine the range of the intercepted targets.

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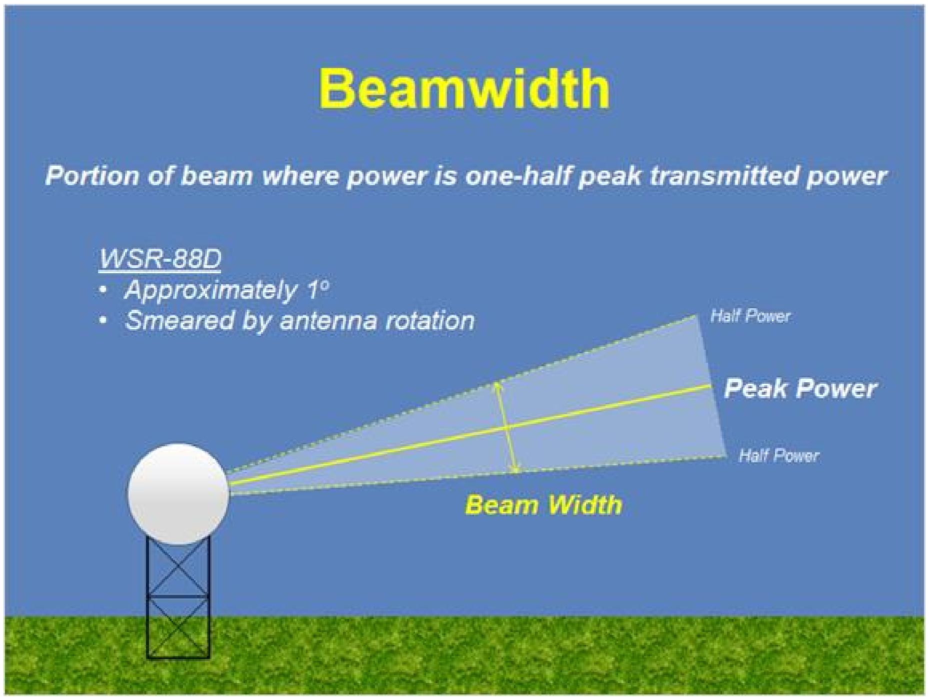
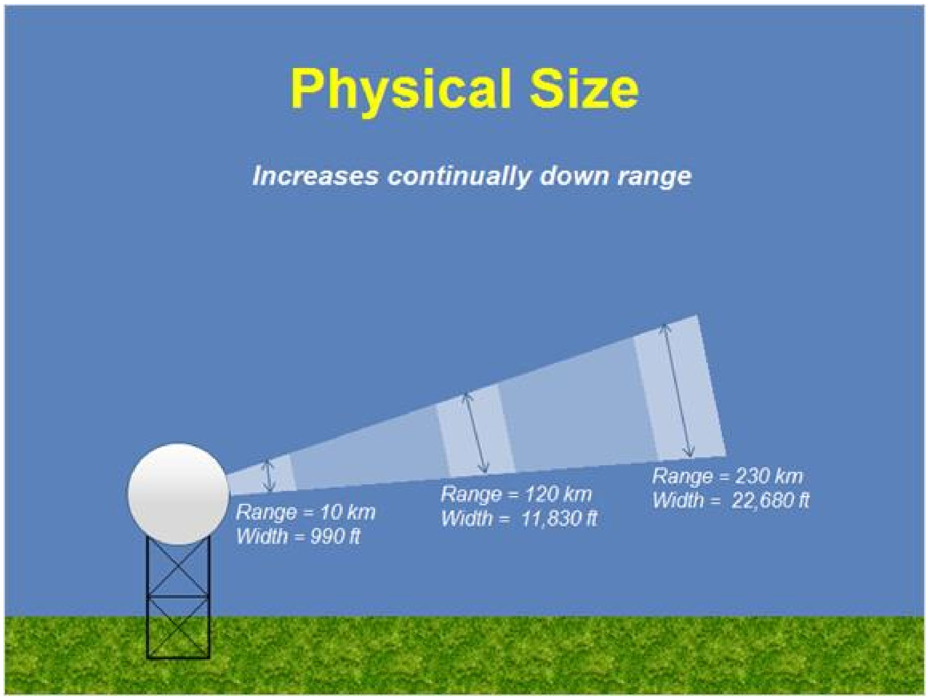
2.3 Beamwidth



Notes:

The radar generates the electromagnetic radiation at the transmitter and the antenna focuses this radiation into a beam that is then reflected into the atmosphere toward the intended targets. Since the radiation doesn't magically have boundaries, the width of the beam is defined as the point at which the power along the beam reaches one-half the peak transmitted power. For the WSR-88D, this width is approximately 1 degree, but is somewhat broader due to the rotation of the antenna while the beam is being transmitted which is referred to as the effective beam width.

2.4 Physical Size



Notes:

While the beam width does not change down range from the radar, the physical size does increase quite dramatically down range. Let's quickly look at how big the WSR-88D pulse gets as we approach the far reaches of the WSR-88D range. At 10 km from the radar, the width of the beam is already 990 feet. That's almost 3 football fields! When the beam gets to 120 km range, the width is over 2 miles! And, when the beam gets to the outer edges of the first trip (which we'll define later), the beam is over 4 miles. So, targets within one radar beam can be as far as 4 miles apart!

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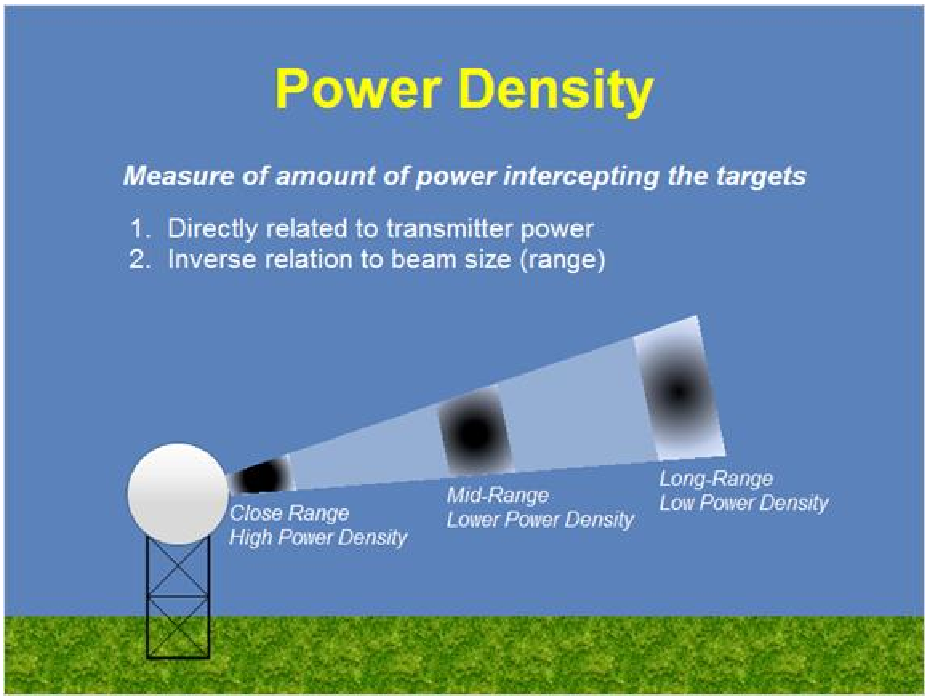
2.5 Power Density



Notes:

The purpose of sending out a pulse of radiation is to have weather targets intercept this energy and reflect some of it back to the radar so we can determine the intensity of the weather targets. The amount of energy that intercepts these weather targets is called the power density, and it is dependent upon two factors: transmitter power and beam size. First power density will increase with increasing transmitter power. However, as the beam goes down range, remember it increases in size, so that same amount of power is spread across a larger area, so the power density actually decreases as the beam goes down range, but it's not equally distributed across the beam. The beam centerline contains most of that power.

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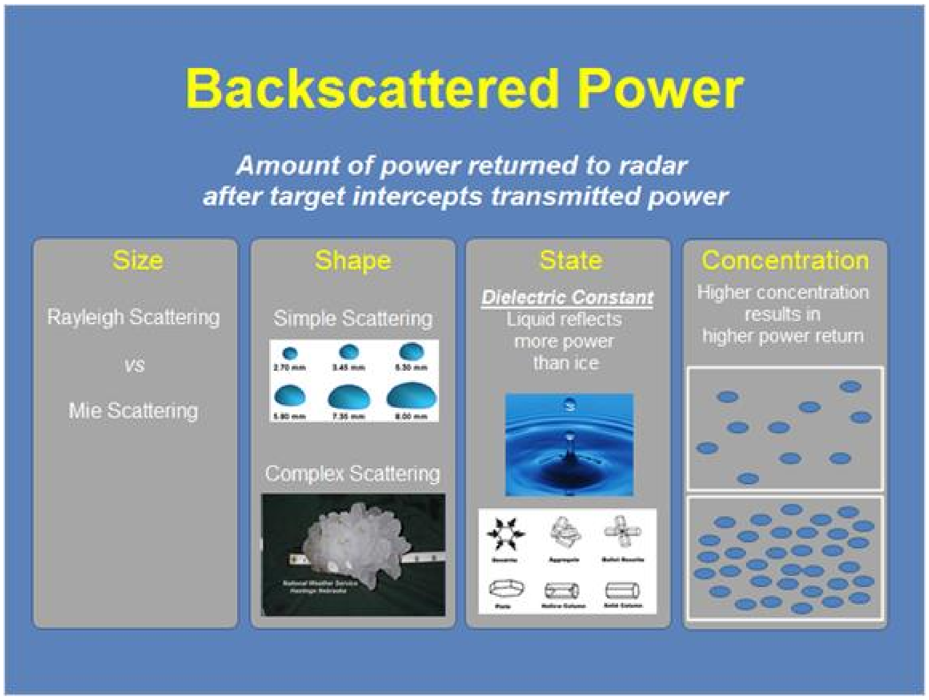
2.6 Backscattered Power



Notes:

Once the radar intercepts some of the transmitted power, it reflects some of the power back to the radar. The amount of power returned back to the radar is referred to as "backscattered power" and is dependent upon 4 characteristics of the weather target. This includes size (which we'll discuss shortly). The next is shape. Fairly smooth-shaped objects like rain drops will have simple scattering properties, but spiky hail stones will have complex scattering properties. The next is the state of the weather target. We'll also refer to this as the dielectric constant which basically means "how reflective is the weather target". Liquid reflects radar energy much more effectively than does ice. Therefore, for the same exact size/shape, water will return a significantly higher amount of power than will the ice particle. Finally, we have concentration. Within a given beam, if there only exists a few rain drops, for example, the power returned will be fairly low. However, if you take those same rain drops and increase the amount by, let's say, triple…the amount of power returned will increase. So, these are the four factors affecting backscattered power, but let's dive a little deeper into the relationship between size and power return.

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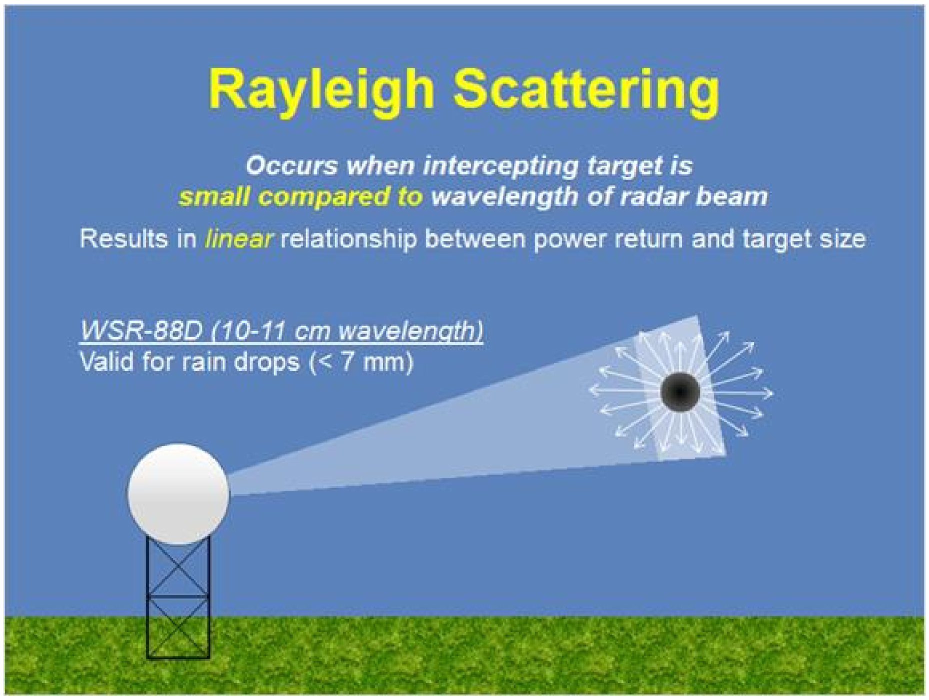
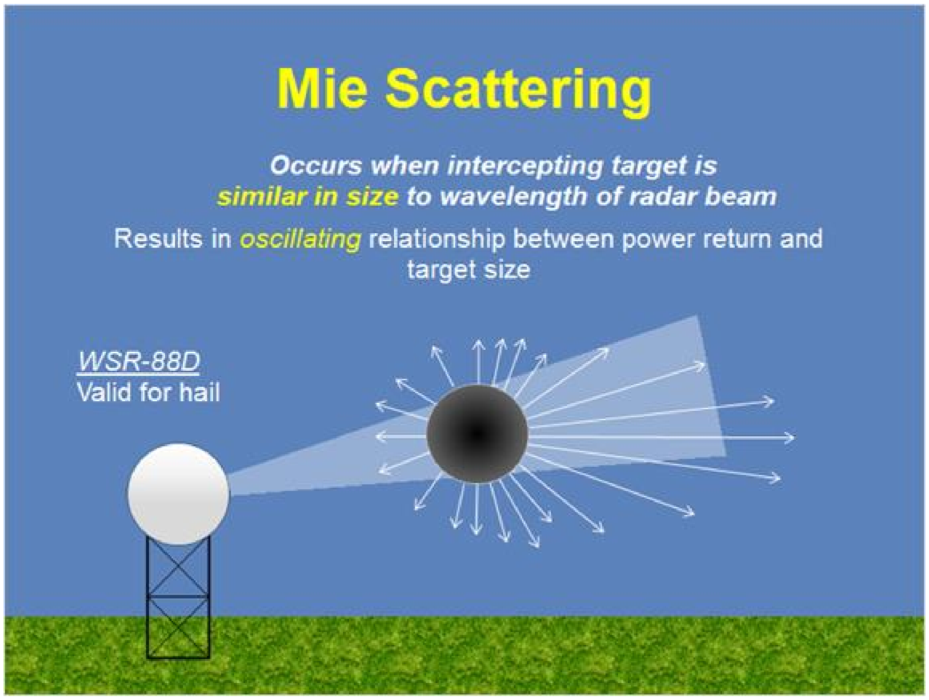
2.7 Rayleigh Scattering



Notes:

The size of the weather target compared to the wavelength of the radar determines the scattering regime. For targets small compared to the wavelength of the radar beam, the scattering is fairly uniform in all directions and the amount of power reflected increases linearly with increasing size. This type of scattering is called Rayleigh scattering and it is preferred because the linear relationship between power return and target size is very helpful (as we'll find out later). The wavelength of the WSR-88D is approximately 10-11 cm. Therefore, Rayleigh scattering is a good assumption for all weather targets smaller than 7 mm which includes practically all rain, but does not include hail. This basically means for most weather objects, the power returned is linearly related to the size of the weather target.

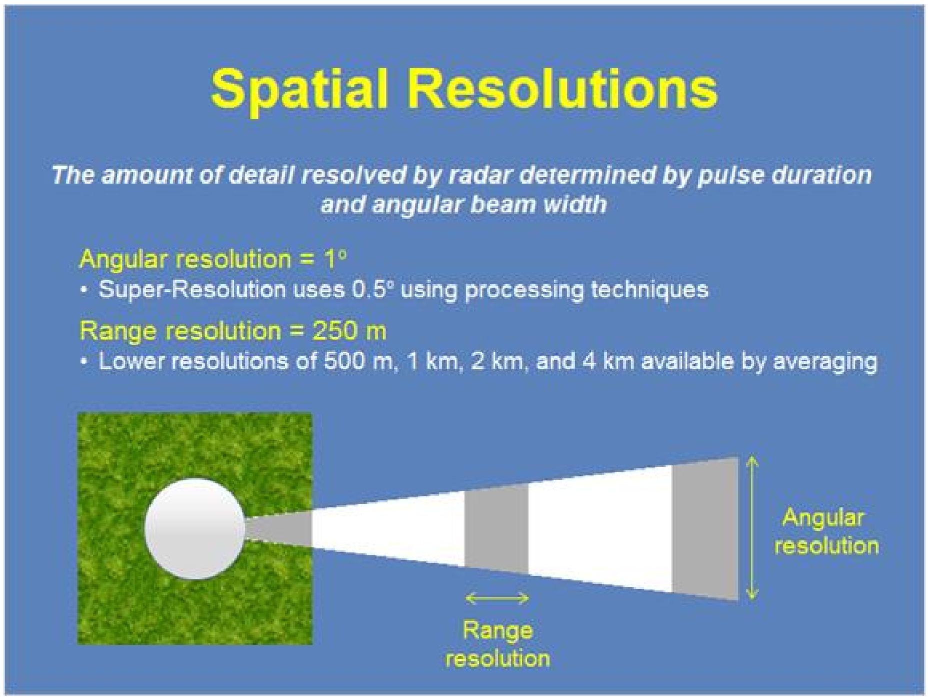
2.8 Mie Scattering



Notes:

When weather targets become roughly similar in size to the wavelength of the radar beam or larger, the scattering properties are no longer linearly related, and most energy is forward scattered. The energy that is reflected back to the radar does not have a linear relationship to size, but rather an oscillating relationship. This is called Mie scattering. So, relating size to power return is not so straightforward. For the WSR-88D, hail is the primary target that falls within the Mie scattering regime.

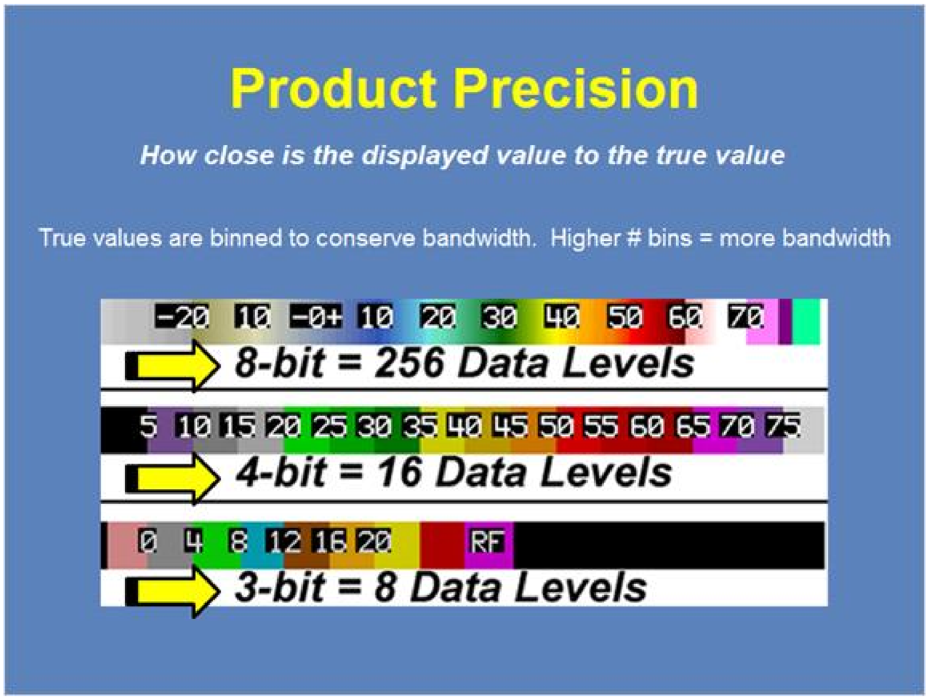
2.9 Spatial Resolutions



Notes:

So, how much detail can we see with data collected by the WSR-88D? That is all dependent upon the pulse duration and angular beam width. Since we already know the beam width is 1 degree, that is the best angular resolution we can get without any processing of the data. I say "without any processing" because recently, radar engineers came up with a processing technique to display 0.5 degree angular resolution data, which is called "super-resolution". This technique will be covered in a later lesson in this section, but for now, just know it is possible to get 0.5 degree angular resolution with the WSR-88D. As for the range resolution, this is determined by the pulse duration (or how long does the pulse transmit). The longer the pulse duration, the coarser the range resolution. For the WSR-88D, the best range resolution possible is 250 m. Other coarser resolutions are available by averaging the individual 250-m bins.

2.10 Product Precision



Notes:

Once the information is received at the radar, it has to be quantified and binned to be displayed. The more bins you have to fit the data into, the more precise the value displayed is to the real value. For example, if you have a bin that contains values from 5 to 10, then any real value from 5 to 10 will be displayed as 5. However, if you have a bin that contains only values from 5 to 7, then only values from 5 to 7 will be displayed as 5. In other words, the second example has higher precision. The reason for binning the data is to conserve bandwidth. For the WSR-88D, there are three basic binning levels… these are 3-bit, 4-bit, and 8-bit. 3-bit has 8 data levels, 4-bit has 16 data levels, and 8-bit has 256 data levels. So, 8-bit data is more precise than the 3-bit or 4-bit counterparts, but takes up more bandwidth. More of this will be discussed in the base and derived products section of RAC, but for now, just know the three different levels of binning.

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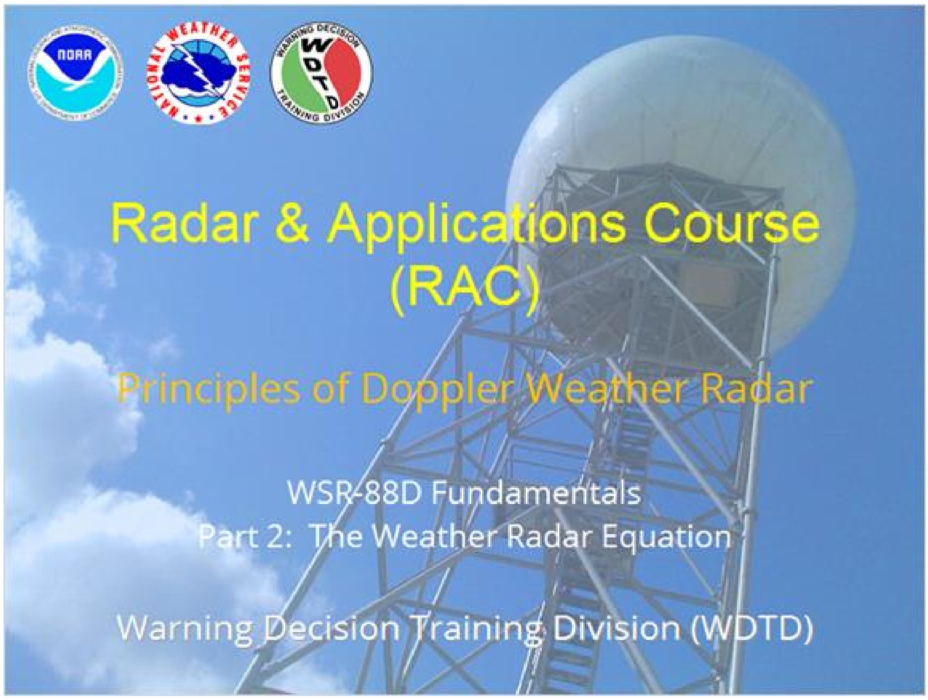
WSR-88D Fundamentals Part 2: Weather Radar Equation

1. Intro to Radar Beam Characteristics

1.1 Welcome



Notes:

Welcome to the Radar & Applications Course (RAC) Principles of Doppler Weather Radar. This lesson is on WSR-88D Fundamentals Part 2: The Weather Radar Equation. It is presented by the Warning Decision Training Division (WDTD). Let's get started!

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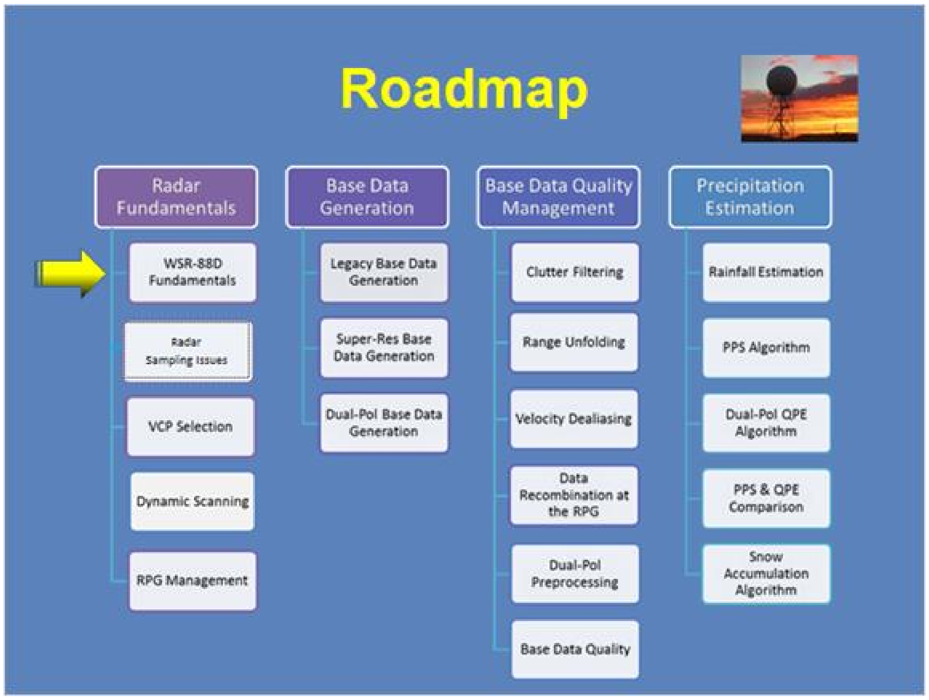
1.2 Roadmap



Notes:

Here is the complete roadmap for the entire "Principles of Doppler Weather Radar" section of RAC. You are currently in the WSR-88D Fundamentals portion of this section, and this portion consists of 5 lessons. Let's keep going!

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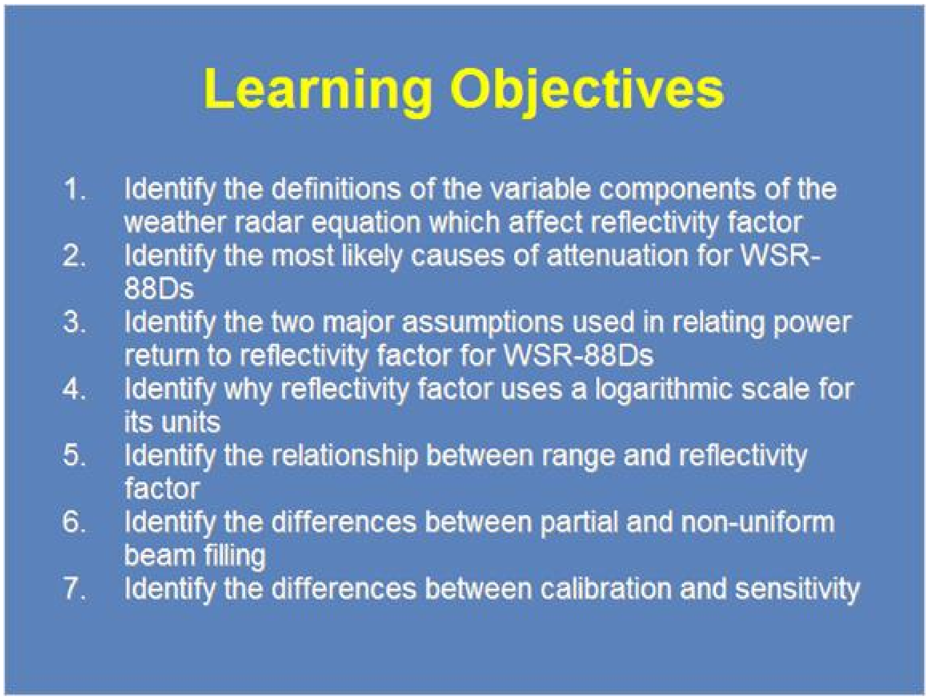
1.3 Learning Objectives

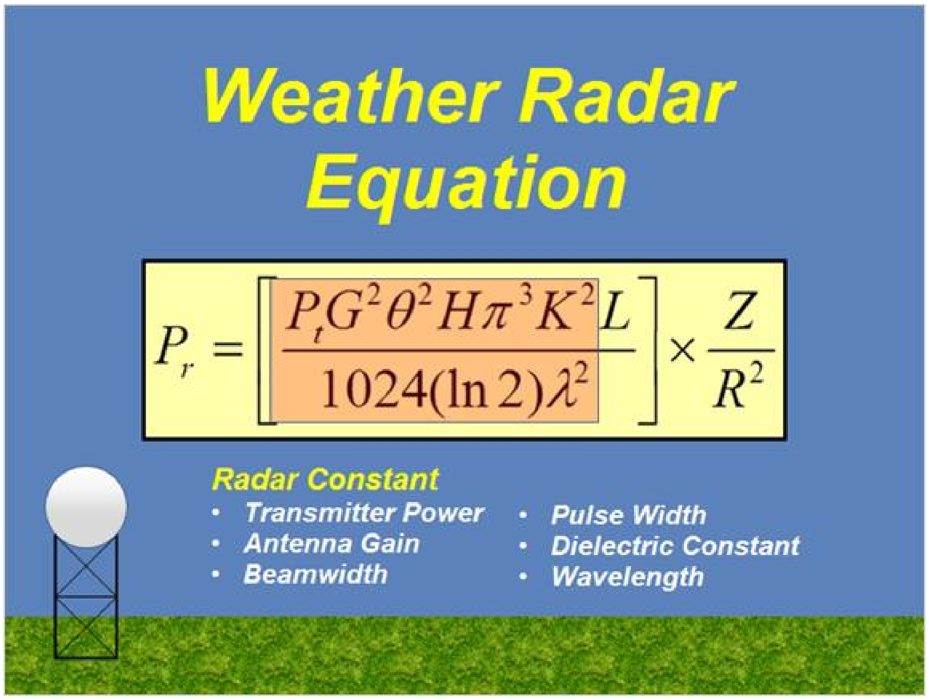


Notes:

Here are the learning objectives for this lesson. Please take a moment to review these objectives, as the quiz at the end of this lesson is based on these objectives.

2. Main Radar Equation

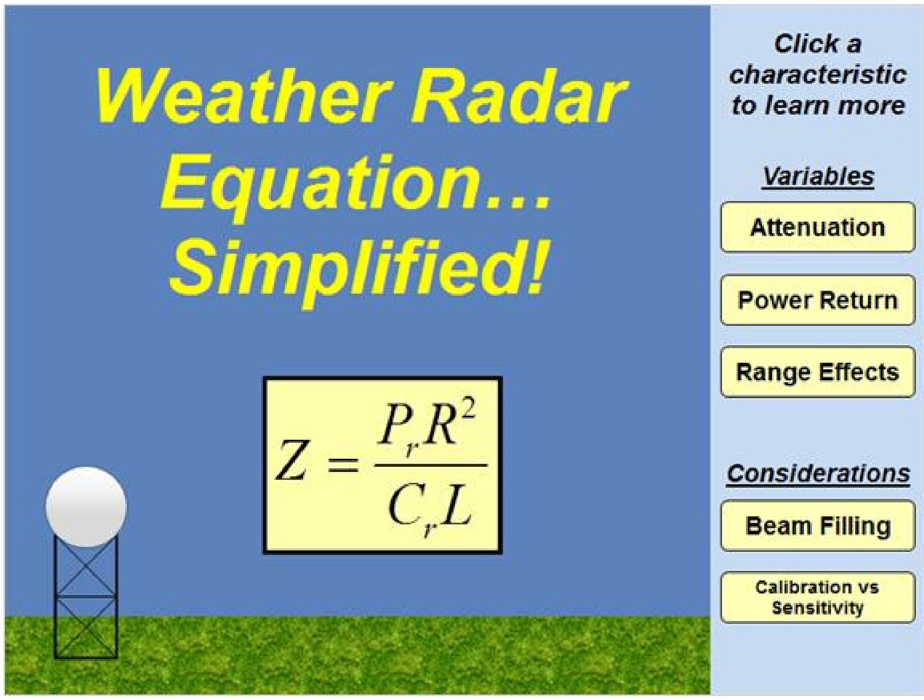
2.1 Weather Radar Equation



Notes:

Here is the full weather radar equation which is full of constants, variables, and equations…OH MY! But don't worry, we can drastically simplify this equation by combining many of these terms into what is called the "radar constant" which is just various aspects of the radar system that usually remain constant or are assumed to be constant with the WSR-88D. These constants are… 1) transmitter power, antenna gain, beamwidth, pulse width, dielectric constant, and wavelength. The entire goal of the weather radar equation is to take the power returned from weather objects, and convert that value into something useful, and this something useful is called reflectivity factor, or Z. So, let's keep moving…

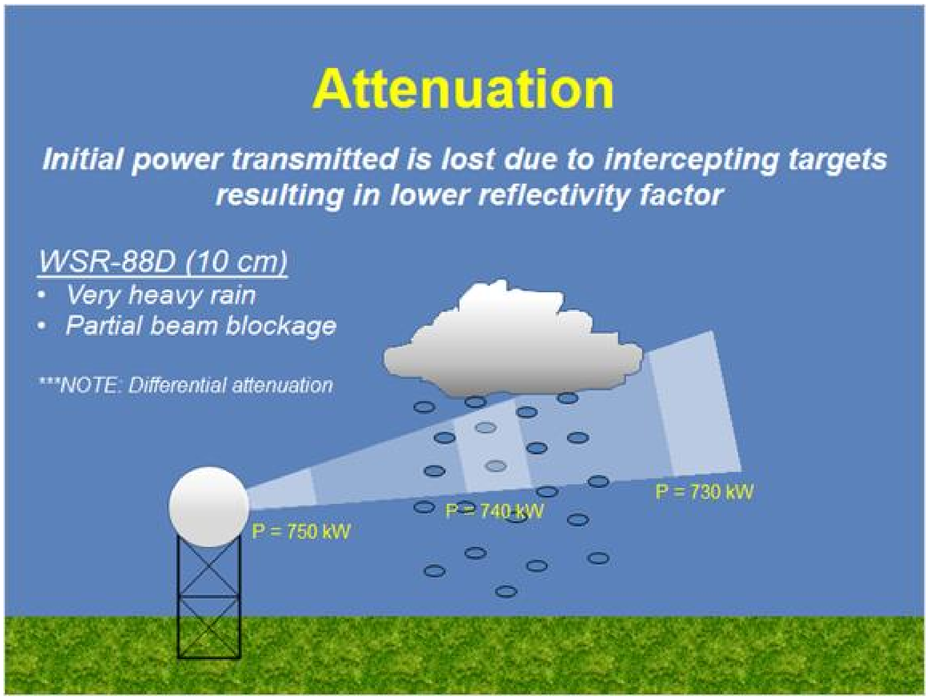
2.2 Weather Radar Equation HOME



Notes:

By combining all those terms into the radar constant, and solving for Z, we get this simplified radar equation (I promise…this is my last attempt at making this sound like a math class). But now that we have this simplified radar equation solved for reflectivity factor, let's examine each component (or variable) of the equation and see how reflectivity factor is affected. We'll also look at some considerations that are important to keep in mind when interpreting reflectivity factor. So, click on each of the variables and considerations listed on the left to learn more about the weather radar equation. Once you have viewed all items, a quiz button will appear and you will be ready to test your knowledge! One last note, because the WSR-88D is dual-polarized, this means it transmits both a horizontal and vertically polarized pulse. How we solve for both polarization is identical, so when referring to Z, just know it applies to both the horizontal and vertical channels.

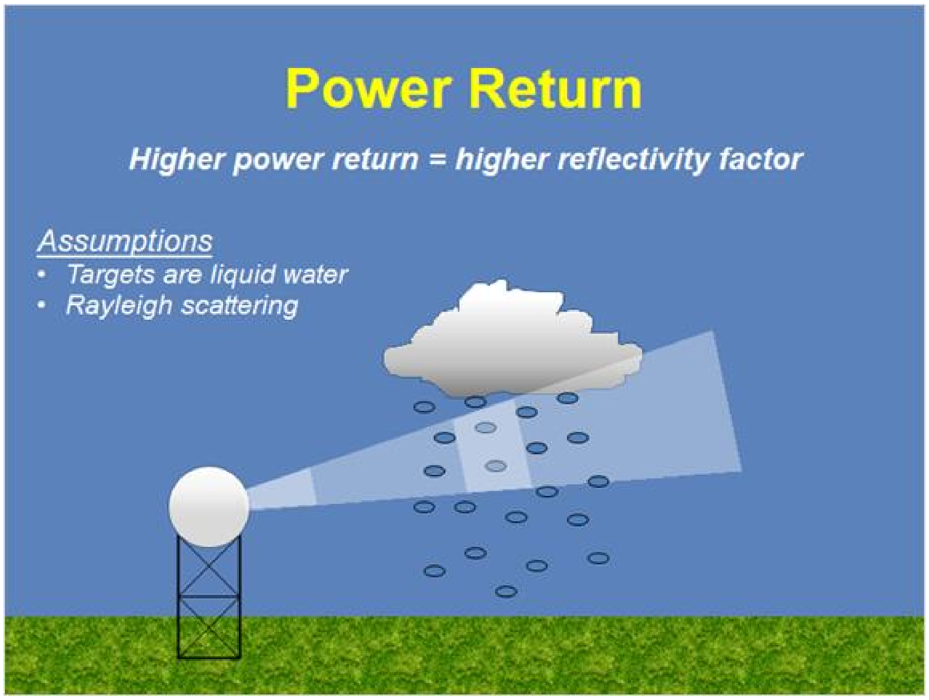
2.3 Attenuation



Notes:

The first term of the radar equation we'll look at is attenuation. It is defined as the loss in initial power transmitted due to intercepting targets. An increase in attenuation results in a lower reflectivity factor. For the WSR-88D, which is a 10-cm wavelength radar, attenuation is often negligible. A couple instances where attenuation may occur is in very heavy rainfall, or in areas of partial beam blockage. One other important consideration related to dual-polarization is differential attenuation. This is an instance where the horizontal channel attenuates slightly more than the vertical channel, or vice versa, and this can result in artifacts seen in the differential reflectivity product. More on this phenomenon will be covered later in this section.

2.4 Power Return



Notes:

The next variable affecting reflectivity factor is the power return. This is pretty simple…higher power return equals higher reflectivity factor. However, our equation makes two very big assumptions when it comes to the power return. First, it assumes the power return is from liquid water targets (remember that K squared term that we rolled into the radar constant?). Ice particles have much lower dielectric constants (or K squared), so the radar equation is going to underestimate the reflectivity factor for ice. Therefore, ice will generally have lower reflectivity factor values than liquid water. The other assumption is that all scattering is Rayleigh in nature. We saw in the previous lesson that this is mostly true for WSR-88Ds, but not always. So, determining reflectivity factor from Mie scattering objects like hail using this equation is not entirely valid, but will get you close.

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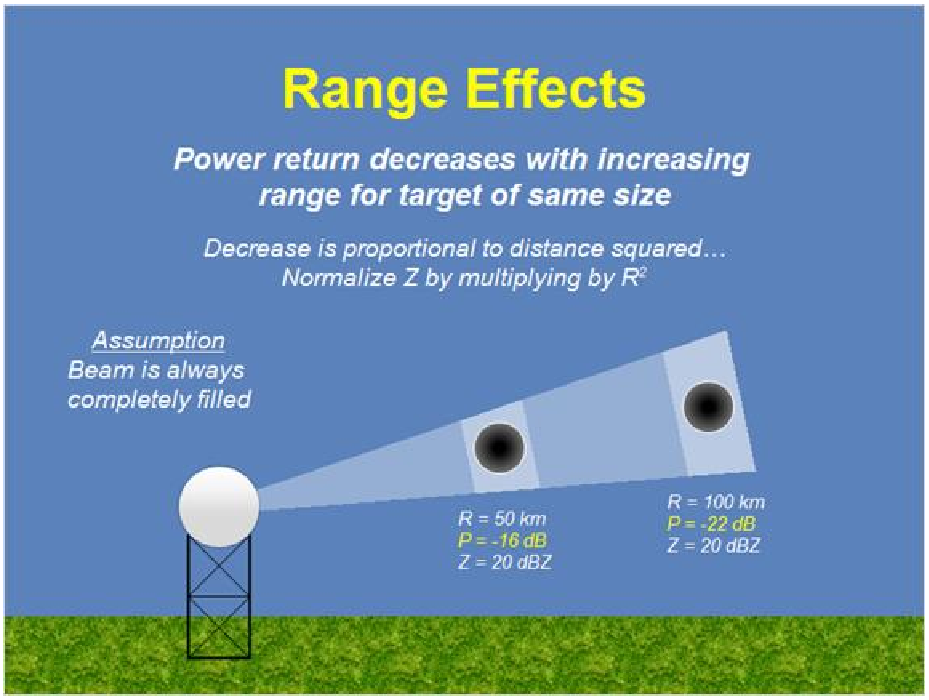
2.5 Range Effects



Notes:

The final variable affecting reflectivity factor is range. Recall that power return decreases with increase range for a target of the same size. This decrease in power is proportional to the distance squared. Therefore, the equation attempts to normalize the reflectivity factor by this distance squared. Look at the example… at 50 km, the target is producing a power return of -16 dB resulting in a Z = 20 dBZ. This same target at 100 km only produces a power return of -22 dB, but because of the range normalization, Z still equals 20 dBZ. One major assumption here is that the radar beam is always completely filled, but we'll find out soon this assumption is rarely valid.

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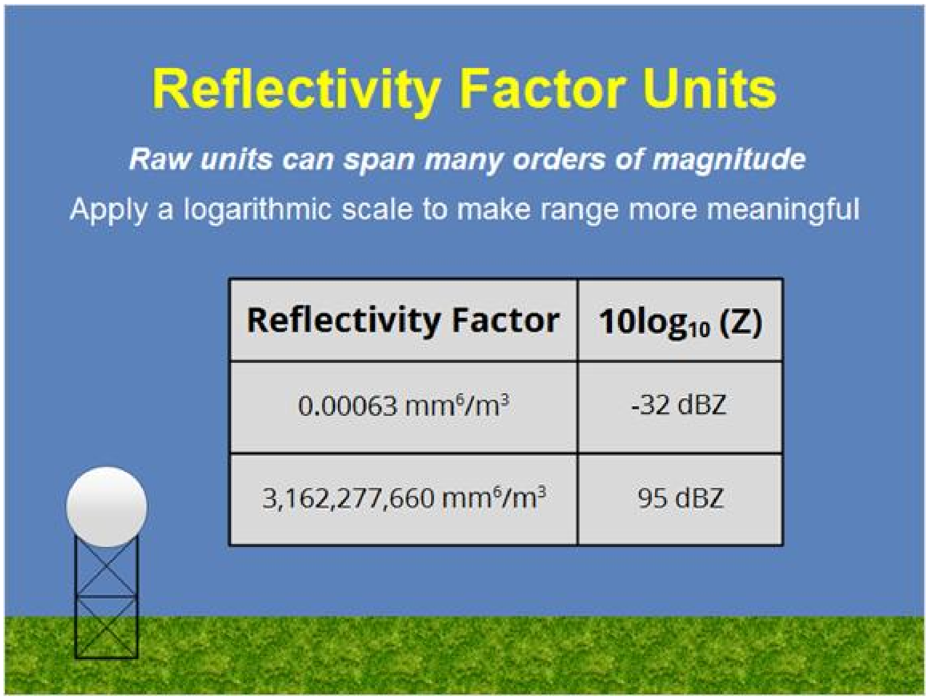
2.6 Reflectivity Factor Units



Notes:

Before we look at the considerations to the assumptions made in the radar equation, I want to quickly take a look at the units of reflectivity factor. The raw units are mm6/m3, and these values can span many orders of magnitude. So, a logarithmic scale is applied to the raw reflectivity factor to compress these values into a more meaningful range. For the WSR-88D, this range is from -32 dBZ to 95 dBZ, and you can see the raw reflectivity values to the left. The low end has a value of much less than 1, but the high end has raw values in the billions!

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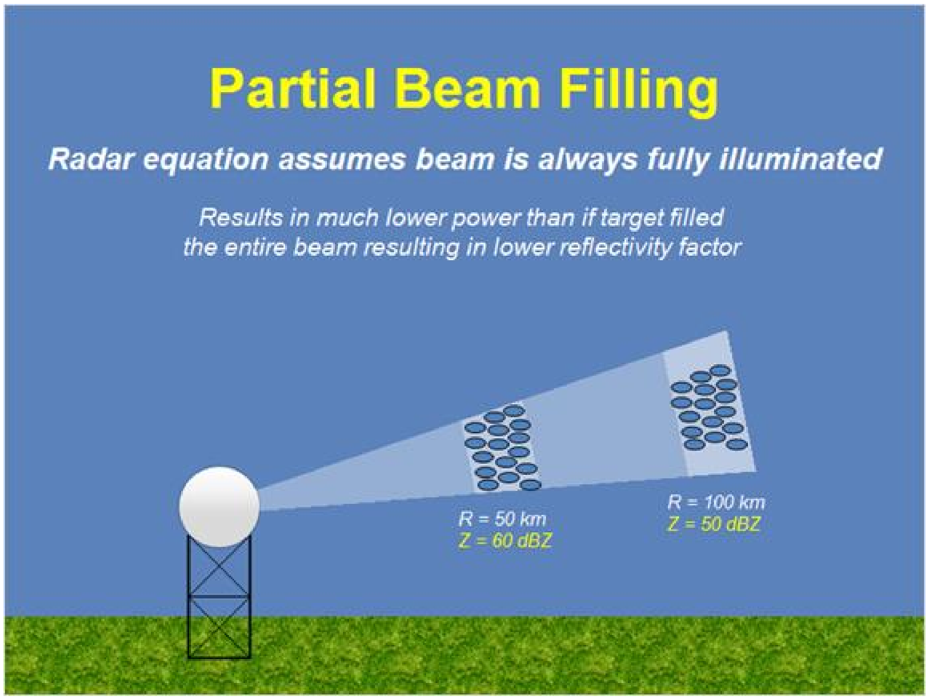
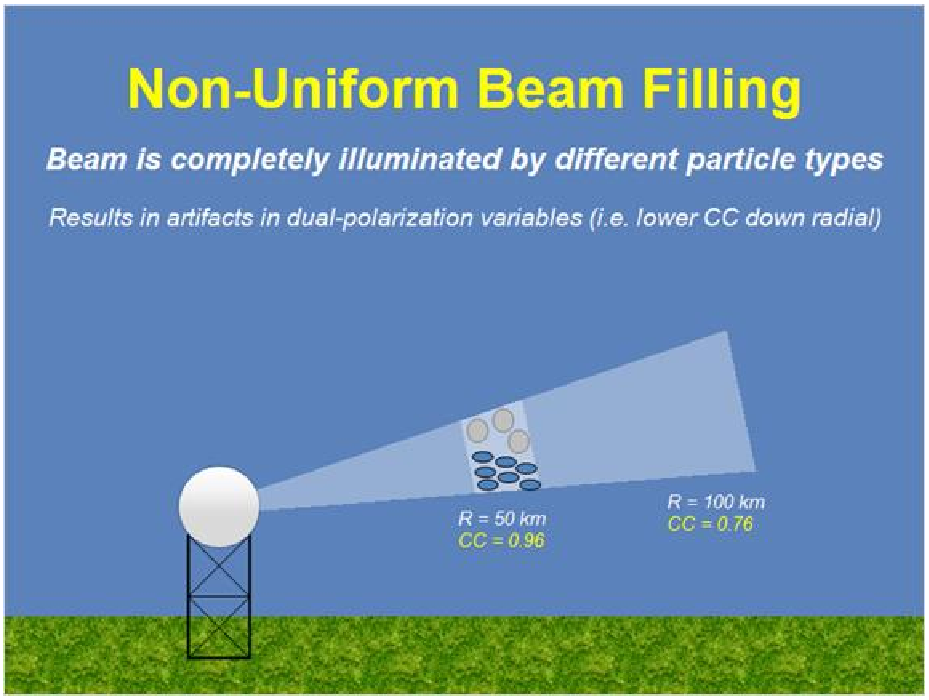
2.7 Partial Beam Filling



Notes:

We'll actually discuss two types of beam filling issues with the WSR-88D, but the first is partial beam filling. This results when the beam is not completely illuminated by weather targets. You might have rain in one portion of the beam and nothing in another portion. This partial beam filling will result in lower power return than if the target completely filled the beam which results in a lower reflectivity factor. In this example, a 60 dBZ echo results when these rain drops completely fill the beam at 50 km, but at 100 km, these same drops do not fill the beam completely, and the reflectivity factor is actually around 50 dBZ.

2.8 Non-Uniform Beam Filling



Notes:

Another type of beam filling issue is non-uniform beam filling, and we'll discuss it more later on in this section, but for now just know that this phenomenon occurs when weather targets of varying type (typcially hail and rain) exist in different portions of the beam. This causes varying propagation effects on the radar beam, and adversely affects the dual-polarization variables (especially CC). It will primarily show up as a valley of reduced CC along the affected radials.

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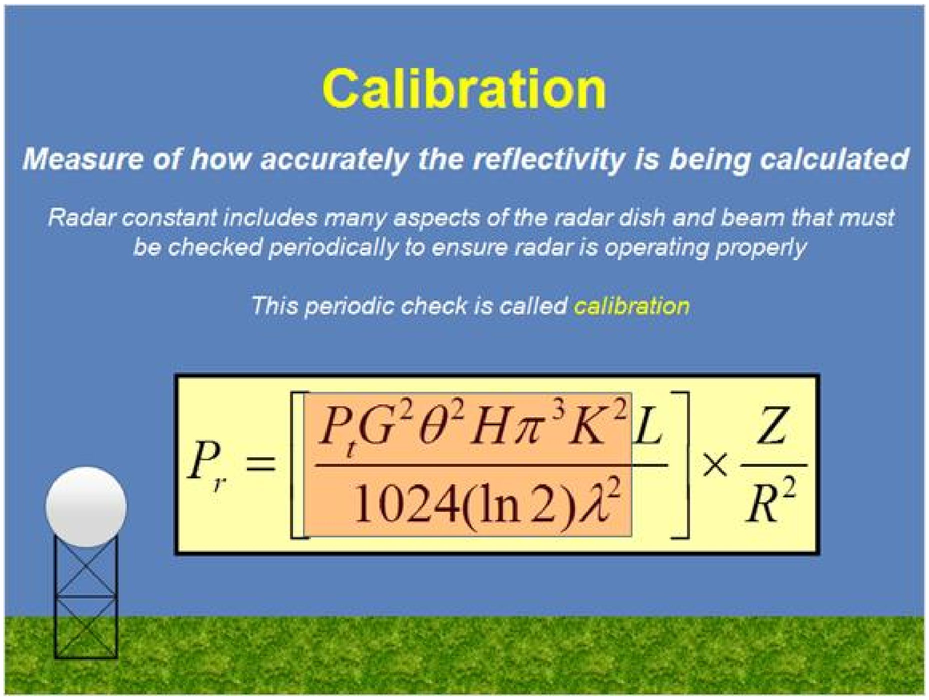
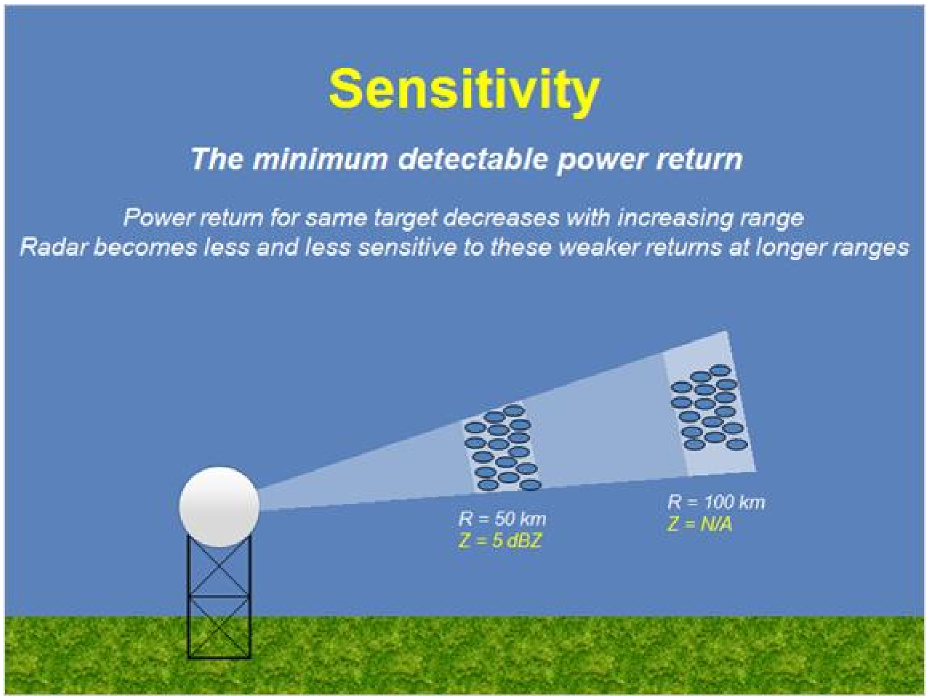
2.9 Calibration



Notes:

Oh no! It's that dreaded full equation again! Stop the insanity! Okay, don't freak out just yet… we need to see all this to better understand calibration of the radar. The radar constant consists of many physical aspects of the radar and radar beam. Because these can actually change with time, the radar operators will periodically check the radar system to see how these "constants" are behaving and make sure they are residing within acceptable limits. This periodic check is called calibration and it helps keep the measurement of reflectivity factor as accurate as possible.

2.10 Sensitivity



Notes:

One other consideration is to look at the sensitivity of the radar itself. This is basically defined as the minimum detectable power return. In other words, if the power return is too weak, the radar can't pick it up. For example, we have this group of weather targets at 50 km which produces a 5 dBZ reflectivity factor. However, at 100 km, this same group of targets will produce a weaker power return which is not detectable by the WSR-88D, and therefore will not assign a reflectivity factor. This ability to detect the power return is the sensitivity.

WSR-88D Fundamentals Part 3: Transmitting & Receiving Characteristics

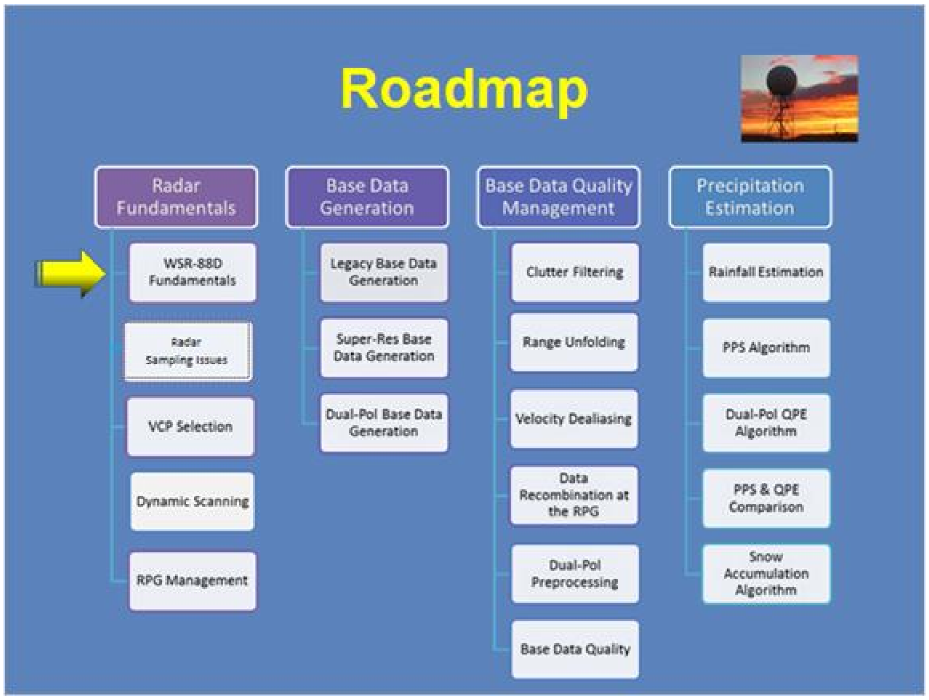
1. Transmitter & Receiver Characteristics

1.1 Welcome

Notes:

Welcome to the Radar & Applications Course (RAC) Principles of Doppler Weather Radar. This lesson is on WSR-88D Fundamentals Part 3: Transmitting and Receiving Characteristics. It is presented by the Warning Decision Training Division (WDTD). Let's get started!

1.2 Roadmap



Notes:

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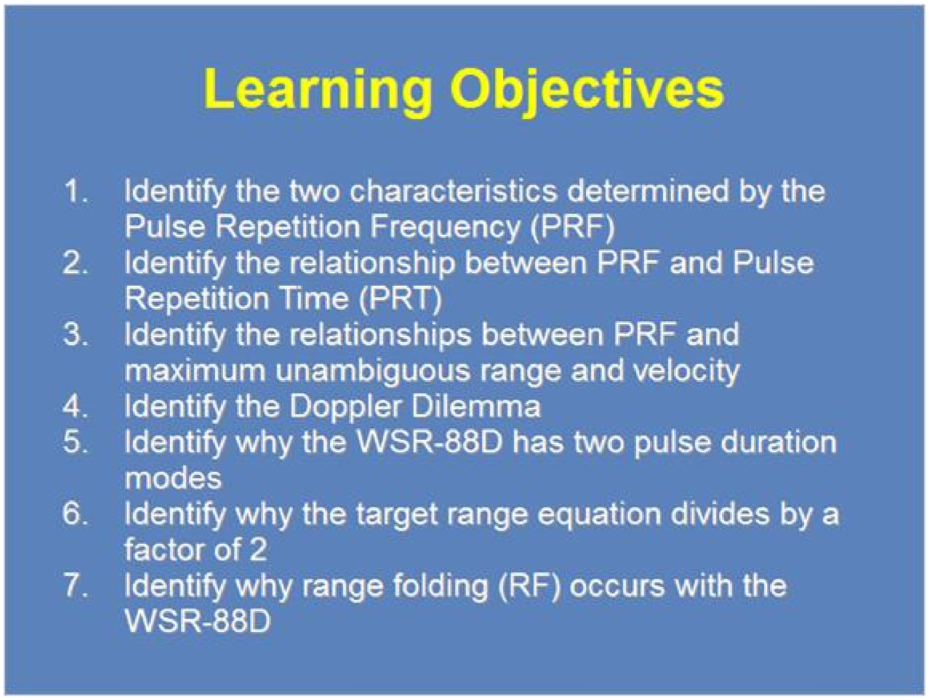
1.3 Learning Objectives

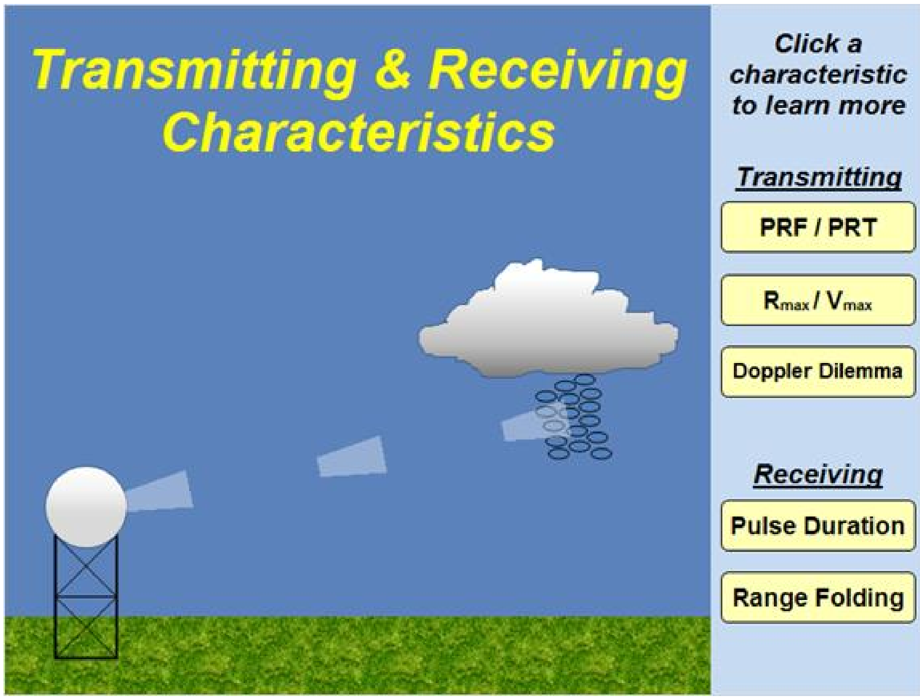


Notes:

Here are the learning objectives for this lesson. Please take a moment to review these objectives, as the quiz at the end of this lesson is based on these objectives.

2. Transmitting & Receiving Characteristics

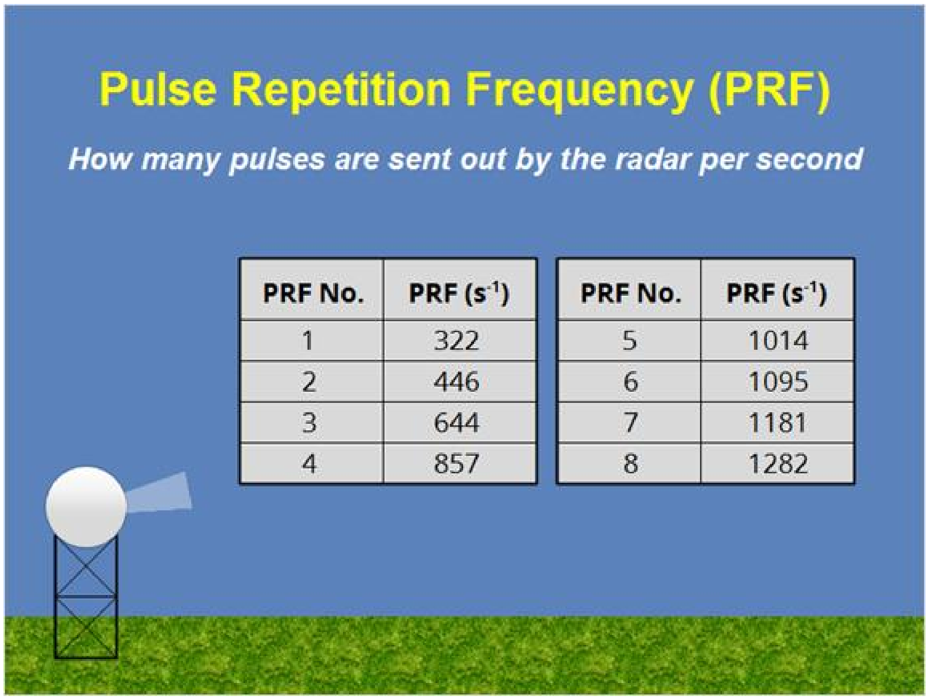
2.1 Transmitting & Receiving Characteristics HOME



Notes:

In the first lesson of this section, we learned that the WSR-88D emits pulsed radiation so that it can determine range to target. Well, there is a limit to the range it can accurately detect, and the WSR-88D also measures velocity which is dependent upon this pulsed transmission. In this lesson, we will take a look the transmitting and receiving characteristics that will affect the range and velocity values we can measure. Click on each of these characteristics on the right to learn more.

2.2 Pulse Repetition Frequency (PRF)



Notes:

The first term we'll introduce is pulse repetition frequency (PRF) which is nothing more than how many pulses are sent out by the radar every second. For the WSR-88D, there are 8 different PRF modes which range anywhere from 322 pulses per second up to 1,282 pulses per second. That's a lot of pulses!

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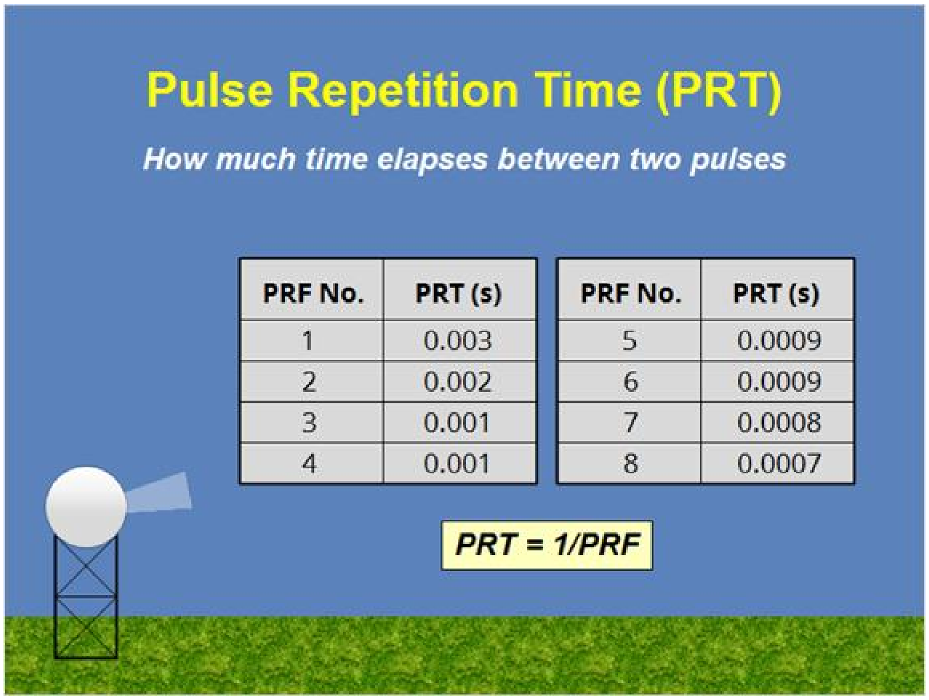
2.3 Pulse Repetition Time (PRT)



Notes:

And, if we just take the reciprocal of the PRF, we get the Pulse Repetition Time (PRT). This just tells you how much time elapses between two consecutive pulses. For the 8 WSR-88D PRF modes, the associated PRTs are listed here in this table. There isn't a lot of time in between pulses.

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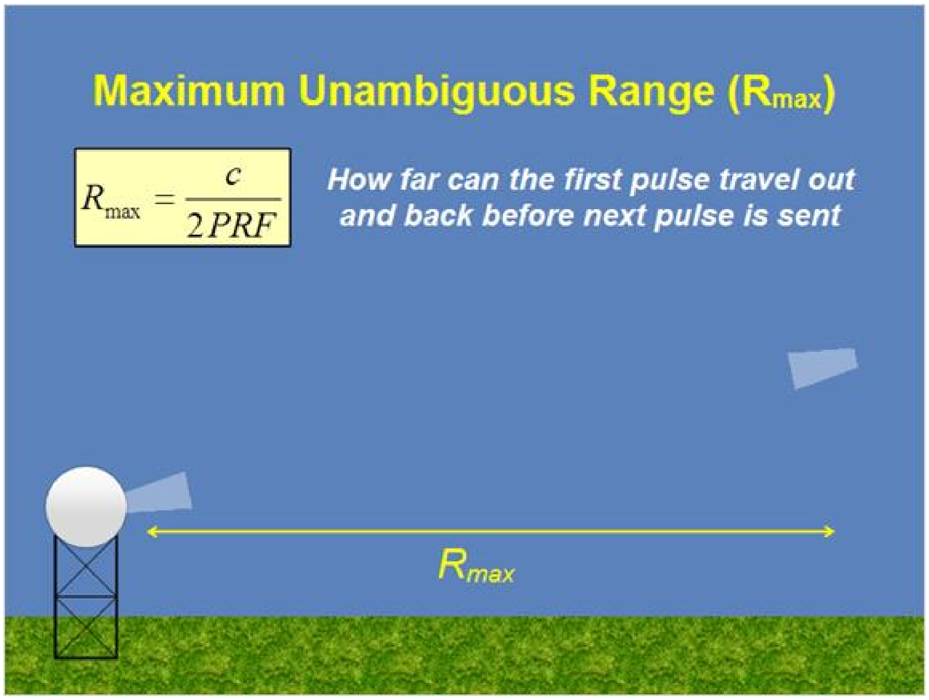
2.4 Maximum Unambiguous Range (Rmax)



Notes:

So we know that the WSR-88D emits pulsed radiation to determine range to targets. But, is there a limit to this range? Yes! This is called the maximum unambiguous range (Rmax) and it tells you how far the first pulse can travel out and back before the next pulse is transmitted. The equation for this is pretty simple… take the speed of light and divide by 2 times the PRF. What this tells us is the maximum unambiguous range increases with decreasing PRF. This makes sense because the fewer pulses we send out, the further it can travel out and back before the next pulse is transmitted.

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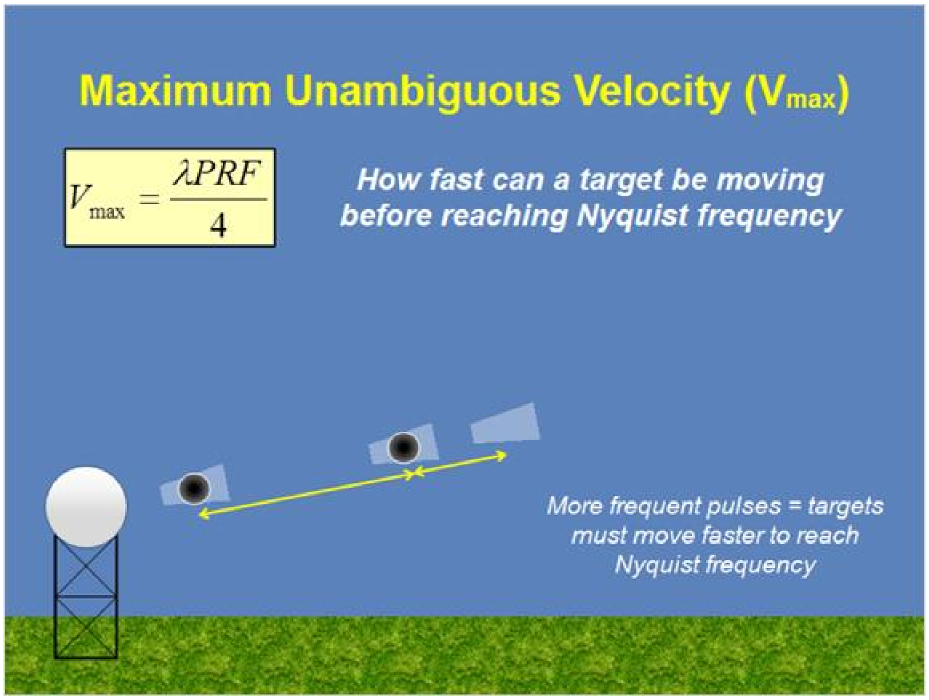
2.5 Maximum Unambiguous Velocity (Vmax)



Notes:

When it comes to measuring velocity, the radar does it by measuring the frequency shift between pulses. It's called the Doppler effect, and hence why we call the WSR-88D, Doppler radars. Well, if only a few pulses are sent out, the radar can only reconstruct a few pieces of the frequency waveform of the intended target. If the target is moving too fast, then the reconstructed waveform from the multiple pulses will have multiple solutions (or ambiguous velocities). The frequency at which we reach these ambiguous velocities is called the Nyquist frequency. Since faster particles have higher frequency shifts, we need to send out more pulses to better reconstruct the waveform. Therefore, higher PRFs lead to higher unambiguous velocities. To put it another way, the more frequently we send pulses, the faster the targets have to move in order to reach the Nyquist frequency.

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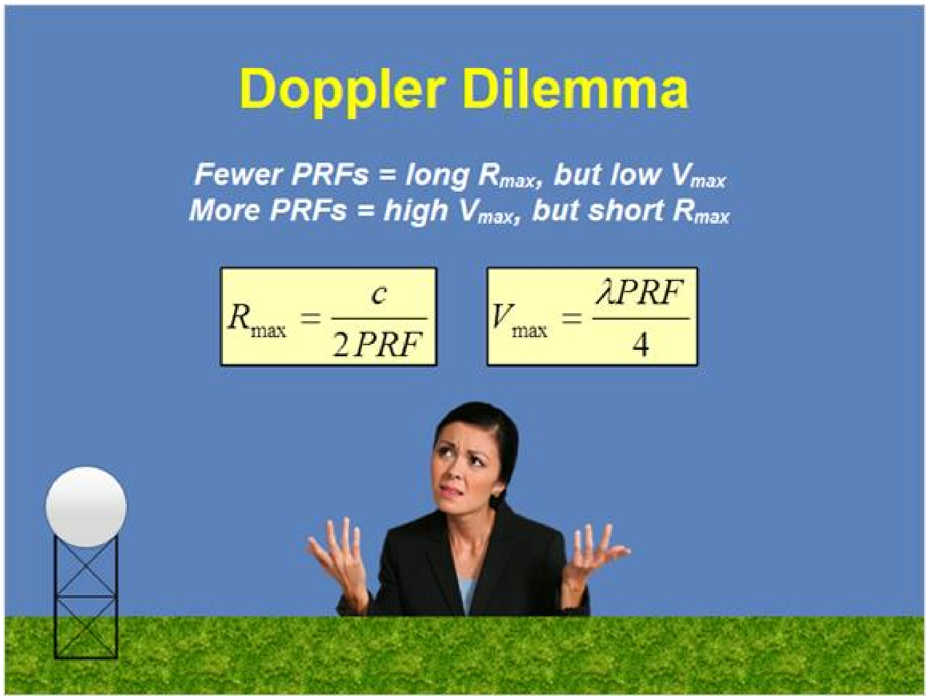
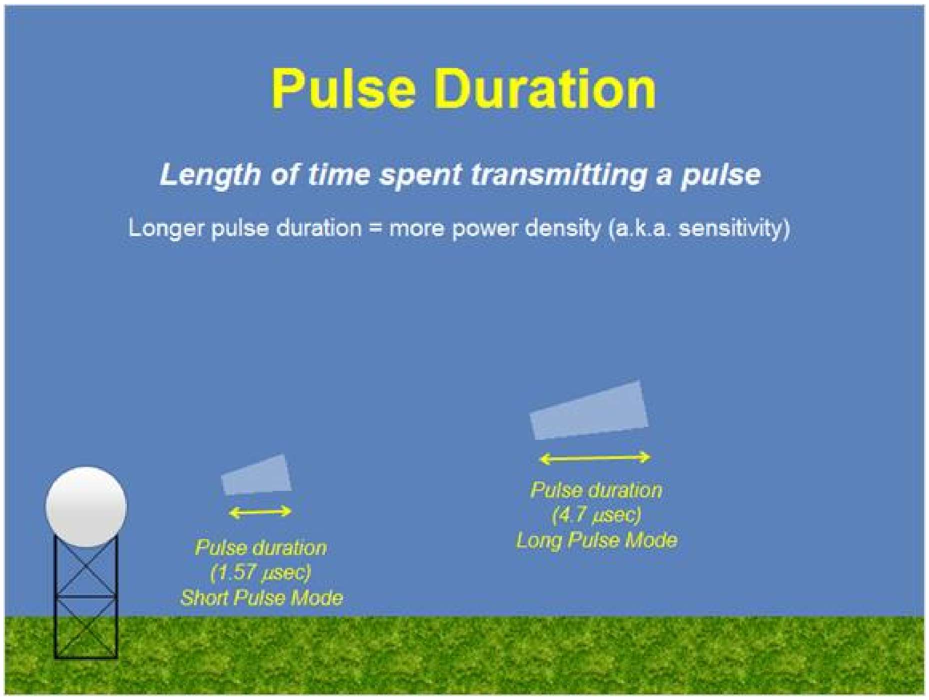
2.6 Doppler Dilemma



Notes:

So, you might be thinking there's a problem here… and you are absolutely right! If lower PRFs give me better range detection, but reduce the velocities that can be unambiguously measured, and vice versa, then we have a dilemma! This is called the Doppler Dilemma. By choosing one PRF, we have to sacrifice either Rmax or Vmax. But don't fret, the radar engineers at the Radar Operations Center have come up with scanning strategies where we can do multiple scanning strategies to maximize both values which we'll discuss later, but just know, Rmax and Vmax both depend on PRF, but in different ways and this can cause a problem.

2.7 Pulse Duration



Notes:

The length of time the transmitter remains on while transmitting a pulse is called the pulse duration. The longer the pulse duration, the more power density resides inside the pulse which can increase its sensitivity. For the WSR-88D, there are two pulse duration modes: short pulse mode and long pulse mode. The short pulse mode is 1.57 microseconds, and the long pulse mode is 4.7 microseconds. All of the scanning strategies employ the short pulse mode except one which uses the long pulse mode. We'll talk more about scanning strategies in a later lesson, but for now we'll look at pulse durations for another reason on the next slide…

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2.8 Listening Period

Notes:

When the radar is transmitting, it can't be listening for radar echo returns. Therefore, longer pulse durations means less time listening for radar echo returns. This listening period is defined as the time between the end of the first pulse and the beginning of the second pulse. For the WSR-88D, the radar is in listening mode while in short pulse mode for 99.8% of the time. In long pulse mode, it is in listening mode for approximately 99.5% of the time. So, you can see, the radar is primarily listening to what's going on in the atmosphere.

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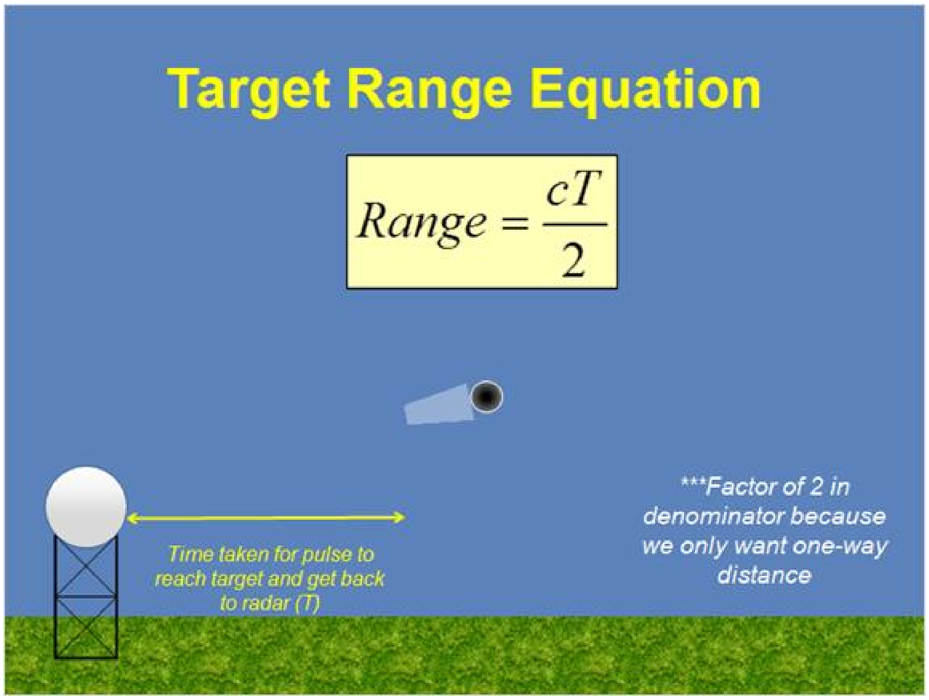
2.9 Target Range Equation



Notes:

When a radar echo return arrives at the radar, it is nice to know how far away the radar echo resides. Since we know how fast the pulse is traveling, and how long it has been since we transmitted the pulse, we just simply multiply the speed of light by the time it took the pulse to be transmitted and then received back at the radar. We have to then divide this value by 2 since the time between transmission and reception is a round-trip value, and we only care about the one-way distance.

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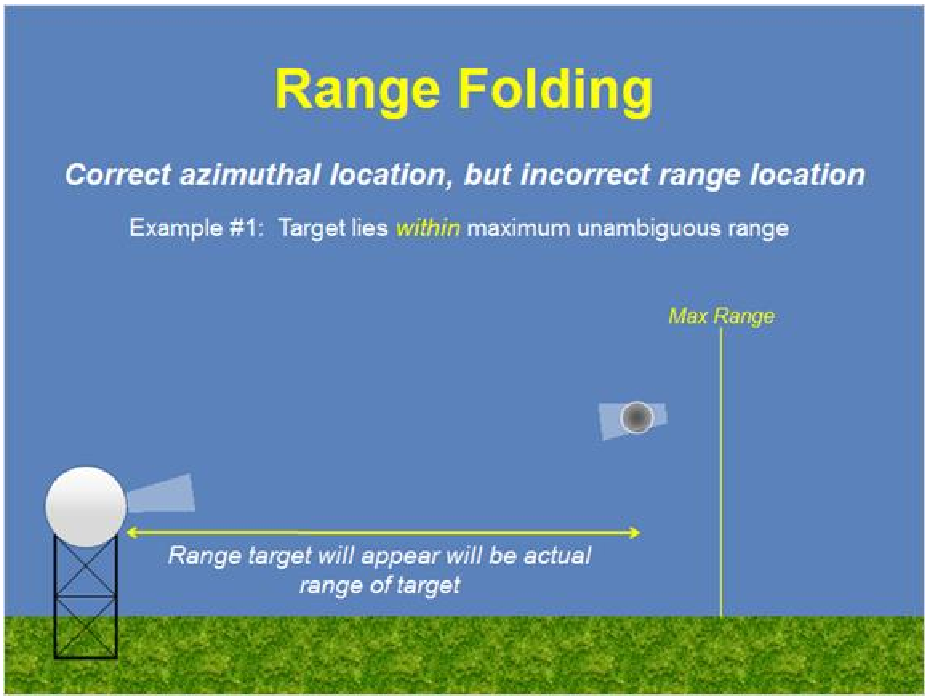
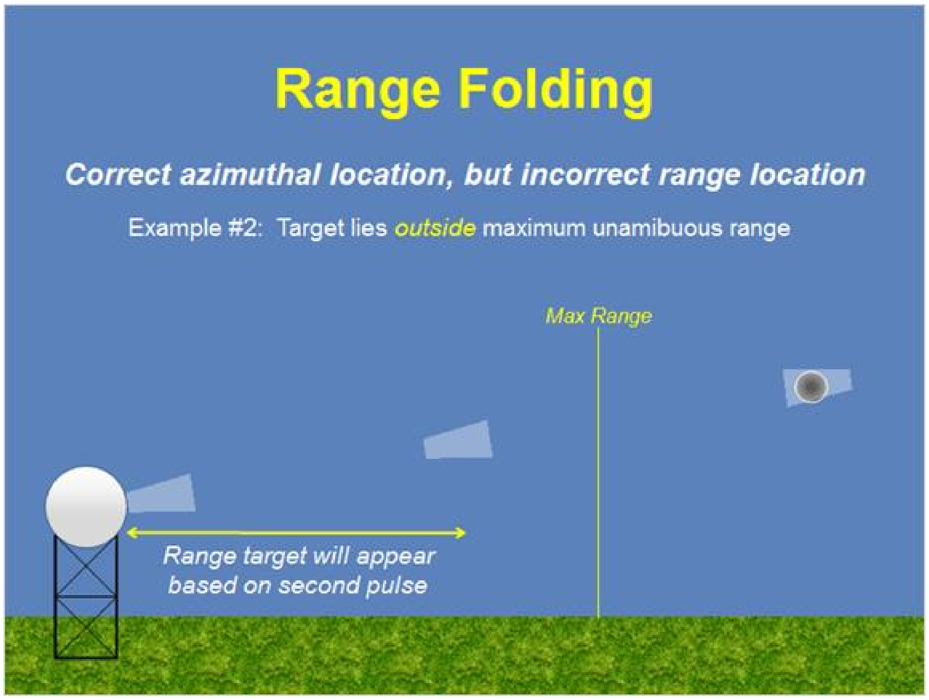
2.10 Range Folding



Notes:

The range equation leads us nicely into the next topic…range folding. As long as the first pulse makes it back to the radar before the second pulse is transmitted, the radar will correctly measure the range to the target. However, if the first pulse makes it back to the radar after the second pulse has been transmitted, then the time variable will be incorrect because it will be based on when the second pulse was transmitted, not the first pulse. This will incorrectly place the return echo at a closer range than where it actually occurred. This phenomenon is called range folding, and let's look at two examples. This first example shows the normal case where no range folding will occur. The pulse is sent out, it encounters a target within the maximum unambiguous range, and returns an echo to the radar. It arrives at the radar before the second pulse is transmitted and therefore gets the correct range applied to it.

2.11 Range Folding



Notes:

However, in this second example, the target lies outside the maximum unambiguous range. Thus, when the first pulse encounters the target, the target returns some of the power back towards the radar. However, before the first pulse return power makes it to the radar, a second pulse is transmitted. Then, when the first pulse finally does make it back to the radar, the radar thinks this power return is from the second pulse, not the first pulse, and therefore thinks the return power is from a target at a range closer to the radar than where it actually resides. It is range folded.

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WSR-88D Fundamentals Part 4: Non-Standard Beam Consequences

1. Intro to Radar Beam Characteristics

1.1 Welcome

Notes:

Welcome to the Radar & Applications Course (RAC) Principles of Doppler Weather Radar. This lesson is on WSR-88D Fundamentals Part 4: Non-Standard Beam Consequences. It is presented by the Warning Decision Training Division (WDTD). Let's get started!

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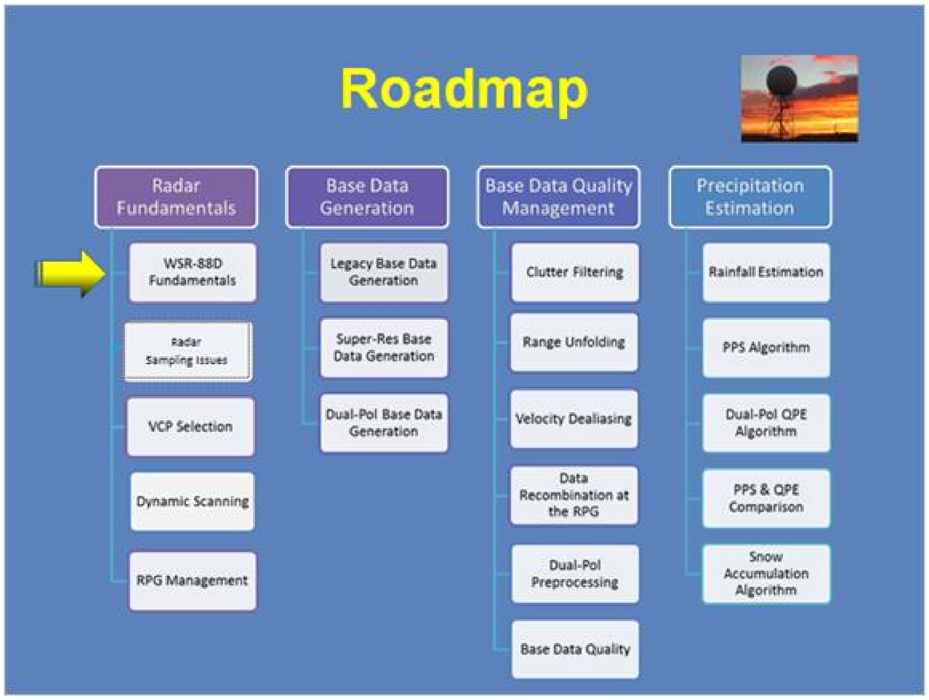
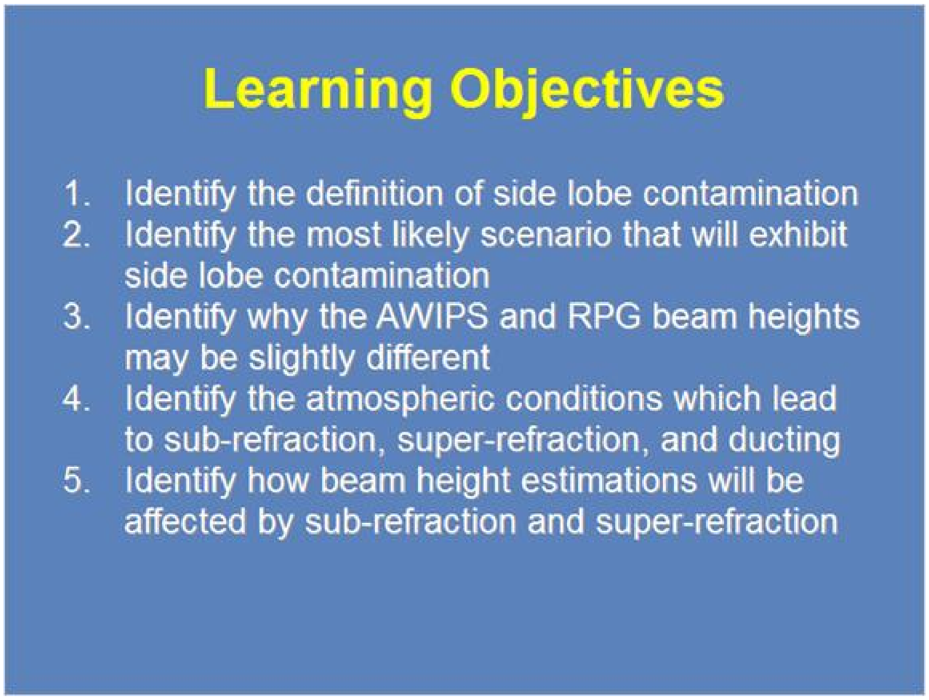
1.2 Roadmap



Notes:

Here is the complete roadmap for the entire “Principles of Doppler Weather Radar” section of RAC. You are currently in the WSR-88D Fundamentals portion of this section, and this portion consists of 5 lessons. Let’s keep going!

1.3 Learning Objectives



Notes:

Here are the learning objectives for this lesson. Please take a moment to review these objectives, as the quiz at the end of this lesson is based on these objectives.

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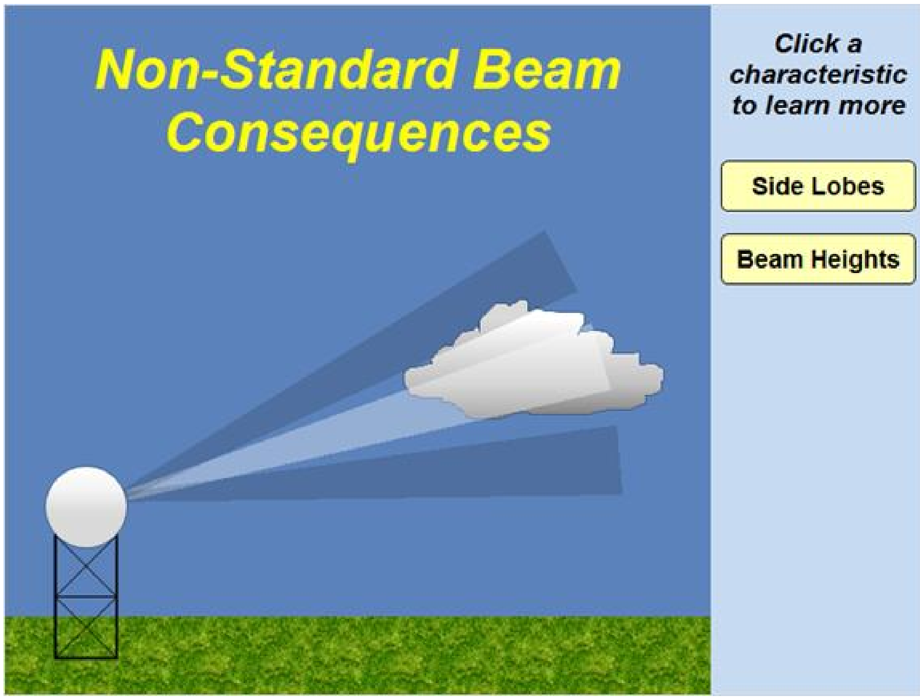
2. Non-Standard Beam Consequences

2.1 Non-Standard Beam Consequences HOME



Notes:

Many of the general concepts of beam propagation are assumed to occur in a "standard" atmosphere, or we assume the beam is a rigid object. Well, the atmosphere is rarely, if ever, "standard" and the beam is not a rigid object. Click on the buttons to the right to learn more about the non-standard beam consequences known as side lobes and beam height estimations.

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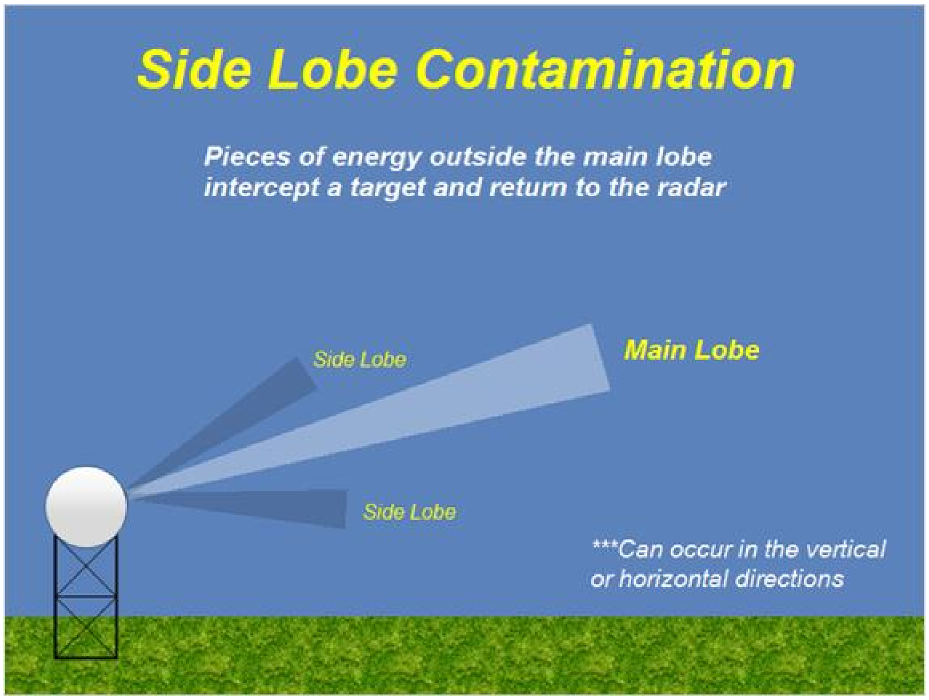
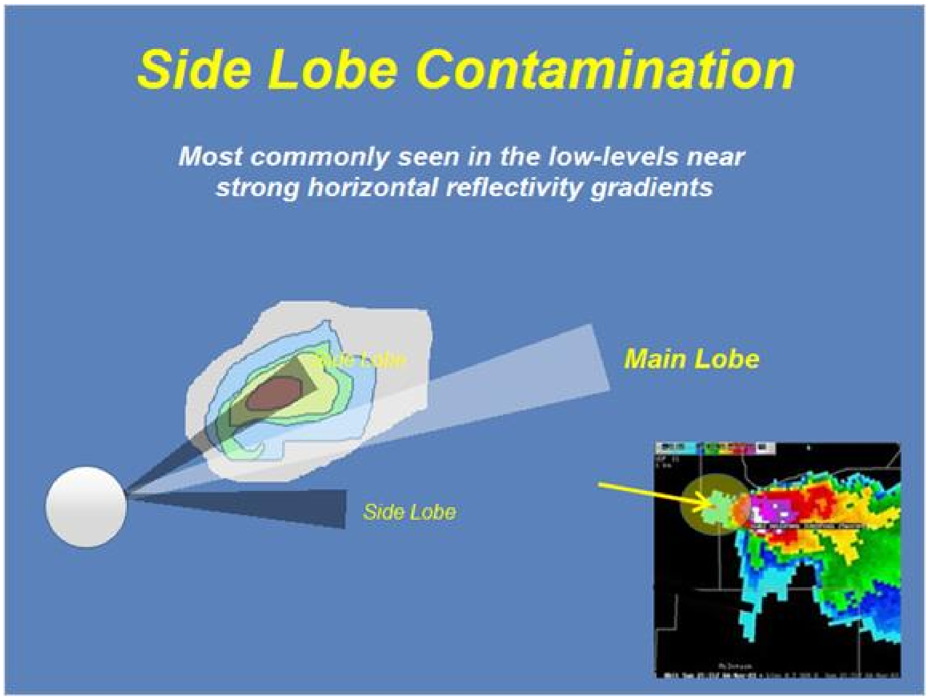
2.2 Side Lobe Definition



Notes:

Recall that the initial energy for the beam is generated by the transmitter and is isotropic in nature (radiates in all directions equally). Well, that's where the radar antenna comes into play. It focuses this energy into the 1 degree beam which is what is sent out into the atmosphere to detect the weather objects. However, the antenna doesn't focus all of the energy into this 1 degree beam. Some of it is focused into regions just outside the main lobe called side lobes. These side lobes contain a very small fraction of the total energy transmitted, but can intercept weather targets and produce returns at the radar which are strong enough to be seen on the radar display. These side lobes can occur either in the vertical or horizontal, and we'll discuss those next.

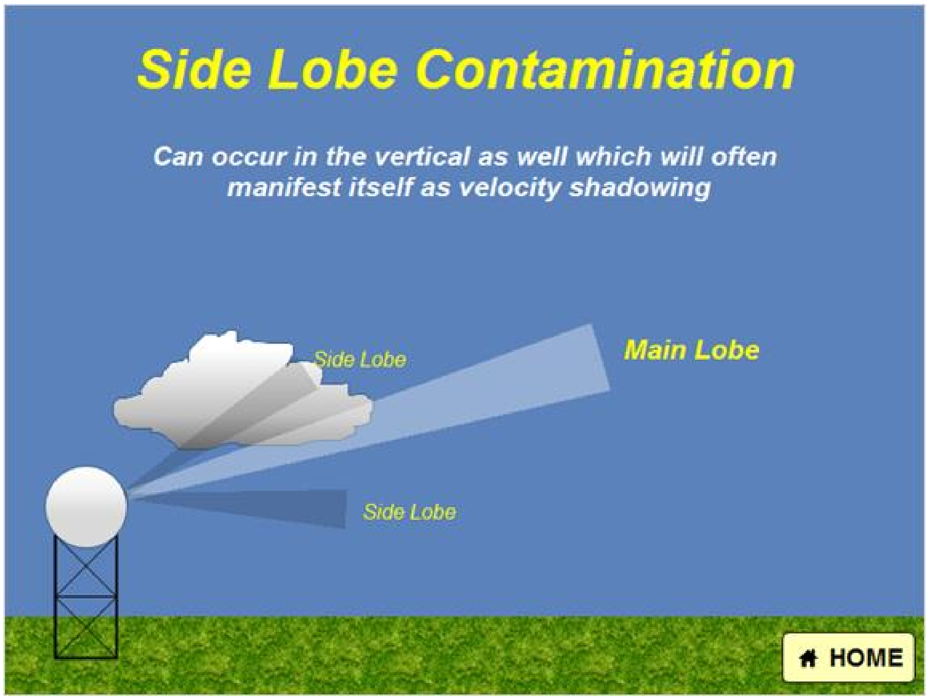
2.3 Side Lobe Horizontal



Notes:

Effects from side lobes are most commonly seen in the horizontal. For example, here is a typical conceptual model of a supercell thunderstorm. Once the main lobe passes by the core of the storm, the side lobe samples the core while the main lobe is sampling very low returns. Because the signal returned to the radar is dominated by the side lobe returns, that is the signal processed by the radar. However, because the radar thinks the return came from the main lobe, it places this return where the main lobe is sampling, which is just off to the side of the core in the clockwise direction. So, side lobe contamination will show up as weak reflectivity just to the side of a core. Here is an example of side lobe contamination.

2.4 Side Lobe Vertical



Notes:

The last example of side lobe contamination was in the horizontal. However, side lobes exist in the vertical as well. The most common scenario where you will see the effects of side lobe contamination is when the main lobe is sampling the low levels, but the side lobe is sampling a fairly intense overhang. However, the reflectivity will not be the prominent feature, but rather the velocity signature. This is often called the velocity shadow. What happens is the velocity signature from the overhang is pretty much superimposed in the low levels. This can lead to spurious velocity couplets.

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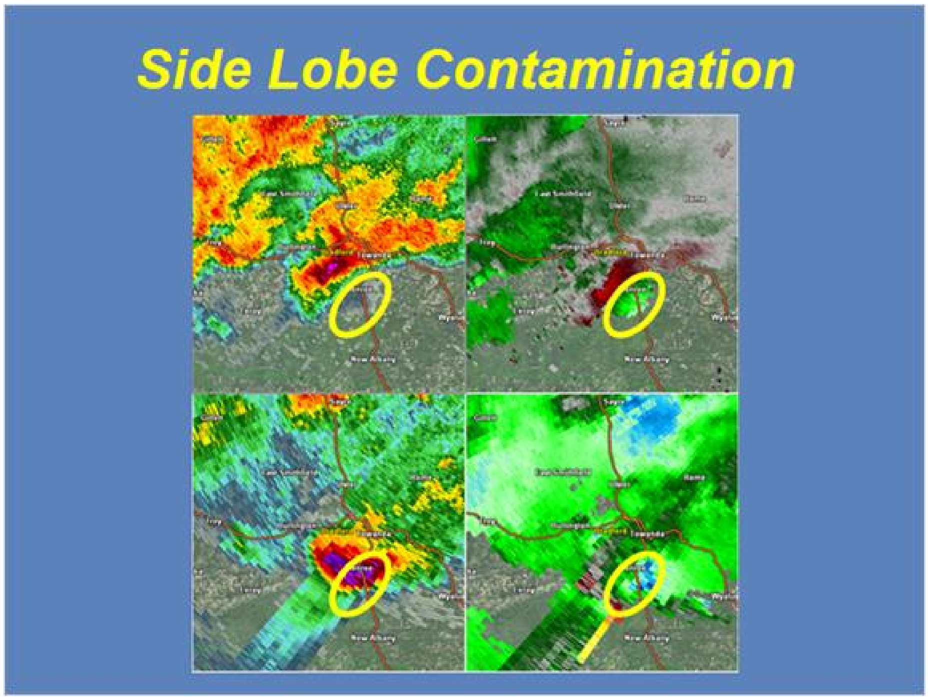
2.5 Side Lobe Vertical



Notes:

Here is an example. The top two images are the low level reflectivity (left) and velocity (right). Notices the intense inbounds well away from the core and near the core there are moderate outbounds which make it appear as though there is rotation. However, stepping up in elevation, there is as strong core directly above with very strong inbound velocity. These strong inbounds aloft are basically being superimposed below because of side lobe contamination. Therefore, be aware of this limitation when viewing velocity values in weak signal areas.

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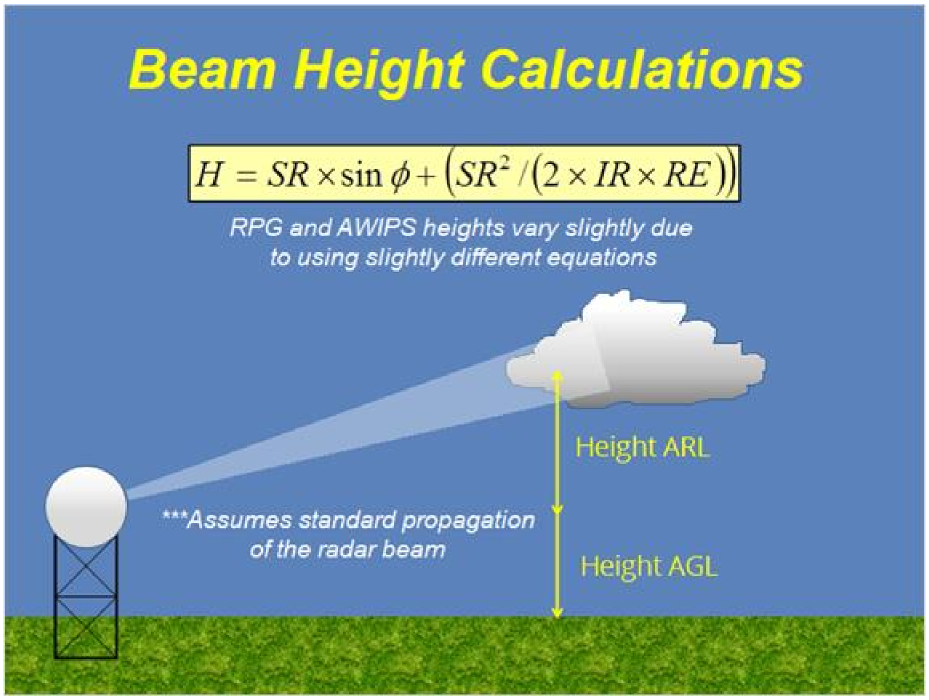
2.6 Beam Height Calcs



Notes:

So, here's another one of them funny equations, but don't worry, you won't be tested on it… okay, seriously, contain your enthusiasm :) The main thing to note here is this equation assumes a standard atmosphere for which the beam propagates through. As we all know, the atmosphere is rarely standard, so the beam will always be somewhere slightly different than the equation suggests. Also, this equation here is used by the RPG, but AWIPS uses a slightly different equation, so RPG heights and AWIPS heights may be off just slightly.

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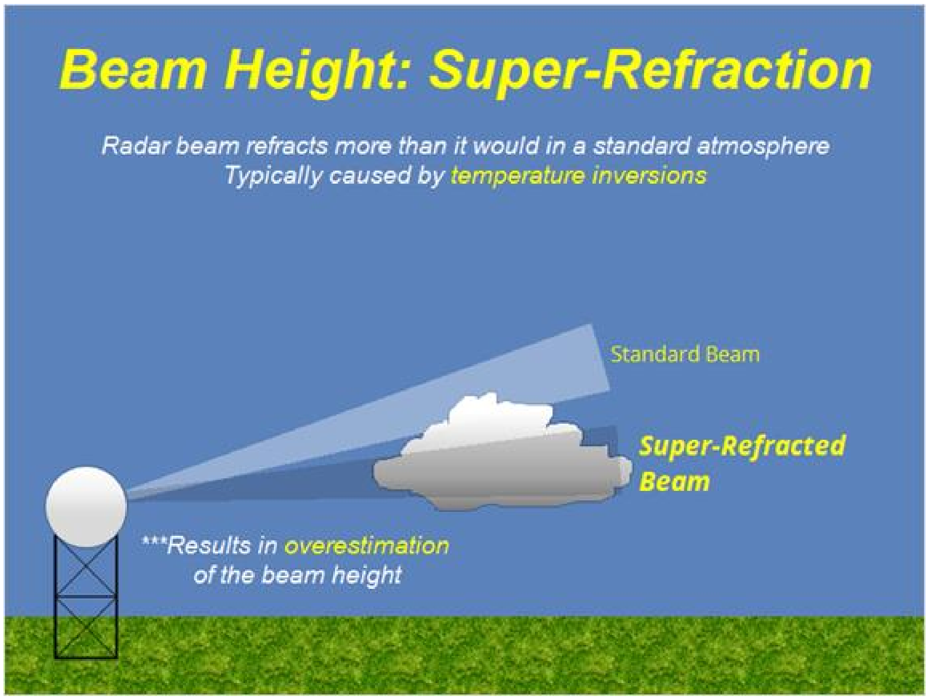
2.7 Super-Refraction



Notes:

Let’s look at these different propagation anomalies. The first case we’ll examine is super-refraction. Super-refraction occurs when the beam bends more than normal towards the ground. This phenomenon typically occurs when there is a temperature inversion near the ground. Because the height of the beam is lower than the equation suggests, then the reported beam height is overestimated. Let’s look at the next case…sub-refraction.

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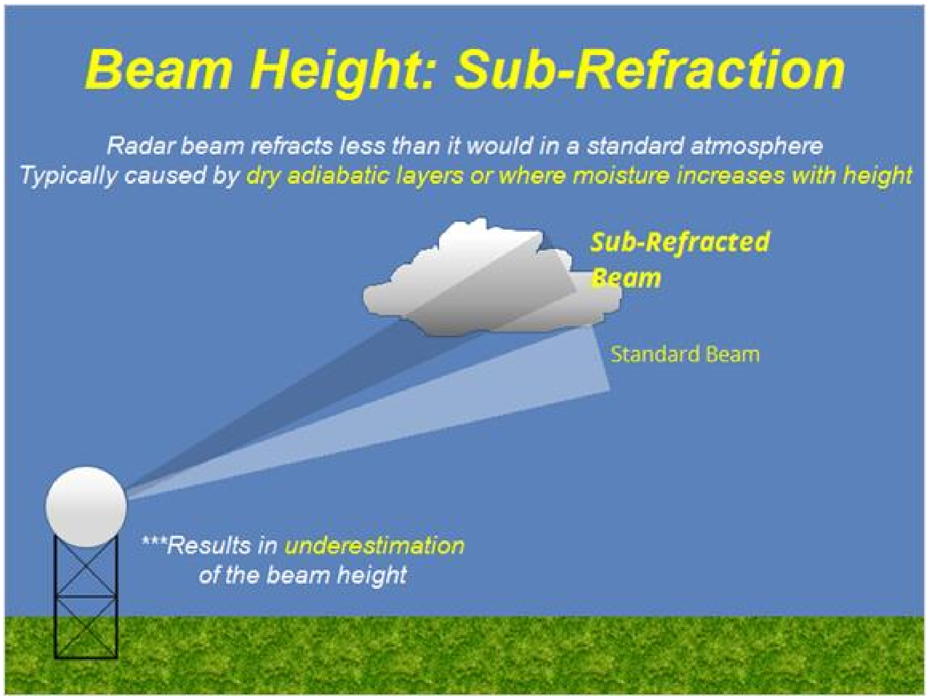
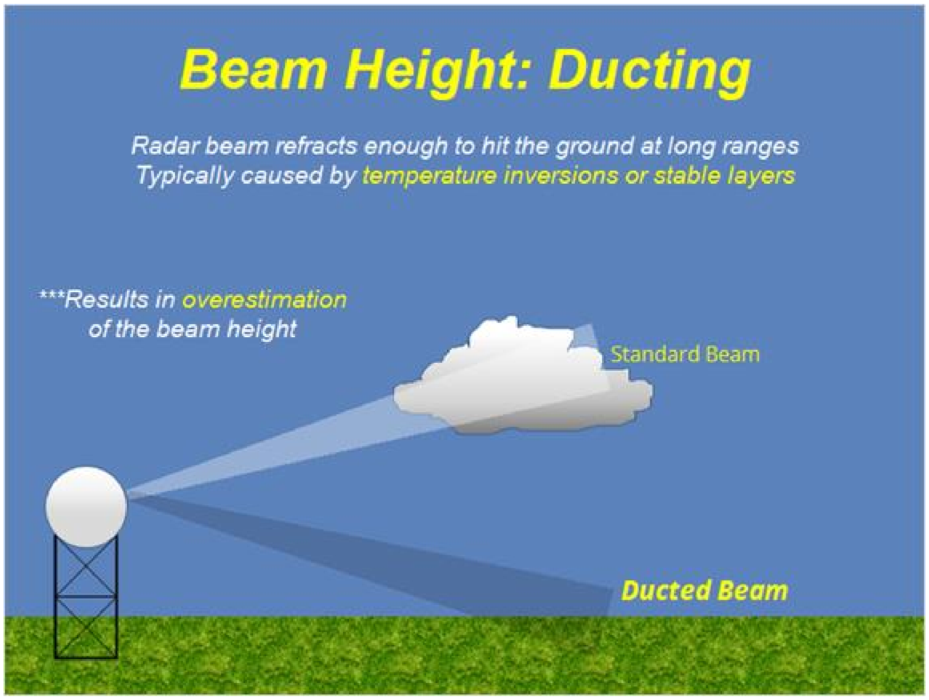
2.8 Sub-Refraction



Notes:

When the beam is sub-refracted, it bends upward a little more than normal, or is refracted a little less than normal. This type of atypical refraction occurs when there are dry adiabatic layers or areas where moisture increases with height. Because the beam is actually higher than the equation suggests, the reported height of the beam is an underestimation. The last case we'll look at is called ducting.

2.9 Ducting



Notes:

A radar beam can sometimes get trapped in a layer and actually bent downward enough that it hits the ground at long ranges. This type of atypical propagation is called ducting. Ducting usually occurs when there are stable layers in the atmosphere or sharp temperature inversions. Because the actual beam height is lower than the equation suggests, the equation is actually overestimating the beam height. This concludes our section on beam height estimations and anomalies.

WSR-88D Fundamentals Part 5: Data Collection

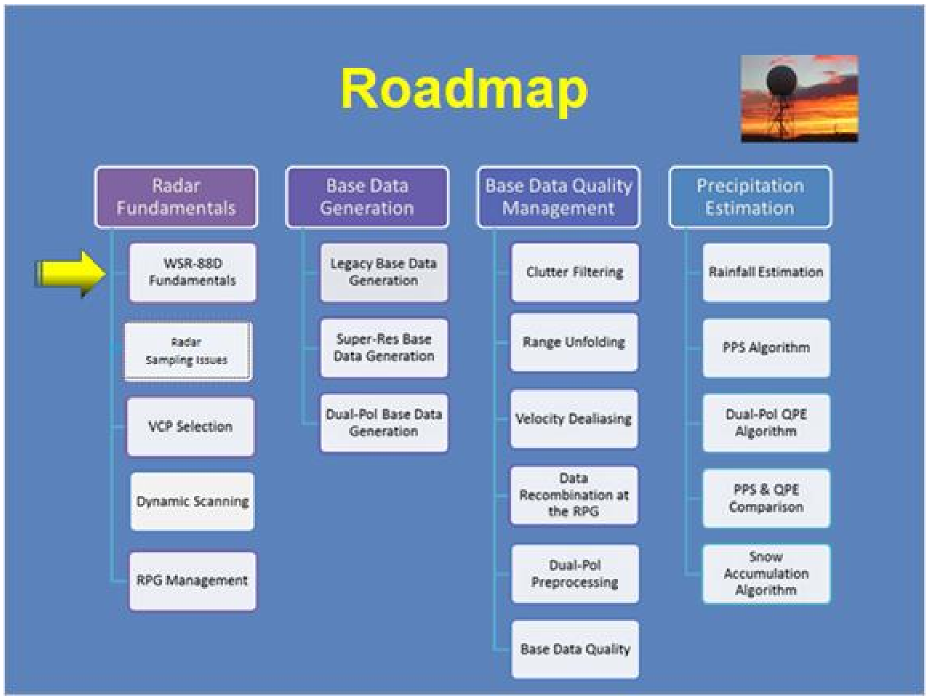
1. Data Collection

1.1 Welcome

Notes:

Welcome to the Radar & Applications Course (RAC) Principles of Doppler Weather Radar. This lesson is on WSR-88D Fundamentals Part 5: Data Collection. It is presented by the Warning Decision Training Division (WDTD). Let's get started!

1.2 Roadmap



Notes:

Here is the complete roadmap for the entire "Principles of Doppler Weather Radar" section of RAC. You are currently in the WSR-88D Fundamentals portion of this section, and this portion consists of 5 lessons. Let's keep going!

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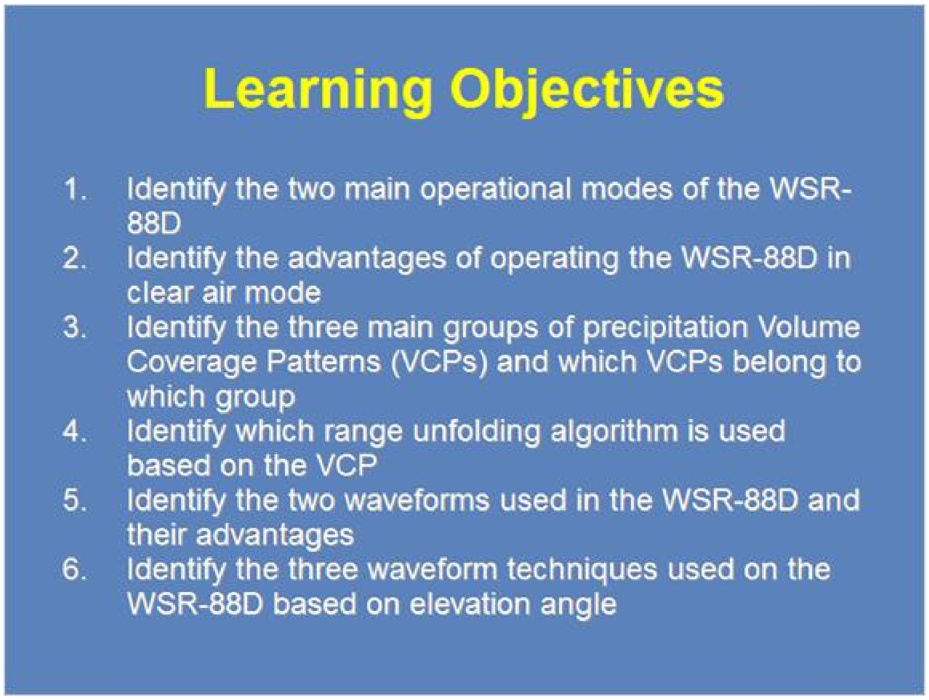
1.3 Learning Objectives



Notes:

Here are the learning objectives for this lesson. Please take a moment to review these objectives, as the quiz at the end of this lesson is based on these objectives.

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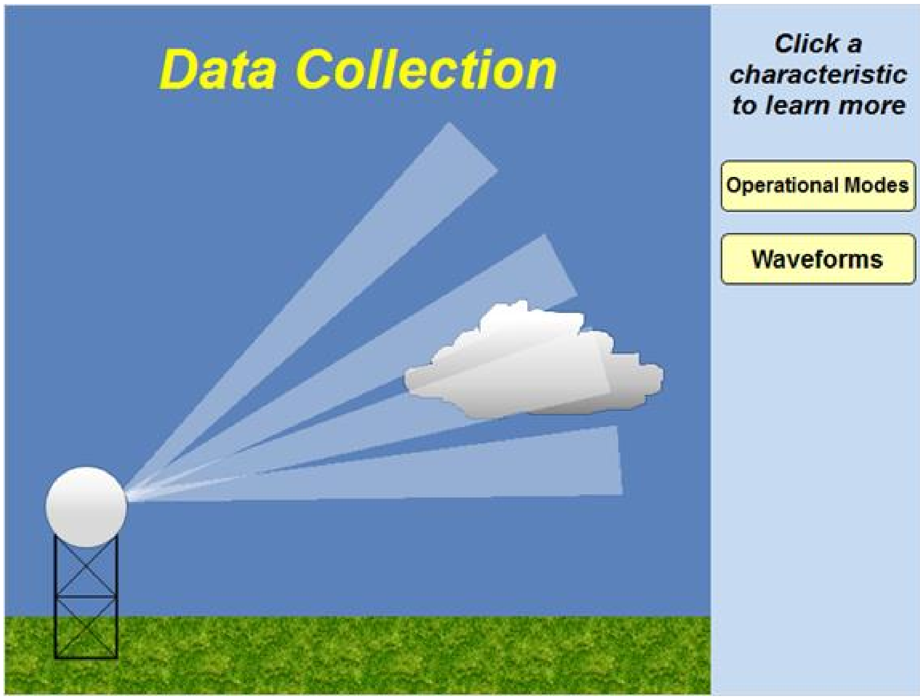
2. Transmitting & Receiving Characteristics

2.1 Data Collection HOME



Notes:

With a solid understanding of how the radar transmits and receives energy in order to detect meteorological targets, we can now take a look at how the radar is operated in order to collect data in the most efficient way possible. Every radar has a number of preset scanning strategies called operational modes and Volume Coverage Patterns (VCPs), and each VCP has various waveform techniques it employs to collect the data in the most efficient manner. More details on VCPs and scanning strategies will be covered in a later lesson. For now, we'll just look at the basics.

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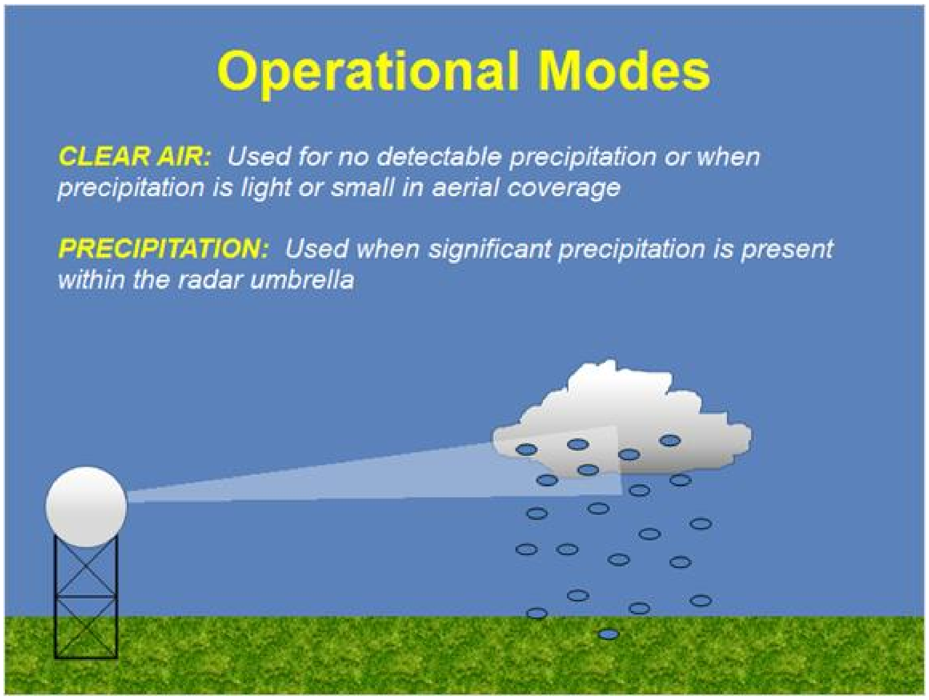
2.2 Operational Modes



Notes:

The whole idea of the WSR-88D is to detect precipitation echoes, but the radars run 24/7, so when weather is not present, the radar is running. So, it naturally follows there are just two operational modes which are Clear Air and Precipitation. Clear Air mode is primarily used when there are no detectable precipitation echoes within range, or when there is light precipitation or aerial coverage is small. When significant precipitation is present, Precipitation mode is enacted. Within each of these operational modes, there is a subset of different scanning strategies, and we'll look at those next…

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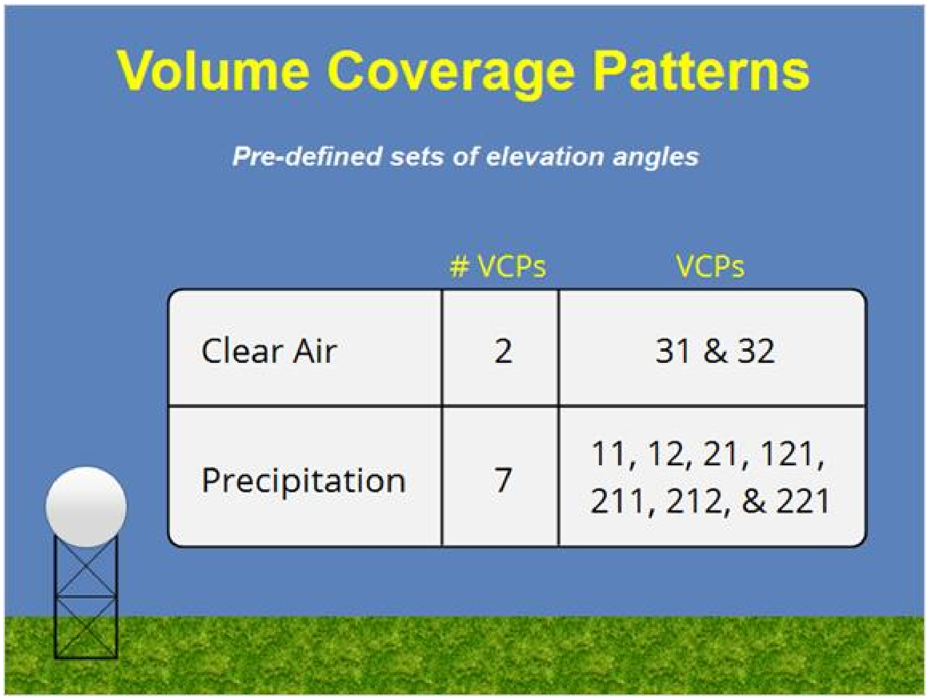
2.3 VCPs



Notes:

The pre-defined set of elevation angles run for each operational mode is called a Volume Coverage Pattern, or VCP. For Clear Air mode, there are two VCPs to choose from which are VCP 31 and 32. For the Precipitation mode, there are 7 different VCPs to choose from which are 11, 12, 21, 121, 211, 212, and 221. In the next couple slides, we'll take a little closer look at the general characteristics of these VCPs…

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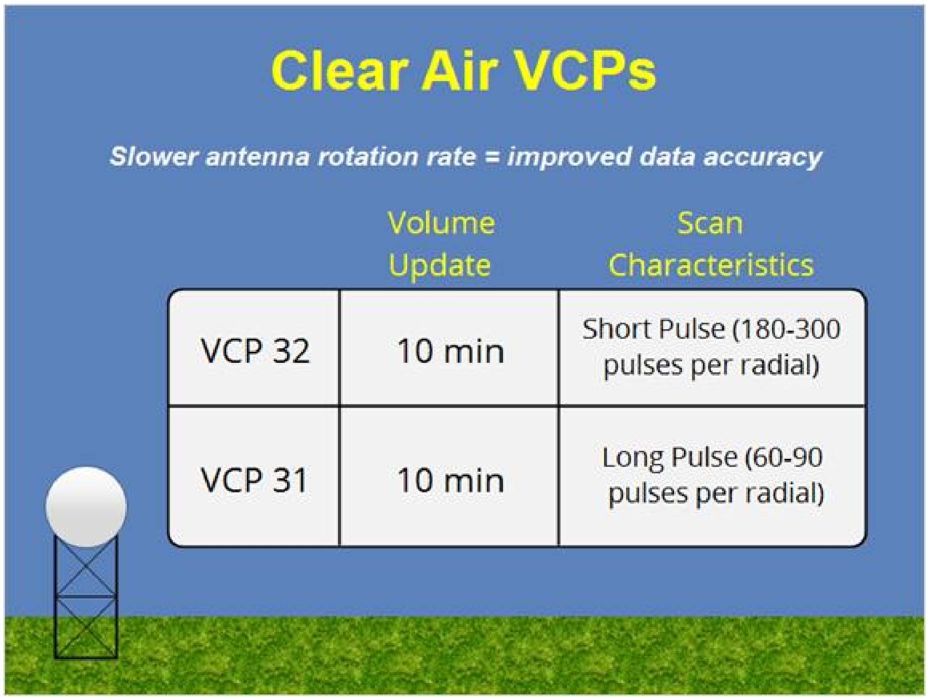
2.4 Clear Air VCPs



Notes:

The Clear Air mode VCPs operate using a much slower antenna rotation rate than any of the other VCPs. This is because the need for rapid updates is minimal. This slower antenna rotation, however, allows for more pulses per radial to be transmitted which allows for improved data accuracy. The total volume update time for the two VCPs is around 10 minutes. One last thing to note is VCP 31 is the only VCP to use long pulse mode for transmission. This long pulse mode allows for greater power density within the beam and therefore increases the sensitivity of the radar by roughly 3 dB. However, the VCP primarily uses low PRF pulses which leads to higher velocity dealiasing failures. Let’s take a look at the Precipitation VCPs next…

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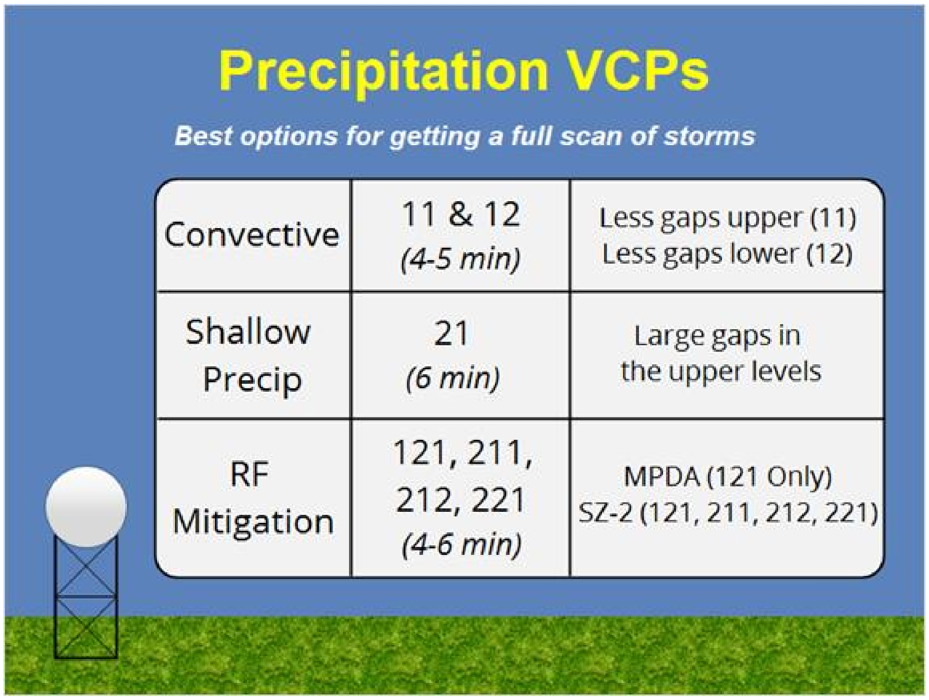
2.5 Precip VCPs



Notes:

The Precipitation VCPs are the best options to choose during significant precipitation events because they scan to higher elevations, therefore giving you a more complete picture of the storms. The seven VCPs can be divided up into 3 main groupings: Convective, Shallow Precipitation, and RF Mitigation. The Convective grouping consists of VCP 11 and 12. VCP 11 was the original convective VCP and it does adequate low level scanning with few gaps aloft. VCP 12 came about to fill in gaps in the lower level but reduced the number of elevations in the upper part of the scan. VCP 21 was developed for those very shallow and slow moving stratiform events, so there is decent low level sampling, but very few scans in the upper levels. Finally, recent upgrades to the WSR-88D have come with new techniques to improve range folding mitigation which are included with VCPs 121, 211, 212, and 221. VCP 121 uses an algorithm called the Multiple PRF Dealiasing Algorithm (MPDA) and the 200 series VCPs use the SZ-2 algorithm to unfold range ambiguities and recover velocity estimates in weaker signals. Alright, that’s the high level overview of the VCPs themselves, let’s go back home and take a look at how scanning strategies change from elevation to elevation.

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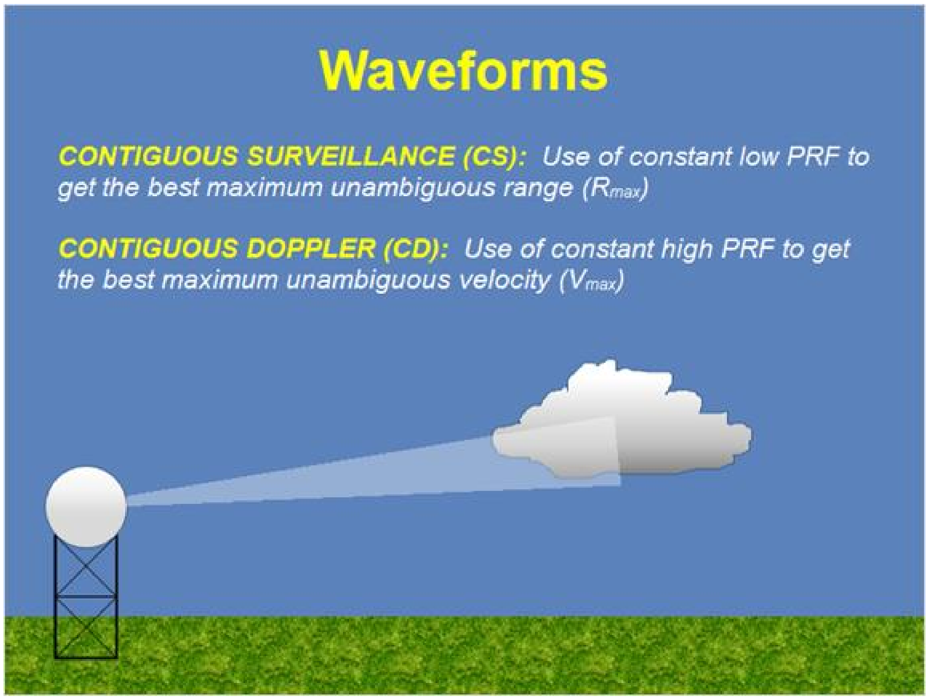
2.6 Waveforms



Notes:

Within each elevation angle, the WSR-88D employs two scanning waveforms. These are either contiguous surveillance (CS) or contiguous Doppler (CD). CS uses a constant low PRF to get the best maximum unambiguous range, while the CD uses a constant high PRF to get the best maximum unambiguous velocity. How these two waveforms are used depends on which elevation the radar is scanning. We'll take a look at this next…

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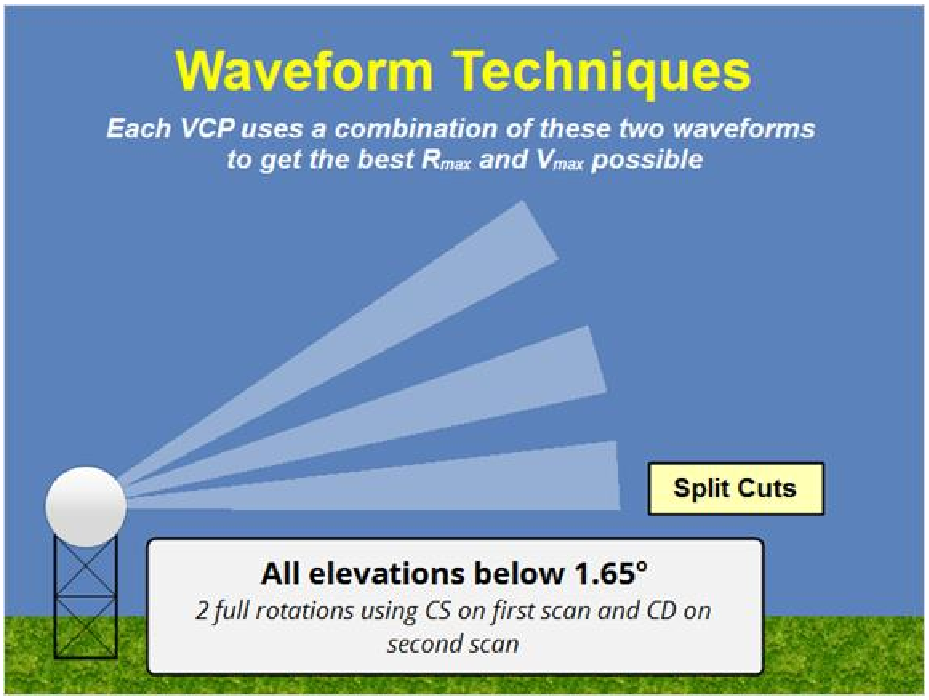
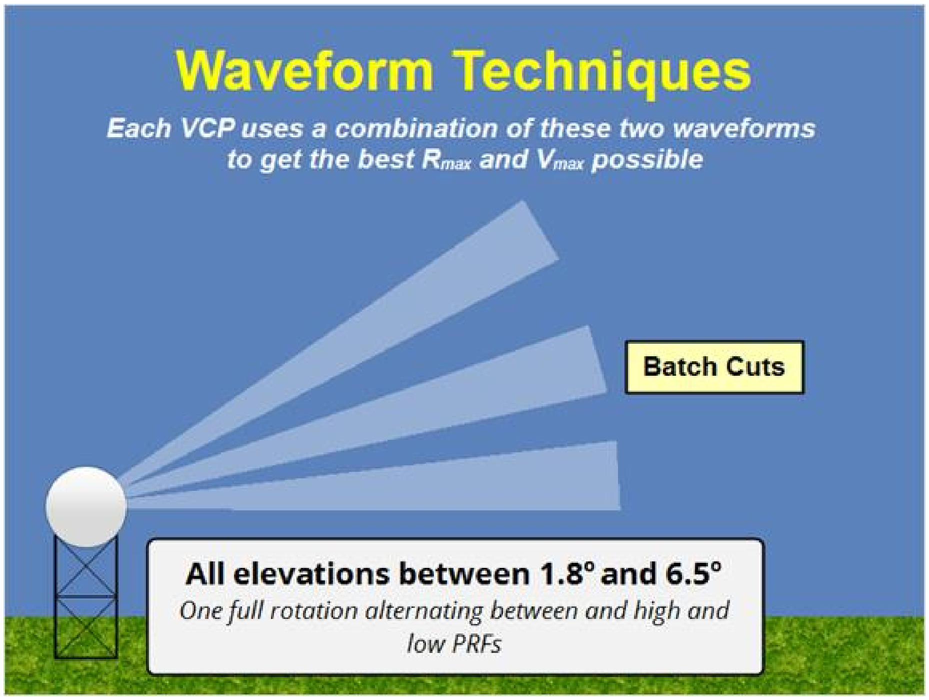
2.7 Waveform Techniques



Notes:

Split cut elevations include all elevations below 1.65 degrees. Each elevation consists of two full scans with the first one being in CS mode and the second scan being in CD mode.

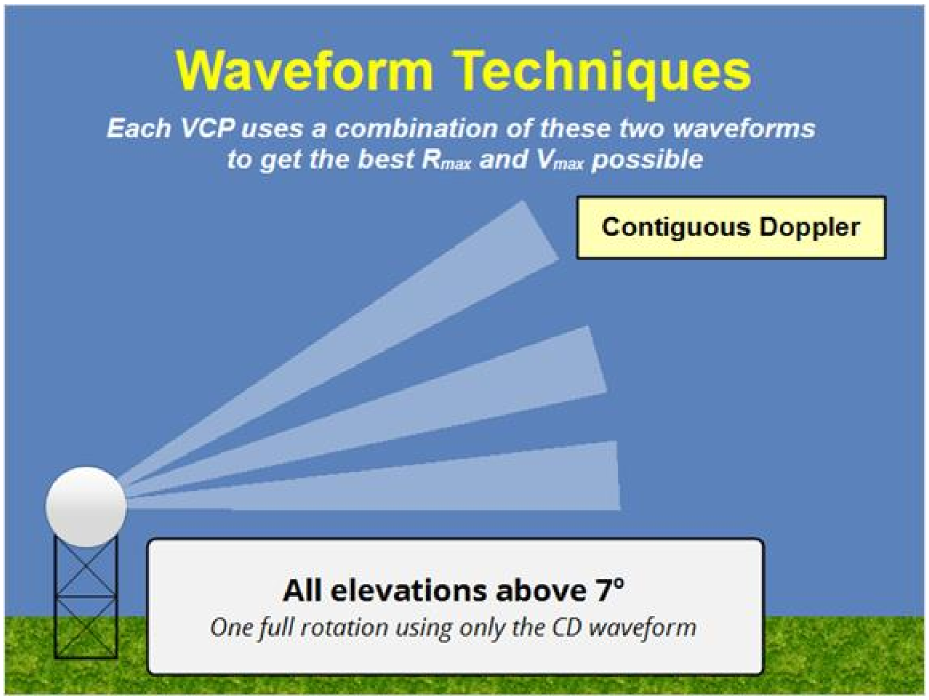
2.8 Waveform Techniques



Notes:

In the Batch elevations, which include all elevations between 1.8 degrees and 6.5 degrees, each elevation does one full scan where the pulses alternate between high and low PRF.

2.9 Waveform Techniques



Notes:

All elevations above 7 degrees perform one scan using the CD mode only.

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Radar Sampling Issues

1. Intro to Radar Beam Characteristics

1.1 Welcome

Notes:

Welcome to the Radar & Applications Course (RAC) Principles of Doppler Weather Radar. This lesson is on Radar Sampling Issues. It is presented by the Warning Decision Training Division (WDTD). Let's get started!

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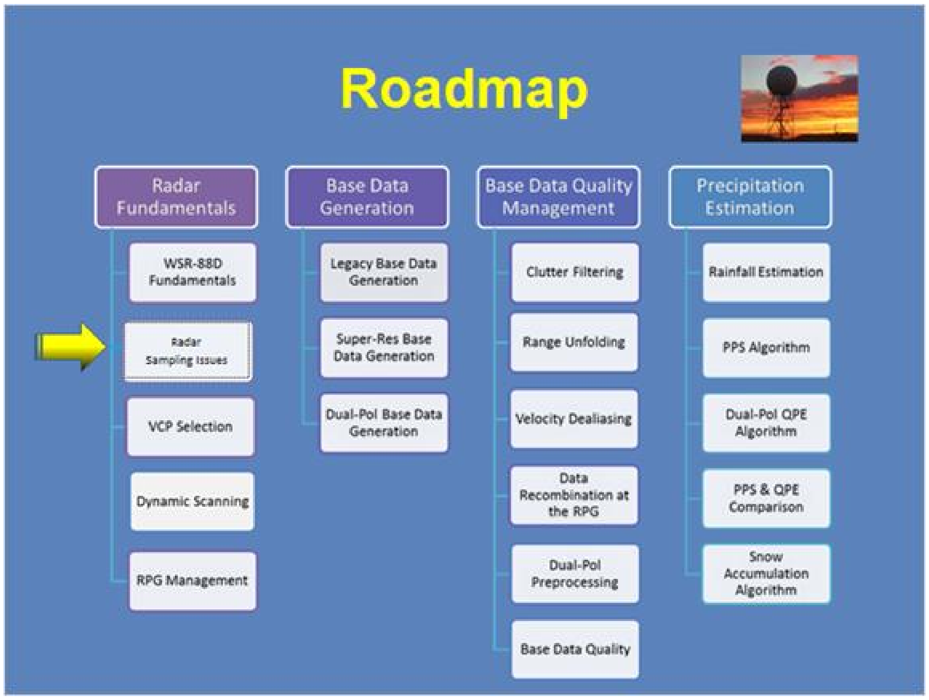
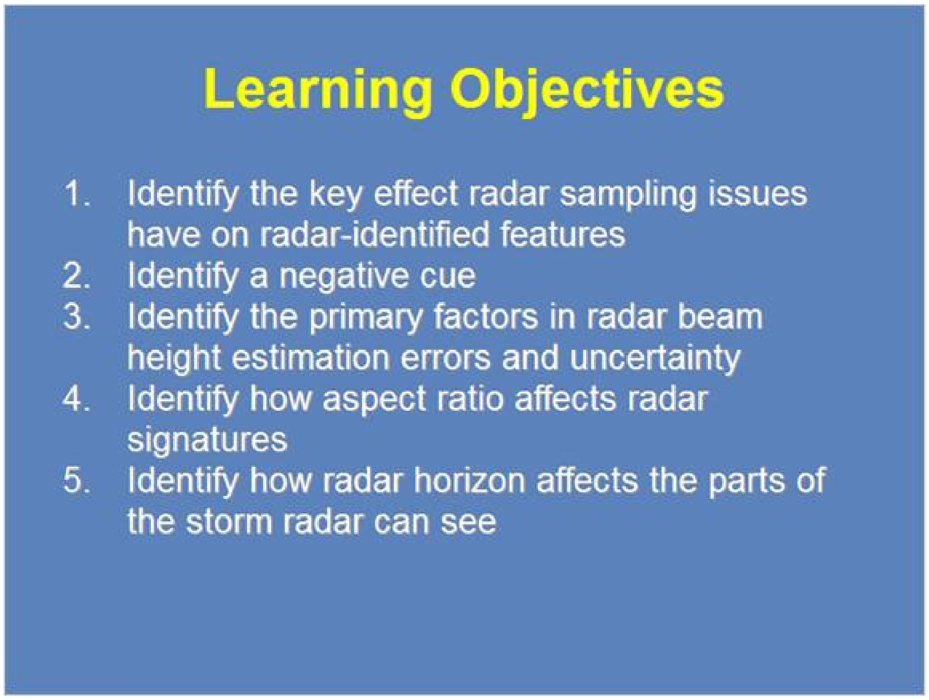
1.2 Roadmap



Notes:

Here is the complete roadmap for the entire “Principles of Doppler Weather Radar” section of RAC. You are currently in the Radar Sampling Issues portion of this section, and this portion consists of 1 lesson. Let’s keep going!

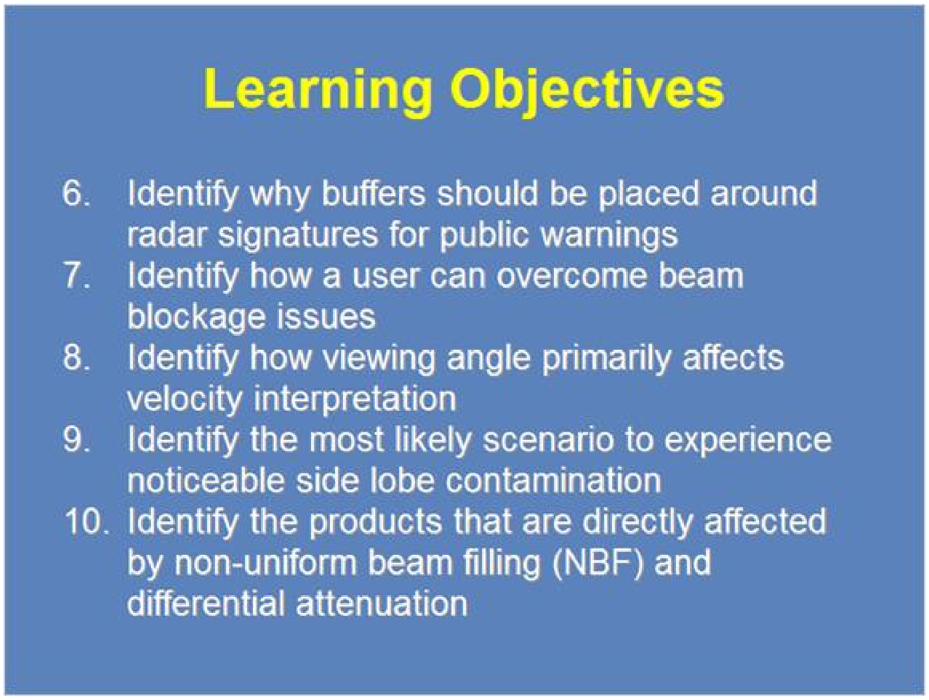
1.3 Learning Objectives



Notes:

There are ten learning objectives for this lesson. Here are the first five, and the last five will be on the next slide. Please take a moment to review these objectives, as the quiz at the end of this lesson is based on these objectives.

1.4 Learning Objectives



Notes:

Here are the last five learning objectives. Feel free to go back and forth between this slide and the previous to jot down these objectives.

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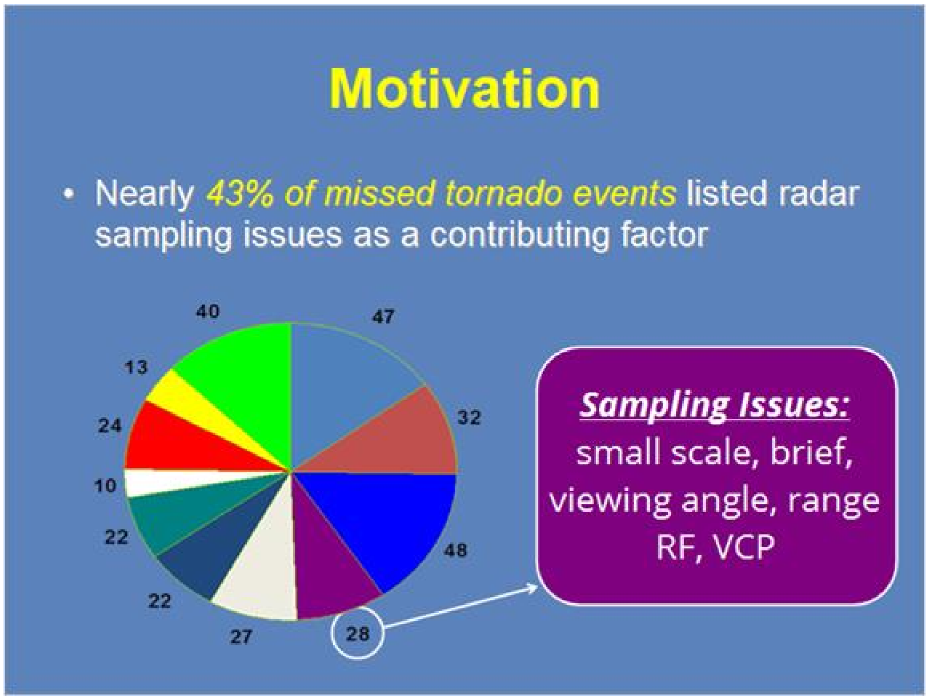
1.5 Motivation



Notes:

A root cause analysis study revealed that in 65 missed tornado events, 28 of those missed events listed radar sampling issues as a contributing factor. Therefore, it is imperative we examine radar sampling issues and try to better understand them so as to avoid future missed events. Let's get started!

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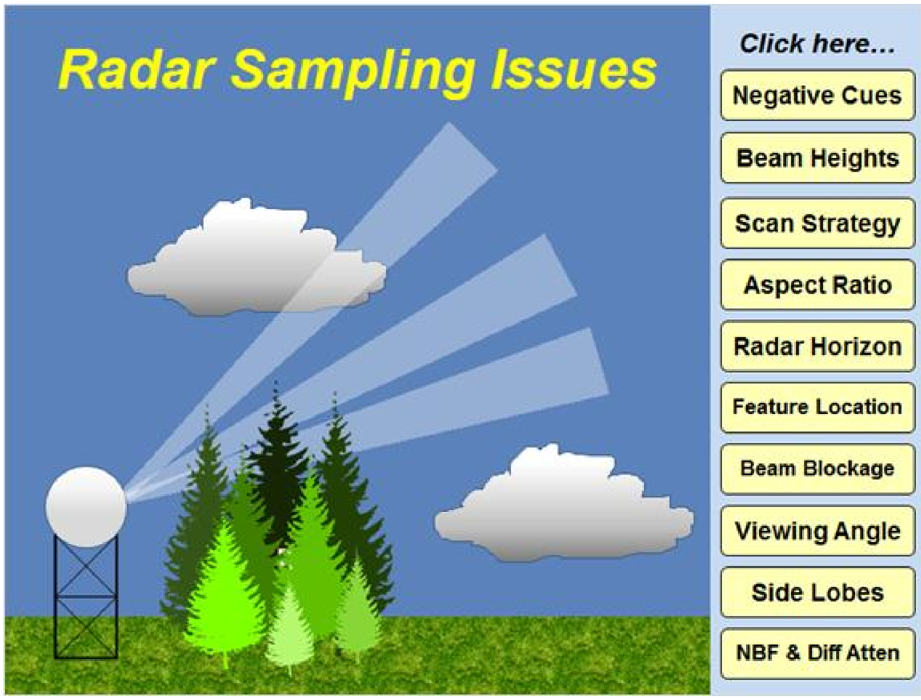
2. Transmitting & Receiving Characteristics

2.1 Sampling Issues HOME



Notes:

Radar sampling issues come in all shapes and sizes. Some can make interpretation almost impossible, and other are just annoyances. However, if you understand the situations in which these sampling issues can occur, there are ways to mitigate them. This lesson will show you common examples where these various sampling issues occur, and discuss how to mitigate them where possible. Let’s get started!

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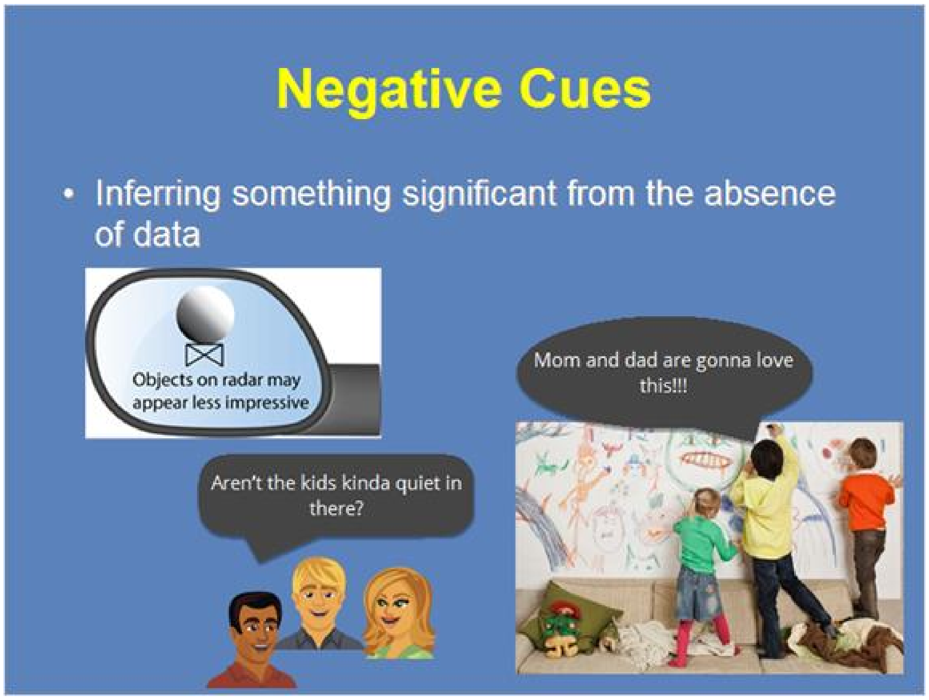
2.2 Negative Cues



Notes:

Before we actually jump into the actual sampling limitations, we need to discuss the concept of negative cues. Many of the sampling limitations we'll discuss impacts radar signatures usually by making the features appear LESS IMPRESSIVE than the features appear in actuality. And sometimes, these limitations mask the feature altogether, and we have to infer something significant by the absence of data. This concept is called negative cues. In every day life, let's say a group of parents are at a house talking in one room, and the kids are playing in another room. All of sudden, the kids' room gets quite. The parents notice there is NO noise coming from the kids' room and therefore gets their attention and they go check on the kids. The absence of noise from the kids' room was a negative cue to the parents that something significant was occurring in the kids' room.

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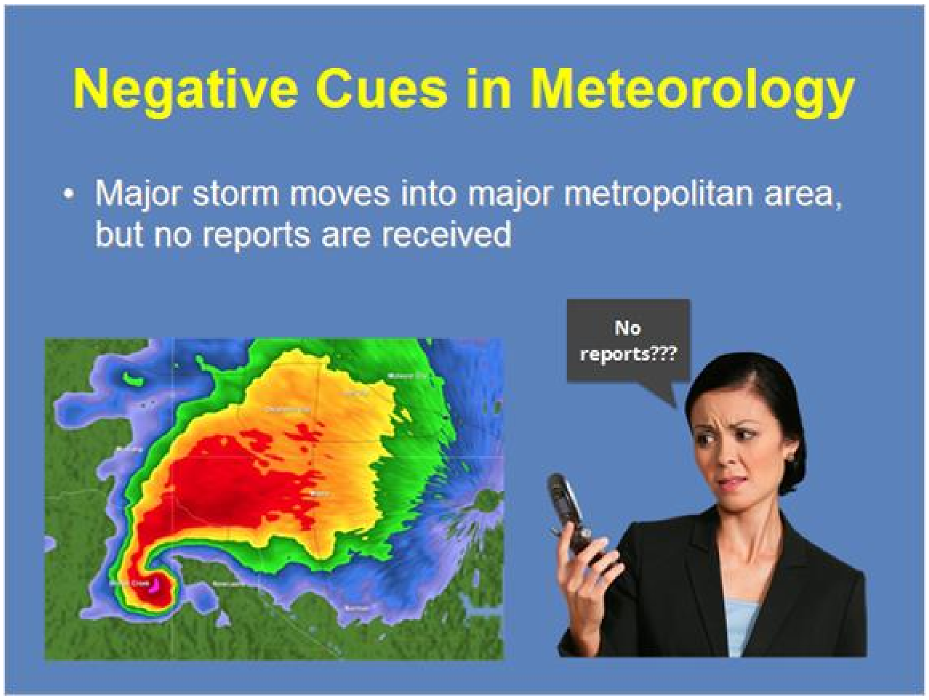
2.3 Negative Cues in Meteorology



Notes:

Let's take a look at some examples of negative cues in the warning world. First example here shows a very classic supercell with a hook echo moving into a major metropolitan area. With such a large population being affected by this storm, a forecaster would certainly expect reports coming into the office, right? What if there were no reports coming in? Wouldn't that seem suspicious? The lack of reports would signal to you, the forecaster, something isn't right. Maybe the storm is causing massive destruction and no one is thinking to call into the office. Maybe your phone lines are down and you can't receive incoming calls. Whatever it is, the lack of reports coming into the office is a negative cue that something significant is happening.

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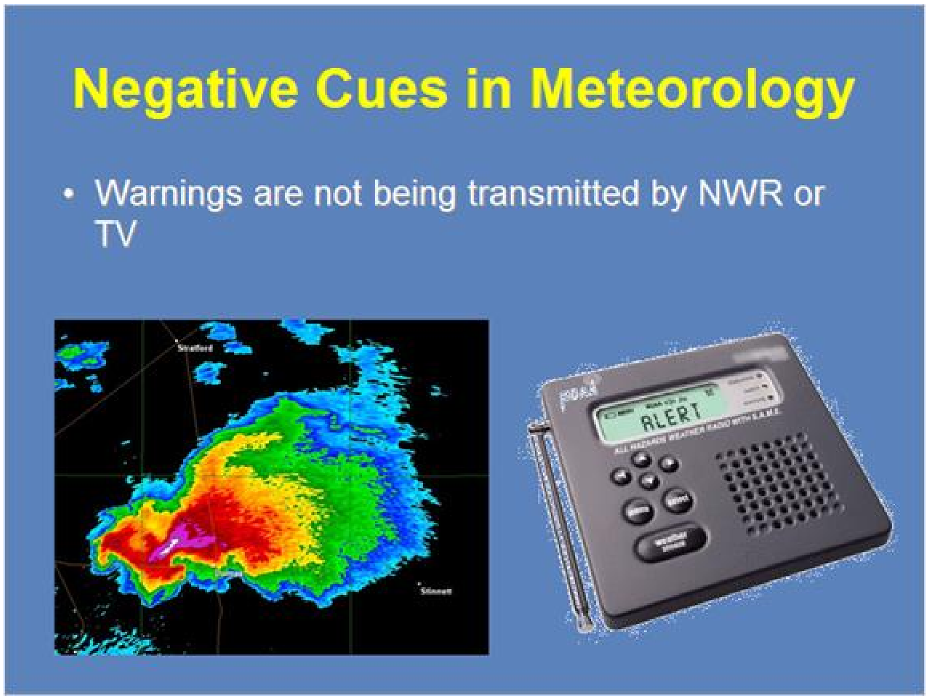
2.4 Negative Cues in Meteorology



Notes:

Another example might be you see this storm and decide to issue a tornado warning (which is a good decision). However, you keep getting calls and tweets from the public and media partners saying, “Where is that tornado warning?” They proceed to tell you that their weather radios aren’t sounding for this storm even though family and friends are saying there’s a tornado. What does this tell you? Did you issue for the right storm? Did you not click submit on the WarnGen interface? Is the NOAA Weather Radio system down? This lack of information to the public is the negative cue to you that something isn’t right.

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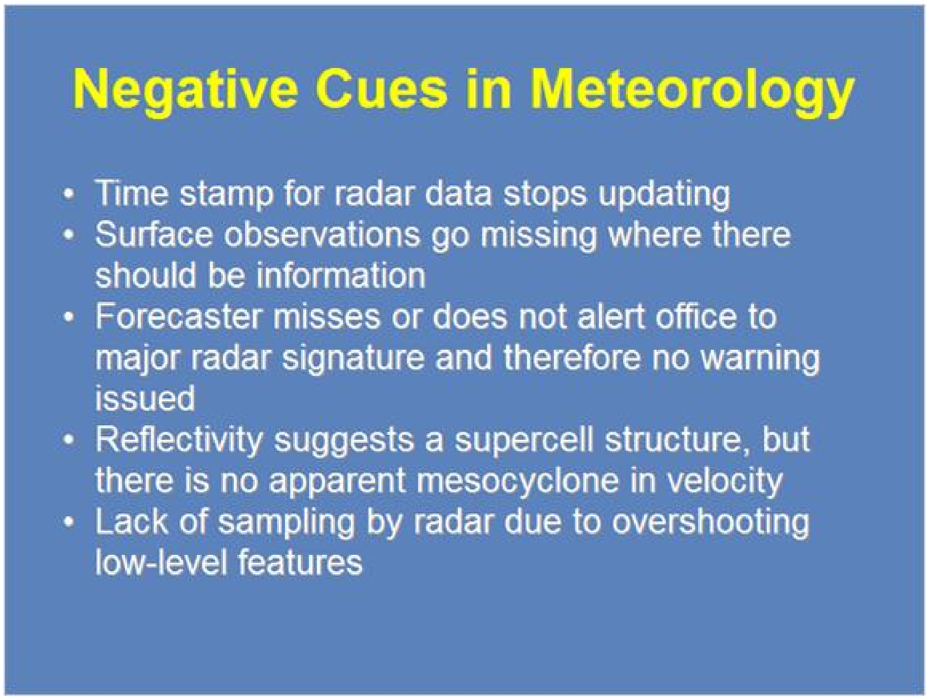
2.5 Negative Cues in Meteorology



Notes:

We could go on and on with great examples of negative cues in warning operations, but we want to learn about radar sampling issues, right? So here are some other examples of how negative cues occur in warning operations. Notice many of them deal with radar interpretation. That's the point of this lesson… radar sampling issues often lead to negative cues in the warning environment. Therefore, having a good grasp on radar sampling issues will help you better spot these negative cues in warning operations and make you a better forecaster. Let's go look at these sampling issues now.

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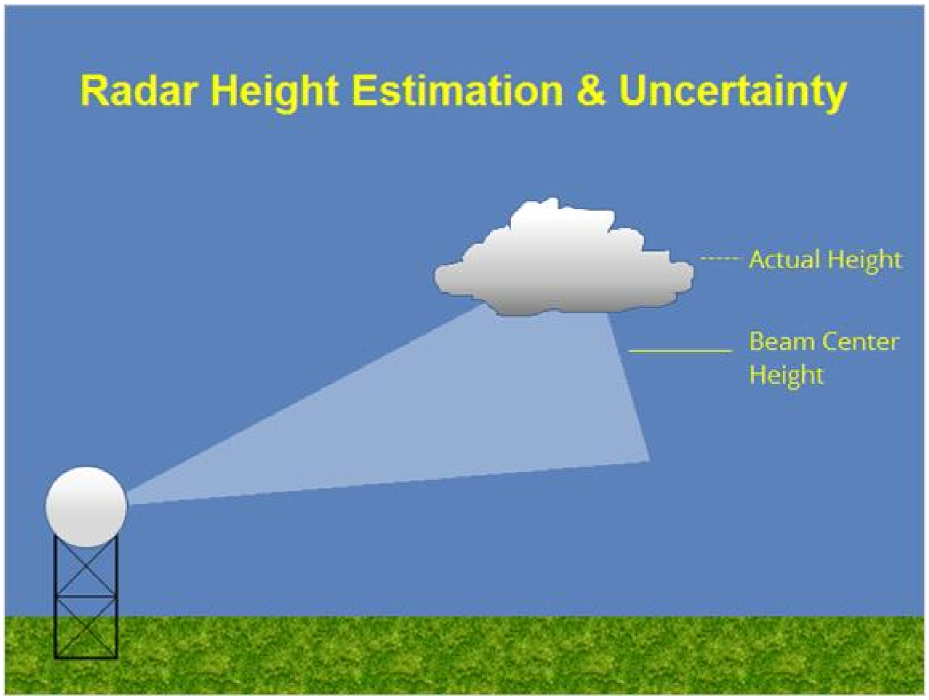
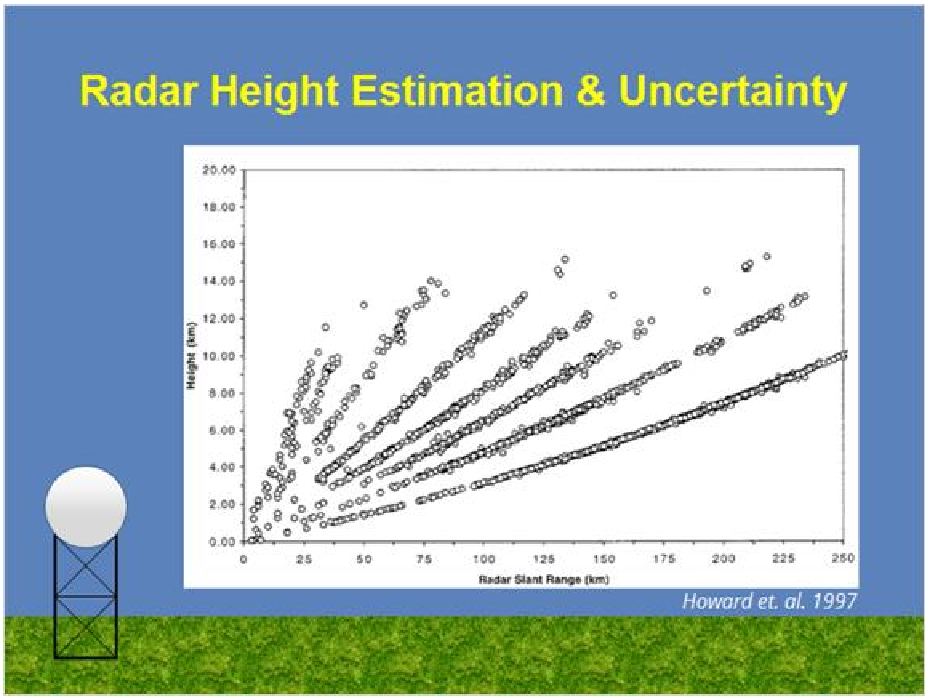
2.6 Beam Heights & Uncertainty



Notes:

Recall the radar beam spreads out as it goes down range making the beam width wider and wider. At distances as close as 60-70 miles, the beam width is over 1000s of feet. Therefore, an object detected at the edge of the beam, like this cloud here, might have an actual height of 22,000 feet, but the beam center is located at 18,000 feet. So, the radar will think the cloud echo is at 18,000 feet, whereas it is really at 22,000 feet. Just keep this fact in mind when interpreting radar echo heights.

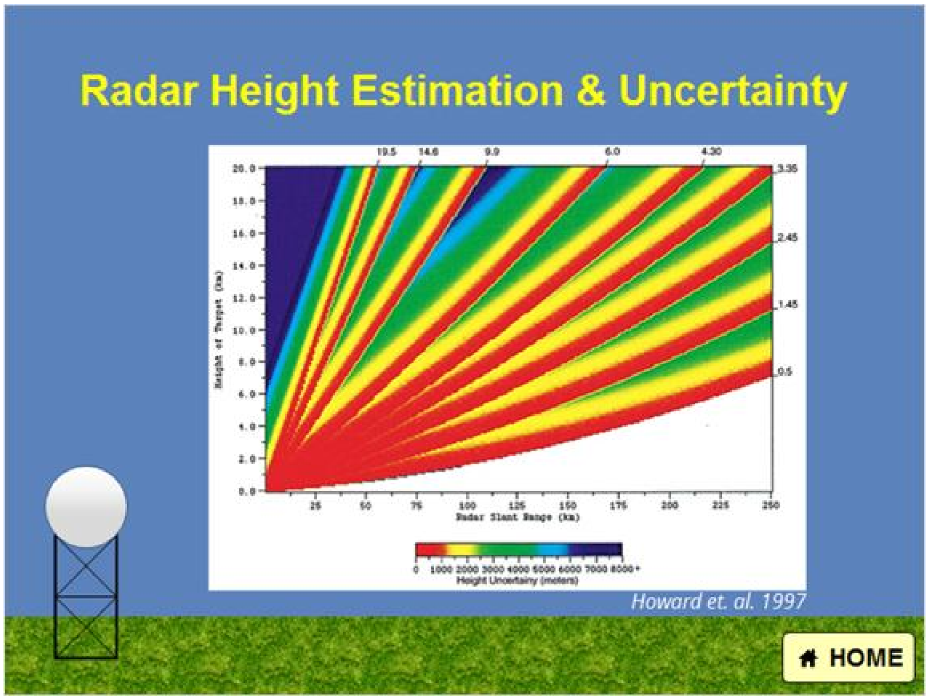
2.7 Radar Height Estimates



Notes:

A study done by Howard et. al. (1997) actually plotted the echo top heights as a function of range from radar. Look at how all those radar echo top heights fall nicely along straight lines. Is this the reality of storms? Absolutely not! This graphic illustrates how assigning all echoes to beam center results in echo heights being constrained to the heights based on the elevation angle scanned. So, storms exist in a continuous space, but the radar can't determine that. So, what is our uncertainty in these heights? We'll look at that next.

2.8 Radar Height Uncertainties



Notes:

This first graphic here shows the uncertainty (in meters) of the height estimations for each elevation angle for VCP 21. Red is good, blue is bad! Notice how within 50 km range and below 4 km height, the estimates are pretty accurate (within 1000 m). However, as you get higher is height, or farther in range, the uncertainty can be as much as 3 to 7 km because there are gaps in the scanning strategy.

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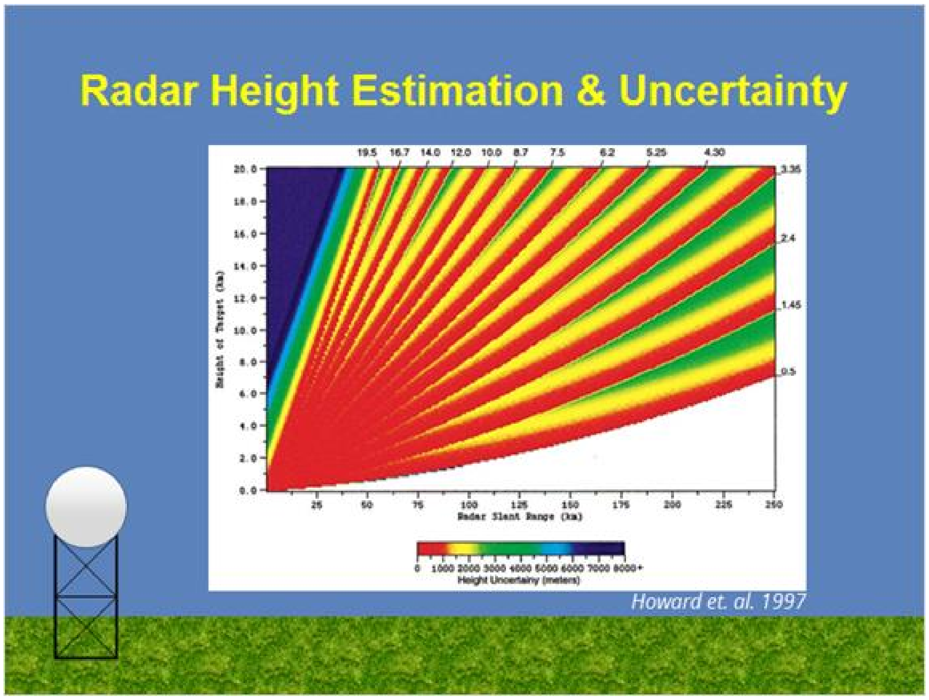
2.9 Radar Height Uncertainties



Notes:

However, look at VCP 11… The uncertainty doesn't really become a factor until past a range of 75 km and a height of 8 km. So, choosing a scanning strategy with more elevation scans can decrease the likelihood of increased height uncertainty in the height estimations.

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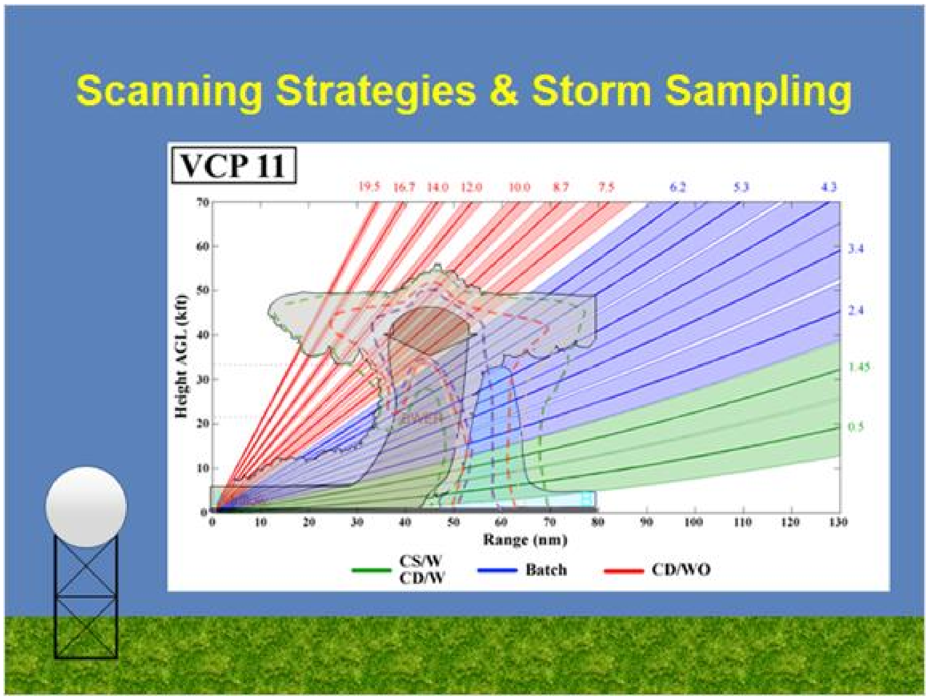
2.10 Scanning Strategies



Notes:

However, if we switch over to VCP 11, notice how those gaps in the upper levels are filled in with more elevation scans. So, different scanning strategies can lead to better or worse sampling. Be mindful of the scanning strategy you are choosing.

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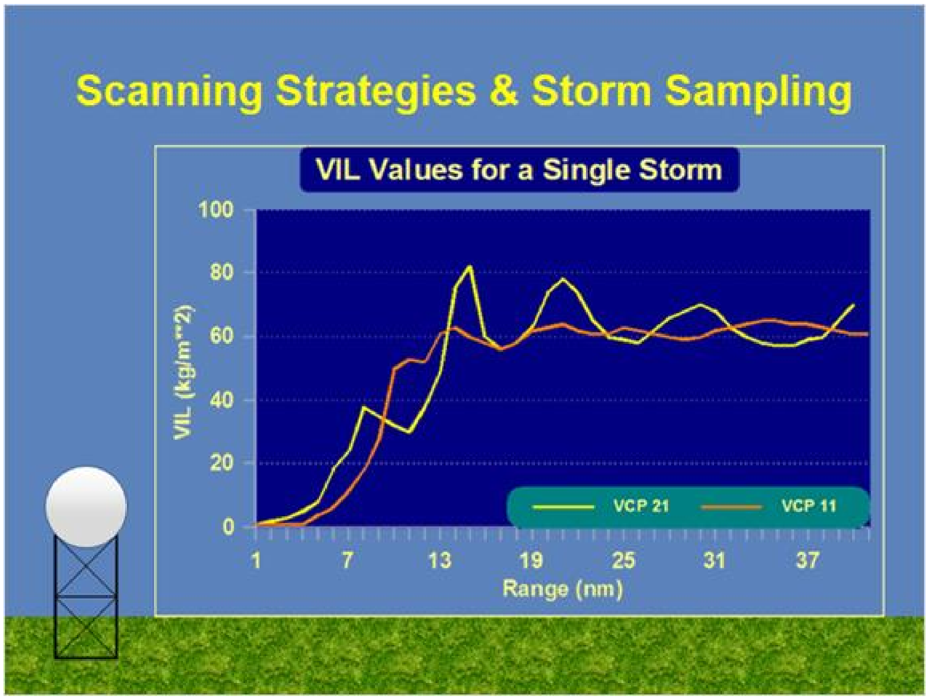
2.11 VIL Differences between Strategies



Notes:

Because sampling is affected by the scanning strategy you choose, so do the algorithm outputs. For example, here is a range plot of the VIL values for a single storm based on VCP 21 and VCP 11 scanning strategies. Notice how they are not the same. In fact, at some ranges, the difference between the two is quite large! Does this mean the storm is less intense because you chose a different VCP? Not at all! It’s just that the storm is not being sampled properly.

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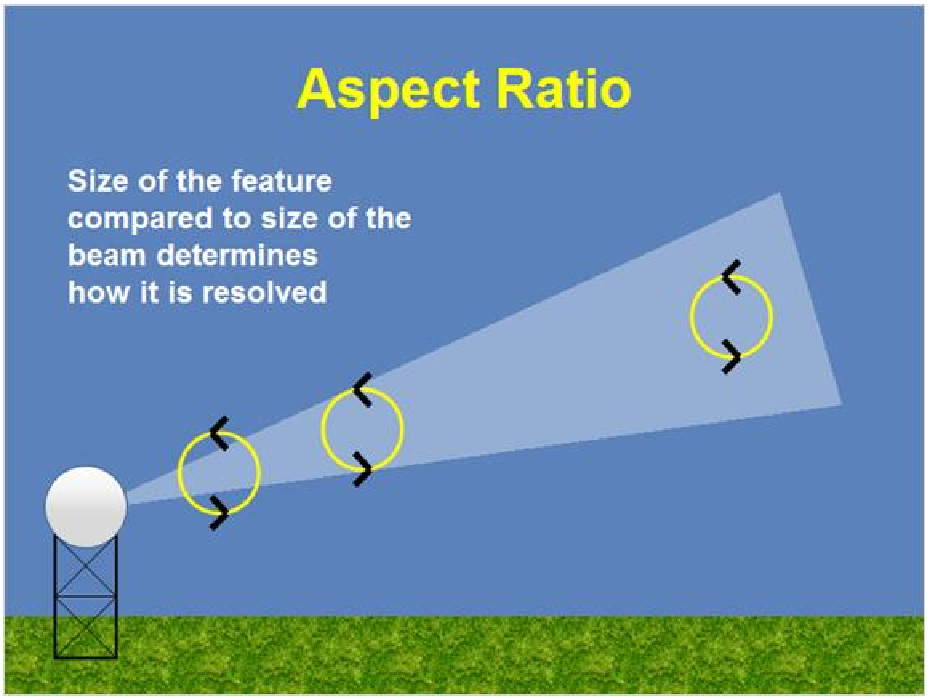
2.12 Aspect Ratio



Notes:

Because the beam spreads out as it propagates down range, a feature of constant size will appear differently at different ranges. The size of the feature compared to the size of the beam is called aspect ratio. How does it affect radar sampling issues? Take for example a circulation feature. At close range, multiple beams will sample the circulation and you'll get a detailed view. At medium ranges, the circulation will be roughly the size of the beam, and so you'll still get some detail, but not as much as if multiple beams are sampling it. At far ranges, only a portion of the beam is sampling the feature, and here you'll get very little detail and, in fact, the feature may not be resolvable at all. Basically, the farther away a feature is, the less impressive a feature will appear, and it will have less detail.

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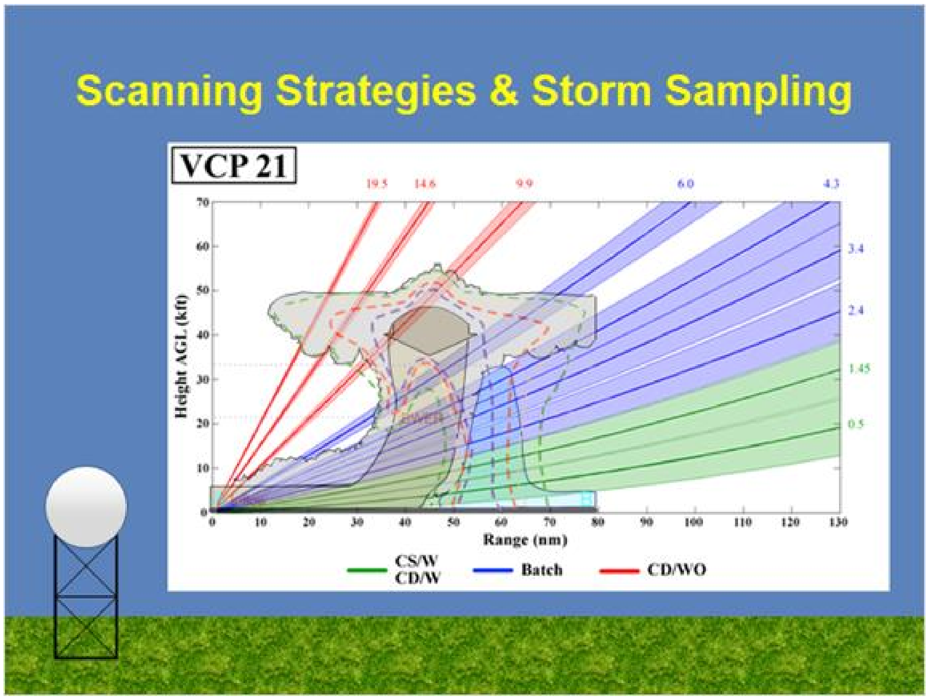
2.13 Scanning Strategies



Notes:

Suppose we have this supercell located down range of the radar. If we were to sample this storm using VCP 21, this is how the sampling would look like. Notice how near the low levels, sampling is such that there aren't many gaps. But, when we get to the higher elevations, there are significant gaps. In fact, some of the gaps are large enough that we possibly could miss some important features like the Bounded Weak Echo Region, etc. However, if we switch over to VCP 11, notice how those gaps in the upper levels are filled in with more elevation scans. So, different scanning strategies can lead to better or worse sampling. Be mindful of the scanning strategy you are choosing.

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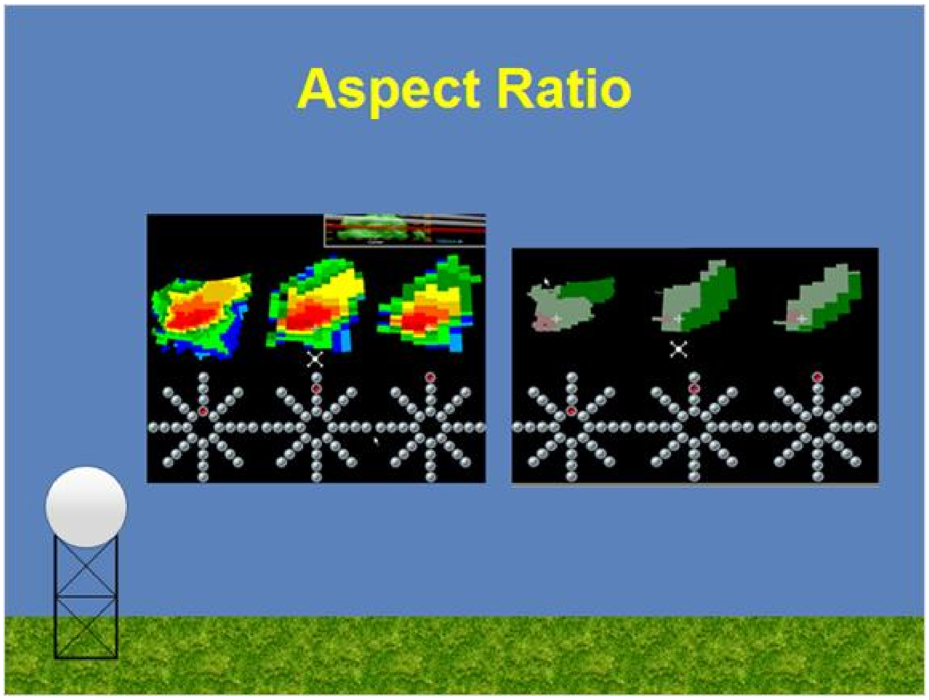
2.14 Aspect Ratio EXAMPLE



Notes:

Here is an example of a storm that is located south of 3 different radars. We'll take a look at the reflectivity and velocity images. The left image is from a radar located very close to the storm. The middle image is from a radar located at mid-ranges from the storm. And, the right image is from a radar located at far ranges from the storm. In reflectivity, notice the detail you see in the image on the left… a very nice reflectivity gradient to the southeast and pixel sizes are small. At mid and long ranges, the reflectivity appears a little more washed out and blocky. Granted, the radar beam is at different heights for each case, and we'll get to that next. But, for now, just pay attention to how the storm just looks different and maybe a little less intimidating at the mid and far ranges, than the close range. For the same storm, toggling over to velocity shows the same pattern. There is a good circulation noted in the radar closest to the storm, but the farther ranges either detect much weaker circulation.

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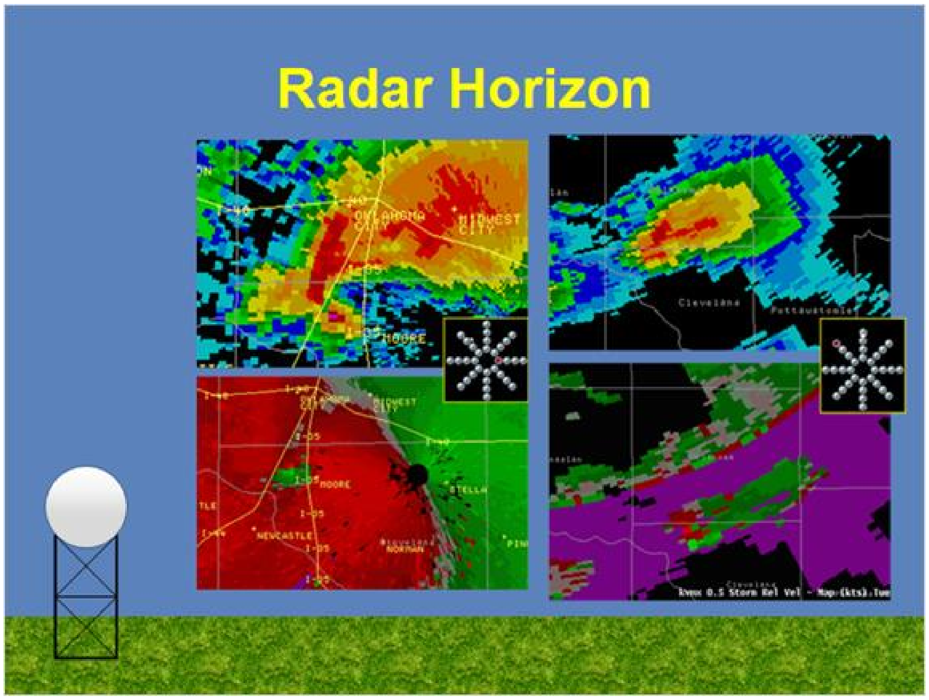
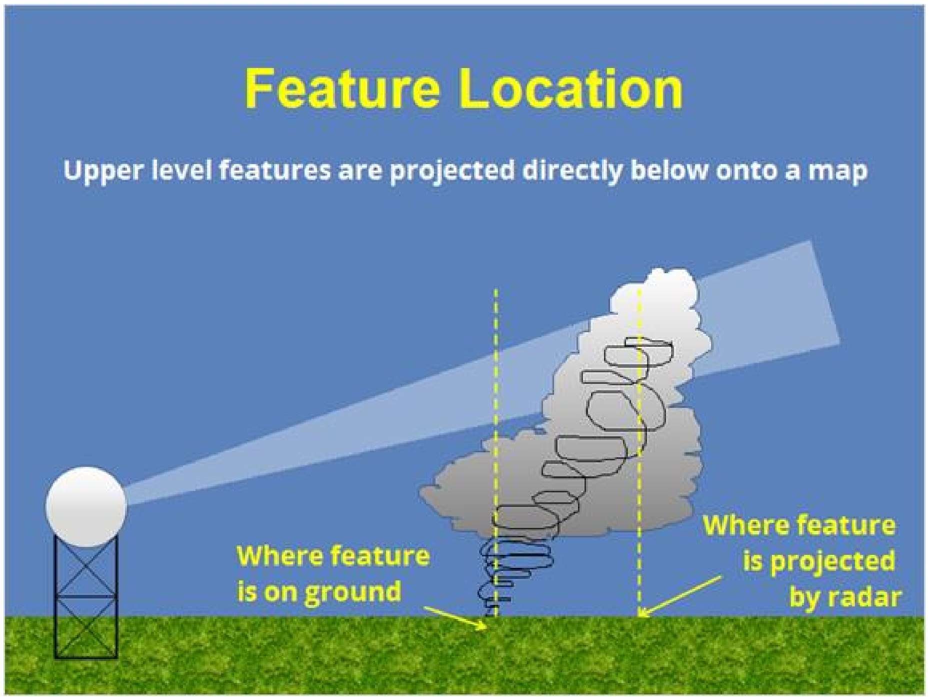
2.15 Radar Horizon EXAMPLE



Notes:

Here is a supercell thunderstorm producing a tornado moving through a major metro area. The two images on the left are from a radar to the east that is very close to the storm. The image on the right is from a radar farther away to the northwest. Notice how on the left, you can see fine-scale features in the reflectivity and velocity, but from the radar to the northwest, you aren't seeing these features. This is because the beam from the radar to the northwest is overshooting these low-level features. Therefore, if low-level features are your primary concern, then make sure you keep this limitation in mind and look for the closest radar.

2.16 Feature Location



Notes:

As we've mentioned before, the radar beam progressively gets higher and higher as the range from the radar increases. However, when we look at radar images on a screen, we are projecting these features onto the ground directly below. Since there is often a tilt to features such as circulations associated with tornadoes, or the decent of hail cores translates horizontally, when we detect features aloft, this usually means it is not going to happen at the surface in the exact location we have projected it on a map. Look at this illustration of a tornadic circulation. The beam intercepts this circulation near the top of the storm, so when it is projected onto a map, it shows this circulation happening over this area on the ground. However, the actual circulation is occurring below the radar beam on the ground in this location. Therefore, be careful with how much preciseness you infer from the circulation you see on radar.

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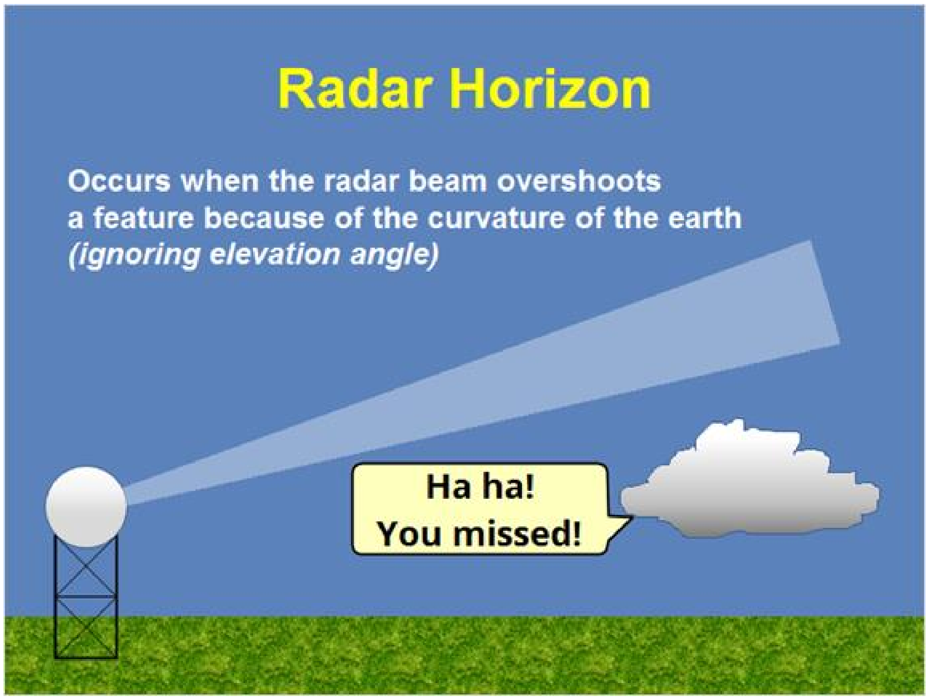
2.17 Radar Horizon



Notes:

Recall as the beam propagates away from the radar, the earth's curvature causes the beam to become higher and higher off the ground (beyond the rise due to elevation angle). This basically means low level features far from the radar will not be seen by radar. Therefore, you will either have to switch to a closer radar, or draw conclusions based on the information you do have. Let's look at an example.

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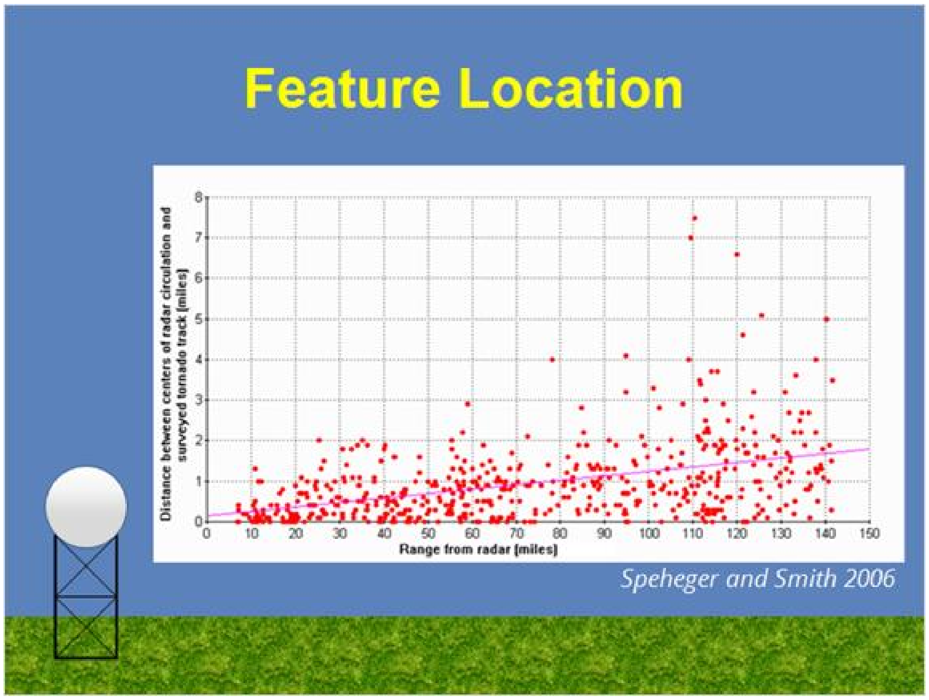
2.18 Feature Location EXAMPLE



Notes:

This study by Speheger and Smith (2006) shows just how far a radar identified circulation exists relative to the actual circulation on the ground. Near the radar, roughly within 50 miles, the error will be small (< 2 miles). However, once you get further away from the radar, these errors can become as large as 7-8 miles! Therefore, be careful with how exact you portray features on radar with where they are occurring on the ground.

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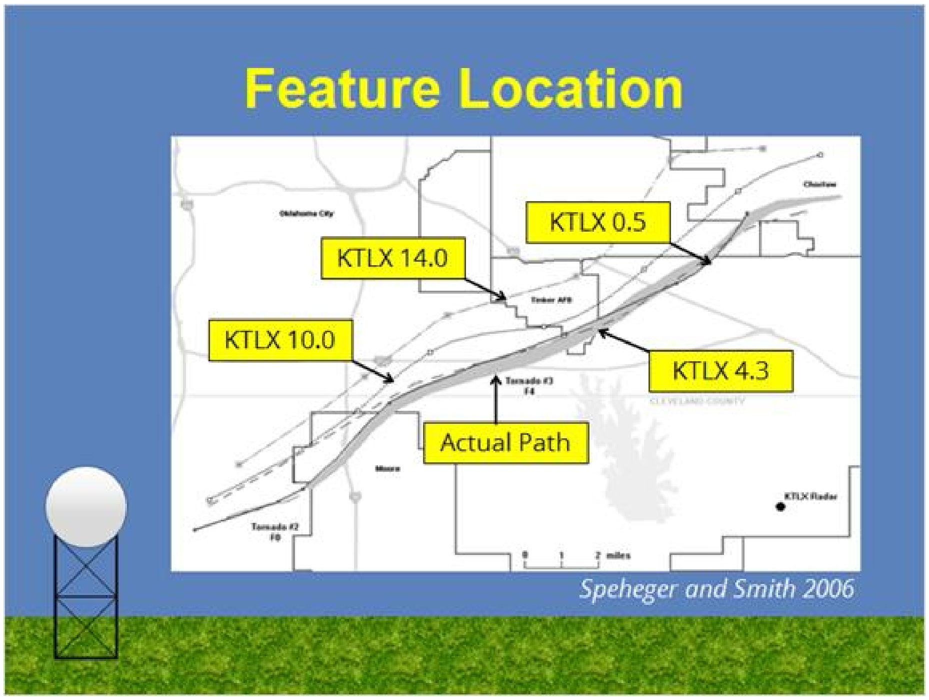
2.19 Feature Location EXAMPLE 2



Notes:

Here's an example of how elevation angle can also affect feature location. This is also from Speheger and Smith (2006). Notice how the radar identified circulations as you go higher and higher up do not coincide exactly with the actual path. Therefore, always be careful assuming a ground location when looking at radar data, especially in the upper levels.

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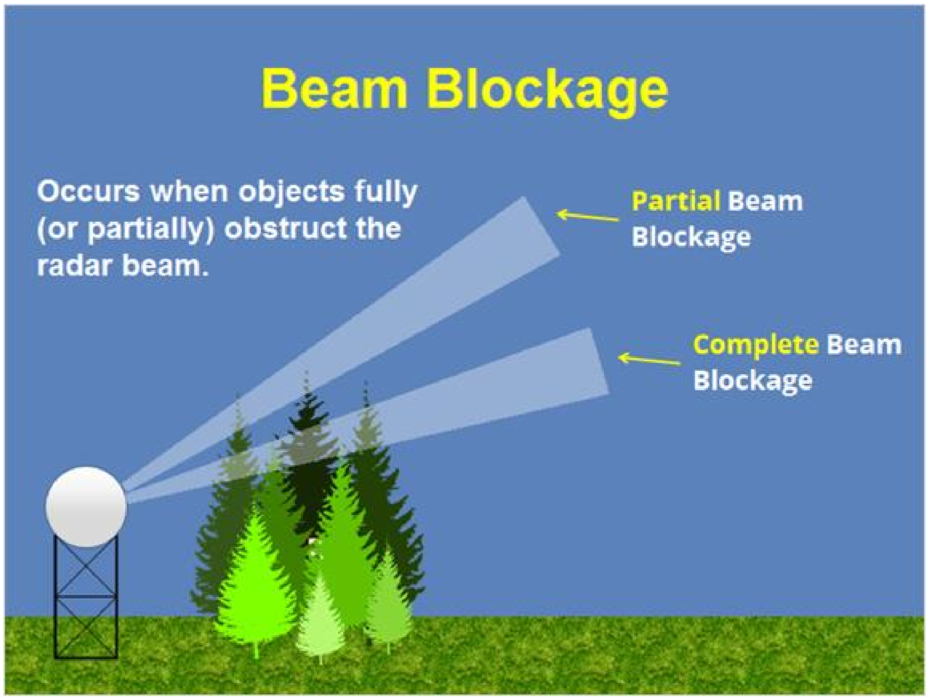
2.20 Beam Blockage



Notes:

When tall objects reside near the radar, they can obstruct the beam and cause the power loss to either be great enough that no features in that line of sight will be visible on radar, or the power returned by the features in that line of sight are much weaker than they would be in the obstructing objects were not there. These objects can be anywhere from trees across the street to giant mountain ranges. In this example, the lower beam is experiencing full beam blockage where the upper beam is experiencing partial beam blockage.

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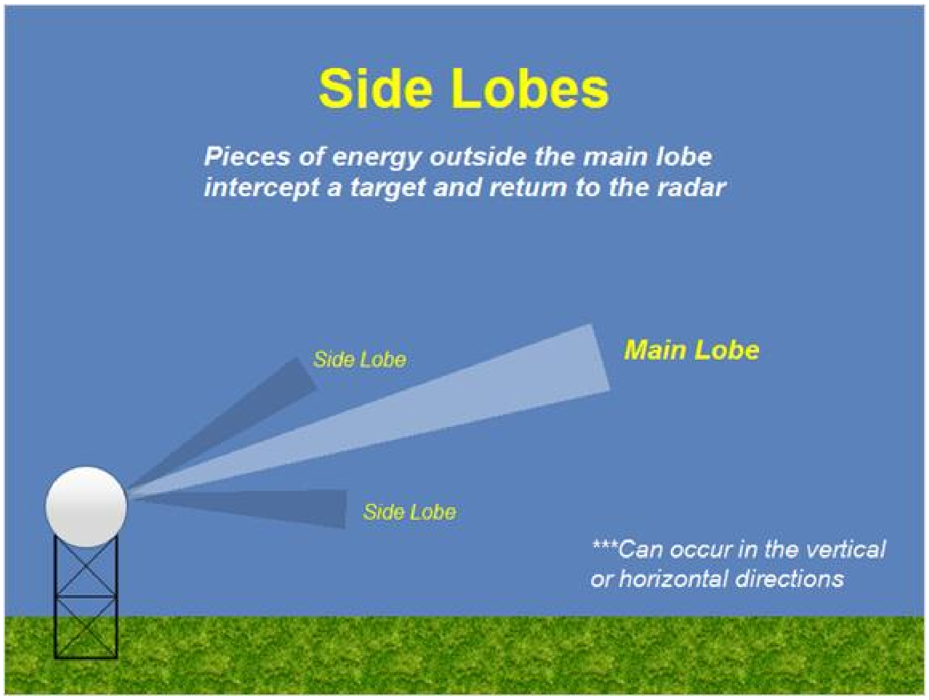
2.21 Side Lobes



Notes:

Recall from the previous section of this topic that there are pieces of energy from the transmitter that exist outside the main lobe that can intercept targets and return power to the radar and show up on your display. These side lobes can occur in the vertical and horizontal. Most of the time, the main lobe is sampling something at the same time the side lobe is sampling another target and the power return from the main lobe dominates, but in some instances, the main lobe will be sampling nothing and the side lobe returns dominate. Let’s briefly look at some examples…

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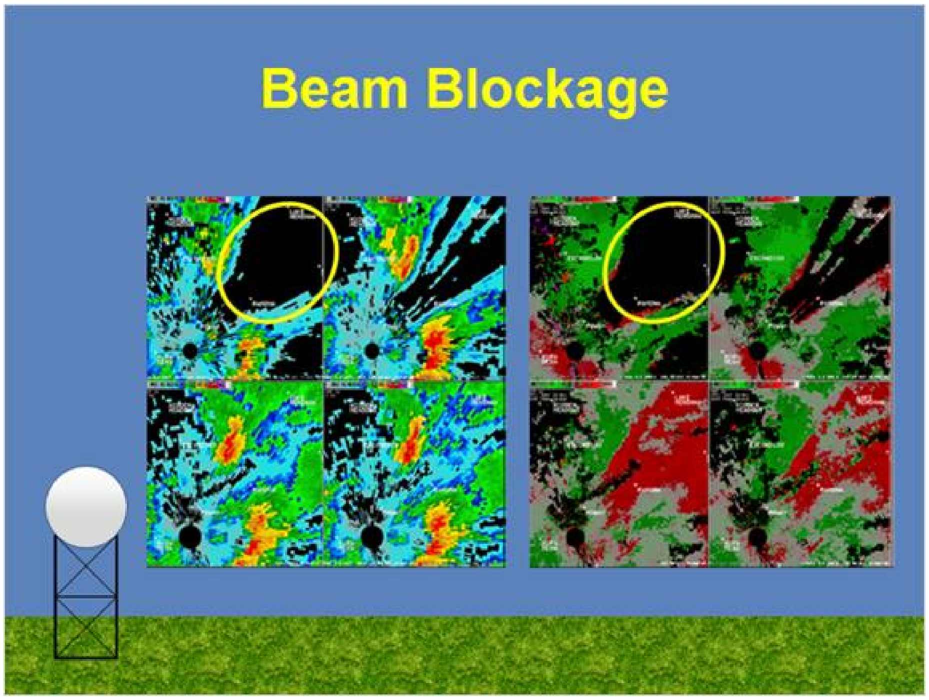
2.22 Beam Blockage EXAMPLES



Notes:

Here is an example of beam blockage from a nearby radar. The lowest elevation angle (top left of both images) shows a data gap to the northeast of the radar. Does this mean there are no storms in this area? No! This area is blocked by a nearby obstacle. And the obstruction is powerful enough to completely block the beam. In this particular example, the beam blockage was blocking a tornadic signature in the lower levels. Aloft (lower two panels), you can see there is a storm there with rotation.

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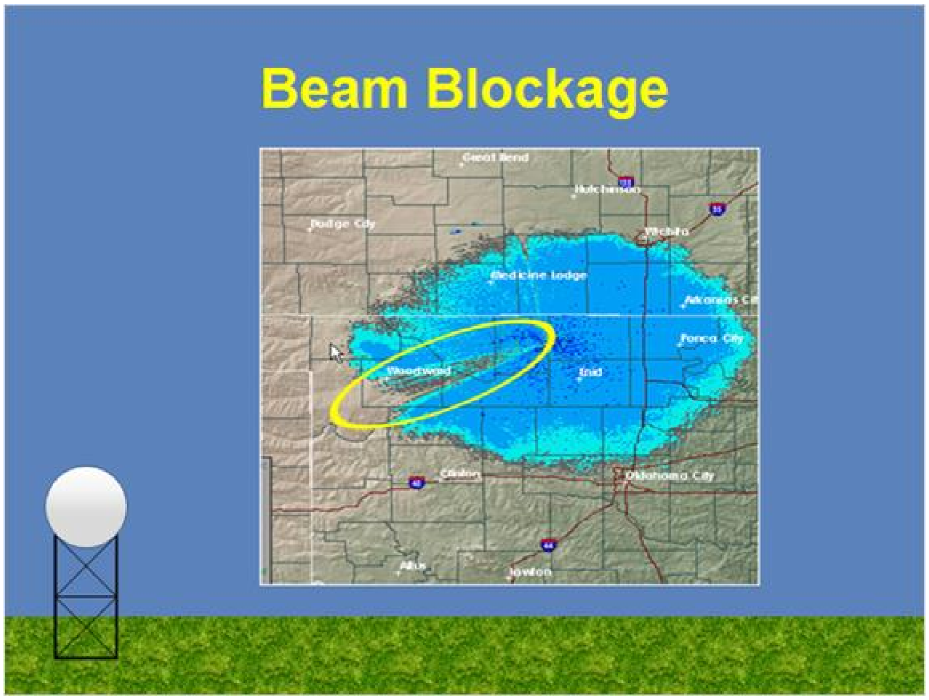
2.23 Beam Blockage EXAMPLES



Notes:

In this example, there is no complete beam blockage at the lowest level, but there is obviously some partial beam blockage. In instances like this, it is good to remember this because in these areas, you will get returns, but they will be weaker than reality. Therefore, you will need to mentally adjust your expectations.

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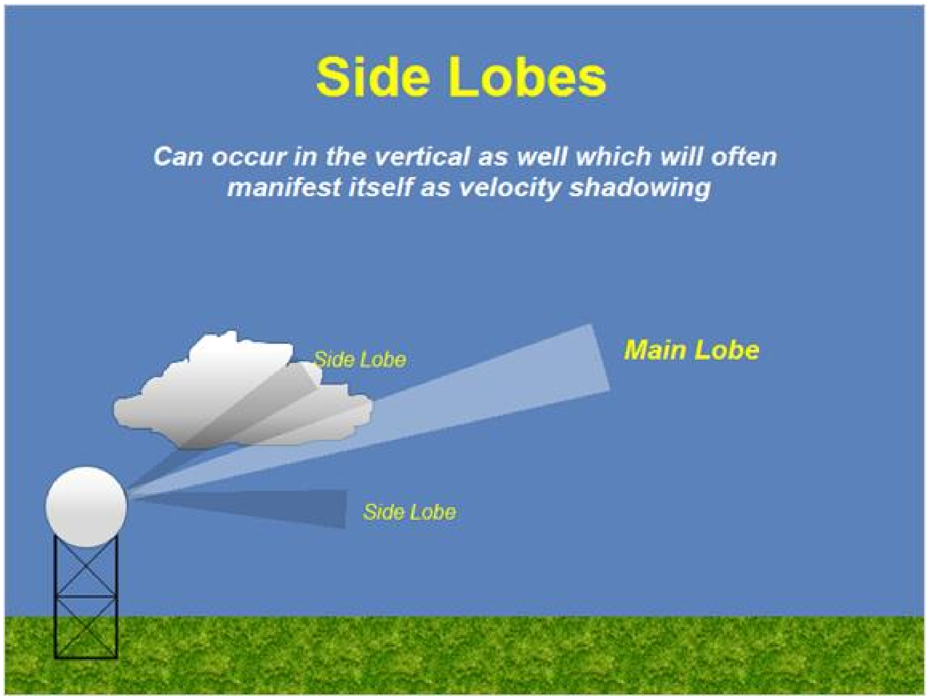
2.24 Side Lobes EXAMPLE 2



Notes:

The last example of side lobe contamination was in the horizontal. However, side lobes exist in the vertical as well. The most common scenario where you will see the effects of side lobe contamination is when the main lobe is sampling the low levels, but the side lobe is sampling a fairly intense overhang. However, the reflectivity will not be the prominent feature, but rather the velocity signature. This is often called the velocity shadow. What happens is the velocity signature from the overhang is pretty much superimposed in the low levels. This can lead to spurious velocity couplets.

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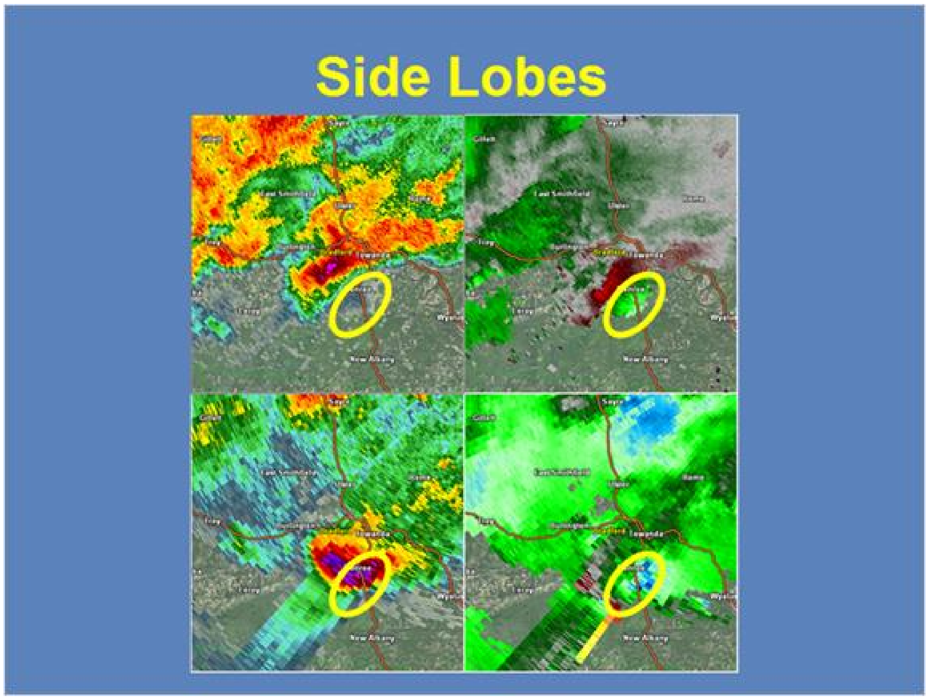
2.25 Side Lobes EXAMPLE 2



Notes:

Here is an example. The top two images are the low level reflectivity (left) and velocity (right). Notice the intense inbounds well away from the core and near the core there are moderate outbounds which make it appear as though there is rotation. However, stepping up in elevation, there is as strong core directly above with very strong inbound velocity. These strong inbounds aloft are basically being superimposed below because of side lobe contamination. Therefore, be aware of this limitation when viewing velocity values in weak signal areas.

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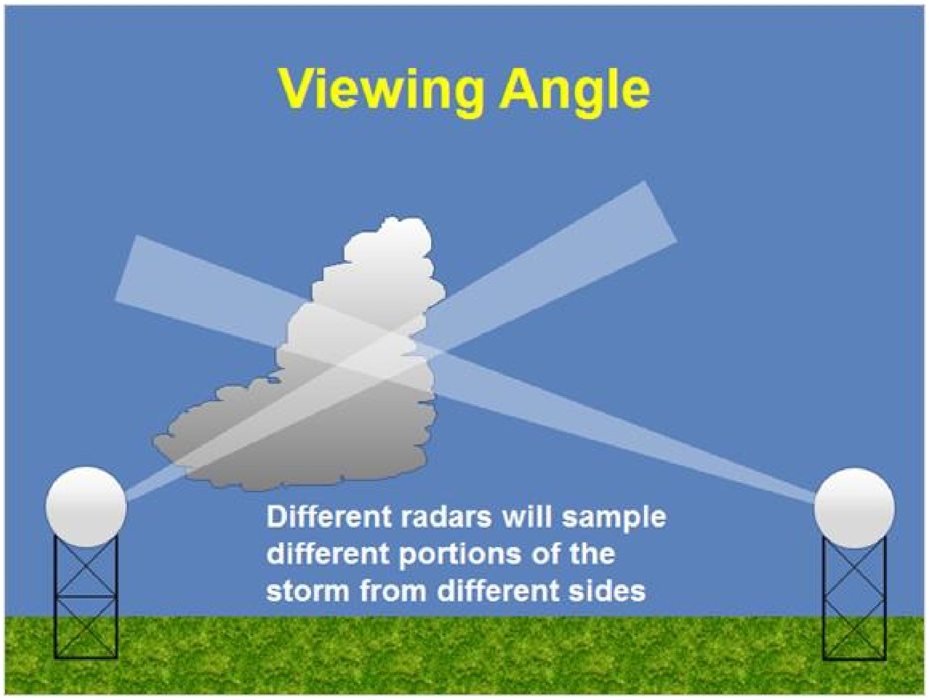
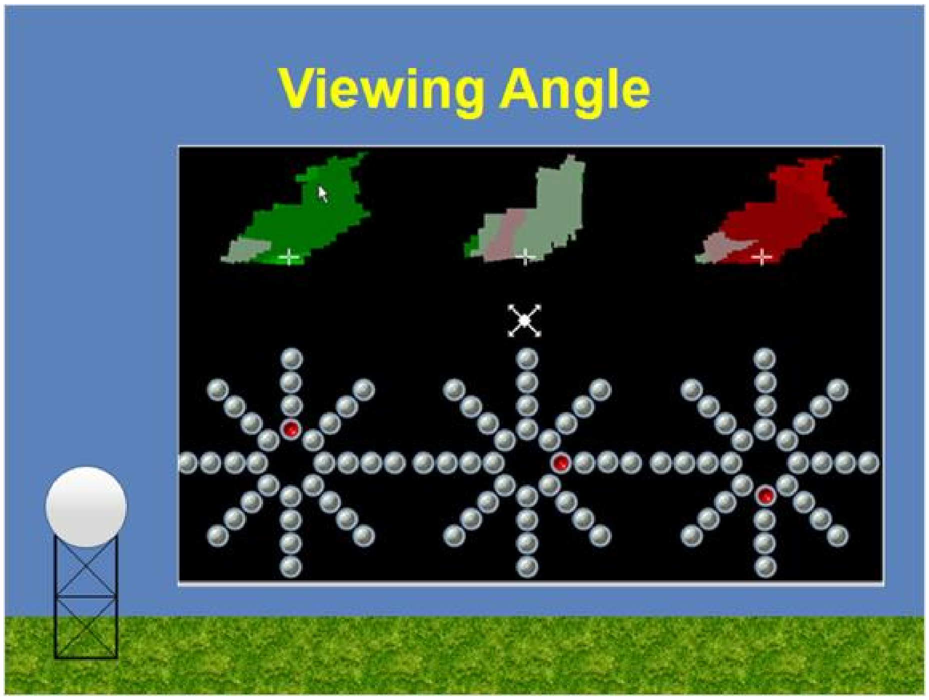
2.26 Viewing Angle



Notes:

Since the radars are somewhat close together throughout most of the US, there are some areas where storms will be sampled by multiple radars. Because storms are not symmetrical in the least bit, getting different views of the storms may be helpful, but this viewing angle can cause some problems such as masking circulations or missing three-body scatter spikes. Let's look at a few examples…

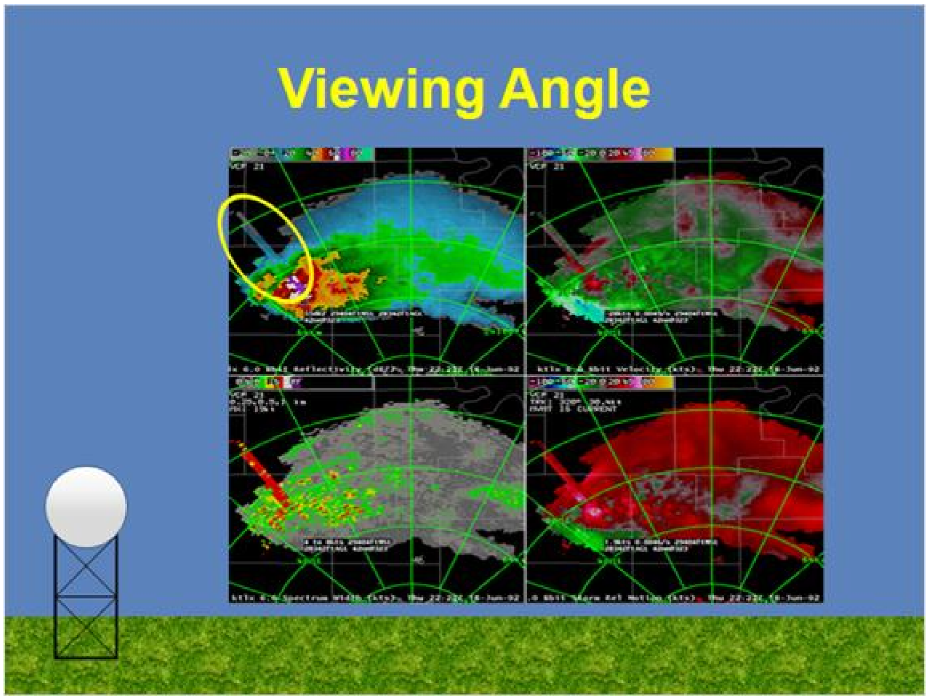
2.27 Viewing Angle EXAMPLE



Notes:

Recall that if the wind is blowing down the radial, you measure all of it. If it's blowing perpendicular to the radial, you measure none of it. Usually it's somewhere in between. This image shows the same radial velocity data when viewed from 3 radars, one north of the echo, one east of the echo, and one south of the echo (the echo is assumed to be in the middle of the "grid" of radars). Notice how the interpretation of the wind field changes with the radar you choose while the actual wind field is not changing. Therefore, keep in mind where your radar is located, and switch radars if you can to get a better look, especially when looking at velocity signatures.

2.28 Viewing Angle EXAMPLE



Notes:

While the velocity is often the victim of viewing angle issues, reflectivity is not immune. Recall the three-body scatter spike (TBSS) is a feature seen in reflectivity that is often down radial of significant hail cores. Here is an example. Notice the TBSS to the northwest of the storm. If another storm was located in this area, the TBSS may be obscured by that storm, but could be visible if the storm was sampled by a radar in a different location. Also, TBSS tend to mess up velocity estimates and TBSS can sometimes occur within the mesocyclonic region, so if a radar beam passes through the hail core first and then into the mesocyclone area, then there could be some potential issues. Therefore, keep viewing angle in mind when looking at velocity and reflectivity signatures.

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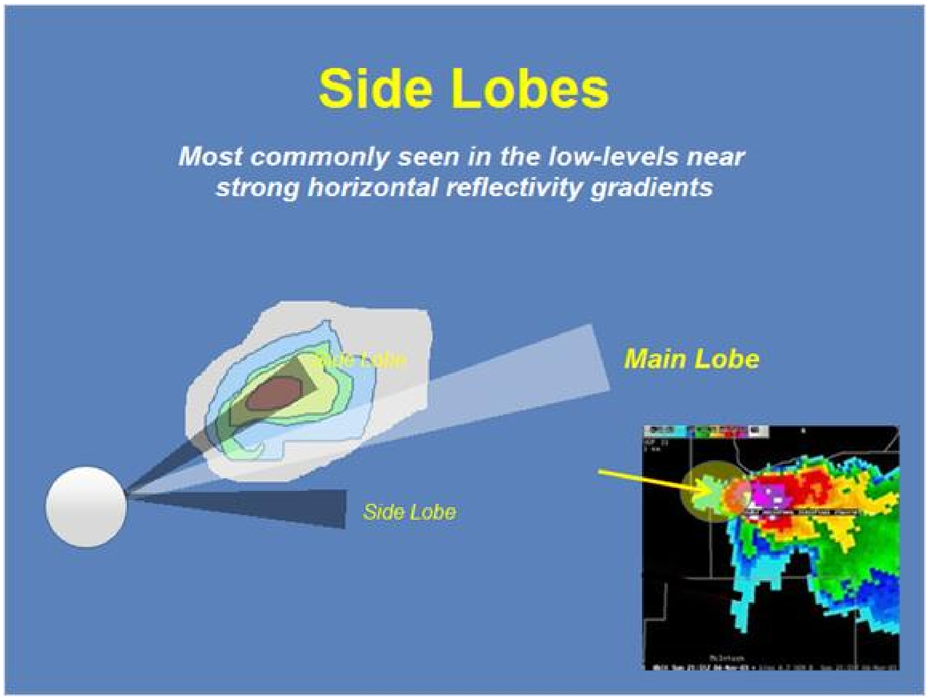
2.29 Side Lobes EXAMPLE



Notes:

Here is a typical conceptual model of a supercell thunderstorm. Once the main lobe passes by the core of the storm, the side lobe samples the core while the main lobe is sampling very low returns. Because the signal returned to the radar is dominated by the side lobe returns, that is the signal processed by the radar. However, because the radar thinks the return came from the main lobe, it places this return where the main lobe is sampling, which is just off to the side of the core in the clockwise direction. So, side lobe contamination will show up as weak reflectivity just to the side of a core. Here is an example of side lobe contamination. The main lobe has passed by the main core and is sampling clear air, but the side lobes are still picking up the main core. So, there is return power at the radar from the side lobes that is dominating the signal but because the main lobe is off to the side, that is where the radar is thinking the power is coming from.

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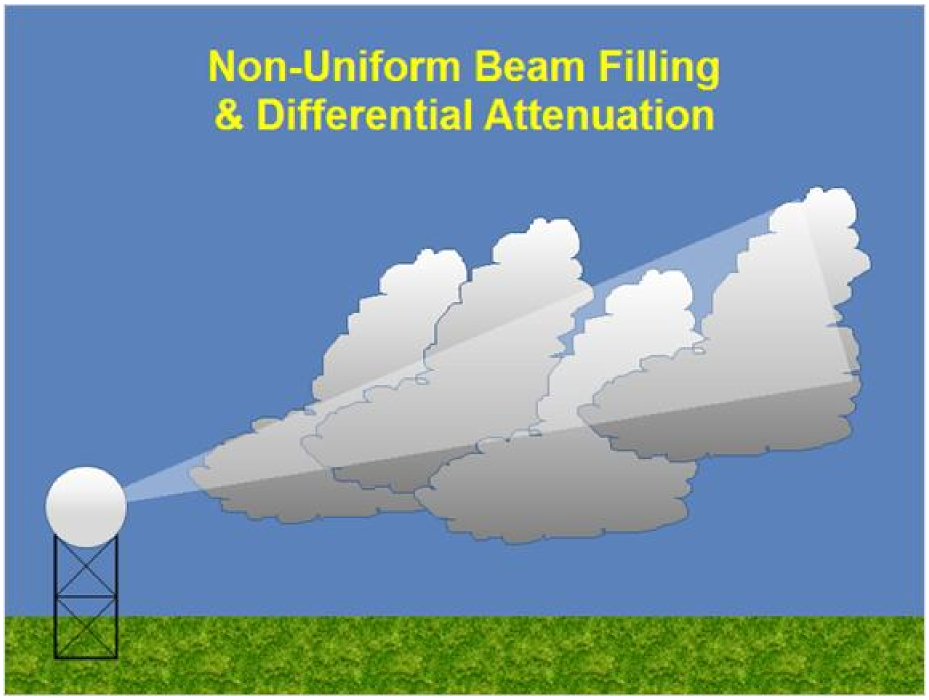
2.30 Non-Uniform Beam Filling

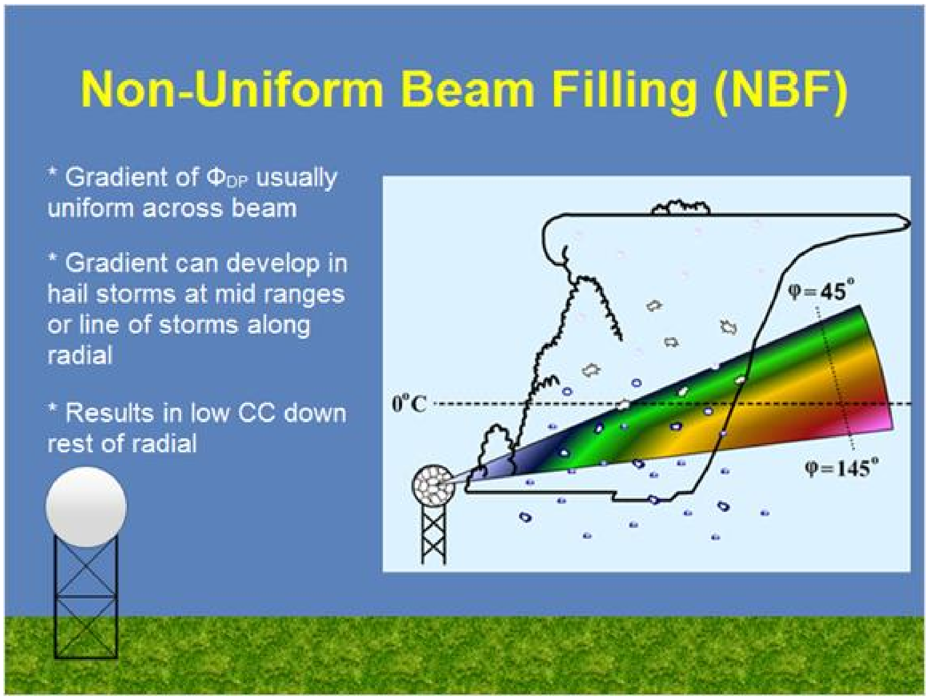
& Differential Attenuation



Notes:

The last two sampling issues we'll look at primarily impact the dual-pol variables of correlation coefficient and differential reflectivity. These two issues are non-uniform beam filling and differential attenuation. As you'll learn soon, these two sampling issues often occur together, but are caused by completely different processes. The most common situation where both of these occur are in very heavy cores with hail present, and when storms align along a radial. So, let's take a look at both of these issues a little more…

2.31 Non-uniform Beam Filling



Notes:

Most of the time, the gradient of precipitation across the beam is such that differential phase shifting is fairly uniform across the beam. However, with hail storms at mid ranges from the radar, the beam can experience little phase shifting at the top of the beam where it is sampling hail, but have large phase shifting at the bottom of the beam where it is sampling rain. You'll learn more about phase shifting later in this topic, but for now this will suffice. This large gradient of phase shifting across the beam causes the correlation coefficient to be reduced and this effect is seen down the rest of the radial. So, NBF is often noted where low CC is noted from the source of the NBF all the way down the radial. Another common place to see the NBF effect is when a long line of storms align along a radial. Let's look at a couple examples…

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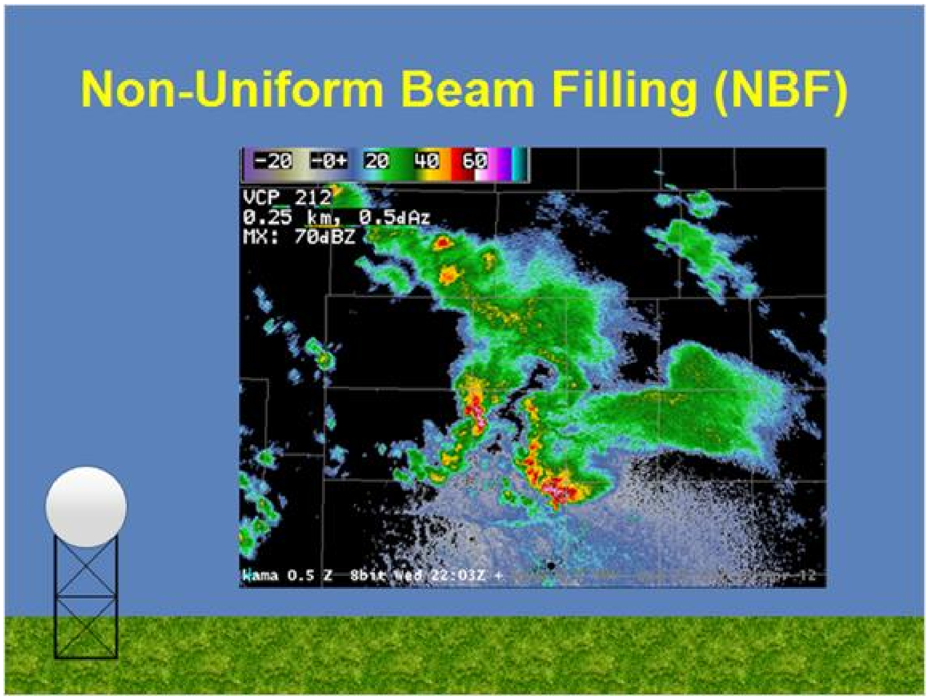
2.32 NBF Example



Notes:

Here is an example of some storms that are causing non-uniform beam filling (NBF) issues. Can you determine which ones are causing issues?

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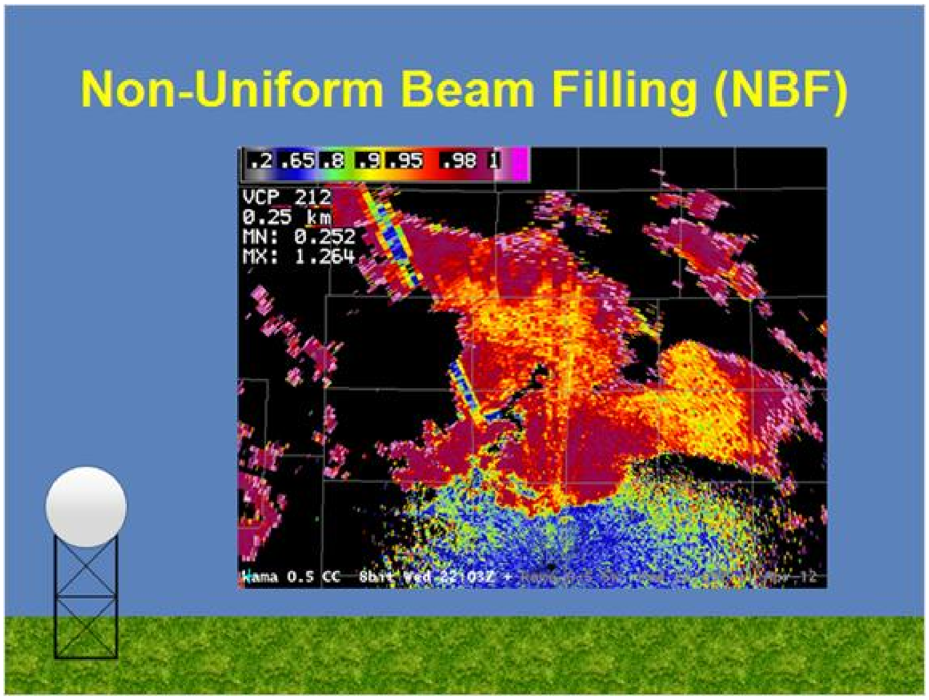
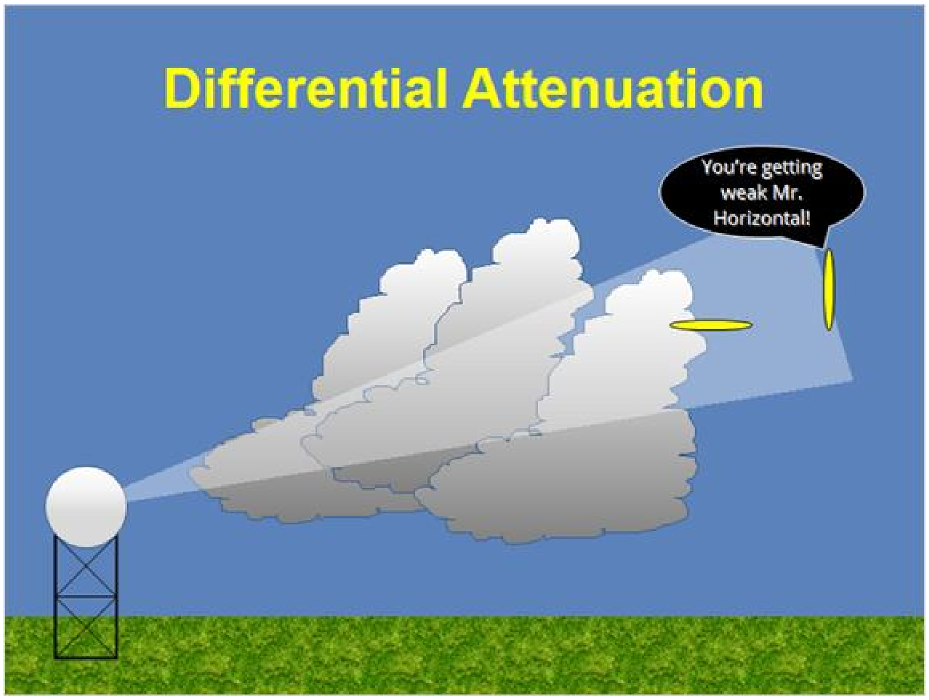
2.33 NBF Example



Notes:

Let's look at the CC product and see if that helps… Better, worse, about the same? Hopefully you said better :) The storm to the northwest is experiencing significant NBF issues and that is evident by the significant drop in CC from where the hail storm is residing all the way down the rest of the radial. The other storm causing issues is just to the north of radar. While the CC drop is not as prominent, there are noticeable drops.

2.34 Differential Attenuation



Notes:

As the two polarizations propagate through the atmosphere, they usually attenuate (or slow down/get weaker) at the same rate because S-band radiation usually does not attenuate much in weather. However, there are some instances where horizontal pulses will attenuate quite a bit, but the vertical pulses will not. This is usually near storms with very heavy rain/hail cores, or when many storms align along a radial. In these instances, the vertical pulse will not slow down/get weaker nearly as much as the horizontal pulse. As a result, when differential reflectivity is computed in areas of differential attenuation (which is the horizontal power return minus the vertical power return), you get a slightly lower value because the vertical is stronger than the horizontal. And many time, these values go negative. Let's look at an example…

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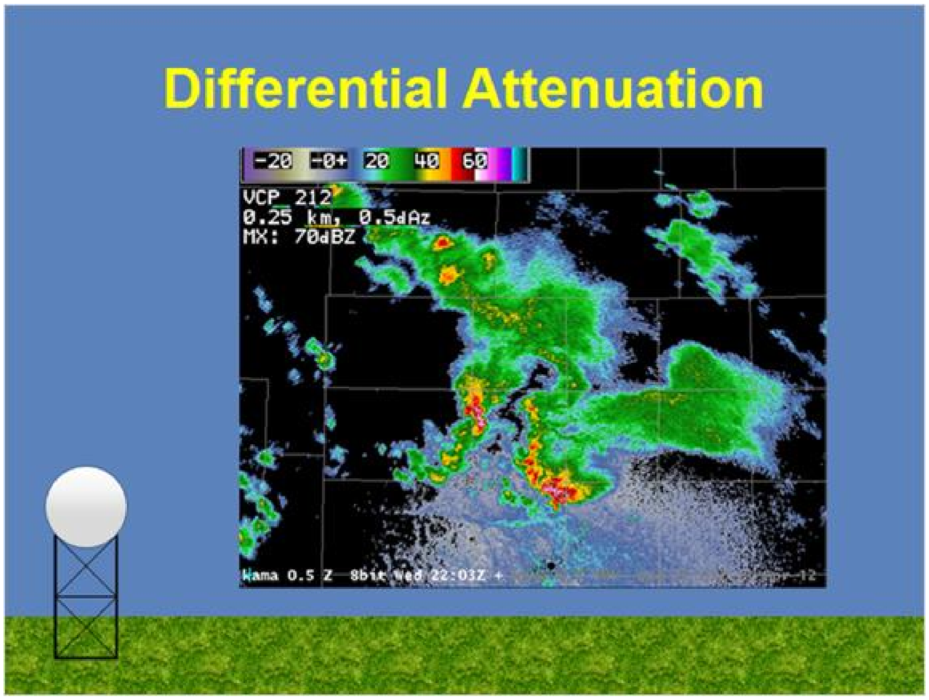
2.35 DA Example



Notes:

This example ought to look familiar :) This is the NBF case, so why I am I showing it here? Because most NBF situations also cause differential attenuation. Look downstream of the two storms we noted before. We don’t see a noticeable change in the horizontal reflectivity even though there is probably some attenuation happening in the horizontal channel.

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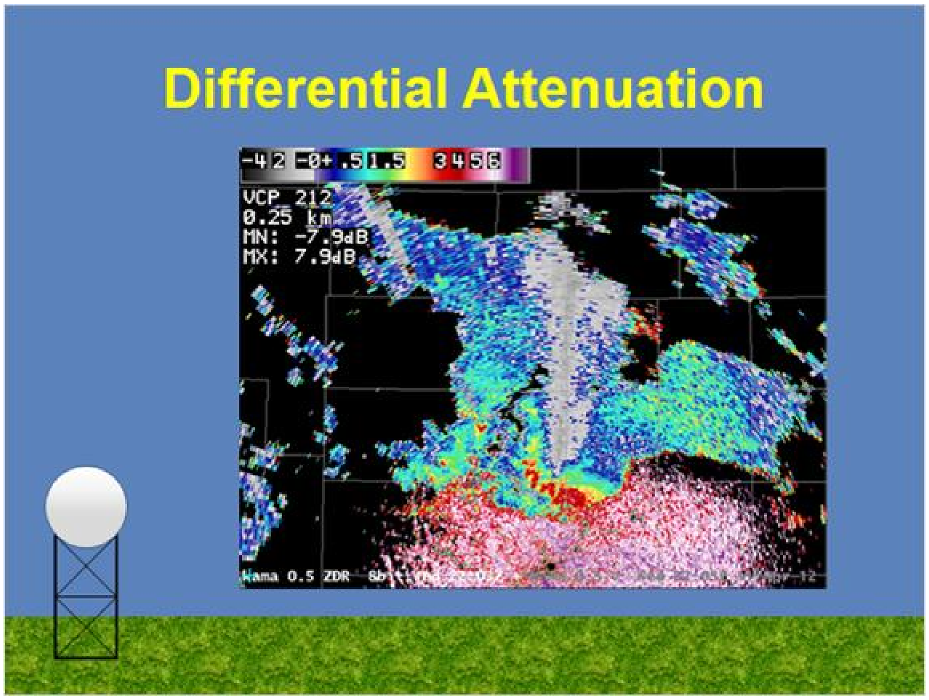
2.36 DA Example



Notes:

However, look at the ZDR product… Behind both of these heavy rain/hail cores, we see significantly lower ZDR values down the rest of the radial. This is the result of differential attenuation.

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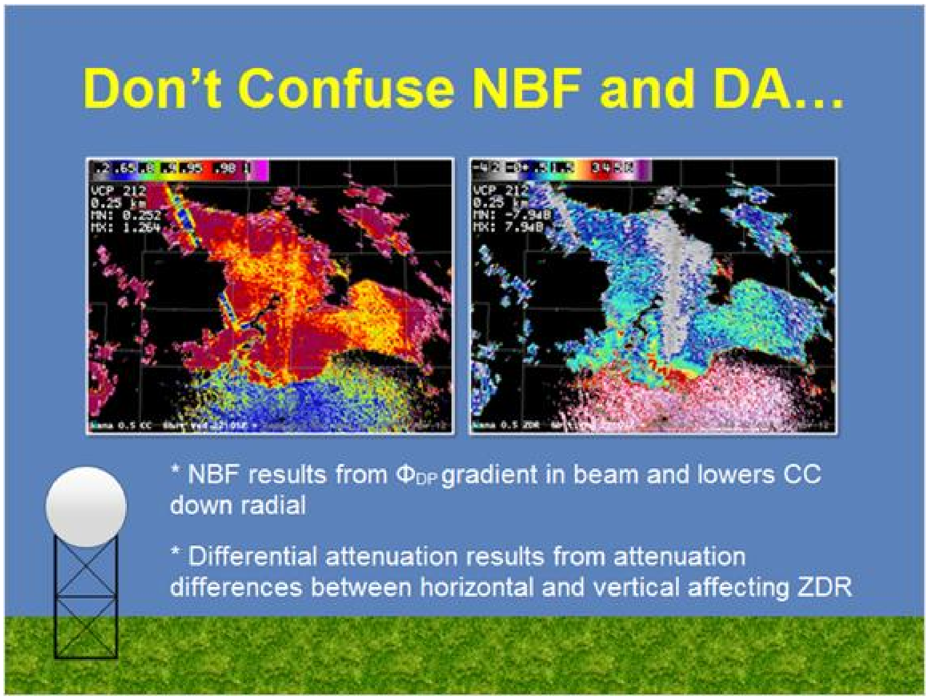
2.37 NBF/DA Differences



Notes:

So I alluded to this before, and I'll state it here again. NBF and differential attenuation often occur in the same situations (heavy hail/rain cores or storms along a radial), but they affect different variables for different reasons. NBF results from a PhiDP gradient within the beam and lowers CC the rest of the radial, and differential attenuation results from attenuation differences in the horizontal and vertical causing ZDR to become lower than expected.

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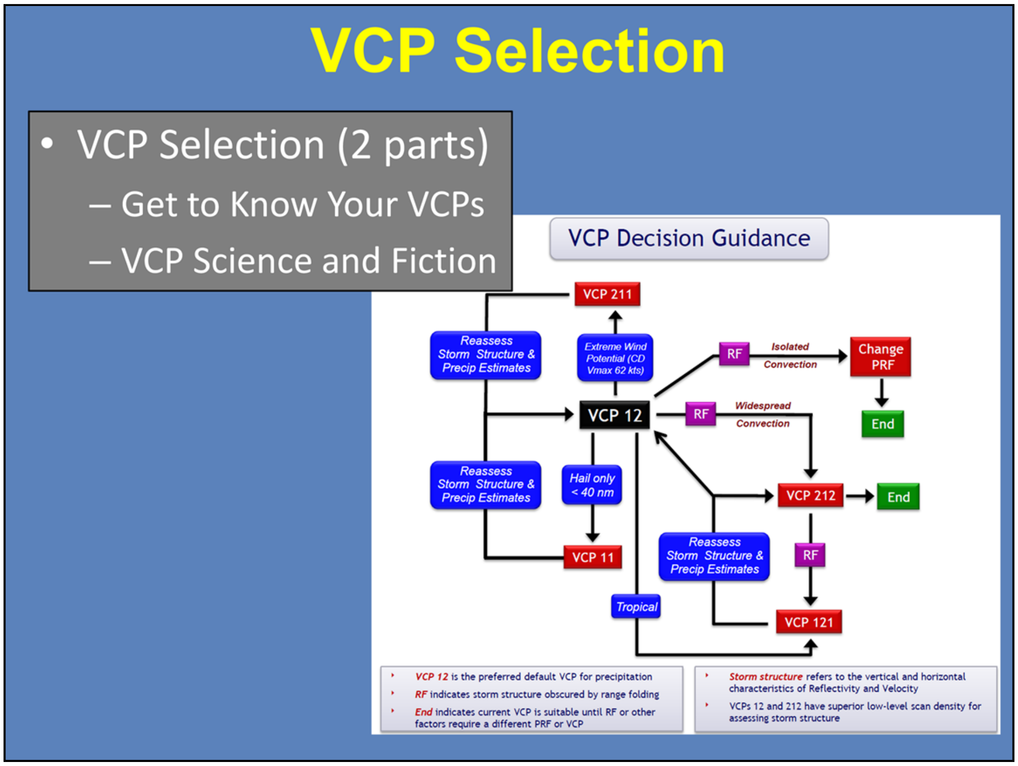
Welcome to Topic 2’s lesson on VCP Selection training, with a little bit of VCP fact or fiction built-in, but this is get you familiar with all the VCPs the Doppler Radar has to offer, so you’ll be equipped when you need to make some choices.



In this lesson on VCP Selection, we will cover the two main parts we want to address in the VCP decision-making process. First, you have to know your VCPs, what their strengths and limitations are – and how they compare to one another. Then, we'll spend some time debunking some VCP myths or fiction in this case, with science. Armed with those two, you should be able to choose the right VCP for the right situation.

Get to Know Your VCPs
Objectives

1. Identify distinguishing characteristics of each VCP, such as vertical sampling, editable Doppler PRFs, or range unfolding techniques.

2. Identify the newer software-based features that enhance current VCPs function better for real-time meteorological situations.

For this lesson's objectives, we'll split it into two slides, with this one showing the learning objectives for getting to know the individual VCPs, their strengths and limitations, and how they compare to one another.

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VCP Science and Fiction Objectives

1. Identify the difference between normal wear and tear vs. excessive wear and tear.
2. Identify the impact of the NEXRAD Technical Requirements on antenna system wear and tear.
3. Identify the two characteristics of antenna motion that contribute to wear and tear.
4. Identify best practices that enable use of all the VCPs with minimum stress to the system.
5. Identify the benefit of VCP 31 in clear air or light precipitation events.
6. Identify the impact of faster VCPs on rainfall estimation.

Here are the learning objectives for VCP Science and Fiction. Notice that the first four focus on VCP choice and how it relates to wear and tear on the WSR-88D hardware, which has been a significant concern with the introduction of the faster VCPs. The remaining objectives address the use of VCP 31 and the impacts of faster VCPs on rainfall estimation.

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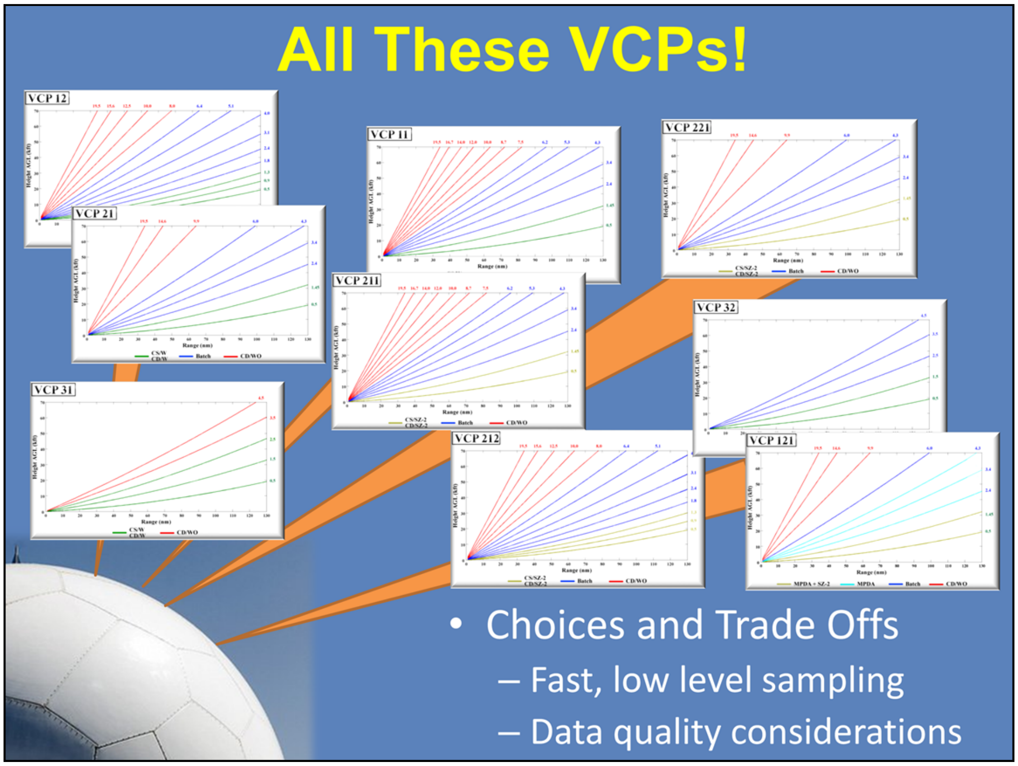

Currently, there are nine different VCPs to choose from, which has evolved over the past couple of decades with from changing needs and derivative capabilities of older VCPs. Your choices involve trade offs, such as the benefits of fast, low level sampling vs. the impact on data quality of fewer pulses per radial. We'll try to demystify the options you see here, showing some advantages and disadvantages of each.

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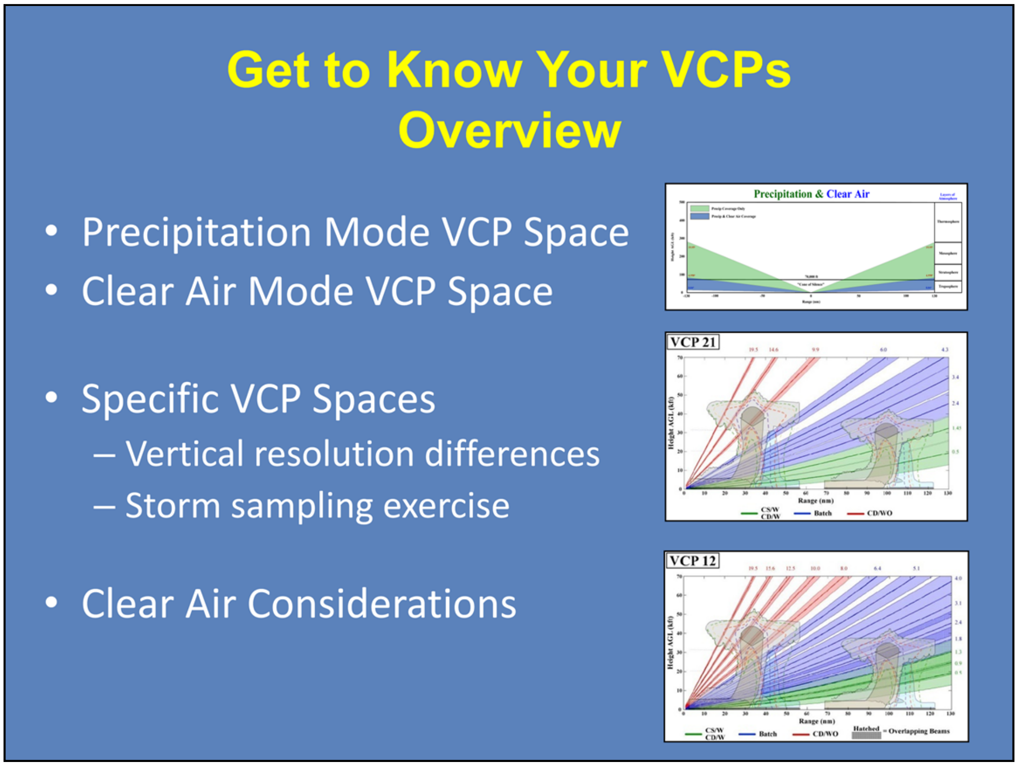

To set the foundation for getting to know your VCPs, we'll start with the atmospheric space that Precipitation Mode and Clear Air mode sample. Then the space sampled for each of the VCPs is presented, along with animations of the angles used during a volume scan. These animations will help you to visualize the elevation angle spacing for the different VCPs. Just from the two still images on this slide, look at the differences between VCPs 12 and 21 with respect to mid and upper level sampling of a storm at close range. Then, we'll close out with some outside the box thinking for our two Clear-Air mode VCPs.

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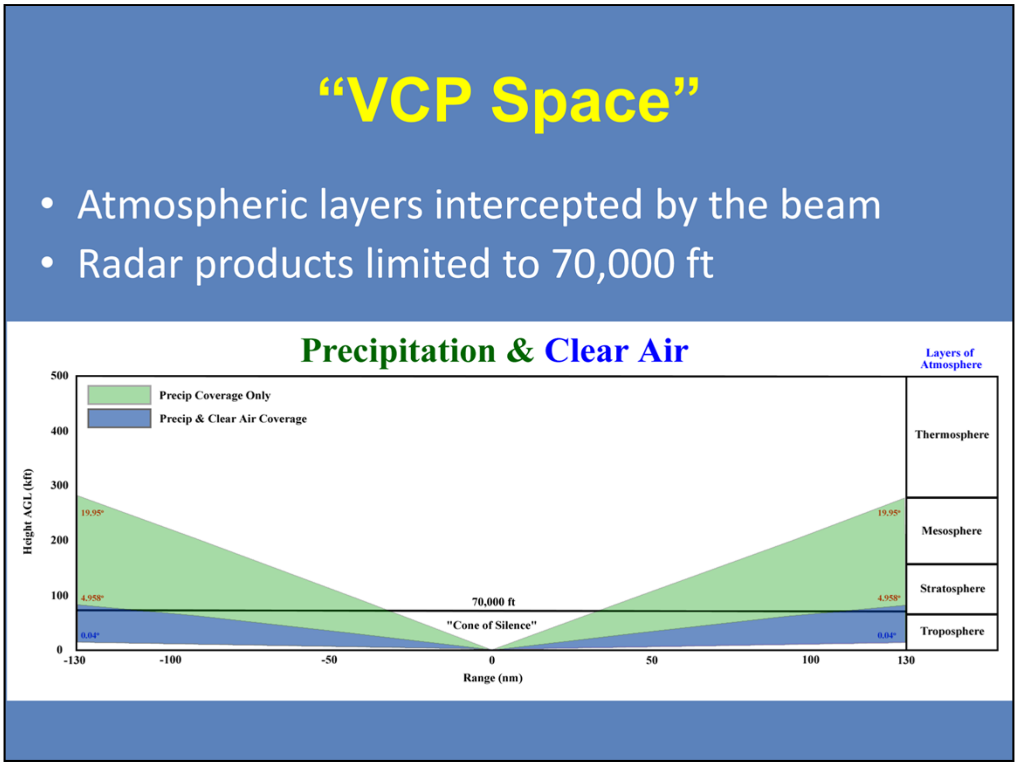
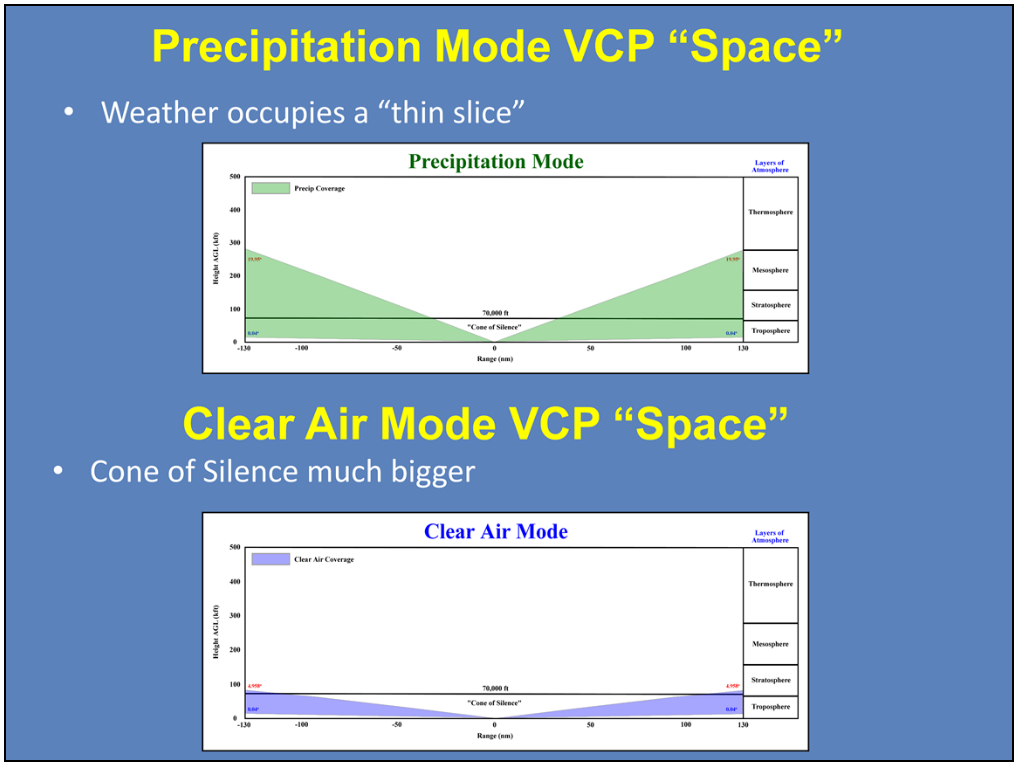
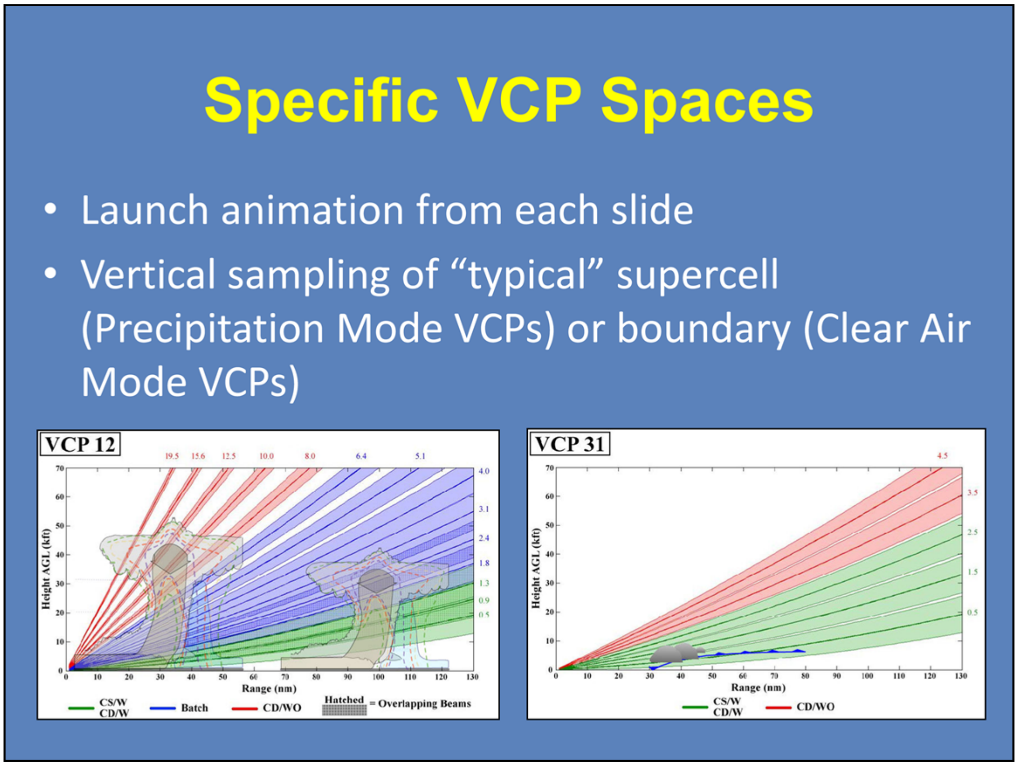


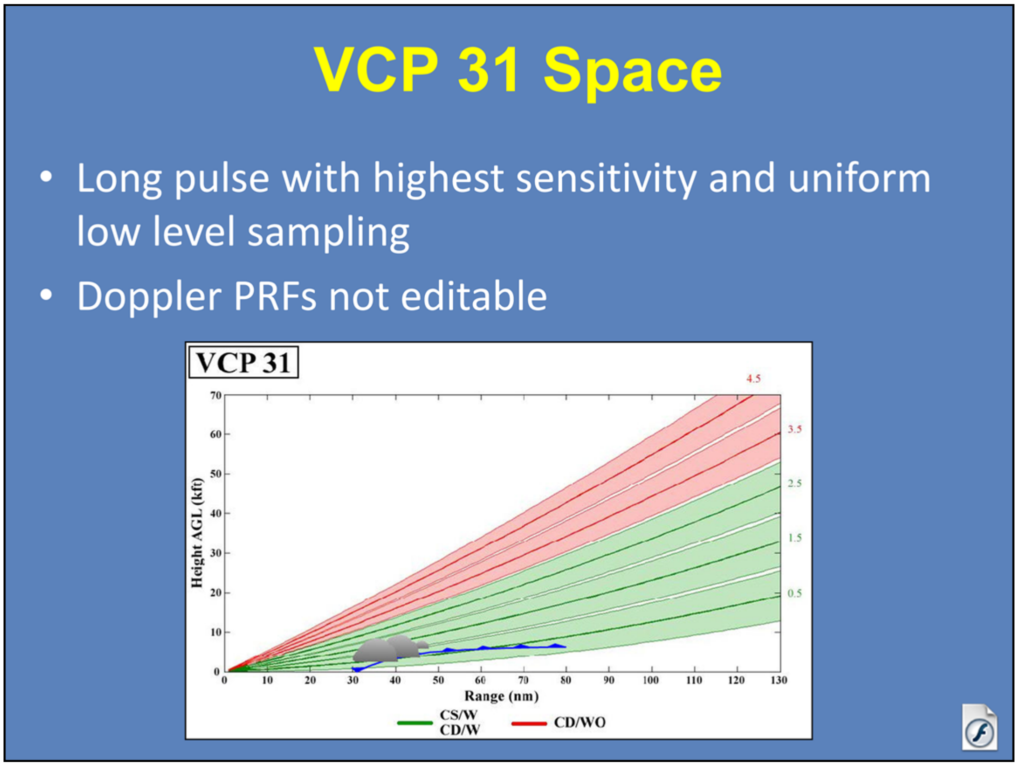
Let's look at a quick cross-section of the quote VCP space, or the amount of atmosphere that's actually being sample by a doppler radar, both in clear air and precip modes – and showing just how vast the cone of silence is above a particular radar. This image is mostly a reminder of how thin the Tropospheric layer is and how remarkable it is that such dramatic weather occurs in this layer. Why is there a line at 70,000 ft? It's because radar data are not assigned to products any higher than 70,000 ft!



Here's a look at the both modes separately. The cone of silence is always something to remember and hopefully you have sufficient adjacent radars to mitigate some of the data loss. Compare the size of the cone of silence for Clear Air mode. By design, it covers much less atmosphere because nothing is going on, at least, if you are in Clear Air Mode, there should be nothing going on...with a few exceptions, which we will discuss later.



Now for a series of animations of the spaces that each VCP occupies. The following slides will each present a particular VCP, and you can launch the animation from that slide. For the Precipitation mode VCPs, you'll see a couple of "typical" (not too big, not too small) supercells, for you to see the sampling strengths and limitations of each VCP. For the Clear Air mode VCPs, you'll see a frontal boundary with small cumulus forming, since convective initiation is one of the applications of the Clear Air VCPs.



We’ll start off with the Clear Air Mode VCPs. VCP 31 is the only VCP that uses long pulse, offering the highest sensitivity with uniform low level sampling. The Doppler PRFs are held constant and are not editable.

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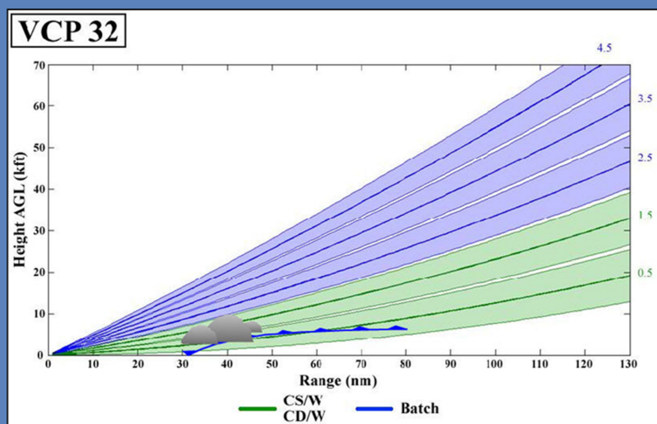
VCP 32 Space

- Uniform low level sampling
- Doppler PRFs editable Split Cuts and Batch



VCP 32 is the short pulse Clear Air mode VCP, with uniform low level sampling. The Doppler PRF is editable for the Split Cut and the Batch elevations.

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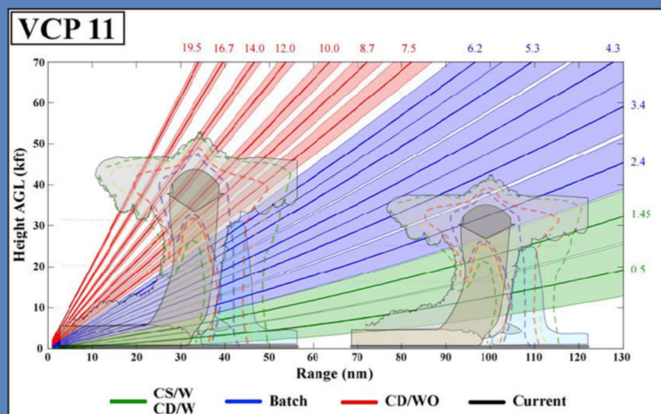
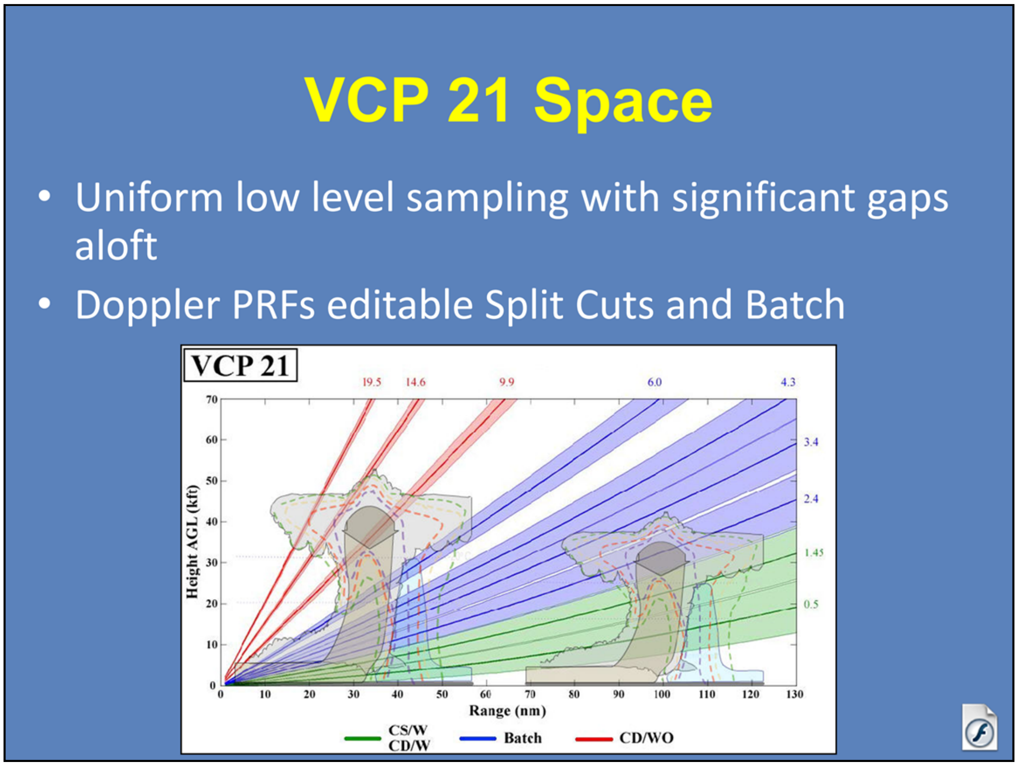
VCP 11 Space

- Generally uniform vertical sampling
- Doppler PRFs editable Split Cuts and Batch



Now to the Precip Mode VCPs. We’ll start off with VCP 11, which was actually the original convection VCP with relatively uniform vertical sampling. The Doppler PRF is editable for the Split Cut and the Batch elevations.



The widely used and widely defaulted, VCP 21 was the original stratiform precipitation VCP with uniform low level sampling, but significant gaps aloft. The Doppler PRF is editable for the Split Cut and the Batch elevations.

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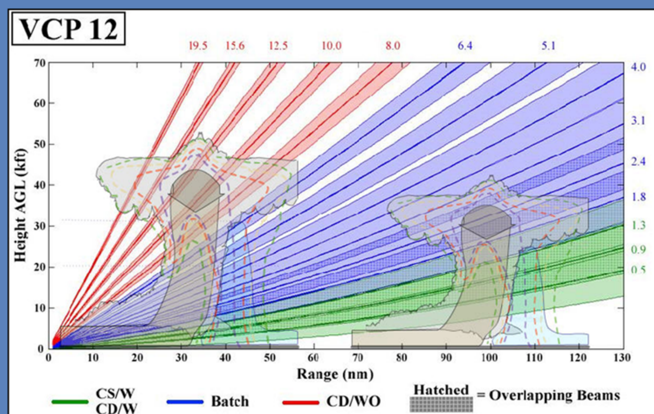
VCP 12 Space

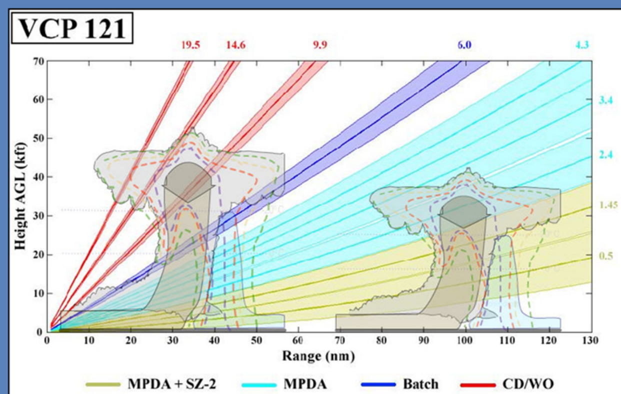
- Best low level vertical sampling with uniform gaps aloft
- Doppler PRFs editable Split Cuts and Batch



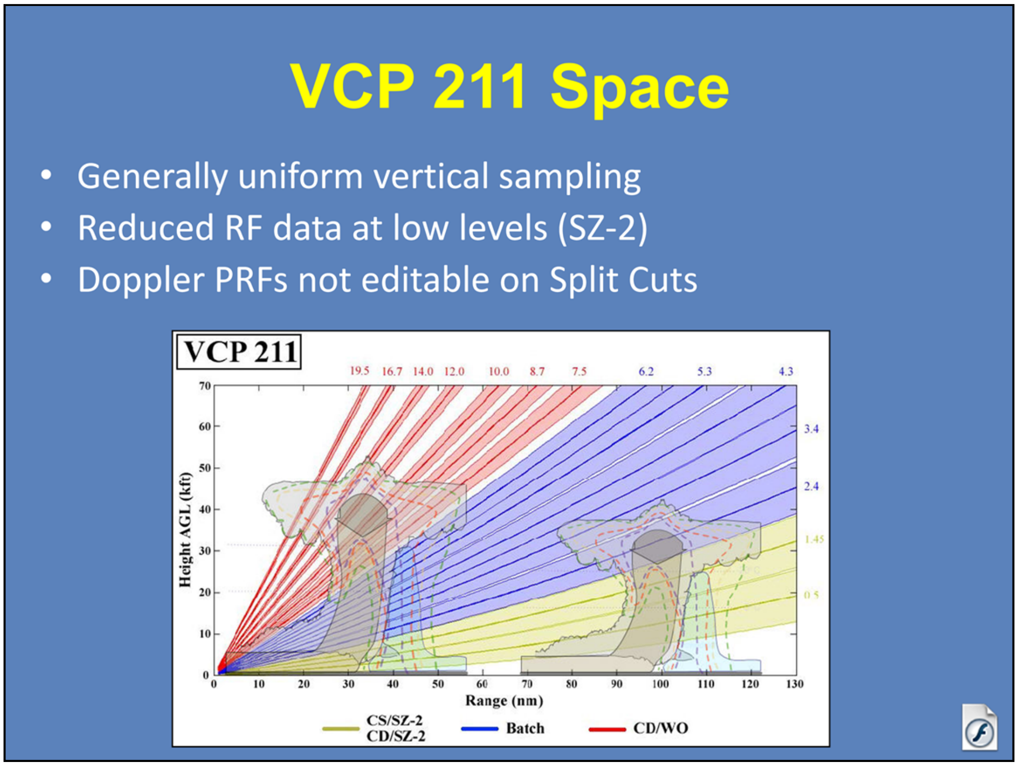
VCP 12 has the best low level vertical sampling with uniform gaps aloft. The Doppler PRF is editable for the Split Cut and the Batch elevations.

VCP 121 Space

- Uniform low level sampling, significant gaps aloft
- Almost no RF data at low levels (MPDA & SZ-2)
- Doppler PRFs not editable



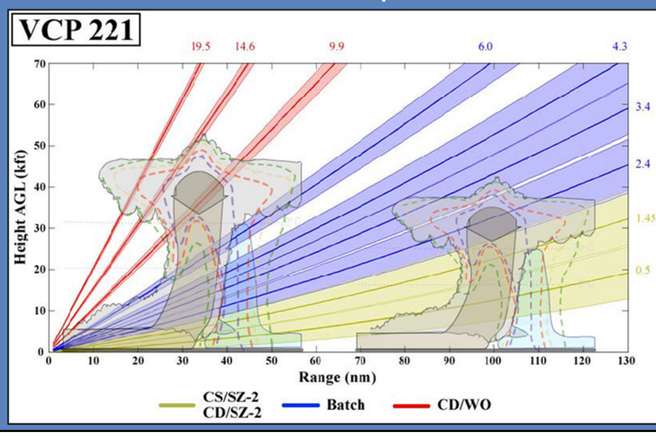
VCP 121 has uniform low level sampling with significant gaps aloft (just like VCP 21!). It's strength lies in the processing of the lower elevations, combining the SZ-2 and MPDA techniques. The result is almost no RF data for the lowest two elevation angles. The Doppler PRFs are held constant and are not editable.



VCP 211 has relatively uniform vertical sampling, with reduced RF data due to SZ-2 processing on the lowest 2 elevations. The Doppler PRFs are not editable on the Split Cuts, but can be edited on the Batch elevations.

VCP 221 Space

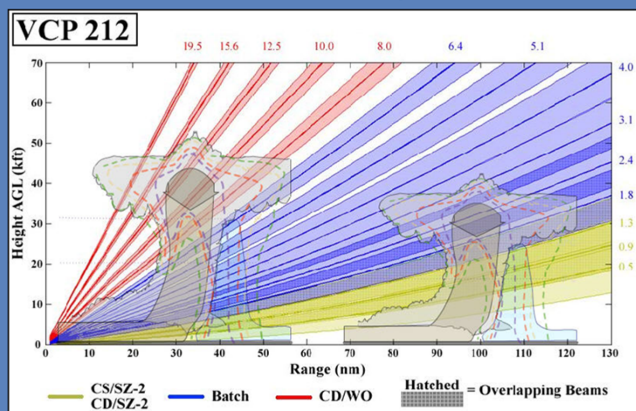
- Uniform low level sampling, significant gaps aloft
- Reduced RF data at low levels (SZ-2)
- Doppler PRFs not editable on Split Cuts



Like VCP 21, VCP 221 has uniform low level sampling with significant gaps aloft. Due to SZ-2 algorithm processing on the lowest 2 elevations, RF data is reduced. The Doppler PRFs are not editable on the Split Cuts, but can be edited on the Batch elevations.

VCP 212 Space

- Best low level vertical sampling, uniform gaps aloft
- Reduced RF data at low levels (SZ-2)
- Doppler PRFs not editable on Split Cuts



VCP 212 has the best low level vertical sampling with uniform gaps aloft. Due to SZ-2 processing on the lowest 3 elevations, RF data is reduced. The Doppler PRFs are not editable on the Split Cuts, but can be edited on the Batch elevations.

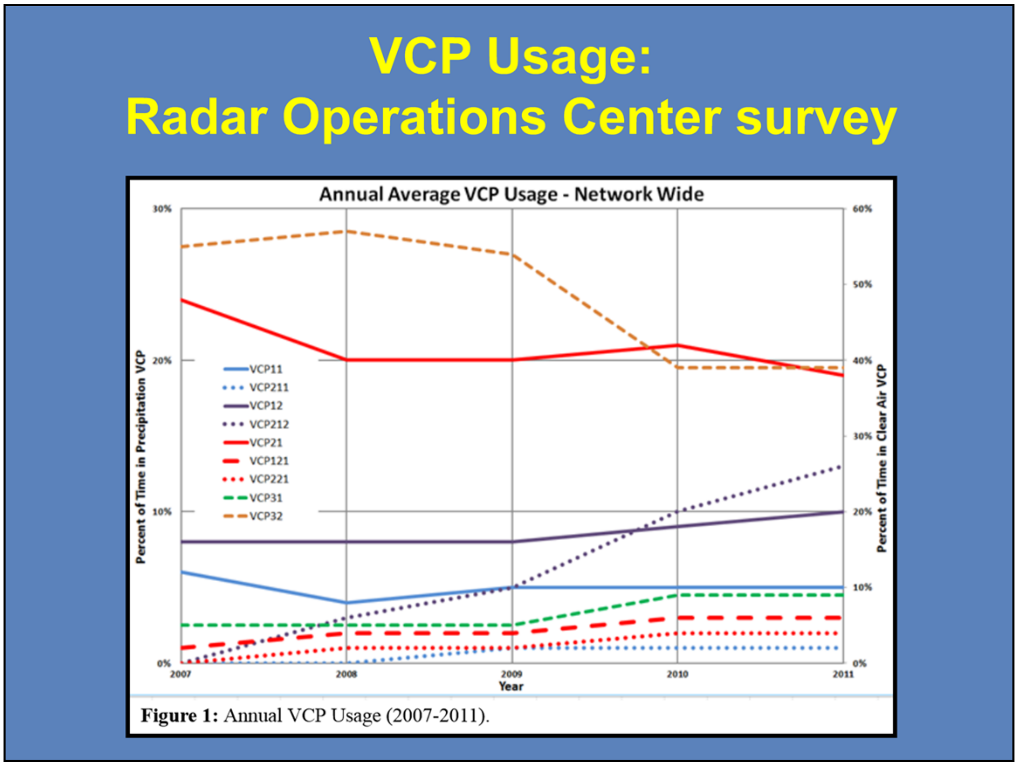


Figure 1: Annual VCP Usage (2007-2011).

The most recent figures from the Radar Operations Center were placed into this graphic, a survey of VCP usage nationwide, averaged out and graphed from 2007 to 2011. This period of time was occurring when offices were getting used to the newer SZ-2 VCPs, the 200-series VCPs. Though we don't have updated values since then, you can see the general trends here during this period. For one, notice the slight increase in VCP 31 and the larger drop in 32 for clear air modes. Then, we have most popular precip mode, 21, showing a flat-lining for a while but a bit of a recent decrease, which may be continuing, while the 200-series VCPs are starting to become more of a part of WFO operations, especially 212.

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The Future of VCPs

- Dynamic scanning has changed the way VCPs operate (AVSET, SAILS, MESOSAILS)

VCP	Without AVSET	Shortest Update with AVSET
11	~5 min	3 min, 12 sec (up to 6.2°)
12	~4.5 min	3 min, 10 sec (up to 6.4°)
212	~4.5 min	3 min, 30 sec (up to 6.4°)
21	~6 min	4 min, 55 sec (up to 9.9°)

One of the major changes to VCPs over the past few years is not even related to VCPs themselves – as in, making new ones or combining them, it is software changes that enhance the current ones. You all now know them as AVSET, SAILS, and the newer MESO-SAILS. AVSET terminates a volume scan early if there is no longer relevant data at the higher elevations. This means that products will update faster with AVSET, depending on the location and height of echoes. If storms are at close range, the entire volume scan up to 19.5 degrees may be needed. If storms are more distant, AVSET can terminate the volume scan once the beam is above the storms, giving you faster product updates. The table shows the shortest possible product updates for some of the VCPs. On top of that, we now have SAILS and MESO-SAILS which both serve to add 0.5 degree scans into one volume scan, so instead of just one, you can get an additional one, two, or three lowest cuts, depending on the setting you choose.

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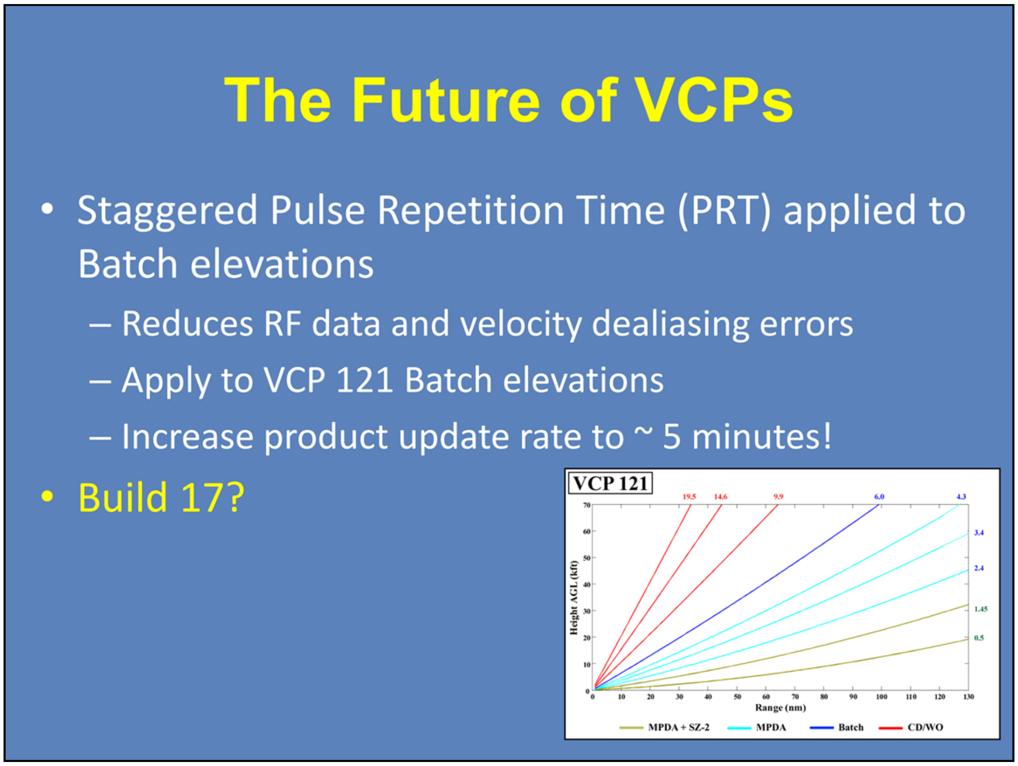

Staggered PRT is a technique that is currently being developed, reducing both RF data and velocity dealiasing errors in the Batch elevations. It is expected to be implemented with VCP 121, with an improved product update rate. This would result in very little RF data for both the Split Cut and Batch elevations for VCP 121.

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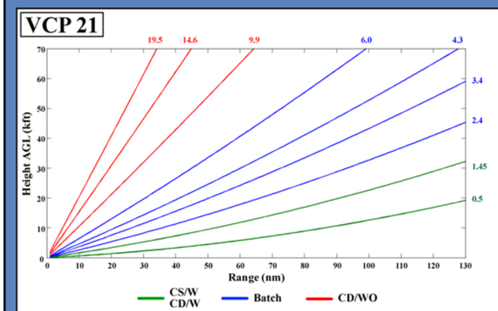
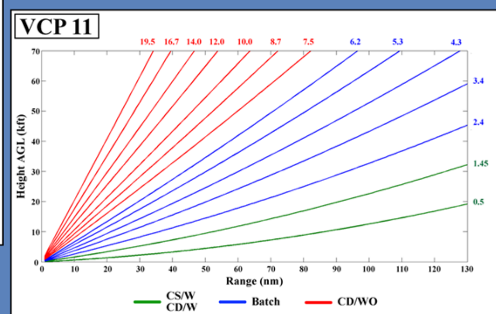
The Future of VCPs

- Build 18 (not yet determined)
  - Replace VCPs 11 ***and*** 21 with a "general surveillance" precipitation mode VCP





As of this recording, it is already in the works to combine VCPs 11 and 21, creating a new general surveillance VCP. This combination takes the uniform angle spacing of VCP 11 and the slow antenna speeds of VCP 21 to generate a VCP with better vertical sampling and data quality for non-severe precipitation.

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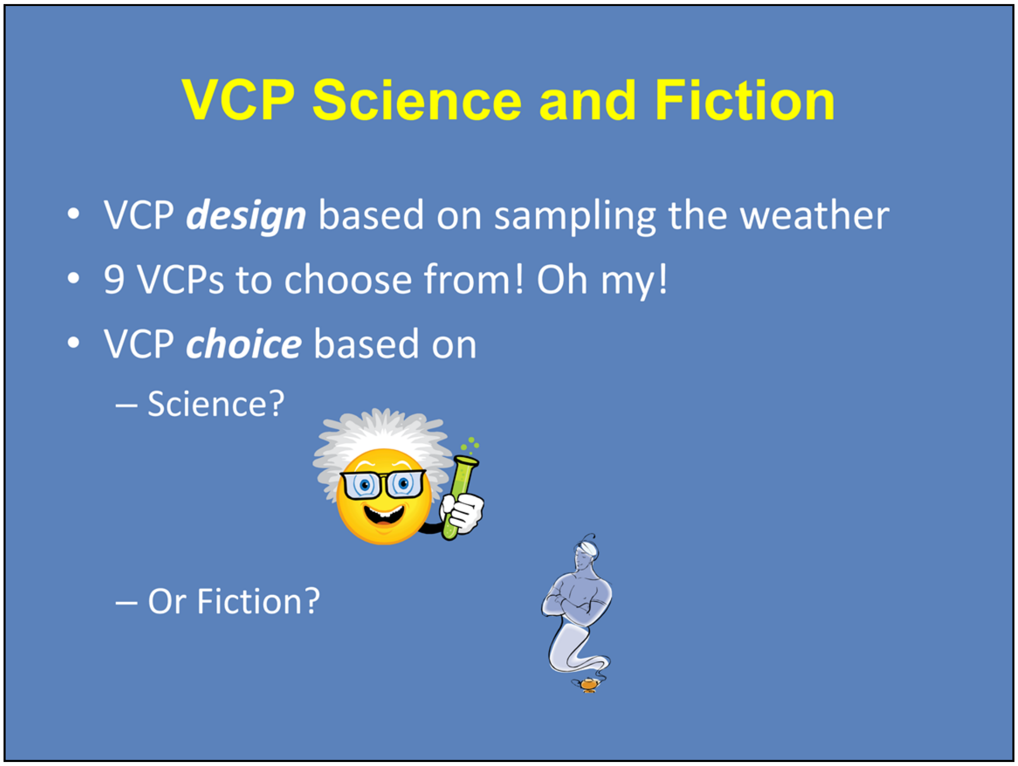

Given all of these VCP choices, we'll now examine some of the factors affecting VCP selection in real time. Each VCP was designed to sample the atmosphere in a different way. What we want to address here is whether VCP choices are based on science or fiction.

VCP Science and Fiction

- VCPs were ***designed*** for weather
- VCP ***choices*** based on
  - Expected weather hazard(s)
  - Concerns about ***potential*** hardware impacts and unplanned outages
  - Are these sometimes in conflict?

VCP choice is certainly driven by the current or expected weather, especially hazardous weather. Another concern may be potential impacts on hardware due to use of the faster VCPs. These factors can be in conflict. A radar outage during a severe weather event is something we would all want to avoid.

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Use of VCP 12, 212 and 121

- Do VCPs 12, 212 and 121 cause ***too much*** wear and tear on the system?
- Antenna ***speed*** matters
- ***Change*** in antenna speed ***also*** matters

We want to look at the true impact of the use of VCPs 12, 212 and 121, because these VCPs do have the fastest antenna rotation rates. Antenna speed does matter. Along with antenna speed is how often the antenna speed changes during a VCP. Speeding up and slowing down such a large antenna also imposes hardware stress.

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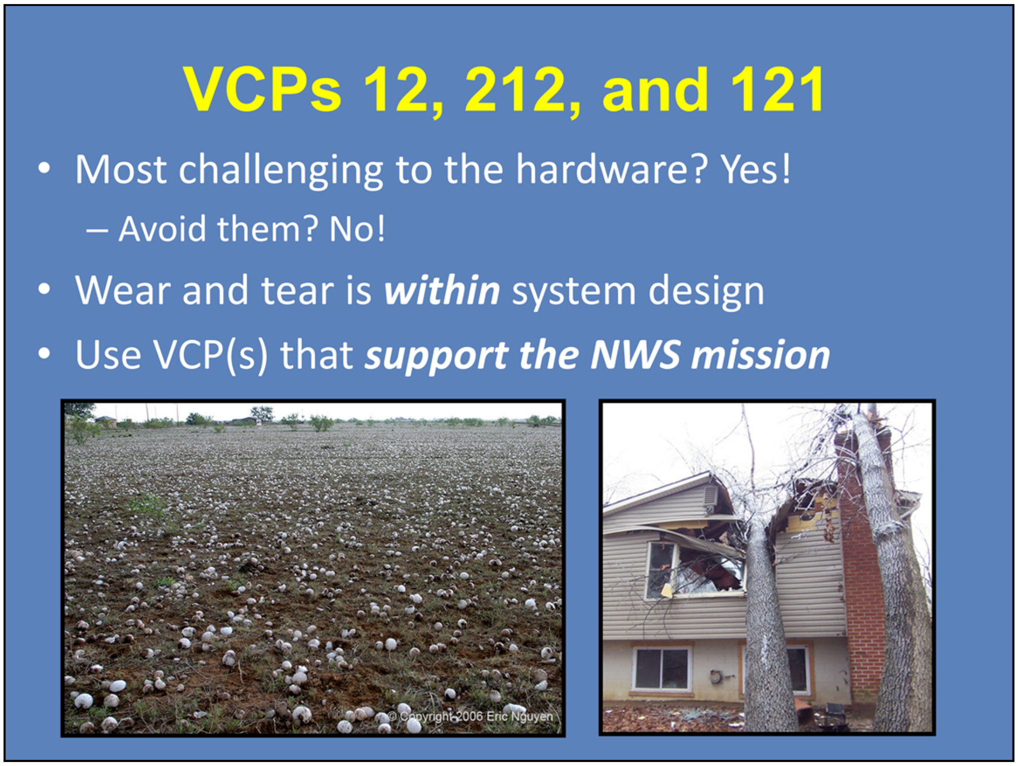

It is true that VCPs 12, 212 and 121 are the most stressful to the hardware. That does not mean that they should be avoided. Any associated wear and tear is within system design, and this will be explored in subsequent slides. Given thoughtful overall VCP usage, at appropriate times, VCPs 12, 212 and 121 can be critical to supporting the NWS mission.

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Wear and Tear Contributors

- VCP Choice
  - Antenna rotation rate
  - Changes in antenna rotation rate
- Other factors
  - RDA environment (temperature, dust, moisture)
  - Lack of regularly scheduled preventative maintenance
  - Not following established maintenance procedures

VCP choice does contribute to wear and tear, specifically fast antenna rotation rates and frequent changes in antenna rotation rates. There are other, equally important factors. Some RDAs are located in pretty tough environments with respect to extremes in temperature, dust, or moisture. The greater these extremes, the greater the need for regularly scheduled preventative maintenance that closely follows established procedures.

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Pedestal Wear and Tear

- Antenna speed ***and*** changes in the speed ***both*** affect
  - Gear Box for azimuth (small gear + bull gear)
    - Mechanically turns the antenna
  - Servo motor
    - Drives the gear box
  - Encoder
    - Sensor for antenna position/tells motor what to do

There are many parts of the antenna pedestal that are affected by both VCP choices and frequency of preventative maintenance. The gears (small gear and bull gear) for the antenna azimuth, the servo motor, and the encoder are some examples. The bull gear is the larger one because it lies at the base of the antenna. The small gear and the bull gear together mechanically rotate the antenna. The servo motor drives the gear box, while the encoder tells the motor what to do.

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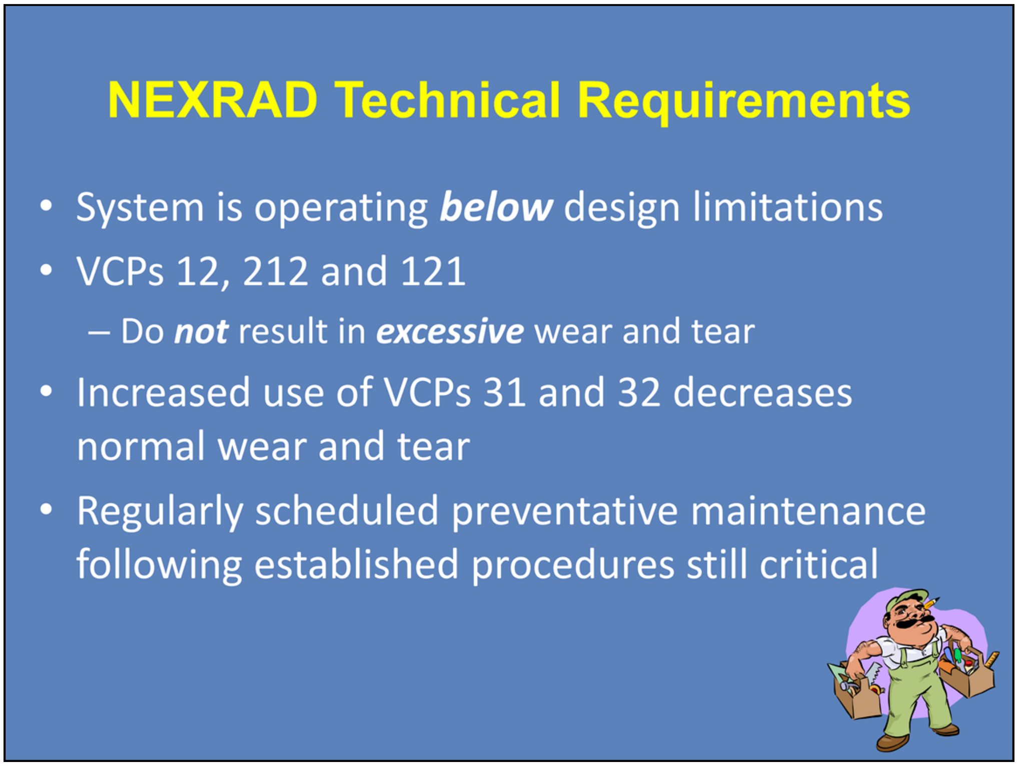
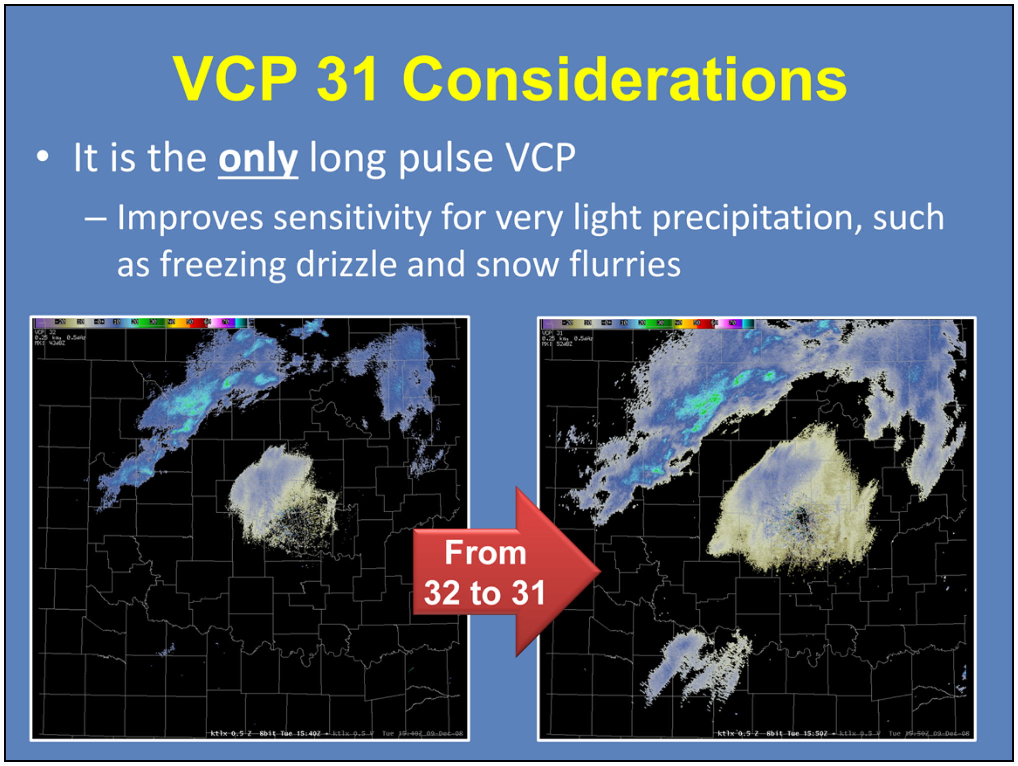


Given the NEXRAD Technical Requirements, even the fastest VCPs are operating well within the system design. VCPs 12, 212 and 121 do not result in excessive wear and tear. Also, the Mode Selection Function has resulted in an increased use of VCPs 31 and 32, which are the slowest, decreasing normal wear and tear overall. Regularly scheduled preventative maintenance following established procedures is still critical.

The bottom line is that the National Weather Service’s mission of protecting lives and property comes first. If VCP 12 or 212 is the best option for your convective event or other hazardous weather event, use it and don’t look back. If parts break, they will get fixed. So, use the faster VCPs when you need them, but DO be mindful to switch to slower VCPs when the event is over. Even the most chaotic weather events have a relatively short life, so use the faster VCPs for the time period, then downgrade to 21 or even clear air if the precip is gone. A combination of thoughtful VCP usage and pro-active maintenance can protect both the pedestal components and the public!



What is the operational advantage of VCP 31? Long pulse provides greater sensitivity, which means seeing returns from very light precipitation that you would not see with short pulse. In this freezing drizzle event, VCP 31 detects this very light, but high impact type of precipitation much more effectively than 32. Neither VCP will be producing precip accumulation products, so keep that in mind, but if you want to basically see the most plausible areas of very light falling precipitation, you won’t do better than VCP 31. If you’re getting reports of flurries and the radar is in 32 or even one of the precip modes, switch over to 31 and see if scope begins to fill up much more with echoes.

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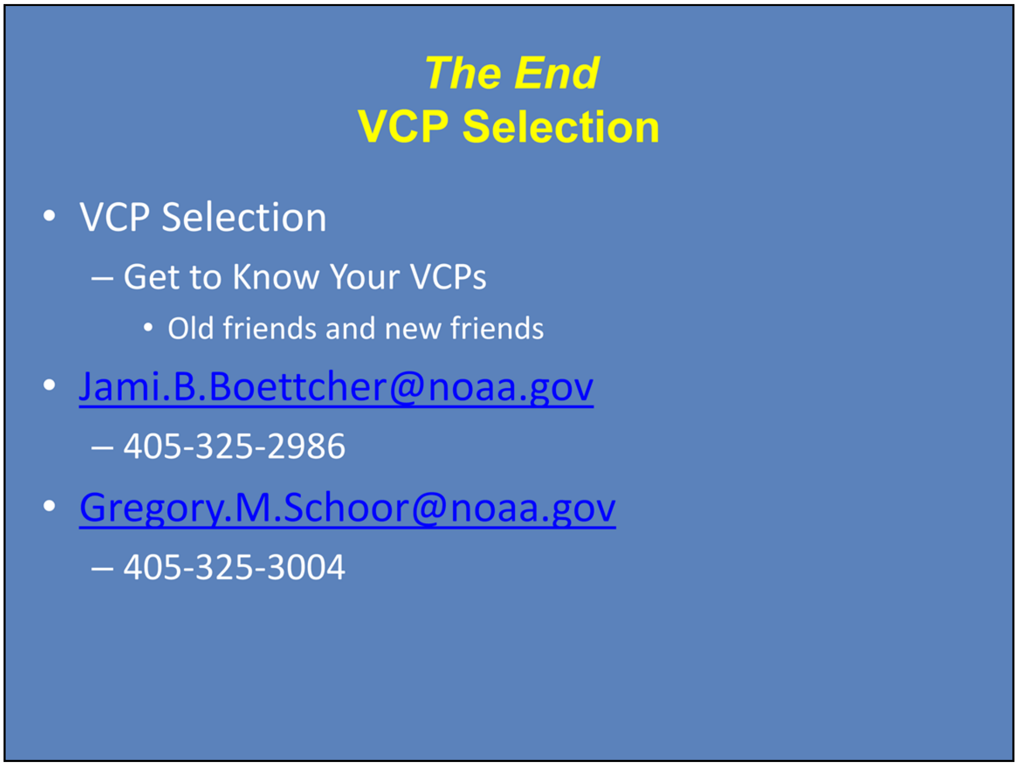


This concludes our lesson on VCP selection training, if you have any questions – here are the resources.

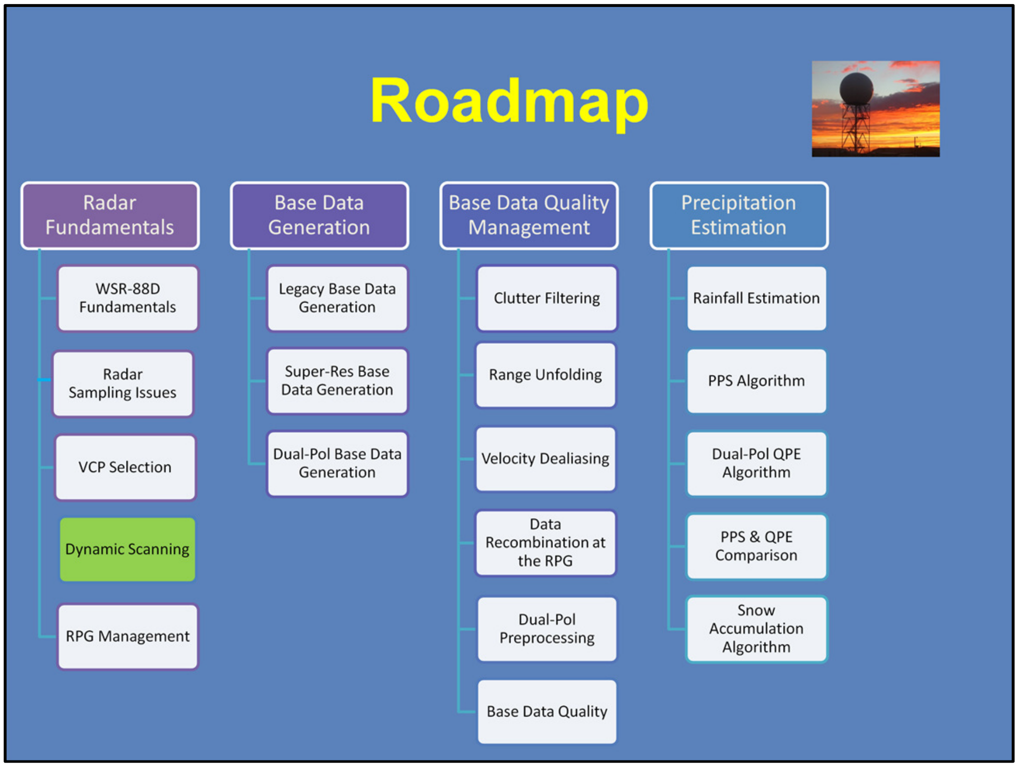
Radar & Applications Course (RAC)

Principles of Meteorological Doppler Radar

Lesson: Dynamic Scanning

WARNING DECISION TRAINING DIVISION (WDTD)

Welcome to this lesson on Dynamic Scanning. What is “dynamic scanning”, you may ask? This is a term we will utilize to describe how the WSR-88D radars have, in recent years, attained a capacity for more robust and user-defined ways to scan the skies. In this lesson, we will take a closer look at the applications of AVSET, SAILS, and MESO-SAILS.



Here is the “roadmap” with your current location.

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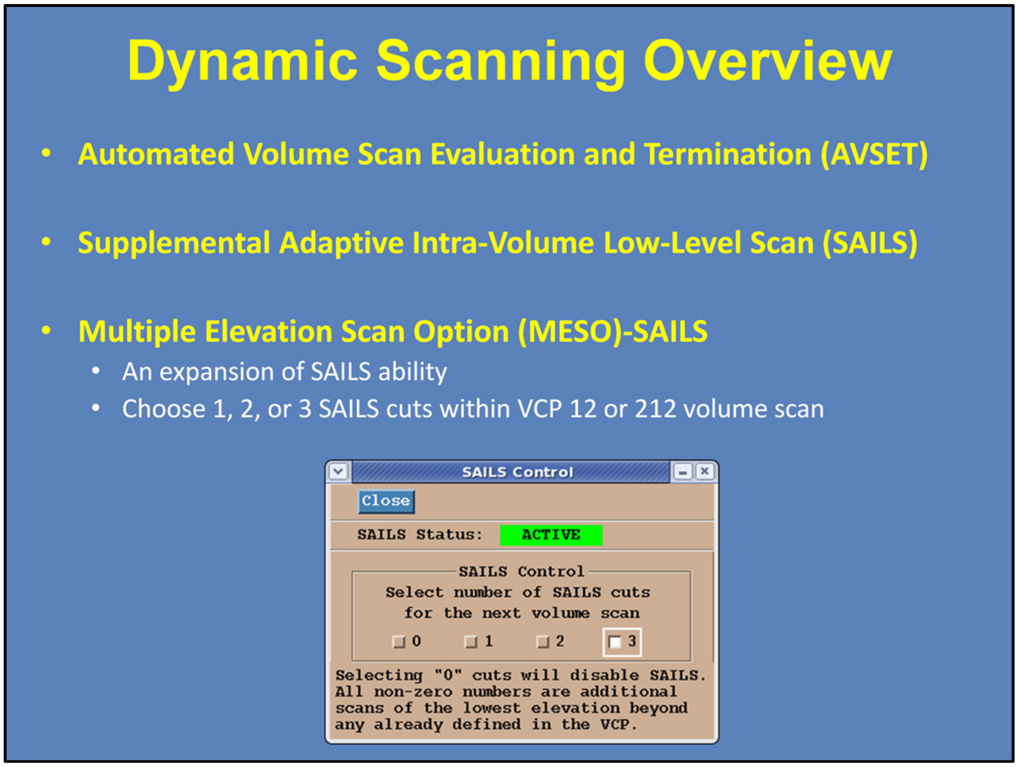

Before we define the lesson objectives, we will spell out the components of this Dynamic Scanning ability of the WSR-88Ds. The first application is called the Automated Volume Scan Evaluation and Termination, or AVSET. This allows any of the Precip mode VCPs to truncate the upper level tilts of a particular volume, if there is no detected echoes above a certain level. The fewer unnecessary tilts, the faster the VCP will be completed and the faster you'll get more data in the lower tilts.

Next is the SAILS application, which stands for Supplemental Adaptive Intra-Volume Low-Level Scan. For precip VCPs, this feature adds a 0.5^{o} degree tilt to every volume right in the middle of the volume, giving you twice as many lowest degree products per volume. Then, taking that idea one, two, and even three steps further, MESO-SAILS to allow one, two, or three additions 0.5^{o} cuts in one volume. With three SAILS cuts, you get almost one-minute updates on the 0.5^{o} products.

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Dynamic Scanning

Learning Objectives

1. Identify the purpose of AVSET, and which VCPs utilize it.
2. Identify how AVSET's design mitigates potentially missed detection of developing elevated convection.
3. Identify the purpose of MESO-SAILS, and which VCPs utilize it.
4. Identify why MESO-SAILS will not result in excessive hardware wear and tear.

Here are the learning objectives for this lesson, please read through them and keep them in mind as you go through the lesson.

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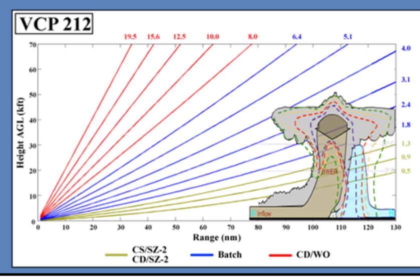
Dynamic Scanning History

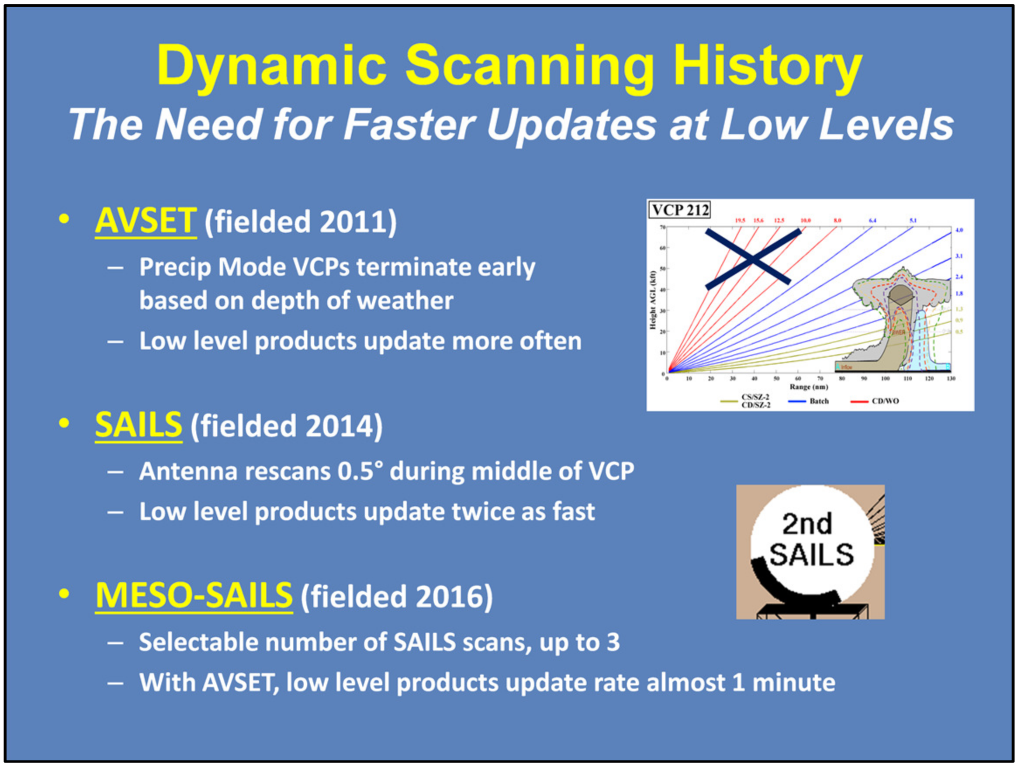
New VCPs were the start of it all

- VCP 11 (original convective VCP)
  - Updates around 5 minutes, gaps between low elevations
- VCP 12 (fielded 2002)
  - Overlapping low elevation vertical sampling ; evenly spaced vertical sampling aloft; updates a little over 4 minutes
  - Data quality & antenna movements within specs
- VCP 212 (fielded 2007)
  - VCP 12 angles with better range unfolding of velocity data
  - Part of the SZ-2 algorithm series

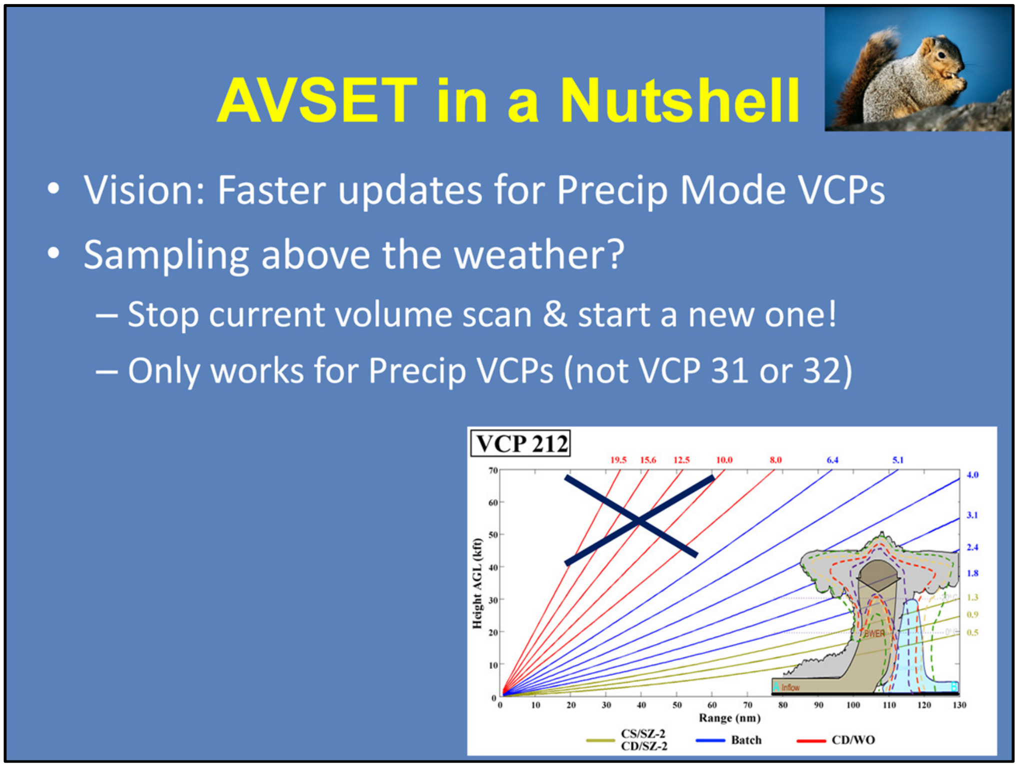


Let's start off with a short background of how we even got to this era of Dynamic Scanning. Some of the VCPs currently in use did not exist from the beginning. They were developed over time and the Radar Operations Center folks looked for more effective ways to use the radars. VCP 11 was the original convective VCP which generated volumes in about 5 minutes and had a fairly uniform scan strategy from top to bottom. However, in real time, people were noticing that this created gap in the low elevations, which are usually the tilts you would use for much of your storm interrogation. So, back in the early 2000s, VCP 12 was created, which helped to fill in the gaps in the low elevations, the antenna was sped up a bit to account for the additional elevation angles with a little over 4-minute full volumes. The data quality and antenna movements for VCP 12 are within the NEXRAD specifications. In the mid to late 2000s, the SZ-2 algorithm was created, to better mitigate range folding with velocity data. VCP 212 is the result, with VCP 12 angles and better velocity data collection.

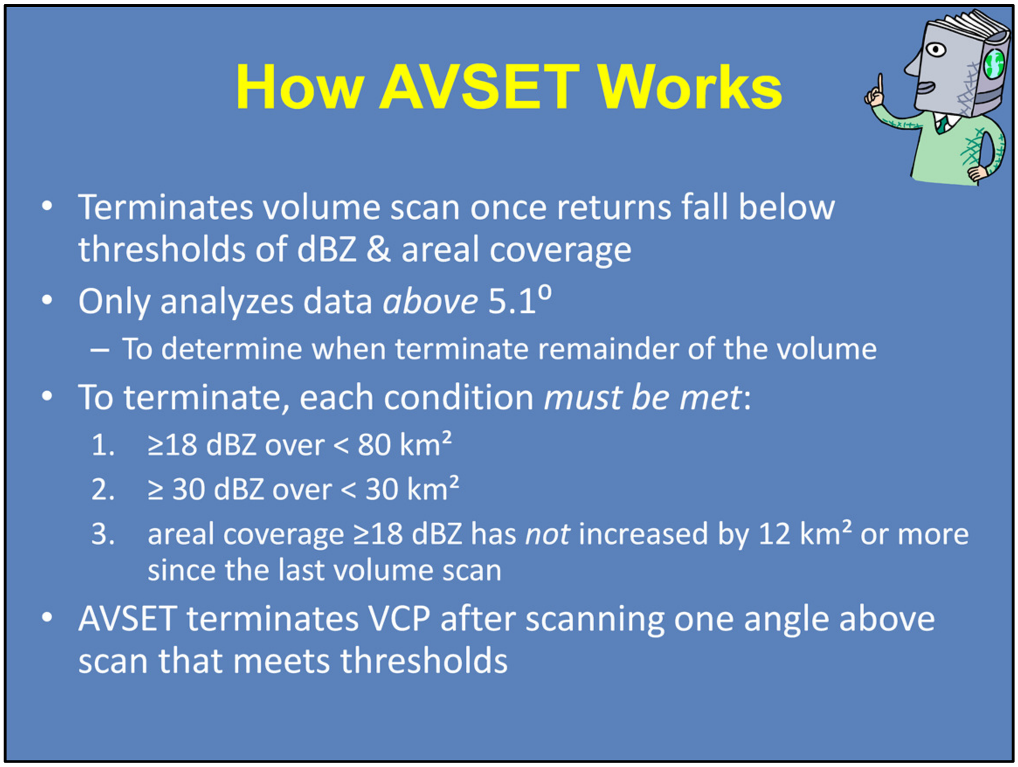
Even still, with all these enhancements, the fastest we could get new radar products was to 4 minutes.



A few years ago, knowing that even faster rotation rates would mean data quality below NEXRAD specifications, the attention turned to getting the most of each individual volume scan. First came AVSET, which began with the question – "why do we need to scan clear air at the higher tilts, above any sampled precipitation?" The response was to terminate the volume for situations like this, where the radar would be scanning above any sampled echoes, resulting in faster product updates by not scanning these upper tilts. AVSET brought the update rate to every 3 and a half to 4 minutes at best. Terminal Doppler Weather Radars, or TDWRs, have a capacity for one-minute lowest degree tilts with their scan strategies. So the next thought was, "why can't we meet that in the middle and have at least one additional lowest degree tilt in a volume?" So, SAILS was created to foster this ability. When SAILS was deemed a success, then MESO-SAILS was created and recently deployed, to allow an addition one, two, or three lowest degree tilts within one volume.



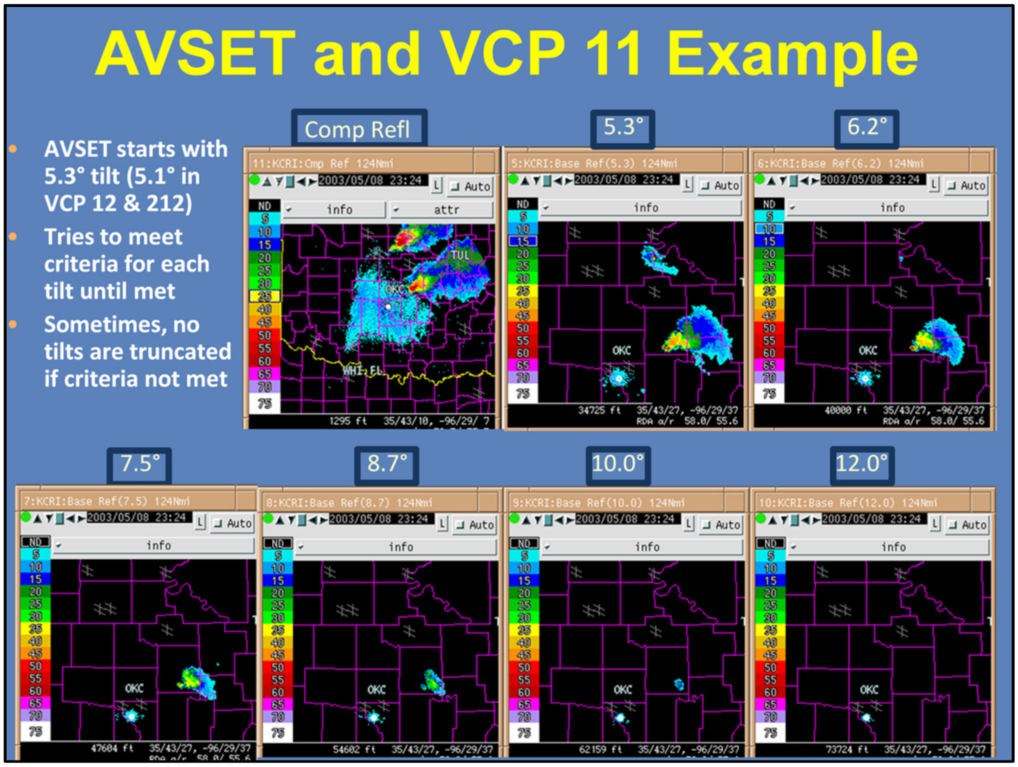
As we learned in the history of these applications, there has long been a desire for faster VCP updates. AVSET can meet this need when the weather return is limited to the lower elevation angles, though it is dependent on the depth of any detected precipitation and its range from the radar. This image illustrates how a convective storm is at a long enough range that the middle and upper elevations of the VCP are sampling nothing of significance. AVSET only runs on the Precip Mode VCPs, and can truncate different numbers of the upper elevations each volume scan because it dynamically works in each individual volume – which makes for maximum efficiency of the application.



How does this process work? Once the radar gets above 5.1^{o}, it starts to calculate whether the sampling of precipitation meets certain dBZ and areal coverage thresholds. AVSET checks the ***total*** areal coverage of returns above both 18 and 30 dBZ. To terminate the volume scan, there are three conditions and all three of them must be met.

The coverage at or above 18 dBZ must be less than 80 km^2.
The coverage at or above 30 dBZ must be less than 30 km^2.
The coverage at or above 18 dBZ has not increased by 12 km^2 or more since the last volume scan.

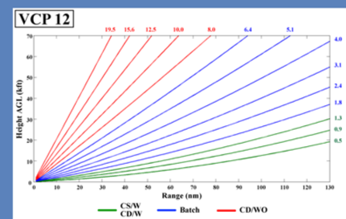
If these three conditions exist, AVSET then truncates the rest of the volume after sampling the next higher elevation. For the angle where returns fall below the threshold, AVSET samples one angle higher, then terminates.



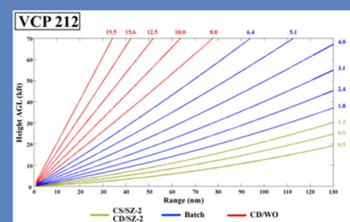
Here is a quick example of how AVSET works with a couple of storms on the display. You can see in the Composite Reflectivity, the first image on the top-left, there are a couple of storms to the north and east of the radar. Starting with the 5.3° tilt, which is 5.1° degrees in VCPs 12 and 212, AVSET will calculate the area of returns above 18 and 30 dBZ throughout that scan. As we go up in elevation, you see the returns decreasing and if the thresholds from previous slide is met, AVSET will scan one more elevation above, then terminate the VCP. In this example, 10.0° is where AVSET is able to meet its criteria, it adds the 12.0° tilt, which is the final elevation for that volume scan. Thanks to AVSET, 3 unnecessary elevation angles were avoided and the volume time was shortened about 45 seconds.

What is the fastest possible volume scan time?

- **VCP 12** full volume scan time **4 min, 18 sec**
  - With AVSET: shortest update **3 min, 12 sec**



- **VCP 212** full volume scan time **4 min, 36 sec**
  - With AVSET: shortest update **3 min, 30 sec**



- **Equates to ~one entire volume per hour** ***(best possible)***

So, after all this talk of speeding up VCPs, what ***IS*** the fastest possible volume scan time with AVSET enabled? Here, we use the two fastest VCPs, 12 and 212. With AVSET disabled and performing a full volume scan, the times are 4 and 4.5 minutes, respectively. But with AVSET enabled and able to truncate all elevation tilts above 6.4°, the volume scan time drops by nearly one minute for each VCP. This means, over the course of one hour, you would receive one extra volume that you wouldn't have without AVSET.

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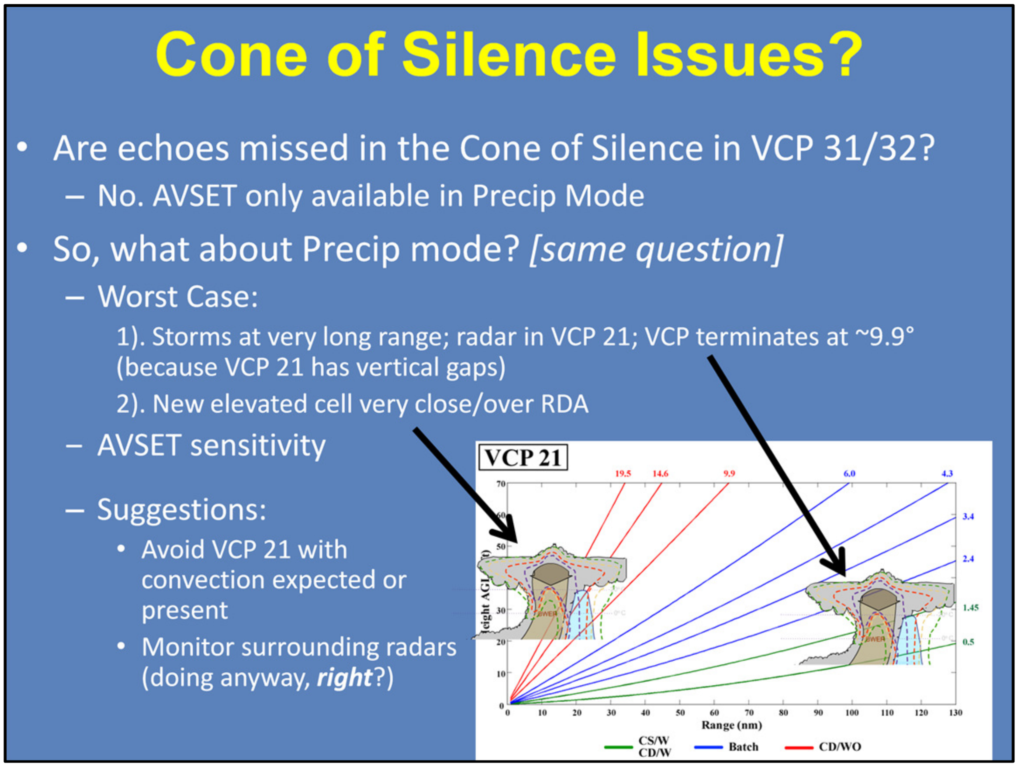

One more consideration for AVSET is the Cone of Silence. Since AVSET starts at 5.3^{o}, it has no affect on VCPs 31 and 32. There is no change in detection of elevated convection in Clear Air Mode.

So, what about the Precip Mode? Could AVSET miss any cells aloft? The first possibility is with echoes that don't have much areal extent and are very far from the radar and you're in VCP 21, which has sizeable vertical scanning gaps at long ranges. The other is if there is a cell developing aloft very near or right over the radar, and VCP 21 again contributes to potentially missing the cell due to gaps aloft. Also, AVSET is very sensitive to developing returns (18 dBZ cannot increase more than 12 km^2).

The suggestions for this are to avoid using VCP 21 when you expect convection or there is ongoing convection. It's also important to monitor surrounding radars (a practice you're already doing, right?). This includes the TDWRs, if you have them, to get a more complete regional picture.

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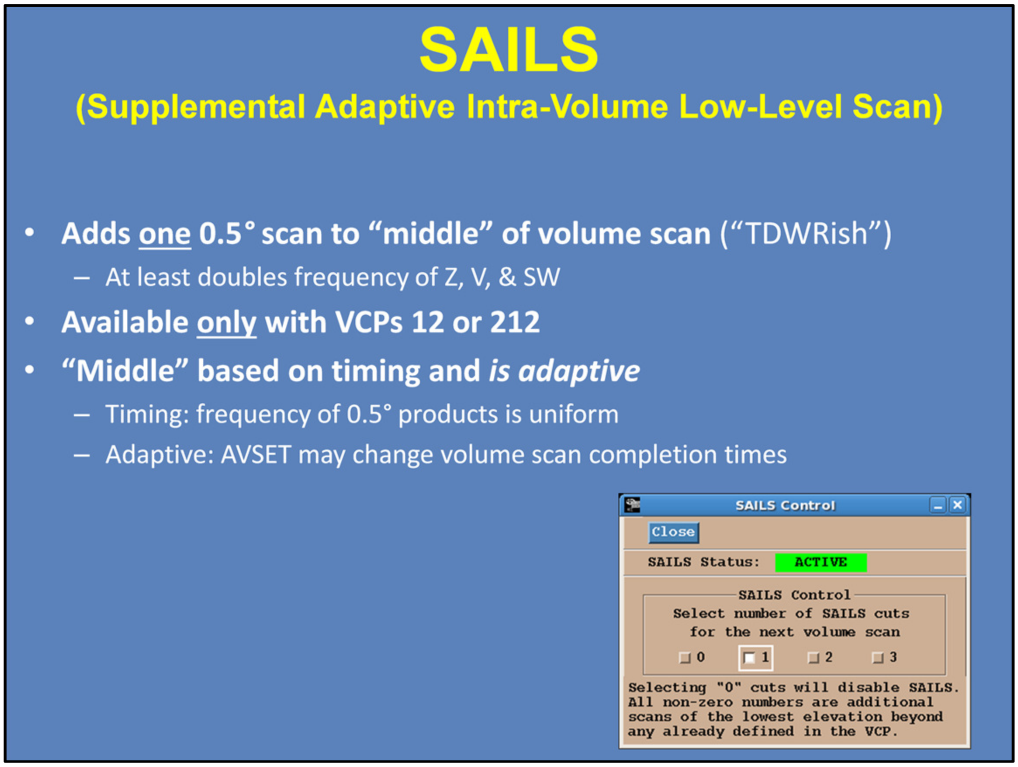
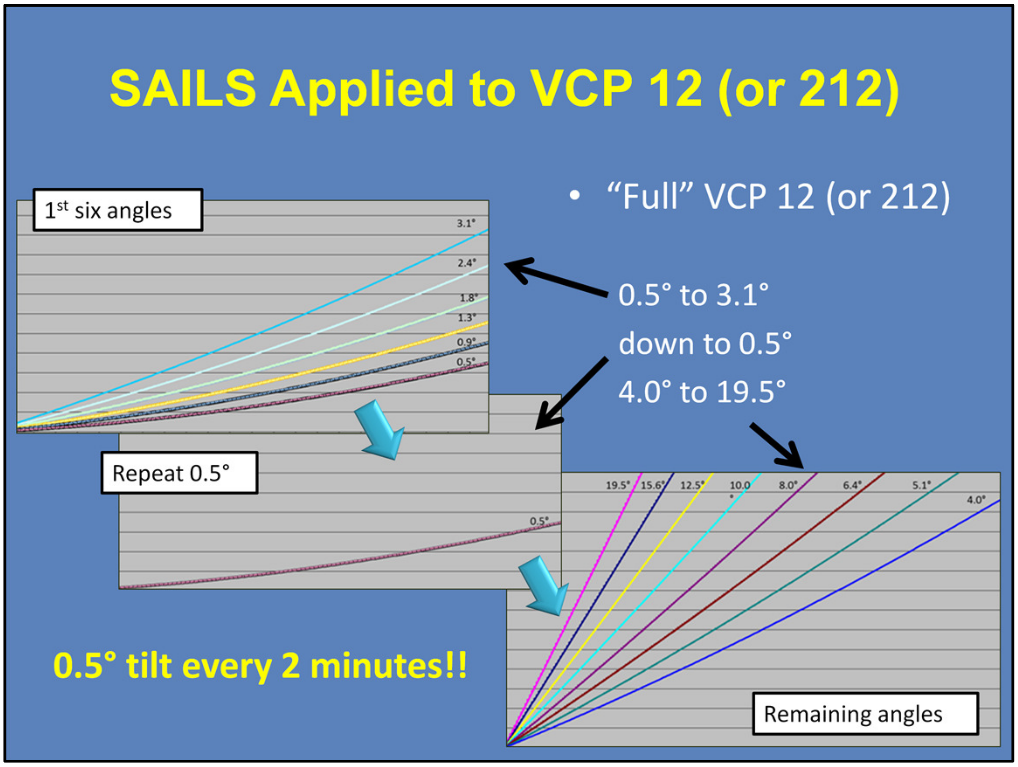
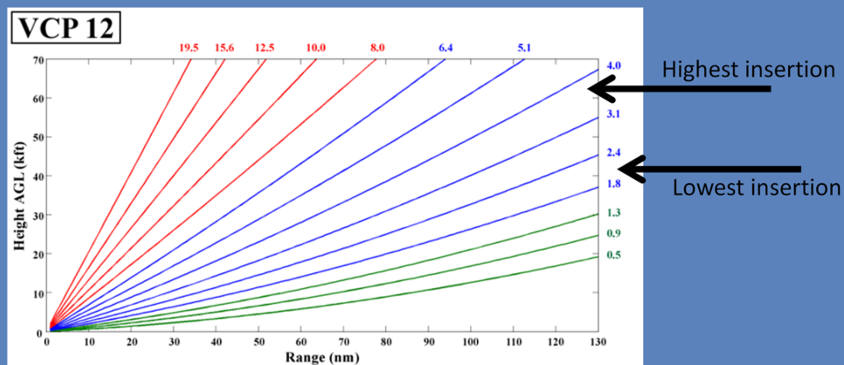


Next in our utility belt of Dynamic Scanning is SAILS, which stands for – Supplemental Adaptive Intra-Volume Low-Level Scan. The lowest degree tilt is by far the most widely used tilt, especially when scanning for low-level features that contribute to tornadogenesis. TDWRs are well known for their one-minute lowest tilt updates and SAILS was the first iteration of the WSR-88D to move toward that capability. SAILS is only an option for VCPs 12 or VCP 212 and it adds an extra 0.5° tilt in the "middle" of the volume scan. This "middle" of the volume scan is based on timing, as you'll see in the next slide. It is also adaptive when AVSET is on because the volume scan completion times will change.



Here's an example of SAILS applied to VCP 12 – or 212, with all the angles sampled, so this would be either with AVSET disabled or there are enough storms that no upper tilts are truncated. The first six angles are samples as normal, elevations 0.5° through 3.1°. The antenna then drops down to sample 0.5°, which is the SAILS cut, then returns to complete the volume scan, elevations 4.0° through 19.5°. The total volume scan time for this example would be around 4 and a half minutes, so the additional SAILS cut results in low level products updating in just over 2 minutes.

SAILS and AVSET

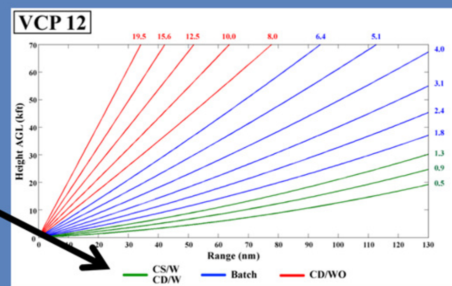


- Insertion dependent on AVSET's termination angle
  - Lowest is between 1.8° – 2.4°
  - Highest is between 3.1° – 4.0°
- Want SAILS cut products to update "timing middle" of VCP

Speaking of AVSET… When it is active and the termination angle changes from volume to volume, the timing of the extra SAILS cut, or the insertion point, will also change. The lowest insertion is between 1.8° and 2.4°, while the highest is between 3.1° and 4.0°. This variation meets the goal of having the SAILS cut product in the middle of the volume scan with respect to timing.

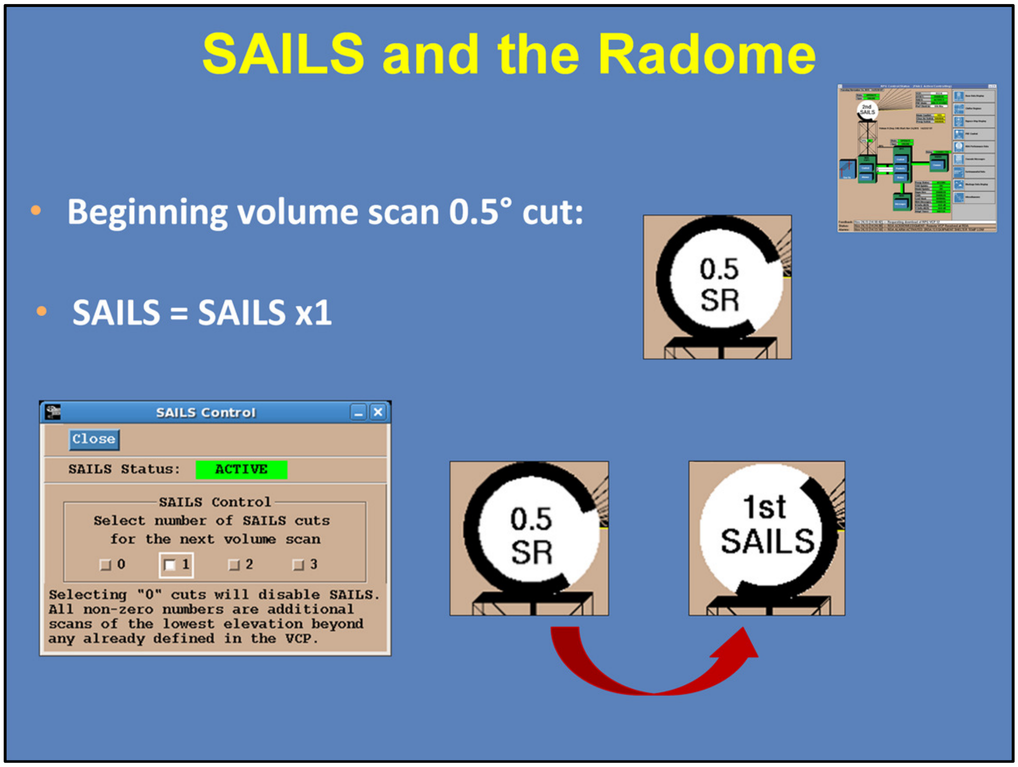
"SAILS Scan" Characteristics

- 0.5° SAILS scan processed as Split Cut
  - 1st rotation low PRF (CS)
  - 2nd rotation high PRF (CD)



- Needed for:
  - Best clutter identification & filtering/range unfolding (V & SW)
  - Super Resolution data processing

This extra 0.5° scan is known as the SAILS cut. It is processed as a Split Cut, which means the first rotation is at low PRF (Contiguous Surveillance), followed by a second rotation at high PRF (Contiguous Doppler). The Split Cut sampling is needed for the best data quality, better clutter identification and filtering, super resolution data processing, and better range unfolding of velocity and spectrum width.



With both SAILS and AVSET active, there is a need to know when the SAILS cut is executed. To support this, there are two features on the radome on the RPG Control/Status Window. At the beginning of the volume scan, the radome displays 0.5° and SR. In this example, SAILS x1 has been selected, which is the same as what started as just "SAILS". When the SAILS cut is executed, "1st SAILS" appears on the radome.

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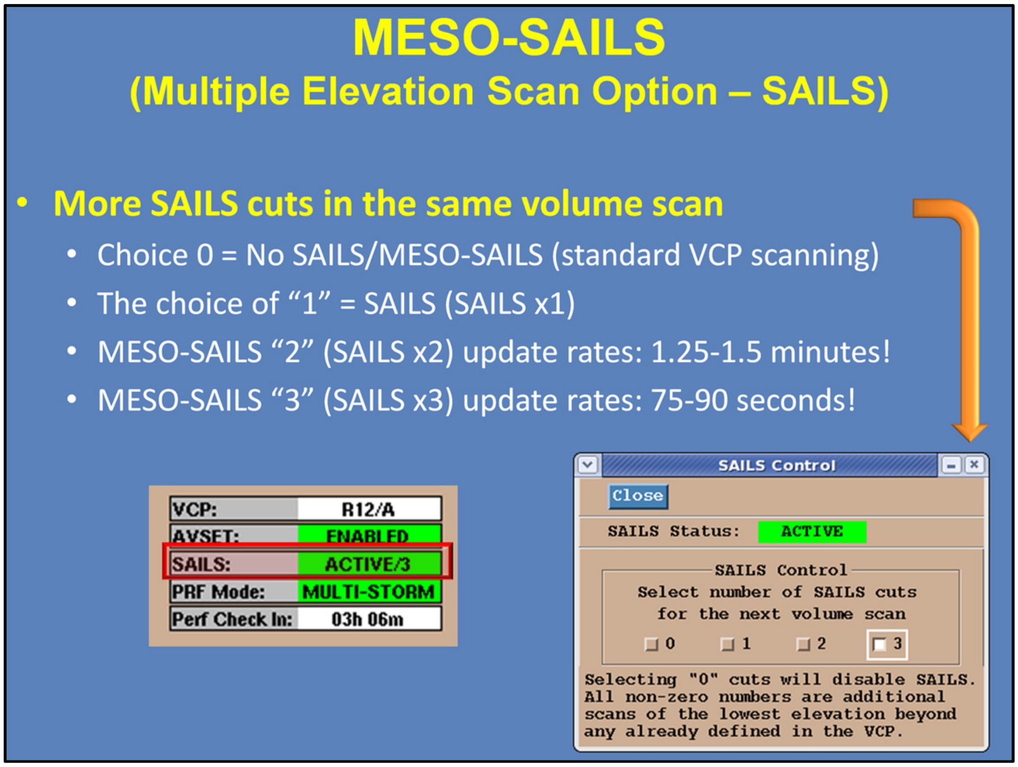

While SAILS adds one additional 0.5° cut in the “middle” of VCP 12 or 212, MESO-SAILS takes this two and even three steps further, giving you the option of having an additional 2 or 3 0.5° cuts. From the image in the lower-right, you can see the options for 0, 1, 2, or 3. Zero, means that SAILS and MESO-SAILS are disabled, so no additional 0.5° cuts. Choosing “1” is basically SAILS, so you just get one additional 0.5° cut. So, the choice of either 2 or 3 additional 0.5° cuts is the function of MESO-SAILS. Choosing “2” gives an update rate of around a minute and a half, while MESO-SAILS “3” gives an 0.5° update rate of just over one-minute!

SAILS x2 with AVSET

Elevation Angles (VCP 12)	Term Angle 19.5°	AVSET Term 15.6°	AVSET Term 12.5°	AVSET Term 10.0°	AVSET Term 8.0°	AVSET Term 6.4°
0.5°	31 sec	31 sec	31 sec	31 sec	31 sec	31 sec
0.9°	31 sec	31 sec	31 sec	31 sec	31 sec	31 sec
0.5°						31 sec
1.3°	31 sec	31 sec	31 sec	31 sec	31 sec	31 sec
0.5°	31 sec	31 sec	31 sec	31 sec	31 sec	
1.8°	15 sec	15 sec	15 sec	15 sec	15 sec	15 sec
2.4°	14 sec	14 sec	14 sec	14 sec	14 sec	14 sec
0.5°						31 sec
3.1°	14 sec	14 sec	14 sec	14 sec	14 sec	14 sec
0.5°					31 sec	
4.0°	14 sec	14 sec	14 sec	14 sec	14 sec	14 sec
0.5°			31 sec	31 sec		
5.1°	14 sec	14 sec	14 sec		14 sec	14 sec
0.5°		31 sec				
6.4°	14 sec	14 sec	14 sec	14 sec	14 sec	14 sec
0.5°	31 sec					
8.0°	13 sec	13 sec	13 sec	13 sec	13 sec	
10.0°	13 sec	13 sec	13 sec	13 sec		
12.5°	13 sec	13 sec	13 sec			
15.6°	13 sec	13 sec				
19.5°	13 sec					
Duration	305 sec	292 sec	279 sec	266 sec	253 sec	240 sec
0.5° Update Times	*Avg 1 min 48 sec	*Avg 1 min 44 sec	*Avg 1 min 40 sec	*Avg 1 min 36 sec	*Avg 1 min 30 sec	*Avg 1 min 24 sec

*Avg estimate includes 10 secs for retrace and 10 sec for elevation transition

The next couple of slides show tables for the update rate times of all possible AVSET and MESO-SAILS interactions. This table is for SAILS x2. You can see that with AVSET enabled and the termination angles, or “term” in the header, the red values are where the SAILS 0.5° cuts appear in the scanning strategy for each AVSET possibility. Then, at the bottom, you can see the average update times for the 0.5° cuts and above it, the times for the full volume. With AVSET disabled or terminating at 19.5°, the volume will take just over 5 minutes to complete, but you also get two additional 0.5° cuts during that volume.

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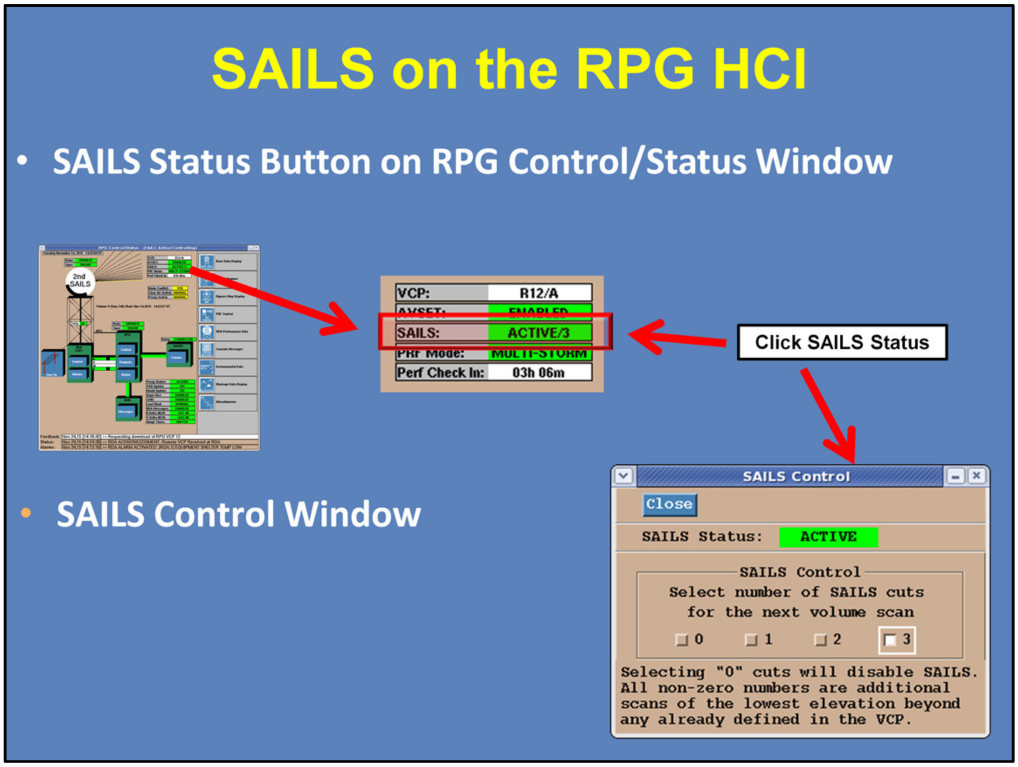
SAILS x3 with AVSET

Elevation Angles (VCP 12)	Term Angle 19.5	AVSET Term 15.6°	AVSET Term 12.5°	AVSET Term 10.0°	AVSET Term 8.0°	AVSET Term 6.4°
0.5°	31 sec	31 sec	31 sec	31 sec	31 sec	31 sec
0.9°	31 sec	31 sec	31 sec	31 sec	31 sec	31 sec
0.5°			31 sec	31 sec	31 sec	31 sec
1.3°	31 sec	31 sec	31 sec	31 sec	31 sec	31 sec
0.5°	31 sec	31 sec				
1.8°	15 sec	15 sec	15 sec	15 sec	15 sec	15 sec
0.5°			31 sec	31 sec	31 sec	31 sec
2.4°	14 sec	14 sec	14 sec	14 sec	14 sec	14 sec
3.1°	14 sec	14 sec	14 sec	14 sec	14 sec	14 sec
0.5°		31 sec				31 sec
4.0°	14 sec	14 sec	14 sec	14 sec	14 sec	14 sec
0.5°	31 sec				31 sec	
5.1°	14 sec	14 sec	14 sec	14 sec	14 sec	14 sec
0.5°			31 sec	31 sec		
6.4°	14 sec	14 sec	14 sec	14 sec	14 sec	14 sec
0.5°		31 sec				
8.0°	13 sec	13 sec	13 sec	13 sec	13 sec	
0.5°	31 sec					
10.0°	13 sec	13 sec	13 sec	13 sec		
12.5°	13 sec	13 sec	13 sec			
15.6°	13 sec	13 sec				
19.5°	13 sec					
Duration	336 sec	323 sec	310 sec	297 sec	284 sec	271 sec
0.5° Update Times	*Avg 1 min 29 sec	*Avg 1 min 26 sec	*Avg 1 min 23 sec	*Avg 1 min 19 sec	*Avg 1 min 16 sec	*Avg 1 min 13 sec

*Avg estimate includes 10 secs for retrace and 10 secs for elevation transition

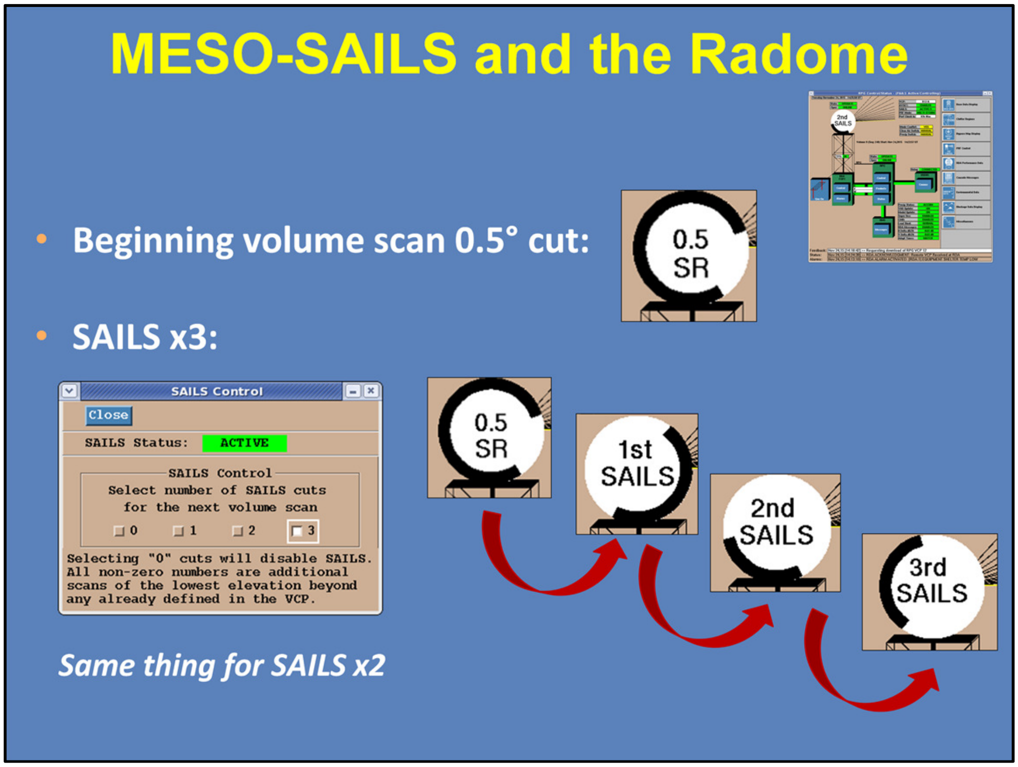
Here's the table for SAILS x3. When might you need nearly one-minute 0.5° products? Are you monitoring low-level circulations near the radar that are more important than monitoring the upper tilts? Possibly and maybe for only a brief period. You may have some QLCS or mesovortex features appearing that would be missed completely if you had standard VCP scanning with 4 to 5 minute updates. But, with SAILS x3 enabled, you wait longer for the upper tilts, sometimes almost 6 minutes if AVSET is not terminating early.

The key takeaway is: **there is always a trade off**. The MESO-SAILS benefit is not "set it and forget it". You may have to change strategies multiple times during an event, just depends on what is happening.

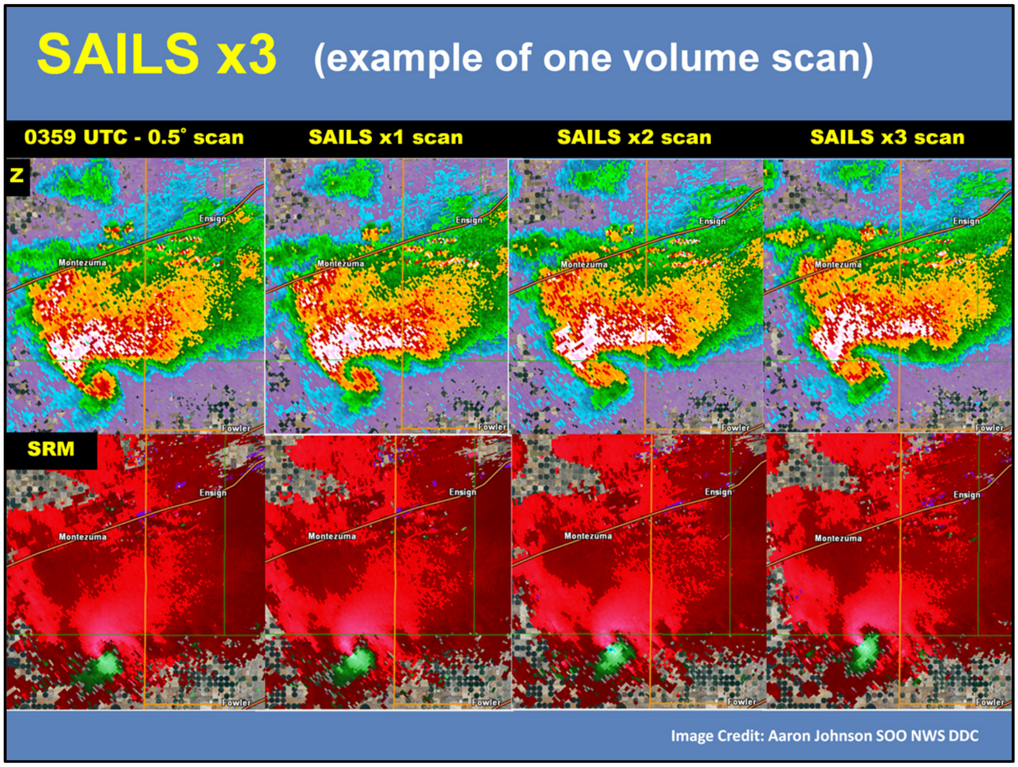


How do you invoke the number of SAILS cuts desired? Starting on the RPG Control/Status Window, the SAILS Status button tells you the current setting. In this example, it is SAILS x3, and since we're in VCP 12, SAILS is ACTIVE.

Click on the SAILS Status button and the SAILS Control Window appears. This window allows you to select the number of SAILS cuts you desire.

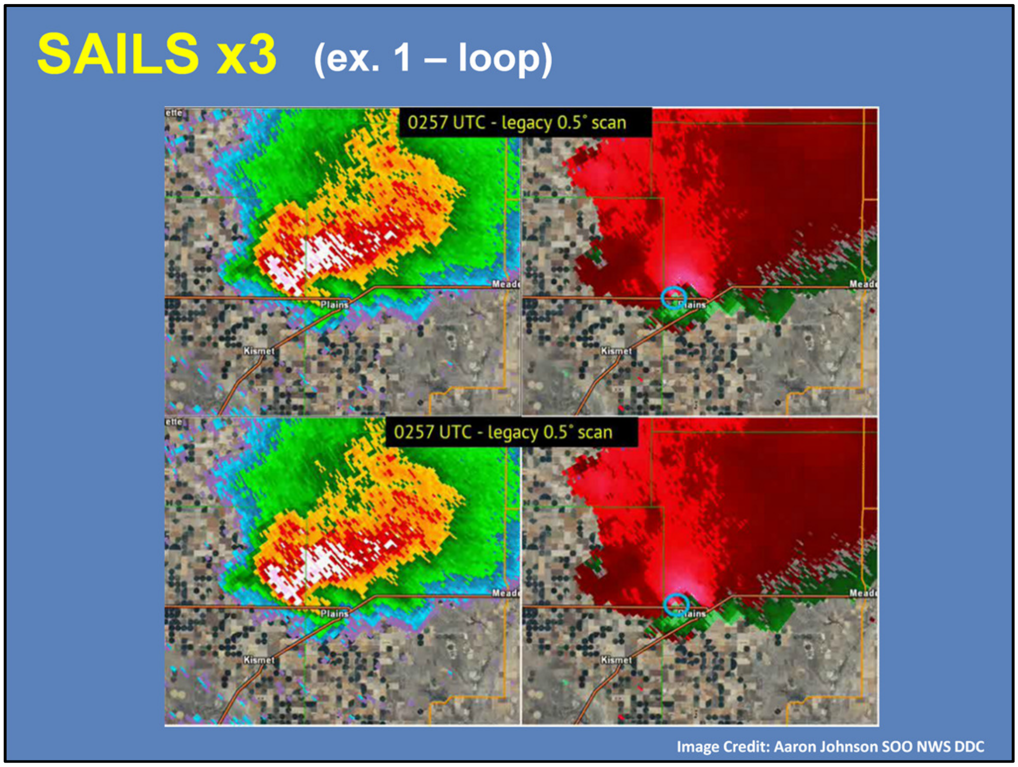


As with the SAILS x1 example, the radome tells you when the SAILS cuts are scanned, identified as 1st, 2nd, or 3rd, depending on the number of cuts selected. Here we have an example of each of the SAILS cuts on the radome when SAILS x3 has been selected.

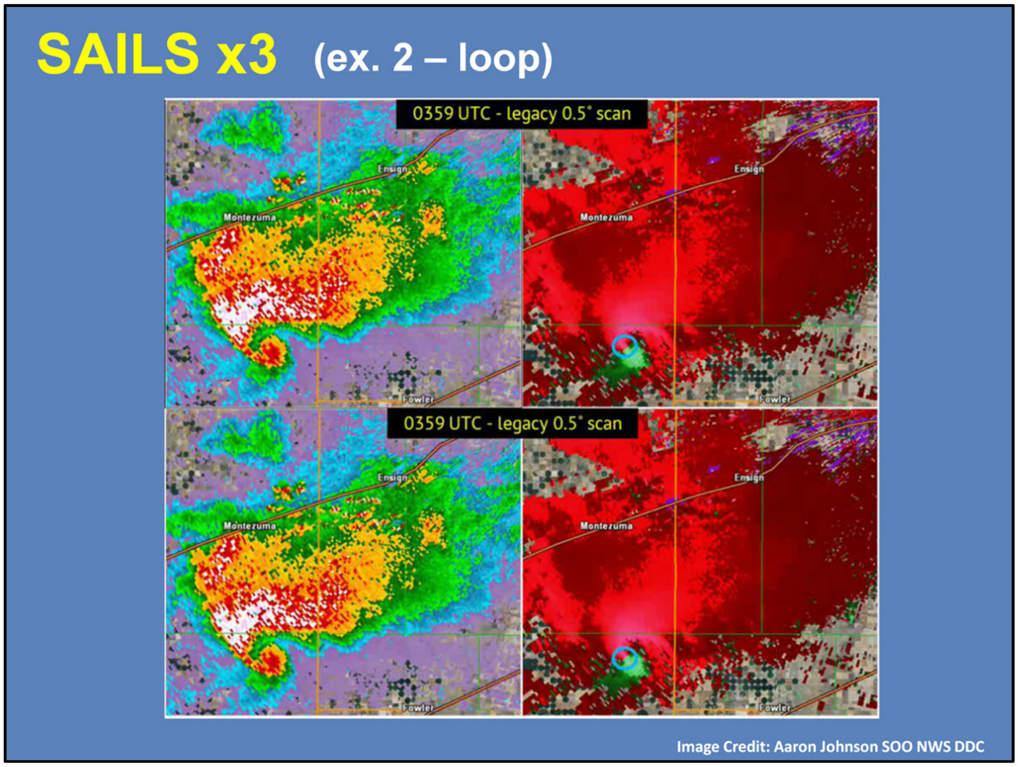


It is fairly intuitive what one additional 0.5° set of products would look like, updating at twice the "normal" rate. But what does almost one-minute 0.5° data look like and what could it mean in terms of watching the evolution of features?

The following examples were provided by Aaron Johnson, SOO at the WFO in Dodge City, KS. This one shows a clear evolution of a tornadic supercell fairly close to the radar – for just one volume scan. We're at 03:59 Z starting on the left, with Base Reflectivity and Storm-Relative Velocity. Between these image on the left and on the right, about 3 to 4 minutes later, the velocity couplet in the cell's hook echo has moved at least a few miles. With no MESO-SAILS enabled, there would be no intermediate images, and you would have to wait 4 to 5 minutes to see where this strong tornadic signature has moved.



This is the first of 3 examples that are all short gif animations, that will keep replaying from start to finish. SAILS x3 is enabled, with Base Reflectivity on the left and SRM on the right. The top half of these loops are the SAILS x3 cuts and the bottom half show just the first 0.5° cut from each consecutive volume – so, standard VCP scanning. Notice that while the bottom half images are basically "standing still", the top half move consistently through scans that are coming in at intervals of just over one minute! Notice how the estimated track of the mesocyclone, added by Aaron, shows a more detailed and refined track then the legacy side which looks like it's just connecting the dots with much lower spatial accuracy.



Now for the second example, again showing the tracks of multiple possible mesocyclones. Not only are we able to better track a more exact path of a potential tornado or at least the best area of rotational velocities, but we now have a bit more lead time on the precursors of these types of signals. As you watch, the second couplet doesn't quite develop and the third one does. The second, which may have been a brief satellite tornado, wasn't even detected with the legacy scan timing.

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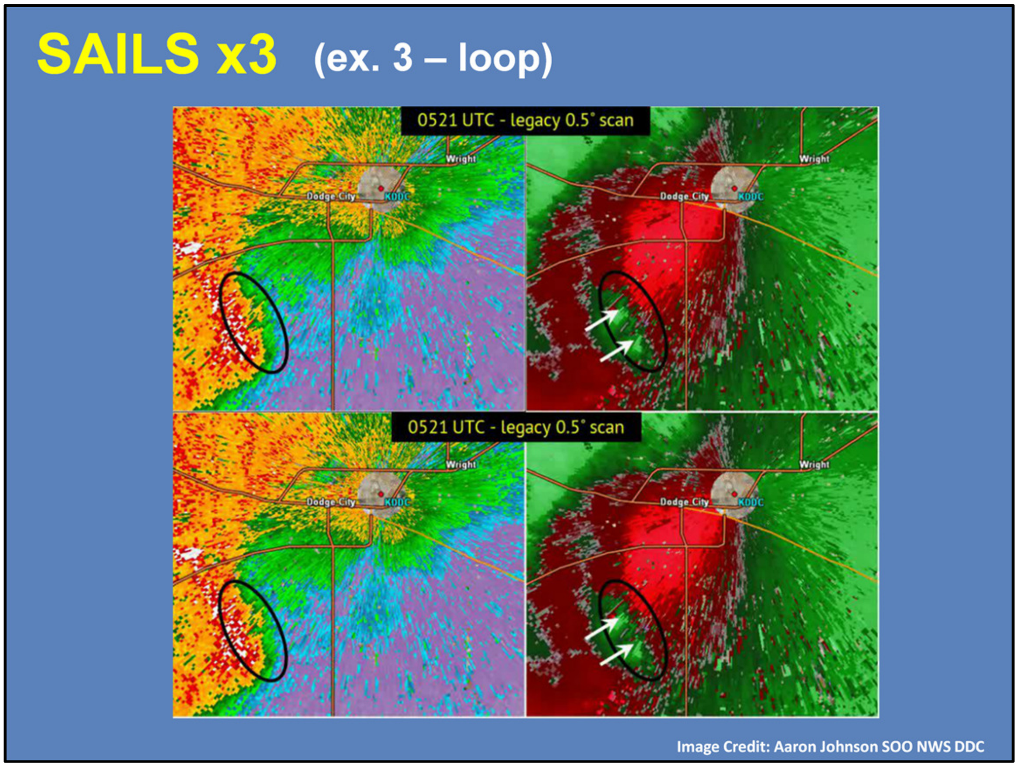

The last example is of an RFD surge that swept just south of Dodge City, KS – just a few miles away from the RDA. There are some brief and embedded couplets with this surge. Notice the difference in the evolution of this feature with SAILS x3 enabled and compare it to the legacy scan timing on the bottom. With a feature like this so close to the radar, you are probably not getting very good data from the upper level tilts anyway. It may be of more benefit to have SAILS x3 running in cases like this, so you can track the low-level progression of such features. If you are more concerned about a core height, you may not have good sampling of the upper tilts of the storm or the core aloft anyway and may have to utilize another nearby radar for that. All of this is a balancing act, where you need to determine, sometimes in real-time, which option is the best to see the features you are looking for.

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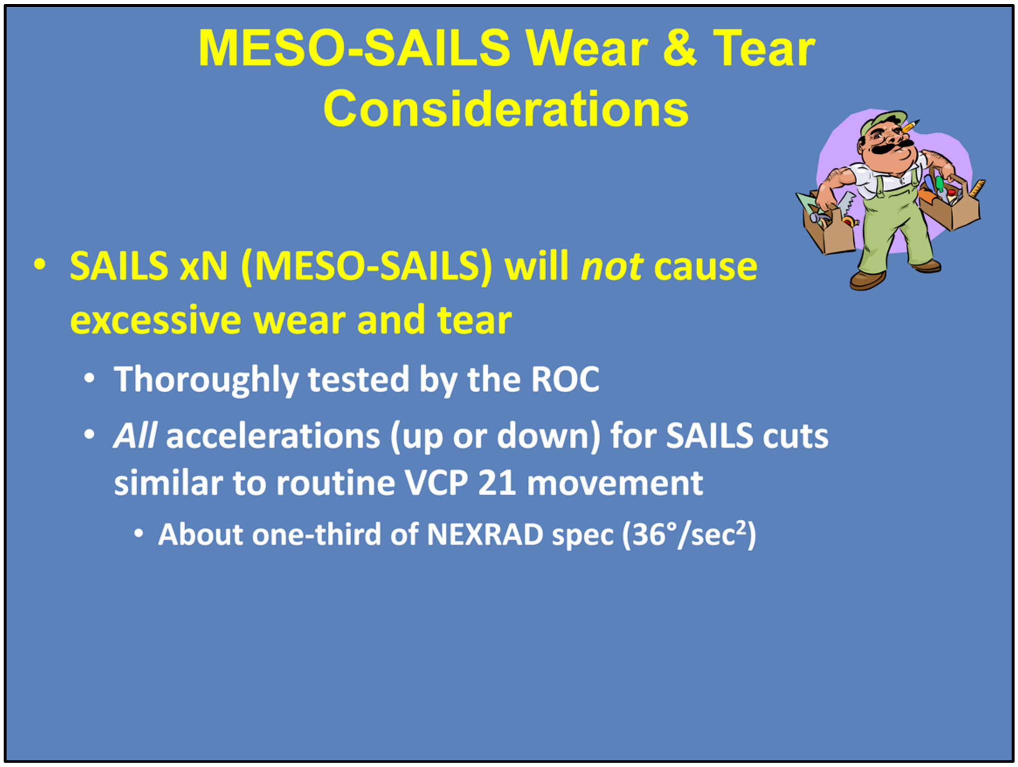
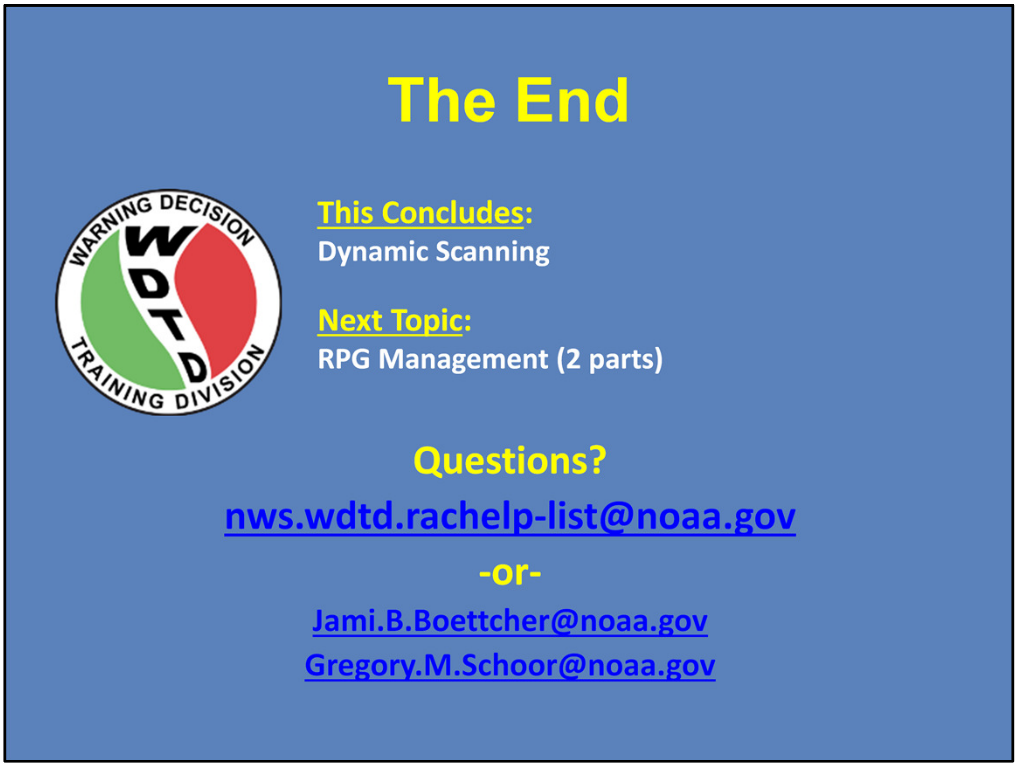


When the faster VCPs, 12 and 212, were fielded, there was initial concern about more wear and tear on the moving hardware of the WSR-88Ds. When SAILS and MESO-SAILS were being tested before deployment, it was understood that no feature was going to be deployed that resulted in excessive wear and tear. The engineers at the Radar Operations Center have evaluated these features and have found no need for concern. SAILS uses the ***same*** azimuthal rotation rates as VCPs 12 and 212 and the antenna acceleration and deceleration rates are comparable to VCP 21, with it's wide gaps between elevations. The antenna motions for both VCP 21 and MESO-SAILS are, at most, ***one third*** of the design specification.



This concludes the lesson on Dynamic Scanning. The next lesson will dive into a 2-part lesson on working with understanding the RPG – or Radar Product Generator. If you have any questions, please direct them to any of the email addresses listed.

Welcome to Topic 2 and the first of two lessons for RPG Management. RPG stands for Radar Product Generator and is basically what creates the products you see that come from the RDA, the radar itself. This lesson will focus on the interface itself for the RPG, showing you the buttons and what they mean. The next lesson will be about the operational functionality of these buttons and features. So, let's get started!

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Lesson: Radar Product Generator (RPG) Human Control Interface (HCI) Controls

Learning Objectives

RDA Controls

- Identify the 4 RDA control options
- Identify the 3 RDA control permissions groups
- Identify the 3 ways RDA status messages can be filtered

RPG Controls

- Identify the 4 commands to control the RPG
- Identify the 2 operational modes for the RPG
- Identify the 3 RPG alarm groups seen when checking the RPG status
- Identify the purpose of the wideband & narrowband lines
- Identify the 2 repositories for data archiving
- Identify the location for console message dissemination

With so many buttons and features we will go over in this lesson, here are the objectives which are all essentially the identification of the various options with each button and feature. So, please read through these and keep them in mind as you go through the lesson. The next slide is the performance objectives which is a more hands-on version of these objectives.

Lesson 1: RDA Unit Status & Control
Performance Objectives

RDA Controls

- Control the RDA from the Human Control Interface (HCI) GUI
- Monitor the status of the RDA system from the HCI GUI

RPG Controls

- Control the RPG system from the Human Control Interface (HCI) GUI
- Monitor the status of the RPG system from the HCI GUI
- Monitor the status and control the wideband line from the HCI
- Monitor and administrate narrowband line connections
- Locate and configure the archival of level II data
- Send a console message to narrowband users

As mentioned on the previous slide, these are the performance objectives for this lesson, please read through them and keep them in mind as you go through the lesson.

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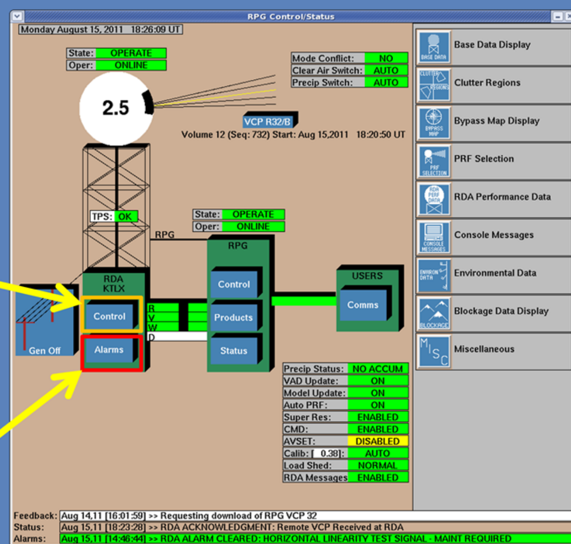
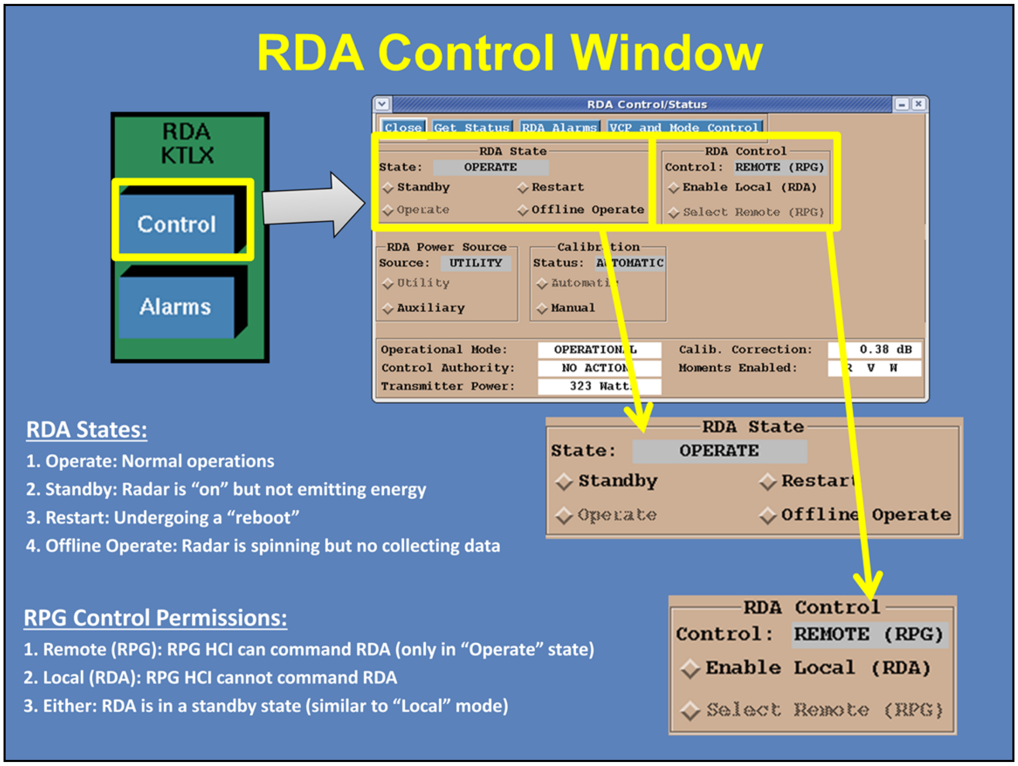
RDA Control & Monitoring

- Z, V, SW base data created at RDA and sent to the RPG
- RDA Control
  - Control icon in the RDA section
- RDA Monitoring
  - Alarms icon in the RDA section

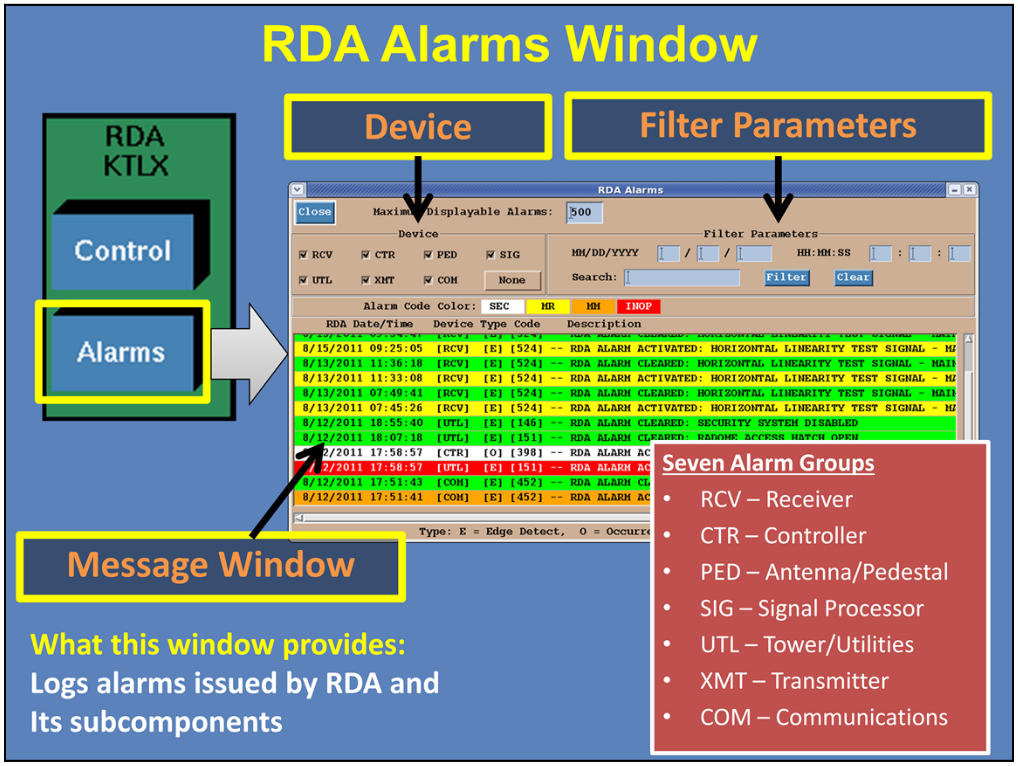


So this window you see is the RPG HCI. HCI stands for Human Control Interface. This is your control panel for the entire radar, if you will, the one module you will use to view, modify, and monitor settings of the radar itself and the products it generates. The RPG, or Radar Product Generator, basically converts base data from the RDA into other products that are derived and displayed in AWIPS and other display modules. This lesson is all about the three darker green modules in the middle of the image you see, which is an example of an RPG HCI window. These three modules hold clickable buttons, the blue buttons, where you'll find a number of other important settings. The next few slides will talk about how the RDA can be controlled and monitored.

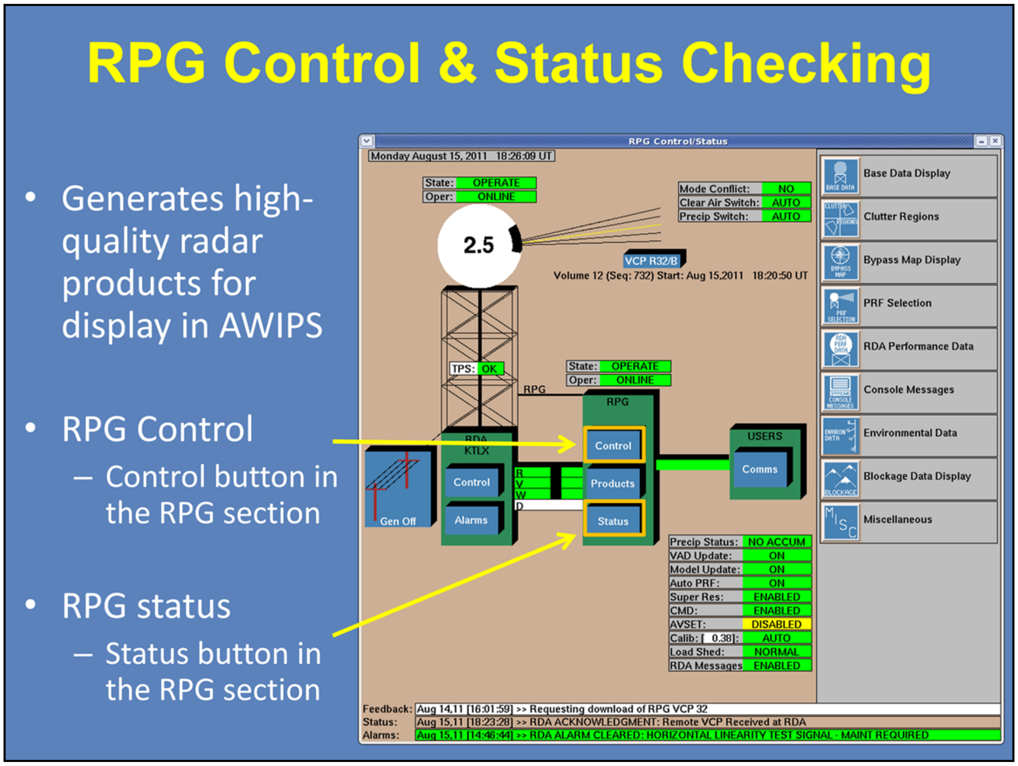


The RDA control window is just for that purpose – to control the functions of the RDA. First of all, if the RDA is running routinely, the state is called "Operate" which you'll see in the status window on the main GUI as well. When you click on the 'Control' icon in the RDA as shown here, the window on the right will appear, showing the current state of the RDA. This is also where you would change the operational state of the RDA if necessary. Since the RPG is also a part of this equation, the RDA control portion of the window allows the user to specify whether or not the RPG can send commands to the RDA.

Please take a moment to look through the different states and aspects of these two sections of the window, down on the left hand side and continue when you're ready.



You can monitor the RDA, click on the 'Alarms' button. From this window, you can view and filter all current and previous alarms issued by the RDA. Messages are displayed as a scroll list in the message window. The Device Box allows you to sort and isolate messages by the RDA sub-component that triggered the alarm. There are seven alarm sub-groups from the RDA, which are spelled out in the red box on the lower right for reference. Unchecking a box will only hide the alarms from the message window not fix the alarm. As a result, you will have to be careful with keeping these boxes unchecked from long periods of time. In general, a vast majority of the yellow and green alarms can be ignored. Most of them as just status messages as opposed to actual alarms. There are so many different components and algorithms that go into a radar's operating system, that many of these are just internal checks on the system. However, when you see orange and especially red alarms that don't clear themselves within a least a couple of minutes, then you should alert the El Techs or shift supervisor so that troubleshooting techniques can be administered.



Now that we've covered the 2 big buttons on the RDA, let's go down the line to the RPG, which has 3 big blue buttons. Recall that the RDA is basically the radar itself and the various receiving hardware in the shelters underneath the radar. The RPG is the box that receives this data and converts it into what we know as products that can be displayed either in AWIPS or other platforms.

The RPG is controlled through the Control button you see here, and RPG status monitoring is accessed through the Status button. We will address each of these components on the slides ahead. The products button is geared toward the actual products generated, which you won't need to monitor or modify, so we will skip that for this lesson.

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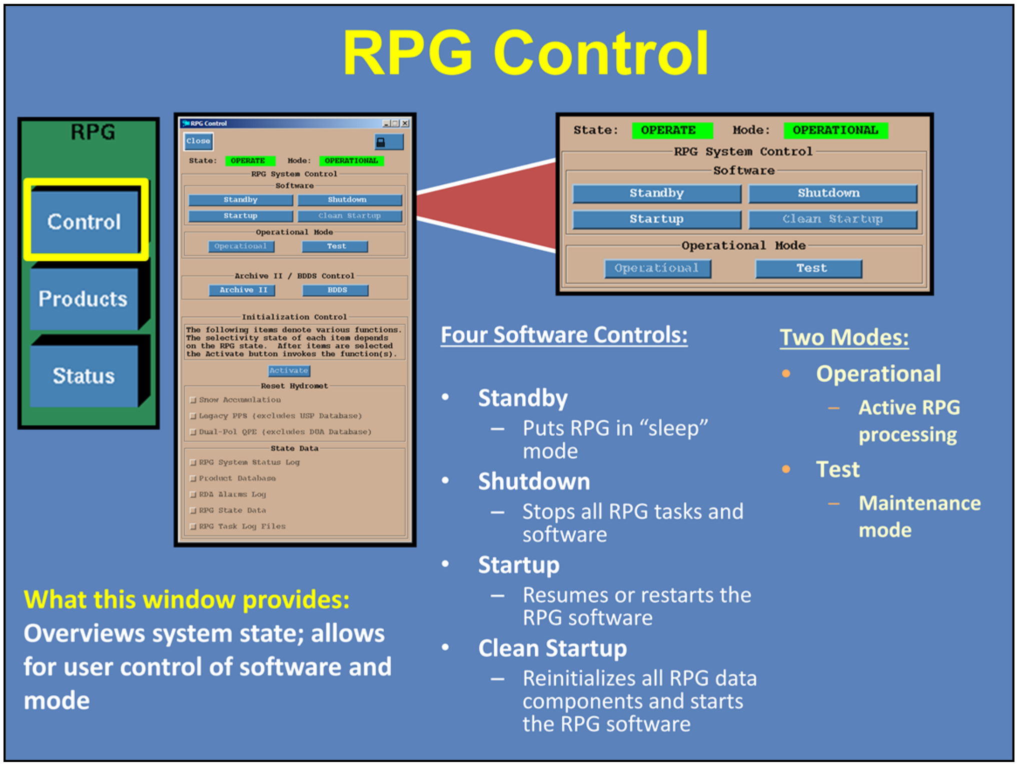

There are 4 software control commands that can be initiated on the RPG software, there in the lower middle – Standby, Shutdown, Startup, and Clean Startup. Read through each of the control functions and know that these are options for times when the radar needs to go into some other mode that is not fully operational. If the radar goes down unexpectedly or for routine maintenance, these are the different functions to react to in those cases, much like a regular PC. The RPG also has two similar modes but slightly different because of the configuration it has compared to the RDA. The RPG's two mode are Operational, which means the RPG is active and processing data and then you and Test it, which can be initiated for a number of reasons such as maintenance at either the RDA or the RPG. With an idea of the different control types available to the RPG, we will now focus our attention on monitoring the status of the RPG.

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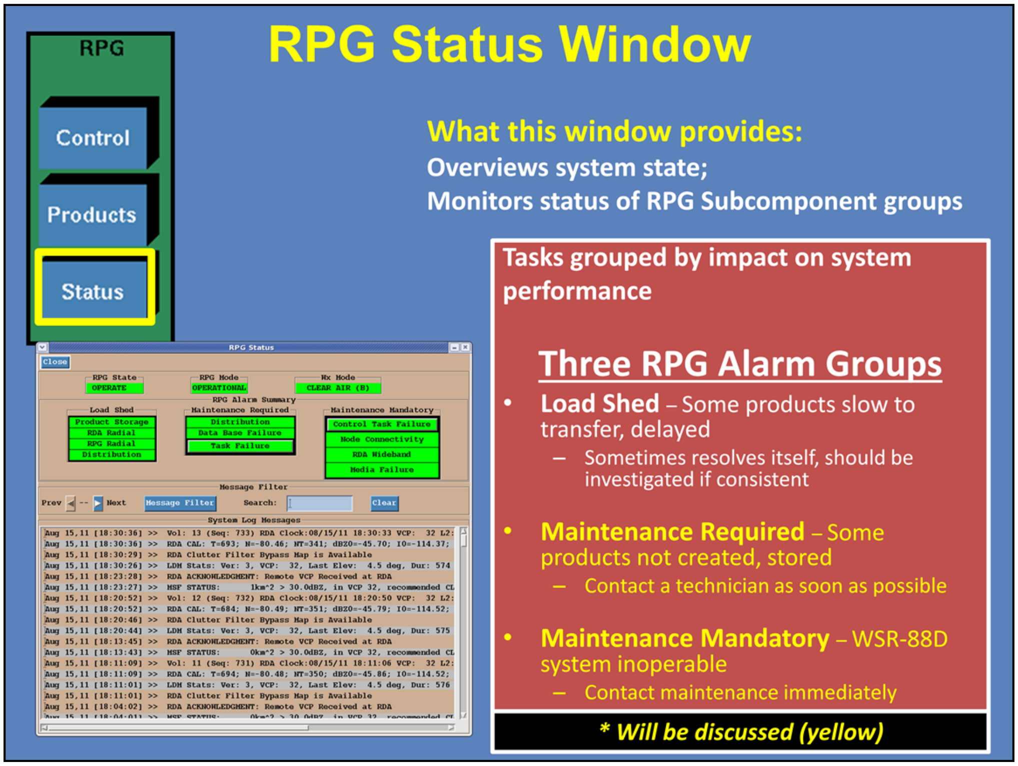
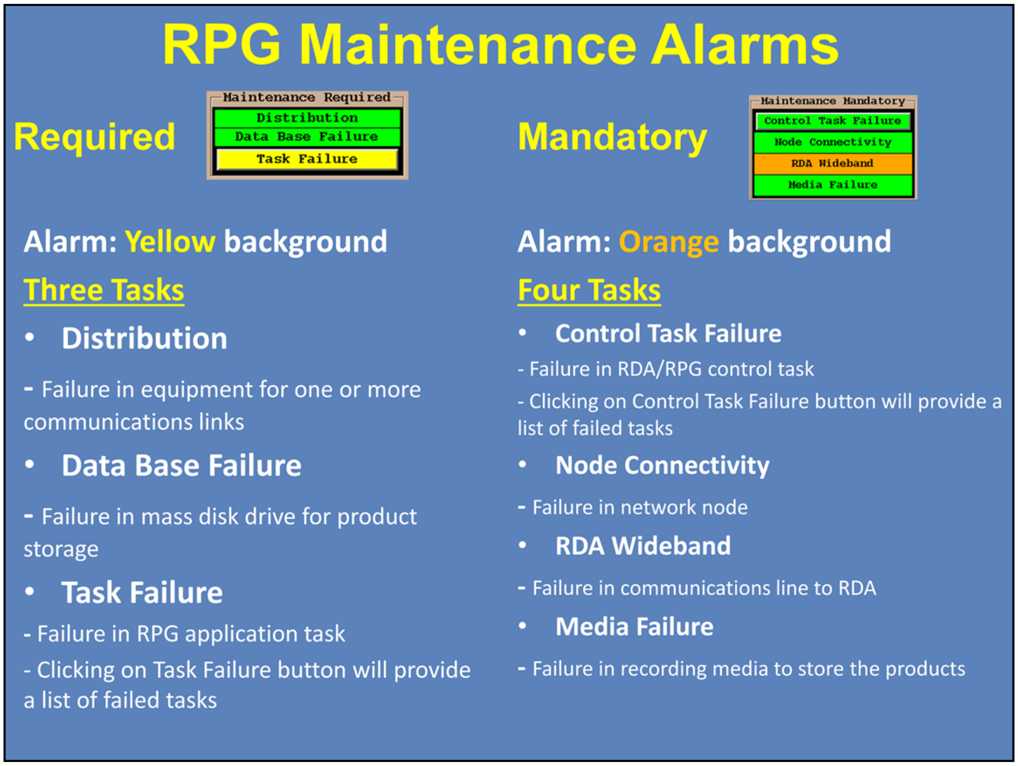


To launch the RPG status window, click on the ‘Status’ icon in the RPG section of the HCI. This window provides an overview of the RPG system state and current mode, along with the status of several RPG subcomponents. We will elaborate on the two types of maintenance alarms you see in the lower right window, the required and mandatory maintenance types. Load Shed type alarms sometimes appear but are less critical and mostly clear themselves up.

Consistent alarms should be investigated for a potential data bottlenecks.



The other two types of alarms are the ones that will require action to be taken, if they don't clear themselves automatically or appear consistently. The RPG's alarms differ from the RDA in that they are more about the software side of things than the hardware and parts of the RDA – or the radar itself. So common issues for the RPG usually have to do with a backlog of products, improper generation of products for various reasons, and connectivity issues. On the left, the "Required" alarms are the slightly less serious but still important alerts, which appear in yellow. Then, on the right, you have the more time-sensitive alarms – which are called mandatory because the RPG cannot do it's job, relative to this alert, and needs immediate attention. Please also take a moment to read through the types of associated mandatory alerts.

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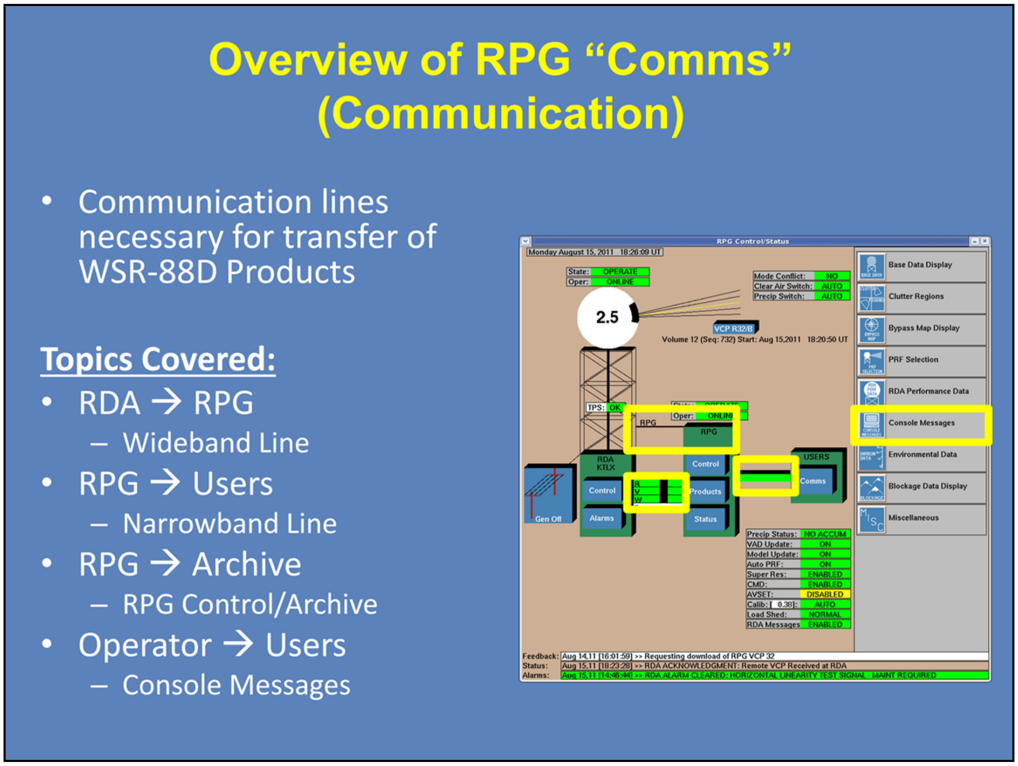

In this last section, we will cover system communication. Communication lines are important for the transfer of data throughout the WSR-88D system and ultimately to it's end-location, such as your AWIPS environment. While there are numerous communication procedures employed by the WSR-88D system, we will focus our efforts to 4 communication topics:

1) First, how data are transferred between the RDA and the RPG
2) Second, how data flows between the RPG and the users
3) Third, how data are archived to use by external partners to the NWS
4) And finally, how you the radar operator can relay information and messages with other end-users

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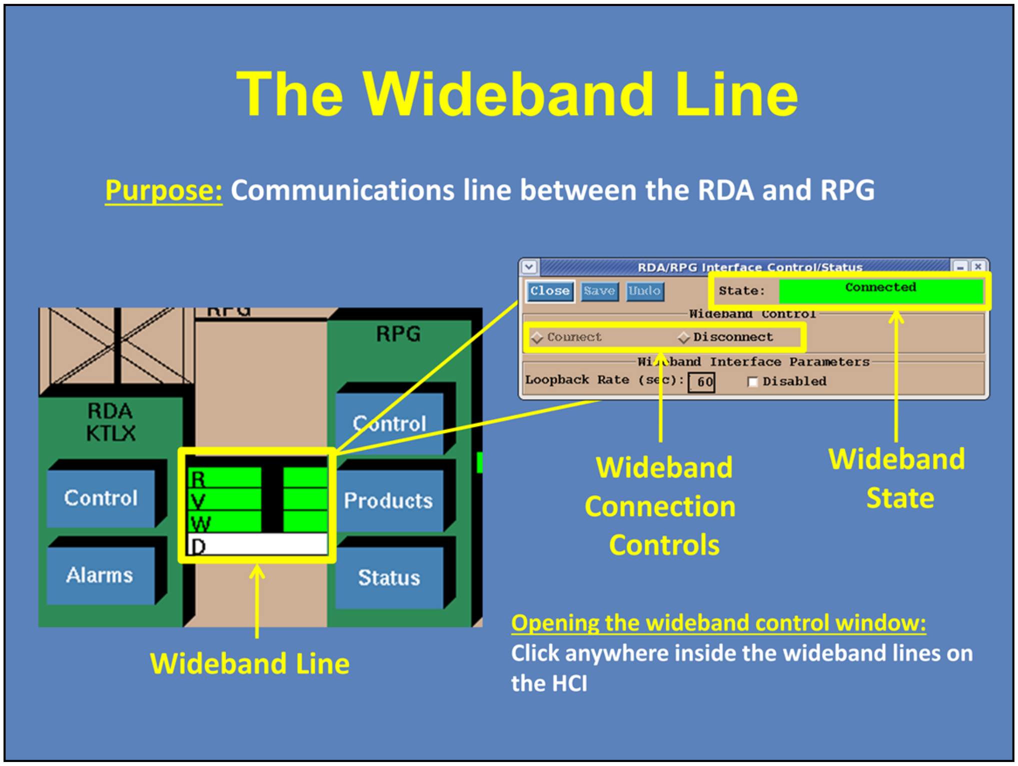

The wideband line is basically the main communications link between the RDA and the RPG. See the 4 lines there in the image on the left? This basically is showing the data stream of base products produced at the RDA and is sent directly through this line to the RPG, so that the RPG can generate the various derived products *from* the base products.

If there is ever an instance where it is necessary to disconnect, the Electronics Technicians or El Techs should perform this task. But clicking on this zone will pop up the window you see on the right.

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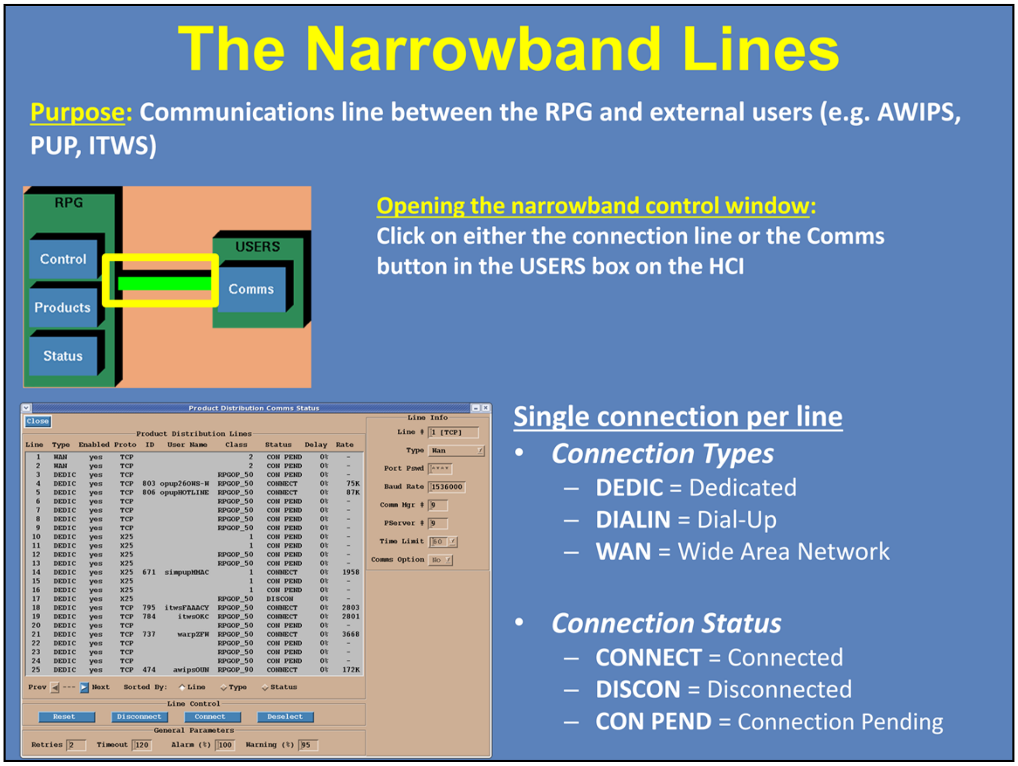
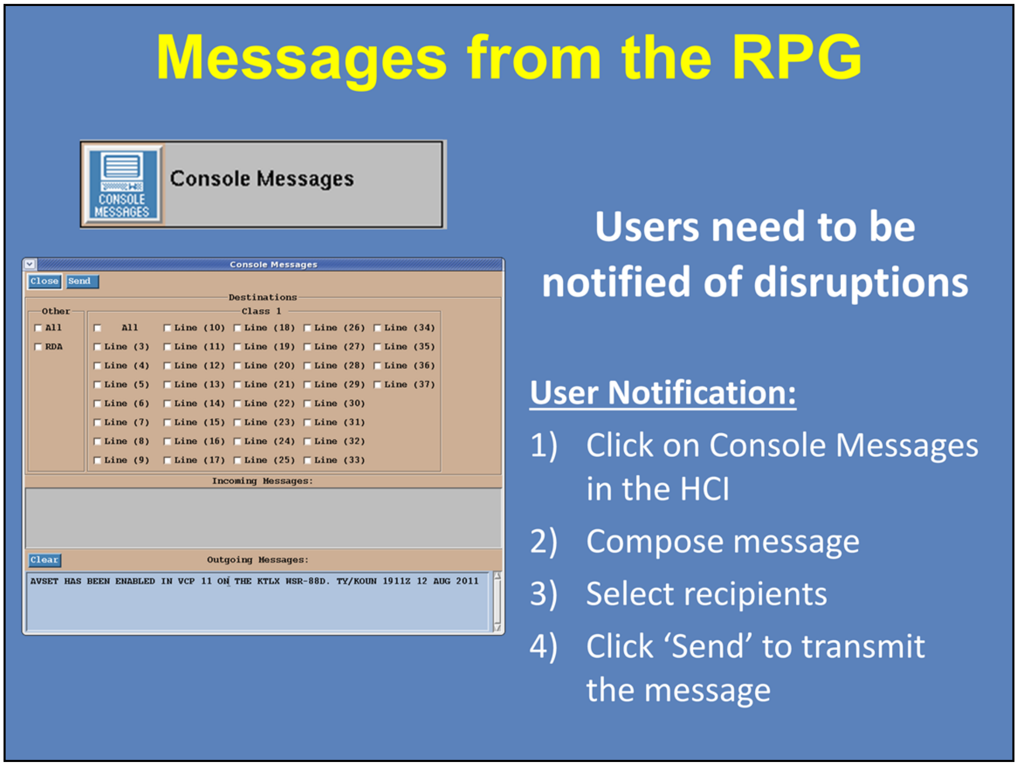


The other type of communications lines are the narrowband lines. They serve as the communication medium between the RPG and external display systems, such as your operational AWIPS. Users are typically entities with their own RPG and use it to receive products from this radar through this line. Think of it as a dial-up internet connection to a server, with differences in the technicalities. Your Radar Program Leader should have a list of what's called the "Dedicated Users" or entities that have one of these line feeds. The main thing to monitor is whether one of your users is having problems with their connection, which will either show Disconnect or Connect Pending. Not every entry that has this status has a problem though, most or all of these that you'll see are set up a certain way for specific purposes – but something to keep in mind when doing a routine checklist check.



Messages can be sent from the RPG which, in AWIPS 2 for instance, will show up as an FTM product – or "Free Text Message", which will go out to the users. The main purpose of this feature is to notify end users of something having to do with the radar's operability. If the radar has failed for some reason yet unknown, or if a technician is taking it down for routine maintenance, this is the way to do the quick notification.

To generate a message, click on "Console Messages" on the right side of the HCI. Compose the message on the bottom of the window. All caps is default and the only way it will appear. Make sure that "All" and "RDA" and selected on the left-side – which will send it to everyone. Unclicking them will make it an internal message. Then click "Send". Nothing will happen on this end, but you will see the message if you type FTM and the 3-letter WFO identifier in an AWIPS text window. In fact, that's a good practice to make sure the message sent.

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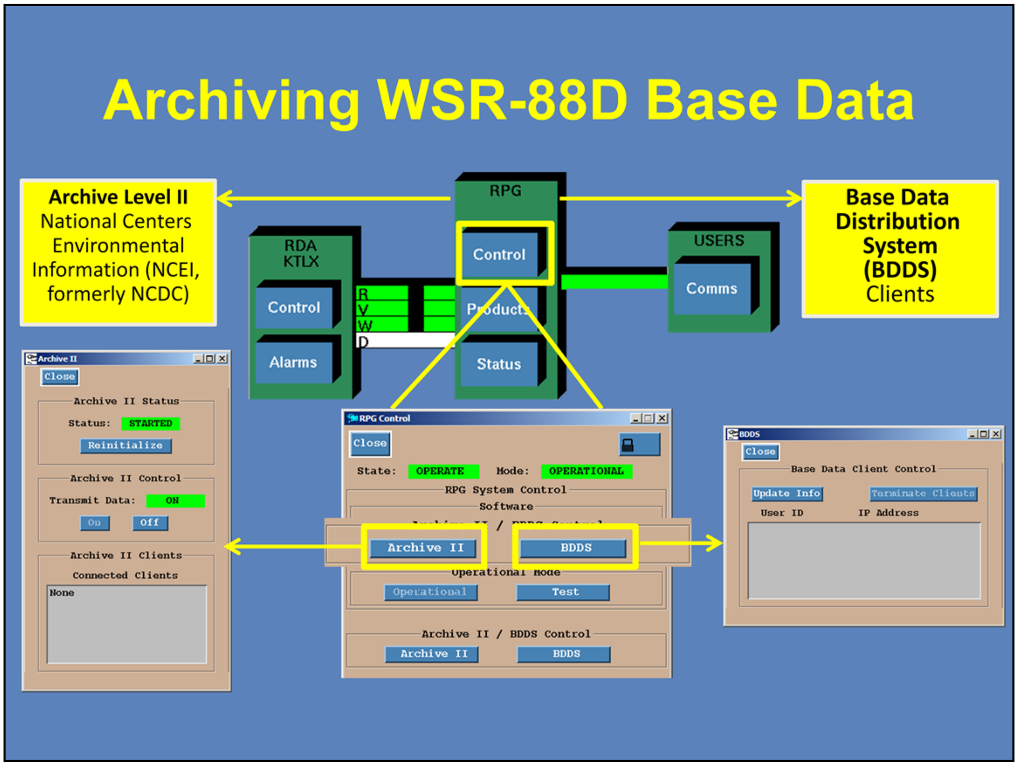


Finally, let's look at how WSR-88D data are archived. In addition to the base data being transferred to the narrowband lines, the base data can also be transferred to the following two places:

1) First, all the level II and level III data goes directly to the National Centers for Environmental Information, NCEI which is the former NCDC. They inventory the base data and make it available for public distribution.
2) Second, Level II base data will also be provided to specific clients through the Base Data Distribution System (BDDS).

Archive status can be viewed and modified by clicking on the RPG control button. Inside, you will find 2 buttons, "Archive II" and "BDDS". Clicking on each of these will reveal their individual configuration windows. Here, you can monitor the status of the archive and manage the sites receiving the data. All of this should already be set up for your radar with no real reason to make modifications.

RDA Control & Monitoring Summary

Four commands for RDA software

- **Operate** – the radar is scanning and processing data
- **Standby** – the radar is on but not emitting energy
- **Restart** – the RDA components will be restarted
- **Offline Operate** – the system is operational but not collecting data

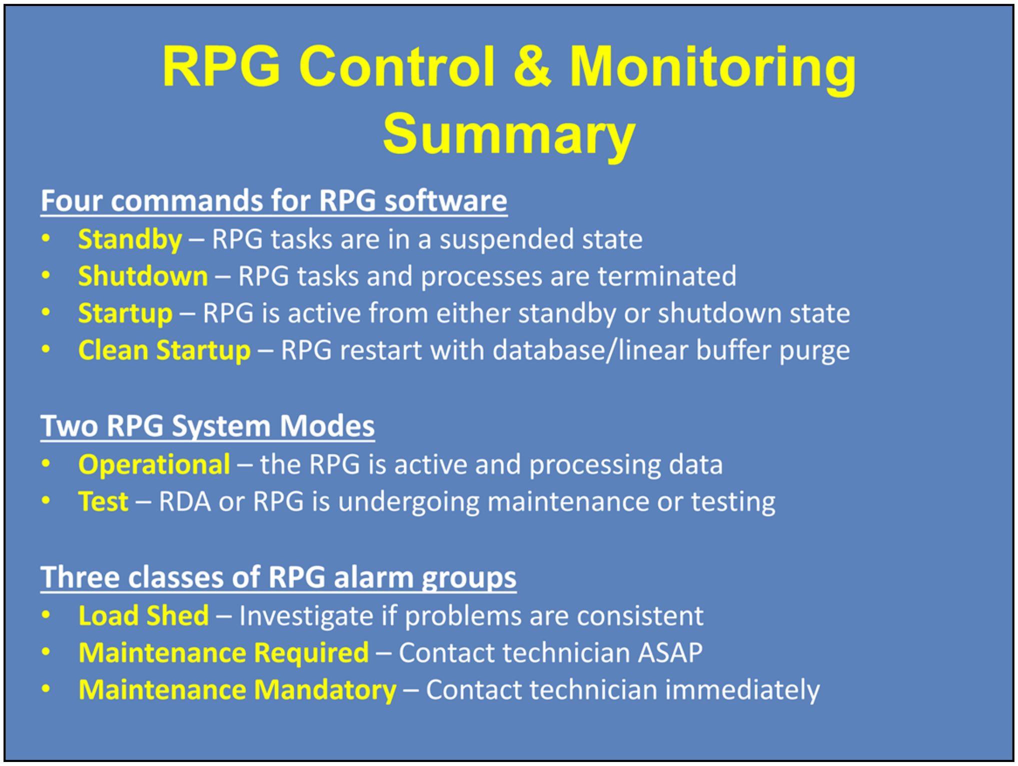
Three control permissions

- **Remote (RPG)** – commands can be sent from the RPG
- **Local (RDA)** – commands can only be sent locally from the RDA
- **Either** – RDA is in a standby state ; similar to Local (RDA)

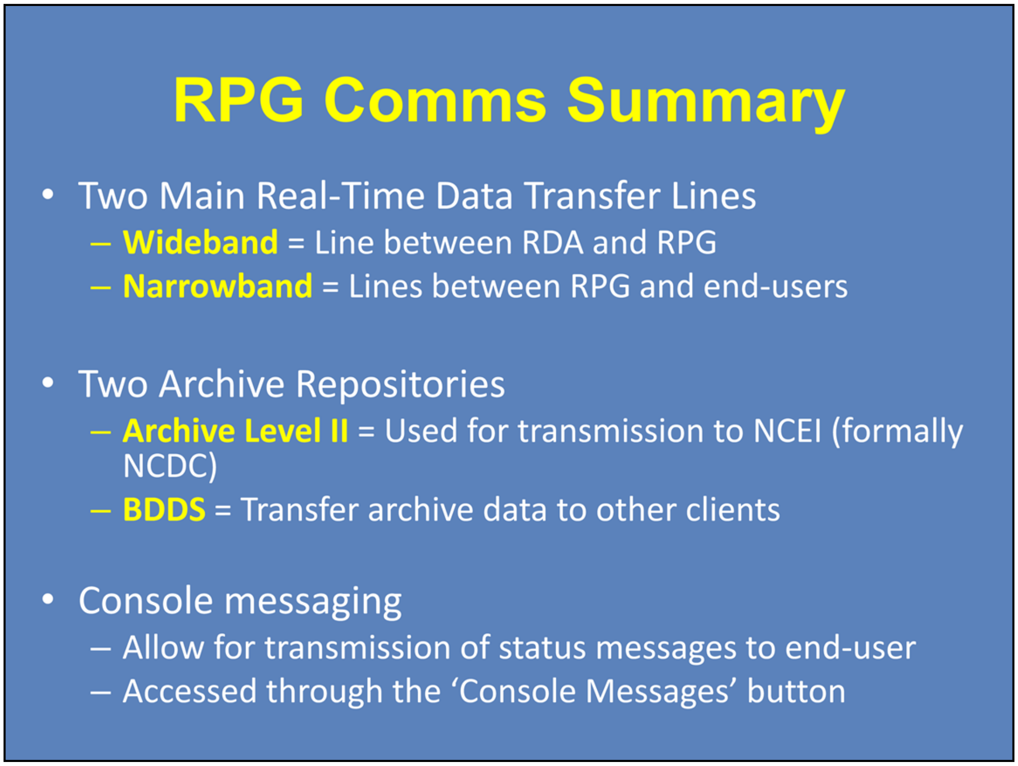
RDA Status Monitoring

- Alarms are separated by RDA component (7 total alarm groups)
  - receiver, controller, antenna/pedestal, signal processor, tower/utilities, transmitter, communications
- Messages can be filtered by
  - Date, search term, and/or RDA component

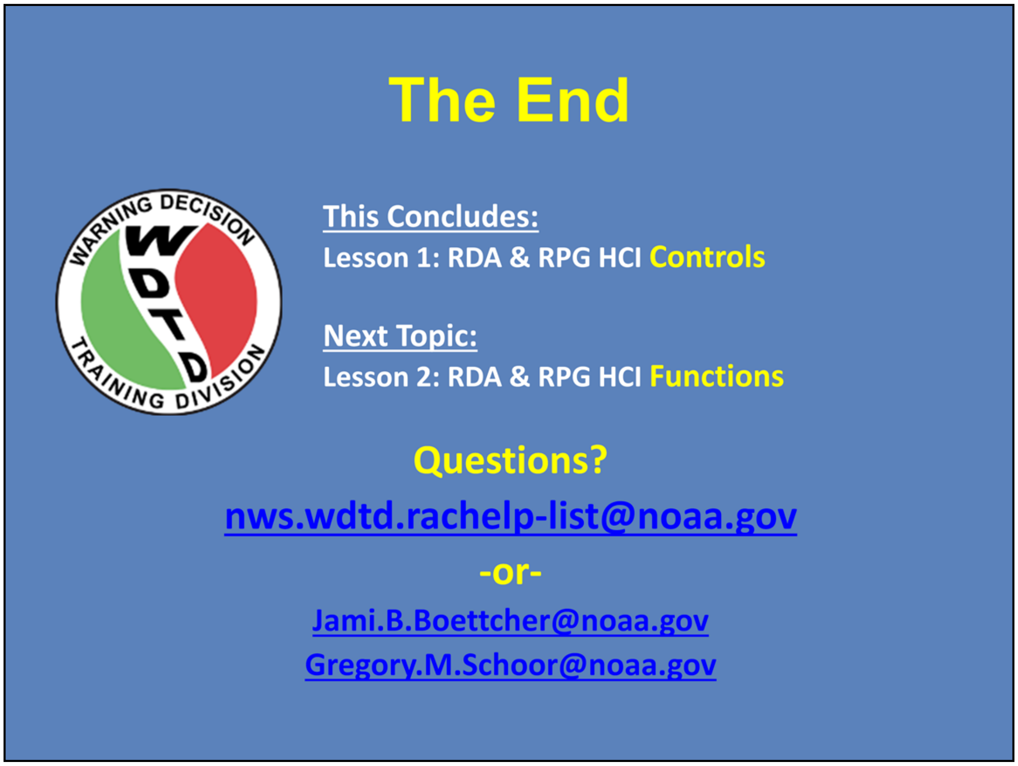
Since this lesson was essentially 3 separate topics rolled into one with a lot of options associated with each feature of the RDA and RPG, we'll have 3 separate summary slides for you to act as a reference for each. First off, this is a summary of the RDA control and monitoring window. Please read through them and go to the next slide when you're ready.



Next, we jump over to the RPG, which initially looks like it has similar characteristics to the RDA's features, which it does, but the RPG, being mostly a software operation, has some very different status options and associated alerts. Please read through this summary and go to the next slide when you're ready.



Lastly, the 88D comms must also be taken into account. Since there is a radar or radars that are based out of your office, it is up to you to monitor where the data is going and if it is getting there, through the communication lines and making sure the data and products go to internal and external users. Please read through this summary and go to the next slide when you’re ready.



This concludes the lesson on the RDA and RPG interface management. The next lesson will dive into the operational usage and functions of these windows. If you have any questions, please direct them to any of the email addresses listed.

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Welcome to Topic 2 and the second of two lessons for RPG Management. After learning about the different buttons and windows in the RPG HCI for controlling and monitoring the system, we will now focus on the functionality of some of these buttons and windows, to see what they can do for you in an operational sense. So, let's get started!

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Learning Objectives

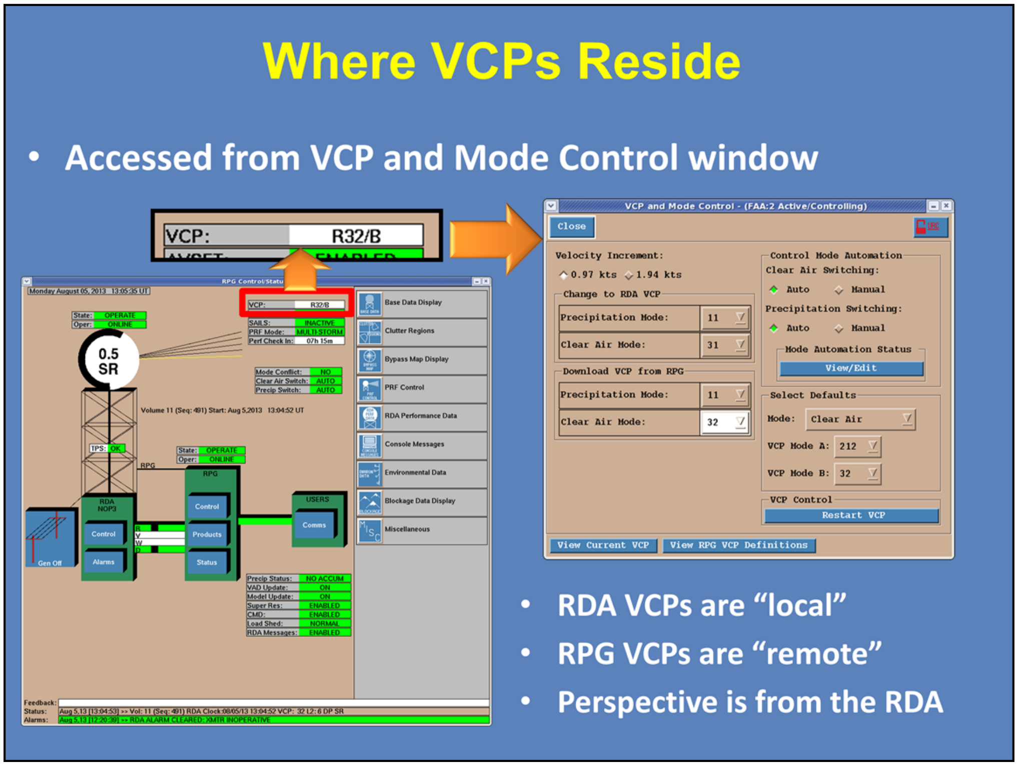
Through the RPG HCI:

- Define the three VCP groups in the system
- Identify the 3 PRF Control options
- Identify the 2 mode types for switching between VCP groups
- Identify and define the 3 environmental data parameters configured in the HCI

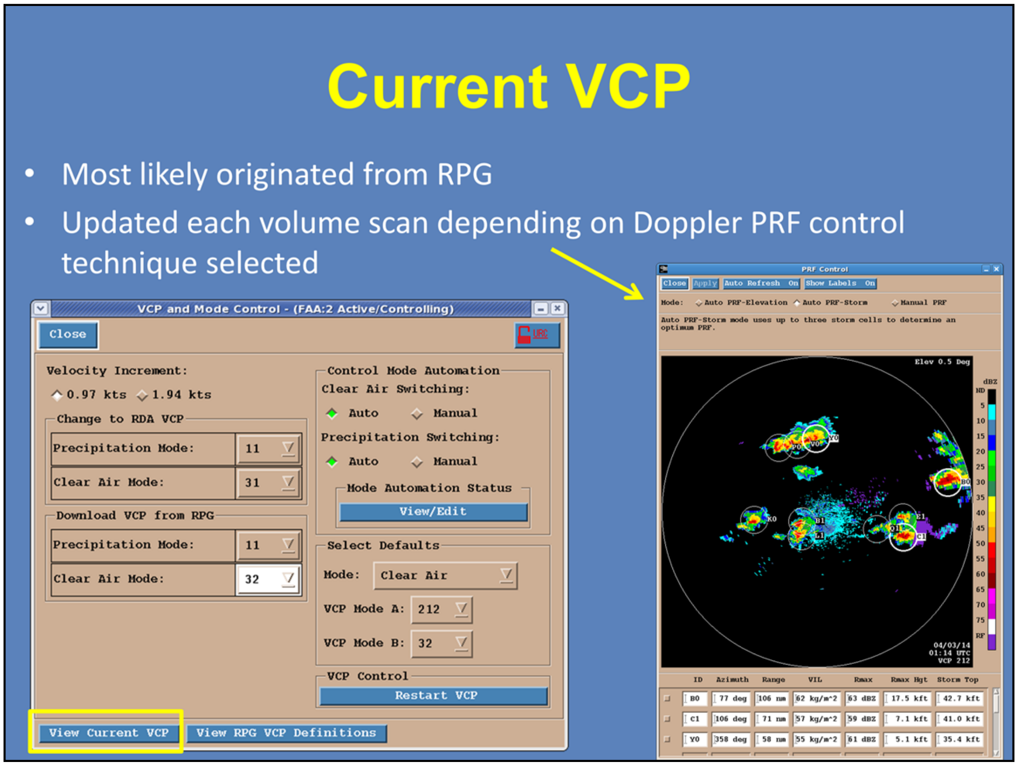
Performance Objective

- View and edit the 3 environmental data parameters from the HCI

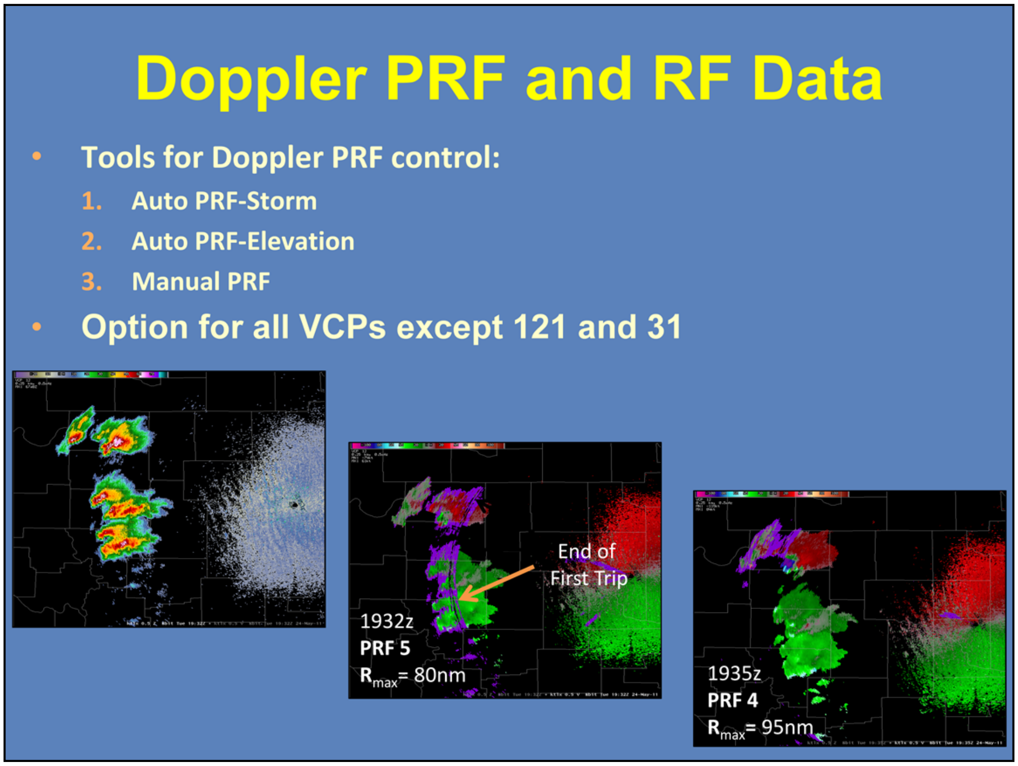
There are four learning objectives with this lesson and one performance objective. Please take a moment to read through these and move to the next slide when you're ready.



All of the VCPs are accessed from the VCP and Mode Control window. From the RPG HCI main page, clicking on the VCP button reveals the VCP and Mode Control window. There are VCPs stored at both the RDA and the RPG. The RDA VCPs, 11, 21, 31, and 32, have been stored at the RDA since the original WSR-88D deployment. At the RPG, the original 4 are available, as well the newer VCPs, such as 12 and 212. The VCPs stored at the RDA referred to as Local VCPs. The VCPs stored at the RPG are referred to as the Remote VCPs. The concept of Local vs. Remote is from the perspective of the RDA. If you look closely at the current VCP as it is listed on the front page of the RPG HCI, there are some extra letters. In this case, the R that precedes VCP 32 means that it's origin was Remote. Remote means it was downloaded from the RPG to the RDA. The /B that follows VCP 32 is a reminder that 32 is a Clear Air Mode VCP.



On the previous slide, VCP 32 was the current VCP. There is a “Current VCP” every volume scan. Though it may have the same VCP number, some characteristics of the Current VCP can change as often as every volume scan. For example, the Doppler PRF for the lower elevations can change, depending on the option chosen for PRF control – which is what we will take a closer look in the next slide.



The WSR-88D routinely displays velocity data beyond the first trip, and there are five different Doppler PRFs. Each of these PRFs has a different resulting R_{max}. The end of the first trip can range from ~65 - 95 nm, depending on the Doppler PRF used. There are three different tools for Doppler PRF control, and they will be discussed in the order presented on this slide. None of these options apply to VCPs 121 or 31. The reflectivity and velocity images here show the power of applying the appropriate PRF Control technique.

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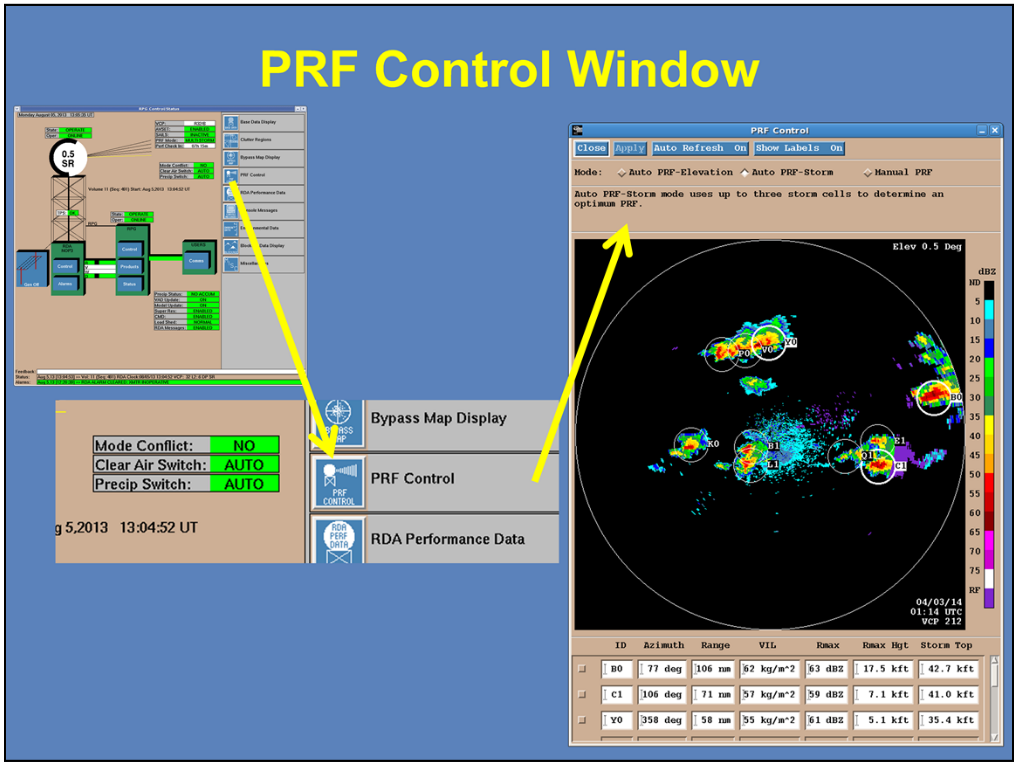

All of the PRF Control techniques are selected from the PRF Control window. This window is accessed from the RPG HCI Main Page by clicking on the PRF Control applications button. The graphical portion of this window shows the 0.5° Reflectivity and the RF from the Velocity data only. Details of the graphical and table portions of the display change dependent on the PRF Control method chosen.

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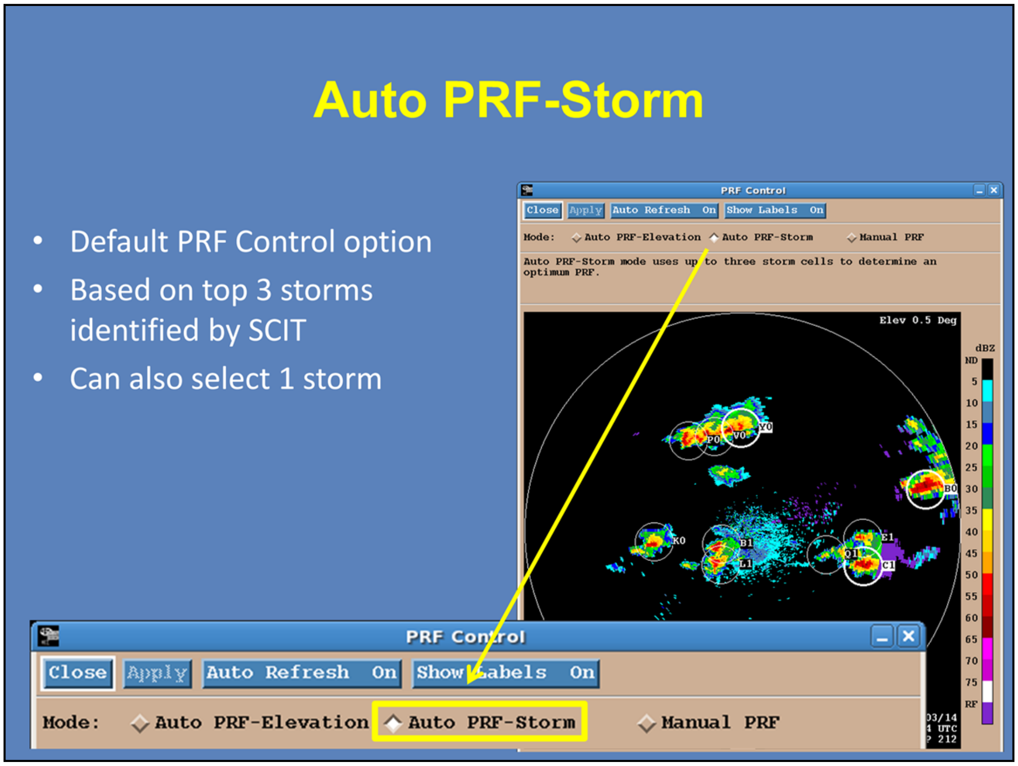
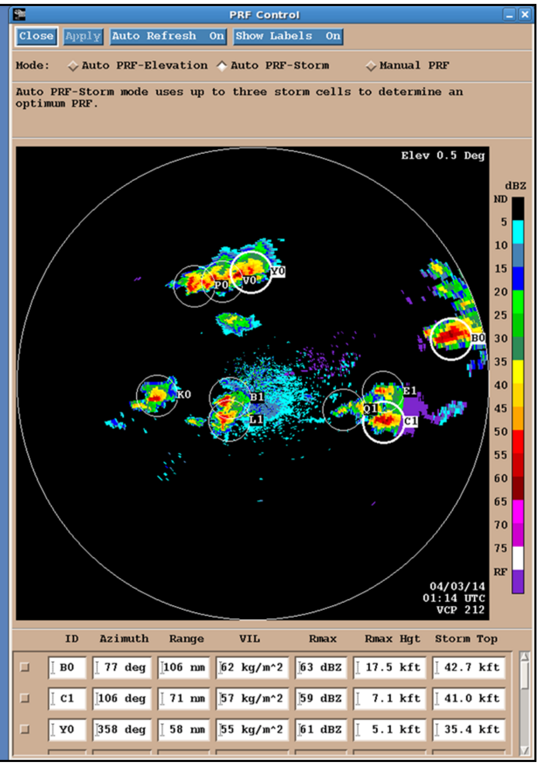


The default option is “Auto PRF-Storm”. It chooses the Doppler PRF that has the least amount of RF data for the top 3 storms. Auto PRF-Storm also has the option of protecting a single storm from RF data.

Auto PRF-Storm Process

- Default is top 3 storms
  - Ranking by Storm-Based VIL (≥ 20 kg/m²)
- SCIT forecast positions for next volume scan
  - 20 km radius circles around storms
  - PRF (#5-8) of least RF in all 3 circles chosen
- Process repeated every volume scan



Auto PRF-Storm is reliant on storms identified by the Storm Cell Identification and Tracking (SCIT) algorithm, and the storm-based VIL of these storms. The default setting for Auto PRF-Storm selects the 3 most significant storms, based on storm-based VIL. The IDs and attributes (such as VIL) of the top three storms are listed in the table at the bottom of the PRF Control window. Those storms also have wide circles around them on the graphical area of the PRF Control window.

For these storms, the SCIT forecast positions for the next volume are used to create 20 km radius circles around each storm. The Doppler PRF (#5-8) with the least RF in these 3 circles is downloaded to the RDA for the next volume scan. This process is repeated every volume scan.

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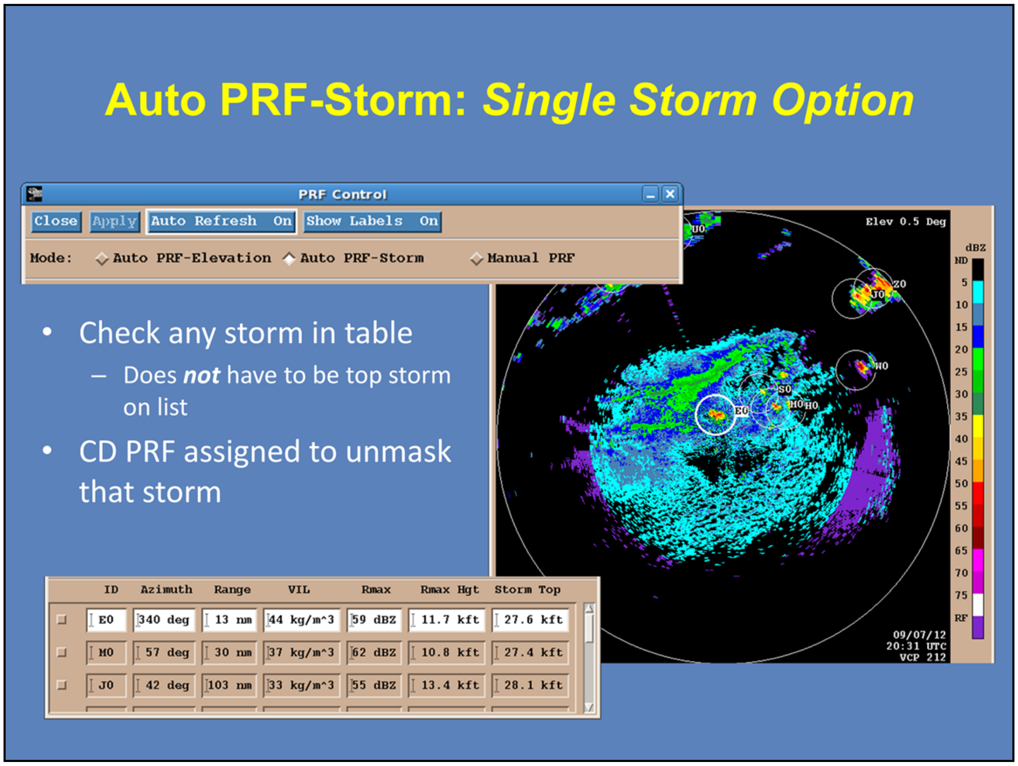

Auto PRF-Storm also has a single storm option, which can be invoked by clicking on the checkbox associated with a single storm in the table at the base of the PRF Control window. The chosen storm does not have to be the one with the highest VIL.

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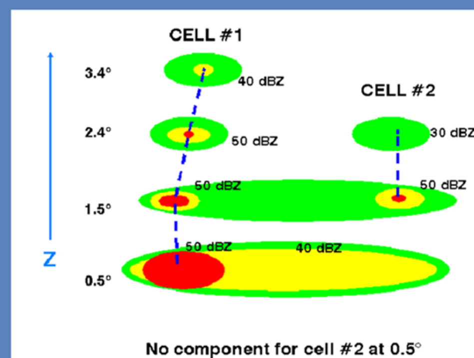
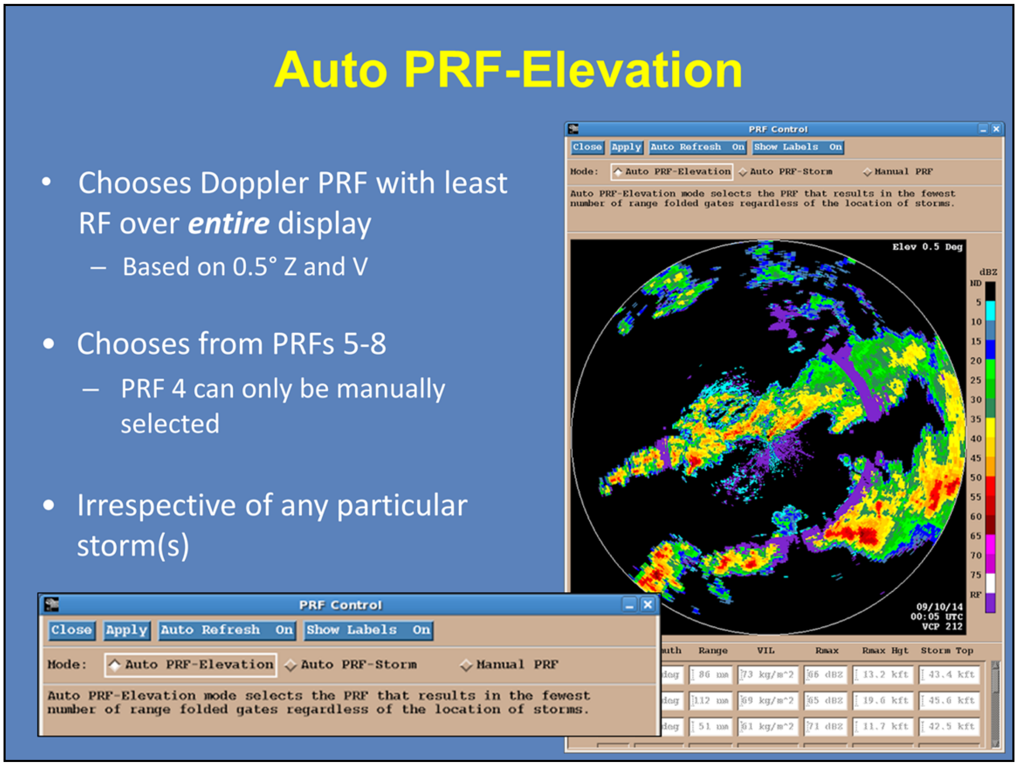
Auto PRF-Storm: *Limitations of SCIT*

- SCIT performs best with isolated storms
  - More consistent storm IDs over time
- Changing VCPs may change SCIT storm IDs
- Merging and splitting storms can result in changes to the SCIT storm IDs



Since “storms” as defined by Auto PRF-Storm are those that are identified by the Storm Identification and Tracking Algorithm (SCIT), the limitations of SCIT must be kept in mind when using Auto PRF-Storm. SCIT performs best with isolated storms, which retain the most consistent storm IDs over time. There are many things that can change the ID for a given storm, such as changing the VCP or storms that merge or split. The diagram below shows how the SCIT algorithm loses cell #2 at the lowest degree because it is elevated and cell #1’s echoes bleed over into cell #2’s area. So SCIT would have trouble putting a track on cell 2 with this type of issue.



Auto PRF-Elevation uses the 0.5° reflectivity and velocity data, and examines the total areal coverage over the display for Doppler PRFs 5-8. The PRF with the lowest areal coverage of RF over the entire display is chosen and downloaded to the RDA for the next volume scan. Auto PRF-Elevation pays no attention to actual storms or intensities on the scope, only the area of RF coverage, so keep that in mind when choosing this option.

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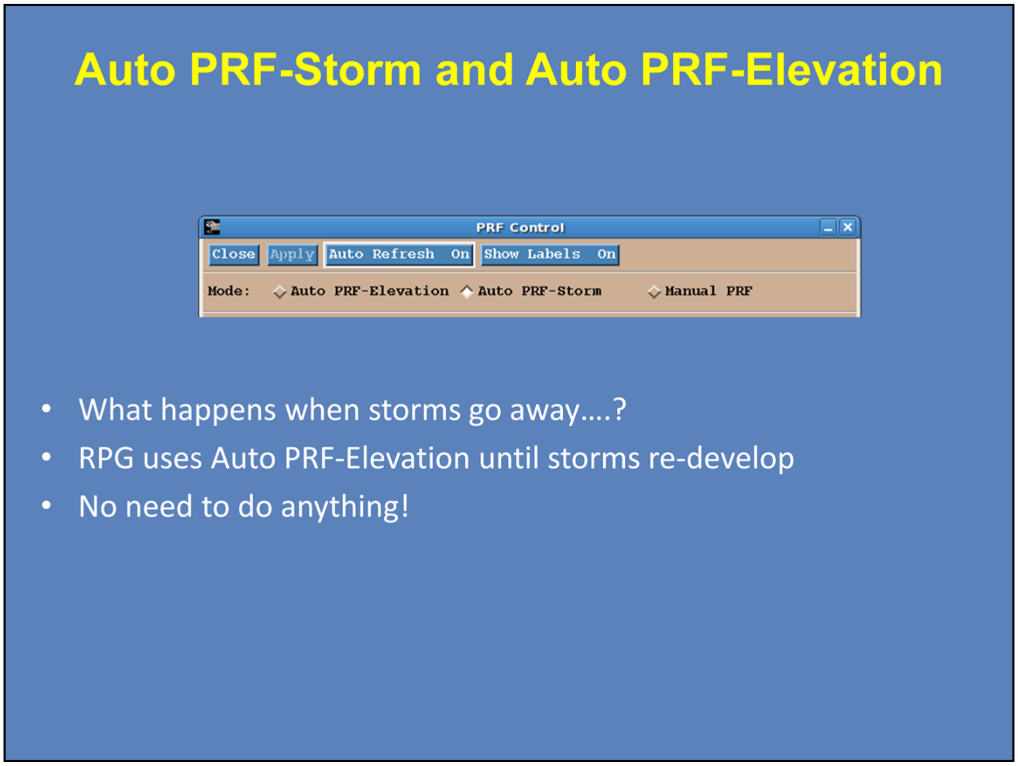

Now that the basics of Auto PRF-Storm and Auto PRF-Elevation have been presented, the RPG has an additional feature that is a good thing to know. When storms dissipate, Auto-PRF Elevation will automatically control the Doppler PRF. Once storms redevelop, Auto PRF-Storm will automatically control the Doppler PRF selection. There is no need to do anything!

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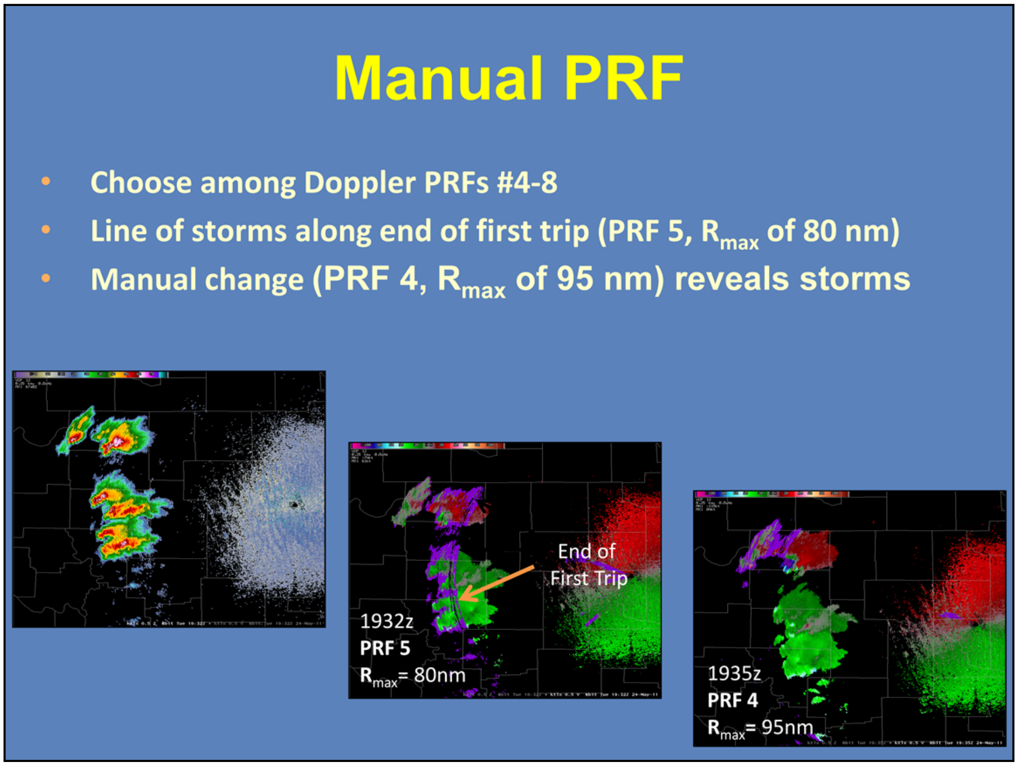
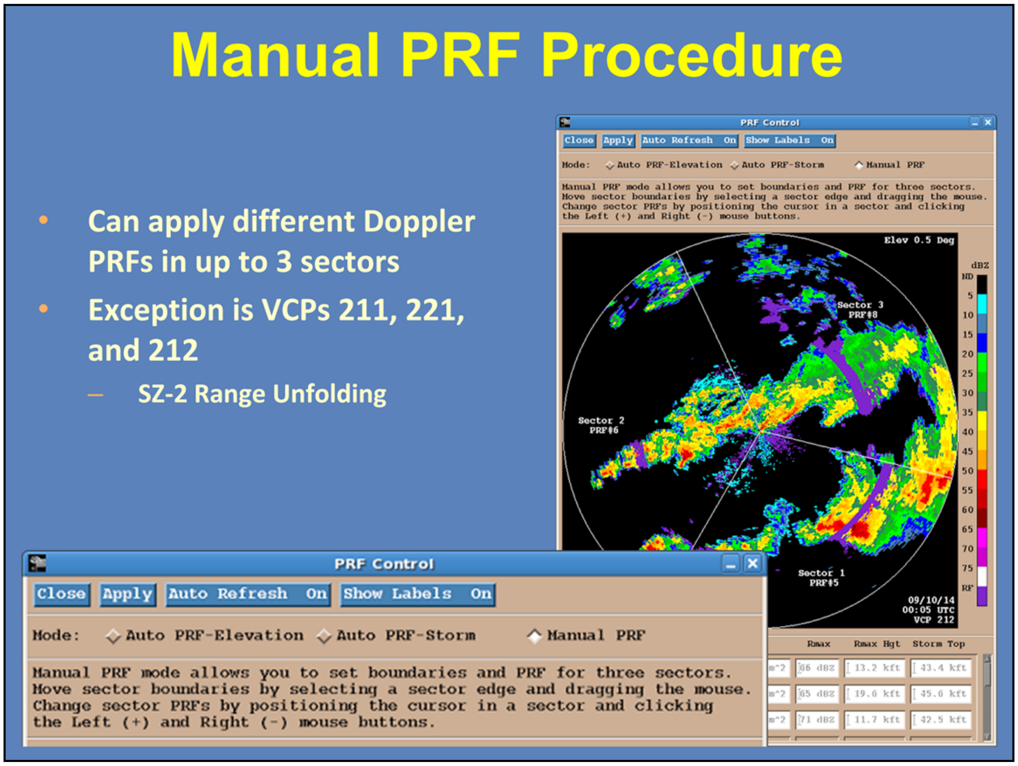
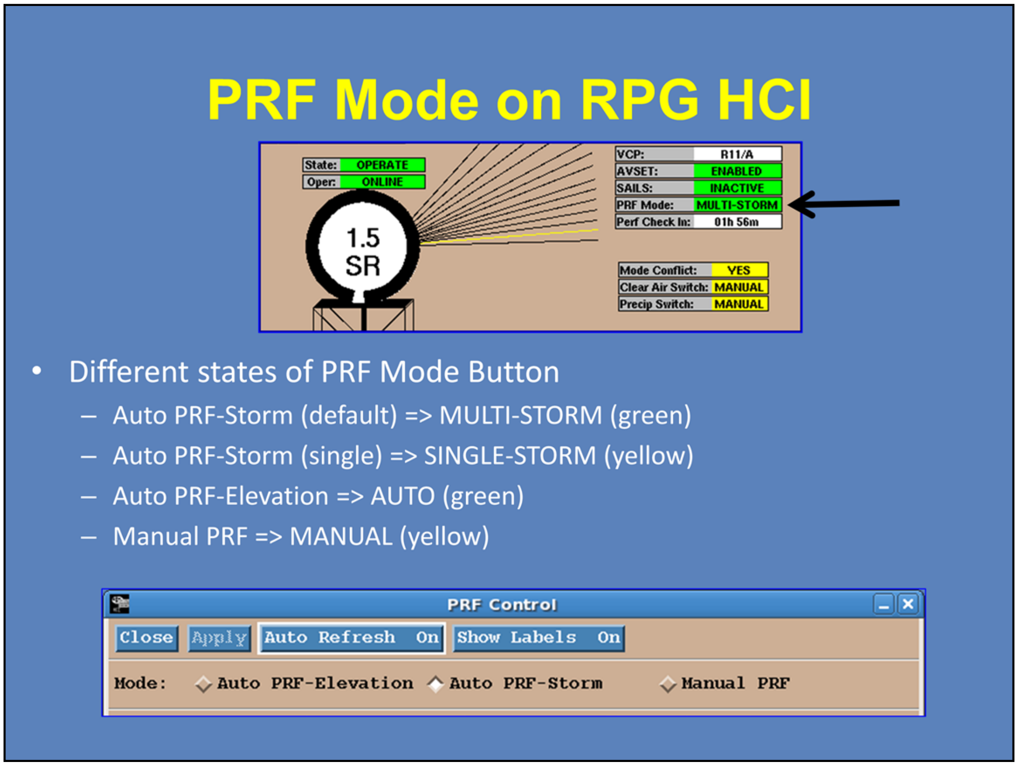


The last option for PRF Control is Manual PRF. This allows for Doppler PRF selection directly. In this example, a line of storms is approaching the end of the first trip with PRF 5 chosen, which has an R_{max} of 80 nm. By choosing PRF 4, the R_{max} moves to 95 nm, and the velocity data for this line is no longer obscured by RF data.



The Manual PRF option allows for different Doppler PRFs in up to 3 different sectors. In the window on the right, probably the easiest thing to do is to take the mouse cursor, left-click once on the display portion of the window until you get the most appealing option for PRF sectors, with the least amount of purple haze and especially the least amount within the strongest storms on the scope. This sectorizing of Doppler PRFs is not available for VCPs 211, 221, and 212.



Depending on the PRF control option selected, there are four possible states for the PRF Mode button on the RPG HCI main page.

For Auto PRF-Storm (default), the button reads MULTI-STORM with a green background

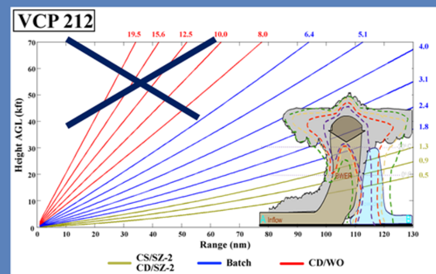
For Auto PRF-Storm (single), the button reads SINGLE-STORM with a yellow background

For Auto PRF-Elevation, the button reads AUTO with a green background.

For Manual PRF, the button reads MANUAL with a yellow background

AVSET
(Automated Volume Scan Evaluation and Termination)

- Meets need for faster VCP updates
- Sampling above the weather?
  - Stop current volume scan & start a new one!
- AVSET makes each volume scan “dynamic”



- AVSET Enable/Disable toggle at RPG HCI
- AVSET default state is “Enabled”
  - AVSET begins looking at coverage of returns above 5.0°
  - Not active for Clear Air Mode VCPs

VCP:	R32/B
AVSET:	ENABLED
SAILS:	INACTIVE
PRF Mode:	MULTI-STORM
Perf Check In:	07h 15m

Mode Conflict:	NO
Clear Air Switch:	AUTO
Precip Switch:	AUTO

AVSET stands for Automated Volume Scan Evaluation and Termination, and is active for the Precipitation Mode VCPs. AVSET meets the need for faster VCP updates when the weather return is limited to the lower elevation angles. This is dependent on both the depth of any weather and it’s range from the radar.

In this graphic, a convective storm is at a long enough range that the middle and upper elevations of the VCP are sampling nothing of significance for the NWS mission. AVSET makes each volume scan “dynamic”. Once we are sampling “above the weather”, AVSET stops the current volume scan and starts a new one. AVSET runs at the RDA and is commanded from the RPG.

AVSET is controlled by a toggle at the RPG HCI, and it is Enabled by default. Since AVSET begins checking the areal coverage of returns above 5.0°, it is Enabled, but not active for the Clear Air Mode VCPs.

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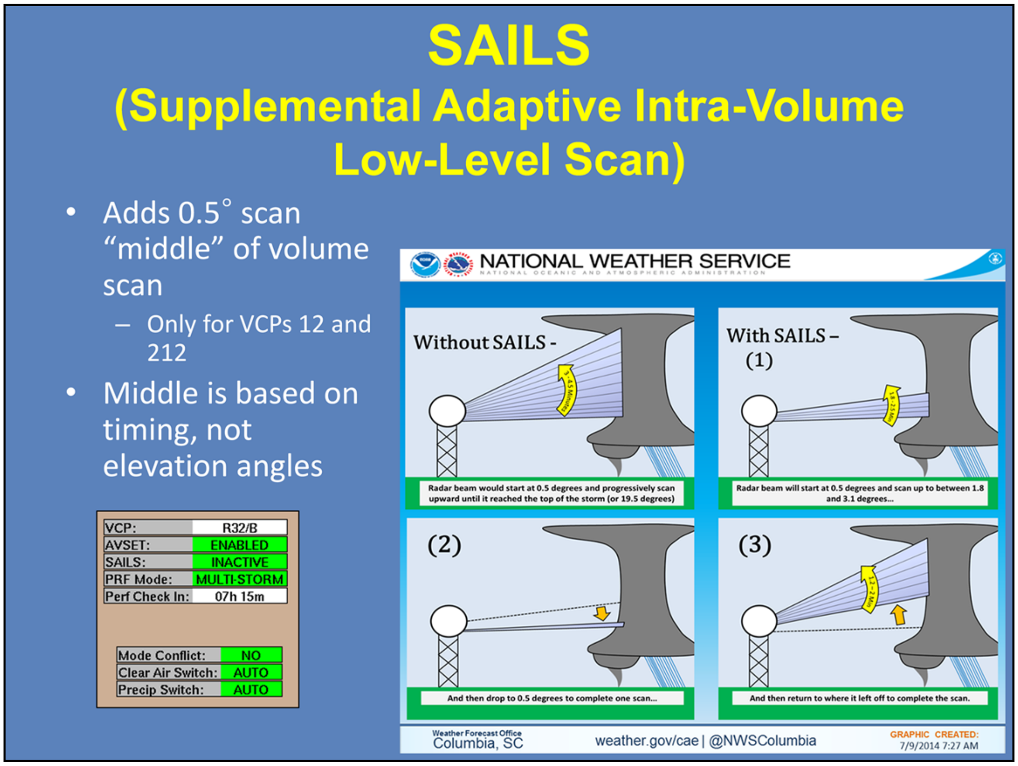

Another significant feature that makes VCPs dynamic is the Supplemental Adaptive Intra-Volume Low-Level Scan (SAILS). It is available only for VCPs 12 and 212. SAILS adds a 0.5° scan in the "middle" of the volume scan. The middle is not defined by the elevation angle, but by timing. The goal is for the 0.5° products to arrive with uniform timing. With AVSET on, the volume scan time changes, thus the timing of the SAILS scan changes. Many thanks to WFO Columbia, SC, for this great SAILS graphic posted to their Facebook page!

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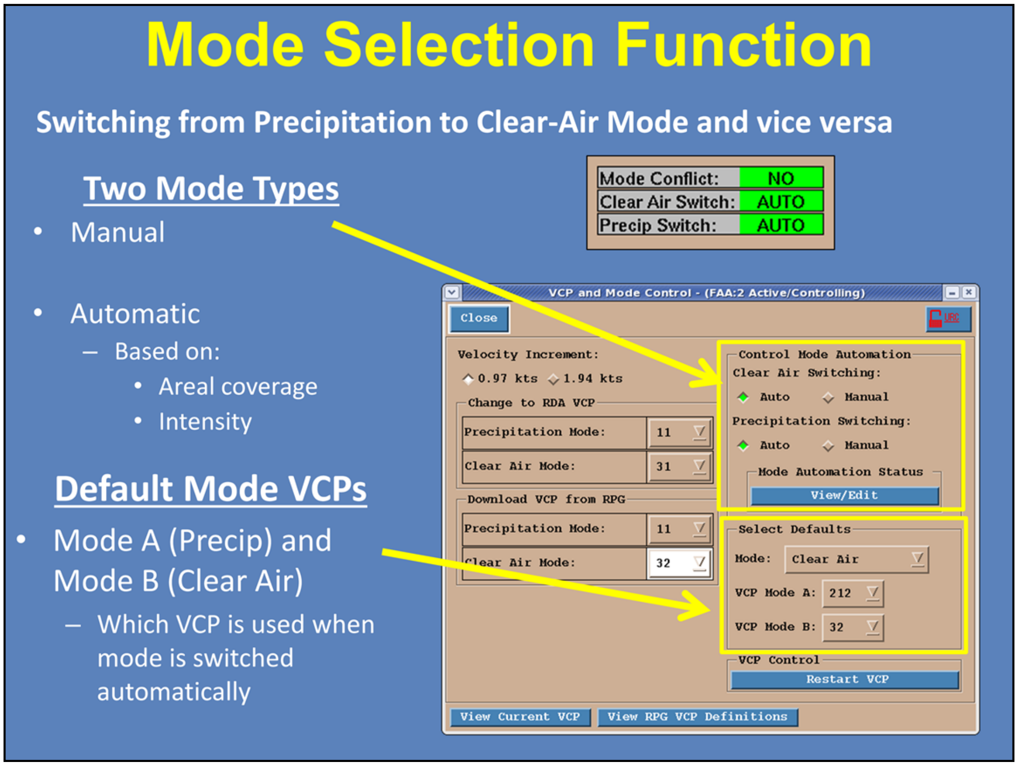
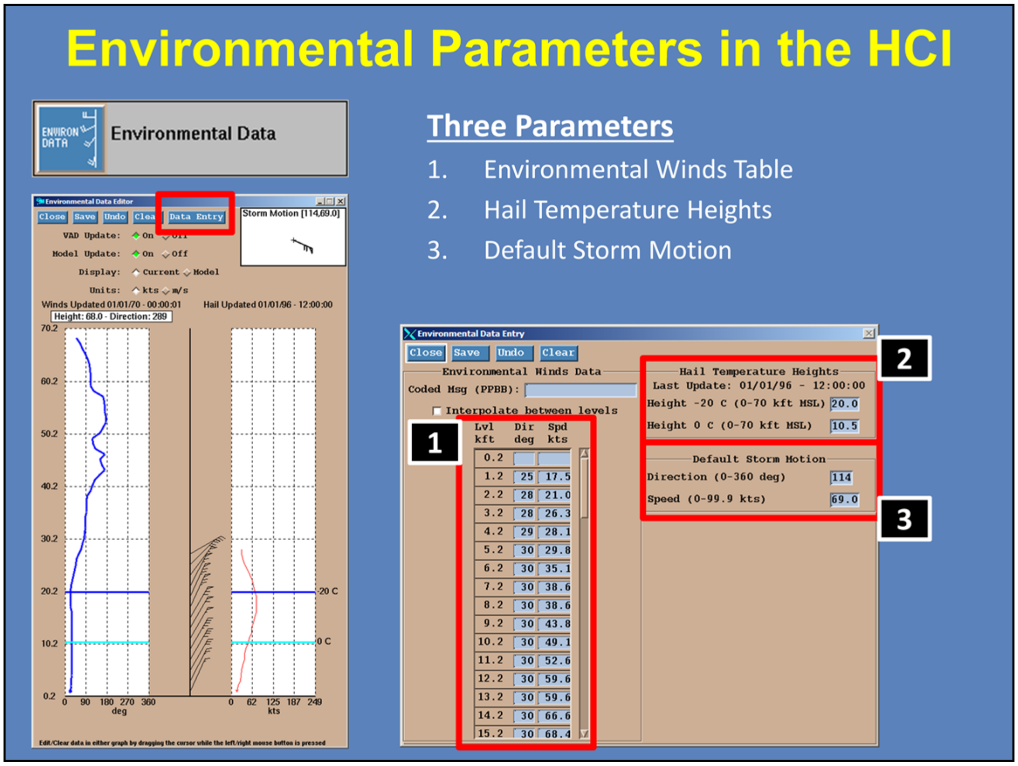
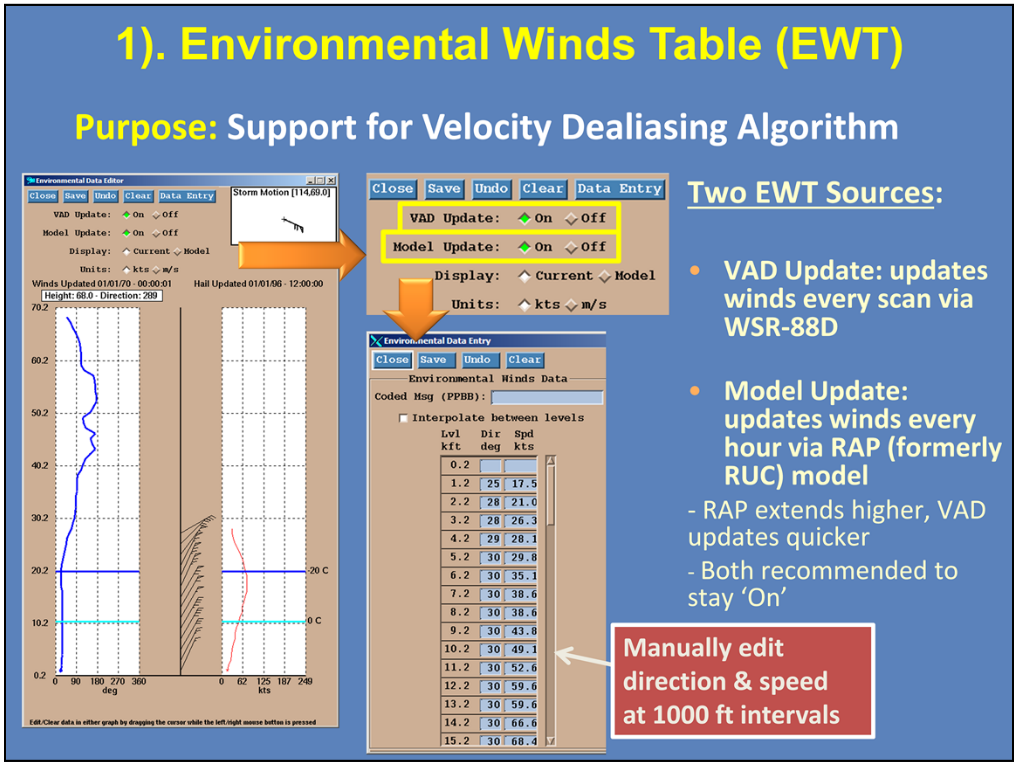


On to the Mode Selection Function, which controls how the WSR-88D transitions to and from Clear Air and Precipitation Mode. Notice that we are back to the VCP and Mode Control window. The two methods are Manual and Automatic. The Manual method requires more oversight and communication from shift to shift. The Automatic method is based on the areal coverage of returns with a given intensity. For Automatic Mode switching, there is the need for a Default VCP for each of the modes. Once the URC password is provided, these Default VCPs can be selected for each mode. This choice may be made seasonally. For example, for Precipitation Mode, VCP 212 may be preferred during the warm/convective season, while VCP 11 or 21 may be preferred during the cool season.



We'll close out this lesson with the overview of the features and functions on the Environmental Data collected and used by the radar. The main purpose of the Environmental Data is that it is utilized to support several RPG algorithms that go on to create output for AWIPS. On the HCI, you can monitor and configure the data or just let the data ride that already exists and is updated automatically. The three main environmental data parameters configured from this window are: the environmental winds table, the hail temperature heights, and default storm motion. All of which, we are going to delve into over the next 3 slides.



The environmental winds table parameter is very important to the quality of the base data as it supports the velocity dealiasing algorithm. In the Environmental Data Editor, the EWT components are displayed graphically on the window and are controlled through radio buttons at the top of the window. With the EWT supporting the velocity dealiasing algorithm, the EWT must be representative of winds aloft in real-time. To do this, the EWT can be updated from two sources.

1) When Velocity Azimuth Display (or VAD) Update is set to On, the VAD algorithm will update the EWT with WSR-88D generated winds aloft every volume scan.
2) When Model Update is set to On, RAP (formerly RUC) model output will send its gridded u/v components to the EWT table on an hourly basis.

Under most conditions, the RAP data will extend higher than the VAD, but the VAD will provide more frequent updates to the lower-level winds. As a result, it is recommended that VAD Update and Model Update are set to On most of the time. The current environmental winds can be interrogated in the graphical display below the command buttons. Here, wind direction and speeds are plotted as a function of height. Sometimes, you may have to manually modify the environmental winds table. This can be done in one of two ways. First, graphically by drawing your environment wind speed and direction inside the environmental data editor window. Second, you can insert wind speeds and directions into a table launched from the 'Data Entry' button at the top of the environmental data editor window. Inside, you will find heights separated out by default in 1000 ft. intervals.

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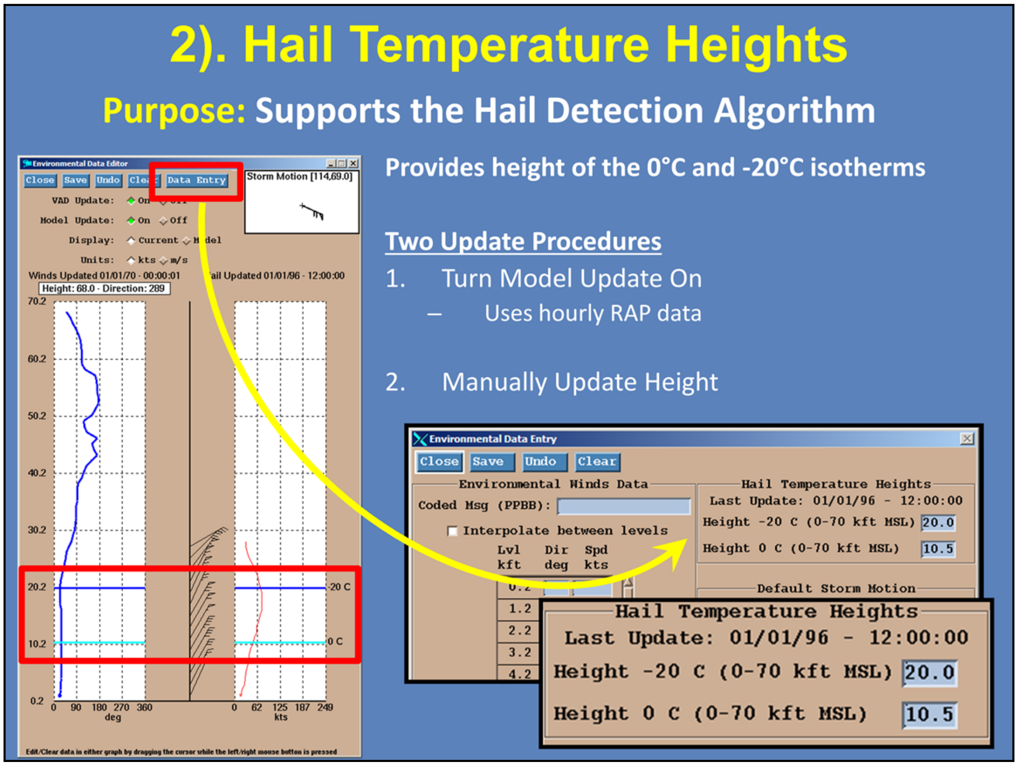

The hail temperature heights parameter supports the hail detection algorithm by providing the altitude of the 0 and -20 degrees Celsius isotherms.

There are two ways these isoterm heights are generated:

1) First, if Model Update is turned On. The RAP temperature analysis will be ingested hourly and this will set the hail temperature heights.
2) Second, you the operator can manually set these values based on another ingest source, such as current sounding data.

You can edit the heights graphically by clicking and dragging the 0 and -20 degree isotherm lines on the environmental winds table but that is much less precise than just inputting the values in the Environmental Data Entry window, as shown on the lower right.

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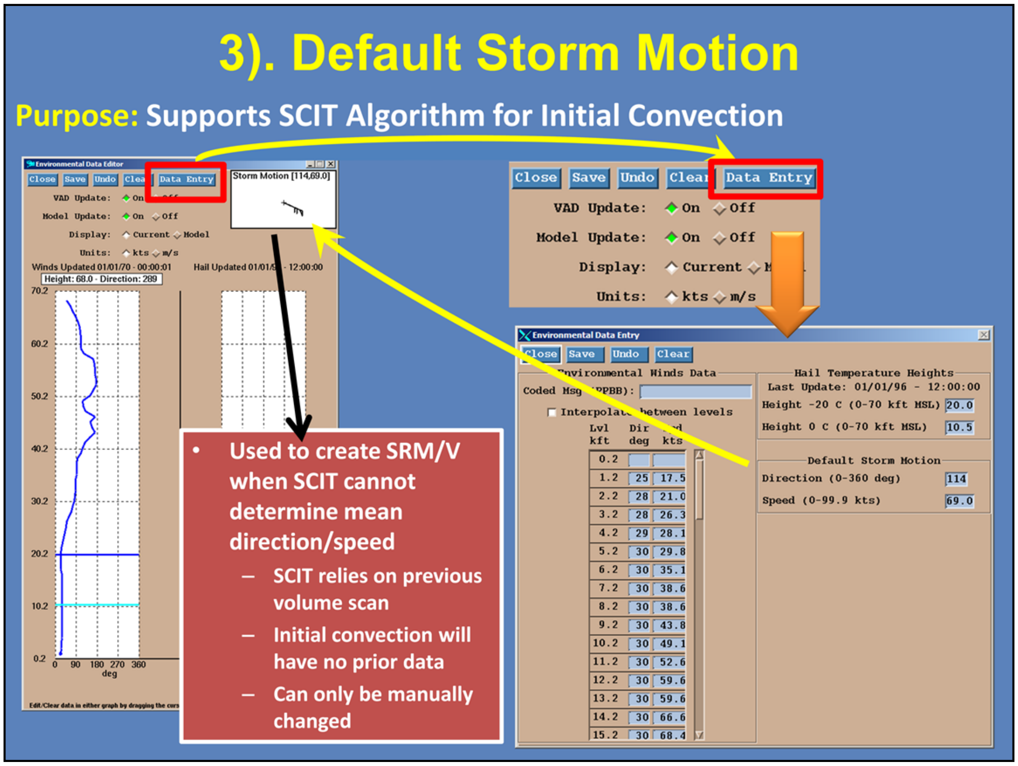
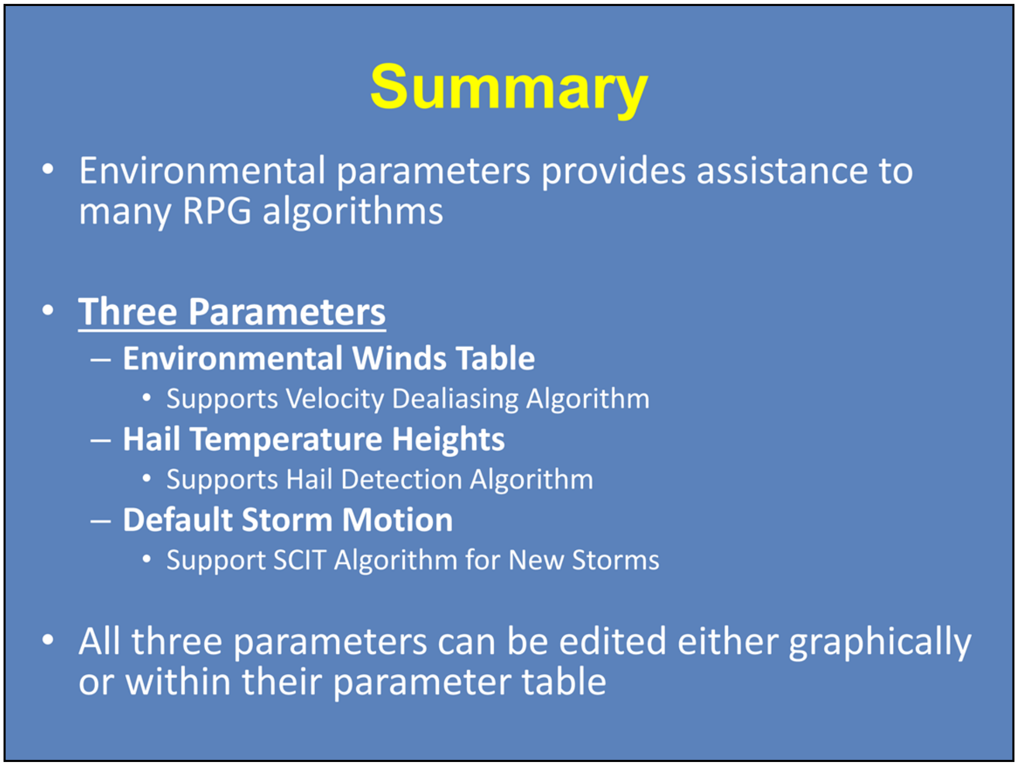
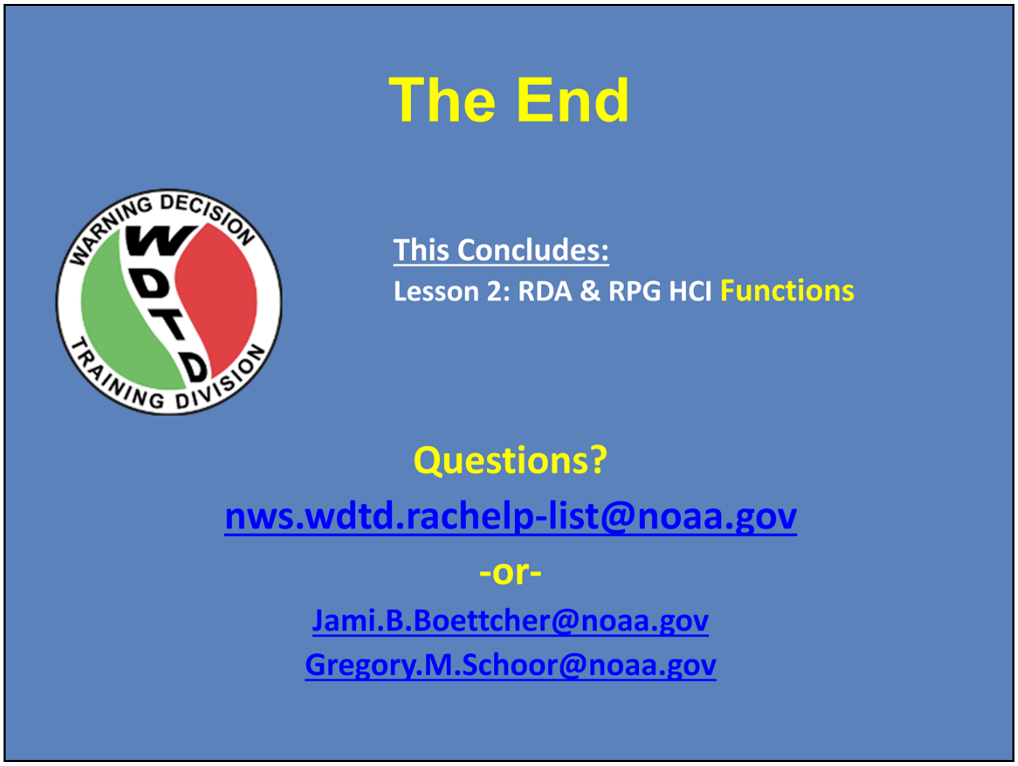


The default storm motion parameter supports the Storm Cell Identification and Tracking (or SCIT) Algorithm, specifically by using the default speed and direction for the creation of Storm Relative Mean Radial Velocity Products. In this example, though it's small, the storm motion is set to 114 degrees at 69 knots. To change this, if your hodograph analysis says different, click on the "Data Entry" button which will pop up this larger window on the bottom-right. You'll see the Default Storm Motion section with the 114 and 69 values, which you would then change and click "Save".

In most cases, this will be used only on initial cell development since the SCIT relates storms found in the current volume scan to storms in the previous volume scan. With new convection, no prior data exists so default storm motion will be used. This environmental parameter does not rely on any other ingested meteorological data and as a result can only be manually changed.



This is a summary of the features and functions of the most widely used and necessary buttons and windows from the RPG HCI. Please take a moment to review these and head out to the closing slide when you're ready.



If you have any questions, please direct them to any of the email addresses listed.

Welcome to Legacy Base Data Generation.

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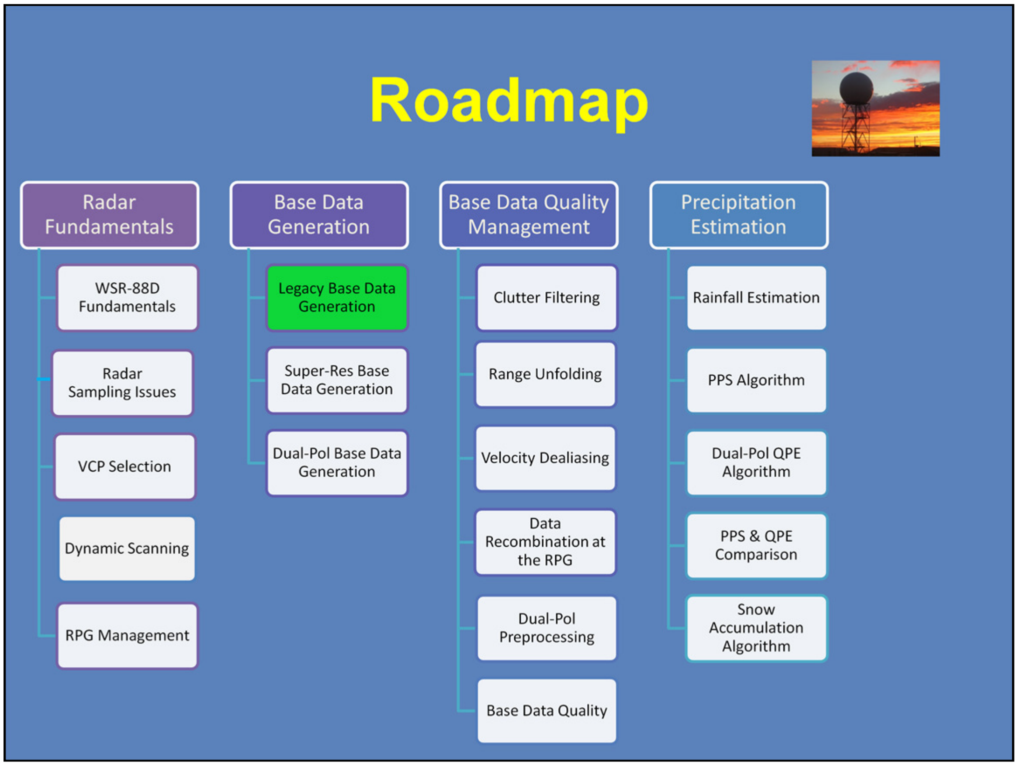

Here is the “roadmap” with your current location.

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Base Data Generation

Objectives

1. Identify how Doppler information is obtained by the WSR-88D to determine atmospheric motion
2. Identify the relationship between V_{max} and the interval of first guess velocities
3. Identify how the returned signal is used to generate:
   a) Reflectivity (Z)
   b) Radial Velocity (V)
   c) Spectrum Width (SW)

There are 3 objectives in Legacy Base Data Generation, and these objectives will be taught in sequence during this module.

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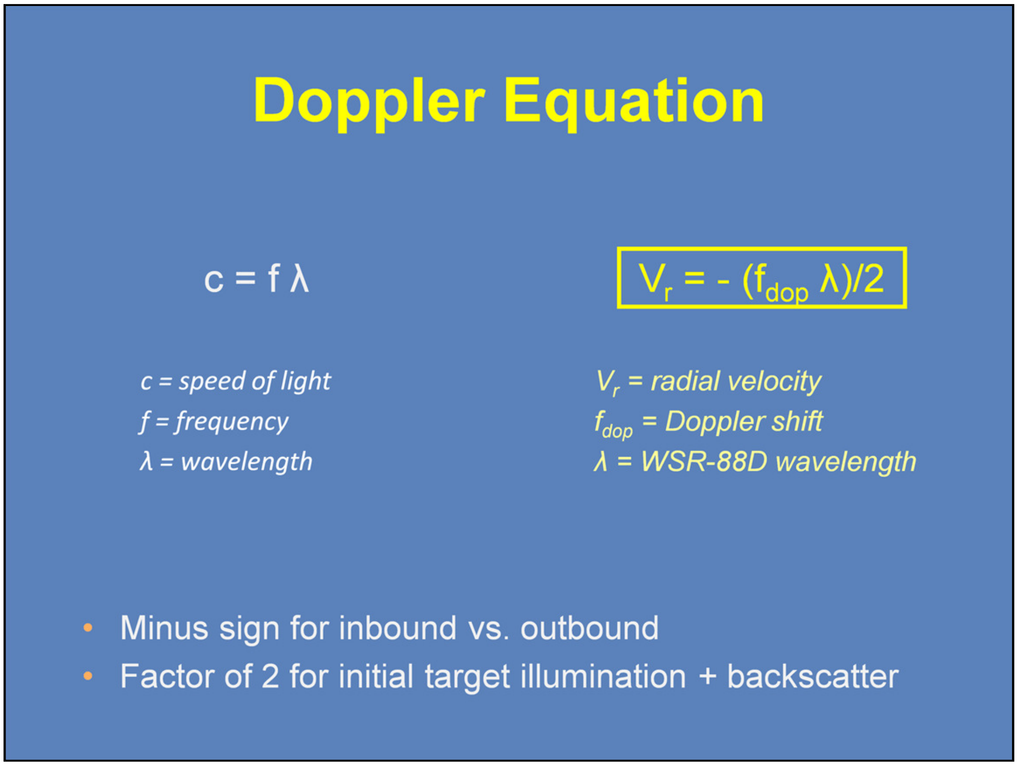
Doppler Effect

- "The change in frequency with which energy reaches a receiver when the receiver and the energy source are in motion relative to each other."
- **What matters: Frequency shift proportional to target motion**

You're likely familiar with the definition of the Doppler Effect. Since the radar location is fixed, any relative motion comes from the target's motion. The good news is the any Doppler frequency change is directly proportional to the target's motion.



On the left is the basic relationship of frequency and wavelength to the speed of light. Based on that equation, on the right, is the relationship of the Doppler shift to radial velocity for Doppler weather radar (derivation not required!).

The factor of two is there because the signal is transmitted and interacts with the target, then is reflected back. The minus sign is there for target direction. By convention, inbound velocities are negative and outbound velocities are positive. For example, an inbound target produces a positive Doppler shift, making the velocity negative. An outbound target produces a negative Doppler shift, making the velocity positive.

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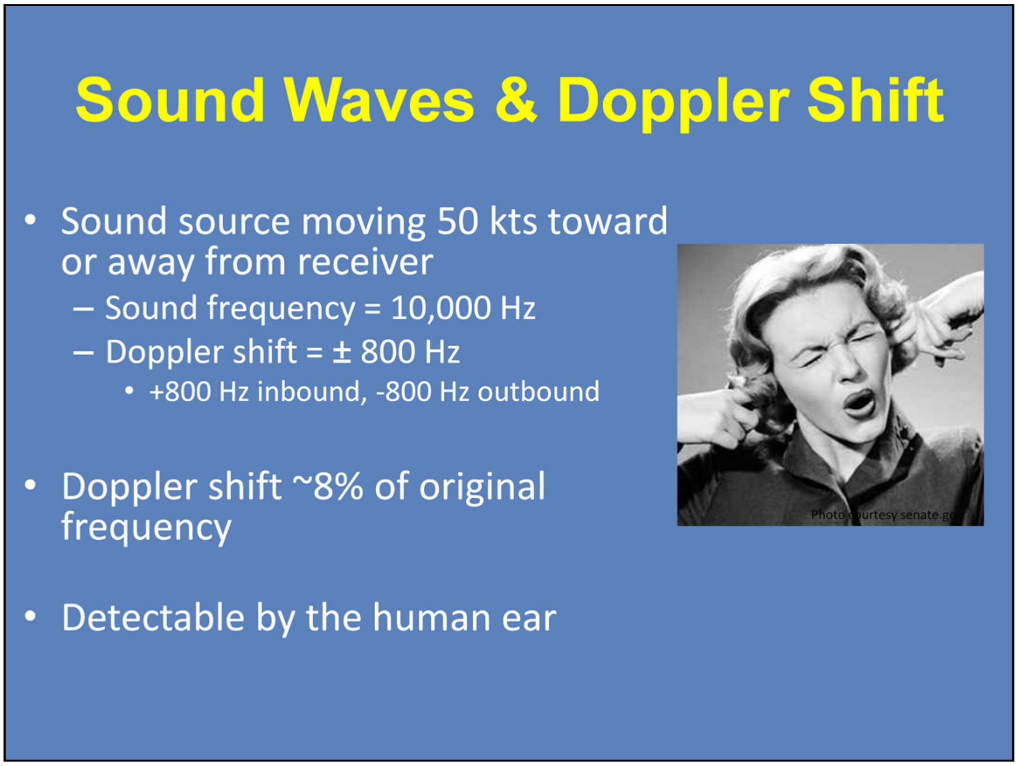

A common way to demonstrate the Doppler effect is with the change in pitch of the sound of a train or ambulance as it first moves toward you, then moves away. In this example with a speed of 50 kts, the frequency shift is 800 Hz, +800 when the sound source is moving toward you and -800 Hz when the sound source is moving away from you. This Doppler shift is then 8% of the original frequency. That is why this type of Doppler shift is detectible by the human ear. We next look at the WSR-88D's listening ability, which is much more precise compared to the human ear!

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WSR-88D & Doppler Shift

- Target moving 50 kts toward or away from WSR-88D
  - Transmitted frequency = 2850 MHz (2,850,000,000 Hz)
  - Doppler shift = ± 487 Hz
- Doppler shift ~.00002% of original frequency
- WSR-88D does not directly measure such small frequency changes

Now for the same target motion of 50 kts, but the listening device is the WSR-88D. We are no longer dealing with sound waves. Note that the frequency of transmission is very high compared to the frequency of a sound wave. The frequency shift is tiny compared to the original frequency…too small to be measured. Thus the shift in frequency is not what is used to determine target motion. We need something else.

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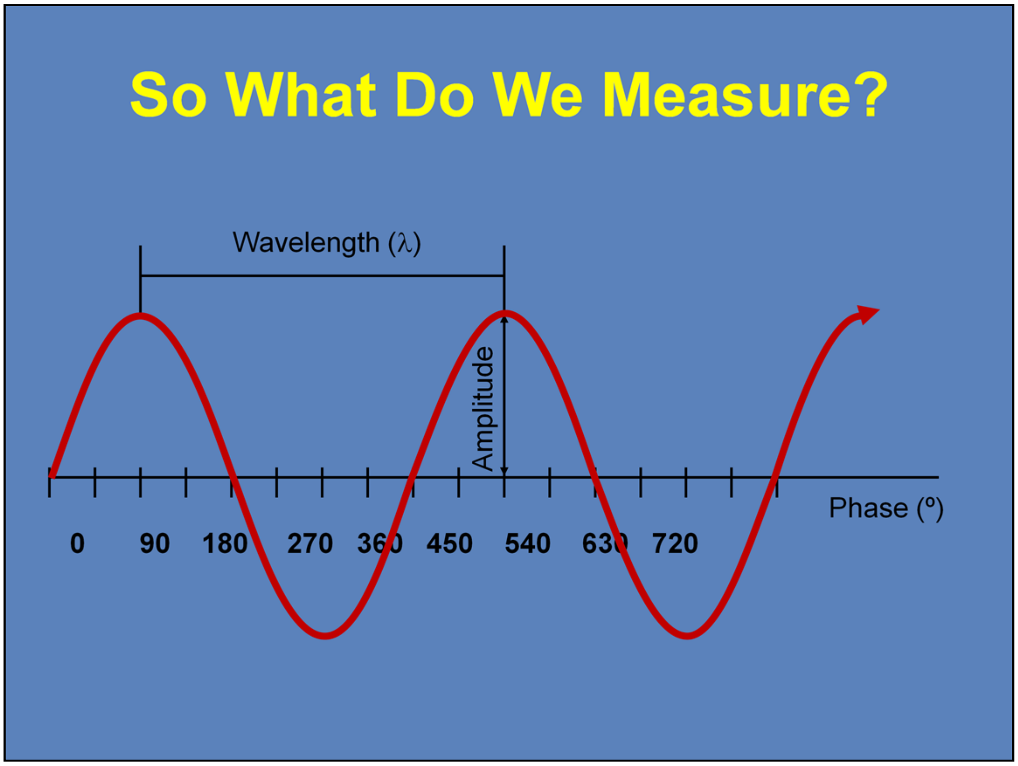
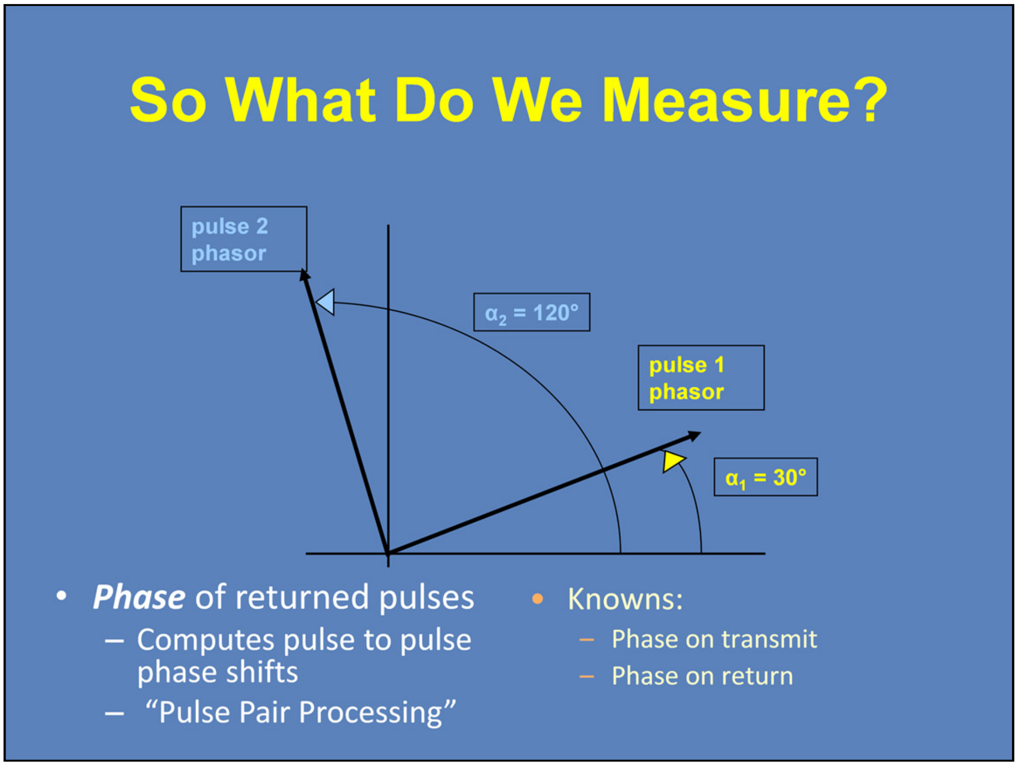
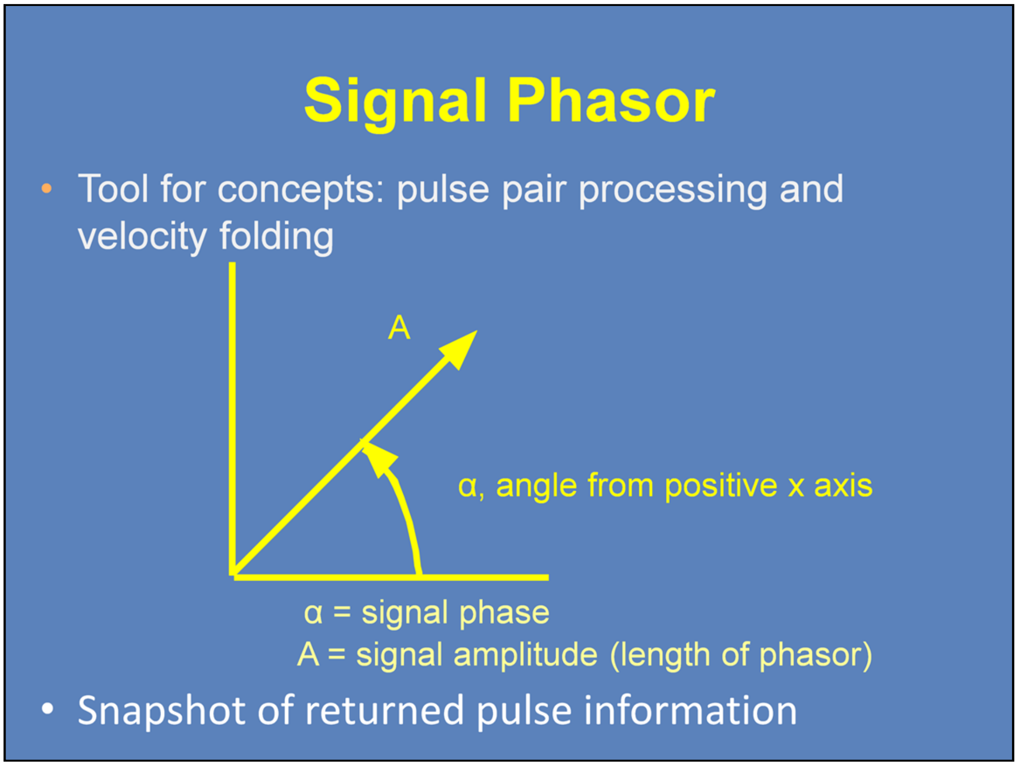


Since we don't measure the frequency shift, what else is there? Here is a reminder of the various characteristics of wave energy. The wavelength is the distance for one complete cycle, which is about 10 cm with the WSR-88D. The amplitude is the signal strength, which is directly related to reflectivity. The phase is a particular point along the wave, which can be used to determine velocity information.



It turns out that the WSR-88D measures the phase of each returned pulse and is able to compare the phase values from one pulse to the next. The phase shift from one pulse to the next is directly related to the radial velocity. This technique is called Pulse Pair Processing.

Pulse Pair Processing is possible because the initial phase is known when each pulse is transmitted. The initial phase for each returned pulse is also known. In a nutshell, a phase value is assigned to each pulse, then compared from one pulse to the next.



One way to represent the concept of a pulse pair phase shift is to use phasors. A phasor is a tool for temporary use only to support your understanding of one of the fundamental ambiguities with Doppler weather radar: velocity folding or aliasing. A phasor represents the necessary information from each returned pulse. The phase of that pulse is the angle of the phasor from the positive x axis. The length of the phasor is the signal amplitude. If the WSR-88D were continuously transmitting and receiving, the phasor would be rotating. However, pulses are needed for target range, and each phasor is a snapshot of information for each returned pulse.

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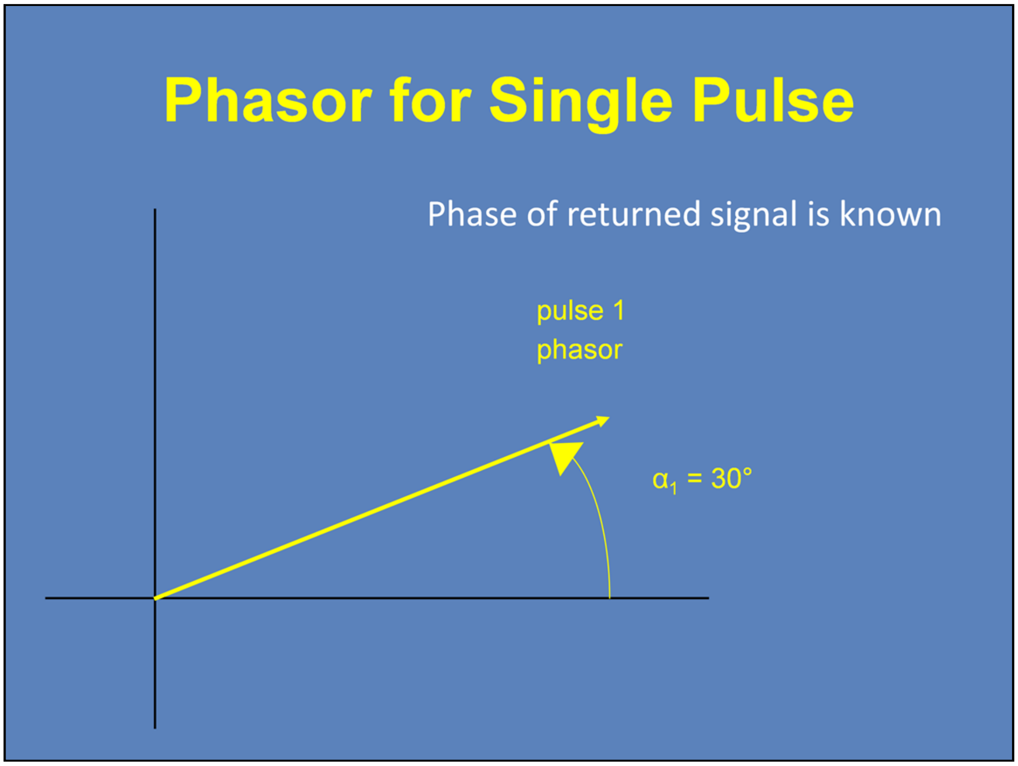

In this example, pulse 1 has been transmitted, has interacted with a target, and the returned signal has been processed. The phase value for pulse 1 is 30°.

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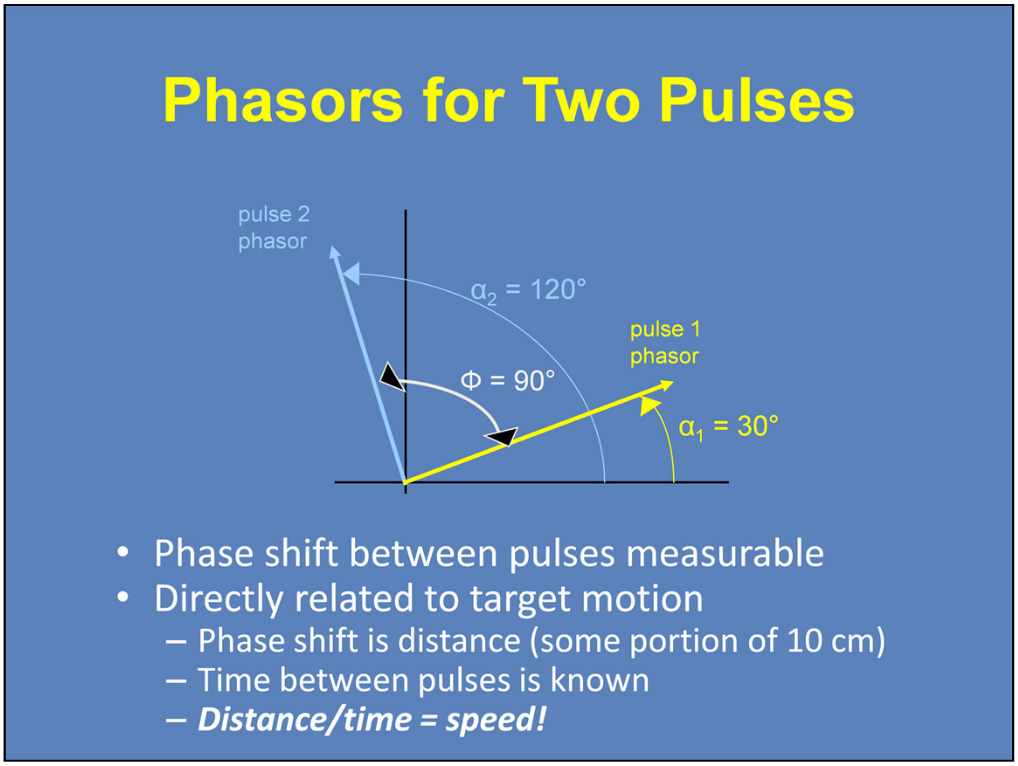
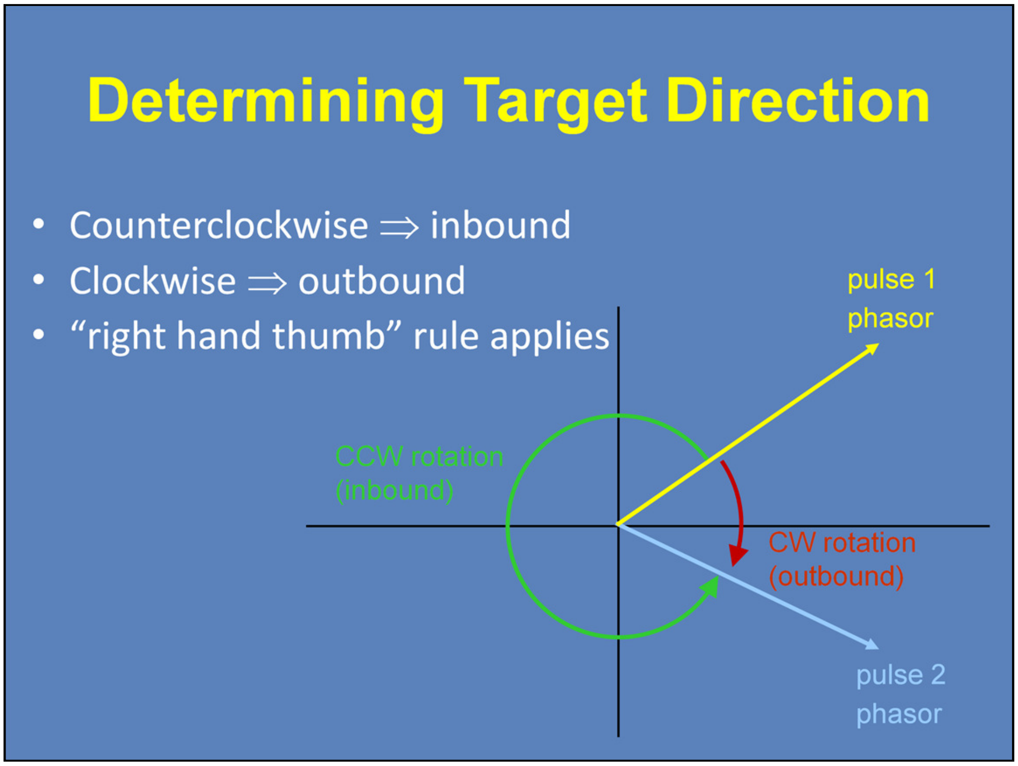


Using the pulse 1 phase of 30°, assume that the target is in motion and the phase value for pulse 2 is 120°. The angle between the two phasors (90°) is called the pulse pair phase shift.

The key here is that the phase shift between pulses is directly related to target motion. Since the wavelength is 10 cm, the phase shift is distance, i.e. some portion of 10 cm. Since the PRF is known, the time between pulses is known. We then have both ingredients for target speed: distance and time.



The target direction, inbound vs. outbound, is determined by the phasor rotation from pulse 1 to pulse 2. If clockwise, the direction is outbound. If the rotation is counterclockwise, the direction is inbound. You can also use the right hand thumb rule for the cross product of two vectors. Using the angle <180°, the result is clockwise rotation and outbound motion. If you use the right hand rule, your thumb would be pointing away from you.

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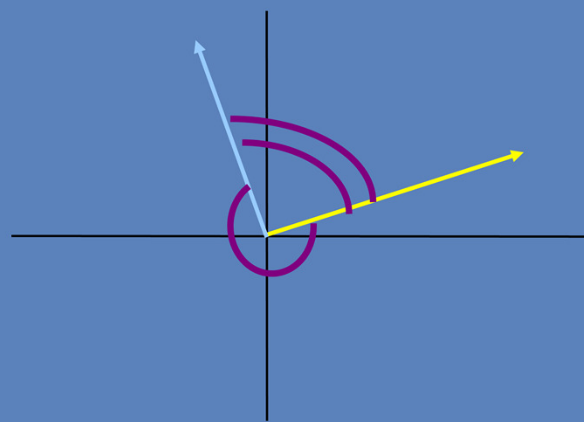
Phasors for Two Pulses

Pulse to Pulse Phase Change



- Two possible angles between pulse pair phasors
- ***The angle < 180° always used***

There are two phasors representing the information for two different pulses. Since these phasors are snapshots, some assumptions have to be made about what happened in between the two pulses. There are two possible angles between the phasors that represent these pulses. Which one is used? It is always the angle < 180°.

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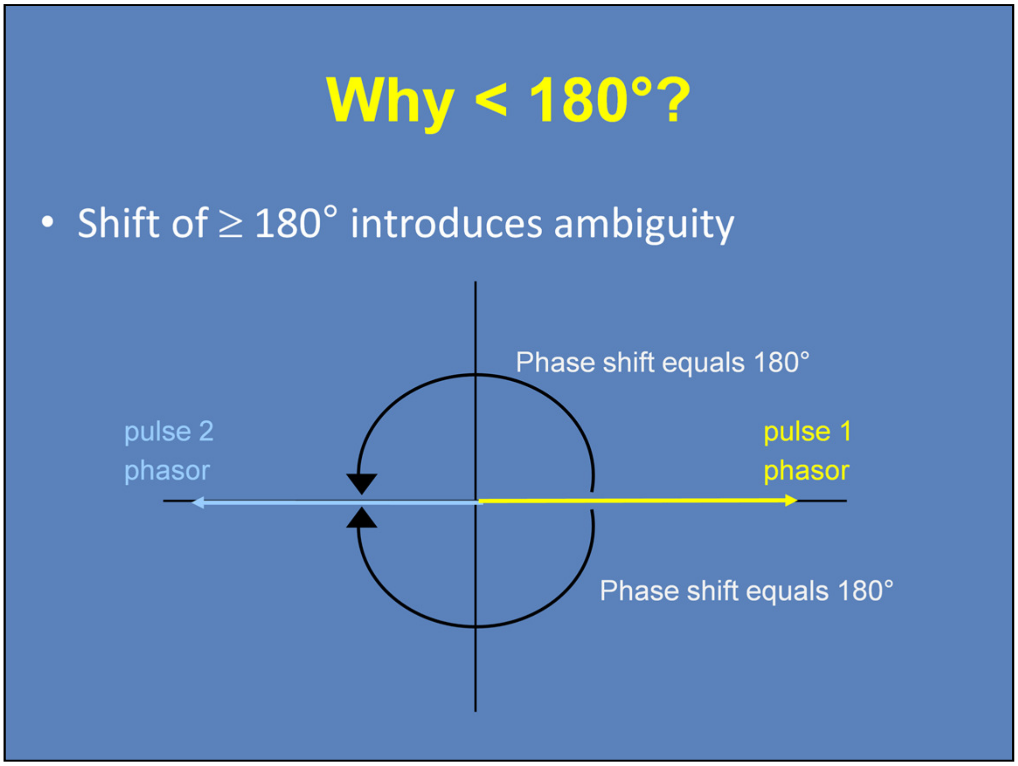

Why use the angle < 180°? A phase shift of exactly 180° introduces ambiguity…it is unknown which direction the phasor rotated to get from pulse 1 to pulse 2. If the target moves so much between pulses that the true phase shift ≥ 180°, there is ambiguity in determining the velocity. Stay tuned for how we deal with that ambiguity.

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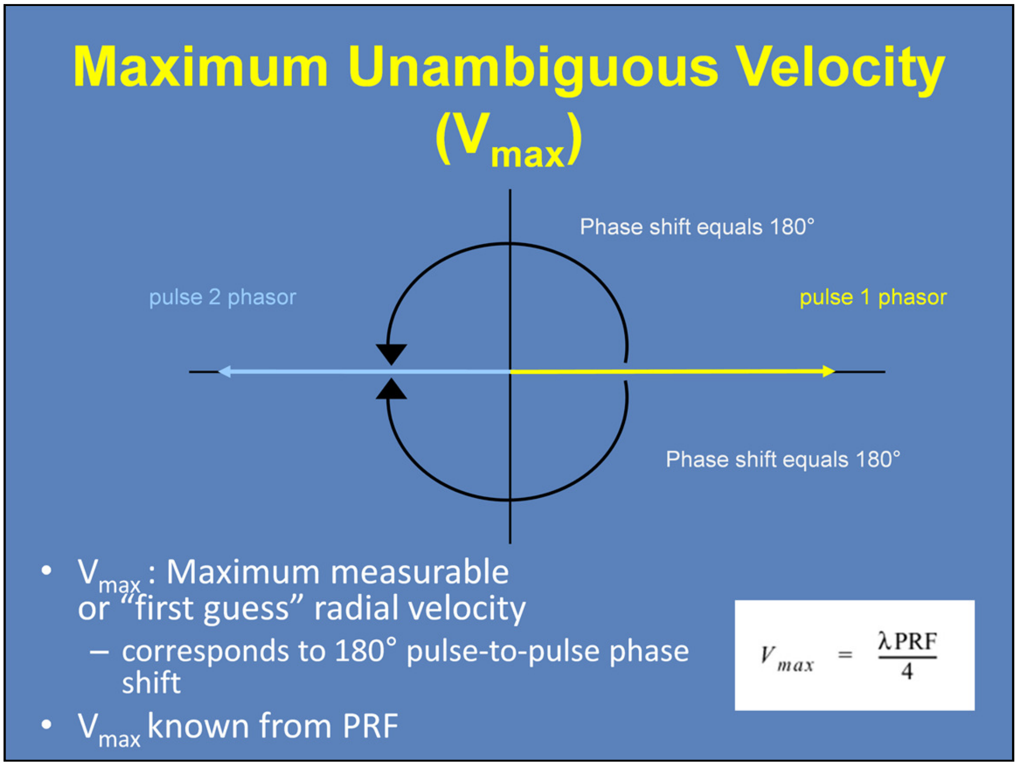

The maximum velocity that can be measured is called the maximum unambiguous velocity. It corresponds to a pulse pair phase shift of 180° (actually 179.99999…°), and is dependent on the pulse repetition frequency (PRF). With the WSR-88D, V_{max} values range from about 16 to about 64 kts.

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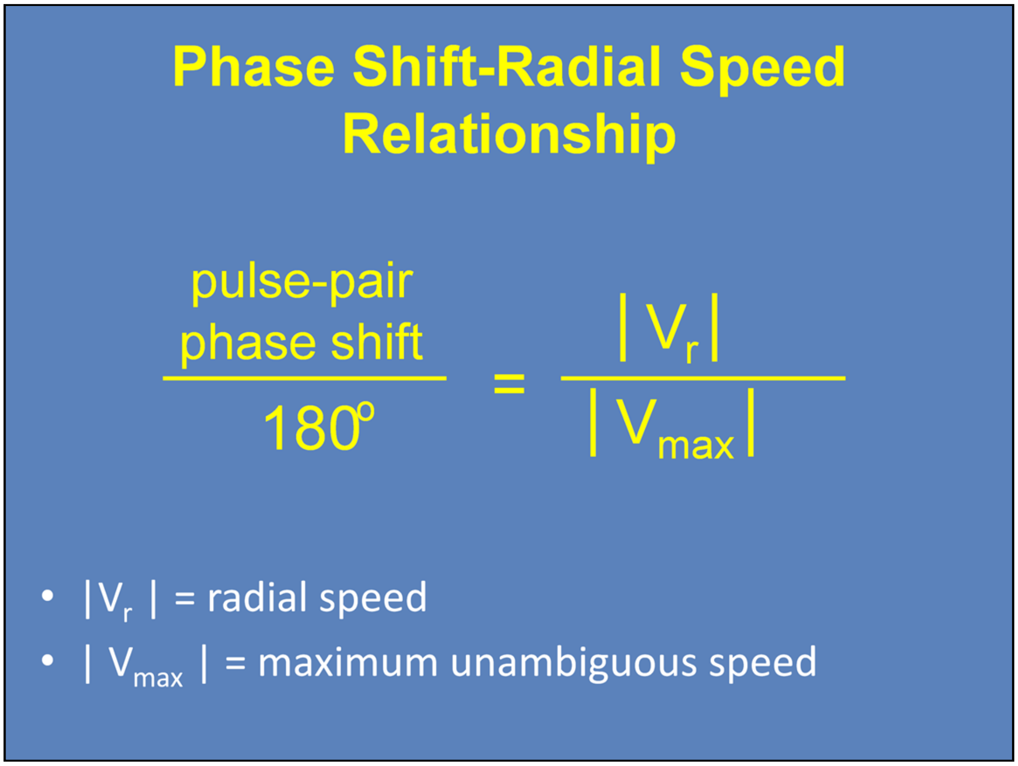
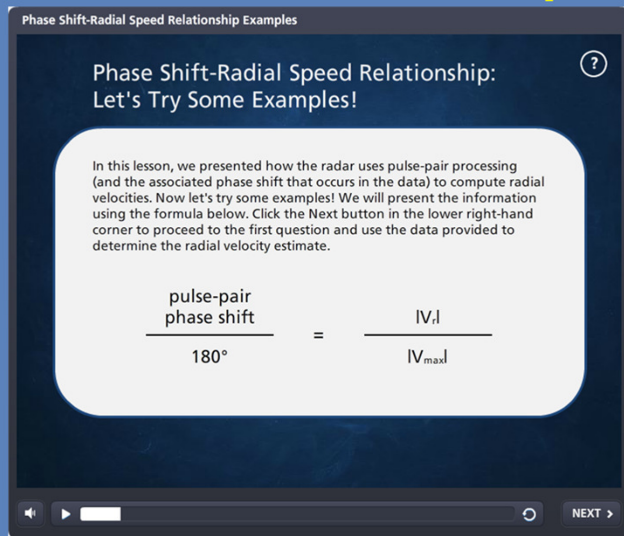
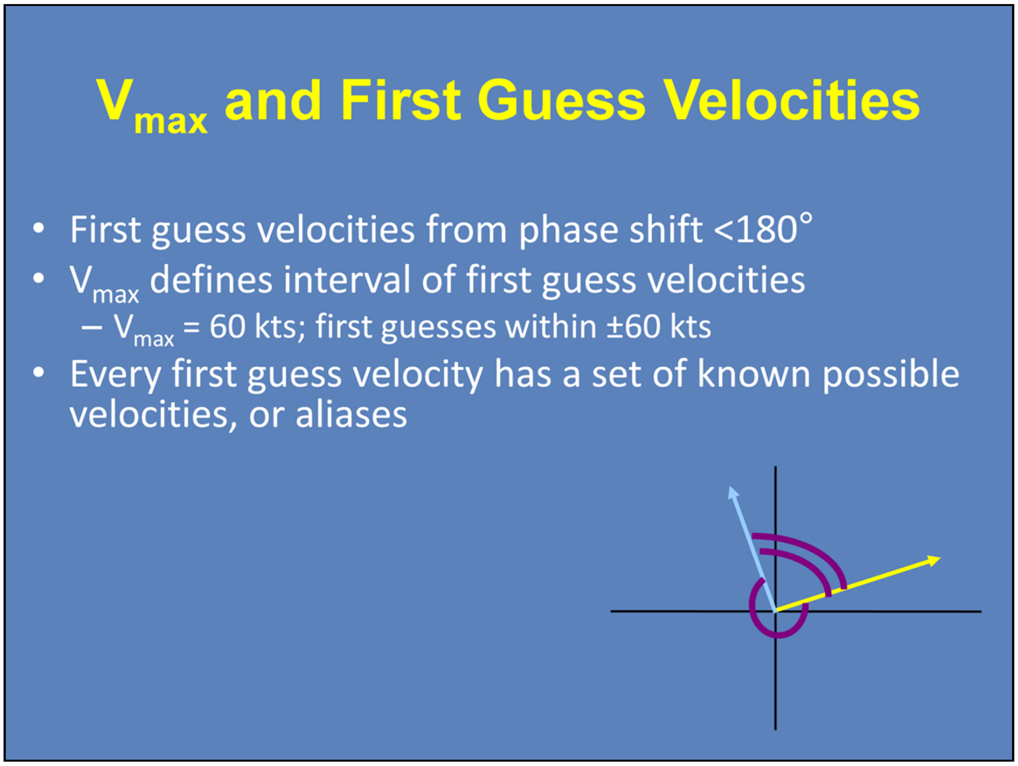


Once the pulse-pair phase shift and the V_{max} are known, computing the first guess radial speed is straightforward. That's because the pulse-pair phase shift is some portion of the maximum shift of 180°, and the radial speed is that same portion of the maximum speed, or absolute value of V_{max}.

Phase Shift - Radial Speed

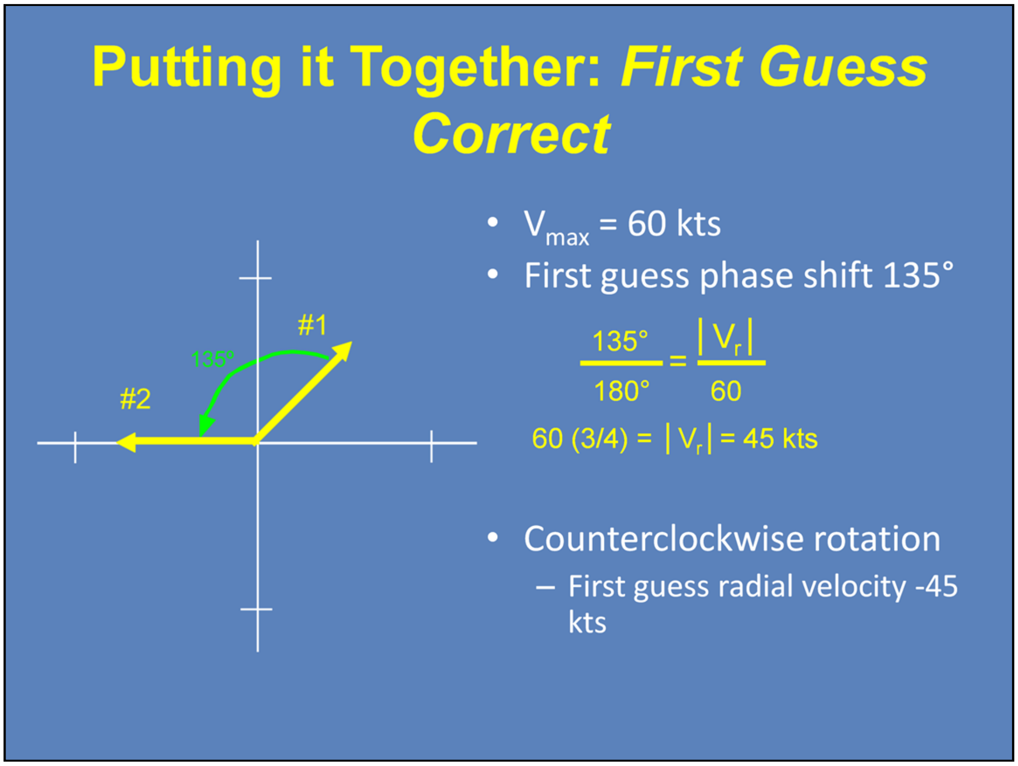


If no pop-up window appears that looks like the above, open a browser and go to:
http://www.wdtd.noaa.gov/courses/rac/principles/interactions/phaseshift-radialspeed/



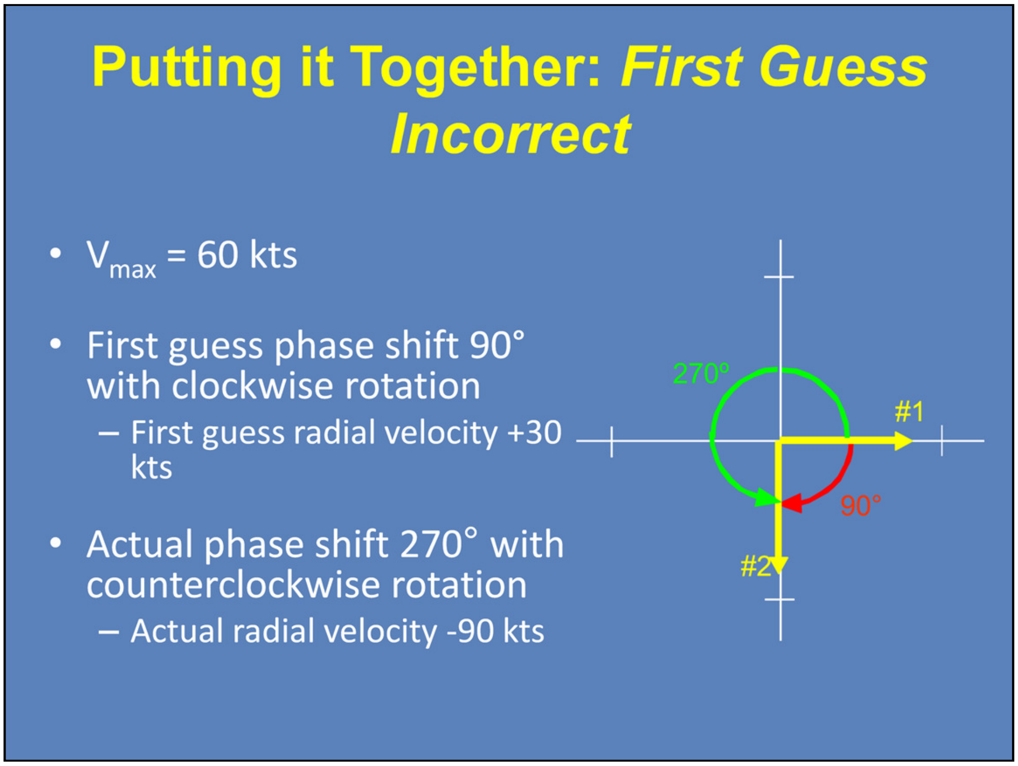
The previous examples were all based on the pulse pair phase shift that is <180°. A velocity that is based on this assumption is called the “first guess velocity”. Since V_{max} is associated with 180°, V_{max} then defines an interval of first guess velocities. For example, when V_{max} = 60 kts, the first guess velocities will be from -60 kts to +60 kts when V_{max} = 54 kts, the first guess velocities will be from -54 kts to +54 kts, etc.

Sometimes the first guess velocity is not the correct one, but the good news is that the other possible velocities are known and can be used if the first guess is incorrect.



This example combines the concepts of pulse pair shift plus V_{max}, which gives us the first guess speed, along with phasor rotation which gives us target direction. In this case, we'll assume that the true phase angle between pulses is the one that is <180°, and that it represents the true target motion.

The true phase shift is 135°, and V_{max} = 60 kts. Since 135° is three fourths of 180°, the first guess speed is 45 kts (three fourths of 60 kts). In this case, using the angle <180°, the phasor rotation is counterclockwise. So the first guess velocity is -45 kts, and in this case, it is the correct radial velocity.



So what happens when the first guess velocity is not correct, i.e. the actual phase shift is >180°? The good news is that for every first guess velocity, there are other possible velocities which are known.

In this example, the first guess velocity is based on the phase shift of 90° in the clockwise direction. With a V_{max} of 60 kts, the first guess is then +30 kts. The true radial velocity, based on the phase shift of 270° in the counterclockwise direction, is -90 kts. Though +30 kts is incorrect, -90 kts is computed as a possibility velocity or alias. How these aliases are used to find the true radial velocity is discussed in a later lesson.

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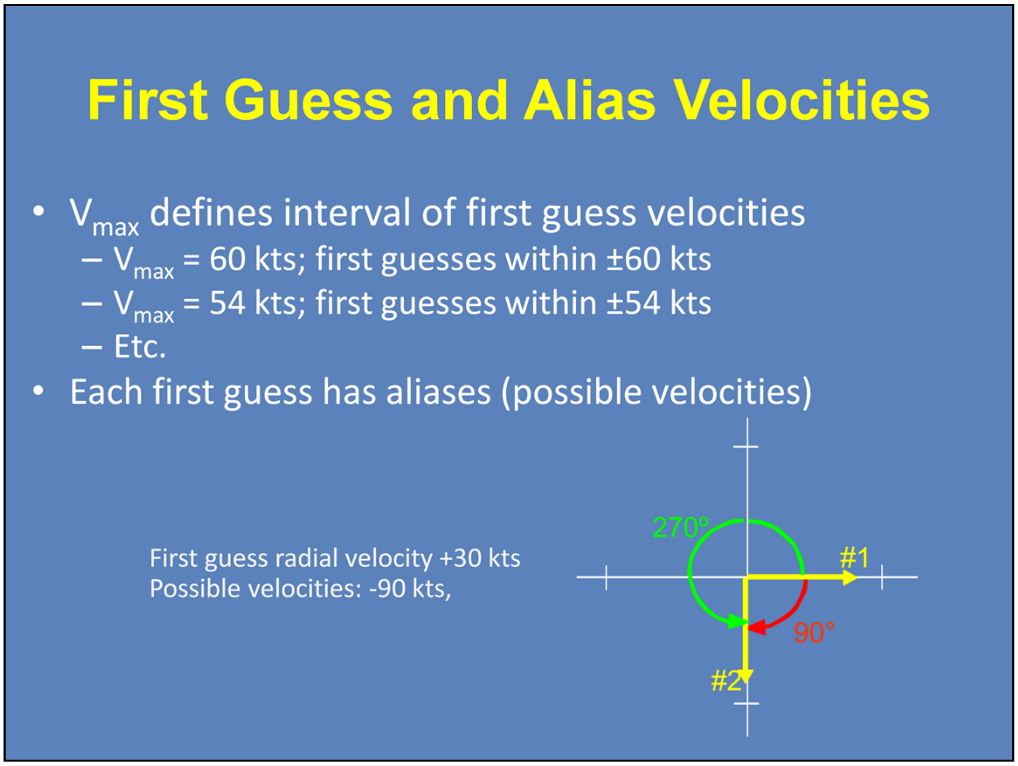
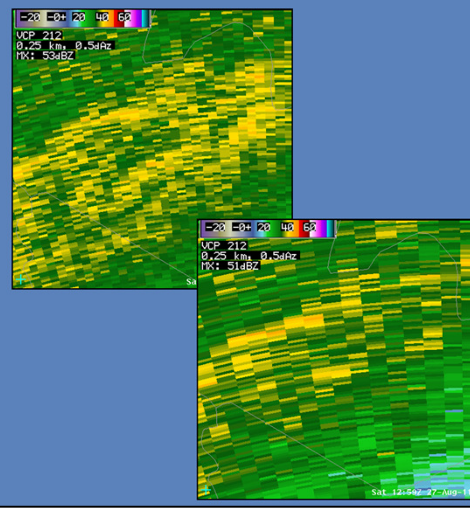


First guess velocities are based on the phase shift <180°, and V_{max} is the maximum unambiguous velocity, associated with a phase shift of 180. Each V_{max} thus defines an interval of first guess velocities. For example, for V_{max} = 60 kts, first guess velocities range from -60 kts to +60 kts, for V_{max} = 54 kts, first guess velocities range from -54 kts to +54 kts, etc. Since we cannot be certain that any first guess is correct, the good news is that the other possible velocities are known and can be used instead (more about that later).

Base Reflectivity (Z) Generation

- Pulses/radial vary (6 to 64) for each .25 km range bin
- Average P_r converted to Z
  - Z converted to dBZ
- Super Res on Split Cuts
  - 0.5° azimuth x .25 km
- Legacy Res Batch & higher
  - 1.0° azimuth x .25 km



For each range and azimuth, there are multiple pulses used to generate base reflectivity. The returned power for these pulses is averaged for each .25 km range bin, then converted to Z using the Probert-Jones radar equation. The Z value is next converted to dBZ for product generation. For the Split Cuts, the best resolution Z product (what you use most of the time) is 0.5° azimuth by .25 km. For the Batch or higher elevation Z products, the best resolution to 1.0° azimuth by .25 km.

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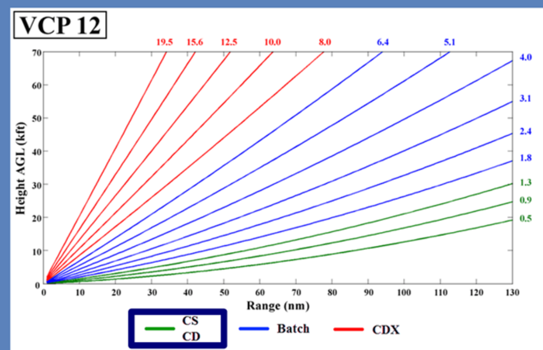
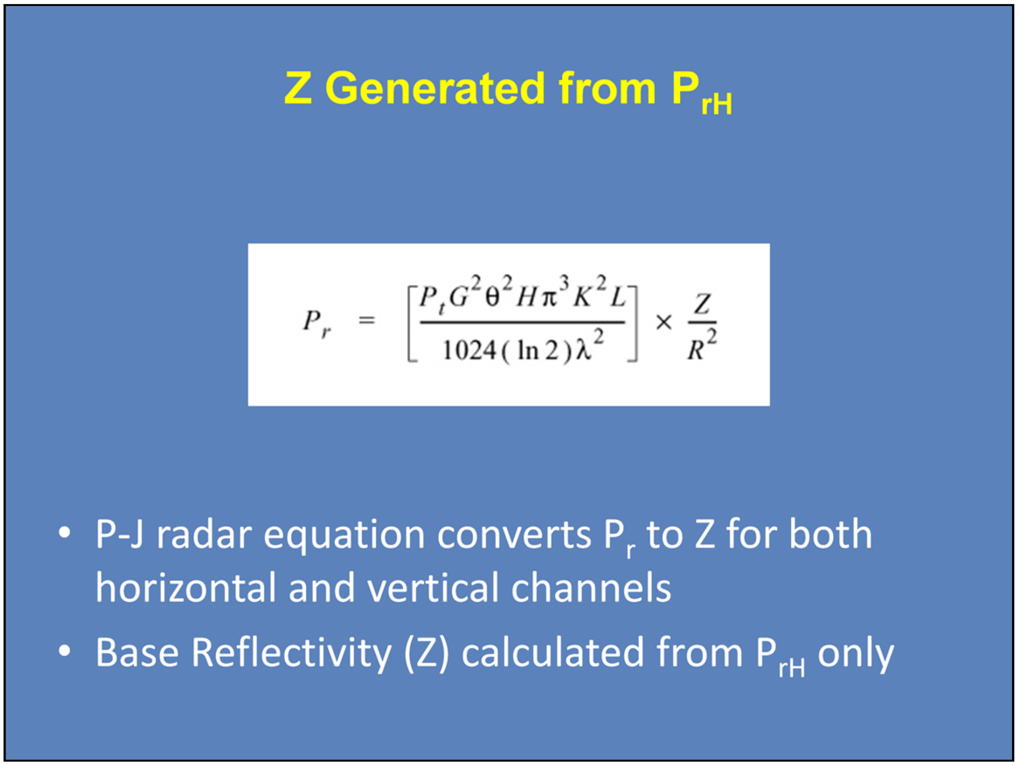
Base Reflectivity (Z) Generation



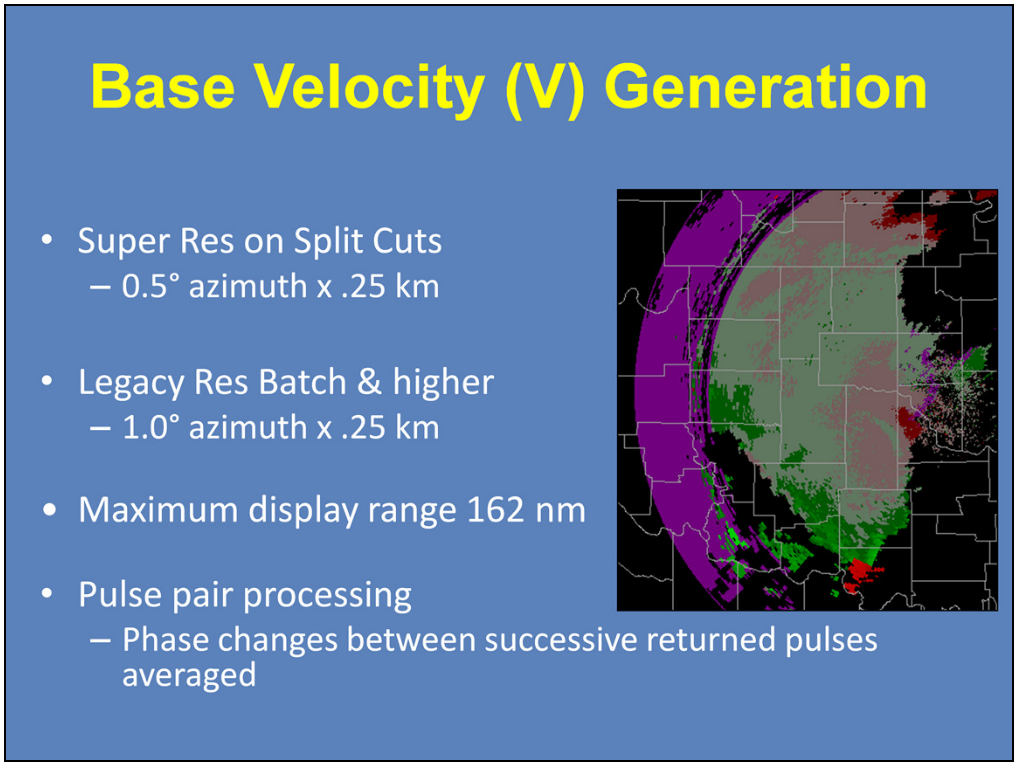
- Low PRF => long R_{max}
- Split Cut
  - 1st rotation CS/low PRF
    - Z & Dual-pol
  - 2nd rotation CD/high PRF
    - V & SW

A low PRF provides a long R_{max} and is used for Reflectivity data. Split Cut mode is used for the lowest 2 or 3 elevations for all the VCPs except VCP 121. Split Cut first uses one rotation in Contiguous Surveillance (CS), which is a low PRF mode. Base reflectivity and the dual-pol data are generated from the CS rotation. Then there is a second rotation at the same elevation in Contiguous Doppler (CD), which is a high PRF mode, used for base velocity and spectrum width. The trade off is that the R_{max} for CD mode is short, and multiple trip, range folded echoes are common.

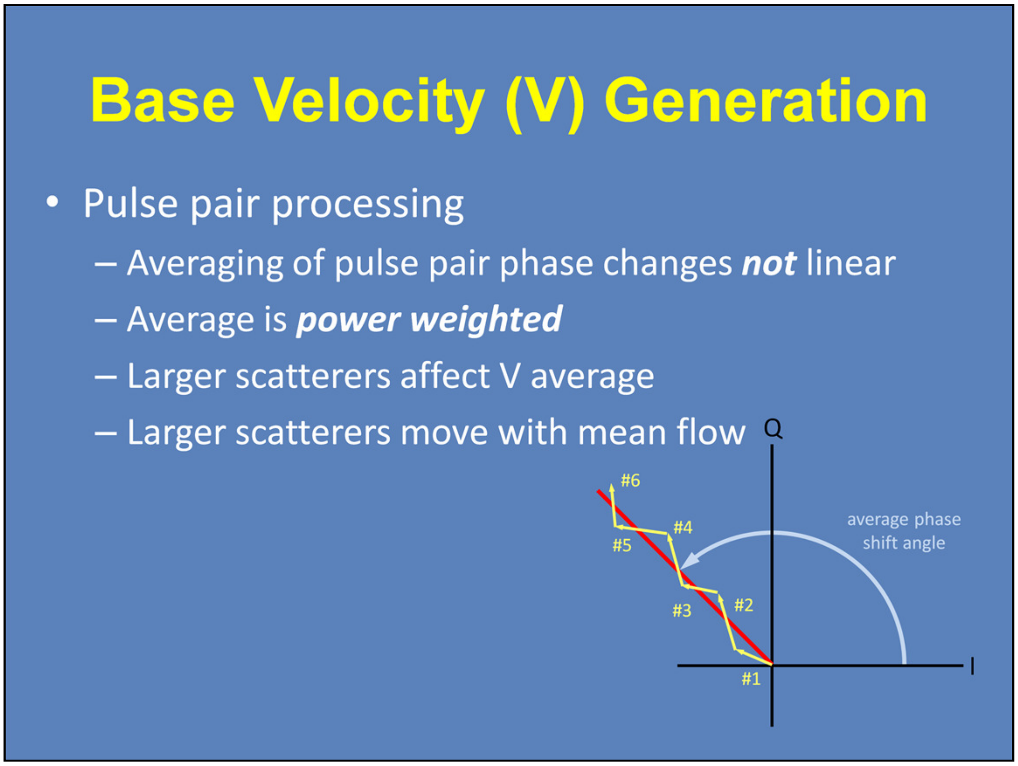
The data collected from these two rotations are used together to “range unfold” velocity and spectrum width. The range unfolding techniques are presented in a later lessons.



Base reflectivity is calculated from the average returned power, that is then converted to reflectivity from the Probert-Jones radar equation. Now that the WSR-88D has been upgraded to dual-polarization, this conversion from returned power to reflectivity is performed on both the horizontal and the vertical channels. However, the Base Reflectivity product is built from the horizontal channel information only.



Velocity also has a .25 km range resolution. Just as with reflectivity, super resolution is defined as 0.5° azimuth and is available only for the Split Cut elevations. For the Batch and higher elevations, velocity data has an azimuthal resolution of 1.0°. The maximum display range for velocity is 162 nm. Pulse pair processing refers to averaging the phase changes between a series of returned pulses to achieve a velocity estimate. However, this is not a linear average.



Instead of a linear average of pulse pair phase shifts, the average is weighted toward those pulses that return higher power. This means that the larger scatterers in the volume will have a greater influence on the velocity estimate, and the larger scatterers are more likely to move with the mean flow.

For the calculation, each phasor in this graphic represents the information for one pulse pair. The phasor's angle from the positive x axis is the pulse pair phase shift, while differences in phasor length relate to the returned powers of the two pulses. It turns out that a vector sum of these phasors results in a power weighted average pulse pair phase shift.

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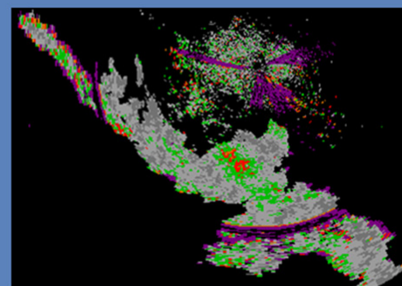
Base Spectrum Width (SW) Generation



- Super Res on Split Cuts
  - 0.5° azimuth x .25 km
- Legacy Res Batch & higher
  - 1.0° azimuth x .25 km
- Maximum display range 162 nm
- Measure of velocity dispersion
  - Proportional to variation in wind speed/direction
- SWs typically high with
  - Boundaries, thunderstorms, high shear

Spectrum width also has a .25 km range resolution. Just as with reflectivity, super resolution is defined as 0.5° azimuth and is available only for the Split Cut elevations. For the Batch and higher elevations, spectrum width has an azimuthal resolution of 1.0°. The maximum display range for spectrum width is 162 nm.

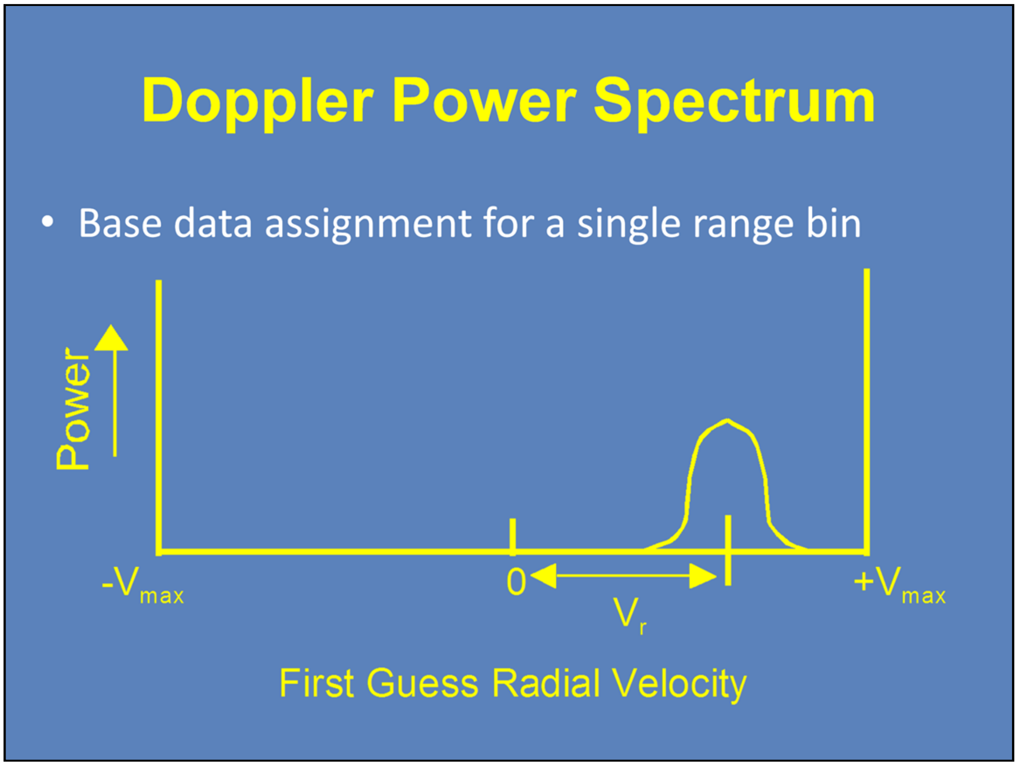
Spectrum width is a measurement of the velocity dispersion or variability within a range bin. It is proportional to the variability of wind speed and direction. Spectrum widths can be expected to be high in areas such as boundaries, thunderstorms or any high shear environment.

Base Spectrum Width (SW) Generation

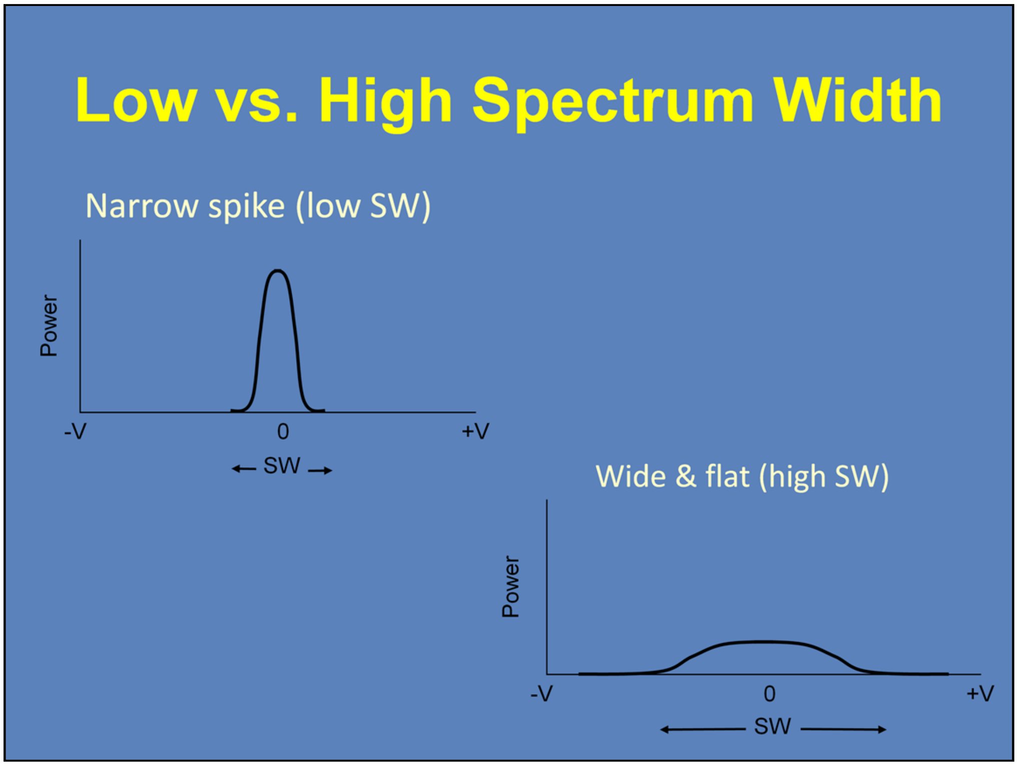
- SW technique “Autocorrelation”
  - How successive pulse pair shifts correlate to one another

- High variation in phase shifts =>high SW
- Low variation in phase shifts =>low SW
- Visual tool: Doppler power spectrum
  - “weather” well approximated by Gaussian curve

The technique used to calculate Spectrum Width is called Autocorrelation. What’s being correlated? The series of phase shifts from one pulse to the next. If there is a lot of variation in the pulse pair phase shifts, the spectrum width will be high. If there is little variation, the spectrum width will be low. The best way to visualize spectrum width is through the “Doppler Power Spectrum”. It turns out that “weather” can be well approximated by a Gaussian curve. The Doppler Power Spectrum is a representation of the base data analysis process.



The Doppler Power spectrum represents the base data analysis process for a single range bin. The power and velocity information from a series of pulses are converted to points known at “spectral coefficients”. A bell curve is fit to these coefficients. The average returned power (thus reflectivity) is the area under the curve. The mean radial velocity is where the midpoint of the curve falls along the horizontal axis. The width of the curve is proportional to the magnitude of spectrum width.



The magnitude of spectrum width will vary depending on the shape of the power spectrum. Returned pulses from ground clutter will likely have strong power and near zero velocity (upper left image). There is minimal variation in pulse pair phase shifts and the Doppler Power Spectrum curve is narrow and centered near zero velocity. This also results in a low spectrum width. On the other hand, some type of weather is returning low power, but a wide variety of velocity values (lower right image). The average velocity is near zero, but the width of the Doppler Power Spectrum is much greater than with the clutter example, and the associated spectrum width value would be high.

Welcome to Super Resolution Base Data Generation.

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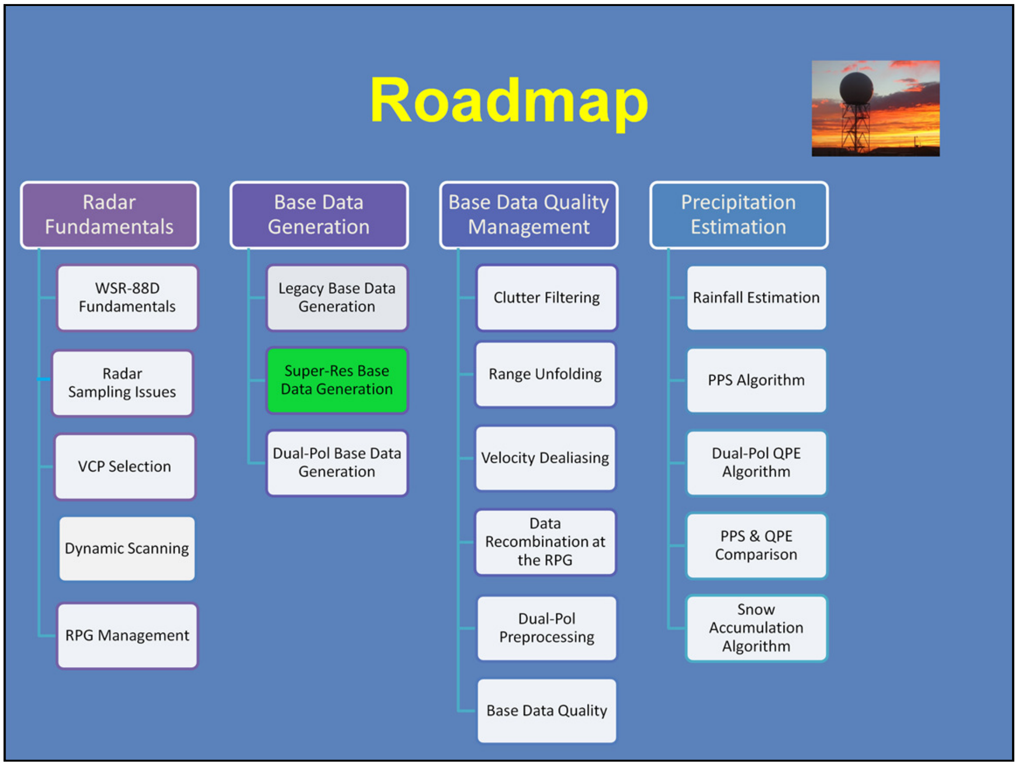

Here is the “roadmap” with your current location.

Super Res Base Data Generation
Objective

1. Identify the operational impacts of the signal processing techniques used to produce super resolution base data.

There is one objective in Super Resolution Base Data Generation.

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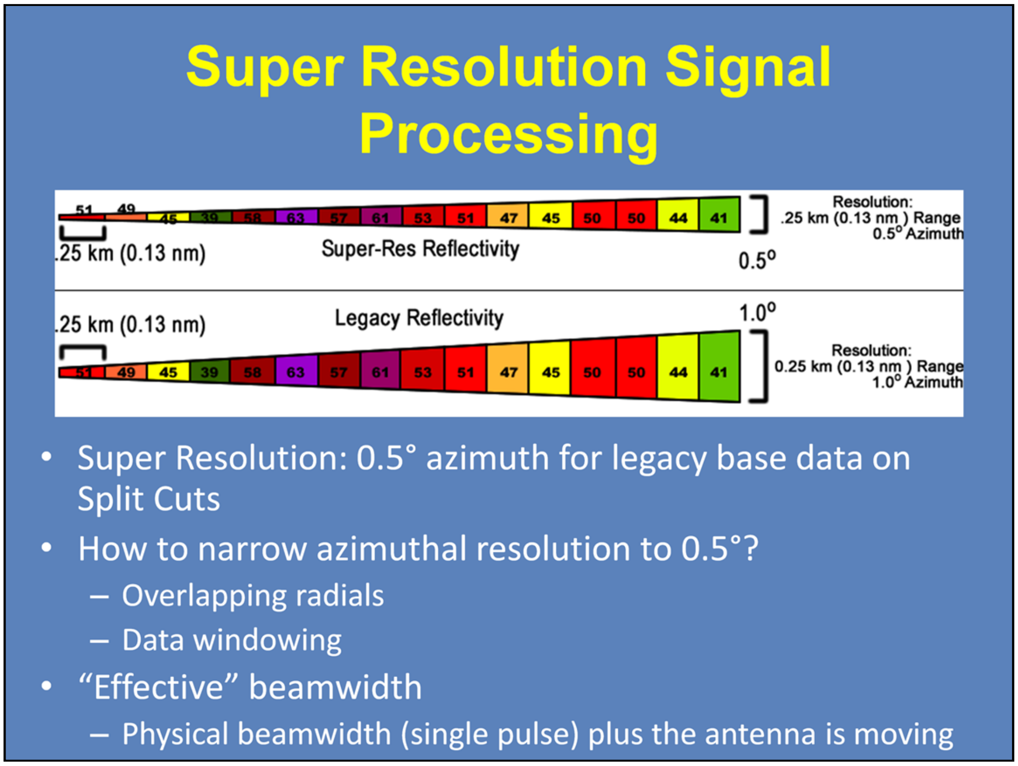
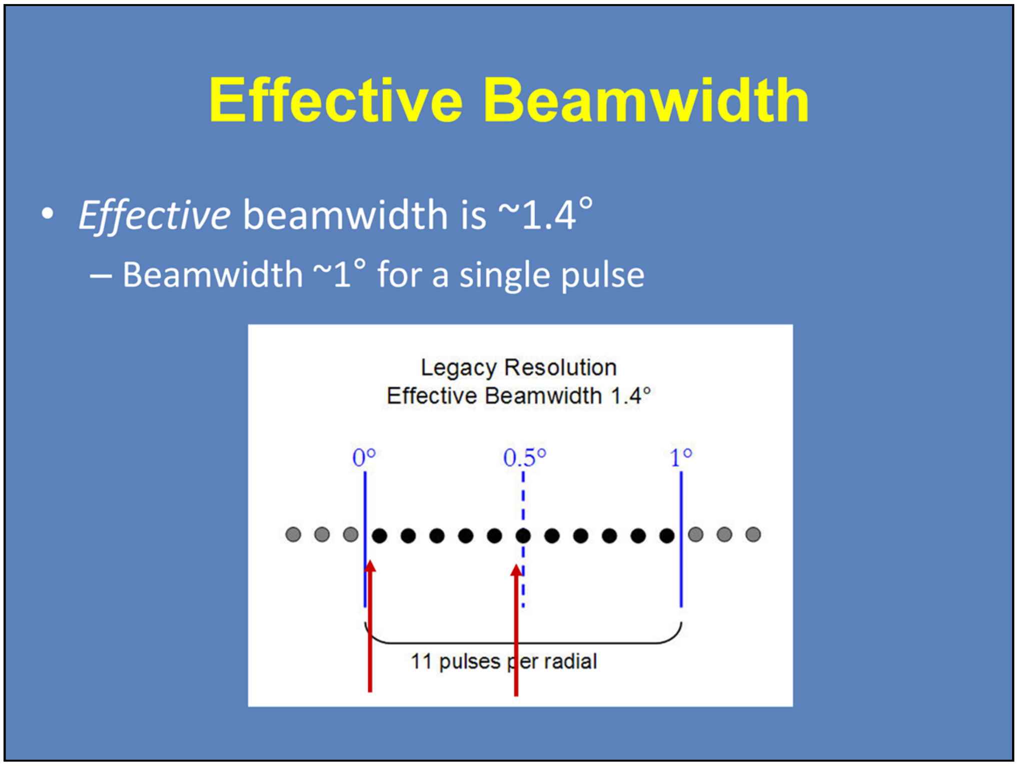


Super resolution is defined as a 0.5° azimuth. It is available only for legacy base data on the Split Cut elevations.

The upgrade to super resolution was based on signal processing techniques, not on new hardware. There are two signal processing techniques used to narrow the azimuthal resolution from 1.0° degree to 0.5°, overlapping radials and data windowing.

In order to understand this approach, we need to start with the concept of effective beamwidth. The "beamwidth" of ~1.0° presented in WSR-88D Fundamentals is based on the antenna being stationary. Antenna motion produces what is know as the effective beamwidth.



In order for a pulse to be used for the base data estimate for a radial, the beam centerline must be somewhere within that radial. In this example, each dot represents the location of the beam centerline for a single pulse. There are 11 pulses that fall within this simplified 1° radial. As the antenna rotates, the pulse with a centerline that is just on the inside edge of this radial still has a physical beamwidth of 1°, so the beam is sampling a volume that is both inside and outside the radial. Only when the beam is centered on this radial is the associated pulse contained within the radial. This process of capturing volumes outside a radial as base data are estimated is what is known as the effective beamwidth, which for the WSR-88D, is about 1.4°.

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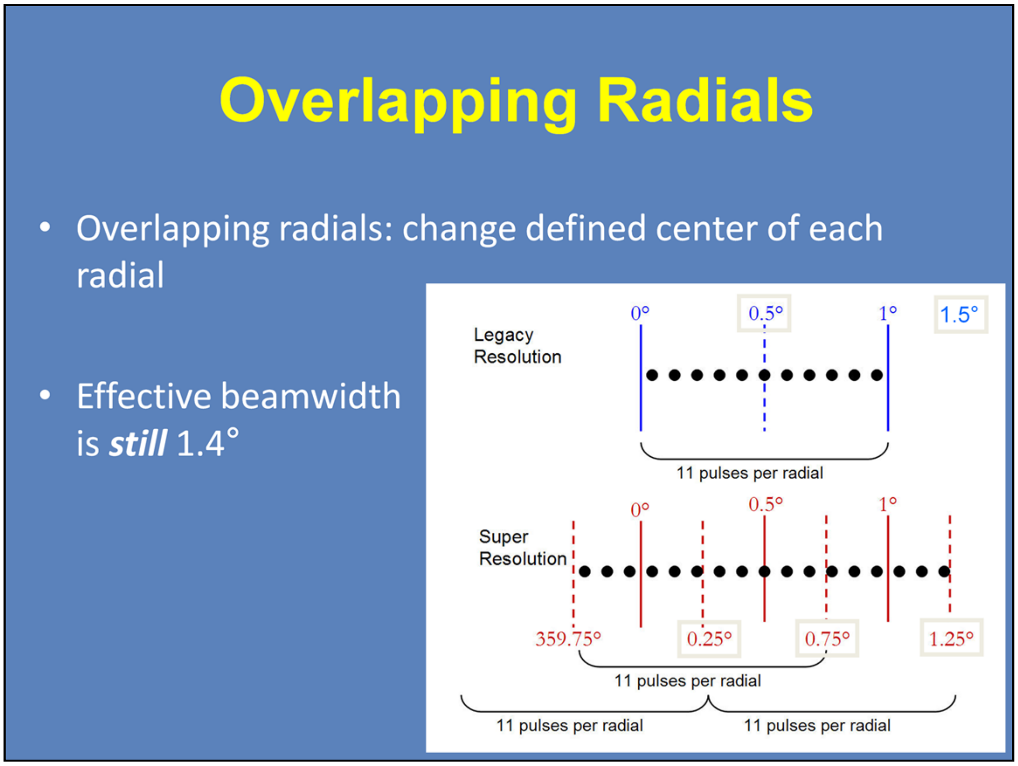
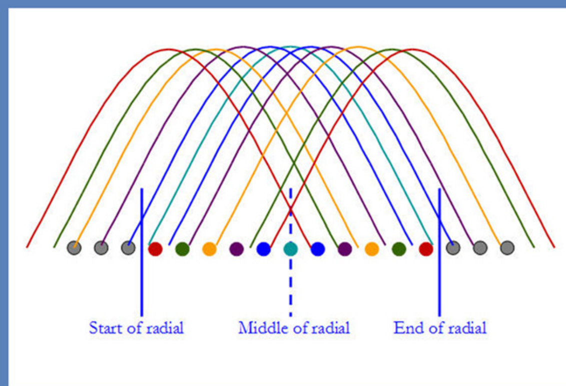


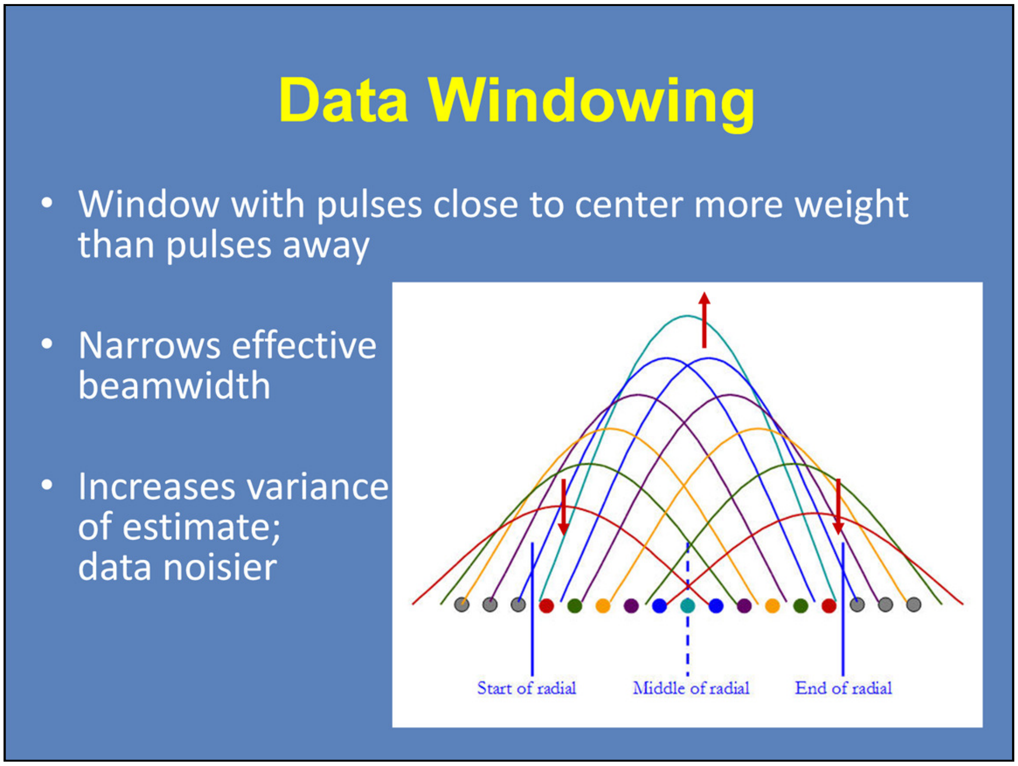
The process of overlapping radials is simply changing the definition of the center of each radial. The radial centers for legacy resolution are 0.5°, 1.5°, 2.5°, etc. The radial centers for super resolution are 0.25°, 0.75°, 1.25°, 1.75°, etc. However, since the number of pulses per radial cannot decrease and the effective beamwidth is still 1.4°, the volume that is sampled outside of each 0.5° radial is too large. Simply choosing new radial centers is not sufficient. The next step is needed to narrow the effective beamwidth.

Data Windowing



- Data Windowing
  - Apply weighting function to pulses that comprise base data for a radial
- Rectangular window: all pulses have equal weight

Data windowing is the next step required to achieve super resolution by narrowing the effective beamwidth. Windowing is a signal processing technique that applies a weighting function to the pulses that are used to generate base data for a particular radial. A technique that applies equal weight to all of the pulses is known as the Rectangular window.



What is needed for super resolution is a window that narrows the effective beamwidth. This is accomplished by giving pulses near the center of the radial more weight, progressing to less weight applied to pulses away from the center. This technique meets the need of narrowing the effective beamwidth, but it does introduce more variance or error in the estimate. This increase in error occurs because some of the pulses are overemphasized while others are underemphasized. The result is that the data on super resolution products is noisier than the legacy resolution.

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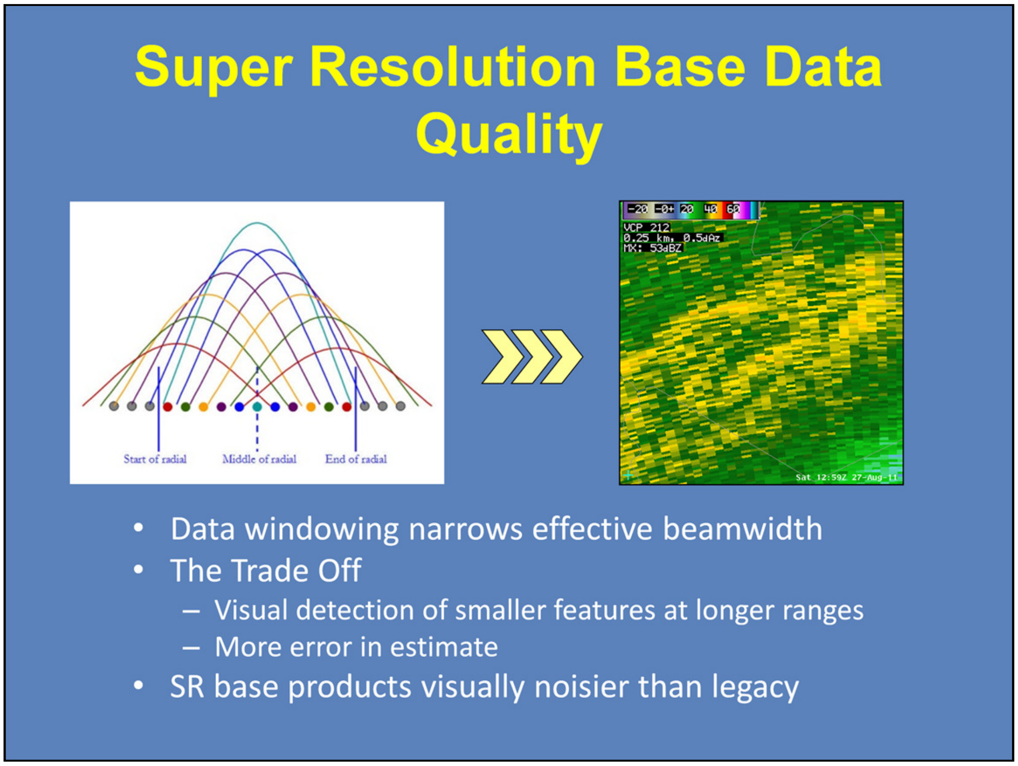

The 0.5° azimuthal resolution is obtained through signal processing techniques, specifically data windowing. This technique narrows the effective beamwidth, but there is a trade off. Smaller scale features are visually detectable at longer ranges with super resolution, but there is also more error in the base data estimate. In general, super resolution base products are visually noisier than corresponding legacy resolution base products. Many of the RPG algorithms were not designed to ingest super resolution base data.

Welcome to Dual Polarization Base Data Generation

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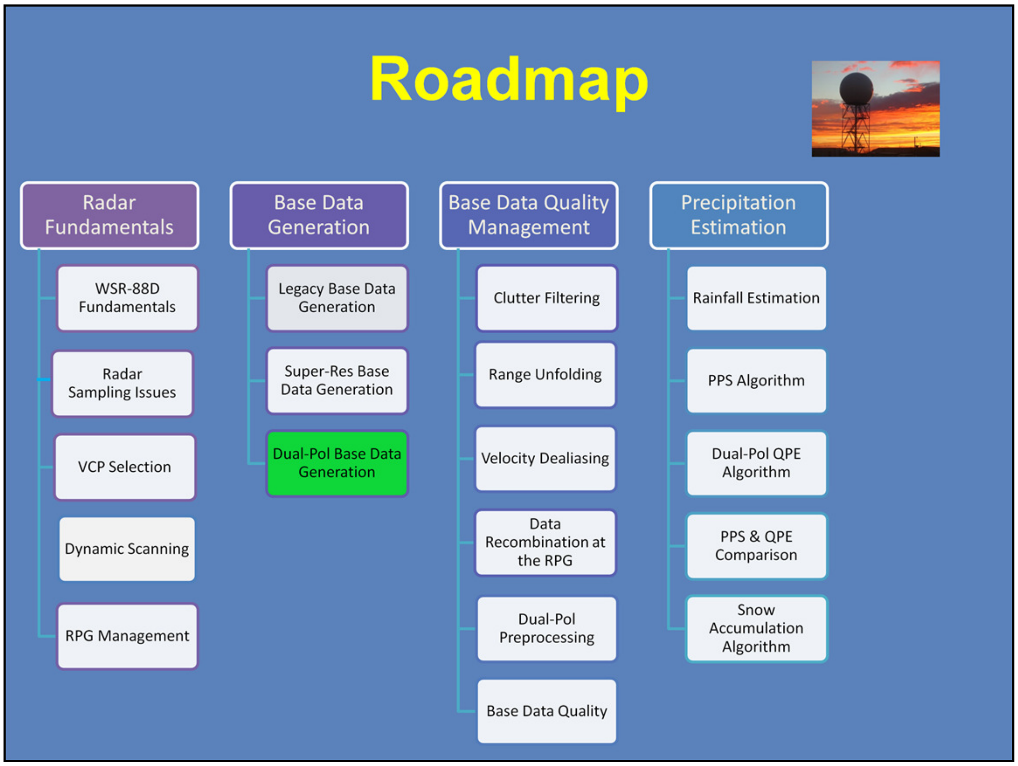

Here is the “roadmap” with your current location.

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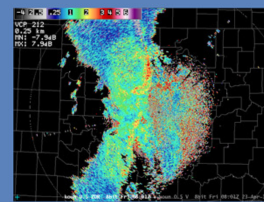
Dual Pol Base Data Generation
Objectives

1. Identify how the returned signal is used to generate
   a) Differential Reflectivity (ZDR)
   b) Correlation Coefficient (CC)
   c) Differential Phase (Φ_{DP}), then Specific Differential Phase (KDP)
2. Identify the similarities and the differences between SW and CC
3. Identify the radar volume characteristic that has the greatest impact on the magnitude of KDP

There are 3 objectives in Dual Pol Base Data Generation. These objectives will be taught in sequence during this lesson.

RDA Generation of ZDR

- ZDR calculated from P_{rH} and P_{rV}
  - $Z_{rH} = P_H C_H r^2$
  - $Z_{rV} = P_V C_V r^2$



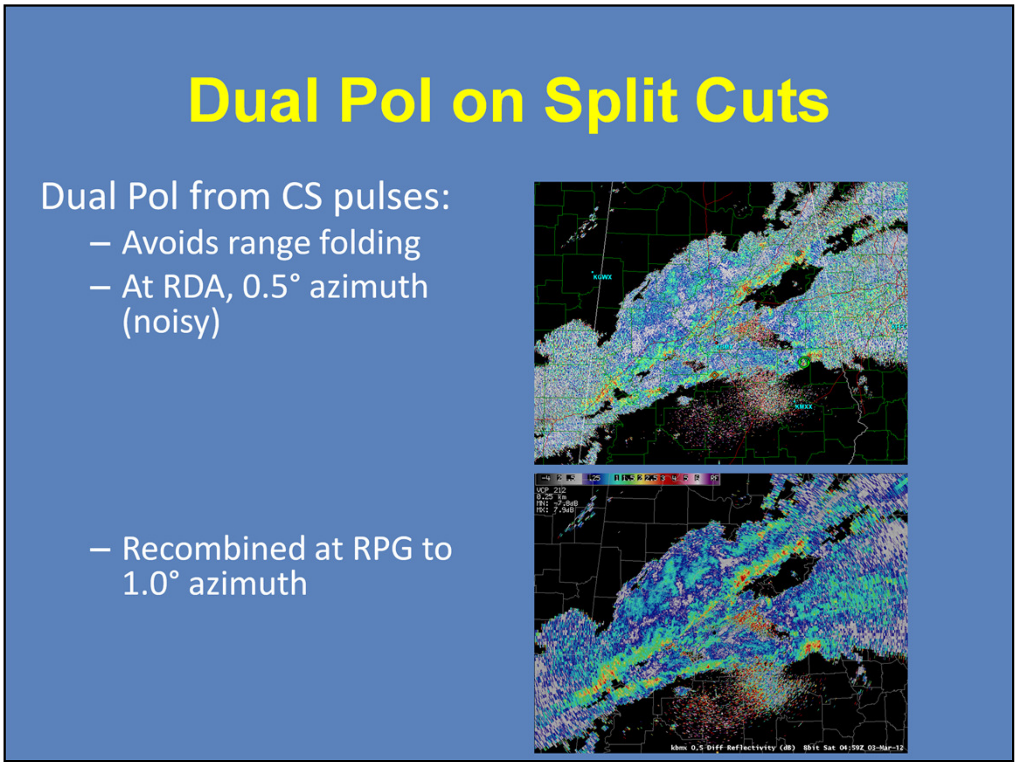
$$ZDR = 10\log_{10}\left(\frac{Z_H}{Z_V}\right)$$

$$= 10\log_{10}\left(\frac{P_h}{P_v}\right) + 10\log_{10}\left(\frac{C_h}{C_v}\right)$$

Calibration of both channels matters!

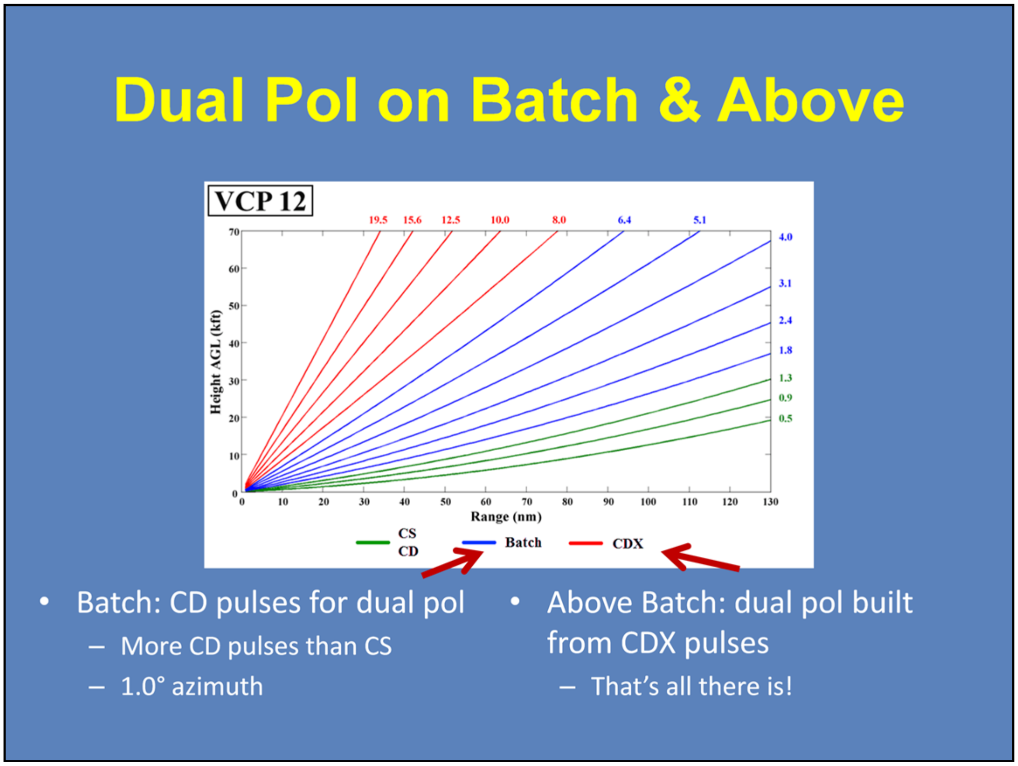
From the Probert-Jones radar equation, the Z value for each channel is equal to the returned power, times the range squared times a constant that is based on the radar's calibration.

Just as with Base Reflectivity, ZDR is calculated from returned power, but ZDR uses returned power from the horizontal and vertical channels. The ZDR equation can be written as ZDR = 10log (Z_H/Z_V). When the Zs are substituted with returned power, the radar constants and the range, the range terms cancel. I'm showing the logarithmic separation of returned power and the radar constant terms to underscore the importance of calibration of both channels for an accurate ZDR. There are operational implications of the need to calibrate both channels that will be presented later in the course.



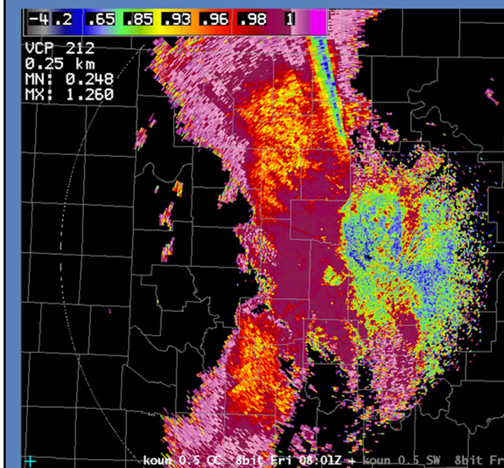
For the Split Cut elevations, ZDR and the other Dual Pol data are built from the low PRF, Contiguous Surveillance pulses on the first rotation. This is to avoid multiple tripping or range folding, and thus the need to “range unfold” the ZDR data. As with the legacy base moments (Z, V, & SW), the azimuthal resolution for ZDR on the Split Cuts is 0.5°. With this resolution, ZDR, and all the other Dual Pol data are even noisier in appearance than Z, V & SW. On the upper right is a ZDR image built from the 0.5° azimuthal resolution Level II data. On the lower right is that same data that has been recombined to 1.0° azimuth and smoothed. This is how ZDR appears on the AWIPS display.

All of the Dual Pol base data are recombined at the RPG to 1.0° azimuth and smoothed, before the products are built, and there will be more about this “preprocessing” in a later lesson.



For the Batch elevations, the antenna makes a single rotation alternating between low PRF, Contiguous Surveillance, and high PRF, Contiguous Doppler, mode. ZDR, and the other Dual Pol data, are built from the Contiguous Doppler pulses for each radial, since there are more of them. It is possible to see range folded, RF, data on the Dual Pol products at these elevations since there is no range unfolding applied. The azimuthal resolution is 1.0°, so no recombination is required. For the elevations above Batch, ZDR and the other Dual Pol data are built from the CDX pulses because that is all that is used. Since multiple trip echoes are so unlikely at these higher elevations, the CDX means Contiguous Doppler with no range unfolding.

RDA Generation of CC



- Correlation Coefficient (CC)
  - AKA "Cross Correlation": H & V channel phases compared to ***one another***
- Reveals dualpol base data quality & nature of scatterers
  - Similar to SW and quality of V estimate
- CC and low signal power

Correlation Coefficient (CC) measures the consistency of the H and V returned power and phase with one another for each pulse. This "cross correlation" looks at how the returned power and phase of one channel compares to the other channel. If the consistency is high (for example, stratiform light rain is being sampled), the phase change with one channel is similar to the phase change with the other channel. CC's measure of consistency reveals information on the nature of the scatterers. For example, uniform hydrometeors are much more consistent than ground clutter or smoke.

CC also provides information on the quality of the Dual Pol base data estimate, in some ways similar to the relationship between spectrum width and velocity. Spectrum width measures the consistency of the phase shifts from one pulse to next, which then relates to the reliability of the associated velocity value. There are both similarities and differences between CC and SW coming up soon, along with what happens to the validity of CC values in areas of very weak returned signal.

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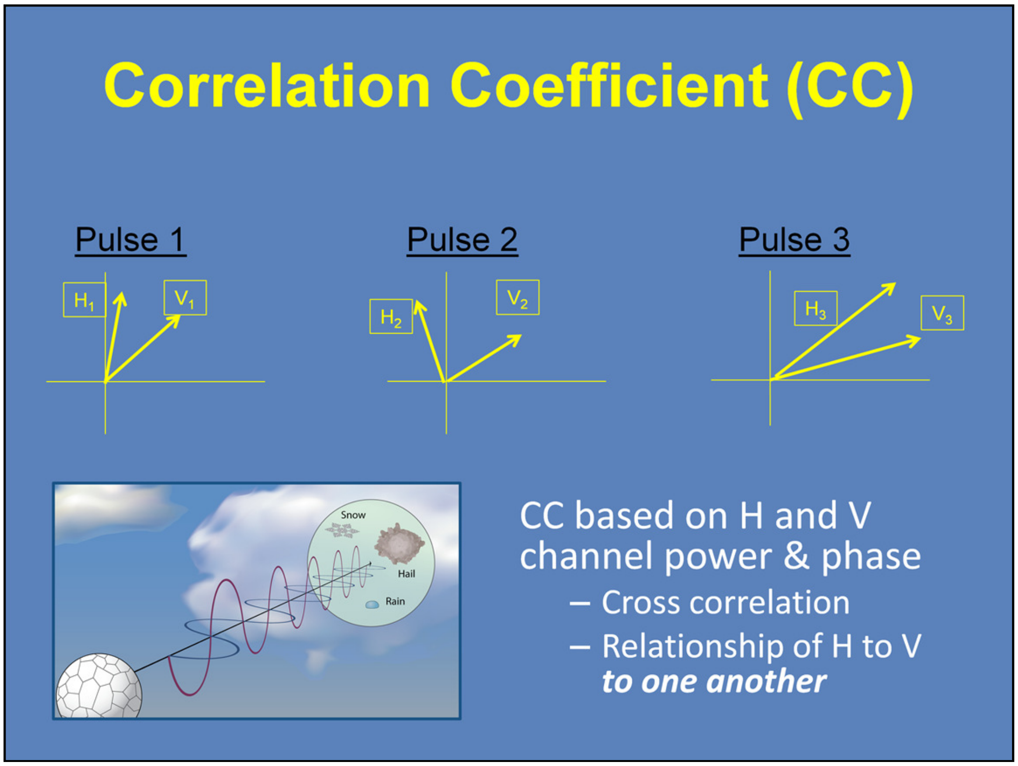
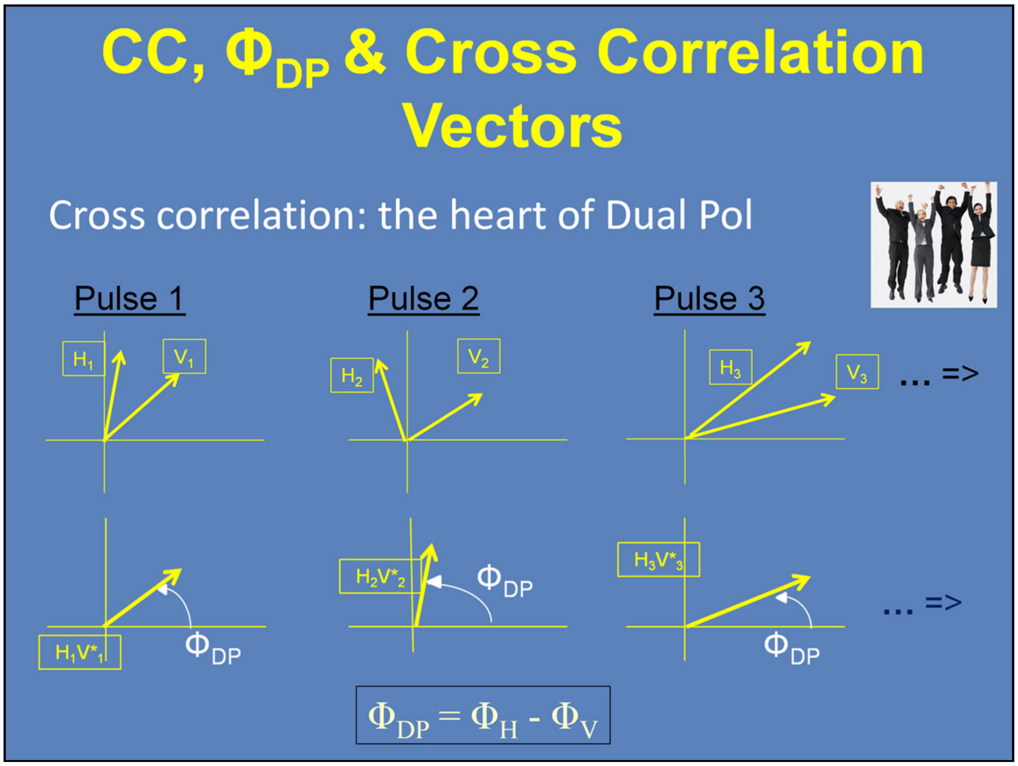


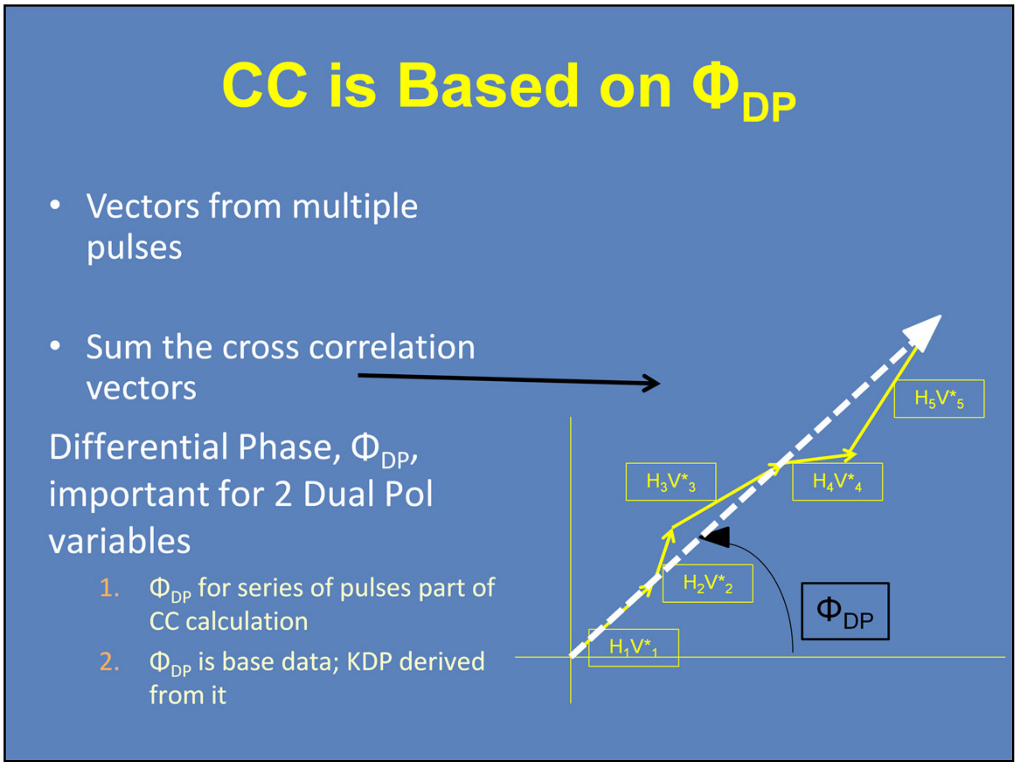
For each pulse, the returned power and phase from the H and V channels is known and can then be compared to one another. This type of comparison is know as a cross correlation. Of interest here is the magnitude of and the angle between the H and V vectors, which can be determined by vector multiplication. This "cross correlation" vector (next slide) of H and V is checked for each pulse.



Cross correlation vectors are at the heart of Dual Pol base data. Here are a series of pulses, with the individual phasors for the H and V channels of each pulse. The cross correlation vector for each pulse captures how the horizontal and vertical information relate to one anther.

The cross correlation vector for each pulse is computed by multiplying the H vector by the complex conjugate of the V vector. This multiplication creates a new vector whose phase is the angle between H and V. This angle is known as Φ_{DP}. It is the horizontal phase minus the vertical phase: $\Phi_{DP} = \Phi_H - \Phi_V$

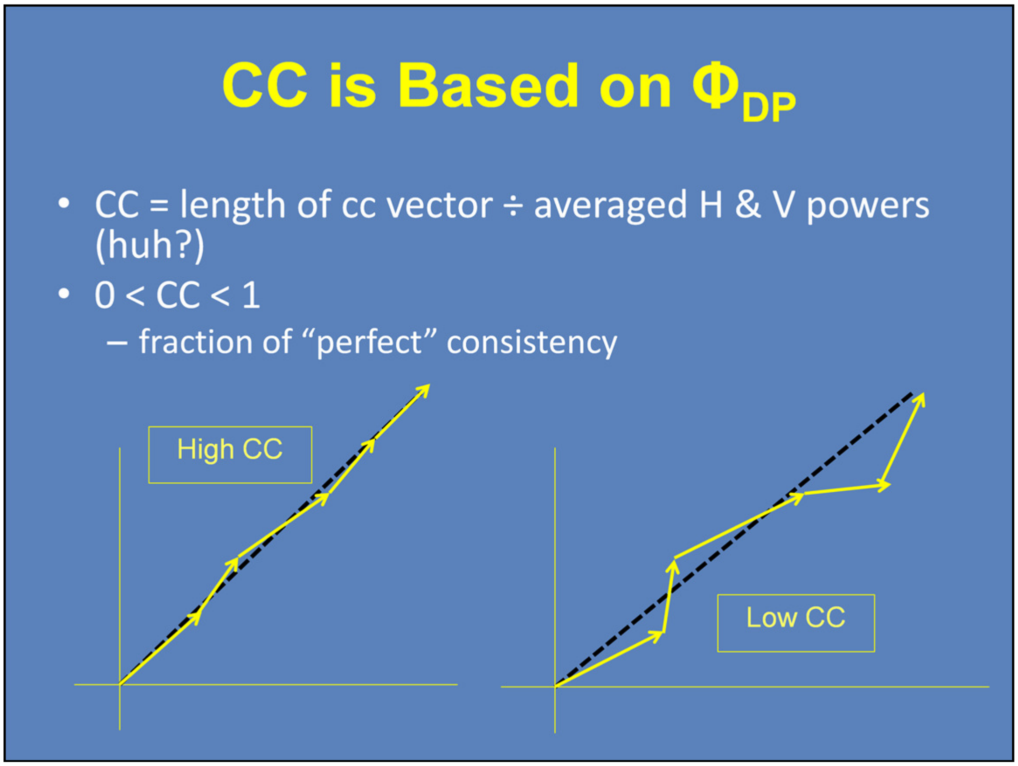
There is a Φ_{DP} for each individual pulse, as well as an average Φ_{DP} value assigned to each range bin, known as the Differential Phase.



Since we don't assign any type of base data with just one pulse, the cross correlation vectors for a series of pulses are summed. This vector sum (white dashed arrow) is what's needed for the remaining two Dual Pol variables. Differential Phase, Φ_{DP}, is the angle of this vector sum, and it is part of the base data generated at the RDA for each range bin.

It turns out that Differential Phase, Φ_{DP}, is important for two of our Dual Pol variables:

1. Φ_{DP} for a series of pulses is part of the calculation of CC.
2. Φ_{DP} is base data generated at the RDA and sent to the RPG. Specific Differential Phase, or KDP, is derived from it.



For a little more detail, CC is calculated by taking the length (or amplitude) of the vector sum of the cross correlation vectors and dividing it by the averaged H and V powers. This calculation captures the variation of the individual cross correlation vectors that contributed to the sum.

CC is a unitless variable, a number between 0 and 1. It is a fraction of "perfect" consistency of scatterers.

If pure rain is being sampled, there is minimal variation between the H and V channels, the cross correlation vectors line up nicely, and CC is close to 1.

The more diverse the scatterers, the more variation with the cross correlation vectors, and CC gets closer to 0.

I have the word perfect in quotes, because CC is never exactly equal to 0 or 1.

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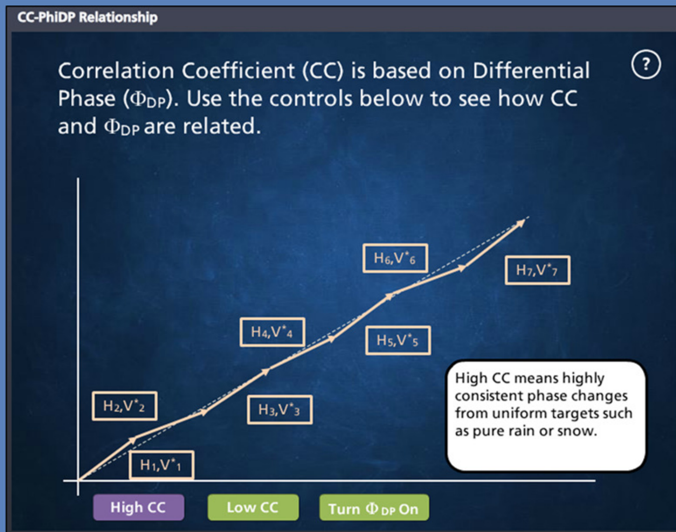
CC-PhiDP Relationship



If no pop-up window appears that looks like the above, open a browser and go to: http://www.wdtd.noaa.gov/courses/rac/principles/interactions/cc-phidp/

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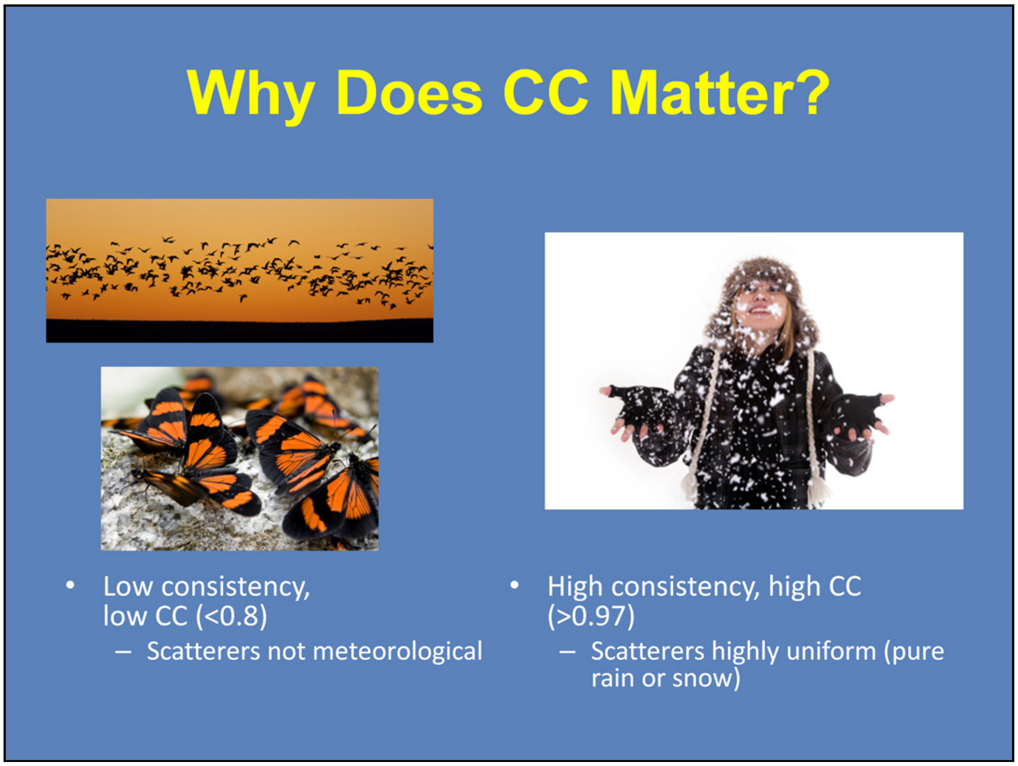
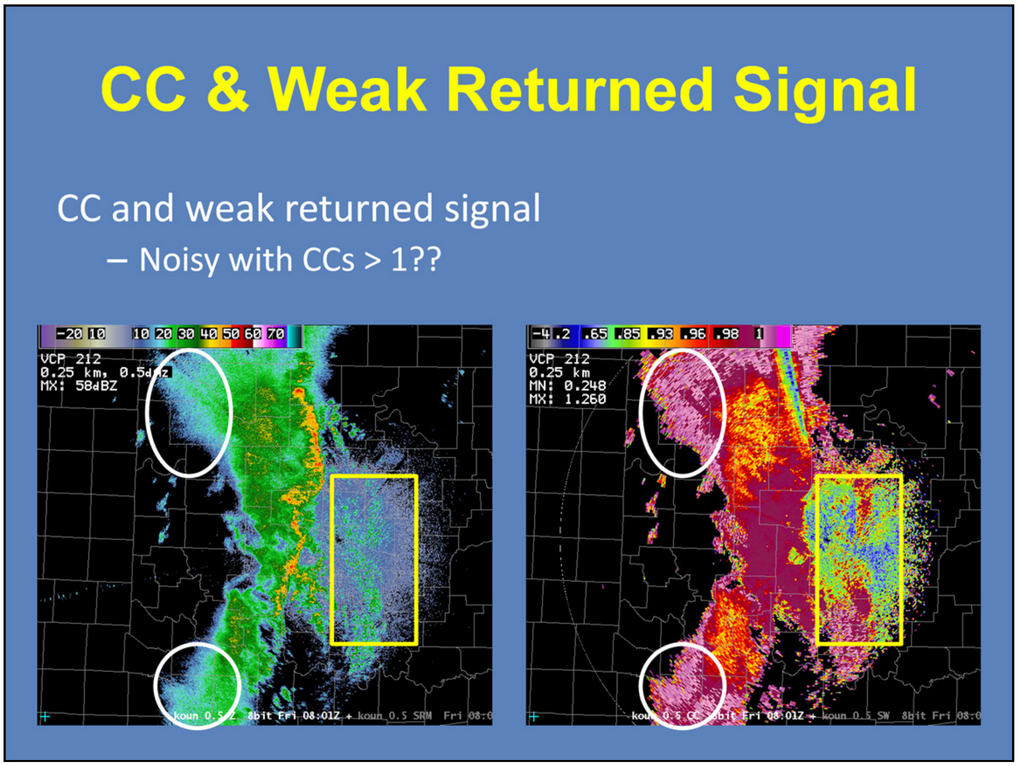


What does CC tell us? Low CC (<0.80) implies low consistency between H and V in the estimate and lot of diversity of the scatterers. In fact, CC <0.80 is so diverse the scatterers are unlikely to be meteorological, such as birds or insects. This distinction between biological and meteorological targets is one of the great benefits of Dual Pol.

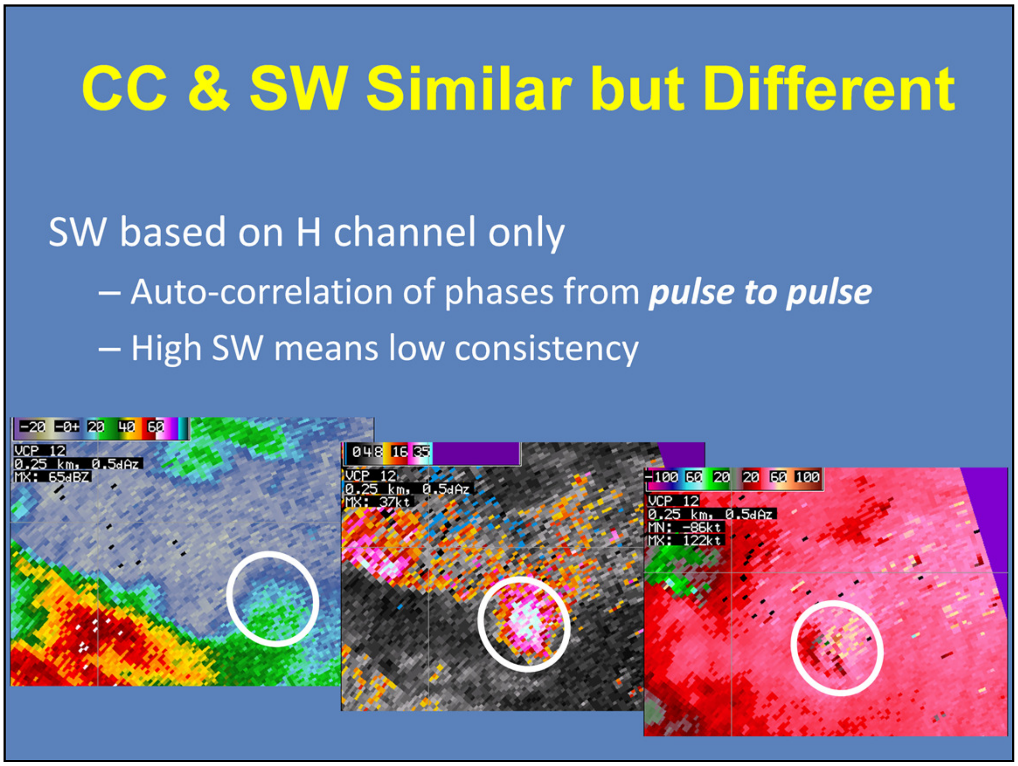
On the other hand, a high CC (>0.97) tells us that the Dual Pol base data estimate is high in consistency between H and V. The scatterers are very uniform in size and shape, such as pure rain or snow.



Correlation Coefficient is an important indicator of Dual Pol data quality. In general, the Dual Pol data will be noisier, and less reliable in weak signal areas than the legacy data. The good news is that CC can help to identify where the Dual Pol data are least reliable.

In areas of weak signal, CC is often noisy in appearance and the magnitudes can vary. Near the radar (boxed area) the CC values are generally low, and there are likely to be non-hydrometeors present. At longer range on the fringe areas of the precipitation (circled areas), the CC values are noisy with values greater than 1. CC > 1 is an estimation artifact, meaning that the estimate is unreliable at that location. It would be misleading to truncate these values at 1, so they are intentionally displayed as > 1.

Though the Z values near the radar and at long range are similar, the CC values tells us more. Z is range normalized, while returned power is not. The weak signal areas at longer ranges and the associated CC values are less reliable than weak signal areas at closer range.

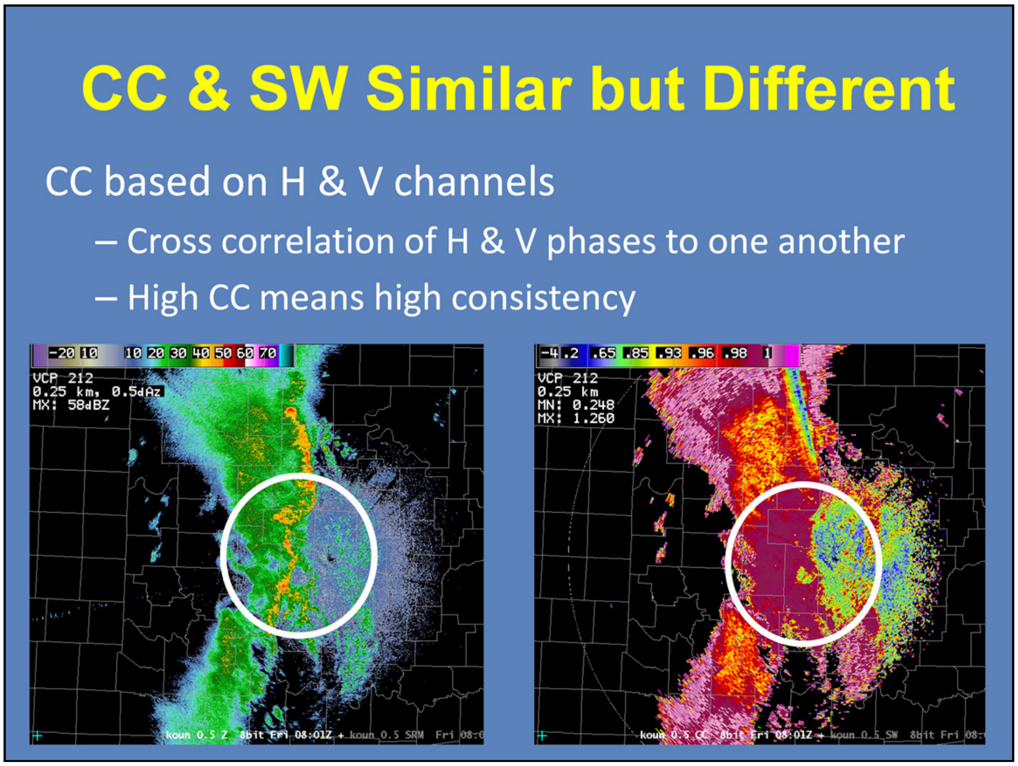


Correlation coefficient and spectrum width are analogous, but there are some important differences. Spectrum width is calculated from the horizontal channel only, and tells us something about the nature of the data from which the base velocity was calculated. Spectrum width is derived from auto-correlation, which compares horizontal channel phase shifts from one pulse to the next.

The greater the variation of these phase shifts, the greater the spectrum width. This means that a high spectrum width implies low consistency as the phase shifts are processed.

The circled area is weak signal close to an intense supercell. There is high spectrum width (middle image) due to both the weak signal and the turbulence. Notice that the velocity field in this same area (right image) is noisy.

A high spectrum width implies a low consistency of pulse to pulse phase shifts. It is an inverse relationship.

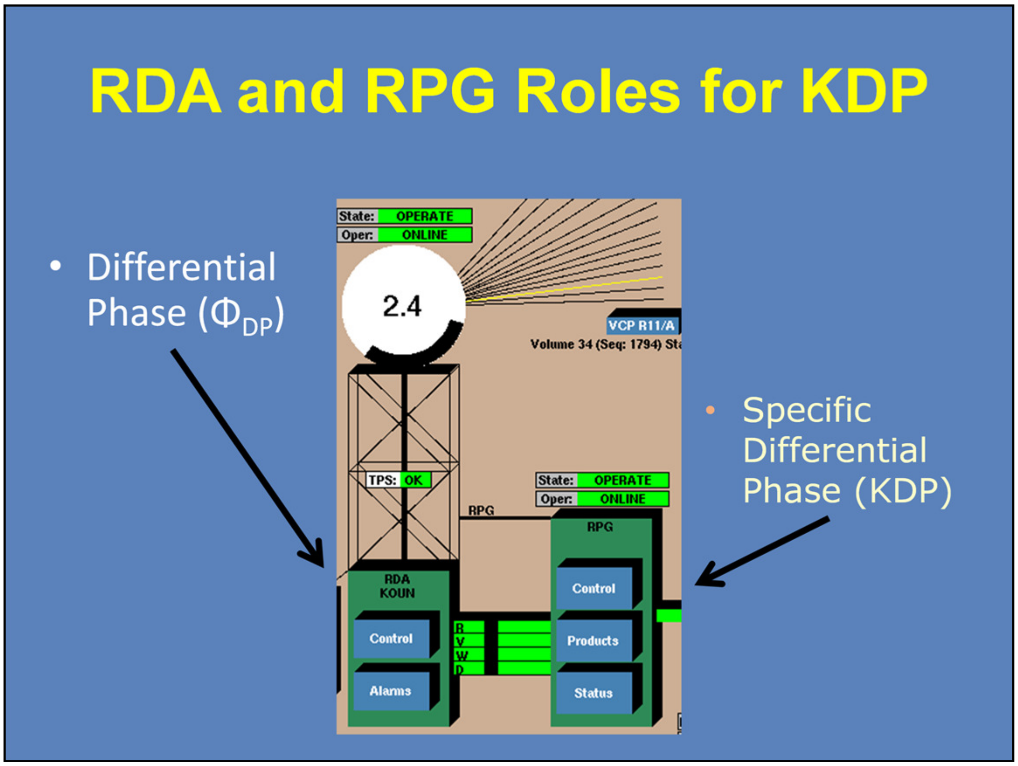


Unlike spectrum width, correlation coefficient is calculated from both the horizontal and vertical channels, and tells us something about the nature of the scatterers that were sampled. CC is derived from cross-correlation, which compares phases from the horizontal and vertical channel pulses to one another.

The greater the variation between the horizontal and vertical channels, the lower the cross-correlation, or CC value. On the other hand, a high correlation coefficient implies lower variation.

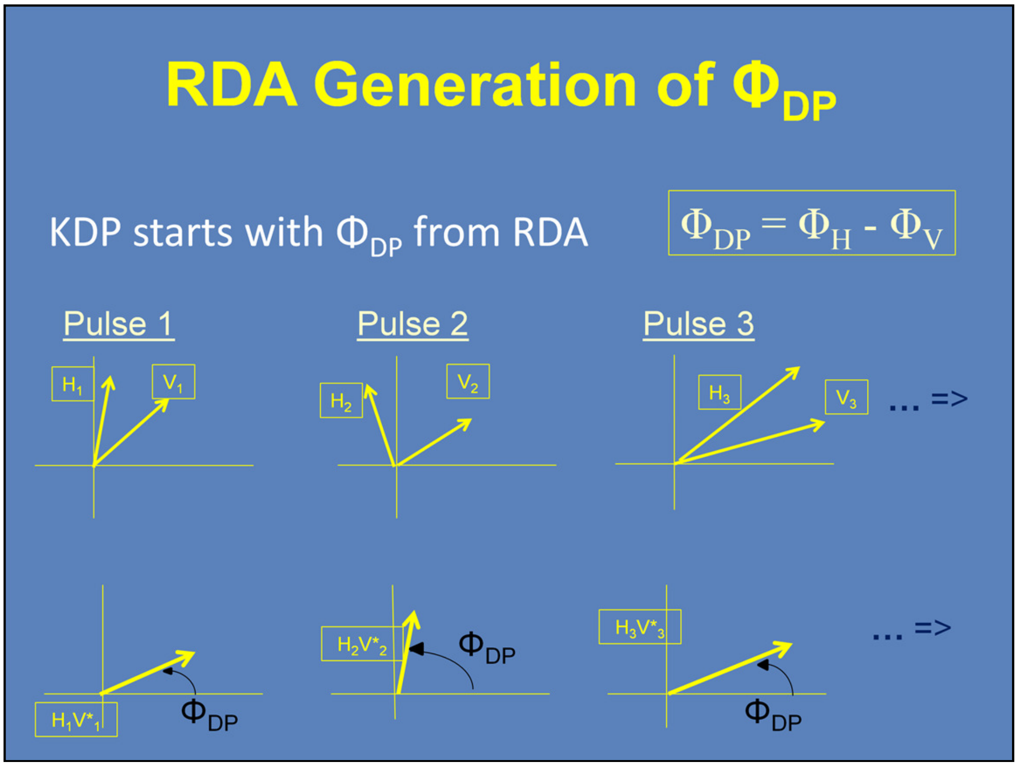
The circled area captures both precipitation and clutter near the radar. The correlation coefficient associated with the precipitation is high compared to the clutter. CC is an excellent discriminator between precipitation and non-precipitation echo. You'll see a lot more related to Correlation Coefficient interpretation later in the course.

A high Correlation Coefficient implies a high consistency between the horizontal and vertical channels. It is a direct relationship.



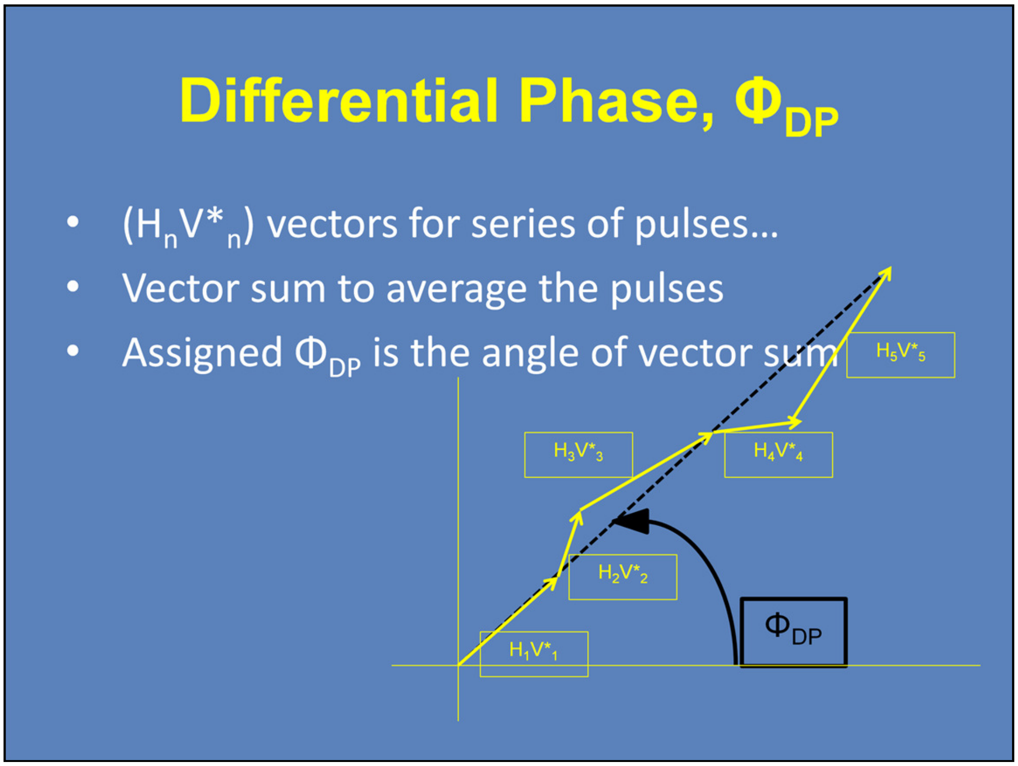
Another Dual Pol base product is Specific Differential Phase, or KDP, though it is technically a derived product generated at the RPG.

KDP is built from the Differential Phase, or Φ_{DP} base data, which are generated at the RDA and sent to the RPG.

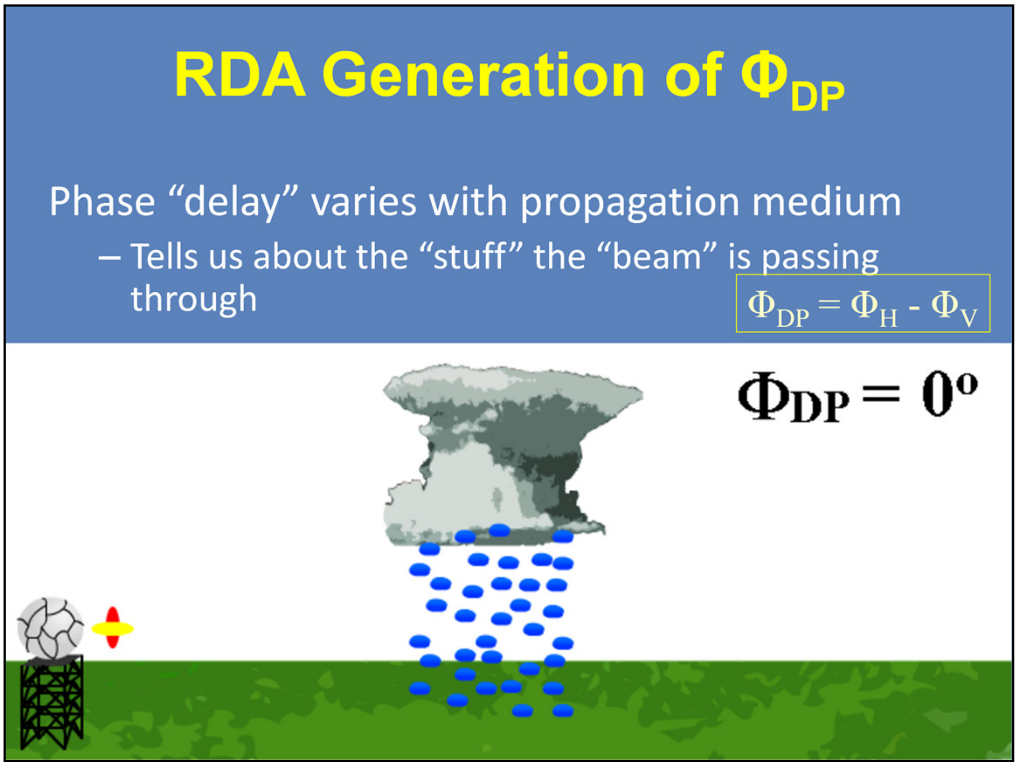


The benefit of KDP is that it tells you something about the type of medium (light rain? heavy rain?) that the beam has passed through.

In order to understand KDP, we must go back to differential phase, Φ_{DP}, which is generated by the RDA signal processor. Recall that for a single pulse, Φ_{DP} is the angle of the cross correlation vector, or the horizontal phase minus the vertical phase. For a series of pulses, Φ_{DP} is the angle of the vector sum of the cross correlation vectors (next slide).

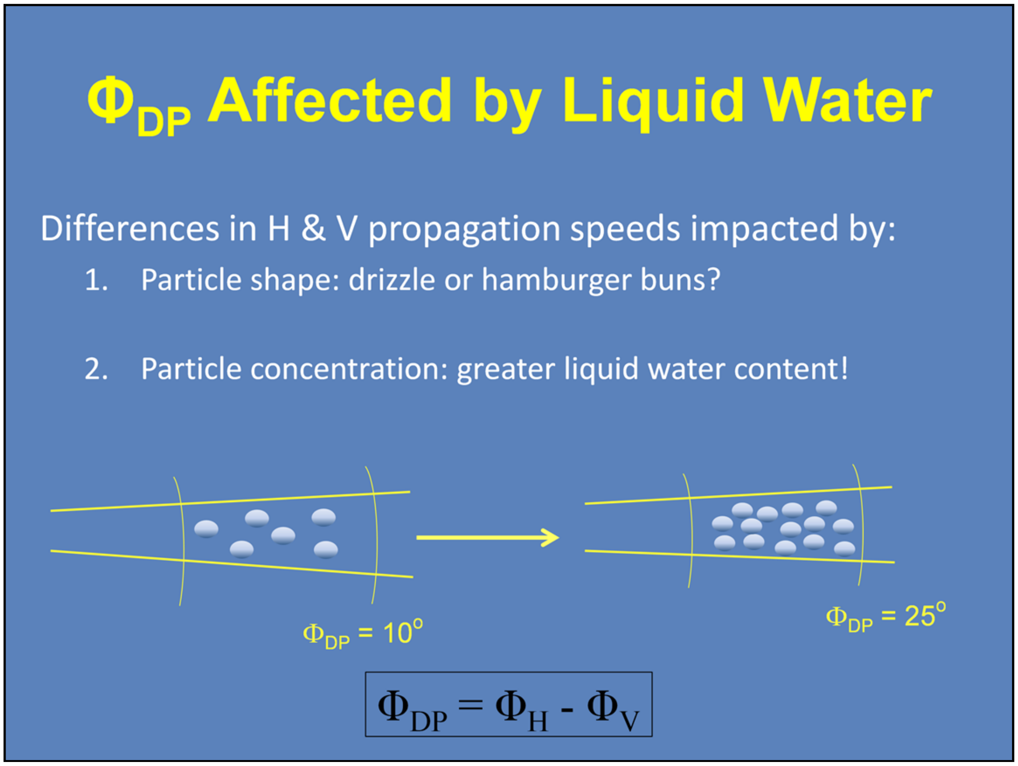


The differential phase, or Φ_{DP} value assigned as base data comes from the vector sum of the single pulse cross correlation vectors. The angle of this vector sum is the assigned Φ_{DP} for that range bin.



As the pulse propagates through different media (light rain, heavy rain, etc.), there is a delay that is apparent in the phase of the returned pulse. Since we have both horizontal and vertical phase, we can compare how the "H delay" differs from the "V delay". This gives us valuable information on the nature of the "stuff" that the radar pulse is passing through.

Liquid water provides "resistance" to the outgoing pulse. In this animation, the pulse is passing through raindrops, which have a larger horizontal extent than vertical. There is more resistance in the horizontal direction compared to vertical, creating a longer delay in the returned H phase compared to the V phase. The returned phase value for H will be greater than for V. This means that Φ_{DP} for that range bin will be positive.



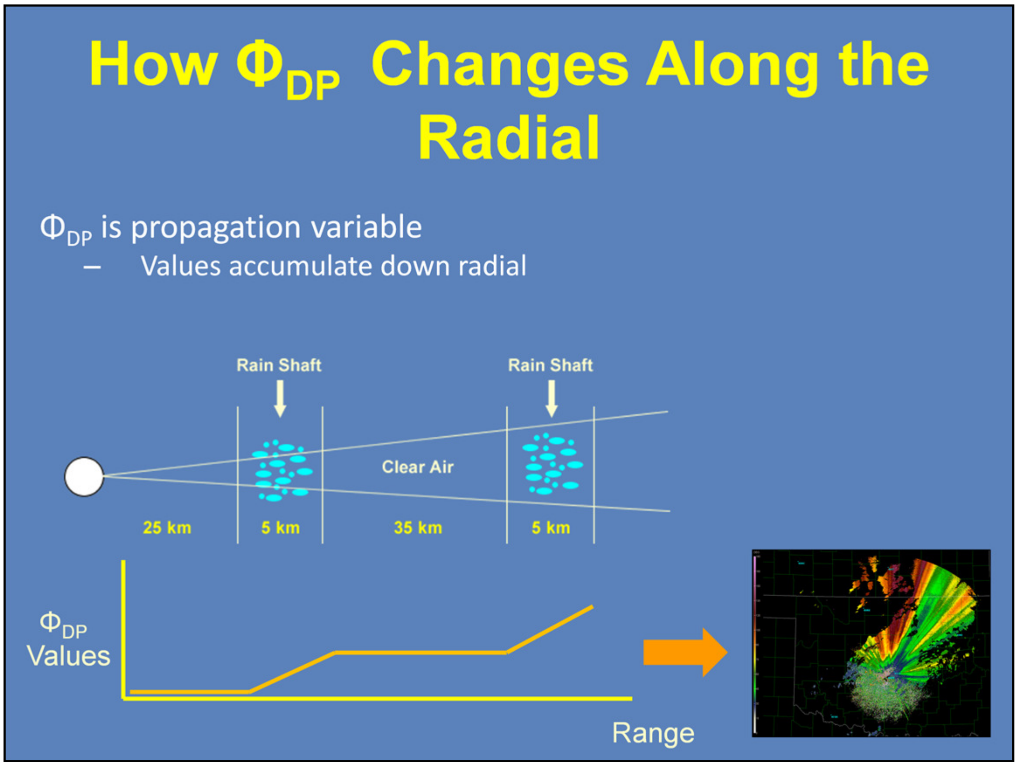
For any given atmospheric volume, the value of Φ_{DP} is affected by differences in propagation speeds of the horizontal and vertical waves. Propagation is slowed by both particle shape and/or by particle concentration.

Here are 2 examples that would result in a slower horizontal propagation compared to the vertical, and thus a higher Φ_{DP}:

1. If the beam is passing through large raindrops (think hamburger buns!), there is more propagation delay in the horizontal direction than in the vertical. That was the example on the previous slide.

2. Assume the same size and shape raindrops in each of two volumes. However, there is a greater concentration of them on the right. This greater concentration, which means more liquid water content, also creates a greater propagation delay in the horizontal direction than in the vertical.

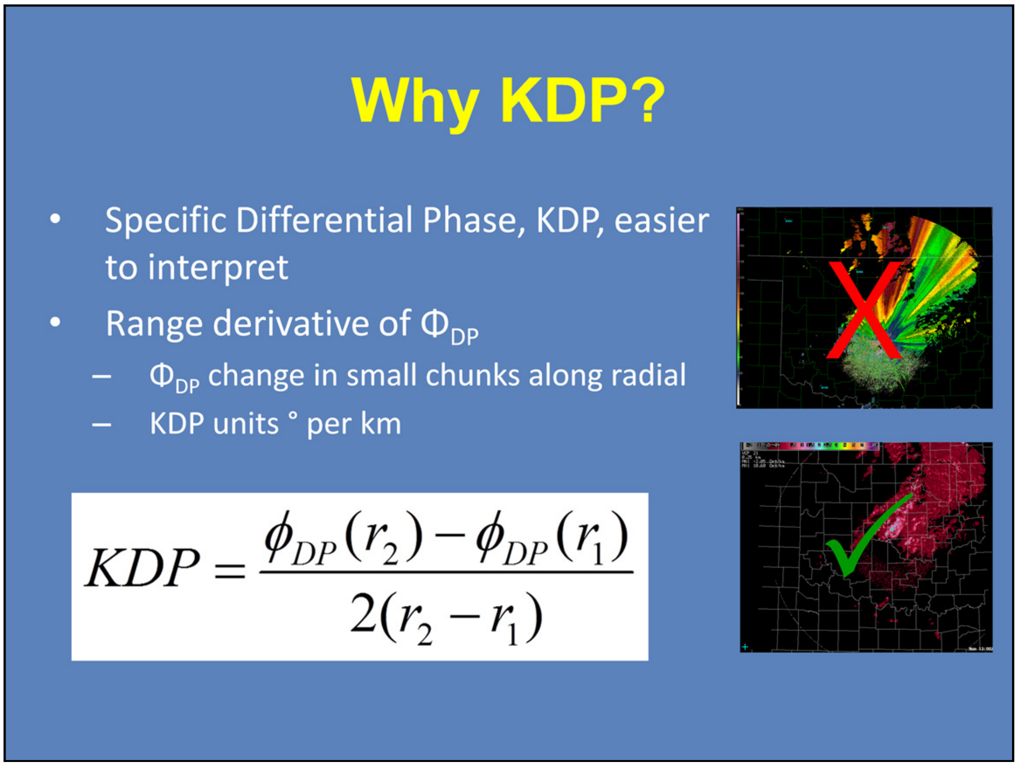
This direct relationship between Φ_{DP} and liquid water content is what makes this Dual Pol variable so valuable.



The value of Φ_{DP} propagates down radial, accumulating with range. There is no way to "reset" Φ_{DP} as the pulse travels outbound, encountering one or more areas of precipitation.

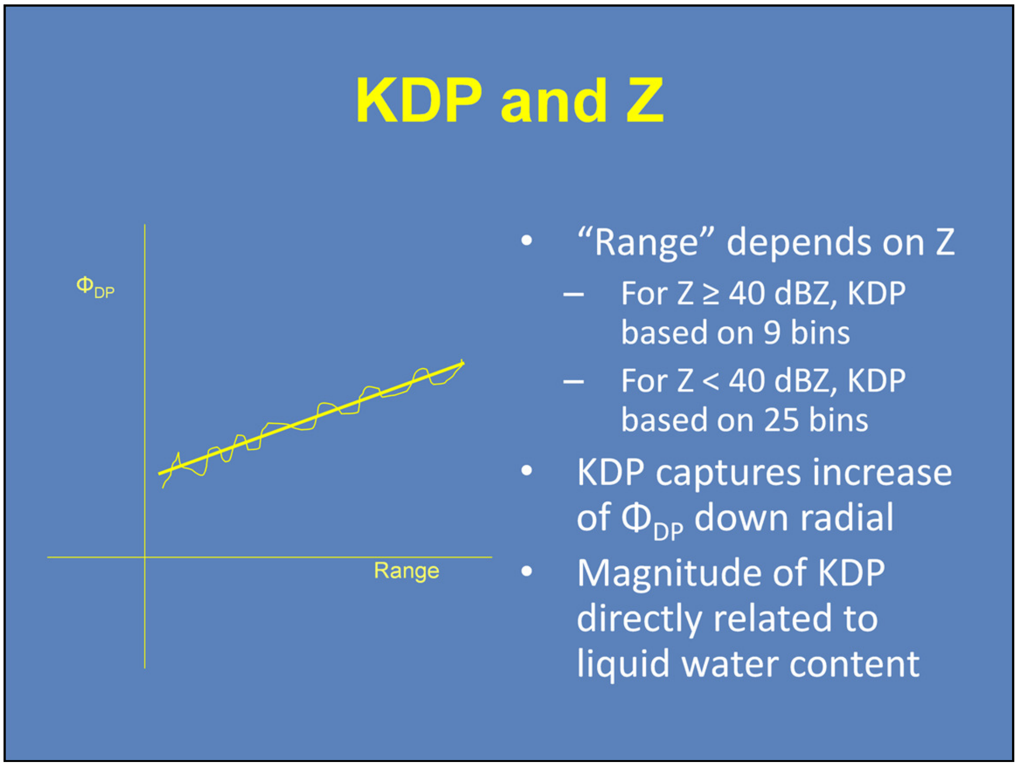
In this super simple example, the beam first passes through clear air, which leaves the Φ_{DP} values unchanged. Then a rain shaft is encountered, which means $\Phi_{DP} > 0$ for a series of range bins, and increases with each bin in the rain shaft. The beam then progresses to another patch of clear air and the Φ_{DP} value stays constant. Finally, another rain shaft is encountered, again increasing the Φ_{DP} value down radial. Throughout this process, the Φ_{DP} value does not "reset" to 0.

Since Φ_{DP} is an angle, the units are degrees, and given enough liquid water, Φ_{DP} will "fold" back to 0°. Φ_{DP} is particularly noisy and subject to data quality problems with the small number of pulses used within many of the WSR-88D VCPs. The possibility of folding, and the general noisiness, make interpretation of Φ_{DP} as a base product challenging.



Differential phase, Φ_{DP}, is sent as base data from the RDA. Though both KDP and Φ_{DP} are available in AWIPS, KDP is easier to interpret. KDP is defined as the range derivative of Φ_{DP}. KDP is a way to capture how Φ_{DP} changes over very short ranges, which gives us more useful information. Thus the units for KDP are ° per km.

This equation does not represent the actual calculation of specific differential phase, or KDP. It is used to represent the concept of subtracting differential phase, or Φ_{DP} , over a range interval. The actual calculation involves a least squares fit of multiple differences along the radial, centered at the range bin.



The span of range bins used for the KDP calculation is dependent on the Z value. Higher reflectivity generally corresponds to better data quality, and less noisy Φ_{DP} values. Thus for higher Z, KDP is calculated along a shorter interval of the radial, as compared to lower Z values.

For Z ≥ 40 dBZ, KDP is based on an integration of 9 bins (4 bins back and 4 bins forward along the radial). For these higher Z values, there is less smoothing required, and fewer bins are used.

For Z < 40 dBZ, KDP is based on an integration of 25 bins (12 bins back and 12 bins forward along the radial). For lower Z values, there is the potential for more noise in the data, thus more bins are used for greater smoothing.

Specific differential phase, KDP, is capturing the magnitude of any increase in differential phase, Φ_{DP}, along a radial. The greater the increase, the greater the liquid water content present.

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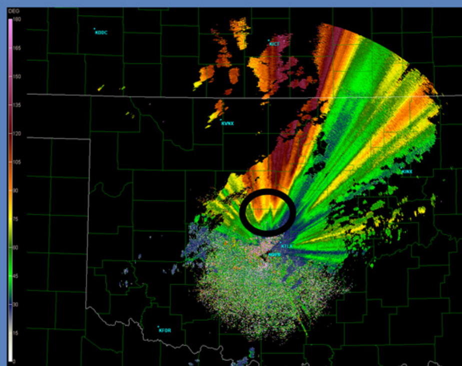
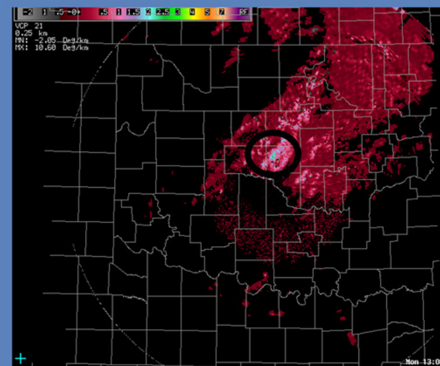
KDP and Liquid Water





- High KDP means high local increase in Φ_{DP}
- KDP depicts relative liquid water content sampled by beam

KDP is the last of the Dual Pol variables. It is of value because of its direct relationship to the amount of liquid water content sampled by the beam. On the left is the Φ_{DP} base data displayed in a Level II viewer (GR Analyst). On the right is the associated KDP product displayed on AWIPS. The higher KDP values correspond to the areas of highest Φ_{DP} gradients along the radial.

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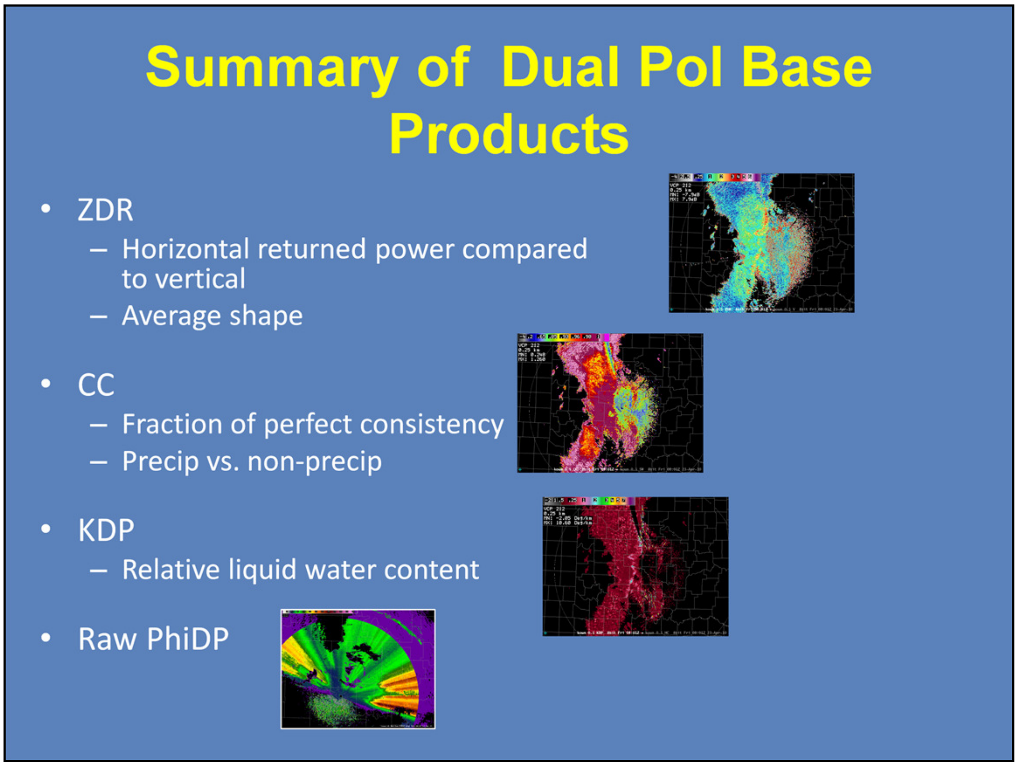

Differential Reflectivity, ZDR, is computed from the returned power in the horizontal and vertical channels. It does not use returned phase information. ZDR tells us about the average shape of the scatterers.

Correlation Coefficient, CC, is based on the returned power and phase, especially how the horizontal and vertical returned phase values compare to one another. CC is a fraction of perfect consistency of these returned phases, which reveals the consistency of the scatterers sampled by the radar. Among many other applications, CC is a highly effective discriminator for precipitation vs. non-precipitation echoes.

Specific Differential Phase, KDP, depicts the relative liquid water content of the volume sampled by the beam.

There is a Φ_{DP} product available, Raw PhiDP. It is the unprocessed, level II Φ_{DP} base data from the RDA. It's use is limited, and it will be discussed in the Products section of RAC.

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Welcome to Clutter Filtering.

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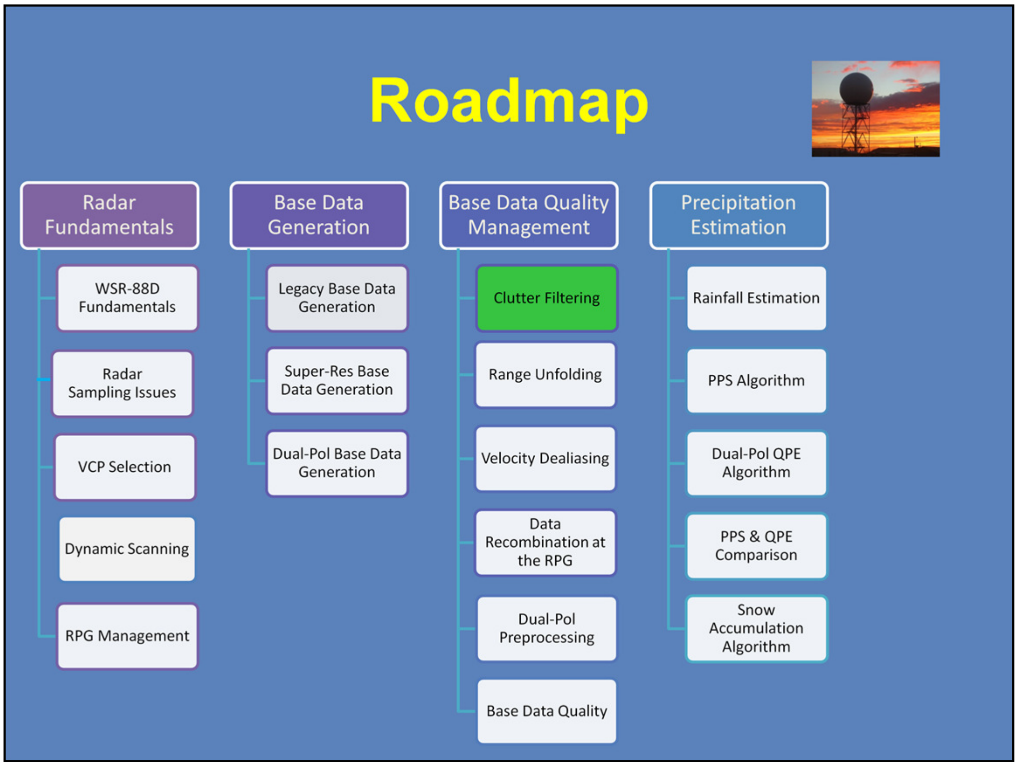
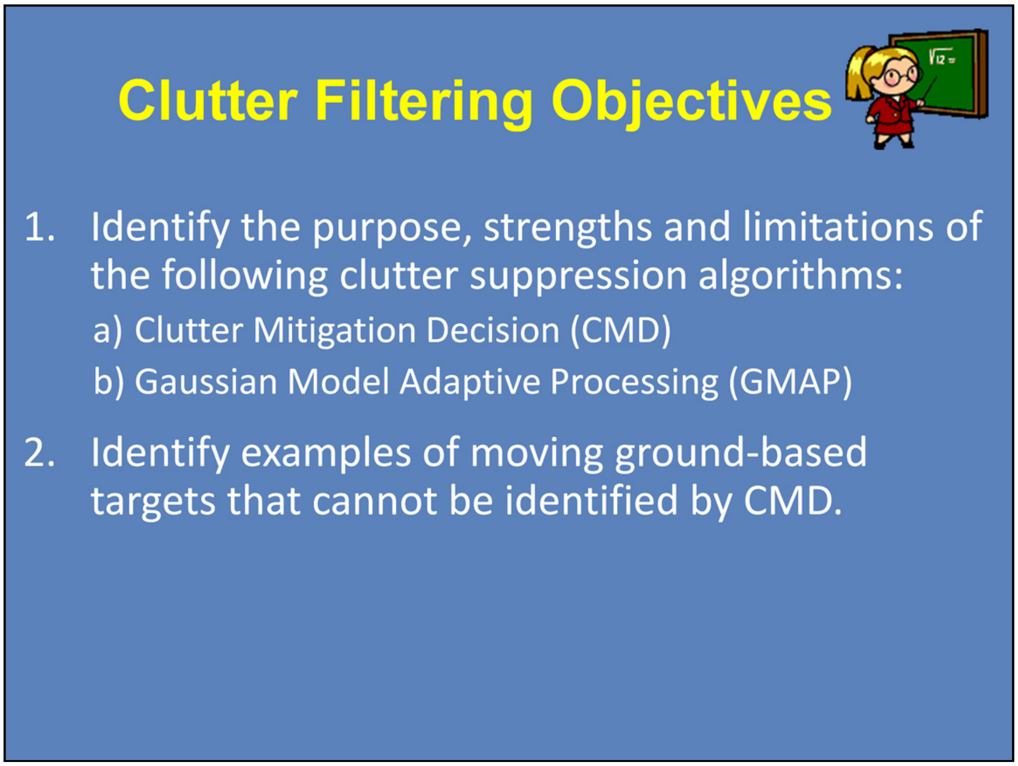
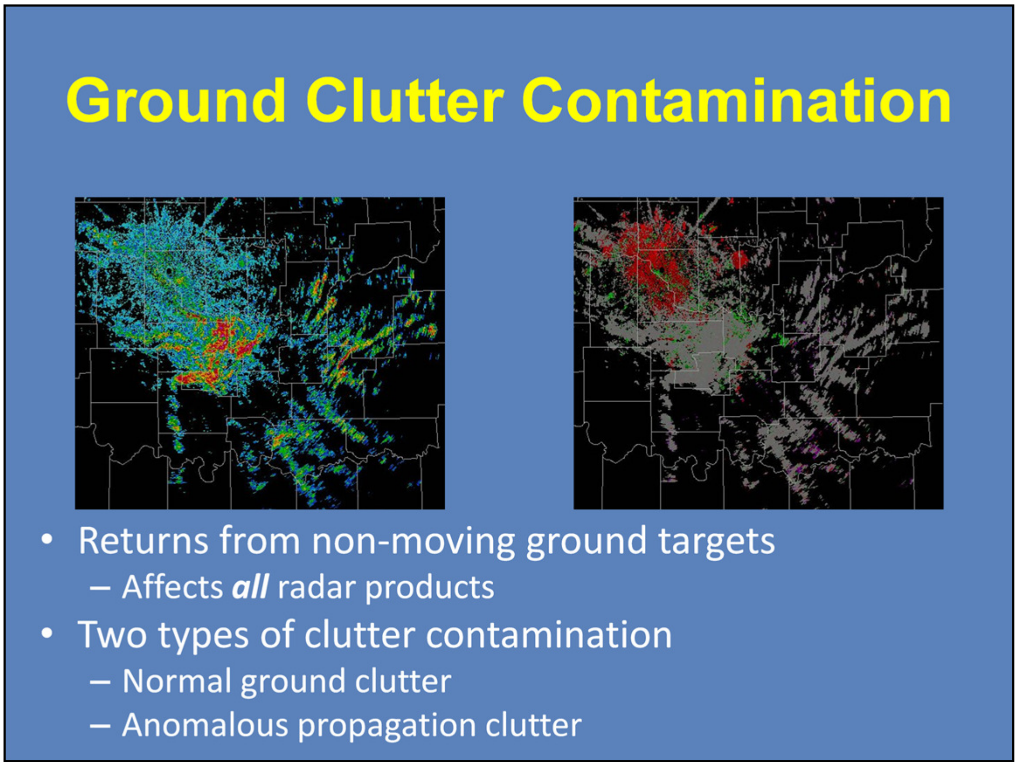


Here is the “roadmap” with your current location.

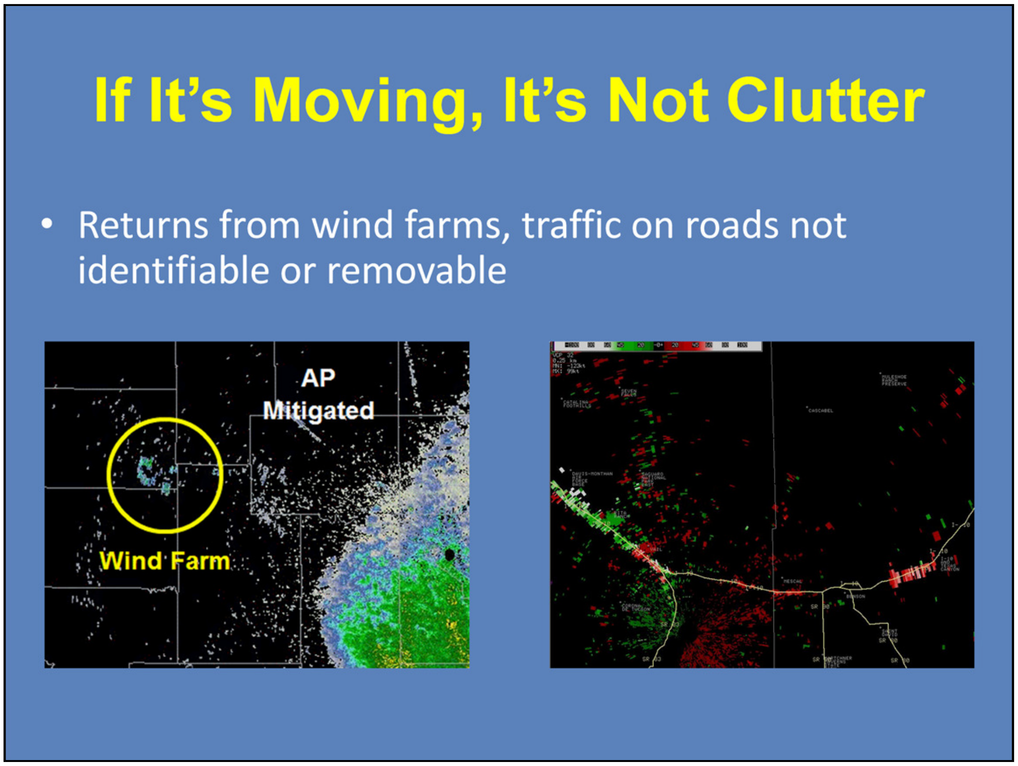


Here are the two objectives for Clutter Filtering, which will be taught in sequence during this module.

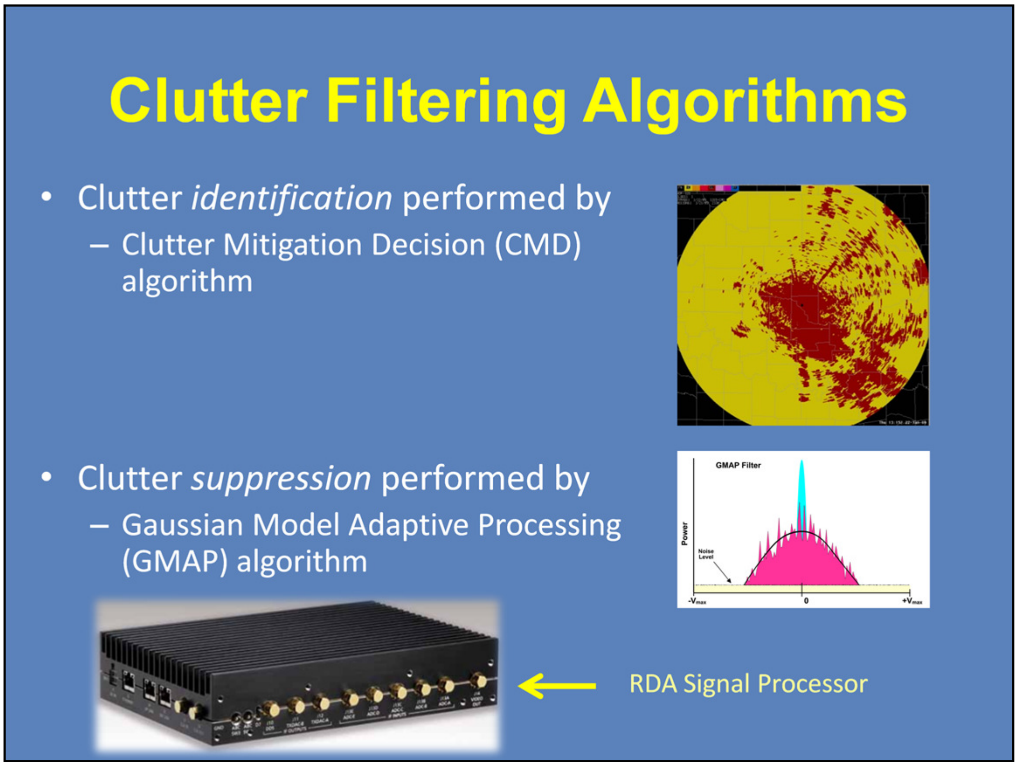


In general, ground clutter on WSR-88D radar products is return from stationary or nearly stationary ground targets that has not been filtered. Clutter suppression is applied at the signal processor just before the base data are built. Since all the base and derived products are built from the base data, unfiltered clutter will negatively impact all the products. There are two types of clutter contamination. The first is normal ground clutter, meaning features that are present all the time, such as terrain, buildings, etc. The second type is transient and dependent on beam propagation, known as anomalous propagation clutter.

For the reflectivity (left) and velocity (right) images, clutter filtering is only applied very close to the radar. There is extensive Anomalous Propagation (AP) clutter contamination to the east through the south of the radar. Note the near zero velocities throughout the AP clutter areas.



The WSR-88D clutter algorithms are designed to detect ground clutter, which means near zero velocity and spectrum width. There will still be contamination from moving ground targets such as wind farms and traffic on highways.



There are two different algorithms in the clutter filtering process. The data are first processed by the Clutter Mitigation Decision (CMD) algorithm, which does the job of identifying clutter on a bin by bin basis. For each bin identified by CMD, the Gaussian Model Adaptive Processing (GMAP) algorithm then applies the signal reduction, or suppression, of the clutter. Both CMD and GMAP are run at the RDA signal processor (the black box!)

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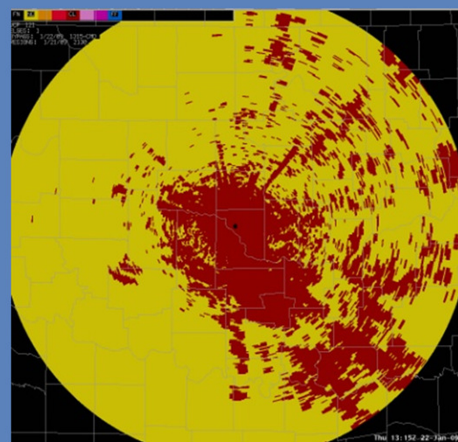
CMD in a Nutshell

- CMD identifies both normal & AP clutter every volume scan
  - Builds "Dynamic Bypass Map" every rotation
- CMD maps used for bin by bin signal removal

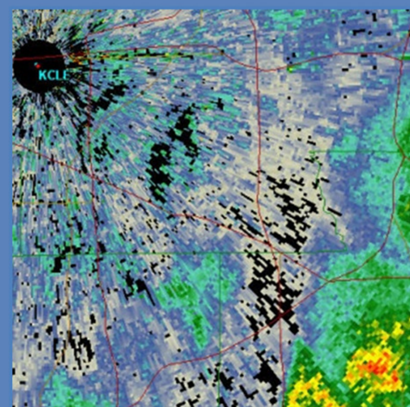


Clutter Mitigation Decision (CMD) offers an automated approach to the management of clutter filtering. CMD can identify both normal and AP clutter every volume scan, which eliminates the need for manually defining and downloading regions files to address AP clutter. CMD builds a dynamic Bypass Map that shows the bins that contain clutter. These maps are then used for a bin by bin signal removal. Suppression of clutter is only performed on the those bins identified by CMD.

The image on the right is a visualization of a CMD generated Bypass Map. It is called the Clutter Filter Control (CFC) product. Each of the red bins has been identified by CMD as containing clutter. The yellow bins do not contain clutter, based on CMD's analysis.

CMD Inputs

- Fuzzy logic with many inputs
- Z texture
  - Smooth (low) = weather
  - Rough (high) = clutter
- Z spin
  - Z gradient sign changes
- CPA (phase consistency)
  - High CPA = clutter
  - Low CPA = weather



CMD is a fuzzy logic algorithm with multiple inputs. It uses nearly all the base data in its most primitive form to determine where clutter exists.

We start with the inputs based on Reflectivity, Z.

1. Z texture, which is smooth (a low value) for a meteorological target and rough (a high value) for a clutter target

2. Z spin, which looks at the number of times that the Z gradient changes sign along a portion of the radial. The higher the number of sign changes, the higher the likelihood of clutter.

In the associated Z image, the weak signal areas close to the radar have a visually rougher texture and one would find more frequent changes in sign of the Z gradient.

3. Clutter Phase Alignment (CPA) captures the variance of pulse to pulse phase changes. Since CMD is looking for clutter targets that don’t move, there is low variation in returned pulse phase changes with clutter. A high CPA means good alignment of phasors, a low variation of returned phase, and a higher likelihood of clutter.

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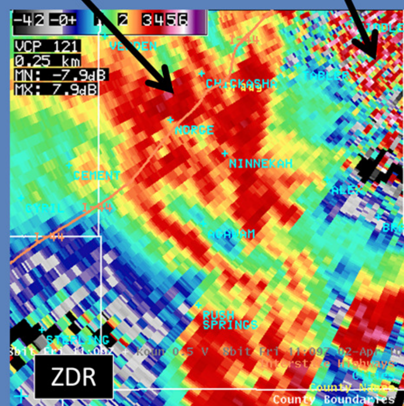
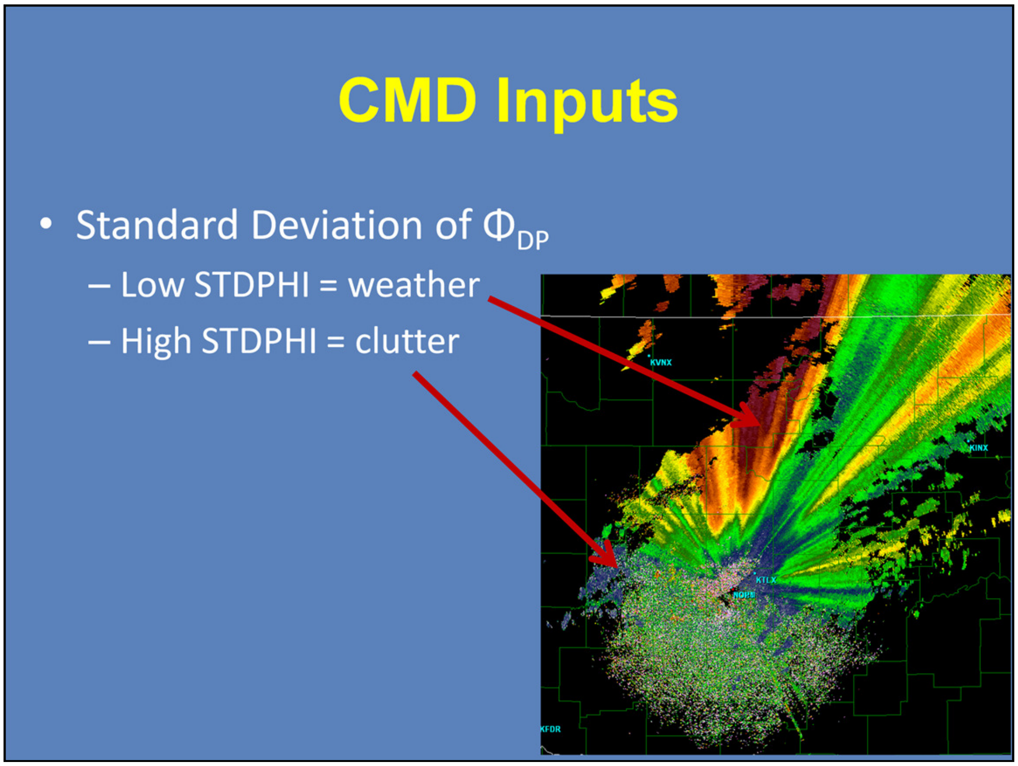
CMD Inputs

Standard deviation of ZDR
- Low STDZDR = weather; High STDZDR = clutter



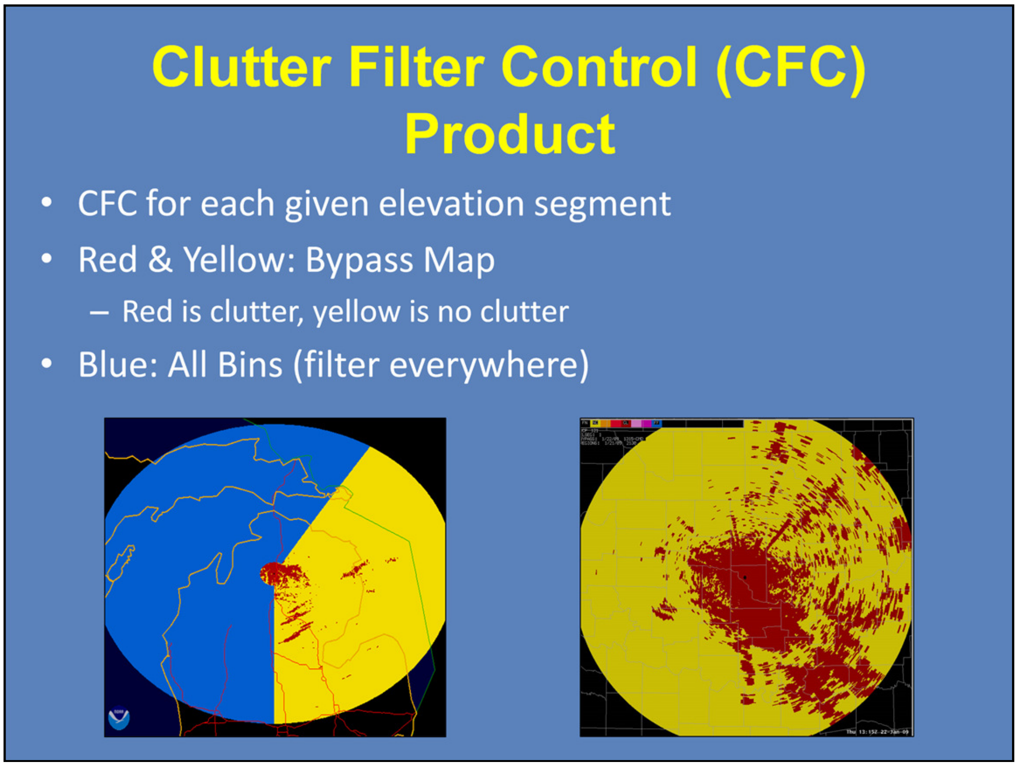
There are two inputs based on Dual-Pol base data. They are standard deviations of ZDR and Φ_{DP}.

The higher the standard deviation of ZDR, the higher the likelihood that the range bin contains clutter. In this example, you can likely tell by looking at the smoothness of the ZDR data where the clutter vs. the weather is located. That variation (or lack of it) is captured in the standard deviation data. The higher the standard deviation of ZDR, the more likely it is that the bin contains clutter.



The second CMD input based on Dual-Pol base data is the standard deviation of Φ_{DP}.

The higher the standard deviation of Φ_{DP}, the higher the likelihood that the range bin contains clutter. In this example, compare the noisiness of the Φ_{DP} data surrounding the radar to the areas of precipitation to the north through the east (trust me on the precipitation part). That variation (or lack of it) is captured in the standard deviation data. The higher the standard deviation of Φ_{DP}, the more likely it is that the bin contains clutter.



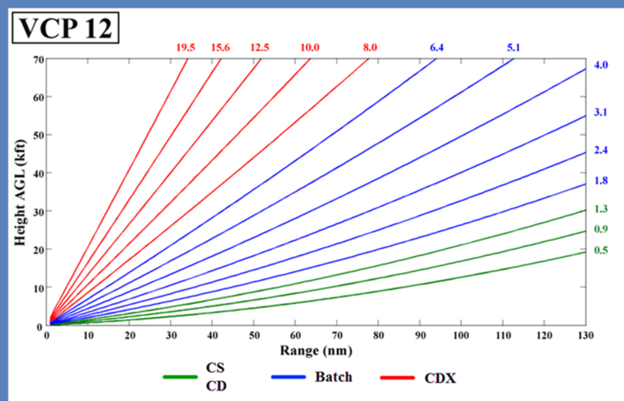
For each elevation segment, the CFC displays the type of clutter filtering that has been invoked for the lowest elevation in that segment. The area with a red/yellow combination are where the Bypass Map is in control. That means there is bin by bin identification of clutter, with red for clutter (to be filtered) and yellow for no clutter (to be left alone). The blue area defines All Bins filtering, which means every bin is going to filtered.

The CFC on the left hand side shows a clutter filtering scheme that has All Bins (blue) in control over a large area from south through northeast. Outside of the All Bins area, the Bypass Map is on control, with red bins identified as containing clutter and yellow bins identified as not containing clutter.

The CFC on the right hand side shows a clutter filtering scheme that has the Bypass Map in control everywhere.

These varying clutter filtering schemes are implemented manually by downloading clutter regions files from the RPG to the RDA.

CMD Implementation



- CMD builds a map for every rotation & every elevation
  - Split Cuts: one for CS, another for CD
  - Batch and higher: one for each elevation

CMD is active for every rotation and every elevation, building a bypass map each time. For the Split Cuts, there are two rotations at the same elevation, Contiguous Surveillance (CS), then Contiguous Doppler (CD). CMD builds a different map for each of these two rotations. For the remaining elevations in the volume scan, CMD builds a new map each time.

There is not a Clutter Filter Control (CFC) product build for every elevation, thus you cannot see all of the maps built by CMD. This may be challenging for CMD troubleshooting efforts.

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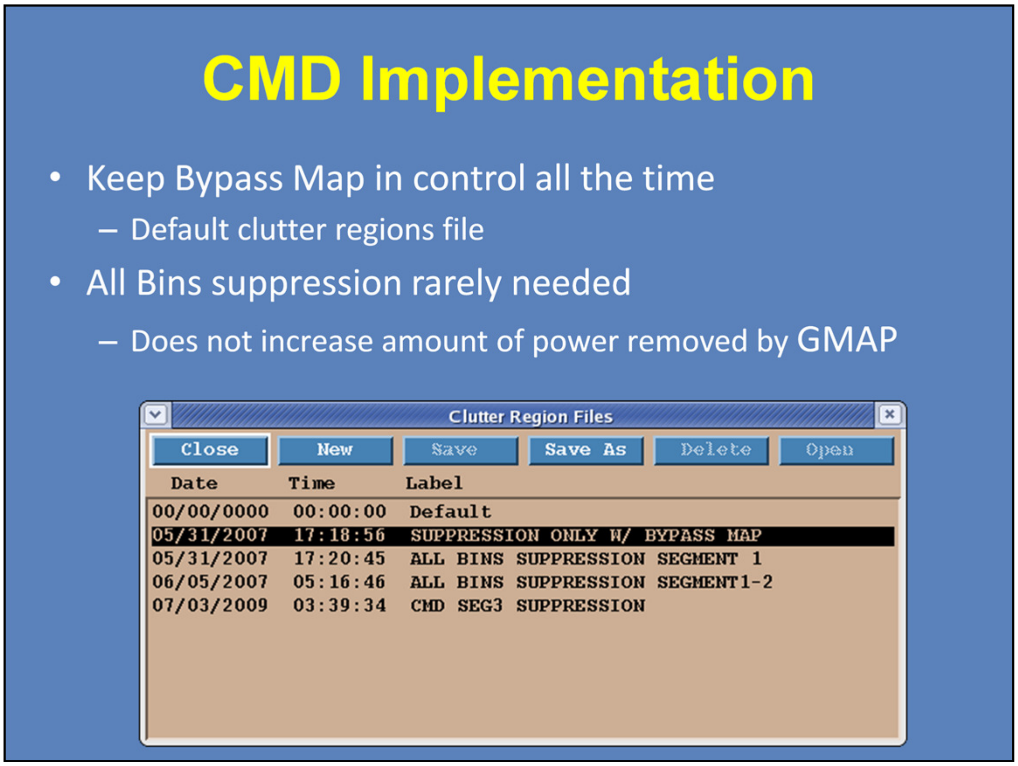

CMD offers “hands off” clutter suppression, though some data quality monitoring may be needed from time to time. In order for CMD to build maps for every elevation, the Bypass Map must be in control for the entire display for all elevations. The “Default” clutter regions file is designed to do just that. It may be necessary (as in this example) to create a local version of this file, “SUPPRESSION ONLY W/ BYPASS MAP”. Whether it is the Default file, or a locally defined version, the key point is to have the Bypass Map in control for the entire display for all elevations.

With CMD active, All Bins suppressions is rarely needed. All Bins only defines where suppression occurs. It has no affect on the amount of power removed by GMAP when the suppression is performed.

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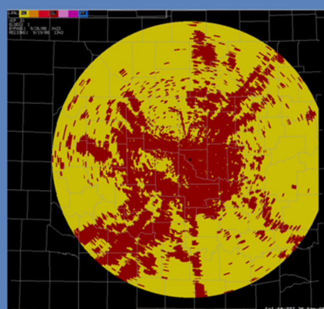
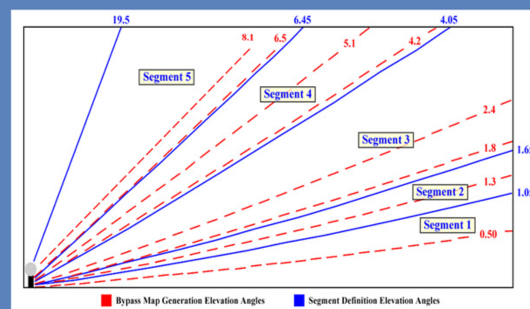
CMD Summary

- CMD identifies clutter
  - Builds map for every rotation & every elevation
  - Performance affected by pulses/radial
- One CFC per elevation segment





In summary, CMD's job is to identify the bins that contain clutter, both normal and AP clutter. CMD performs this identification and builds a clutter map for every rotation and every elevation of every VCP (that's a lot of maps). The Clutter Filter Control product is available to help visualize where CMD has identified clutter. However, CFC products are limited to one map for each of the elevation segments on the graphic on the right, only showing a subset of the maps actually built by CMD.

The number of pulses per radial impacts CMD's performance, especially with respect to discriminating clutter from weather with little movement, like stratiform rain. The faster VCPs, 12, 212, and 121, have the lowest number of pulses per radial. The impact of faster VCPs on data quality will be explored later.

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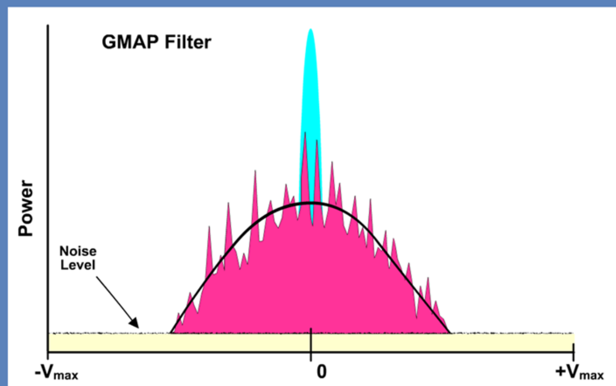
Clutter Filtering Algorithms



- CMD has ***identified*** clutter
- For the bins identified by CMD, filtering performed by Gaussian Model Adaptive Processing (GMAP) algorithm

Now that clutter have been identified by CMD, it is time to perform the filtering, or removal of the power from the clutter portion of the returned signal. The Gaussian Model Adaptive Processing (GMAP) algorithm applies filtering only to those bins identified by CMD.

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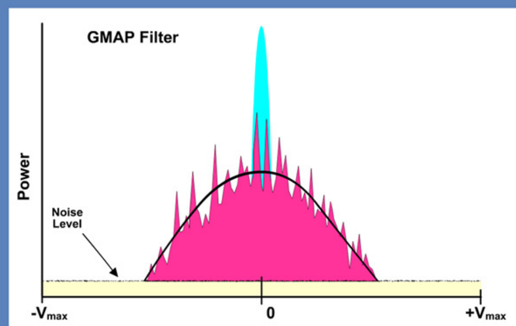
How GMAP Works



- Weather and clutter signals look different
  - Can be approximated by Gaussian curve
- Remove power from narrow spike near zero velocity
- Once power removed, GMAP attempts to rebuild lost weather signal

Weather and clutter signals have different characteristics. A clutter signal (blue green spike) has high power, is centered at zero velocity and has a narrow spectrum width. A weather signal (broader pink blob) will have varying power, velocity and spectrum width. This difference between clutter signals and weather signals can be used to filter out the clutter signal with minimal damage to the weather signal. Another aspect that is part of GMAP's design is that both clutter and weather signals can be well represented by Gaussian curves. This is a super simple graphic. For example, weather signals are not usually centered at zero velocity.

GMAP first removes power from the signal near zero, hopefully as much of the "spike" as possible. If there is enough of the weather signal remaining, GMAP can rebuild it.

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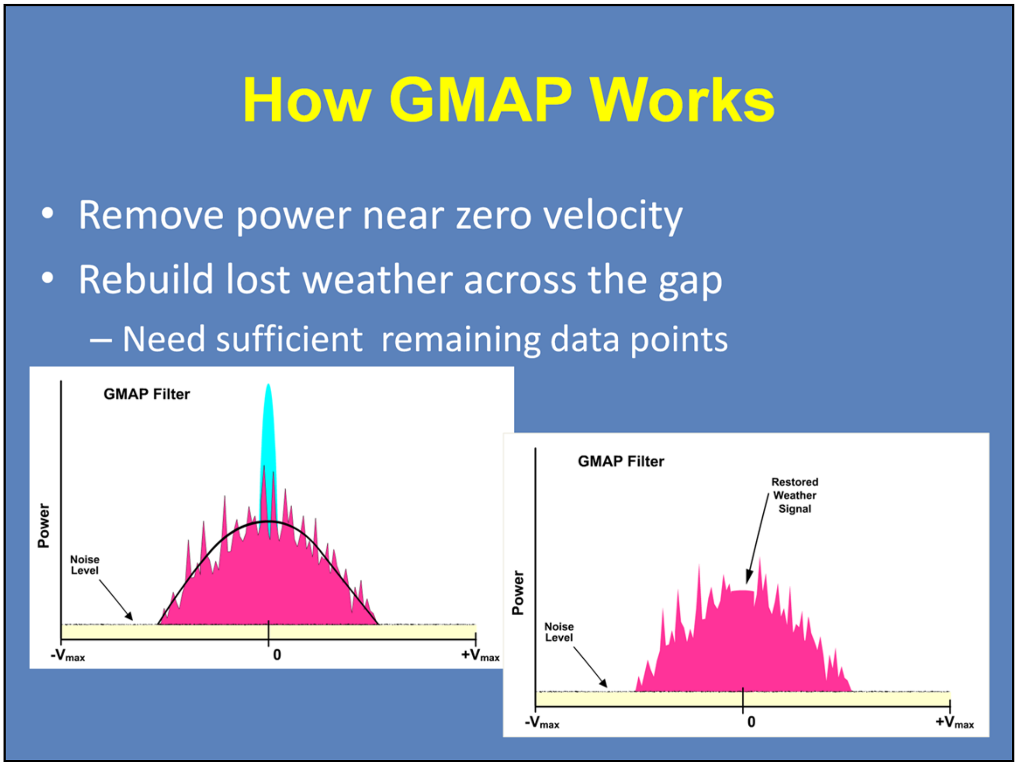
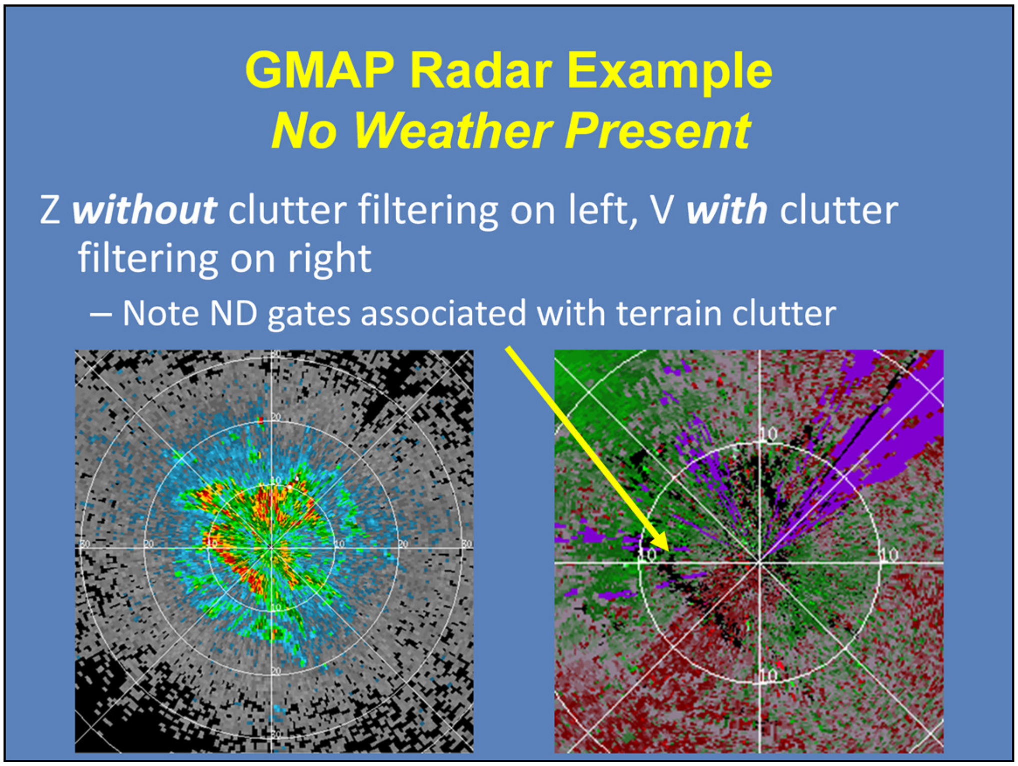


Once the width for signal removal is determined, filtering is applied to all of the signal within that width. In this case, both the clutter and weather signal within this interval will be removed. However, GMAP has the ability to rebuild the weather signal that was lost. This is dependent on the availability of data points outside of the gap. If there is sufficient weather signal data outside the gap to be represented as a Gaussian curve, GMAP can rebuild the weather signal across the gap using the Gaussian estimate. To see an animation of this process, click on the beginning image on the left hand side.

The number of pulses per radial impacts GMAP's performance, especially with respect to the rebuilding of the signal. The faster VCPs, 12, 212, and 121, have the lowest number of pulses per radial. The impact of faster VCPs on data quality will be explored later.

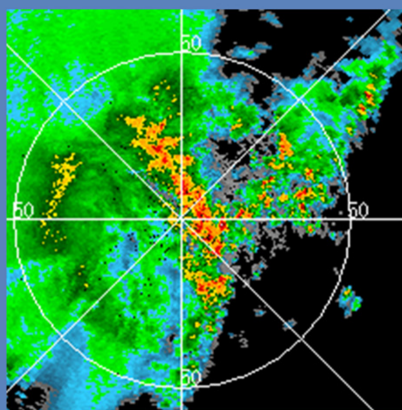


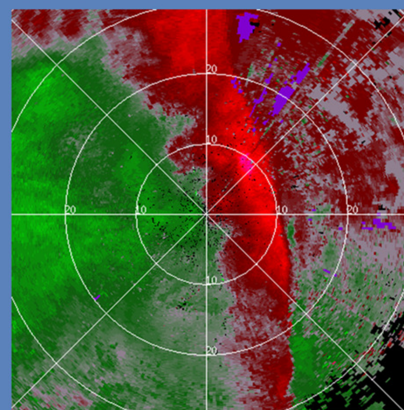
As an example of GMAP performance, we start with no weather with either of these images. On the reflectivity on the left, clutter filtering has been turned off to identify the local terrain clutter. Of particular importance is the ridge line to the southwest. On the velocity on the right, clutter filtering has been applied. There is also a second step known as clutter censoring, which attempts to remove additional signal for bins with only clutter in them. Clutter filtering and censoring have produced the bins with no data on the velocity product. Again, the ridge to the southwest is apparent.

GMAP Radar Example
Squall Line Passes Through

Z & V as squall line passes through:

- Clutter has been filled in with data



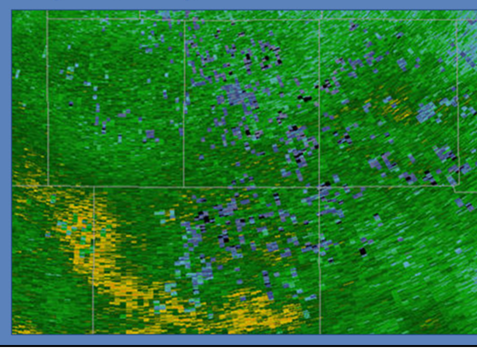


At a later time, a squall line has passed through the area. The reflectivity on the left and the velocity product on the right show the squall line. Compared to the reflectivity, the velocity product has been zoomed in.

Note that in both products the ridge and other terrain clutter areas are no longer apparent. The weather signal is strong enough, and there are enough pulses available, for GMAP to rebuild the weather for the bins that contain clutter.

CMD & GMAP Summary

- CMD *identifies* clutter! GMAP *filters* clutter!
- Fast VCPs (12, 212 & 121)
  - Fewest pulses/radial
  - CMD less likely to accurately identify clutter
  - GMAP less likely to rebuild lost weather

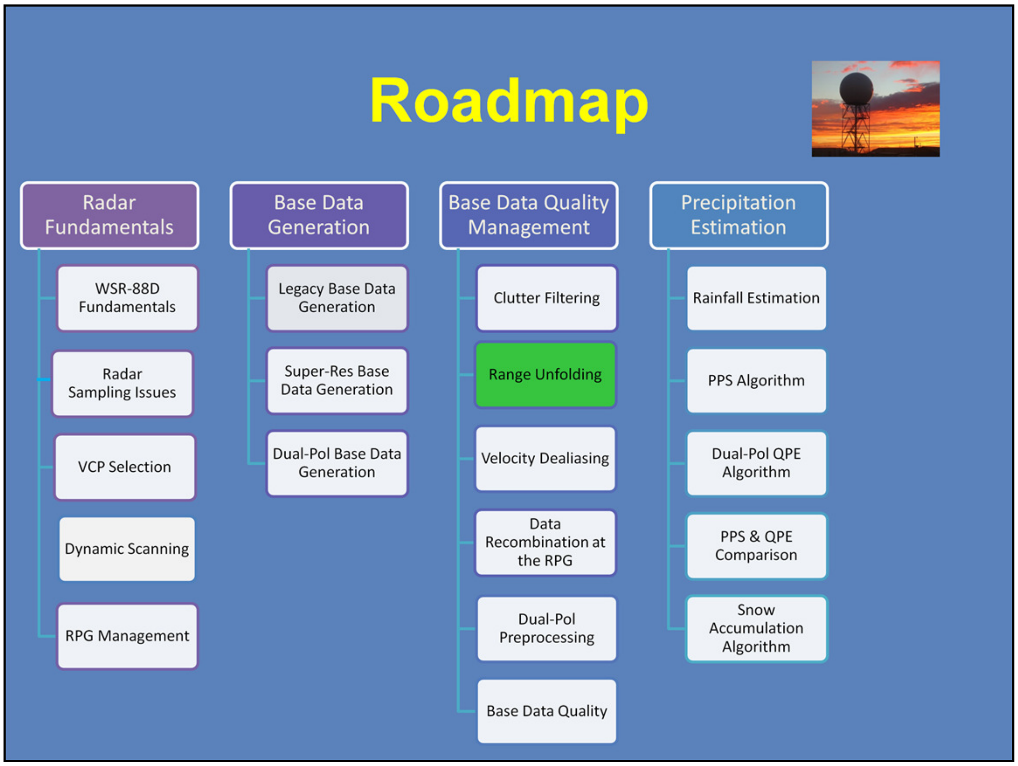


In summary, Clutter Mitigation Decision (CMD) and Gaussian Model Adaptive Processing (GMAP), work together to suppress clutter. CMD first identifies clutter, both normal and AP, on a bin by bin basis. CMD builds maps for each elevation and rotation showing which bins contain clutter and which do not. GMAP then applies filtering only to the bins identified by CMD. GMAP removes power from the signal near zero velocity, then rebuilds the weather signal "across the gap" if there are sufficient pulses remaining.

The performance of both CMD and GMAP are impacted by the number of pulses per radial. The faster VCPs, 12, 212, and 121, have the lowest number of pulses per radial. For these VCPs, it is more difficult for CMD to discriminate clutter from weather with little movement, like stratiform rain. For these VCPs, it is more difficult for GMAP to rebuild the weather signal after the clutter has been removed.

This reflectivity product is a stratiform rain event with VCP 12 invoked, even though VCP 12 is designed for more intense convective precipitation. The low number of pulses per radial with VCP 12 in stratiform rain makes it harder for CMD and GMAP, resulting in numerous gates of "lost" data.

Welcome to Range Unfolding.



Here is the "roadmap" with your current location.

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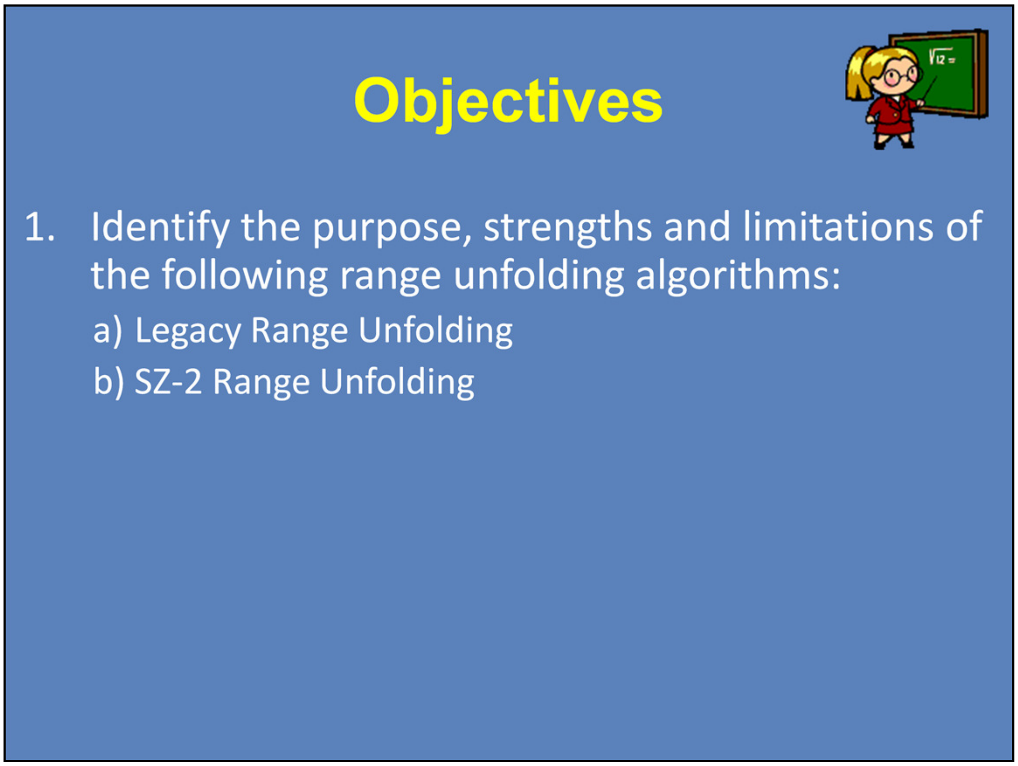
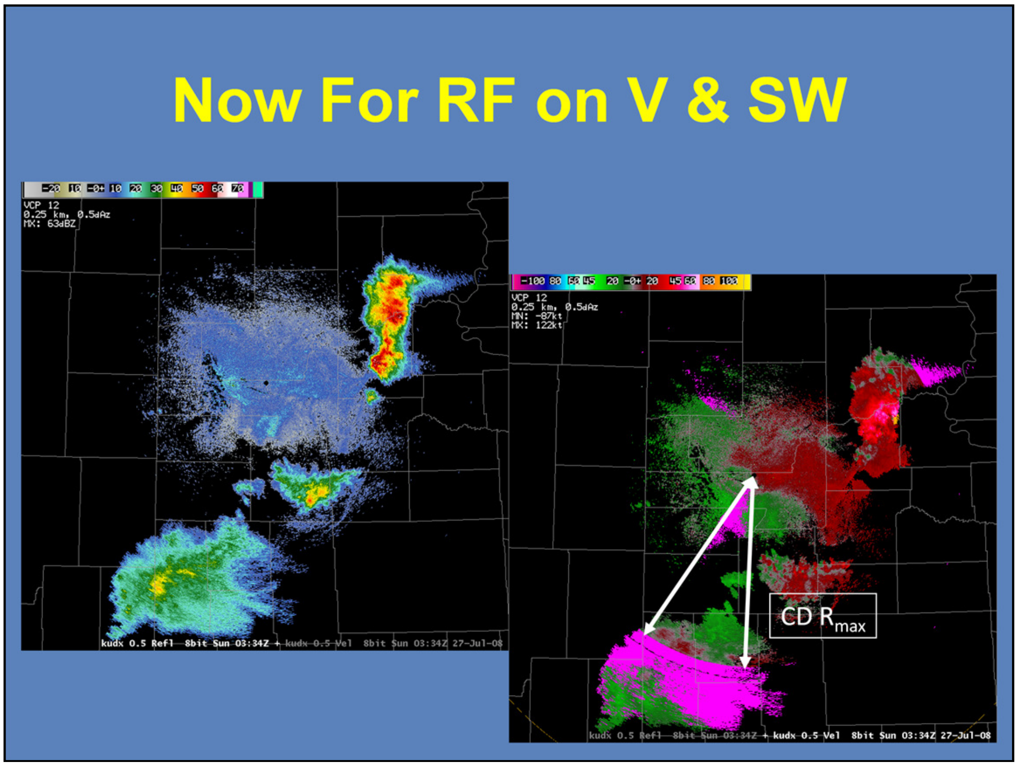


There is one objective for Range Unfolding, which will be taught in sequence during this module.



Now for range unfolding of velocity and spectrum width base data. Recall that high PRFs are needed for good velocity estimates, but a high PRF also means a short R_{max}. It is necessary to "unfold" the velocity data to its appropriate range.

The next several slides will help explain how the purple "RF" data area assigned on the velocity and spectrum width products. Notice the discontinuity in the velocity data at a fixed range. You will often see this on velocity and spectrum width as long as there is sufficient areal coverage of echo. This range is the R_{max} for the Contiguous Doppler/high PRF mode that is used for velocity data collection. You are seeing the end of the first trip and the beginning of the second trip. The question is "how did any velocity data end up being assigned beyond the first trip?"

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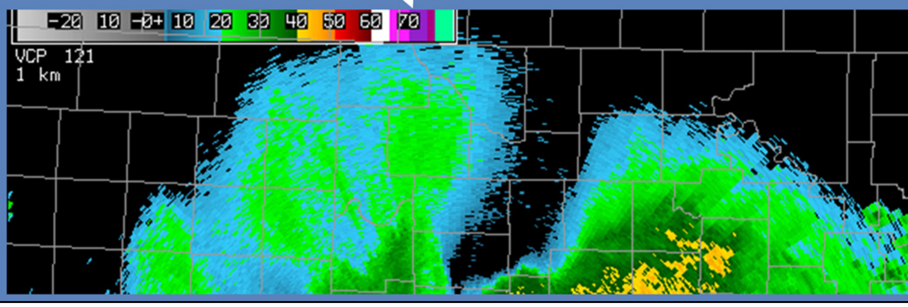
Range Folding Rarely on Reflectivity

- Multiple tripping rare on Z products
  - Low PRFs; R_{max} typically ~250 nm
- No RF assigned to Z products
  - Purple means very high dBZ!



It's important to remember that when the reflectivity data are collected, low PRFs are used, resulting in long R_{max} values. For the lowest elevation angles, the reflectivity data were collected with an Rmax ≈ 250 nm, so all the data are within the first trip.

The color purple on reflectivity products indicates very high dBZ values, not RF.

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Legacy Range Unfolding Algorithm

- In action since WSR-88D original deployment
- Assigns V & SW to proper range
  - May be beyond CD R_{max}
- Run at RDA signal processor for all VCPs except 121

The first Range Unfolding algorithm to present will be known as the legacy Range Unfolding Algorithm. That is because this technique has been in use since the WSR-88D was originally deployed. The goal of the Range Unfolding algorithm is to assign velocity and spectrum width data to its appropriate range. This may be in the first trip, the second trip, and in rare cases, the third trip. The Legacy Range Unfolding algorithm is run at the RDA signal processor, which is literally a black box!

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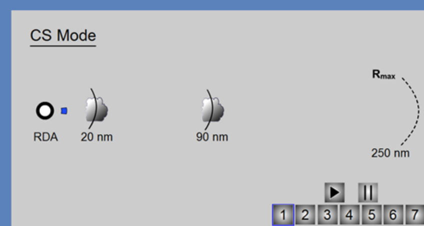
Exploring the Range Unfolding Algorithm

- Following slides have step by step demo of Range Unfolding Algorithm
  - Play animation in external window
- Two cases
  - Without echo overlay
  - With echo overlay
- Proceed at your own pace



The following slides give you a step by step demonstration of how the Range Unfolding algorithm works. Each slide has an animation in an external window that you can play over and over again, at your own pace. You'll see two cases. The first one has no echo overlay. The second case involves no echo overlay.

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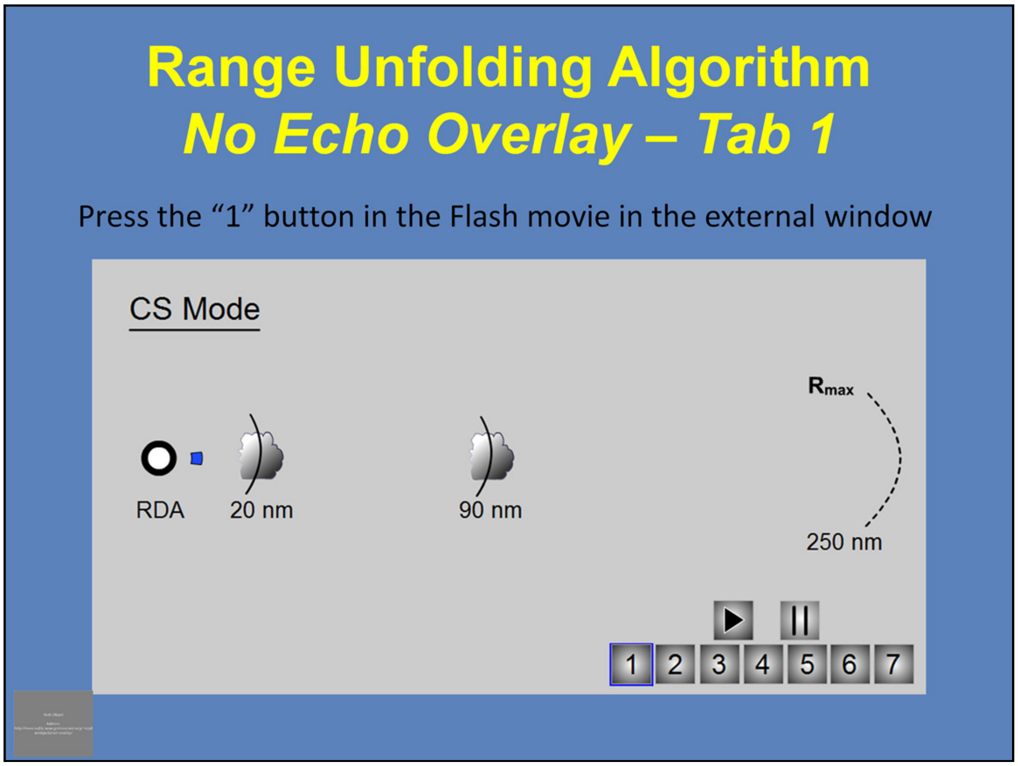
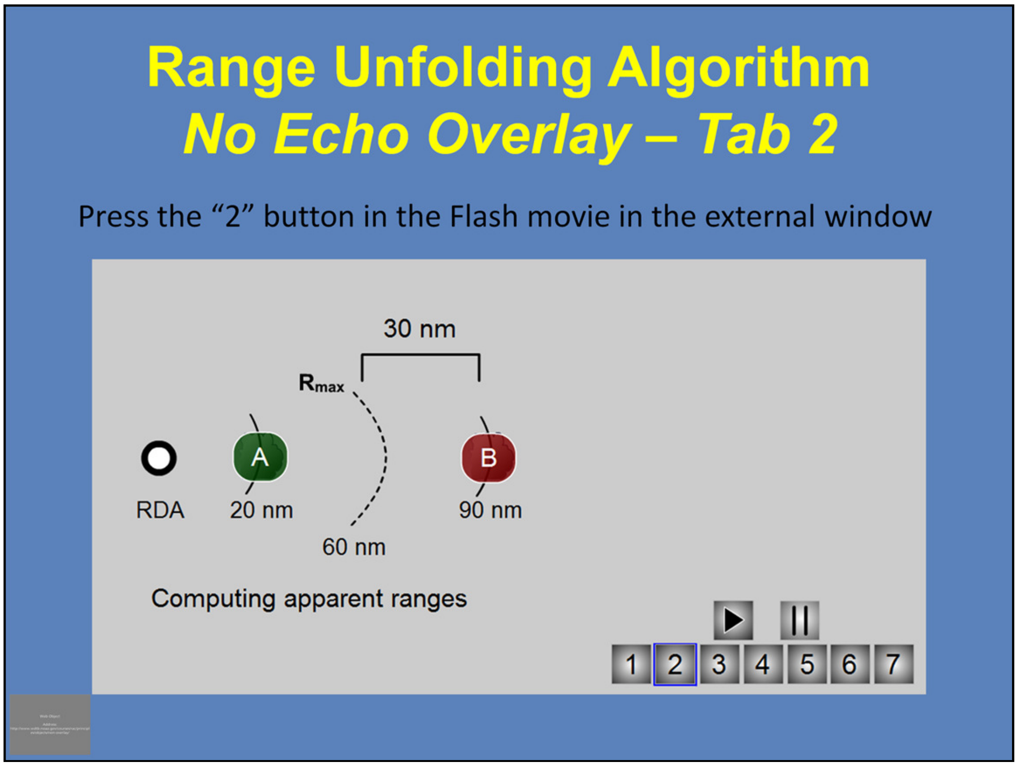
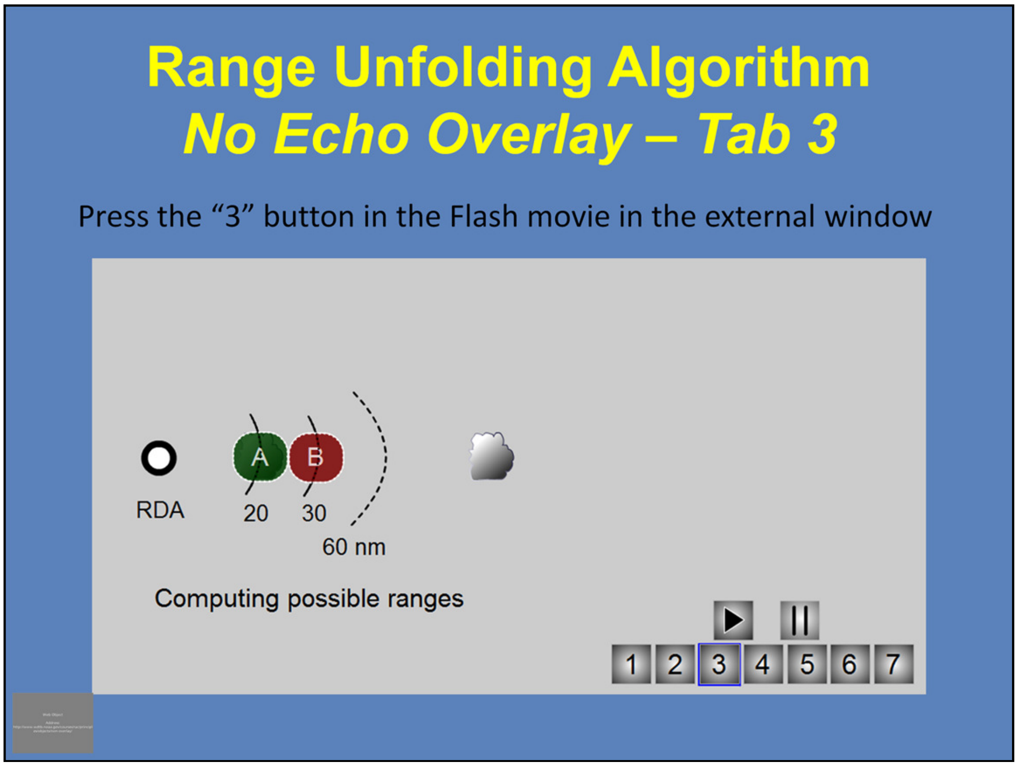


Tab 1. We are looking down a single radial in Contiguous Surveillance mode. That means we have a nice long unambiguous range. We have two targets. The first one is at 20 nm, the second one is at 90 nm. Since both of these targets are within the first trip, we know their true range and we know their returned power.



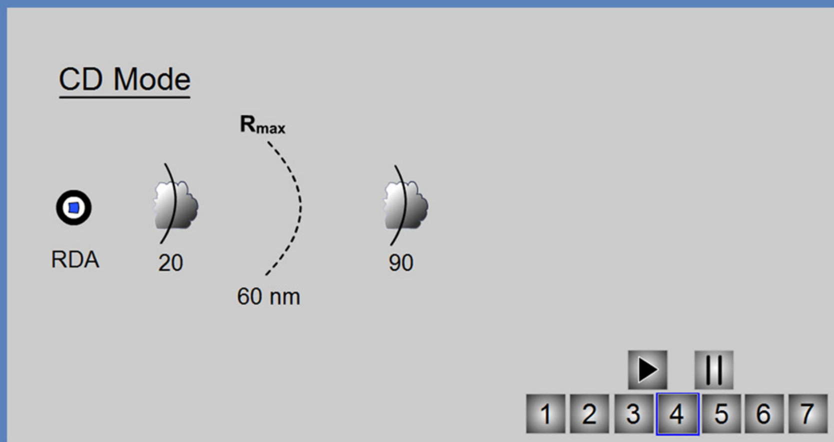
Tab 2. In anticipation of going to Doppler mode in the next rotation, the algorithm is able to compute what the apparent ranges of these two targets will be, and in this case, we're going to have an Rmax of 60 nm when we go into Doppler mode. So that means target A will stay at 20 nm, target B will be folded into an apparent range of 30 nm.



Tab 3. We know that target B is going to have an apparent range of 30 nm. At this step, we're going to compute all the possible ranges for all of the targets that show up in the first trip, and these possible range go out into the second, third, and even fourth trips.

Range Unfolding Algorithm
No Echo Overlay – Tab 4

Press the "4" button in the Flash movie in the external window



Tab 4. Now we're actually collecting data in Doppler mode, and the energy from pulse 1 for target B which was at 90 nm is on its way back, but it does not arrive before the energy from pulse 2 is transmitted. That is how we get an apparent range for target B at 30 nm.

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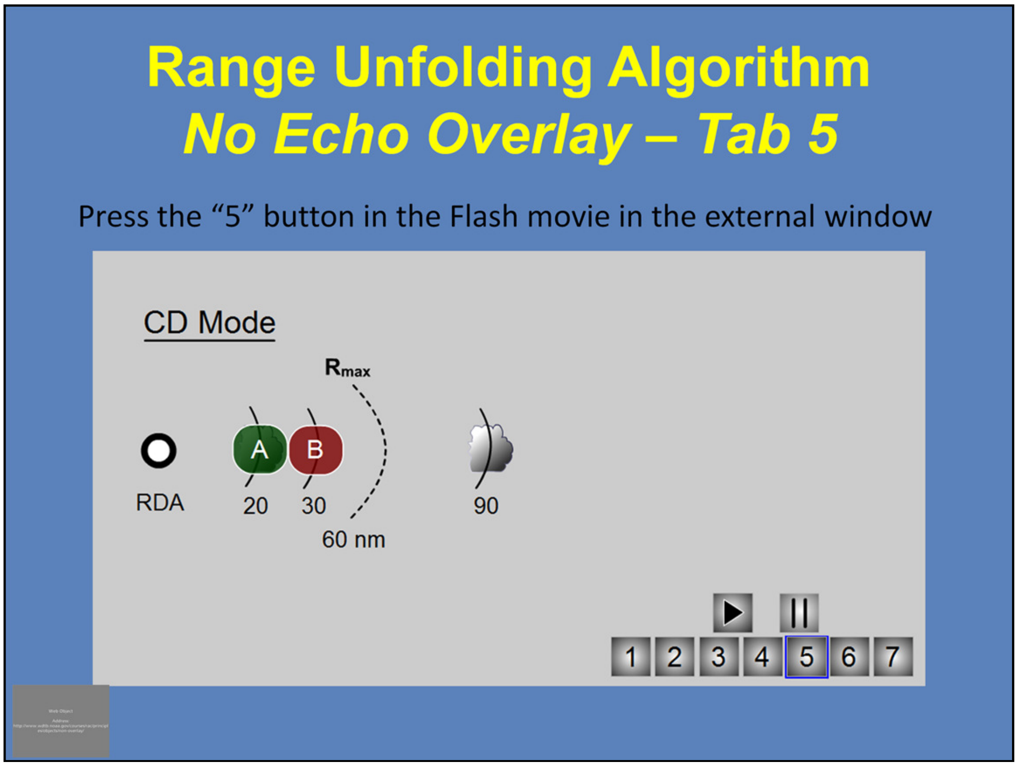

Tab 5. Now we begin the actual comparison down radial of the Surveillance data vs. the Doppler data, checking to see along the radial wherever there is a target to see if there was something at that same range in Surveillance mode. So when we get to target A at a range of 20 nm, we ask the question "was the something at 20 nm in the Surveillance data?" And the answer is Yes, so we know the velocity for target A belongs at the range of 20 nm.

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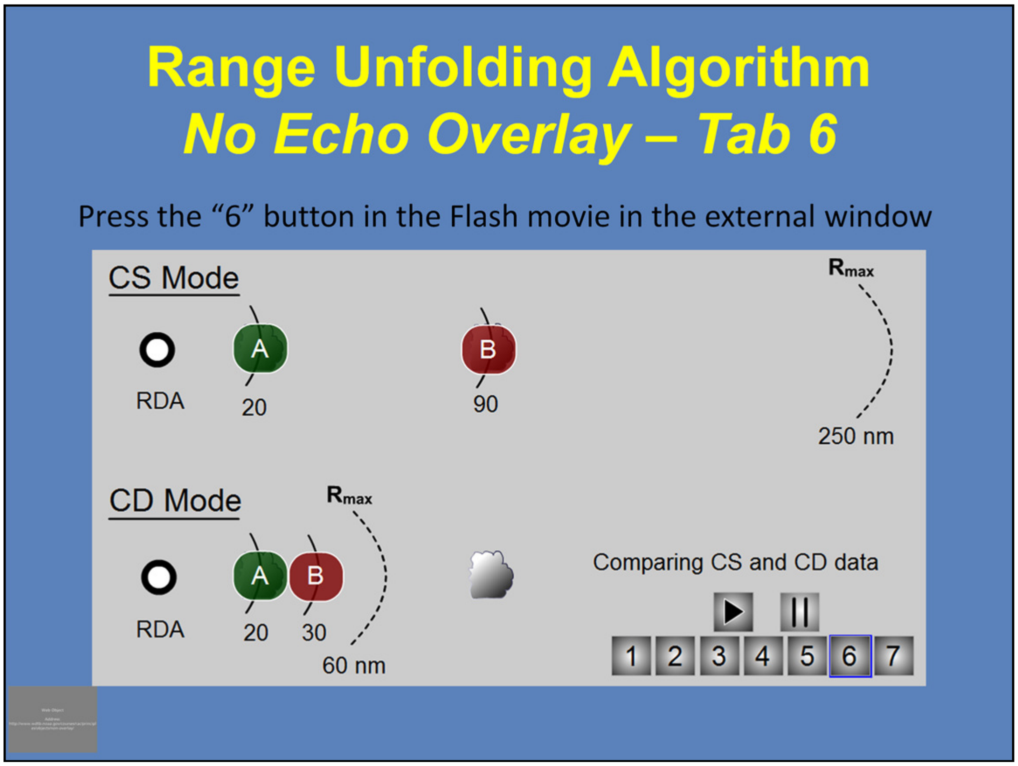
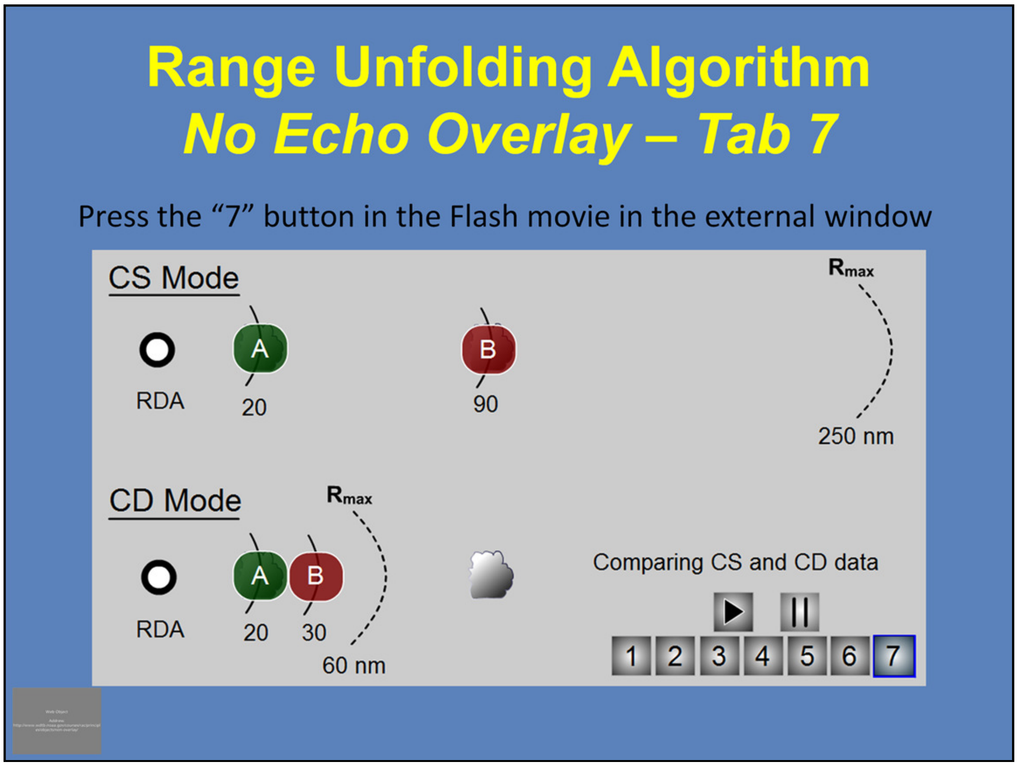
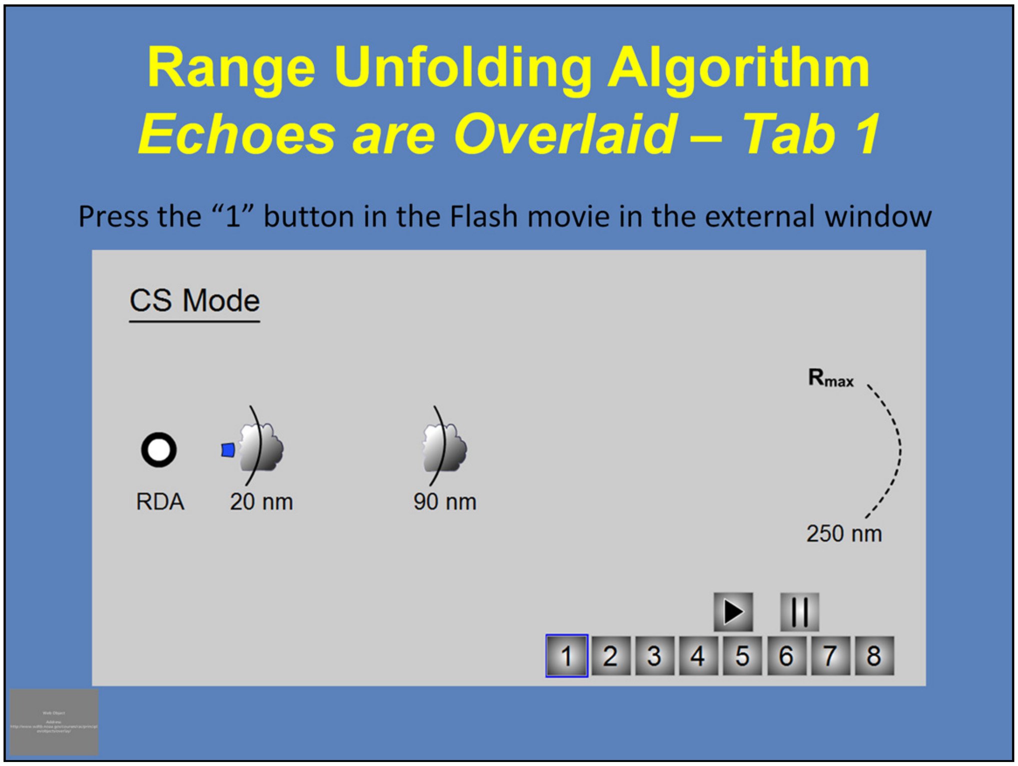


Tab 6. Now we find a target at an apparent range of 30 nm, compare that to the Surveillance data to ask the question “was there something at 30 nm?” No, there wasn’t.



Tab 7. Since we don't have anything at 30 nm, the next step is to check the next possible range which is 90 nm, and yes, there was something in the Surveillance data at that range. That's how we know that the velocity value that appears to be coming from 30 nm actually belongs at 90 nm.



Tab 1. We start off with the same initial conditions. We’re in Surveillance mode, we have a target at 20 nm and another target at 90 nm, maximum unambiguous range is 250 nm, so we have returned power and we have range for each of these returned targets.

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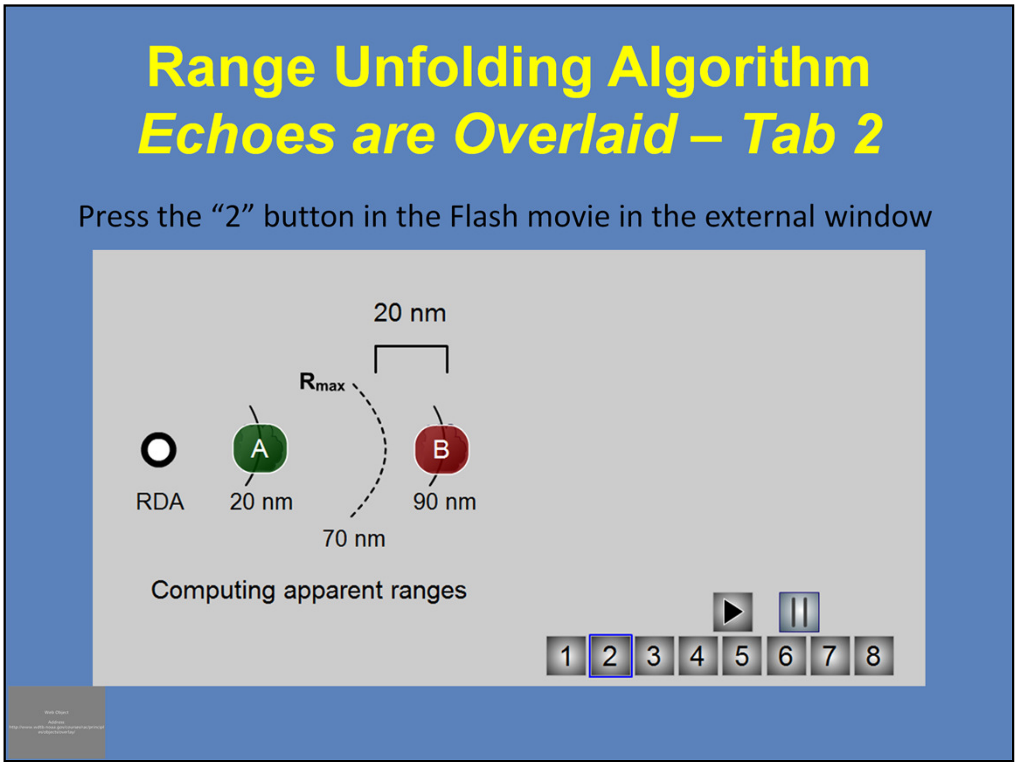
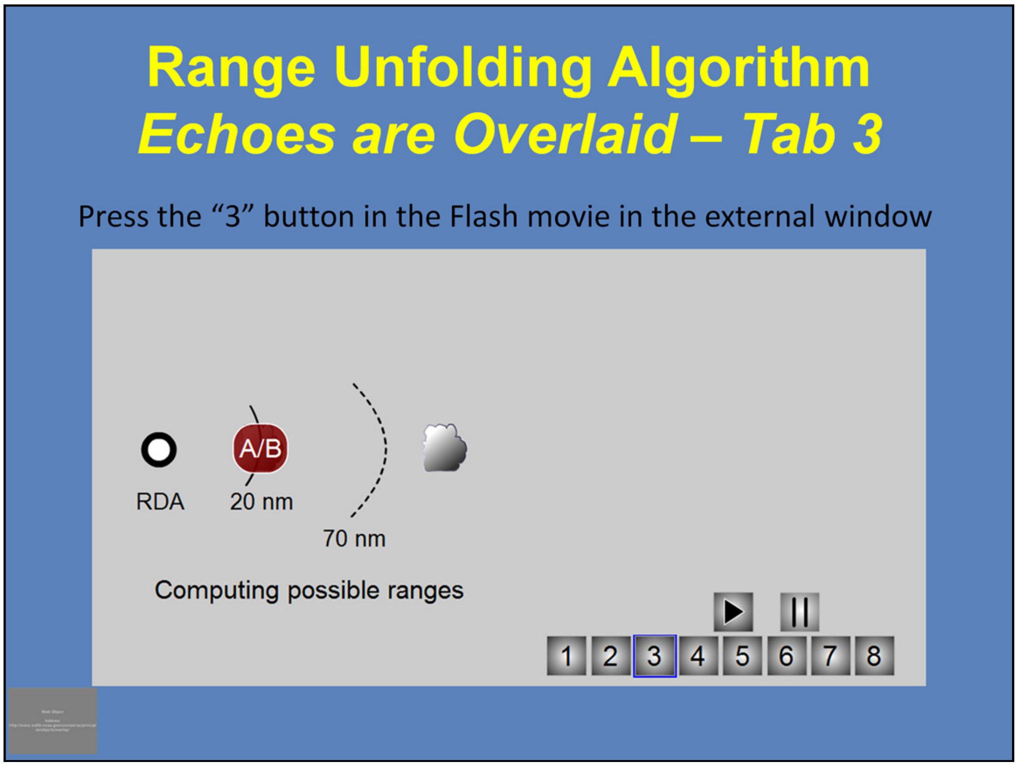
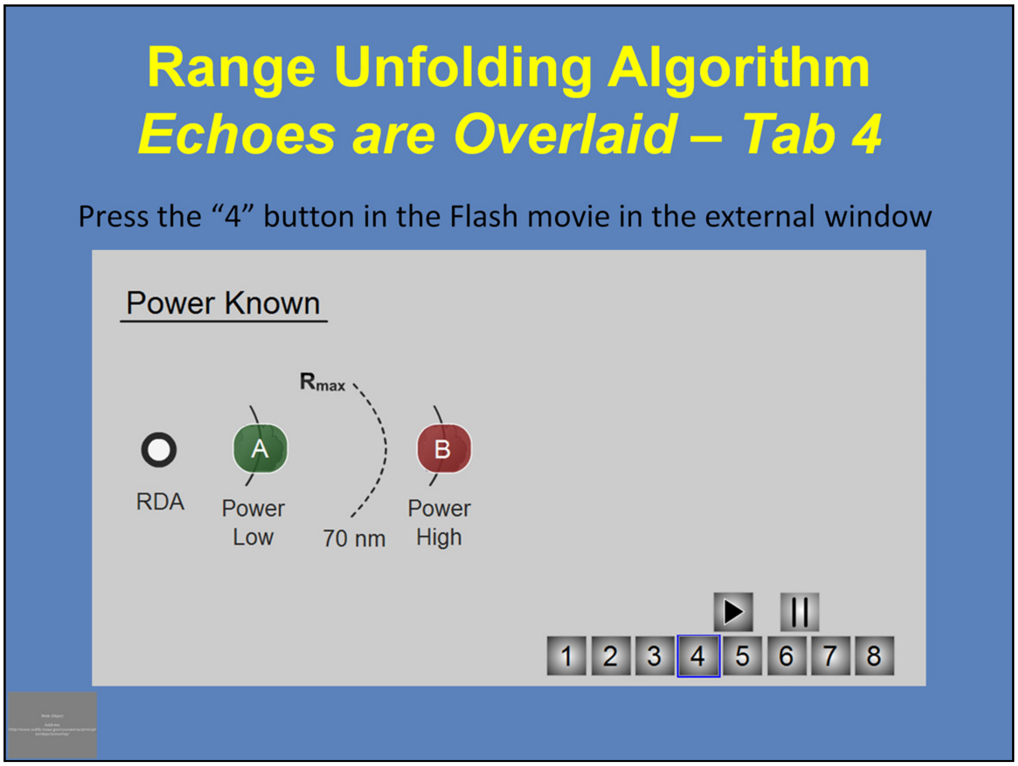


Tab 2. This time, when we go to Doppler mode, the maximum unambiguous range is going to be 70 nm. That means that both our targets will have an apparent range of 20 nm. It also means that we'll be getting pulses back from both of these targets at the same time, so this is an overlay situation.



Tab 3. Just as before, not only does the algorithm account for the apparent ranges of the targets, it accounts for the possible ranges out into the second, third and even fourth trips.



Tab 4. Here's where we take advantage of the fact that we know the returned power for each of these two targets and their original range. Those returned powers can be compared to one another, and a threshold, called TOVER, is used to determine whether we are going to assign velocity and spectrum width to one of these two targets. So the higher power is compared to the lower power, and if we reach this threashold, we have the ability to assign velocity and spectrum width to one of these overlaid targets.

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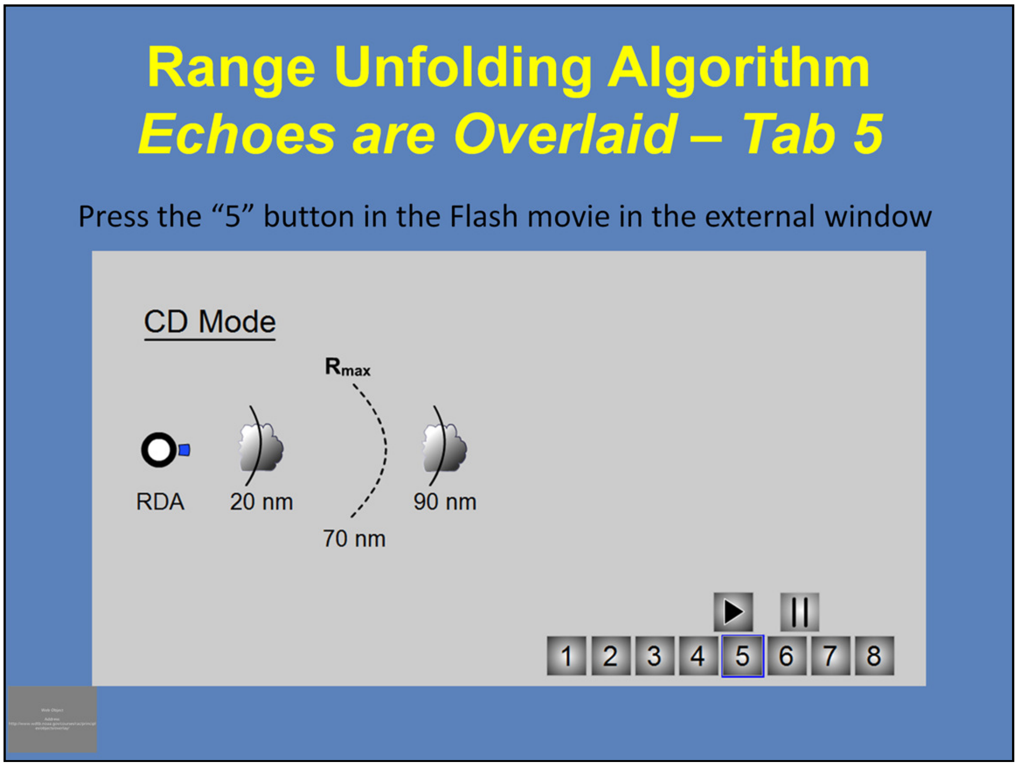
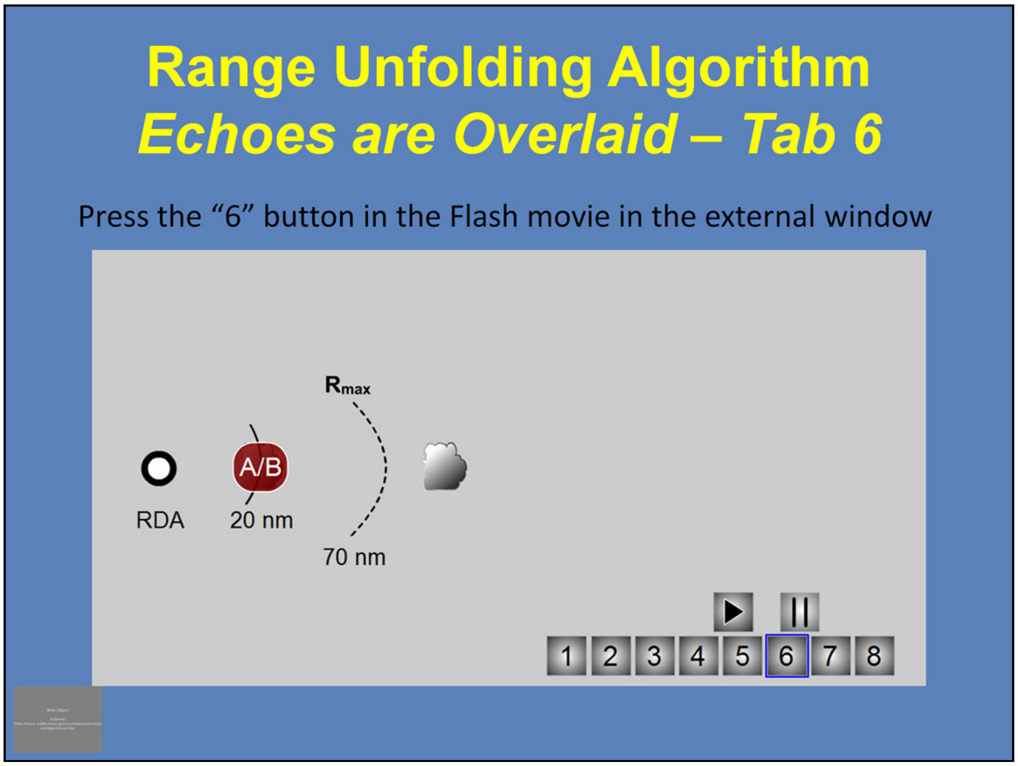


Tab 5. Now we actually do the Doppler data collection, and notice that information from pulses 1 and 2 come back the radar at the same time. So we have a velocity value with an apparent range of 20 nm, that is composed of pulses from both targets A and B.



Tab 6. Now we begin the comparison of the Doppler data to the Surveillance data, asking the question of whether a target was at a specific range, but actually including the question “was that the target that had the higher power?” And in this particular example, Target B had the lower power, so the answer is No at a range of 20 nm.

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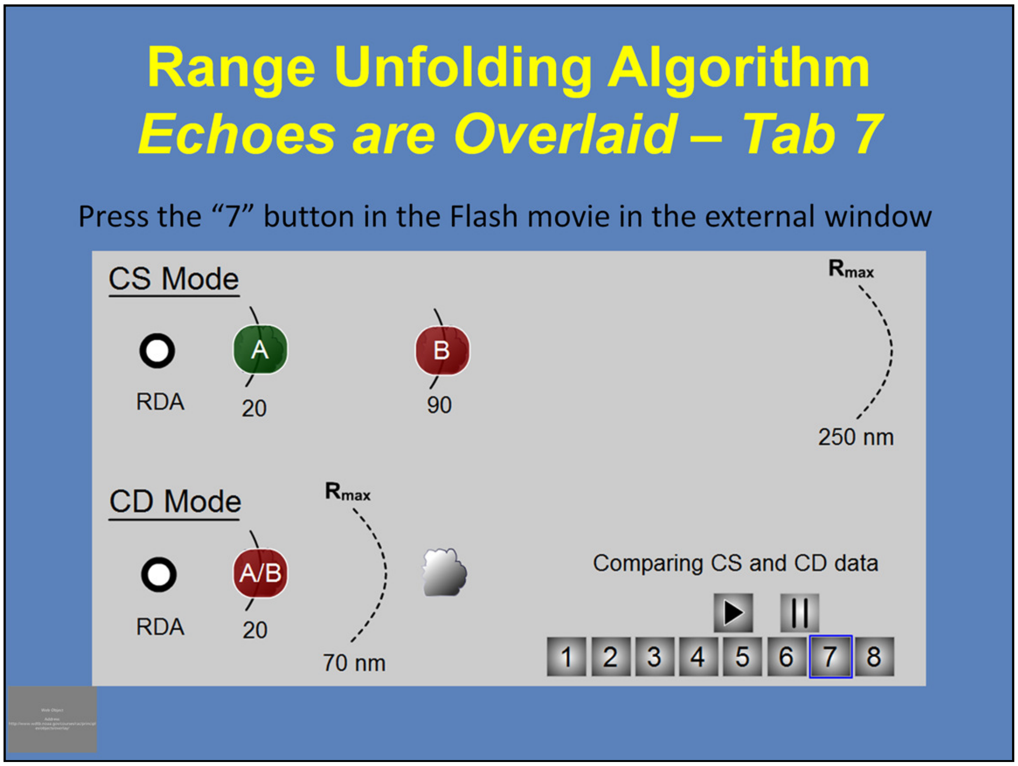

Tab 7. Now asking the same question, looking for a possible range for this target, “was there something at 90 nm?” Yes, and “was this the higher power target?” and the answer is Yes.

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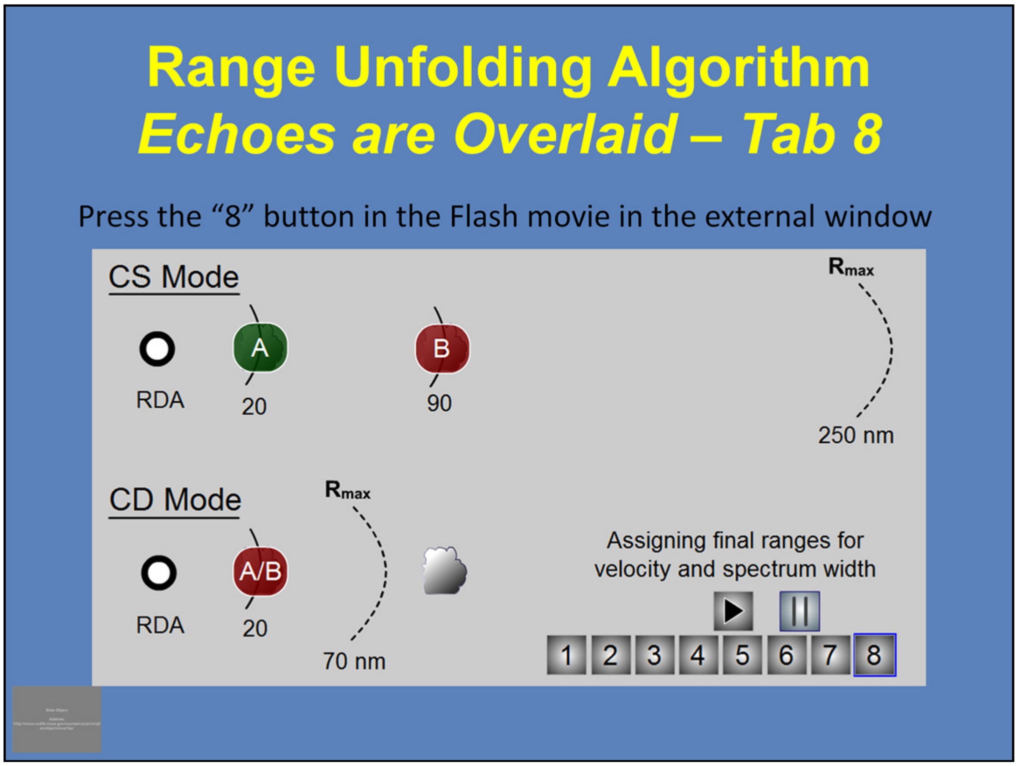

Tab 8. Now that we know that this velocity value that appears to be coming from a range of 20 nm, is more representative of the target that was at 90 nm. So we assign velocity at 90 nm, and range folding, or purple at 20 nm.

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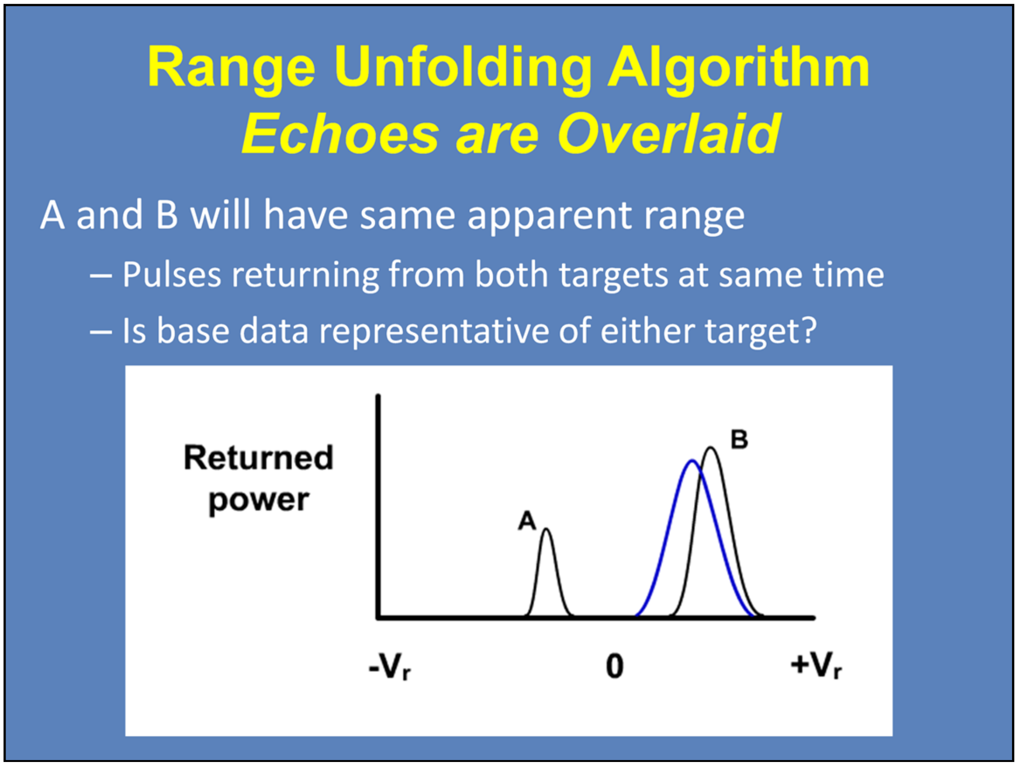


This graphic represents the base data estimation process for a range bin when there is an echo overlay case, such as 20 nm from our previous example. Pulses from two different targets are received and processed at the same time, apparently from 20 nm. If the pulses from these two different targets could be analyzed separately, the result would be the black bell curves for targets A and B. However, they can only be analyzed as a single target, which is represented by the blue bell curve.

Which one of the original targets does the blue curve better represent? Target B, and that is because B is returning significantly more power than target A. Recall that velocity estimates are power weighted, so this “hybrid” velocity estimate is going to be much closer to target B than target A, since B is returning much more power.

Now we need to determine if the power returned by B is sufficiently greater than A for the “hybrid” velocity to be assigned to target B.

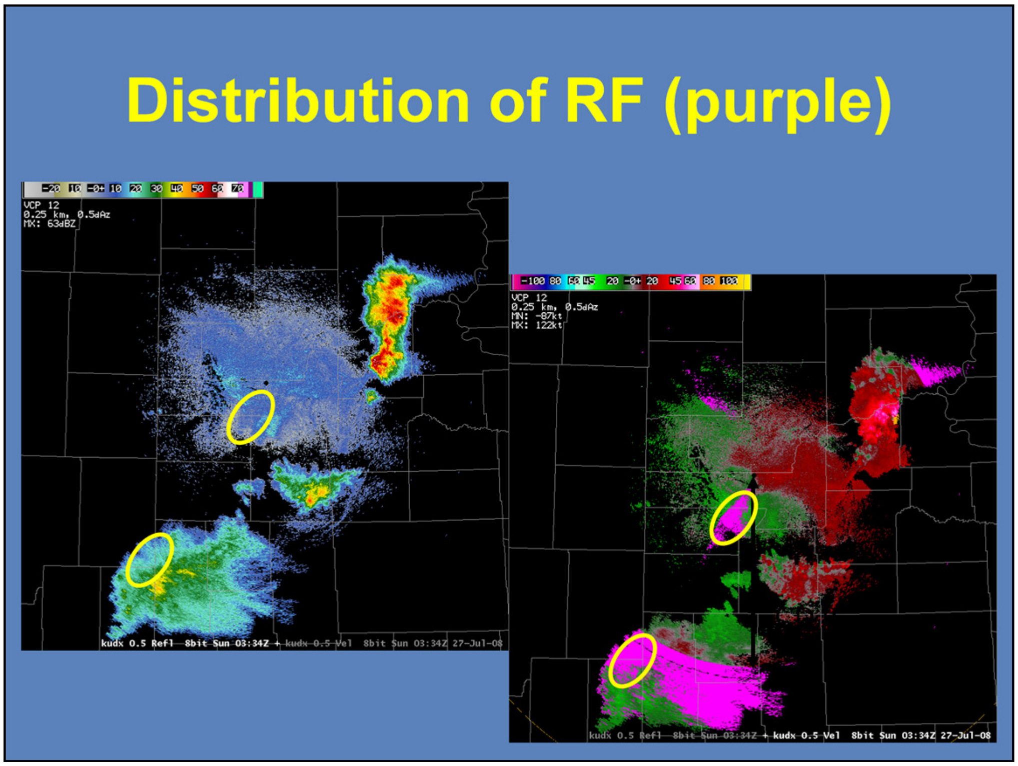
Range Unfolding Algorithm
Echoes are Overlaid

- If power ratio exceeds TOVER (5 dB)
  - V & SW assigned to echo with higher power
  - Other echo assigned RF
- If power ratio does not exceed TOVER
  - Both echoes assigned RF

The Range Unfolding algorithm uses a parameter known as “threshold over” or TOVER, to determine if overlaid echoes have a sufficiently higher returned power difference to assign the hybrid velocity to one of them.

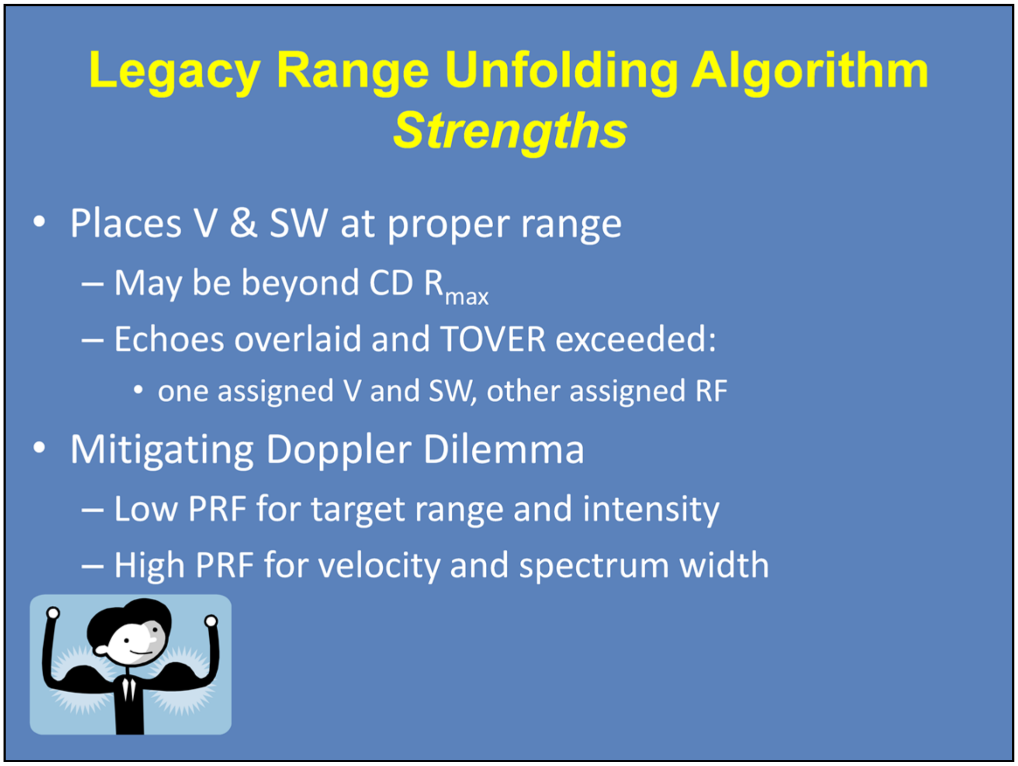
The current setting for TOVER is 5 dB, and if the power ratio exceeds TOVER, velocity and spectrum width are assigned to the echo which returned higher power. The other echo is assigned RF.

If the power ratio does not exceed TOVER, both of the overlaid echoes are assigned RF.



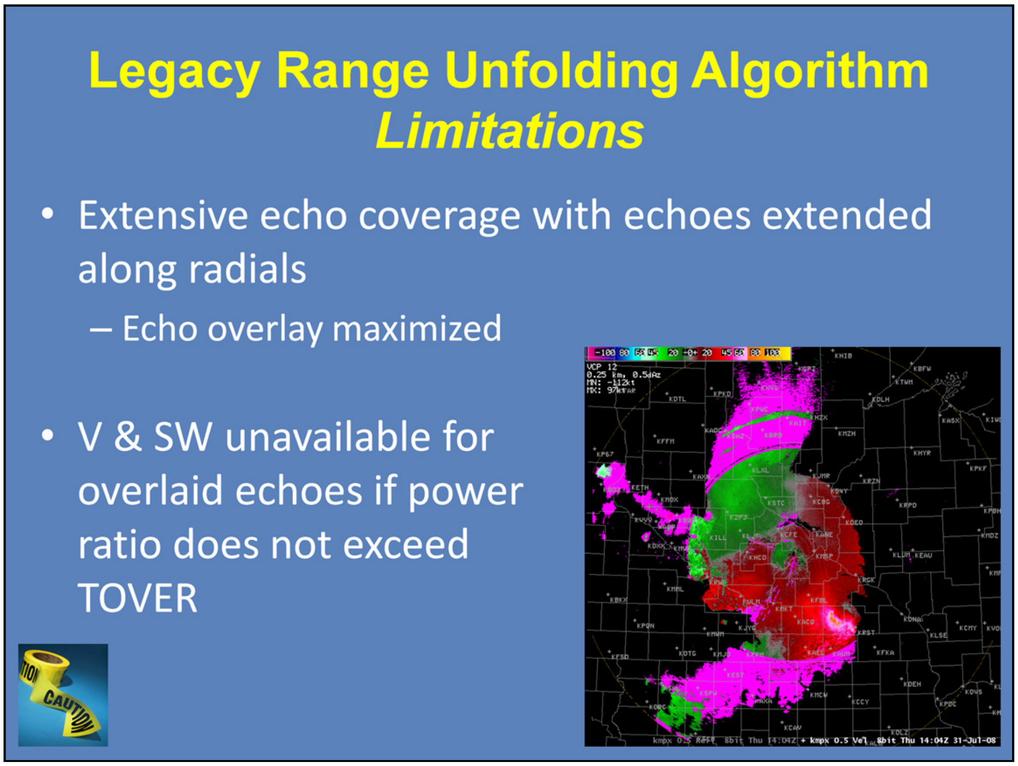
Now for another look at the distribution of RF on the velocity product, given the location of the echoes on the reflectivity. The strongest storms to the northeast are within the first trip, so there is no issue with the availability of the associated velocity data. There is a “blob” of weaker echo to the south and southwest of the radar, some of which falls within the first trip of the velocity data, some of which falls within the second trip.

The yellow ovals are meant to capture a group of gates in the same relative positions in the first and second trips, with purple assigned to both of the bins. The overlaid echoes here did not return enough of a power difference to accurately assign velocity data to either one, so purple (RF) was assigned to both.



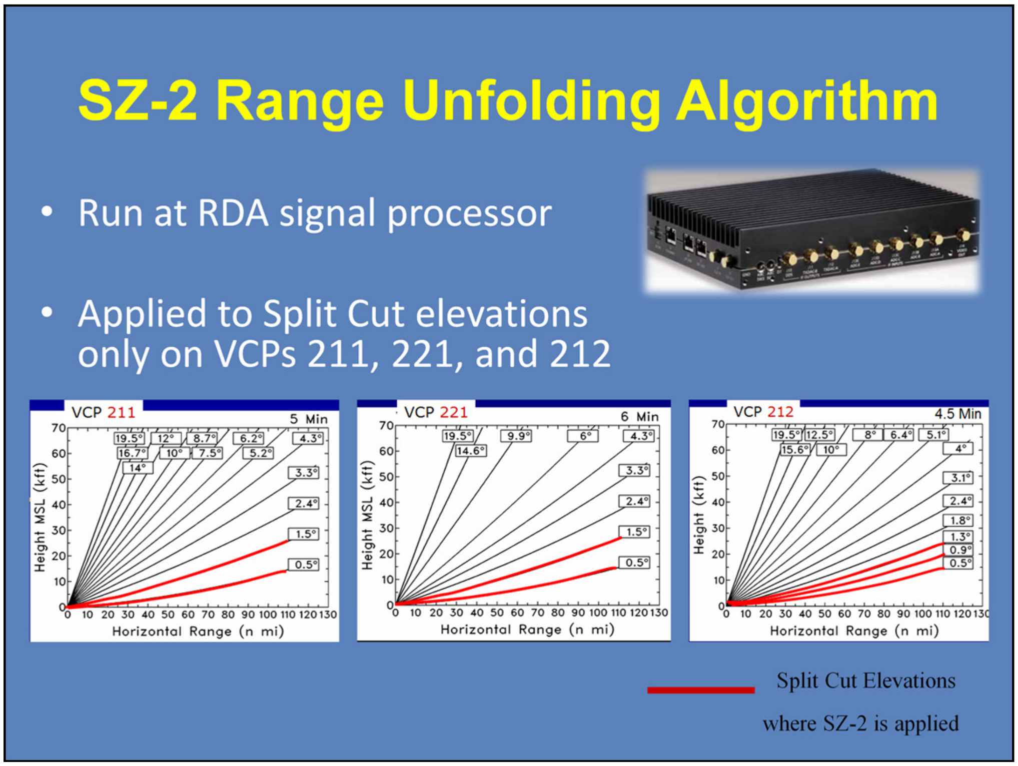
Now for the strengths of the Legacy Range Unfolding algorithm. Most of the time, it is able to achieve its objective of assigning velocity and spectrum width data to the appropriate range, which may be beyond the R_{max} for Contiguous Doppler (CD) mode. When echoes are overlaid, the Legacy Range Unfolding algorithm can, at best, assign velocity and spectrum width to one of the overlaid echoes. This assignment is based on the returned power of the separate echoes that contribute to the overlay. If TOVER is exceeded, that means one of the echoes has returned power that is sufficiently high to be assigned the velocity and spectrum width. The other echoes are assigned RF.

The Legacy Range Unfolding algorithm is designed to mitigate the Doppler Dilemma. For every radial, the low PRF, Contiguous Surveillance (CS) pulses provide returned power and target range. For that same radial, the high PRF, CD pulses provide accurate velocity and spectrum width data. Comparing the information from CS and CD along the radial allows for "unfolding" the velocity and spectrum width to its appropriate range.



The Legacy Range Unfolding algorithm is going to have the greatest limitation on its performance when there is extensive echo coverage aligned along radials, through both the first and second trips in the CD data. This situation maximizes the echo overlay along the radial. Since the Legacy Range Unfolding algorithm can assign velocity and spectrum width to, at best, one of the overlaid echoes, the result is a lot of RF data. In this example, the echo coverage is extensive for both the first and second trips to the north and the south of the radar. There is extensive RF coverage in the second trip because the TOVER requirement was met by the echoes in the first trip.

In some echo overlay cases, RF will be assigned to both trips if TOVER is not exceeded.



The next technique for range unfolding the velocity and spectrum width data was fielded in 2007, and is know as SZ-2 Range Unfolding. This technique is named for the two research scientists who developed it: Mangalore Sachidananda and Dusan Zrnic. It is also run at the RDA signal processor.

SZ-2 is available only for the Split Cut elevations of the three SZ-2 VCPs, 211, 221, and 212. The “2” as the first digit in the VCP name indicates that it is an SZ-2 VCP. The second two digits in the name tells you the structure of the VCP with respect to the angles used and the update rate. For example, VCP 212 is just like VCP 12 expect that SZ-2 is used to range unfold velocity and spectrum width on the Split Cuts.

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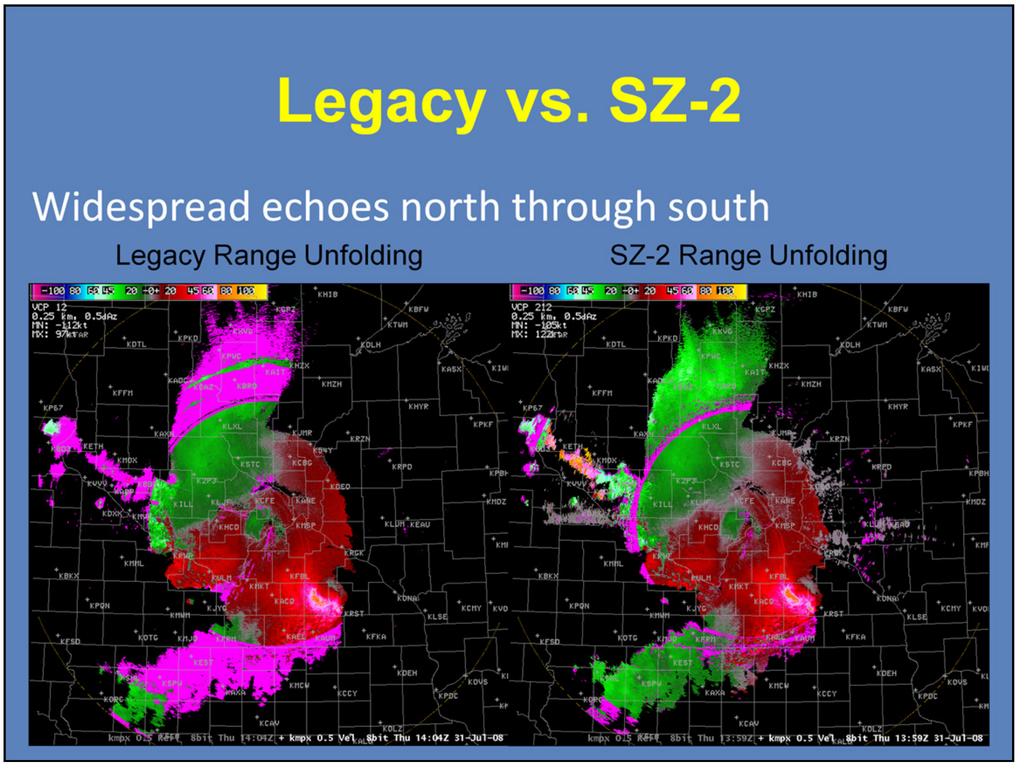
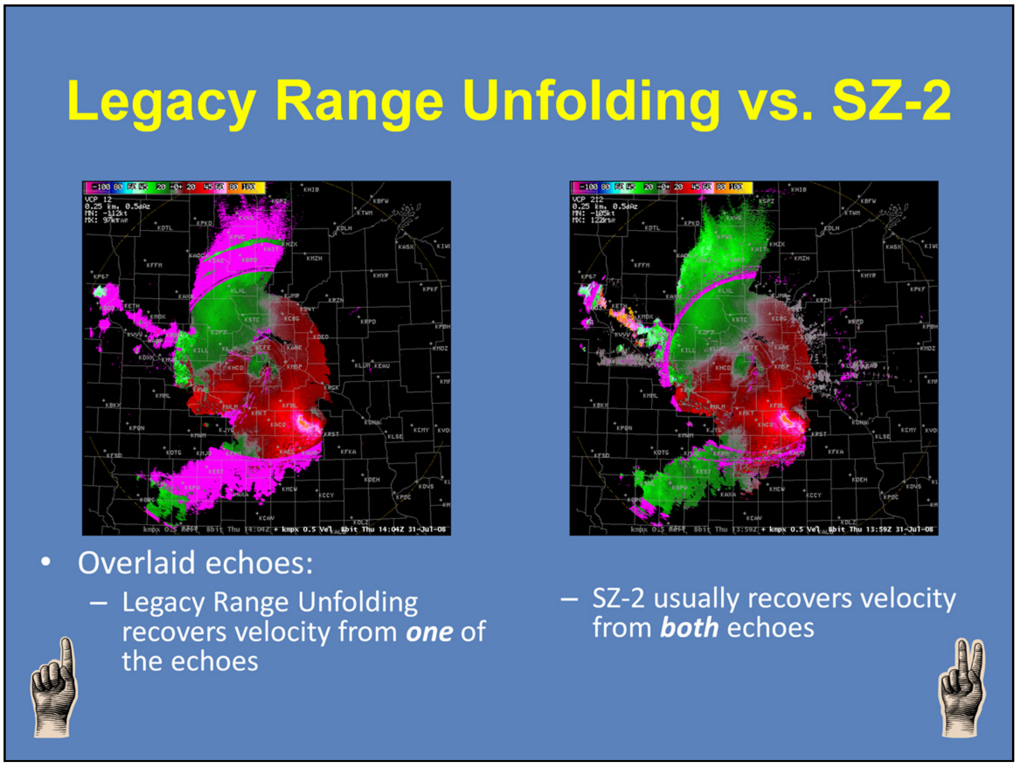
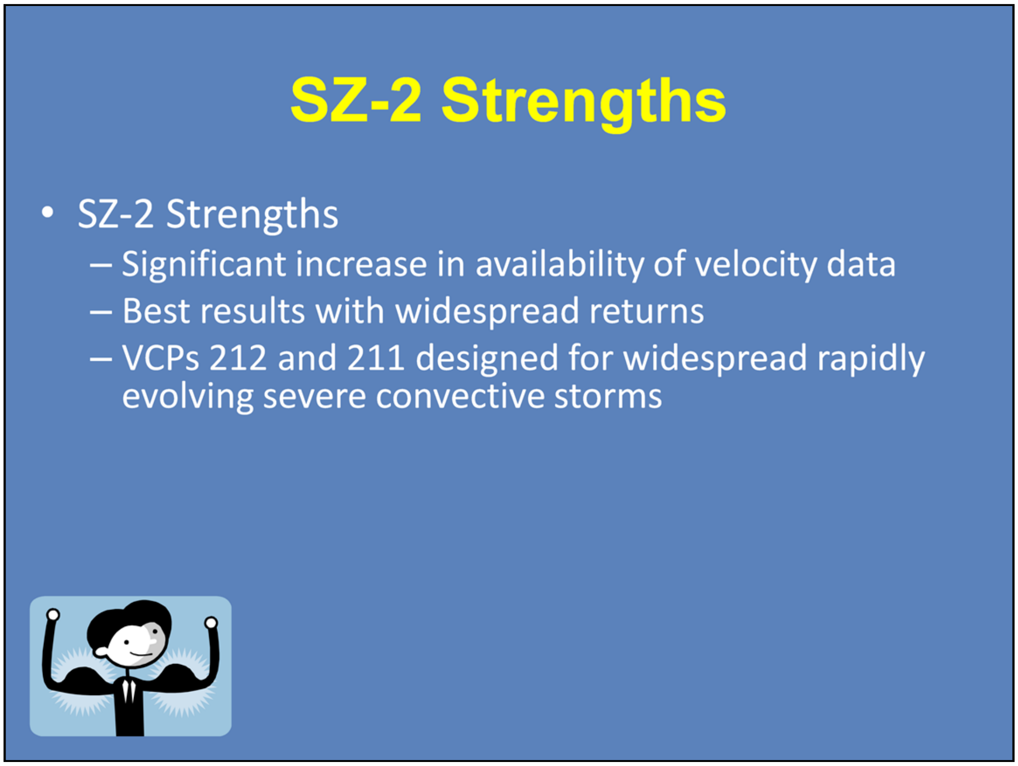


The SZ-2 Range Unfolding algorithm is particularly effective with widespread echo coverage. In this case, the Legacy Range Unfolding algorithm (VCP 12) is used for the data on the left, with SZ-2 (VCP 212) on the right. There is a dramatic improvement in the availability of velocity and spectrum width when VCP 212 is used.



This example also demonstrates the key difference between the two range unfolding techniques currently available when there is echo overlay, i.e. returns from multiple trips in the CD data. When there is echo overlay, the Legacy Range Unfolding algorithm can recover, at best, one of the echoes. On the other hand, SZ-2 can usually recover both overlaid echoes.



The strength of the SZ-2 Range Unfolding algorithm is the increased availability of velocity data for multiple trips. The best results come with events with widespread echo coverage. VCPs 212 and 211 are designed for widespread rapidly evolving severe convective storms. However, VCP 212 has superior low level vertical resolution, just as VCP 12 does.

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SZ-2 Limitations

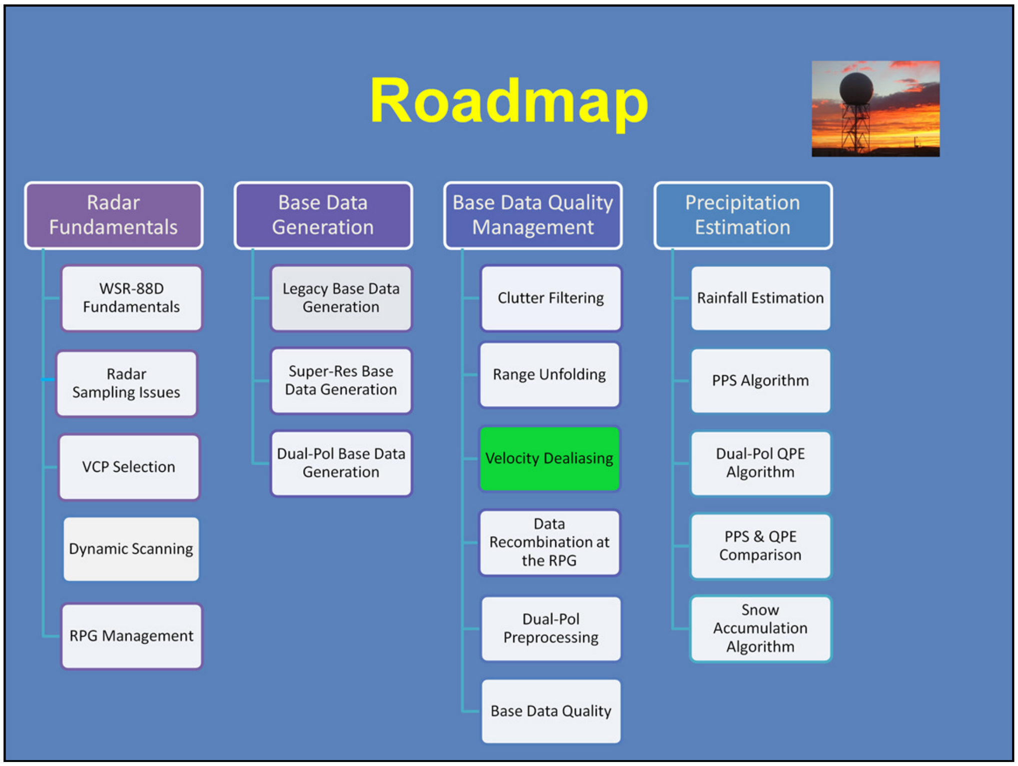
- All Bins degrades SZ-2 velocity
  - CMD enabled: Default clutter file downloaded with SZ-2 VCP
  - CMD disabled: CMD enabled and Default clutter file downloaded with SZ-2 VCP

With CMD active, the need for All Bins clutter suppression is nearly zero (never say never?). SZ-2 is another reason to avoid All Bins suppression, as it can degrade the velocity data when SZ-2 is applied. The RPG software has some steps in place to avoid having All Bins and SZ-2 active at the same time.

If CMD is enabled, and an SZ-2 VCP has been downloaded, the Default clutter regions file will be downloaded along with it. This ensures that the Bypass Map is in control everywhere, overwriting any All Bins filtering that may already be in place.

If CMD has been disabled, and an SZ-2 VCP has been downloaded, CMD will be enabled, and the Default clutter regions file will be downloaded along with the SZ-2 VCP.

Welcome to this lesson on Velocity Dealiasing.



Here is the "roadmap" with your current location.

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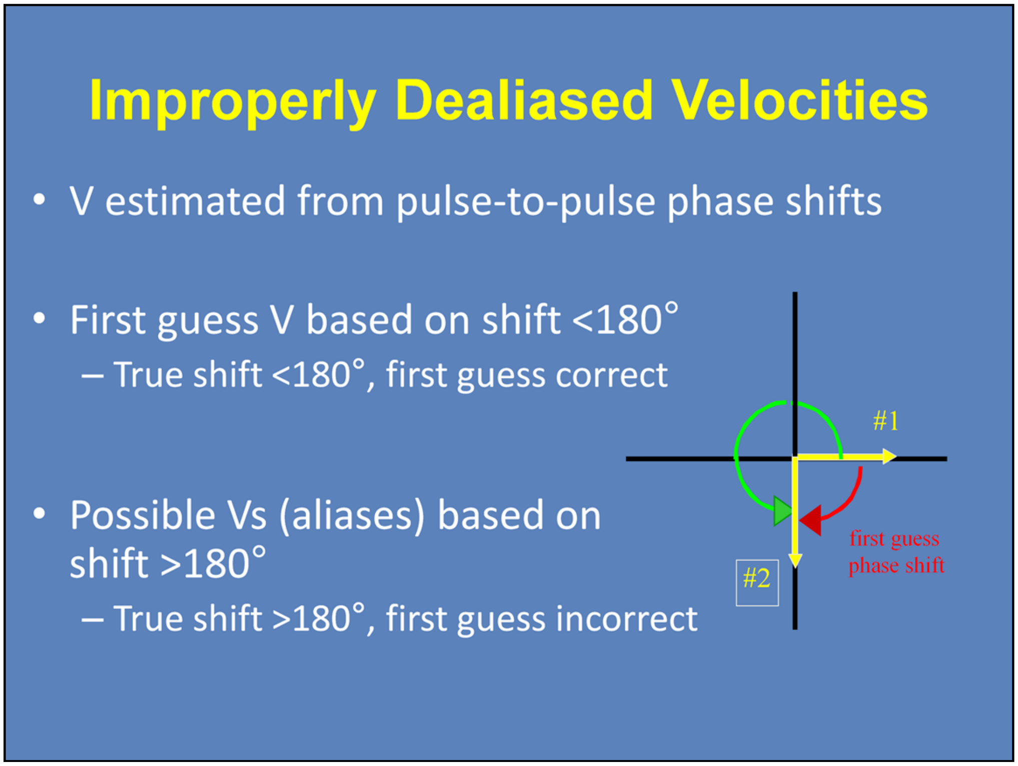
Objectives

1. Identify the purpose, strengths and limitations of the following techniques to dealiase velocity data
   a) Legacy Velocity Dealiasing Algorithm (VDA)
   b) 2 Dimensional Velocity Dealiasing Algorithm (2D-VDA)
   c) VCP 121: Multiple PRF Dealiasing Algorithm

There is one objective for Velocity Dealiasing, and the different algorithms will be taught in sequence in this module.



The previous lesson presented the process for assigning velocity and spectrum width to its appropriate range. The radial velocity value itself is the first guess velocity, which may not be correct. Perhaps one of the aliases of that first guess is the correct velocity. The example used in Base Data Generation had a first guess velocity of +30 kts, while the correct velocity was -90 kts.

Doppler velocity is estimated based on pulse-to-pulse phase shifts, with the first guess velocity calculated from the phase shift < 180°. For each first guess velocity, there are possible velocities, or aliases, based on phase shifts > 180°.

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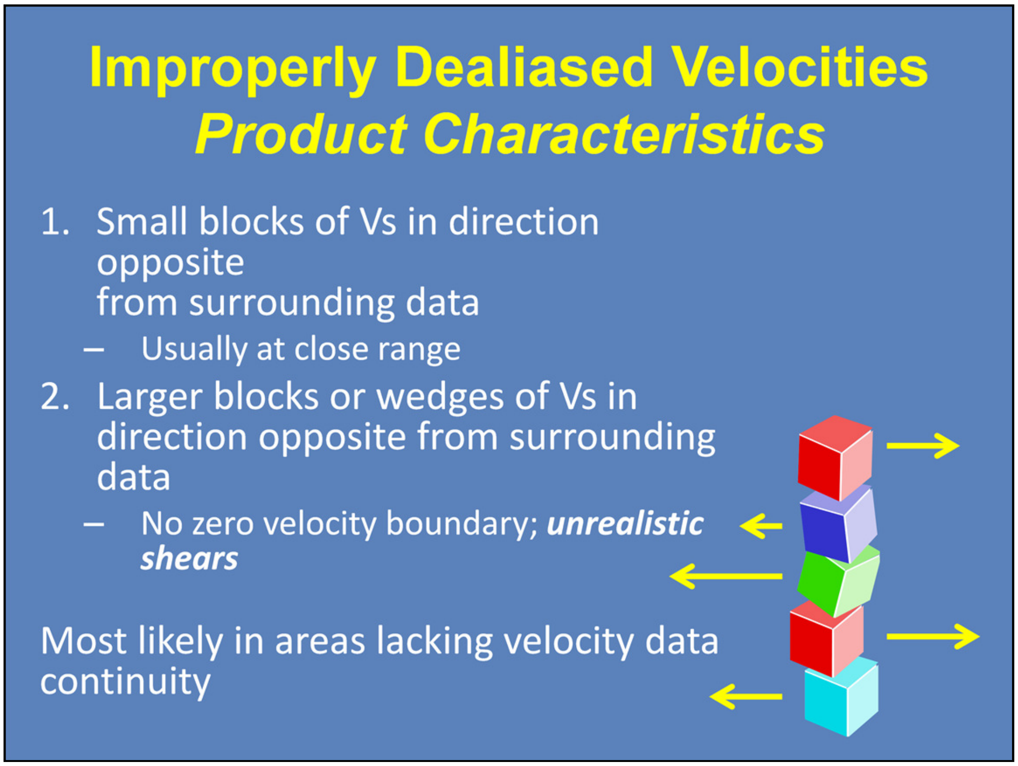
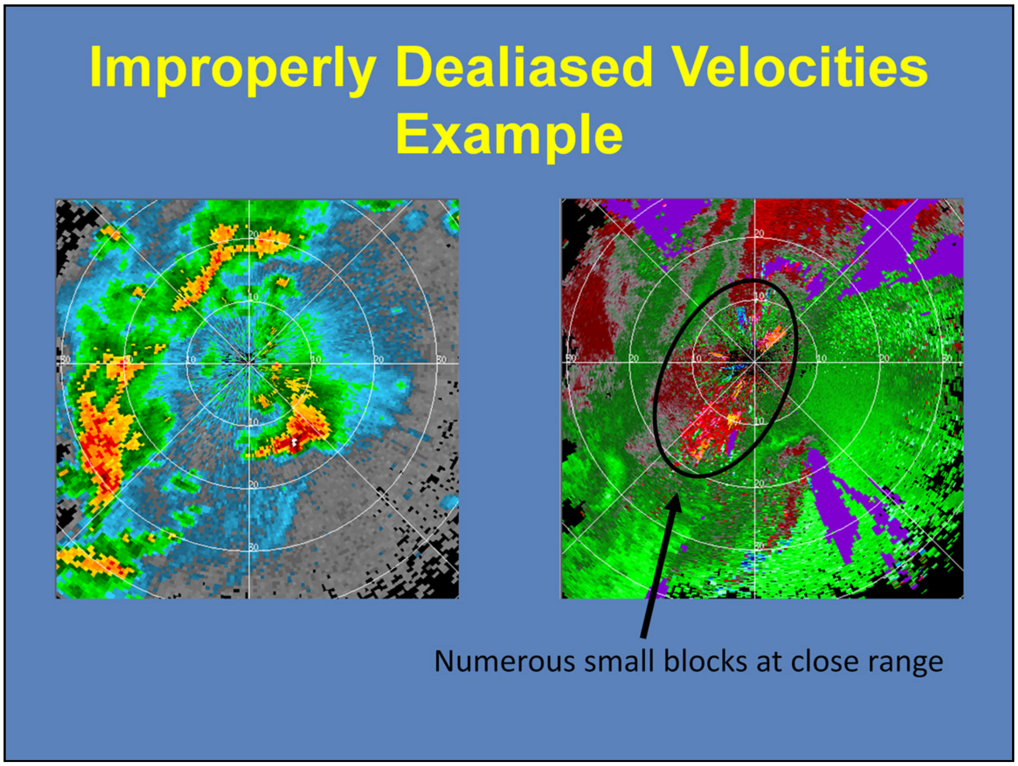


Before looking at the algorithm that “de-aliases” velocities, we first look at the impact of improperly dealiased velocities on the radar products. There are two types of improperly dealiased velocities. At close range, especially in residual ground clutter, small blocks of velocity values opposite in direction from the surronuding data often occur. Typically away from very close range, is another type of improperly dealiased velocity. These blocks or wedges of values opposite in direction from the surrounding data are generally larger. Sometime more challenging are the shears that appear along an azimuth. In some cases, it is difficult to determine if these azimuthal shears are meteorological, or the result of improperly dealiased velocities.



Here is an example of the type of improperly dealiased velocities frequently seen near the radar in the residual clutter region. They are usually not operationally significant.

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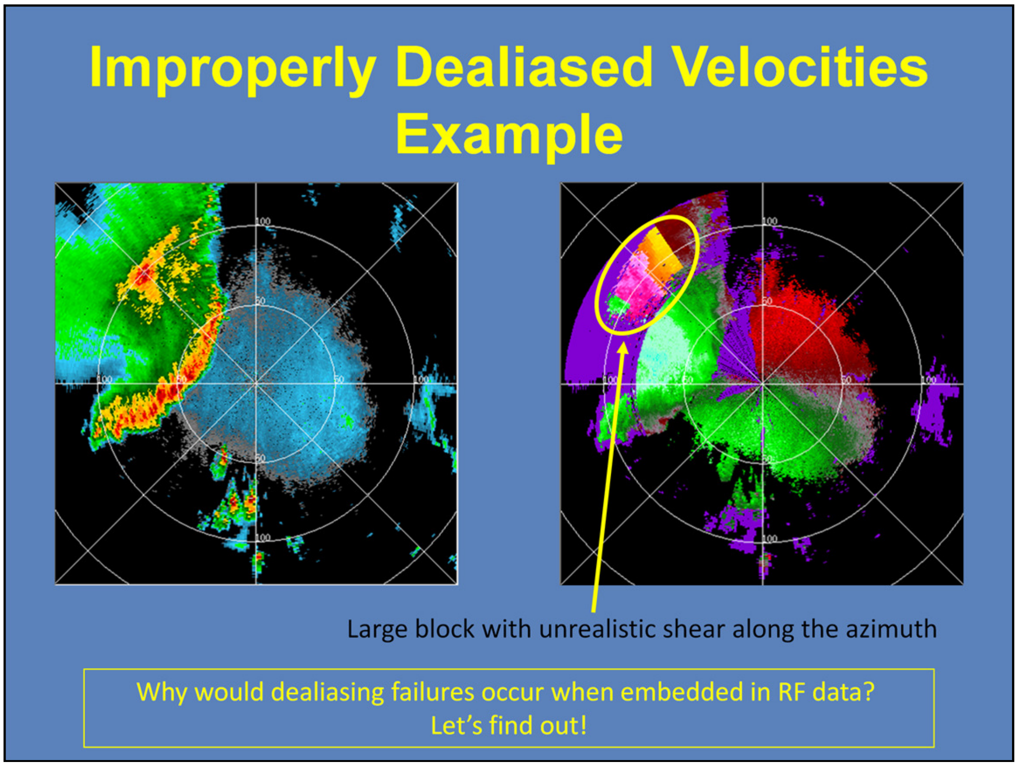

This is an example of improperly dealiased velocities resulting in two azimuthal shears that are clearly not meteorological. Another term for this data artifact is dealiasing failures. The fact that these failures occur while embedded in an area where RF has been assigned is related to how the dealiasing algorithm works.

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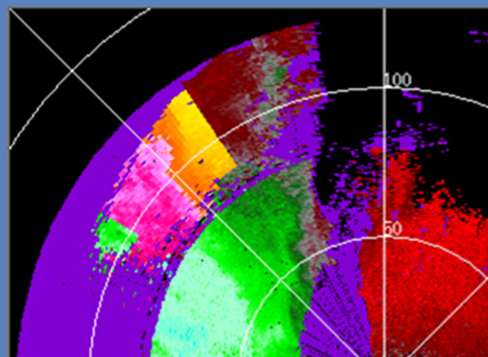
Velocity Dealiasing Algorithm



- Identify & fix incorrect first guess velocities
- Primarily based on continuity
  - Compares each first guess velocity to nearby velocity estimate(s)
- Preserves important meteorological features

The goal of the Velocity Dealiasing algorithm is to assign the correct radial velocity to each range bin. It first identifies any first guess velocities that are “suspect”, then attempts to assign one of the aliases if that is more appropriate. The decision making for what is “appropriate” comes from comparing each first guess velocity and its aliases to neighboring velocity values.

There are additional steps in this algorithm that are designed to preserve real meteorological shears, both from one azimuth to the next (for example, a circulation), and along a radial (for example, storm top divergence).

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Velocity Dealiasing Algorithm

- First 3 steps search for V close to each 1st guess
  - Compare 1st guess against V neighbor
  - Compare 1st guess aliases against V neighbor
- Does +59 make sense?

-68	-56
-74	+59
-68	+50
-67	+53
-64	+53
-62	+59
-15	-18
-3	-14
0	-8
+9	-4
+9	0

The first three steps of the Velocity Dealiasing algorithm are similar in function, and are transparent to the user. Once a first guess velocity is identified along a radial, it and its aliases are compared to a “velocity neighbor”. What constitutes a “velocity neighbor” varies with each step, getting a little further away from the first guess velocity. The essence of steps one through three is to assess whether than first guess velocity makes sense given the surrounding velocity field.

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Velocity Dealiasing Algorithm
Significance of Steps 1 through 3

- Common goal of steps 1, 2 & 3:
  - Compare each 1st guess V to nearby, already dealiased V
- Each step looks a little further away for V to compare to 1st guess
- Step 4 most important since ***you*** have ***input and oversight***!

The first three steps of the Velocity Dealiasing algorithm have the common goal of comparing each first guess velocity to a “velocity neighbor”. That “velocity neighbor” varies with each step, getting a little further away from the first guess velocity. With respect to everyday operations, the most important step with the Velocity Dealiasing algorithm is step four. This final step is the most important, because this is where users have both input and oversight, meaning here’s where dealiasing failures can be mitigated.

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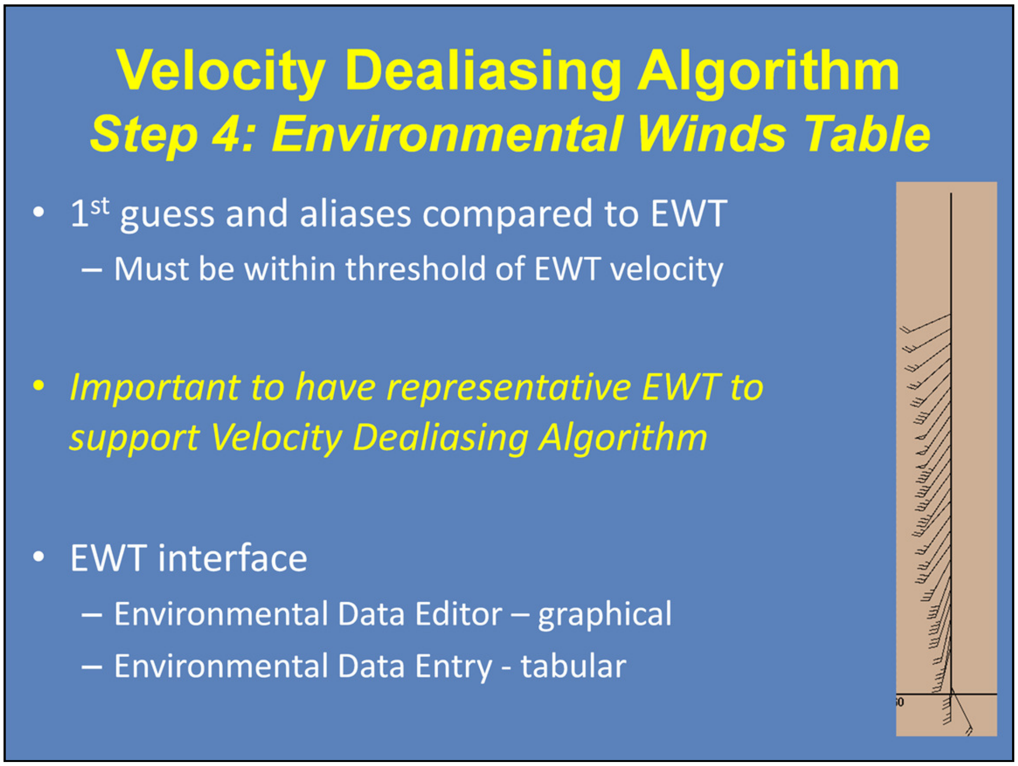
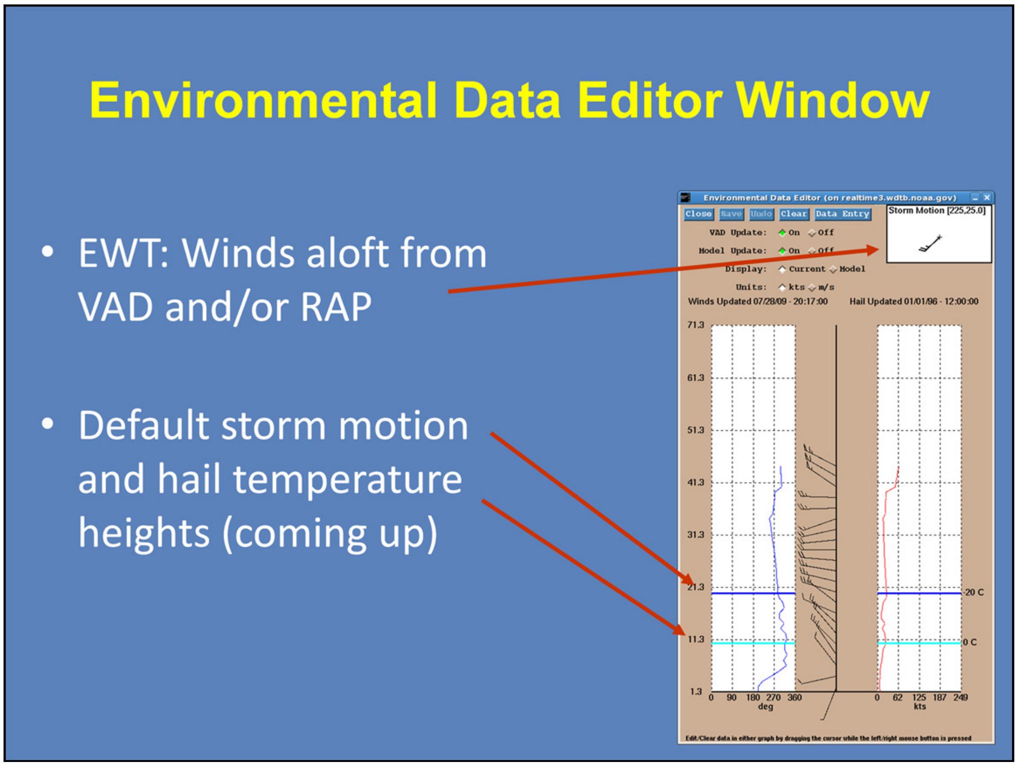


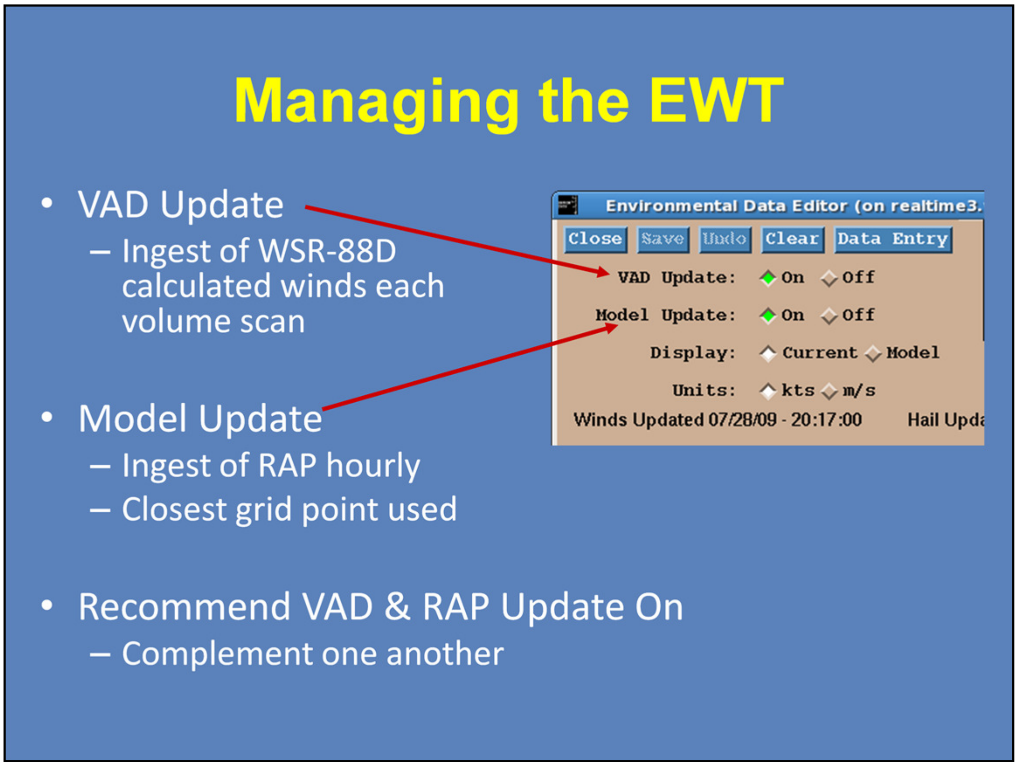
When the previous steps do not resolve a possible incorrect first guess velocity, the Velocity Dealiasing algorithm accesses the Environmental Winds Table to find a representative velocity for the given range and height. It is important that the Environmental Winds Table, which is stored and updated at the RPG, has a realistic picture of the state of the winds aloft.

There are two interfaces related to the Environmental Winds Table, one which is graphical, and another which is a table. The titles are actually Environmental Data, because environmental information other than winds aloft are stored, such as the height of 0° C.



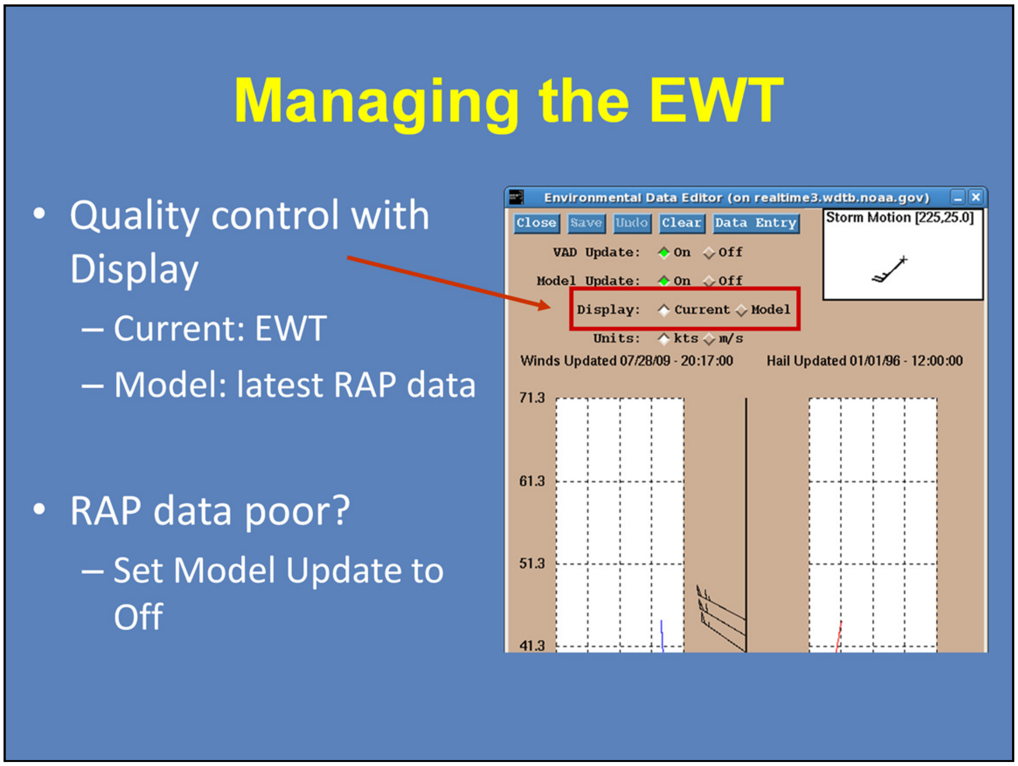
When initially accessing Environmental Data, this window provides multiple types of data. The local winds aloft is presented with the wind barbs in the center, as well as the wind direction and speed represented on the graphs. The input for the wind information is usually a combination of input from the Velocity Azimuth Display (VAD) and the Rapid Refresh (RAP) model. The VAD is an RPG algorithm that uses WSR-88D data to generate winds at a series of heights, while “Model Update” on this RPG window is referring to the RAP.

The Environmental Data Editor window also has the default storm motion and the hail temperature heights.



Here's a closer look at the buttons that control inputs to the Environmental Winds Table. When VAD Update is set to On, the EWT is updated every volume scan by VAD-generated winds aloft. When Model Update is set to On, the RAP data for the closest grid point are used hourly to update the EWT.

It is recommended that both of these updates be set to On, unless there is some kind of problem. These two data sources complement one another. The VAD provides updates every volume scan, but the data are limited to available scatterers to generate radar detected winds. The RAP is available hourly, with wind data available throughout the column at the grid point closest to the radar.



Managing the EWT is a task of monitoring it for relevance, and the Display button can help. When Current is selected, the window is displaying the current state of the EWT. Based on knowledge of winds aloft from other sources, you can verify if the EWT is representative. If there is a need to check the quality of the RAP data, then select Model after Display. The window will display the last hourly model input. If these data are poor, Model Update can be set to Off.

Legacy VDA
Strengths

- Best possible velocity data for algorithms
  - MDA, TDA, SCIT….
- Provides velocity estimates > V_{max}
- Preserves significant meteorological features
  - Gust fronts
  - Storm top divergence
  - Mesocyclones
  - TVS

The Velocity Dealiasing algorithm is designed to provide the best possible velocity data, primary to support the RPG algorithms that look for significant features such as circulations. The Velocity Dealiasing algorithm attempts to assign the true radial velocity, even when it exceeds V_{max}. There are quality control steps with the Velocity Dealiasing algorithm that are designed to preserve significant meteorological shears, such as gust fronts, storm top divergence, mesocyclones and tornadic vortex signatures.

Legacy VDA
Limitations

- Performance degraded by
  - unfiltered clutter
  - weak returned power
  - limited pulses per radial required for faster VCPs
- VDA failures
  - can mask real shears
  - can contaminate algorithms (false MDA detections)
  - most likely in sparse data (leading edge of storms)

The performance of the Velocity Dealiasing algorithm is degraded by data quality problems that reduce the reliability of the first guess velocity. This includes unfiltered clutter, weak returned power, and in some cases, the low number of pulses per radial with the faster VCPs. When dealiasing failures occur, the result can mask real shears that you would want to see. Dealiasing failures can also contaminate the results of the RPG algorithms, such as false circulations from the Mesocyclone Detection Algorithm (MDA). Dealiasing failures are mostly likely to occur in areas of sparse data, which means there are no neighboring velocity values for comparison with a first guess velocity.

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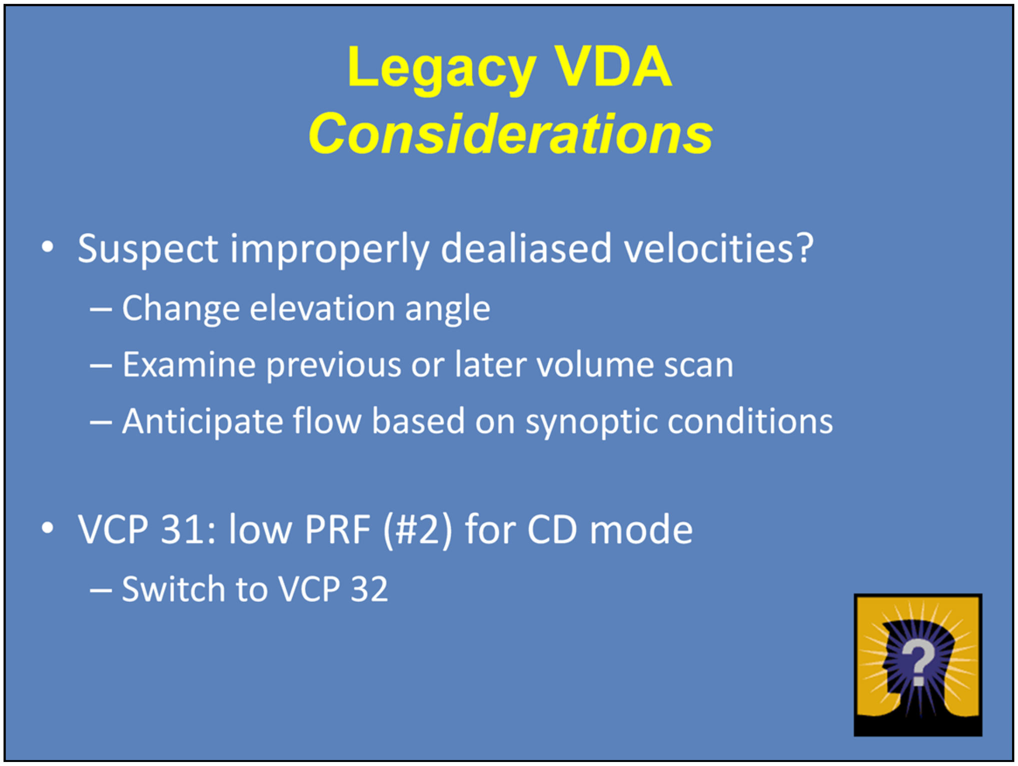

Sometimes dealiasing failures are subtle, and it can be hard to determine if you are seeing a valid shear. It is helpful to be aware that improperly dealiased velocities are not usually preserved from one elevation angle to the next, or from one volume scan to the next. For synoptic or mesoscale flow, it can be helpful to have an expectation based on other data sources.

For Clear Air mode operations, VCP 31 uses long pulse, which provides the best sensitivity, and is good for detecting light precipitation such as snow. However, VCP 31 uses a low PRF for velocity data, and dealiasing failures are more likely. For Clear Air mode operations, if velocity detection is the highest priority, VCP 32 is recommended.

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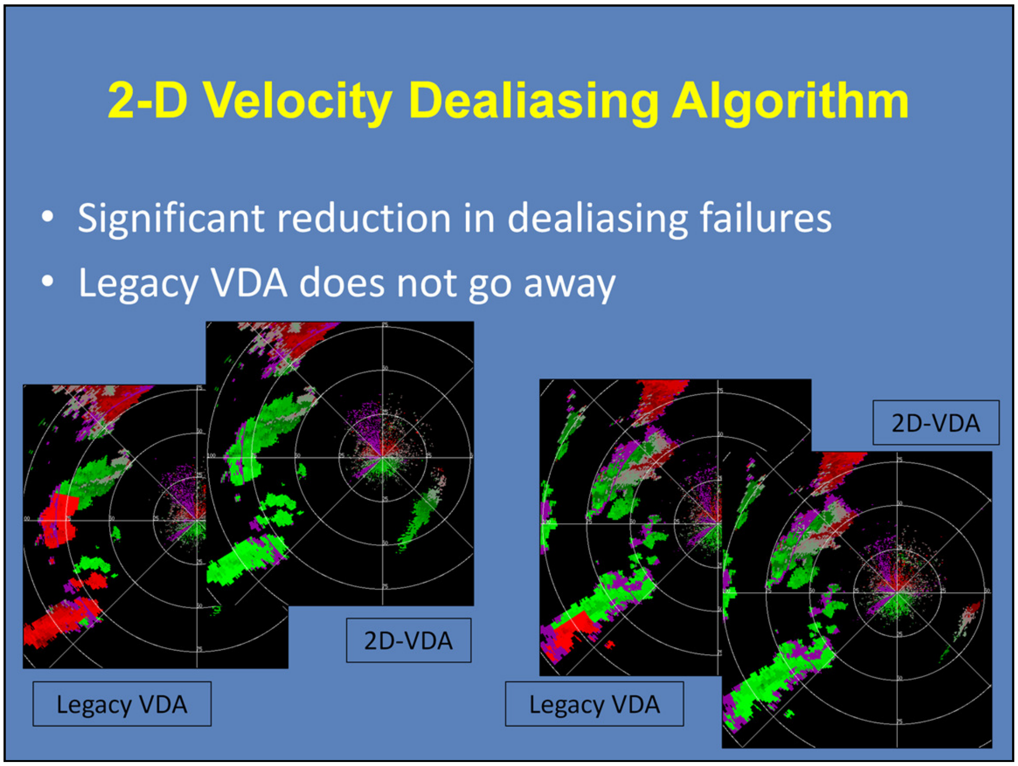
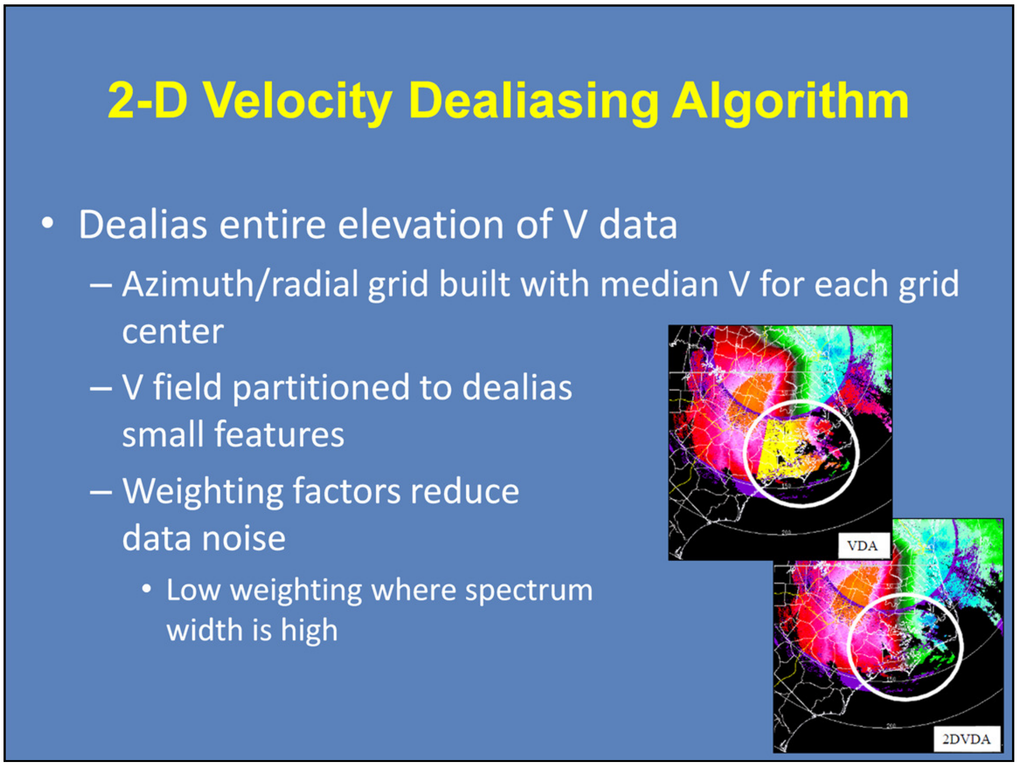


The Two Dimensional Velocity Dealiasing Algorithm (2D-VDA) was deployed in 2013, and offers a significant reduction in dealiasing failures. These examples come from an event with storms that were moving so fast that the legacy Velocity Dealiasing Algorithm had numerous dealiasing failures, while the 2D-VDA did much better.

Though the 2D-VDA is the default velocity dealiasing algorithm, it does not completely replace the legacy Velocity Dealiasing Algorithm.



The 2D-VDA is much more robust than the Legacy VDA, and this slide provides a very brief overview. The overall approach is to use a least squares method to minimize errors in the velocity. For each elevation, 2D-VDA first builds a 2 dimensional grid (azimuth and radial) of the velocity data, with a median velocity value for each grid center point. This serves as a large scale dealiasing step. The velocity field is then partitioned in order to dealias small scale features such as mesocyclones and tornadic vortex signatures. There are also steps that involve applying weighting factors, primarily to reduce noisiness in the velocity data. For example, bins with a high spectrum width would have lower weighting, because velocity estimates are usually less reliable where spectrum width is high.

2D-VDA Implementation

- 2D-VDA is default dealiasing algorithm
- RPG software reverts back to legacy VDA:
  - Differing Doppler PRFs in sectors
  - VMI set to 1.94 kts
- All other conditions: RPG uses 2D-VDA
- Switching to/from 2D-VDA automated

It is important to be aware of how the 2D-VDA has been implemented. Unless it is turned off, the 2D-VDA is the default velocity dealiasing algorithm. There are two conditions where the RPG software will automatically revert back to the Legacy VDA. The first is when a VCP with different Doppler PRFs in the three sectors has been downloaded and is active. The second condition is when the Velocity Measurement Increment (VMI) is set to 1.94 kts (the default VMI is 0.97 kts).

Outside of these two conditions, the 2D-VDA will be active unless it is manually turned off in the Algorithms window. The RPG will automatically switch to and from the 2D-VDA as needed.

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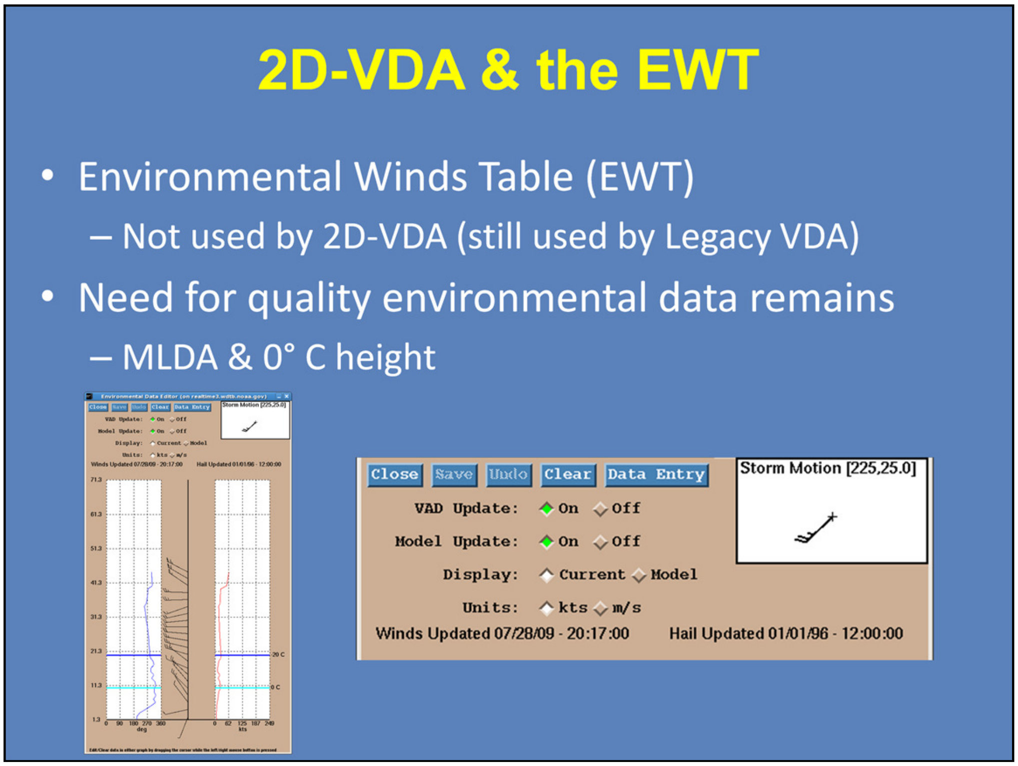
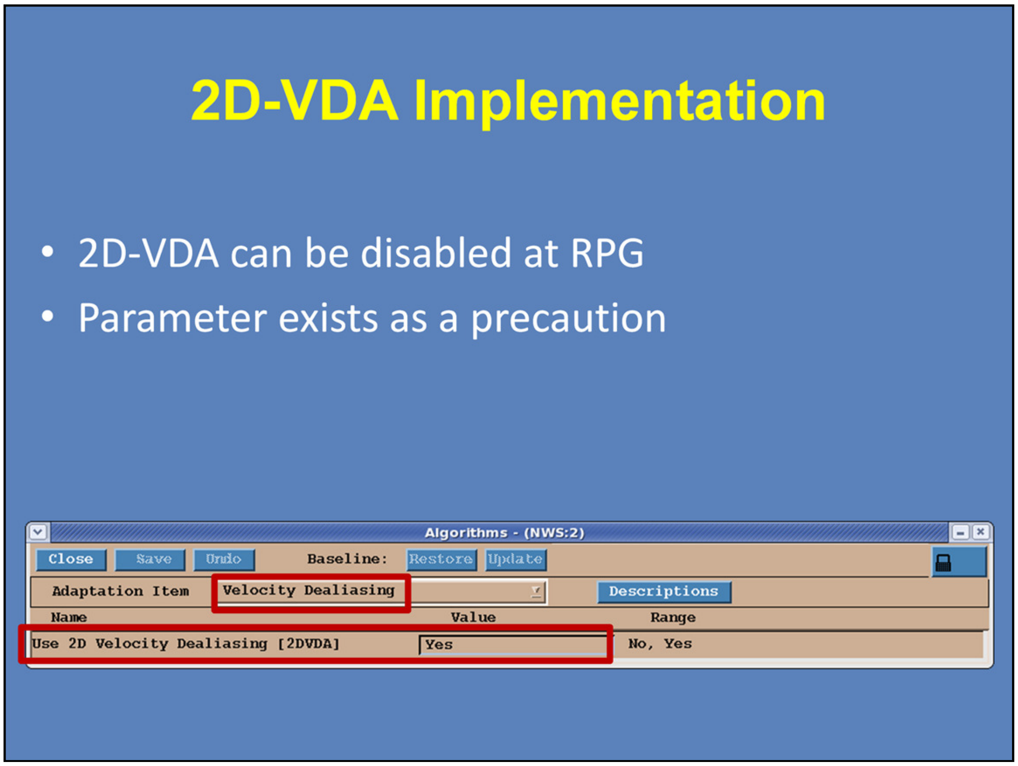


The Environmental Winds Table (EWT) supports the performance of the Legacy VDA, and will continue to do so whenever the Legacy VDA is running. The 2D-VDA does not rely on the EWT.

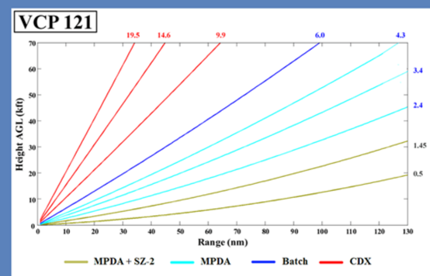
Though the environmental winds will likely be used less often for dealiasing velocity data, maintaining the validity of all the environmental data, such as the 0° and -20° C heights, remains important. For example, the Melting Layer Detection Algorithm (MLDA) will not always have sufficient radar detections to identify a melting layer. When that occurs, the MLDA relies on the RPG 0° C height, which was either manually entered or from the model data.



There is a new entry at the Algorithms window at the RPG, called “Velocity Dealiasing”. The parameter, “Use 2D Velocity Dealiasing”, controls whether the 2D-VDA is used, and the default setting is Yes. Setting this parameter to No is not expected to be needed, but is available as a precaution.

Multiple PRF Dealiasing Algorithm (MPDA)

- Designed to mitigate range folding ***and*** improperly dealiased velocities



- VCP 121 used solely for MPDA
  - VCP 121 is MPDA version of VCP 21
  - Additional CD rotations at lower elevations
    - At 0.5°, 1 CS and 3 CD rotations

The Multiple PRF Dealiasing Algorithm (MPDA) is a special application uniquely used for VCP 121. It is designed to mitigate both range folding and improperly dealiased velocities, with range folding mitigation the most apparent. VCP 121 samples the same elevations as VCP 21, and thus has the same limitations. VCP 121 has additional Doppler rotations for the lower elevations. For example, at 0.5, there is one CS rotation followed by 3 CD rotations. Each of these CD rotations uses a different Doppler PRF.

VCP 121

- SZ-2 + Legacy Range Unfolding + extra CD rotations

VOLUME COVERAGE PATTERN 121
SCAN STRATEGY MPDA/SZ2 SHORT PULSE

Scan				Surveillance		Doppler PRF No.				
Elevation (deg)	AZ Rate (deg/sec)	Period (sec)	WF Type	PRF No.	No Pulses	4 No. Pulses	5 No. Pulses	6 No. Pulses	7 No. Pulses	8 No. Pulses
0.5	18.677	19.28	SZCS	1	17	-	-	-	-	-
0.5	19.754	18.22	SZCD	8	-	43	51	55	59	64
0.5	27.400	13.14	CD	6	-	31	37	40	43	46
0.5	21.401	16.82	CD	4	-	40	47	51	55	59
1.45	19.842	18.14	SZCS	1	16	-	-	-	-	-
1.45	19.754	18.22	SZCD	8	-	43	51	55	59	64
1.45	27.400	13.14	CD	6	-	31	37	40	43	46
1.45	21.401	16.82	CD	4	-	40	47	51	55	59
2.4	19.205	18.75	B	1,8	6	27	32	34	37	40
2.4	27.400	13.14	CD	6	-	31	37	40	43	46
2.4	21.401	16.82	CD	4	-	40	47	51	55	59
3.35	21.599	16.67	B	2,8	6	28	33	35	38	40
3.35	27.400	13.14	CD	6	-	31	37	40	43	46
3.35	21.401	16.82	CD	4	-	40	47	51	55	59
4.3	16.304	22.08	B	2,4	6	40	48	52	56	61
4.3	29.498	12.20	CD	7		29	34	37	40	43
6.0	20.204	17.82	B	3,5	6	34	40	43	47	51
9.9	29.498	12.20	CD	7	-	28	34	37	40	43
14.6	29.795	12.08	CD	8	-	28	33	36	39	43
19.5	29.795	12.08	CD	8	-	28	33	36	39	43

Here’s a snapshot of the design of VCP 121. For the lowest two elevation angles, there are three CD rotations with different Doppler PRFs, and one of these CD rotations uses SZ-2 to range unfold the velocity data.

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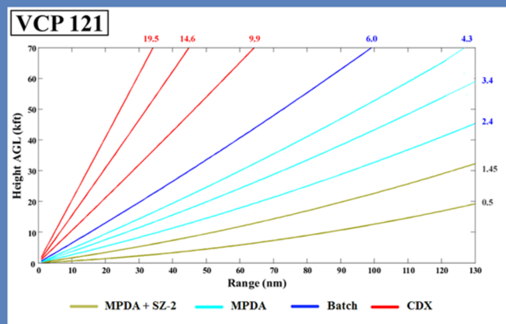
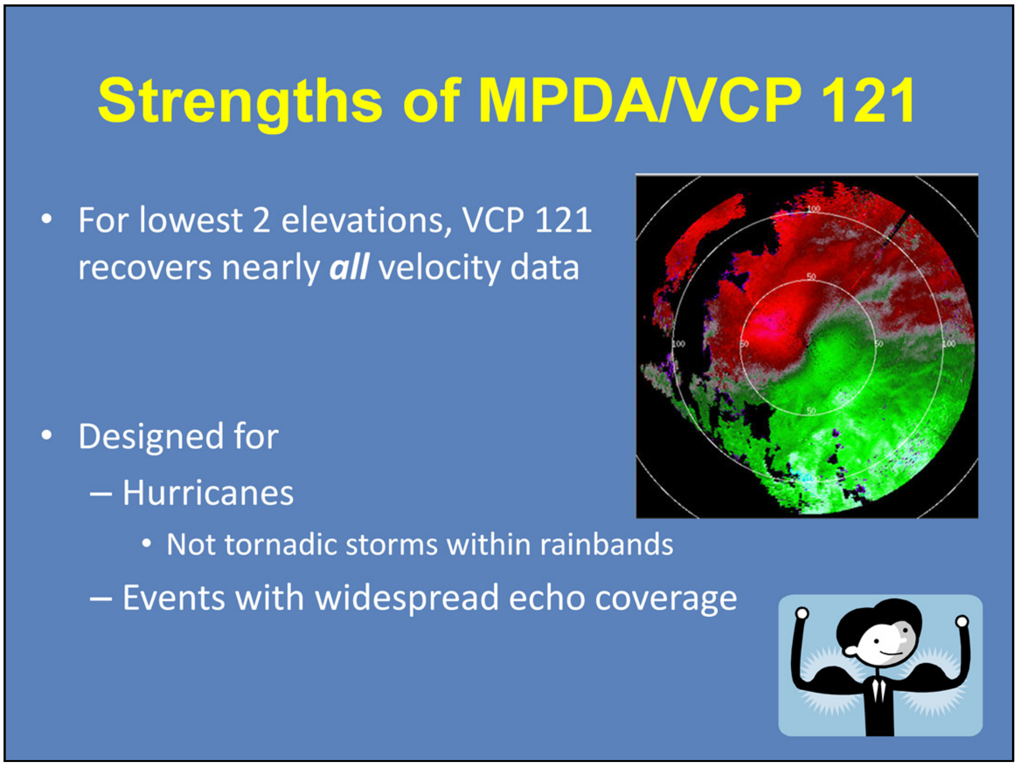
VCP 121 Considerations

- VCP 21 angles; ***fastest antenna rotations***
  - 20 rotations in 5 mins 45 secs

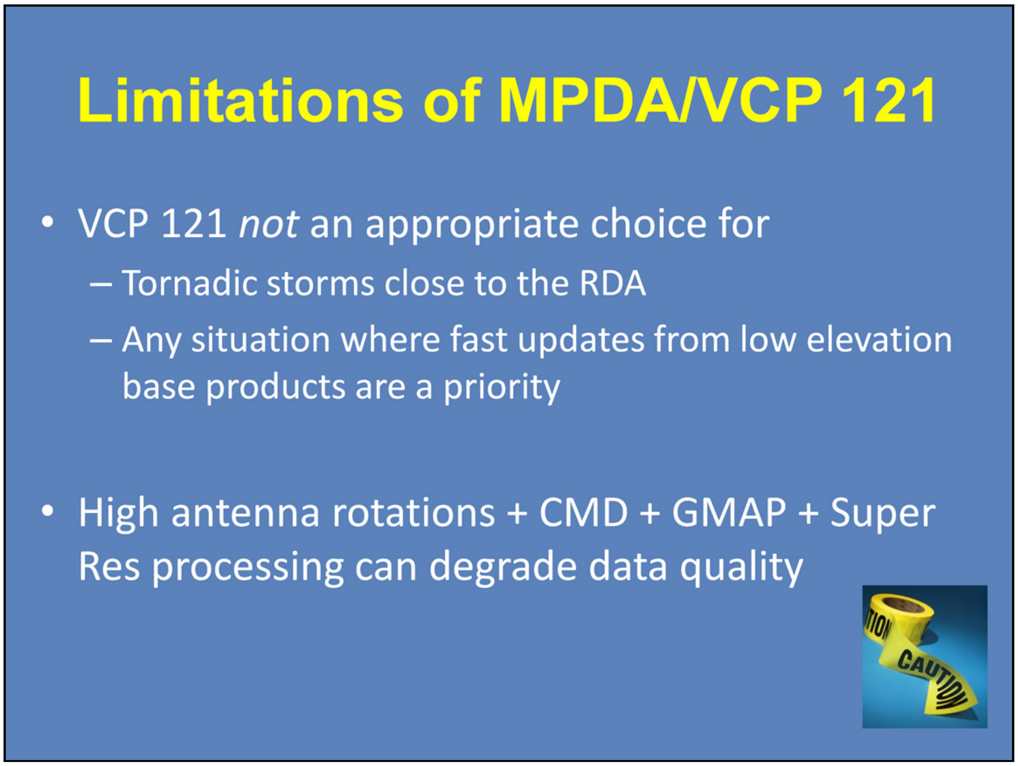


- VCP 121 ***not*** appropriate for fast moving or rapidly evolving storms
  - Use VCP 12 or 212
  - Better vertical sampling & faster updates

Since VCP 121 has additional rotations for several elevations, it has the greatest number of total rotations of any VCP. With an update rate of just under 6 minutes, VCP 121 has the fastest antenna rotation rates of any VCP, and a low numbers of pulses per radial. VCP 121 is not appropriate for fast moving and/or rapidly evolving storms. VCPs 12 or 212 are the appropriate choices, given their better low level vertical sampling and their faster updates.

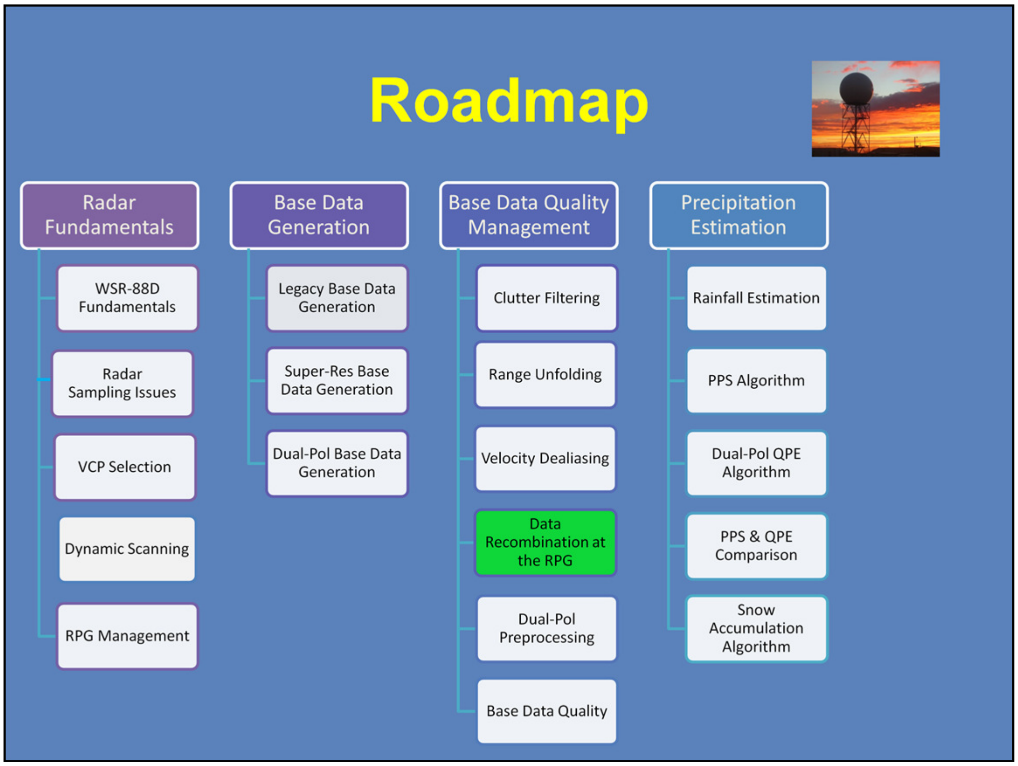


MPDA, aka VCP 121 is capable of recovering nearly all velocity data for the lowest two elevations. It is designed for sampling hurricanes while still offshore when large scale velocity structure is the priority. Once operations shift to looking for potentially tornadic storms within the rainbands, VCP 121 is no longer appropriate (VCPs 12 or 212 are better choices). VCP 121 is designed for events with widespread echo coverage, provided there are no severe convective cells to interrogate.



VCP 121 is not an appropriate choice for tornadic storms close to the radar, or any situation where fast updates from low elevation base products are a priority. VCP 121 has the highest antenna rotation rates, with low numbers of pulses per radial. With the application of CMD, GMAP, and super resolution processing, VCP 121 is more vulnerable to data quality problems.

Welcome to Recombination at the RPG.



Here is the “roadmap” with your current location.

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Recombination at the RPG

Objective

1. Identify the purposes of the different recombination tasks at the RPG.

There is one objective in Recombination at the RPG.

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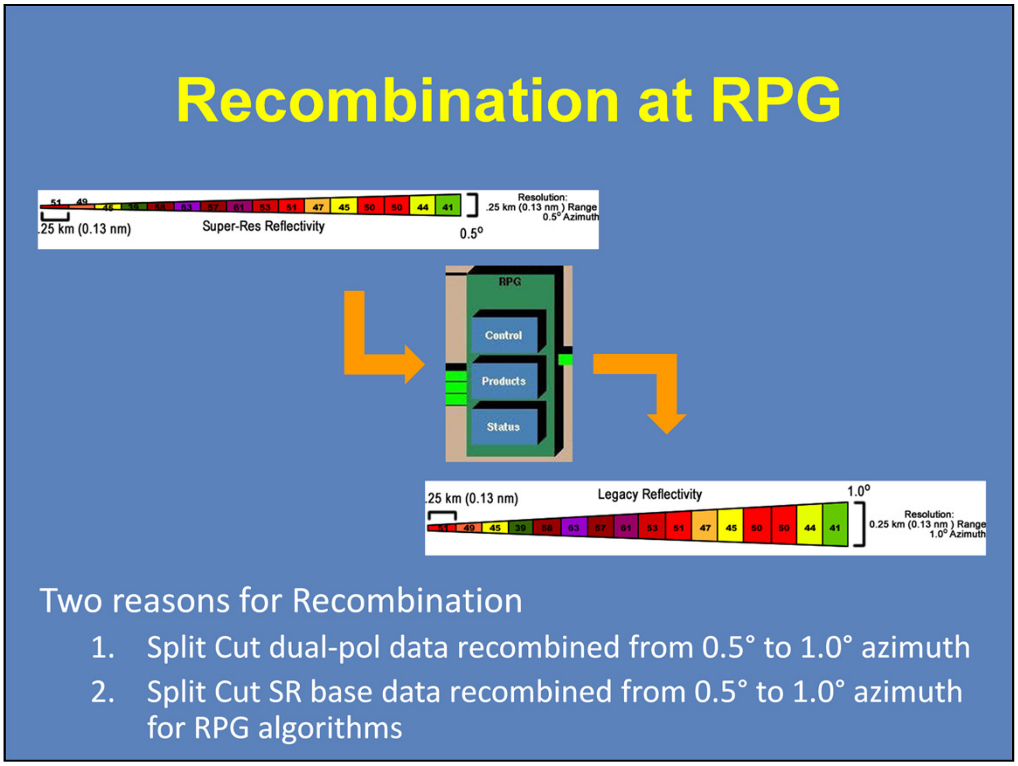

Recombination is a process run at the RPG before many of the products are built. There are two cases where the base data that comes directly from the RDA needs adjustment before it can be used to build products or to be used for algorithm input.

1. For the Split Cut elevations, the dual-pol base data are processed at the RDA with an azimuthal resolution of 0.5°, then sent via the wideband to the RPG. This includes Differential Reflectivity, ZDR, Correlation Coefficient, CC, and Differential Phase, Φ_{DP} , all of which are too visually noisy for direct product generation.

2. For the Split Cut elevations, the legacy base data (reflectivity, velocity and spectrum width) are super resolution. Many of the RPG algorithms cannot ingest data with 0.5° azimuth, so it must first be recombined to an azimuth of 1.0°.

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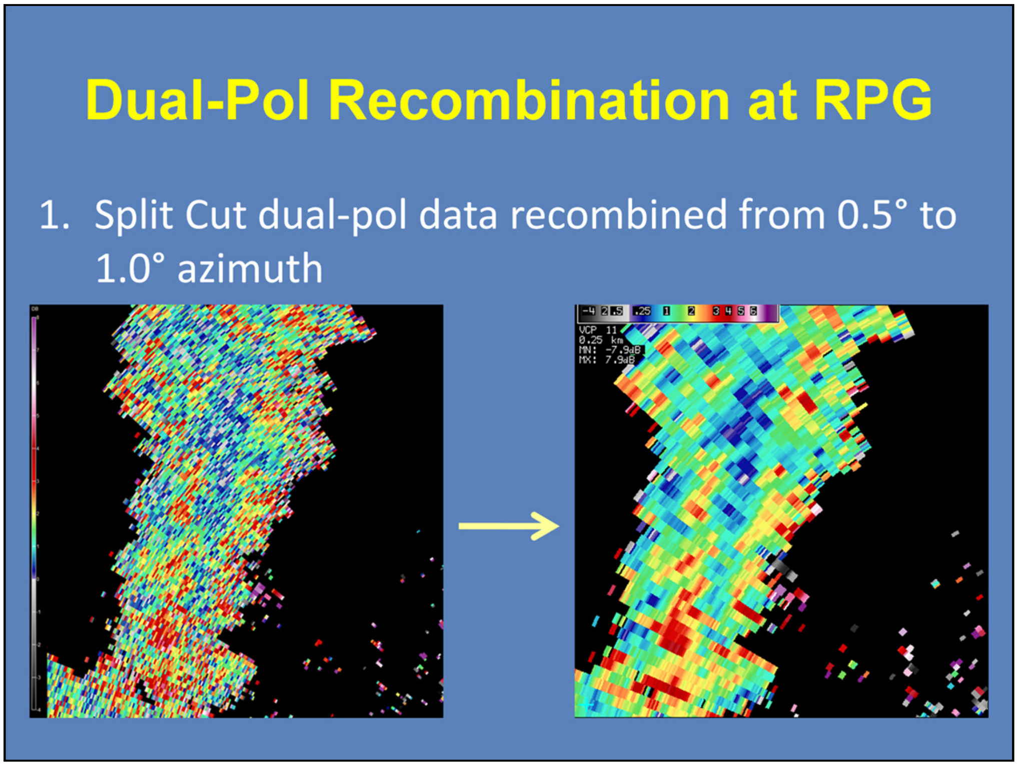

The dual-pol base data arriving from the RDA are ZDR, CC, and Φ_{DP}. For the Split Cuts, all of these data have an azimuthal resolution of 0.5°, and are too visually noisy for direct product generation. These data are recombined to an azimuth of 1.0°.

The dual-pol base data are also “preprocessed”, which includes smoothing and converting Differential Phase, Φ_{DP}, into Specific Differential Phase, KDP. The Dual-Pol RPG Preprocessor algorithm will be discussed in a later lesson. On the left is the ZDR base data displayed in a Level II viewer (GR Analyst). On the right is the associated ZDR product displayed on AWIPS. The data have been recombined to 1.0°, as well as preprocessed.

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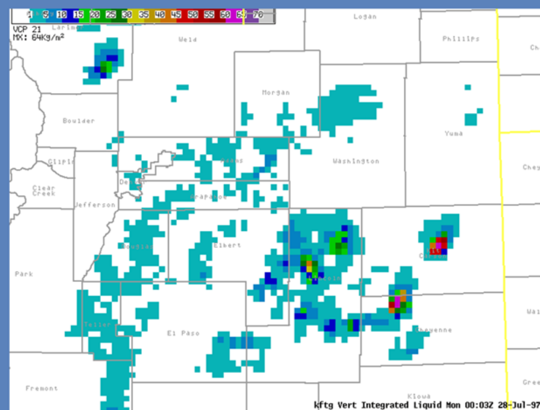
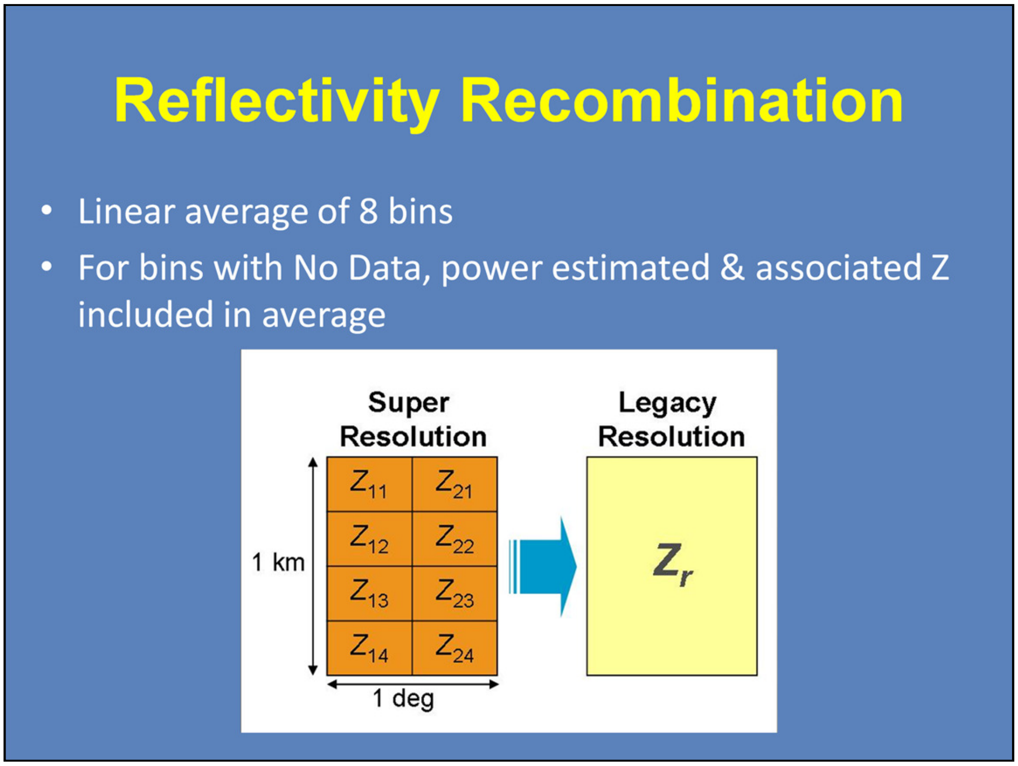
Recombination at RPG



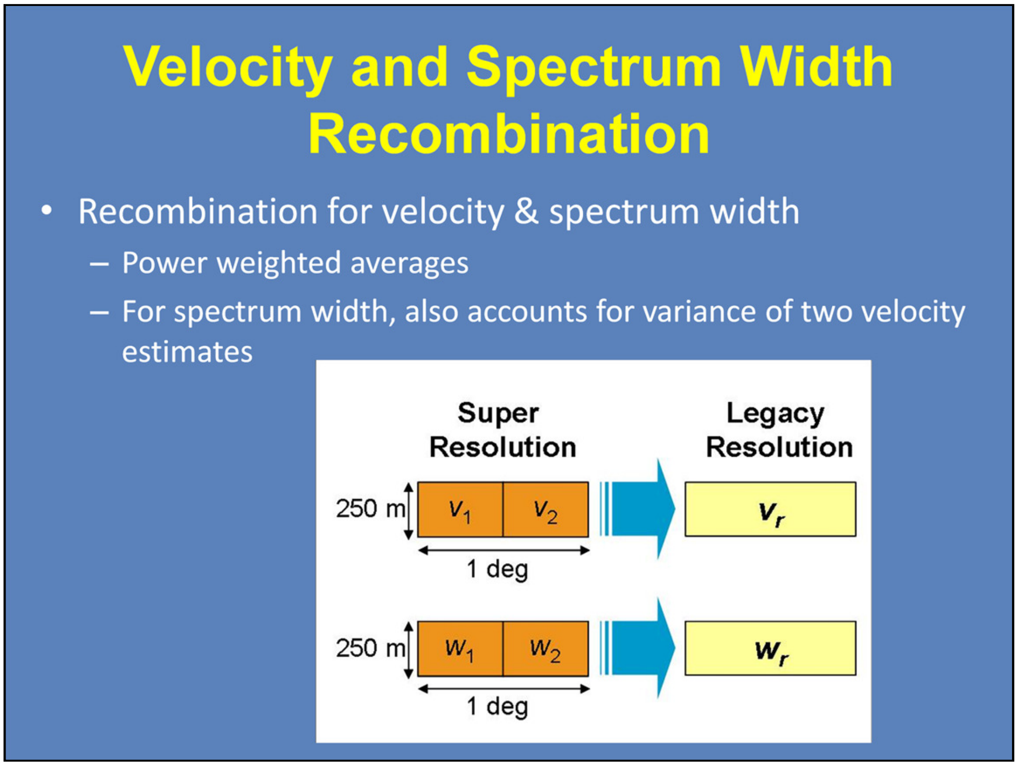
2. Many RPG algorithms (VIL, PPS, TDA,…) cannot ingest SR base data
   – MDA is an exception

Most of the RPG algorithms that rely on legacy base data cannot accept super resolution (0.5° azimuth) for input. Many also were designed for reflectivity base data with 1 km range resolution. Examples include the tornado detection algorithm, precipitation processing, vertically integrated liquid, and many others. One exception is the Mesocyclone Detection Algorithm (MDA). You will learn much more about the derived products later in this course.



This step is to support RPG algorithms that require 1.0° azimuth by 1 km range resolution for reflectivity input.

For reflectivity, the recombination process is a linear average of the 8 super resolution bins into the corresponding 1 legacy resolution bin. For bins that are assigned No Data, the associated power is estimated, converted to Z and included in the average.



This step is to support RPG algorithms that require 1.0° azimuth by .25 km range resolution for velocity and spectrum width input.

For velocity and spectrum width, the recombination process is a power weighted average of the 2 super resolution bins into the corresponding 1 legacy resolution bin. There is an additional step in the spectrum width processing to account for the variance of the two corresponding velocity values. If both bins are assigned No Data or RF, then the legacy bin is also assigned No Data or RF. If one of the two super resolution bins is assigned No Data or RF, then the remaining valid bin is assigned as the legacy resolution value.

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Welcome to Dual-Pol Base Data Preprocessing at the RPG

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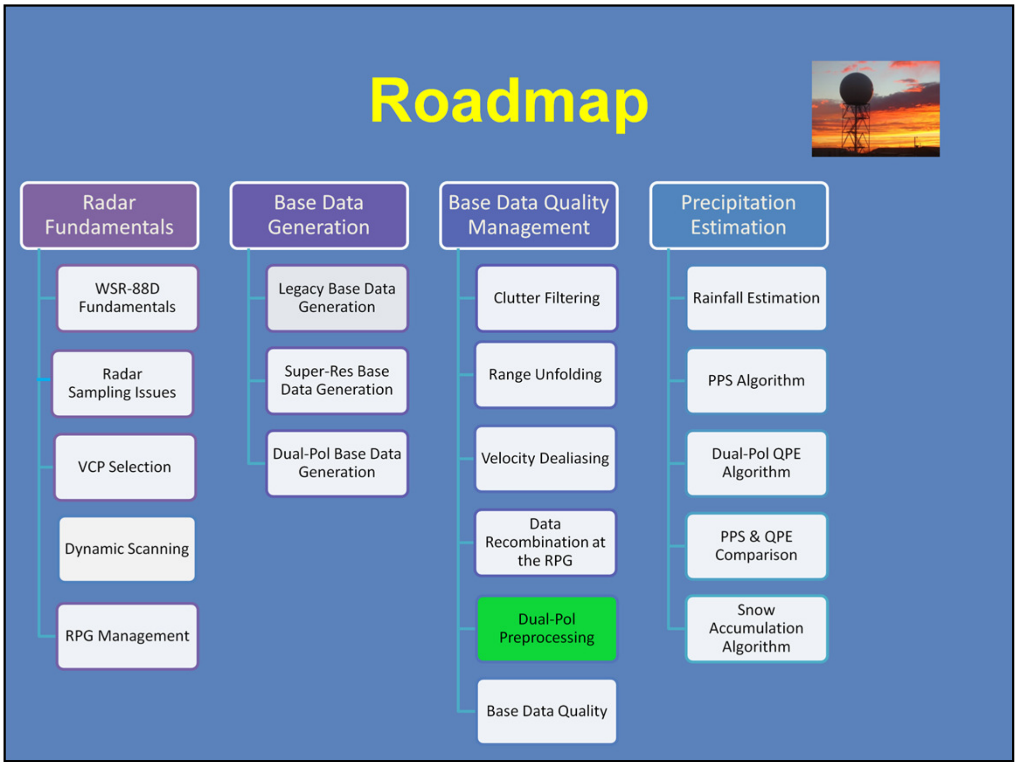

Here is the “roadmap” with your current location.

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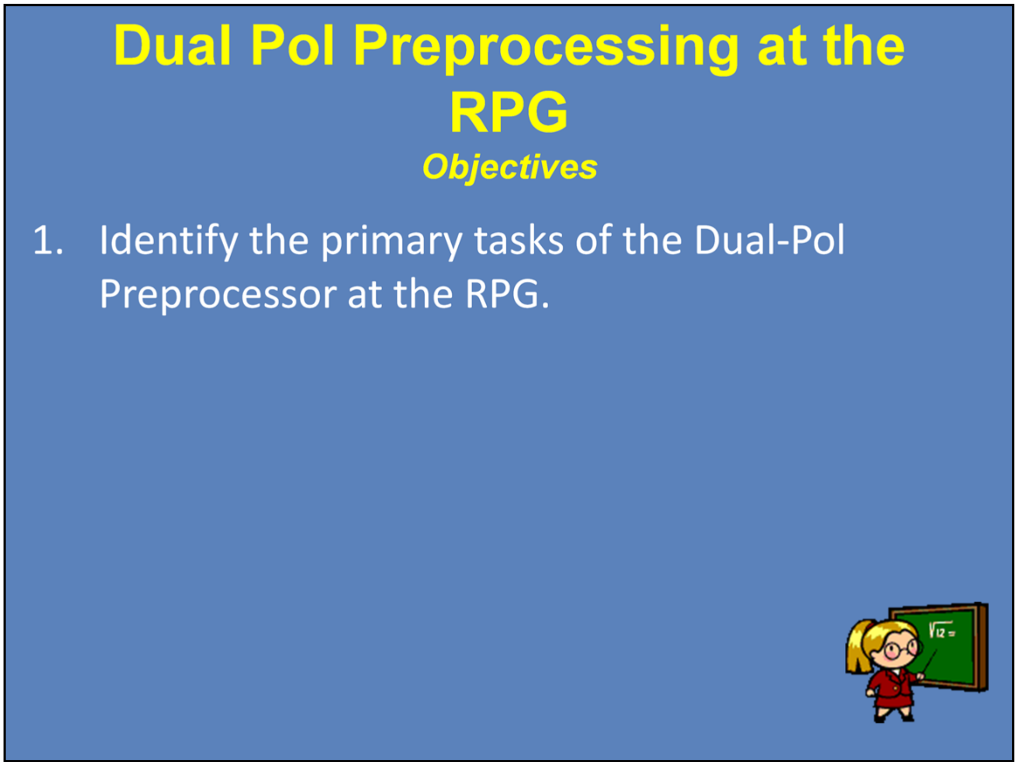
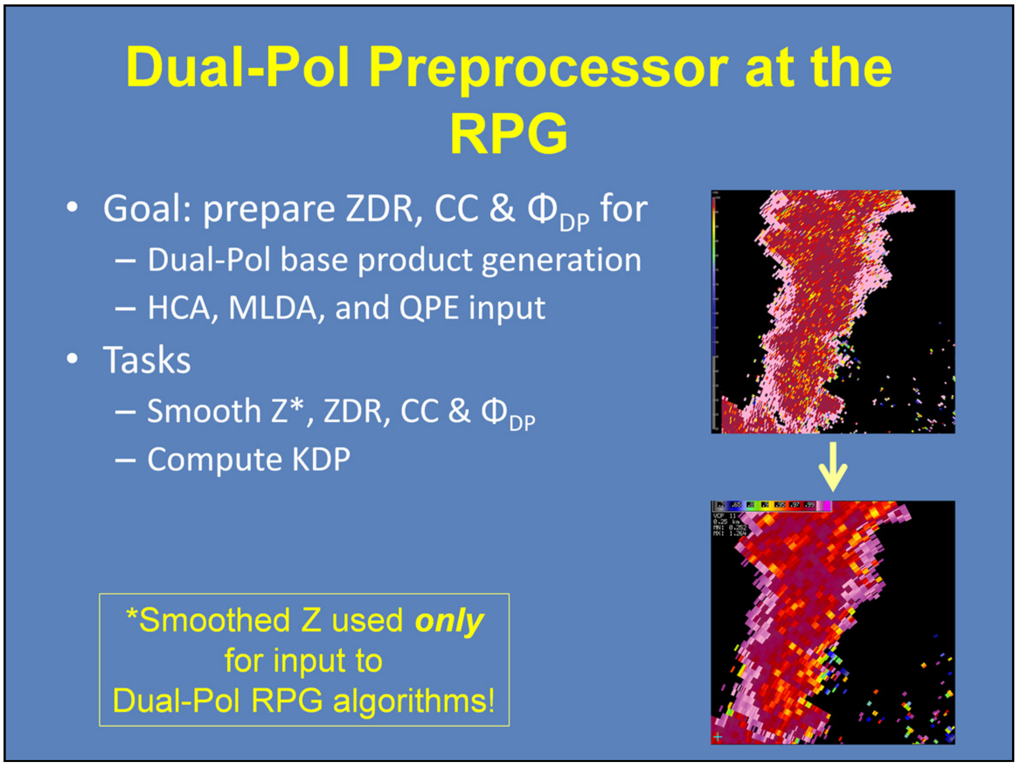


There is one objective for Dual Pol Preprocessing.



The RPG Dual-Pol Preprocessor is an RPG algorithm. It's purpose is to prepare the Dual-Pol base data for base product generation and for input into the RPG Dual-Pol algorithms: the Hydrometeor Classification Algorithm (HCA), the Melting Layer Detection Algorithm (MLDA), and the Quantitative Precipitation Estimation Algorithm (QPE).

The Dual-Pol base data sent from the RDA have a 0.5° azimuthal resolution, and are too noisy for human interpretation and algorithm input. For each range bin, the Dual-Pol base data are first recombined to 1.0° azimuth.

The Preprocessor smoothes Z, ZDR, CC & Φ_{DP} data along each radial. These smoothed Z data are only used for input to the Dual-Pol RPG algorithms. There is no change to the Z values used to generate all the reflectivity-based products that you are familiar with.

The remaining task for the Preprocessor is computing the Specific Differential Phase (KDP) value.

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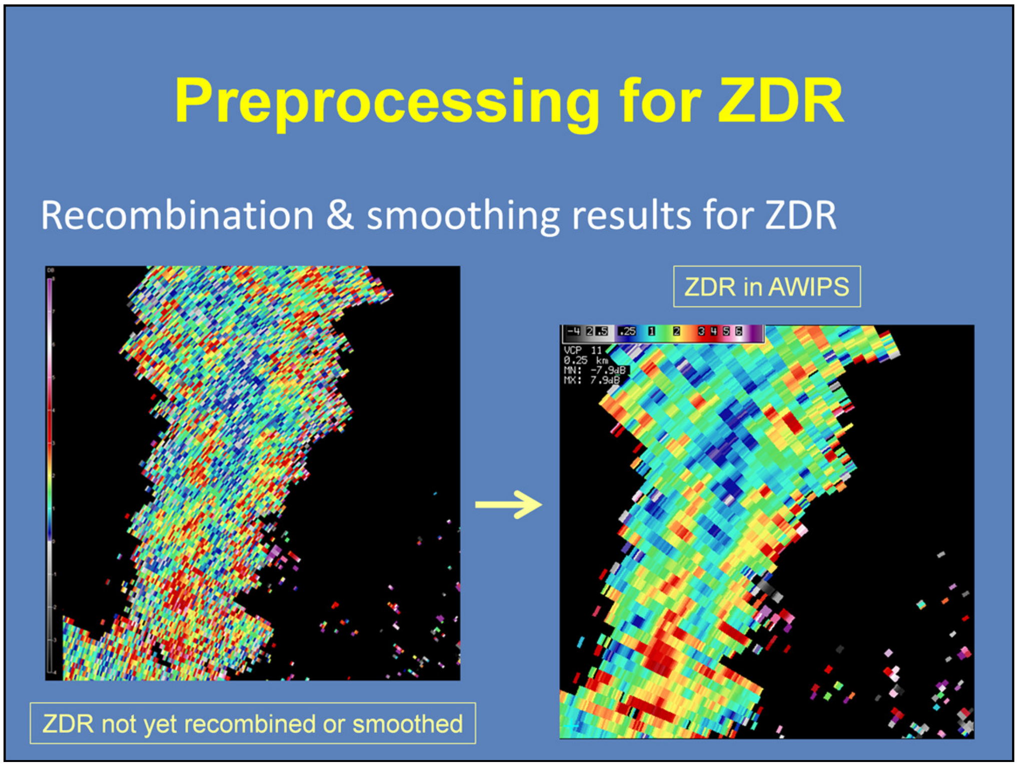

The example on the left is raw Differential Reflectivity, ZDR, from the RDA, at 0.5° azimuthal resolution and .25 km range resolution. It has not yet been recombined or smoothed. It is pretty noisy for even human interpretation. The image on the right is the same data displayed in AWIPS after recombination and Preprocessor smoothing. The Preprocessor smoothing technique applies a linear average to a segment (of varying length) of data along the radial. This average value is then assigned to the original range bin, which is at the center of the segment.

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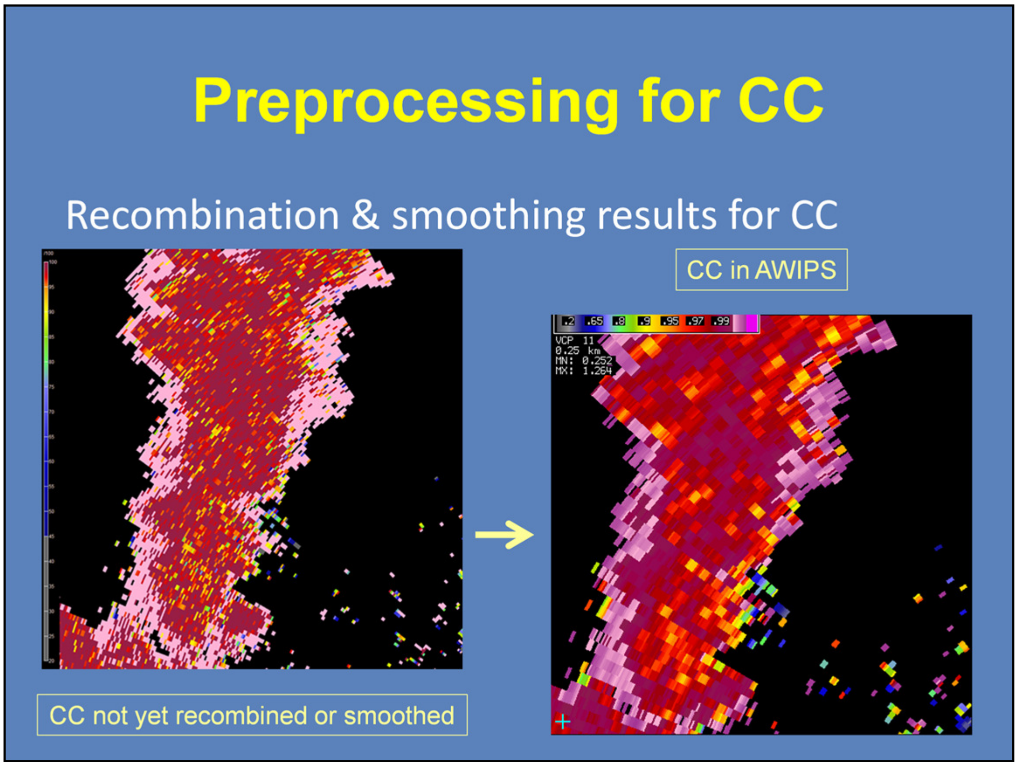
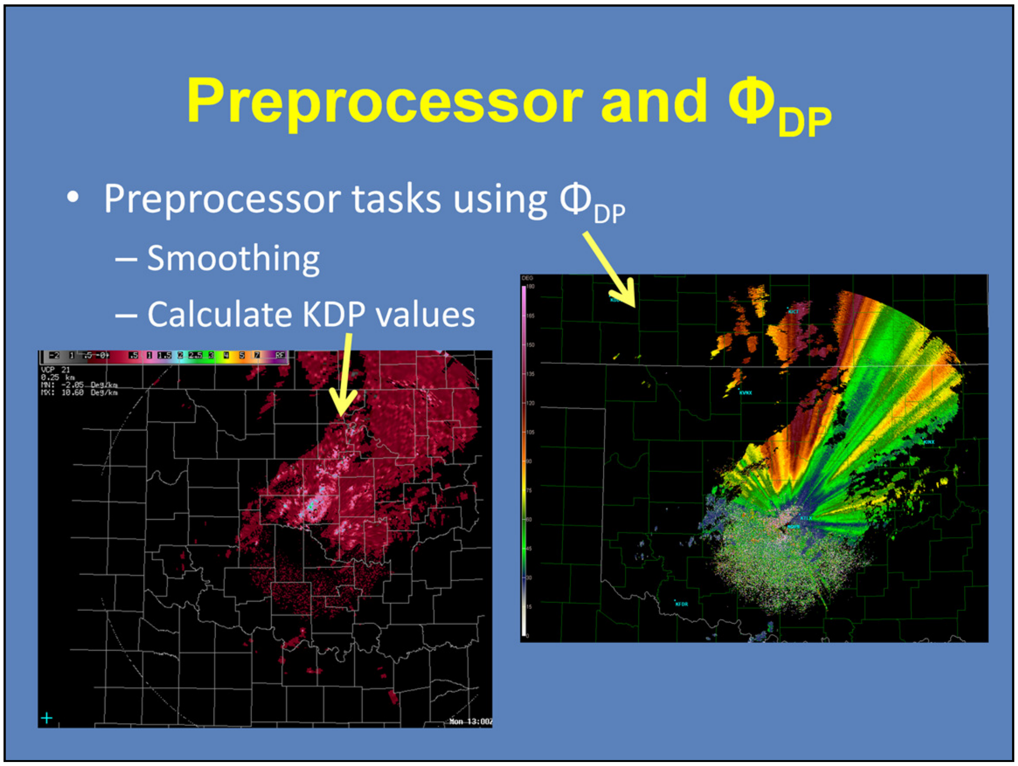


Here’s a similar comparison for Correlation Coefficient, CC. We have raw CC on the left and the recombined and smoothed CC that becomes a product in AWIPS on the right. As with ZDR, the Preprocessor smoothing technique applies a linear average to a segment (of varying length) of data along the radial. This average value is then assigned to the original range bin, which is at the center of the segment.



As with ZDR and CC, the Differential Phase, Φ_{DP}, base data are first recombined, then smoothed. On the right is an example of Φ_{DP} base data, not yet recombined or smoothed. This image is from GR Analyst, showing the raw Level II data.

Once the Φ_{DP} data have been smoothed, the Preprocessor then calculates Specific Differential Phase, or KDP. The KDP values are then available for generation of the KDP product (image on the left) and for input to the Dual-Pol algorithms.

These two images are a good example of why Φ_{DP} can be more difficult to interpret than KDP.

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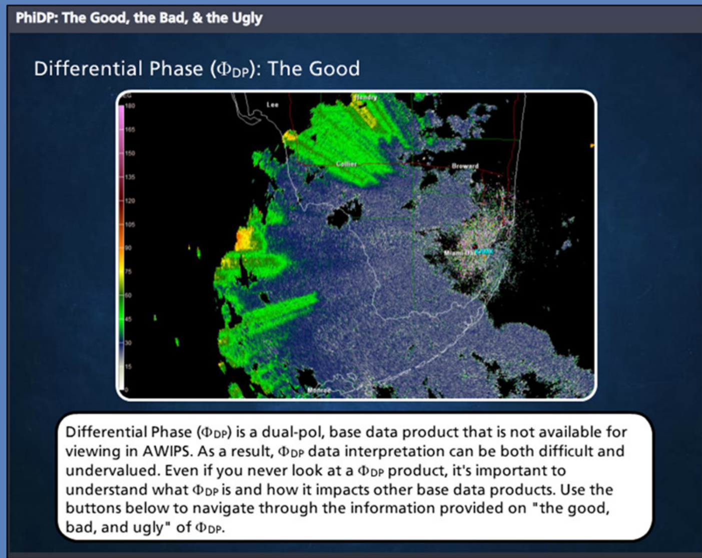
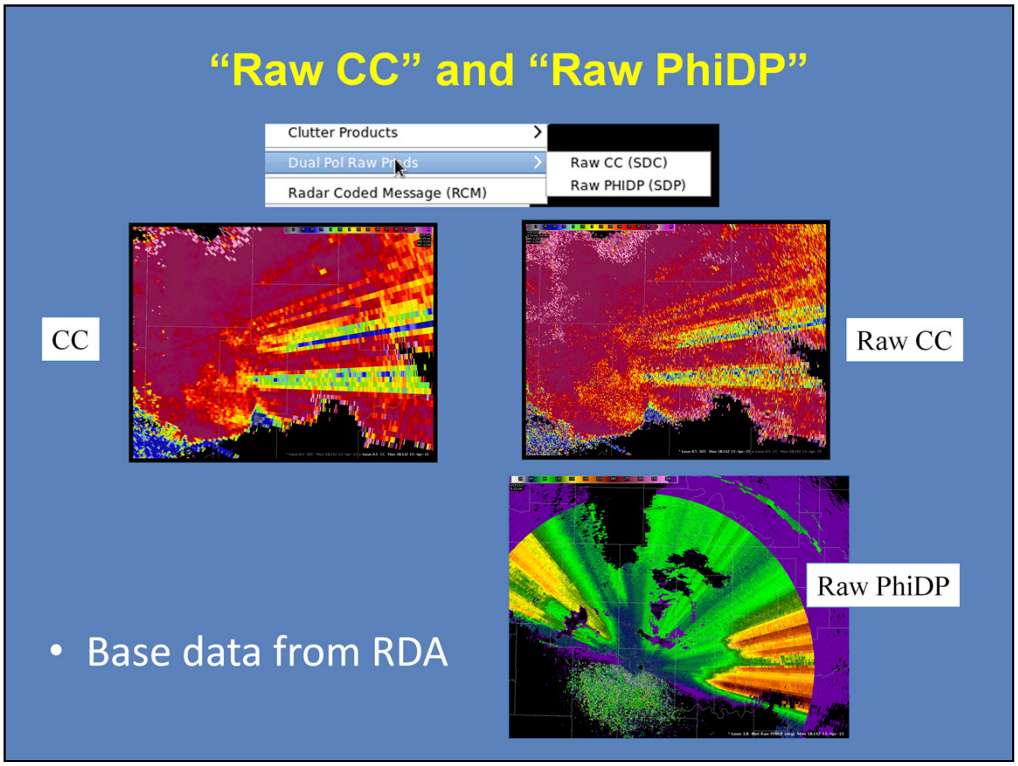
PhiDP: The Good, the Bad, and the Ugly



If no pop-up window appears that looks like the above, open a browser and go to:
http://www.wdtd.noaa.gov/courses/rac/principles/interactions/phidp-gbu/

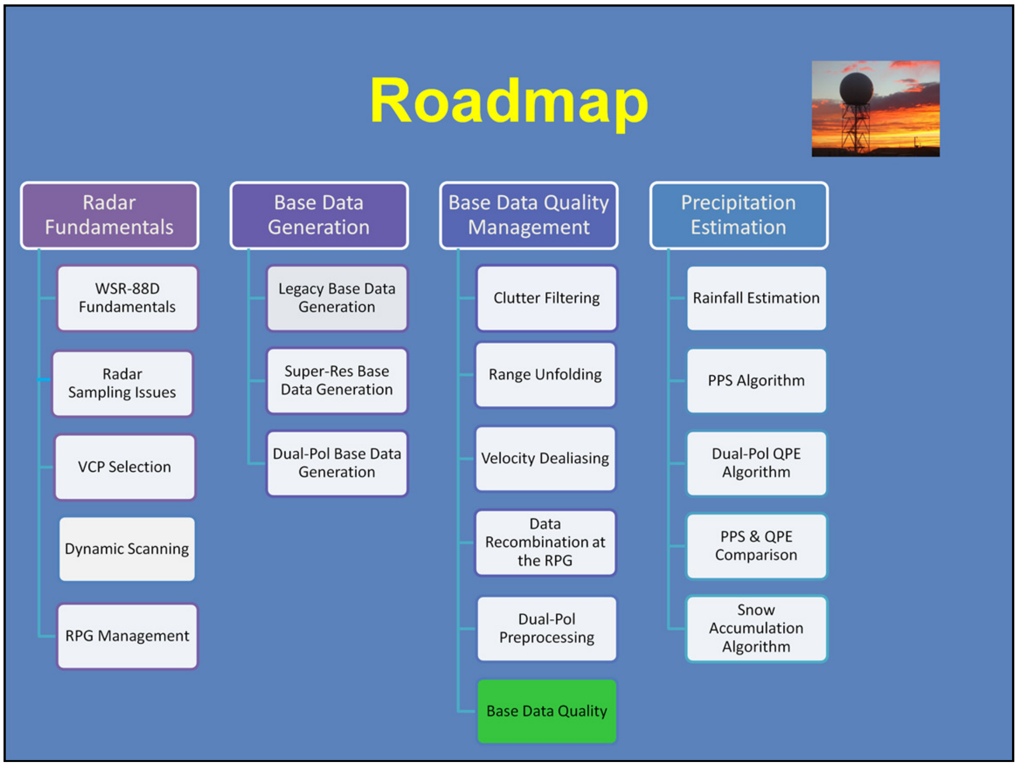


There are two dual pol products in AWIPS that ***not*** Preprocessed. They are both titled "Raw" to indicate that you are seeing ***only*** the base data sent from the RDA.

The Raw CC has higher azimuthal resolution (0.5º), however it is not a substitute for CC. The dual pol base data are noisier than the legacy base data, and the use of Raw CC is limited to (perhaps) earlier detection of a Tornadic Debris Signature (TDS).

The Raw PhiDP may be helpful for diagnosing dual pol base data quality issues. You will see both of these products described in the Products set of the course.

Welcome to WSR-88D Base Data Quality

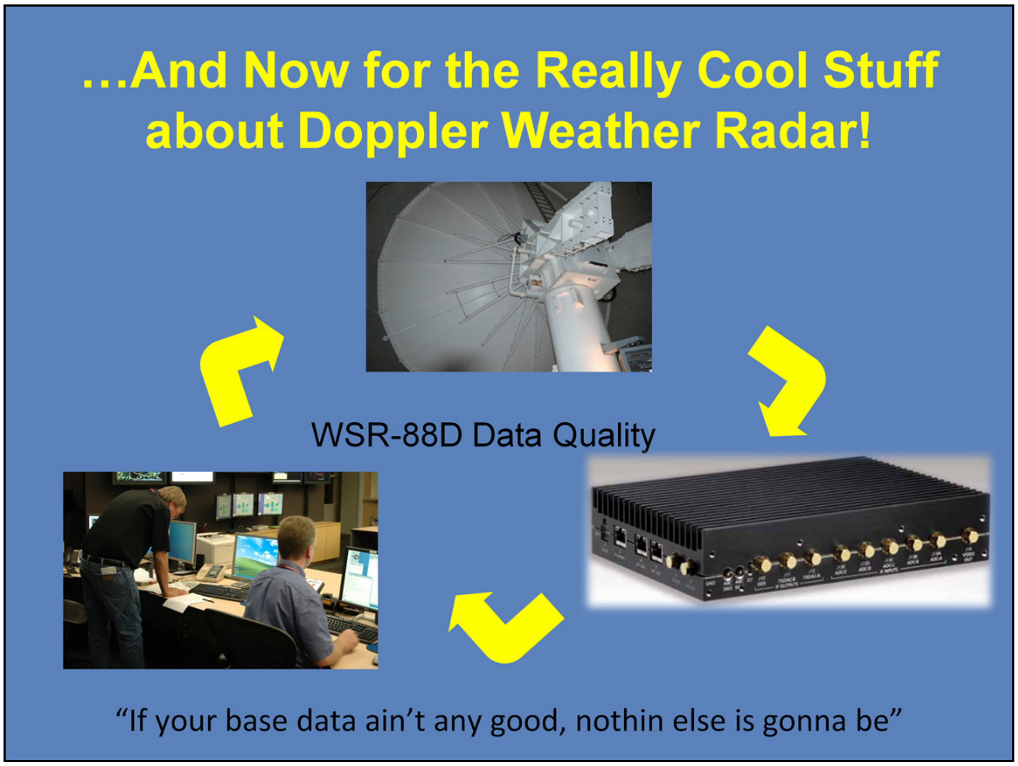


Here is the “roadmap” with your current location.

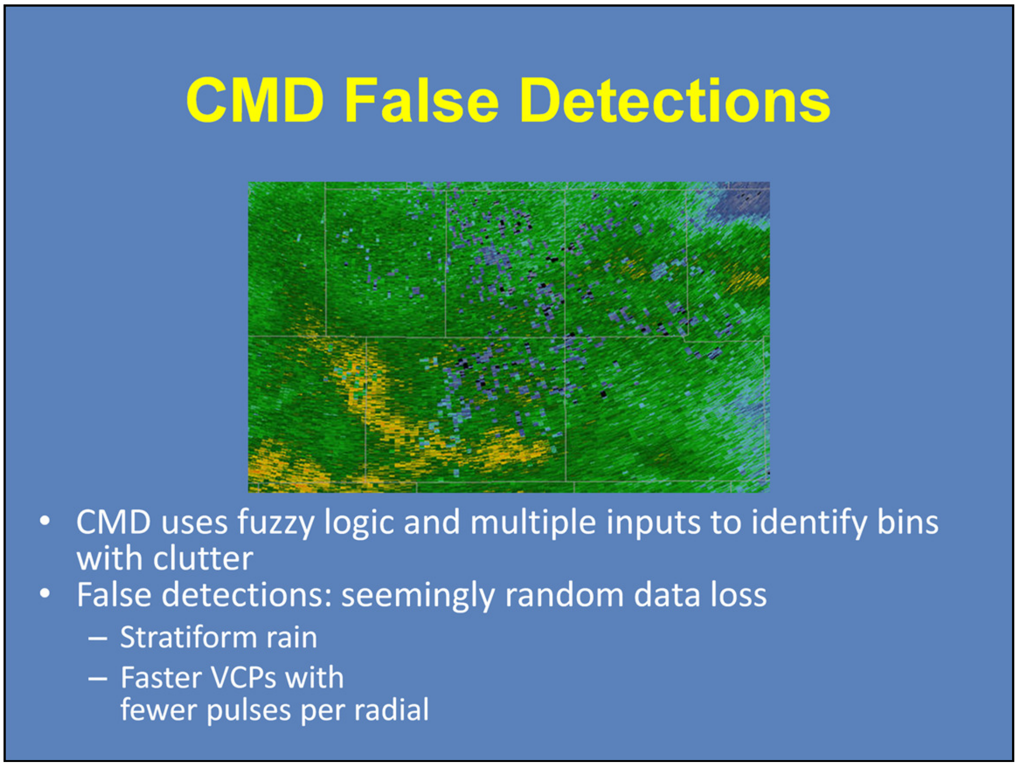
Objectives

1. Identify areas of CMD false detections, and the trade off that can contribute to these false detections
2. Identify the strengths and limitations of the VCPs that are designed to mitigate RF data
3. Identify the impact of differential attenuation, non-uniform beam filling, and depolarization on the Dual-Pol products
4. Identify the “trade offs” involved with producing high quality base data vs. meeting operational constraints

Here are the 4 objectives for WSR-88D Base Data Quality, which will be taught in sequence during this lesson.



This lesson brings together all the previous Radar Principles concepts, exploring how you can optimize your base data quality, as well as recognizing the trade offs between optimal base data vs. operational needs for fast updates.



CMD is a complex algorithm with multiple inputs, and performs best with strong returned signal and lots of pulses per radial. CMD performance is most challenged with weak stratiform precipitation, especially when one of the faster VCPs is also being used. With these conditions, CMD is more likely to falsely identify bins without clutter. These false detections can result in noisy data with sporadic gates of signal removed that are not clutter.

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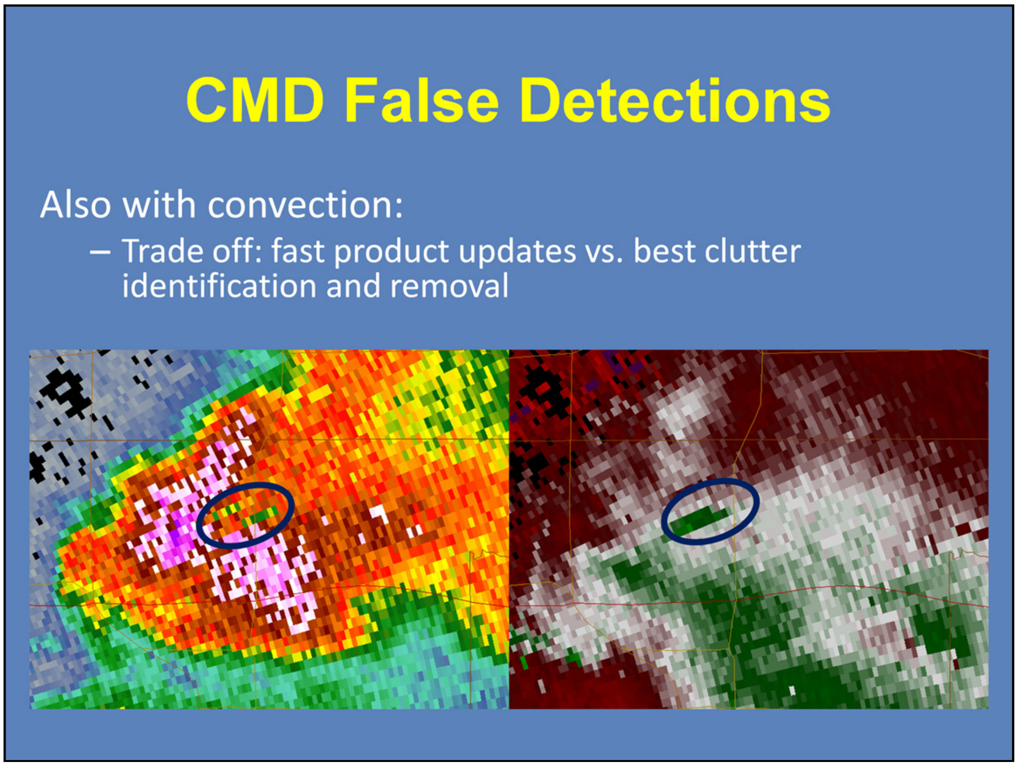
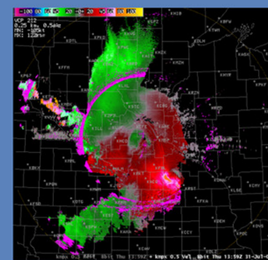


CMD false detections can even occur in or near convective storms. The result is seemingly random blocks of data loss that do not persist in space or time. The trade off at work here is the need for fast product updates with convective events, which means fewer pulses per radial, vs. the best performance of the clutter suppression algorithms: CMD for identification and GMAP for removal.

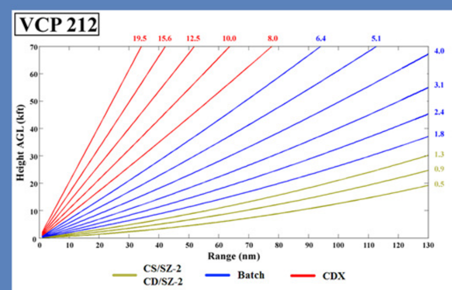
For severe convection, the need for VCP 12 or 212 overrides the need for perfect clutter suppression. For stratiform rain, VCP 21 is the better choice, providing more pulses per radial. Events between these two extremes are where the trade off can make the VCP decision tougher, though it is usually best to choose the VCP that is designed for the threat.

Range Folding Mitigation VCPs

- SZ-2 VCPs: 211, 212 & 221
  - Better velocity recovery Split Cuts
  - VCP 212 usually best for widespread severe convection



- VCP 212 limitations
  - Fast antenna rotations
  - Narrow band of RF

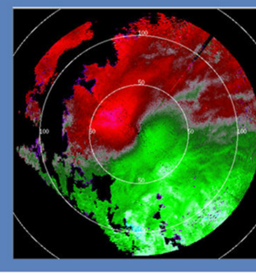


There is a class of VCPs that are designed to mitigate or minimize range folding in the velocity data. The first three in this group, VCPs 211, 212, and 221, share the fact that SZ-2 Range Unfolding is applied on the Split Cut elevations. The advantage of SZ-2 is much greater availability of velocity data, even with echo overlay conditions.

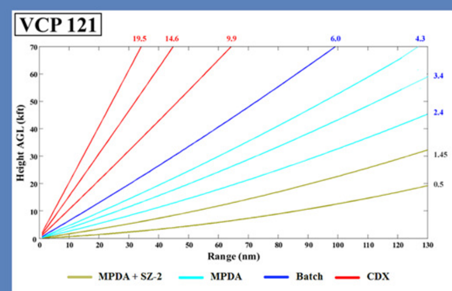
VCP 212 is the most frequently used VCP of this group, being a good choice for widespread severe convection. VCP 212 provides an update rate of about 4.5 minutes, with good vertical resolution, especially for the lower elevations. VCP 212 has fast antenna rotation rates, which can degrade data quality, especially when used for events other than severe convection.

Range Folding Mitigation VCPs

- VCP 121
  - Best velocity recovery Split Cuts
  - Offshore hurricanes

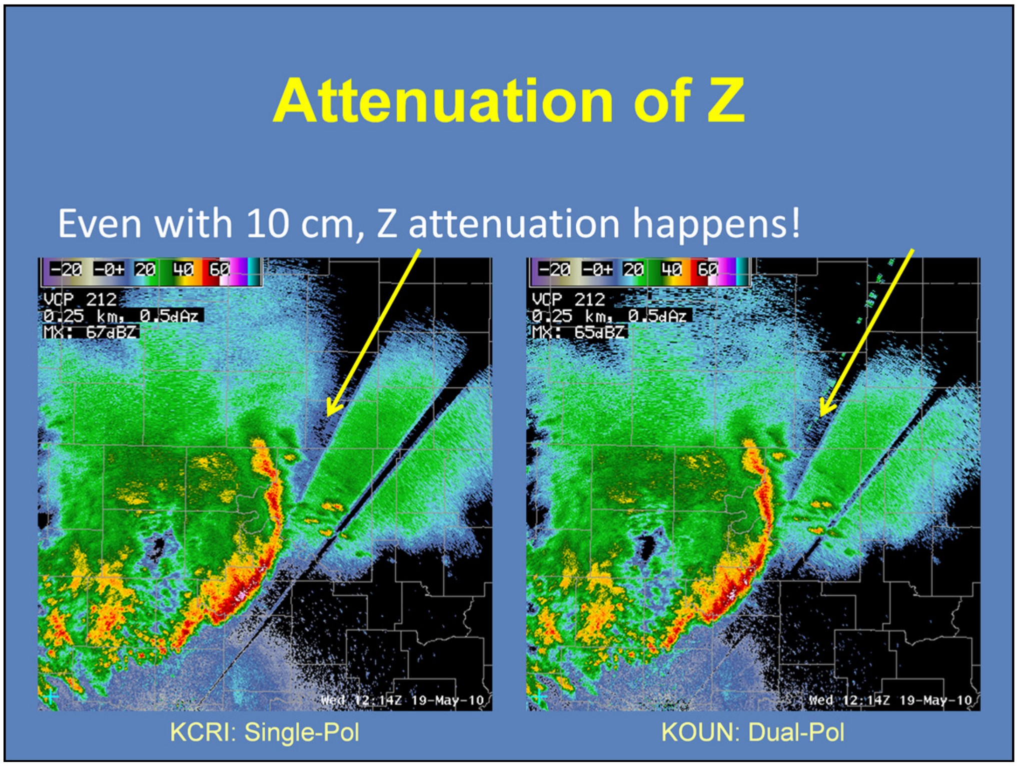


- VCP 121 limitations
  - Angles poor for storm interrogation
  - Update ~6 mins
  - Fast antenna rotations



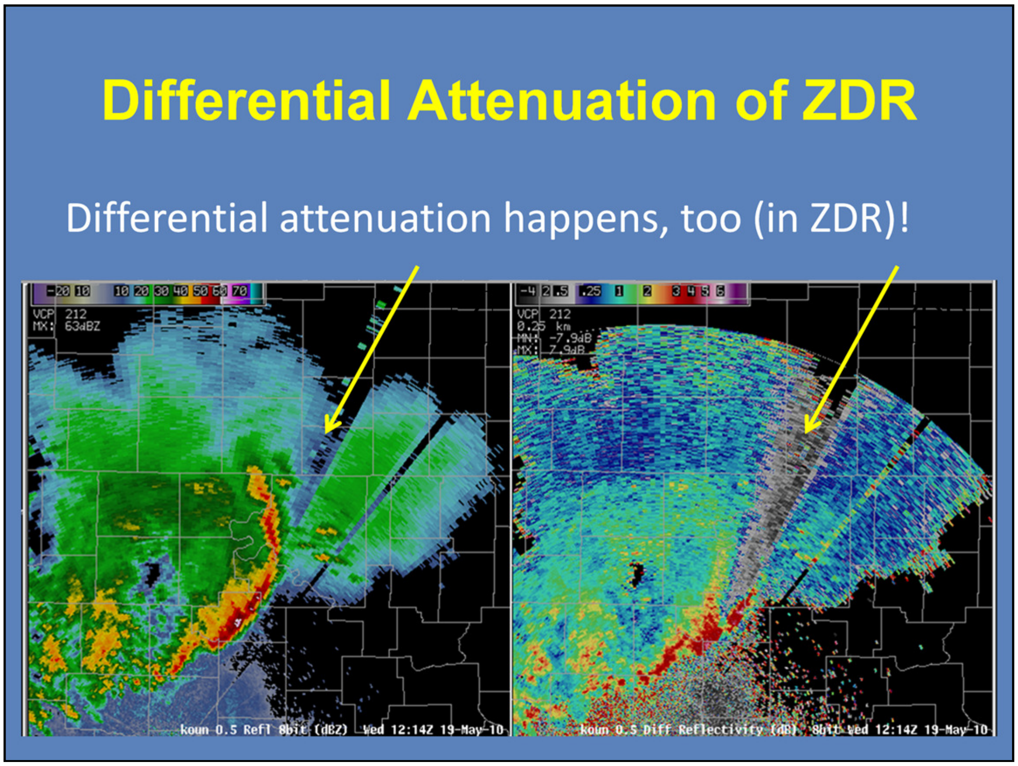
The other VCP in the group of range folding mitigation VCPs is 121. The primary benefit of VCP 121 is that for the lowest two elevations, nearly all the velocity data are recovered. VCP 121 is usually the best choice for offshore hurricanes or widespread non-severe convection.

VCP 121 is not a good choice for severe convection, with respect to both sampling and data quality. The elevation angles used by VCP 121 are not optimized for storm interrogation, especially at the lower levels. The update rate of almost 6 minutes is slow for severe convection. Since VCP 121 has multiple rotations at the same elevation, it has the fastest antenna rotation rates of any VCP, which can degrade data quality.



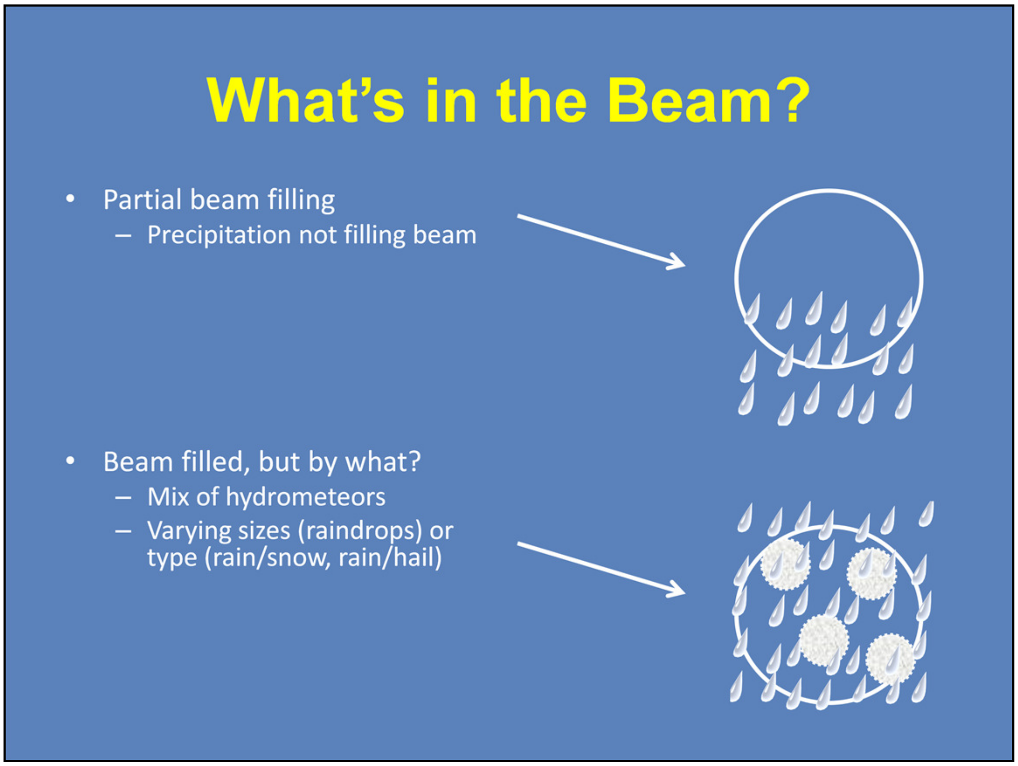
Attenuation of Z has always been with us, and will continue to be with Dual-Pol. We are very fortunate that the WSR-88D is a 10 cm radar, which attenuates much less than 5 cm radars. Of course, attenuation still happens and we need to take a look at how the Dual-Pol variables are impacted.

Here is a squall line sampled by two nearby WSR-88D radars, a Single Pol on the left and a Dual-Pol on the right. The squall line parallel is parallel to several radials and you can see the attenuation down radial in both of the Z products. Once the signal is attenuated, that loss cannot be recovered and propagates down radial.



With this same squall line case, there are very low ZDR values down radial (right image) that visually correlate with the Z attenuation. With ZDR, it is possible to have “differential attenuation”.

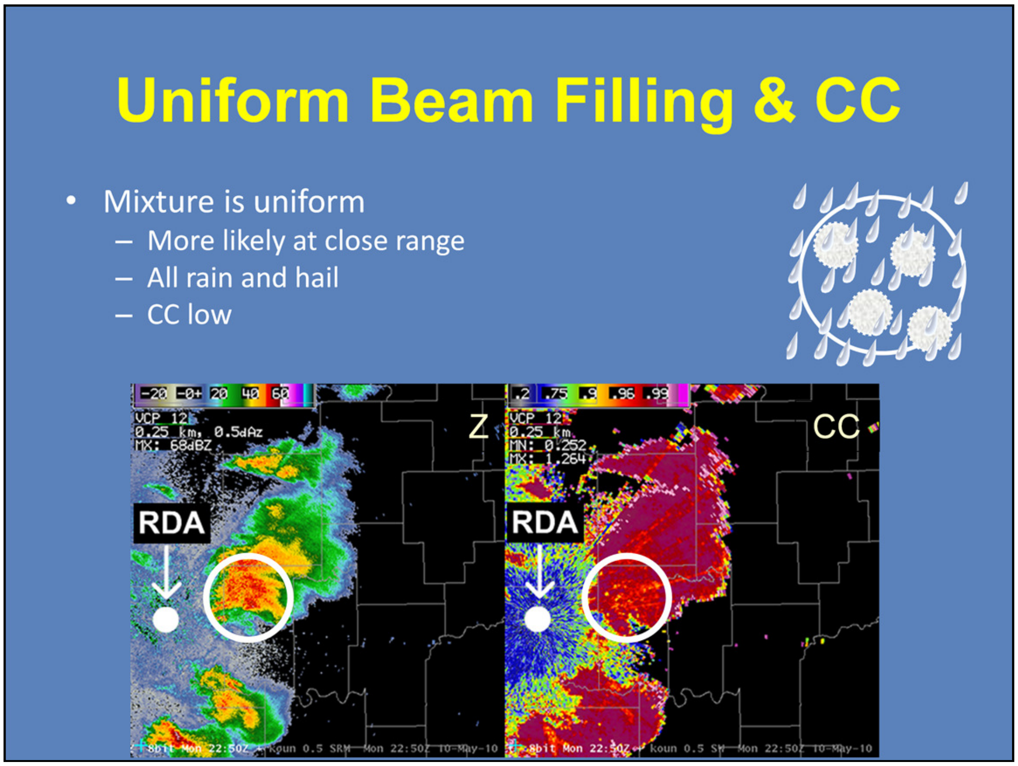
In this case, the beam encounters heavy rain with large drops. These large liquid drops results in more attenuation in the H direction compared to the V. With more signal loss in the H direction than the V direction, the ZDR is much lower that expected. For example, in areas where we know large to medium sized raindrops exist, large positive ZDR values are expected. Instead, ZDR values are generally negative, and extend down radial from the storm cores. Once the signal is attenuated, the loss in ZDR cannot be recovered and propagates down radial.



Non-uniform beam filling often occurs, and has always had implications with weather radar data quality, especially as range increases. However, the impacts have not been as apparent as it can sometimes be with Dual-Pol data. Even with Dual-Pol data, a specific type of non-uniform beam filling is required for the base data quality to be compromised. In these graphics the white circle represents the radar beam as if you were standing at the RDA looking outbound along a radial.

The top image represents partial beam filling, which is familiar, resulting in underestimated Z values.

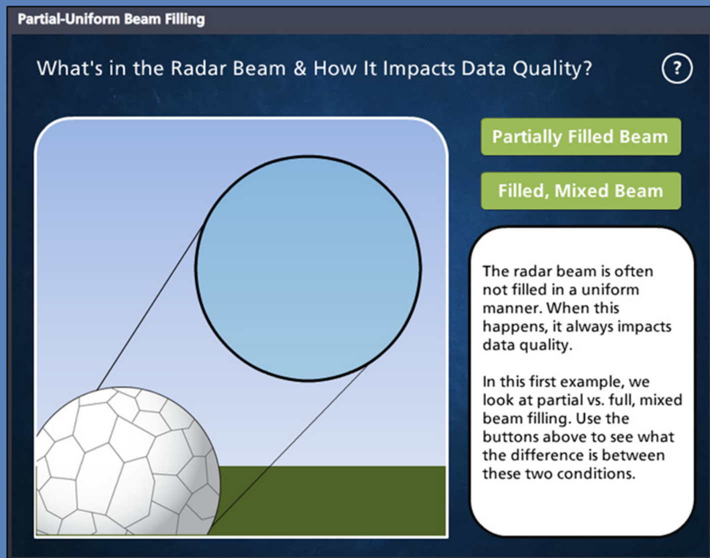
On the lower image, the beam is filled, but by a mix of precipitation sizes and types. The mix may be varying sizes of raindrops or hail stones or it could be varying precipitation types such as a rain/snow mix or a rain/hail mix. The nature of this mix and its distribution within the beam is relevant for Dual-Pol data quality.



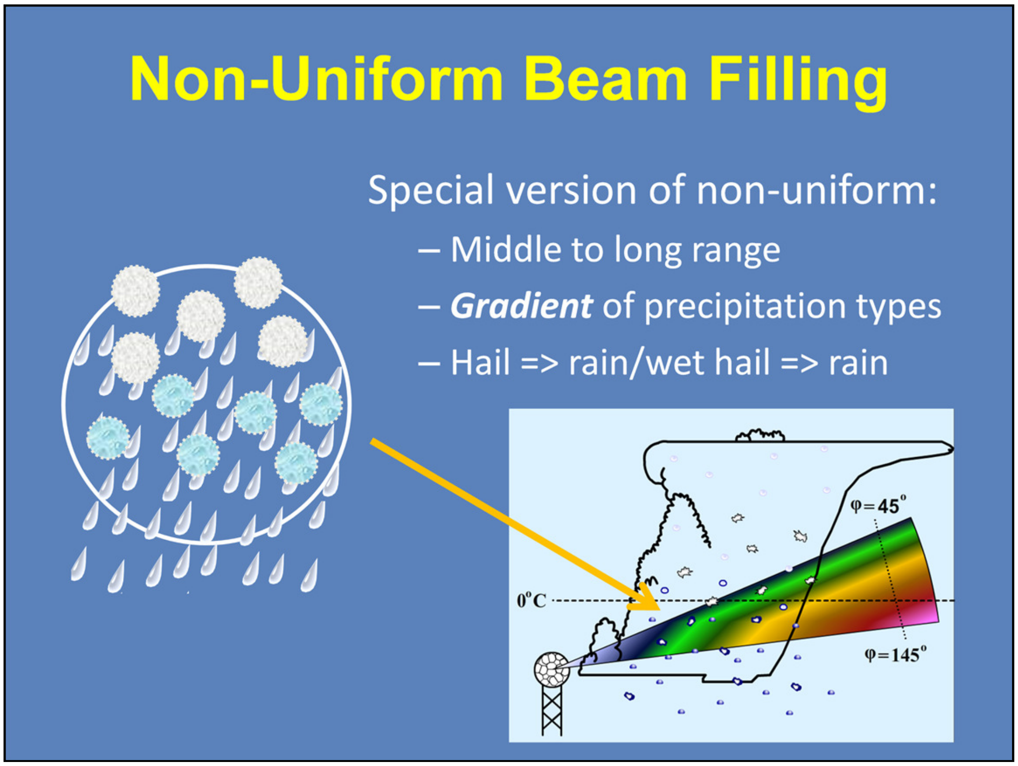
It turns out that Dual-Pol products are negatively impacted by what is called Non-Uniform Beam Filling (NBF), and there are examples coming up. Though non-uniform beam filling in the literal sense occurs frequently, we also use NBF to describe a specific type of signature on Dual-Pol products that results from a specific type of non-uniform beam filling.

In this image, there is a supercell close to the radar and the associated CC product is on the right. In the circled area, the radar is sampling a mixture of rain and hail. Note that the CC values are lower within the core areas of the storm. This is expected when the radar samples a mixture of rain and hail that is relatively uniformly distributed across the radar beam cross section.

Partial-Uniform Beam Filling



If no pop-up window appears that looks like the above, open a browser and go to: http://www.wdtd.noaa.gov/courses/rac/principles/interactions/partialbf/



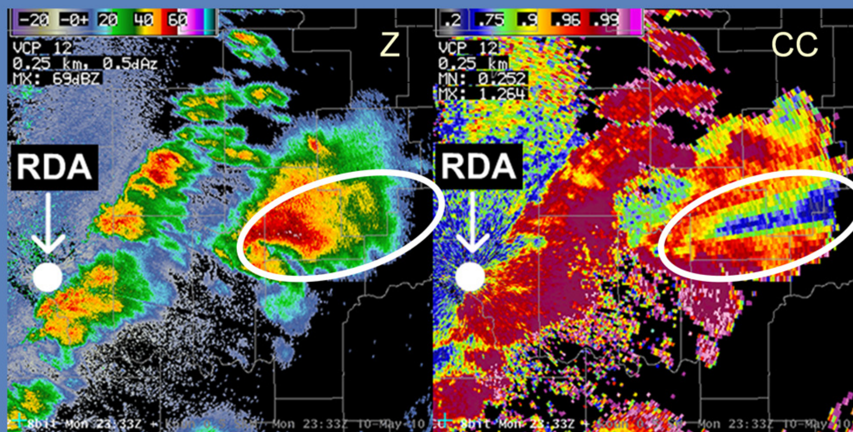
A non-uniform mixture can produce a gradient of precipitation types within the beam. This is more likely to occur at middle to long range. For example, the top of the beam may be sampling mostly hail, the middle sampling rain and wet hail, and the bottom of the beam sampling rain only. This gradient of precipitation types produces the version of non-uniform beam filling that is most likely to result in the Dual-Pol data artifact that we call Non-uniform Beam Filling (NBF).

Recall that Φ_{DP} contributes to both CC and KDP. With this gradient of precipitation type, this graphic represents the associated gradient of Φ_{DP} from the top to the bottom of the beam, if we had the vertical resolution to measure it. The gradient of precipitation types and the associated gradient of Φ_{DP} is the bottom line for low CC values locally and down radial.

Non-Uniform Beam Filling & CC

Supercell at longer range:

– CC low at storm core and down radial due to NBF



In the radar example, the supercell has moved to the east and is at a longer range, with the beam sampling a larger volume of the storm. There are radial swaths of low CC that originate from the storm core. This is an example of non-uniform beam filling and its impact on the CC product. This has impacts on other Dual-Pol products, with examples coming up.

By now you've probably seen a new window pop up with an animation of this event. You see Z and CC every other volume scan as the storm moves away from the radar. Once the storm is at a longer range, the non-uniform beam filling results in low CC values over a large wedge. This wedge persists even after the last frame of this loop. We know from the associated Z product that these low CC values do not make sense.

It is important to be aware of the potential for NBF on the CC products, because it has consequences for other Dual-Pol products.

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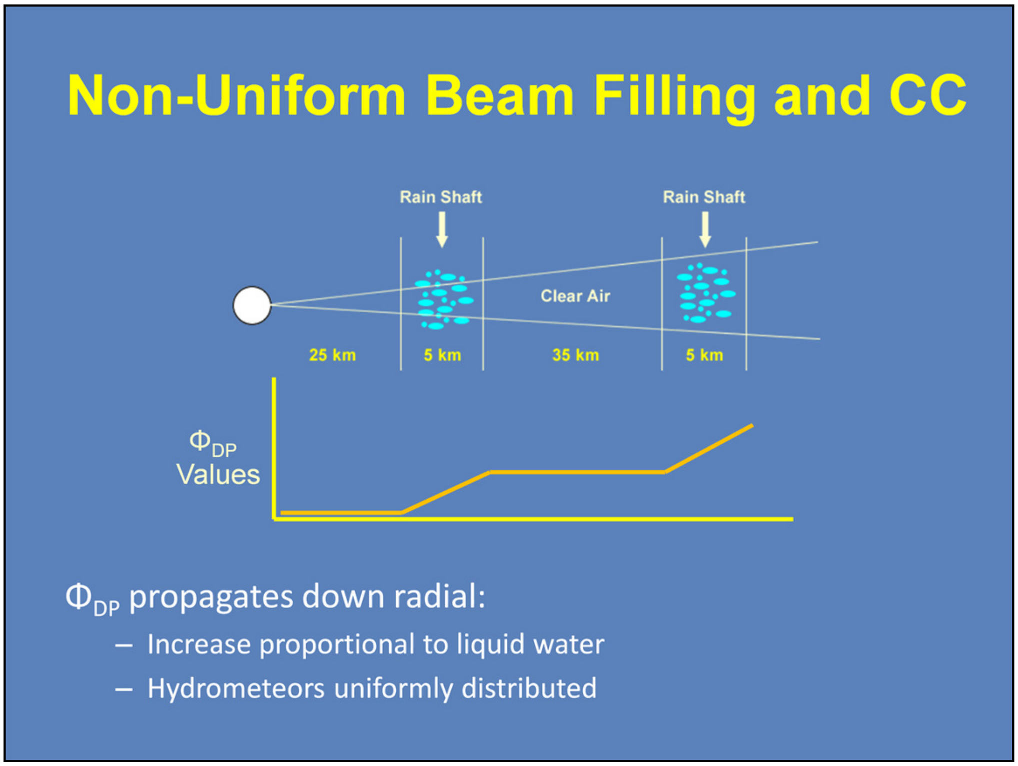
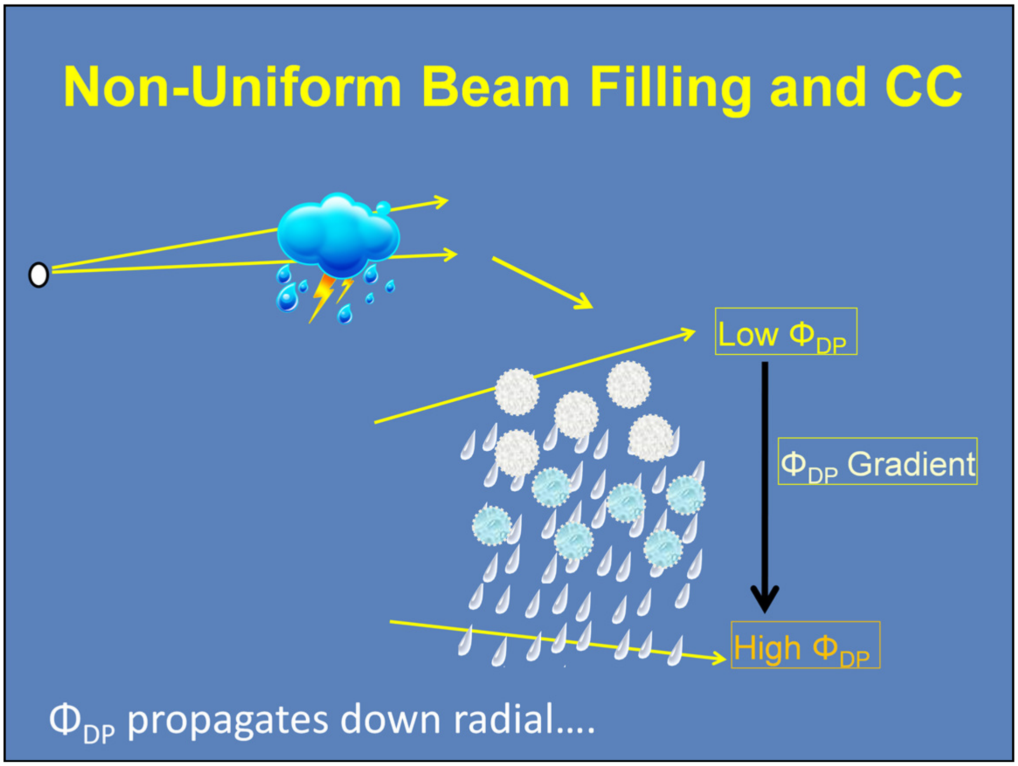
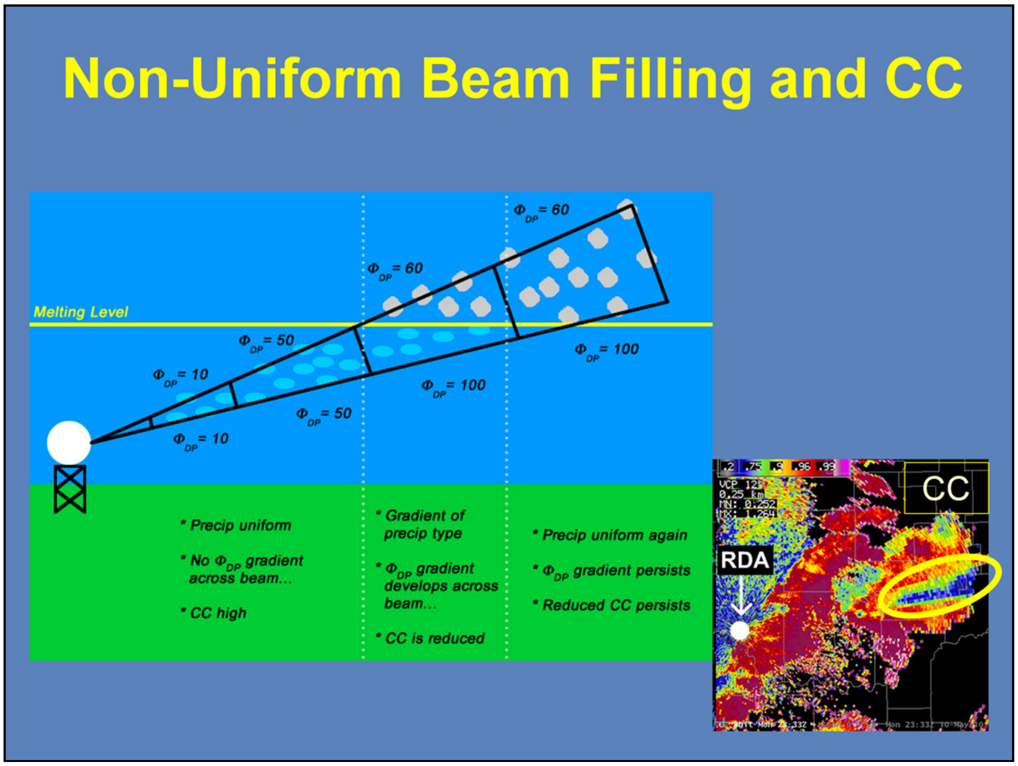


First recall that Φ_{DP} values propagate down radial. When the hydrometeors are uniformly distributed, life is good. Φ_{DP} increases down radial as the beam passes through areas of pure rain. Since Φ_{DP} does not reset, the values are cumulative down radial.



When sampling a convective storm at longer range or a squall line along a radial, there is an increasing chance of capturing a gradient of precipitation types within the beam. At the top can be hail and/or graupel, while the bottom of the beam is sampling liquid drops.

This matters with Dual-Pol base data because the Φ_{DP} values are significantly different for ice than for liquid water. This is because Φ_{DP} responds to the amount of liquid water content. Though we cannot measure it, there is a significant gradient of Φ_{DP} within the beam. Since Φ_{DP} propagates down radial, this gradient does not “reset” down the radial.

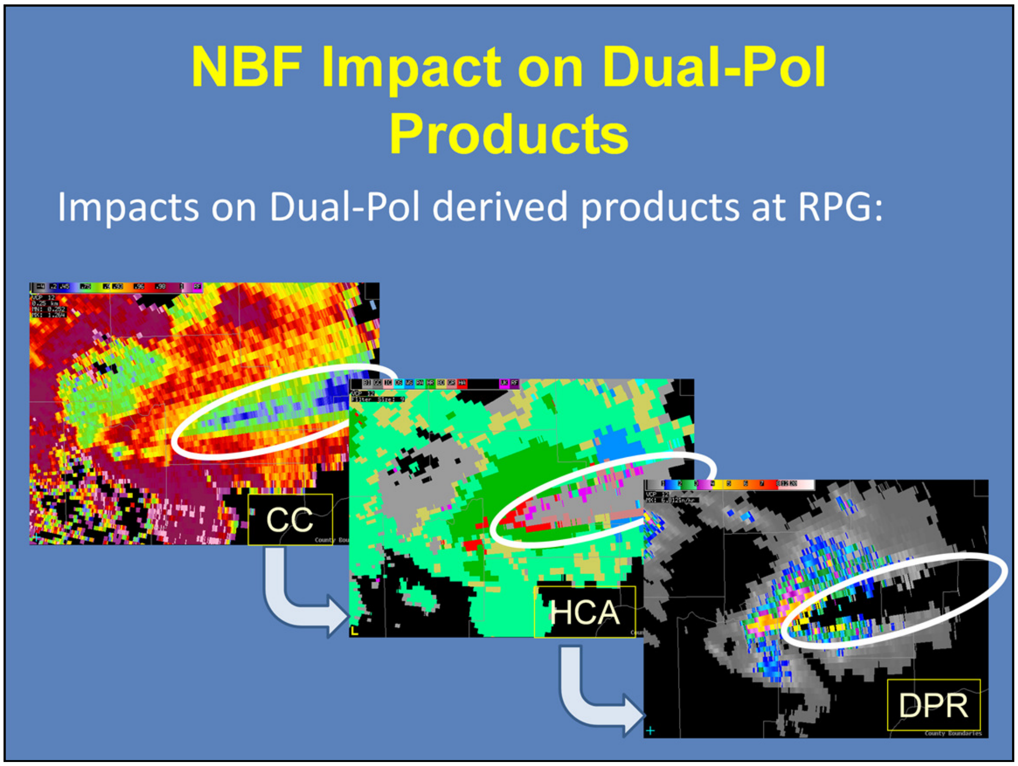


Here's a super simple example of what happens to the CC down radial with only four range bins. Note the Φ_{DP} values at the top of the beam and at the bottom of the beam for each of these bins.

The first two bins closest to the radar are sampling pure rain. Since the beam is uniformly filled, there is no Φ_{DP} gradient across the beam. CC values would be high for these bins.

The next bin encompasses the melting layer, with frozen hydrometeors at the top of the beam and liquid at the bottom of the beam. For this range bin, the CC value is low, there is a gradient of precipitation type across the beam, and thus a significant Φ_{DP} gradient across the beam.

Since Φ_{DP} does not reset down radial, this Φ_{DP} gradient will persist even as the beam is sampling uniform hydrometeors above the melting layer. This also means that the lowered CC will persist down radial.



The artifact of a swath of low CC values due to NBF can be either easy to spot or subtle. By comparing it to other radar data and understanding the environment, you can ask yourself if the CC values make sense.

It is important to be mindful of this artifact because of the potential impact on the RPG algorithms that use CC as input. For example, CC affects the Hydroclass value that gets assigned, which then affects whether or nor rainfall is accumulated.

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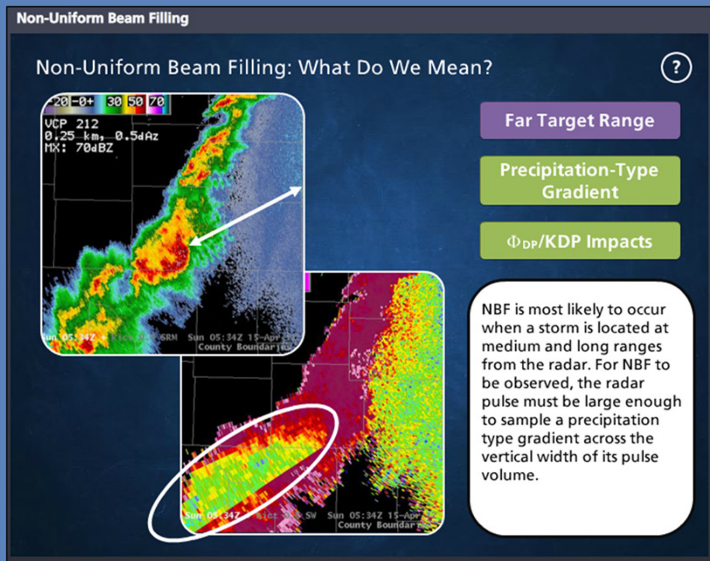
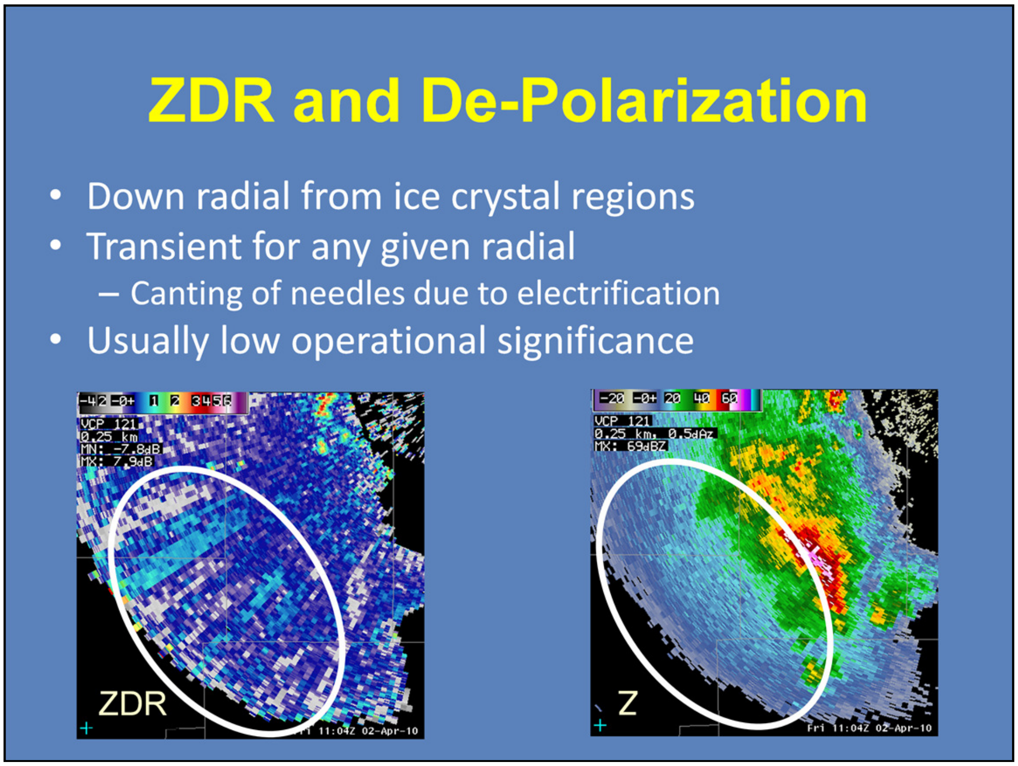
Non-Uniform Beam Filling



If no pop-up window appears that looks like the above, open a browser and go to:
http://www.wdtd.noaa.gov/courses/rac/principles/interactions/nbf/



Depolarization will sometimes be apparent on the ZDR product. Depolarization means that the reflected energy from a particle switches polarization, from horizontal to vertical, vertical to horizontal, are maybe both.

Depolarization only affects the ZDR product. It appears as radial spikes which are transient with time. Though it may rarely occur in hail, depolarization is far more likely to happen in the upper regions of thunderstorms when the electrification causes canting of the ice crystals. Since the electrification varies with time, so does the impact of depolarization.

Fortunately, regions that are down radial from thunderstorm tops are usually of low operational significance. Be aware that this is a known ZDR data artifact, and is not a cause for concern.

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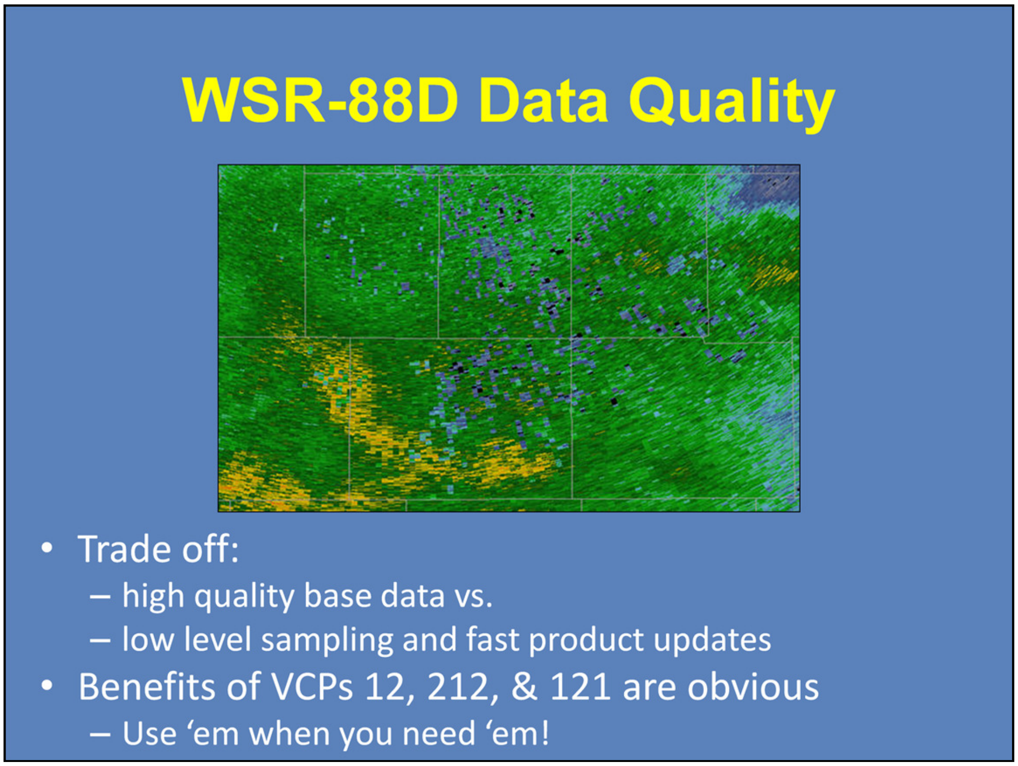
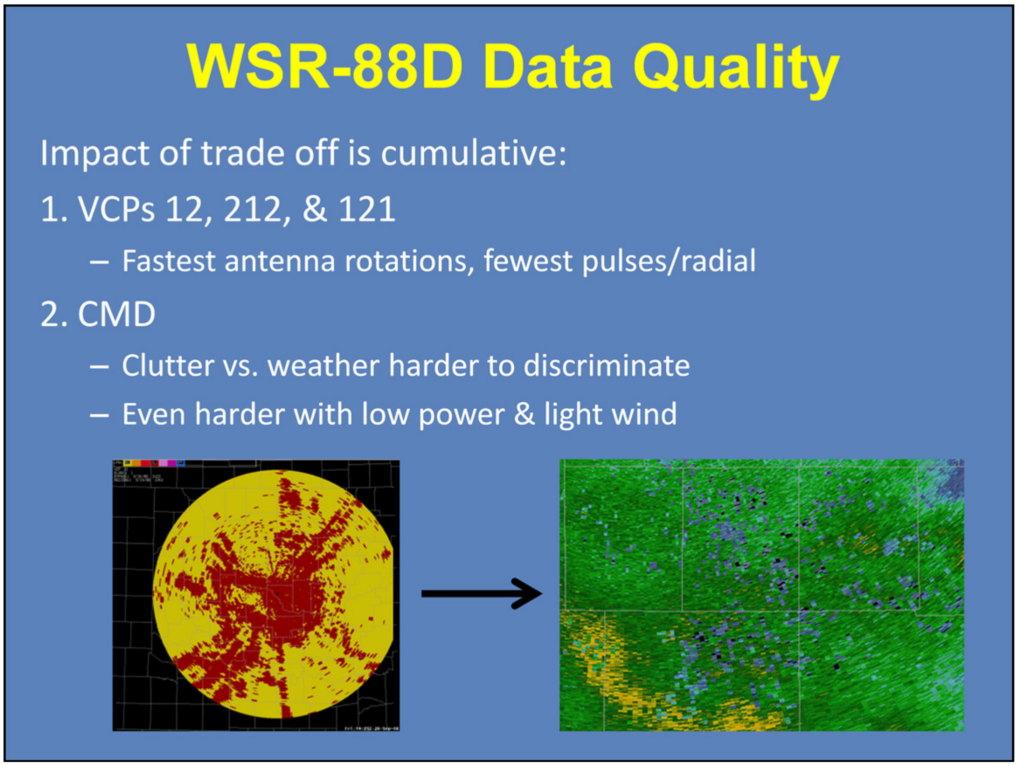


The WSR-88D is the most robust Dual-Pol Doppler radar fleet in the world. There is a big difference between the needs of operating a weather radar for research vs. operating one to meet the NWS mission.

There is an inherent trade off between having the best quality base data, and meeting operational goals such as fast product updates and sufficient vertical resolution of elevation angles, especially at the lower levels. Our fastest VCPs, in terms of antenna rotation rates, have very obvious benefits for sampling severe convection (12 and 212) or offshore hurricanes (121). Do not be reluctant to use these VCPs when it is appropriate, though the fast antenna rotation rates push the limit of base data quality.



The impact of this trade off is cumulative, and I focus on VCPs 12, 212, and 121, since they have the fastest antenna rotation rates and thus the fewest number of pulses per radial.

For this group of VCPs, CMD can be less effective at discriminating clutter from weather. CMD false detections are also typically higher in areas of lower returned power and light winds. For example, using VCP 12 or 212 for a stratiform rain event is likely to result in more CMD false detections than when using VCP 12 for severe convection.

In this example, VCP 12 is active with no severe convection, only stratiform rain. Notice the seemingly random distribution of gates with reduced power (or data missing entirely) throughout the image. CMD is one of the contributors, by falsely identifying bins that contain clutter.

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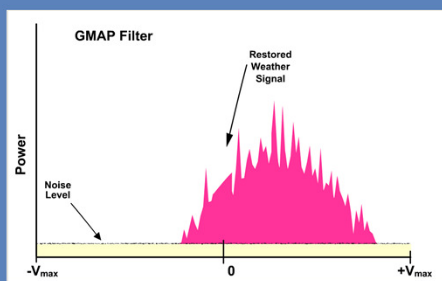
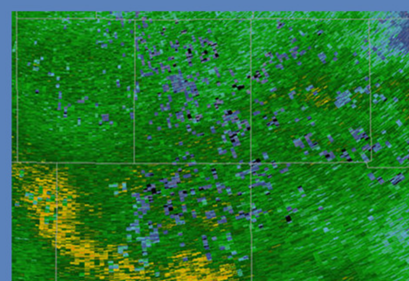
WSR-88D Data Quality

Impact of trade off is cumulative:

3. GMAP
   - Filtering applied only to bins identified by CMD
   - Less effective at rebuilding lost weather signal with fewer pulses
   - More bins with significant signal loss





Once CMD identify which bins need to have clutter suppression applied, GMAP does the actual signal removal. It first isolates the clutter signal near zero velocity, then removes power just from the notch, or interval, around zero velocity. One of the strengths of GMAP is its ability to rebuild a lost weather signal across the zero velocity “gap”. However, this rebuilding is dependent on having a sufficient number of pulses remaining after the clutter portion has been removed. For the faster VCPs, there are fewer pulses per radial to work with, increasing the chance that GMAP will not be able to rebuild the weather portion of the signal. The result on the products is that more of the bins identified by CMD have data loss because GMAP cannot rebuild the weather signal.

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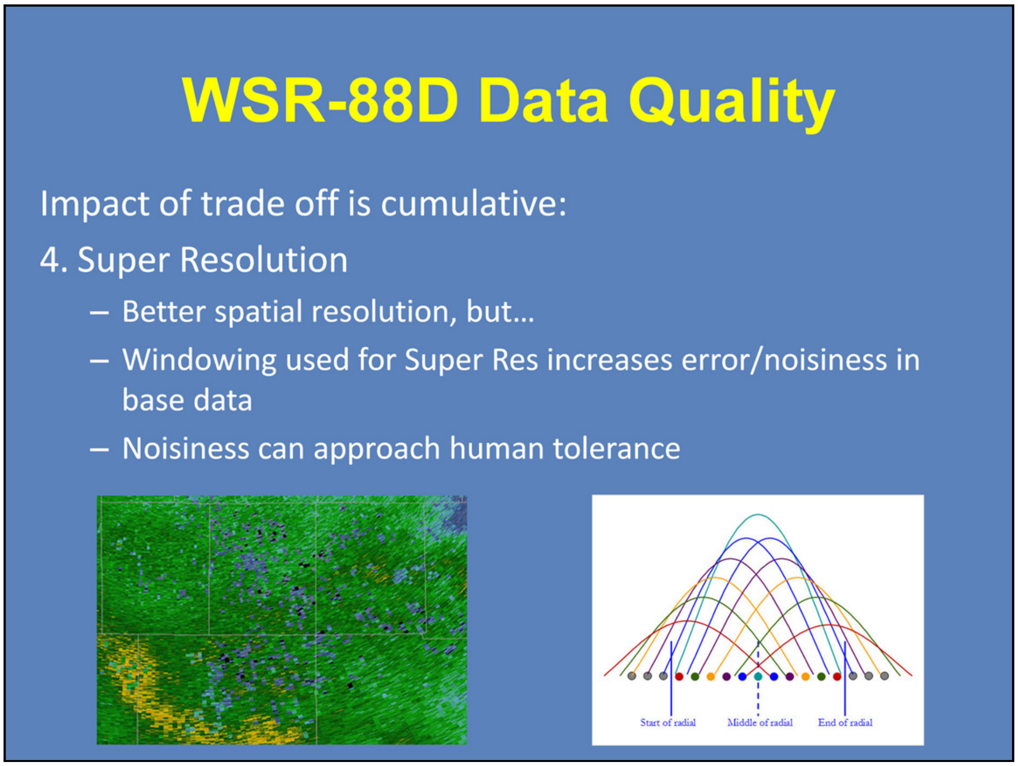
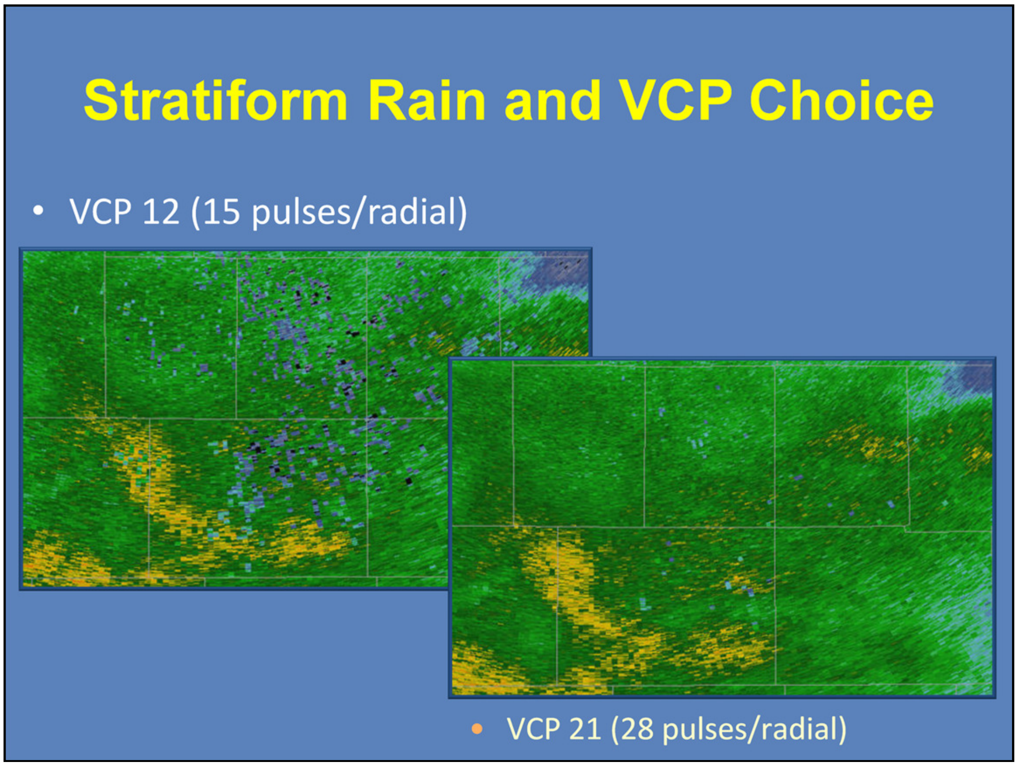


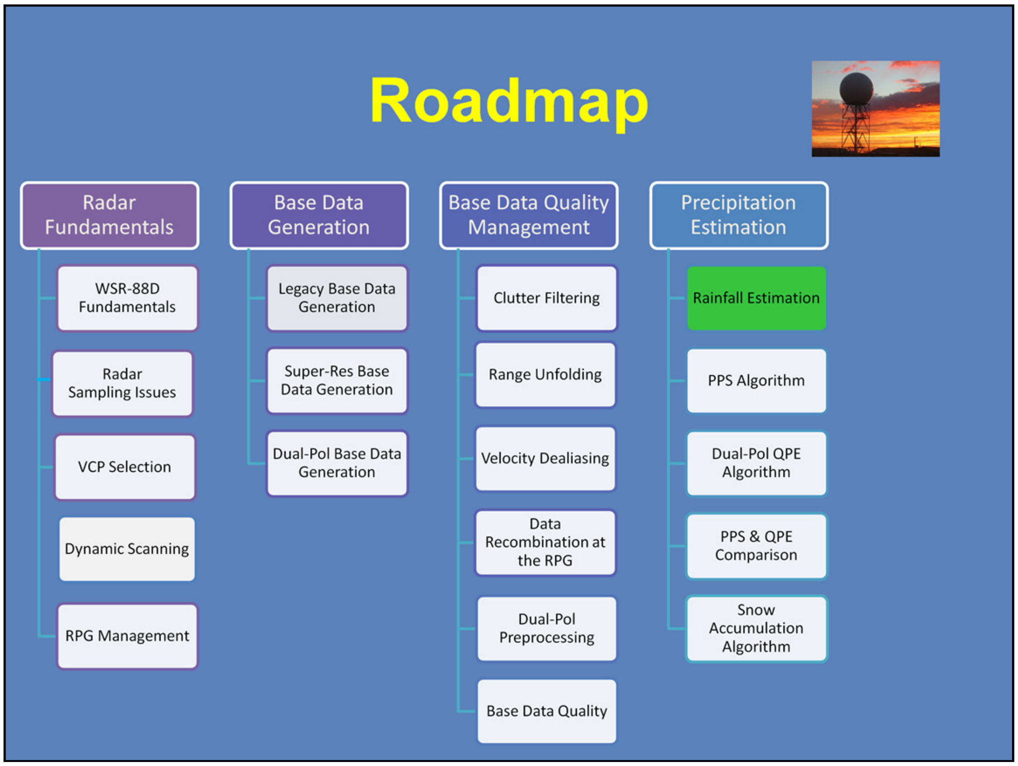
Super resolution processing is another trade off. The benefit of better spatial resolution is obvious, but super resolution processing includes a windowing technique that introduces some error in the base data estimate. The cost is an increase in noisiness in the base data. The fewer the pulses per radial, the greater this noisiness can be.



Now for the grand finale on the impact of this trade off between the need for high quality base data, along with fast product updates and low level sampling. This is a stratiform rain event, initially with VCP 12, which is the image on the left hand side. The staff noticed numerous gates of data loss over the rain area. These gates varied in space and time, but were numerous enough to cause concern. They decided to switch to VCP 21, which for the lowest elevation, has 28 pulses per radial. VCP 12 has 15 pulses per radial, almost half the number of VCP 21.

For severe convection, do not hesitate to use VCP 12 (or 212). That is what they are designed for, and the higher power returns will mitigate most of these errors. For stratiform rain, VCP 21 is recommended, as the larger number of pulses per radial will mitigate the errors due to weak signal plus light winds.

Welcome to Radar Rainfall Estimation Errors.



Here is the “roadmap” with your current location.

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Radar Rainfall Estimation Errors
Objectives

1. Identify the impact of the given potential error sources associated with using a radar to estimate rainfall.
2. Identify the available radar base data inputs for generating a rainfall rate, and their limitations.

There are two objectives for Radar Rainfall Estimation Errors.

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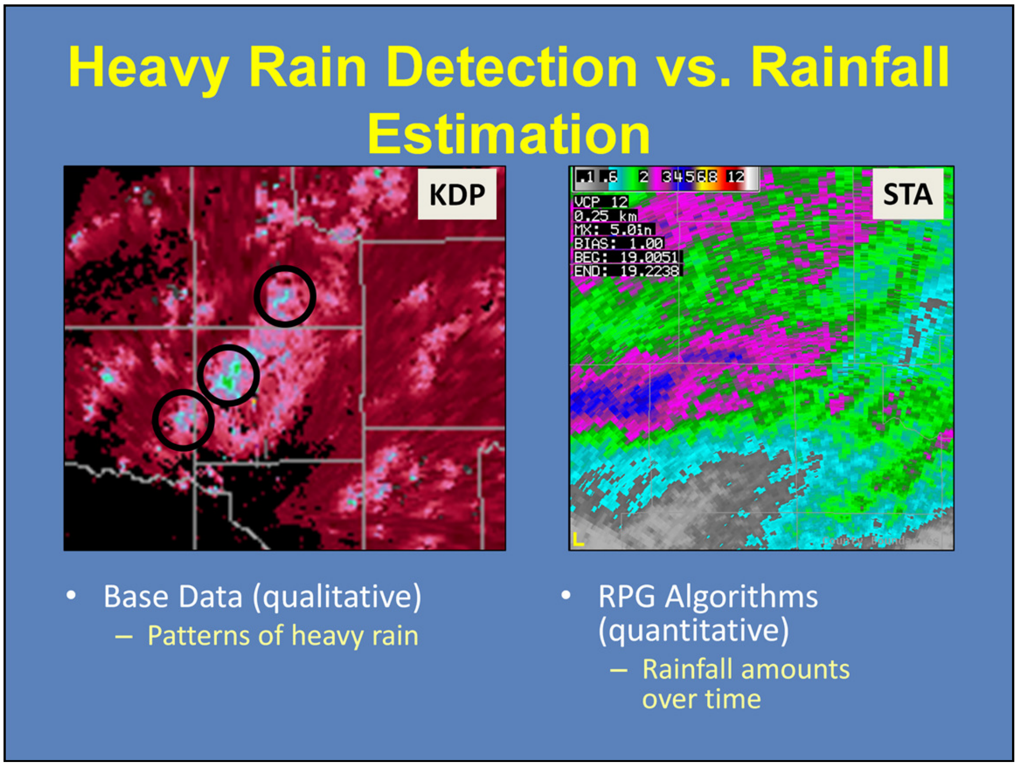

It's important to make a distinction between using the base products to identify areas of heavy rainfall vs. using the output from an RPG algorithm to estimate rainfall amounts.

Assume that we are looking at radar data that is below the melting layer where hydrometeors should be liquid. Among the available base products, Specific Differential Phase, KDP, is the best indicator of relative liquid water content. That means that observing KDP over time can identify areas that are most vulnerable to significant rainfall. Observing areal coverage patterns over time can reveal areas of potentially significant rainfall, growth and movement of precipitation, as well as linear vs. circular patterns.

On the other hand, using the output from the RPG algorithms to estimate rainfall amounts over specific durations first requires some situation awareness based on a thorough analysis of the base products. For example, do the locations of greatest rainfall make sense? Next, an understanding of the strengths and limitations of these algorithms is needed to use these products effectively.

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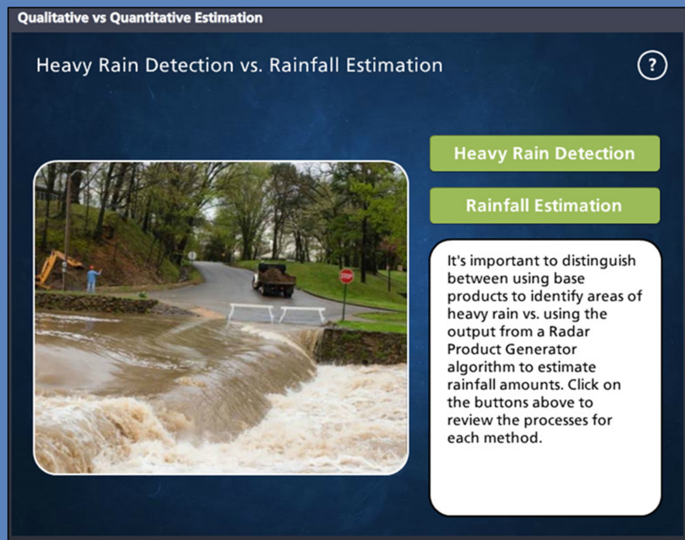
Qualitative vs Quantitative Estimation



If no pop-up window appears that looks like the above, open a browser and go to:
http://www.wdtd.noaa.gov/courses/rac/principles/interactions/qual-vs-quant/

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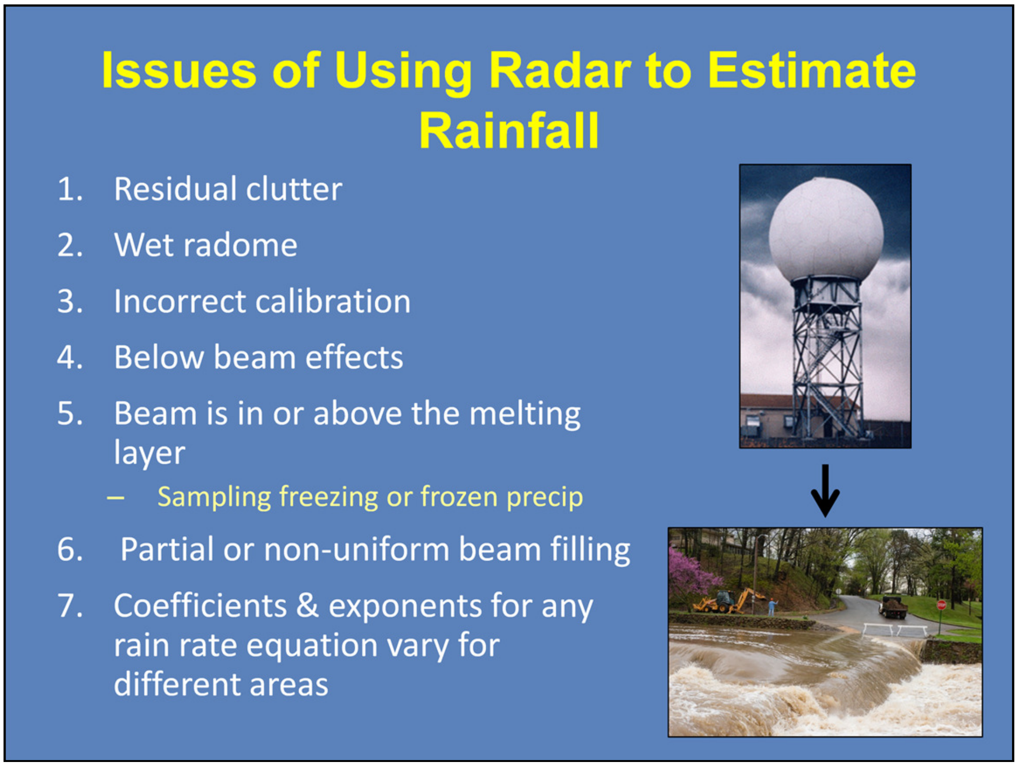

There are many issues that make using a radar to estimate rainfall amounts extraordinarily challenging, even before we discuss the algorithm design! Each of these items will be explored on the remaining slides.

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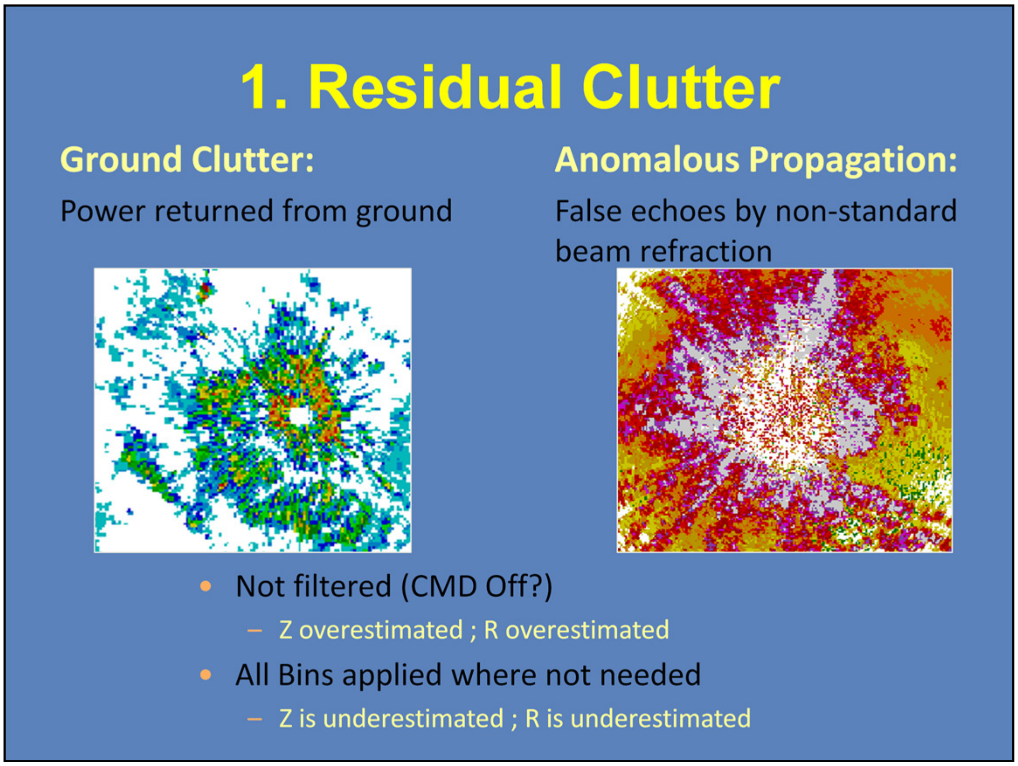
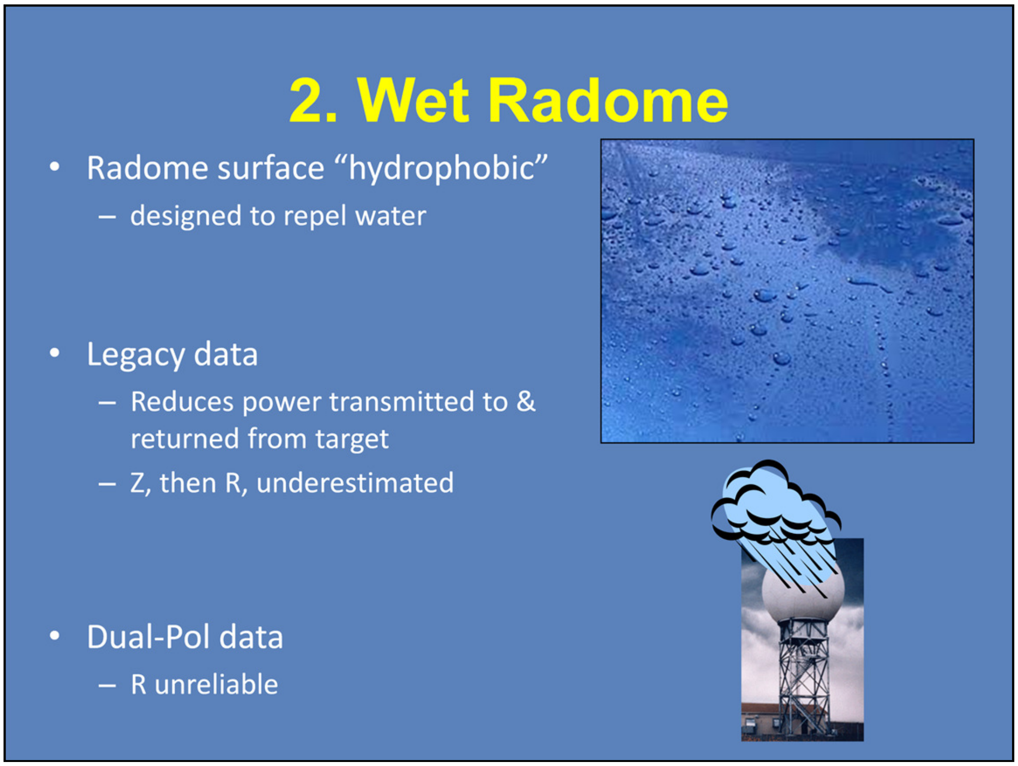


Residual Clutter describes unfiltered clutter, and can occur when clutter filtering has been turned off or when clutter remains after filtering is applied. Ground clutter indicates returns from certain ground based targets are always present, such as buildings and terrain. Technically, Anomalous Propagation (AP) clutter refers to any returns due to a superrefracting beam. AP often describes any clutter contamination that results when the beam is striking ground targets at varying ranges due to superrefraction. Unlike ground clutter, AP clutter is transient in space and time.

If no filtering is applied to either normal ground or AP clutter (CMD set to off?), Reflectivity values will be overestimated. Overestimated Z values will result in an overestimate of rainfall rate (R). Though the Dual-Pol RPG algorithms should better identify clutter and prevent it from being converted to rainfall, the potential for overestimation still exists.

It is also possible to apply clutter suppression where it is not needed through the use of All Bins suppression. Applying All Bins suppression can result in underestimated Reflectivity values, that then result in an underestimate of rain rate. The data quality impact of applying All Bins suppression unnecessarily to the Dual-Pol base data has the potential to negatively impact the quality of the dual-pol rainfall estimates.



A wet radome can cause multiple issues with base data. The radome surfaces are designed to be “hydrophobic”, repelling water like wax on a car, in order to prevent water coating the surface. It still happens, of course, but the condition is usually transient.

A water coating on the radome reduces the amount of transmitted power. For the legacy base data (i.e., the horizontal channel), the reduction in transmitted power results in a reduction in returned power, which leads to an underestimate of both reflectivity and rain rate. For the dual-pol data, which is based on both horizontal and vertical channels, the impact of a wet radome on R can be either underestimated or overestimated.

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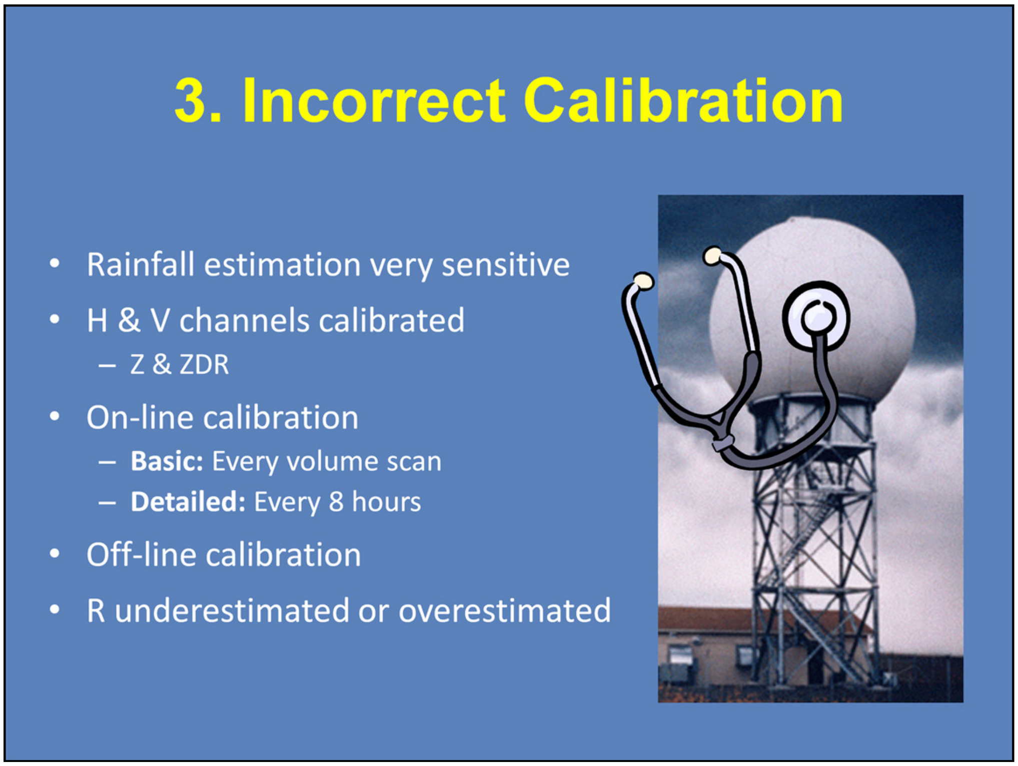
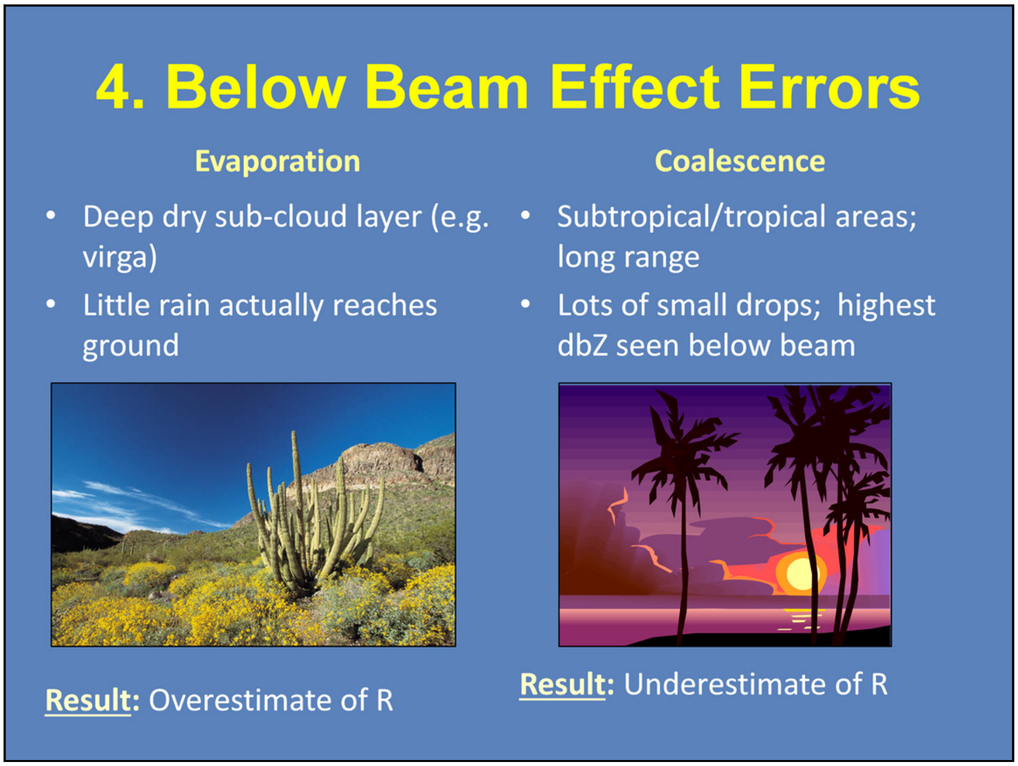


Rainfall estimation is particularly sensitive to calibration errors. A valid Z value is dependent on a well calibrated horizontal channel, while a valid ZDR value depends on each of the horizontal and vertical channels being well calibrated.

There are two different types of calibration: on-line and off-line. One on-line calibration is performed at the end of every volume scan, as the antenna is moving back to 0.5° to begin the next volume scan. A second on-line calibration is performed every 8 hours. This 8 hour “Performance Check” also includes multiple tests to assess the “health” of the radar. Off-line calibration requires the technicians to have control of the radar for a more lengthy process.

With respect to rainfall estimation, calibration errors can result in either an underestimate or an overestimate.



Below beam effects are a fundamental challenge when using a radar to estimate rainfall. We must remember that rainfall estimates are based on the hydrometeors that were sampled within the radar beam. Depending on range, it may be a very long way down to reach the ground! Consideration of the layer below the beam is very important.

Evaporation below the beam can occur in the presence of a deep, dry sub-cloud layer. The desert southwest often has convection with significant below beam evaporation. This layer will evaporate some (or even all) of the rain leaving the cloud, causing a smaller amount rain to reach the ground. As a result, overestimates of rainfall by the radar are likely when sub-beam evaporation is possible.

Coalescence below the beam occurs primarily in subtropical or tropical areas and at long distances from the radar. Where warm rain processes are dominant, a large number of small drops collide and lead to raindrop growth. Except for precipitation at short ranges, the largest drops are often too low to be sampled by the radar beam. As a result, underestimates by the radar are likely when coalescence occurs beneath the radar beam.

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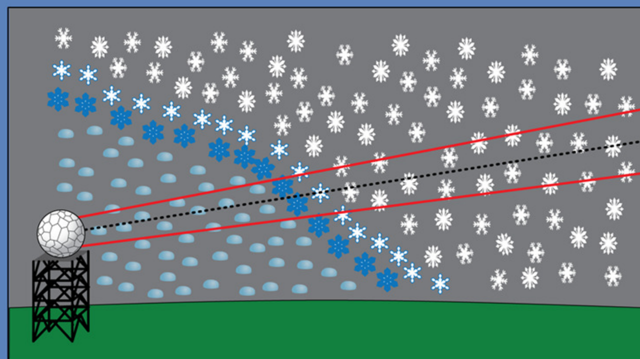
5. Beam Sampling in & above Melting Layer



- PPS & QPE designed to assess liquid
  - Much more reliable below melting layer
- Freezing or frozen precipitation sampled
  - Much harder to accurately convert to liquid

It is important to remember that both the RPG rainfall algorithms are designed to estimate liquid rainfall. Algorithm performance is much more reliable at locations where the radar beam is intercepting liquid hydrometeors below the melting layer. Within the melting layer and above, hydrometeors are frozen (or freezing), and converting to liquid rainfall on the ground really requires a snow conversion algorithm, which will be discussed in a later lesson in this topic.

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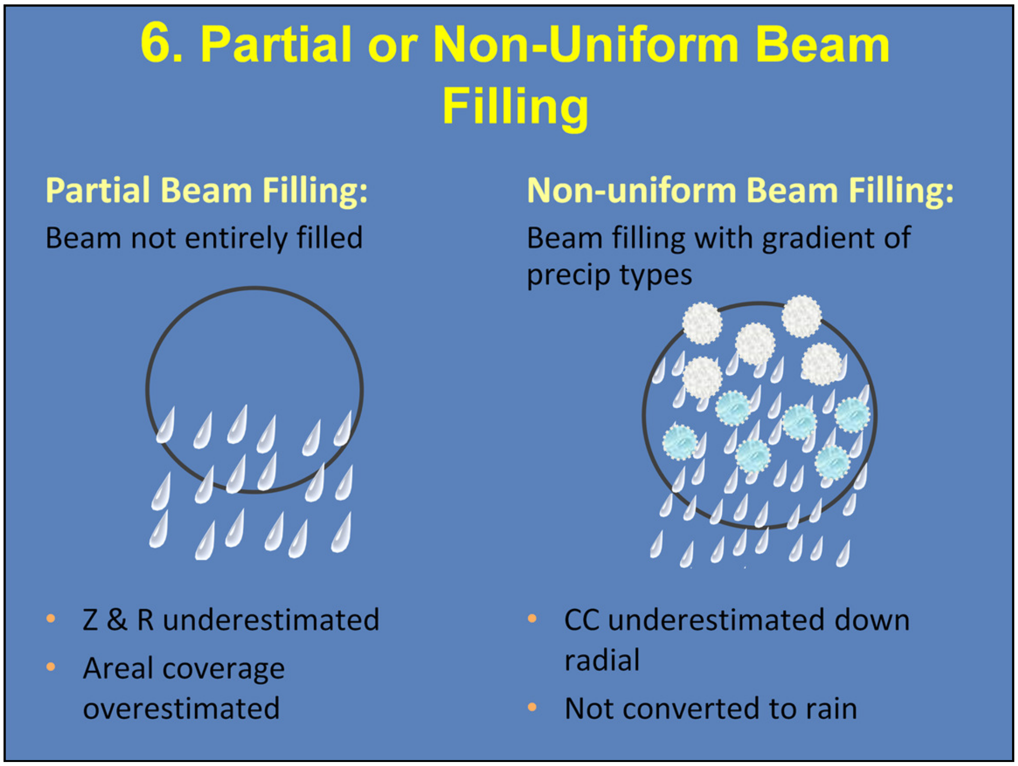

The Probert-Jones radar equation converts returned power to reflectivity with the assumption that the beam is uniformly filled with scatterers. You can probably guess how hard that condition is to meet, especially as the beam increases in size with range.

Here we look at two specific cases that do not meet that condition. The first is partial beam filling, where only a portion of the beam is sampling precipitation. The radar beam spreads with range, increasing the chance that targets may only partially fill the beam. When partial beam filling happens, the reflectivity and rainfall rates are both underestimated. Since the beam volume is greater than the actual precipitation volume, the areal coverage is overestimated, also.

Literally speaking, non-uniform beam filling is likely a common phenomenon. However, a particular type of non-uniform beam filling has a significant impact on the dual-pol products. When a gradient of precipitation types exists across the beam, CC can be underestimated down the radial from that gradient. Active precipitation areas down radial from the non-uniform beam filling may not be converted to rainfall. There was an example of this problem in an earlier lesson in this topic.

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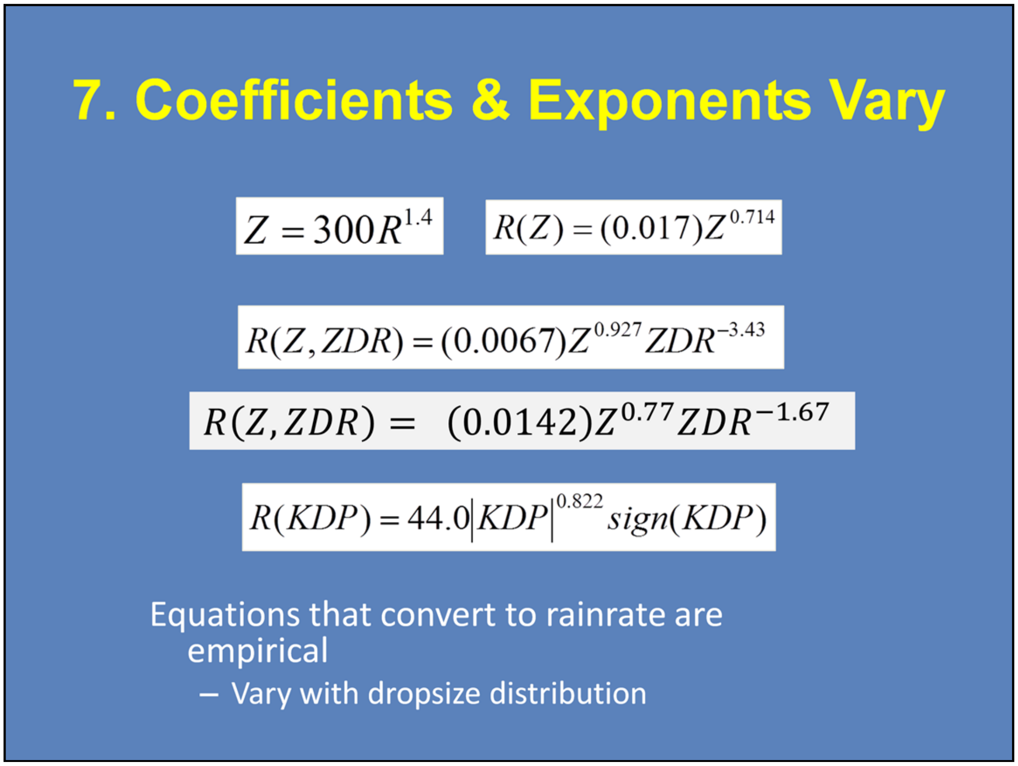
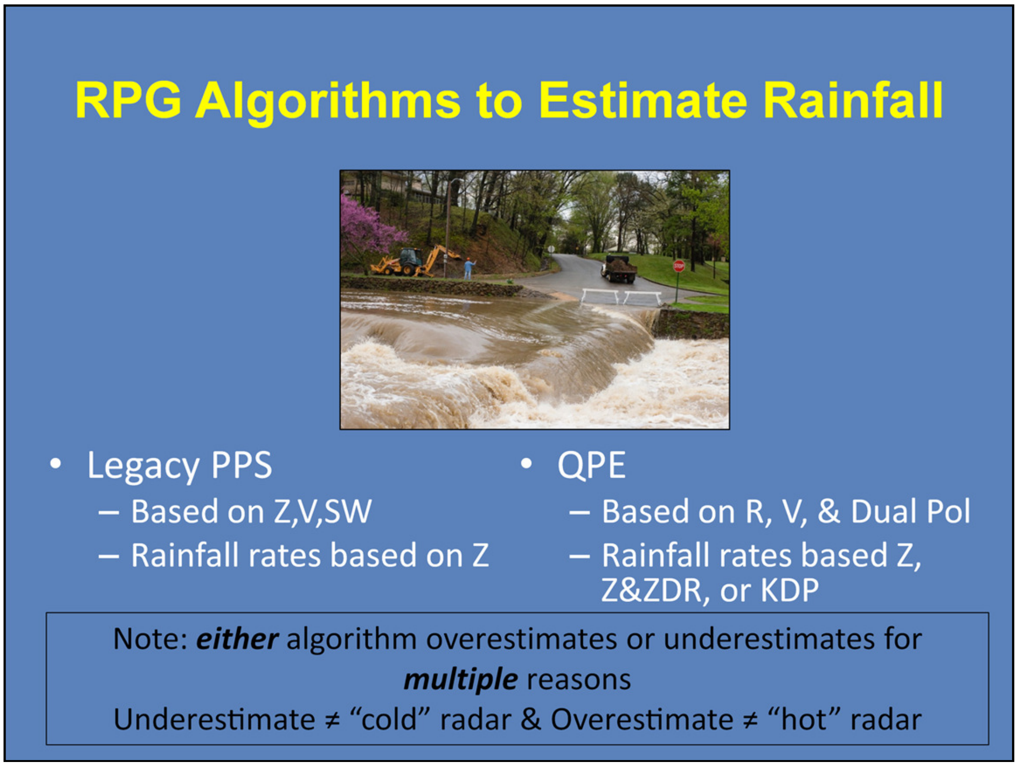


You will see these equations again later in the lessons that discuss the specific rainfall estimation algorithms. For now, just understand that these rain rate equation use empirical coefficients and exponents. The applicability of these equations varies when dropsize distributions differ significantly from those used to determine these values.



There are two RPG algorithms designed to estimate liquid rainfall at the surface. The first is called the Legacy Precipitation Processing SubSystem (PPS), and it has been in place since the original deployment of the WSR-88D. The PPS has seen substantial design changes over the years, as with many of the RPG algorithms. It's inputs are reflectivity, velocity and spectrum width. The PPS computes rainfall rates based on Z, from a choice of Z-R relationships.

The second rainfall algorithm is the Quantitative Precipitation Estimation (QPE) algorithm. The QPE algorithm was recently fielded as part of the Dual-Pol upgrade. Along with reflectivity, and velocity, QPE uses the dual-pol base data and related algorithms as inputs.

There is a misconception that rainfall estimate errors from either of these algorithms are directly related to radar calibration. Given the number of potential errors possible with either algorithm, forecasters should not assume underestimates imply a "cold" radar, or that overestimates imply a "hot" radar.

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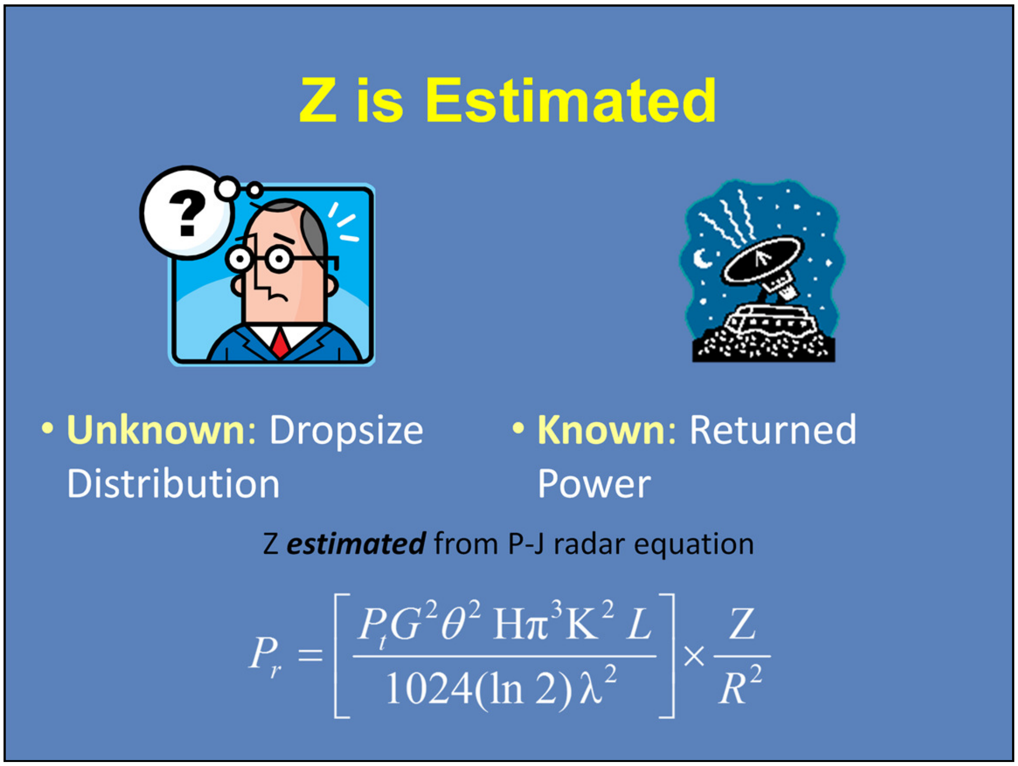
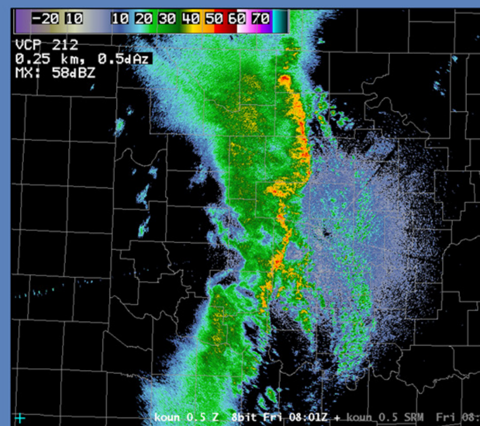


Reflectivity, Z, is an obvious input for estimating rainfall. It is important to remember how Z itself is estimated, and its associated limitations.

If any given dropsize distribution could be measured, Z (as well as the rainfall rate, R) could be computed directly. However, dropsize distribution cannot be measured directly and is unknown. What is known is the power that is returned to the radar. Based on that returned power, reflectivity is an estimate that comes from the Probert-Jones radar equation.

Rain Rate Equation Input: Z

- Z is estimated from P_r
- Confidence in Z for rainfall estimation dependent on
  - Range
  - Dropsize distribution
  - Calibration
  - Non-uniform or partial beam filling
  - Attenuation



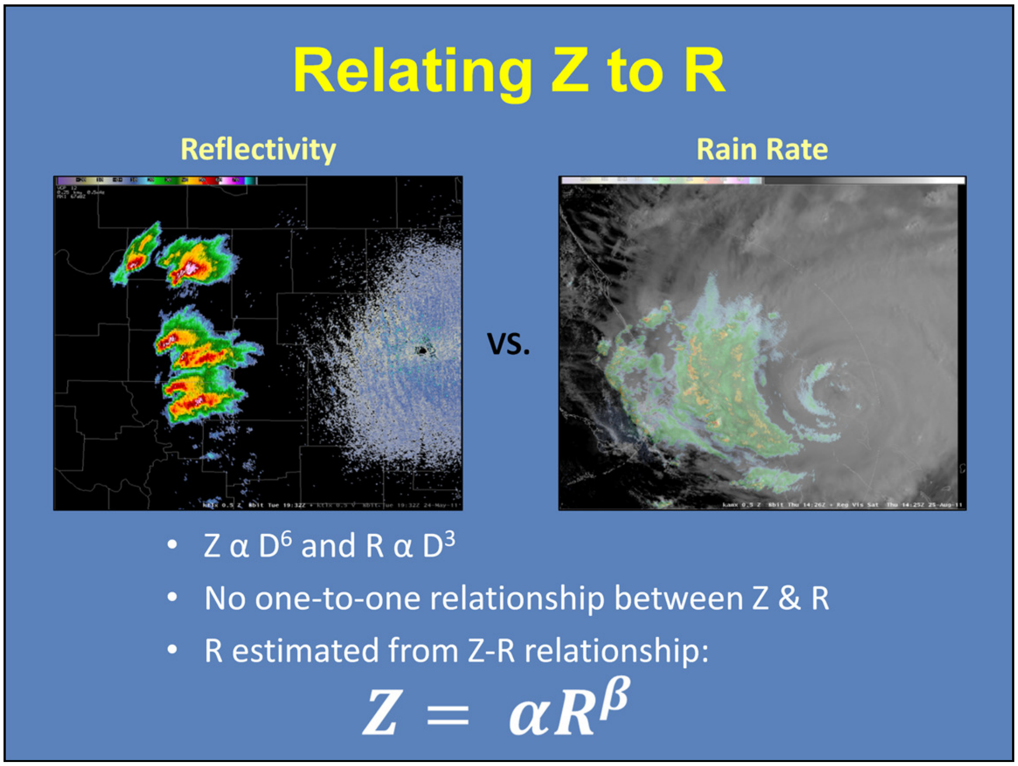
Estimating rainfall from radar is a very complicated business. It's amazing it works as well as it does! Remember that there are potential errors in the Z values even before a rain rate is calculated. Here are the limitations on the validity of the Z value itself.

As range increases, so does the size of the volume that is sampled by the beam. At far ranges, the chance that the radar beam is sampling above the melting layer (i.e., all snow and/or ice crystals) increases dramatically. The Probert-Jones radar equation assumes liquid (not frozen) hydrometeros, affecting the accuracy of Z.

Variations in dropsize distribution can occur at multiple spatial scales, from within the radar umbrella to within a sample volume.

A Z value from a poorly calibrated radar can introduce significant errors in the rainfall estimate.

When the beam is partially or non-uniformly filled by hydrometeors (which is typical at longer ranges), the Z value may not be representative. Though the WSR-88D is a 10 cm radar (yeah!), signal attenuation still happens with heavy rain, resulting in significant underestimates of Z down radial.



Both Z and R are dependent on the dropsize distribution, which is unknown, but with different dependencies. Z is proportional to the drop diameter to the sixth power, while the rainfall rate is proportional to the drop diameter to the third power. There is no one-to-one relationship between Z and R. As a result, R is estimated though a Z-R relationship, expressed as a power law equation. Here, alpha and beta are empirical constants that change depending on the meteorological event being analyzed.

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PPS: Z-R Relationships are Editable

Relationship	Optimum for:	Also for:
Convective $Z = 300 R^{1.4}$	Deep convection	non-tropical convection
Tropical $Z = 250 R^{1.2}$	Tropical convective systems	
Marshall-Palmer $Z = 200 R^{1.6}$	General stratiform	
East-Cool Stratiform $Z = 130 R^{2.0}$	Winter *rain* east of continental divide	Orographic rain east
West-Cool Stratiform $Z = 75 R^{2.0}$	Winter *rain* west of continental divide	Orographic rain west

All used for estimating *liquid* precipitation

The Precipitation Processing Subsystem (PPS) relies solely on Z for rainfall estimation, by applying a Z-R relationship. There are five Z-R relationships that have been developed over the years, and they can be selected by editing the multiplier and the coefficient at the RPG. This table summarizes the available WSR-88D Z-R relationships, along with their optimal environments.

First, notice the differing empirical constants used in each relationship. Second, even though two of these relationships are optimized for wintertime, the goal is still to estimate liquid precipitation on the ground.

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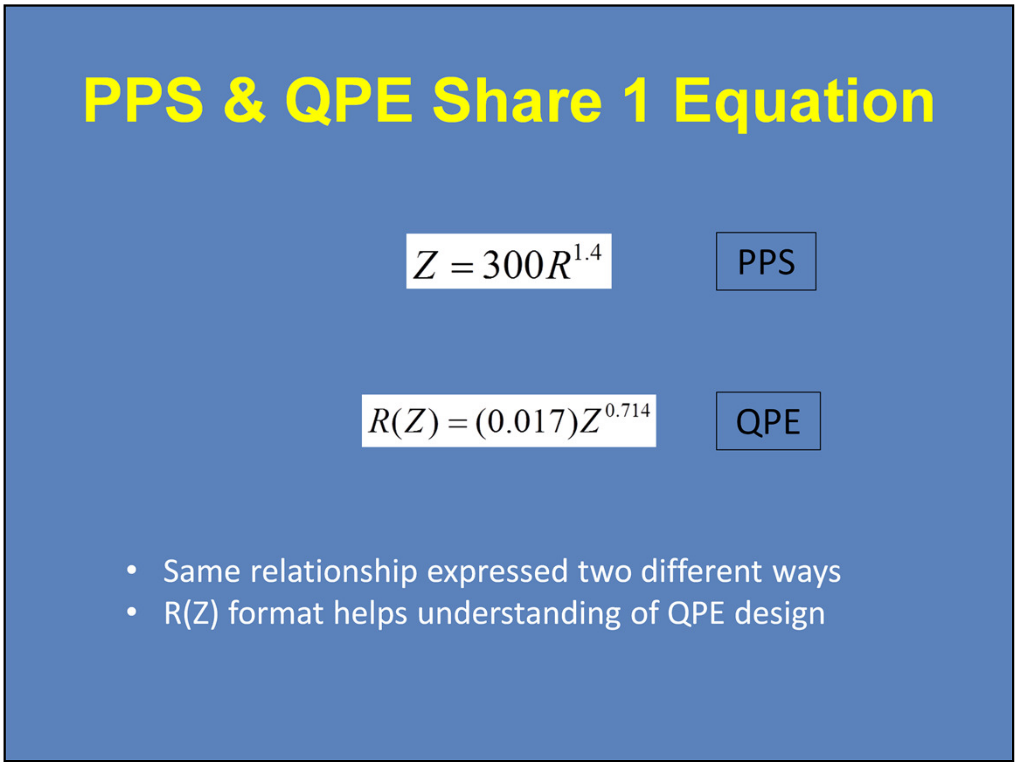
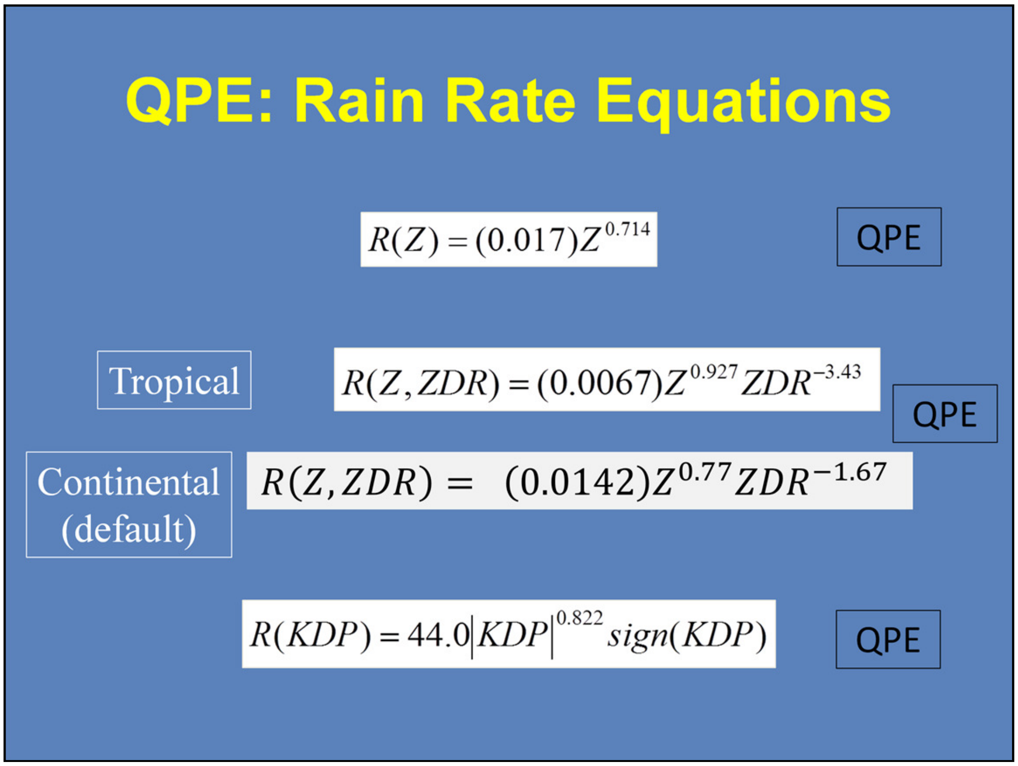


The legacy PPS and the Dual-Pol Quantitative Precipitation Estimation (QPE) algorithm share one equation for converting Z to rainfall rate. The first equation shows the more familiar format, solved for Z. The second equation is the same as the first, just rewritten in a format that is solved for R. We introduce the R(Z) format here to help your understanding of the QPE design (coming up!). Though you’ve just seen five different Z-R relationships available for use with the PPS, the only Z-R relationship used by QPE is Z=300R**1.4.

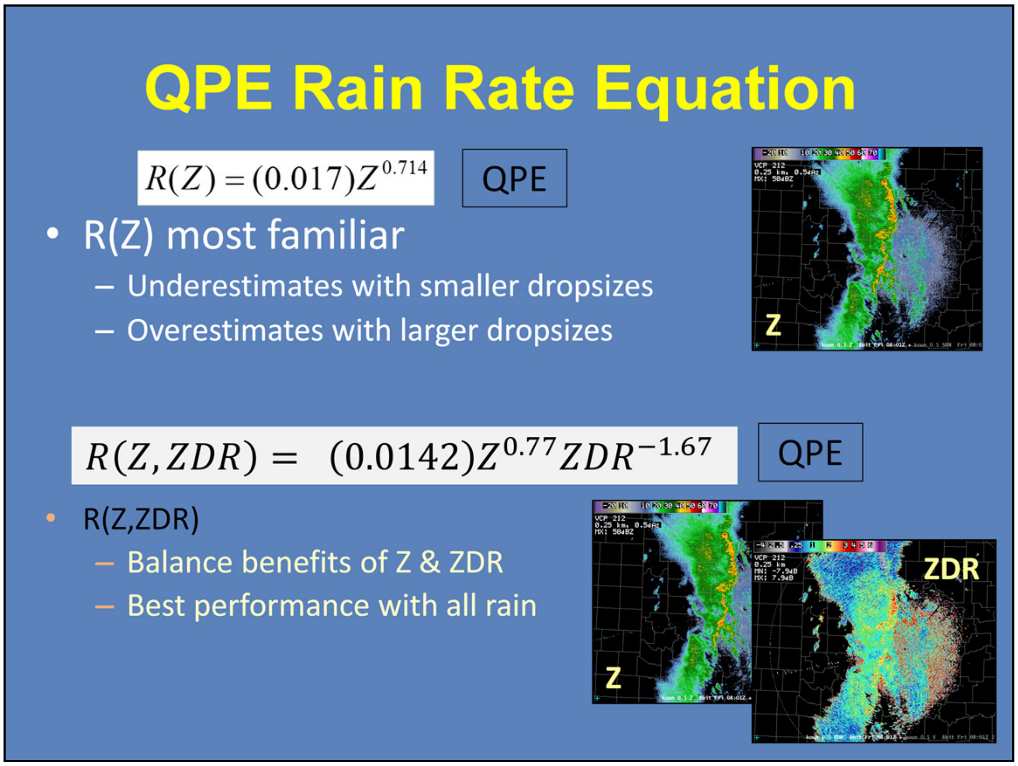


There are four equations for computing rain rate used by QPE. How QPE determines which of these equations to use will be explored in a later lesson.

The first equation is the Z=300R**1.4 relationship solved for R, as you saw on the previous slide.

The second and third equations combine Z and ZDR as input, in linear units (mm^6/m^3). The R(Z,ZDR) equation labeled Continental is the default, is recommended for the cool season and for warm season deep convection. The Tropical R(Z,ZDR) is recommended for the warm season and for events that are dominated by warm rain processes, especially hurricanes and tropical systems. Southern and coastal locations may find the Tropical R(Z,ZDR) sufficient for a majority of events.

The R(KDP) is used where hail has been identified. You may notice that the R(KDP) equation includes the possibility of a negative rain rate. The QPE algorithm logic rejects R(KDP) when the rate is negative, so don't worry about that possibility.



The limitations of $Z = 300R^{1.4}$, now presented in its R(Z) format, are probably familiar. It often underestimates rainfall in a warm rain dominant event, while overestimates the water at the surface from mixed precipitation types, such as wet snow and hail.

R(Z,ZDR) combines input from both Z and ZDR. The goal is to balance the benefits of each of these inputs, and this combination is generally best where the beam is sampling all rain.

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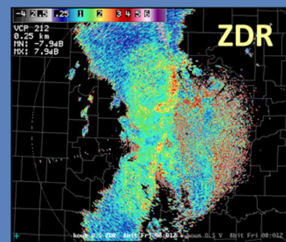
Rain Rate Equation Input: Z & ZDR

Z estimated from P_{rH}



ZDR estimated from P_{rH} & P_{rV}

Confidence in Z & ZDR for rainfall estimation dependent on:

- Range
- Non-uniform or partial beam filling
- Dropsize distribution
- Calibration
- Attenuation or differential attenuation

$$R(Z, ZDR) = (0.0142)Z^{0.77}ZDR^{-1.67}$$

QPE

Using Z and ZDR as inputs for computing rain rate have similar dependencies that affect their reliability for rainfall estimation. As a reminder, Z is estimated from the returned power in the horizontal channel, while ZDR is estimated from the returned power in both the horizontal and vertical channels.

As range increases, the volume sampled also increases. The larger radar volume makes it harder for the beam to be uniformly filled with the same hydrometeors. Also at longer ranges, the beam can be filled with by all snow and/or ice crystals. Frozen hydrometeors differ from those assumed in the Probert-Jones radar equation, which affects the accuracy of both Z and ZDR.

Variations in dropsize distribution, especially the presence of hail, affect both Z and ZDR values.

Both Z and ZDR are sensitive to calibration errors.

Even at 10 cm, attenuation (or differential attenuation) happens. Significant attenuation of either kind can make the Z or ZDR estimates less reliable.

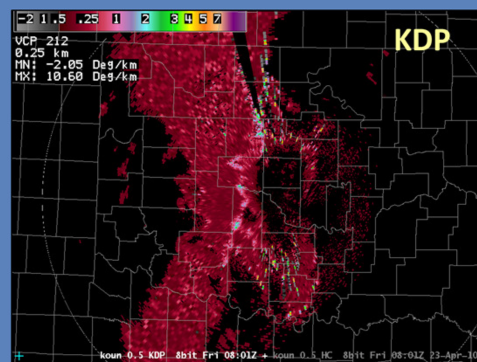
QPE Rain Rate Equation

$$R(KDP) = 44.0\left|KDP\right|^{0.822} sign(KDP)$$

QPE

R(KDP):

- KDP mostly immune to partial beam blockage & hail
- Helps QPE mitigate hail contamination
- Sign(KDP) is a quality control



R(KDP) has the advantage that KDP is mostly immune to both partial beam blockage and hail contamination. The magnitude of KDP is related to the liquid water content in the volume, but not to ice. For example, if a volume contains mostly hail, KDP values can be quite low. On the other hand, a large quantity of small melting hail can result in KDP being very large. Since KDP is mostly immune to hail, it can be used to estimate rainfall where hail is present. This equation includes the term “sign(KDP)”. Negative KDP values are possible, and this term is included as a quality control. If R(KDP) < 0, it is not used to estimate rainfall.

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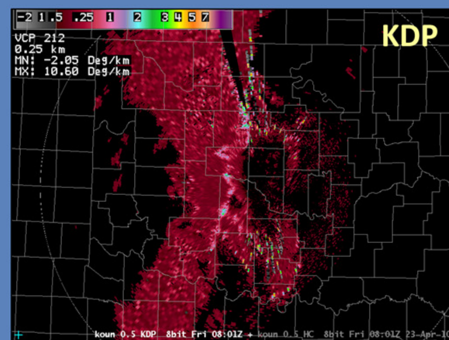
Rainrate Equation Input: KDP

$$R(KDP) = 44.0|KDP|^{0.822}\, sign(KDP)$$

QPE

- KDP
  - Less dependent on dropsize distribution
  - Mostly immune to partial beam blockage & hail
- Confidence in KDP for rainfall estimation dependent on
  - Returned signal strength
  - Number of pulses per radial
  - Associated CC value



KDP as input for computing rainrate is less dependent on dropsize distribution than Z and ZDR. KDP can be useful where hail is present or there is partial beam blockage.

Compared to Z and ZDR, KDP is noisier and more dependent on sufficient signal strength and pulses per radial. Where the returned power is low (or fast VCPs are used), KDP is noisy and thus less reliable for conversion to rainfall. However, the noisiness is usually not a problem for qualitative human interpretation. So, KDP can still be very useful for identifying areas of heavy rain even when noisy. The use of KDP for rainfall estimation is also dependent on the associated CC value. The details of this will be presented in the QPE lesson, but for now, if CC is low, R(KDP) is not used for rainfall estimation.

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Welcome to Legacy Precipitation Processing Subsystem (PPS) Algorithm.

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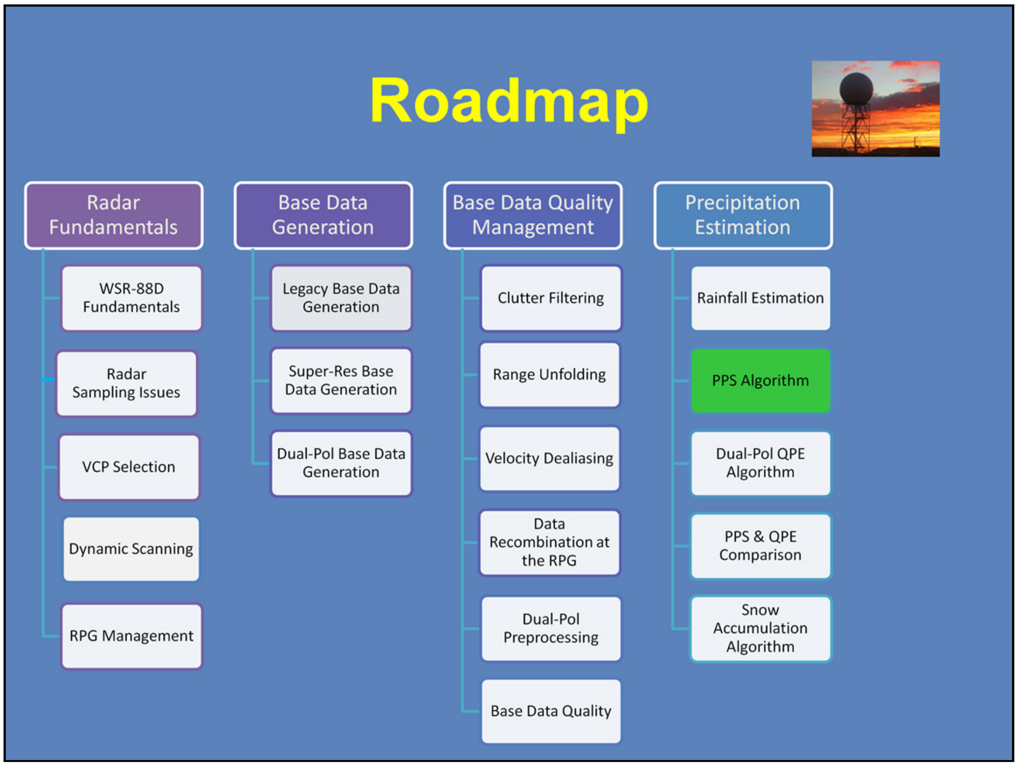


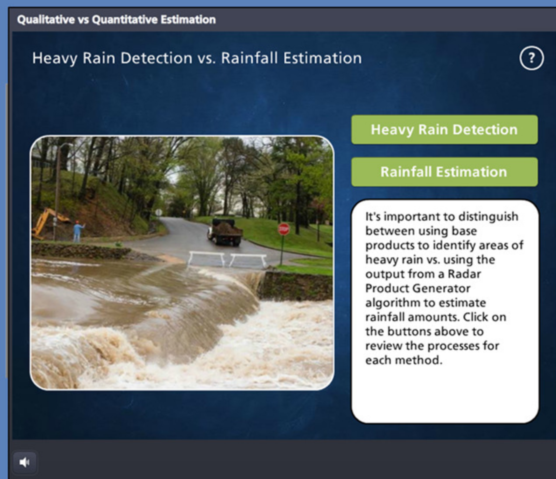
Here is the “roadmap” with your current location.

Precipitation Estimation
Objectives

1. Identify strengths & limitations of the Legacy Precipitation Processing Subsystem (PPS).

There is one objective for this lesson, focusing on the design of the PPS.

Review: Heavy Rain Detection vs. Rainfall Estimation



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http://www.wdtd.noaa.gov/courses/rac/principles/interactions/qual-vs-quant/

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Now for a “tour” of the Legacy (aka been around awhile) Precipitation Processing Subsystem (PPS). The PPS is a series of algorithms that use base reflectivity, velocity and spectrum width data as input, then estimate rainfall and generate rainfall products. This process contains several quality control steps and the rainfall estimates are provided out to a range of 124 nm. In addition, there are several adaptable parameters utilized that provide configuration flexibility.

This is a complex algorithm with multiple steps. The focus of this “tour” will be the portions of the PPS where there is some operator control.

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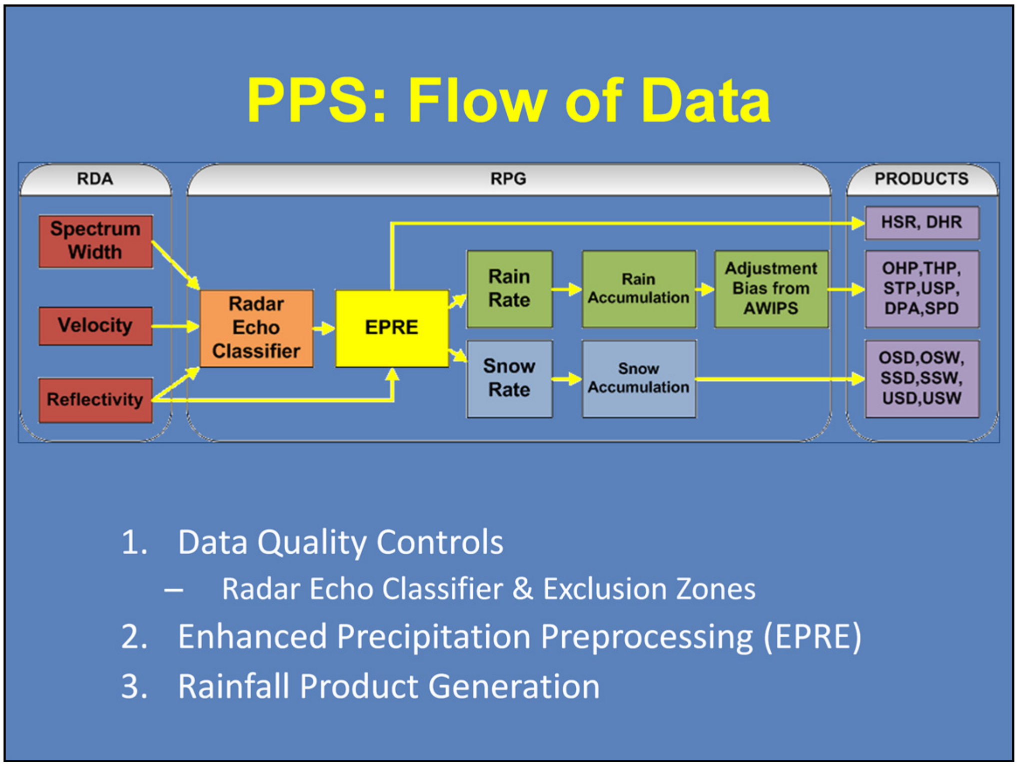
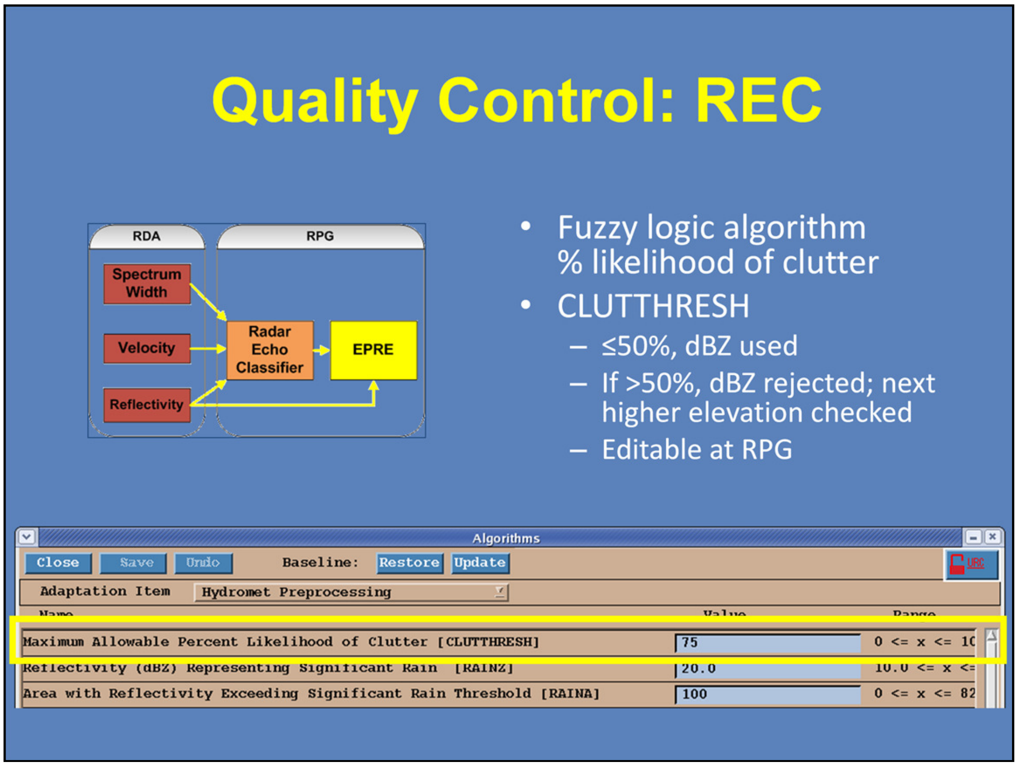


This graphic provides a high-level look at the flow of information through the Precipitation Processing Subsystem (PPS) and will serve as an outline for the PPS components. There are multiple quality control steps that will be highlighted, including a look at how the base data are "prepared" by the Enhanced Precipitation Preprocessing (EPRE) algorithm. Some important steps that affect product generation will also be provided.

The two boxes that have the word "snow" on them are not related to the PPS. They will be discussed in a later lesson, which presents the Snow Accumulation Algorithm.



The Radar Echo Classifier is a fuzzy logic algorithm that uses reflectivity, velocity, and spectrum width to assign a likelihood that a particular bin contains clutter.

EPRE ingests this guidance for comparison against a parameter called CLUTTHRESH which determines whether or not that dBZ is used in rainfall product generation. The default setting for CLUTTHRESH is 50%, which means that if a bin is assigned less than or equal to 50% by the REC, the dBZ for that bin is used for conversion to rainfall. If the REC has assigned a % greater than the CLUTTHRESH value, the bin is rejected. For rejected bins, the next higher elevation bin is then checked.

The CLUTTHRESH parameter is editable at the RPG. Here’s an example where CLUTTRESH was increased to 75% during the warm season for a location with very little terrain clutter. The intent was to use the lowest elevations possible for rainfall estimation to better avoid hail contamination.

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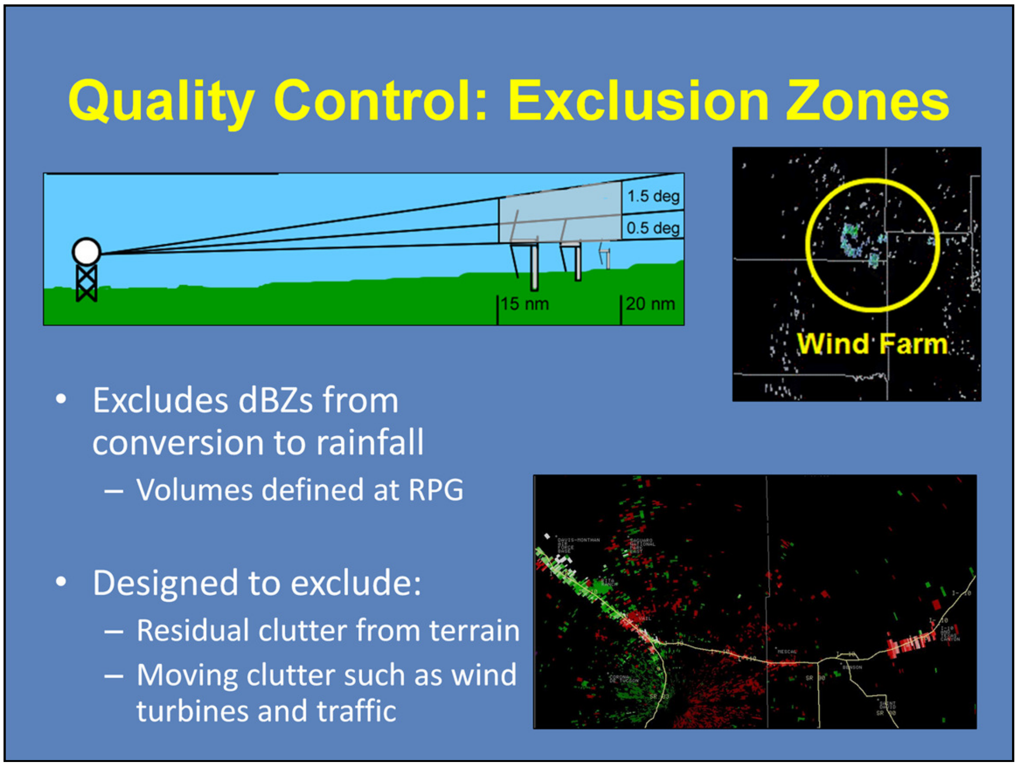
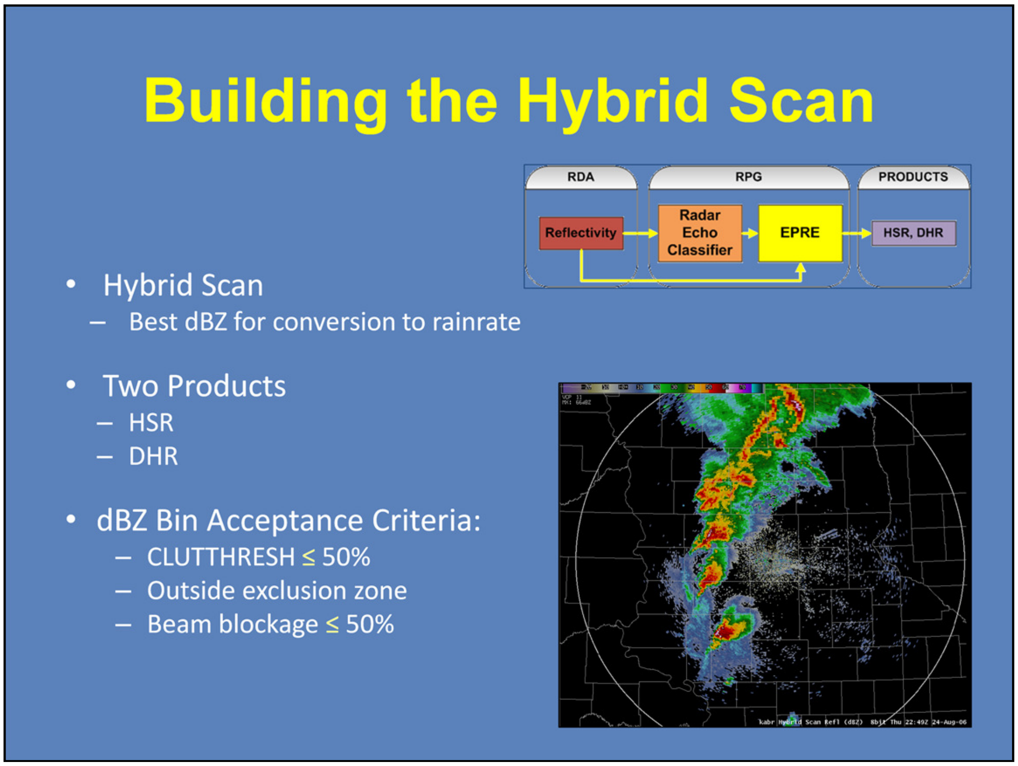


Another quality control option that is part of EPRE is the application of Exclusion Zones, which are defined locally. Exclusion zones are used to prevent reflectivity from specific areas and elevations from being converted to rainfall. An exclusion zone is actually a volume, defined from azimuth to azimuth, range to range, and up to a maximum elevation. Exclusion zone definition is done at the RPG.

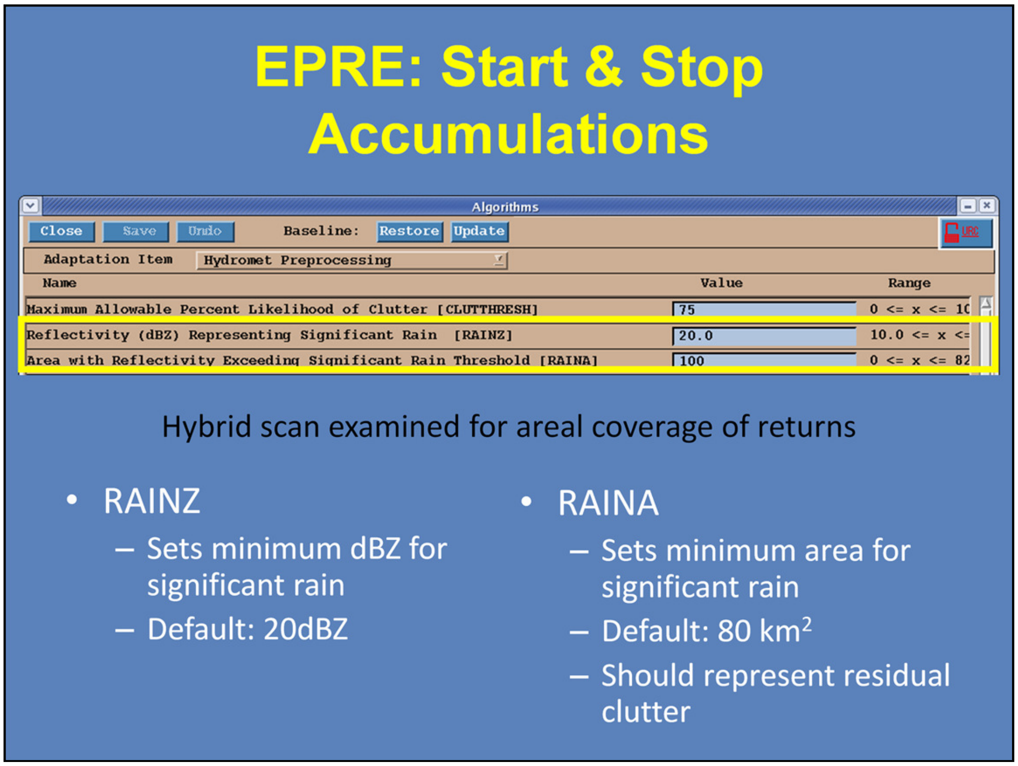
Optimally, these zones will be used to prevent residual clutter from terrain and moving clutter originating from sources like wind turbines and traffic from being converted to rainfall. These areas, especially at close ranges to the radar will cause high reflectivity that cannot be removed by the clutter filters.



The “grand finale” of the EPRE algorithm is the building of the hybrid scan. The idea of a hybrid scan is to find an optimal dBZ value at each range bin only for the purpose of converting to rainrate. There are two Hybrid Scan products that represent the reflectivity field that was used by the PPS for that volume scan. Specific products generated are the Hybrid Scan Reflectivity and Digital Hybrid Scan Reflectivity. More information on these products will be presented in products portion of this course.

In order for the EPRE to accept a dBZ bin into the hybrid scan, it must meet the following criteria:

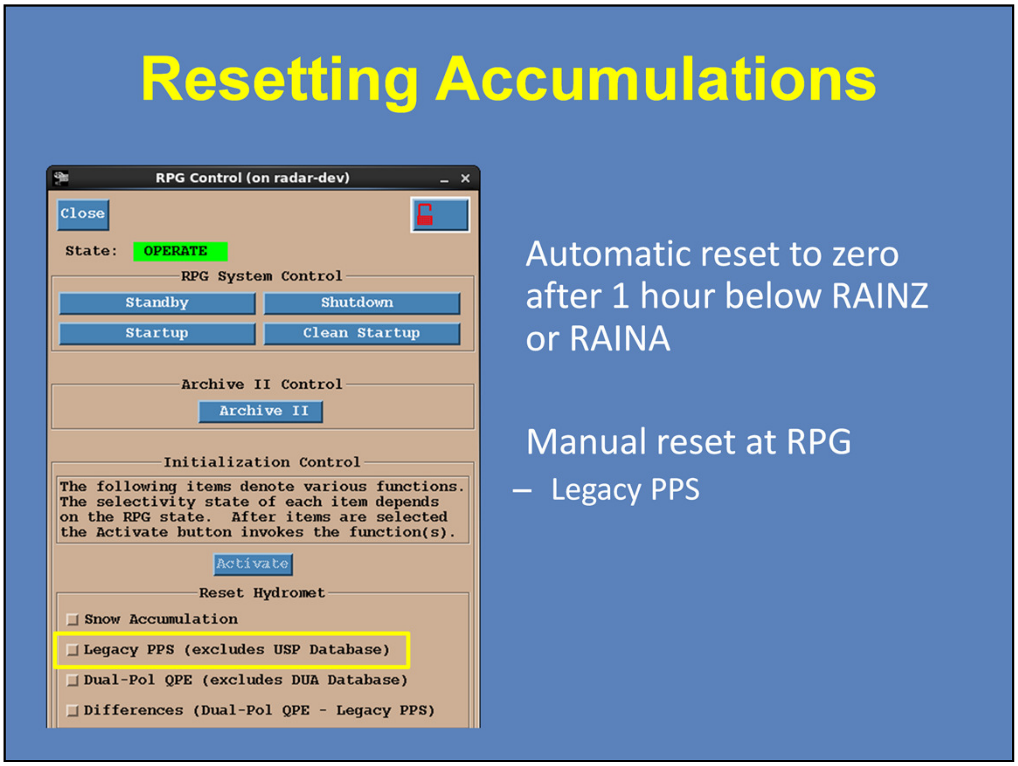
1) Must have a clutter likelihood of less than the CLUTTRESH setting (50% by default)
2) Must fall outside of a defined EPRE exclusion zone.
3) Beam blockage must be no more than 50%



Based on the hybrid scan, EPRE determines when accumulations begin and when they end. The idea of whether or not it is "raining" is based on the areal coverage of returns above a certain dBZ value. There are two EPRE adaptable parameters that govern the start and stop of rainfall, RAINZ and RAINA. RAINZ is the minimum dBZ that "counts" as rain. The default value for RAINZ is 20 dBZ, which is generally considered to be the minimum dBZ for precipitable returns.

RAINA is the minimum areal coverage of returns at or above RAINZ for accumulation to either begin or to continue. The default value for RAINA is 80 km^2, which is often too small. RAINA is meant to represent the average areal coverage of residual clutter for each radar. If RAINA is smaller than the residual clutter area, the PPS may be accumulating clutter instead of precipitation.

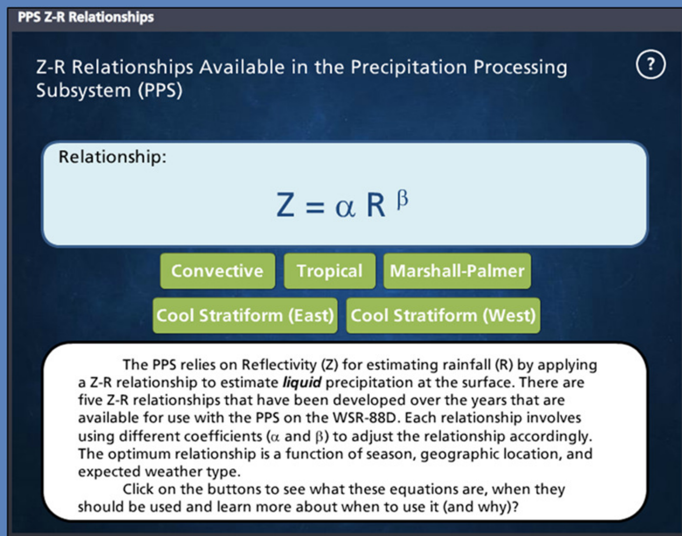
With the default settings for RAINZ and RAINA above, if 80 km^2 of returns at or above 20 dBZ are detected, the PPS processes for accumulating rainfall begin, and will continue each volume scan that the thresholds are met. The rainfall accumulations are automatically reset to zero once conditions fall below the RAINZ or RAINA thresholds for one hour.



There are two approaches to resetting rainfall accumulations to zero. The first is the automatic reset when the conditions fall below RAINZ and RAINA for one hour. The storm total is a type of accumulation that continues as long as RAINZ and RAINA are exceeded. For some locations, this can be too long!

There is a manual reset of the storm total accumulation available at the RPG, specifically the RPG Control window. Manual resets are actually available for both the rainfall algorithms, as well the snowfall algorithm, but for now, we focus on the “Legacy PPS”.

PPS Z-R Relationships



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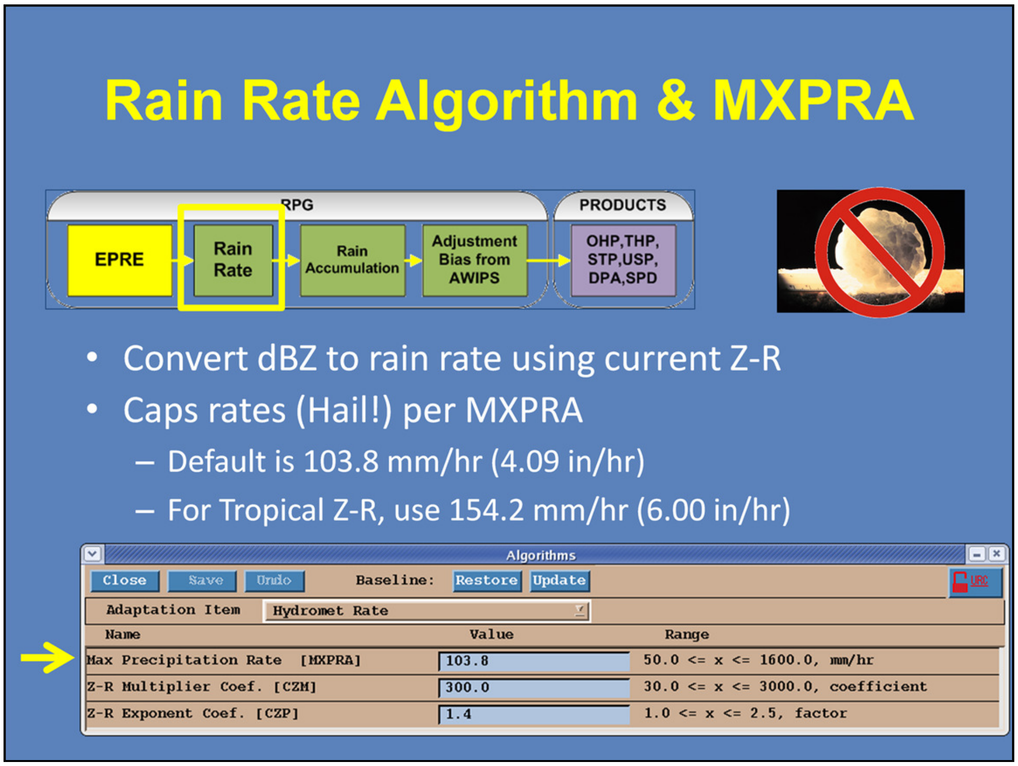
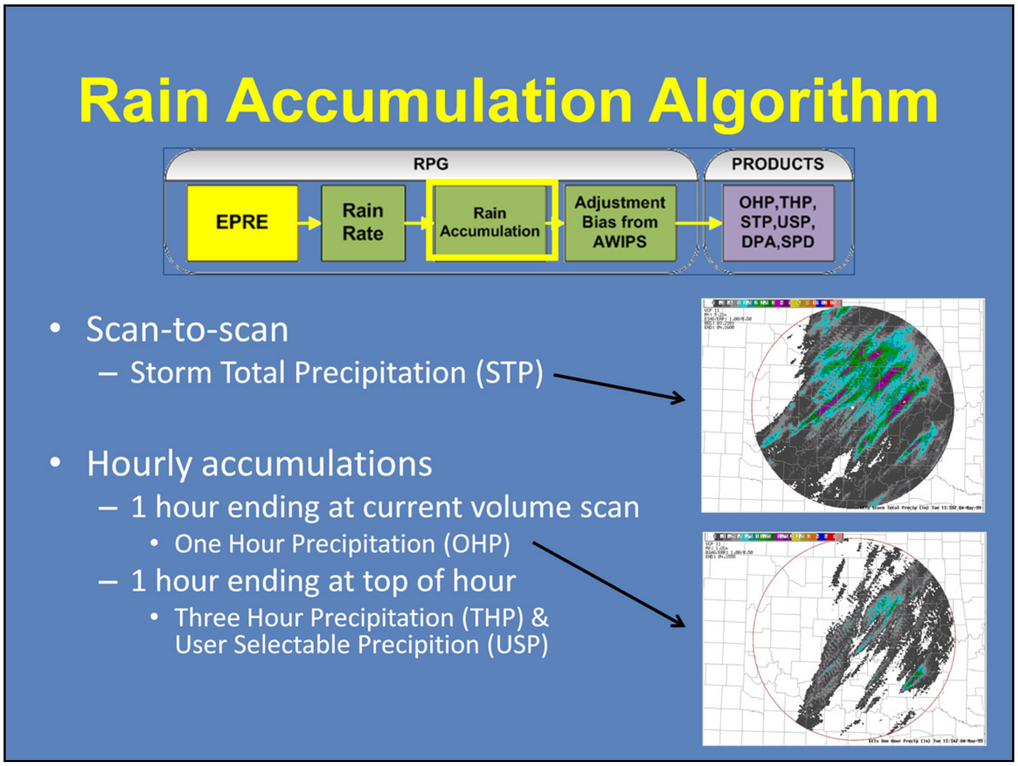


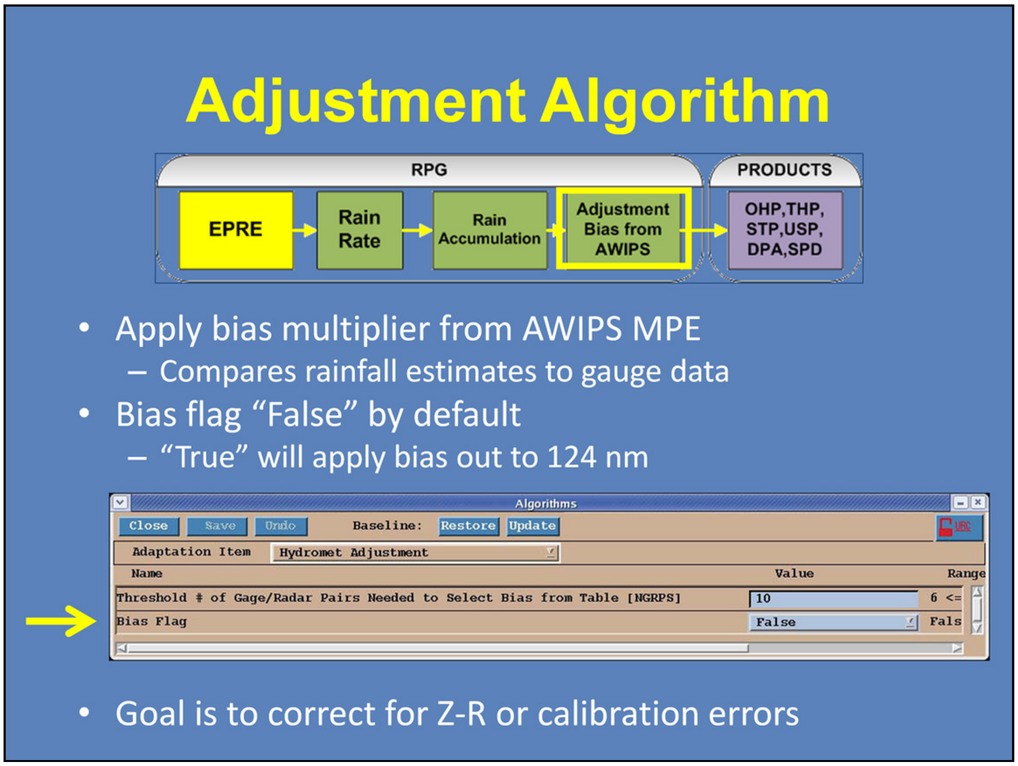
The Rain Rate algorithm converts the dBZ values from the hybrid scan to rain rate using the current Z-R relationship applied at the RPG. The Rate Algorithm also applies a parameter called the Max Precipitation Rate (MXPRA). MXPRA works as a cap to prevent hail contamination. The default setting for MXPRA is 103.8 mm/hr, which is 4.09 in/hr. This means that any rain rates that exceed 4.09 in/hr will be capped at this value. If the Tropical Z-R is used, it is recommended that MXPRA also be adjusted to allow for higher rain rates. The recommended setting is 154.2 mm/hr, or 6.00 in/hr.



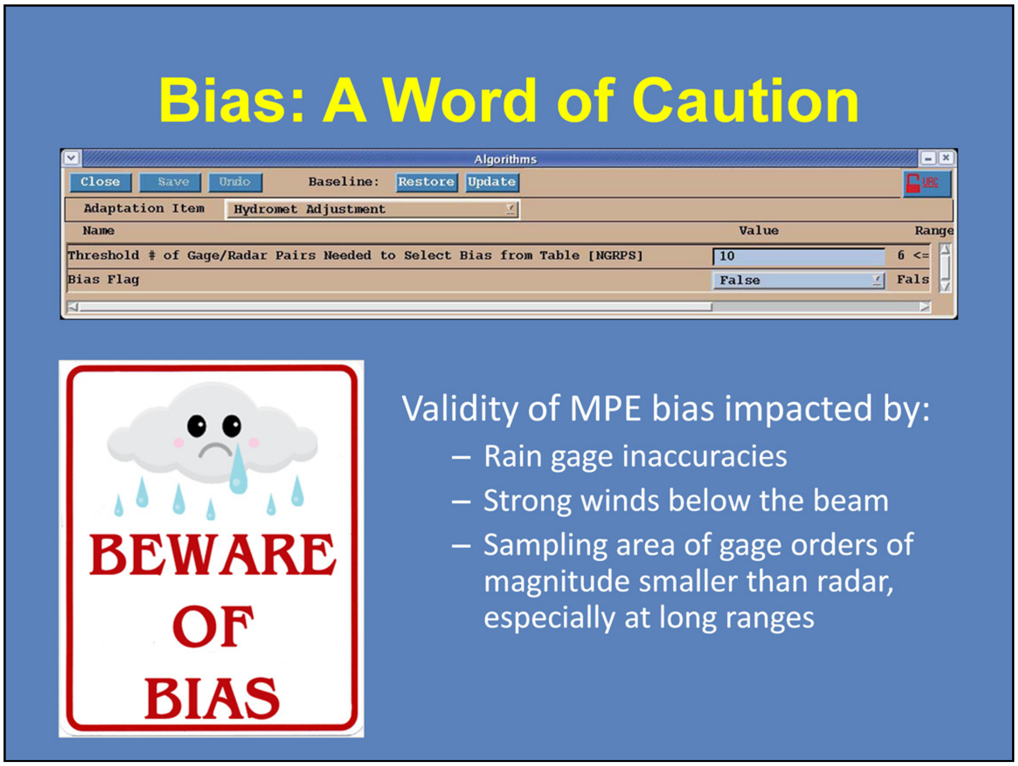
The Accumulation Algorithm, uses the calculated rain rates and differing durations to accumulate rainfall. There are two different types of accumulations.

Scan to scan accumulations continue every volume scan as long as RAINZ and RAINA are exceeded. Scan to scan is the accumulation displayed on the storm total products, the one most commonly used is the Storm Total Precipitation (STP) product.

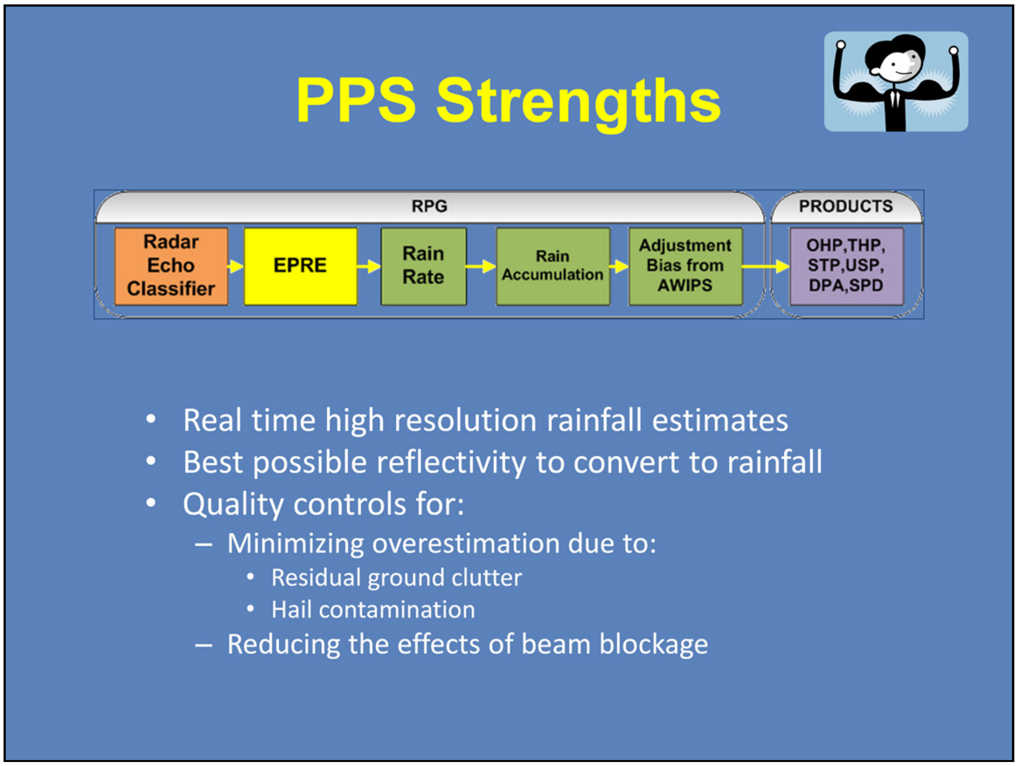
The second type of accumulation is hourly. There is a one hour accumulation ending at the current volume scan time. This is the accumulation displayed on the one hour products, the one most commonly used is the One Hour Precipitation (OHP) product. There is also a one hour accumulation that ends at the top of each hour. These hourly ending at the top of the hour accumulations are used to build the Three Hour Precipitation (THP) and User Selectable Precipitation (USP) products.



The adjustment algorithm is the last of the PPS algorithms, providing the option of applying a bias multiplier to the rainfall accumulations. The AWIPS Multi-Sensor Precipitation Estimator (or MPE) compares radar rainfall estimates to gauge data and sends a bias table to the RPG once an hour. Applying the bias is controlled by a parameter known as the Bias Flag. It is set to false by default. Setting the Bias Flag to true will apply the best bias generated by the MPE out to 124 nm. The goal of the bias adjustment is to correct for a non-representative Z-R relationship or calibration errors.



The MPE bias output isn’t perfect and there are some scenarios to consider that could affect the validity of this bias. Rain gage values can be inaccurate for a variety of reasons. There may be strong winds below the beam. The most important consideration is that the rain gage sampling area is orders of magnitude smaller that the radar.



Here are the strengths of the PPS algorithm. This is the only source of real time high resolution rainfall estimates. It is important to remember that the qualitative spatial information of the rainfall pattern can be valuable.

The PPS uses the reflectivity value closest to the ground that is not contaminated with clutter. There are quality control steps to minimize hail contamination and to avoid radials with beam blockage.

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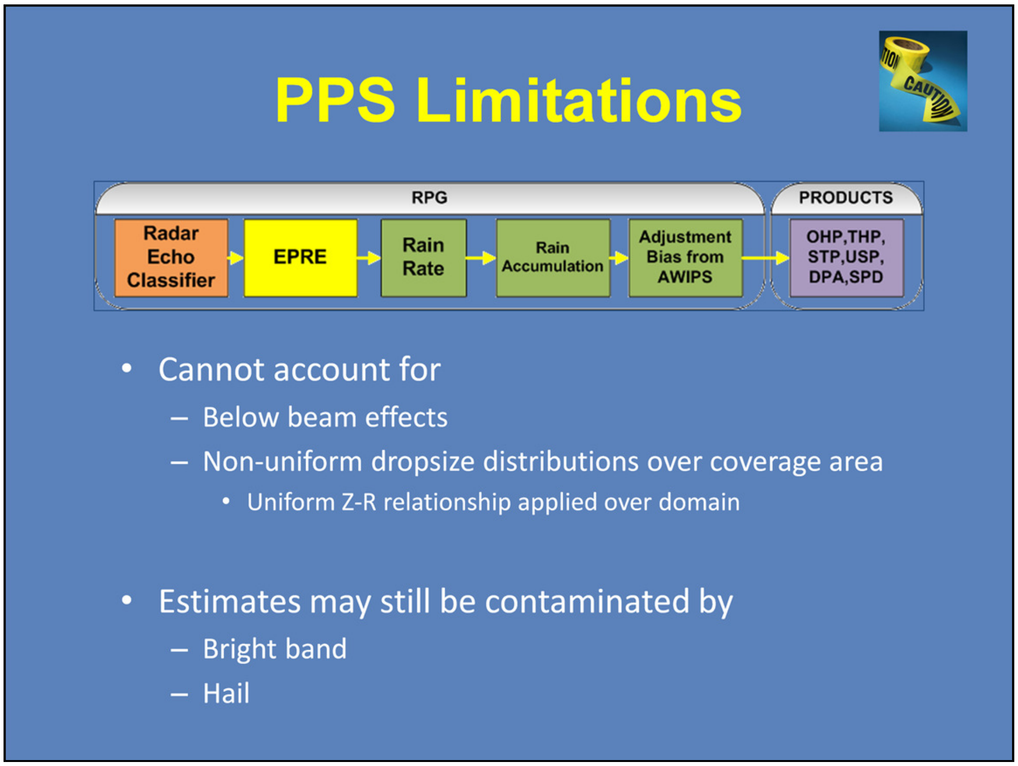

There are also some limitations to the PPS. The PPS cannot account for below beam effects such as strong winds, evaporation, or coalescence. Since a single Z-R relationship is applied over the entire domain, the PPS estimates can be compromised by non-uniform dropsize distributions in the radar area.

While the PPS does attempt to mitigate some errors, it may not always be 100% successful. Even though the PPS chooses the lowest viable reflectivity with sufficient coverage, the beam will strike the melting layer and bright band contamination can occur. Even with the application of the Max Precipitation Rate parameter, hail contamination may not be completely removed.

Welcome to the Dual-Pol Quantitative Precipitation Estimation (QPE) Algorithm

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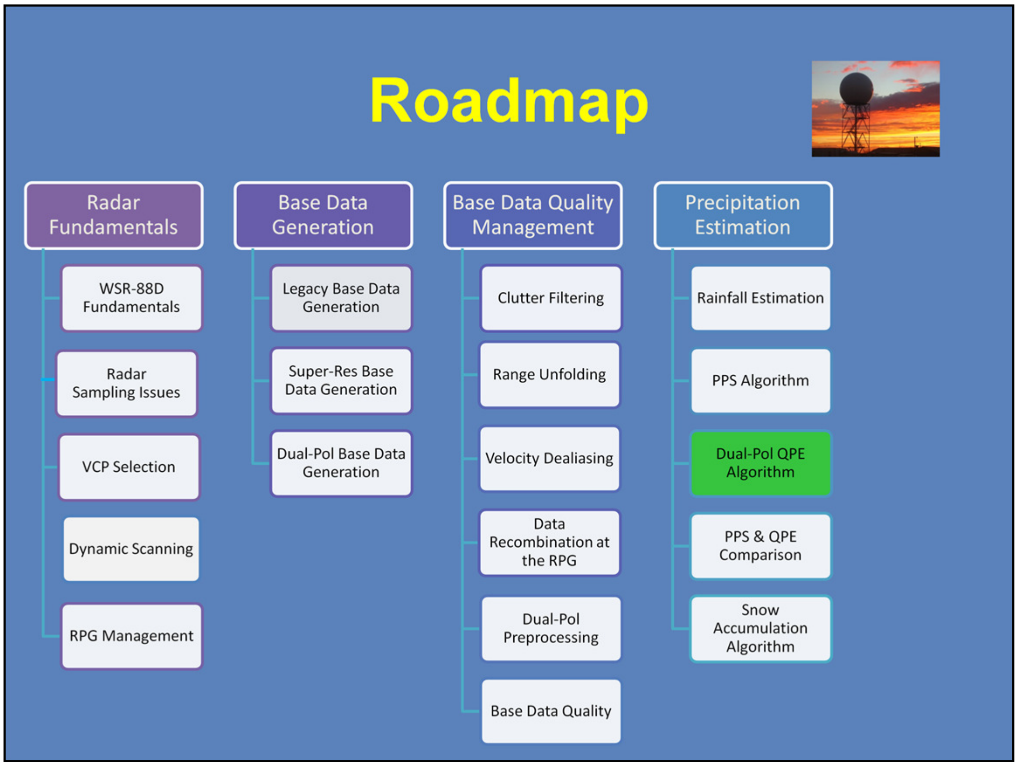


Here is the “roadmap” with your current location.

Learning Objectives

1. Identify strengths & limitations of the Quantitative Precipitation Estimation (QPE) algorithm

There is one objective for this lesson, focusing on the design of the QPE algorithm.

QPE Tour

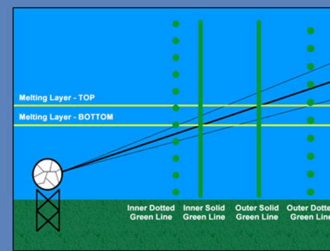
$$R(Z) = (0.017)Z^{0.714}$$

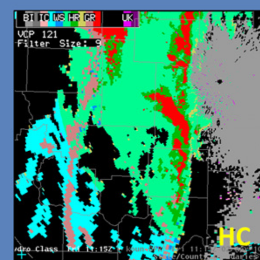
$$R(Z, ZDR) = (0.0067)Z^{0.927}ZDR^{-3.43}$$

or

$$R(Z, ZDR) = (0.0142)Z^{0.77}ZDR^{-1.67}$$

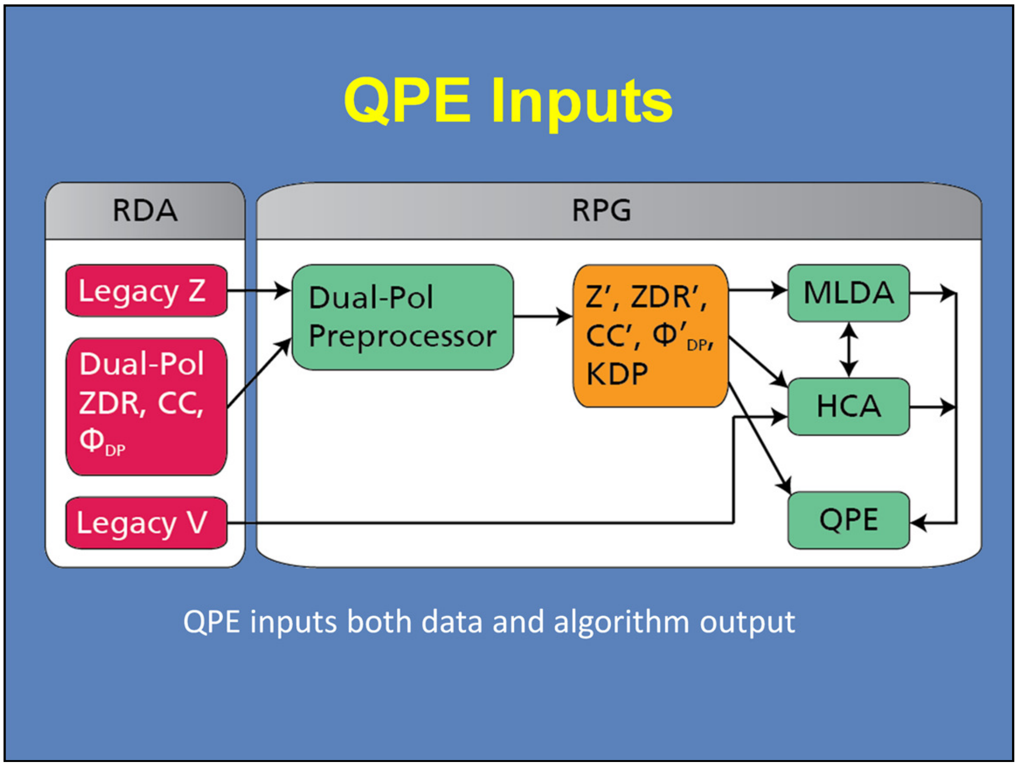
$$R(KDP) = 44.0|KDP|^{0.822}sign(KDP)$$





- PPS has sequential quality control steps
- QPE's quality control implemented by
  - Three different rain rate equations
  - Input from MLDA & HCA determines which equation is used

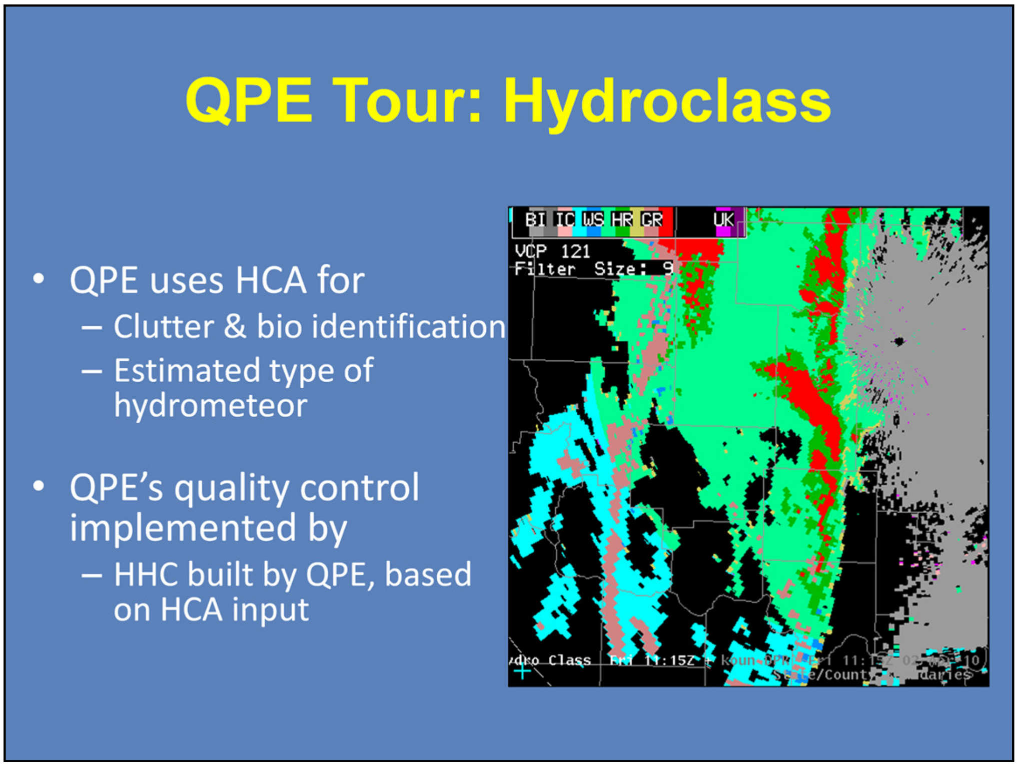
The QPE Tour will be somewhat different from the PPS Tour. The Legacy Precipitation Processing Subsystem (PPS) was presented as a sequence of quality control steps. The QPE Tour will be less sequential, but focused on key design elements of the QPE. This QPE Tour also provides more information on how QPE relies on the output from the Melting Layer Detection Algorithm (MLDA) and the Hydrometeor Classification Algorithm (HCA), which both determine which rain rate equation is used for any given range bin. The use of three different rain rate equations and the reliance on MLDA and HCA makes QPE significantly more complex than any other RPG algorithm.



The Dual-Pol Quantitative Precipitation Estimation (QPE) algorithm is the most complex RPG algorithm yet implemented. QPE relies on multiple base data inputs, as well as the output from two new RPG algorithms. These algorithms are the Melting Layer Detection Algorithm (MLDA) and the Hydrometeor Classification Algorithm (HCA).

With the exception of velocity, the base data inputs are first passed through the Dual-Pol Preprocessor. Reflectivity (Z), Differential Reflectivity (ZDR), Correlation Coefficient (CC), and Differential Phase (Φ_{DP}) are smoothed and (in some cases) corrected for attenuation. The "prime" notation is being used to denote the data that have been preprocessed. Specific Differential Phase (KDP) is also generated by the Dual-Pol Preprocessor and input to all of the Dual-Pol RPG algorithms.

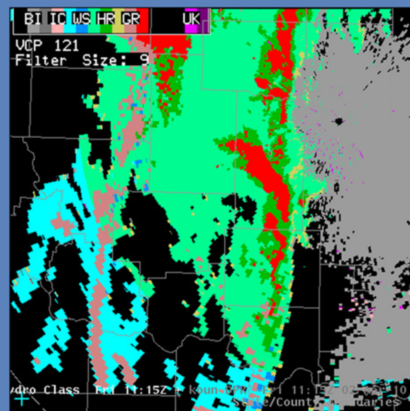
In addition to the base data, QPE is reliant on the assessed height of the melting layer from MLDA and the expected hydrometeor (or non-hydrometeor) type from the HCA.



The QPE relies on the HCA in two ways. Bins that have clutter or biological targets identified by HCA are not converted to rainfall by the QPE. For bins that HCA identifies as having some type of precipitable hydrometeor, the QPE uses one of the different rain rate equations based on the type of hydrometeor (much more about that soon)!

The Hybrid Hydrometeor Classification (HHC) product is output from the QPE. It shows you, on a bin by bin basis, which HCA values were used by QPE to generate the rainfall accumulation products. The HHC can be very useful as a quality control check for the QPE rainfall products.

Importance of HHC

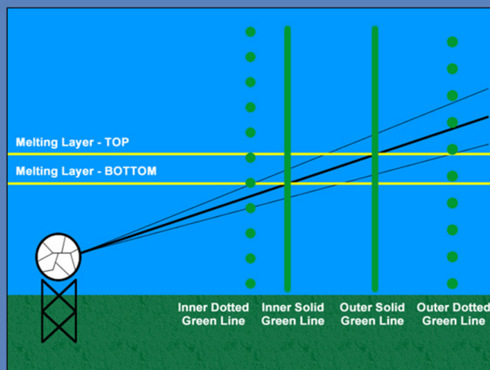


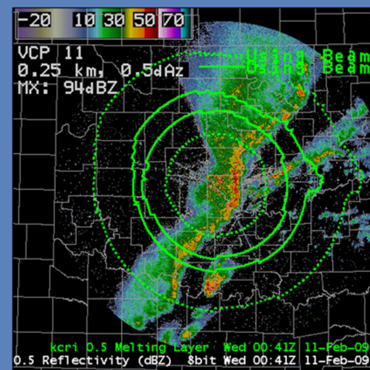
- HHC built each volume scan by QPE
  - HC value used to select rain rate equation
  - Overall quality control
  - Data are smoothed

The Hybrid Hydroclass (HHC) product is built by the QPE and represents the hydrometeor classification values that were used to determine the rain rate equation applied, on a bin by bin basis, for each volume scan.

This product can be used for an overall quality control check, but be cautious about checking every single bin. The data on this product are smoothed. The technique is called a 9 bin filter. For each bin, the most common hydroclass value for the surrounding 9 bins is assigned. This has the effect of reducing speckling on the product.

QPE Tour: Melting Layer





QPE's quality control implemented by Melting Layer Heights from MLDA

The QPE also relies on output from the MLDA. For each elevation angle, the MLDA provides four different heights related to the melting layer, which are displayed on AWIPS as an overlay product. For the purpose of QPE quality control, the top and bottom of the melting layer are used along with the Hydrometeor Classification values. Here's an example: for the Hydroclass value of Dry Snow (DS), one rain rate equation is used where DS is above the top of melting layer, while something different is used where DS is in or below the melting layer.

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How QPE Assigns Rain Rate

$$R(Z, ZDR) = (0.0142)Z^{0.77}ZDR^{-1.67}$$

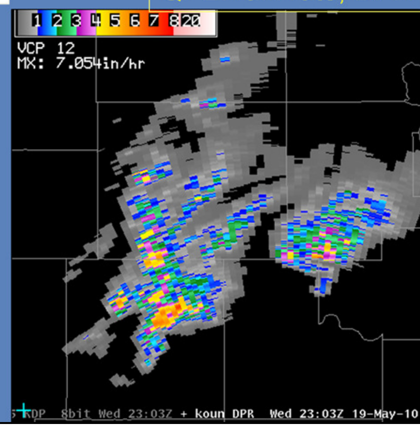
(Default)

$$R(Z) = (0.017)Z^{0.714}$$

$$R(KDP) = 44.0|KDP|^{0.822} sign(KDP)$$

- Which rain rate gets used for which HC?
  - Depends on hydroclass & melting layer
- DPR product unique to QPE
  - Quality control check

QPE: rain rate, DPR



There are a number of steps involved in determining which rain rate equation is used, given the Hydroclass value and position of the range bin with respect to the melting layer. In some cases, a multiplier is used with the Z-R equation, such as 0.8* R(Z). Variations of the R(Z) are used in or above the melting layer. The R(Z,ZDR) and R(KDP) equations are used below the melting layer where the expectation is that the beam is sampling rain (or where hail possibly mixed with rain is identified).

QPE has one product that has no PPS counterpart. It is the Digital Precipitation Rate (DPR) product. It is generated every volume scan and presents the rainfall rates in inches per hour that were used to generate the suite of QPE rainfall accumulation products. The DPR can be used as a quality control check to determine if the precipitation rates seem reasonable.

How QPE Assigns Rain Rate

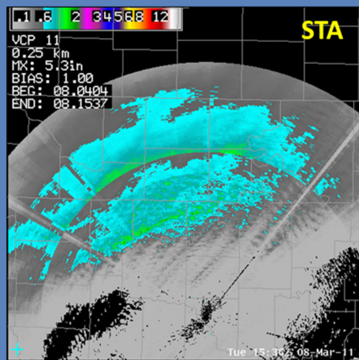
Classifications & Conditions	Equation
No Echo (ND) or Biological (BI)	0
Light/Moderate Rain (RA) or Big Drops (BD)	R(Z, ZDR)
Heavy Rain (HR) *and* Z ≤ 45 dBZ	R(Z, ZDR)
Heavy Rain (HR) *and* Z > 45 dBZ	R(KDP)
Rain/Hail (HA)	R(KDP)
Rain/Hail (HA) *and* echo is ***at or below*** top of ML	R(KDP)
Rain/Hail (HA) *and* echo is ***above*** top of ML	0.8*R(Z)
Graupel (GR)	0.8*R(Z)
Wet Snow (WS)	0.6*R(Z)
Dry Snow (DS) *and* echo is ***at or below*** top of ML	R(Z)
Dry Snow (DS) *and* echo is ***above*** top of ML	2.8*R(Z)
Ice Crystals (IC)	2.8*R(Z)

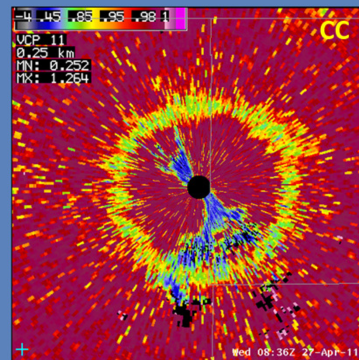
Editable

This table is a summary of the hydroclass values and position relative to the melting layer that determines which rain rate equation is used by the QPE. The primary idea to note is that rain rate equations that include the dual pol variables, R(Z,ZDR) and R(KDP) are used where the hydroclass values are mostly liquid and below the melting layer. The exception is Rain/Hail at or below the top of the melting layer. This group is in the top of the table.

At the bottom of the table, for hydroclass values that non-liquid, R(Z) is used with or without a multiplier. For Dry Snow (DS) above the top of the melting layer and Ice Crystals (IC), the 2.8 multiplier has resulted in significant overestimates in many cases. This multiplier is now editable, once sufficient local research has been done to determine a more appropriate value.

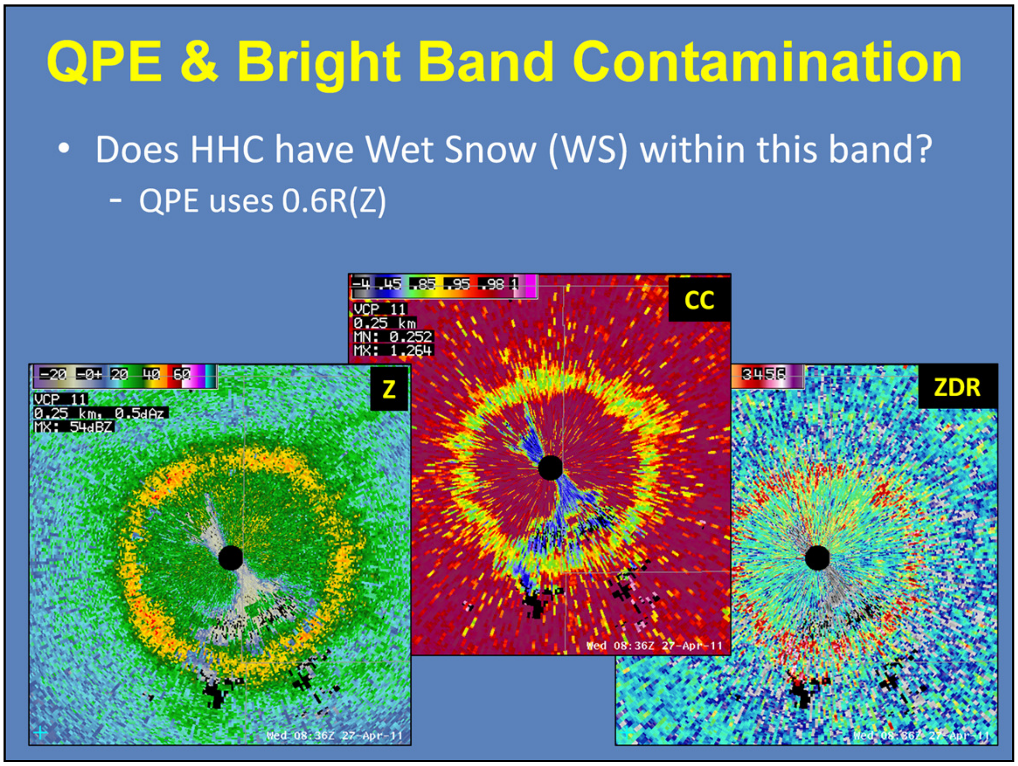
QPE Expectations





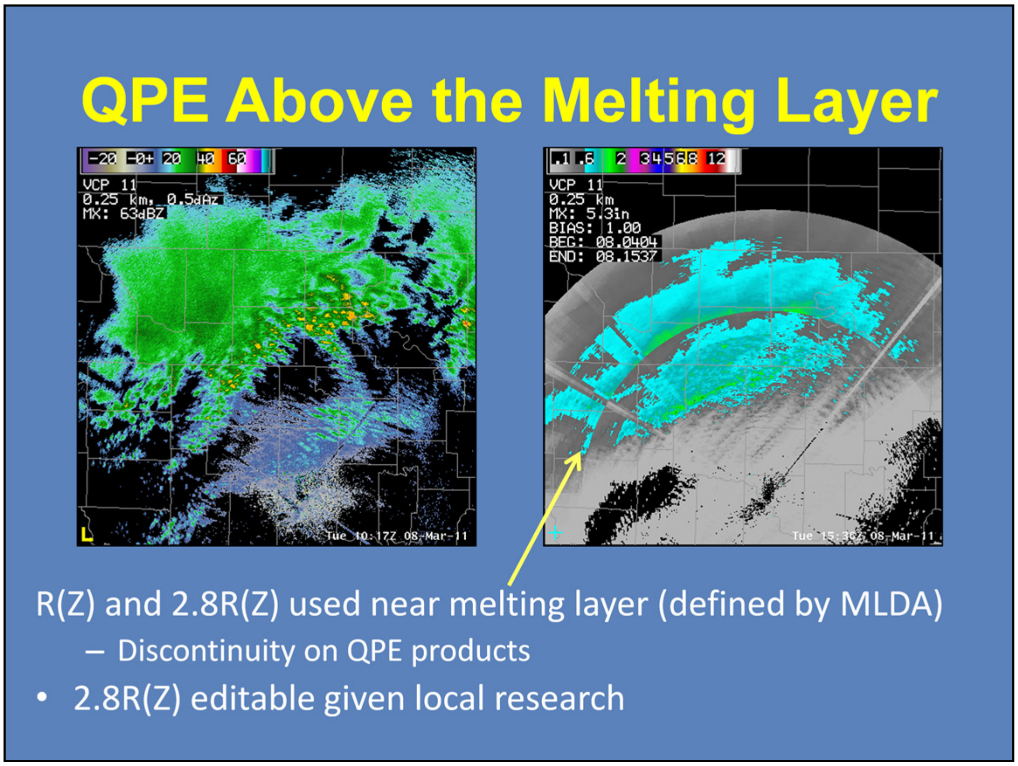
- Bright band contamination
- Above the melting layer
- Hail contamination
- Non-uniform beam filling

The next several slides summarize how QPE is designed to mitigate some of the most difficult problems with using a radar to estimate rainfall.



Bright band contamination has long been a challenge for using a radar to estimate rainfall. The QPE approach is to adjust the rain rate equation for water coated frozen hydrometeors such as wet snow that are typically located within a mesoscale melting layer (stratiform rain event). A multiplier of 0.6 is applied to the R(Z) relationship for the WS bins. There are some considerations to remember. The 0.6R(Z) equation is only applied to bins that fall within the melting layer (as defined by MLDA) and are identified as Wet Snow (WS) by the HCA.

The bright band is often apparent on Z, or CC, and ZDR, allowing for a base data quality control check for these algorithms. It is important to remember that QPE's ability to mitigate the overestimate of rain within the bright band is totally dependent on a band of Wet Snow (WS) being properly identified by the HHC coincident with the bright band on the base data products.



When the HHC assigns IC (Ice Crystals) or DS (Dry Snow), and the DS is above the melting layer, 2.8R(Z) is used to generate a rainfall rate. The location of the melting layer is based on output from the MLDA. This multiplier is now editable, given sufficient local research.

For DS in or below the melting layer, R(Z) is used. This use of R(Z) in or below the melting layer and 2.8R(Z) above can result in a discontinuity on QPE products near the melting layer for long term stratiform events. Here's an example Storm Total Accumulation (STA) product from an lengthy stratiform rain event.

This illustrates the difference between a human assessment of a transition vs. an algorithm. For an algorithm, the "top" of the melting layer is a sharp transition, while our human understanding is that the top is really a layer in itself.

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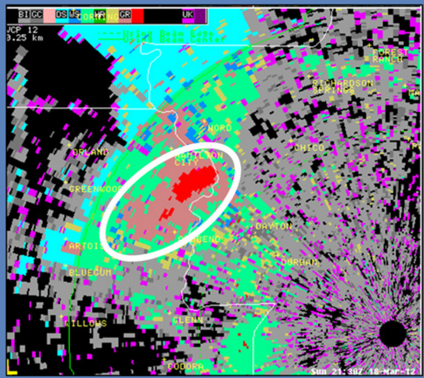
QPE & Hail Contamination

$$R(KDP) = 44.0|KDP|^{0.822}\, sign(KDP)$$

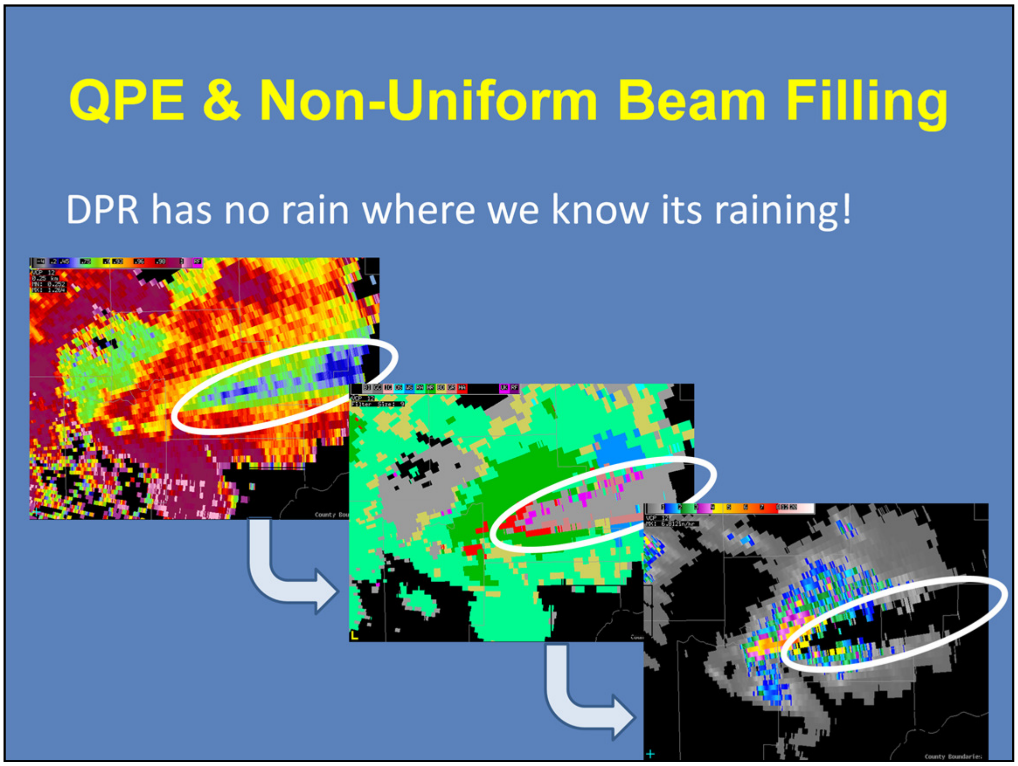
$$R(Z) = (0.017)Z^{0.714}$$



- Does HHC have Graupel (GR)?
  - Use 0.8R(Z)
- Does HHC have Hail Possibly Mixed with Rain (HA)?
  - Use R(KDP) if positive or 0.8R(Z)

QPE addresses hail contamination for range bins that are likely to contain hail or graupel, as identified by the HHC. The approach is to use 0.8R(Z), which lowers the rain rate by the 0.8 multiplier, or to use R(KDP). KDP is the Dual-Pol variable that is sensitive to the liquid water content in the volume. The presence of hail or the size of hail has little impact on the KDP value, so it is a good choice for conversion to rain rate. The R(KDP) equation includes the term sign(KDP) to check for the possibility that KDP is negative. Negative rain rates based on KDP are not used by QPE.

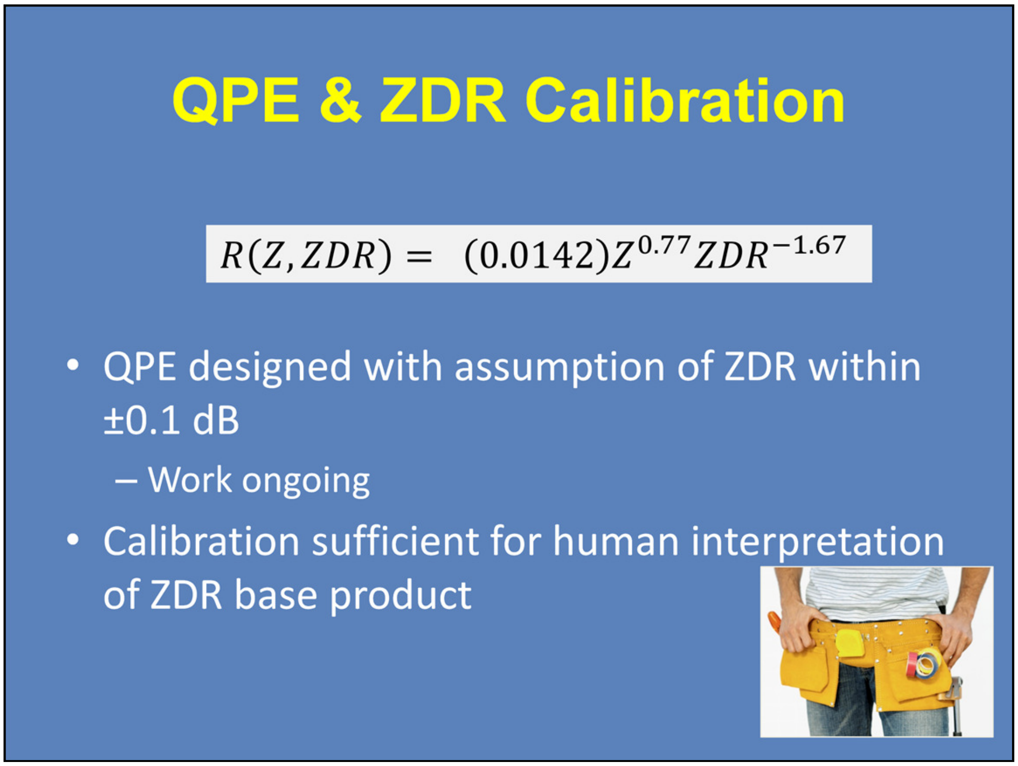
In this HHC example, most of the bins within the white circle are either Graupel (GR) or Hail.



The artifact of a swath of low CC values due to non-uniform beam filling (NBF) can be either easy to spot or subtle. By comparing it to other radar data and understanding the environment, you can ask yourself if the CC values make sense.

It is important to be mindful of this artifact because CC affects the Hydroclass value that gets assigned, which then affects whether or nor rainfall is accumulated. In this case, biological targets are identified by the Hydrometeor Classification Algorithm, and QPE assigns no rain rate to bins with the Biological Hydroclass value.

There are steps within the RPG Dual Pol Preprocessor to identify bins with NBF, though they may not always be successful.



The QPE logic and parameter design was based on an assumption of ZDR values that are calibrated to within ±0.1 dB. As of this writing, it is not known if that level of accuracy has been achieved.

ZDR calibration is based on an accurate calibration of the horizontal and the vertical channels. With rare exceptions, ZDR values are sufficient for human interpretation. For example, many of the benefits of ZDR, such as updraft or hail detection, are based on relative values of ZDR. A relative minimum, rather than a specific value of ZDR adds confidence in the presence of hail.

The QPE, and the other RPG Dual-Pol algorithms have a higher sensitivity to ZDR calibration, and work is underway to develop techniques to refine calibration of the horizontal and vertical channels.

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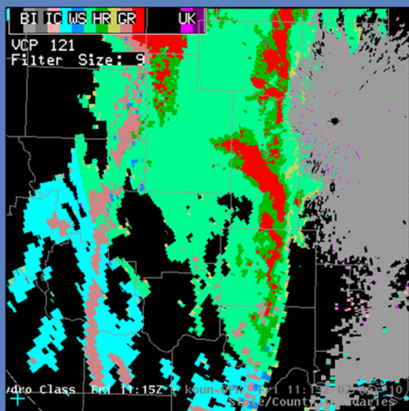
QPE "Ground Rules"



- Frequently investigate the:
  - ML product to verify that it makes sense
  - HHC product to verify that it makes sense
- Recognize situations when QPE performance is likely to be negatively impacted
  - Expect better performance below the melting layer

Since QPE relies so heavily on the output of the MLDA and the HCA, it is important to avoid using the QPE products "as is". The QPE "ground rules" include monitoring the output from the MLDA and looking at the HHC product to verify that the melting layer and the hydroclass values make sense.

It is also important to be mindful of situations where QPE performance is likely to be negatively impacted, such as above the melting layer. Better performance can be expected below the melting layer.

The strengths of QPE are mostly based on using the benefits of Dual-Pol to mitigate long standing challenges with using any radar to estimate rainfall.

Preventing returns from non-meteorological targets from conversion to rainfall is based on identification of Ground clutter and biological returns by the HCA.

For bins that are identified with precipitable returns, QPE has three different rain rate equations that are applied based on the hydroclass value and the height with respect to the melting layer. These choices help to mitigate both bright band and hail contamination.

QPE also has a rain rate product generated every volume scan, which can be an asset for quality control.

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QPE Limitations

1. QPE "tuning" continues
2. Non-uniform beam filling unique impact on Dual-Pol base data
3. Sensitivity to ZDR calibration
4. Invalid hydroclass increases error
5. Discontinuity at top of melting layer
6. Reliance on MLDA and HCA
   – Must monitor these to ensure they "make sense"

As with most new algorithms, there are a number of limitations to QPE that will likely improve over time. The original QPE design and associated parameters were based on research in Oklahoma, and regional "tuning" is ongoing.

Non-uniform beam filling has a unique impact on Dual-Pol base data, which translates to the QPE performance.

The performance of the R(Z,ZDR) equation is highly dependent on accurate ZDR values. The accuracy of ZDR is sufficient for human interpretation of the ZDR base product, but QPE performance is more sensitive to ZDR.

If an assigned hydroclass value is invalid, that will increase the error of the rainfall estimate.

For long term stratiform events, especially in winter, a discontinuity at the top of the melting layer is likely, unless the 2.8*R(Z) multiplier has been edited based on local research.

QPE is different than other RPG algorithms in terms of its reliance on the output from both the MLDA and the HCA. This means that using QPE in operations requires monitoring (at least) the HHC product to ensure that the outputs "make sense".

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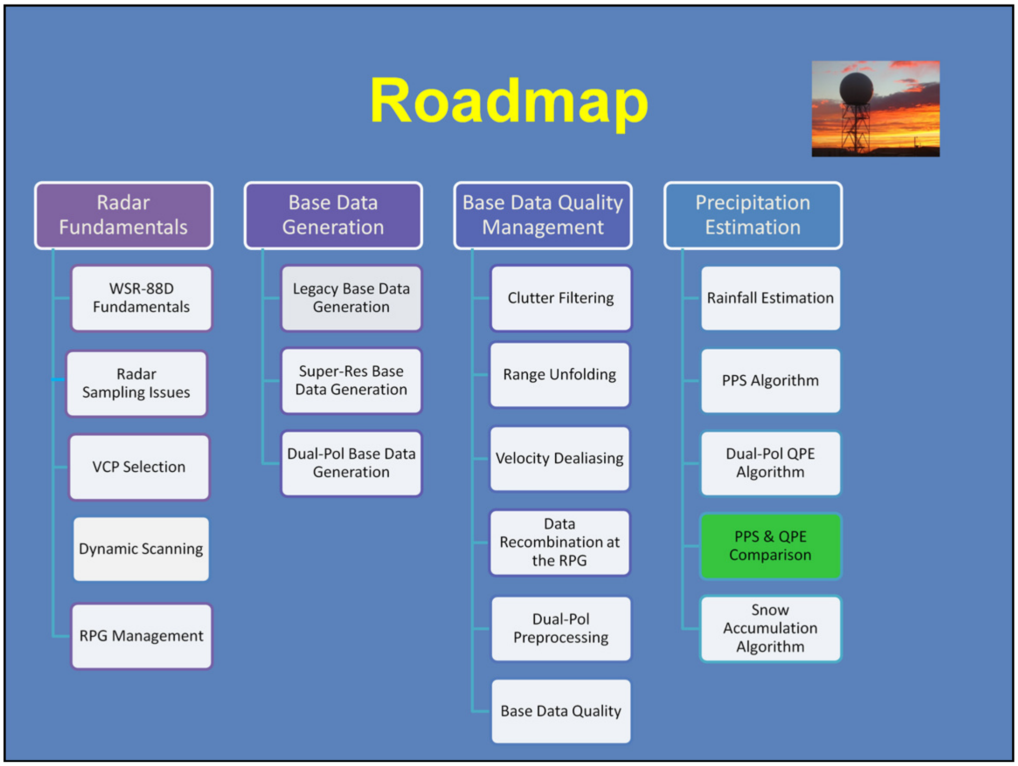
Welcome to the PPS and QPE Comparison lesson



Here is the “roadmap” with your current location

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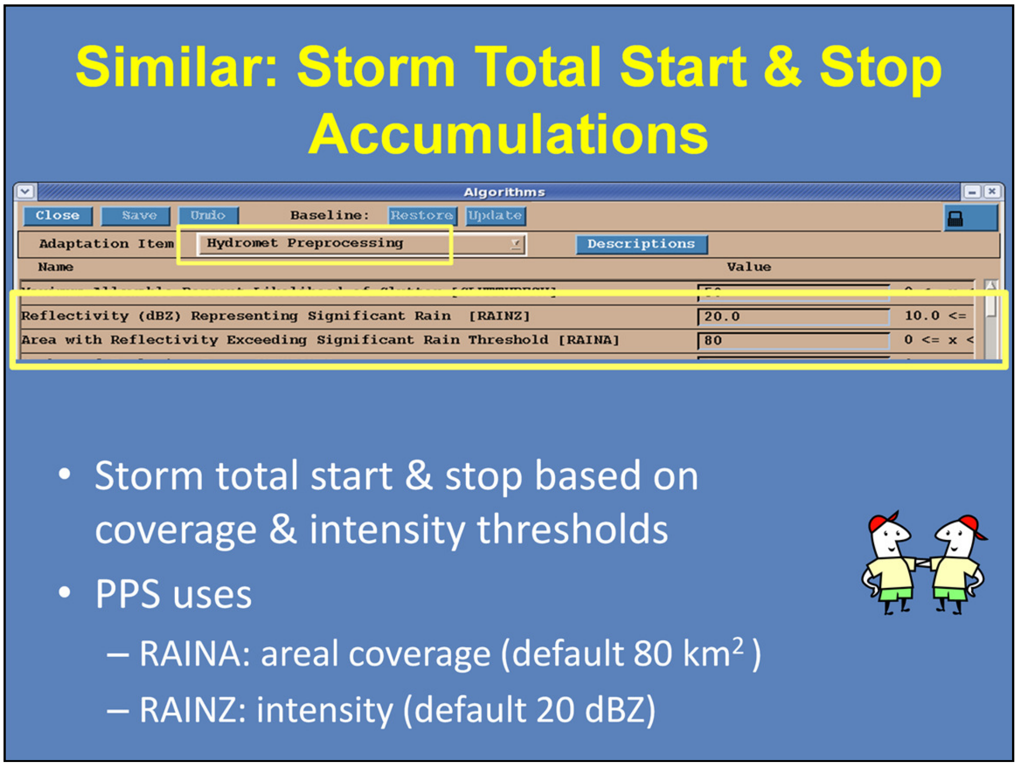
PPS and QPE Comparison
Objectives

1. Identify design similarities between the PPS and QPE

2. Identify design differences between the PPS and QPE

There are two objectives for PPS and QPE Comparison, and they will be taught in sequence during this module.



The next several slides present the similarities and differences between the PPS and the QPE.

The first similarity between the PPS and QPE is how the storm total accumulations start and stop. They both use the same concept. If the radar returns exceed thresholds of areal coverage and intensity, accumulations begin. Once the returns fall below the thresholds for one hour, accumulations stop.

Here are the thresholds for the PPS, along with their default values. RAINA is the areal coverage, while RAINZ is the intensity, or dBZ, threshold. RAINA and RAINZ are accessed from the Algorithms window at the RPG under “Hydromet Preprocessing”.

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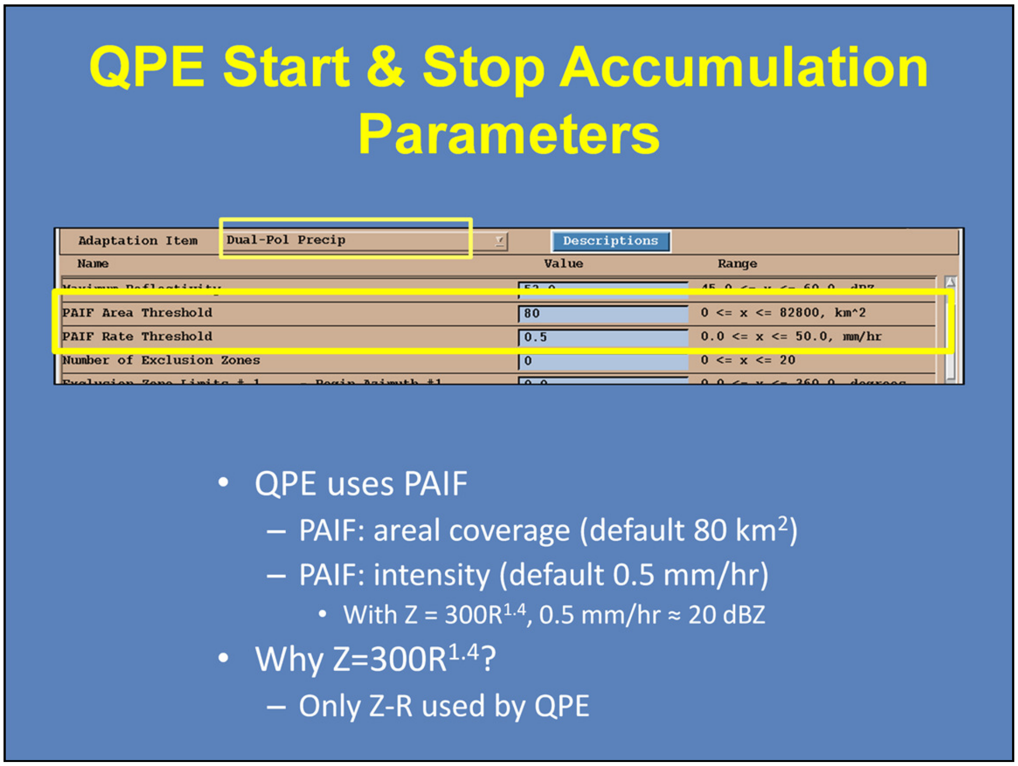

QPE uses the same concept for start and stop of storm total accumulations, it just uses different threshold names. The QPE thresholds start with the Precipitation Accumulation Initiation Function (PAIF). The PAIF Area Threshold is analogous to RAINA, while the PAIF Rate Threshold is analogous to RAINZ. Though the units differ, the default values are the same as for the PPS. The PAIF area threshold is 80 km^2, while the PAIF intensity threshold is 0.5 mm/hr. You probably don't spend your time converting dBZ to mm/hr, but for $Z=300R^{1.4}$, 0.5 mm/hr is equivalent to 20 dBZ. Why use $Z=300R^{1.4}$? In the QPE, this is the only direct Z-R relationship used.

The PAIF thresholds are accessed from the Algorithms window at the RPG under "Dual-Pol Precip".

Though the units differ, the PPS and QPE parameters for starting and stopping accumulations have the same default values.

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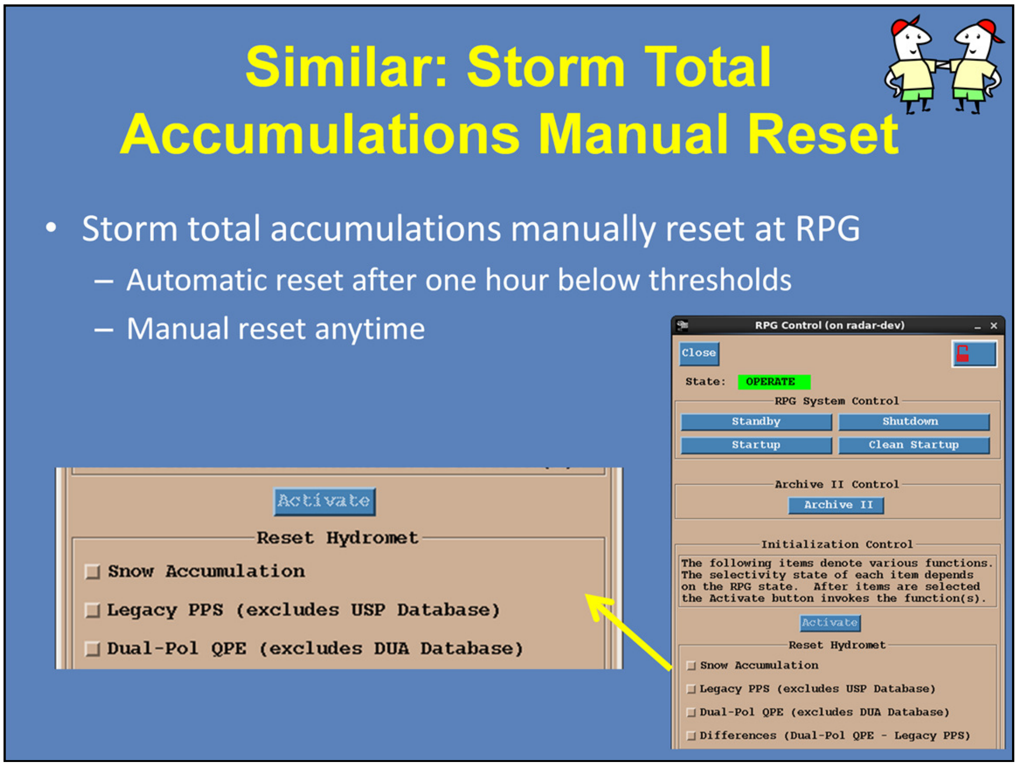
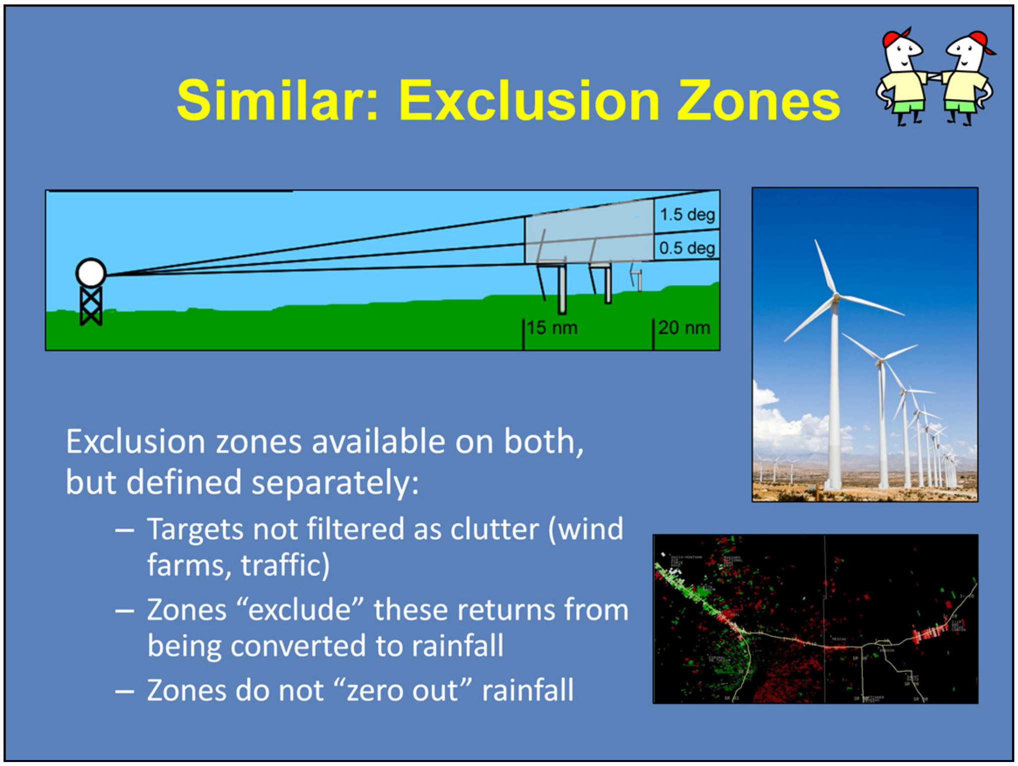
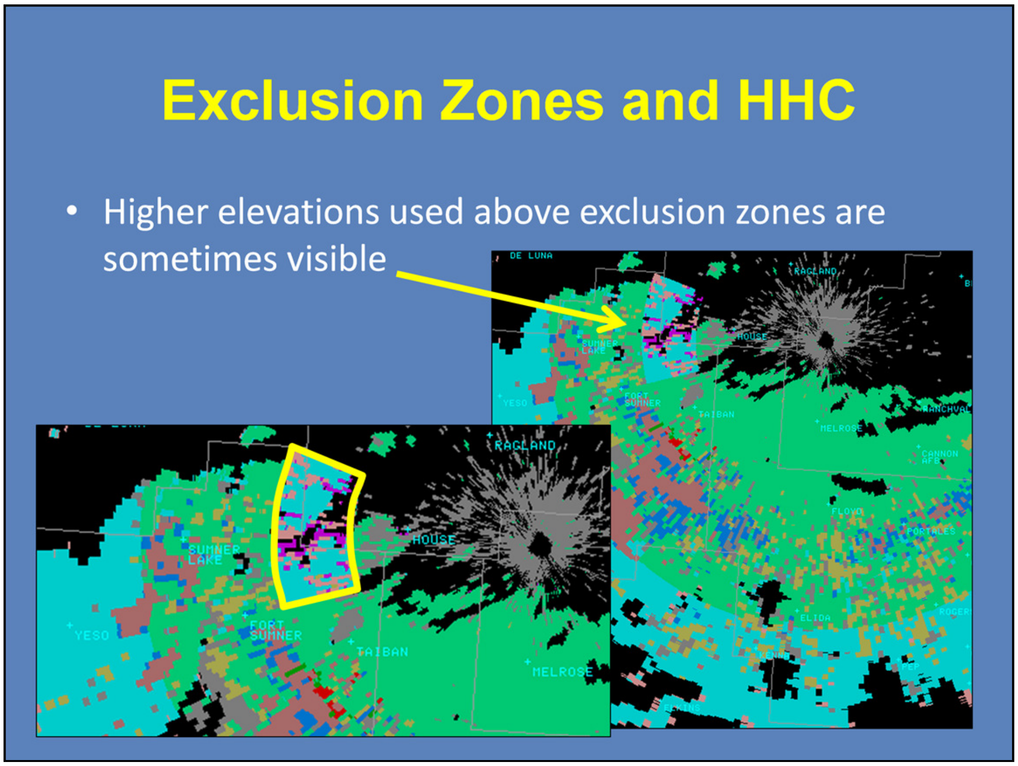


Both the PPS and the QPE have an automatic reset of the storm total accumulations after one hour of radar returns below their respective thresholds. Both the PPS and the QPE allow for a manual reset, which can be done from the RPG Control Window, selecting the “Legacy PPS” and the “Dual-Pol QPE”, respectively.

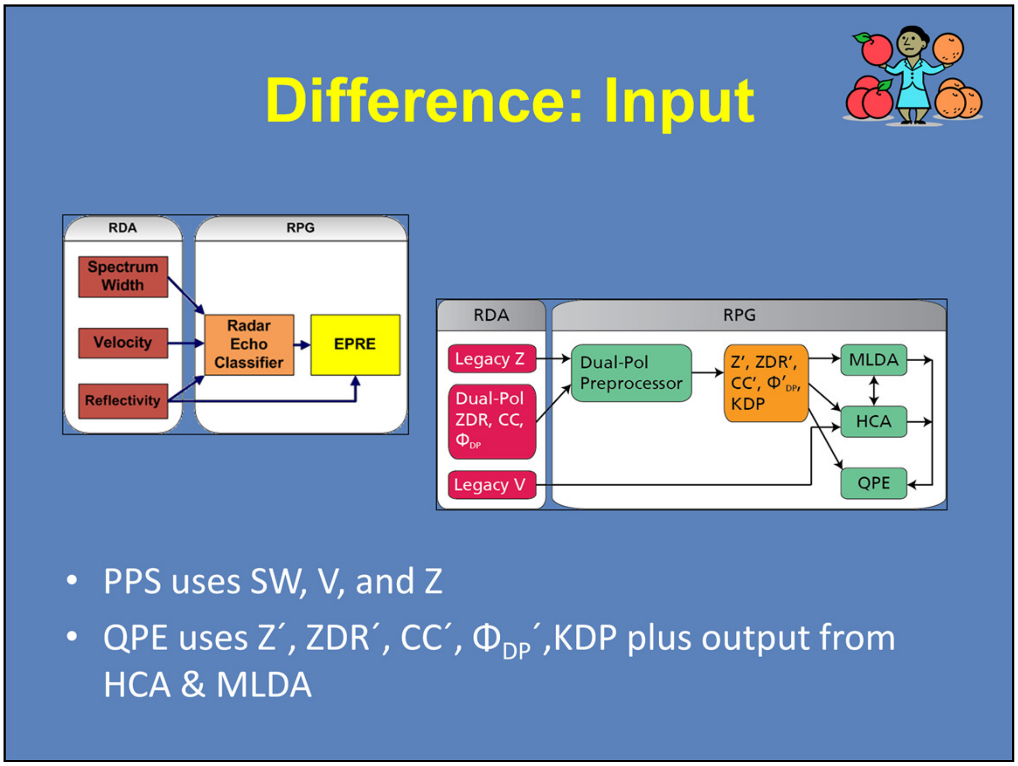


The next similarity between the PPS and the QPE is the use of exclusion zones. There are moving ground targets that are not filtered as clutter, such as rotating wind turbine blades and traffic on roads. Returns from targets like this usually exceed the intensity thresholds (RAINZ and PAIF Rate). Exclusion zones can be applied to both the PPS and QPE, preventing this type of radar return from being converted to rainfall.

Exclusion zones are an important tool, defining a volume from azimuth to azimuth, range to range, and up to (and including) a maximum elevation angle. There is a misconception that exclusion zones "zero out" rainfall estimates within the zone. If a range bin falls within an exclusion zone, PPS and QPE use the lowest elevation that is above the exclusion zone to estimate rainfall.



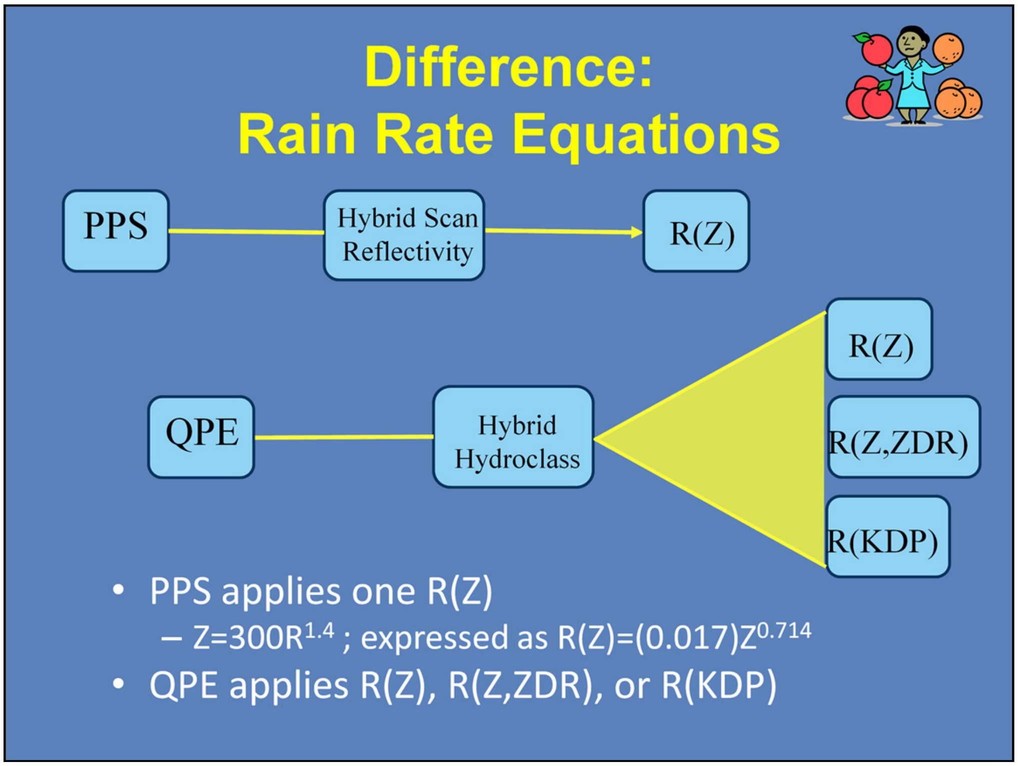
Here is an example where the use of exclusion zones for QPE becomes evident in the HHC product. Higher elevations are used by QPE for the azimuths and ranges within the exclusion zone, and that can sometimes be reflected in the hydroclass types on the HHC. In this case, you can see the transition from light to moderate rain (light green) to dry snow (light blue) at a consistent range from the radar. The exception is the block just to the west of the radar, which has mostly dry snow and some graupel. This is the result of the higher elevation above the exclusion zone intersecting the melting layer.



The Legacy PPS relies on the legacy base data: spectrum width, velocity and reflectivity. Though reflectivity is the only input for conversion to rainfall, spectrum width and velocity are used by the Radar Echo Classifier to identify bins that likely contain clutter.

QPE relies on the reflectivity and Dual-Pol base data, but only after it has passed through the RPG Dual Pol Preprocessor algorithm. QPE also uses the output from the HCA and the MLDA to choose the rain rate equation for each range bin. HCA and MLDA help to prevent non-meteorological returns from being converted to rain rate and to determine the best rain rate equation for the particular range bin.

So there is a significant difference with the inputs to the PPS, compared with the QPE.



A key difference between the PPS and the QPE is the approach for converting base data to rainfall rate.

The PPS relies solely on a Z-R relationship, with editable Z-R relationship parameters. The familiar $Z=300R^{1.4}$ can be represented as $R(Z)=(0.017)Z^{0.714}$, which is a better representation to understand the QPE rainfall rate equations. The 3 different QPE rain rate calculation methods are each based on different inputs, and the notation tells you the input. These equations are selected based on the type of hydroclass assigned on the HHC product. For some hydroclass values, R(Z) is used with a multiplier.

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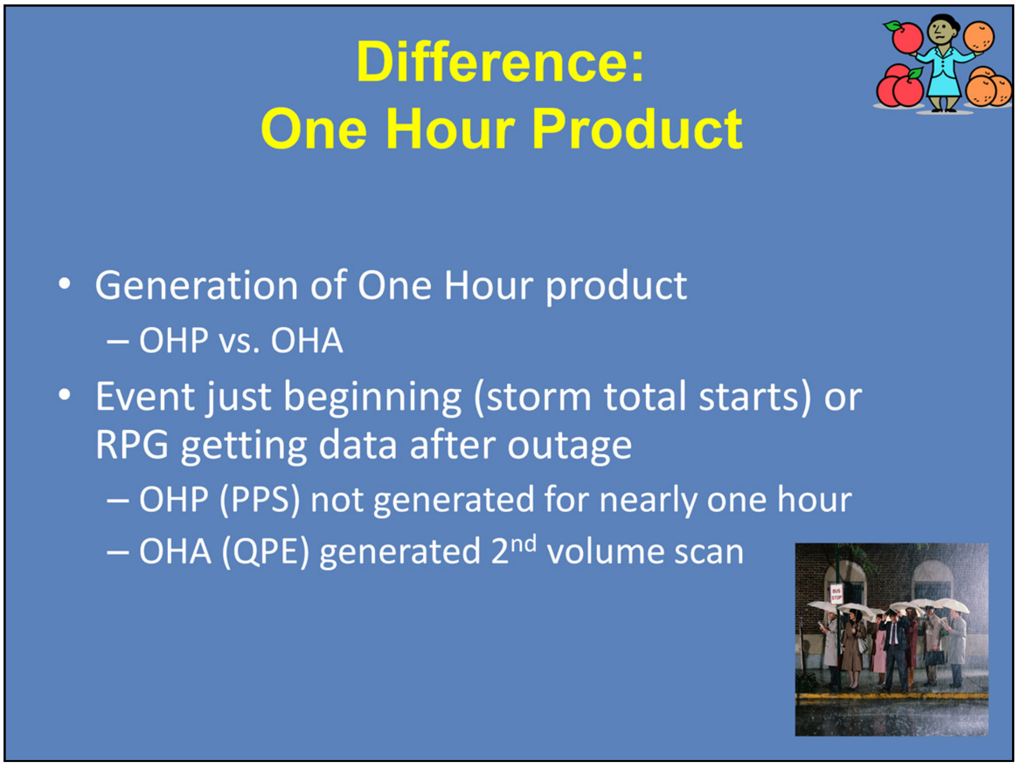

There is a significant difference between the PPS and QPE on the generation of their respective one hour products, the OHP and the OHA. This difference occurs for the beginning of an rainfall event or the return of base data to the RPG after an outage. The beginning of an event means that the storm total thresholds have been exceeded and accumulations have begun. The return of base data to the RPG after an outage means that there has been some kind of failure (wideband or RDA) that prevents base data from getting to the RPG.

In either case, the PPS will not generate an OHP for nearly one hour, while the OHA will be available beginning with the 2nd full volume scan.

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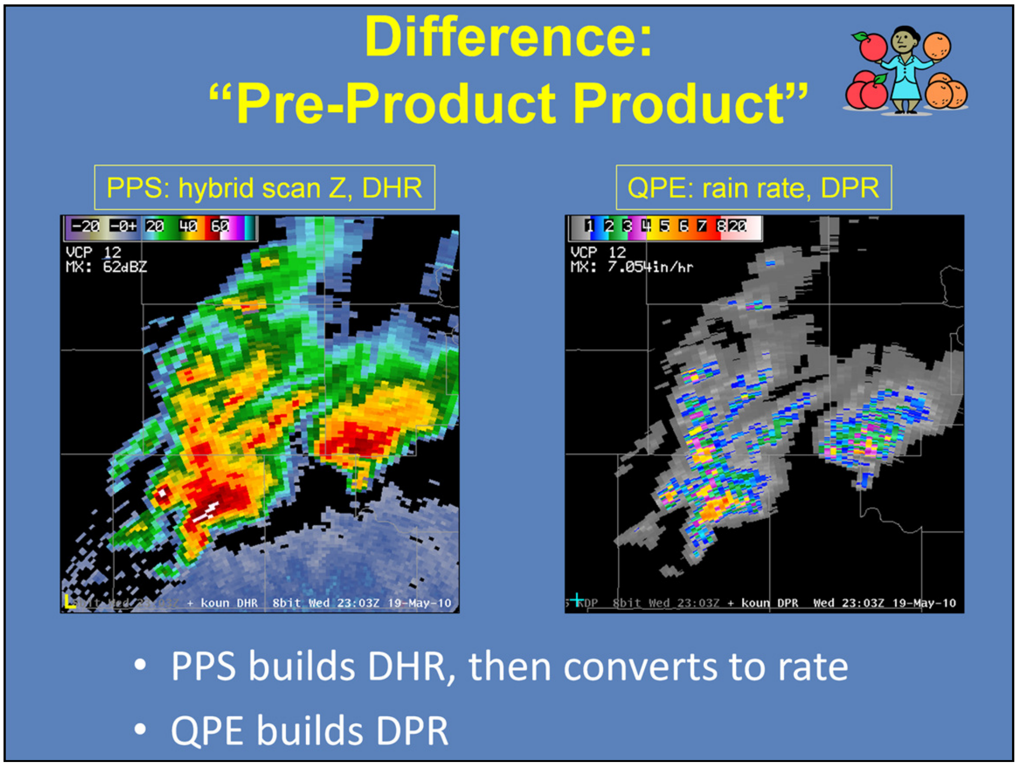

Both the PPS and QPE end up with rain rates assigned to every range bin before the products are built, but the respective methods are different, and the products available to see what was used to generate the accumulations differ.

In terms of a "pre-product" product, the PPS gives you the Digital Hybrid Scan Reflectivity (DHR), which is the dBZ value for each range bin before it is converted to rainfall rate (example on the left). The QPE gives you the rainfall rate directly, via the Digital Precipitation Rate (DPR), which is the instantaneous rate for each range bin that is used for the product accumulations (example on the right).

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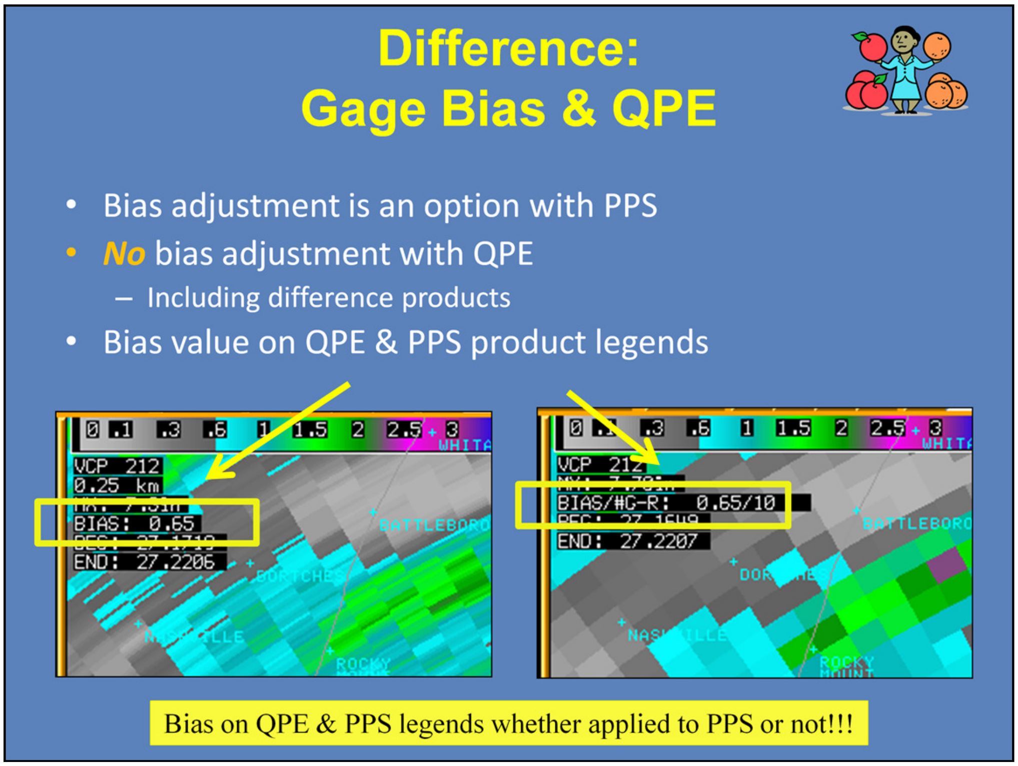

There is also a difference between the PPS and the QPE with respect to the application of a rain-gage bias. Bias adjustment is an option with the PPS, but there is no such option to apply a rain-gage bias to the QPE accumulations. All of the QPE-generated products are un-biased, including the QPE Difference products. You will learn more about the QPE products in the topic on base and derived products.

Unfortunately, a bias value is shown in the product legends of both the PPS and QPE products, irrespective of whether the bias has been applied to the PPS. For QPE products, always disregard the bias value. For the PPS products, if there is a decision to apply the bias, it must be communicated to the current staff and to forecasters on subsequent shifts.

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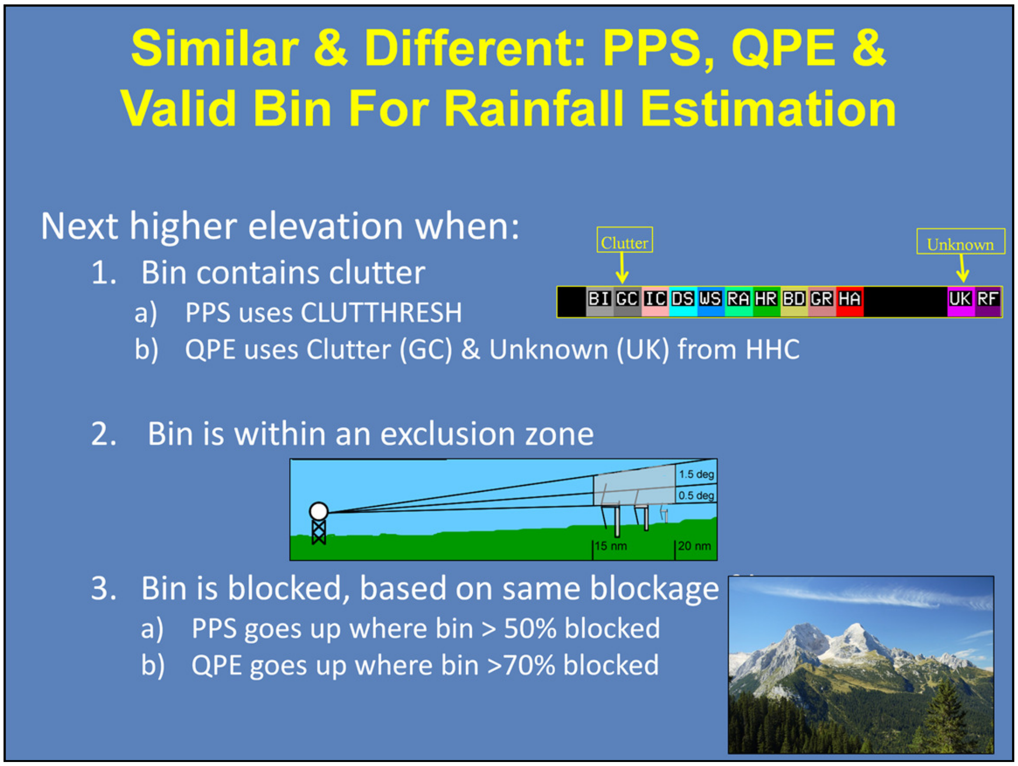

In a general way, the approach for selecting a bin to be converted to rainfall is similar for the PPS and the QPE. There is some difference in the implementation. There are three requirements that can cause the PPS or the QPE to use a higher elevation angle.

1. If the bin is suspected of containing clutter, the next higher elevation is used. For the PPS, this decision is based on whether the output of the Radar Echo Classifier exceeds the setting of CLUTTRESH. For the QPE, this decision is based on whether ground clutter (GC) or Unknown is assigned from the HHC.

2. If the bin falls within an exclusion zone, the next higher elevation is used. It is recommended that the same exclusion zones be defined for both the PPS and the QPE.

3. Based on the same blockage data file, if the bin is partially blocked beyond a threshold, the next higher elevation is used. For the PPS, the next higher elevation is used if the partial blockage exceeds 50%. For the QPE, the next higher elevation is used if the partial blockage exceeds 70%.

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Welcome to the lesson on the Snow Accumulation Algorithm.

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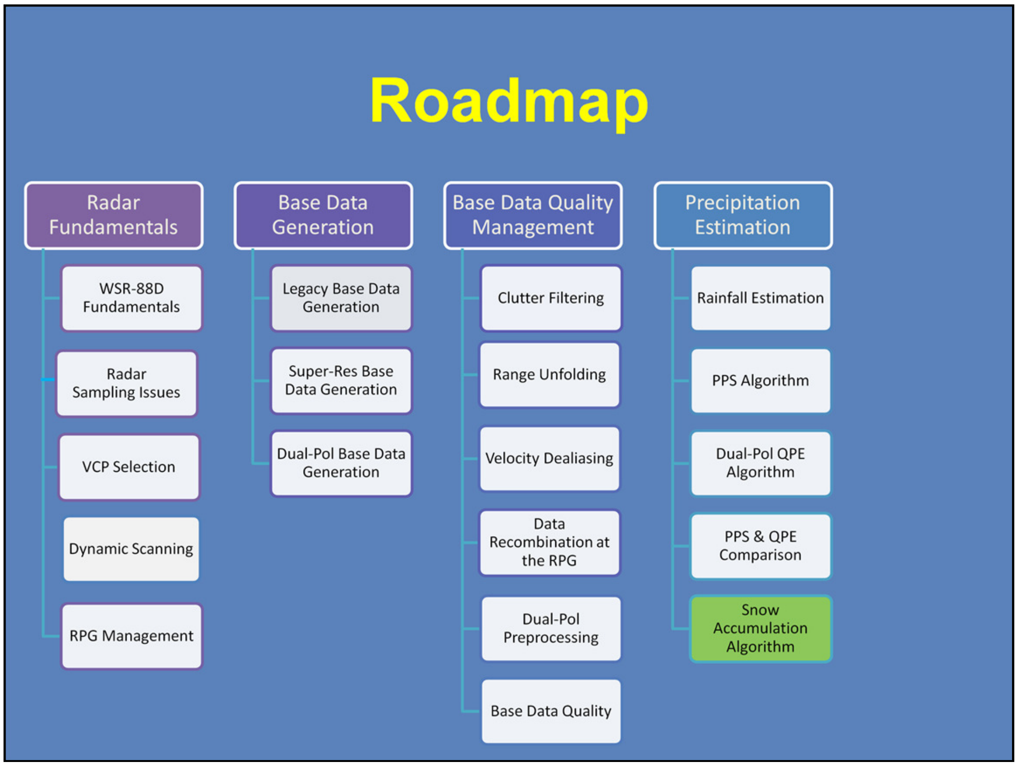
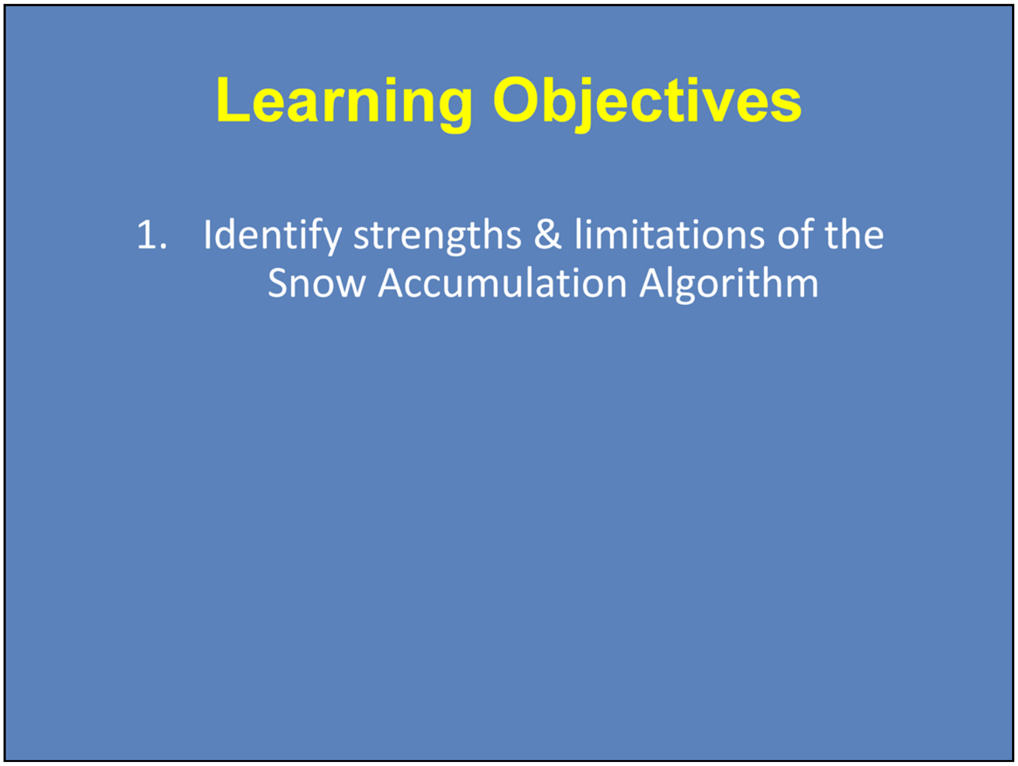
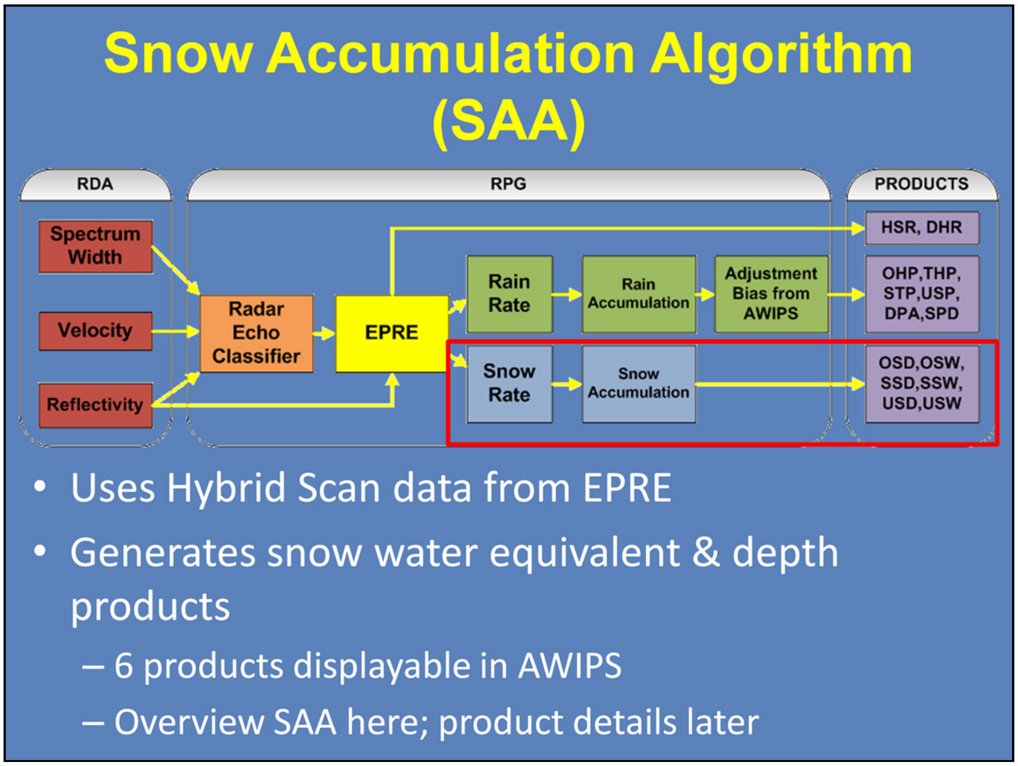


Here is the Roadmap with your current location.



There is one objective for this lesson.



We now focus on the generation of snow water equivalent and snow depth products from the Snow Accumulation Algorithm (or SAA).

The SAA uses hybrid scan data from the Enhance Preprocessing Algorithm (EPRE)

After data processing, this algorithm produces 6 total products in AWIPS that represents values for snow water equivalent and depth over various time ranges.

Currently 6 products in AWIPS and more information on the products will be presented in a later lesson.

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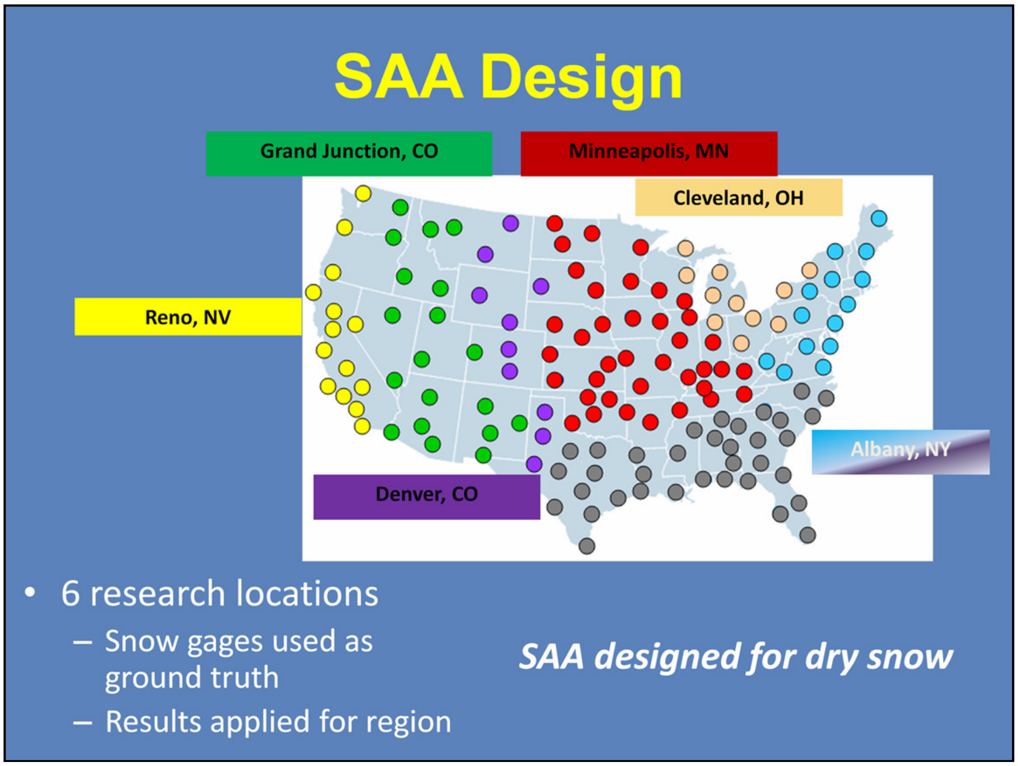
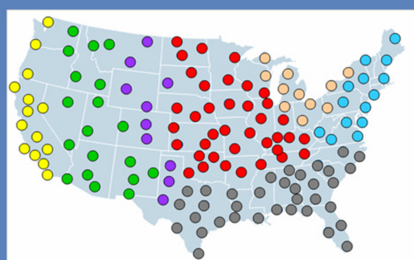


The SAA was developed from data collected at 6 different research locations. At each of these locations, a network of high quality snow gages was used as ground truth against the radar snowfall estimates. The output of this research provided default adaptable parameters that are used at each of the regions on the map. Note that there was not a research site selected in the southern United States. The data for Albany was selected for use in both the Northeast and Southern United States.

One of the most important assumptions with the SAA is that it was designed for dry snow events.

Z-S Relationships

- Reflectivity (Z) to rate of snow water equivalent (S)
- Same default Z-S relationship for each region



Research Location	Relationship
Albany, NY	$Z = 120\ S^2$
Cleveland, OH	$Z = 180\ S^2$
Minneapolis, MN	$Z = 180\ S^2$
Denver, CO	$Z = 130\ S^2$
Grand Junction, CO	$Z = 40\ S^2$
Reno, NV	$Z = 222\ S^2$

Similar to how there are Z-R relationships to estimate rainfall rates from reflectivity, there are Z-S relationships developed to estimate snow water equivalent from reflectivity. Using the EPRE Hybrid Scan data as input, the returned power is plugged into a Z-S relationship using coefficients developed from one of the regional research locations.

This table lists the default Z-S relationships for each research location.

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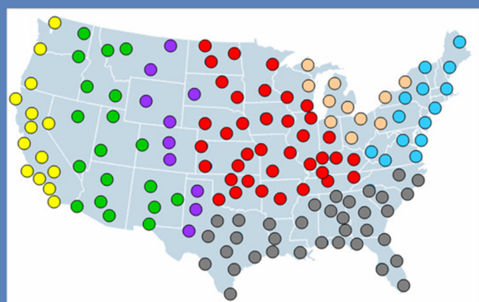
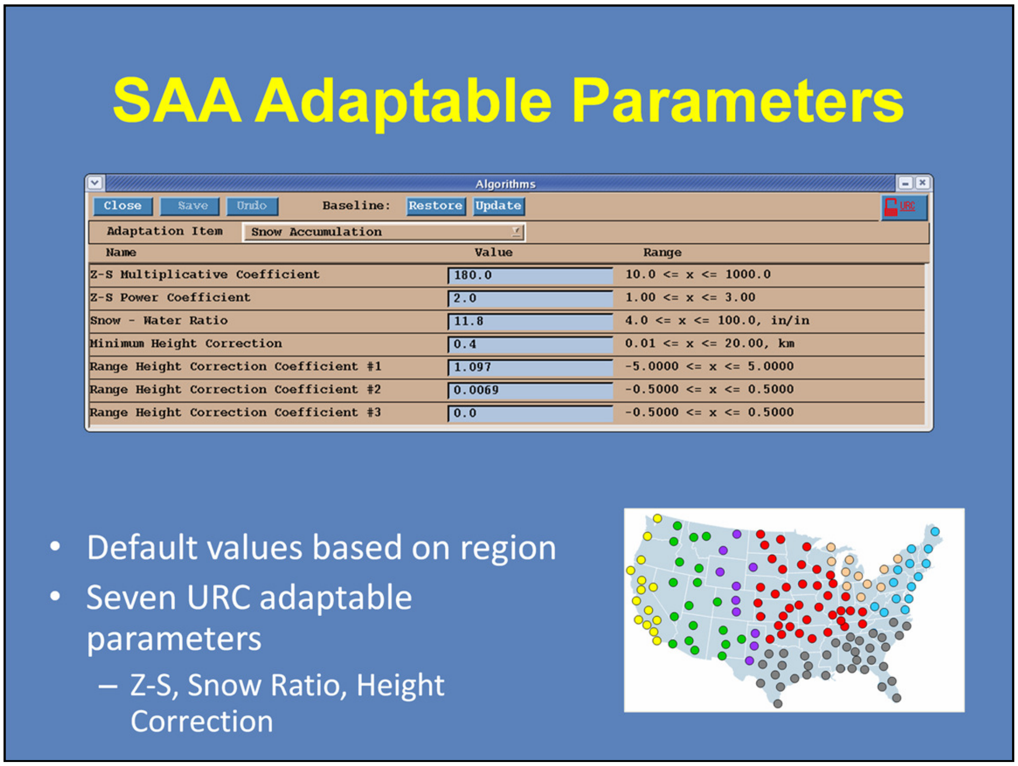
SAA and Snow Ratio

- Snow ratio
  - Water equivalent to snow depth
- Same default Snow Ratio for each region

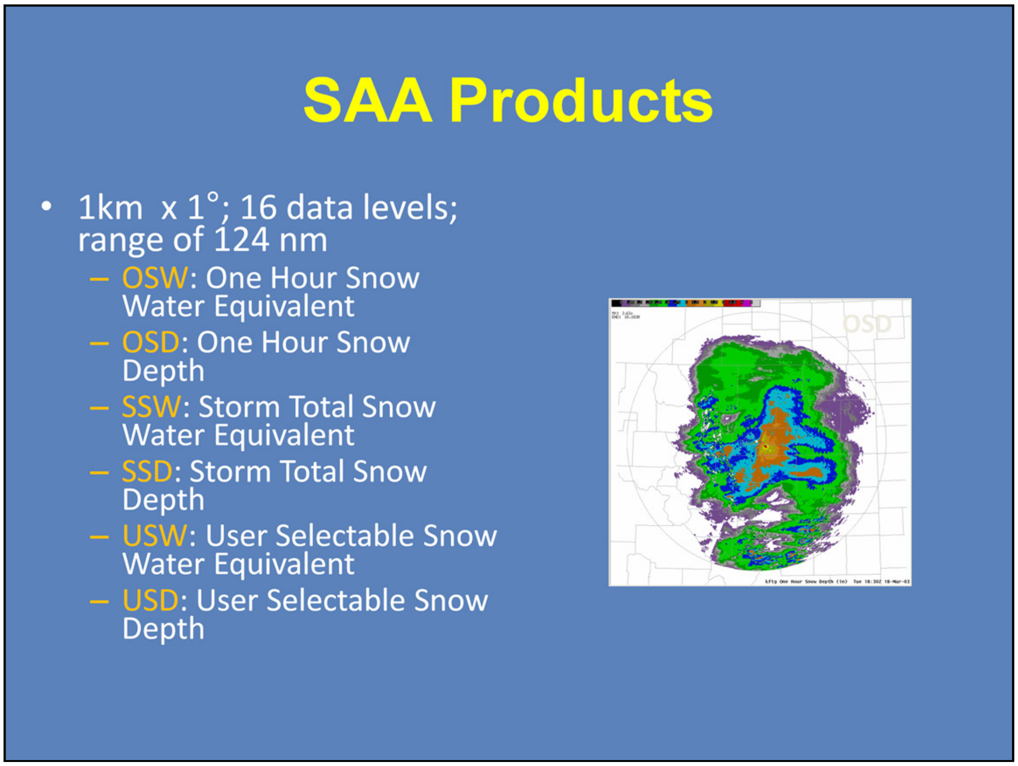


Research Location	Snow Ratio
Albany, NY	11.8
Cleveland, OH	16.7
Minneapolis, MN	11.8
Denver, CO	13.3
Grand Junction, CO	14.3
Reno, NV	8.0

The snow ratio used for converting snow water equivalent to snow depth is another adaptable parameter and the default values for each region are listed here. Even within a given region, it is expected that the appropriate ratio will vary from event to event.



All the sites within a given region have the same default values for the SAA adaptable parameters. There are seven SAA adaptable parameters that are editable under URC guidelines in the RPG. Here you can edit the coefficients in the Z-S relationship, and modify the snow-water ratio.



There are six snow products generated, all with 16 data levels, a resolution of 1km by 1 degree and a range of 124 nm. There are three durations: one hour, storm total and user selectable. For each of these durations, there is a snow water equivalent and a snow depth product. Examples of the products will be shown with more information in a later lesson.

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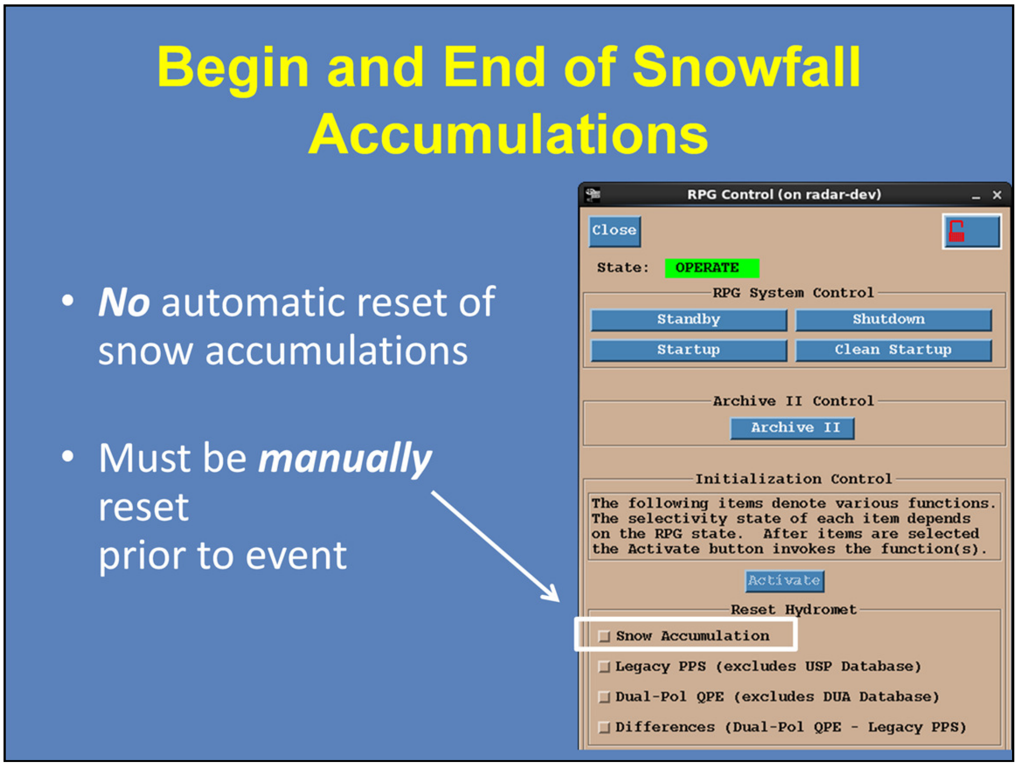
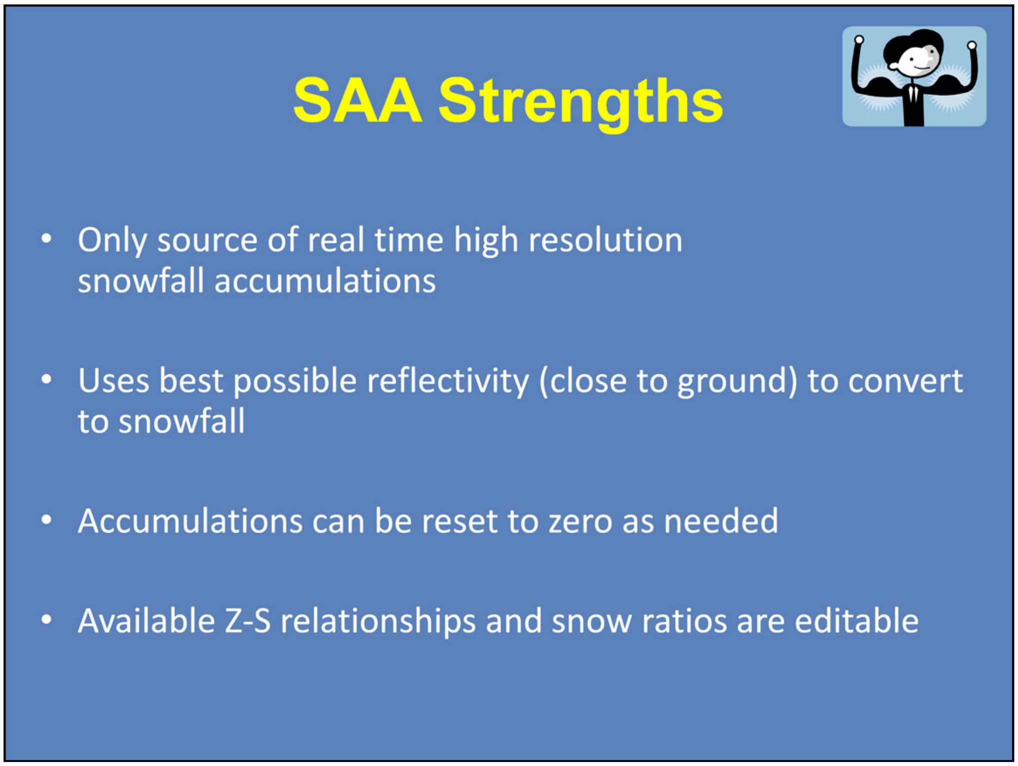


The SAA is designed to be event driven, and there is no automatic reset of the accumulations. This means the snow accumulations must be reset to zero at the beginning of an event. Resetting is done at the RPG Control window, just as with a reset of the PPS or QPE storm total accumulations.



The first strength of the SAA is that it is the only source for real time high resolution snowfall accumulations.

Since the SAA also uses EPRE as input, the SAA uses a reflectivity value closest to the ground that is not from clutter and is not blocked by the beam.

At the RPG, snow accumulations can be reset to zero as needed.

The Z-S relationships and snow ratios are editable.

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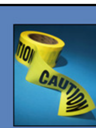
SAA Limitations



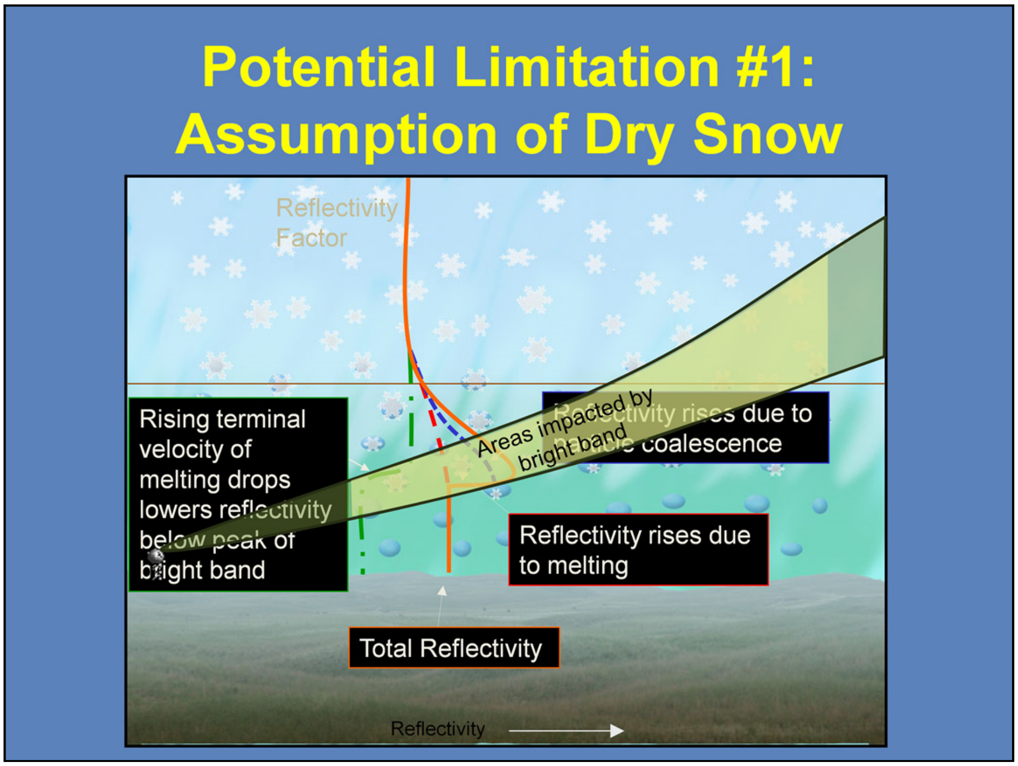
- SAA designed for dry snow
- Ground truth likely needed
  - to verify precipitation type
  - to determine onset of accumulation
- No automatic reset of accumulations; must be done manually
- Available Z-S relationships and snow ratios may not be representative

Perhaps the most important thing to remember about the SAA is that it designed for dry snow, snow that does not melt as it falls or when it hits the ground.

Ground truth will likely be needed to verify precipitation type and to determine the onset of snow accumulation.

The onset must be known in order to reset the snow accumulations, which must be done manually.

Finally, the default Z-S relationship were developed at specific locations and applied across an entire region. So both the Z-S relationship and the snow ratio may not be representative for your CWA and may require adjusting.



The Z-S equation in the Snow Accumulation Algorithm is based on the assumption that the precipitation at the surface is dry snow. We know this assumption isn't true in the bright band, and here is a closer look at what's going on.

As snow flakes approach the melting layer, liquid resides on their ice surfaces. The increased water coating helps colliding ice particles to stick together and snow flakes begin to increase in size. Larger particles form and the radar reflectivity increases. The liquid water coating itself also helps to increase radar reflectivity. An offset to the increasing reflectivity occurs when the terminal velocity of these particles increases with melting. Increasing terminal velocity increases the separation between hydrometeors and lowers the reflectivity.

Due to these mechanisms, overestimation can occur in areas where the radar samples the bright band because wet snow has a higher reflectivity than dry snow. This overestimation can occur even when only portions of the beam (i.e., the top or bottom) are sampling the bright band.

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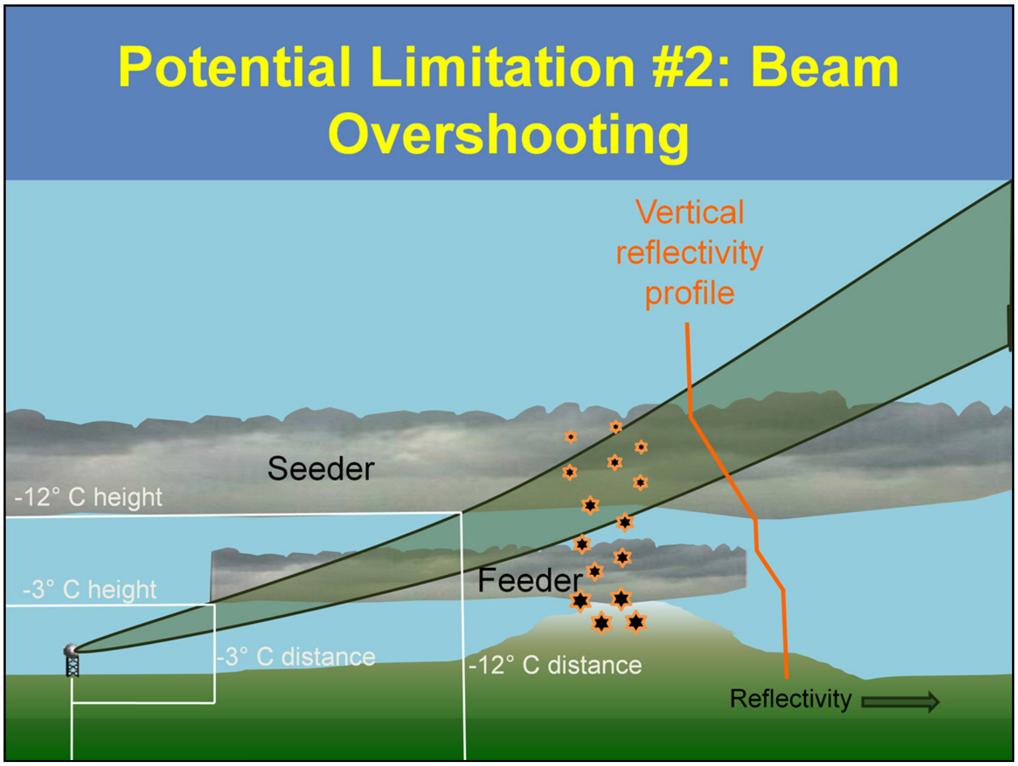
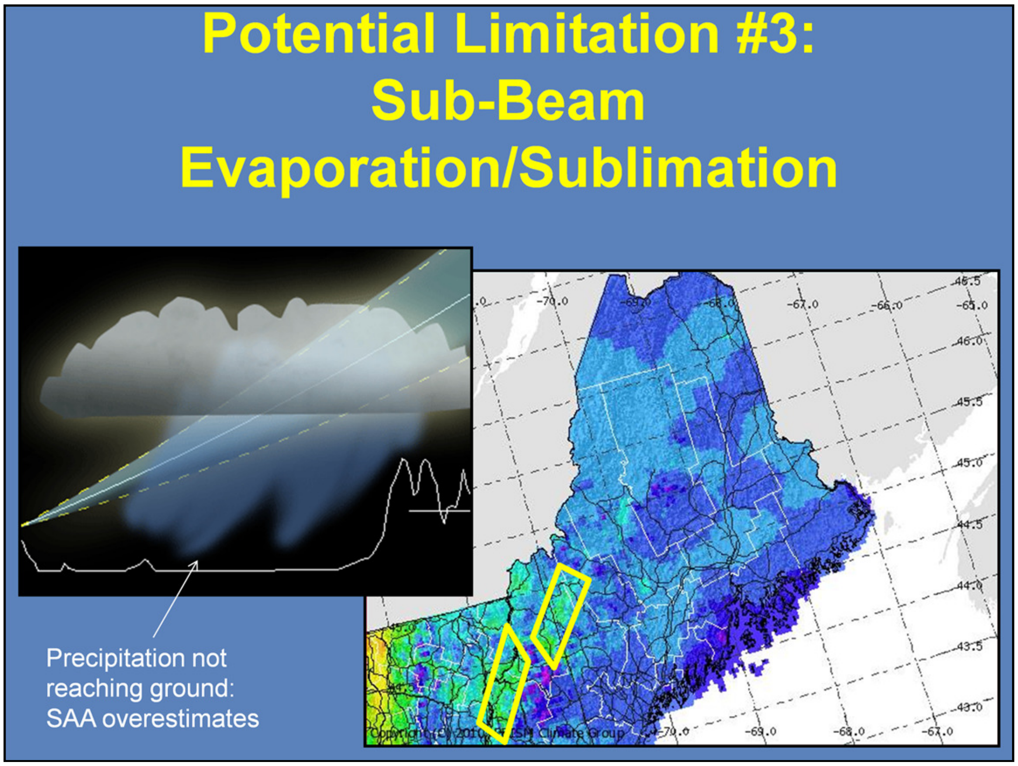


Assume we have a cloud pictured here actively generating precipitation so the intensity increases from top to bottom. Reflectivity begins to degrade once the top of the radar beam is above this precipitation production layer, and the signal is lost once the bottom of the beam is above the cloud.

The dendritic growth zone (i.e., -12 to -18 degrees Celsius) is usually the region of maximum growth. However, high cloud liquid water content between the dendritic growth zone and the bright band can contribute significant amounts of riming and needles. Collision-coalescence becomes more active in warmer, saturated clouds. Any of these precipitation production zones can be shallow, causing reflectivity to degrade quickly as range from the radar increases.

A particularly acute example of this problem is with orographic precipitation. With precipitation very close to upslope terrain, it's difficult to separate ground returns from real precipitation. So, even when the beam does sample the precipitation generation regions, reflectivity can be degraded.



Another data quality issue to consider is sub-beam evaporation (or sublimation). When sub-beam evaporation/sublimation occurs, expect the Snow Accumulation Algorithm to overestimate the liquid equivalent precipitation at the surface. The problem is most common when the near-surface airmass is dry (such as in areas of downslope winds or valleys/basins with locally low elevations). These areas may have lower annual precipitation totals such as areas north of the White Mountains in Northern New Hampshire and adjacent parts of Maine shown in the figure on the right.

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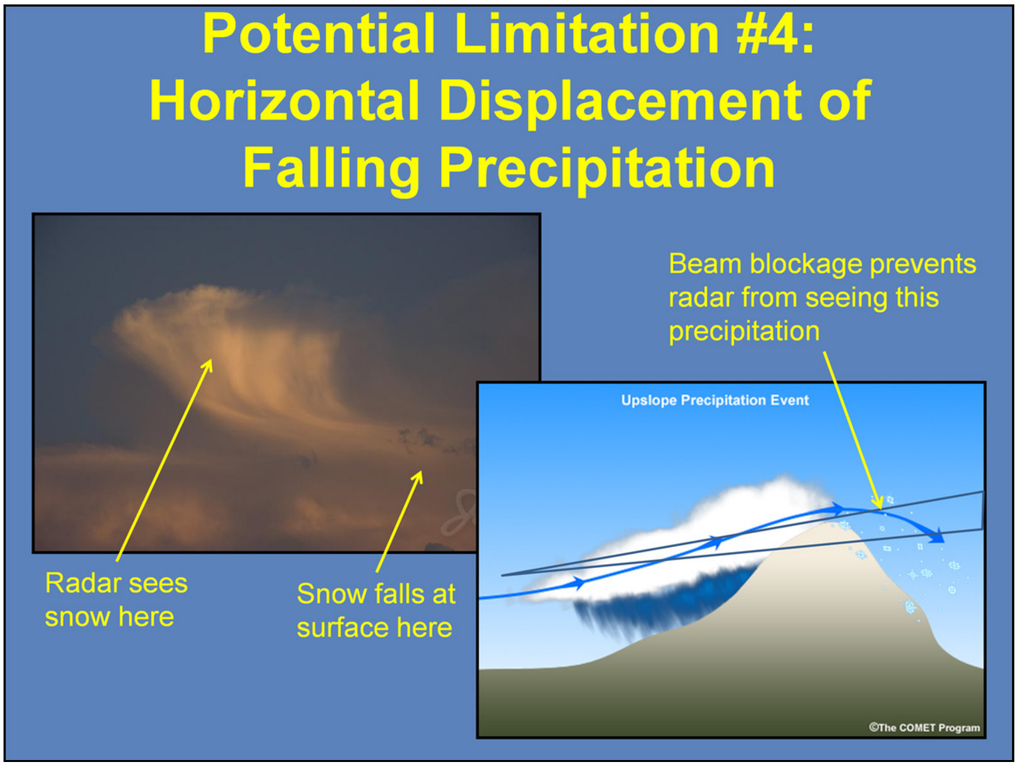

Under strong, sub-beam horizontal wind conditions (or areas of strong sub-beam vertical wind shear), precipitation may drift horizontally a long distance before reaching the ground. In some cases, the radar may not observe the precipitation that reaches the ground, such as when there is lee side spillover of orographic precipitation.

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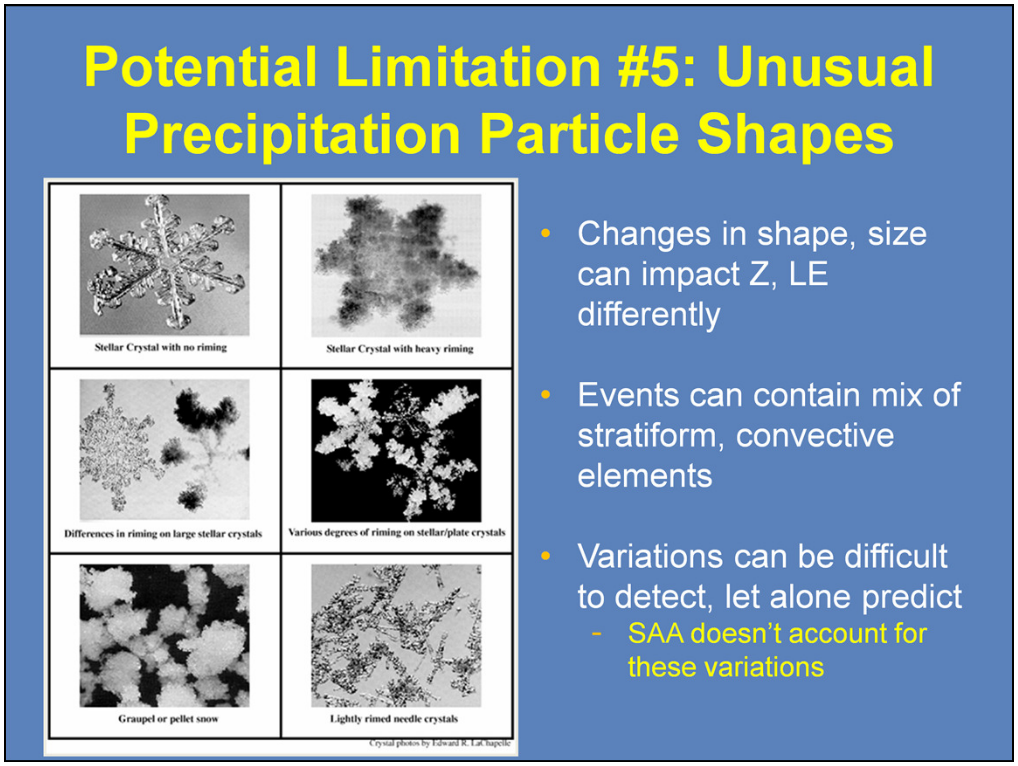

Precipitation particle shape and size can significantly alter reflectivity without a corresponding change in the liquid equivalent precipitation rate. If you experience snow events, take a look at how the shapes and sizes of the snowflakes change over short periods of time.

Many precipitation systems can contain a mixture of stratiform and convective elements with variations in vertical velocity profiles with respect to the thermal profile. The result is a rapid change in particle shapes.

This error source can be very difficult to detect, let alone predict. You may notice areas of precipitation particles that vary significantly from the "average" for your region using dual-pol base data. While you could identify these areas as likely deviating from the Z-S equation being used, you can't edit for localized areas within the radar coverage area.