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Topic: Principles of Radar

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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 Radar Beam Characteristics. It is presented by the Warning Decision Training Division (WDTD). Let's get started!

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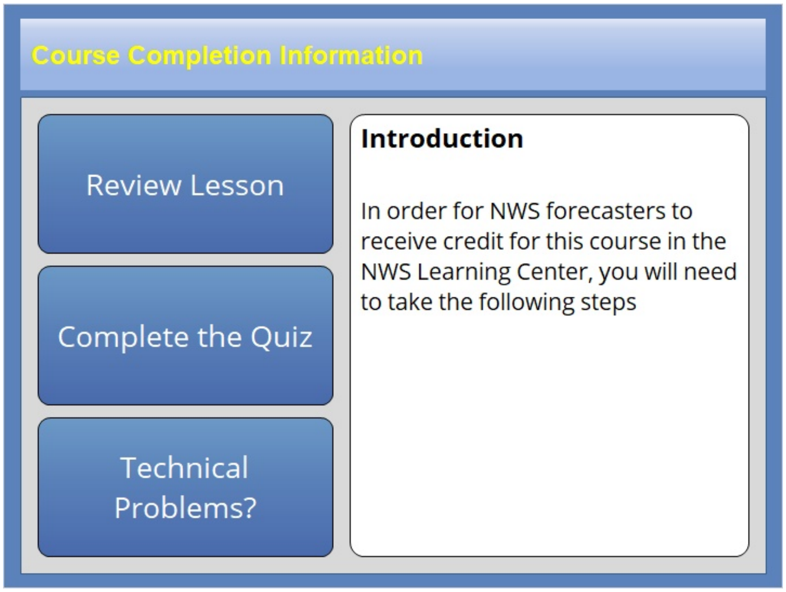
1.2 Course Completion Information



Notes:

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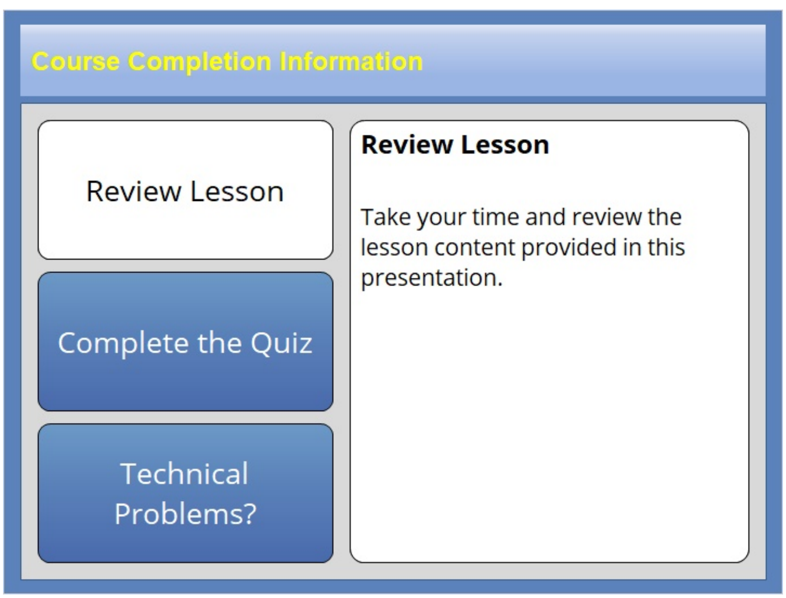
Review Lesson (Slide Layer)



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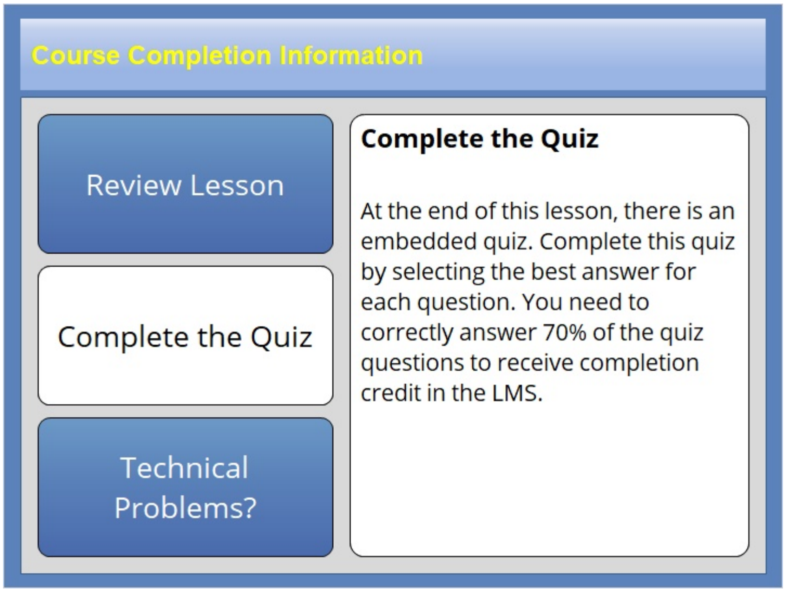
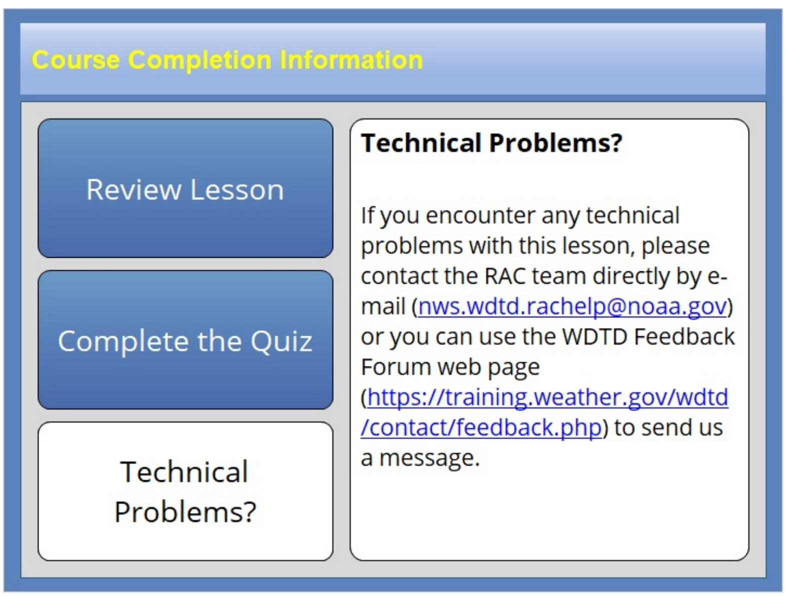
Complete the Quiz (Slide Layer)



Technical Problems (Slide Layer)



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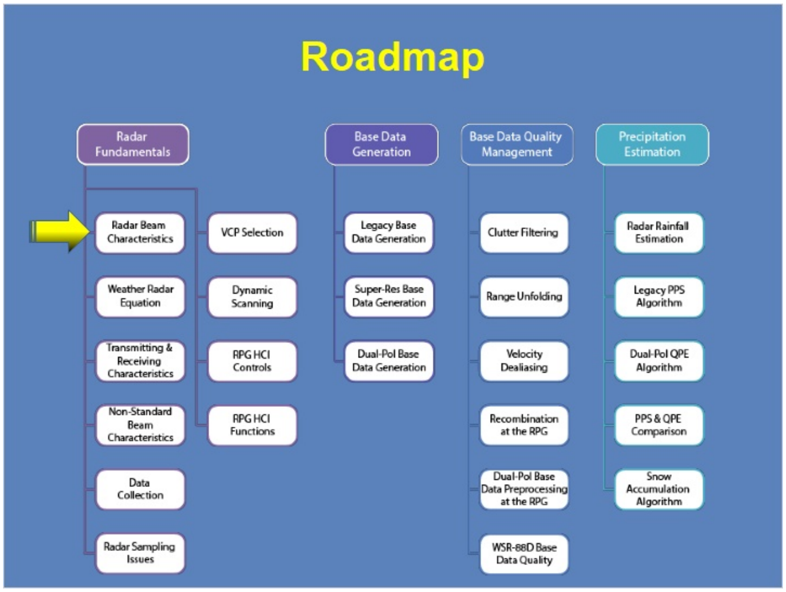
1.3 Roadmap



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. Let’s keep going!

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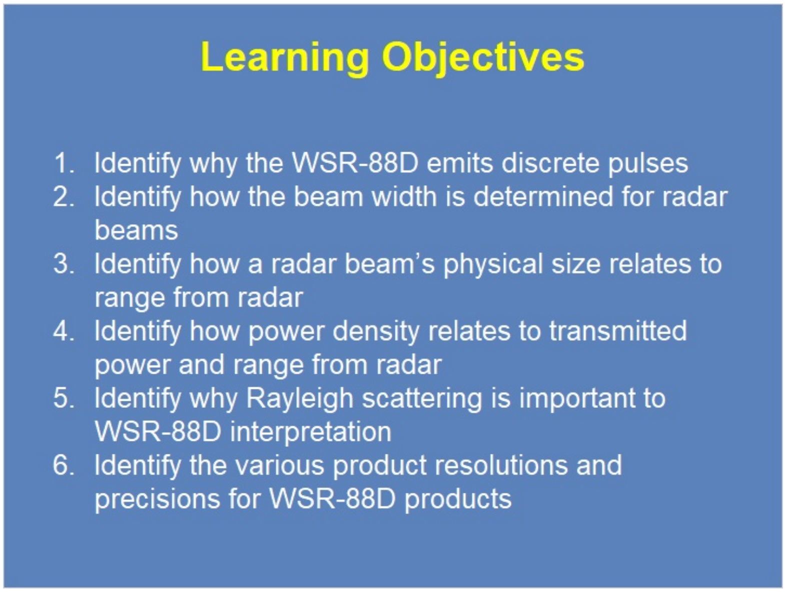
1.4 Learning Objectives



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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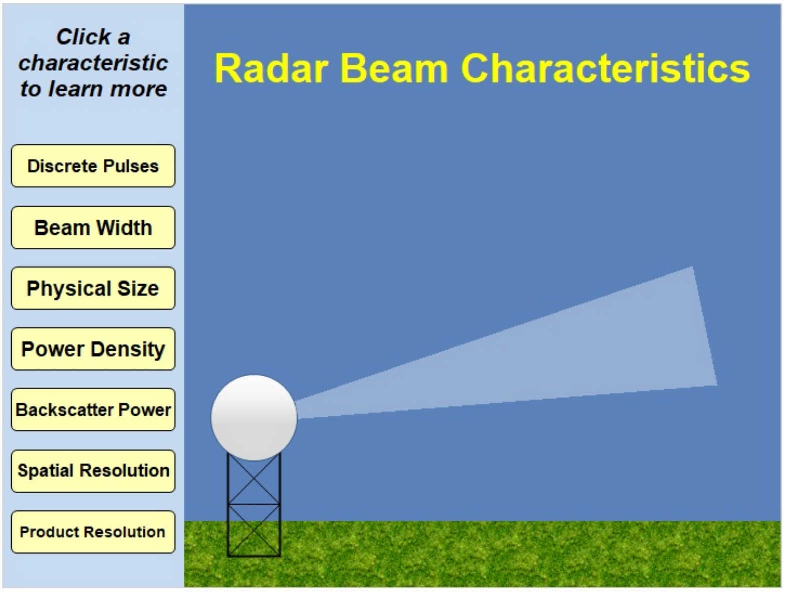
2. Main Radar Graphics

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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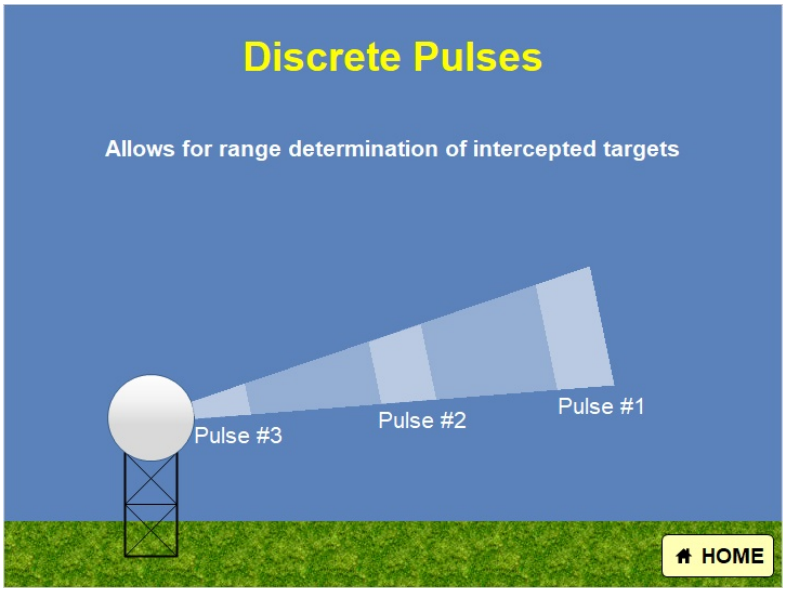
2.2 Discrete Pulses



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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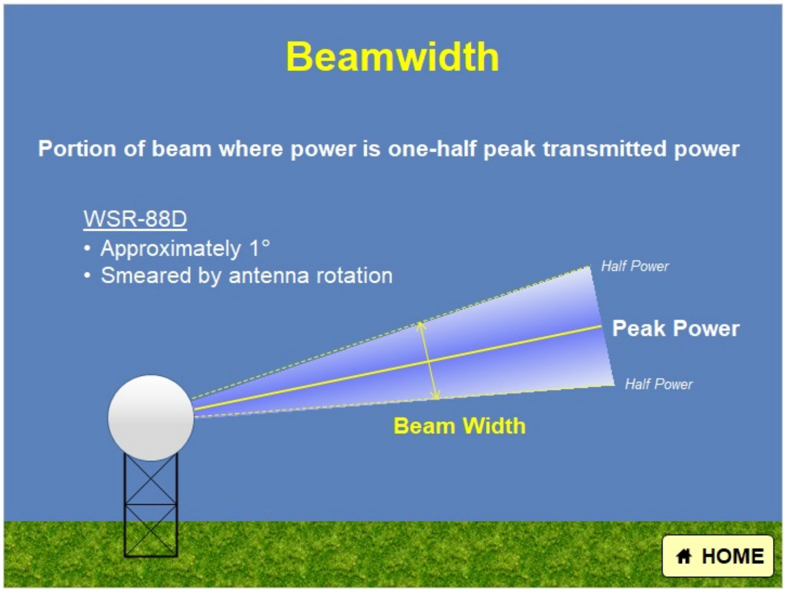
2.3 Beamwidth



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.

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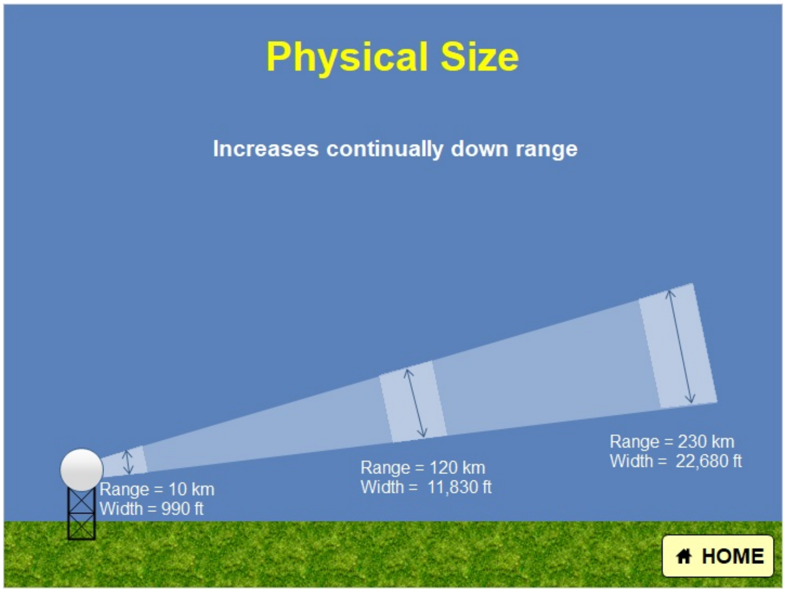
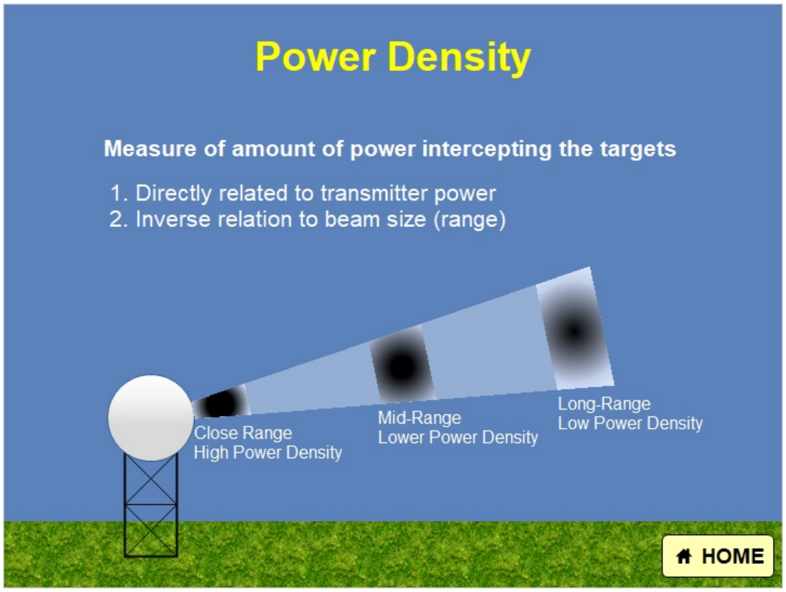
2.4 Physical Size



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!

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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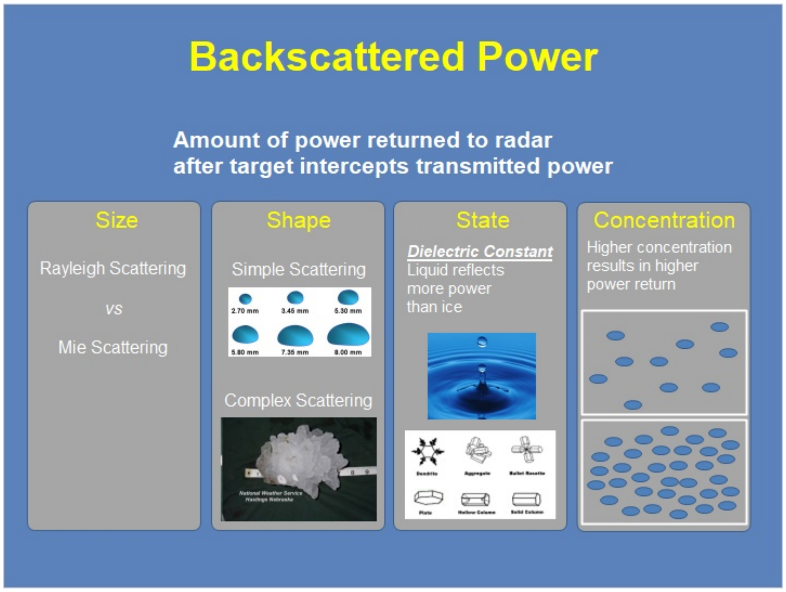
2.6 Backscattered Power



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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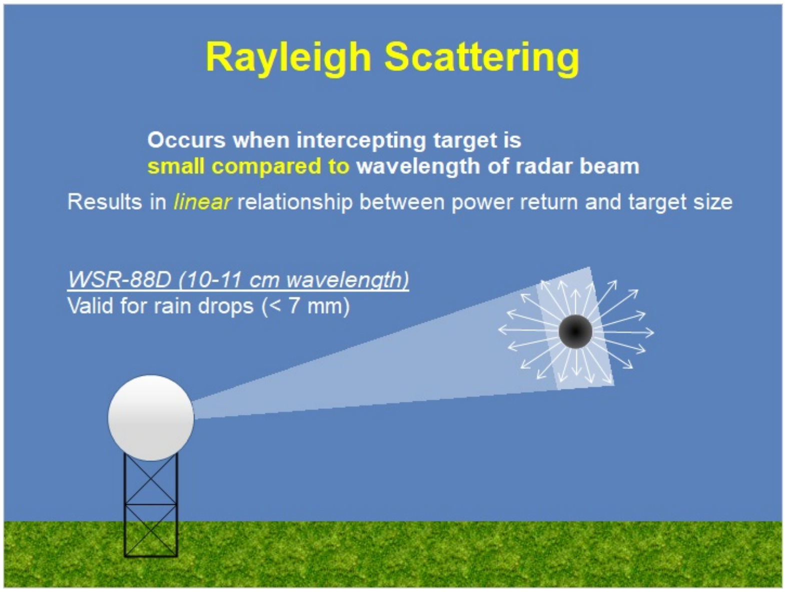
2.7 Rayleigh Scattering



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.

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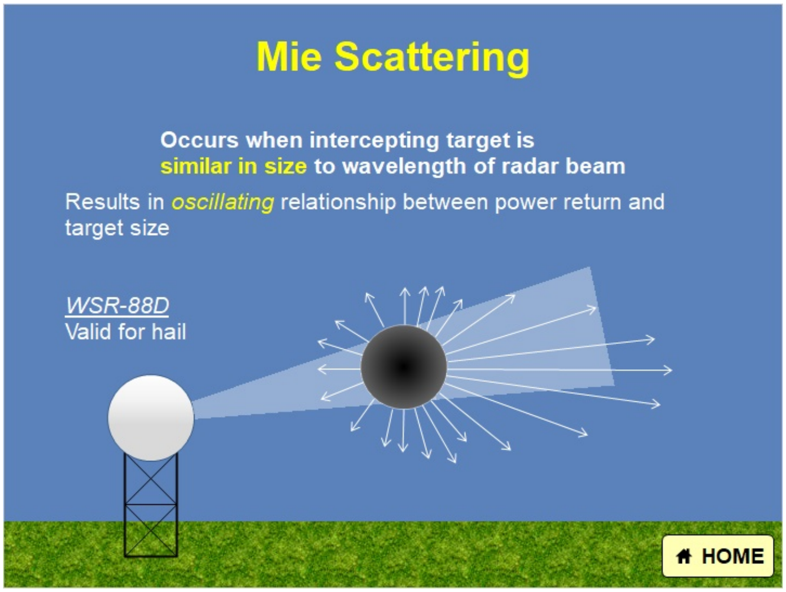
2.8 Mie Scattering



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.

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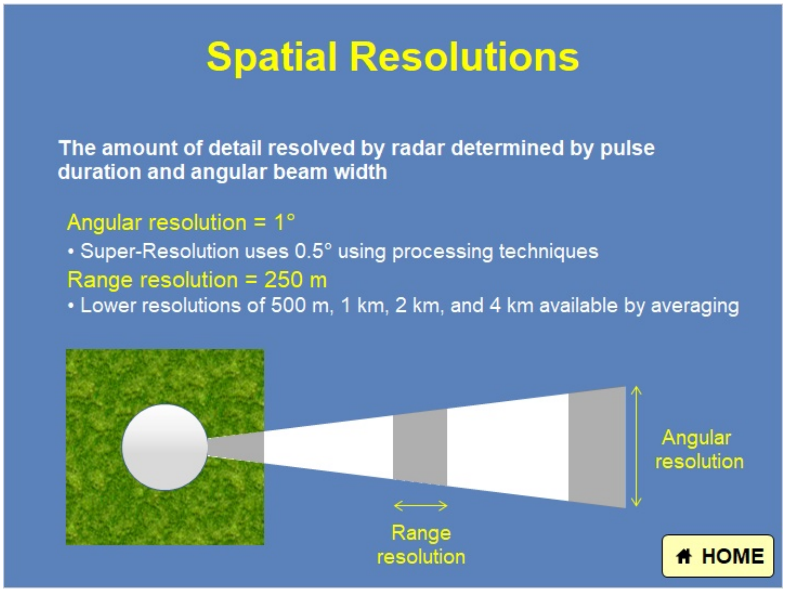
2.9 Spatial Resolutions



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 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.

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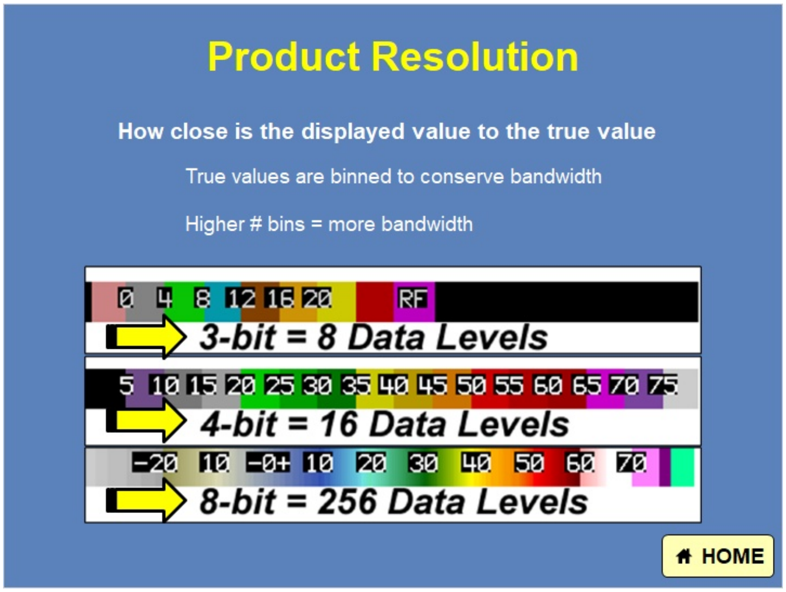
2.10 Product Resolution



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.

4. Completion

4.1 Completion!

Notes:

Thanks for your attention! You are now complete for this lesson.

The 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 The Weather Radar Equation. It is presented by the Warning Decision Training Division (WDTD). Let's get started!

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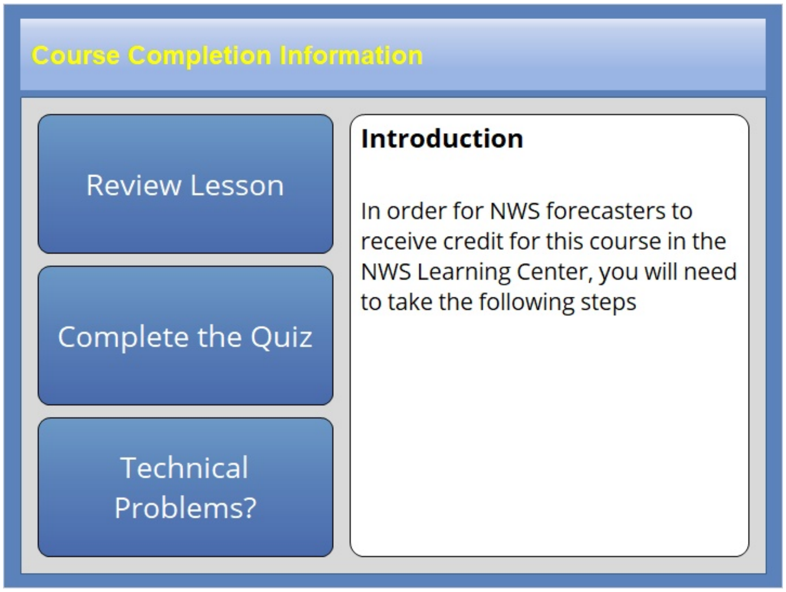
1.2 Course Completion Information



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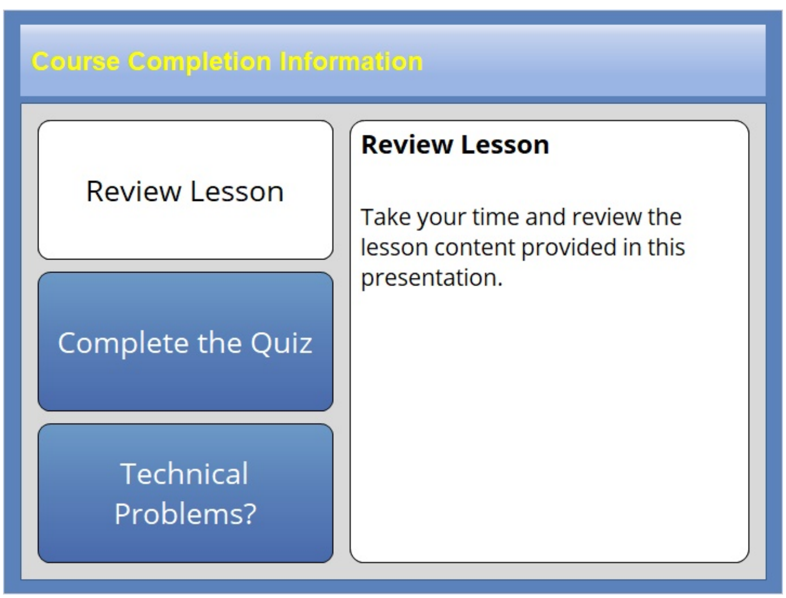
Review Lesson (Slide Layer)



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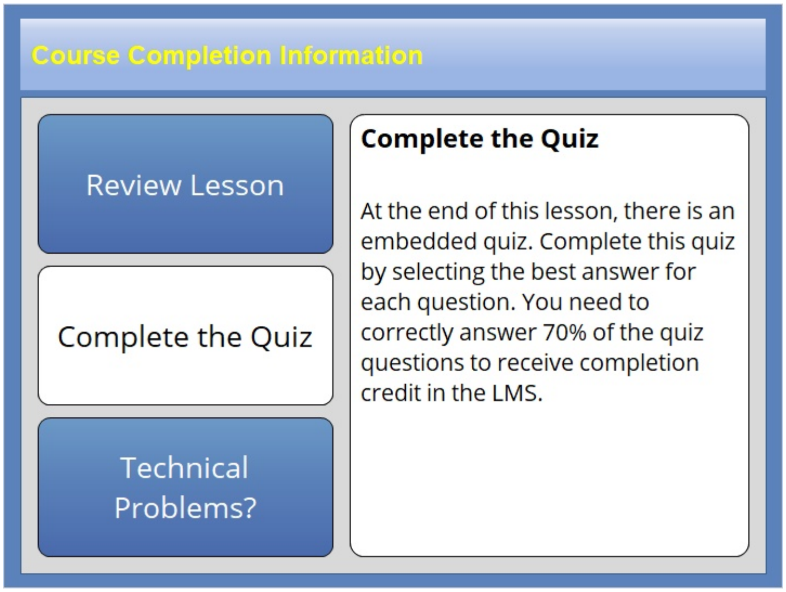
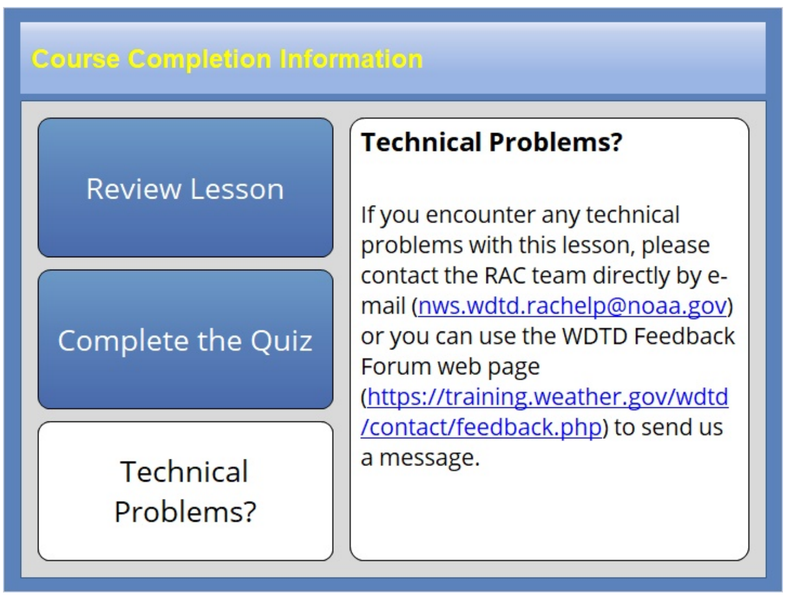
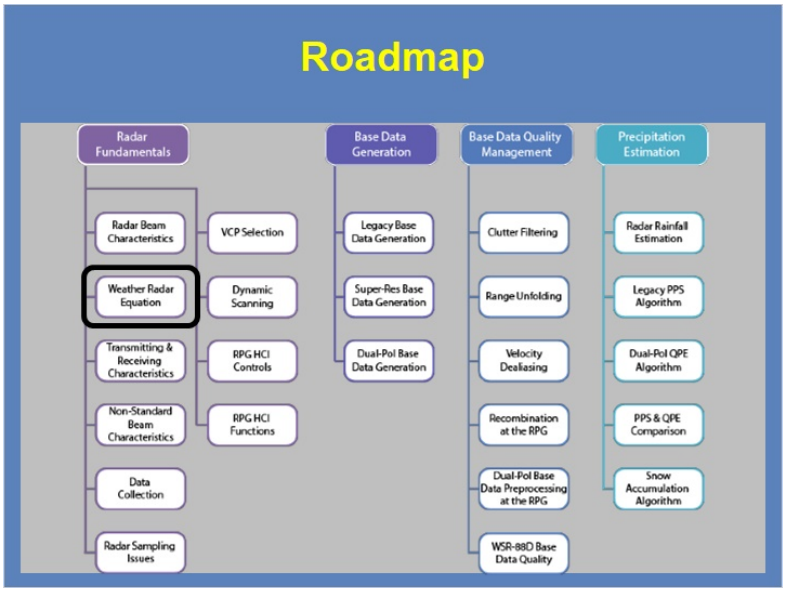
Complete the Quiz (Slide Layer)



Technical Problems (Slide Layer)



1.3 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. Let’s keep going!

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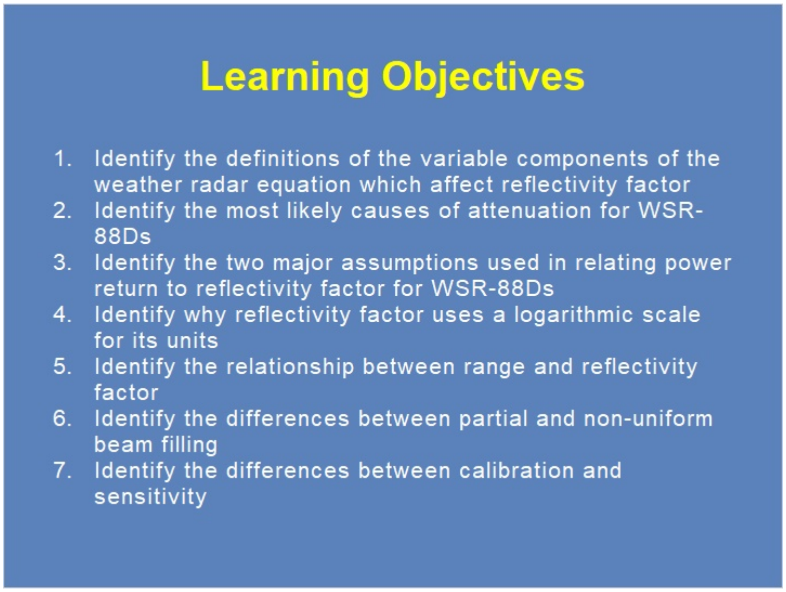
1.4 Learning Objectives



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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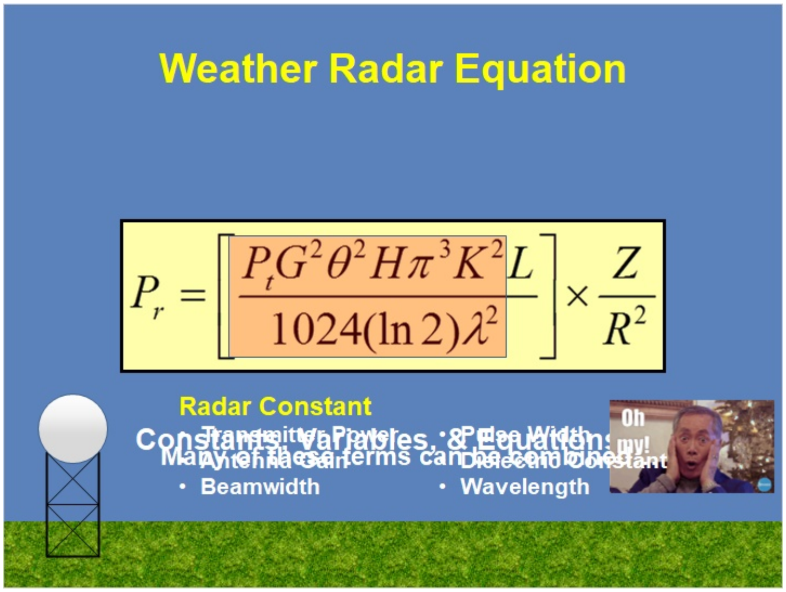
2. Main Radar Equation

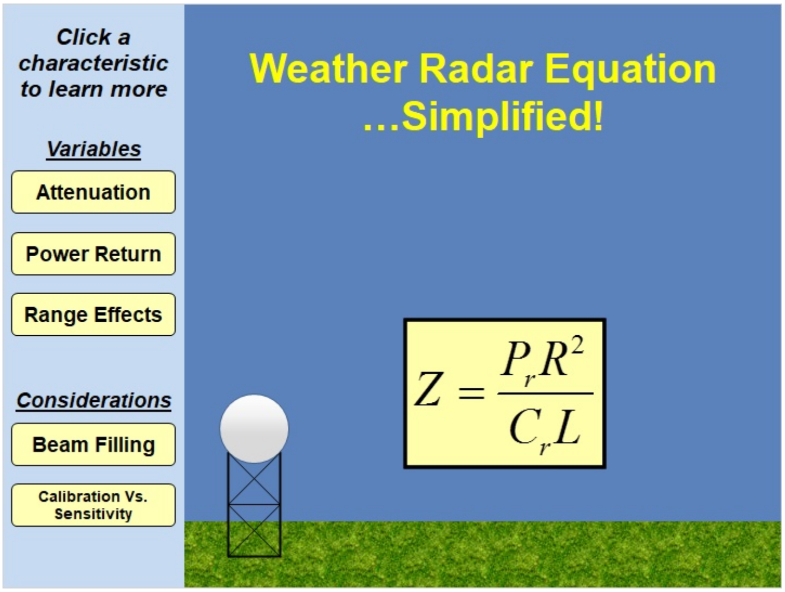
2.1 Weather Radar Equation



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.

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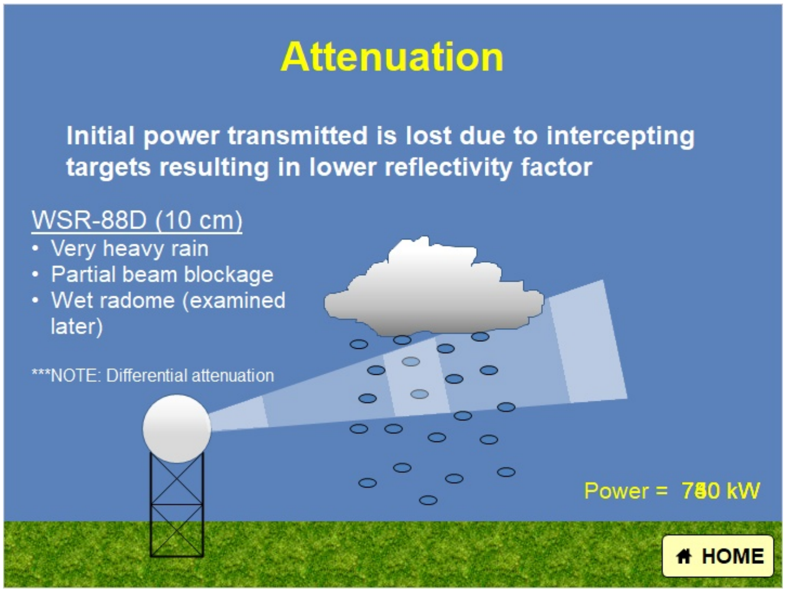
2.3 Attenuation



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.

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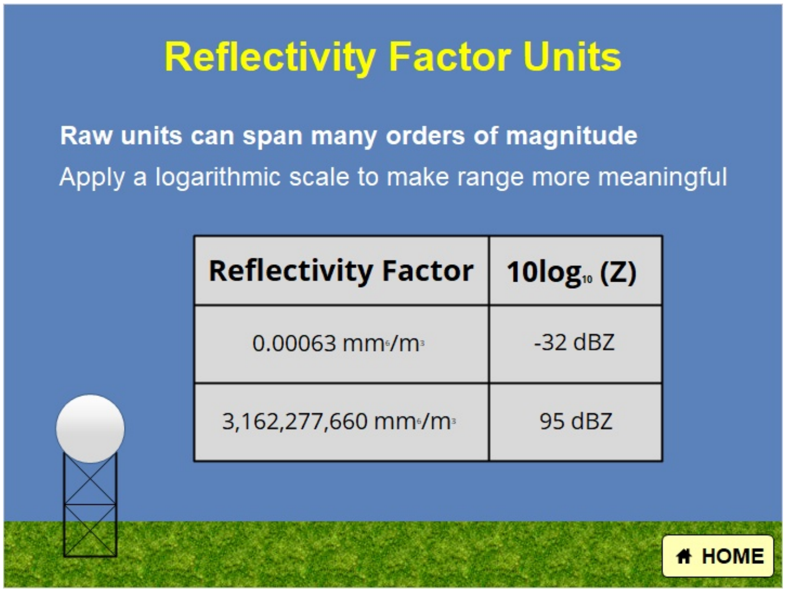
2.4 Reflectivity Factor Units



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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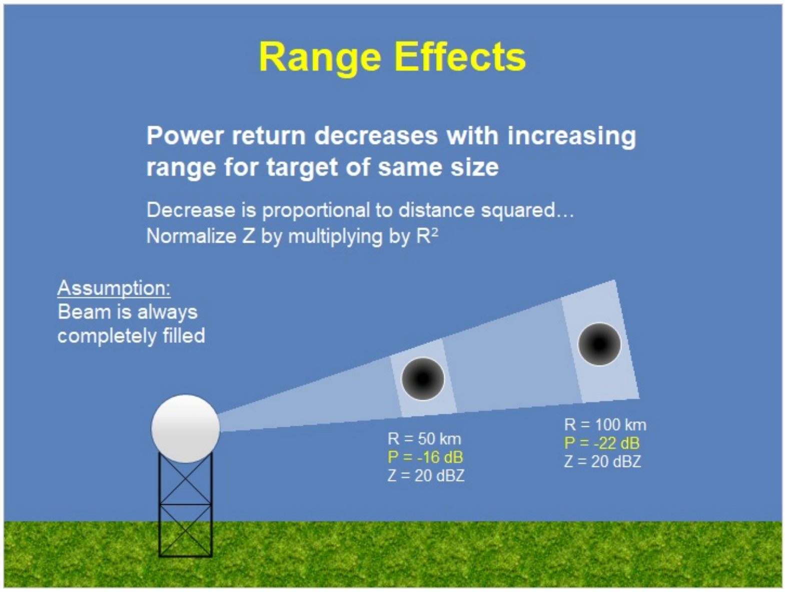
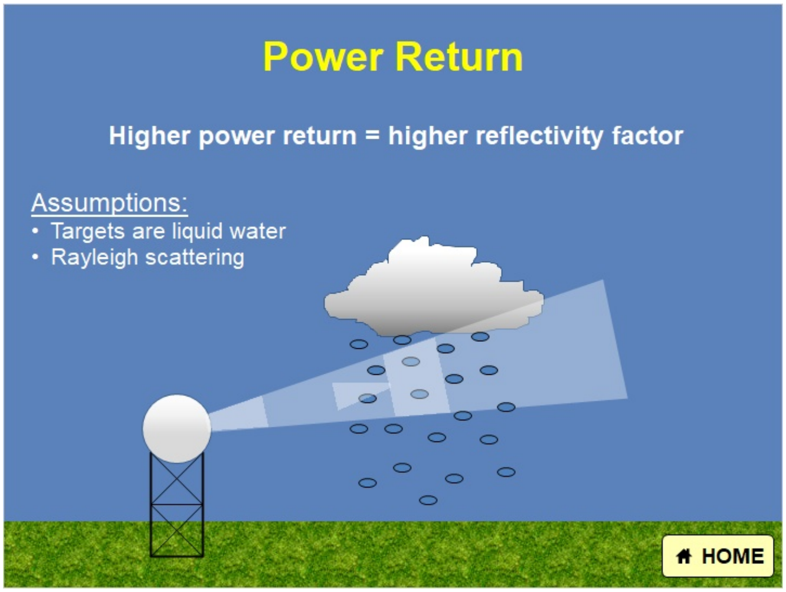
2.5 Range Effects



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.

2.6 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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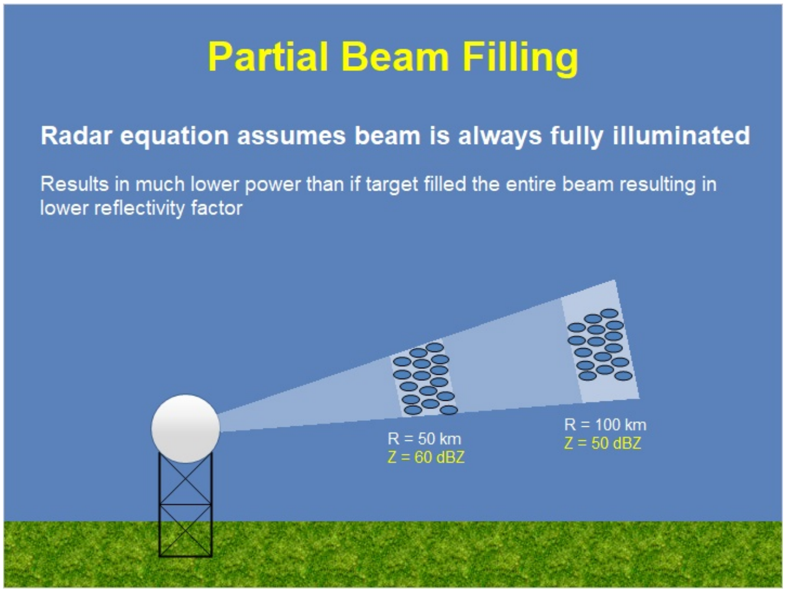
2.7 Partial Beam Filling



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.

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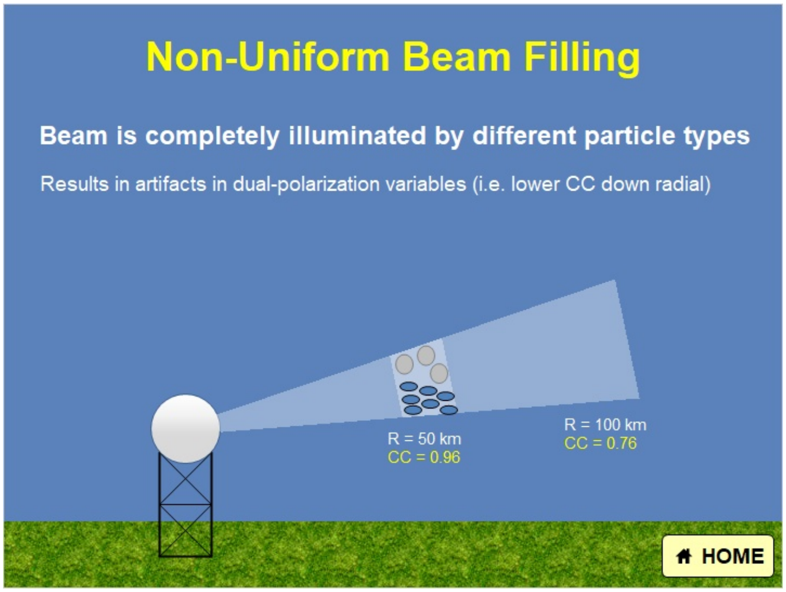
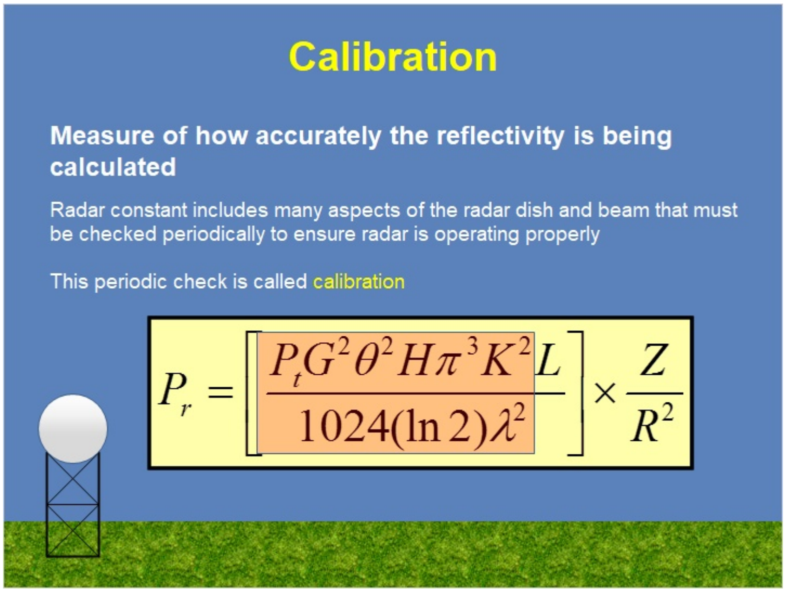
2.8 Non-Uniform Beam Filling



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.

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.

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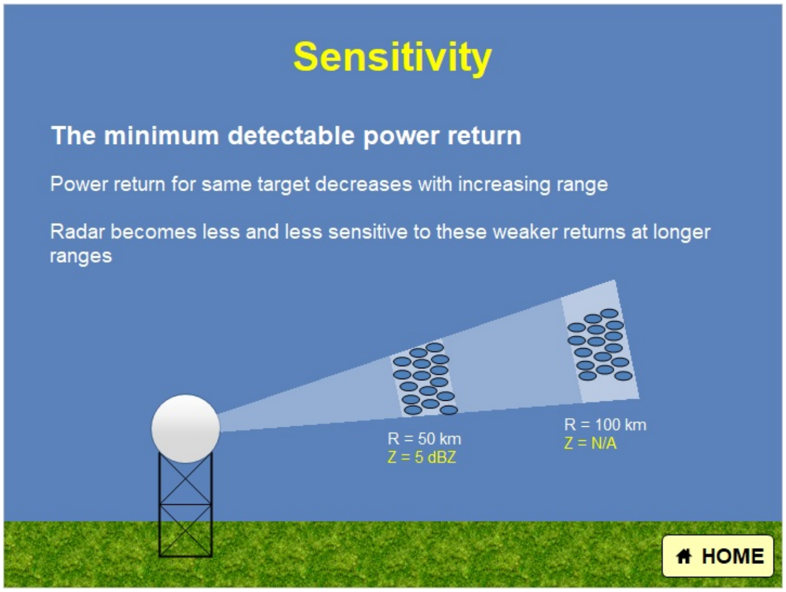
2.10 Sensitivity



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.

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4. Completion

4.1 Completion!

Notes:

Thanks for your attention! You are now complete for this lesson.

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Transmitting & Receiving 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 Transmitting and Receiving Characteristics. It is presented by the Warning Decision Training Division (WDTD). Let's get started!

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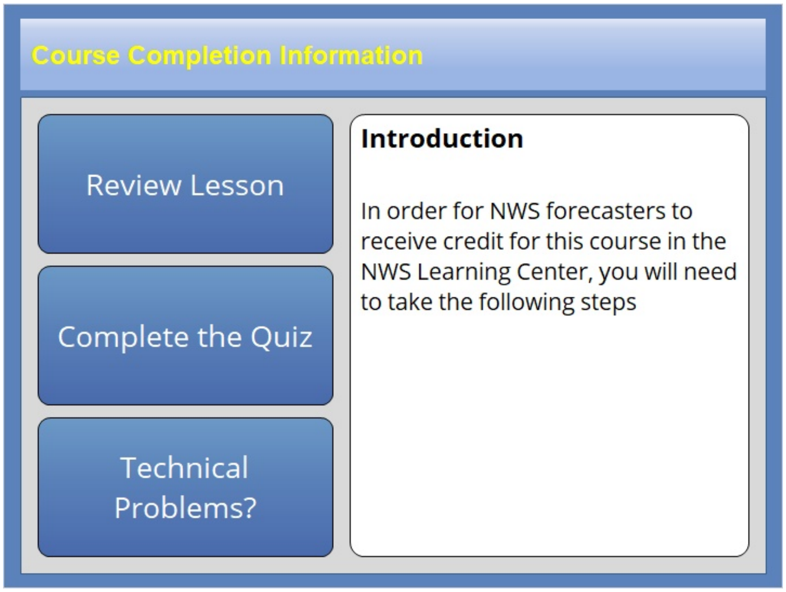
1.2 Course Completion Information



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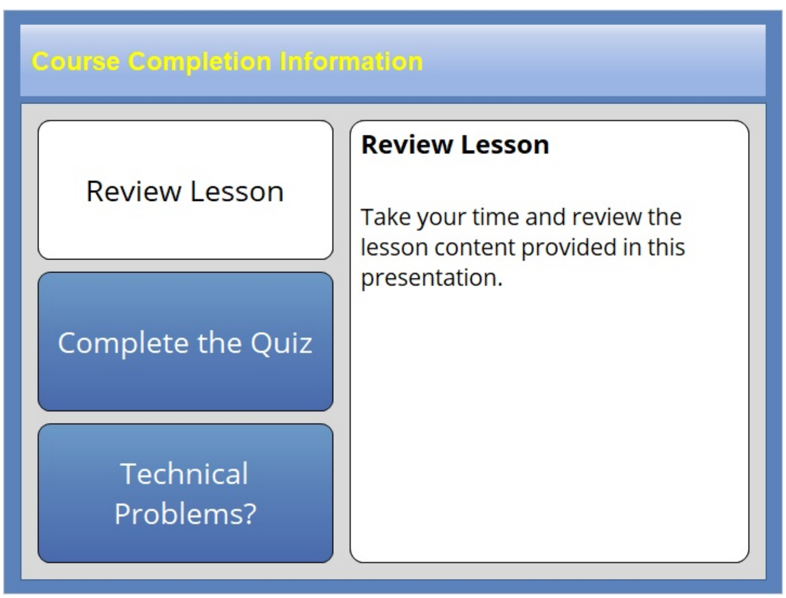
Review Lesson (Slide Layer)



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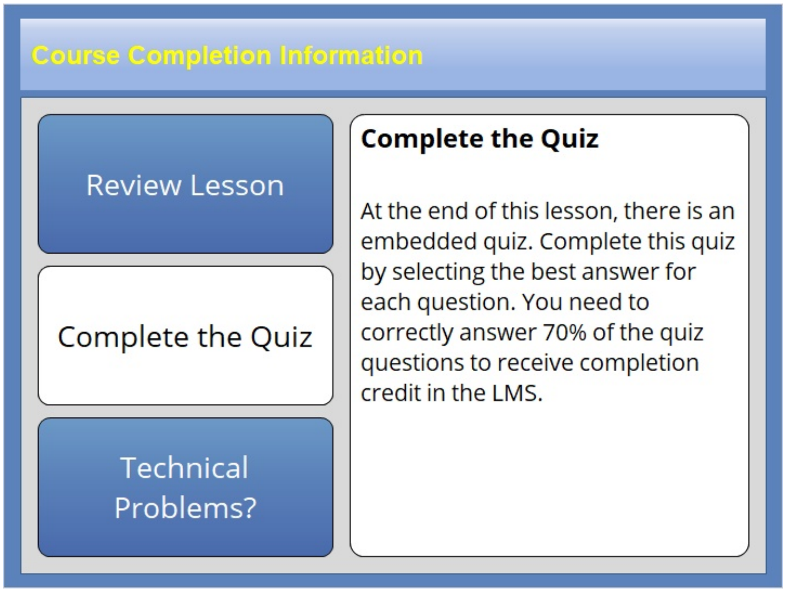
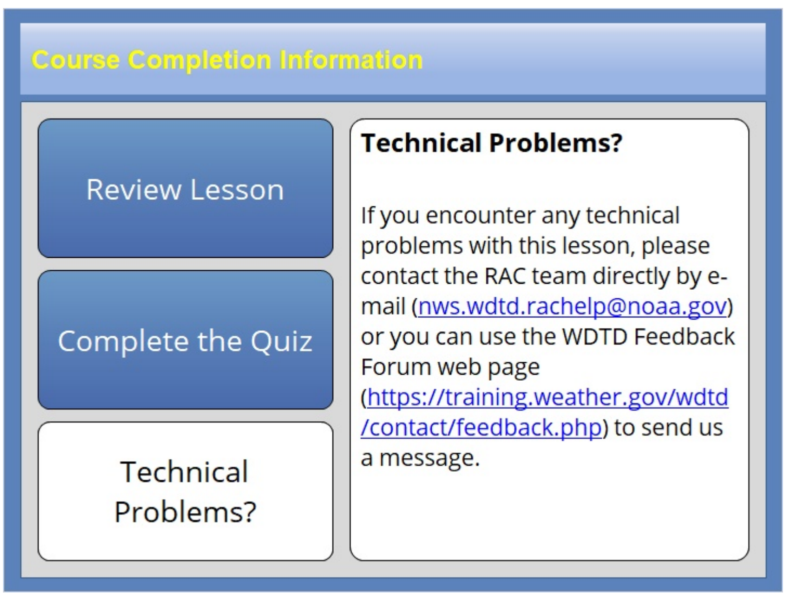
Complete the Quiz (Slide Layer)



Technical Problems (Slide Layer)



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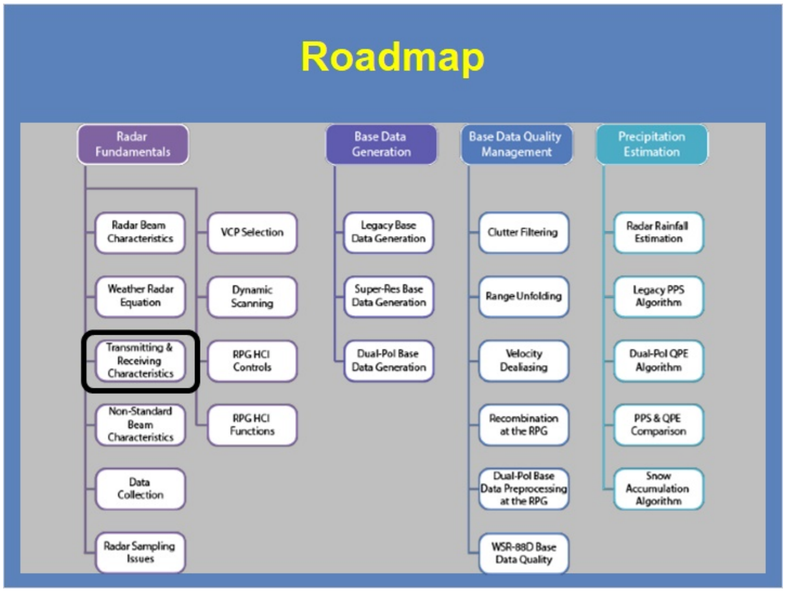
1.3 Roadmap



Notes:

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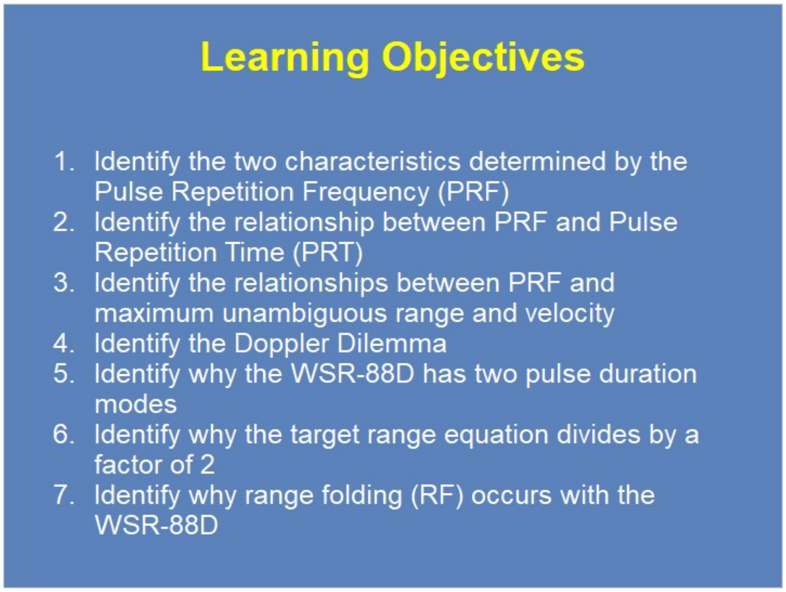
1.4 Learning Objectives



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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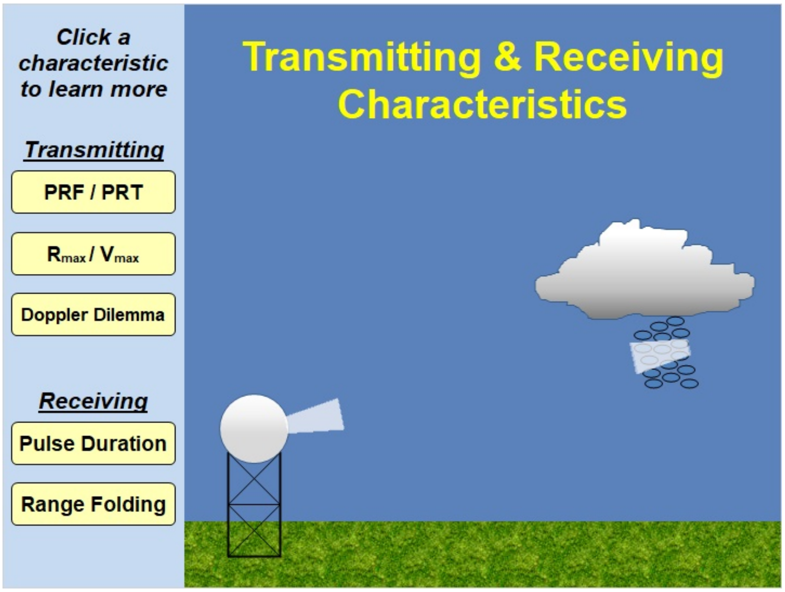
2. Transmitting & Receiving Characteristics

2.1 Radar Beam 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 to learn more.

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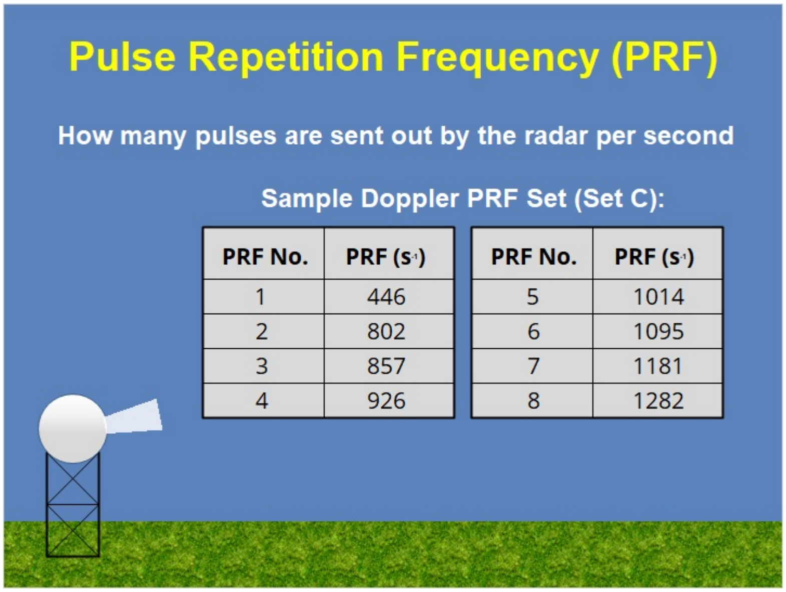
2.2 Pulse Repetition Frequency (PRF)



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, each radar is assigned a set of 8 different PRFs that can be implemented depending on the waveform in use. This slide shows an example of those 8 options for one of the Doppler scans with PRF values that range from 446 pulses per second up to 1,282 pulses per second. That's a lot of pulses!

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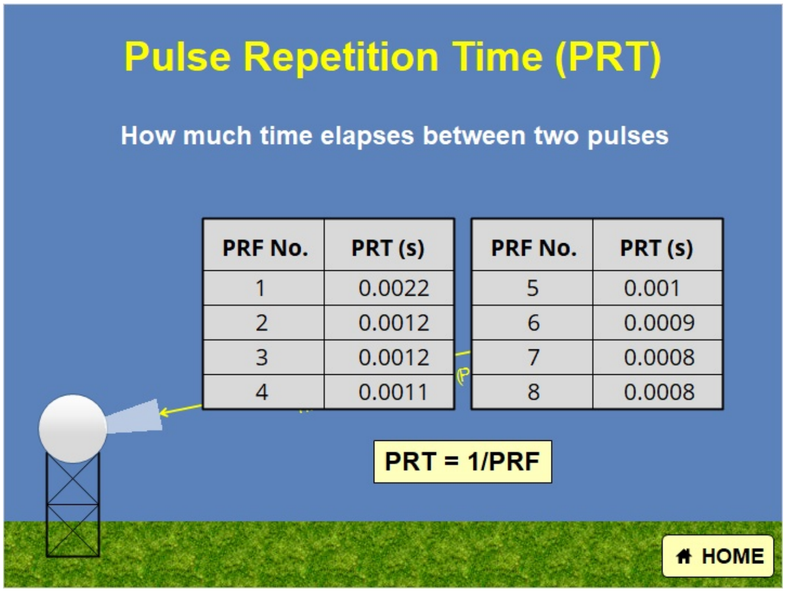
2.3 Pulse Repetition Time (PRT)



PRF No.	PRT (s)	PRF No.	PRT (s)
1	0.0022	5	0.001
2	0.0012	6	0.0009
3	0.0012	7	0.0008
4	0.0011	8	0.0008

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 PRF options shown previously, their associated PRTs are listed here in this table. Notice, there isn't a lot of time in between pulses.

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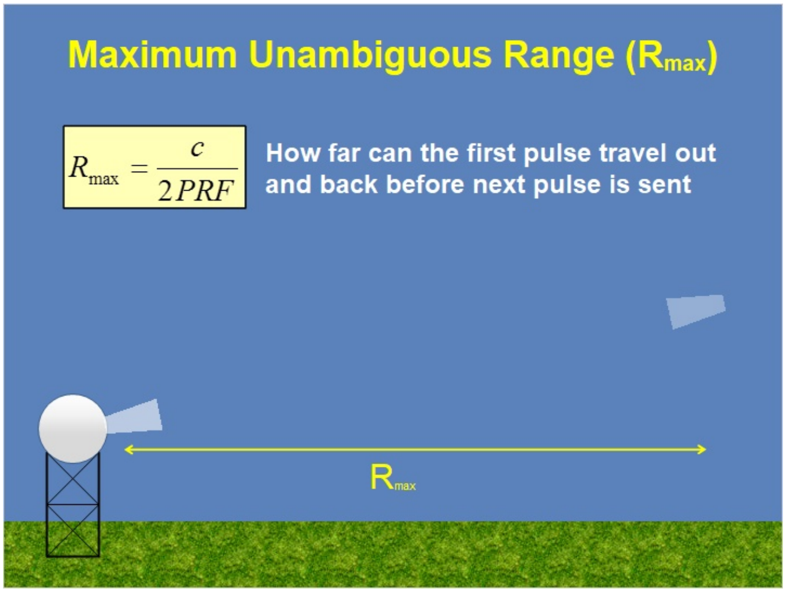
2.4 Maximum Unambiguous Range (Rmax)



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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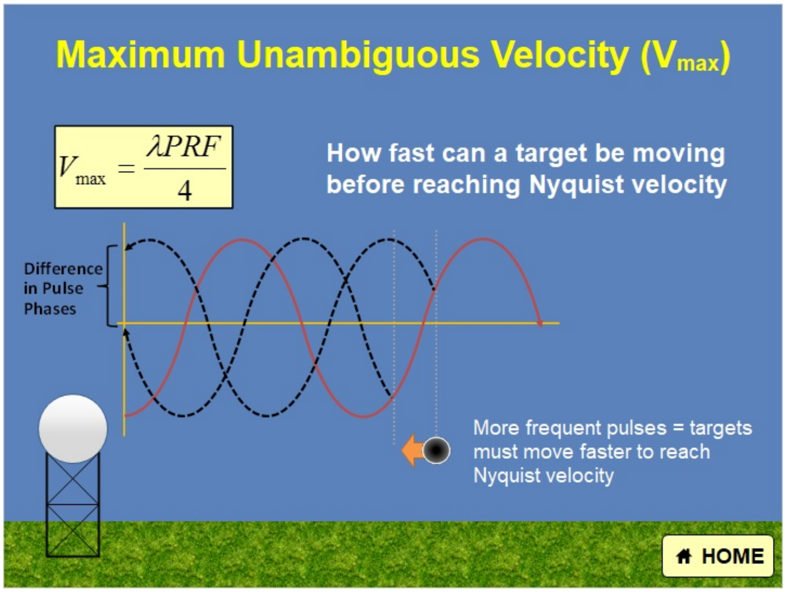
2.5 Maximum Unambiguous Velocity (Vmax)



Notes:

When it comes to measuring velocity, the radar measures the phase shift between pulses through a technique called pulse-pair processing. This technique uses the difference in phase of the return signal from one pulse to the next. A target's phase will change from pulse to pulse because the target intercepts the transmitted wave at a different phase position along the wave. However, if the target moves too fast, phase ambiguity can result in an ambiguous determination for velocity. For a given sampling rate, the speed limit where this ambiguity is reached is called the Nyquist Velocity. An easy fix to this is to sample more often, so that scatterers haven't moved far enough between pulses to cause ambiguity. To put it another way, the higher the PRF, the higher the Vmax since targets can move faster before reaching the problematic Nyquist velocity.

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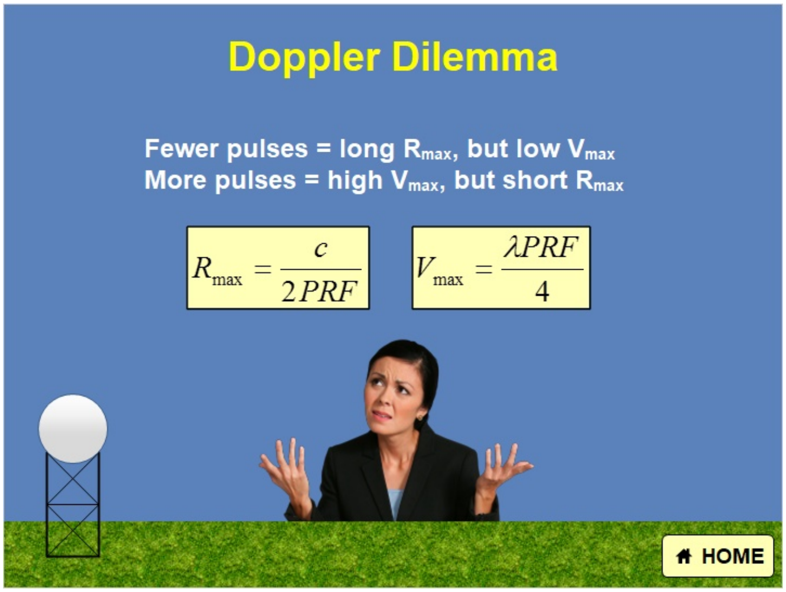
2.6 Doppler Dilemma



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.

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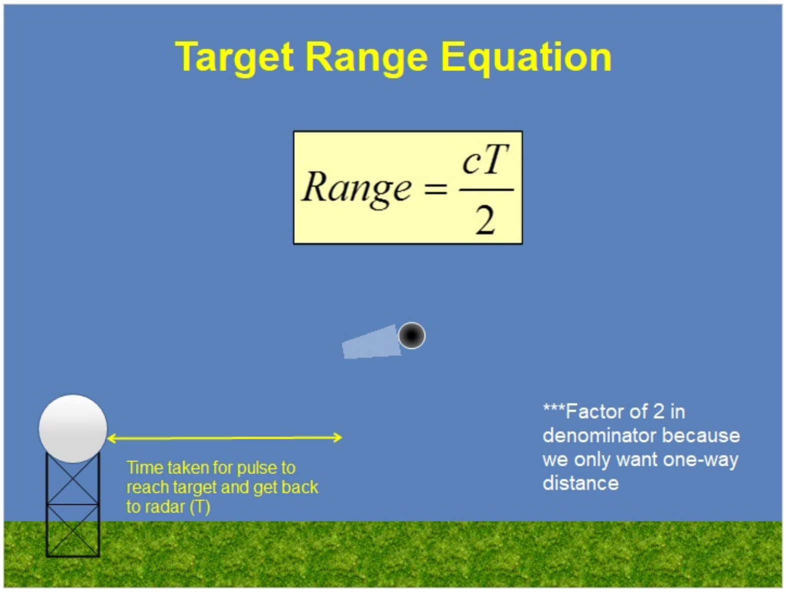
2.7 Target Range Equation



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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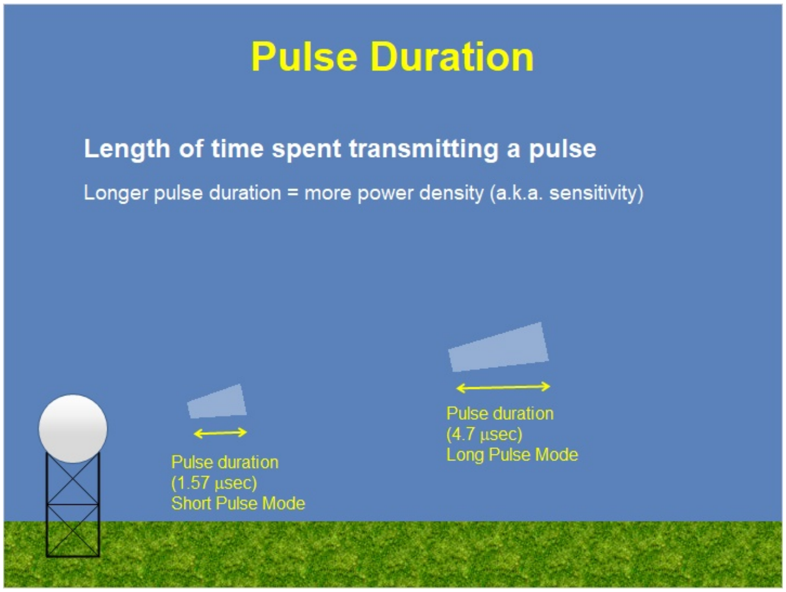
2.8 Pulse Duration



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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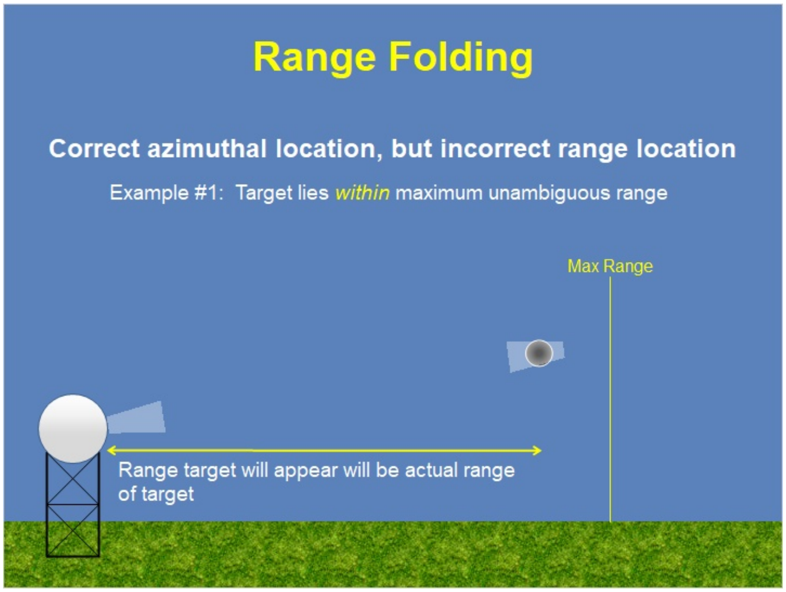
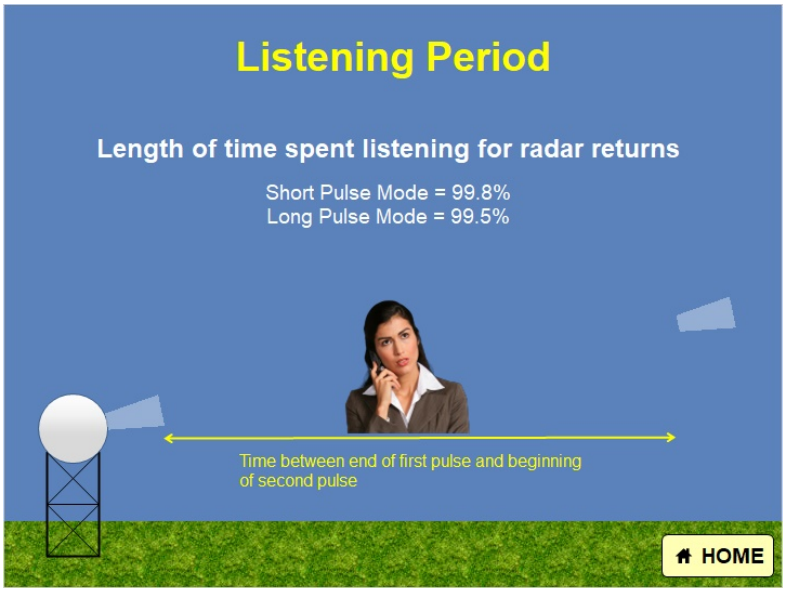
2.9 Range Folding



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 radar 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.

2.10 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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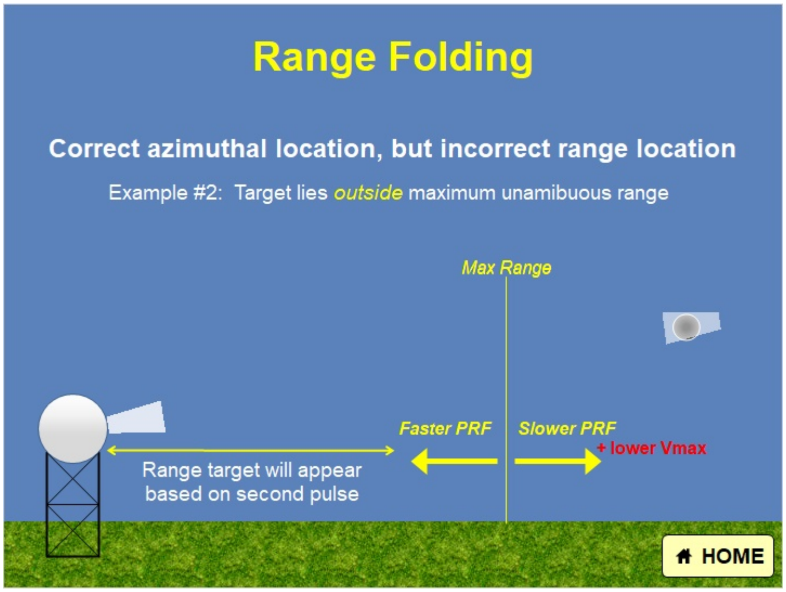
2.11 Range Folding



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.

But remember from earlier how our selection of the pulse repetition frequency, or PRF, affected max range? A slower PRF results in a farther max range, since it gives echoes more time to return before a new one is sent. So by adjusting your PRF (such as with a different VCP) you can sometimes reduce problems with range folding. But remember that this comes at the cost of a more restricted maximum ambiguous velocity, thanks to the Doppler Dilemma.

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4. Completion

4.1 Completion!

Notes:

Thanks for your attention! You are now complete for this lesson.

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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 Non-Standard Beam Consequences. It is presented by the Warning Decision Training Division (WDTD). Let's get started!

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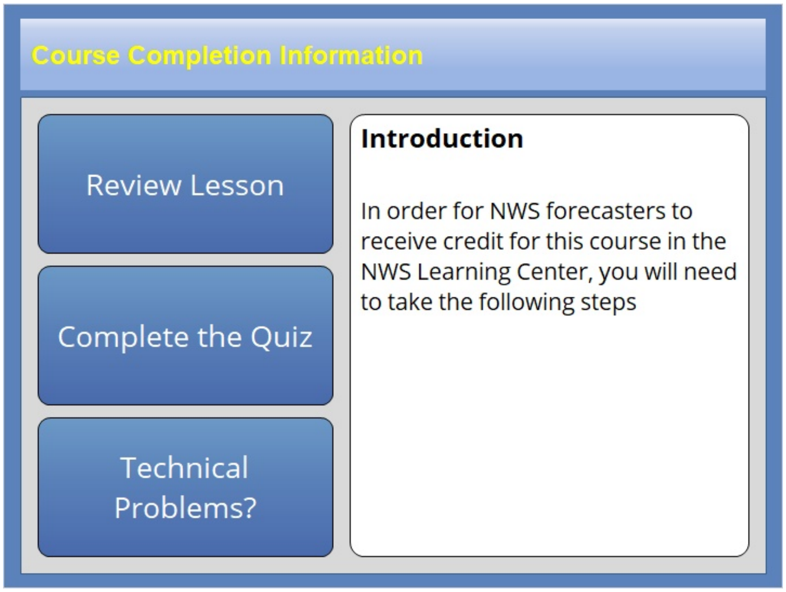
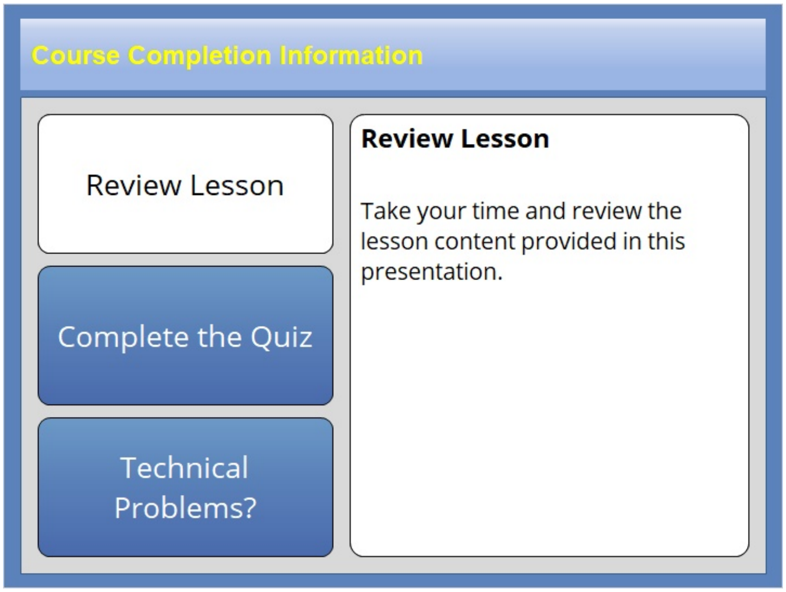
1.2 Course Completion Information



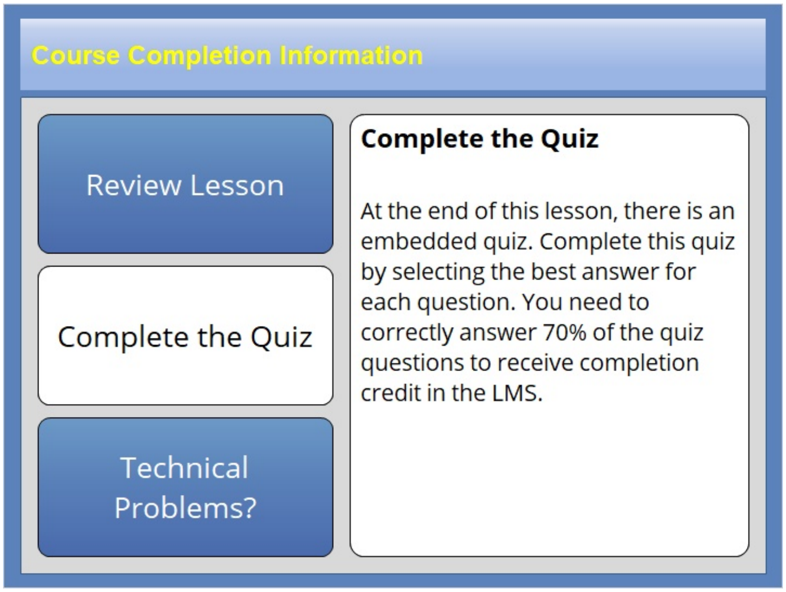
Notes:

If you are completing this course for credit, please review this interaction on how to complete this course within the NWS Learning Center. After viewing all the slides, click "Next" to continue.

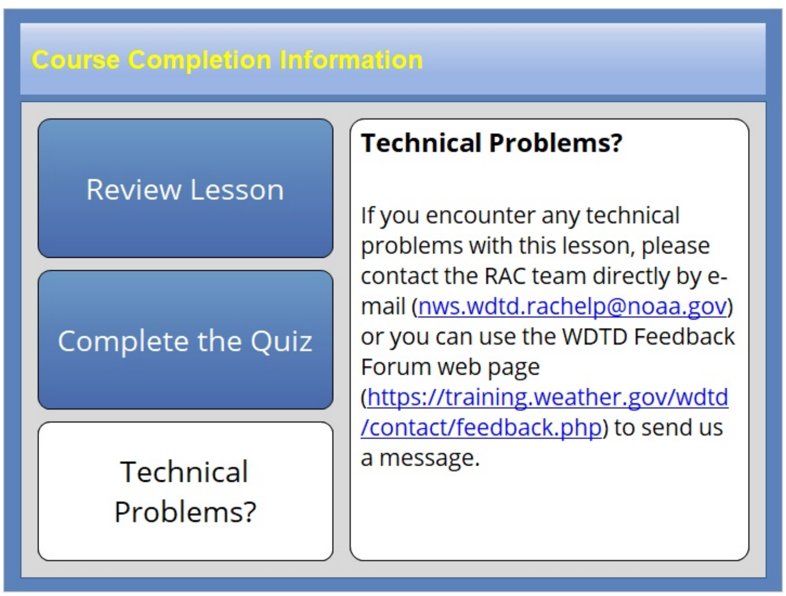
Review Lesson (Slide Layer)



Complete the Quiz (Slide Layer)



Technical Problems (Slide Layer)



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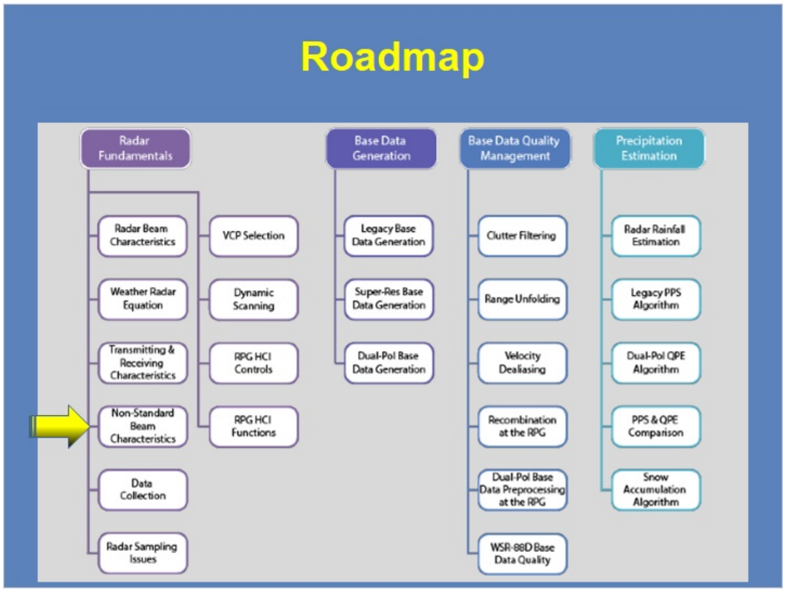
1.3 Roadmap



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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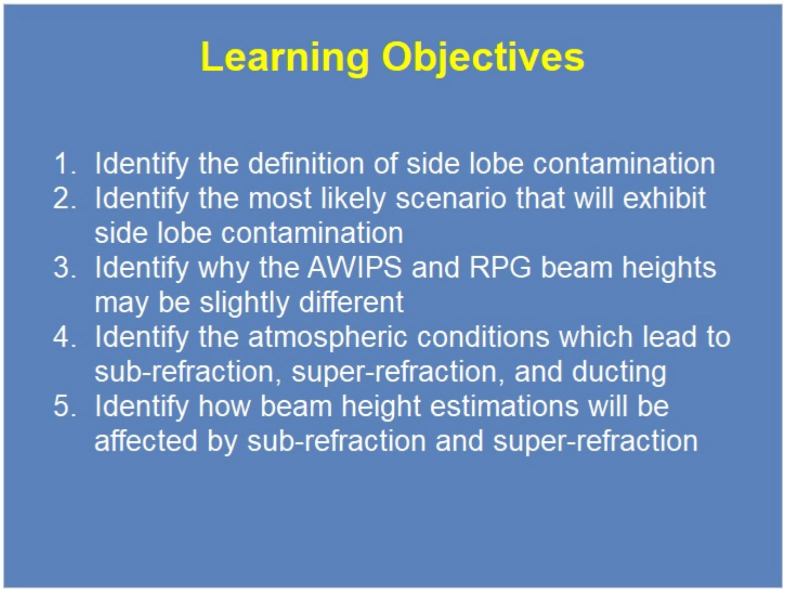
1.4 Learning Objectives

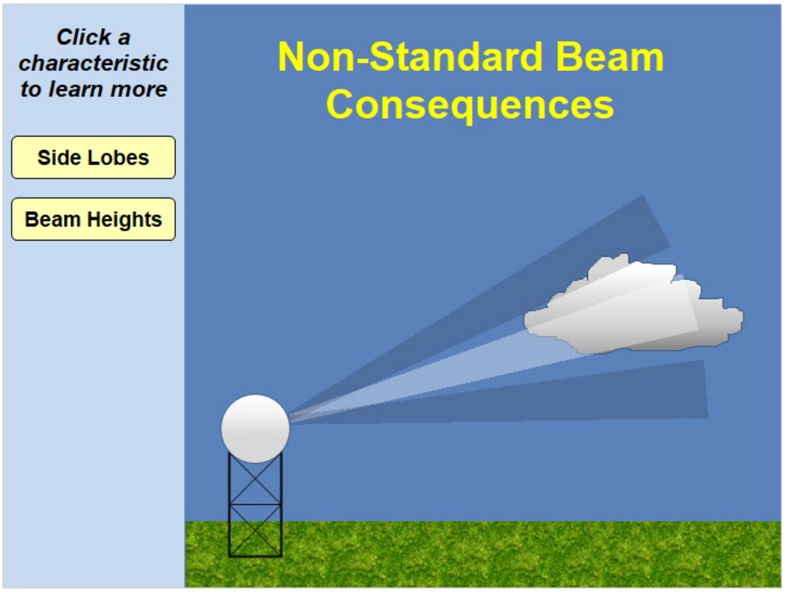


Notes:

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 Non-Standard 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 learn more about the non-standard beam consequences known as side lobes and beam height estimations.

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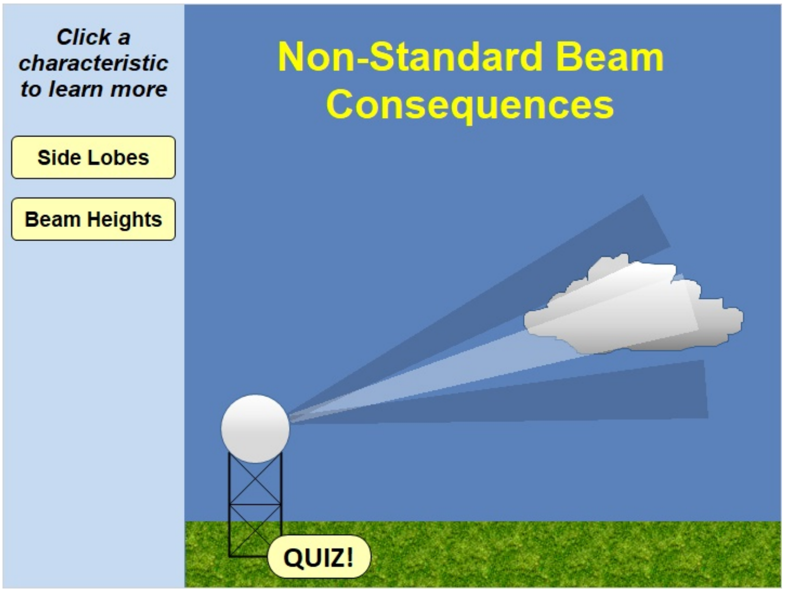
Quiz Button (Slide Layer)



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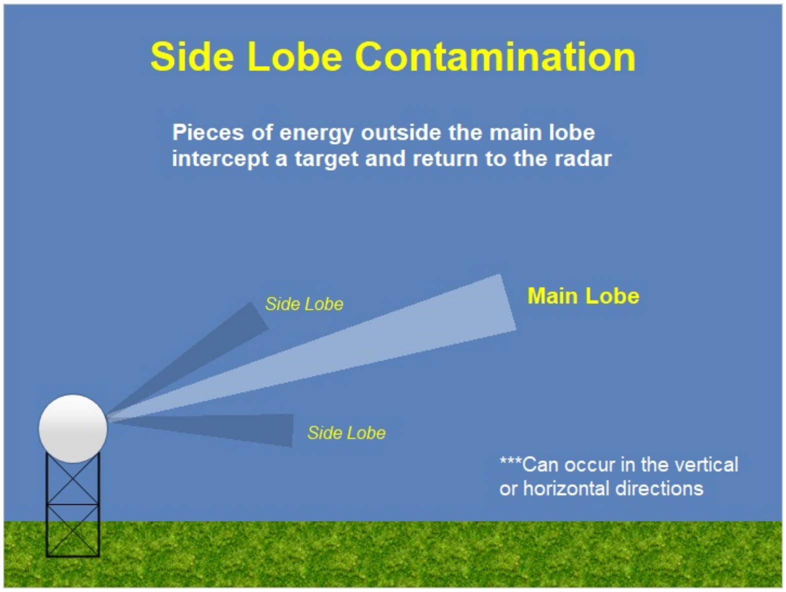
2.2 Side Lobe Definition



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.

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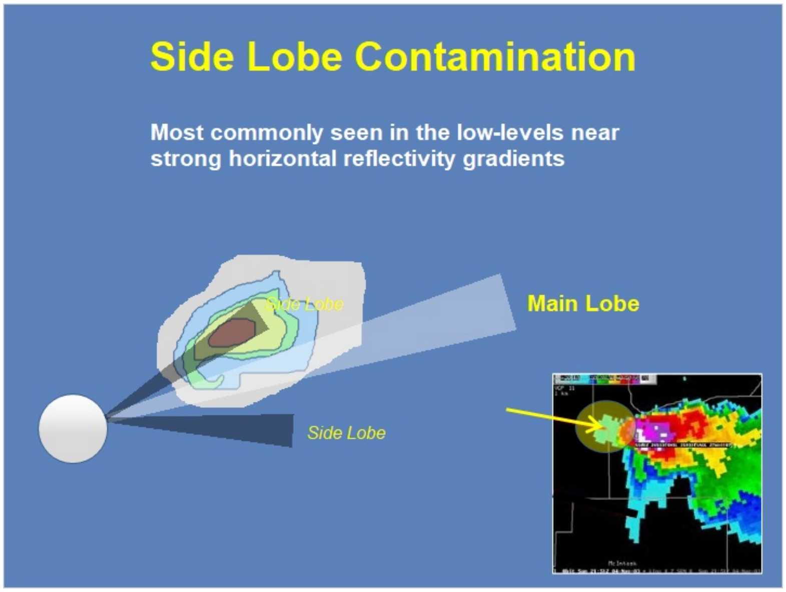
2.3 Side Lobe Horizontal



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.

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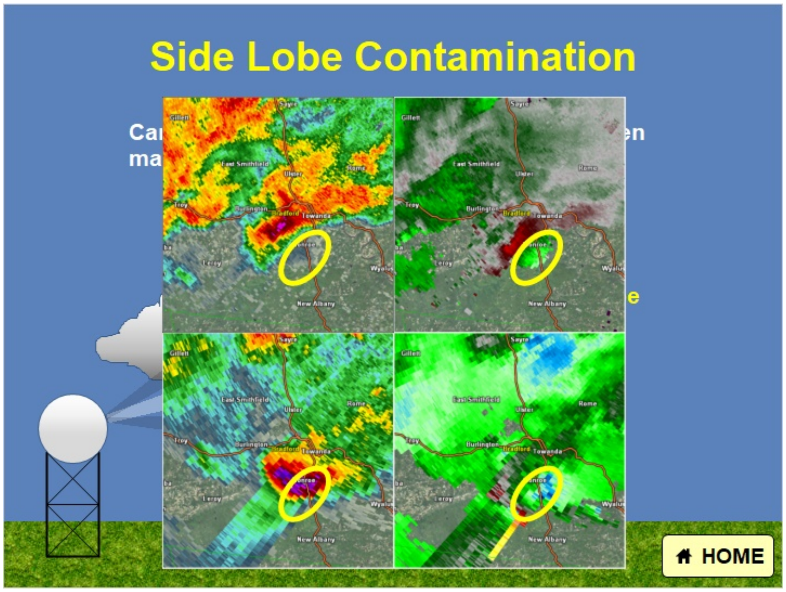
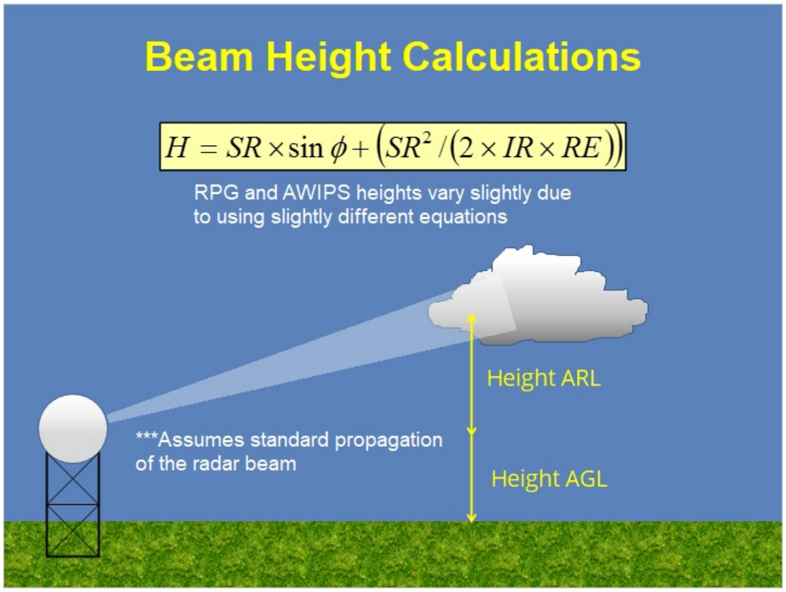
2.4 Side Lobe Vertical



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. 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.

2.5 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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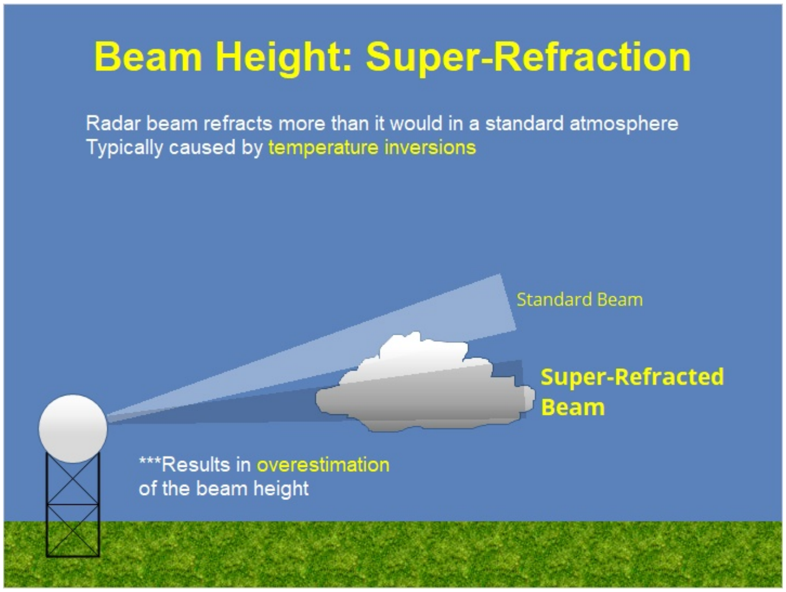
2.6 Super-Refraction



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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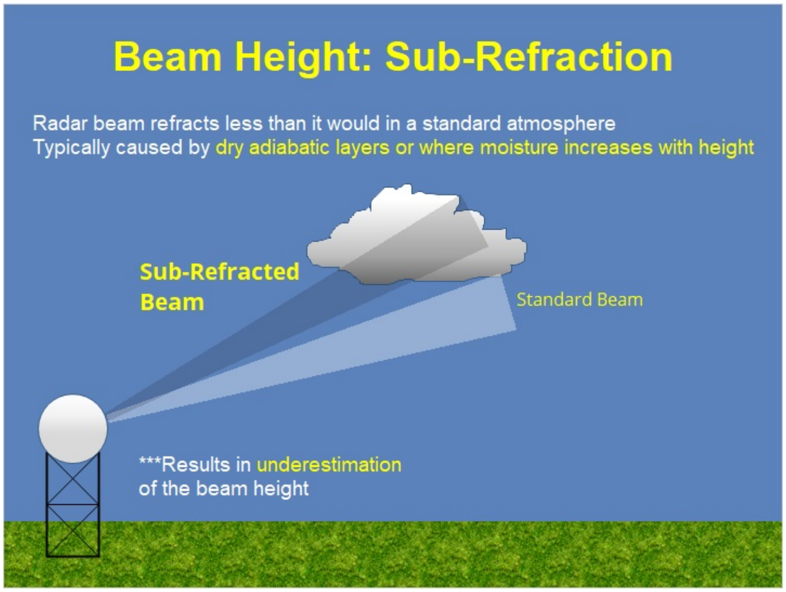
2.7 Sub-Refraction



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.

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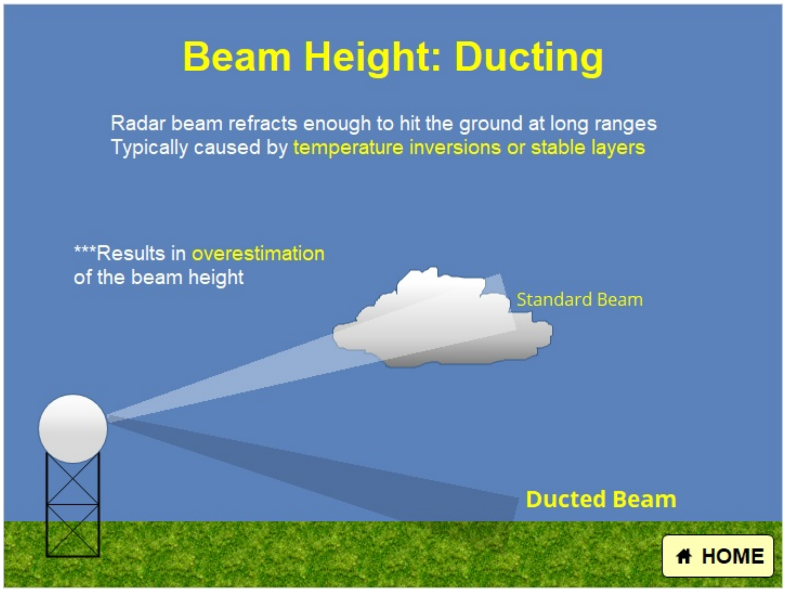
2.8 Ducting



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.

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4. Completion

4.1 Completion!

Notes:

Thanks for your attention! You are now complete for this lesson.

Data Collection

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 Data Collection. Let's get started!

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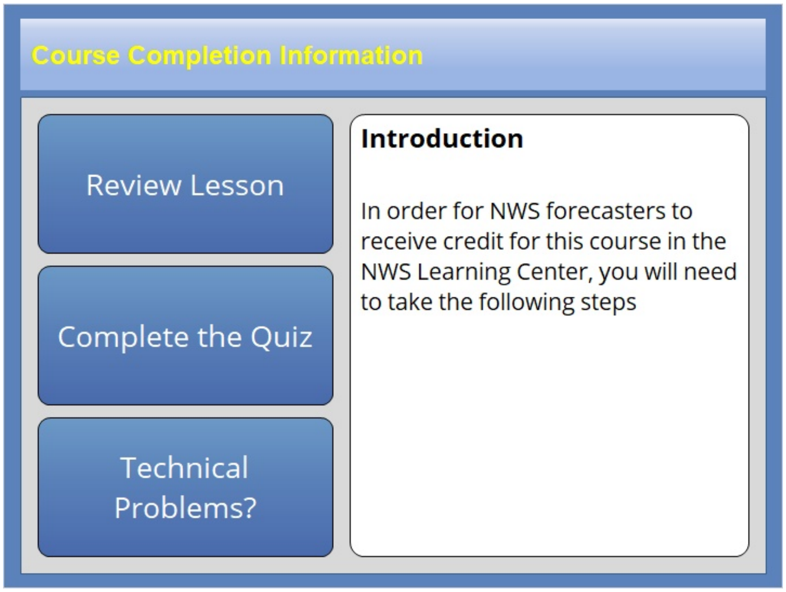
1.2 Course Completion Information



Notes:

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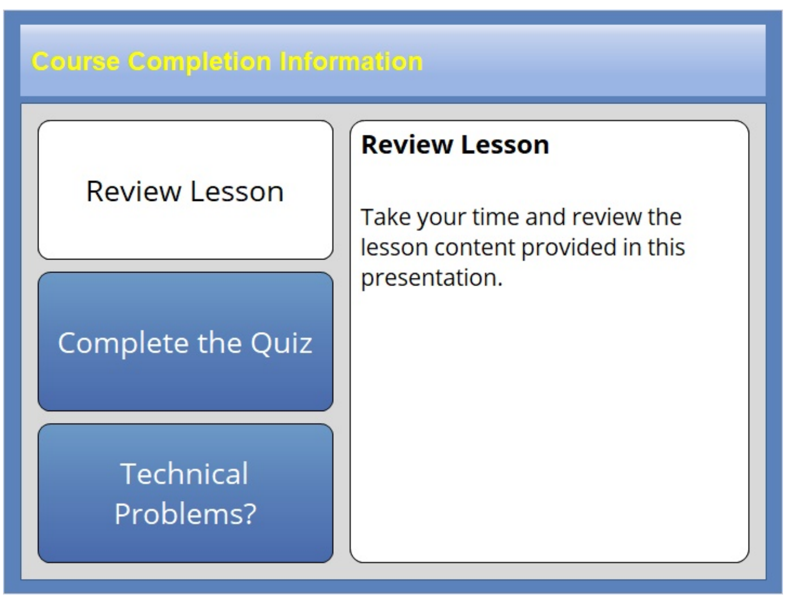
Review Lesson (Slide Layer)



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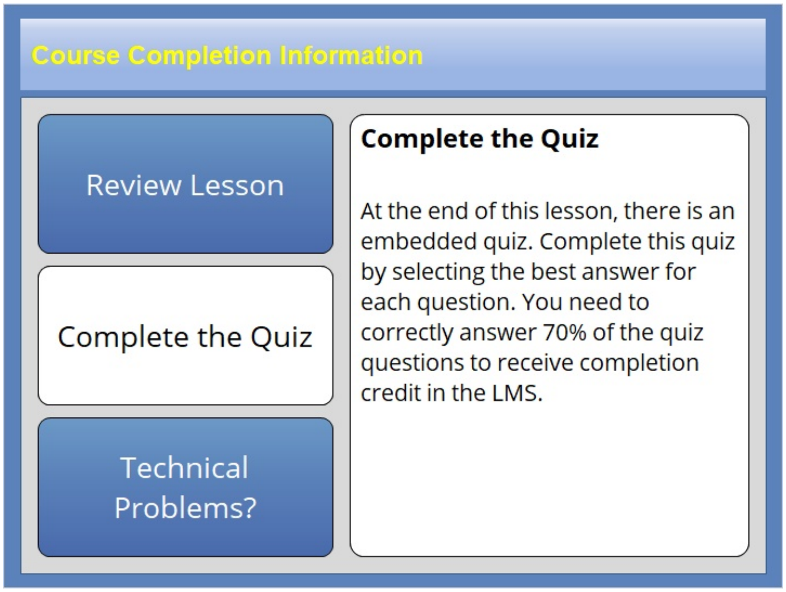
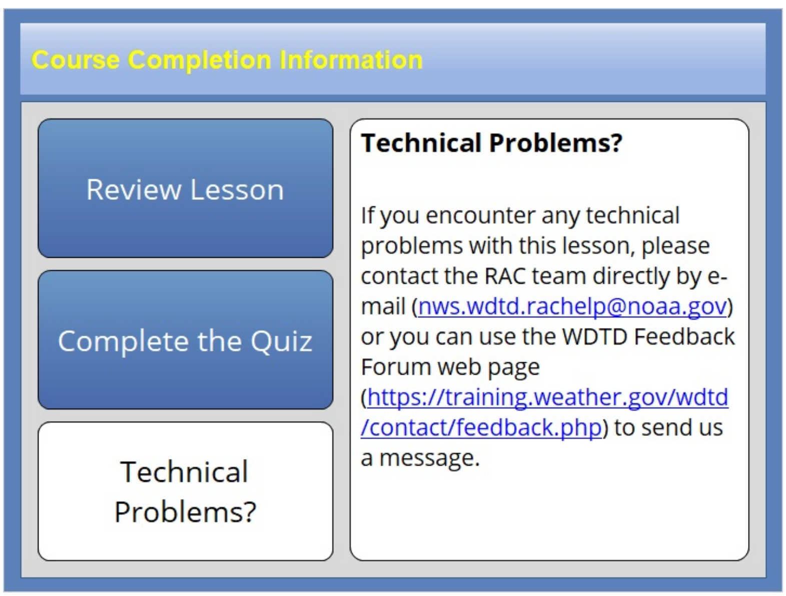
Complete the Quiz (Slide Layer)



Technical Problems (Slide Layer)



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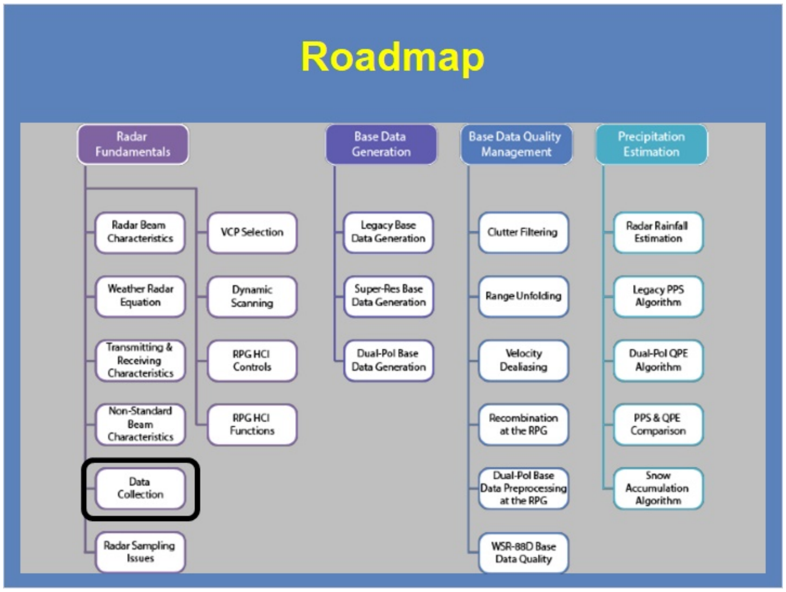
1.3 Roadmap



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. Let’s keep going!

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1.4 Learning Objectives

Learning Objectives

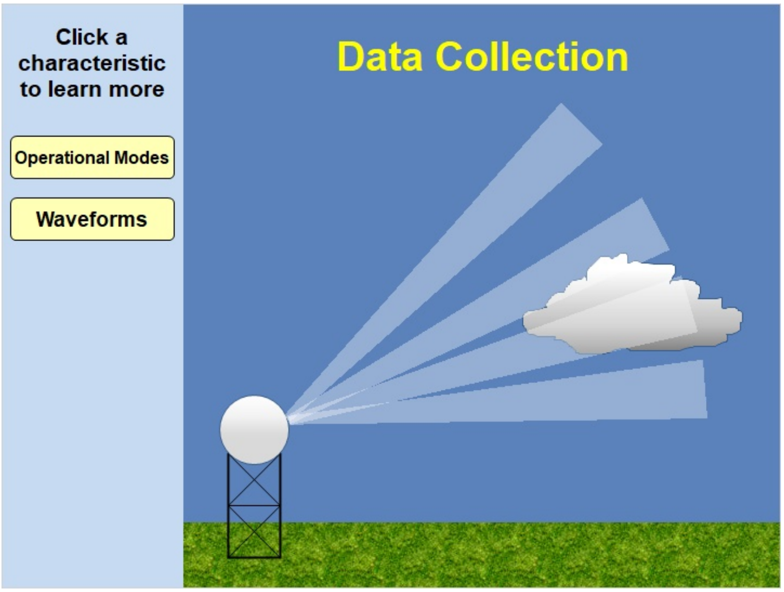
1. Identify the two main operational modes of the WSR-88D
2. Identify the advantages of operating the WSR-88D in clear air mode
3. Identify the three main groups of precipitation Volume Coverage Patterns (VCPs) and which VCPs belong to which group
4. Identify which range unfolding algorithm is used based on the VCP
5. Identify the two waveforms used in the WSR-88D and their advantages
6. Identify the three waveform techniques used on the WSR-88D based on elevation angle

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 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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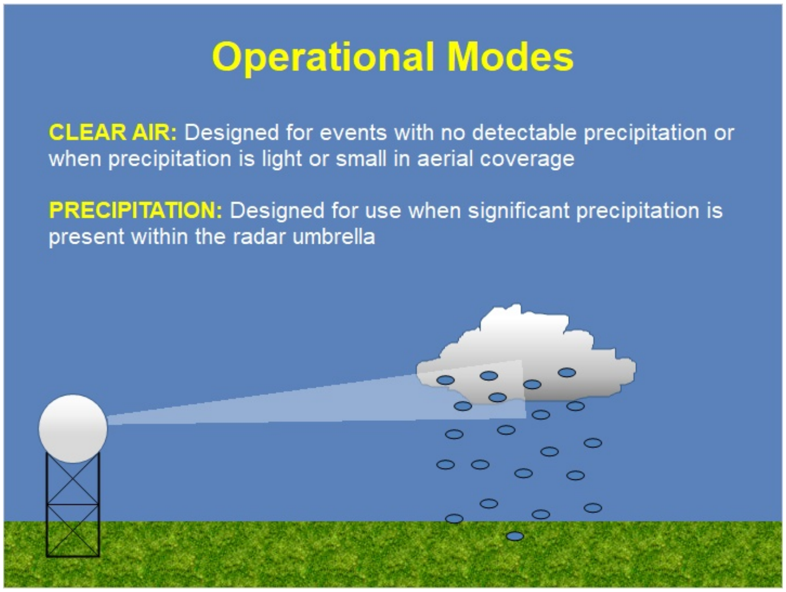
2.2 Operational Modes



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 still 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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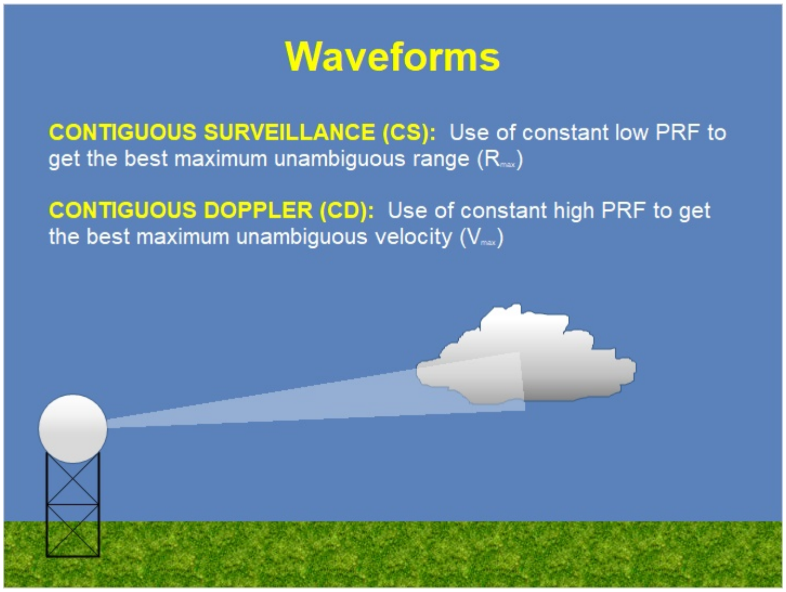
2.3 Waveforms



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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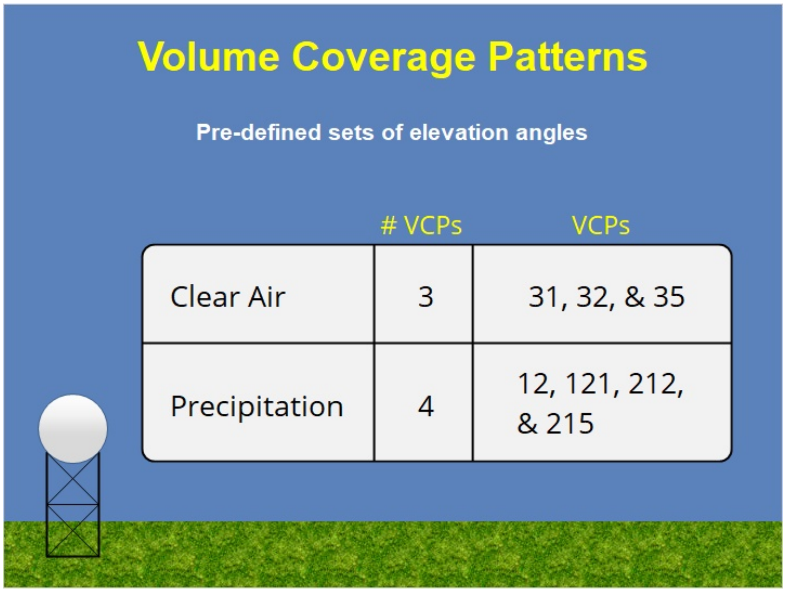
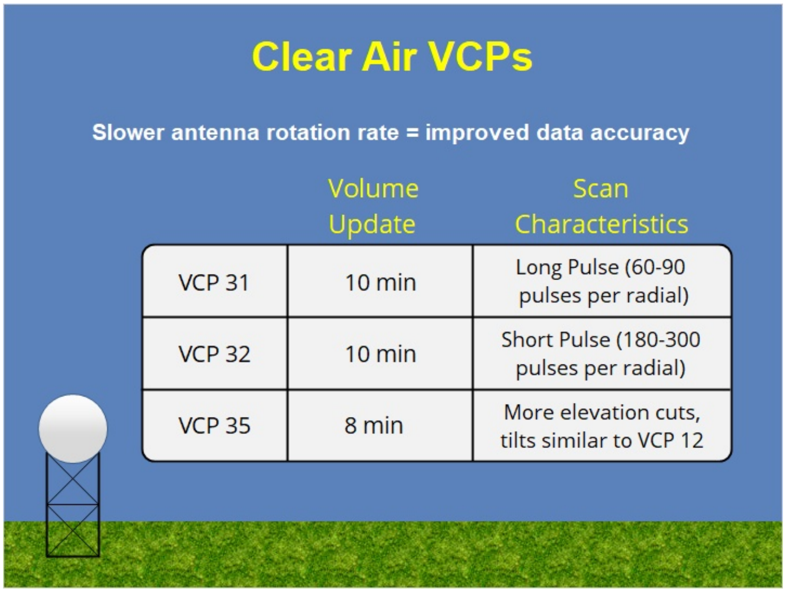
2.4 VCPs



Notes:

The pre-defined set of elevation angles run for each operational mode is called a Volume Coverage Pattern. For Clear Air mode, there are three VCPs to choose from which are VCPs 31, 32, & 35. For the Precipitation mode, there are 4 different VCPs to choose from which are 12, 121, 212, and 215. In the next couple slides, we'll take a little closer look at the general characteristics of these VCPs…

2.5 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 VCPs 31 and 32 is around 10 minutes. VCP 35 has more tilts and takes only 8 minutes to complete, but you get fewer pulses per radial than the other two. 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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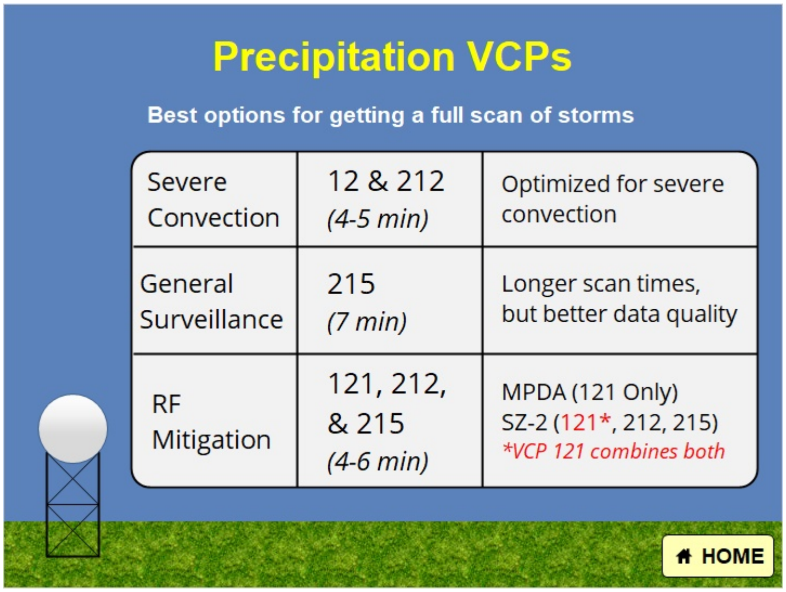
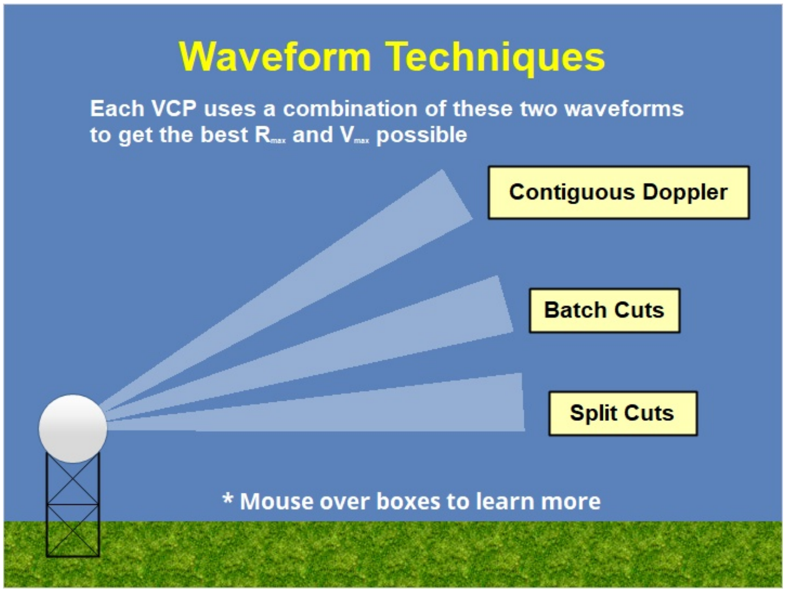
2.6 Precip VCPs



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 four VCPs can be divided up into 3 main groupings: Severe Convection, General Surveillance, and RF Mitigation. The Severe Convection grouping consists of VCP 12 and 212. Both VCPs 12 and 212 provides good coverage in the lower levels with fast update times. The only significant difference between them results from the range folding mitigation technique used. VCP 215 was developed for general surveillance situations that don't require the extensive low-level coverage of VCPs 12 or 212. Finally, recent upgrades to the WSR-88D have come with new techniques to improve range folding mitigation which are included with VCPs 121, 212, and 215. 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.

2.7 Waveform Techniques



Notes:

There are three main grouping of elevation angles with the WSR-88D. Mouse over each of the descriptions on the right to see which elevations are included and what the scanning strategy is for each of those elevations. 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. 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. Finally, all elevations above 7 degrees perform one scan using the CD mode only. Now it's time for your quiz, so go back home and click the Quiz button to test your knowledge!

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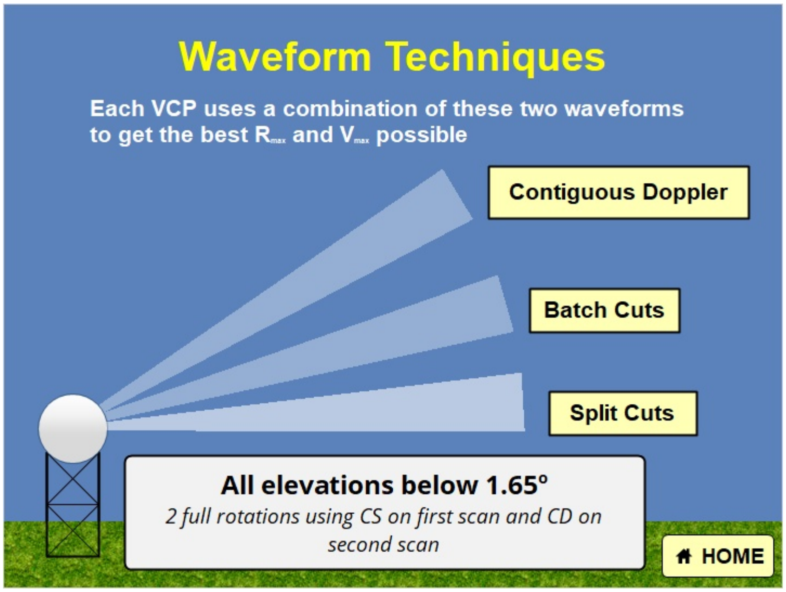
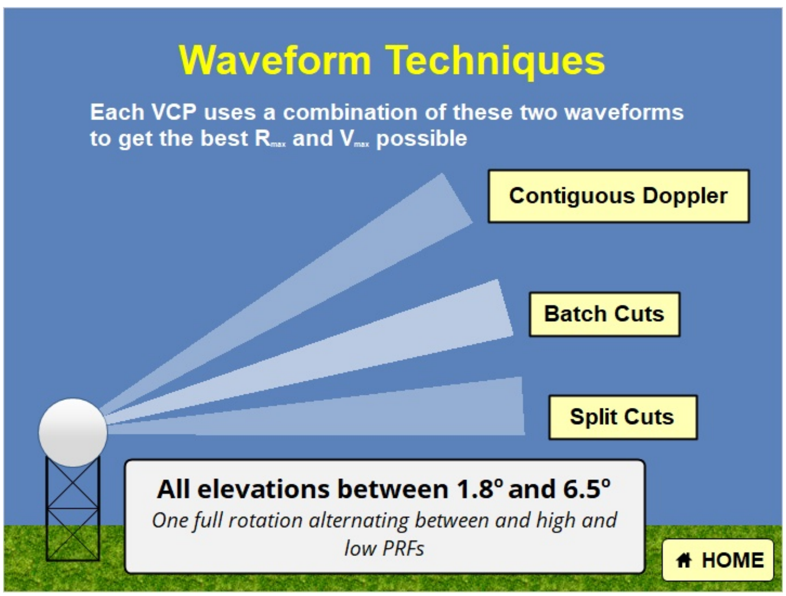
Split Cuts (Slide Layer)



Batch Cuts (Slide Layer)



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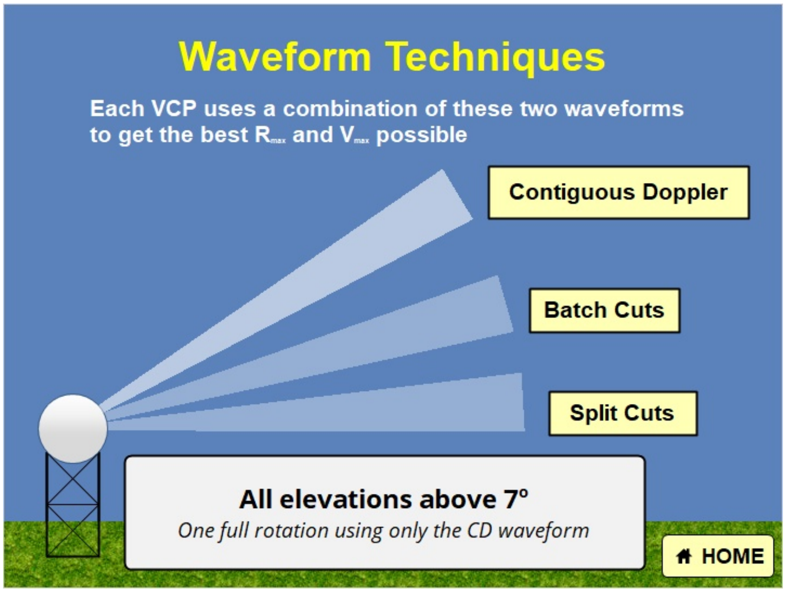
CD Cuts (Slide Layer)



4. Completion

4.1 Completion!

Notes:

Thanks for your attention! You are now complete for this lesson.

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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 covers common radar sampling issues with the WSR-88D. Let's get started!

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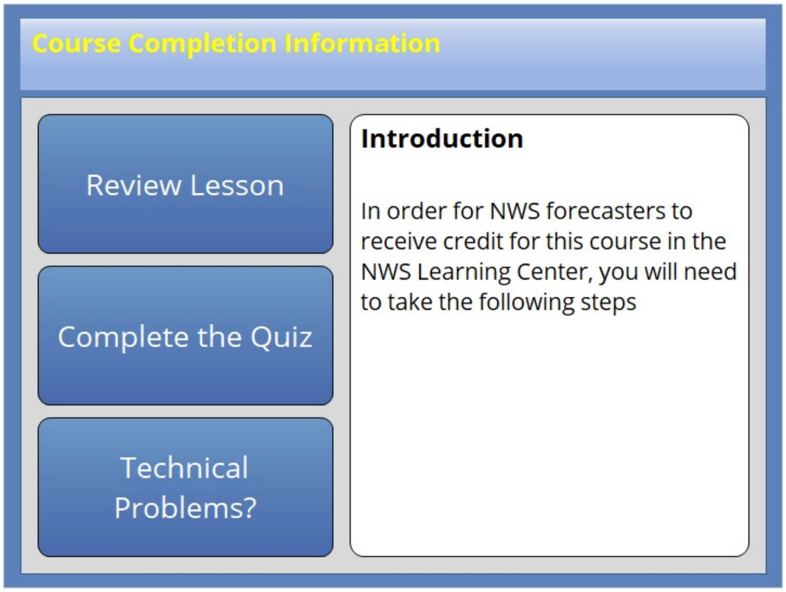
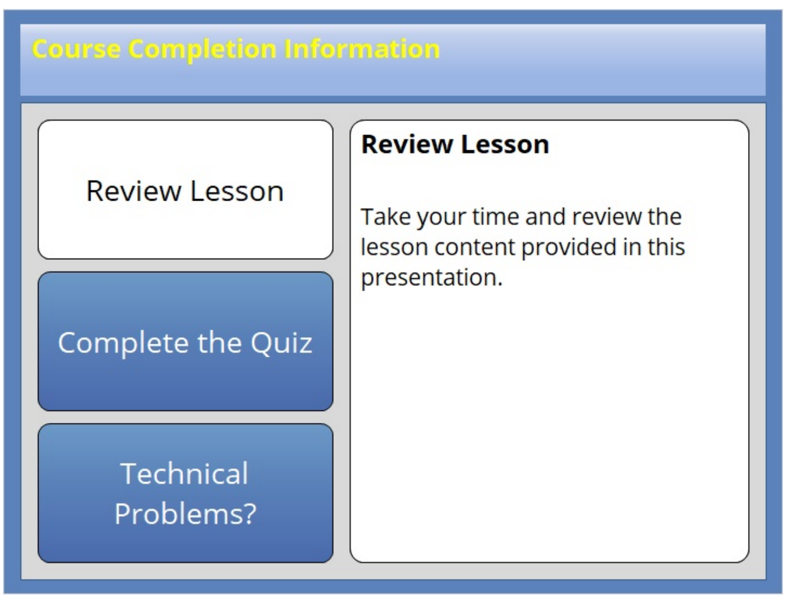
1.2 Course Completion Information



Notes:

Review Lesson (Slide Layer)



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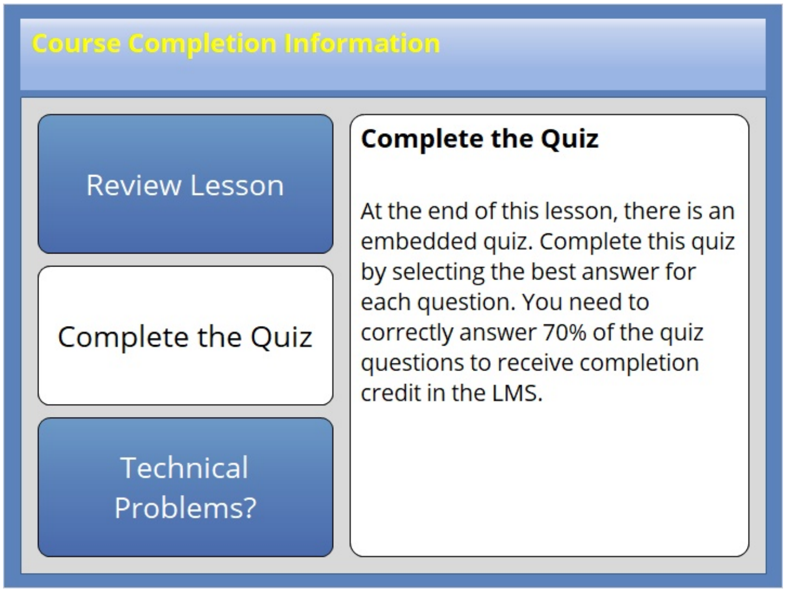
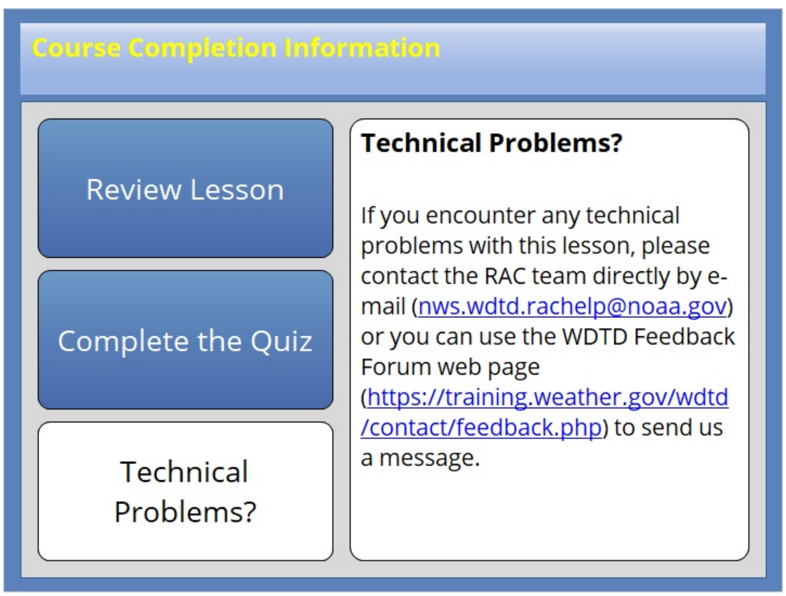
Complete the Quiz (Slide Layer)



Technical Problems (Slide Layer)



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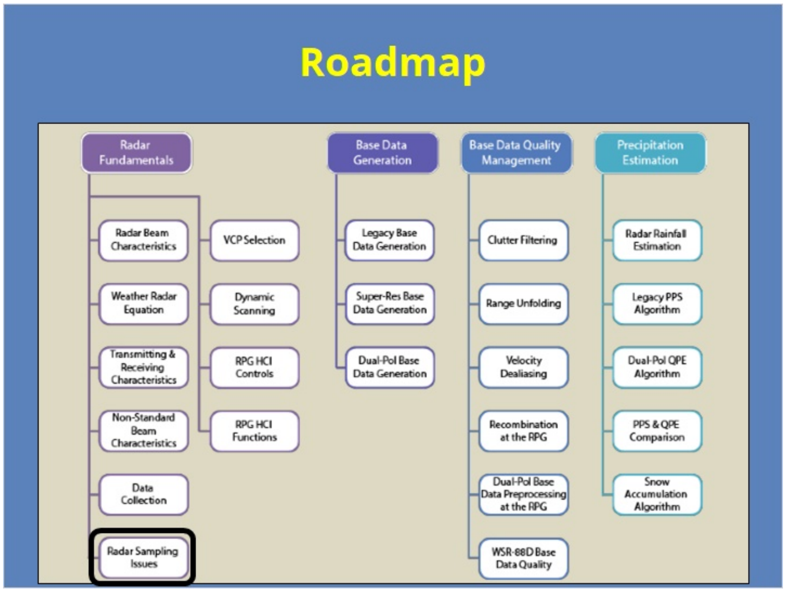
1.3 Roadmap



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 topic. Let's keep going!

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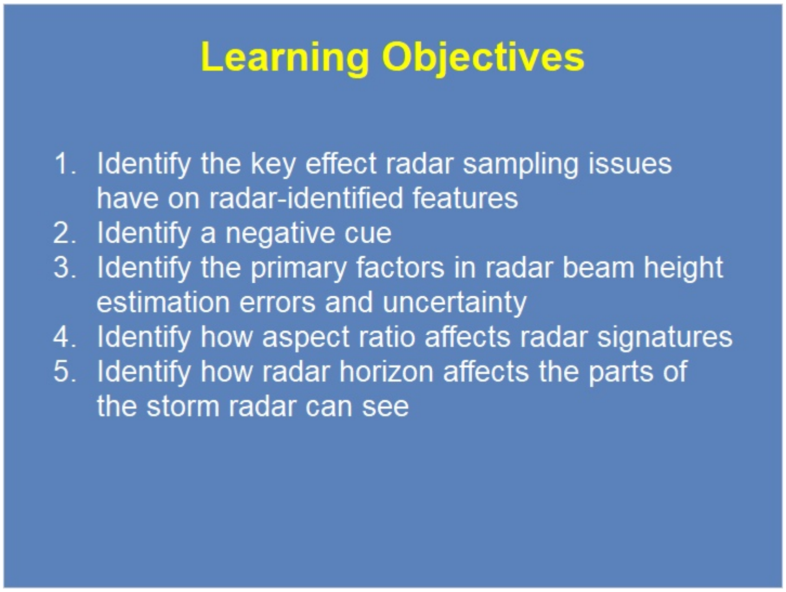
1.4 Learning Objectives



Notes:

There are ten learning objectives for this lesson. Here are the first five. 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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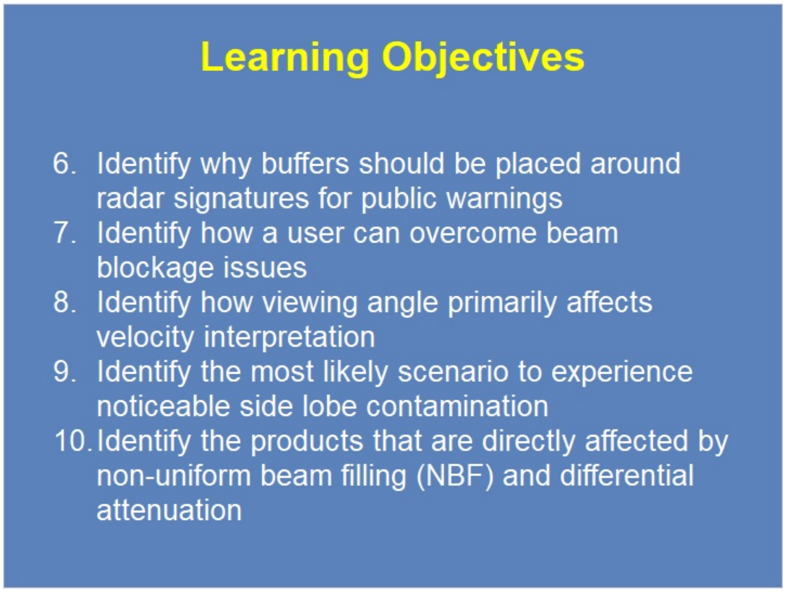
1.5 Learning Objectives



Notes:

Here are the last five learning objectives. Feel free to go back and forth between this slide and the previous one as needed.

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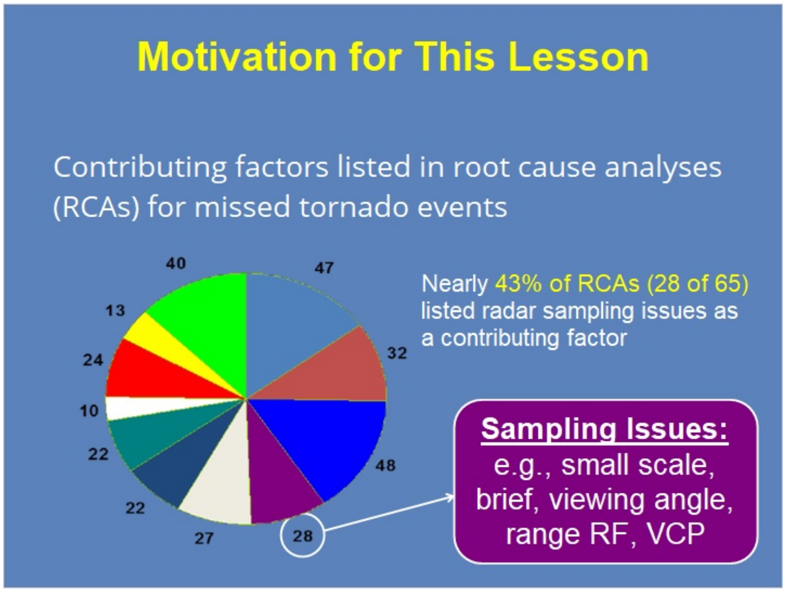
1.6 Motivation for This Lesson

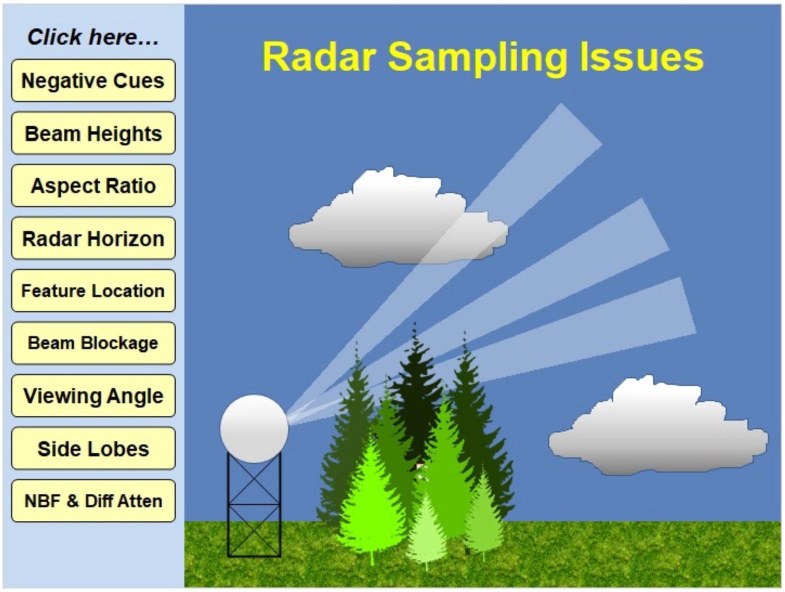


Notes:

A root cause analysis study revealed that in 65 missed tornado events, 28 of those events (or nearly 43%) listed radar sampling issues as a contributing factor. As a result of this research, understanding common radar sampling issues helps forecasters mitigate these issues and avoid future missed events. Let's take a look at these common issues.

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, while others are just annoyances. However, when we understand how these situations can occur, then we can take steps to mitigate their impacts (if possible). This lesson introduces 9 common issues that are shown on the left. Click on the button for each issue to learn more. When you are done with each section, you will be directed back to this page. After completing all 10 sections, a button shall appear to take you to the quiz.

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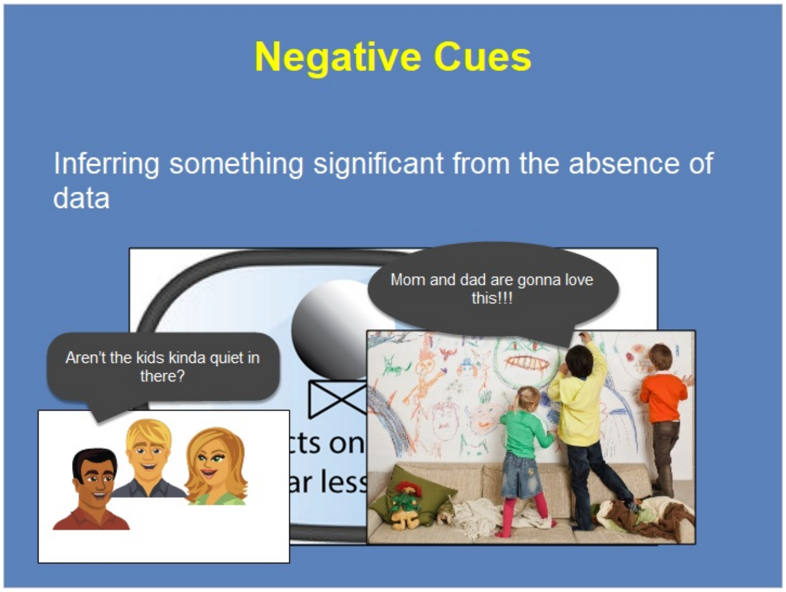
2.2 Negative Cues



Notes:

Before we tackle actual sampling limitations, we need to discuss the concept of negative cues. Many of the sampling limitations we'll discuss in this lesson impact forecasters by masking radar signatures and making them appear LESS IMPRESSIVE than they are in actuality. In some situations, the sampling issue masks the feature altogether. In these situations, we must infer that something significant is present by the absence of data. This task requires the observation of negative cues.

To better understand concept of negative cues, let's look at an everyday situation. Let's say a group of families gather at a house. The parents talk in one room while the kids play in another room. After some time, the parents notice the kids' room is quiet. I mean too quiet. The parents notice there is NO noise coming from the kids' room which gets their attention. The absence of noise when noise is expected provides a negative cue to the parents that something significant could be occurring in the kids' room.

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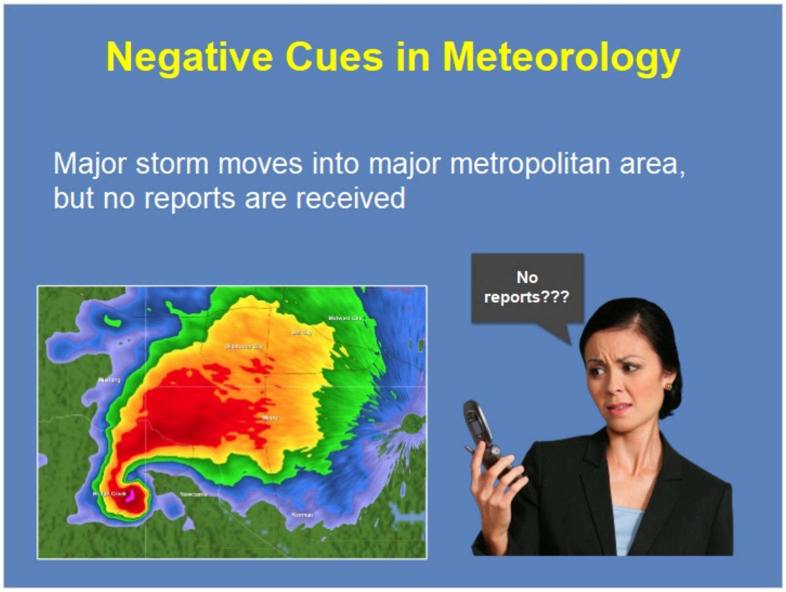
2.3 Negative Cues in Meteorology



Notes:

Let's take a look at some examples of negative cues in the warning world. Our first example shows a classic supercell with a hook echo moving into a major metropolitan area. With such a large population being affected by this storm, you would certainly expect reports coming into the office, right? What if your office received no reports at all? Would that seem suspicious? The lack of reports from what appears to be a very severe storm should signal that something isn't right. The lack of calls may be due to the storm's damage, either because people aren't thinking of calling the office. Maybe you've lost your phone lines 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 could be happening.

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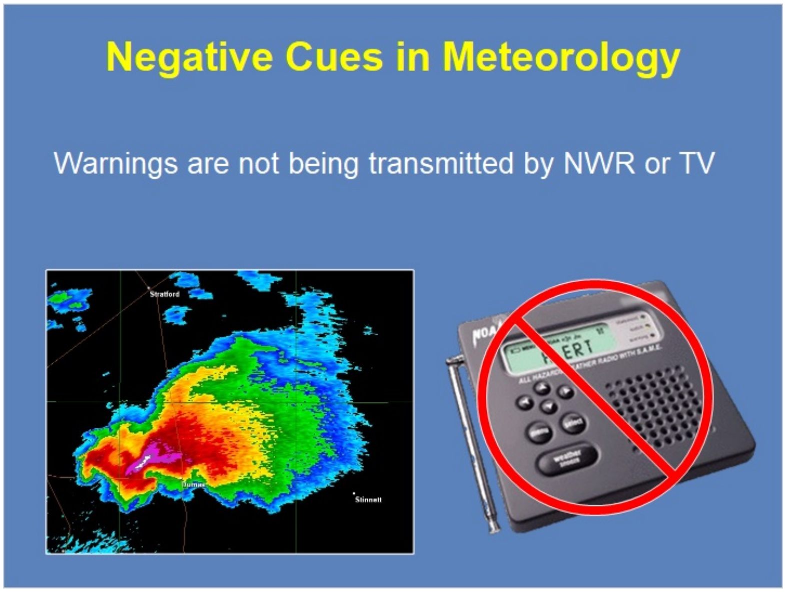
2.4 Negative Cues in Meteorology



Notes:

Here's another example from real life. Your office sees this storm shown on the left and decides to issue a tornado warning (which is a good decision). However, you keep getting calls and tweets from the public and media partners asking, "Are you going to issue a Tornado Warning?" When you tell them that you have issued one, they proceed to tell you that they are getting no indication of a warning…even from weather radio. Oh, and by the way, they are also getting reports of a tornado.

In this situation, your partner is observing the negative cue with this storm that should have a Tornado Warning. What does this situation tell you? Maybe you issued a warning for the wrong storm. Maybe you forgot to click that last button to submit your product in WarnGen. Maybe the NWS network is down and warnings aren't being disseminated to the public. You can learn a lot from the negative cues that others observe.

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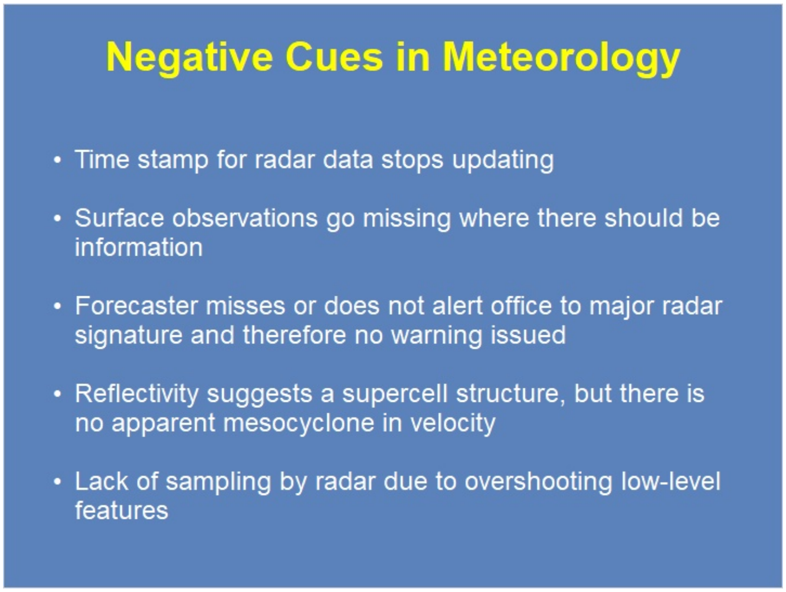
2.5 Negative Cues in Meteorology



Notes:

Numerous examples of negative cues exist in warning operations. However, how do these apply to radar sampling issues? Well, this slide lists some negative cues that are related to radar interpretation. One of the main points of this lesson is radar sampling issues often lead to negative cues in a warning environment. Therefore, have a good grasp on radar sampling limitations and you'll be a better warning forecaster because you will be better equipped to observe and respond to negative cues.

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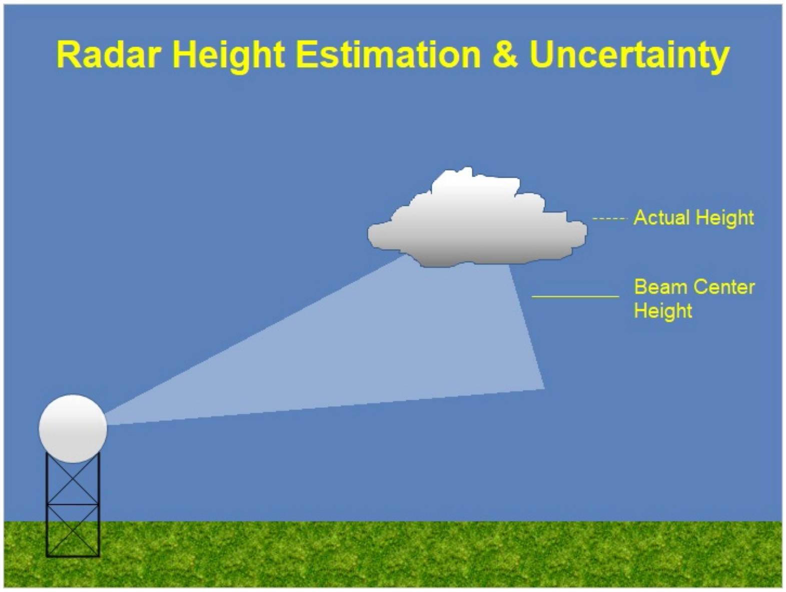
2.6 Beam Heights & Uncertainty



Notes:

Recall the radar beam spreads out as the pulse travels away from the radar, making the sampling area wider and wider. For locations as close as 60-70 miles from the radar, the beam's width extends 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 even though it is much higher. Just keep this fact in mind when interpreting radar echo heights in AWIPS.

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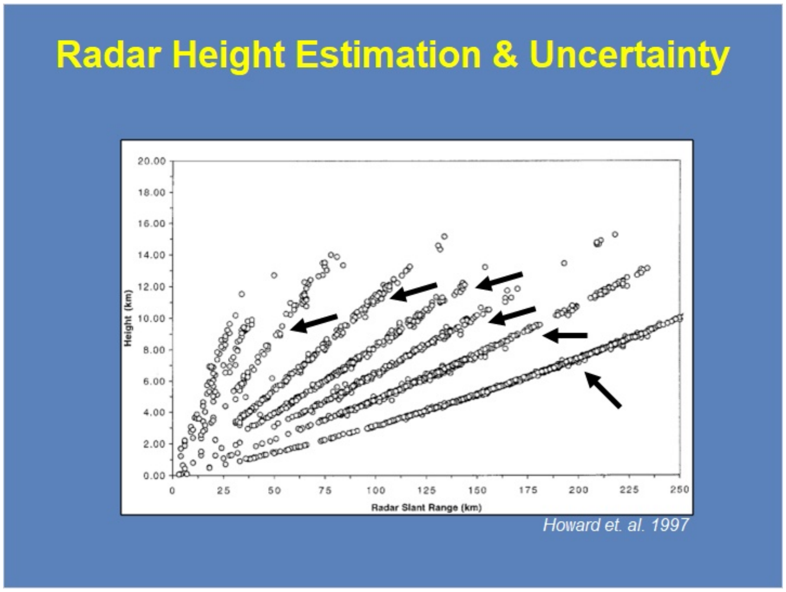
2.7 Radar Height Estimates



Notes:

A study done by Howard et. al. (1997) actually plotted the echo top heights as a function of range from the radar. Notice how all those radar echo top heights fall nicely along straight lines. Do you think this plot shows reality? Absolutely not! This graphic illustrates how using the beam center height to compute echo top heights is not the most accurate. In reality, storms exist in a continuous space, but the radar can only measure echo heights at discrete levels. So, what uncertainty exists in these height estimates? We'll look at that next.

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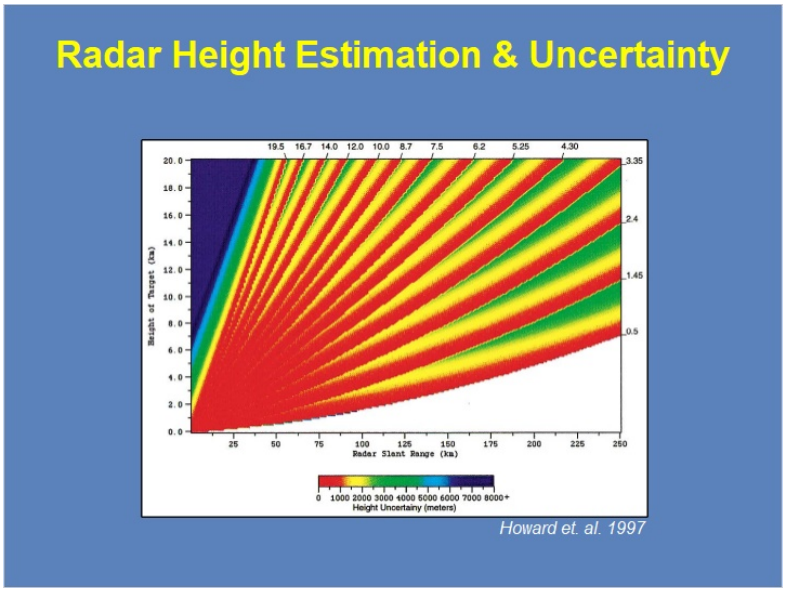
2.8 Radar Height Uncertainties



Notes:

This first graphic shows the uncertainty (in meters) of the target height estimate for each elevation angle in one of the original VCPs intended for general weather surveillance. This color scheme is a little unusual in that red shades are good, and green and blue tones are bad! Notice how accurate the estimates are within 50 km range and below 4 km height. Almost all estimates are within 1000 m. As height or range increases, the uncertainty increases to as much as 3 to 7 km due to the gaps in the scanning strategy.

Now, look at a similar graphic for a different VCP that was intended for severe convection that has more tilts in the volume scan. The uncertainty increase happens at further ranges (past 75 km) and higher heights (above 8 km). So, choosing a scanning strategy with more elevation scans reduces the likelihood of uncertainty in your echo top height estimates.

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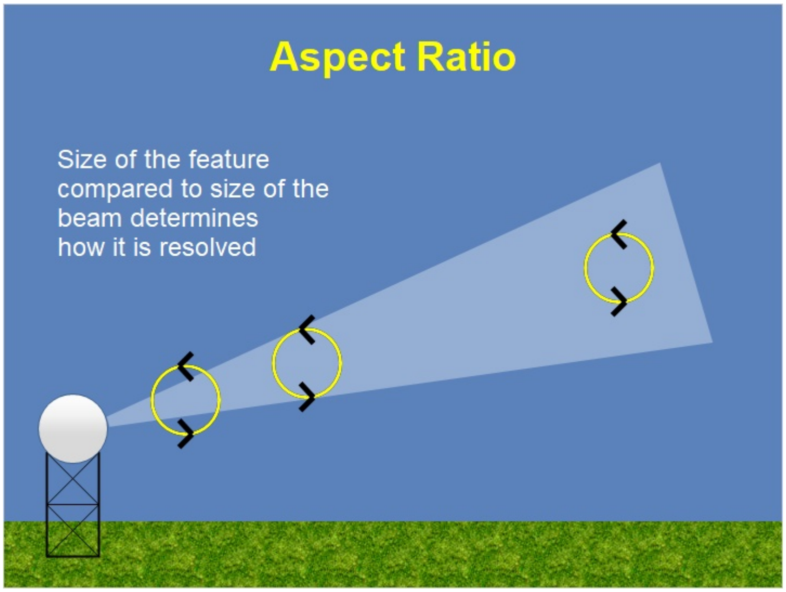
2.9 Aspect Ratio



Notes:

A target's size compared to the size of the radar beam is called the aspect ratio. Apsect ratio matters because the radar beam spreads out with increasing range. So, a target of constant size will look different in the radar base data at different ranges. Take, for example, the idealized circulation shown on this slide. Close to the radar, the radar needs multiple beams to sample the circulation, providing a more detailed view of the feature. At medium ranges, the circulation may be roughly the size of the beam. So, you still get some detail, but not as much as you would at close ranges. At far ranges, only a portion of the beam is sampling the feature. In these cases, you'll either get very little detail or the feature may not be resolvable at all. In other words, the greater the targets range, the less impressive a feature will appear because less detail is apparent.

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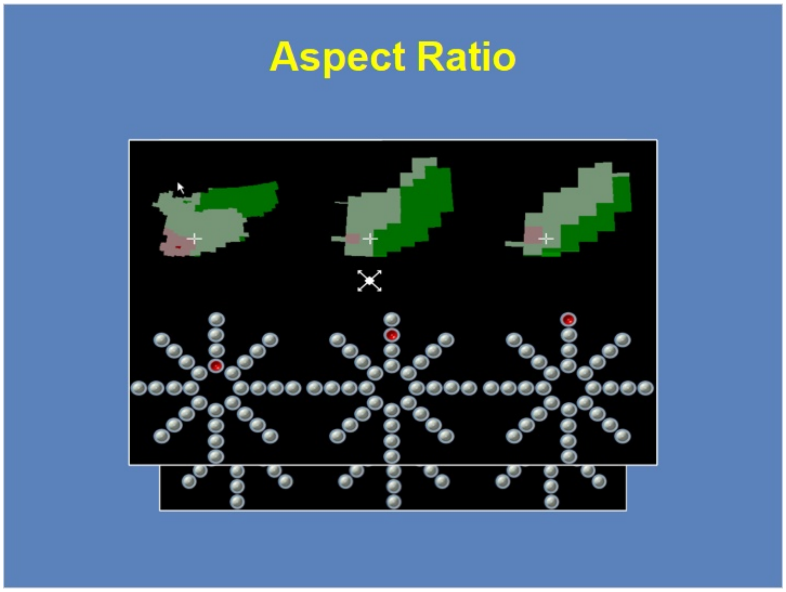
2.10 Aspect Ratio EXAMPLE



Notes:

To further illustrate the concept of aspect ratio, we show an example of the same storm that is viewed to the south of a radar at three different ranges. I should note this example is from an old application that predates both the dual-pol and super-res upgrades to WSR-88D, so we will focus on the reflectivity and velocity displays. The displays show what the same storm looks like with range from the radar increasing from left to right among the examples. Notice the details you can see on the left at the closest ranges, especially the reflectivity gradient on the southeast side of the storm. At further ranges, the reflectivity appears less detailed, almost blocky. Remember that the beam will be observing the storm at a higher altitude at these farther ranges. Still, you can see how the storm might appear less intense when looking at the farther ranges as compared to the closer distances.

Switching over to velocity shows a similar pattern. On the closest look, you can see more details of the circulation. At the further ranges, the circulation appears weaker.

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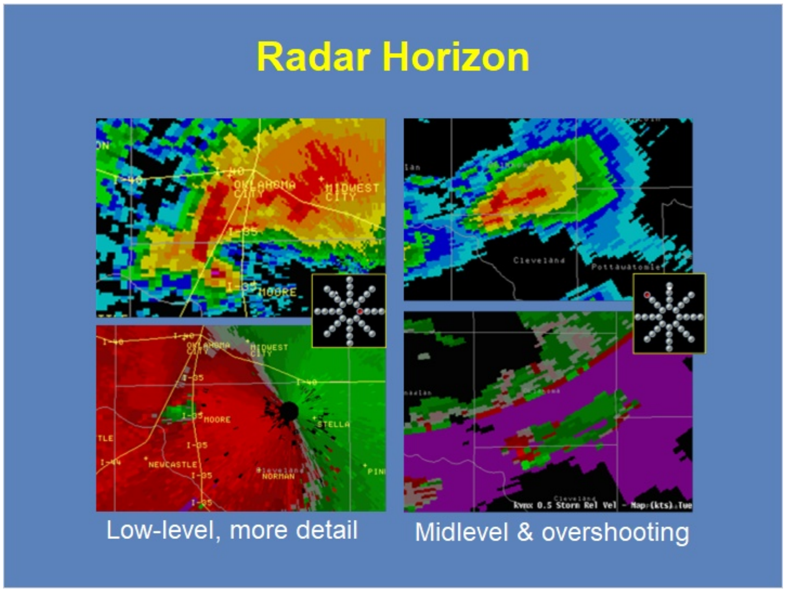
2.11 Radar Horizon EXAMPLE



Notes:

This example shows a supercell thunderstorm producing a tornado moving through a major metro area. The reflectivity and velocity images on the left show the storm from a radar located to the east at very close range. The comparable images on the right display data from a radar located much further away to the northwest of the storm. Notice how the images on the left show more details in both products. The images on the right show the storm's structure at midlevels, where the radar beam is overshooting the low-level hook echo in reflectivity, among other features. Therefore, if low-level features are your primary concern, then make sure you keep this limitation in mind and use the closest radar to observe these features.

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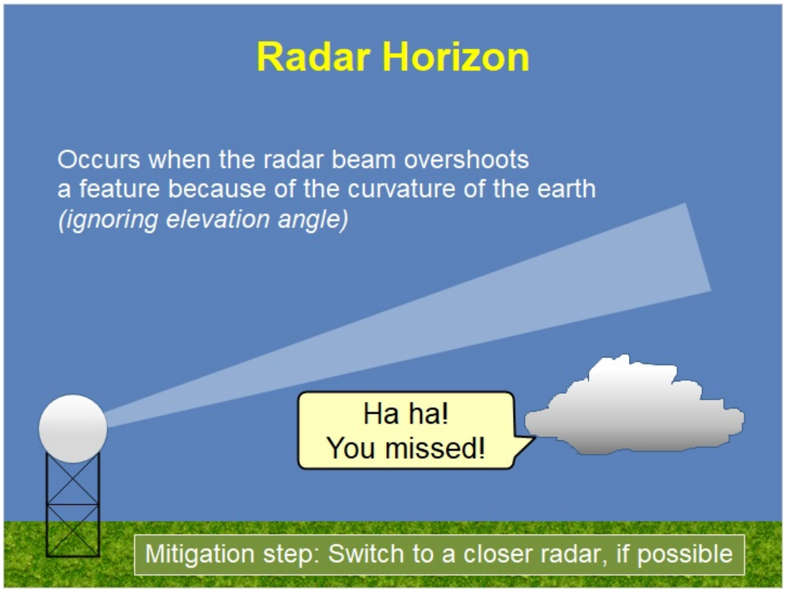
2.12 Radar Horizon



Notes:

Recall, as the beam propagates away from the radar, the earth's curvature causes the radar pulse to sample areas of increasing height as its range from the radar increases. In practical terms, this relationship of increasing beam height with increasing range means low level features will not be seen by the radar at far ranges. To mitigate this problem, forecasters can switch to a closer radar when one is available. When you can't switch to a closer radar, forecasters are forced to draw conclusions about unseen storm features based on the data you do have. Let's look at an example on the next slide.

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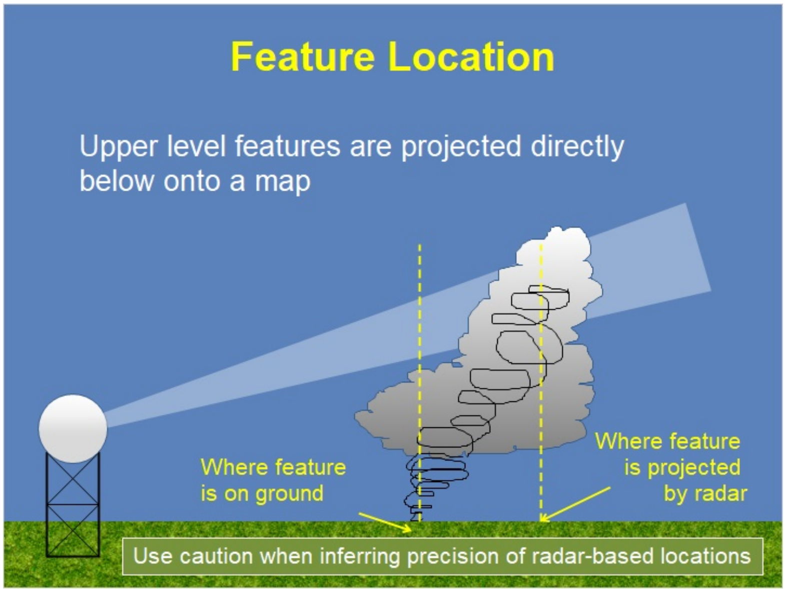
2.13 Feature Location



Notes:

As mentioned in another area of this lesson, the radar beam samples higher elevations of the atmosphere as its range from the radar increases. However, radar imagery projects these data onto the ground surface directly below that point. Many meteorological targets tilt vertically. In other words, features observed in the radar beam are not vertically stacked. For example, tornadic circulations will likely not be located directly underneath the midlevel mesocyclone. You can see from the illustration on the slide that the surface projection based on radar is here, but the actual surface feature is located here. Another example would be hail cores, which travel horizontally as they fall and not be located directly underneath the hail core aloft. So, what's the lesson here? Be careful about how much precision you infer from a circulation's location based on what you see on radar.

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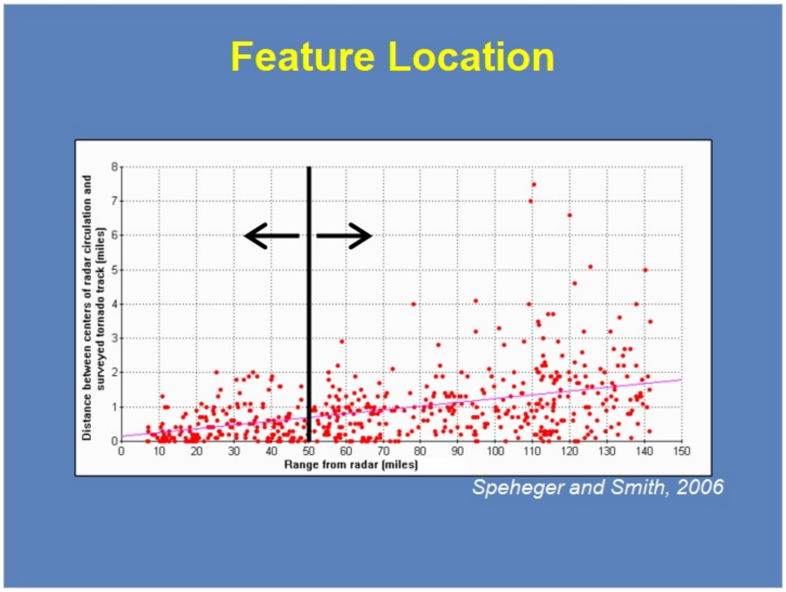
2.14 Feature Location EXAMPLE



Notes:

The scatter plot shown here comes from a study by Speheger and Smith (2006). The diagram identifies the distance between where a radar identified circulation exists relative to the actual circulation location at the surface. Within 50 miles of the radar, errors remain small, averaging less than 3/4 mile and usually less than 2 miles. Once you get past a range of 50 miles, the distribution becomes more noticable. In this study, several circulations had errors as large as 4-8 miles! Therefore, be careful with how precisely you portray feature locations on radar compared with where they occur on the ground.

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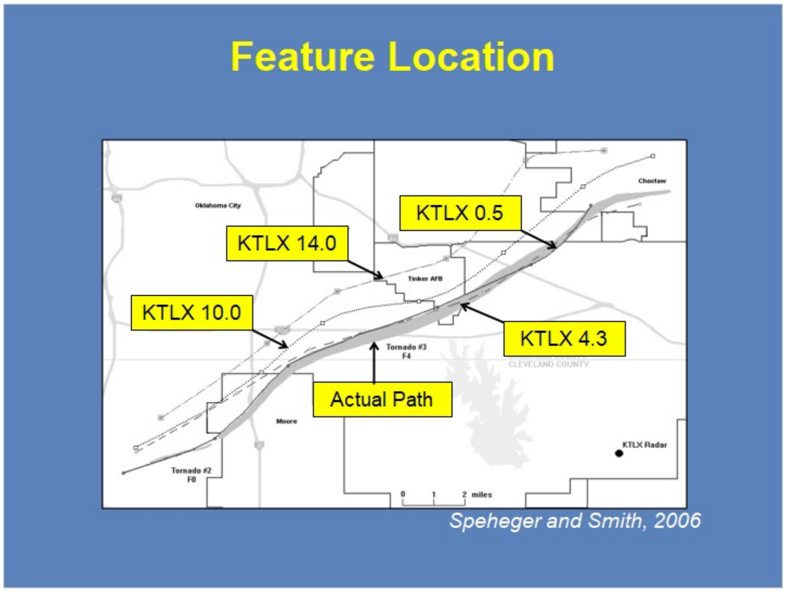
2.15 Feature Location EXAMPLE 2



Notes:

Let’s look at a specific example illustrating this issue, also from Speheger and Smith (2006). Notice how, as the radar elevation angle increases, the distance between the radar circulation location and the actual tornado path increases. So, again, be careful assuming that a radar-determined location precisely identifies the surface circulation location, especially on the higher tilts.

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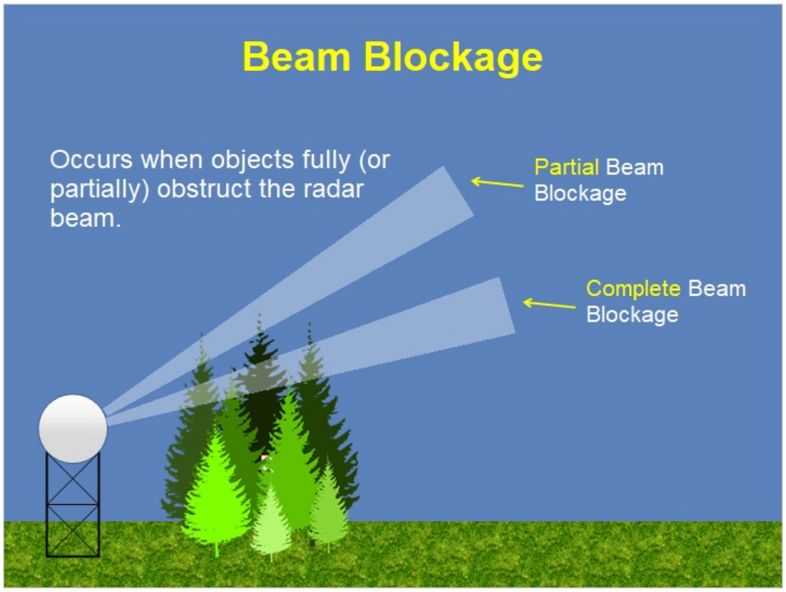
2.16 Beam Blockage



Notes:

When tall objects reside near the radar, these objects can obstruct the beam and cause a power loss significant enough where either no targets down radial from the object will be visible at all, or the targets will appear much weaker than if the obstruction was not present. Objects that can obstruct the beam include nearby trees, buildings, or even a mountain range. In the example shown, the trees block the entire beam where as the higher beam experiences only partial beam blockage.

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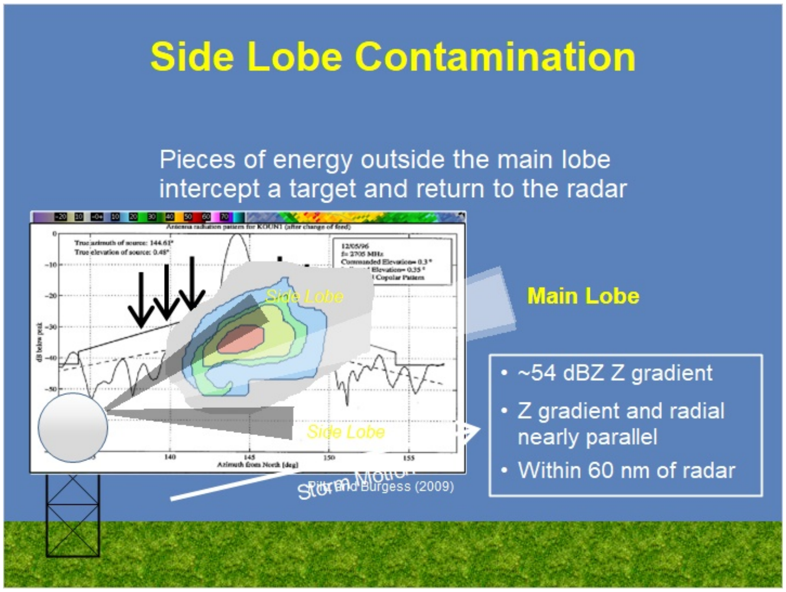
2.17 Side Lobe Contamination



Notes:

Recall from the WSR-88D Fundamentals lessons that some of the transmitted energy propagates outside the main lobe in areas called side lobes. During some situations, targets reflect this energy back to the radar and corrupt the returns collected in the main lobe (Piltz and Burgess, 2009). While these situations are rare, forecasters should know when side lobe contamination tends to occur. Side lobes can occur when a strong storm has a significant azimuthal reflectivity gradient…usually where low-level inflow enters the storm's updraft. The gradient should be at least 54 dBZ over 3 degrees of azimuth of the main beam for the primary side lobe to contribute. Secondary and tertiary side lobes exist between 5 and 8 degrees, but reflectivity gradients would need to be over 70 dBZ across those azimuths for contamination to occur. Likewise the storm core in question needs to be relatively close to the RDA, say 60 nm or less, for side lobe contamination to be possible.

Lastly, when the storm motion vector also aligns nearly parallel to the reflectivity gradient and the radial, side lobe contamination may occur over several volume scans. It's during these situations that side lobes cause the most problems. Let's look at some examples to see why that is the case.

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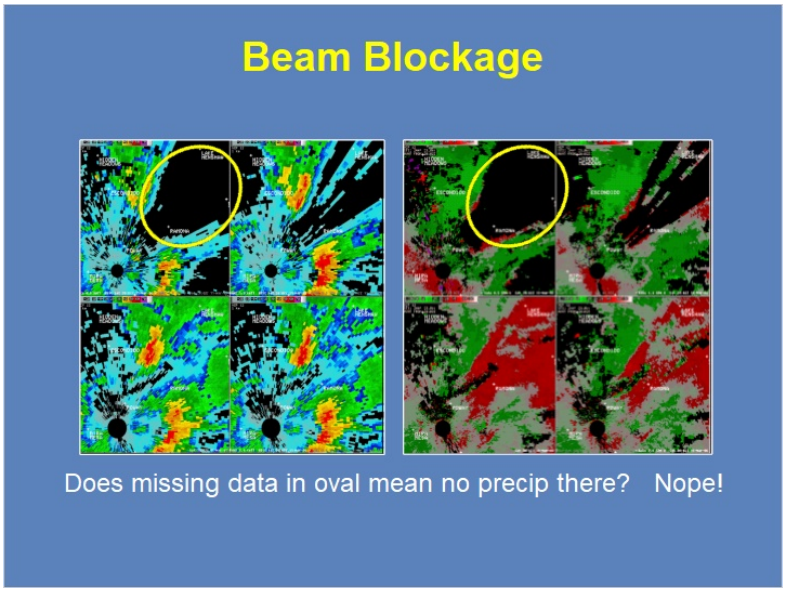
2.18 Beam Blockage EXAMPLES



Notes:

Let’s look at an actual example of beam blockage near a radar. The lowest tilt (top left panel of both images) shows a data gap to the northeast of the radar. Does this gap mean no precipitation is present here? Nope. An obstacles blocks the radar from seeing down radial targets in this area. In fact, the blockage looks complete. So, what might we have missed due to this beam blockage? In this case, there was a tornado with the storm located on the left edge of the beam blockage. Some cyclonic shear is visible aloft. However, we don’t know if the radar would have shown the circulation better near the surface because the data are unavailable.

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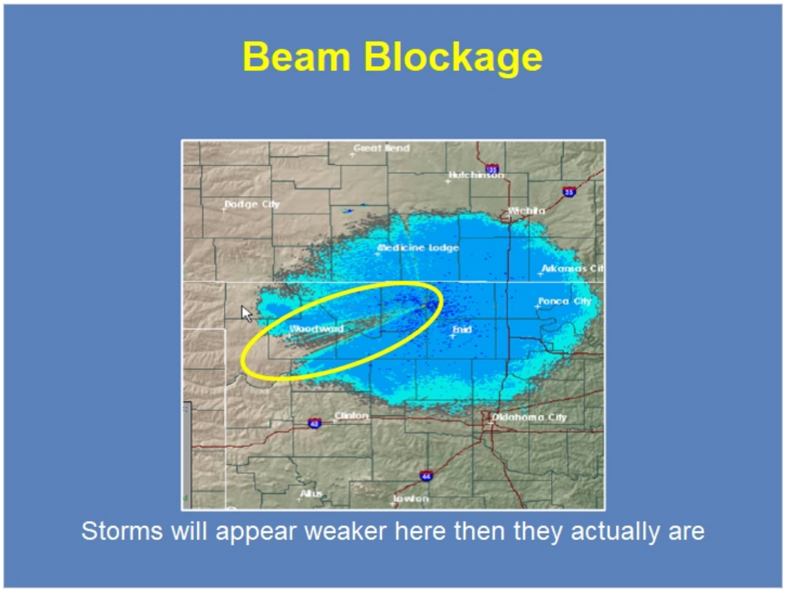
2.19 Beam Blockage EXAMPLES



Notes:

This example shows a situation where there is partial beam blockage to the west-southwest of the radar. In instances like this one, remember that any storms down radial of the blockage will appear weaker than if no blockage was present. Therefore, you will need to make some mental adjustments to your expectations.

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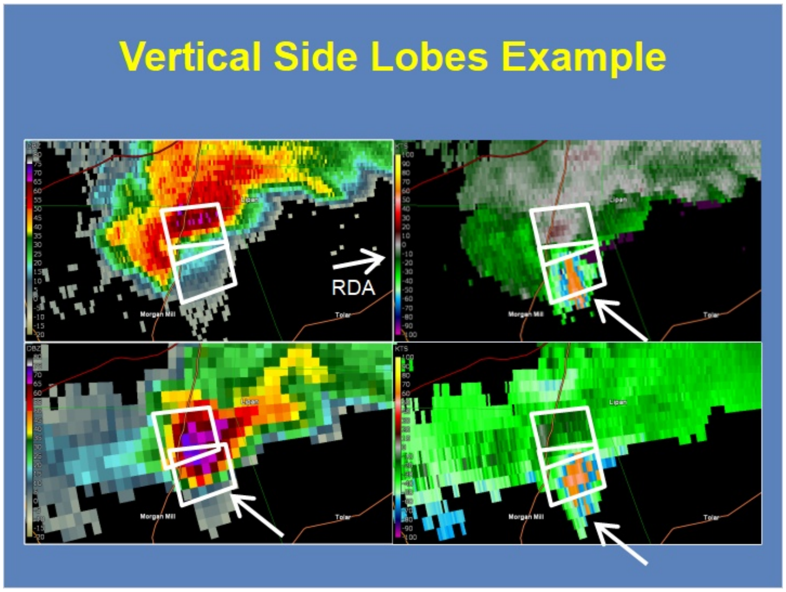
2.20 Side Lobes EXAMPLE 2



Notes:

This next example results from side lobe contamination in mostly the vertical direction. The radar (located to the ENE) samples the storm at a range of 40 nm. As in the previous example, the reflectivity gradient on the inflow side of the storm lines up nearly parallel to the radar beam at 0.5 degrees. Unlike the previous example, the horizontal reflectivity gradient doesn't meet the criteria as its only around 40 dBZ over 3 degrees. Yet, the velocity and storm-relative motion look suspicious. If we look aloft, at 3 .4 degrees, we see stronger Reflectivity values than we did in the storm core at 0.5 degrees. Notice, also, how the velocity values in these areas match the core aloft better than the core at the surface. The Spectrum Width is very high, also, in the same area where the velocity values are anomalously high.

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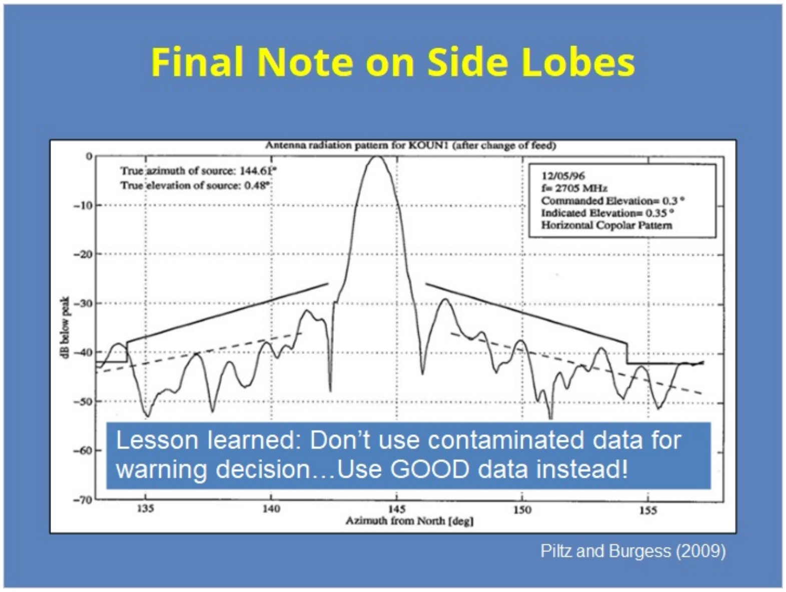
2.21 Final Note on Side Lobes

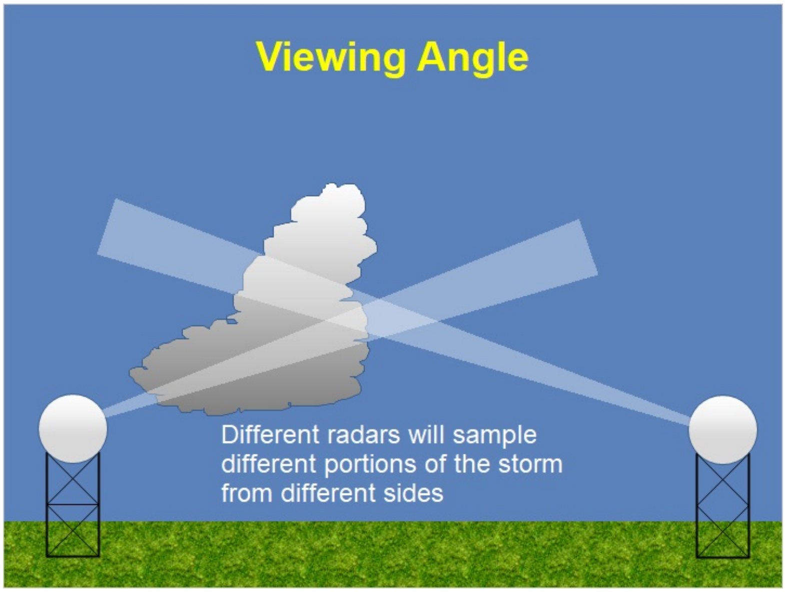


Notes:

Let me make one final note on side lobe contamination. Side lobe contamination has not been thoroughly researched, and supposition and inference both play a role when investigating errors related to this topic in live radar data (Burgess, 2017). We assume all WSR-88D antenna patterns look like the one I show here. With over 150 radars in the fleet (and with most of them having been in service for over 20 years), some variances likely exist between different radars. Some sites may have side lobes that run a little hot (i.e., where contamination happens at slightly weaker gradients). Other sites may have a misaligned feedhorn that could result in the azimuth angle of the primary side lobe being a little more or less than 3 degrees. Your office knows your radar better than just about anyone else, so use that local knowledge to help you know when data are contaminated.

So what's the key takeaway when it comes to side lobe contamination? Well, you need to know when data are contaminated and then don't use that data as part of your warning decision. Now, I'm not saying that storms with side lobe contamination should never have a warning. Instead, use the other GOOD data available to you to make that decision. More on this subject will be discussed in later topics of this course.

2.22 Viewing Angle



Notes:

In several places in the US, especially in the Central & Eastern US, storms are often sampled by multiple radars. Storms lack symmetrical structure both in the horizontal and in the vertical, so getting multiple views of a storm improves storm sampling and generally helps you see what you want to see. Forecasters need to know when a better viewing angle for a storm is available. Let's look at a few examples.

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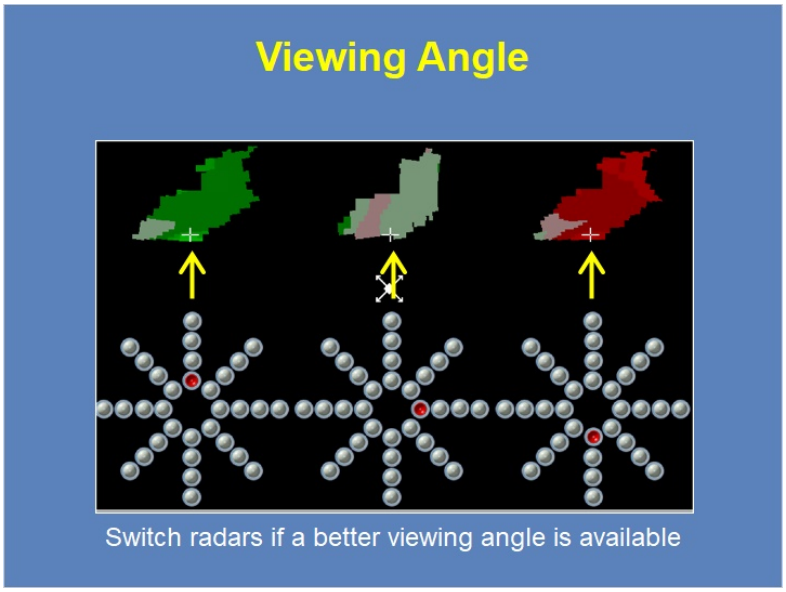
2.23 Viewing Angle EXAMPLE



Notes:

Recall that your radial velocity measurements depend on your viewing angle. When the radar's beam aligns with the wind direction, wind speed measurement accuracy maximizes. When the radial looks perpendicular to the wind direction, the radar can't measure the wind speed at all. Usually, the radar observes an individual storm at some angle in between.

This image shows the same radial velocity data when viewed from 3 radars: one located north of the echo on the left, one located east of the echo in the center, and one located south of the echo on the right. Notice how the radial velocity changes depending on the radar's viewing angle, even though the actual wind field remains the same. Therefore, know your radar's location relative to your area of interest, and switch radars when another site provides a better look…especially when looking at velocity signatures.

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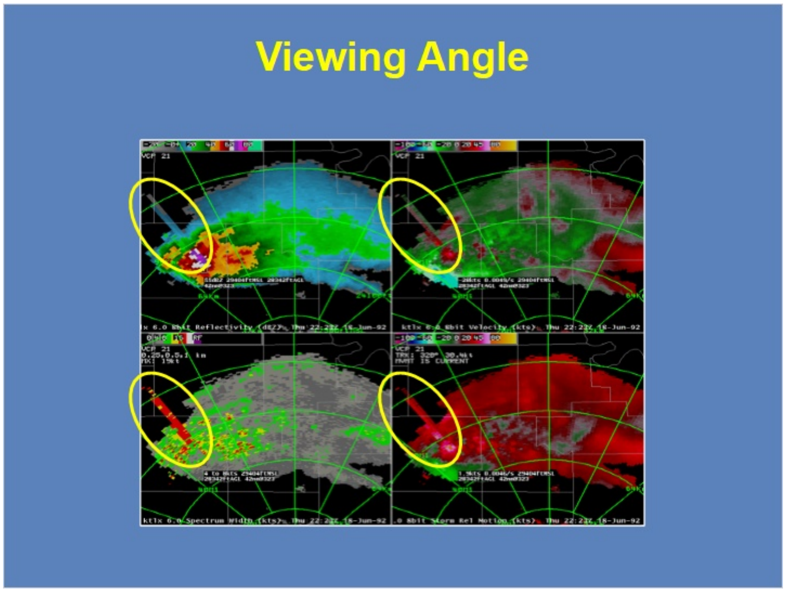
2.24 Viewing Angle EXAMPLE



Notes:

Viewing angle impacts Radial Velocity the most frequently of all the base data, but other products, such as Reflectivity, are not immune. Three-body scatter spikes (TBSSs) often appear down radial of significant hail cores. The example on the slide show an example of a TBSS to the northwest of the storm's core. If another storm was located in this area, this signature might not be visible from this radar. To see the TBSS, you would likely need to switch to a radar with a different viewing angle. Likewise, data from other products in a TBSS region can be corrupted. If the radar beam passes through a hail core and then through a mesocyclone, then the velocity data for the mesocyclone could be negatively impacted by the TBSS. The solution to this problem: Pick a different viewing angle.

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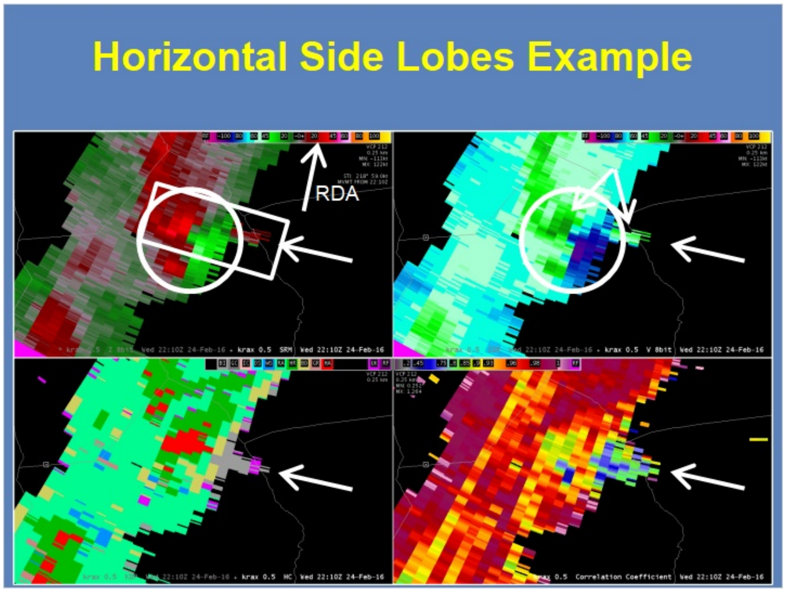
2.25 Side Lobes EXAMPLE



Notes:

Here's a good example of primarily horizontal side lobe contamination. The radar (located to the NNE) samples the storm at a range of ~50 nm. A fairly tight gradient of reflectivity exists on the east side of the storm. Directly to the east of, and at the same range as, the storm core, a weak reflectivity feature protrudes out to the east of the storm. In this area, side lobe contamination has occurred. Notice the ZDR and CC values in this area aren't indicative of precipitation. If we switch over to the other products, you see the HC algorithm has tagged the data as biological. Notice how the radial velocity values in this area better match those from the storm core then those in the adjacent radials.

The storm motion (218 degrees at 59 kts) takes this storm on a path roughly parallel to the radial. This orientation allowed the side lobe contamination to occur for several volume scans. Fortunately, forecasters can quickly identify the corrupted data and see that it doesn't impact their interpretation of the key feature in the velocity data: the mesocyclone located directly to the west of the bad data. However, data corruption can be more difficult to spot and result in poor warning decisions if forecasters are not careful. Let's look at another example to see how that can happen.

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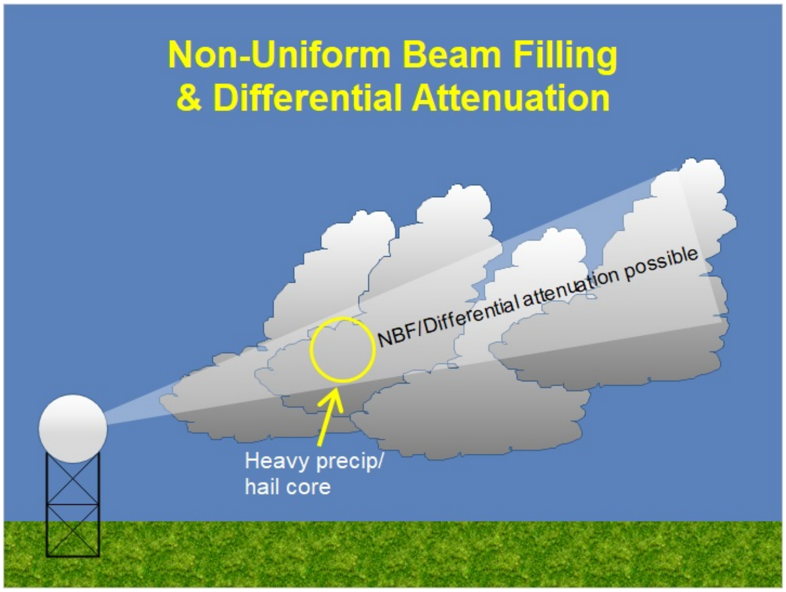
2.26 Non-Uniform Beam Filling & Differential Attenuation



Notes:

The last two sampling issues on our list impact the dual-pol variables of Correlation Coefficient (CC) and Differential Reflectivity (ZDR), albeit in different ways. The first artifact, non-uniform beam filling, impacts CC while the second artifact, differential attenuation, impacts ZDR. As you'll see on the next few slides, these two sampling issues often occur in tandem, but they are caused by completely different processes. The most common situation occurs when strong hail cores exist, especially when the cores are aligned down a radial from the radar. Let's look at both of these issues in more detail.

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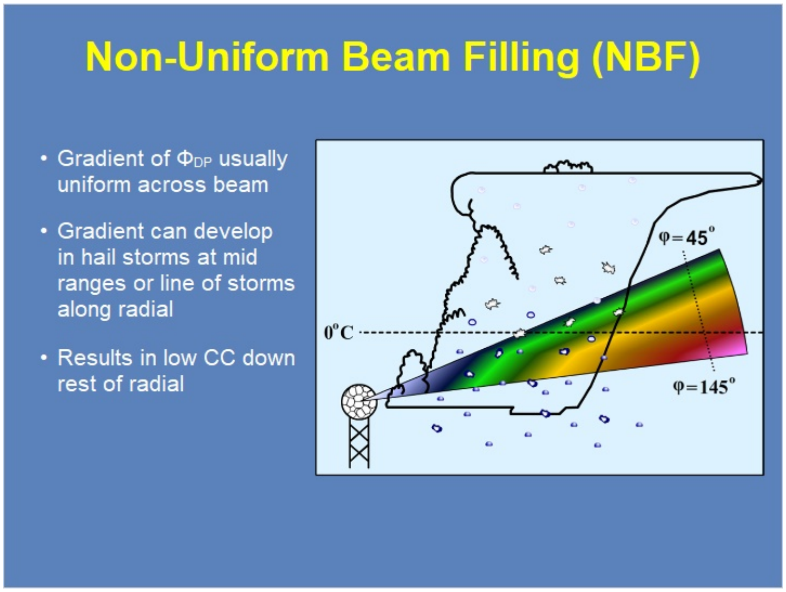
2.27 Non-uniform Beam Filling



Notes:

In most circumstances, differential phase remains uniform across the radar beam. One instance where this condition isn’t true occurs when hail storms are observed at medium ranges from the radar. Under these conditions, the radar beam can sample significant hail melt across the beam. When this happens, differential phase experiences little phase shift at the top of the beam, but a large phase shift toward the bottom of the beam where more liquid hydrometeors exist. This gradient in phase shift across the beam causes Correlation Coefficient to be reduced from that point and the rest of the gates located down radial. This condition, called non-uniform beam filling (or NBF), occurs down radial from the hail core. Now let’s look a similar situation where NBF can occur.

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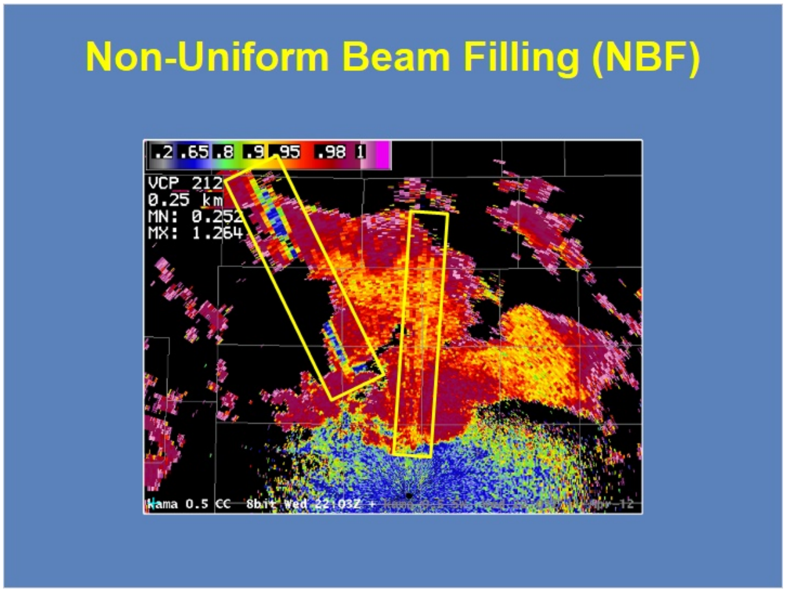
2.28 NBF Example



Notes:

This image shows storms that are causing non-uniform beam filling issues. Can you determine which storms are causing problems? Does it help when we switch over to CC? Hopefully, you said yes. The storm to the northwest caused significant NBF issues, as is visible in the reduced CC values down radial from the storm's core. Just north of the radar, another storm appears to have some NBF issues, too. The CC values drop less prominently, but they are still noticeable.

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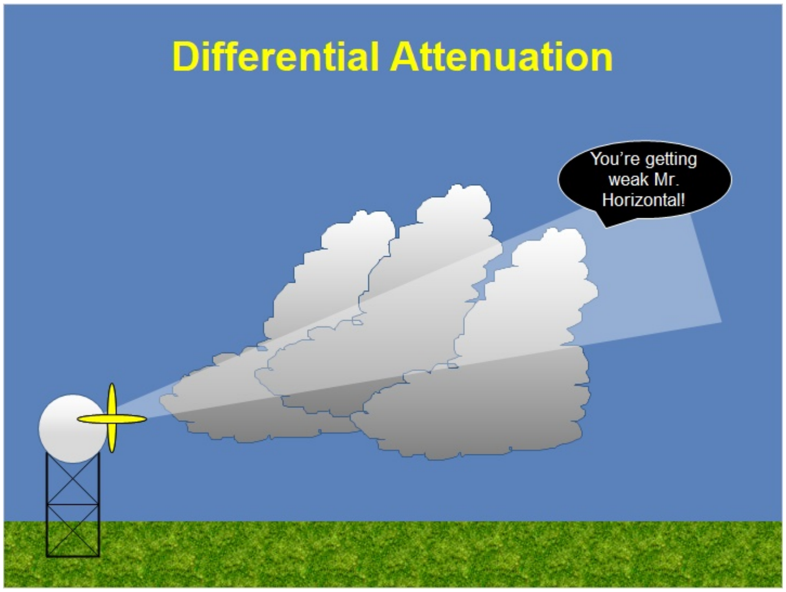
2.29 Differential Attenuation



Notes:

Now let's move on to the second, related sampling issue that impacts ZDR. The radar transmits its pulse with two polarizations. As the pulse propagates through the atmosphere, each polarization usually attenuates (or slows down and weakens) at the same rate because most hydrometeors don't attenuate S-band radiation significantly. In some cases, however, the horizontal pulse will attenuate significantly, but the vertical pulse will not. These situations occur when the pulse travels through storms with very heavy rain and hail cores, or when several storms are aligned along a radial. In these cases, the precipitation impacts the vertical pulse far less than the horizontal pulse. As a result, the differential reflectivity skews toward lower values down radial of differential attenuation regions than they would otherwise be. In fact, the values are often negative. Let's look at an example.

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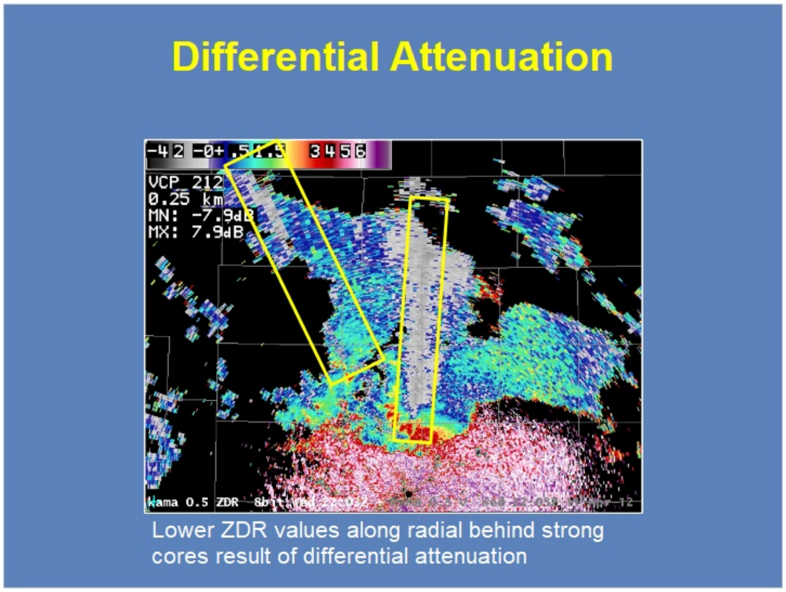
2.30 DA Example



Notes:

This example should look familiar. It's the same case we just showed for the non-uniform beam filling example. Remember how we said that NBF and differential attenuation often occur in the same areas. Well, let's look downstream of the two storms we noted before. We don't see a noticeable change in Reflectivity even though there is probably some attenuation happening in that channel. Switching over to ZDR, we can see the attenuation more clearly down radial of both of these heavy rain and hail cores. These areas of negative ZDR oriented along the radial result from differential attenuation.

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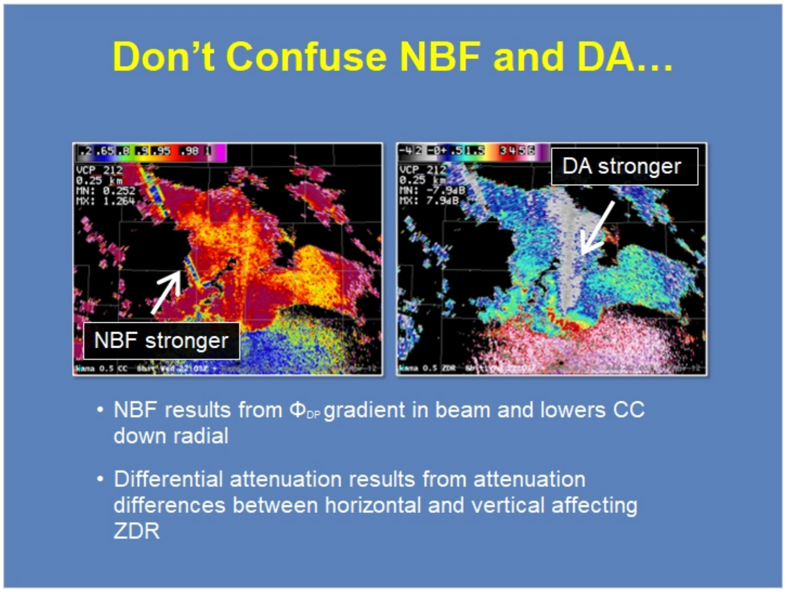
2.31 NBF/DA Differences



Notes:

As I showed previously, NBF and differential attenuation often occur in similar situations. The causes include the radar beam passing through a heavy rain and hail core or strong storms aligned along a radial. However, the physical reasons they occur are very different. NBF results from a gradient in Differential Phase, or PhiDP, within the radar beam that reduces correlation coefficient values for all the down radial range bins. Differential attenuation results from the horizontal channel being attenuated more in these situations than the vertical channel, causing ZDR to be lower than expected. It may not seem like a big deal that these are different processes, but it helps to know the differences when you only observe one phenomenon, but not the other.

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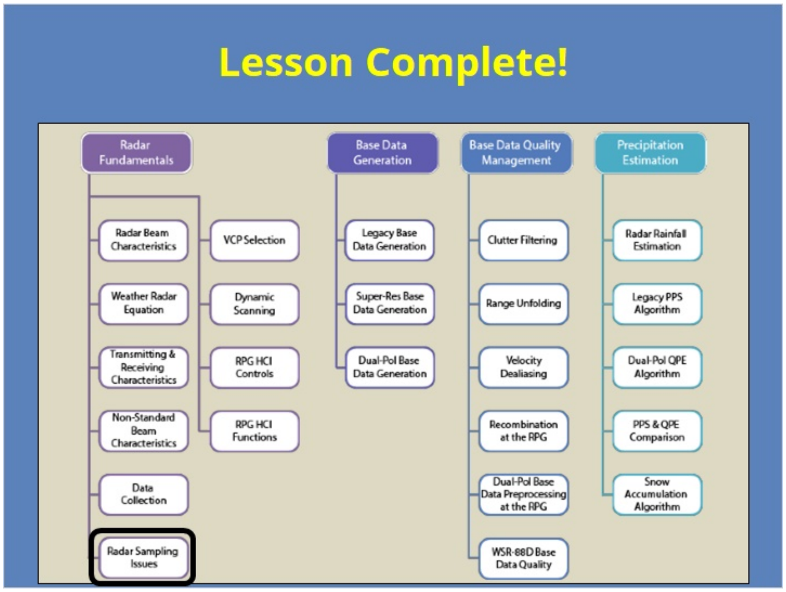
4. Completion

4.1 Completion!



Notes:

Thanks for your attention! You are now complete for this lesson.

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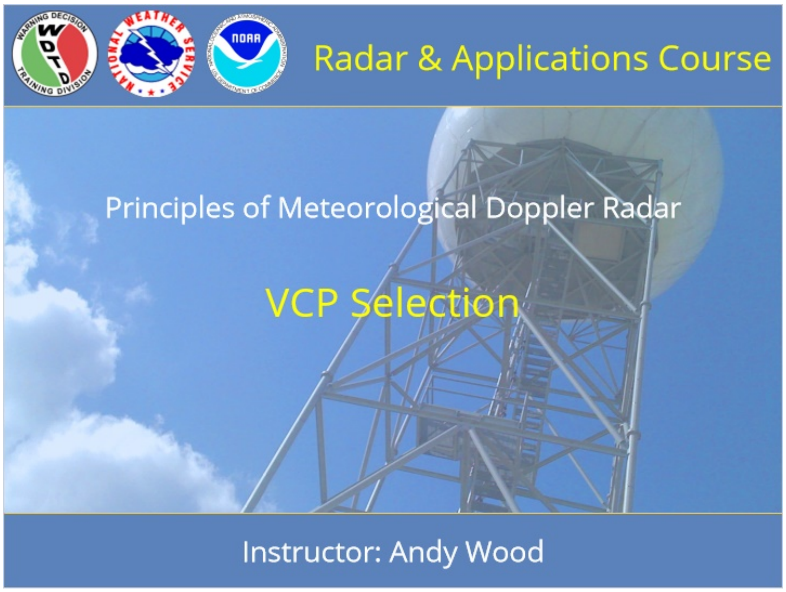
VCP Selection

1. Introduction

1.1 Introduction



Notes:

Welcome to this lesson on VCP Selection. This lesson is part of the Principles of Meteorological Doppler Radar topic in the Radar & Applications Course.

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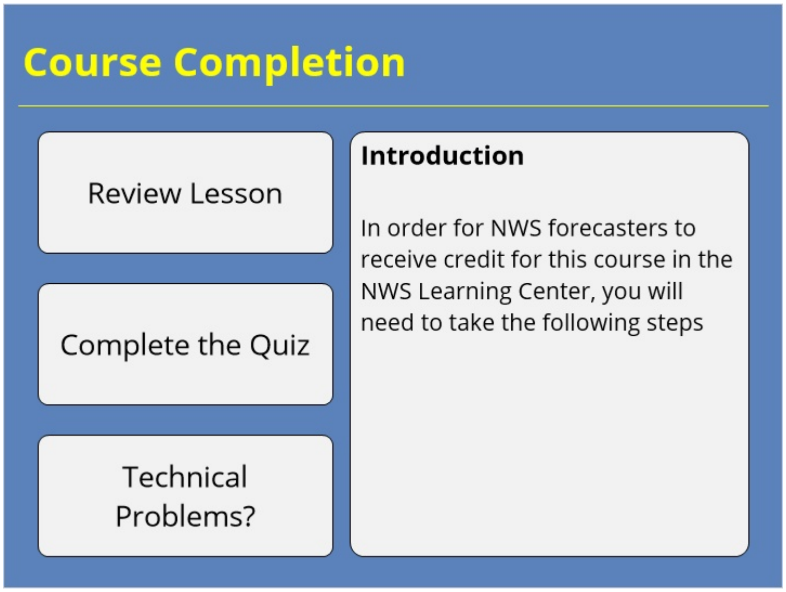
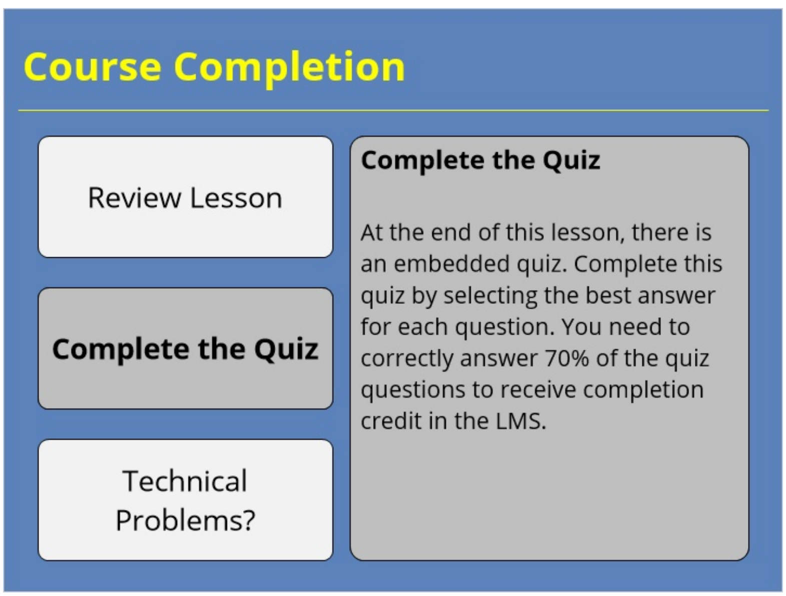
1.2 Course Completion



Complete the Quiz (Slide Layer)



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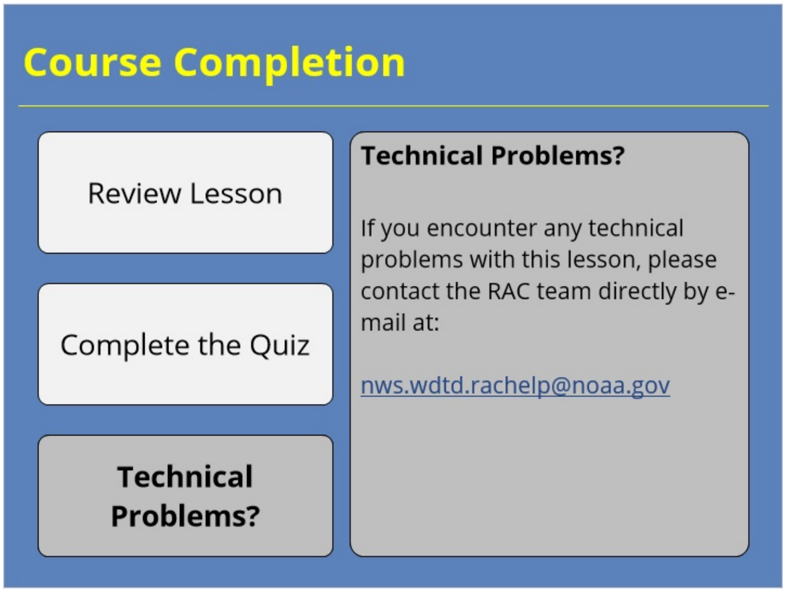
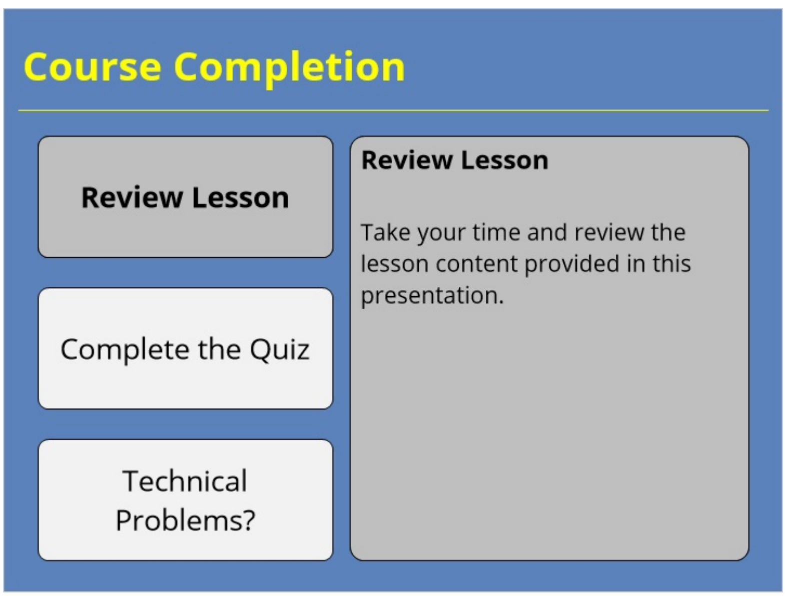
Technical Problems (Slide Layer)



Review Lesson (Slide Layer)



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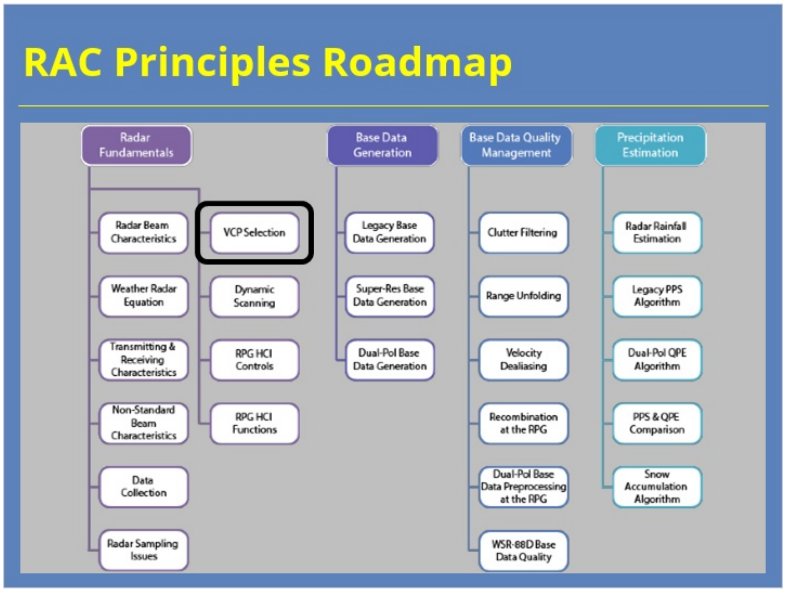
1.3 RAC Principles Roadmap



Notes:

Here is a roadmap for the RAC Principles topic. This lesson, which is part of the Radar Fundamentals section, is highlighted. Once you have had a chance to look over the roadmap, advance to the next slide.

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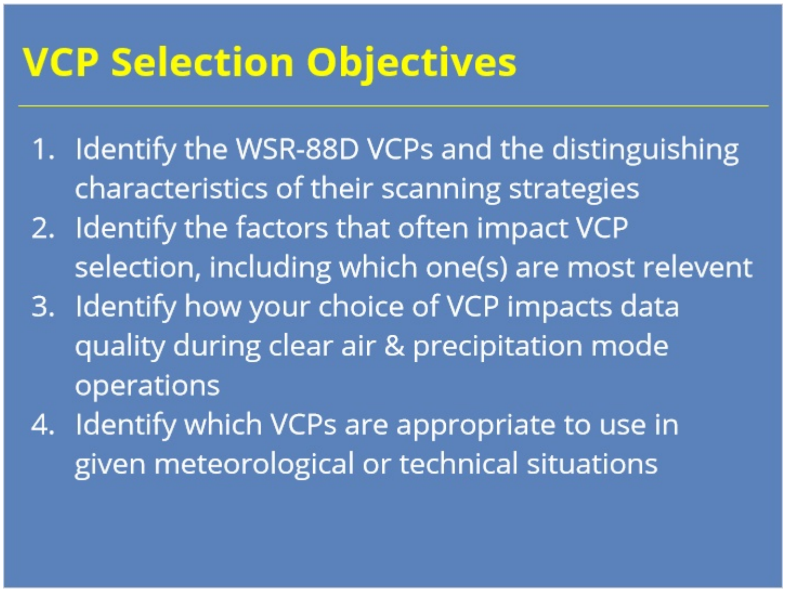
1.4 VCP Selection Objectives



Notes:

This lesson has four learning objectives. Please take a moment to review them, and advance to the next slide when you are ready to proceed.

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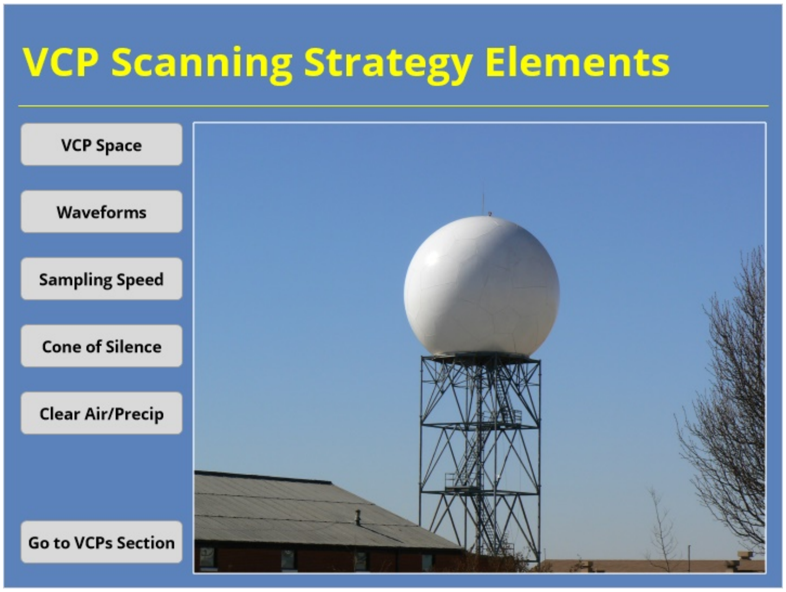
2. Get to Know Your VCPs

2.1 VCP Scanning Strategy Elements



Notes:

With the release of RDA/RPG Build 18, seven different VCPs are available to use at each WSR-88D. Each VCP uses its own scanning strategy that makes it different from the others. Some of the elements that make one VCP different from another include: the VCP space, the waveforms used to sample the atmosphere, the sampling speed, the cone of silence, and whether the VCP was designed for clear air or precipitation. Use the buttons on the left to learn a more about these topics. Then, use the “Go to VCPs” button to learn more about each VCP.

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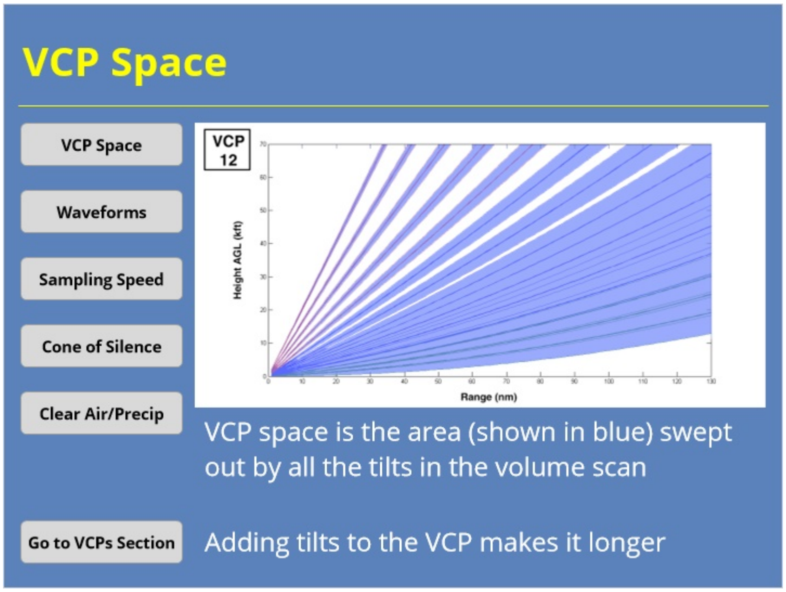
2.2 VCP Space



Notes:

Each VCP uses a variety of elevation angles to sample a “VCP space” in the atmosphere. These regions, which are highlighted in blue in the example shown, show what the radar beam can observe with a particular VCP. Assuming all other scanning strategy elements stay the same, increasing your VCP space (by adding more tilts) will increase the length of time it takes to complete the volume scan. To prevent volume scans from taking to long, VCPs contain gaps between tilts in certain regions based on the goals of the scanning strategy.

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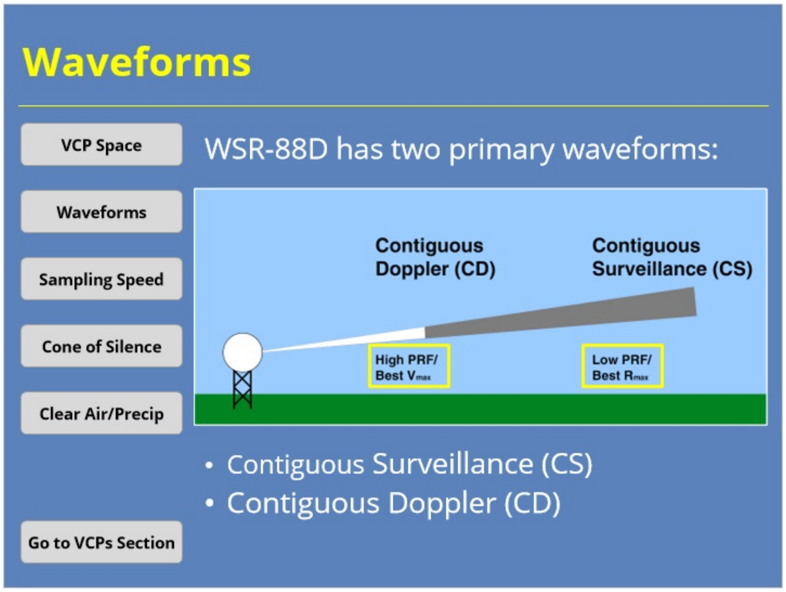
2.3 Waveforms



Notes:

The WSR-88D uses two primary waveforms to measure meteorological echoes: Contiguous Surveillance (CS) and Contiguous Doppler (CD). CS scans use a low PRF to provide the best maximum unambiguous range, while CD scans use a high PRF to provide the best maximum unambiguous velocity. Some scanning strategies will include both CS and CD scans on some tilts. Sometimes even multiple CD scans are used to minimize range unfolding. More on that in the range unfolding lesson.

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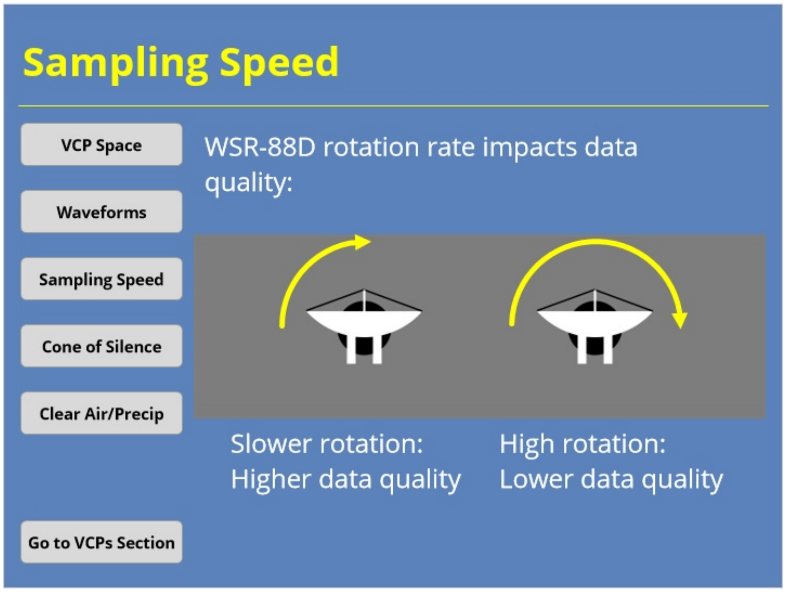
2.4 Sampling Speed



Notes:

Different scanning strategies often require the antenna to sample the atmosphere at different rates. As a result, the radar antenna will rotate at different speeds to meet those needs. The faster that the radar rotates, the fewer independent samples the radar can acquire to build the various radar products. So, all other scanning strategy elements being equal, the faster the rotation rate, the lower the data quality.

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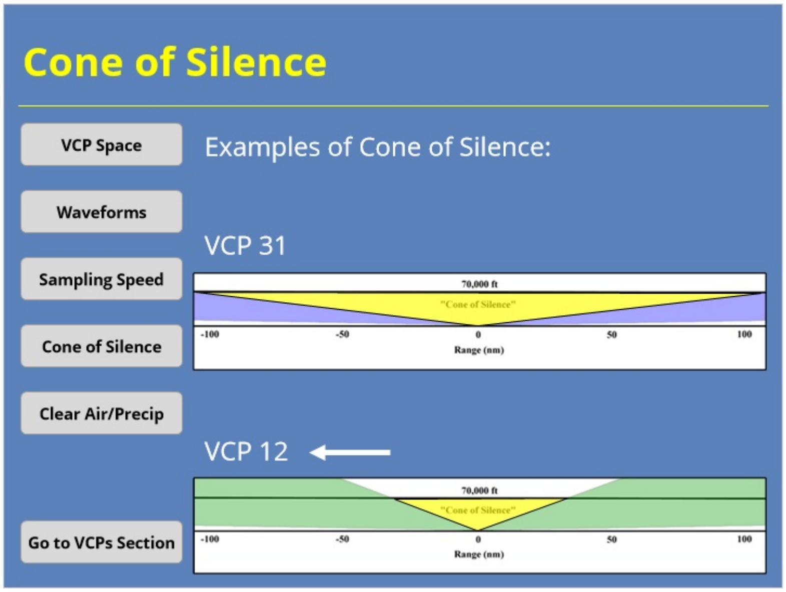
2.5 Cone of Silence



Notes:

The "cone of silence" is the conical region located above the RDA that cannot be sampled by that radar. The size of the cone of silence is directly related to the highest elevation tilt included in the volume scan. When your goal is to sample deep convection or other meteorological targets near the RDA, you want to use a VCP with a smaller cone of silence. Even when you take this step, you will need to switch to a nearby radar to observe meteorological targets that fall with the original radar's cone of silence.

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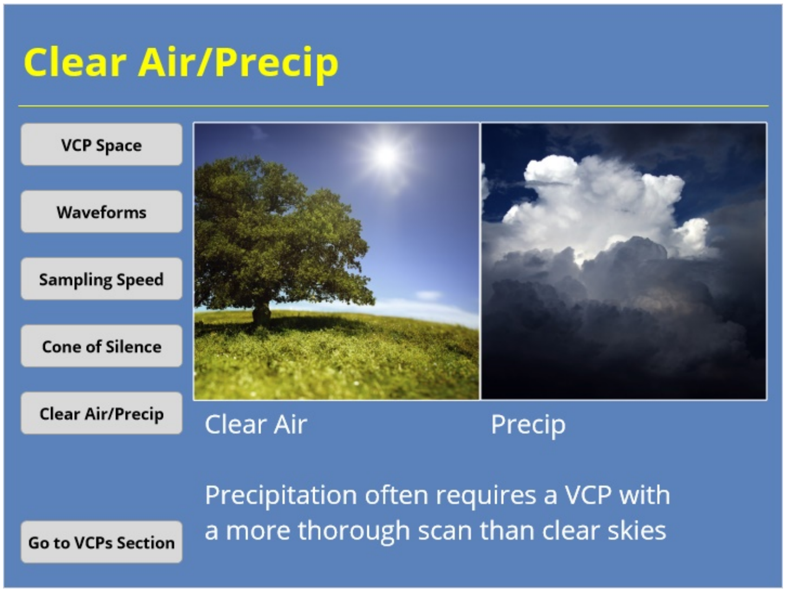
2.6 Clear Air/Precip

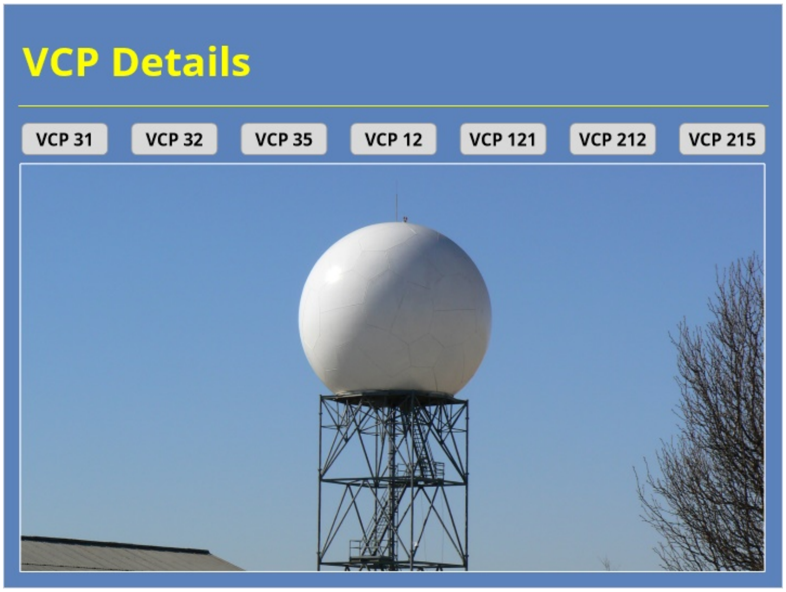


Notes:

VCPs generally fall into two categories: Clear air and precip modes. Precipitation events often require a VCP with a more thorough scan of the atmosphere. The clear air mode VCPs use scanning strategies to maximize data quality when there is little to no meteorological returns visible to the radar. So, the antenna tends to rotate slower and sample fewer elevations angles in clear air mode.

3. VCP Details

3.1 VCP Details



Notes:

So, now that you know the basic concepts that go into a volume coverage pattern, let's look at each able VCP in more detail. Use the buttons on the slide to toggle between all seven of the VCPs.

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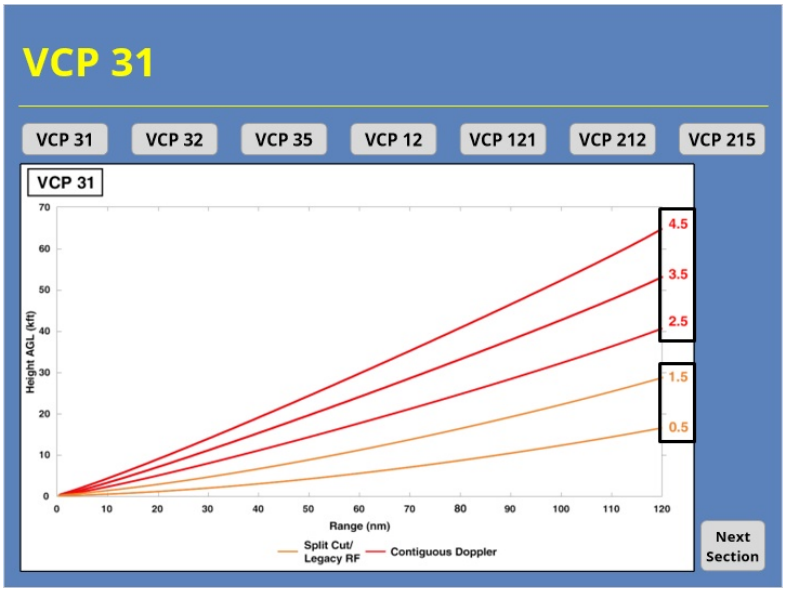
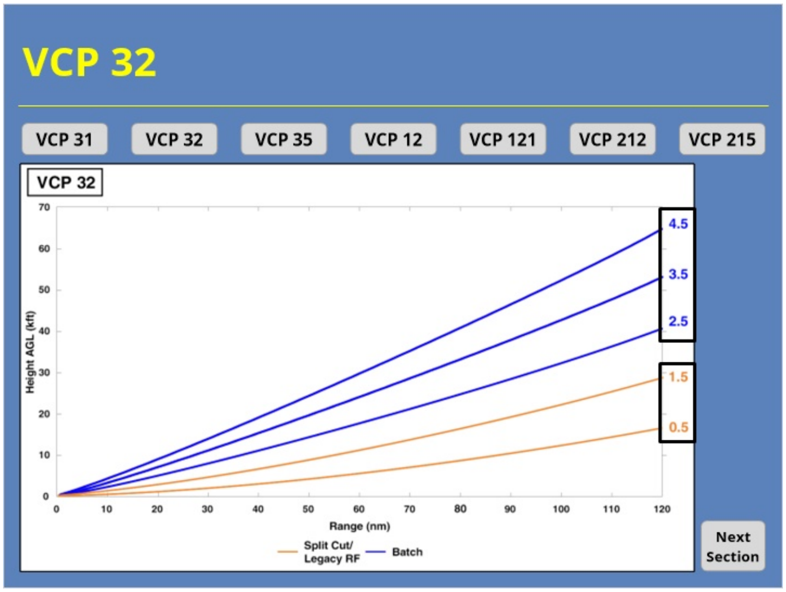
3.2 VCP 31



Notes:

VCP 31 is one of three clear air VCPs. This scanning strategy uses 5 tilts with no gaps. The lowest two tilts uses a split cut with a CS and CD scan where as the higher three tilts use just a Contiguous Doppler scan. VCP 31 is unique in that it uses a long pulse. The longer pulse offers higher sensitivity, but a lower maximum unambiguous velocity. A full VCP 31 volume scan takes approximately 10 minutes to complete.

3.3 VCP 32



Notes:

VCP 32 is one of three clear air VCPs. This scanning strategy uses 5 tilts with no gaps. The lowest two tilts uses a split cut with a CS and CD scan. The higher three tilts use a batch cut that alternates between CS and CD waveforms in a single scan. While VCP 32 look the same as VCP 31, it uses the standard short pulse. Besides having a higher unambiguous maximum velocity, the radar operator can adjust the PRF used on the CD pulses to prevent range folding in any returns collected. A full VCP 32 volume scan takes approximately 10 minutes to complete.

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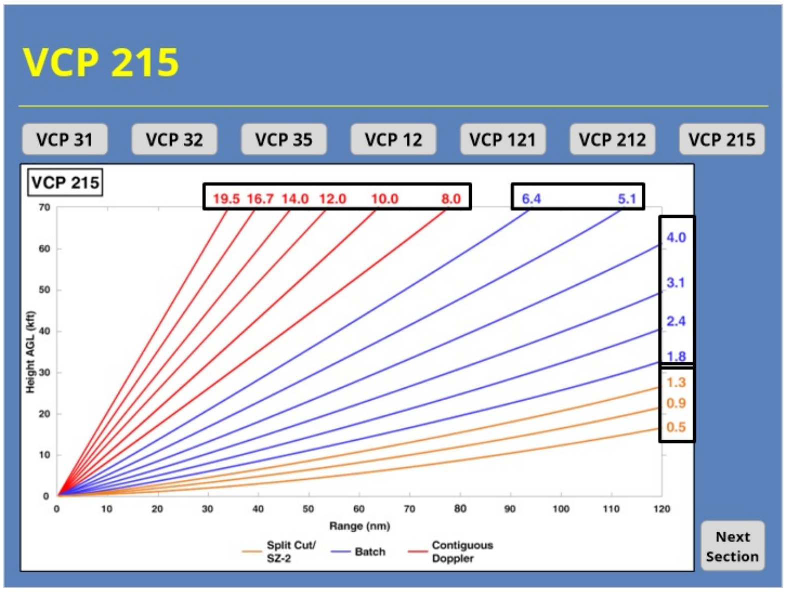
3.4 VCP 215



Notes:

VCP 215 is one of four precipitation scanning strategies and was designed for general surveillance. VCP 215 provides the greatest VCP space coverage of all the VCPs with 15 different elevation angles. The radar uses split cuts with SZ-2 range unfolding on the lowest three tilts, batch cuts for the middle six tilts, and contiguous Doppler scans on the highest six tilts. The radar antenna rotates more slowly in VCP 215 than other precipitation mode VCPs, so this strategy offers the best data quality of that group. A full VCP 215 volume scan takes approximately 6 minutes to complete.

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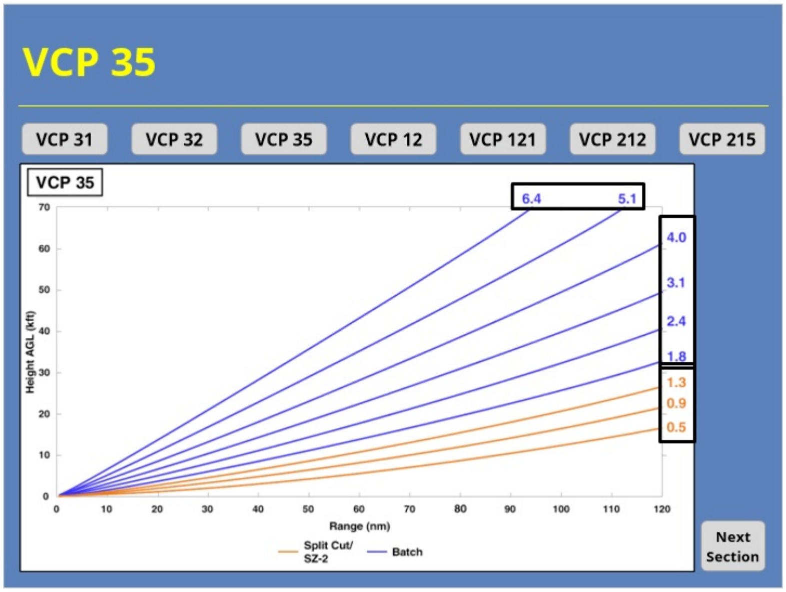
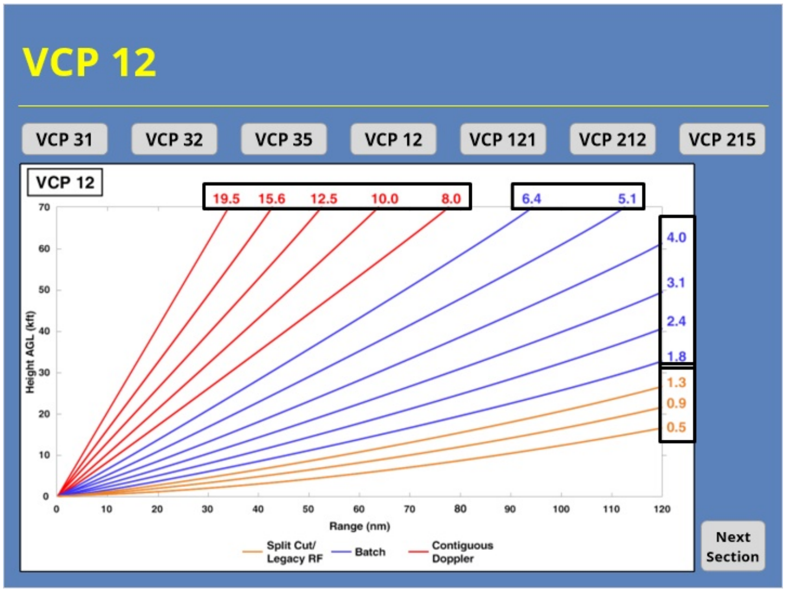
3.5 VCP 35



Notes:

VCP 35 is a new clear air VCP. The VCP space for this scanning strategy is similar to VCP 12, except that only 9 elevation angles up to 6.4 degrees are included. The lowest three tilts are split cut scans that use the SZ-2 range unfolding technique. The highest six scans use batch cuts with alternating CS and CD scans. While VCP 35 has the smallest cone of silence and includes the capability for one SAILS cut per volume scan, there is one drawback: The CD scans have fewer pulses per radial than VCP 32, meaning that the velocity estimates may not be as good. A full VCP 35 volume scan takes approximately 8 minutes to complete.

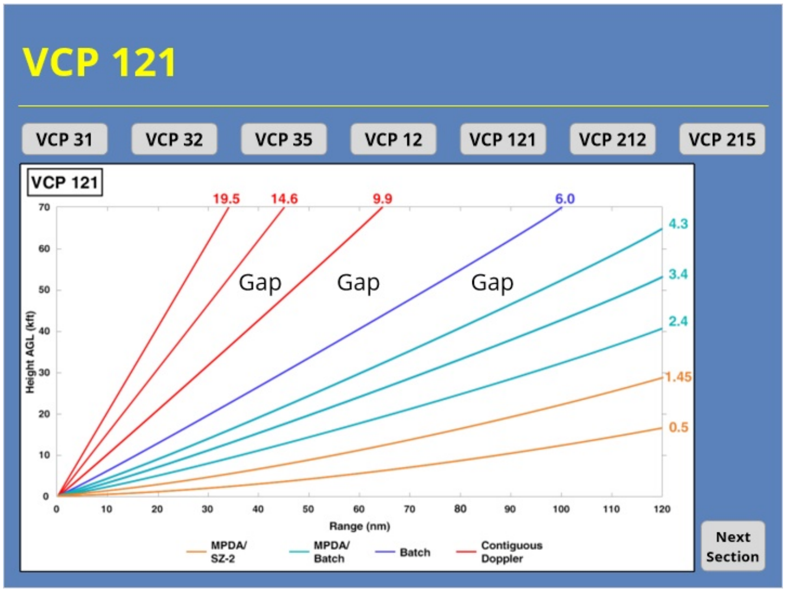
3.6 VCP 12



Notes:

VCP 12 is a precipitation mode VCP designed for convective weather situations. This scanning strategy has 14 tilts, and offers the best low level vertical sampling of the atmosphere. The tilts use a combination of split cuts down low, batch cuts at medium elevations, and Contiguous Doppler scans up high. The radar operator has the ability to adjust the PRF on the split cut and batch CD pulses, too. Up to 3 SAILS tilts can be included in a single volume scan. A complete VCP 12 scan without SAILS tilts takes approximately 4.5 minutes.

3.7 VCP 121



Notes:

VCP 121 is a precipitation mode VCP designed for tropical systems or widespread precipitation where range folding minimization is important. The scanning strategy has 9 tilts, with no overlapping low level scans and significant gaps aloft. This VCP also uses the fastest antenna rotation speeds, so data quality issues are most likely to be apparent with these data. The strength of this VCP is in the combination of the MPDA and SZ-2 algorithms that virtually eliminate range folded data on the lowest two tilts. However, the drawback to this technique is that the Doppler pulse PRFs aren't editable. A complete VCP 121 volume scan takes approximately 6 minutes to complete.

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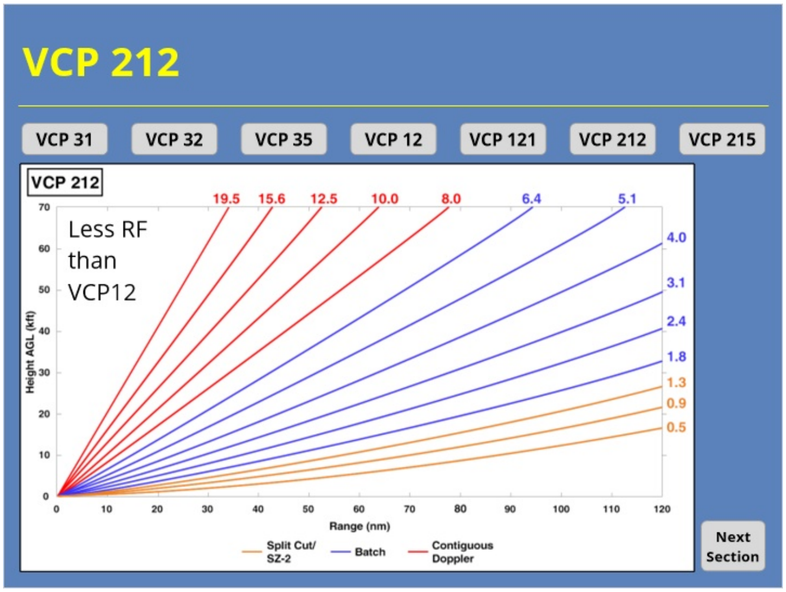
3.8 VCP 212



Notes:

VCP 212 is a precipitation mode VCP designed for convective weather situations and is very similar to VCP 12. This scanning strategy has 14 tilts, and offers good low-level vertical sampling of the atmosphere. Up to 3 SAILS tilts can be included in a single volume scan, also. The primary differences between VCP 212 and 12 involves the techniques used to mitigate range folded data. VCP 212 uses the SZ-2 range unfolding technique on the three lowest split cut tilts. This technique significantly lowers the amount of range folded data. The tradeoff is the Doppler PRFs aren't editable on the split cuts. However, the PRFs used on Batch elelvation CD pulses can be adjusted just as in VCP 12. A complete VCP 12 scan without SAILS tilts takes approximately 4.5 minutes.

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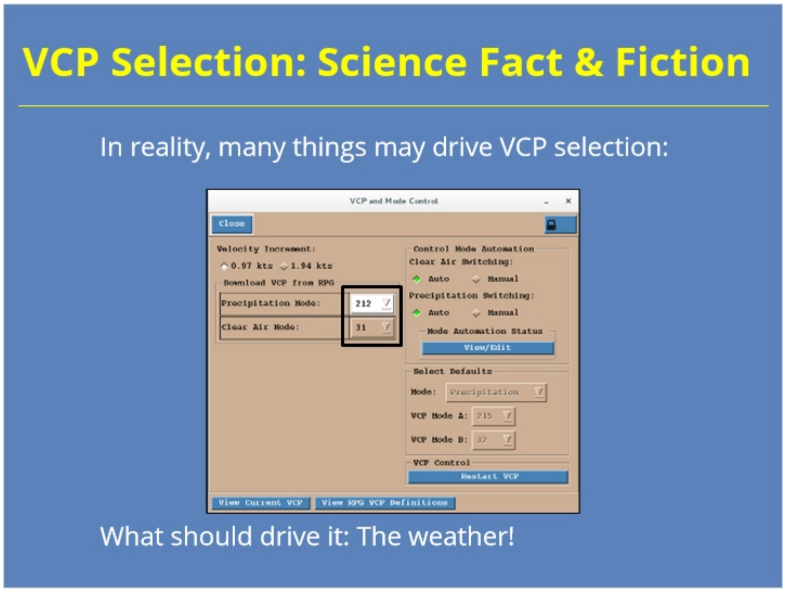
4. Selection & Decision-Making

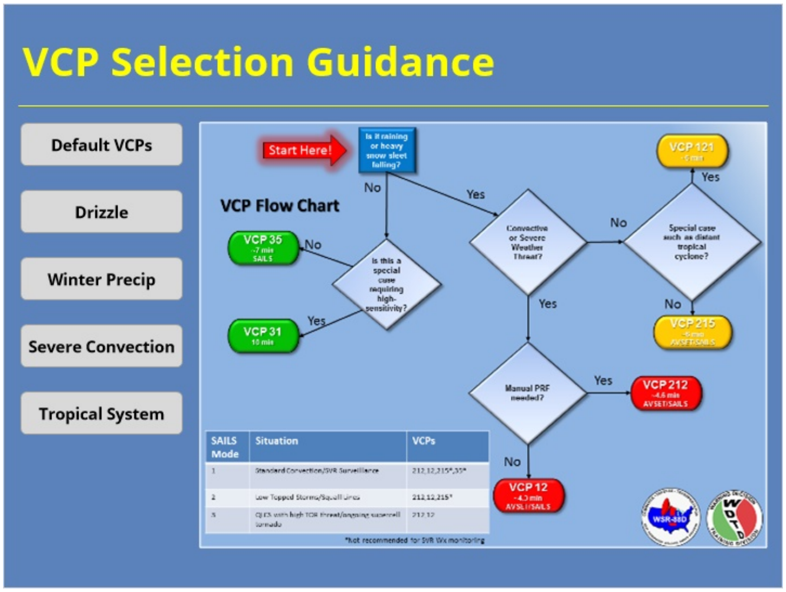
4.1 VCP Selection: Science Fact & Fiction



Notes:

Many factors may go through your mind as you are deciding which VCP to use: How does a particular VCP operate with respect to system specifications, does a particular VCP make the antenna to fast?, has our local staff been talking about hardware failures lately, or even radar maintenance issues. While all of these topics may enter your head, the one factor that should drive your VCP selection decision-making is one that I didn’t mention in that list: the weather.

4.2 VCP Selection Guidance



Notes:

Recent changes to the WSR-88D has helped simplify the VCP selection process. The Build 18 RDA/RPG Training included this flow chart to help identify which VCP to use. Click the buttons on the left to learn more about VCP selection involving specific weather conditions.

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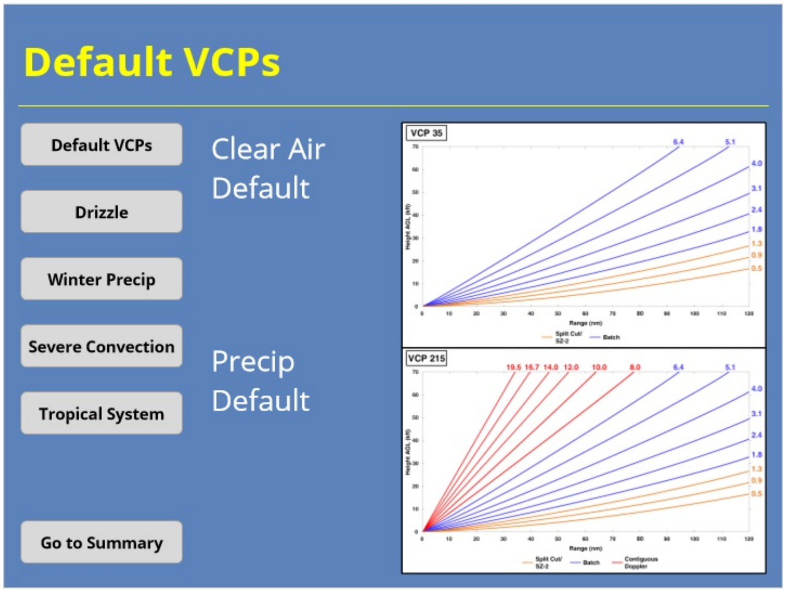
4.3 Default VCPs



Notes:

With RDA/RPG Build 18, all radars reset their default volume coverage patterns to VCP 35 for clear air mode and VCP 215 for precipitation. Offices still have the ability to configure the default VCPs locally, but these defaults are recommended by both the ROC and WDTD.

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4.4 Drizzle

Notes:

Drizzle and other light radar return situations can be tricky when choosing your VCP. VCP 31 offers the best opportunity to detect any echoes that are present due to its use of a long pulse. However, VCP 31 only helps when winds are relatively light because of its shorter listening period. In cases where the environmental winds are stronger, VCP 35 will be a better choice than 31.

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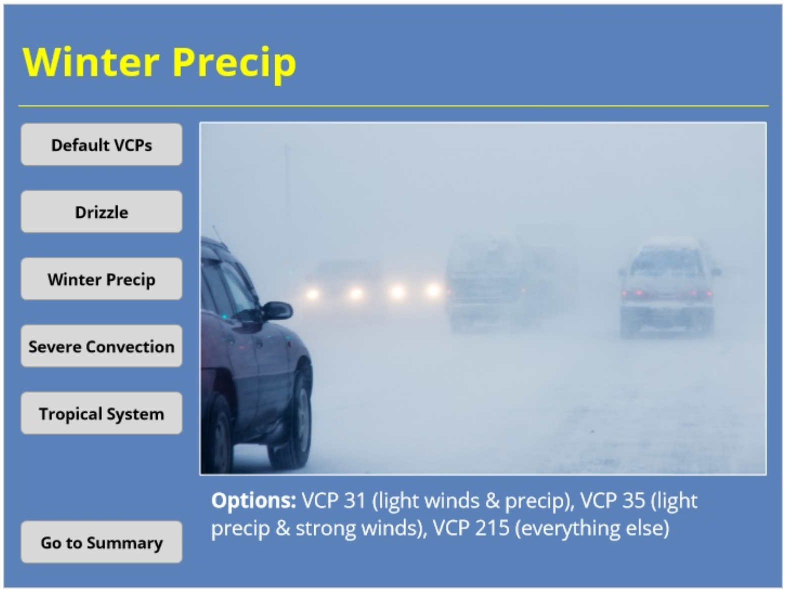
4.5 Winter Precip



Notes:

Winter precipitation events may be the one thing trickier than drizzle. For light winter events, some offices prefer to stay in clear air mode. If that describes your office, than the same guidelines for drizzle apply here: VCP 31 for light winds and VCP 35 for strong winds. For any winter events with significant snow or sleet accumulations, VCP 215 will likely be your best option.

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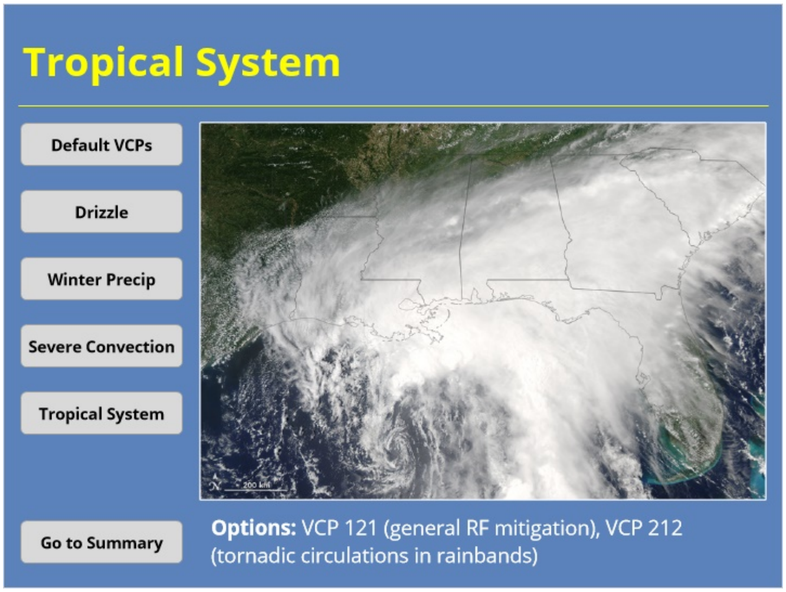
4.6 Tropical System



Notes:

When tropical systems with widespread precipitation are impacting your local area, the best VCP option will be VCP 121 because it performs best at mitigating range folding. However, if your CWA has the chance to be impacted by tornadic circulations in the outer rain bands of a tropical system, consider switching to VCP 212. VCP 212 still provides good range folding mitigation, but also includes better low-level coverage to better monitor potential spin ups.

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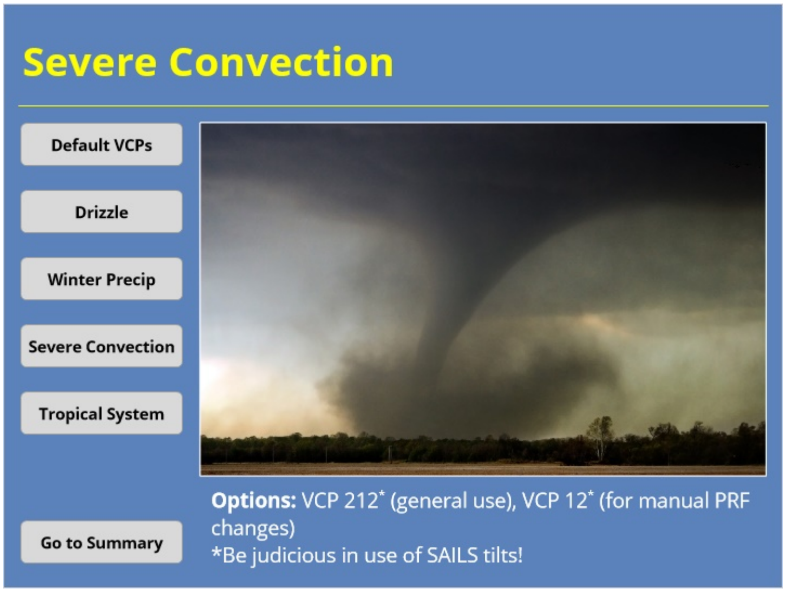
4.7 Severe Convection



Notes:

Anytime your local radar is in precipitation mode and severe convection is expected, VCP 212 is recommended. The one caveat regards the possibility of a storm of interest being impacted by range folding. If this happens, consider switching to VCP 12 and manually selecting a PRF that avoids range folding for your storm of interest.

One last thing: both VCP 212 and 12 allow for up to 3 SAILS tilts per volume scan. Radar operators should be judicious about the number of SAILS scans that are enabled. In most cases, SAILSx1 will be sufficient to meet your operational needs. What you don’t want to do is turn on 2 or 3 SAILS tilts and then forget about it. That would be bad!

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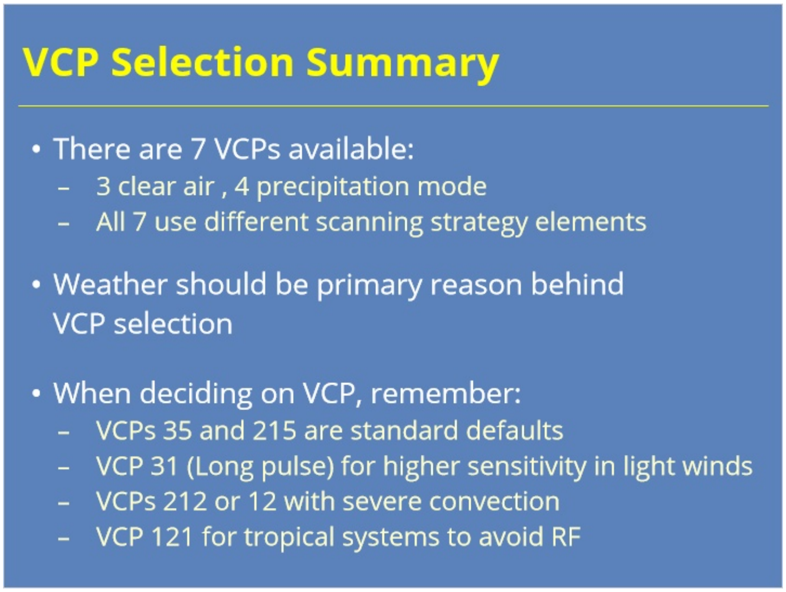
5. Quiz

5.1 VCP Selection Summary



Notes:

In summary, you have 7 different volume coverage patterns to choose from on the WSR-88D: 3 in clear air mode and 4 in precipitation mode. Each VCP uses slightly different scanning strategy elements to set it apart from the others. When choosing which of the 7 to use, the current or expected weather conditions should drive your decision. While choosing the best VCP for a particular situation can be tricky, keep this ideas in mind. VCPs 35 and 215 were designed to be default VCPs for clear air and precip modes, respectively. They work for a lot of situations. If you need higher sensitivity to detect light returns (and the winds aren't too strong), try VCP 31. During severe convection VCPs 212 or 12 are best. Lastly, VCP 121 can be beneficial when trying to avoid range folded returns during tropical systems where severe thunderstorm and tornado warnings aren't likely.

Now you are ready to take the quiz. Advance to the next slide to proceed.

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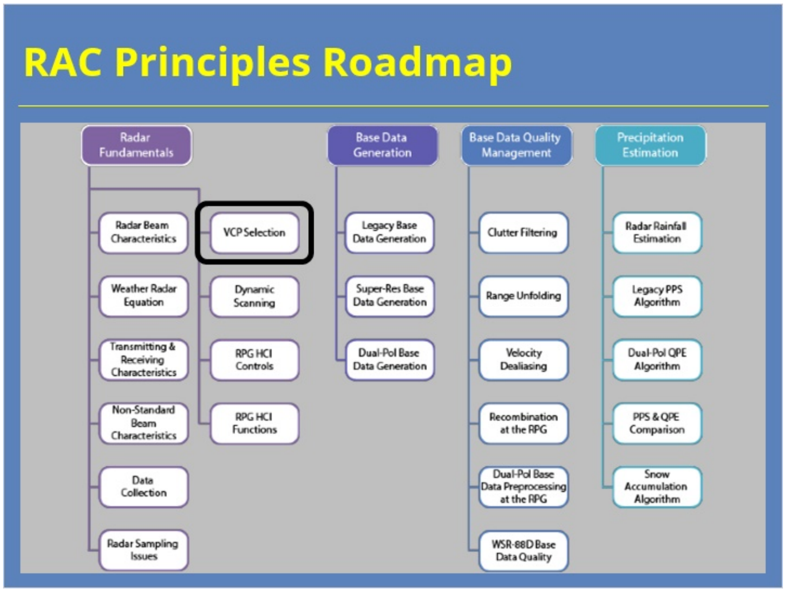
5.11 RAC Principles Roadmap



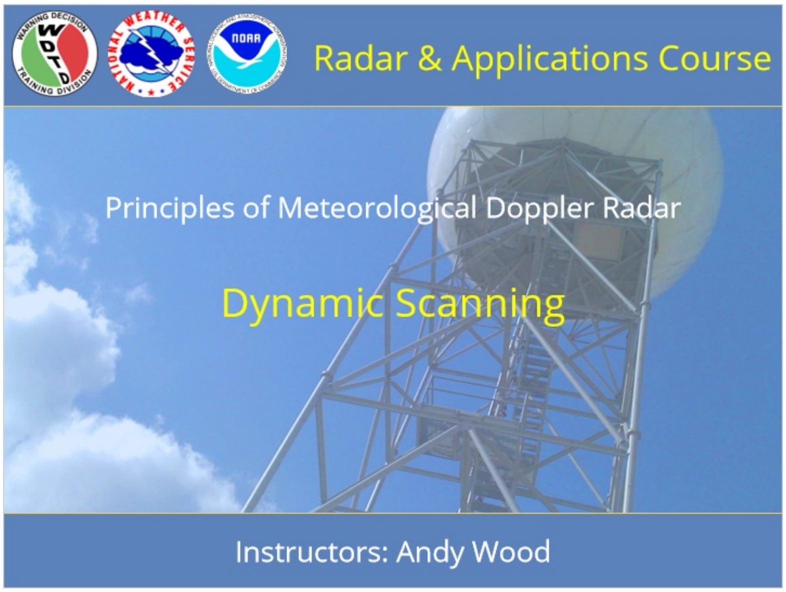
Notes:

Congratulations on passing the quiz and completing this course! Here is the roadmap again for the RAC Principles topic so you can see what comes next. When you are finished, click the “Exit” button to close this lesson.

Dynamic Scanning

1. Introduction

1.1 Title



Notes:

Welcome to the lesson on Dynamic Scanning. This lesson is part of the Principles of Meteorological Doppler Radar topic in the Radar & Applications Course.

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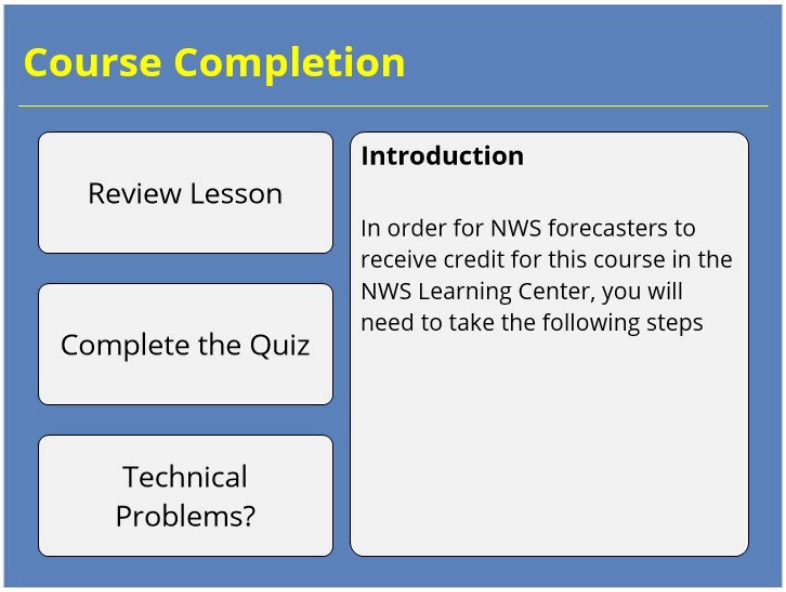
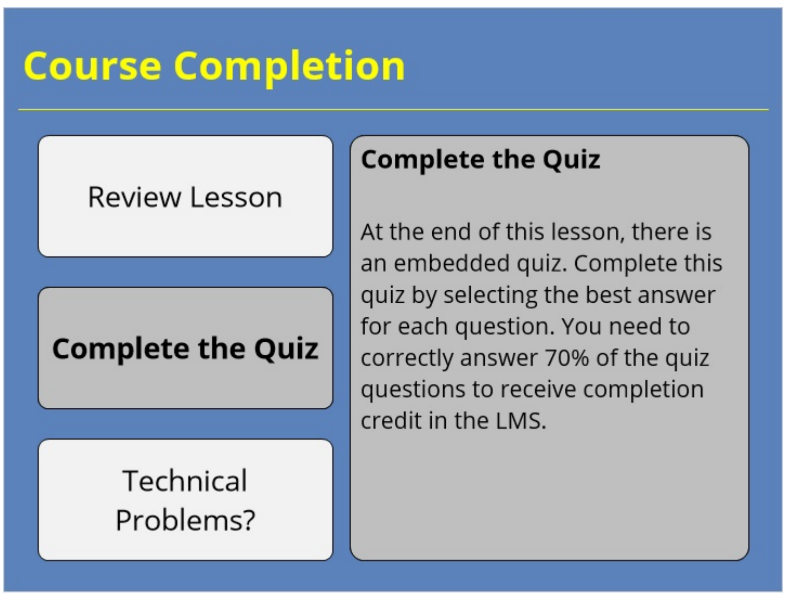
1.2 Course Completion



Complete the Quiz (Slide Layer)



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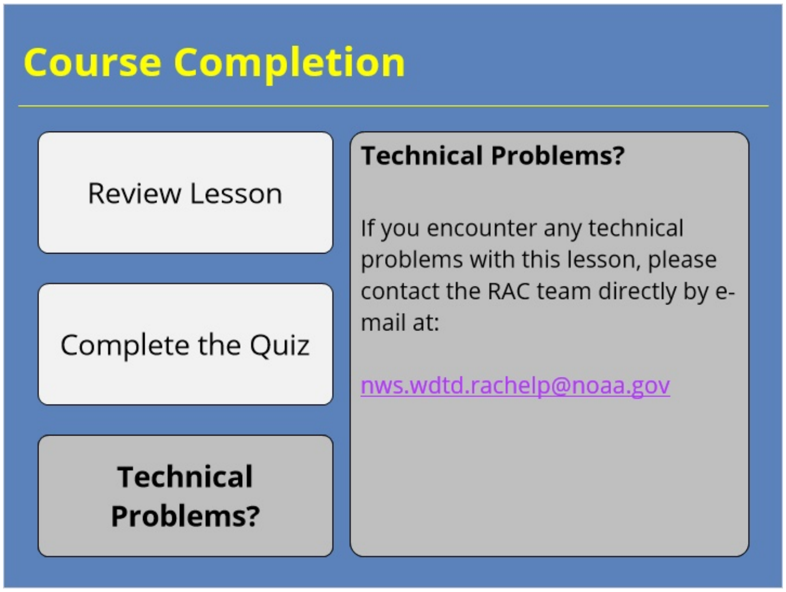
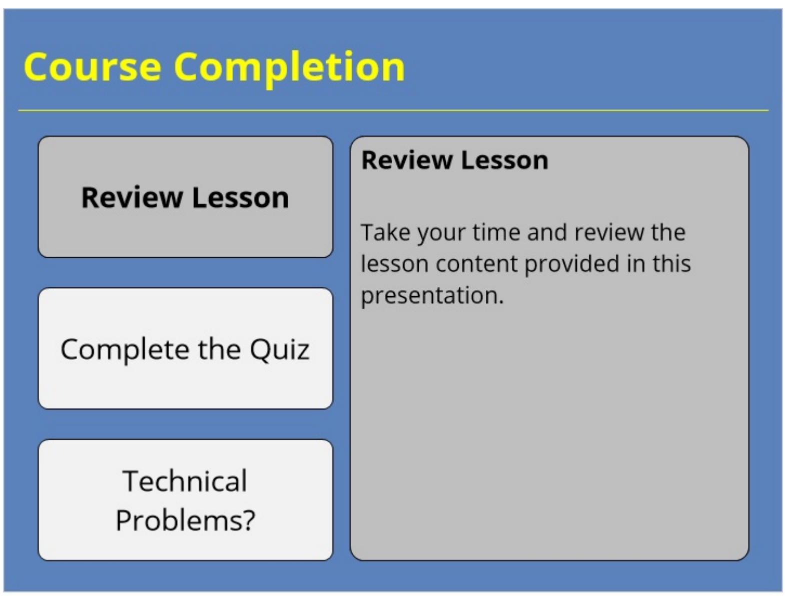
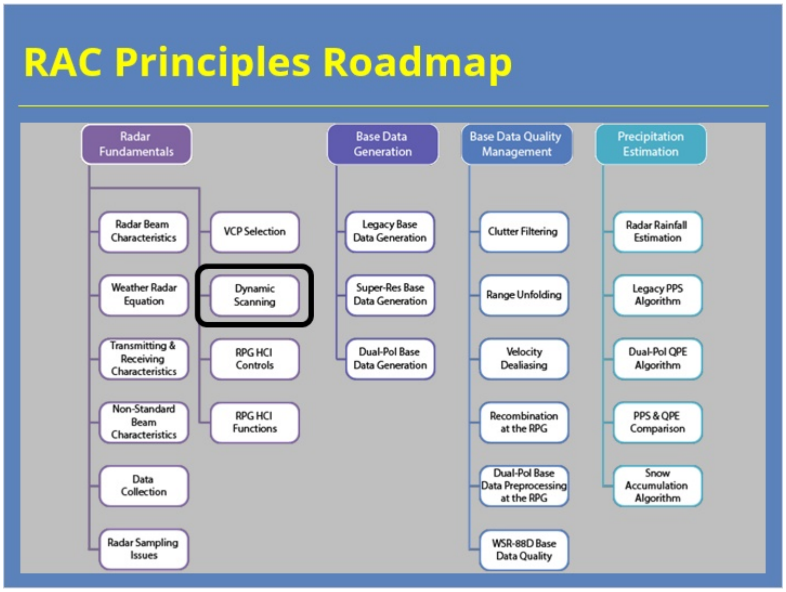
Technical Problems (Slide Layer)



Review Lesson (Slide Layer)



1.3 RAC Principles Roadmap



Notes:

Here is a roadmap for the RAC Principles topic. This lesson, which is part of the Radar Fundamentals section, is highlighted. Once you have had a chance to look over the roadmap, advance to the next slide.

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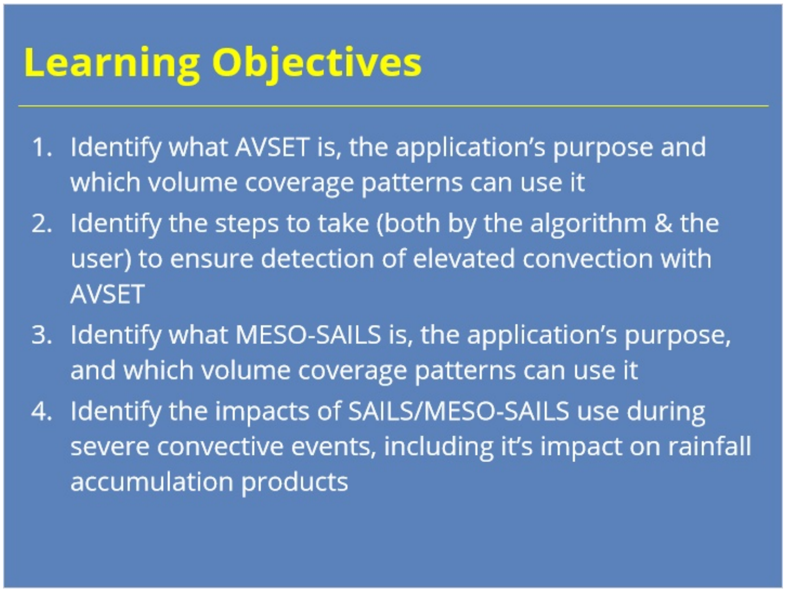
1.4 Learning Objectives



Notes:

This lesson has four learning objectives. Please take a moment to review them, and advance to the next slide why you are ready to proceed.

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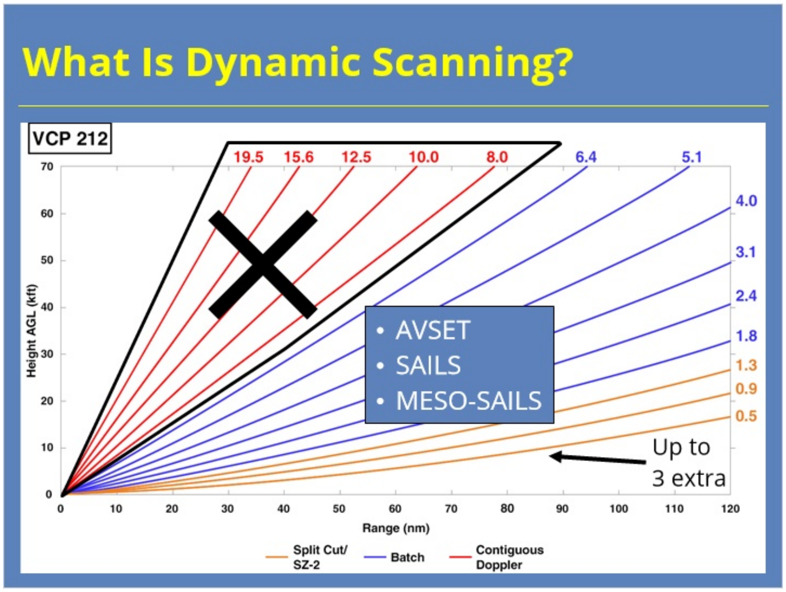
2. Dynamic Scanning Basics

2.1 What Is Dynamic Scanning?



Notes:

So, what exactly do I mean by dynamic scanning? Dynamic scanning describes the radar operator’s ability to adjust the defined scanning strategy of a particular volume coverage pattern on a scan by scan basis, as needed. The WSR-88D currently has three applications that allow for dynamic scanning: AVSET, SAILS, and MESO-SAILS. The last two are closely related, so I will discuss them jointly.

AVSET is short for Automated Volume Scan Evaluation and Termination. The AVSET application allows the WSR-88D to terminate a volume scan early if it doesn’t detect a sufficient number of radar echoes on a particular elevation tilt aloft. SAILS stands for the Supplemental Adaptive Intra-Volume Low-Level Scan. This tool allow the radar operator to include an extra lowest level tilt in each volume scan. The Multiple Elevation Scan Option of SAILS, called MESO-SAILS, allows the radar operator to add up to three of these extra scans per volume scan.

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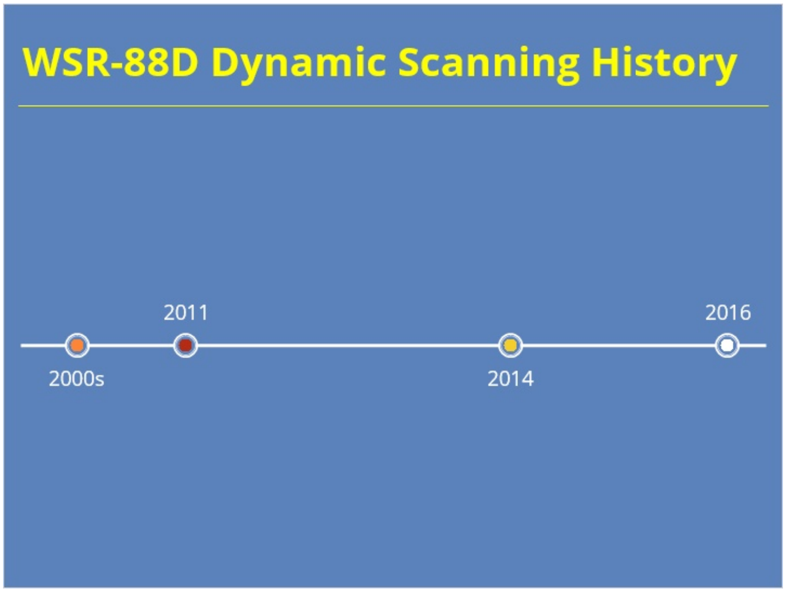
2.2 WSR-88D Dynamic Scanning History



Notes:

In order to get some context on why this capability is important, let's look at a brief history of dynamic scanning at the WSR-88D. Click on the different points on the timeline to learn more. Once you are done with the timeline, click the next button to learn more details about each dynamic scanning application.

2000s: Originally, the WSR-88D only contained static VCPs that allowed for a complete volume scan every 5-6 minutes. During the 2000s, NWS forecasters started integrating Terminal Doppler Weather Radar into their workflow on AWIPS. The TDWR already had dynamic scanning built into its design in order to better support the FAA misssion. It didn't take long for WSR-88D users to inquire about getting dynamic scanning capabilities, too.

2011: With the release of RPG Build 12.3, AVSET was fielded. For the first time, radar operators had the option to terminate volume scans early if little to no detectable precipitation was present aloft. On average, use of AVSET reduced volume scan time during precipitation mode to three-and-a-half to four minutes.

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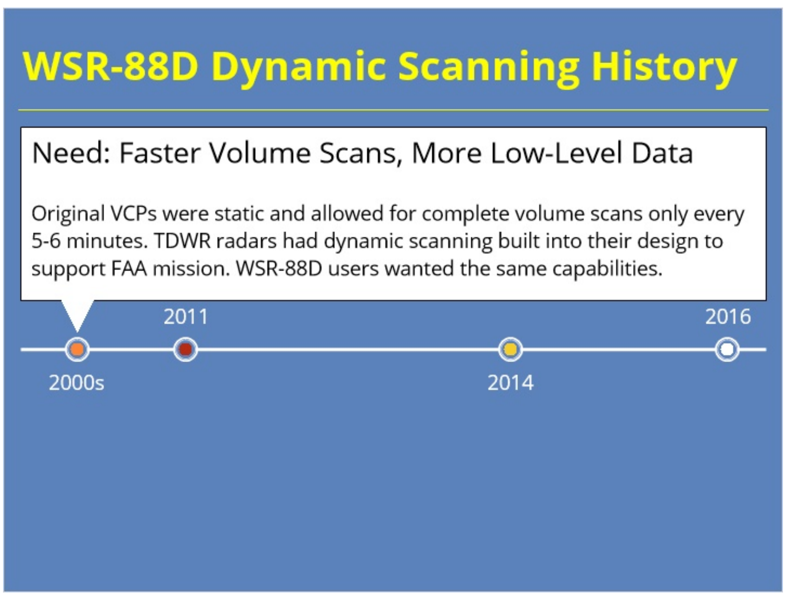
2014: The release of RDA/RPG Build 14.0 gave radar operators SAILS tilts for the first time. When enabled, SAILS provided users with an extra low-level scan (the 0.5 degree tilt at all but a site or two) during VCPs 12 and 212. The original SAILS tilt only collected legacy base data. However, subsequent updates allowed for the collection of dual-pol base data on the SAILS cuts and the gradual inclusion of SAILS cut data into various derived products.

2016: Once the SAILS proof of concept was realized, RDA/RPG Build 16 upgraded the capability to MESO-SAILS. With MESO-SAILS, up to 3 SAILS scan per volume can be collected. With both MESO-SAILS and AVSET enabled, it was now theoretically possible to collect radar data on the lowest tilt approximately every minute.

2000s (Slide Layer)



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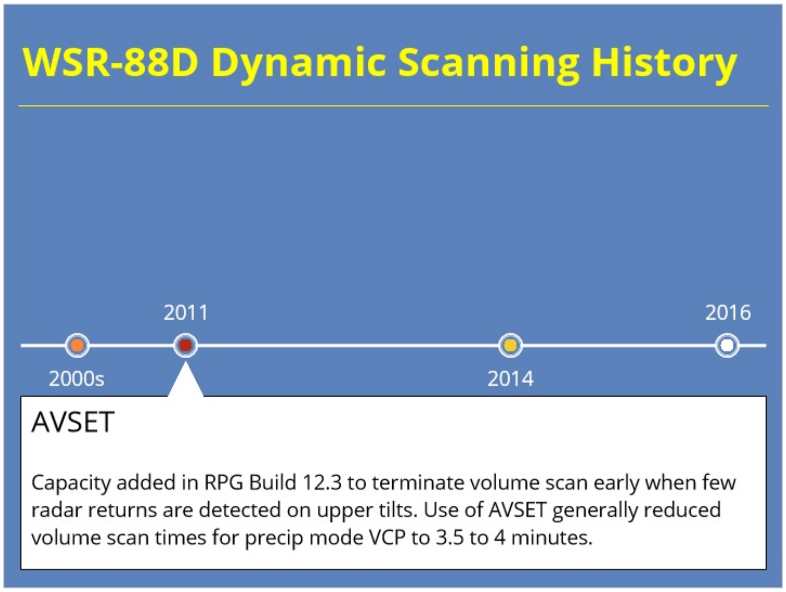
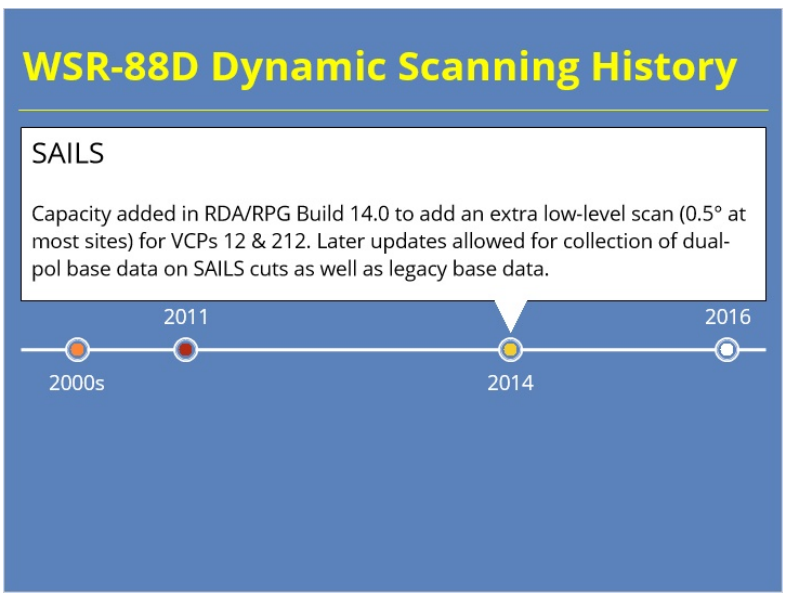
2011 (Slide Layer)



2014 (Slide Layer)



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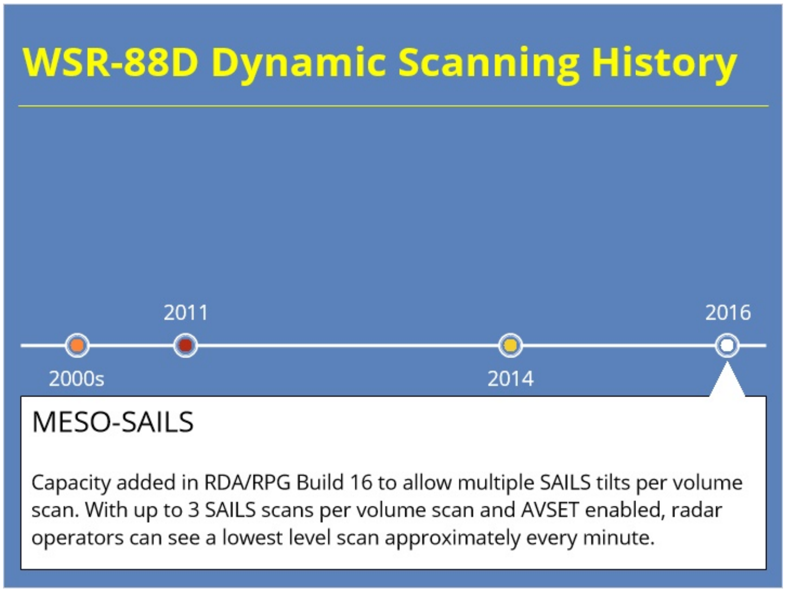
2016 (Slide Layer)



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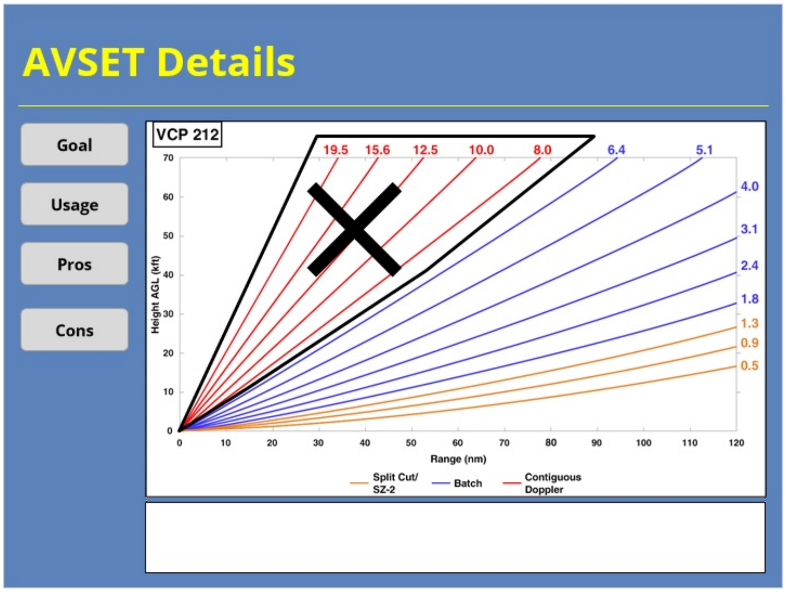
3. AVSET

3.1 AVSET Details



Notes:

Let's quickly run through some of the Details on AVSET. Use the buttons on the left-hand side of the slide to learn more.

Goal: The goal of AVSET is to eliminate unnecessary elevations aloft in order to shorten the length of the volume scan

Usage: AVSET can be used on VCPs 12, 121, 212, 215

Pros: The primary benefit of AVSET is the potential for faster volume scans which can lead to more volume scan over time (up to 1 scan per hour more)

Cons: The primary downside of using AVSET is the potential for missing elevated convection that develops near the RDA

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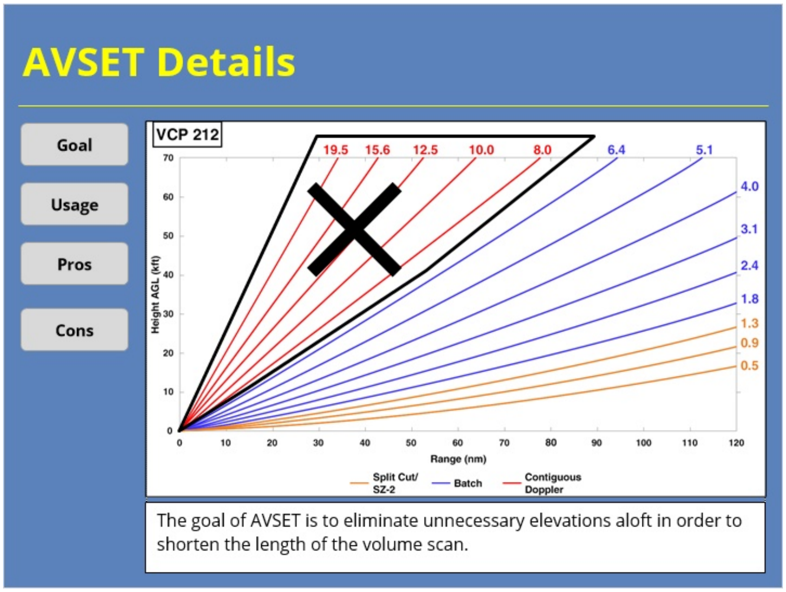
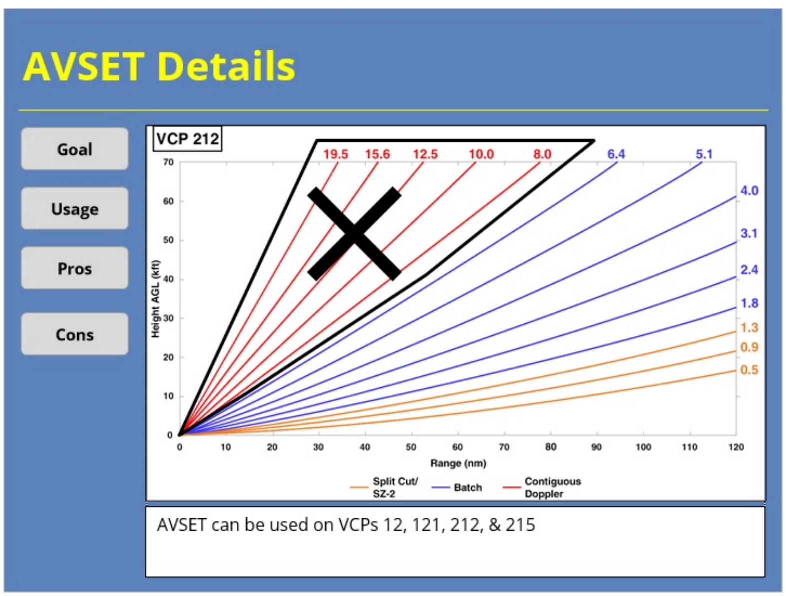
Goal (Slide Layer)



Usage (Slide Layer)



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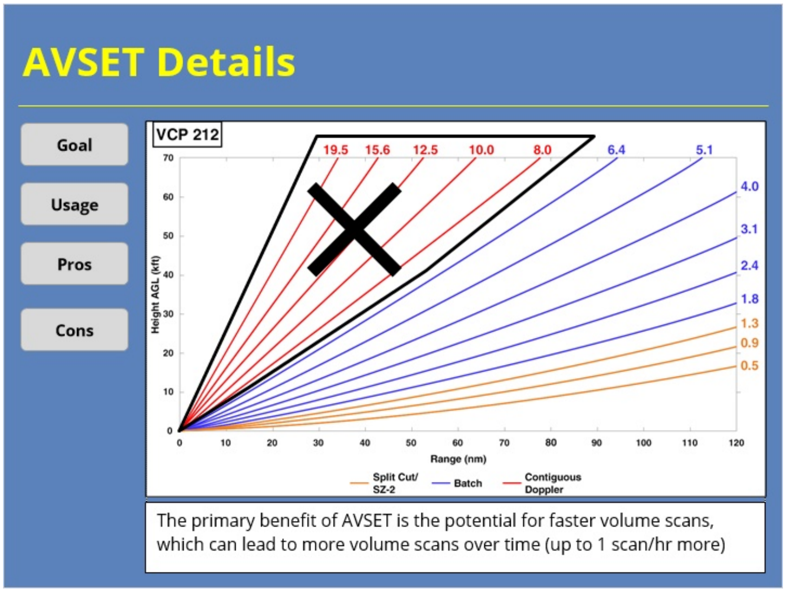
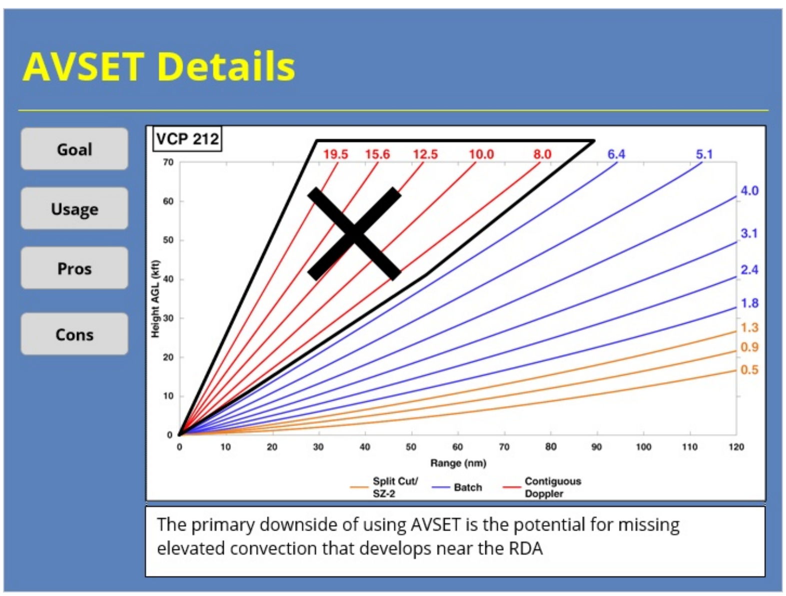
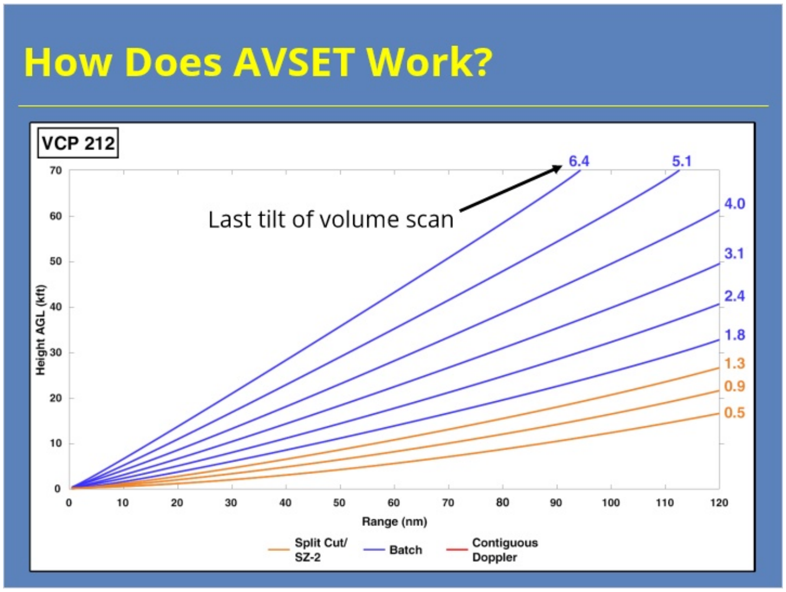
Pros (Slide Layer)



Cons (Slide Layer)



3.2 How Does AVSET Work?



Notes:

So, how does AVSET actually work? If AVSET is enabled, it will start analyzing data on the first elevation tilt above 5 degrees. For most VCPs, this tilt will be 5.1 degrees. As the radar collects Reflectivity data, it determines if the echoes' dBZ values and areal coverage meet certain thresholds. In order for the volume scan to terminate early after the next highest tilt, all three of the following criteria must be met on the current tilt:

- The total coverage of 18 dBZ echoes must be less than 80 km2
- The total coverage of 30 dBZ echoes must be less than 30 km2 and
- the 18dBZ echo coverage area cannot increase by 12 km2 or more since the last volume scan.

In this case, if these conditions are met on the 5.1 tilt, then the 6.4 degree tilt would be the last elevation sampled in this volume scan.

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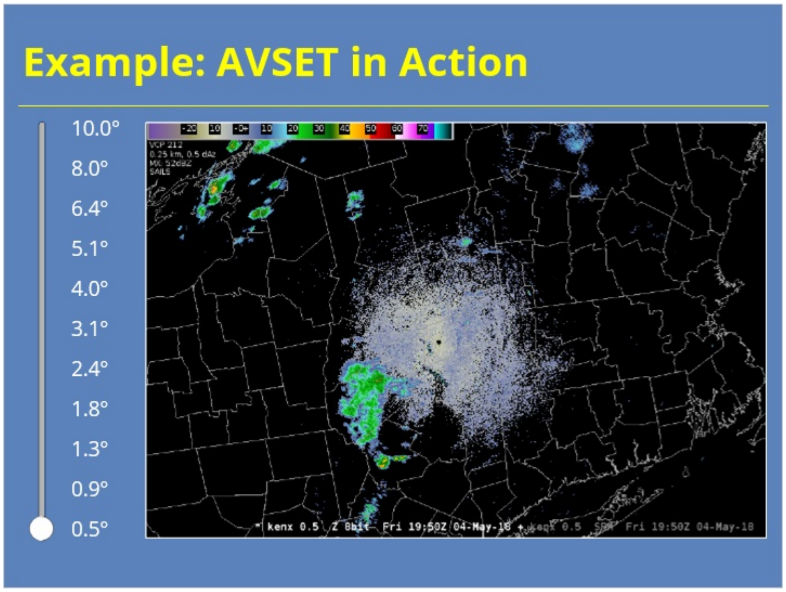
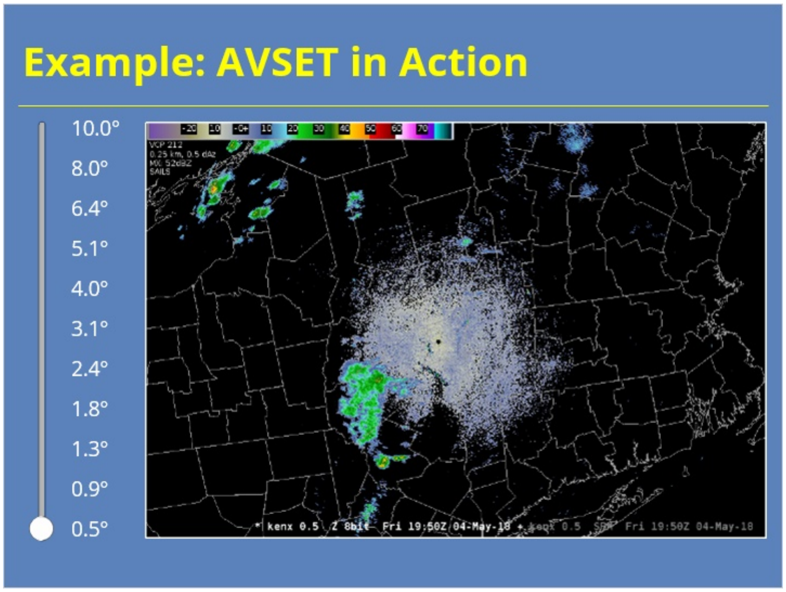
3.3 Example: AVSET in Action



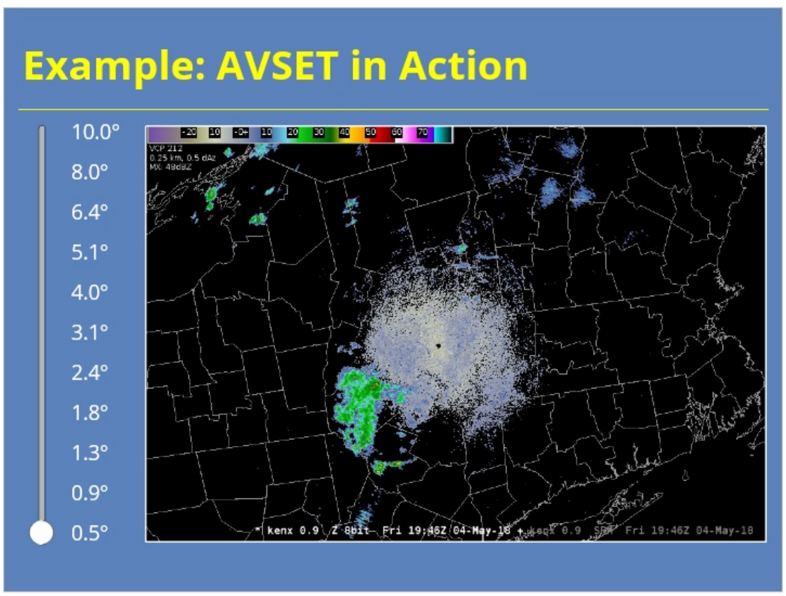
Notes:

This interaction shows an actual volume scan where AVSET is enabled and criteria for termination are ultimately met. Use the slider bar on the left-hand side of the slide to look at each elevation angle of data. Once you get to 5.1 degrees, you will see notes detailing whether the AVSET criteria or met on that tilt. Once you are done viewing the interaction, use the next button to advance to the next slide.

0.5 (Slide Layer)



0.9 (Slide Layer)



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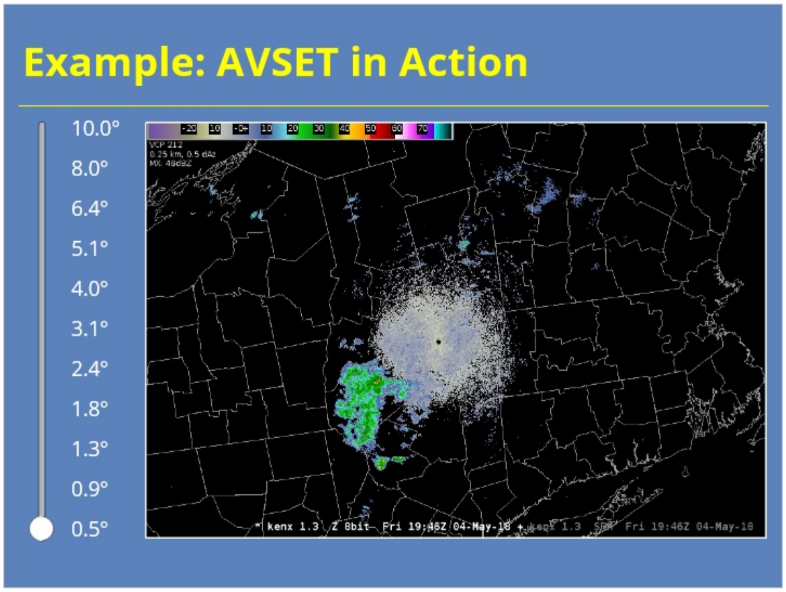
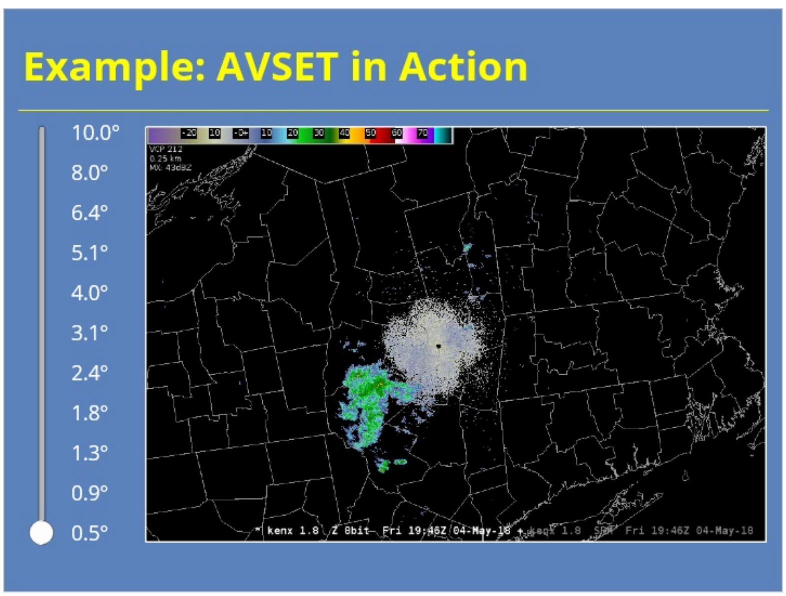
1.3 (Slide Layer)



1.8 (Slide Layer)



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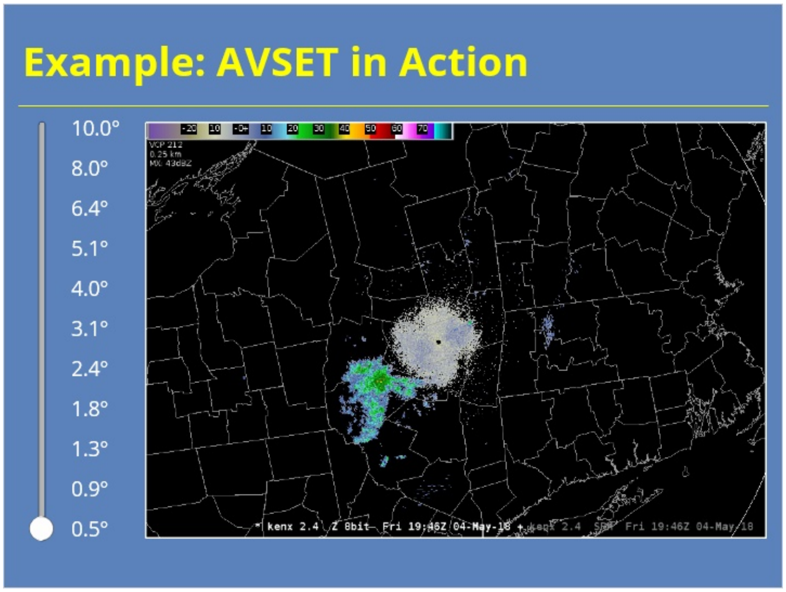
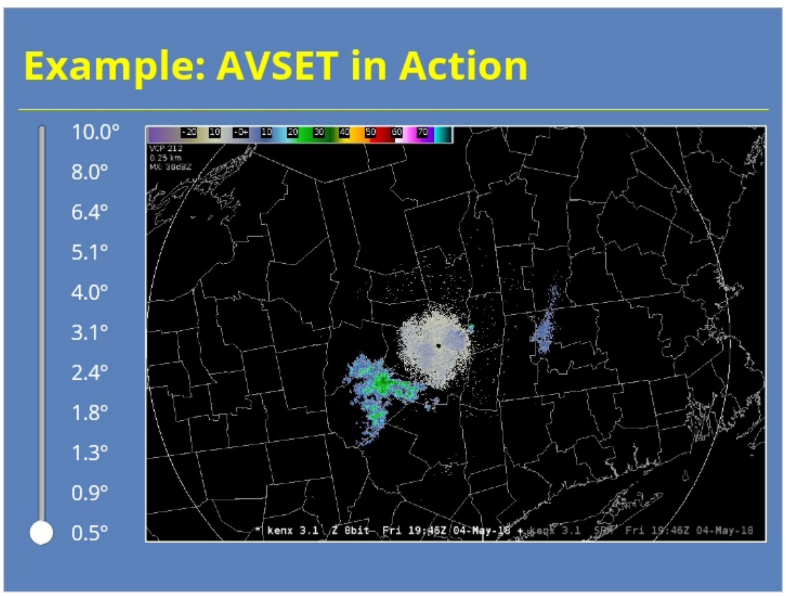
2.4 (Slide Layer)



3.1 (Slide Layer)



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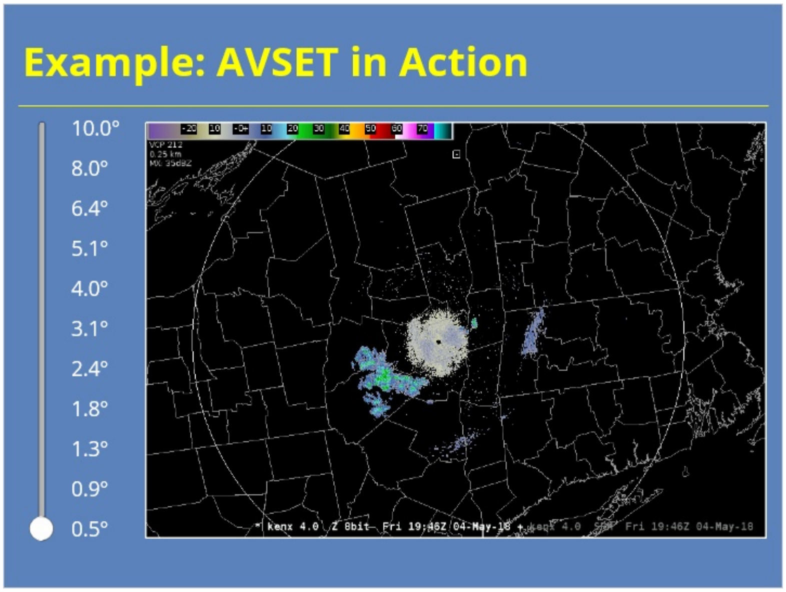
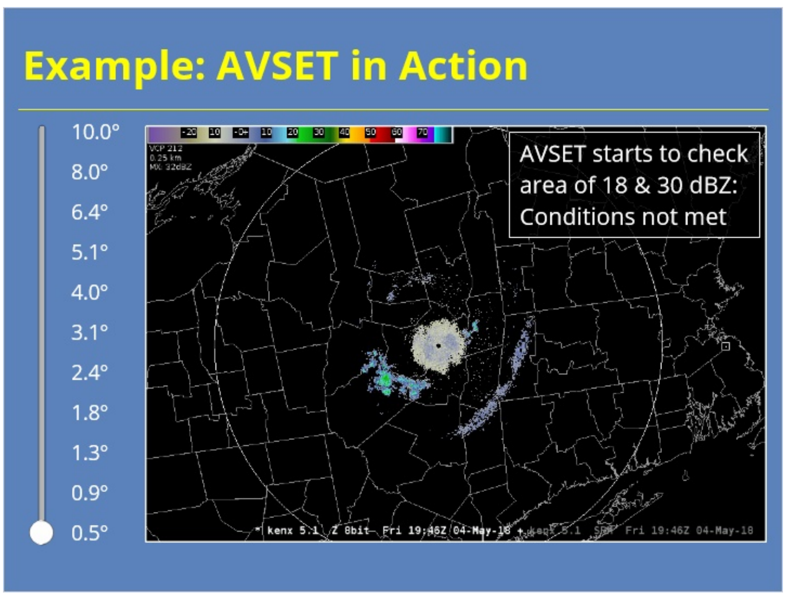
4.0 (Slide Layer)



5.1 (Slide Layer)



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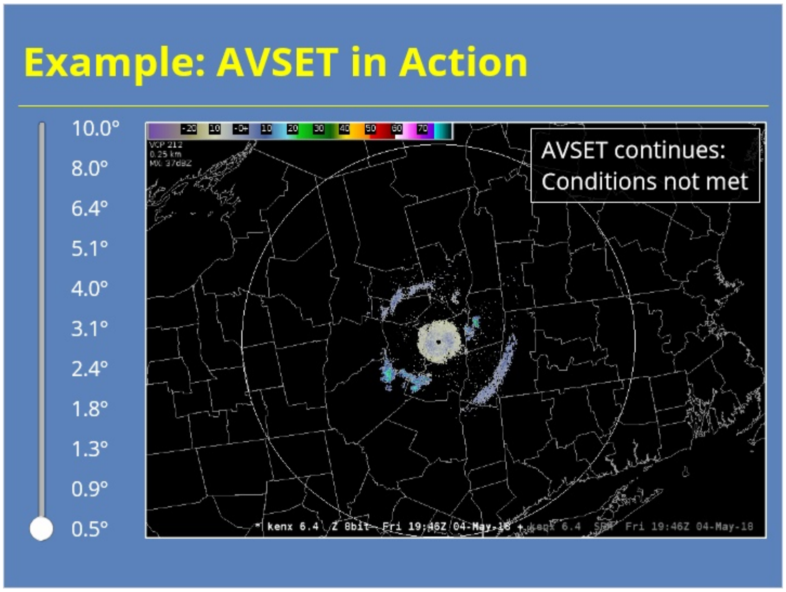
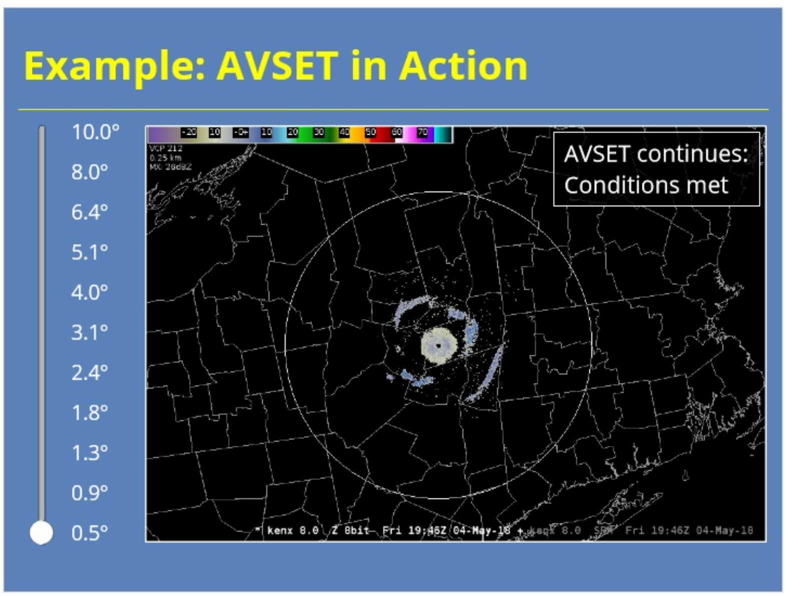
6.4 (Slide Layer)



8.0 (Slide Layer)



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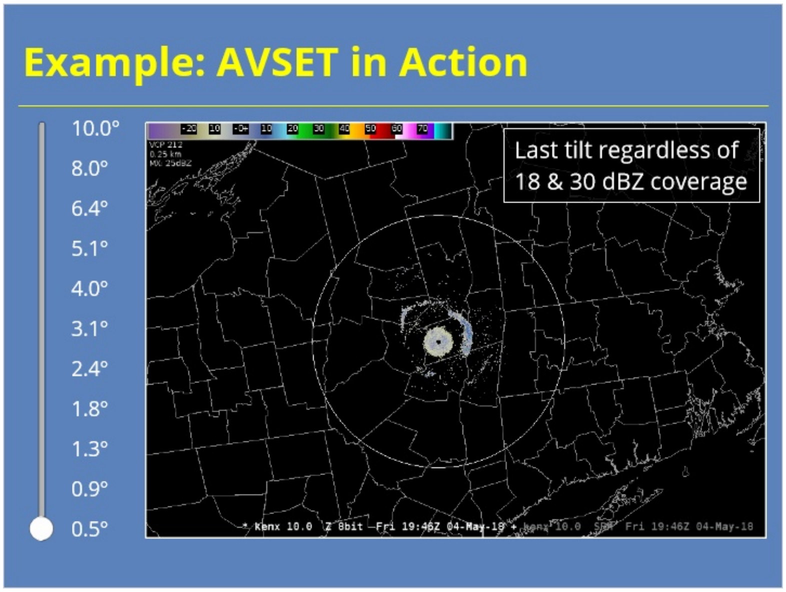
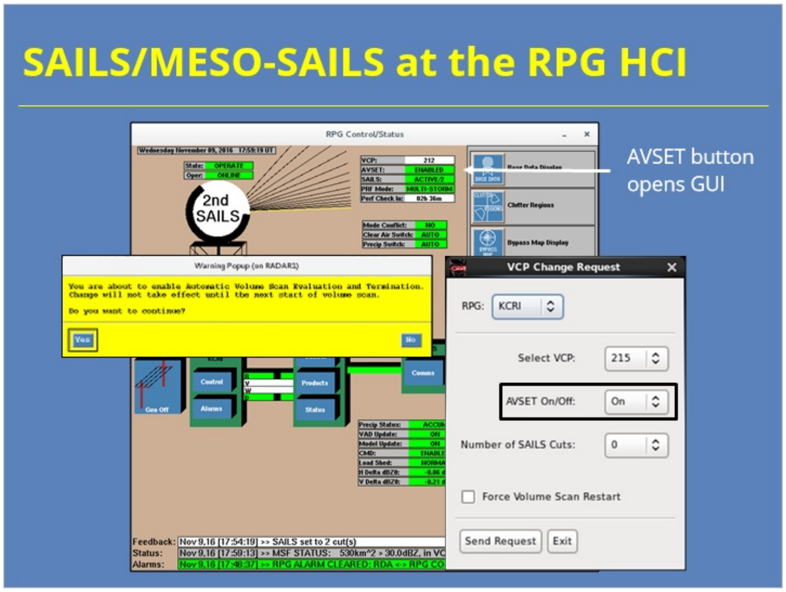
10.0 (Slide Layer)



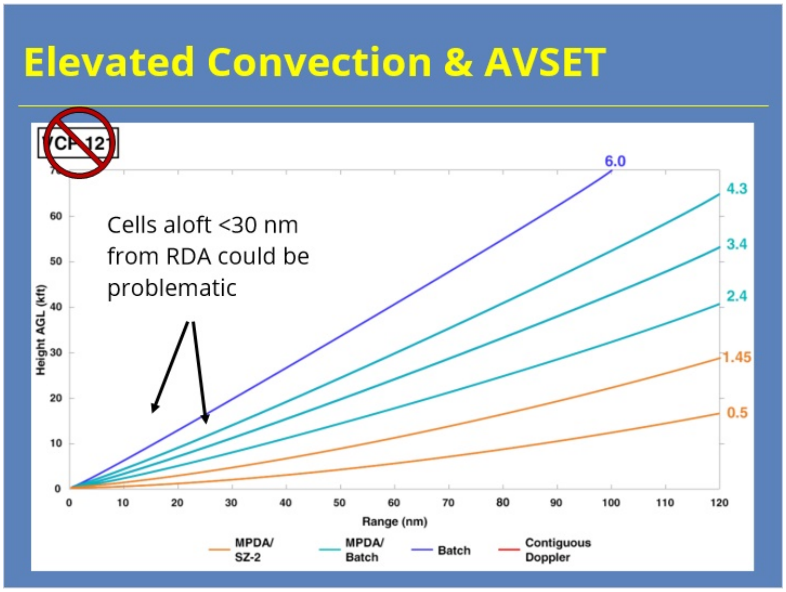
3.4 SAILS/MESO-SAILS at the RPG HCI



Notes:

AVSET is enabled by default at the RPG. If you decided that you need to change your AVSET status for some reason, you have two options. You can toggle AVSET on and off for a compatible VCP at the RPG HCI by clicking the AVSET button. You will get a warning message that you will need to confirm before the change takes effect. You can also make this change at the VCP Change Request GUI on your AWIPS workstation.

3.5 Elevated Convection & AVSET



Notes:

The one downside to AVSET involves elevated convection. If elevated convection were to bubble up near the RDA and you were using VCP 121, you could potentially miss cells within the nearest 30 nm of the RDA…at least for a few volume scans. Now, if we remember back to the VCP Selection lesson, you should remember that VCP 121 should only be used with tropical systems. So, if you are doing your do diligence as a radar operator, you shouldn't run into this problem. Still, if you suspect that your radar is not detecting elevated cells in your primary radar's cone of silence (even in VCPs 12 or 212), switch to another nearby radar to monitor that area. It doesn't have to be a WSR-88D, either. Consider using a nearby TDWR if you have one.

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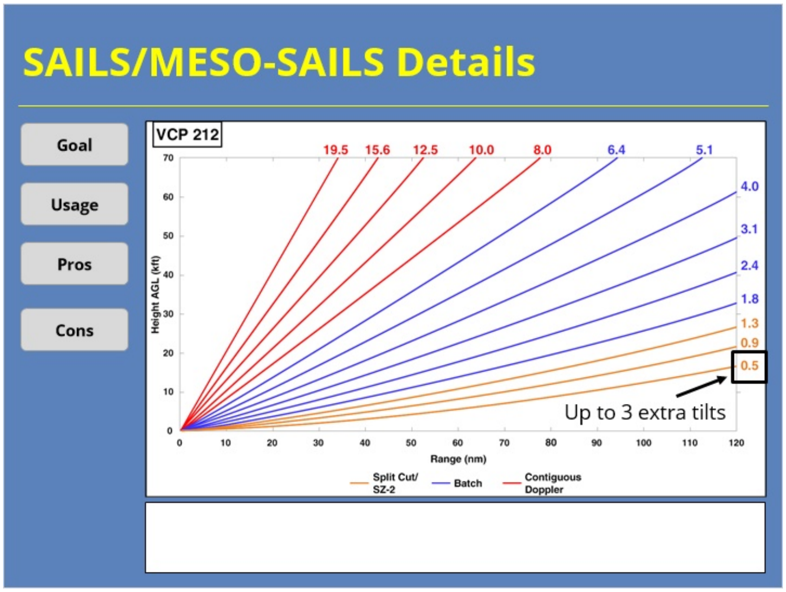
4. SAILS & MESO-SAILS

4.1 SAILS/MESO-SAILS Details



Notes:

Now let's quickly go through the details of SAILS and MESO-SAILS. Use the buttons on the left-hand side to learn more.

Goal: Provide more frequent low-level tilts

Usage:

- MESO-SAILS: VCPs 12 & 212
- SAILS: VCPs 35 & 215

Pros: Better low-level sampling of atmosphere

Cons:

- Potentially less frequently sampling aloft
- Potential issues with rainfall estimates

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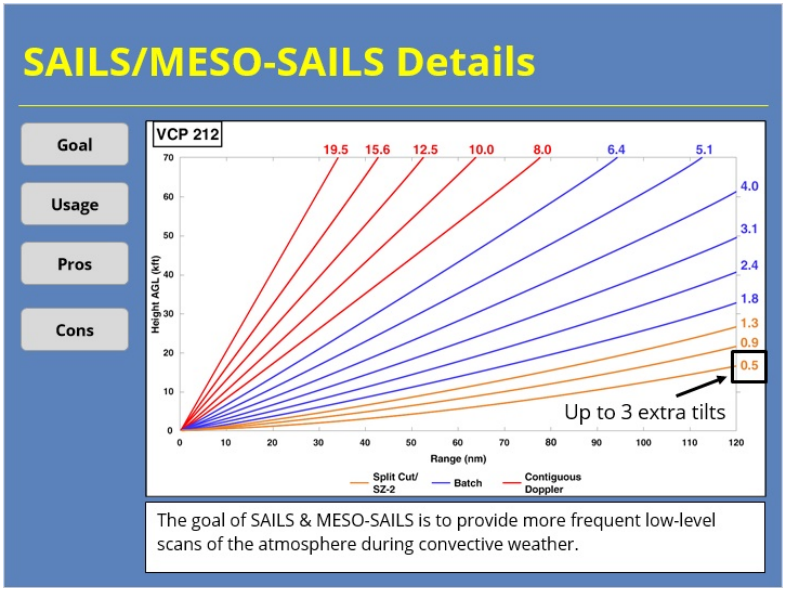
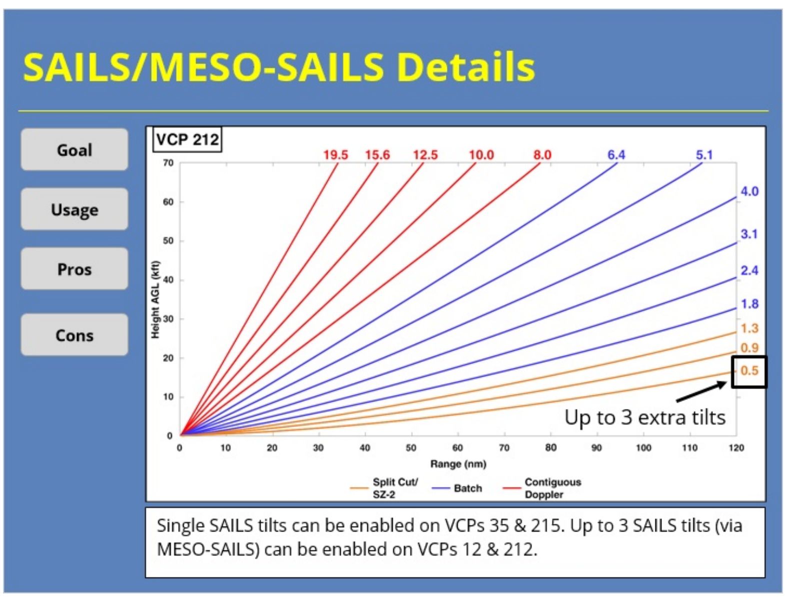
Goal (Slide Layer)



Usage (Slide Layer)



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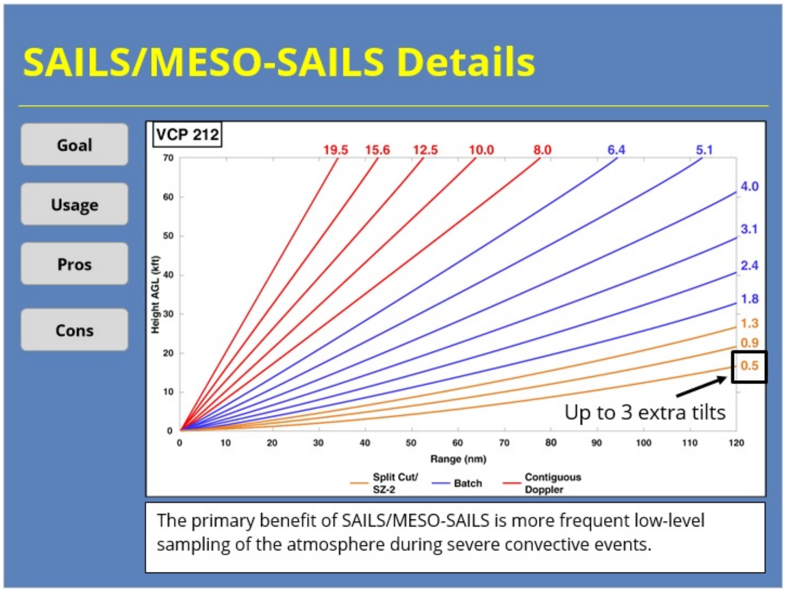
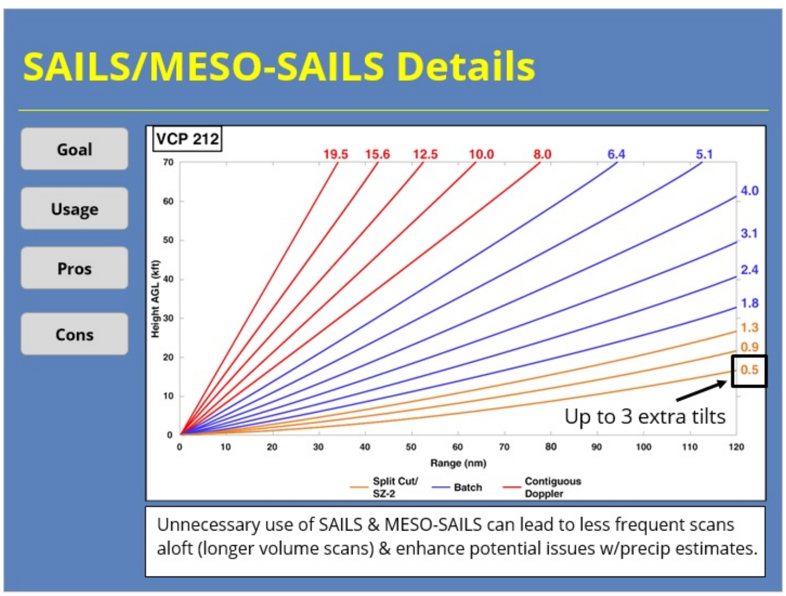
Pros (Slide Layer)



Cons (Slide Layer)



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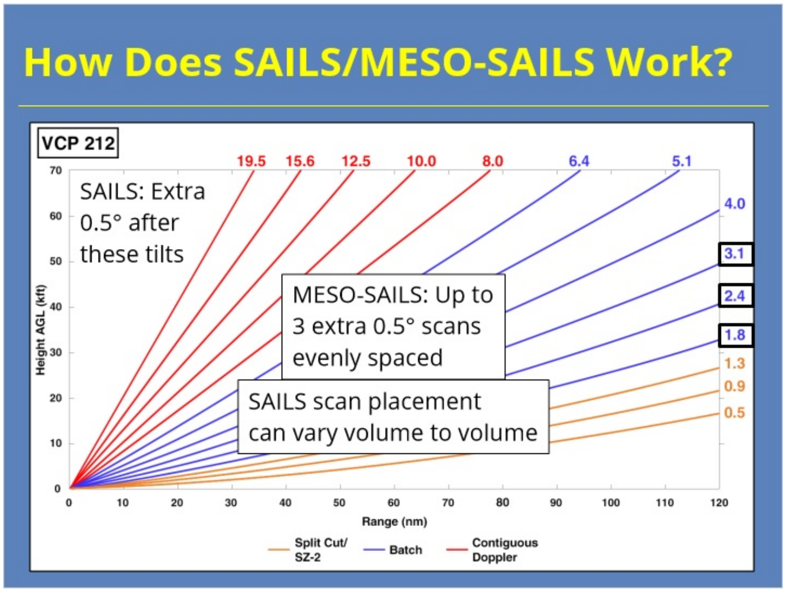
4.2 How Does SAILS/MESO-SAILS Work?



Notes:

So, how does the radar implement these additional low-level scans? Well, the radar inserts them in the volume scan so that they are evenly spaced in time. Let's use VCP 212 as an example to illustrate. If a single SAILS tilt is enabled, then that scan will occur sometime after the 1.8, 2.4 or 3.1 tilts. If multiple SAILS tilts are enabled, then those scans will fall at various points in the volume scan that are evenly spaced in time. Regardless of there being a single or multiple SAILS tilts enabled, the insertion points will be highly sensitive to AVSET use as the RPG uses the last tilt from the previous volume scan to forecast what the last scan will be on the current one. So, it's possible that the placement of the SAILS scans will vary from volume scan to volume scan.

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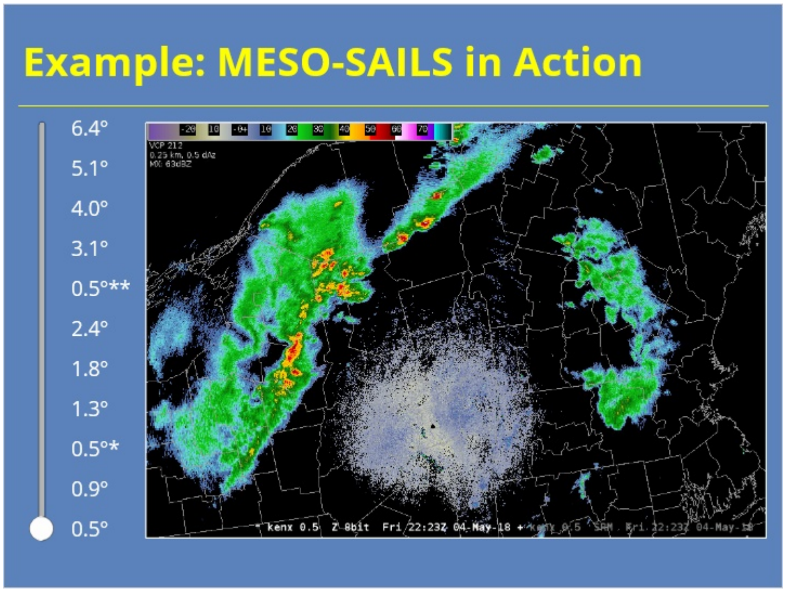
4.3 Example: MESO-SAILS in Action



Notes:

This interaction shows an actual volume scan where MESO-SAILS was enabled. Use the slider bar on the left-hand side of the slide to look at each elevation angle of data. The SAILS tilts will be annotated with an asterisk in the slider labels and annotated on the upper left-hand-side of the graphic. Once you are done viewing the interaction, use the next button to advance to the next slide.

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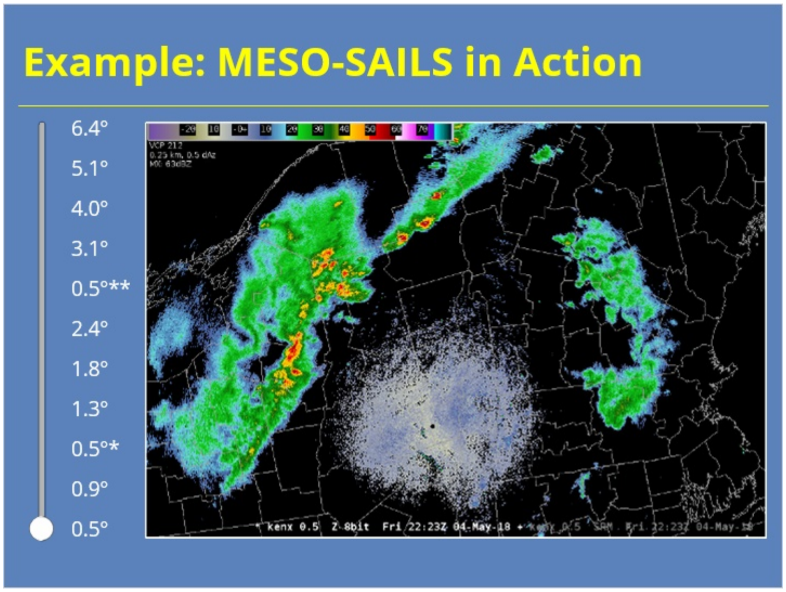
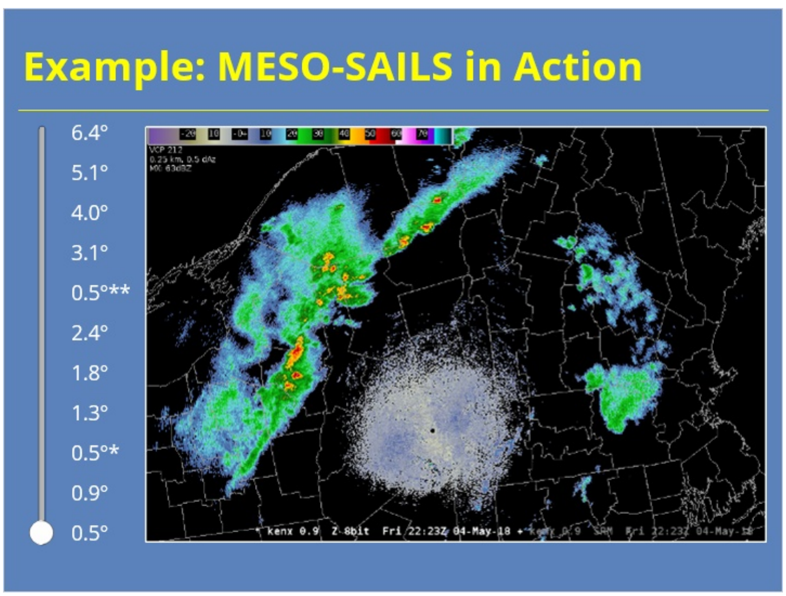
0.5 (Slide Layer)



0.9 (Slide Layer)



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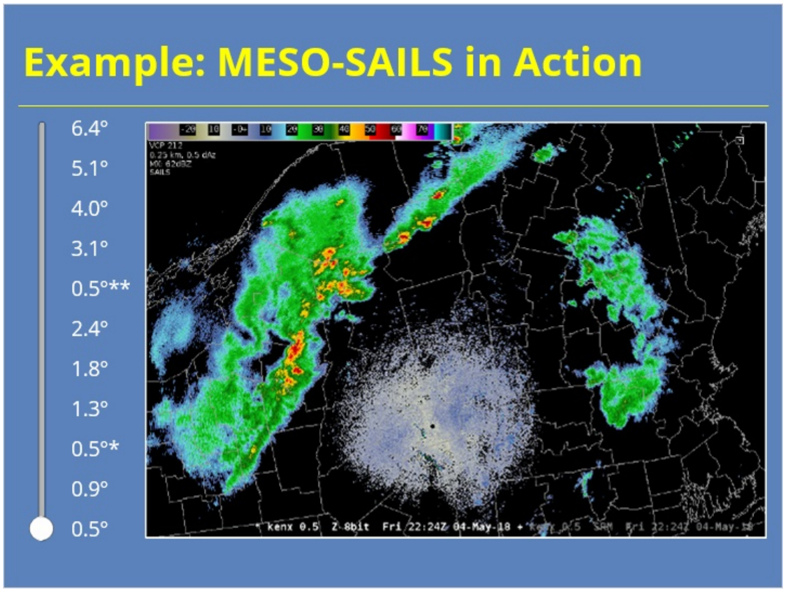
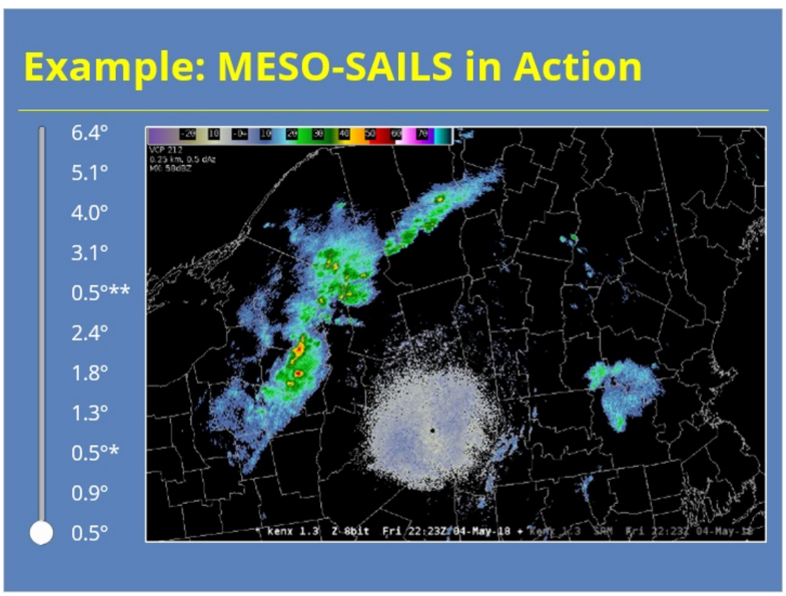
0.5 - SAILS 1 (Slide Layer)



1.3 (Slide Layer)



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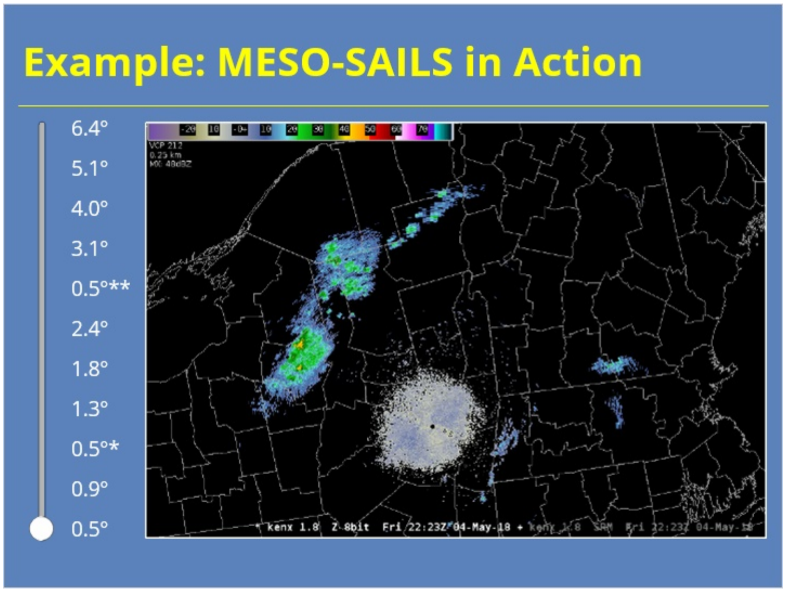
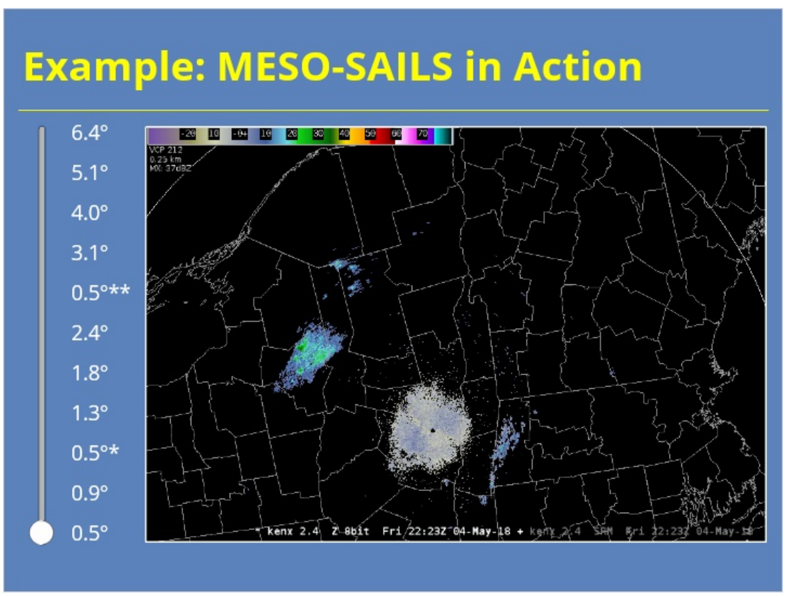
1.8 (Slide Layer)



2.4 (Slide Layer)



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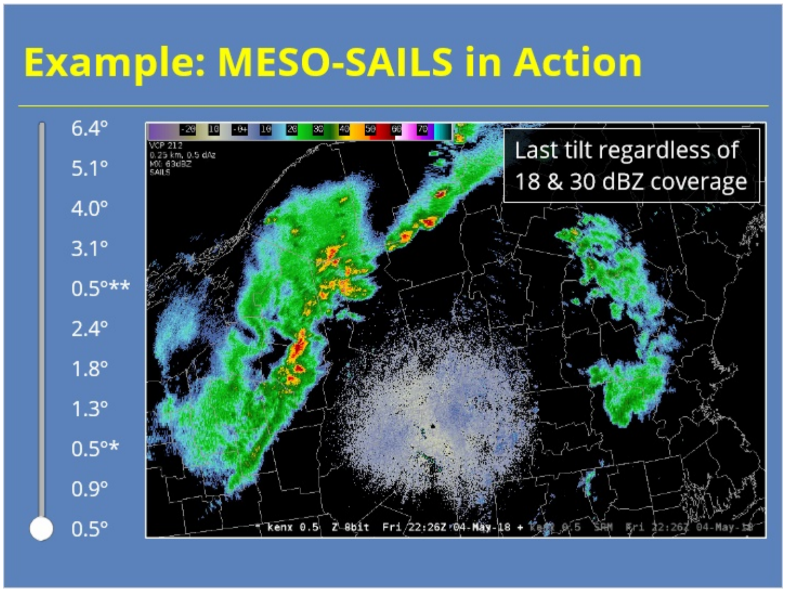
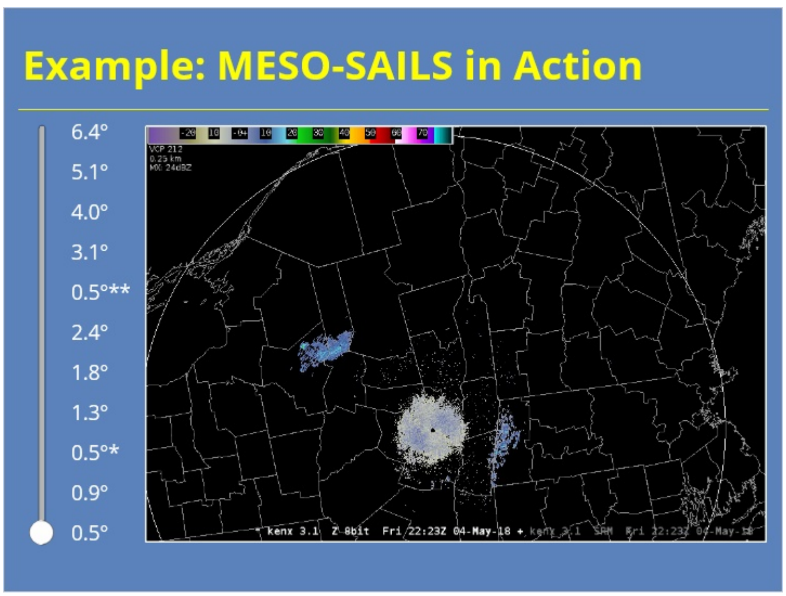
0.5 - SAILS 2 (Slide Layer)



3.1 (Slide Layer)



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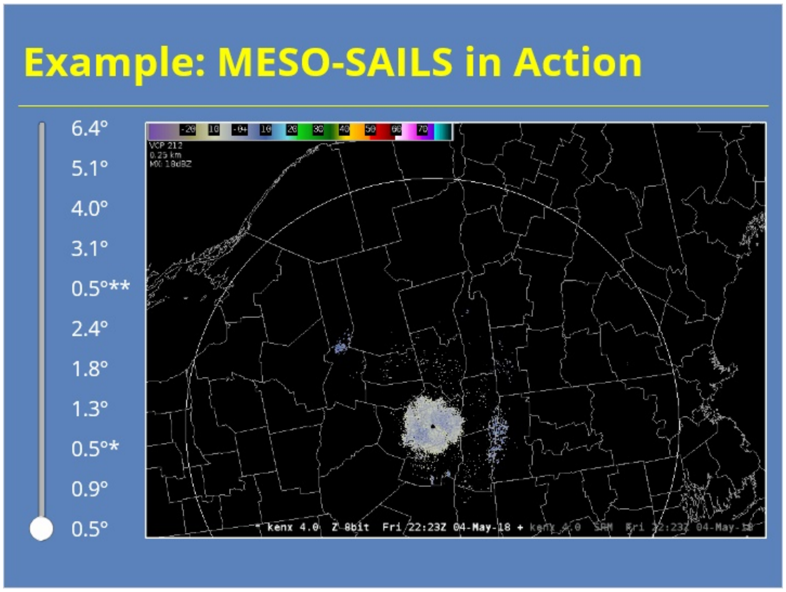
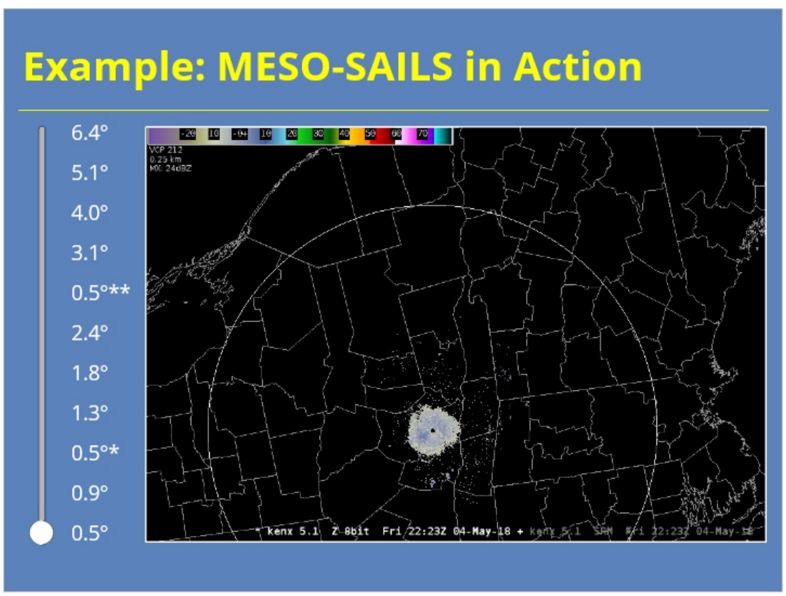
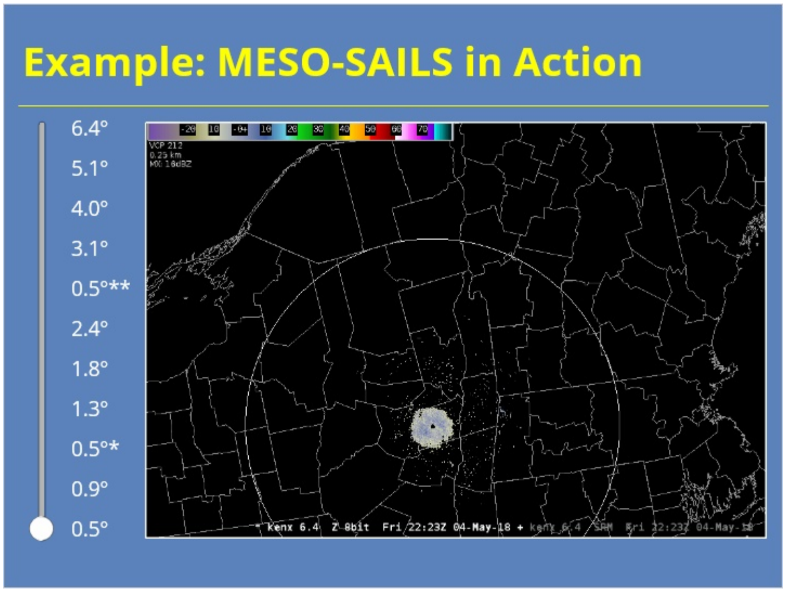
4.0 (Slide Layer)



5.1 (Slide Layer)



6.4 (Slide Layer)



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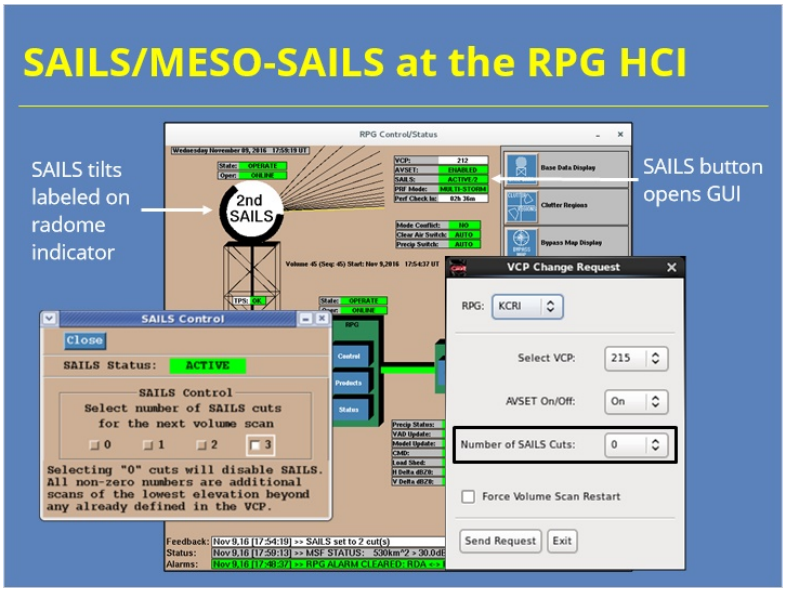
4.4 SAILS/MESO-SAILS at the RPG HCI



Notes:

If you need to know when the SAILS tilts are happening, your best bet is to look at the RPG HCI. In the example shown, the RPG is processing the “2nd SAILS” tilt of the volume scan. So, it’s the third 0.5 tilt. Remember that with Build 18, you can edit the number of SAILS tilts collected at the RPG by clicking the SAILS button. In the SAILS Control GUI, you can change the number of SAILS cuts collected. You can also make this change at the VCP Change Request GUI on your AWIPS workstation.

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4.5 MESO-SAILS Use “Food for Thought”

MESO-SAILS Use “Food for Thought”

Most important point: Don’t “Set it and Forget it”!

Focus Aloft (SAILSx0)	Aloft & Surface (SAILSx1,x2)	Focus Surface (SAILSx3)
Elevated, pulse, and/or hail-specific storm threat		
		QLCS tornado/straight-line wind
	Severe Multicell/Supercell storms (SAILSx1) →	Tornadic “storm of the day” situation
	Severe Multicells/Supercells at far range (SAILSx2) →	Tornadic “storm of the day” situation

Notes:

Radar operators have multiple options during severe convection events on how many SAILS tilts to include. If you only remember one thing from what I’m about to say, it should be you can’t simple “set and forget” your SAILS tilts. You should routinely adjust your SAILS settings based on the needs of the current event. As a general rule, the more focus you want near the surface (and less focus you want aloft) then the more SAILS tilts you want enabled. So, if your primary threat is elevated or pulse storms, or if hail is your main concern, you should probably have SAILS disabled. QLCS tornado or straight-line wind events, where your focus will primarily be at the surface, SAILSx3 is your best bet.

Things can get a little trickier when dealing with multicell or supercell storms with multiple threats. The tendency is to think SAILSx3 is always your best bet. During these events, however, the hail or flash flood threats may be just as important an issue as tornadoes. Plus, the evolution of the mesocyclone above 0.5 degrees is an important predictor for warning lead time (and possibly even severity). So, you need to balance these threats out in order to make a wise choice. If your storms of interest are at close to medium ranges, start at SAILSx1 for this kind of balanced threat. At longer ranges, consider SAILSx2 since the tilts aloft will likely have less useful data (and AVSET may truncate your scans). If you end up with a “storm of the day” type storm where rapid low-level updates are more important, than switch to

SAILSx3. Just remember that you will get less frequent midlevel updates…especially if AVSET doesn't truncate the volume scan early. Also, your precip estimates may be negatively impacted with faster moving storms because SAILS tilts don't contribute to the precip algorithms yet.

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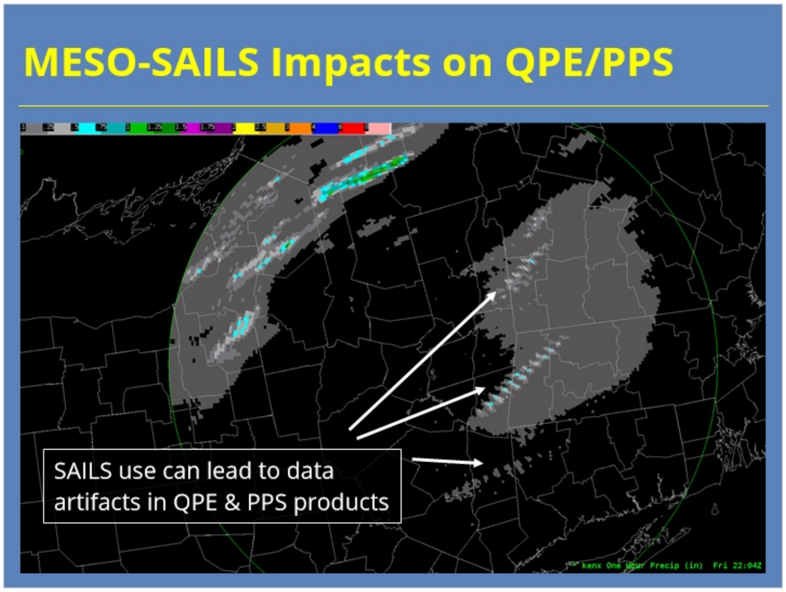
4.6 MESO-SAILS Impacts on QPE/PPS



Notes:

Use of MESO-SAILS can lead to artifacts in both the QPE and PPS products. When rapidly moving, discrete cells exist, the precipitation accumulation algorithms can contain unrealistic patterns due to the cells propagation speed and how the algorithm's work. Since use of SAILS/MESO-SAILS can lead to longer volume scan times, these artifacts will likely be more noticeable when extra scans are enabled. While this is a negative for SAILS use now because only the initial 0.5 tilt is used by these algorithms, there are plans to integrate SAILS scan data into the precipitation algorithm output. So, in the future, SAILS/MESO-SAILS use may actually make the situation better.

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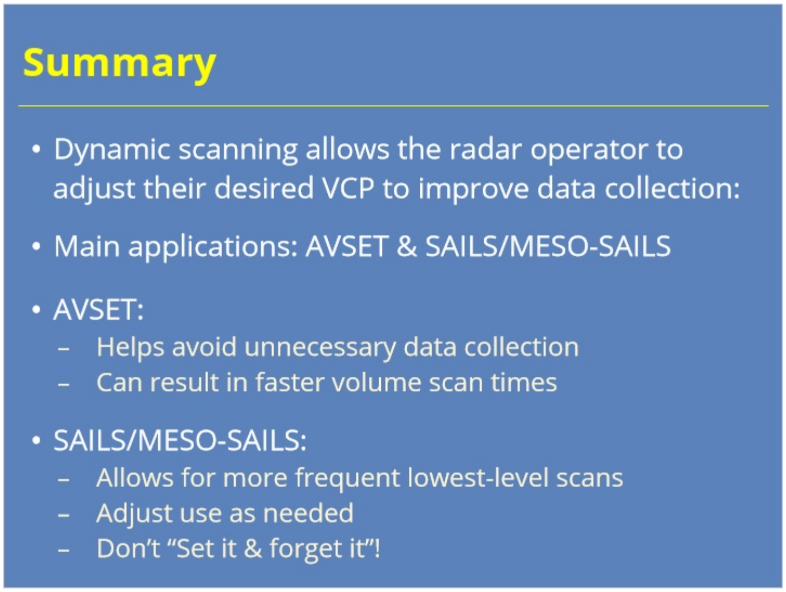
5. Summary & Quiz

5.1 Summary



Notes:

This lesson discussed what dynamic scanning is and how it is implemented at the WSR-88D. Three applications work together to implement dynamic scanning capabilities: AVSET, SAILS, and MESO-SAILS. AVSET works to shorten volume scan times by avoiding collection of unnecessary data at higher elevation angles. SAILS and MESO-SAILS, which are closely related, allow for the collection of extra lowest-level tilts per volume scan. Up to 3 extra tilts can be added to a volume scan during severe convective events, but you should adjust that number depending on what your need is. Most importantly, don't simply set the number of extra SAILS tilts and then forget about it.

The next slide will start the lesson quiz. Click the next button when you are ready to proceed.

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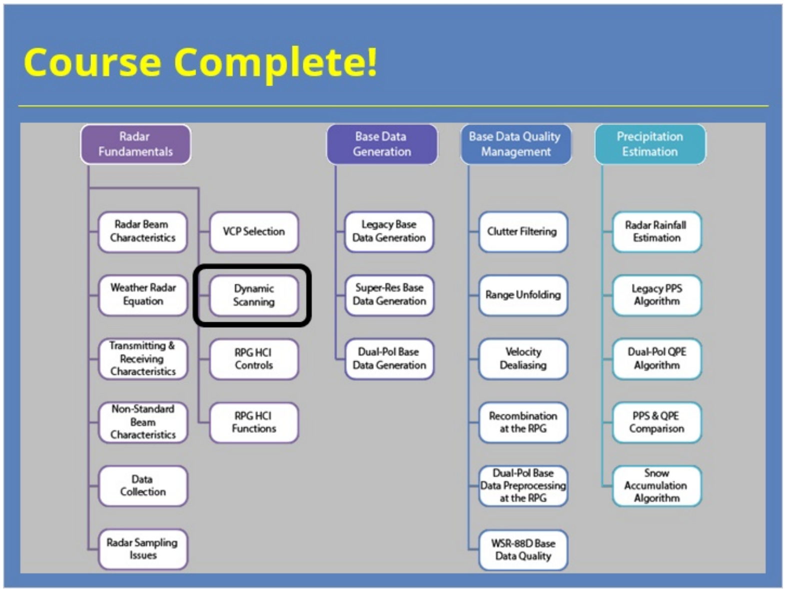
5.9 Course Complete!



Notes:

You have successfully completed this course. You can look over the roadmap on the slide to see what courses remain in this topic or you can click the Exit button to close the window and record your completion.

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RPG HCI Controls

1. Radar Reflectivity Signatures

1.1 Untitled Slide

Notes:

Welcome to this lesson discussing how to monitor and control the WSR-88D system using the Radar Product Generator Human Control Interface. This training is part of the Radar & Applications Course topic on the Principles of Radar. Let's get started!

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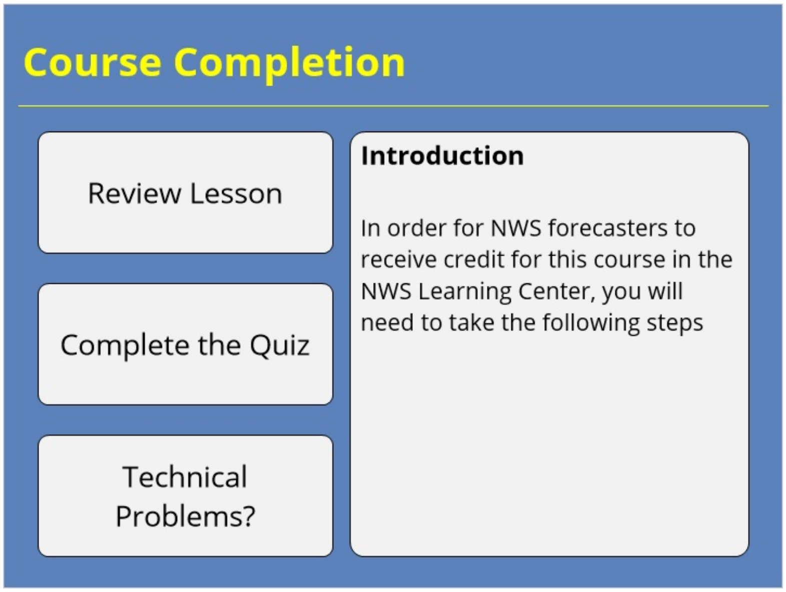
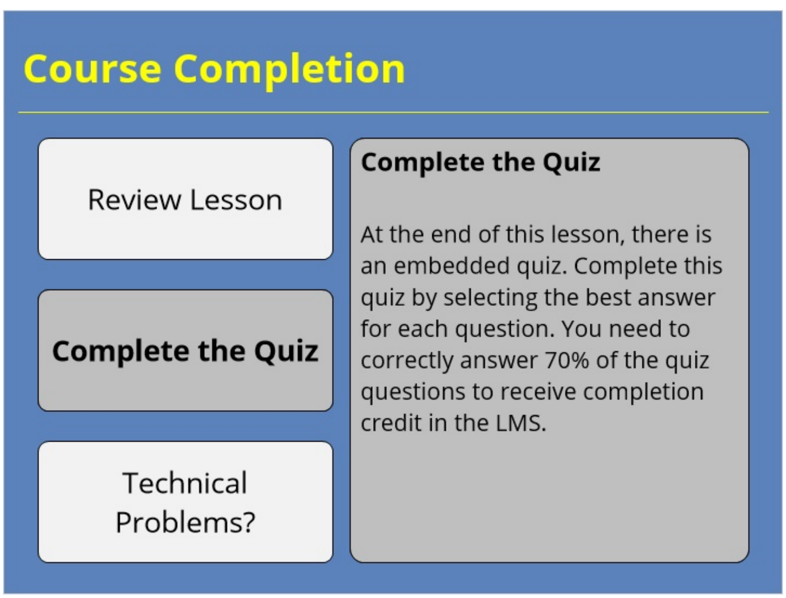
1.2 Course Completion



Notes:

Complete the Quiz (Slide Layer)



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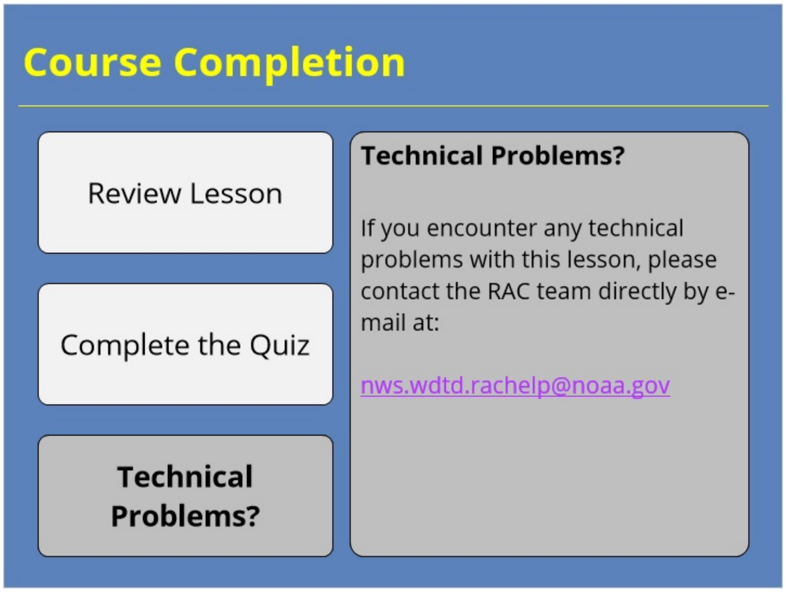
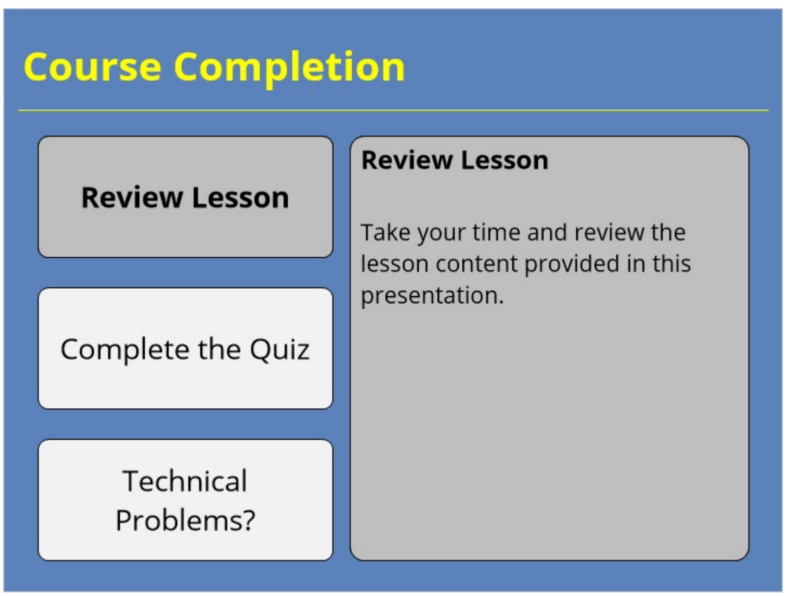
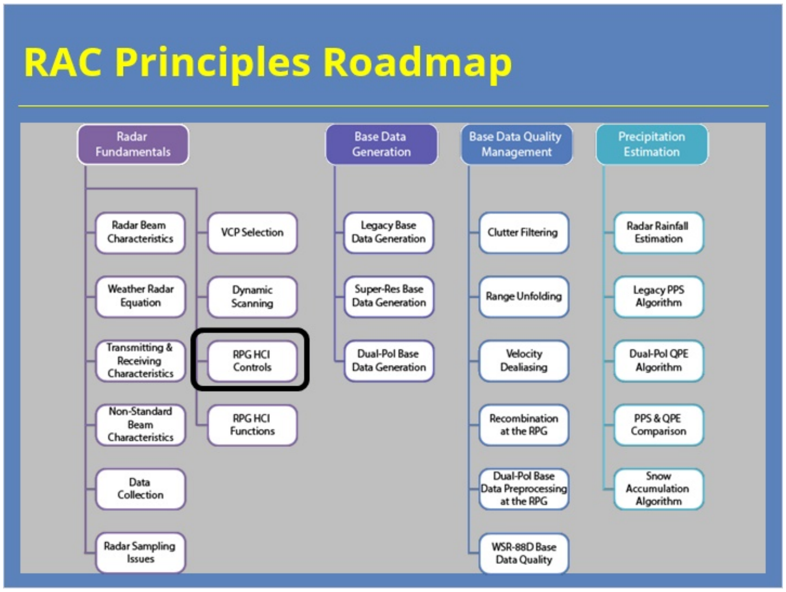
Technical Problems (Slide Layer)



Review Lesson (Slide Layer)



1.3 RAC Principles Roadmap



Notes:

Here is a roadmap for the RAC Principles topic. This lesson, which is part of the Radar Fundamentals section, is highlighted. Once you have had a chance to look over the roadmap, advance to the next slide.

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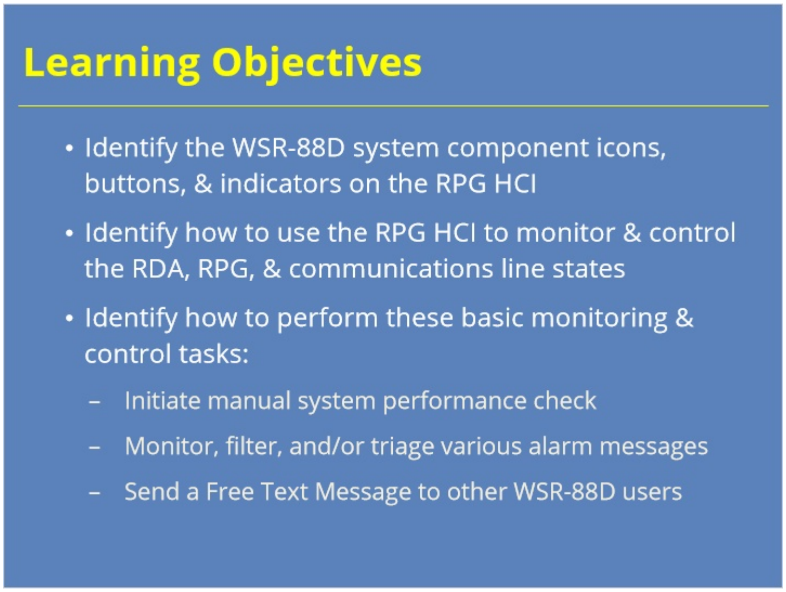
1.4 Learning Objectives



Notes:

Here are the learning objectives for this lesson. Please take a moment to look them over and press the next button when you are ready to advance to the next slide.

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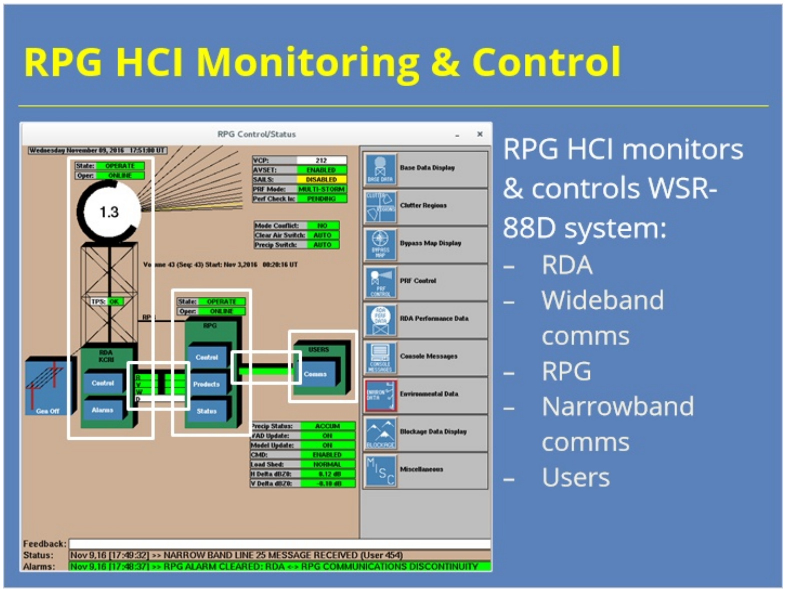
1.5 RPG HCI Monitoring & Control



Notes:

Remember back to the Introduction to the WSR-88D System lesson, that there are 6 components to the radar. The RPG HCI is the tool that the radar operator can use to monitor and control aspects of 5 of these components: the Radar Data Acquisition Unit (or RDA), the wideband communications lines, the Radar Product Generator (or RPG), the product distribution (or narrowband) comms lines, and users. This lesson will discuss some basic ways that you, the radar operator, can perform some of these tasks.

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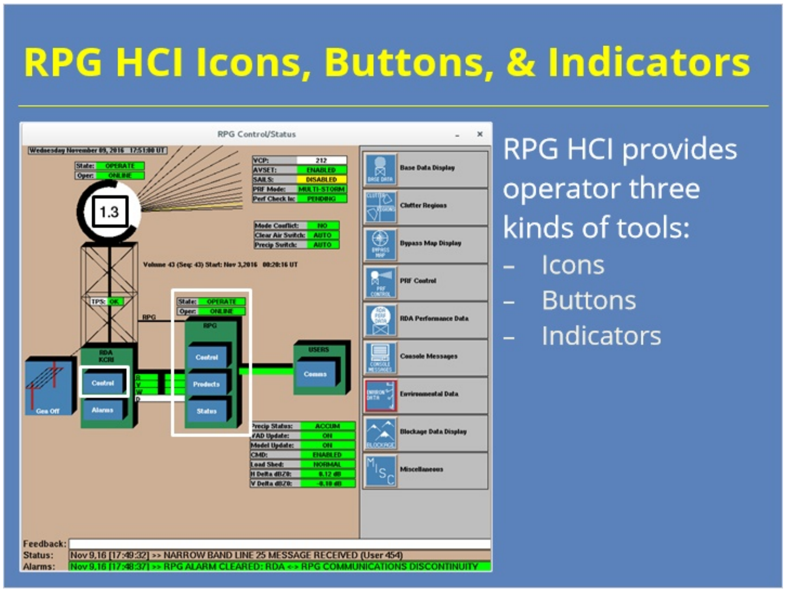
1.6 RPG HCI Icons, Buttons, & Indicators



Notes:

Before we dive into specifics of monitoring and controlling the radar system, we should point out the differences between three kinds of tools the RPG HCI provides you to perform these tasks. Icons provide graphical representations of different parts of the radar system, such as the RPG. Buttons are clickable boxes that launch other windows or run commands, such as the RDA Control button. Indicators give the radar operator information about the state of the system, such as what elevation tilt the radar is currently collecting. All of these items give the radar operator the tools they need to perform key tasks on the system.

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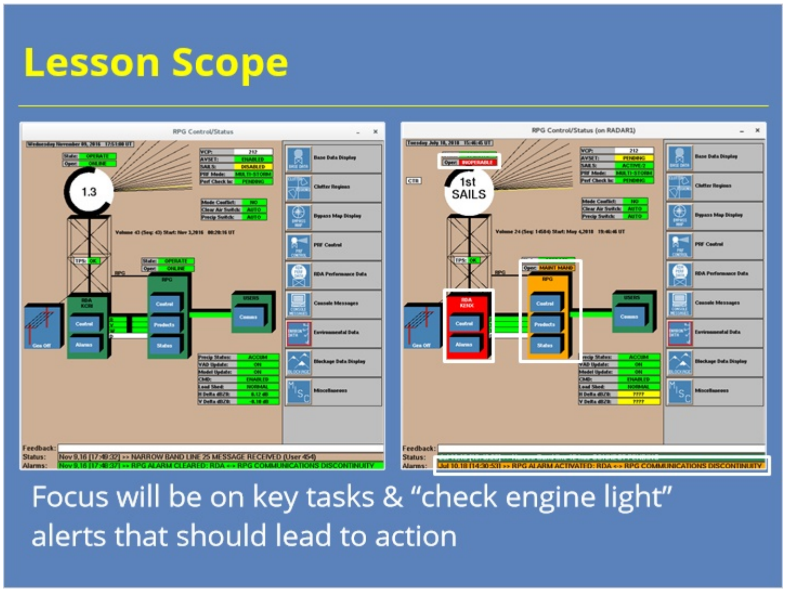
1.7 Lesson Scope



Notes:

Let me make one last point. This lesson has a limited scope, so you will not be taught what every window or command can do. I will focus on key important tasks that radar operators should know how to perform to ensure the radar is operating properly. To use an analogy, I will not be walking you through the user's manual like you might have on your car. Instead, I'm going to teach you about those "check engine" type lights in your car and similar monitoring tasks to ensure you car remains drivable.

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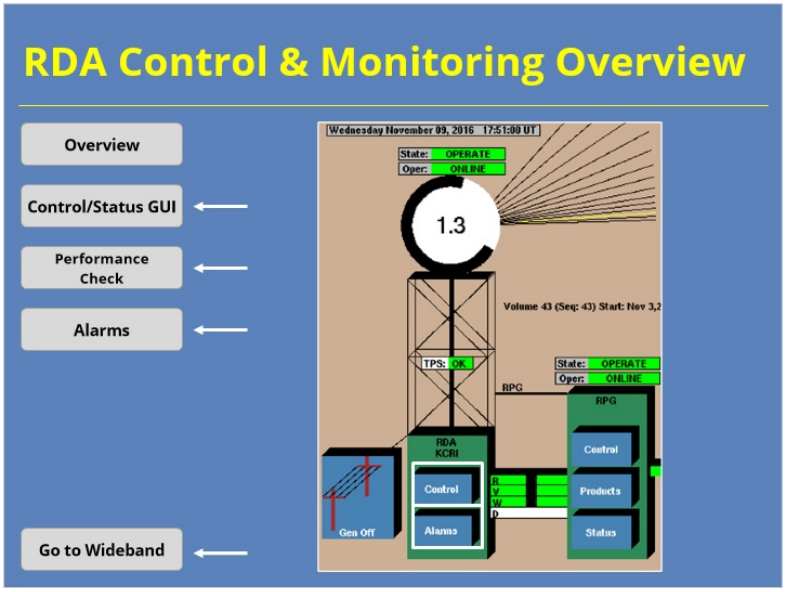
2. RDA Tasks

2.1 RDA Control & Monitoring Overview



Notes:

Let's start by discussing how the RPG HCI can help you control and monitor the RDA's status. We will focus on three areas associated with the RDA icon: the RDA Control/Status GUI, manually initiating a system performance check, and monitoring alarms. Use the buttons on the left-hand side of the slide to navigate between these sections. Once you have viewed all of these topics, click on the "Go to Wideband" button on the slide to advance to the next section of the course.

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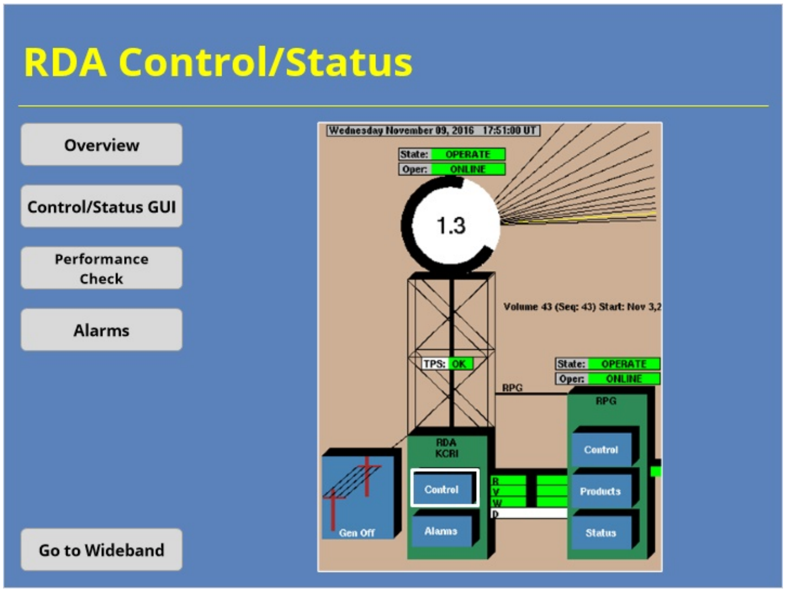
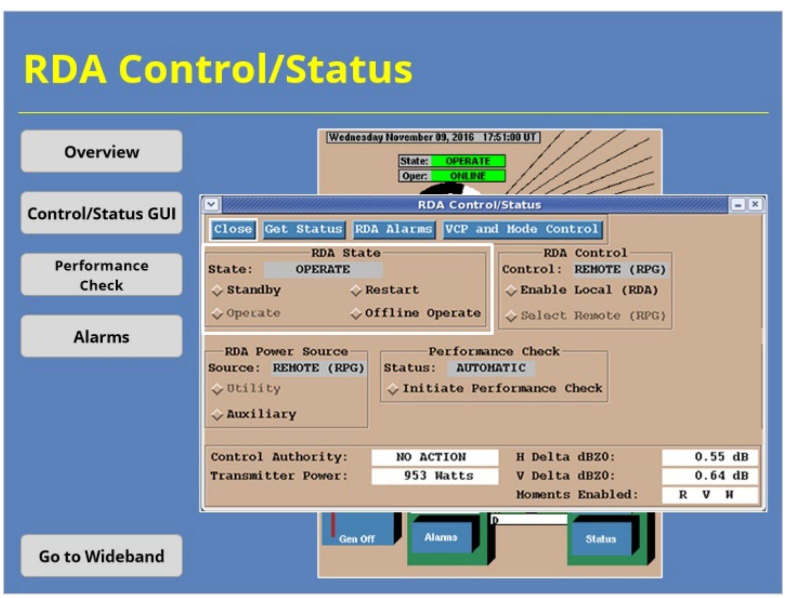
2.2 RDA Control/Status



Notes:

Clicking on the “Control” button on the RDA icon opens the RDA Control/Status Window. This GUI controls the basic functions of the RDA. Click on the button to learn more about the GUI.

GUI (Slide Layer)



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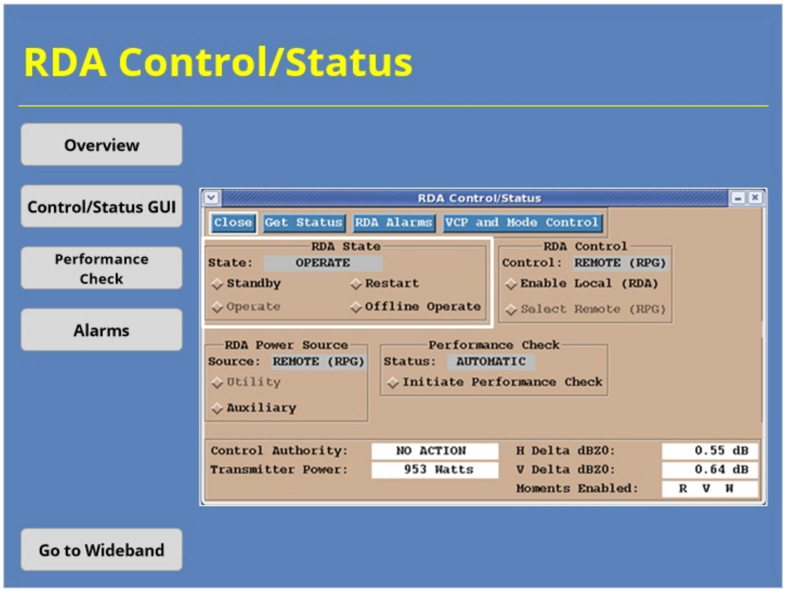
2.3 RDA Control/Status



Notes:

The RDA Control/Status GUI shows you basic information about how the RDA is currently functioning. The RDA State panel allows you to monitor and change which of the four operational states the RDA is in. During most situations, you want this to say “Operate”. If it doesn’t (and you don’t know of a maintenance being done on the system), you should mention this information to your radar focal point, Electronics (or EI) Tech, or shift supervisor.

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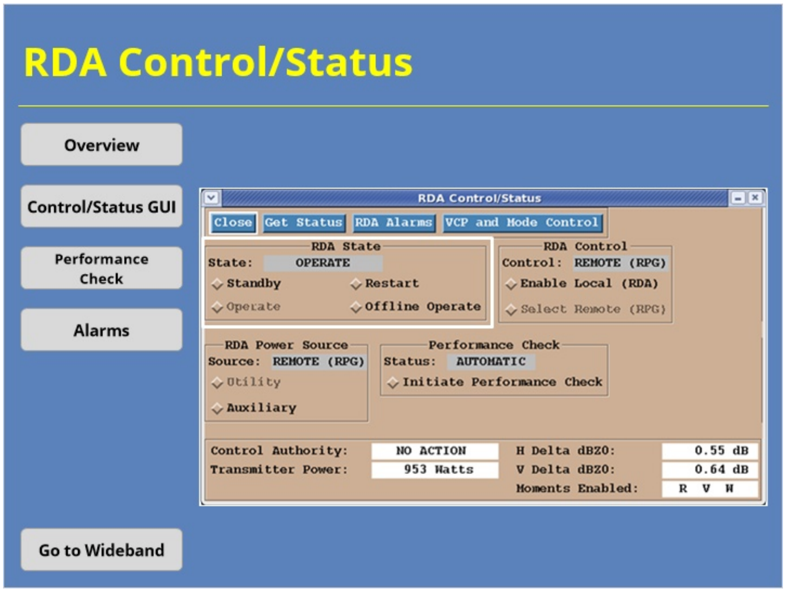
GUI (Slide Layer)



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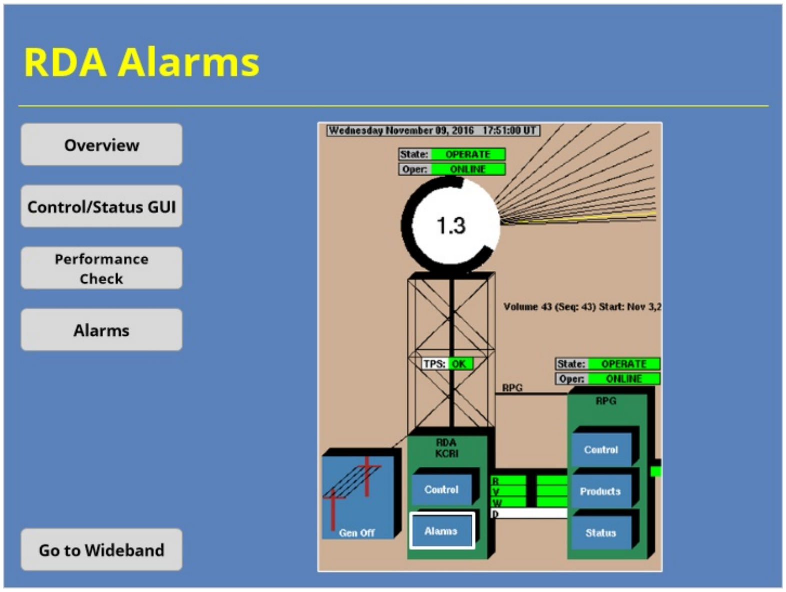
2.4 RDA Alarms



Notes:

Clicking on the “Alarms” button on the RDA icons opens the RDA Alarms Window. This GUI controls the basic functions of the RDA. Click on the button to learn more about the GUI.

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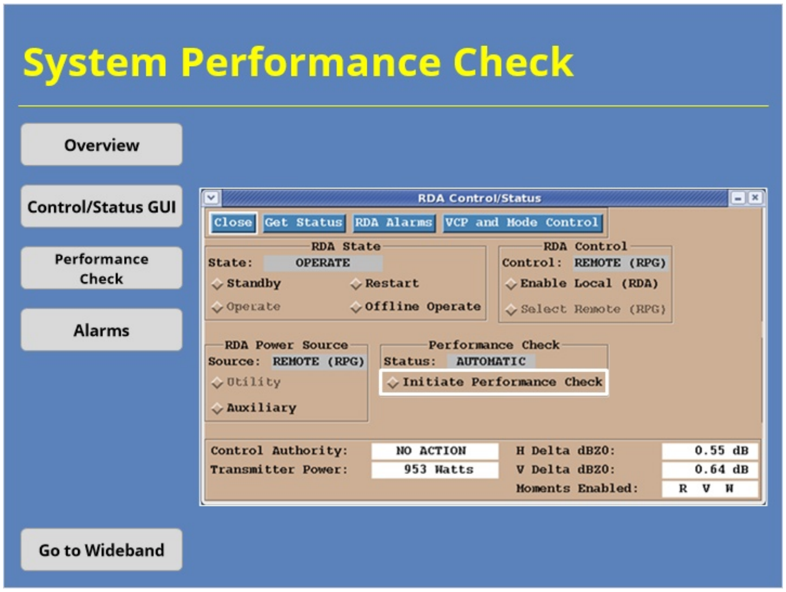
2.5 System Performance Check



Notes:

The task you are most likely to perform in this GUI involves the System Performance Check. The radar runs this performance check every 8 hours to ensure the system operates correctly. During this check, the radar collects no data. If you can prevent it, you don't want the next scheduled performance check to occur while significant weather is on-going. The way you prevent this issue is to initiate a performance check during a quieter period. Click on the "Initiate Performance Check" check box to learn more.

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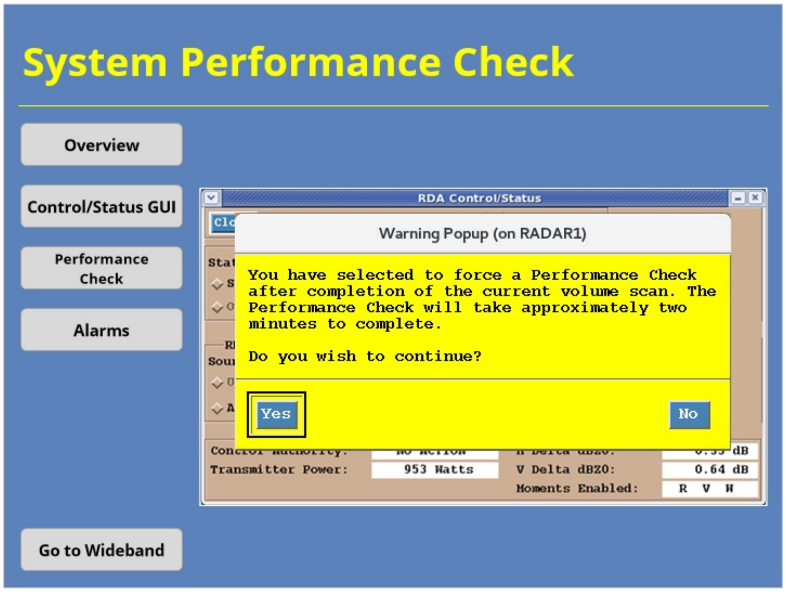
Warning (Slide Layer)



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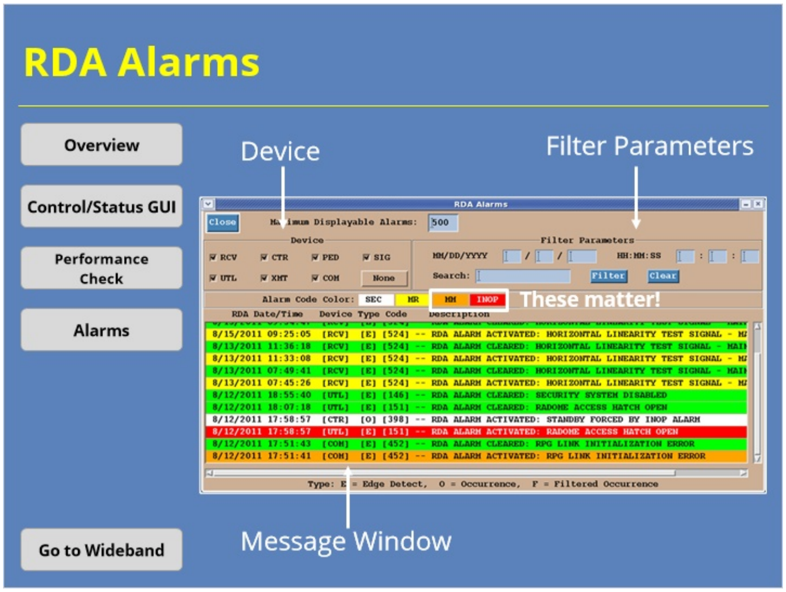
2.6 RDA Alarms



Notes:

The RDA Alarms GUI allows you to monitor RDA performance in more detail than the Control/Status GUI provides. This window displays all of the alarms from the RDA. If the list of alarms seems too much, you can filter the alarms a few different ways. You can sort by device using the 7 checkboxes in the Device panel. Just remember that if you toggle a device off so the alarms don't appear, it doesn't make the underlying problem go away. You can also filter by parameters such as time, date, or message text content. More important is the message color codes. White, yellow, and green messages can generally be ignored as they are usually just status messages. Orange and red labeled messages matter more. If these alarms don't clear themselves quickly, you should alert the El Tech, radar focal point, or shift supervisor so that they can troubleshoot the issue further.

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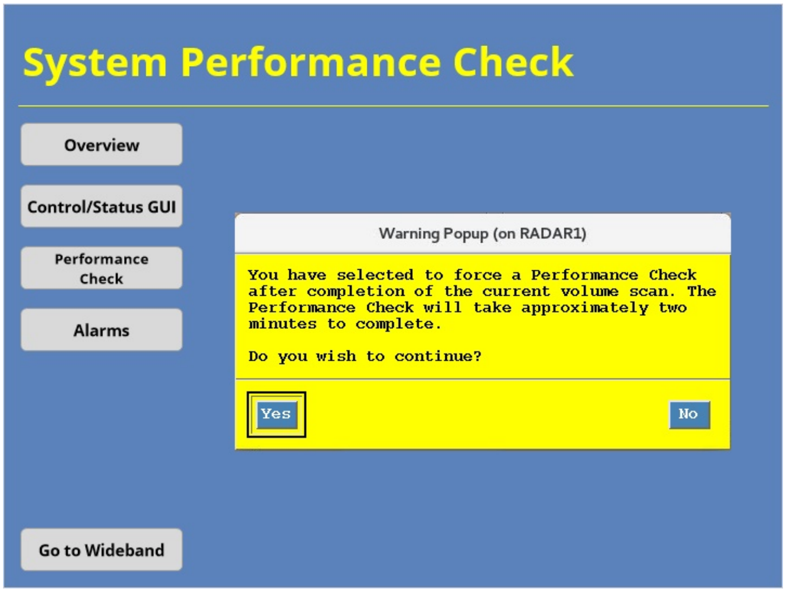
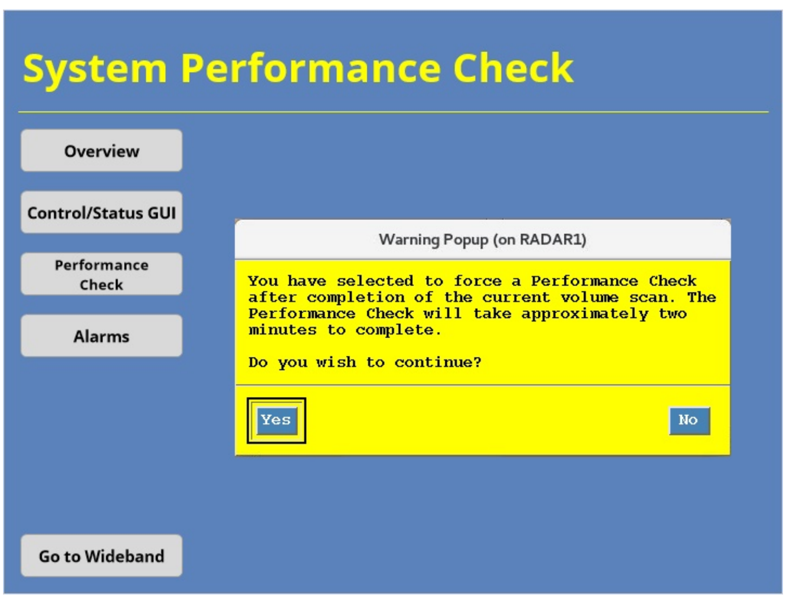
2.7 System Performance Check



Notes:

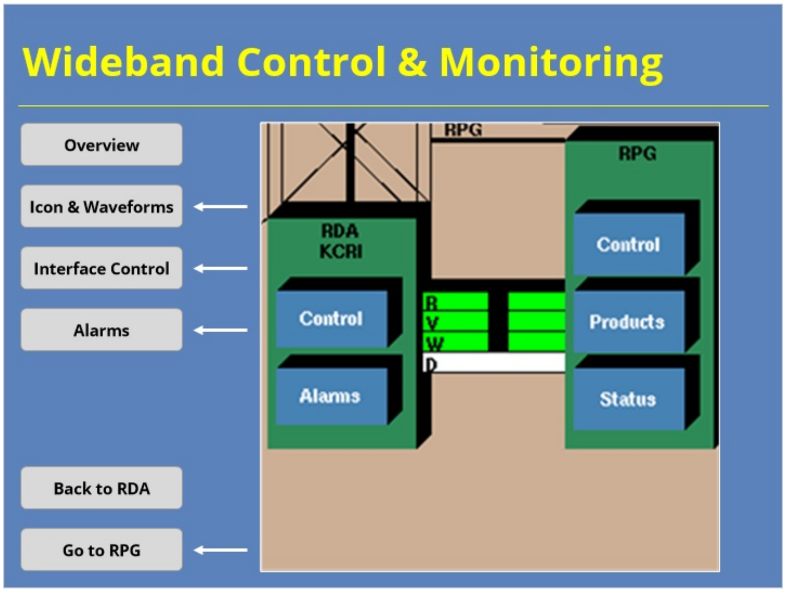
When choose to initiate a performance check manually, you will see this warning message. The current volume scan will continue as normal, then the system check will occur. And you've just bought yourself 8 hours of uninterrupted data collection.

Warning (Slide Layer)



3. Wideband Tasks

3.1 Wideband Control & Monitoring



Notes:

So now let's move on to control & monitoring the wideband communication lines for the WSR-88D. Once again, we will focus on three areas: The wideband comms icon and how it relates to the transmitted waveform, the Interface Control GUI, and alarms related to wideband comms. Use the buttons on the left-hand side of the slide to navigate between these sections. Once you have viewed all of these topics, click on the "Go to RPG" button on the slide to advance to the next section of the course.

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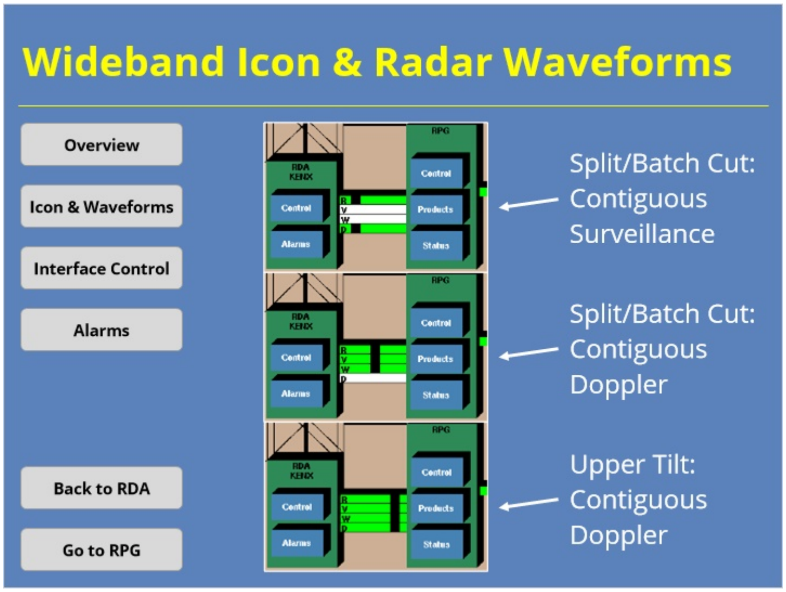
3.2 Wideband Icon & Radar Waveforms



Notes:

When you look at the RPG HCI, the icon that represents the wideband comms line also provides an indicator for what waveform the radar is currently transmitting. So, the icon will show one of three configurations. First, is the Contiguous Surveillance scan from the Split and Batch cuts where Reflectivity and Doppler data are collected. The second configuration will be for the Contiguous Doppler scan from the Split and Batch cuts where Reflectivity, Velocity, and Spectrum Width data will be collected. Lastly, is the Contiguous Doppler scan on the upper tilts where all four channels are transmitted and received simultaneously. More information on why these waveforms are important will be covered in the Range Unfolding lesson in this topic.

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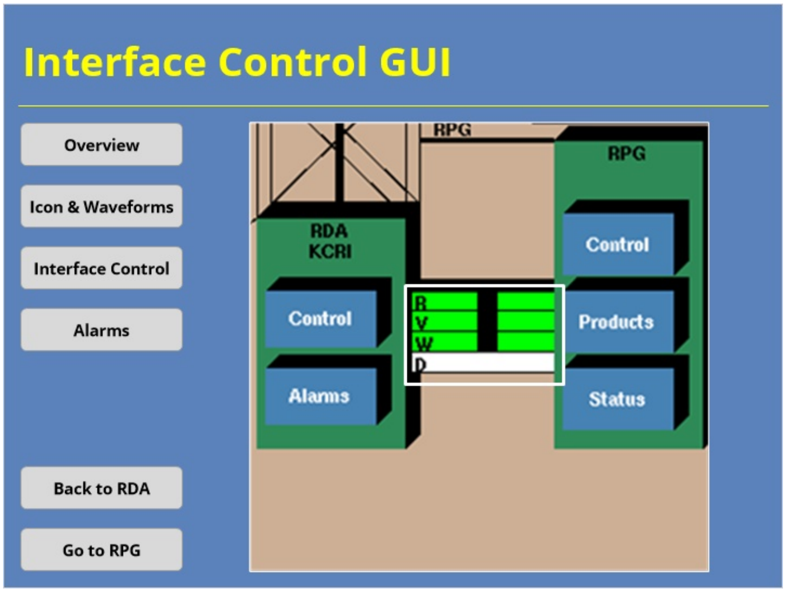
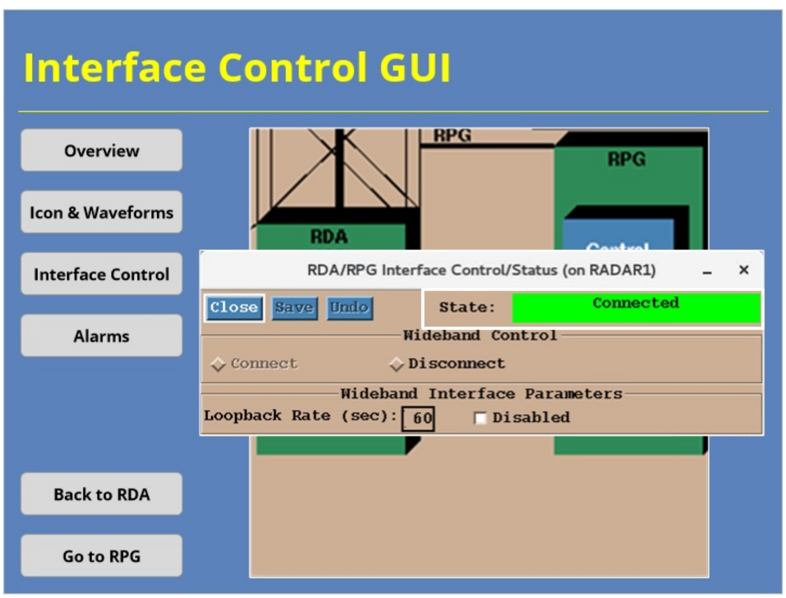
3.3 Interface Control GUI



Notes:

Clicking on the Wideband Comms icon will launch the Interface Control GUI. Click on the icon to learn more about this interface.

GUI (Slide Layer)



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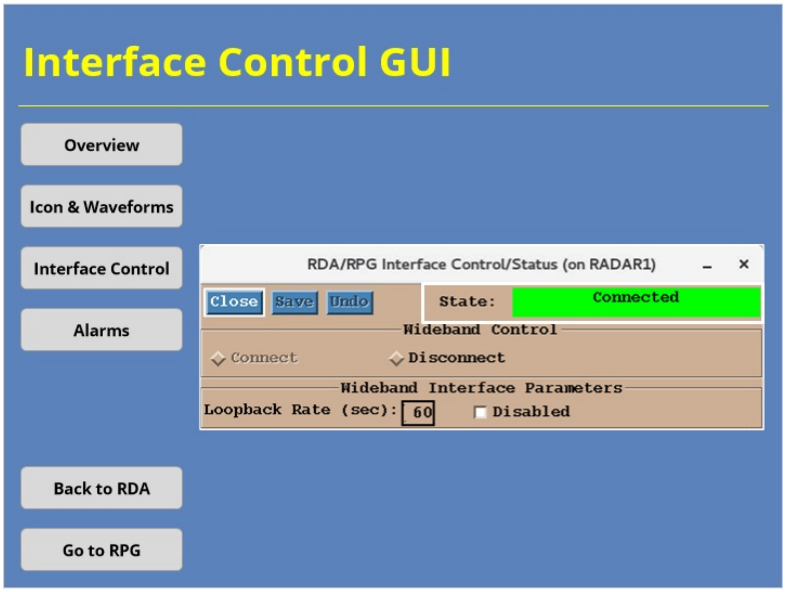
3.4 Interface Control GUI



Notes:

From this window, you can check the state of the comms line and change its status. You want the “State” field to say Connected. If it doesn’t, and your radar isn’t offline for maintenance for some reason, you can attempt to reconnect the connection from the Wideband Control panel. NOTE: Connecting and disconnecting the wideband comms should be handled by your El Tech. However, forecasters should be familiar with how to access this functionality in case they need to reactivate the connection for some reason.

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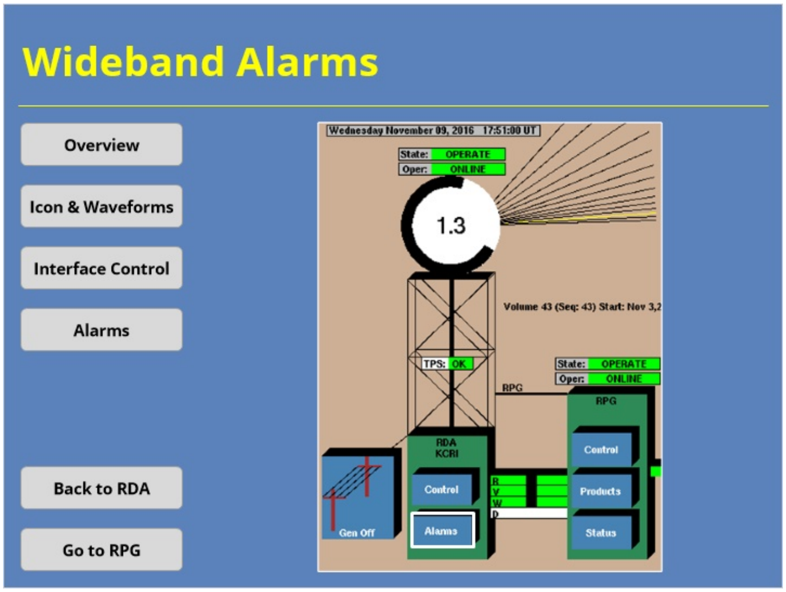
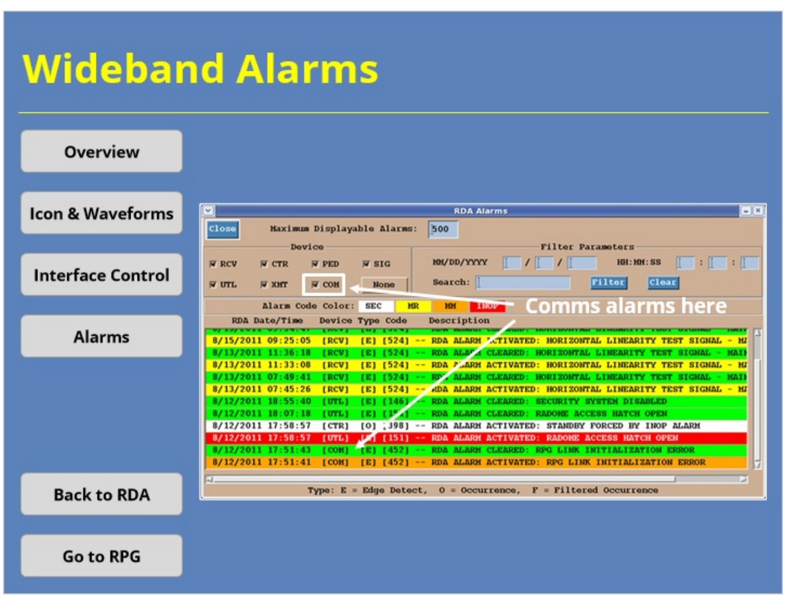
3.5 Wideband Alarms



Notes:

Alarms related to the wideband communications can be monitored from the RDA Alarms Window. Click on the RDA Alarms button to learn more about how to this task.

Alarms GUI (Slide Layer)



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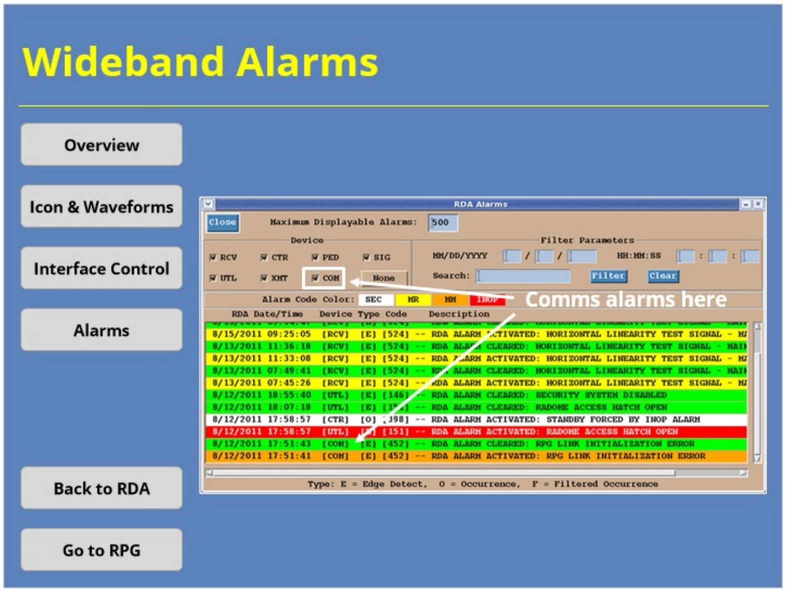
3.6 Wideband Alarms



Notes:

Alarm messages for the Wideband comms lines show up in the display window with a ”COM” designation. You can see a couple of wideband comms messages in this example. Remember how you can filter the messages by device type? Well, one of the devices you can filter by is “COM” if you are looking for wideband comms messages and don’t see one, try setting the filters in the Alarms window to display only that device. As a reminder, only the orange and red colored messages require your attention. In the example shown, a green message clears the orange colored message after a few seconds. So, all is good with the Wideband comms.

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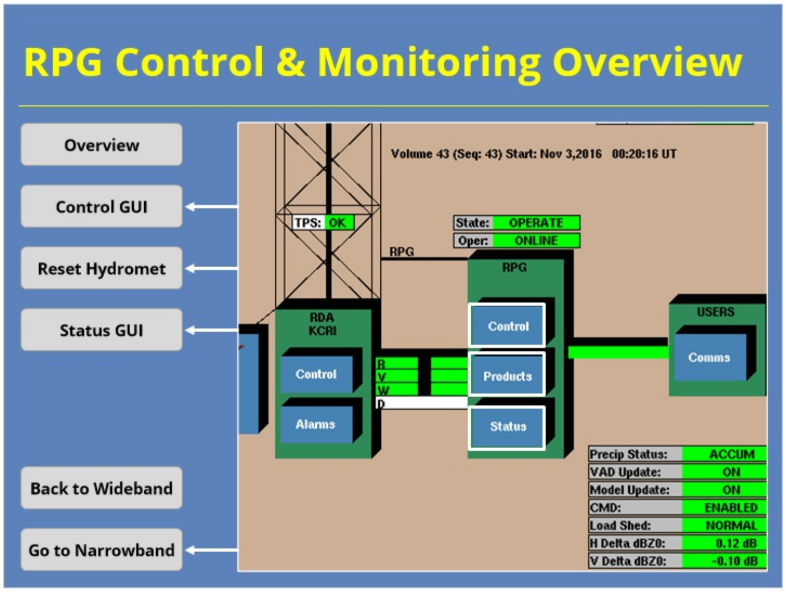
4. RPG Tasks

4.1 RPG Control & Monitoring Overview



Notes:

We will look at the RPG next. The RPG icon on the HCI provides radar operators three buttons and some indicators to control and monitor this component. The Products button provides access to the product generation list and adaptable parameters, among other things, and is outside the scope of this lesson. We will focus on the Control and Status buttons here. Use the buttons on the left-hand side of the slide to navigate between these sections. Once you have viewed all of these topics, click on the “Go to Narrowband” button on the slide to advance to the next section of the course.

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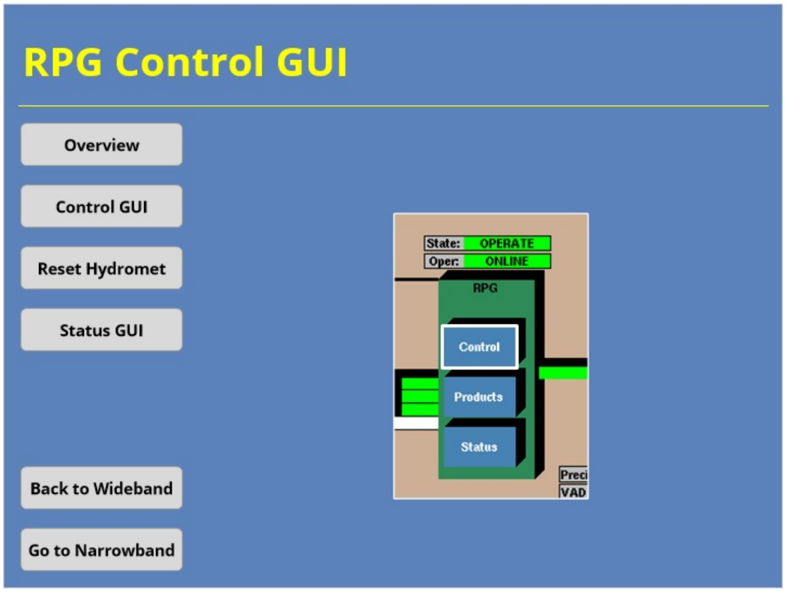
4.2 RPG Control GUI



Notes:

Clicking on the “Control” button on the RPG icon opens the RPG Control Window. This GUI controls the basic functions of the RDA. Click on the Control button on the image to learn more about the GUI.

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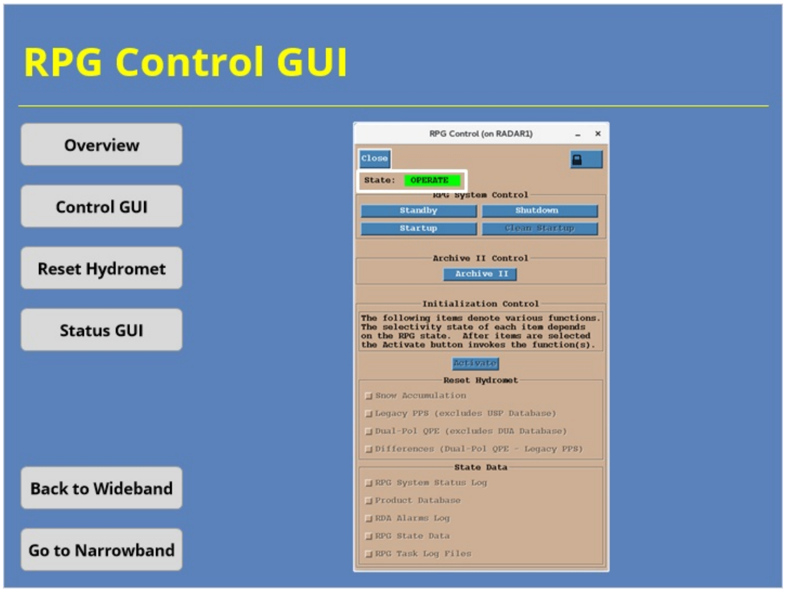
4.3 RPG Control GUI



Notes:

The RPG Control GUI shows you the current state of the RPG and provides some basic user controls. The RPG State should say “Operate” if everything is working normally. If it doesn’t (and you don’t know of maintenance being done on the system), you should mention this information to your radar focal point, El Tech, or shift supervisor.

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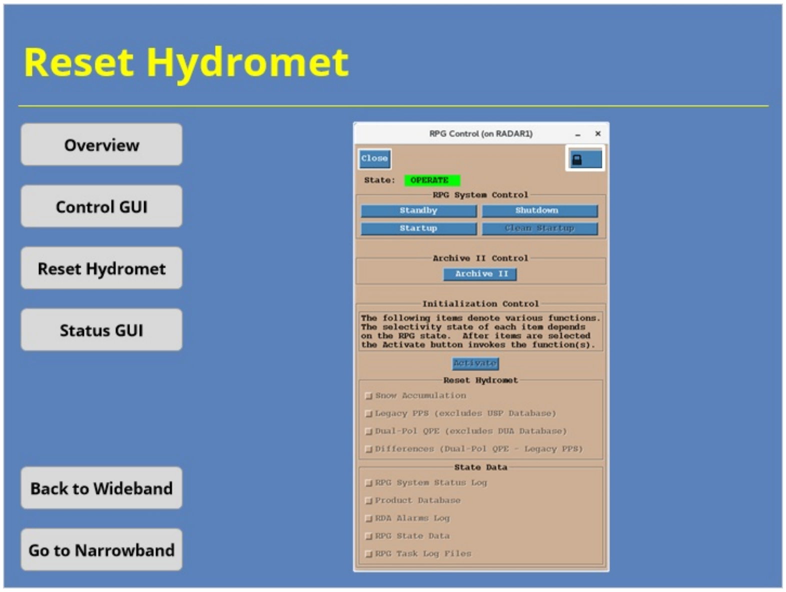
4.4 Reset Hydromet



Notes:

Occasionally, radar operators must manually reset the hydrometeorological data at the RPG. This task is performed at the RPG Control GUI. To perform this task, first you must unlock the GUI. Click the lock button in the upper right-hand corner of the image to proceed.

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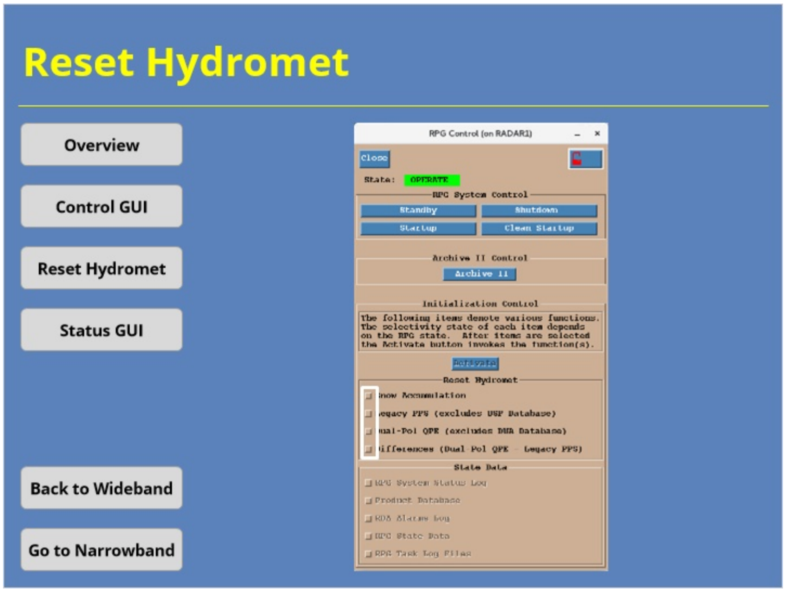
4.5 Reset Hydromet



Notes:

Once unlocked, you can now toggle on the parameters in the Reset Hydromet panel. If you need to manually reset one of these parameters, it's generally a good idea to reset all of them. Click on one of the toggle button in the Reset Hydromet panel to move to the next step.

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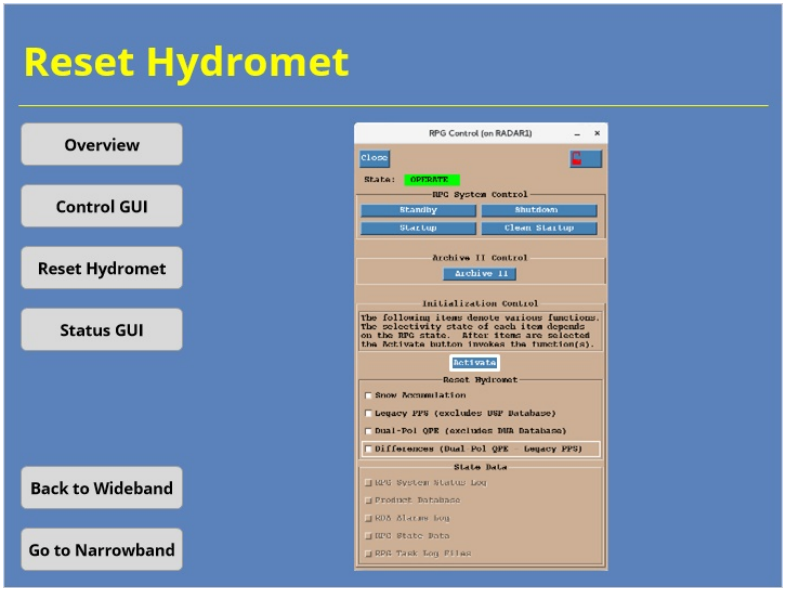
4.6 Reset Hydromet



Notes:

Once all the buttons have been toggled on, you click the Activate button to reset all of these variables back to zero. Click on the “Activate” button to get to the last step.

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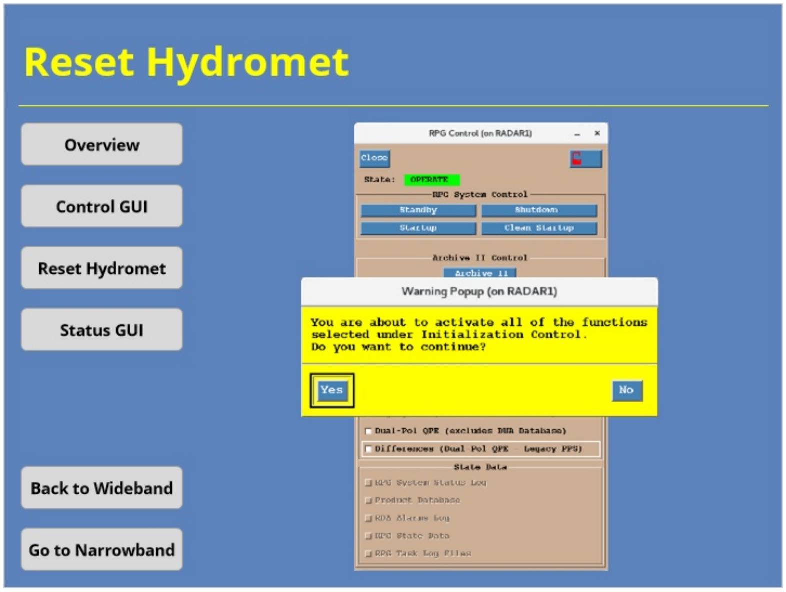
4.7 Reset Hydromet



Notes:

You'll see a warning message like this one when you activate the reset. Just click Yes, and everything will be reset for the next volume scan. To understand why you might need to reset these parameters, check out the precipitation lessons later in this topic.

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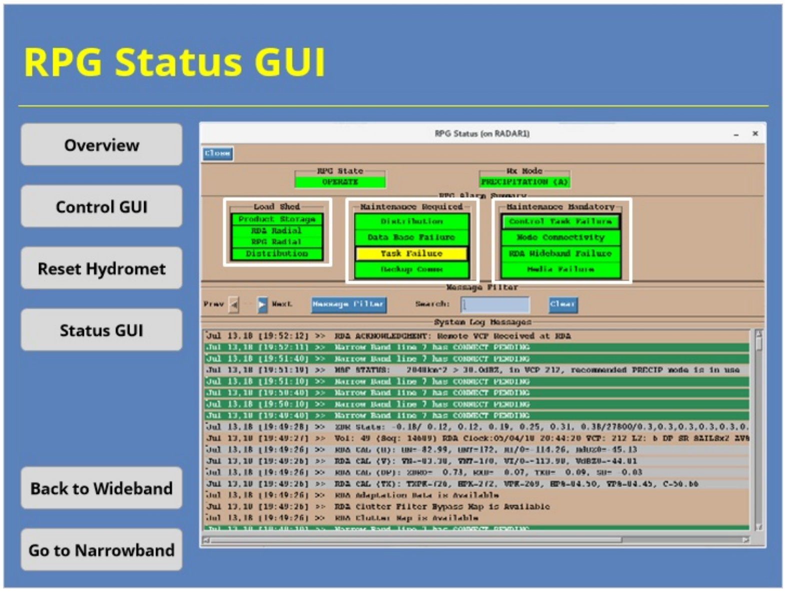
4.8 RPG Status GUI



Notes:

The RPG Status GUI allows users to monitor status messages and alarms. There's information on the RPG State and Weather mode, as well as a variety of status messages. The RPG Alarm Summary panel groups RPG alarms into three categories: Load Shed, Maintenance Required, and Maintenance Mandatory. Load shedding alarms are usually less critical than the others. However, if consistent load shedding errors appear, forecasters should investigate further.

Unless they clear automatically in a short period of time, Maintenance Required and Maintenance Mandatory alarms do require users to take action. Just in case you are wondering, mandatory alarms are more time sensitive than required alarms. These alarms usually relate to RPG software issues. Common issues include a backlog of products, improper generation of products and connectivity issues.

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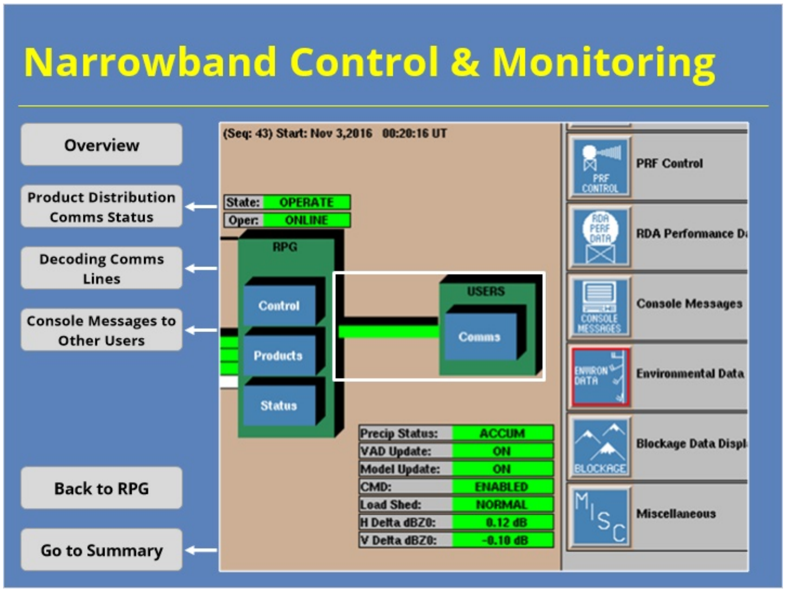
5. Narrowband/User Tasks

5.1 Narrowband Control & Monitoring



Notes:

The last icons we will look at involve the Narrowband (or Product Distribution) communications lines and related communications with other users. The "narrowband" moniker dates back to when these connections were significantly narrower in bandwidth than the wideband comms lines. Use the buttons on the left-hand side of the slide to navigate between these sections. Once you have viewed all of these topics, click on the "Go to Summary" button on the slide to advance to the next section of the course.

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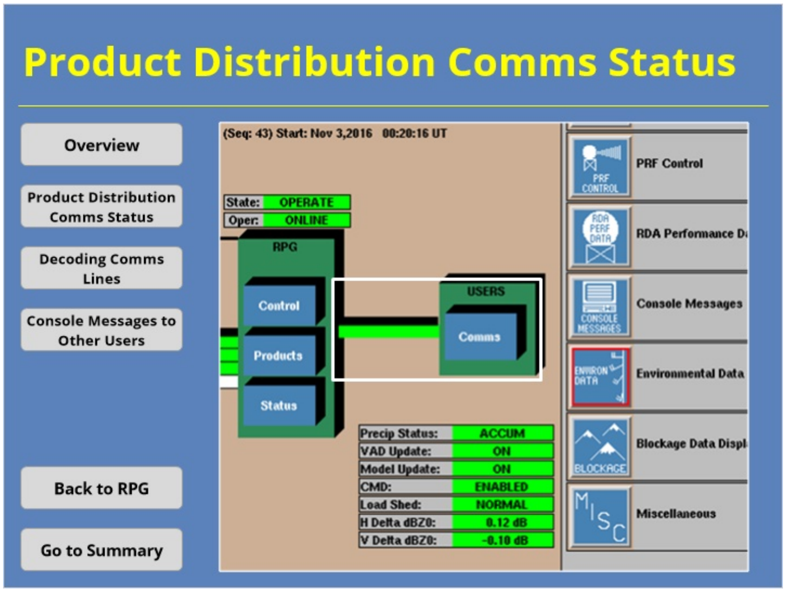
5.2 Product Distribution Comms Status



Notes:

The Product Distribution Comms Status window can be accessed by clicking on either the ”Comms” button on the Users icon or the green connection line between the RPG and Users icons. Click on that button to learn more about this GUI.

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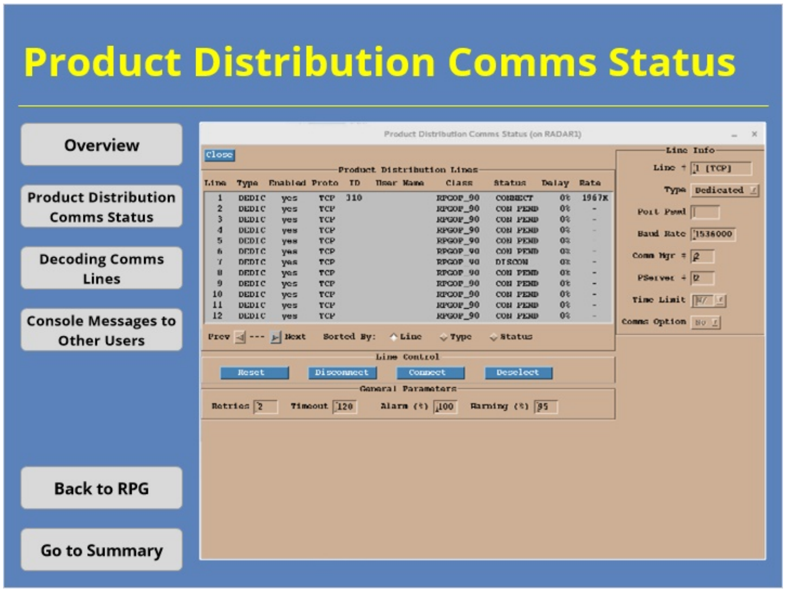
5.3 Product Distribution Comms Status



Notes:

This window shows all of the connection lines available to users and their current status. Your Radar Program leader should have a list of dedicated users who have a pre-defined line on this display. Other users will access the RPG via dial-up or wide area network (or WAN) connections.

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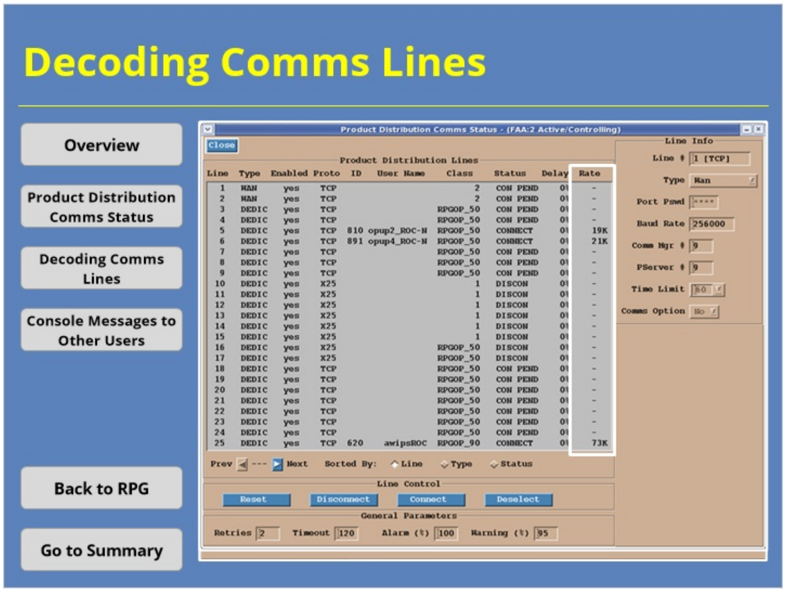
5.4 Decoding Comms Lines



Notes:

The Production Distribution Comms Status display can help you troubleshoot connection issues for other users and should be monitored routinely as part of your shift. If another user has a connection issue, the status should say “DISCON” for disconnected or “COM PEND” for connection pending. Not every line with these states is a problem, though. Another column that can help is Rate. This column shows you the bandwidth available for product transfer. This screenshot is from our local network, so 2 MB/s is a little more bandwidth than you’re likely to see. Here’s another example with more representative rates. Earlier we mentioned that load shedding alarms are less critical than other alarms at the RPG, but investigate them if they persist. You can investigate these issues by monitoring the connection rate here and compare to the user’s product list. Solutions include having the user reduce the number of products requested or possibly using a different connection line.

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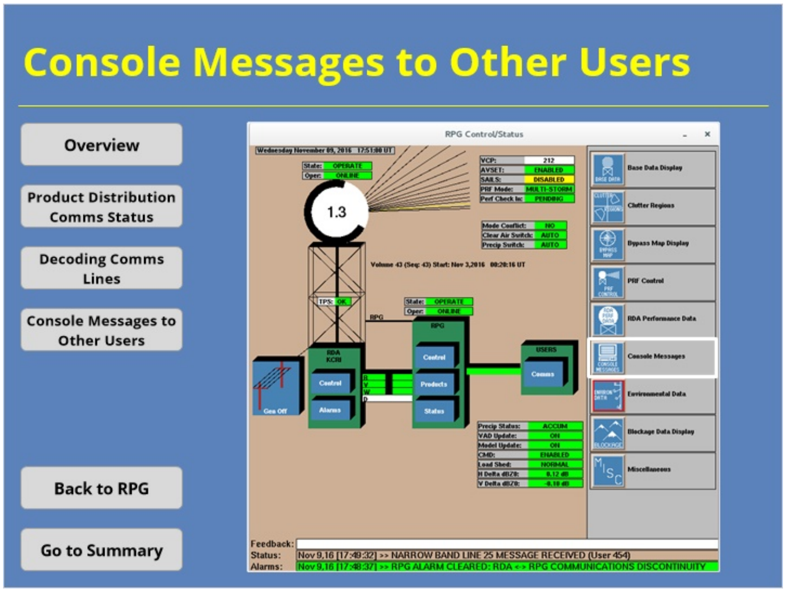
5.5 Console Messages to Other Users



Notes:

The Console Message window can be accessed by clicking on the “Console Messages” button from the list of buttons on the right-hand side of the RPG HCI. Click on that button to learn more about this GUI.

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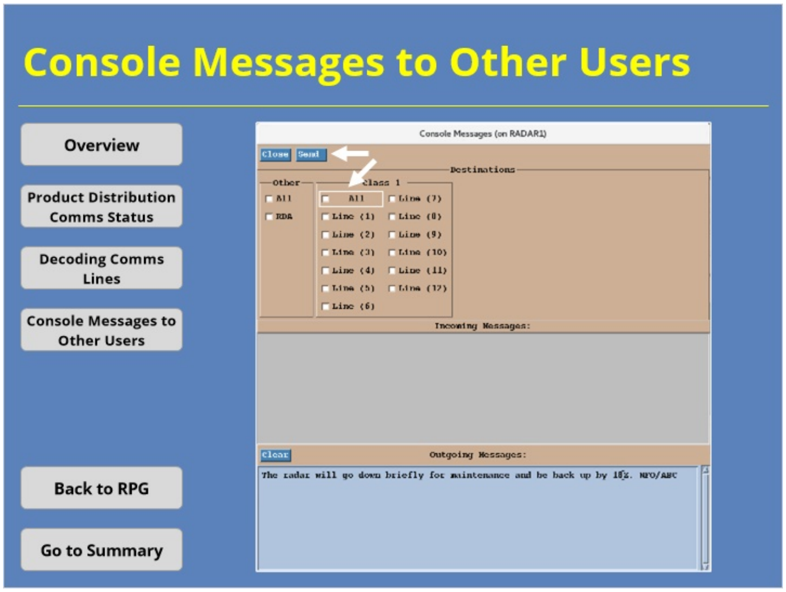
5.6 Console Messages to Other Users



Notes:

When a change in the radar's operating status occurs (or is observed if unplanned), you should notify all radar users of the change as a best practice. A quick way to notify users involves sending a Free Text message product, or FTM. These messages can be generated from this GUI. Generally speaking, you will want to send the FTM to all users if there's an issue. So, choose the "All" checkbox before clicking the "Send" button. When the message is sent, you will not see anything happen on your end. However, you can view the FTM product in an AWIPS test editor window. In fact, we recommend you do just that to ensure the message got sent.

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6. Summary & Quiz

6.1 RPG HCI Controls Summary

RPG HCI Controls Summary

- RPG HCI related components:
  - icons
  - buttons
  - indicators
- Basic control & monitoring at:
  - RDA
  - Wideband
  - RPG
  - Narrowband
- Specific tasks:
  - Manual system performance check
  - Monitor alarm messages
  - Send Free Text Messages

Notes:

During this lesson, we discussed how radar operators can use the RPG HCI to monitor and control the components of the WSR-88D system. We identified the different icons, buttons, and indicators on the RPG HCI related to those components. We looked at some basic control and monitoring functions you can perform for the RDA, wideband communications lines, the RPG, and the product distribution (or narrowband) comms lines. Examples of some of those specific tasks include initiating a manual system performance check, looking at alarm messages for both the RDA and RPG, and sending a Free Text Message to communicate the radar operating status to other users.

Once you are ready to take the quiz, click on the next button below to proceed.

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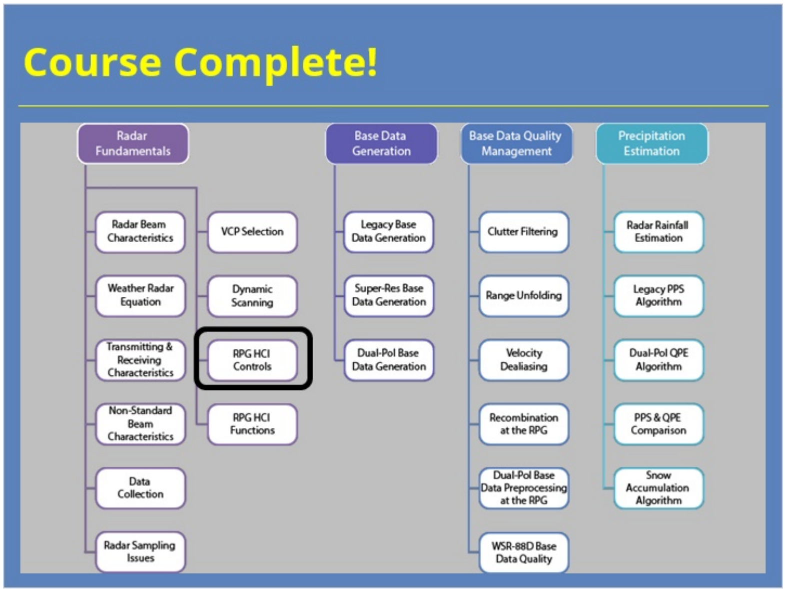
6.9 Course Complete!



Notes:

You have successfully completed this course. You can look over the roadmap on the slide to see what courses remain in this topic or you can click the Exit button to close the window and record your completion.

RPG HCI Functions

1. Radar Reflectivity Signatures

1.1 Untitled Slide

Notes:

Welcome to this lesson on Radar Product Generator (or RPG) Human Control Interface (or HCI) Functions, which is a part of the Principles of Radar topic in RAC. This lesson will discuss some of the core functionality that the RPG HCI provides radar operators. Let's begin!

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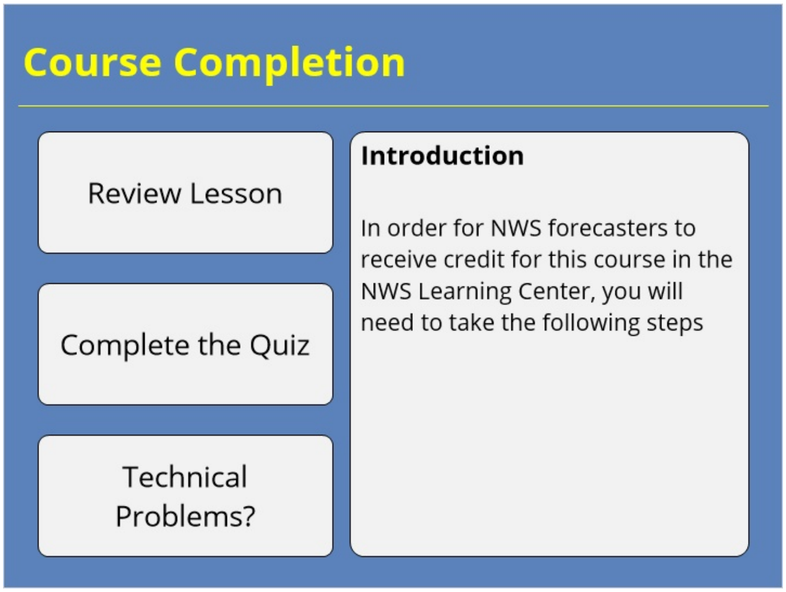
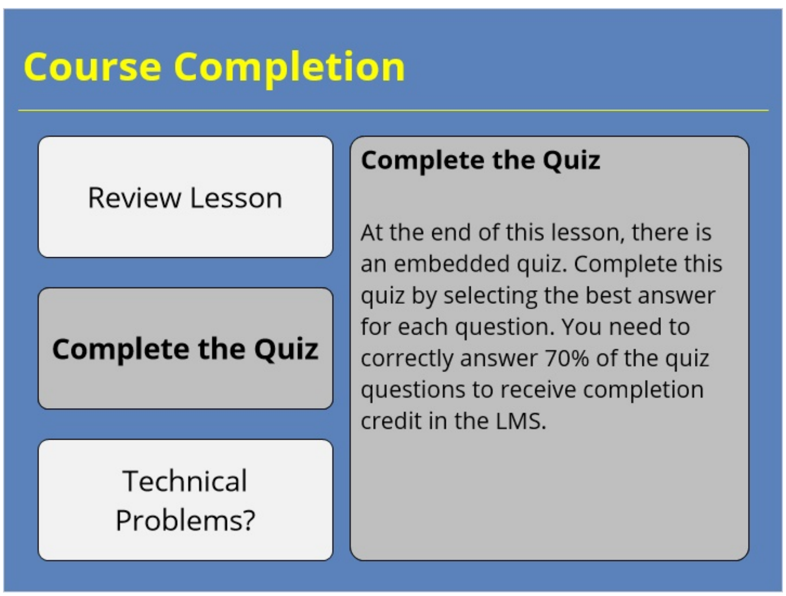
1.2 Course Completion



Complete the Quiz (Slide Layer)



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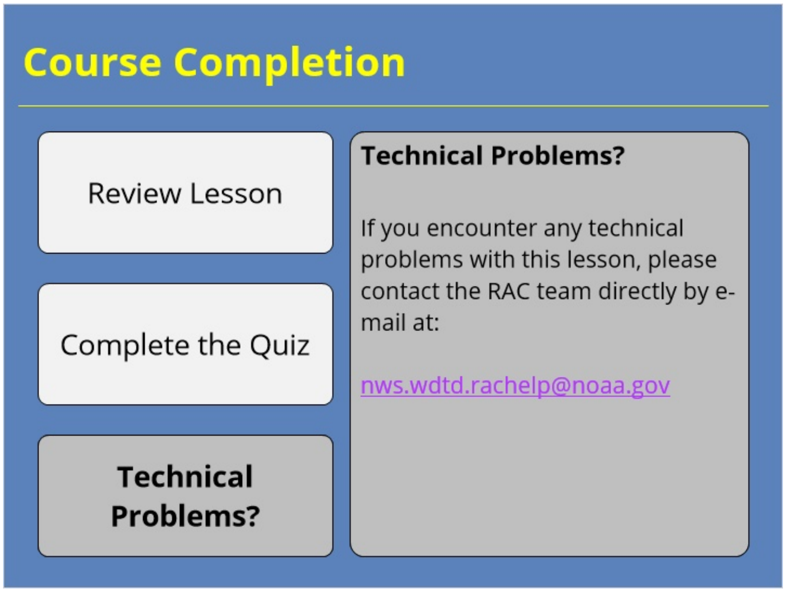
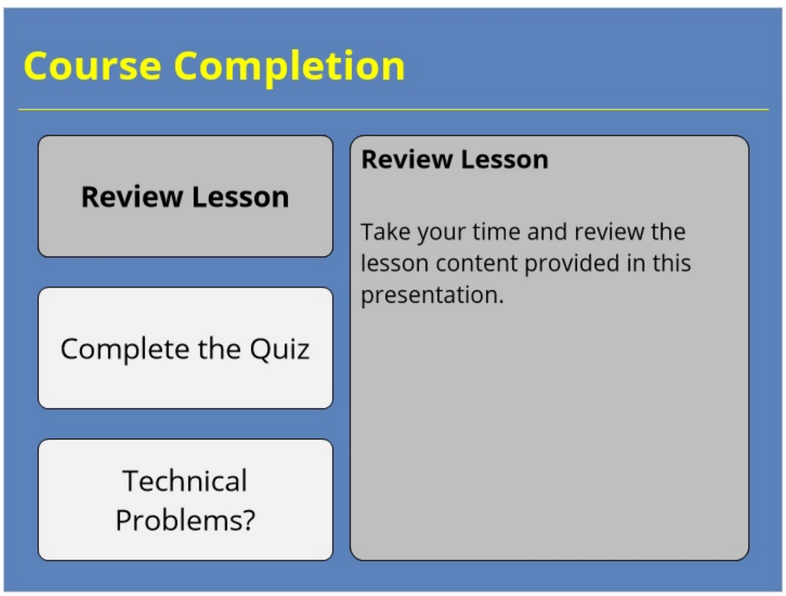
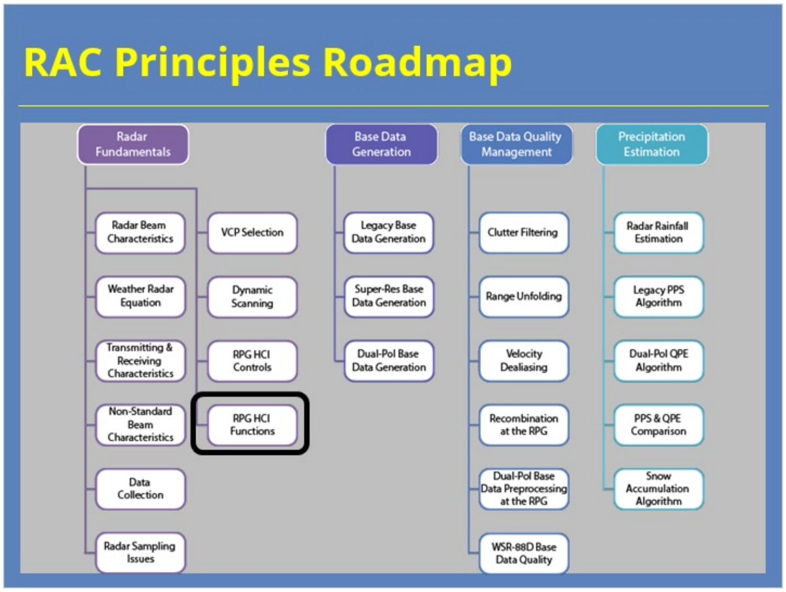
Technical Problems (Slide Layer)



Review Lesson (Slide Layer)



1.3 RAC Principles Roadmap



Notes:

Here is a roadmap for the RAC Principles topic. This lesson, which is part of the Radar Fundamentals section, is highlighted. Once you have had a chance to look over the roadmap, advance to the next slide.

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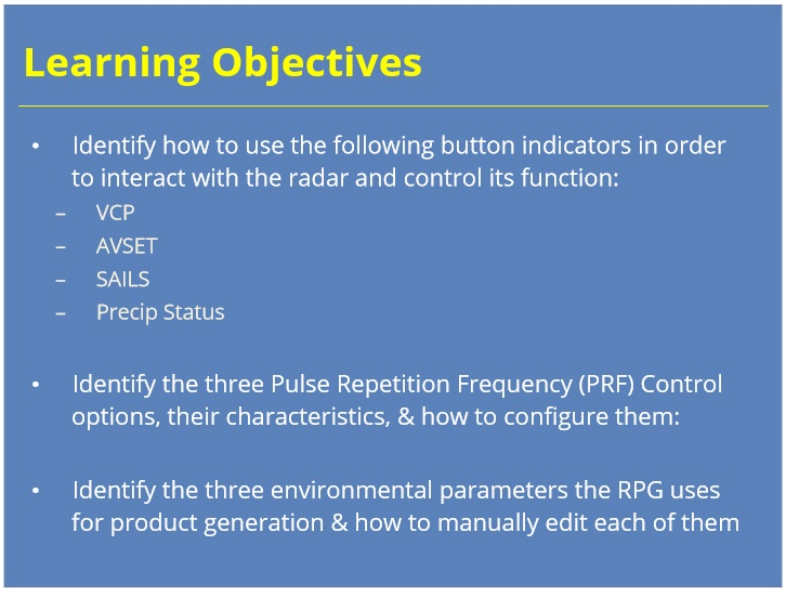
1.4 Learning Objectives



Notes:

Here are the learning objectives for this lesson. Please take a moment to look them over and then advance to the next slide when you are ready.

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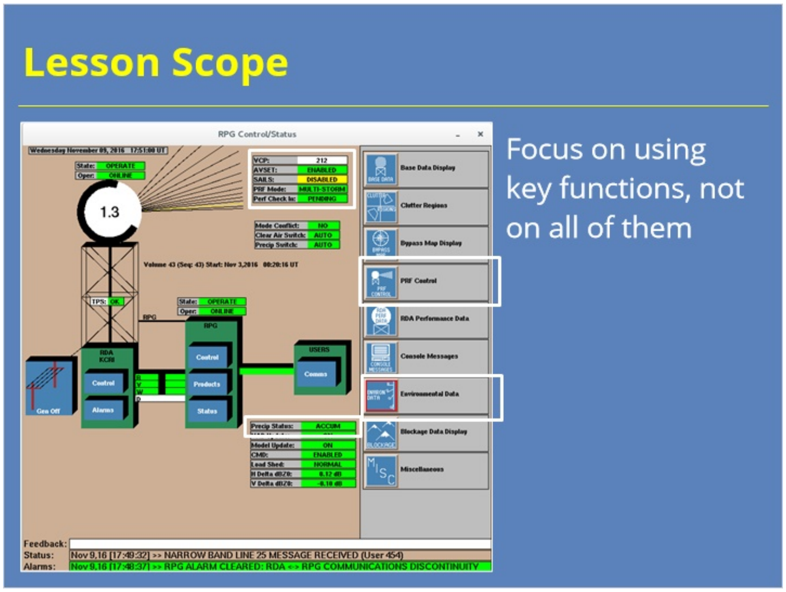
1.5 Lesson Scope

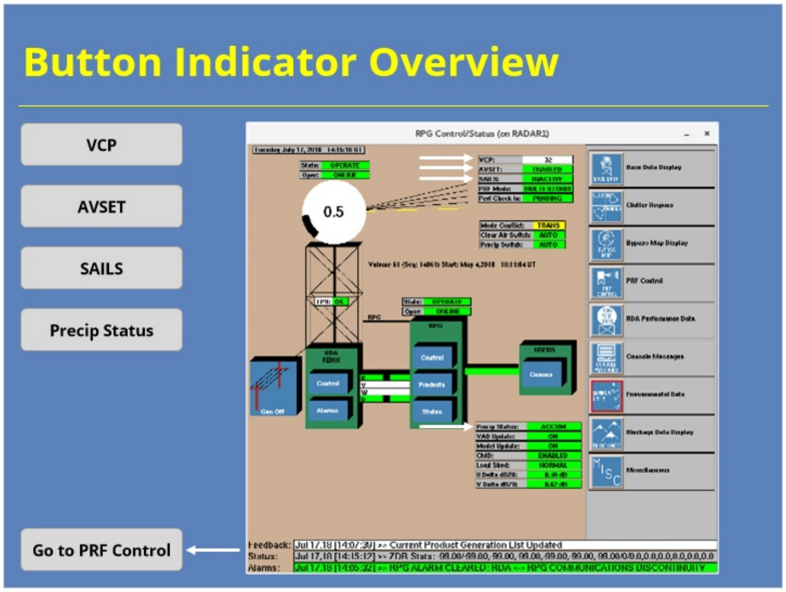


Notes:

Just as with the RPG HCI Control & Monitoring lesson, this lesson has a limited scope. I will not be teaching you how to perform every possible function at the RPG HCI. Instead, I will focus on key functions related to the learning objectives you just read. If you can perform these tasks, in conjunction with what is discussed in the rest of this topic, it will allow you to operate the WSR-88D effectively. So, let’s get started.

2. Key Button Indicators

2.1 Button Indicator Overview



Notes:

We will start our discussion of RPG HCI functions by focusing on some of the most used button indicators on the main display. These are VCP, AVSET, SAILS, and Precip Status. Use the buttons on the left to learn more about how to use each of these buttons to interact with the radar and control its function. Once you are done, click on the Go to PRF Control button to advance to the next section.

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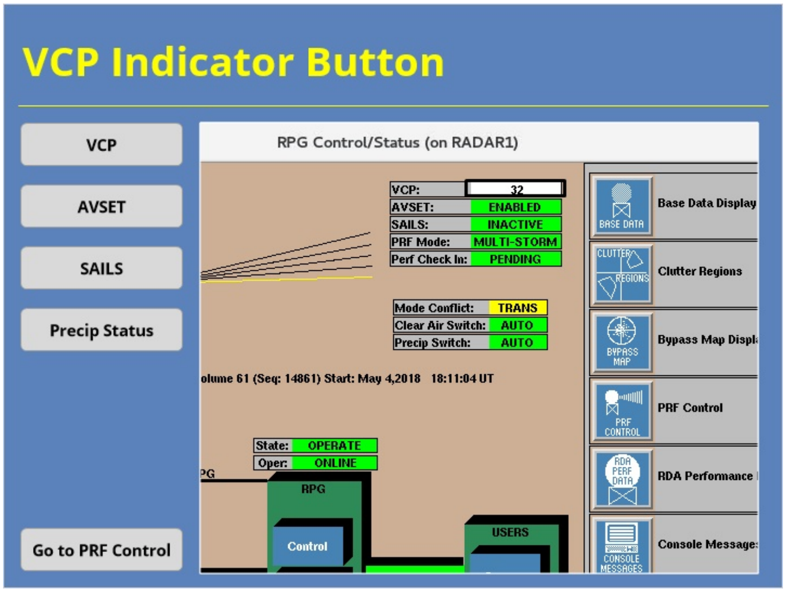
2.2 VCP Indicator Button



Notes:

The first indicator button we'll discuss is for the current volume coverage pattern (or VCP) in use. In the example shown, it indicates the current VCP is 32. Clicking on the button brings up the window where you can edit the settings for default VCPs or even manually change the VCP. Click on the VCP indicator button to learn more.

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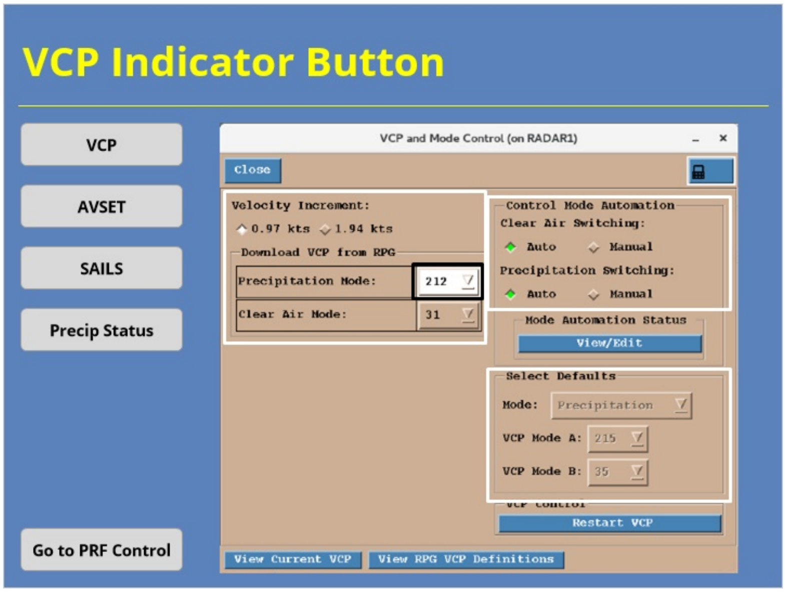
2.3 VCP Indicator Button



Notes:

The VCP and Mode Control window gives the radar operator several options. Radar operators should leave the options on the right alone as they both fall under the purview of the radar focal point (who coordinates with your local radar committee). However, the panel on the left side is significant to you. Here's where you can manually choose which VCP to use for the next volume scan. To see how this works, click on the button labeled "212" next to the Precipitation Mode label.

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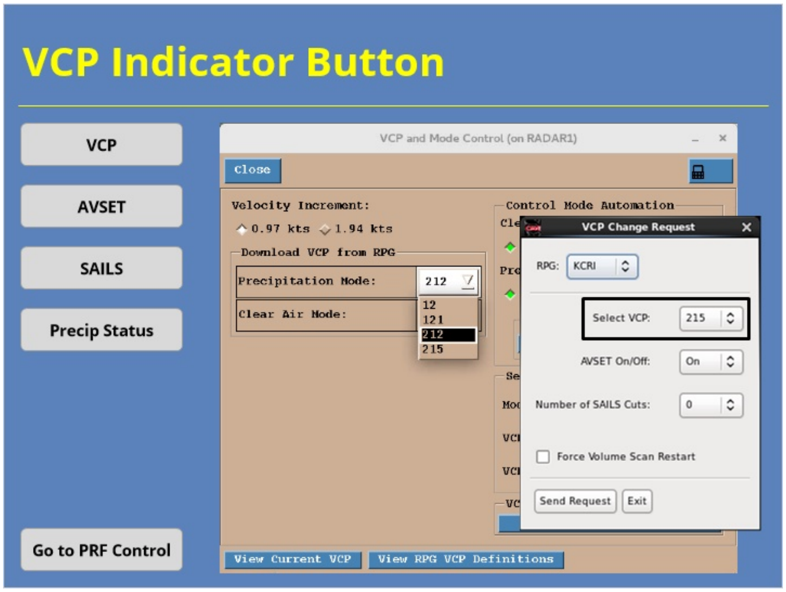
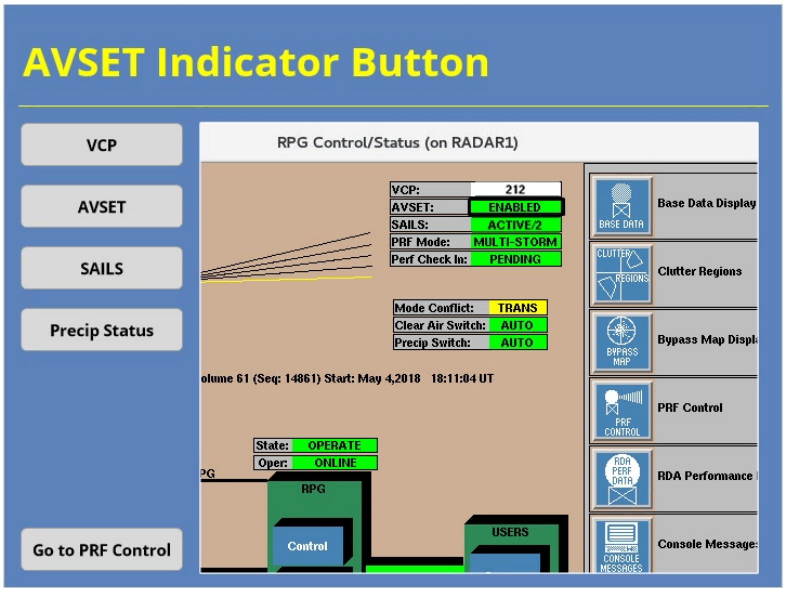
2.4 VCP Indicator Button



Notes:

Clicking on this button displays a pull-down menu where you can choose a different VCP for the next volume scan. This same step can be performed at your AWIPS workstation, too. Just remember that, if you have automatic mode selection turned on, that manually switching from a clear air to precip VCP may result in the radar switching back to the default clear air VCP if the areal coverage criteria for precip mode isn't met in the near future.

2.5 AVSET Indicator Button



Notes:

The next indicator button we'll discuss involves the Automated Volume Scan Evaluation and Termination applications better known as AVSET. Details on AVSET and how it works can be found in the Dynamic Scanning lesson of this course. In the example shown, AVSET is enabled, and that's the default setting. The indicator will say enabled even if you're currently in a Clear Air mode VCP. Clicking on the button brings up the window where you can toggle AVSET on and off. Click on the AVSET indicator button to learn more.

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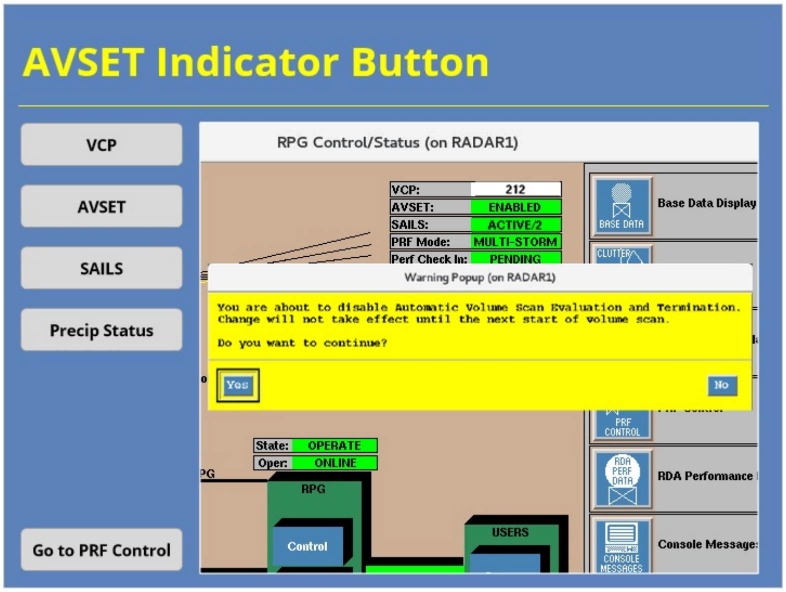
2.6 AVSET Indicator Button



Notes:

So, using the indicator button will return a warning popup like you see here. Clicking the "Yes" button will make the change you requested. NOTE: Unless you are encountering a significant problem related to high altitude ground clutter contaminating your base data (which is pretty rare) or experiencing elevated convection near the RDA, we recommend that you leave AVSET turned on.

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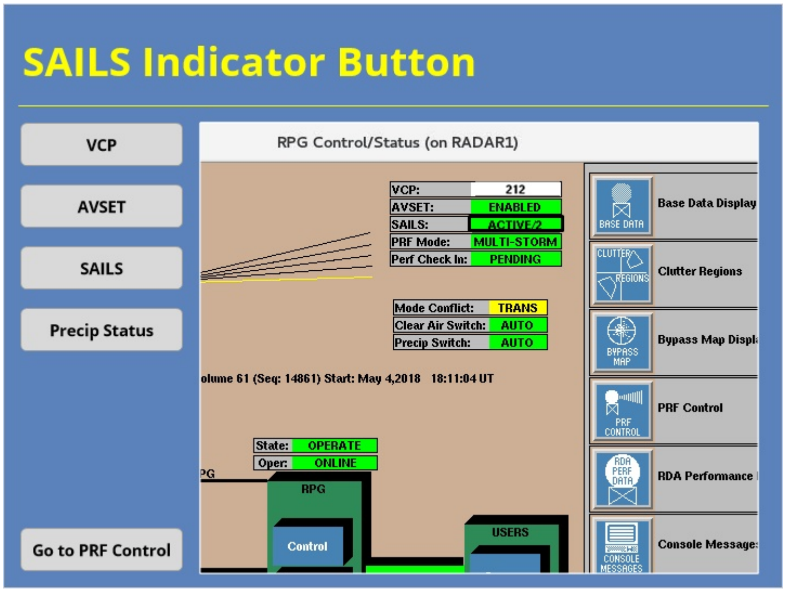
2.7 SAILS Indicator Button



Notes:

Next, we'll discuss the indicator button for the Supplemental Adaptive Intra-Volume Low-Level Scan (or SAILS). Details on SAILS and how it works can be found in the Dynamic Scanning lesson of this course. In the example shown, SAILS is active with two additional low-level tilts selected. Clicking on the button brings up the window where you can choose the number of SAILS tilts you want included in the next volume scan. Click on the SAILS indicator button to learn more.

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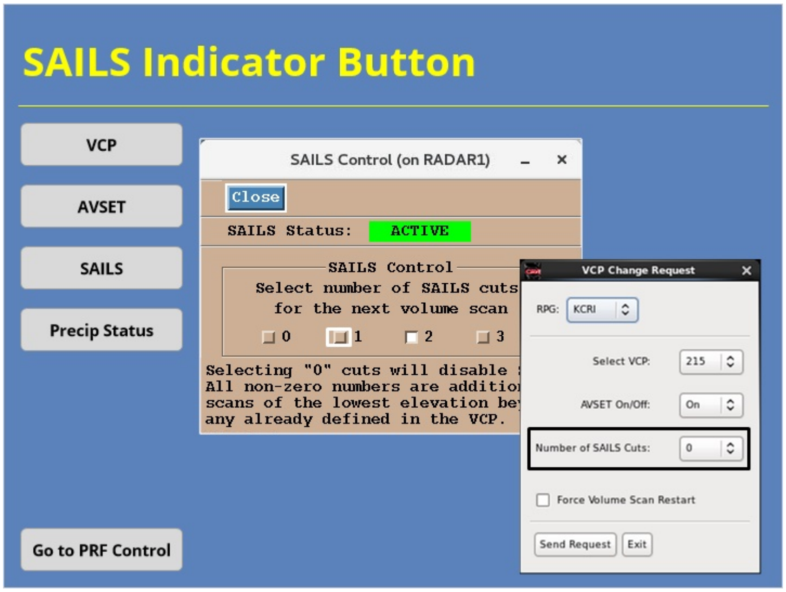
2.8 SAILS Indicator Button



Notes:

The SAILS Control GUI gives the radar operator the choice between 0 and 3 additional low-level cuts on SAILS enabled VCPs. You can also make this change at your AWIPS workstation using the VCP Change Request GUI. To see what happens if you want to change the number of SAILS tilts to 1, click on the checkbox next to the number 1 in the SAILS Control GUI.

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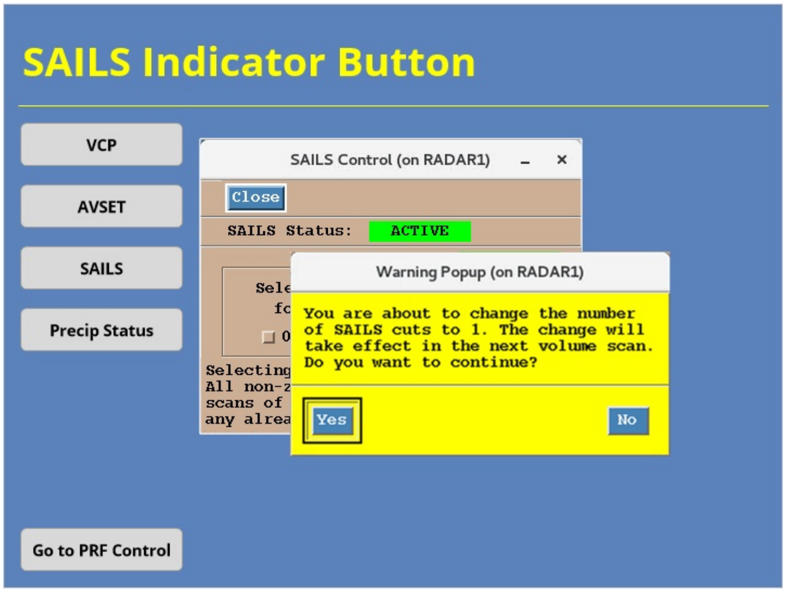
2.9 SAILS Indicator Button



Notes:

Choosing the “1” checkbox results in the following Warning Popup. Clicking “Yes” will put the change into place on the next volume scan.

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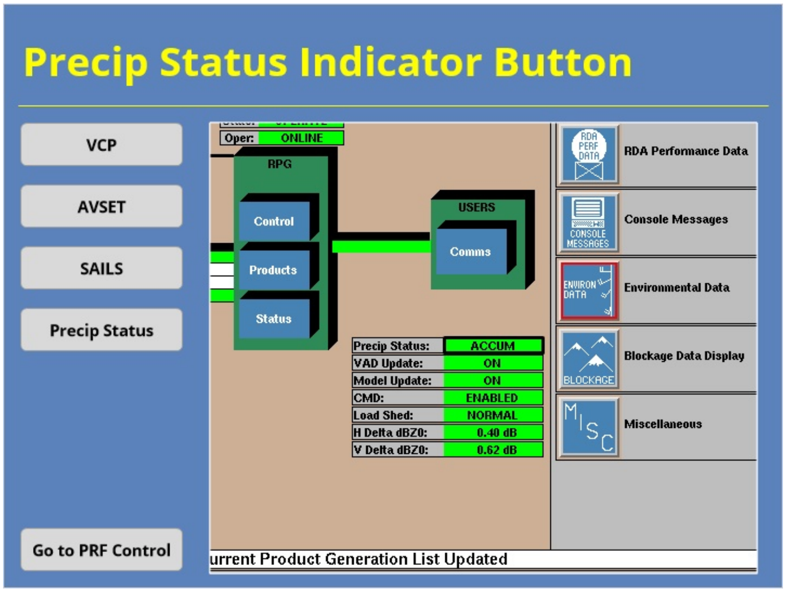
2.10 Precip Status Indicator Button



Notes:

The last indicator button we'll discuss is the Precip Status button. The indicator gives the radar operator insight into whether the algorithms are accumulating precipitation. Remember that the algorithm can accumulate precipitation even if the current VCP is for clear air. Click on the Precip Status indicator button to learn more.

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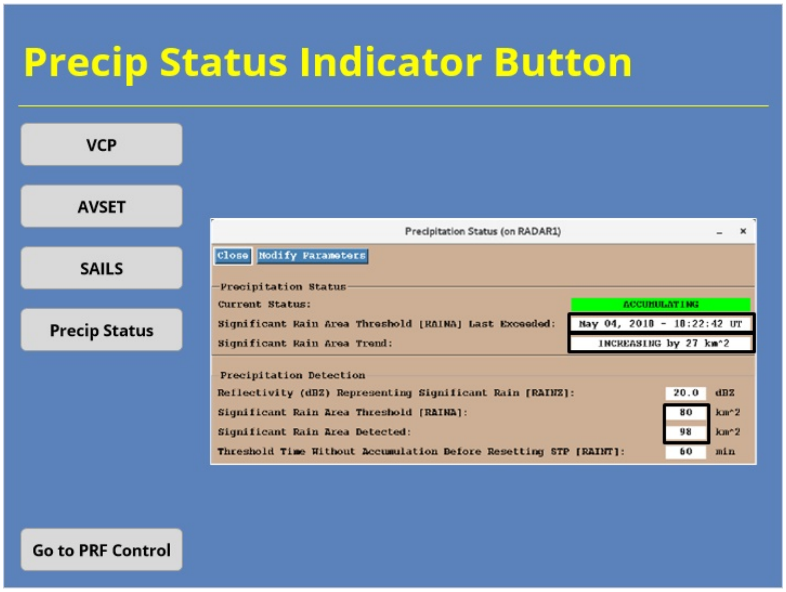
2.11 Precip Status Indicator Button



Notes:

The Precipitation Status GUI provides some important details related to precipitation accumulation. Besides reiterating the accumulation status, you can see the some key variables related to that status…at least for the legacy Precipitation Processing System algorithm. For instance, you can see when the rain area threshold was last exceeded, what the trend is for that area, and what that area is and how it compares to the threshold. So, in a quick glance, you can see some important parameters for why the algorithm is doing what it's doing. You will learn more about the WSR-88D precipitation algorithms later in this topic.

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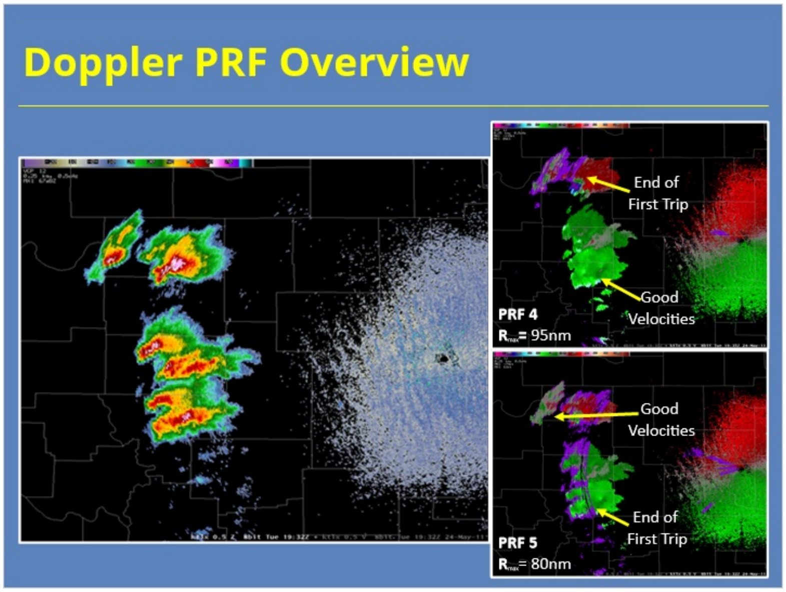
3. PRF Control

3.1 Doppler PRF Overview



Notes:

The WSR-88D gives the radar operator different ways to mitigate the impacts of range folded velocity data. The Range Unfolding lesson will discuss this topic in more detail. What you need to know right now is you have several options to choose from when deciding how to reduce range folded data on velocity products. Contiguous Doppler scans have five different Doppler PRFs available. Each PRF has a different maximum unambiguous range (or R_{max}). So, changing the PRF can move the end of the first trip to specifc values between 65 and 95 nm, depending on the PRF selected. Adjusting R_{max} can help as echoes just beyond the first trip are often susceptible to range folding. The only VCPs that don't allow the PRF to change are VCPs 121 and 31.

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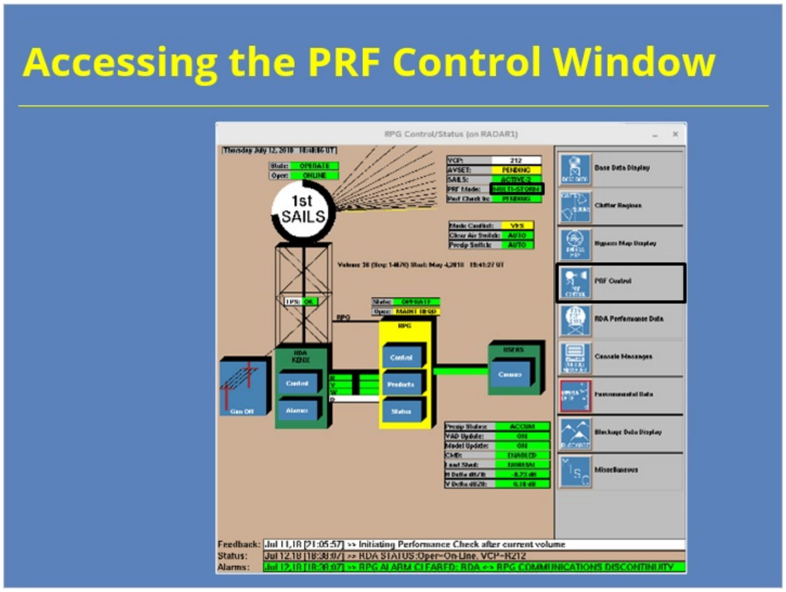
3.2 Accessing the PRF Control Window



Notes:

You can access the PRF Control window in two different ways from the RPG HCI. On the main part of the display, there is a button indicator labeled PRF Mode. Clicking on the indicator for that parameter will launch the window. You can also get there by clicking on the larger PRF Control button on the right-hand side of the HCI. Click on one of these buttons to learn more about the PRF Control window.

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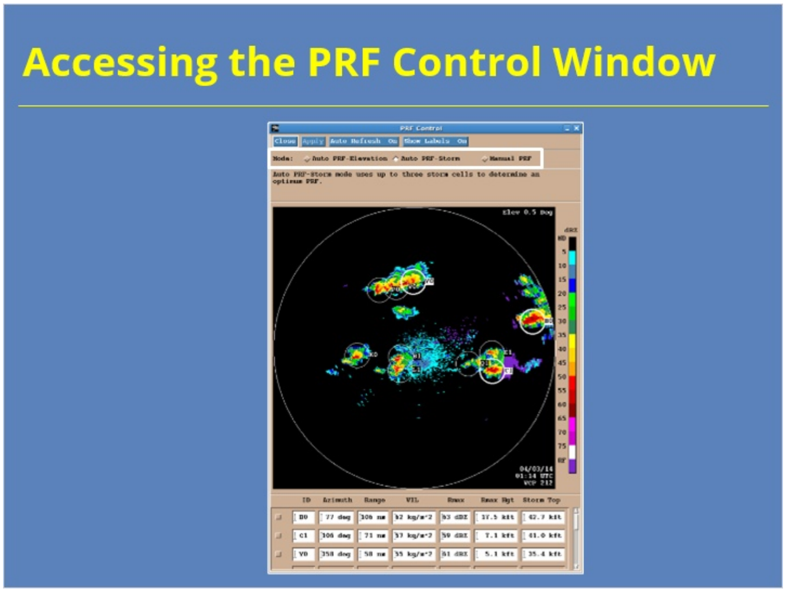
3.3 Accessing the PRF Control Window



Notes:

At the PRF Control Window, you can determine which of the three available modes you want to use to determine the optimum PRF. These three methods are Auto PRF - Elevation, Auto PRF - Storm, and Manual PRF. The next few slides will discuss these three options in more detail.

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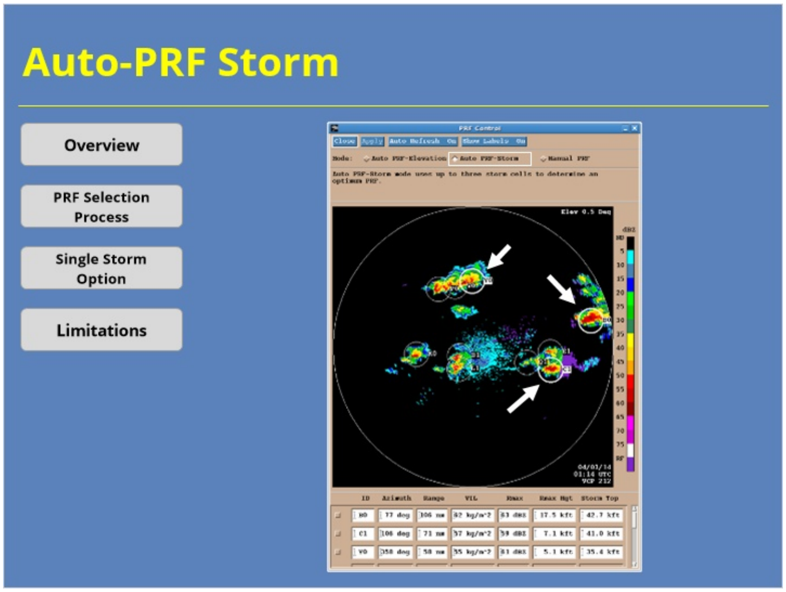
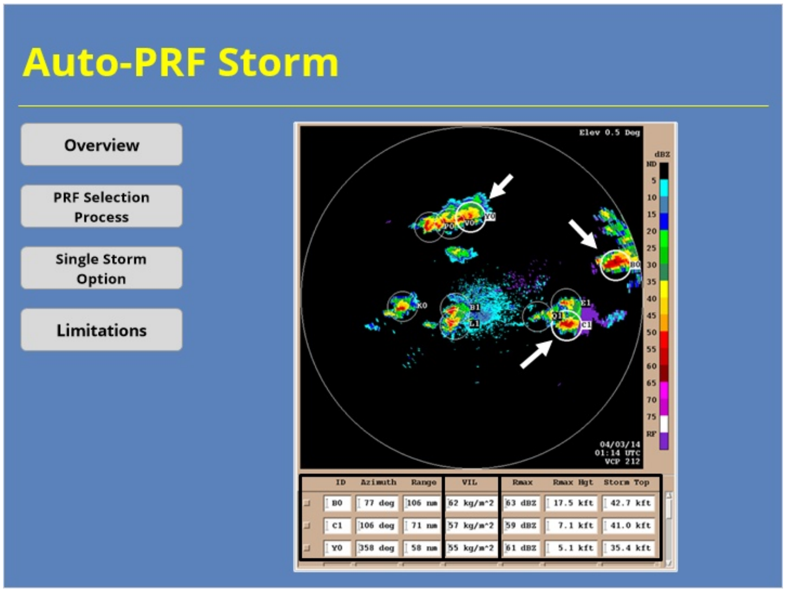
3.4 Auto-PRF Storm



Notes:

We'll start by discussing Auto PRF - Storm as it is the default setting. Auto PRF - Storm works to minimize the range folded data for the three strongest cells as determined by the Storm Cell Identification and Tracking (or SCIT) algorithm. You'll learn more about SCIT in the Base and Derived Products topic of this course. Click on the PRF Selection Process button to learn more about how this application works.

3.5 Auto-PRF Storm



Notes:

Auto PRF - Storm determines which storms are the strongest by using the cell-based Vertically Integrated Liquid (or VIL) values from SCIT. These storms are identified in the PRF Control window by a white circle and their SCIT cell ID. More information about these storms can be found in the table at the bottom of the window. The circle has a 20 km radius around the storm centroid, and that area is what the RPG will use to minimize the range folded data when choosing a PRF. This process occurs on every volume scan. Click on the Single Storm Option button to learn about the Auto PRF - Storm single storm option.

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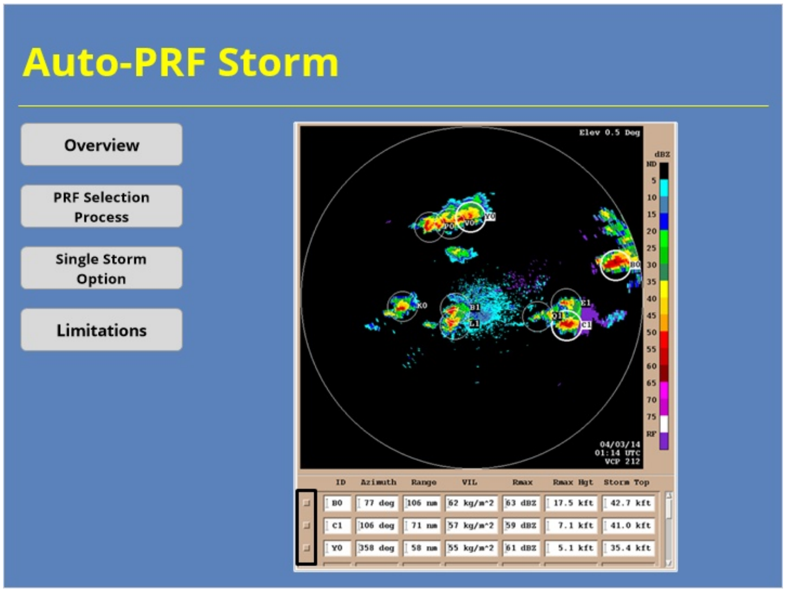
3.6 Auto-PRF Storm



Notes:

You have the option with Auto PRF - Storm to minimize range folding for a specific storm. This single storm option can be invoked by clicking on the check box next to that storms SCIT cell ID in the table at the bottom of the window. The storm you choose doesn’t even have to be one of the three strongest storms. Click on the Limitations button to learn about some of the limitations of Auto PRF - Storm.

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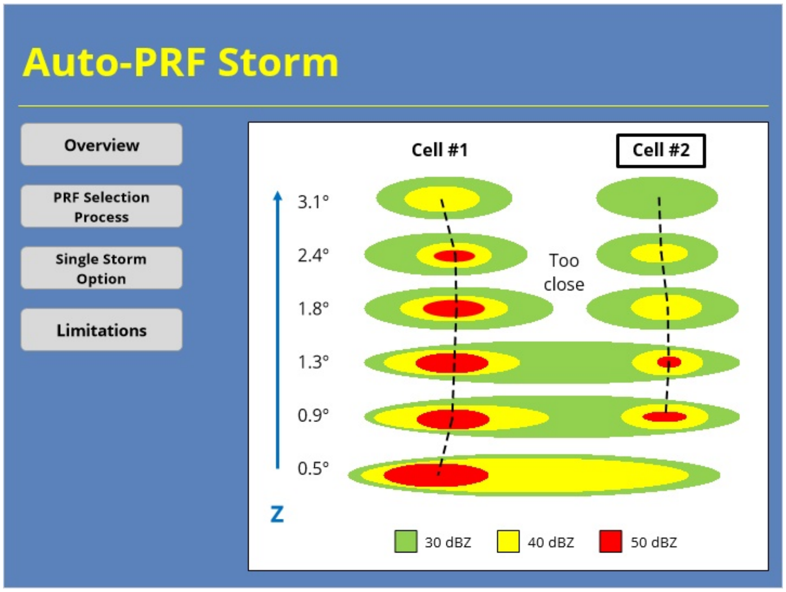
3.7 Auto-PRF Storm



Notes:

Since Auto PRF - Storm uses the output from SCIT, it's subject to the algorithm's limitations. The storm with the highest VIL value may change from scan to scan. You can also have a situation similar to what's in the graphic shown where two cells are in close proximity to each other. SCIT has a hard time tracking storms like Cell #2 because of its close proximity to Cell #1. The algorithm does much better tracking isolated cells. When storms aren't isolated, the preferred PRF may change from scan to scan. Similar issues can happen when storms split or merge, especially if they are located in the 65-95 nm range.

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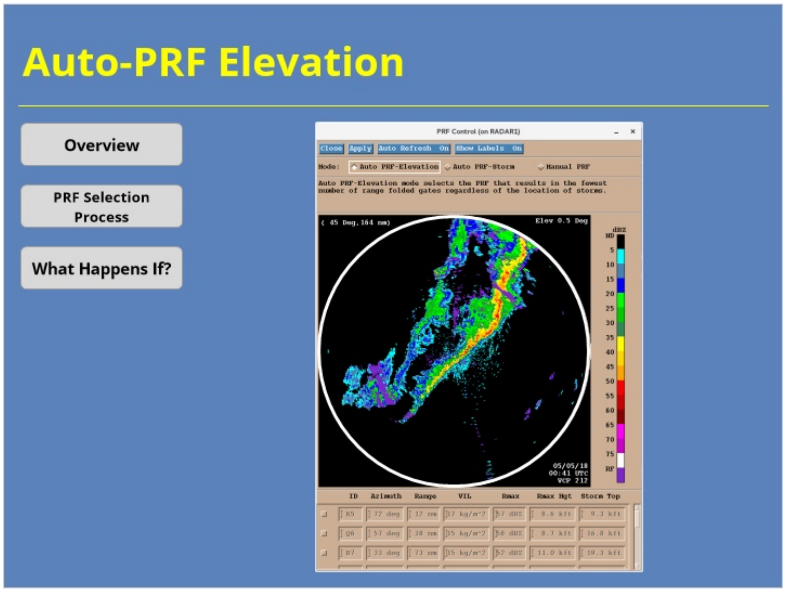
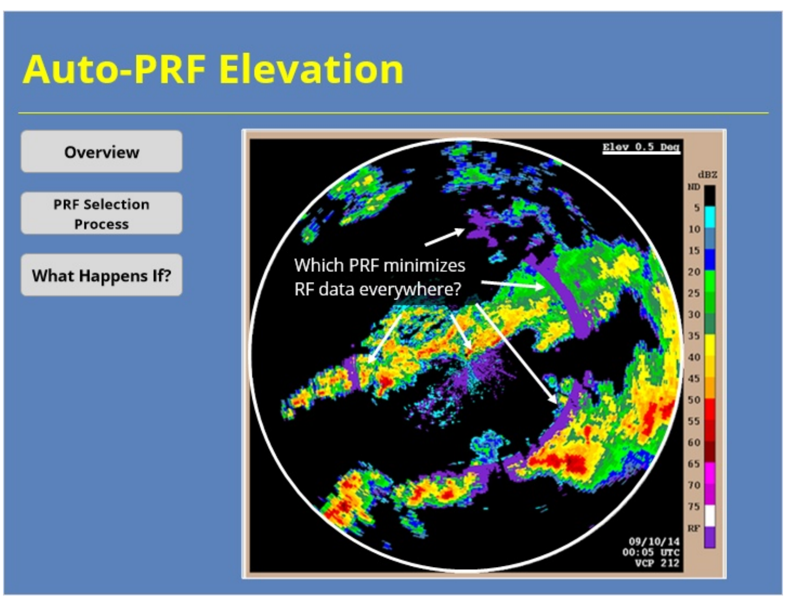
3.8 Auto-PRF Elevation



Notes:

Auto PRF - Elevation works a little differently. This application attempts to minimize the range folded data for the entire display. Click on the PRF Selection Process button to learn more about how this application works.

3.9 Auto-PRF Elevation



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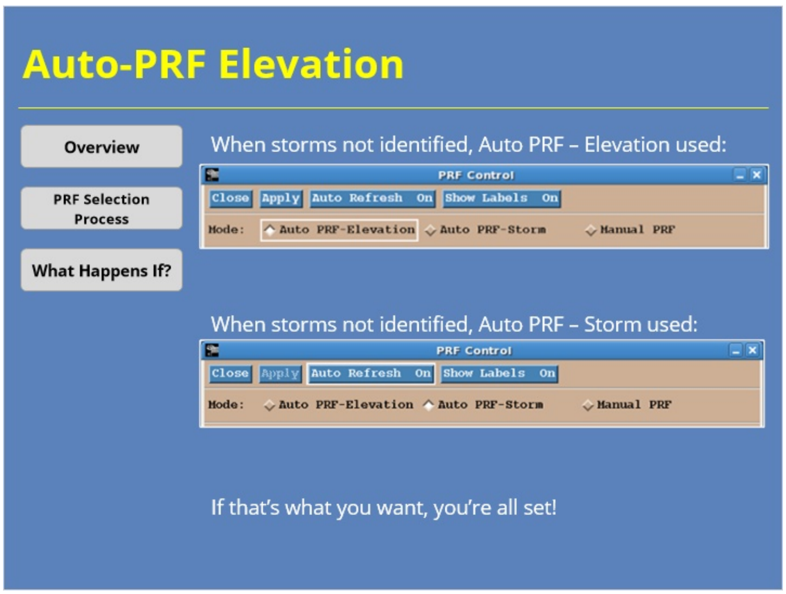
Notes:

Unlike Auto PRF - Storm, Auto PRF - Elevation pays no attention to individual storms or the intensities. The application looks at the Reflectivity and Velocity data for the 0.5 degree scan. It uses that information to determine which of the available PRFs produces the lowest areal coverage over the entire display.

3.10 Auto-PRF Elevation



Notes:

Remembering back to the Auto PRF - Storm, you might have asked yourself a question...What happens when you no longer have any storms? That's a good question! When SCIT fails to identify cells, the RPG switches to Auto PRF - Elevation to control the PRF. When storms redevelop, Auto PRF - Storm takes over again. If that's the behavior you want, then you are all set.

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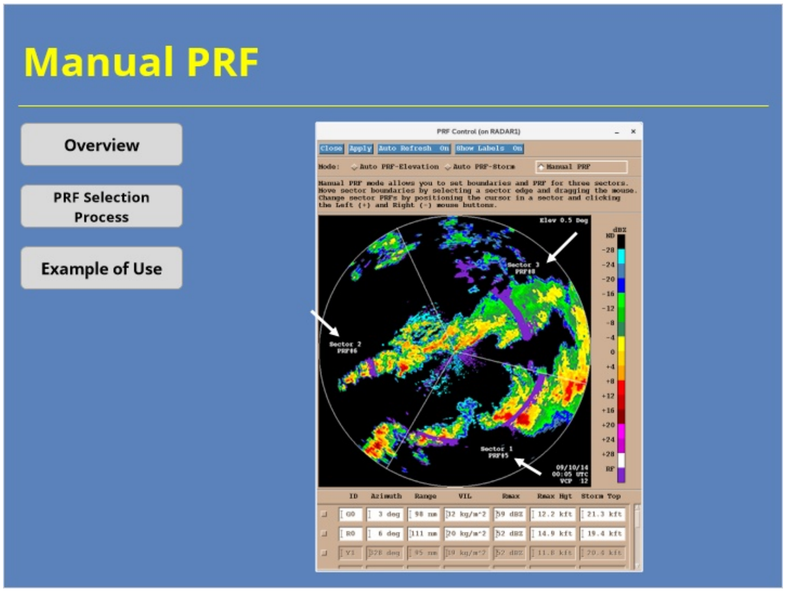
3.11 Manual PRF



Notes:

The last option you can use to mitigate range folded data is Manual PRF. This mode allows the radar operator to specify a specific Doppler PRF from the available options. Users can also specify up to three different Doppler PRFs in configurable sectors like the ones in the example on screen if you use VCP 12. Click on the PRF Selection Process button to learn more how this works.

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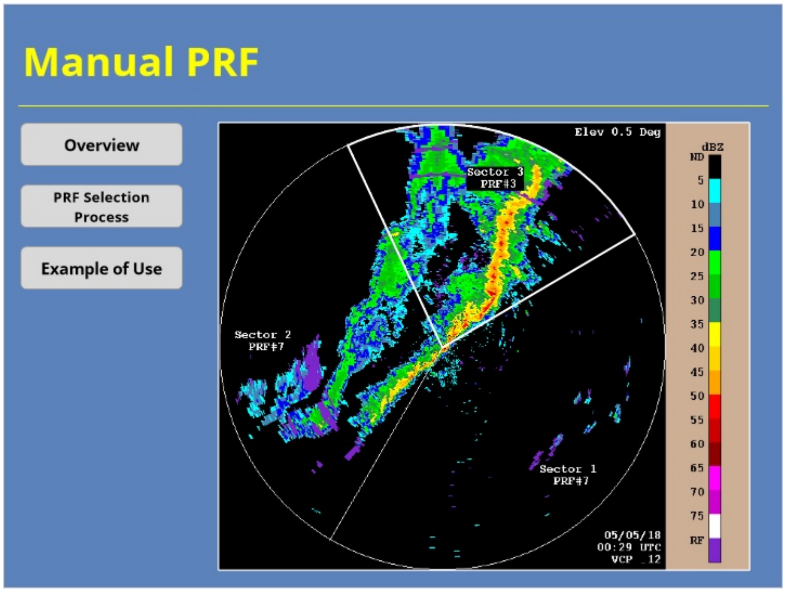
3.12 Manual PRF



Notes:

You can have up to three different sectors with different PRFs that you choose manually. You can reposition the sectors by clicking and dragging on the boundaries. To change the PRF, just position the cursor over a sector, left click to go up in PRF # and right click to go down. Why don't you give changing the PRF a try in Sector 3.

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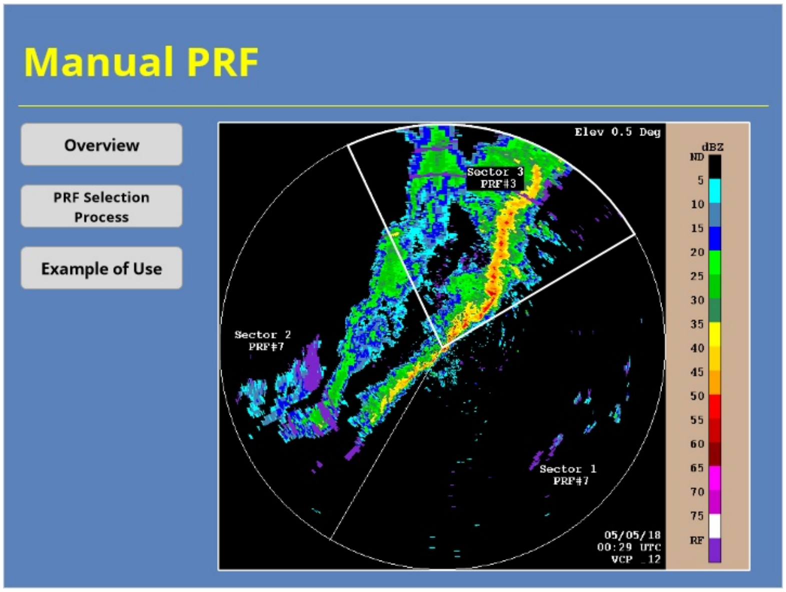
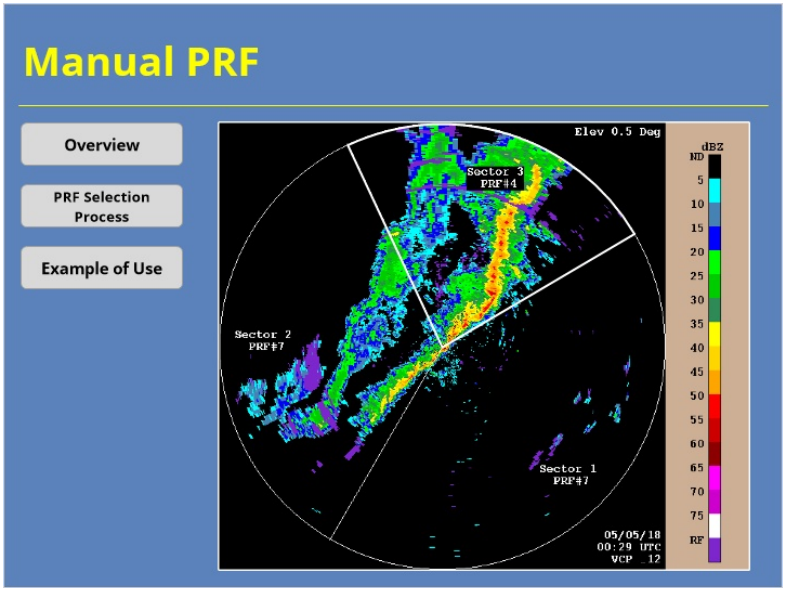
Process - PRF 3 (Slide Layer)



Process - PRF 4 (Slide Layer)



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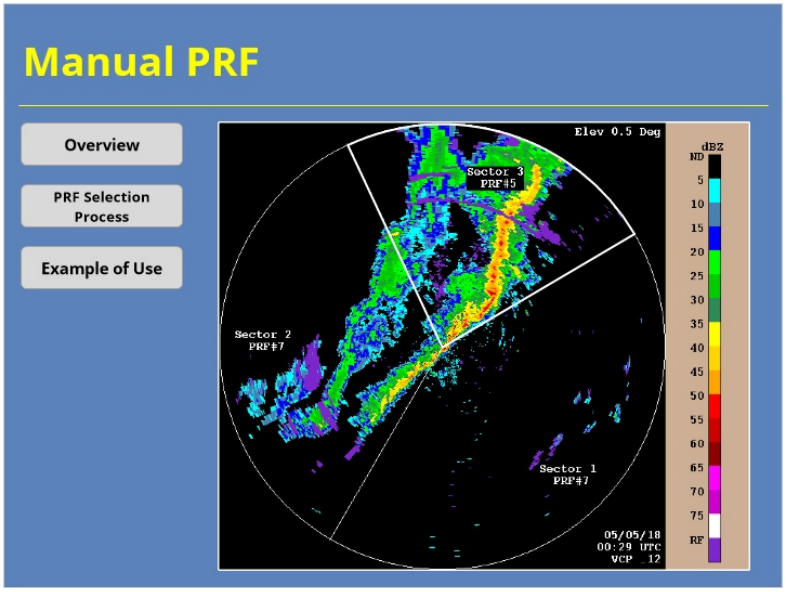
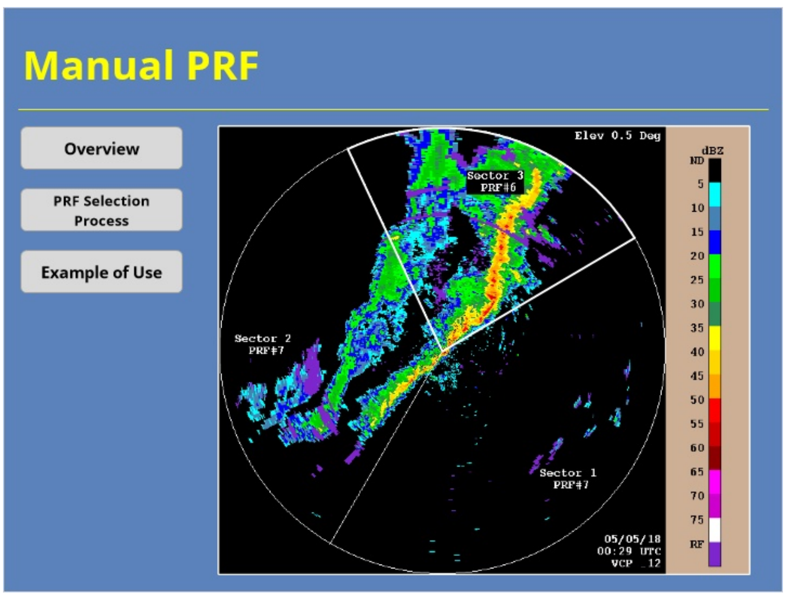
Process - PRF 5 (Slide Layer)



Process - PRF 6 (Slide Layer)



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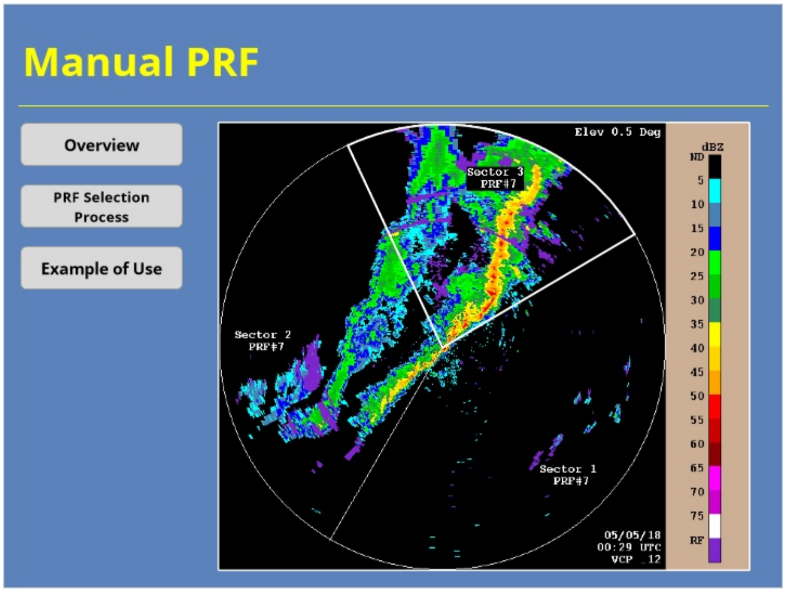
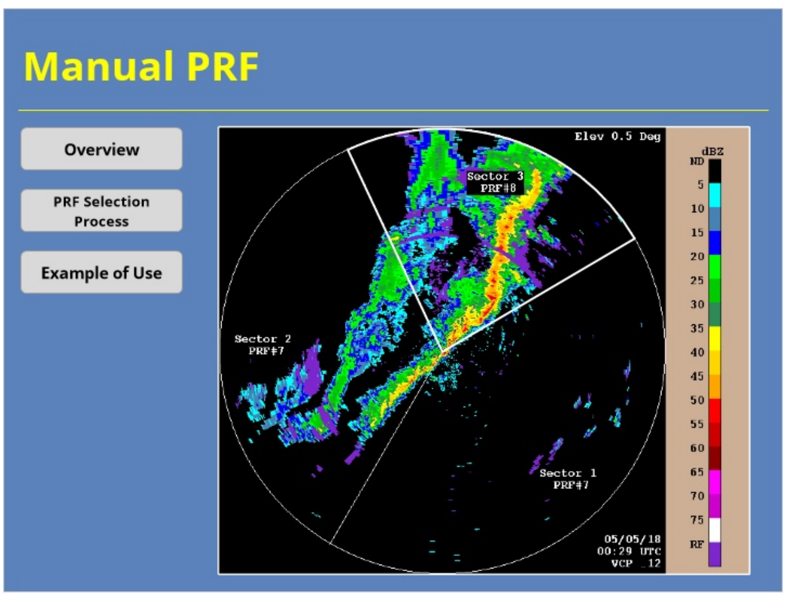
Process - PRF 7 (Slide Layer)



Process - PRF 8 (Slide Layer)



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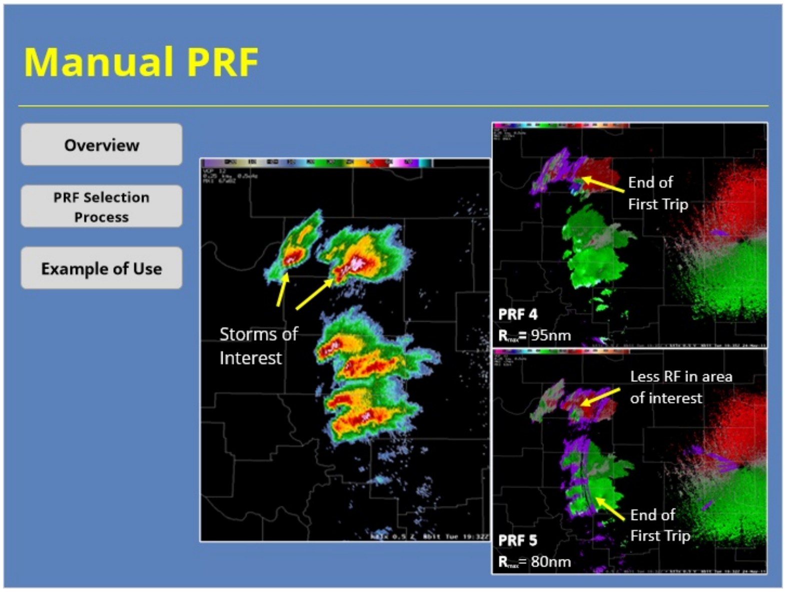
3.13 Manual PRF



Notes:

So, let’s see in an example of how this might look in AWIPS. The Reflectivity image shows a handful of storms. The velocity image on the upper-right shows the starting velocity. Unfortunately, the storms we are currently interested in analyzing are filled with range folded data. However, by switching from PRF 4 to PRF 5 (as shown in the lower-right image), we can now see the velocity data better.

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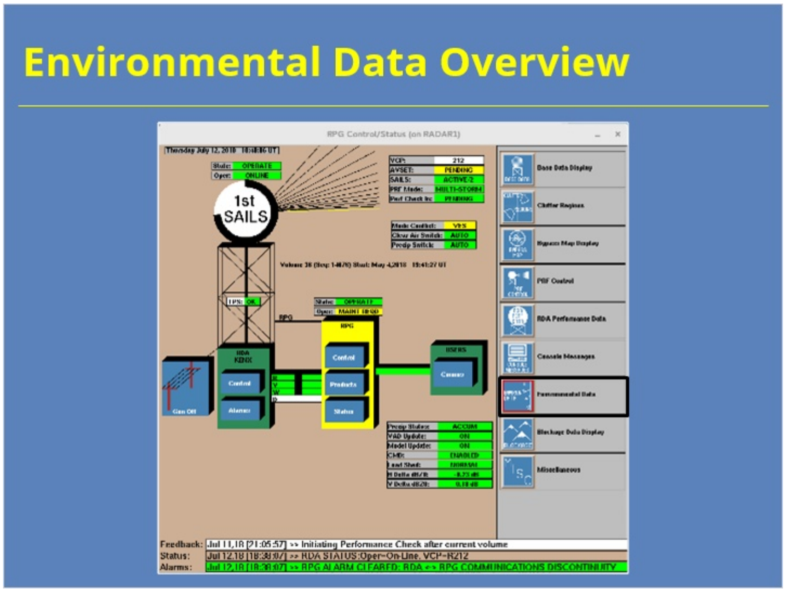
4. Environmental Data

4.1 Environmental Data Overview



Notes:

The last function of the RPG HCI we will discuss is the Environmental Data Editor. From this interface, users can monitor and edit the environmental data required by several radar processes, such as velocity dealiasing, melting layer identification, and hail detection. This window can be accessed from the Environmental Data button on the right-hand side of the HCI. Click on that button to learn more about the GUI.

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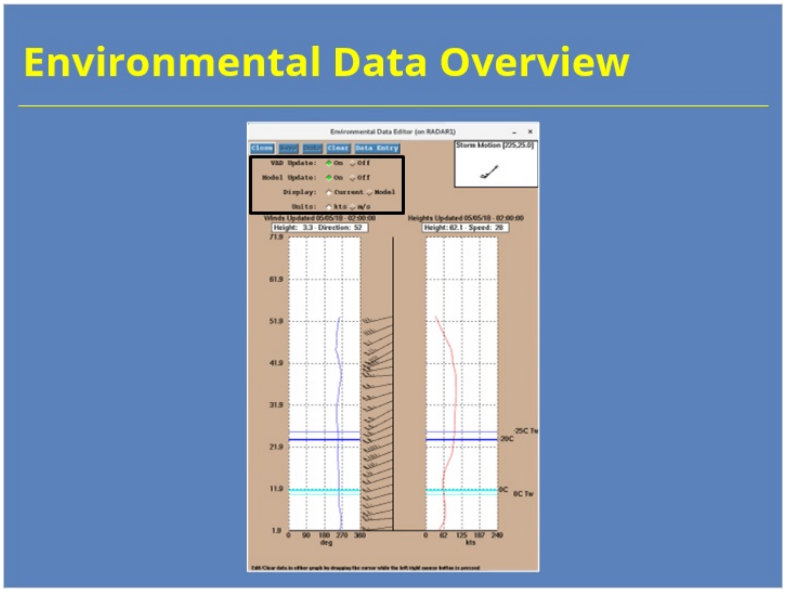
4.2 Environmental Data Overview



Notes:

This window has several different components that radar operators might need to monitor or use. Let’s start by looking at the radio buttons at the top of the GUI. Click on that part of the window to learn more.

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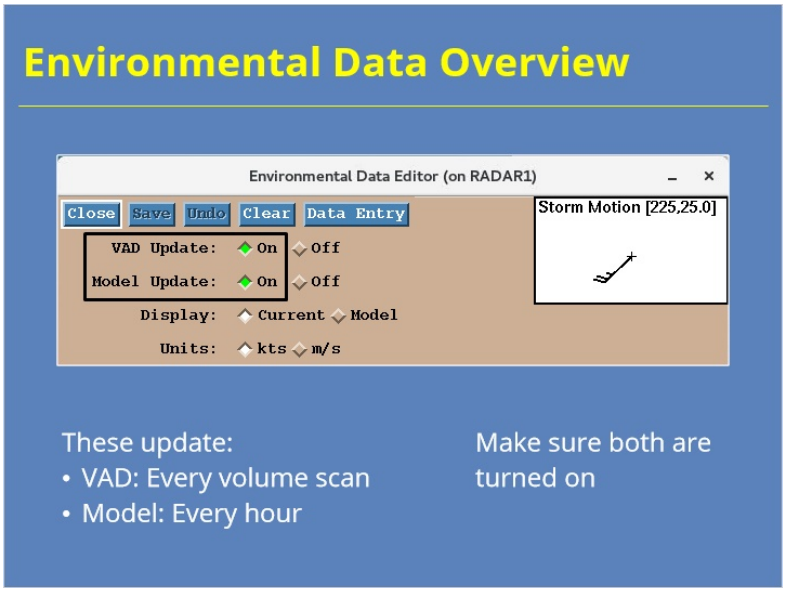
4.3 Environmental Data Overview



Notes:

Of the four options at the top of the Environmental Data Editor, the two most important are the VAD Update and Model Update. When these options are turned on, the environmental wind and temperature data are updated automatically from radar and model data, respectively. When the data are available, the VAD update occurs every volume scan while the model update occurs hourly. 99.9% of the time, you'll want both of these options turned on. Next, we'll look at the Data Entry window and show you how to make updates there.

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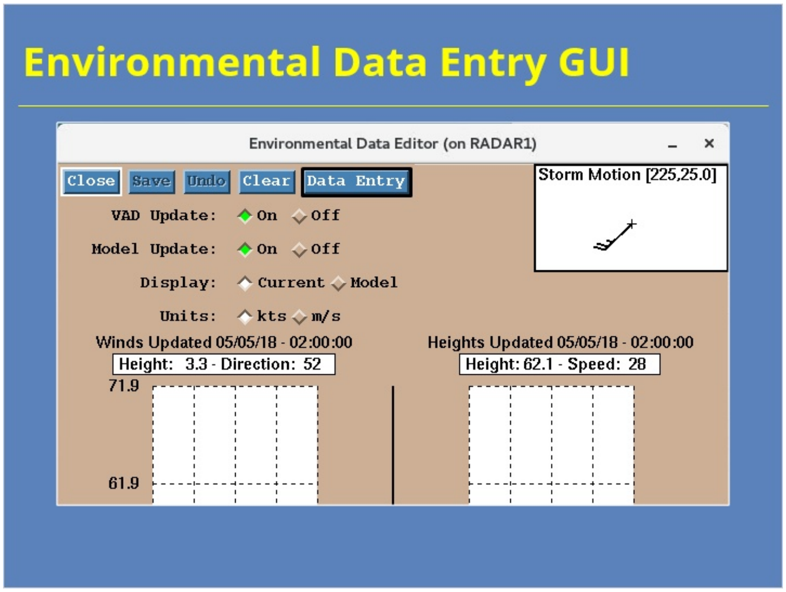
4.4 Environmental Data Entry GUI



Notes:

The Environmental Data Editor provides the radar operator with ways to manually enter input for the various algorithms that need it. To learn more about that, click on the Data Entry button at the top of the Editor Window.

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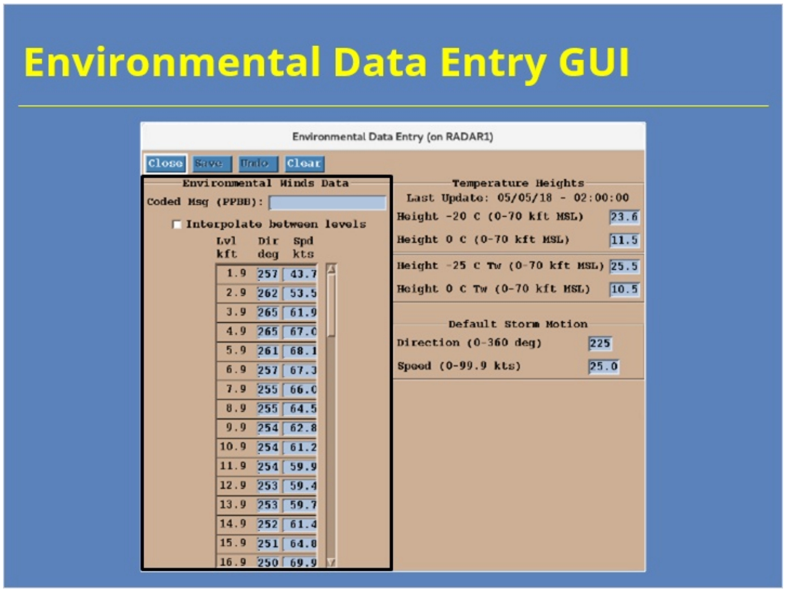
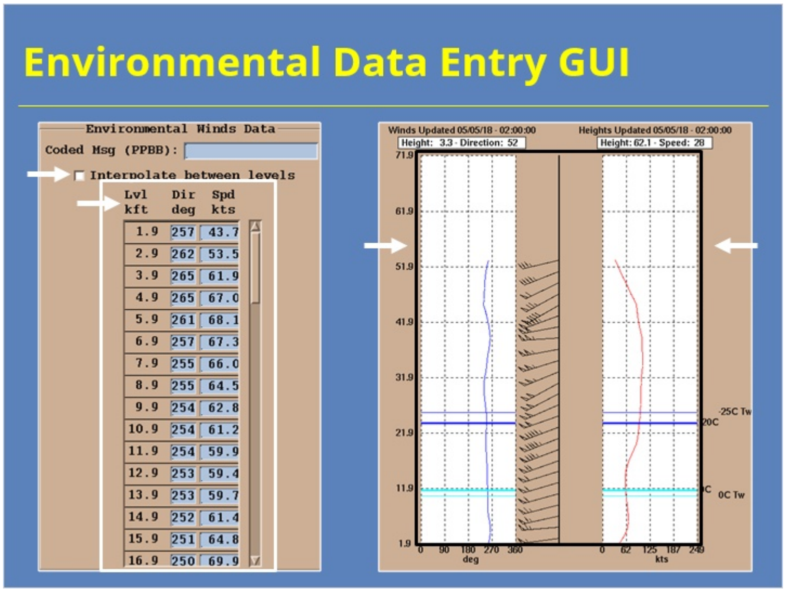
4.5 Environmental Data Entry GUI



Notes:

The environmental data entry window provides you a means to precisely enter data for the environmental winds, temperature heights, and default storm motion. We'll start our discussion with the wind data. To learn more, click on the Environmental Winds Data panel.

4.6 Environmental Data Entry GUI



Notes:

If for some reason you need to manually input the environmental wind data, you can do so in the panel shown on the left side of the slide. If you need to do this step, it usually means that your VAD wind profile has issues. So, your best bet is to pull up a sounding and enter the information from there. You submit the data for every thousand feed above ground level. Make sure to toggle on the “Interpolate between levels” option, too. Another option available to you are the panels on the left that appear in the Environmental Data Editor window we just left. You can click on the white charts to manually edit the data. Most users will find this process a little tedious for the entire vertical profile. However, if you need to fix the wind data at a level or two, you might want to try this tool instead. You adjust the wind direction in the display on the left while the wind speed can be adjusted in the display on the right. Click on one of these panels to learn more about the temperature heights manual data entry.

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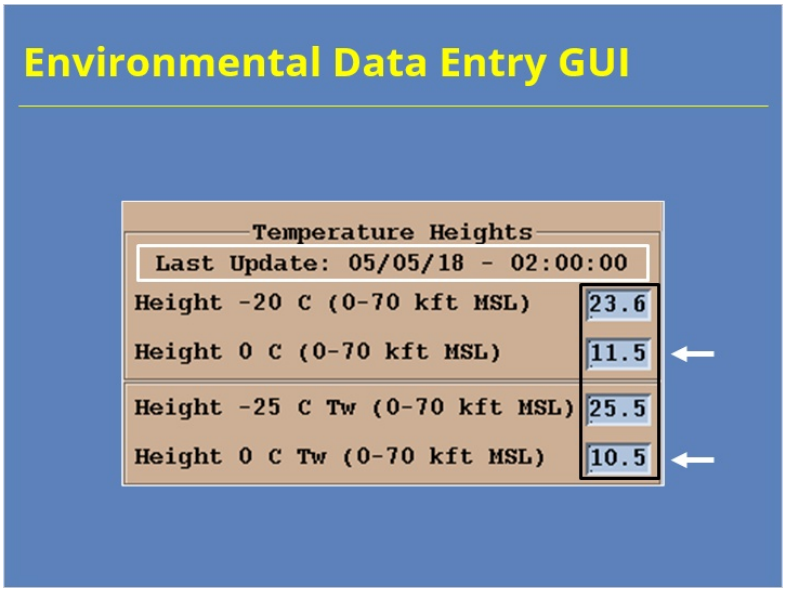
4.7 Environmental Data Entry GUI



Notes:

The temperature data available from the Temperature Heights panel are used by the Hail Detection and Melting Layer Algorithms, respectively. Assuming you have the model update feature turned on, you should only have to manually update these values if the hourly model input isn't representative for some reason or the data feed gets interrupted some how. For the latter situation, you can check the "Last Update" time in the panel to see if the values were updated recently. If you update the data manually, you will want to check these values routinely to ensure they are representative. One last point…It's not uncommon for the freezing level and the wet bulb zero height to be significantly different (as in the example shown). That situation isn't in and of itself a reason to manually change the values. Click on one of the text entry boxes to learn more about changing the default storm motion.

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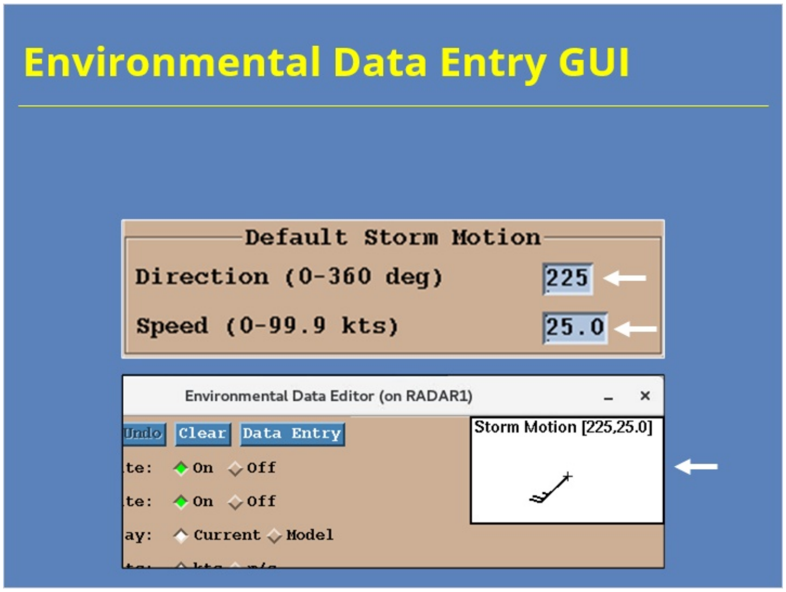
4.8 Environmental Data Entry GUI



Notes:

The Default Storm Motion data support the Storm Cell Identification and Tracking (or SCIT) algorithm in providing a storm motion when a cell is initially identified. The algorithm can figure a cell's storm motion once the cell has been identified for multiple volume scans. The RPG has no way to update these values automatically, so you should monitor these values routinely and change them, as needed. These values change be changed by using the text entry boxes at the Default Storm Motion panel or by interacting with the panel in the upper right-hand corner of the Environmental Data Editor window.

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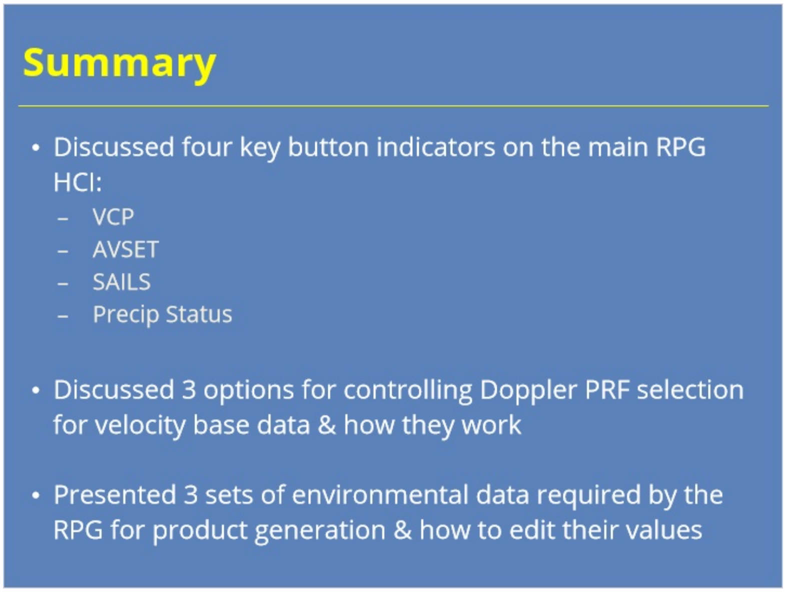
5. Summary & Quiz

5.1 Summary

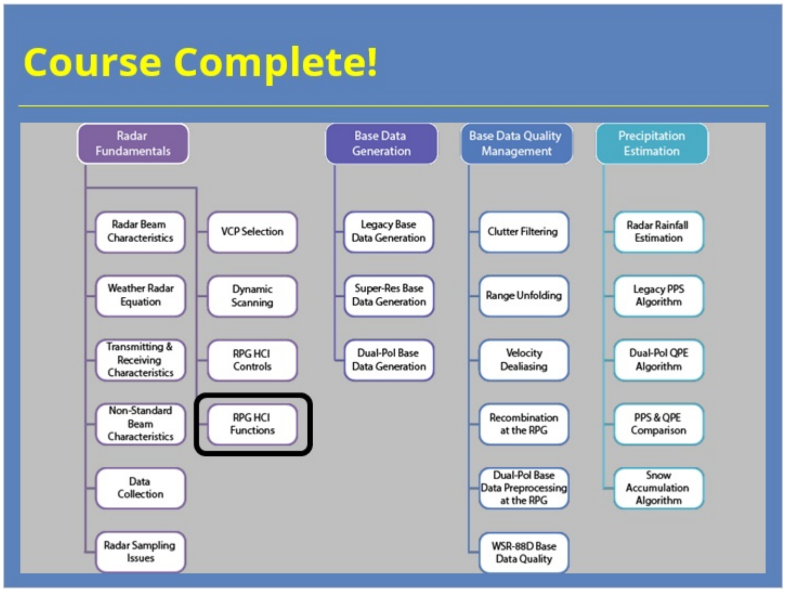


Notes:

This lesson highlighted several different functions radar operators can perform at the RPG HCI. The interface has several different button indicators on the main display. We discussed four important ones you should know how to use: VCP, AVSET, SAILS, and Precip Status. We also went over the three options available for controlling the Doppler PRF used for the generation of velocity base data. The options are Auto PRF - Storm, Auto PRF - Elevation, and Manual PRF. We discussed the options, how they work, and how you can further configure those options. Lastly, we presented the three sets of environmental data the RPG needs to compute various base and derived products. These data, which are the environmental winds, the temperature heights, and default storm motion, can be monitored and edited at the Environmental Data Editor window. Ensuring these values are representative of the current atmospheric conditions allows for the best quality base and derived products possible.

The next slide will start the quiz for this lesson. Click next when you are ready to begin.

5.10 Course Complete!



Notes:

You have successfully completed this course. You can look over the roadmap on the slide to see what courses remain in this topic or you can click the Exit button to close the window and record your completion.

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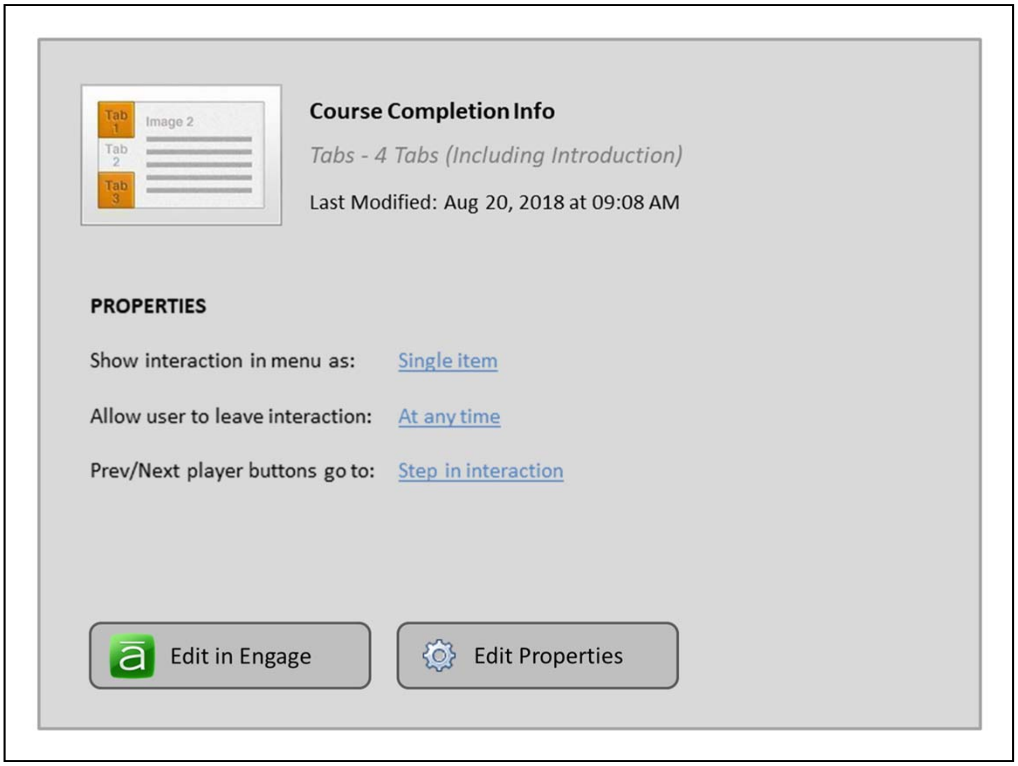
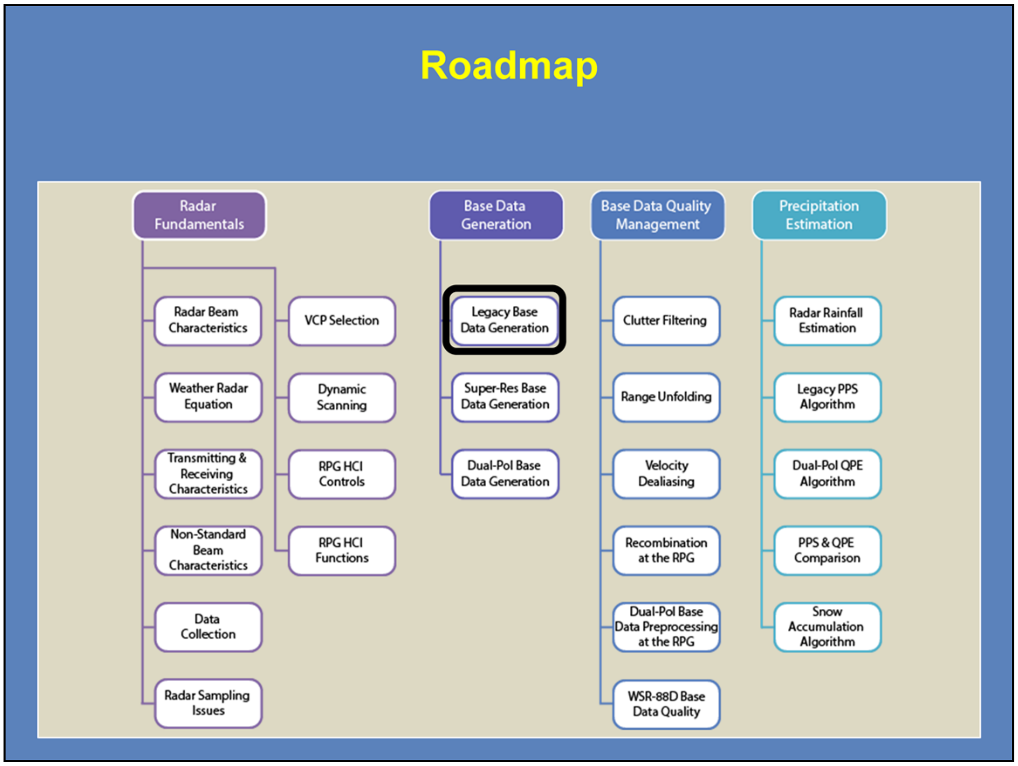
Welcome to Legacy Base Data Generation.


Tab 1
Tab 2
Tab 3
Image 2
Course Completion Info
Tabs - 4 Tabs (Including Introduction)
Last Modified: Aug 20, 2018 at 09:08 AM
PROPERTIES
Show interaction in menu as: Single item
Allow user to leave interaction: At any time
Prev/Next player buttons go to: Step in interaction
Edit in Engage
Edit Properties



Here is the “roadmap” with your current location.

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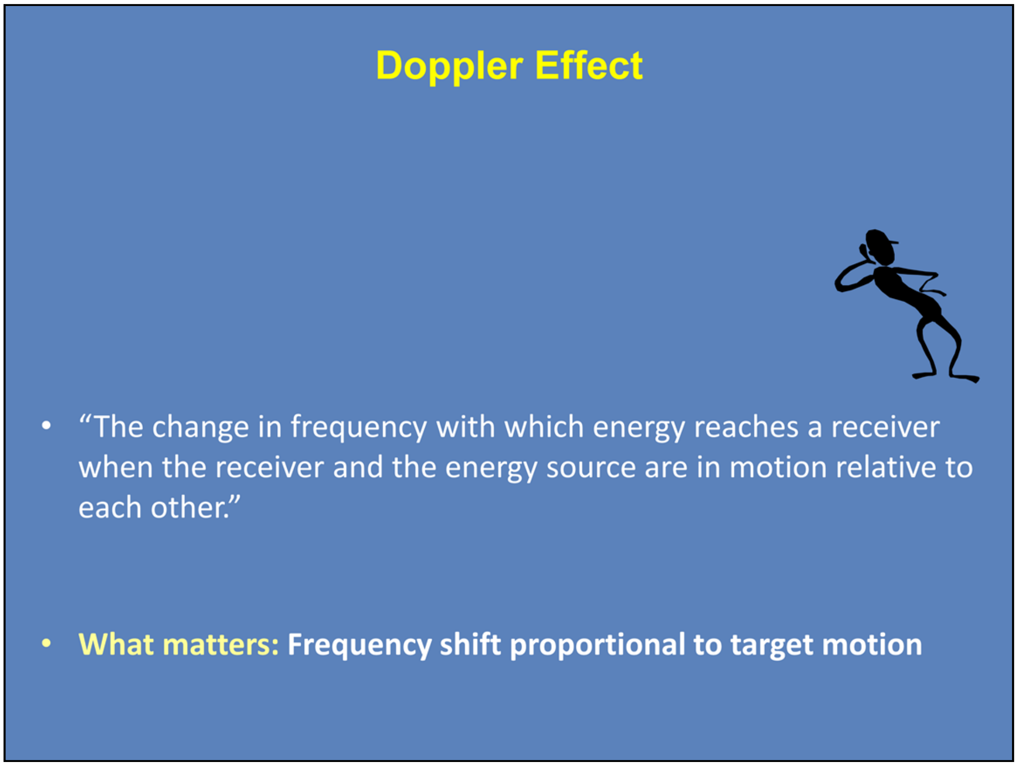
Learning Objectives

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.



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.

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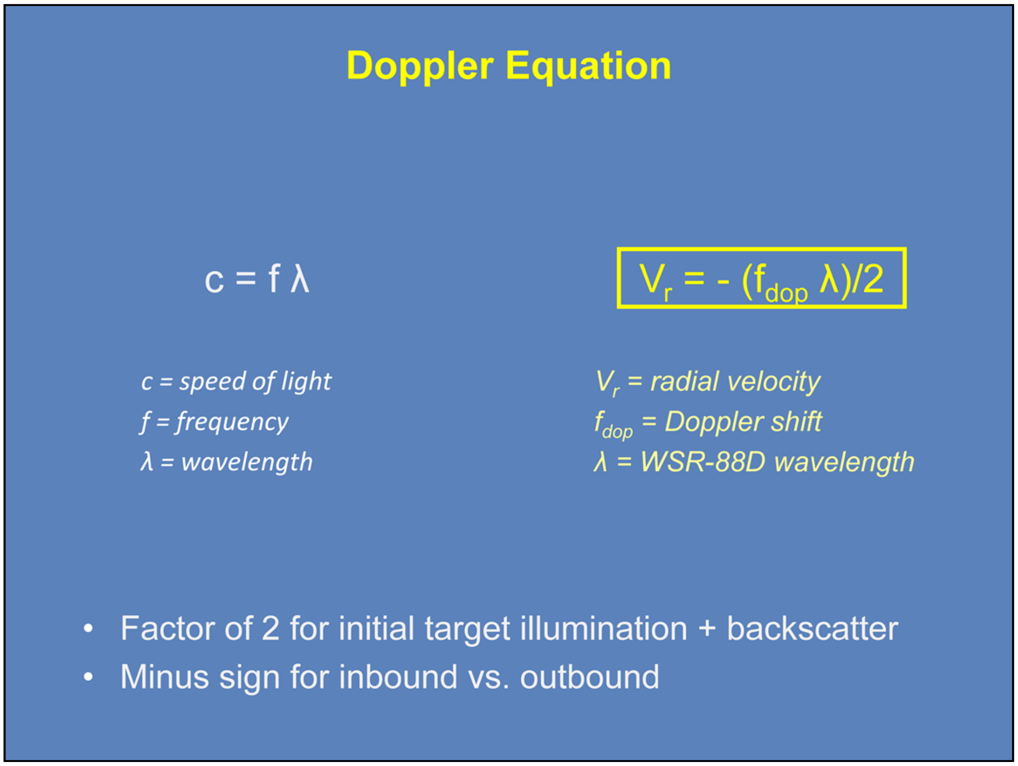
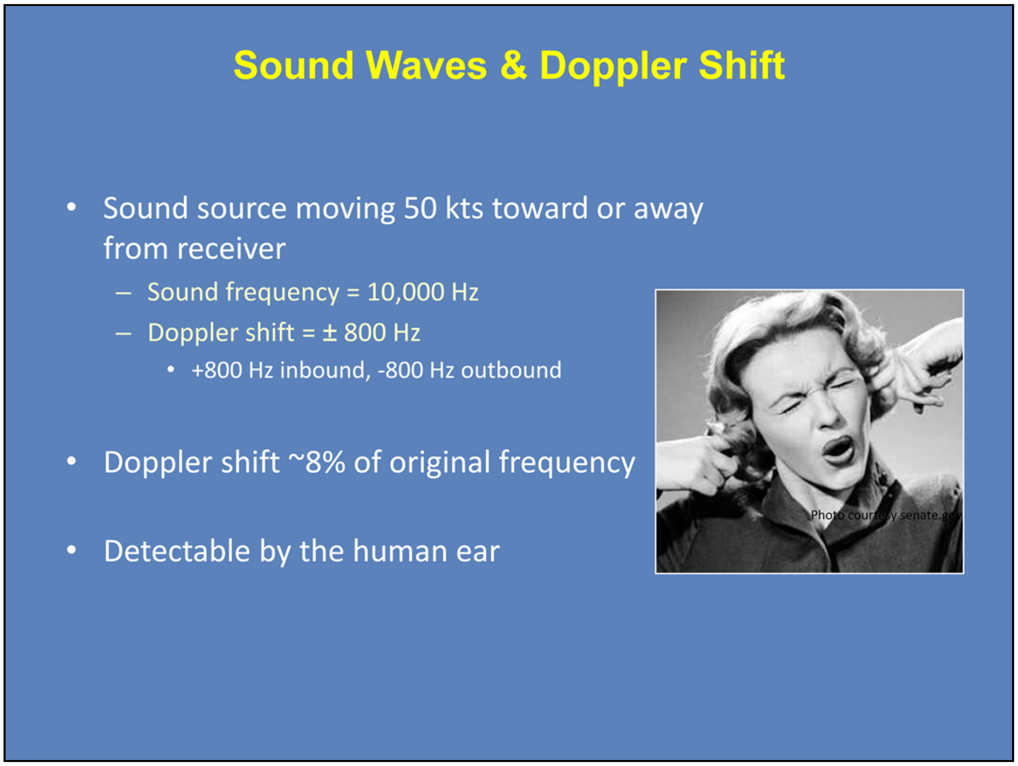


On the left is the basic relationship of frequency and wavelength to the speed of light. Based on that equation, on the right, is the relationship of the Doppler shift to radial velocity for Doppler weather radar (derivation not required!).

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.



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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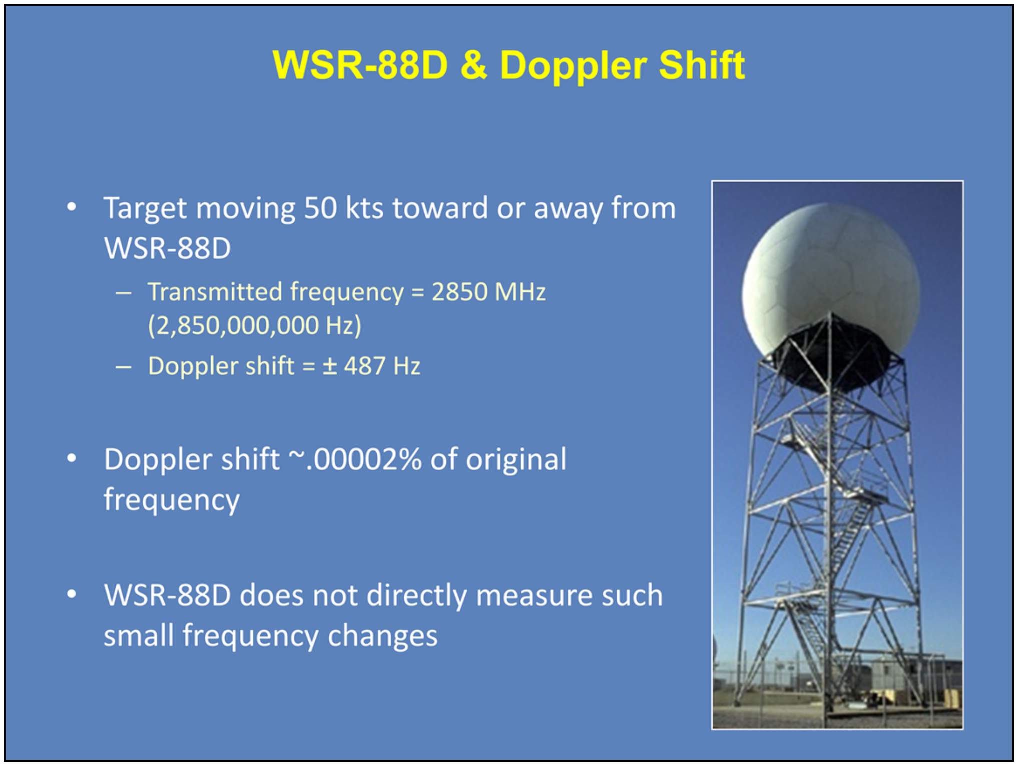
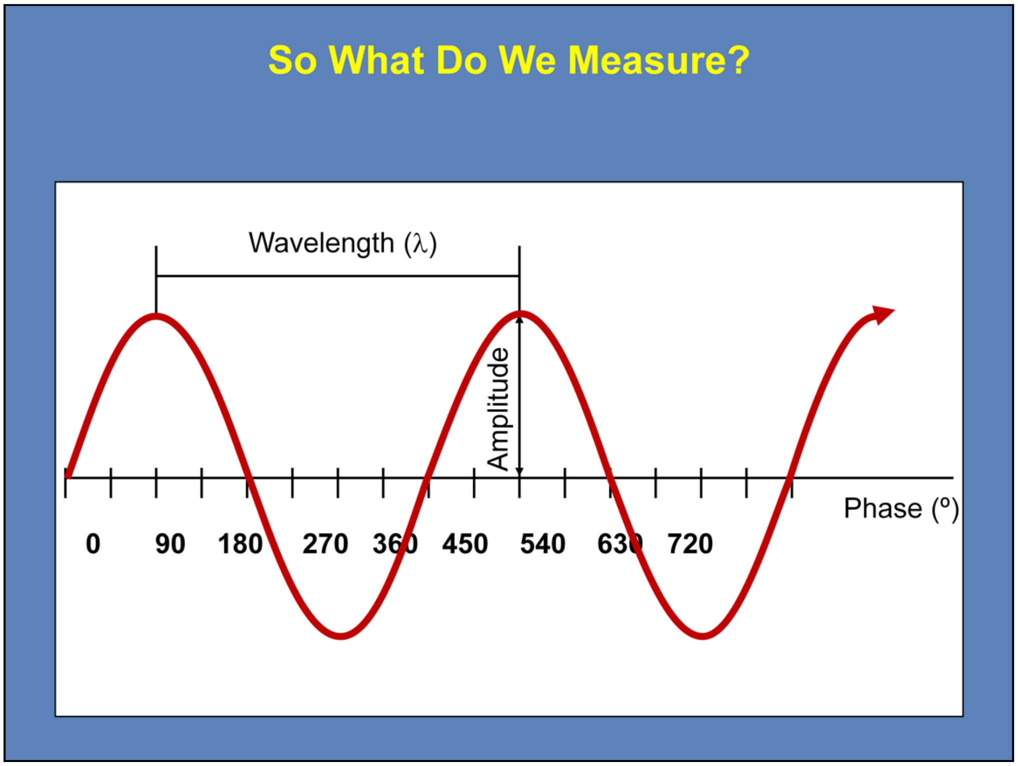


Now for the same target motion of 50 kts, but the listening device is the WSR-88D. We are no longer dealing with sound waves. Note that the frequency of transmission is very high compared to the frequency of a sound wave. The frequency shift is tiny compared to the original frequency…too small to be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



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.

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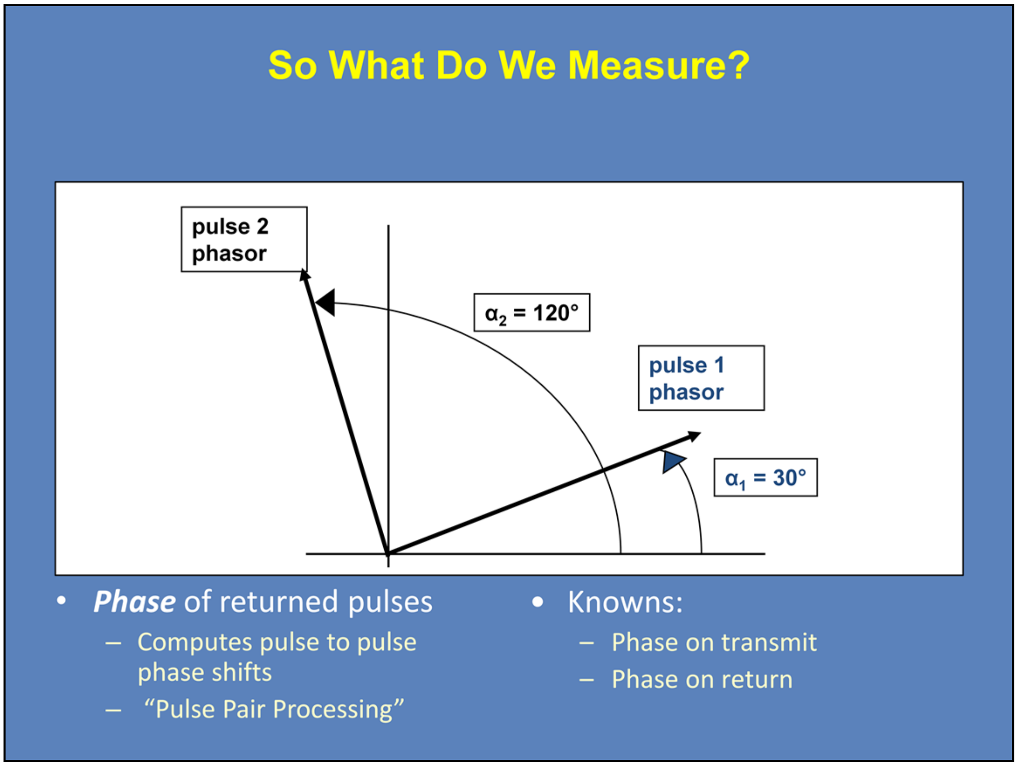
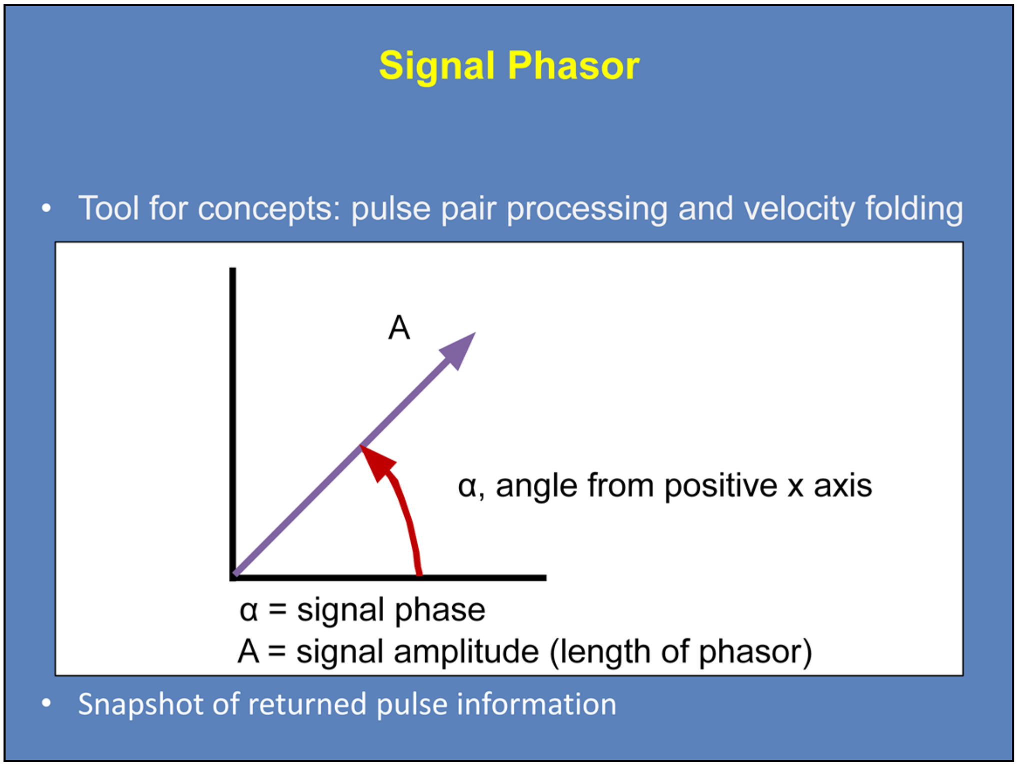


It turns out that the WSR-88D measures the phase of each returned pulse and is able to compare the phase values from one pulse to the next. The phase shift from one pulse to the next is directly related to the radial velocity. This technique is called Pulse Pair Processing.

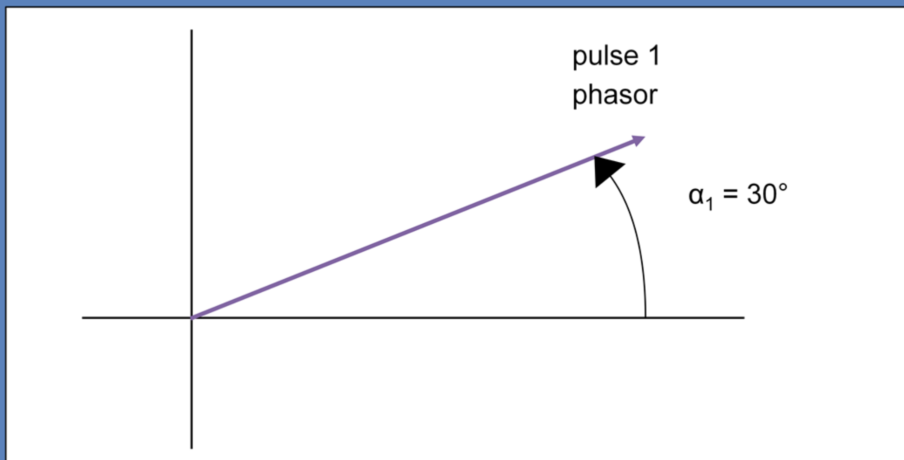
Pulse Pair Processing is possible because the initial phase is known when each pulse is transmitted. The initial phase for each returned pulse is also known. In a nutshell, a phase value is assigned to each pulse, then compared from one pulse to the next.



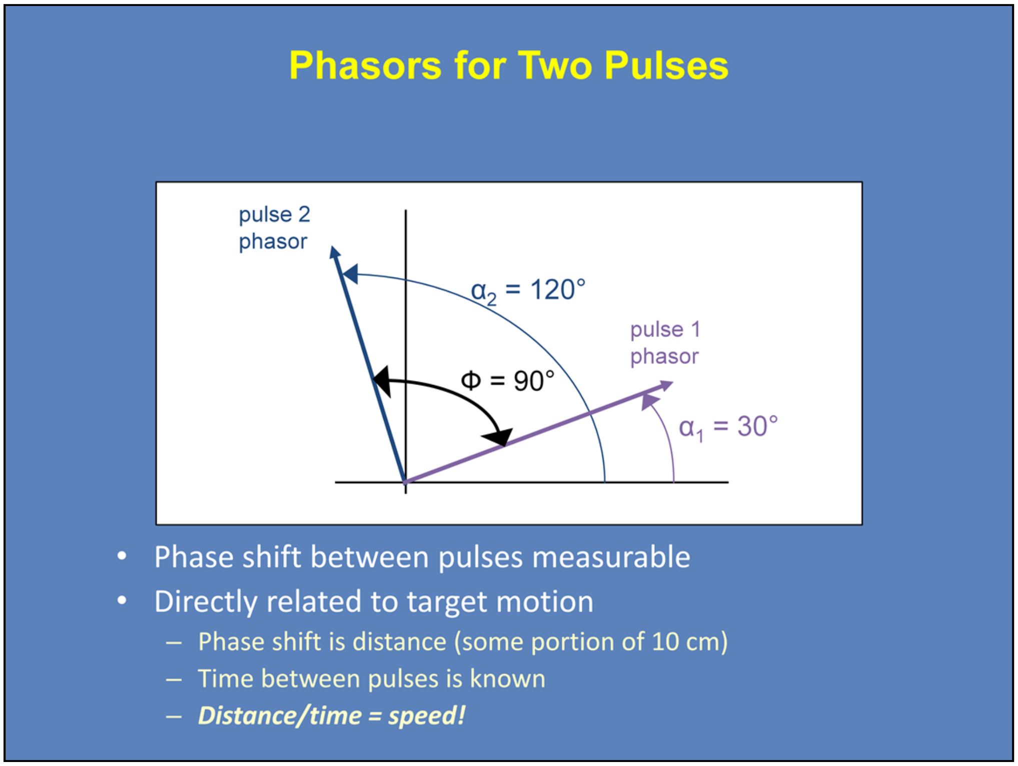
One way to represent the concept of a pulse pair phase shift is to use phasors. A phasor is a tool for temporary use only to support your understanding of one of the fundamental ambiguities with Doppler weather radar: velocity folding or aliasing. A phasor represents the necessary information from each 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.

Phasor for Single Pulse

Phase of returned signal is known



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°.



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.

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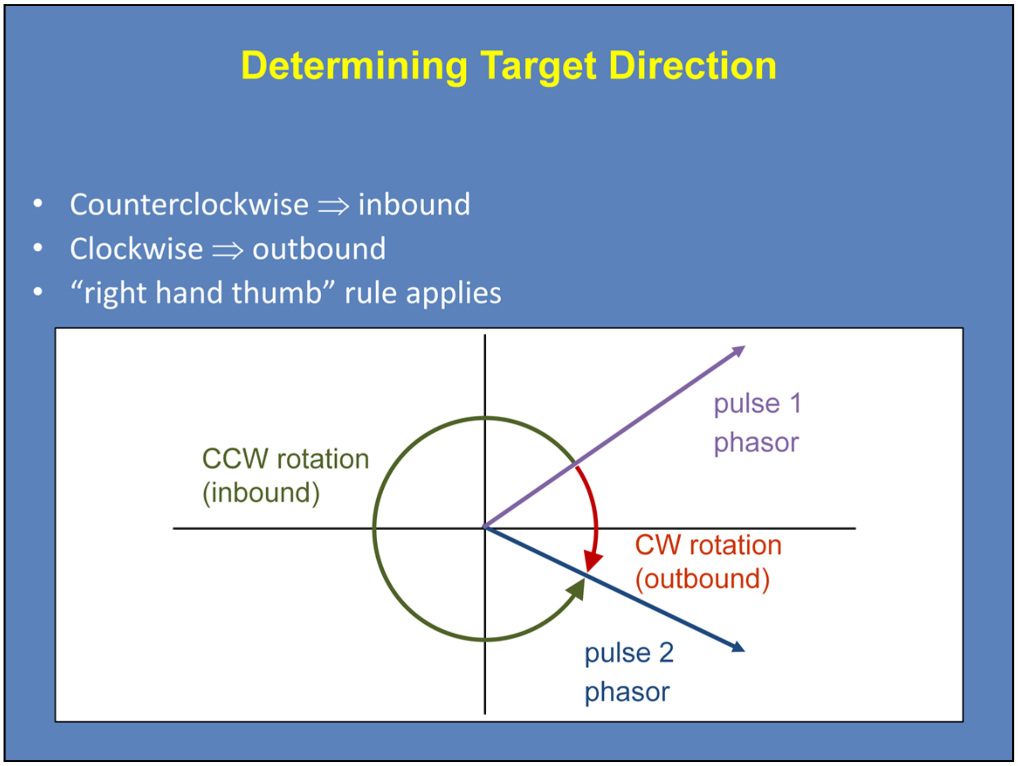

The target direction, inbound vs. outbound, is determined by the phasor rotation from pulse 1 to pulse 2. If clockwise, the direction is outbound. If the rotation is counterclockwise, the direction is inbound. You can also use the right hand thumb rule for the cross product of two vectors. Using the 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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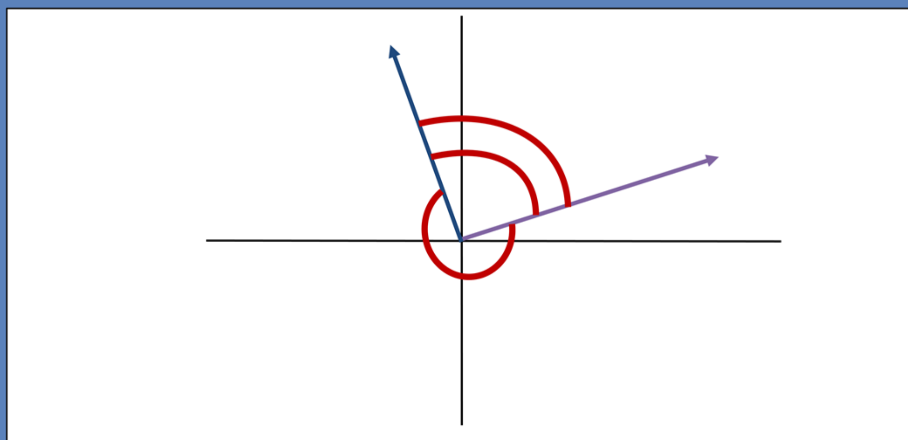
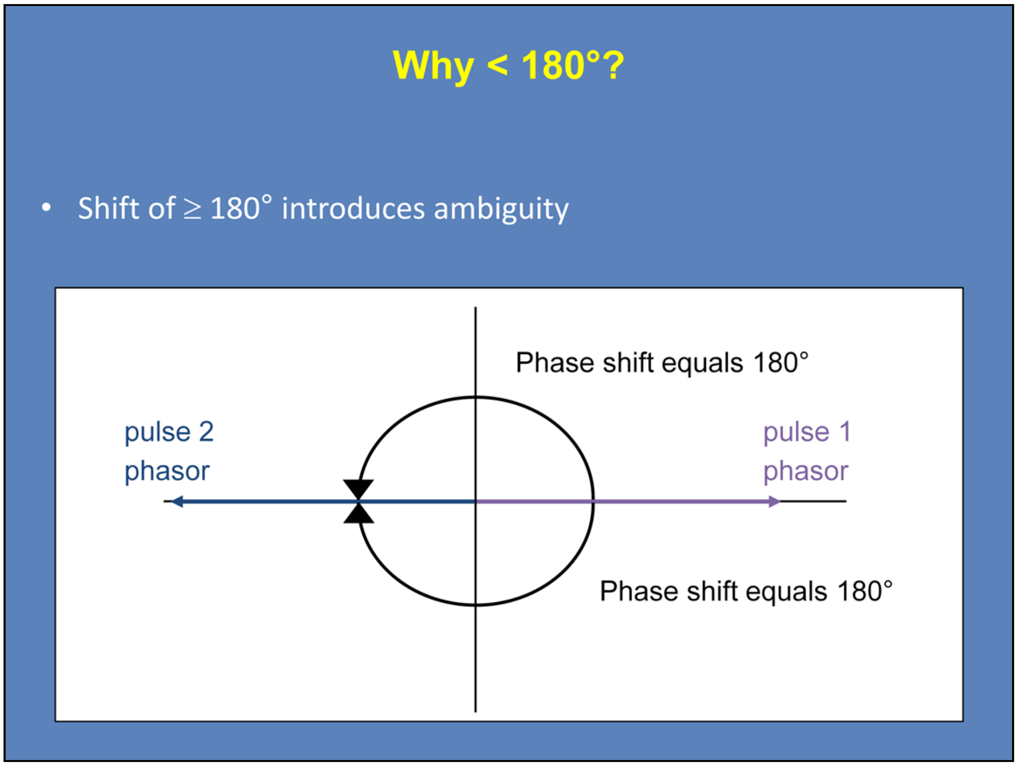
Phasors for Two Pulses:
Pulse to Pulse Phase Change



- 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°.



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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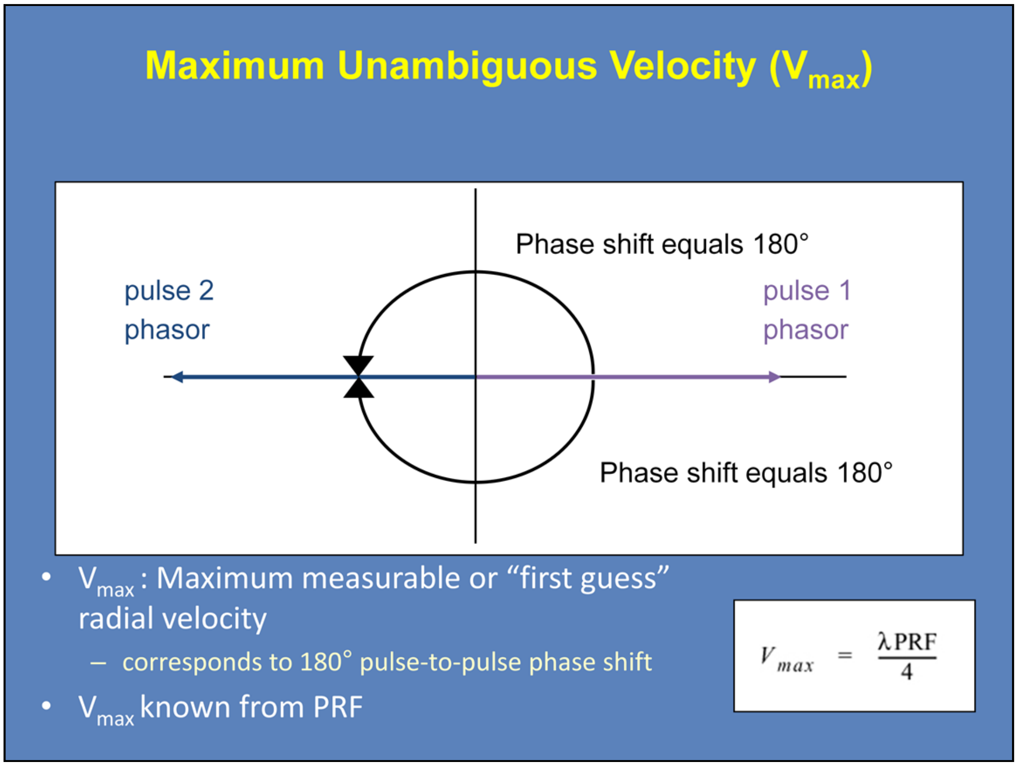

The maximum velocity that can be measured is called the maximum unambiguous velocity. It corresponds to a pulse pair phase shift of 180° (actually 179.99999…°), and is dependent on the pulse repetition frequency (PRF). With the WSR-88D, V_{max} values range from about 16 to about 64 kts.

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Phase Shift-Radial Speed Relationship

$$\frac{\text{pulse-pair phase shift}}{180^\circ} = \frac{|V_r|}{|V_{max}|}$$

- $|V_r|$ = radial speed
- $|V_{max}|$ = maximum unambiguous speed

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}.

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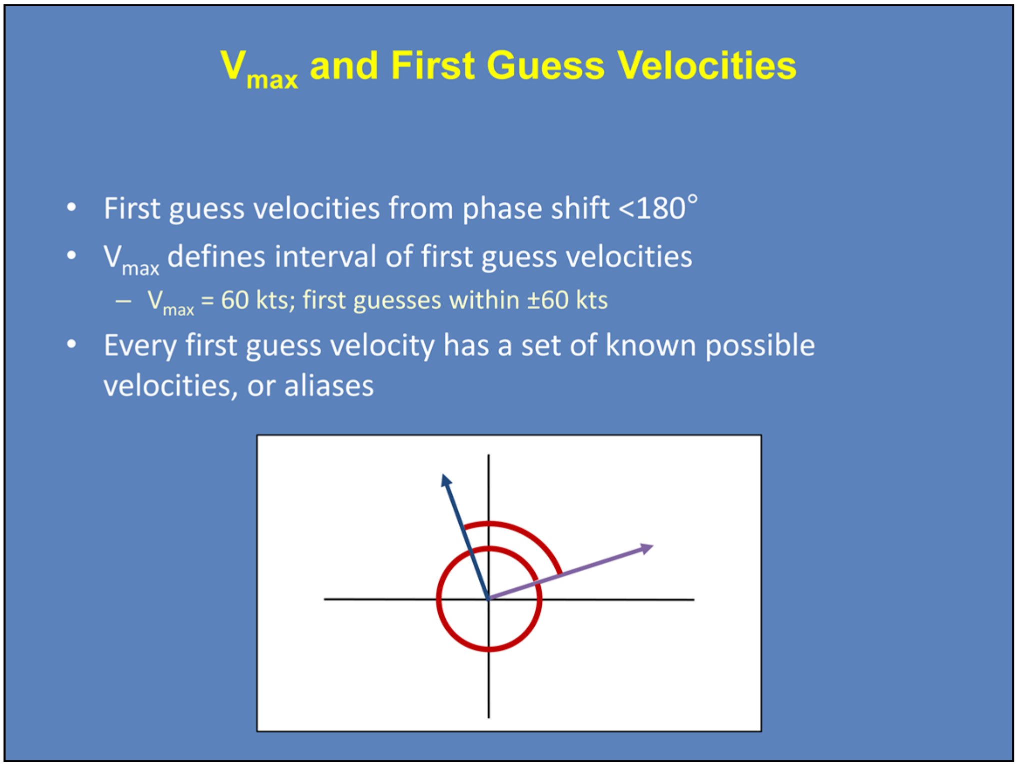
Phase Shift - Radial Speed

Web Object

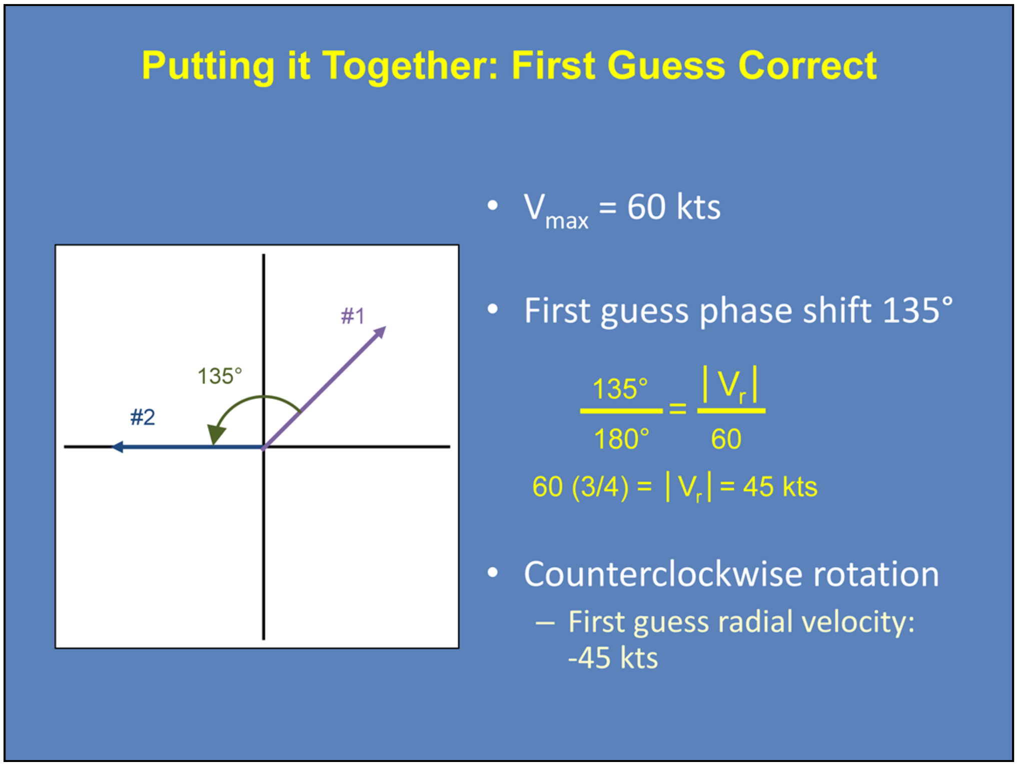
Address:
https://training.weather.gov/wdtd/courses/rac/principles/interactions/phaseshift-radialspeed/

If no pop-up window appears that looks like the above, open a browser and go to:
https://training.weather.gov/wdtd/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.

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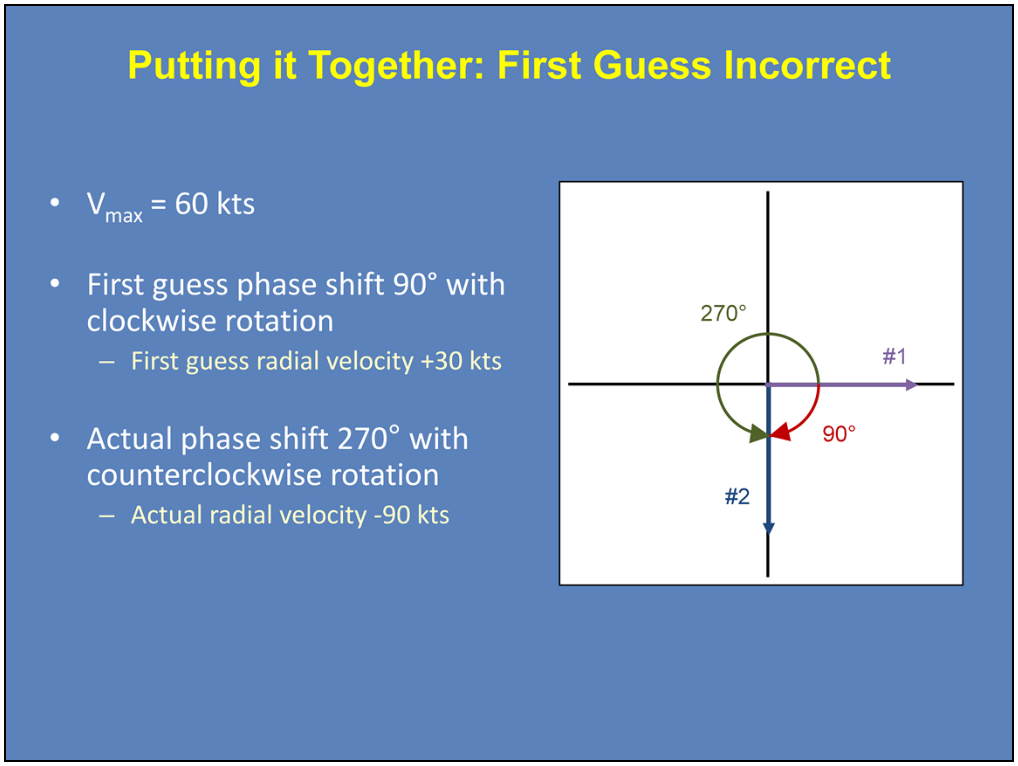
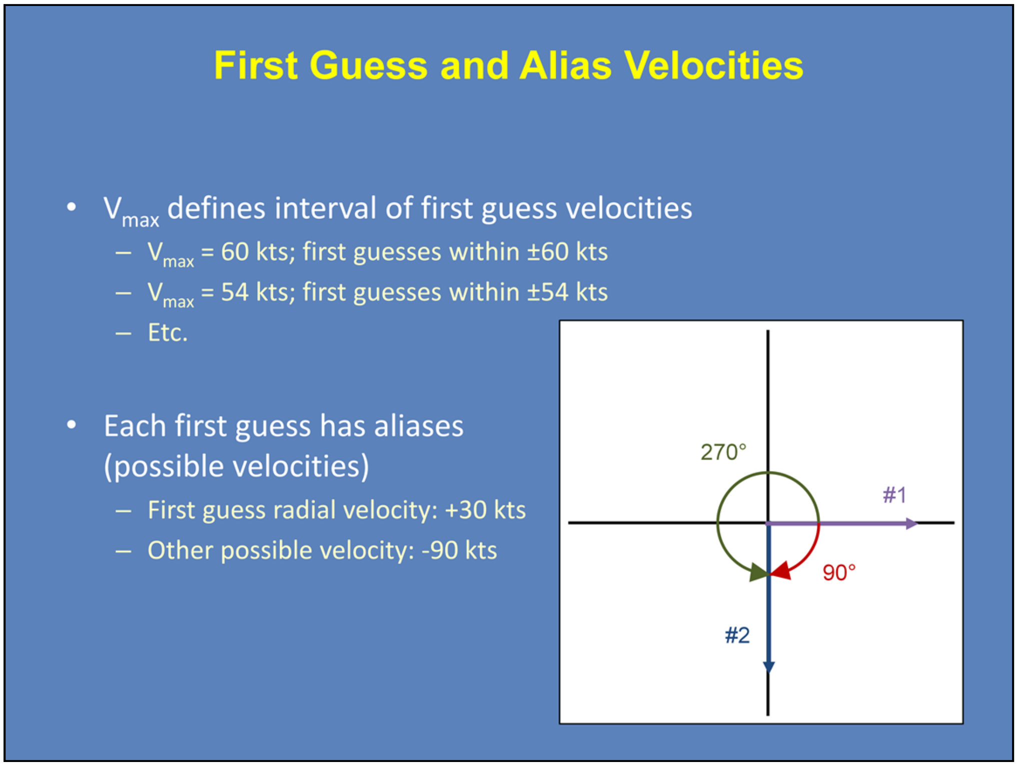


So what happens when the first guess velocity is not correct, i.e. the actual phase shift is >180°? The good news is that for every first guess velocity, there are other possible velocities which are known.

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.



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).

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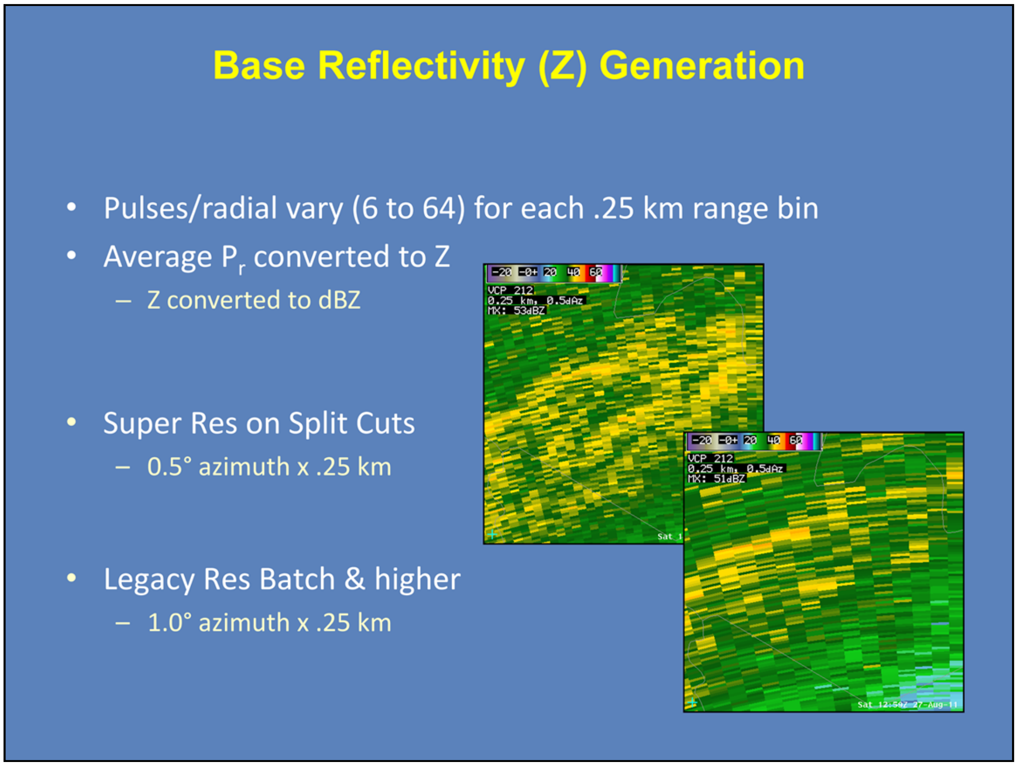
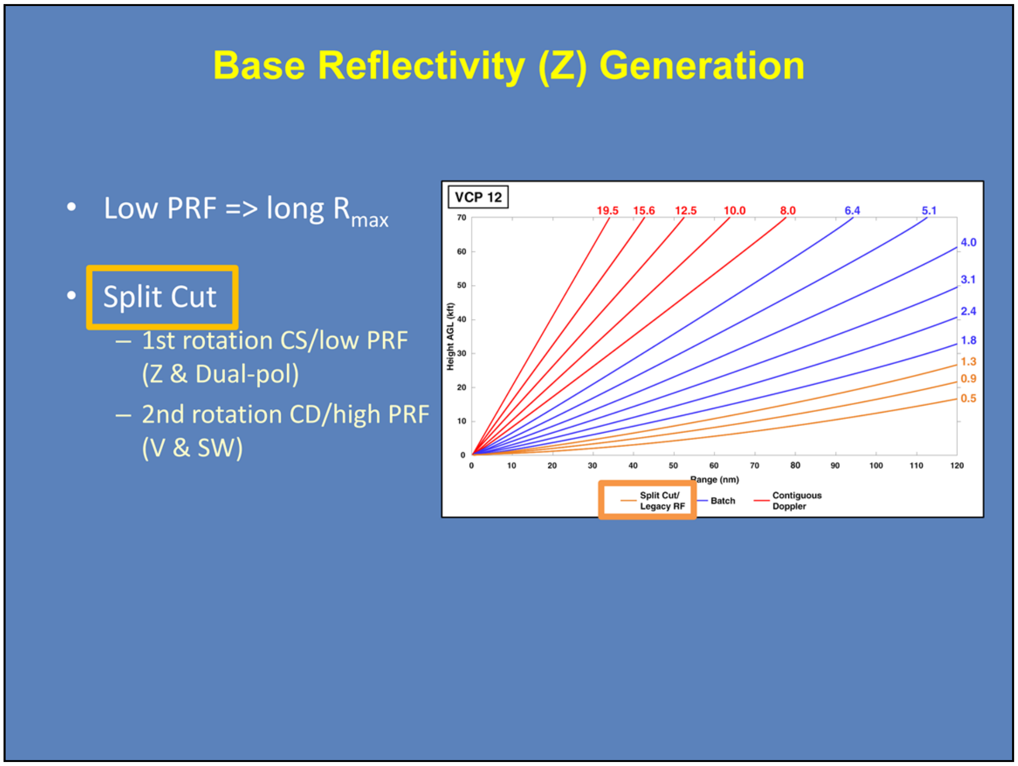


For each range and azimuth, there are multiple pulses used to generate base reflectivity. The returned power for these pulses is averaged for each .25 km range bin, then converted to Z using the Probert-Jones radar equation. The Z value is next converted to dBZ for product generation. For the Split Cuts, 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.



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.

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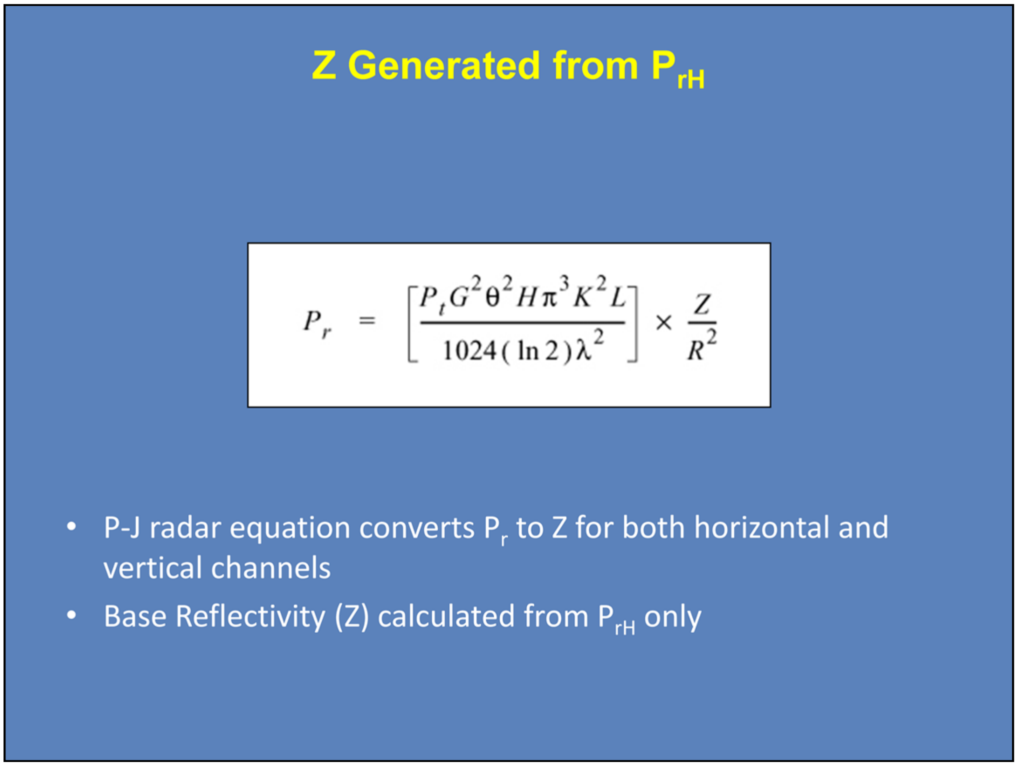

Base reflectivity is calculated from the average returned power, that is then converted to reflectivity from the Probert-Jones radar equation. Now that the WSR-88D has been upgraded to dual-polarization, this conversion from returned power to reflectivity is performed on both the horizontal and the vertical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

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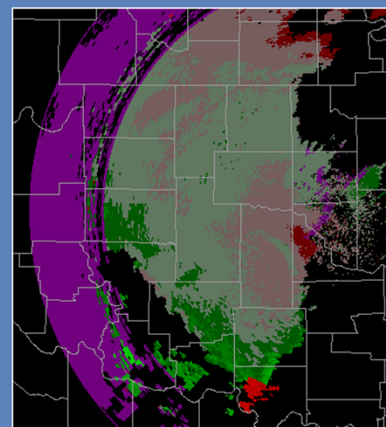
Base Velocity (V) Generation

- 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
- Pulse pair processing
  - Phase changes between successive returned pulses averaged



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.

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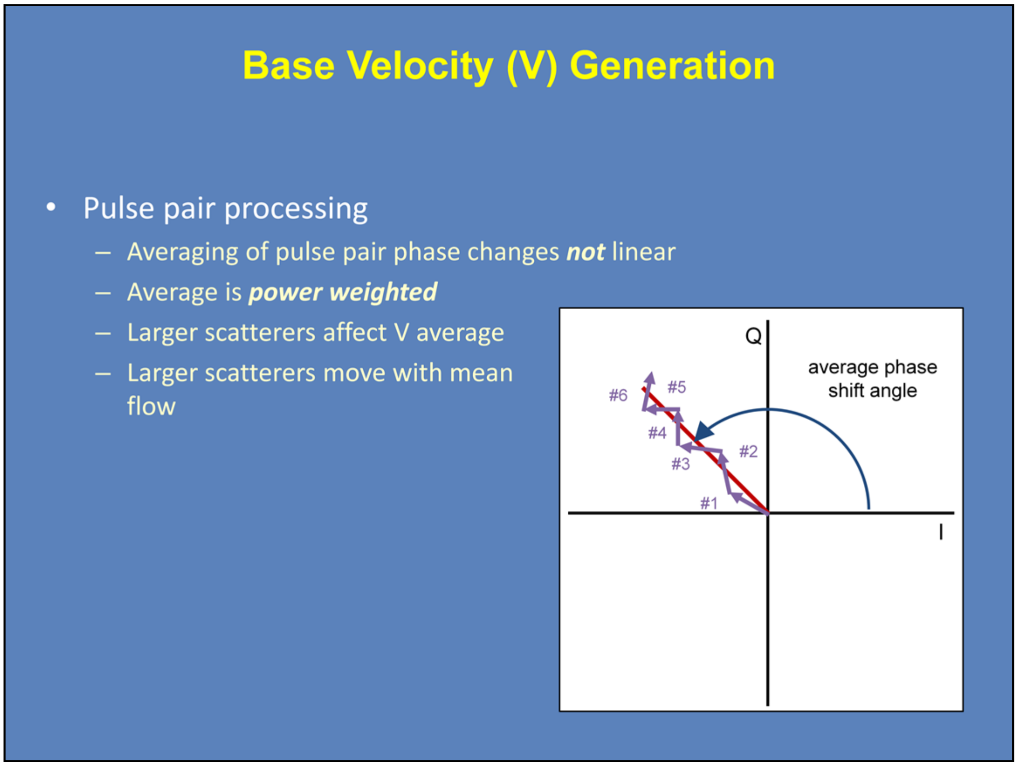

Instead of a linear average of pulse pair phase shifts, the average is weighted toward those pulses that return higher power. This means that the larger scatterers in the volume will have a greater influence on the velocity estimate, and the larger scatterers are more likely to move with the mean flow.

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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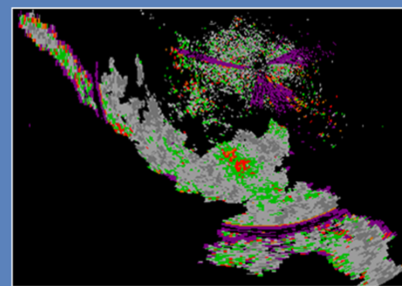
Base Spectrum Width (SW) Generation



- 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.

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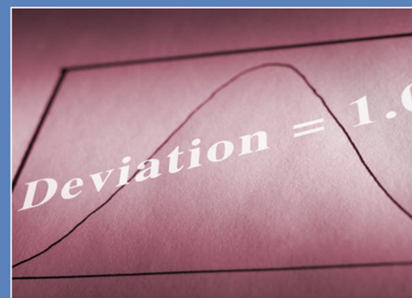
Base Spectrum Width (SW) Generation

- 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.

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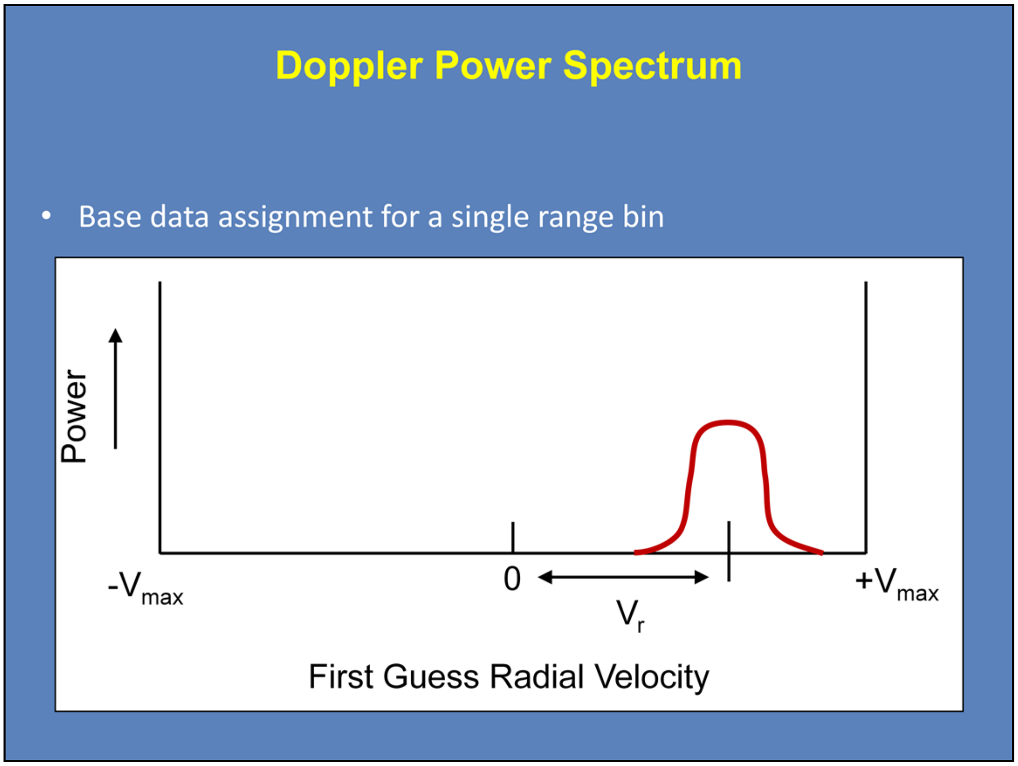

The Doppler Power spectrum represents the base data analysis process for a single range bin. The power and velocity information from a series of pulses are converted to points known at “spectral coefficients”. A bell curve is fit to these coefficients. The average returned power (thus reflectivity) is 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.

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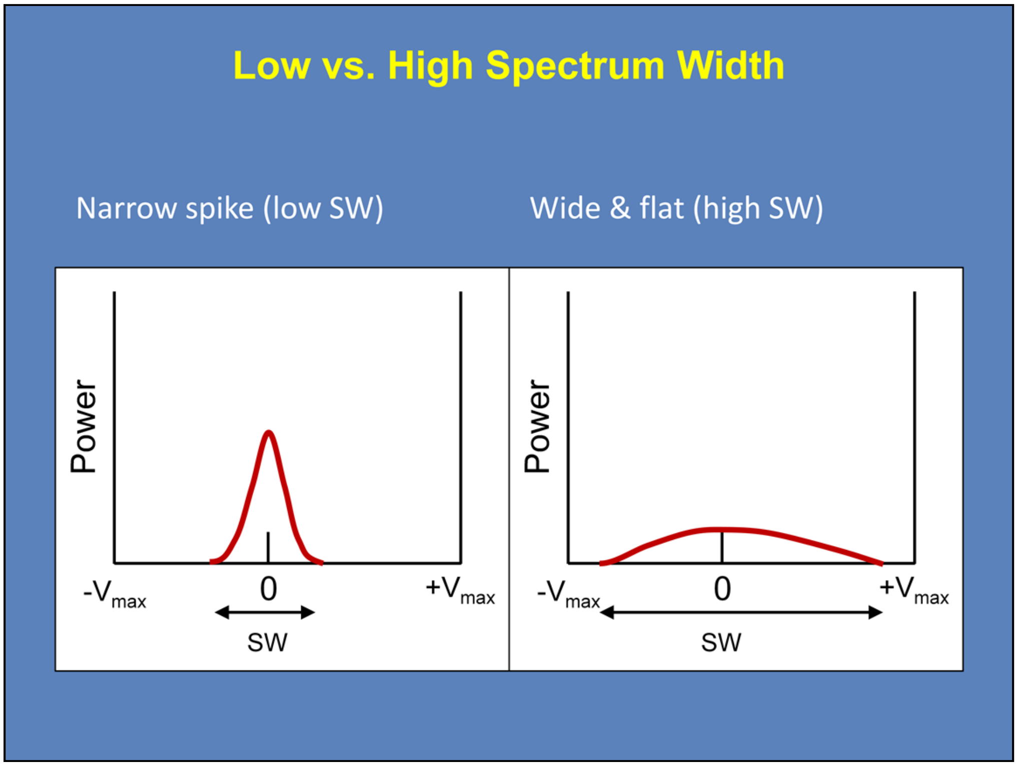

The magnitude of spectrum width will vary depending on the shape of the power spectrum. Returned pulses from ground clutter will likely have strong power and near zero velocity (upper left image). There is minimal variation in pulse pair phase shifts and the Doppler Power Spectrum curve is narrow and 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.

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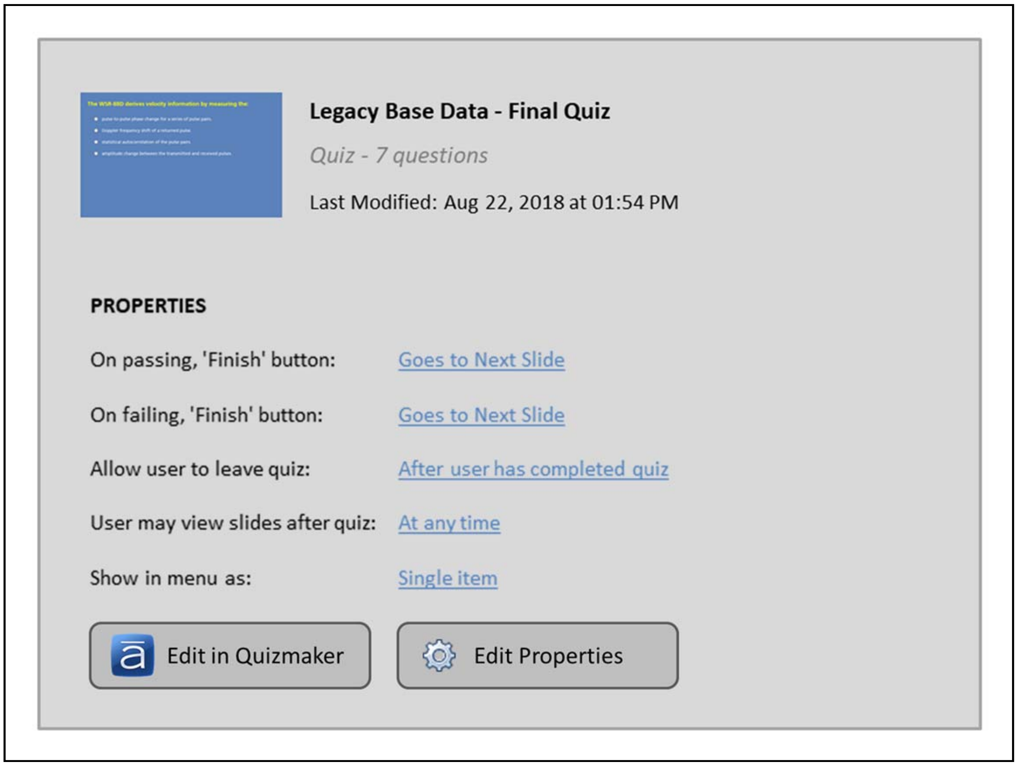
Legacy Base Data - Final Quiz
Quiz - 7 questions
Last Modified: Aug 22, 2018 at 01:54 PM
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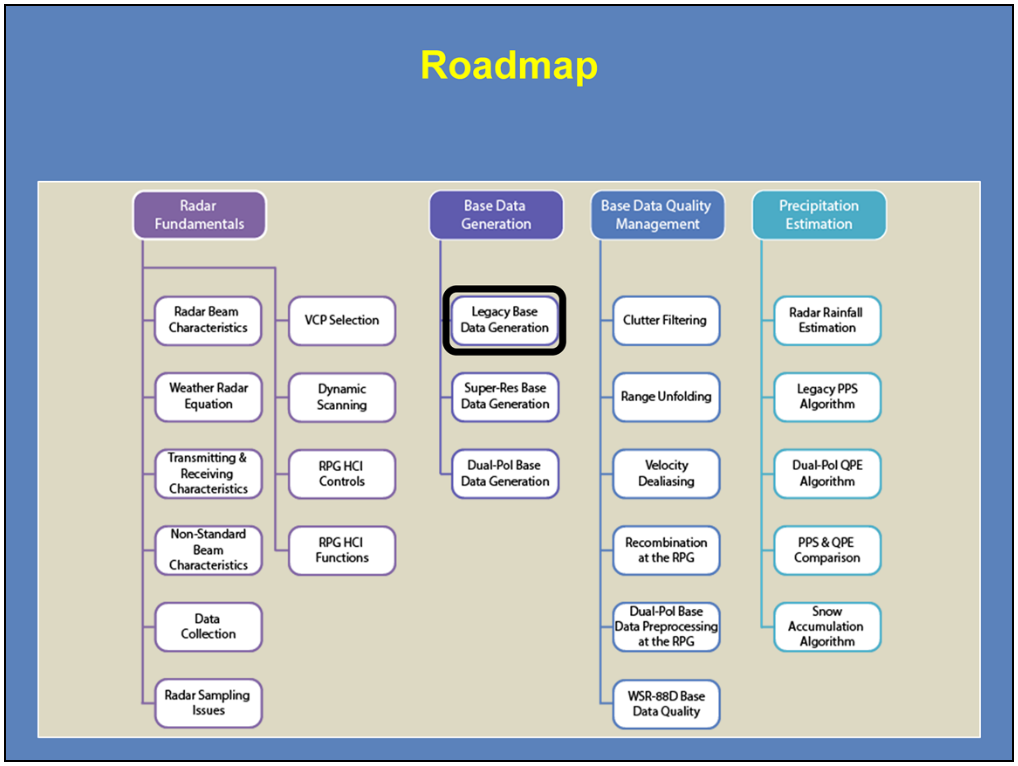

This concludes the lesson and here is the “roadmap” with your current location.

Welcome to this lesson on super resolution base data generation.

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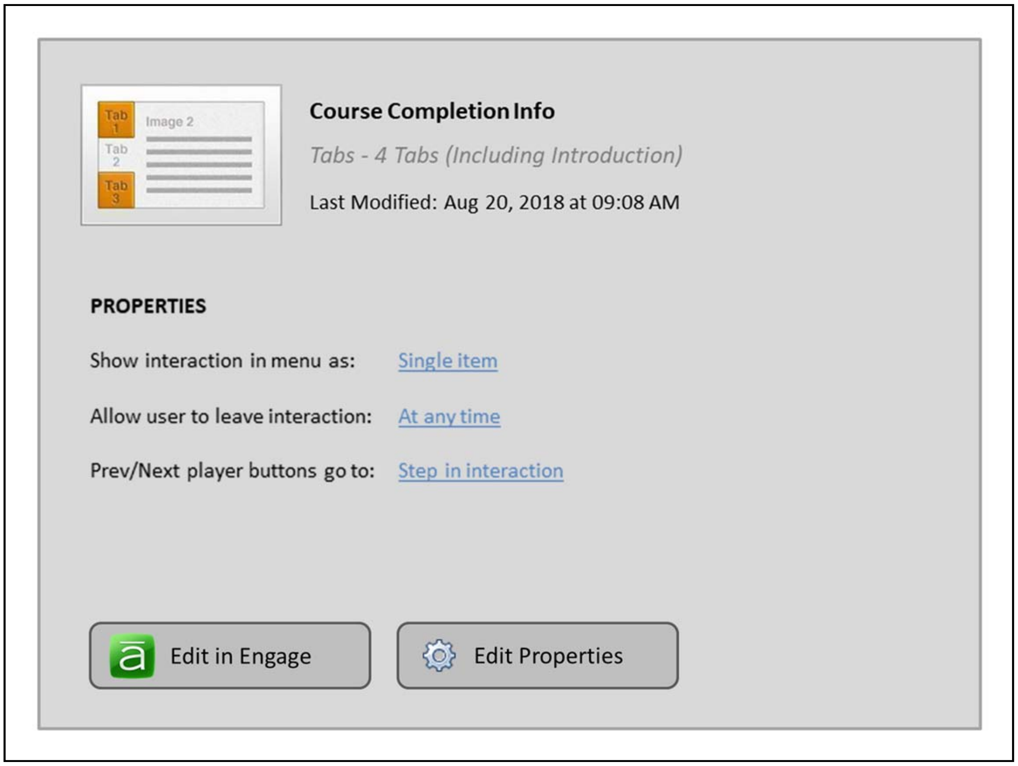
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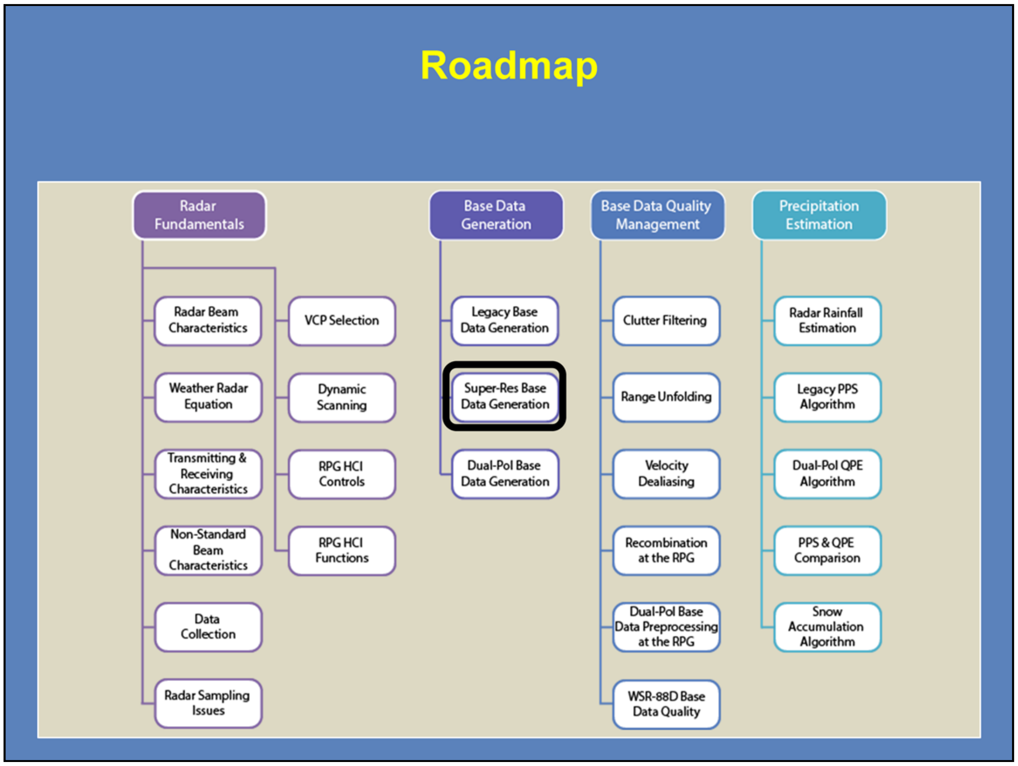

Here is the “roadmap” for this topic in the Radar & Applciations Course, with your current location annotated.

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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 for this lesson. Read it over and click the next button to advance to the next slide.

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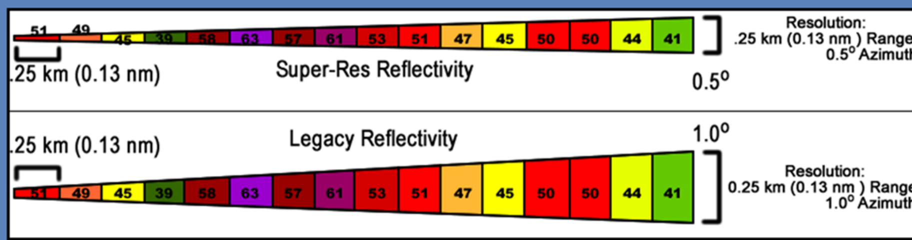
Super Resolution Signal Processing



- Super Resolution: 0.5° azimuth for legacy base data on Split Cuts
- How to narrow azimuthal resolution to 0.5°?
  - Overlapping radials
  - Data windowing
- "Effective" beamwidth
  - Physical beamwidth (single pulse) plus the antenna is moving

Super resolution data are defined as having a 0.5° azimuth. This resolution is only available 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, let's start with the different types of beamwidth. The physical beamwidth of ~1.0° presented previously is based on the antenna being stationary. Antenna motion produces a smearing of the data which leads to a concept known as the effective beamwidth.

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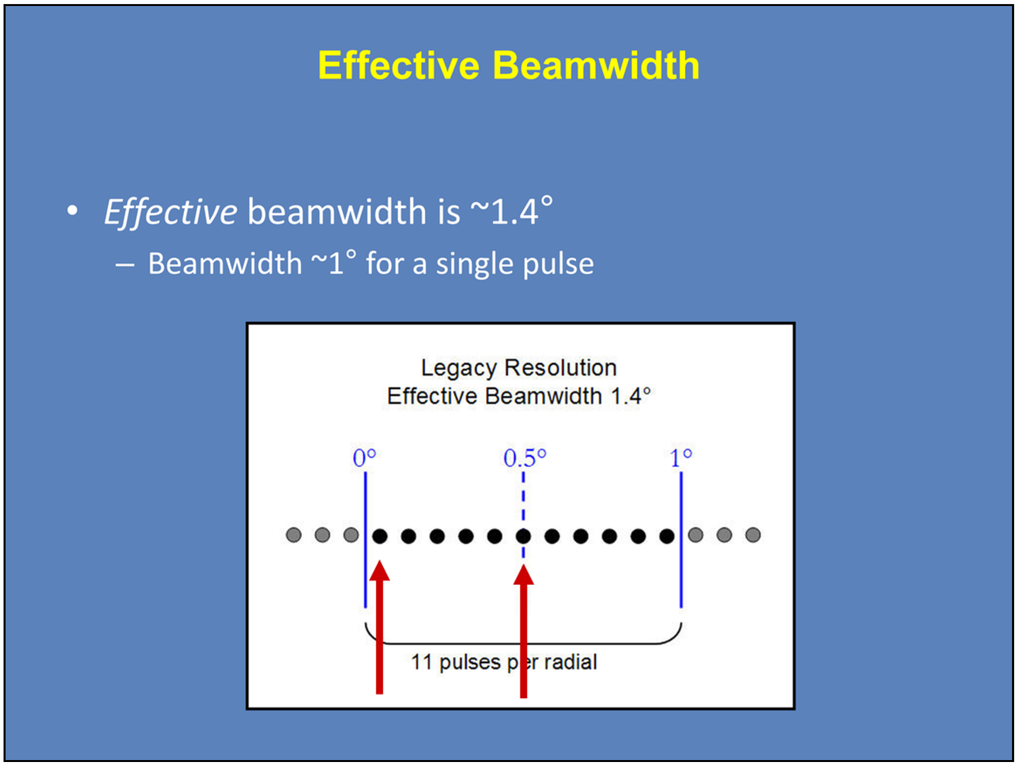
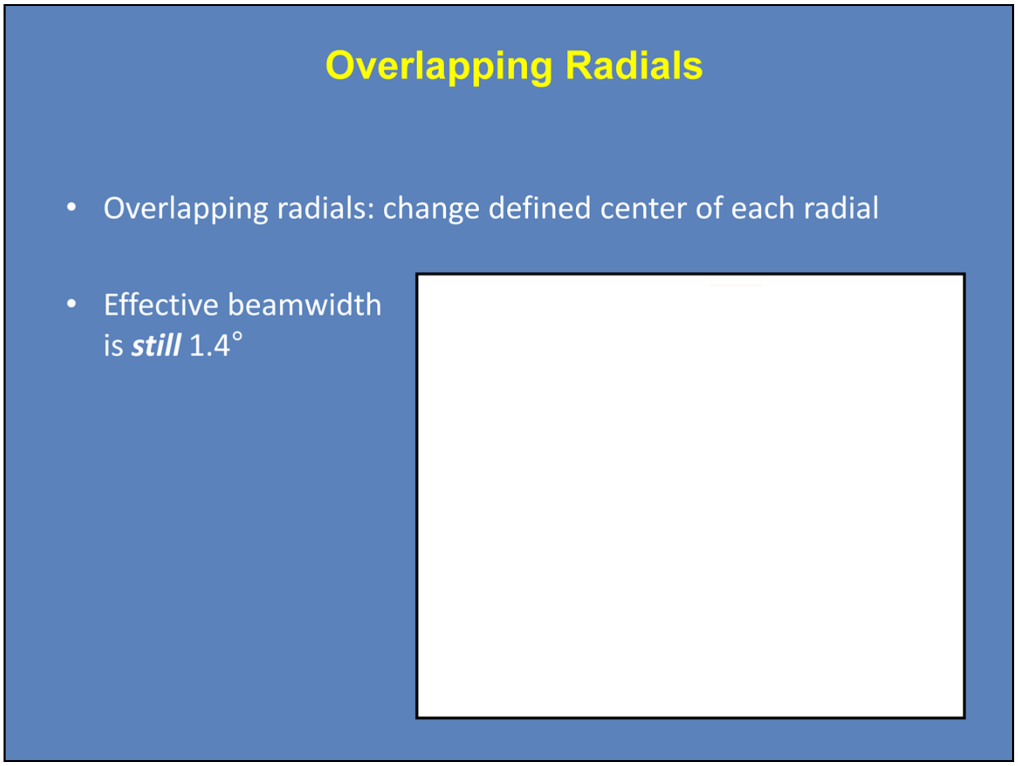
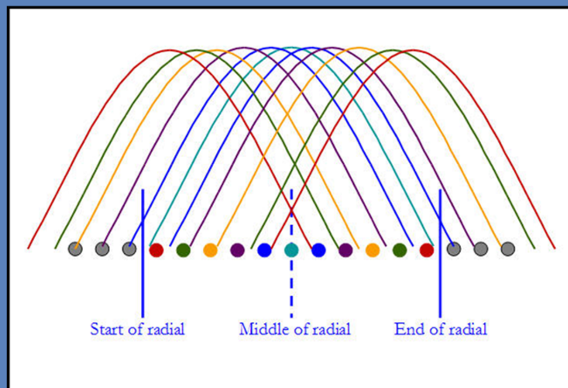


In order for a pulse to be used for the base data estimate for a radial, the beam centerline must be somewhere within that radial. In this example, each dot represents the location of the beam centerline for a single pulse. 11 pulses fall within this simplified 1° radial in this example. As the antenna rotates, the pulse with a centerline that is just on the inside edge of this radial still has a physical beamwidth of 1°. The beam samples a volume that is both inside and outside the radial in these locations. The pulse only samples the radial’s contents when the center of the pulse is the center of the radial. This process of including pulses that capture base data outside the radial increases the physical beamwidth to what we call the effective beamwidth. For the WSR-88D, the effective beamwidth is about 1.4°.



The overlapping radials technique simply changes the definition of the center of each radial. The radial centers for legacy resolution are 0.5°, 1.5°, 2.5°, etc. For super resolution data, the centers change to 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 sampled volume outside of each 0.5° radial continues to be too large. Simply choosing new radial centers is not sufficient. The effective beamwidth must also be narrowed.

Data Windowing



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

The radar can narrow the effective beamwidth using a signal processing technique called data windowing. By applying a weighting function to the pulses included in a particular radial, data windowing can give more value to some pulses than others. If all pulses are given the same weight, that technique would be called a rectangular window. The graphic on the slide demonstrates what a rectangular window looks like.

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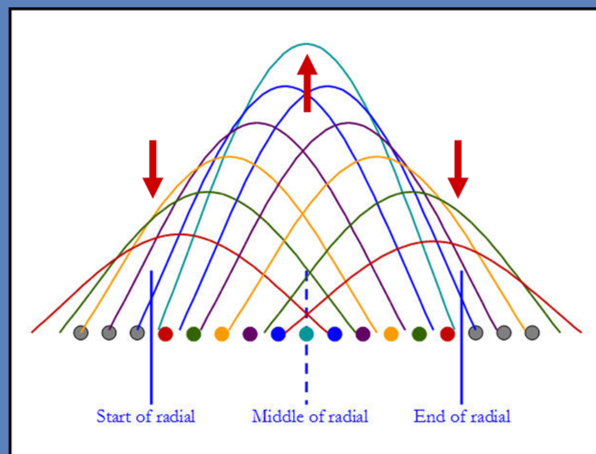
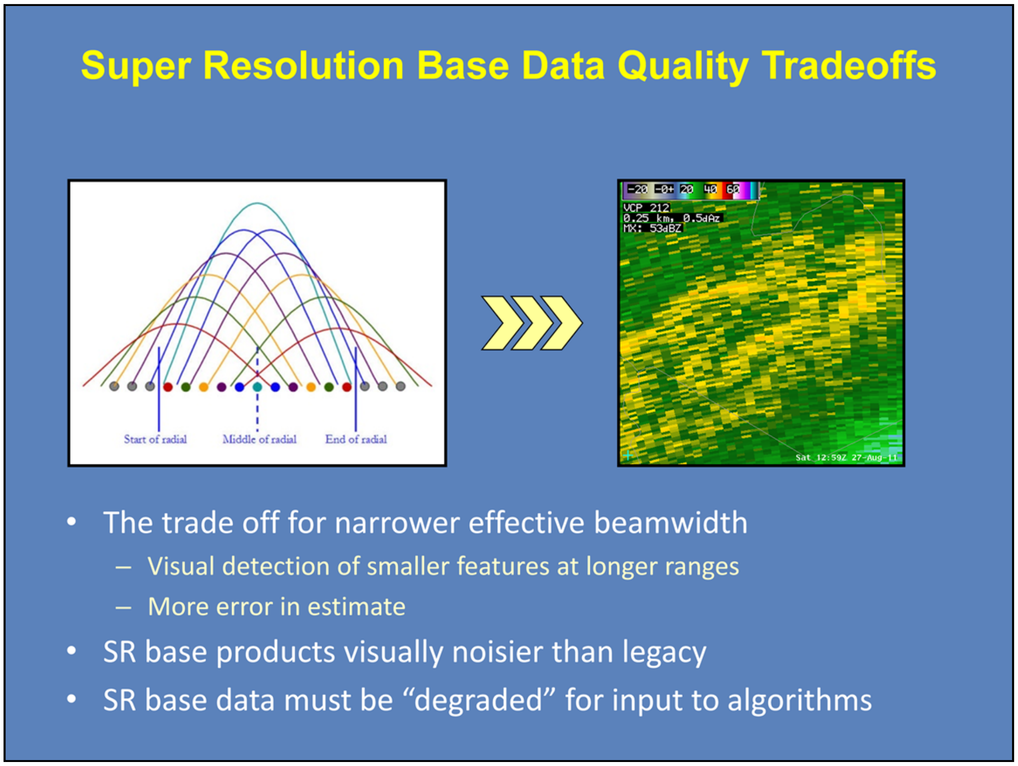
Data Windowing

- Window with pulses close to center more weight than pulses away (Von Hann)
- Narrows effective beamwidth
- Increases variance of estimate; data noisier



A rectangular window will not reduce the effective beamwidth. Instead, you need to use a weighting function that gives more emphasis to pulses that collect data towards the center of the radial. This window is called a Von Hann window. So, pulses with centers near the center of the radial get more weight. Pulses collected near the edges get less weight. This technique reduces the effective beamwidth, but also introduces more variance (or error) in the estimate. The error results due to some pulses being overemphasized while others are under emphasized. The end result is super resolution products are noisier than those that have legacy resolution.



There are two primary tradeoffs related to the quality of super resolution base data. The first tradeoff balances the ability to detect smaller features at further ranges with the increased errors that result. Super resolution base data are visually noisier than legacy resolution data. The second tradeoff with super resolution data is that many of the RPG algorithms were not designed to ingest super resolution base data. As a result, super resolution data must be "degraded" back to legacy resolution before they are input into these algorithms.

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Summary

- WSR-88D Specs:
  - Single pulse beamwidth: 1°
  - Effective beamwidth: 1.4°
- Overlapping radials:
  - Change radial center locations
  - Insufficient by itself to reduce effective beamwidth
- Windowing techniques:
  - Rectangular window (all pulses have same weight)
  - Von Hann window (pulses near center weighted more)
- End result:
  - Non-rectangular window allows for narrowing beamwidth products
  - Super resolution data 0.5°
  - Data noisier because of windowing

In summary, the WSR-88D has a physical beamwidth of 1 degree. However, antenna rotation makes that an effective beamwidth of 1.4 degrees. To produce super resolution base data, first the overlapping radials technique is used to change the radial center locations. However, this change isn't sufficient by itself. The radar must also apply a windowing technique that puts more weight on pulses collected near the center of the radial. By combining the overlapping radials and windowing techniques, super resolution data with an azimuth of 0.5 degrees are possible. Super resolution data contain more noise than legacy resolution products and must be processed back to legacy resolution before used as input for many RPG algorithms.

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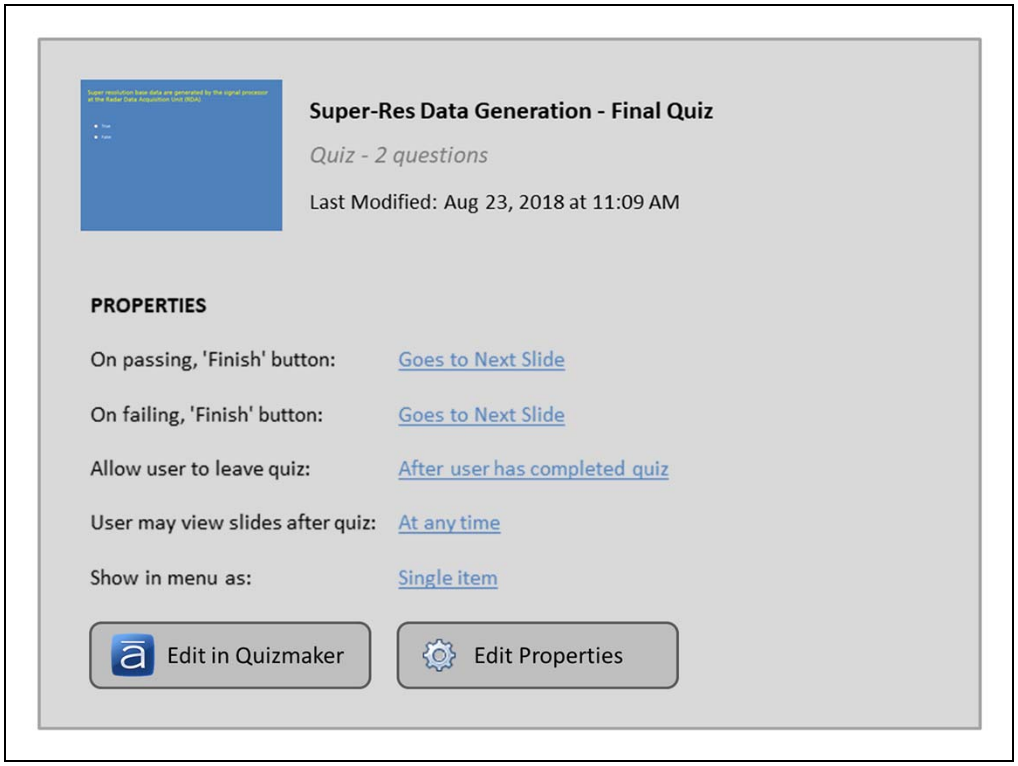
Super-Res Data Generation - Final Quiz
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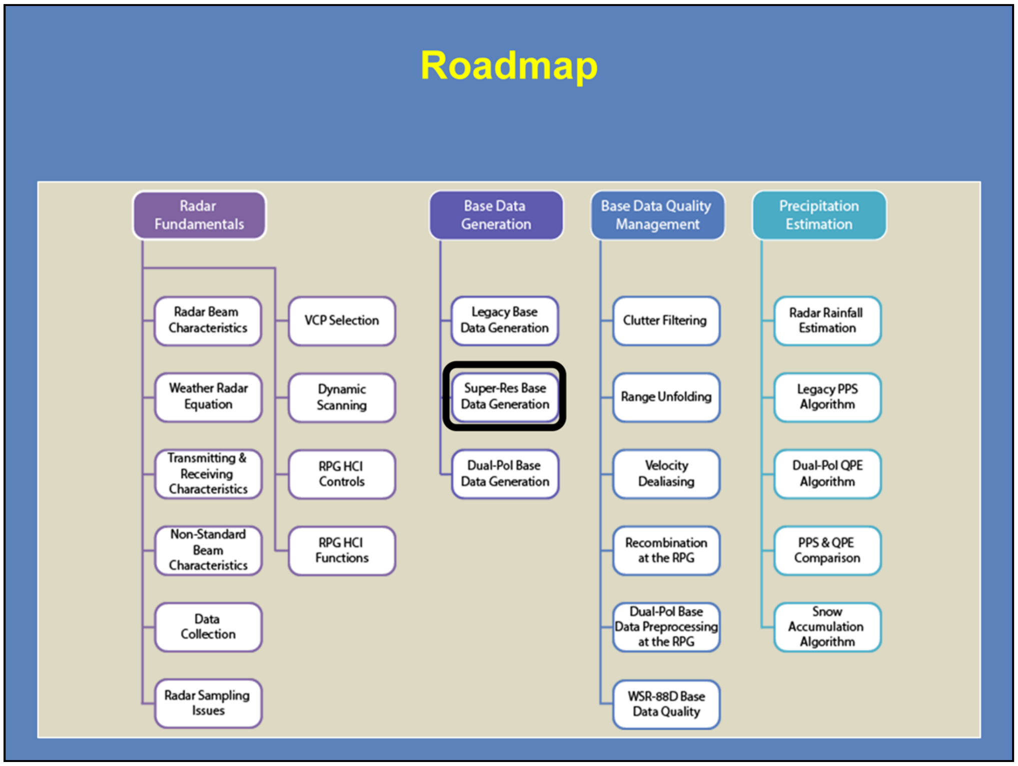

This concludes this lesson. You can use the roadmap shown to see what topics come next after this lesson. Once you are done, click the exit button to conclude this lesson.

Welcome to this lesson on Dual Polarization Base Data Generation. Let's get started!

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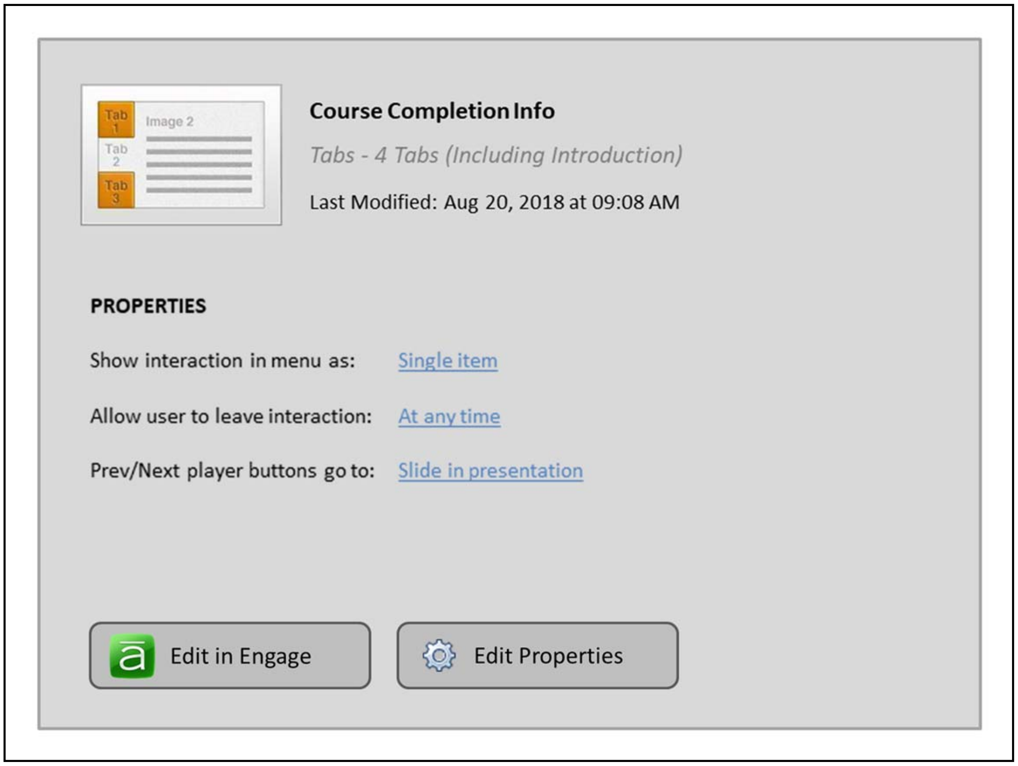
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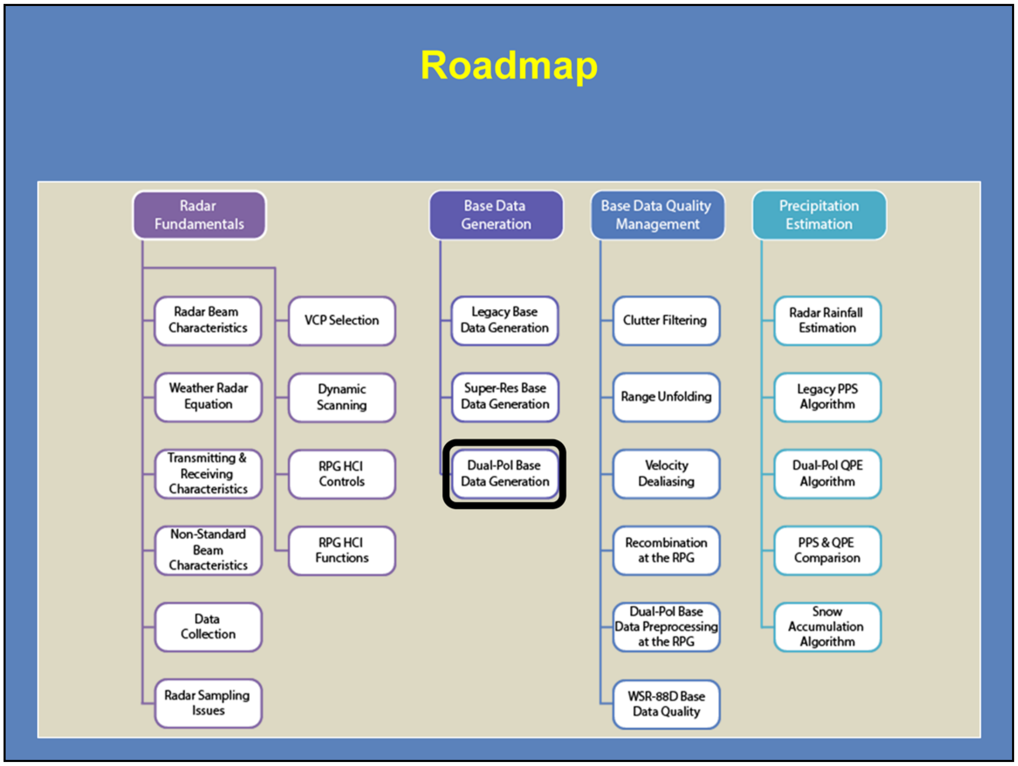

Here is a “roadmap” for the RAC Principles topic with your current location annotated.

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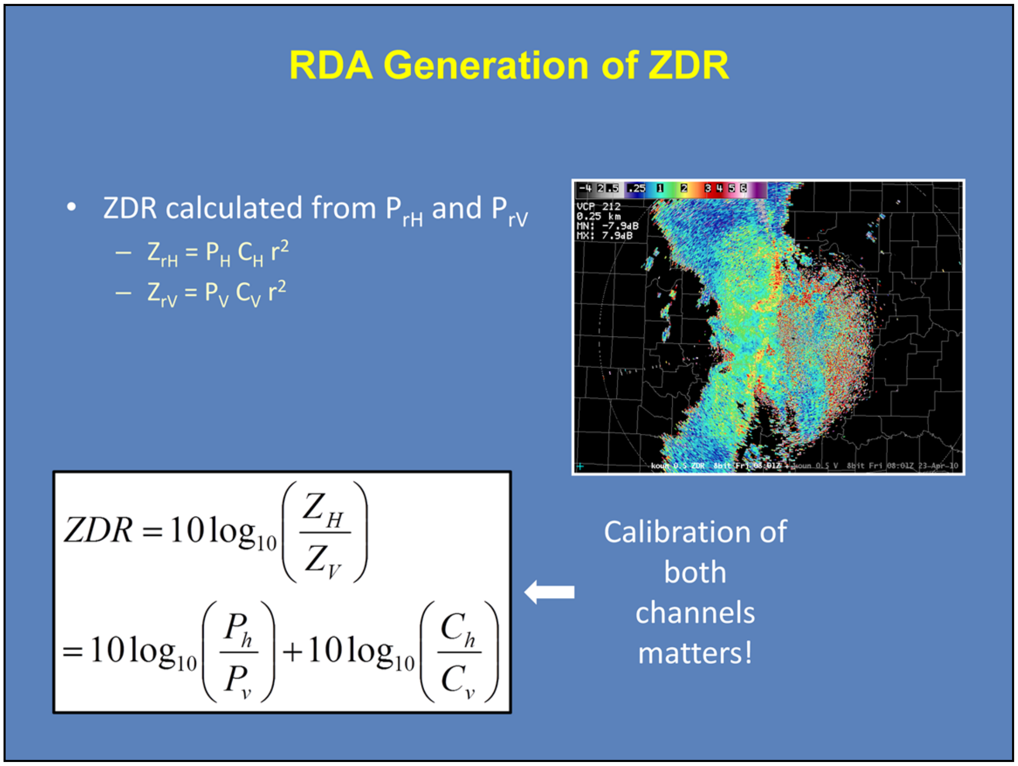
Learning Objectives

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)

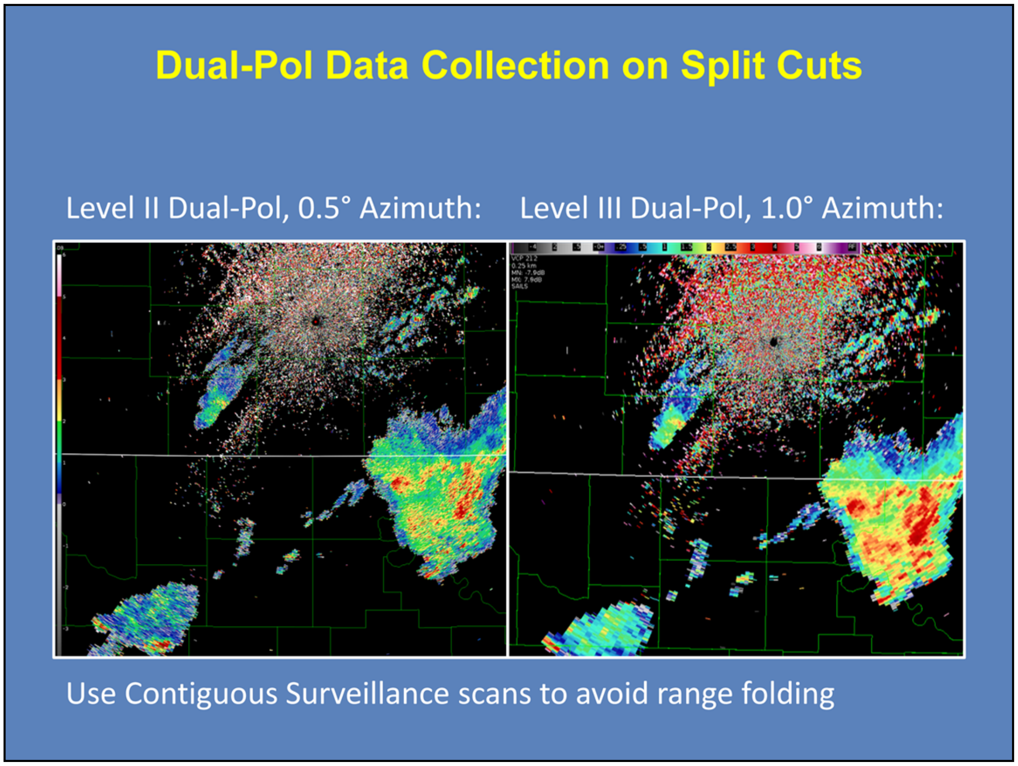
2. Identify the similarities and the differences between SW and CC

3. Identify the radar volume characteristic that has the greatest impact on the magnitude of KDP

There are 3 objectives in this lesson. Take a look at the objectives and advance to the next slide when you are ready to proceed.



Remember from the Probert-Jones radar equation that the Reflectivity value is equal to the returned power, times the range squared, and times a constant based on the radar's calibration. The radar calculates Differential Reflectivity the same way, except that ZDR uses the returned power from both the horizontal and vertical channels. The ZDR equation can be written as seen on the screen. When the reflectivities are substituted with returned power, the radar constants and the range, the range terms cancel out. This final version, with the power and radar constants separated out, underscores the importance of regular calibration of both channels for the accurate measurement of Differential Reflectivity. There are other, operational implications for ZDR calibration that will be presented later on in RAC.



So let's talk a little bit about how Differential Reflectivity and the other dual-pol data are collected based on the waveforms used on a particular tilt. On split cuts, Contiguous Surveillance pulses collect ZDR. Using the CS cut avoids multiple tripping, or range folding, issues. The Level II data from the RDA has 0.5° azimuthal resolution on the split cuts just like the legacy base products. At this resolution, ZDR and the other dual-pol data appear much noisier than the legacy base data. An example of what ZDR Level II data look like is shown on the upper right. The same data after recombination for display in AWIPS is shown on the lower right. The recombined products have 1.0° azimuthal resolution and are noticeably smoother. More on the recombination process will be discussed in a later lesson in this topic.

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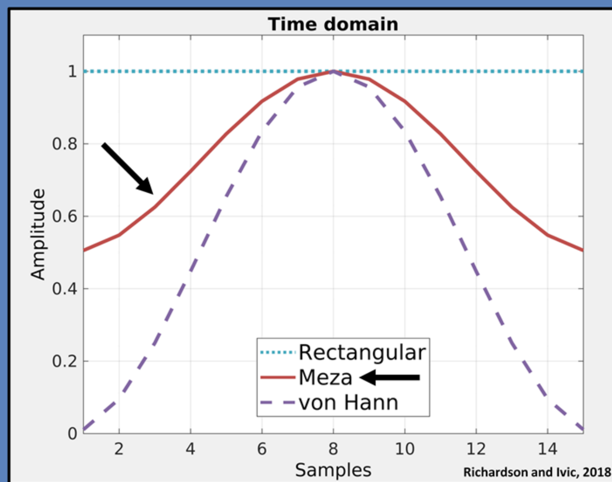
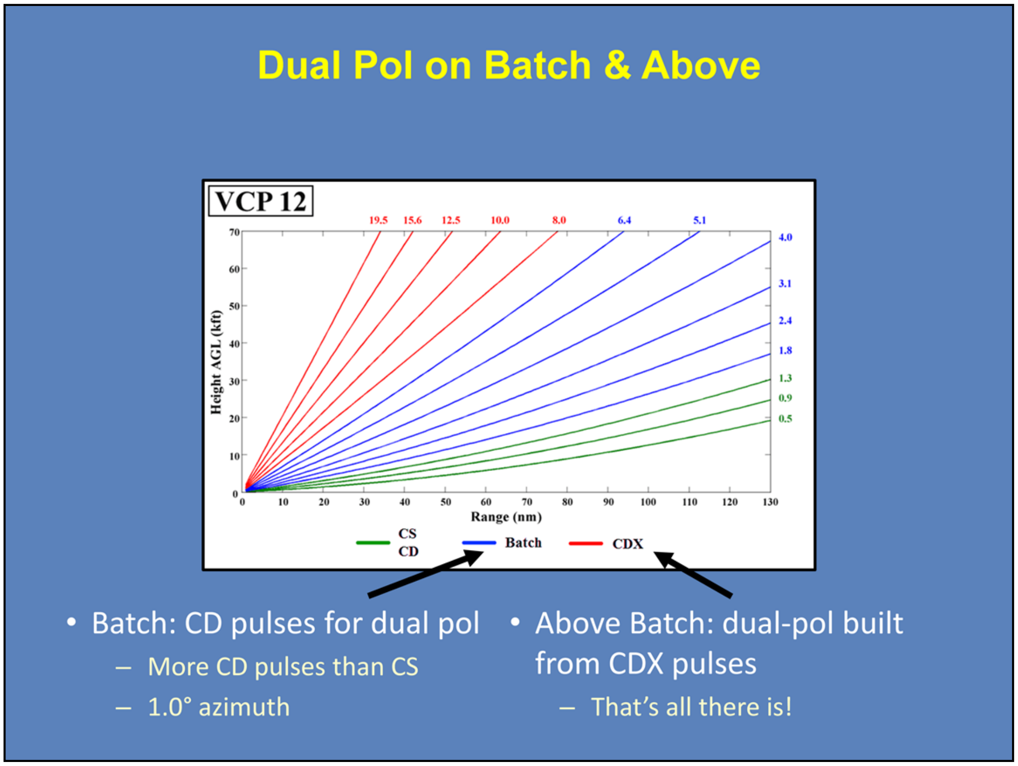
Dual-Pol Data Windowing (Meza Vs. von Hann)

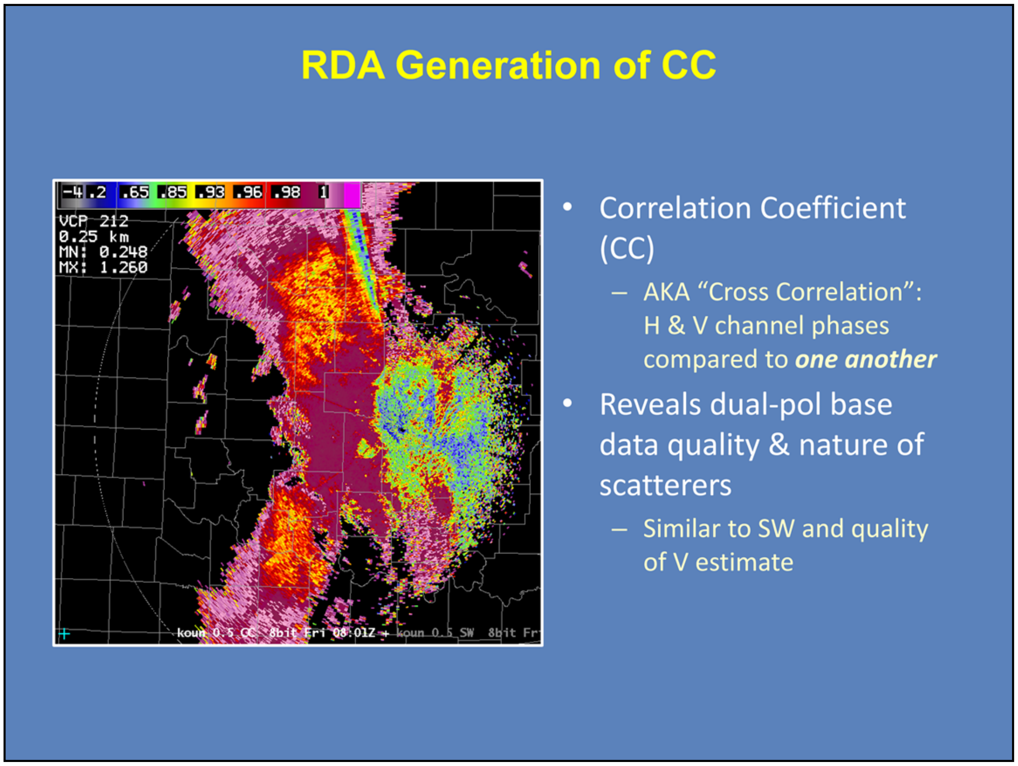


CS pulses use the Meza window to generate Level II dual-pol radials transmitted to the RPG

We should say one more thing about dual-pol data collection on the split cuts. Because the dual-pol base data are so noisy at 0.5 azimuthal resolution, a different windowing technique has been implemented for these data. This different data window, called a Meza window, provides more smoothing than the von Hann window used for the other base data. However, this window results in a smaller reduction of the effective beamwidth. Since the dual-pol data are recombined prior to building the base products and algorithm ingest, that issue isn't significant. Radar operators should notice less noisy dual-pol data (in both Level II and III products) when comparing dual-pol data from RDA Build 18 to that of previous builds.

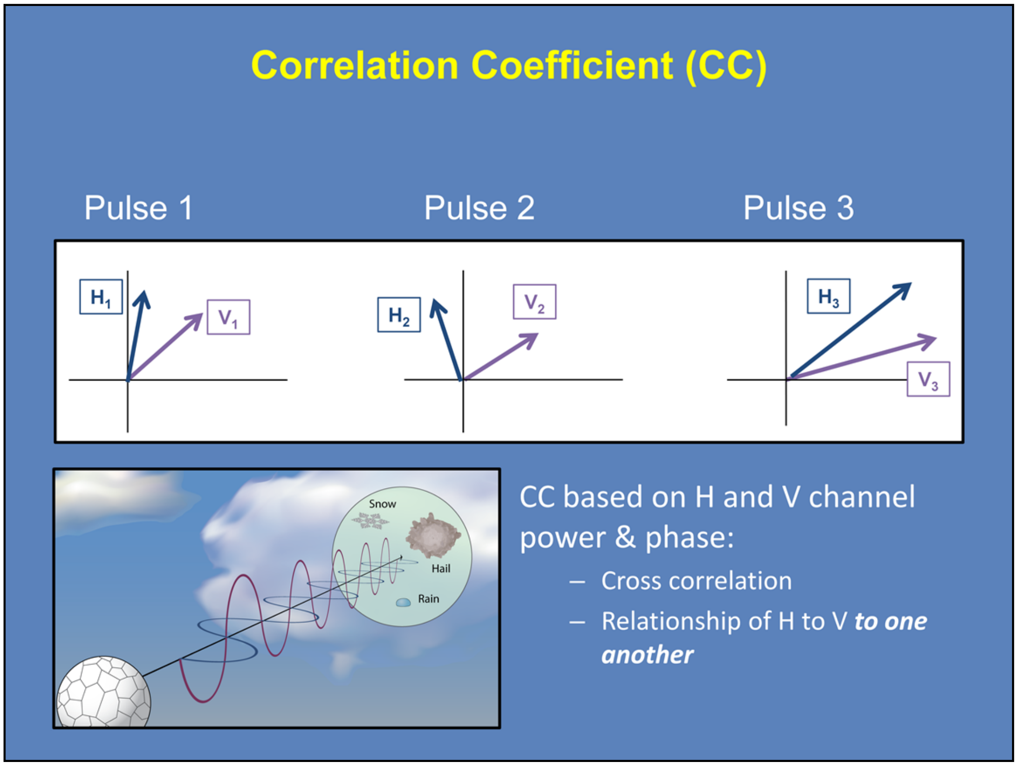


For the Batch elevations, the antenna makes a single rotation alternating between low PRF, Contiguous Surveillance, and high PRF, Contiguous Doppler modes. The dual-pol data on the batch cuts are built from the Contiguous Doppler pulses for each radial since there are more of them. Range folded data are possible on the dual-pol products at these elevations as a result. All of the base data are collected using an azimuthal resolution of 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 there is.

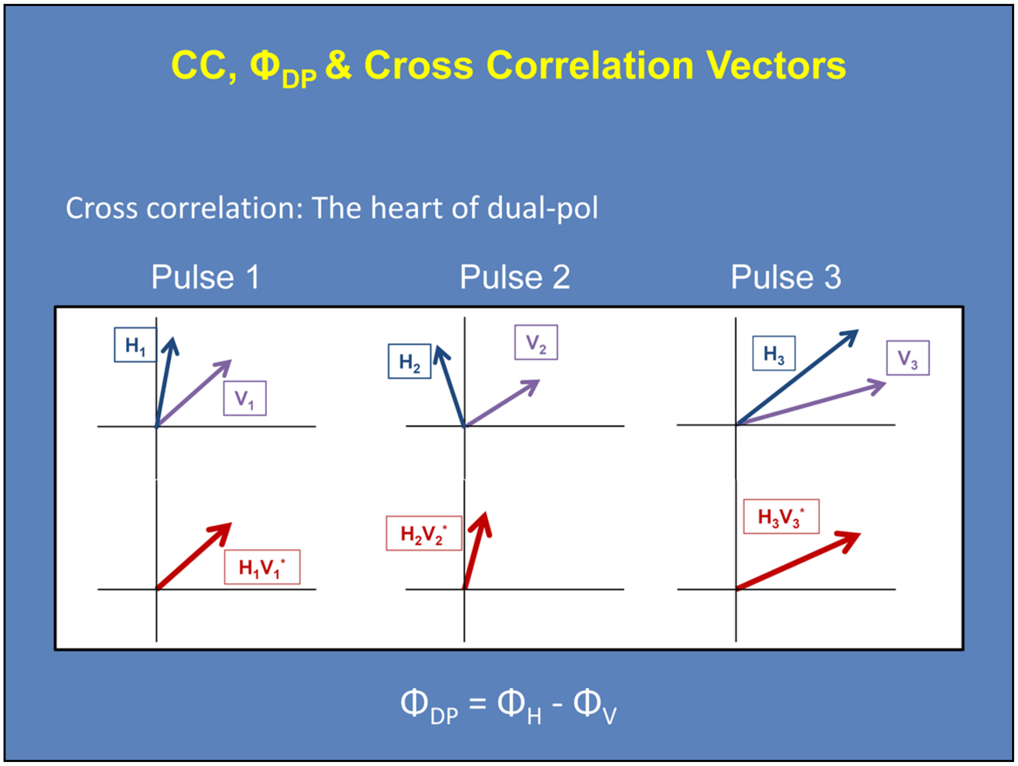


Correlation Coefficient (CC) measures the consistency of the H and V returned power and phase with one another for each pulse. This "cross correlation" looks at how the returned power and phase of one channel compares to the other channel. If the consistency is high (for example, say stratiform light 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, CC is similar to Spectrum Width. 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. We will discuss the similarities between CC and SW in more detail later in this lesson.



For each pulse, the returned power and phase from the H and V channels can be compared to one another. This kind of comparison is know as a cross correlation. The magnitude of and angle between the H and V vectors matter and, fortunately, can be determined by vector multiplication.



These Cross correlation vectors are at the heart of dual-pol base data. The slide shows examples of the horizontal and vertical returned power and phase for three separate pulses. The cross correlation vector for each pulse is shown below the individual vectors and 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: $\Phi_{DP} = \Phi_H - \Phi_V$.

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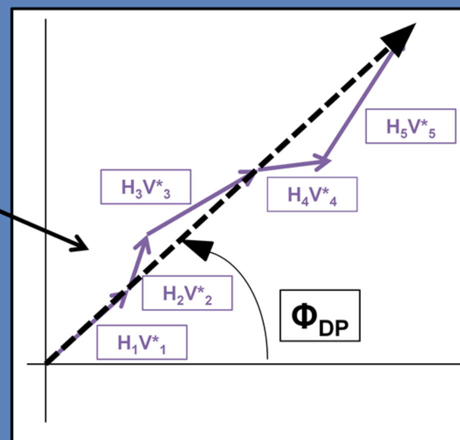
Differential Phase & Other Dual-Pol Variables

- Vectors from multiple pulses
- Sum the cross correlation vectors
- Differential Phase (Φ_{DP}) important for 2 dual-pol variables:
  1. Φ_{DP} for series of pulses part of CC calculation
  2. Φ_{DP} is base data; KDP derived from it



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 (black dashed arrow) is what's needed for the remaining two dual-pol variables. Differential Phase, also called Φ_{DP}, is the angle of this vector sum which is included in the base data generated at the RDA for each range bin.

Differential Phase contributes to two dual-pol variables:

1. As we mentioned on the previous slides, Φ_{DP} for a series of pulses is part of the calculation of CC, and
2. Specific Differential Phase, or KDP, comes from the Differential Phase data as well.

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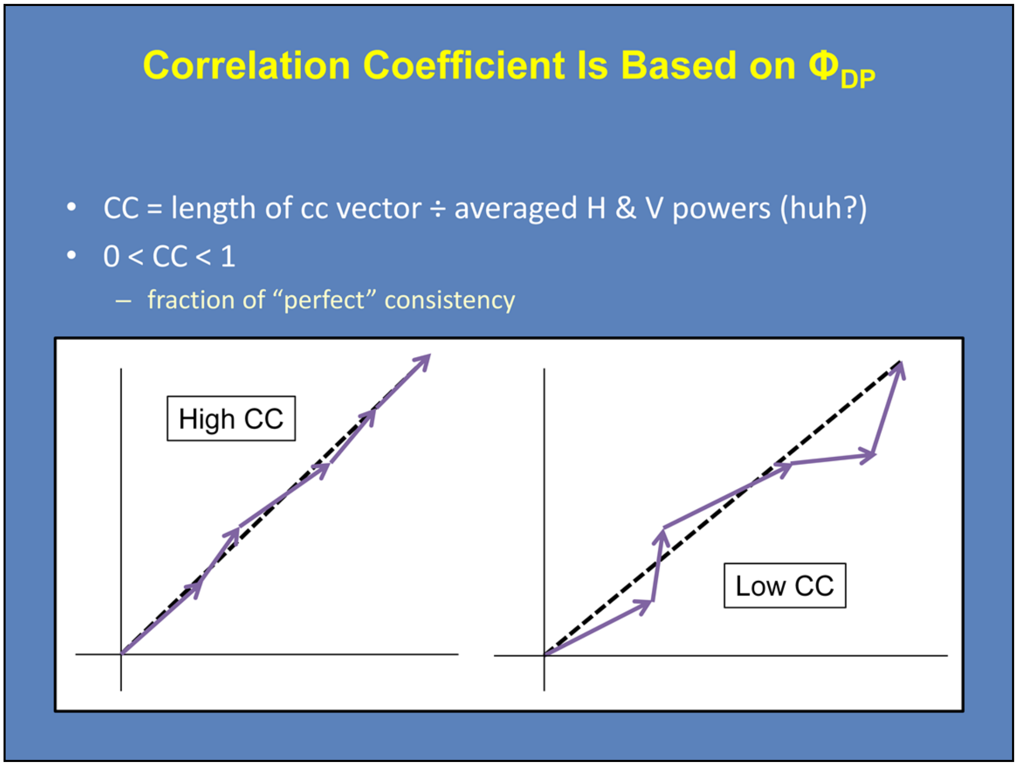

The radar calculates Correlation Coefficient by summing all of the cross correlation vectors into a vector sum. The length (or amplitude) of that vector sum gets divided by the average H and V powers. This calculation captures the variation of the individual cross correlation vectors that contributes to the sum.

The resulting CC value is a unitless number between 0 and 1. Think of it as how close to "perfect" the consistency between the scatterers is. When the scatterers are pure rain, especially stratiform rain, minimal variation between the channels occurs. So, the CC will be close to 1. As the scatterers become more diverse, the CC value will decrease towards 0.

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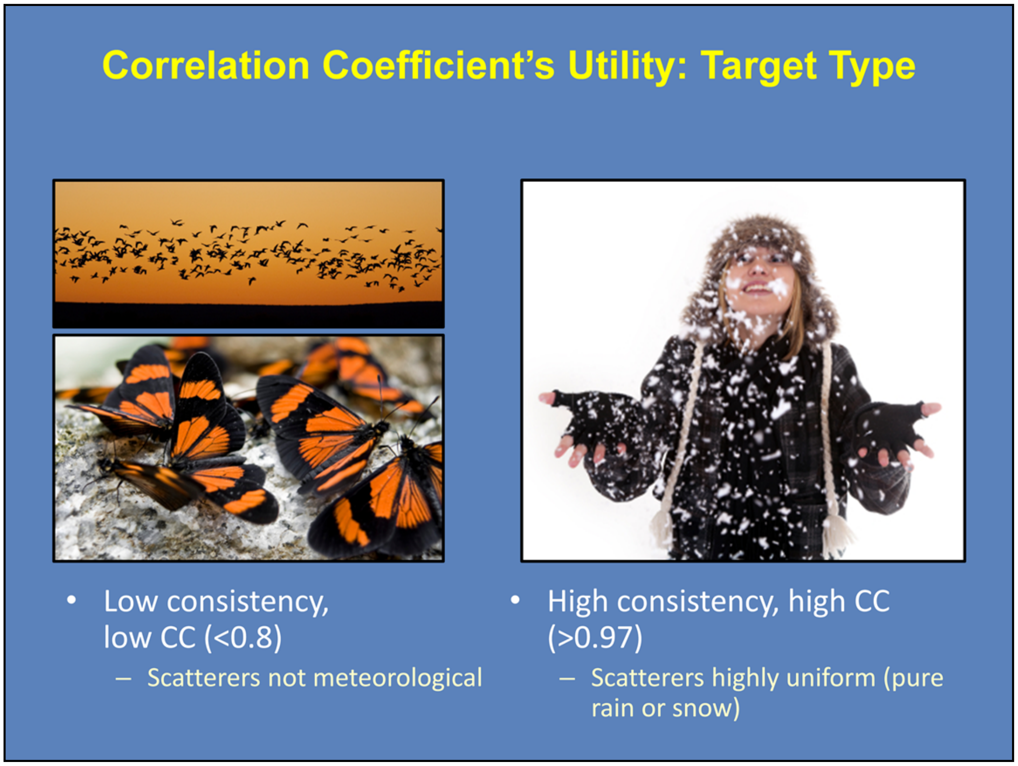

So, what can CC tell us about radar echoes? Well, Correlation Coefficient tells us about target consistency, which provides a clue as to what the scatterers are. When CC is low, say less than 0.8, the consistency between the channels is low. These lower values suggest the scatters are diverse and not meteorological, but likely biological or anthropomorphic in nature. On the other hand, high CC values, say greater than 0.97, indicates a high degree of consistency between the channels. In these situations, the scatterers tend to be nearly uniform in size and shape, such as with pure rain or snow.

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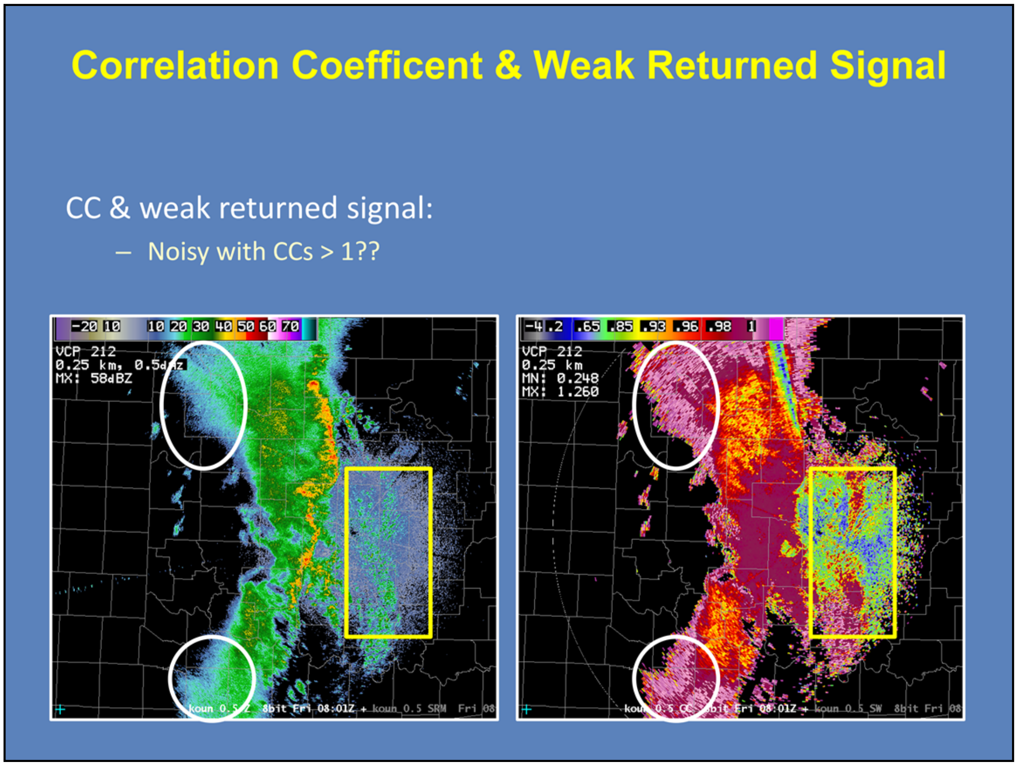

Correlation Coefficient provides an indicator of dual-pol data quality, too. When the return signal is weak, the dual-pol base data will be noisier and less reliable than the legacy base data. CC can help radar operators identify these areas of less reliable data.

CC appears noisy with highly fluctuating values in areas of weak signal. In the boxed area of the graphics shown, the Reflectivity returns are weak and primarily from non-meteorological returns (where CC values are low). You could probably figure that out based on what we've already told you. However, let's look at the two regions contained by the ovals next. These areas also contain weak returns signals, but the CC values are noisy and very high…greater than 1.0. CC values greater than 1.0 result from an estimation artifact that mean the estimate is unreliable at that range bin. The values are purposely shown as greater than 1.0 so that the radar operator will know they are unreliable.

One last thing, weak signal areas at longer ranges are less reliable than those at closer ranges. CC values help the radar operator visualize this relationship better than Reflectivity because Z is range normalized while the returned power is not.

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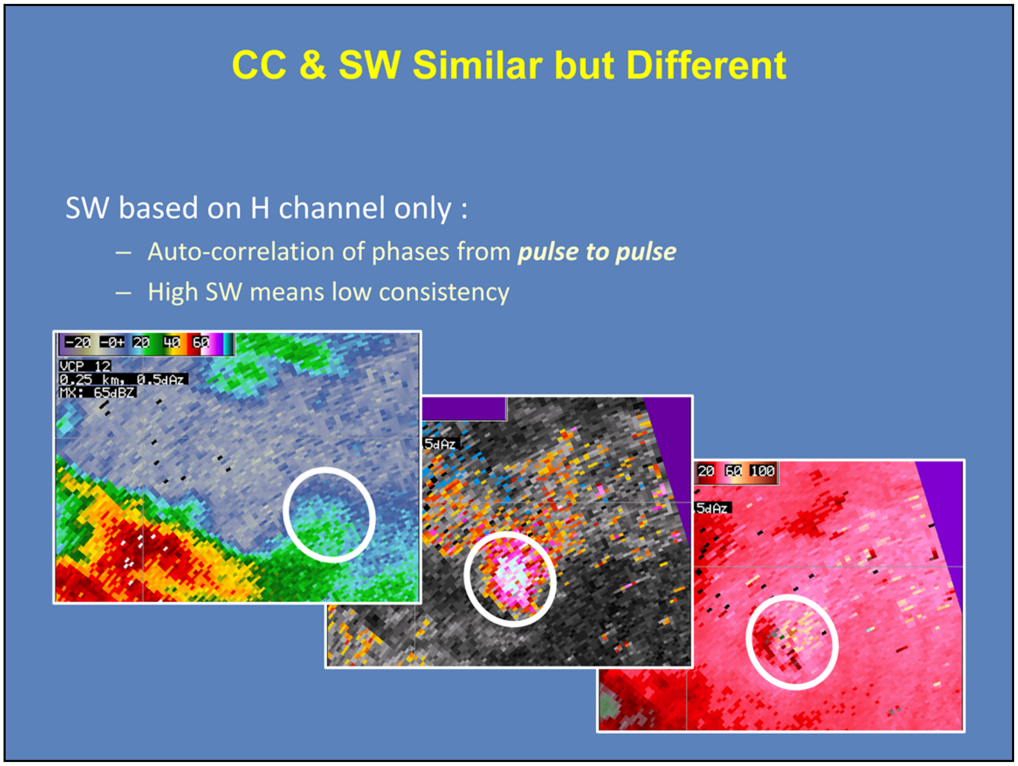

Correlation Coefficient and Spectrum Width are analogous to each other, but they have some important differences. Remember that Spectrum Width uses data from the horizontal channel only and provides a sense of the Base Velocity data quality. Spectrum Width gets calculated from auto-correlation, not cross correlation, by comparing the phase shift from one pulse to the next. The greater the phase shift variation, the greater the Spectrum Width. So, higher Spectrum Width implies lower consistency in the velocity data. The circled area encloses a weak signal region close to an intense supercell. The middle image shows Spectrum Width is high due to the low signal (in the left image) and likely turbulence in the area. Notice how the radial velocities in the right image are noisy, too. So, Spectrum Width has an inverse relationship to data consistency.

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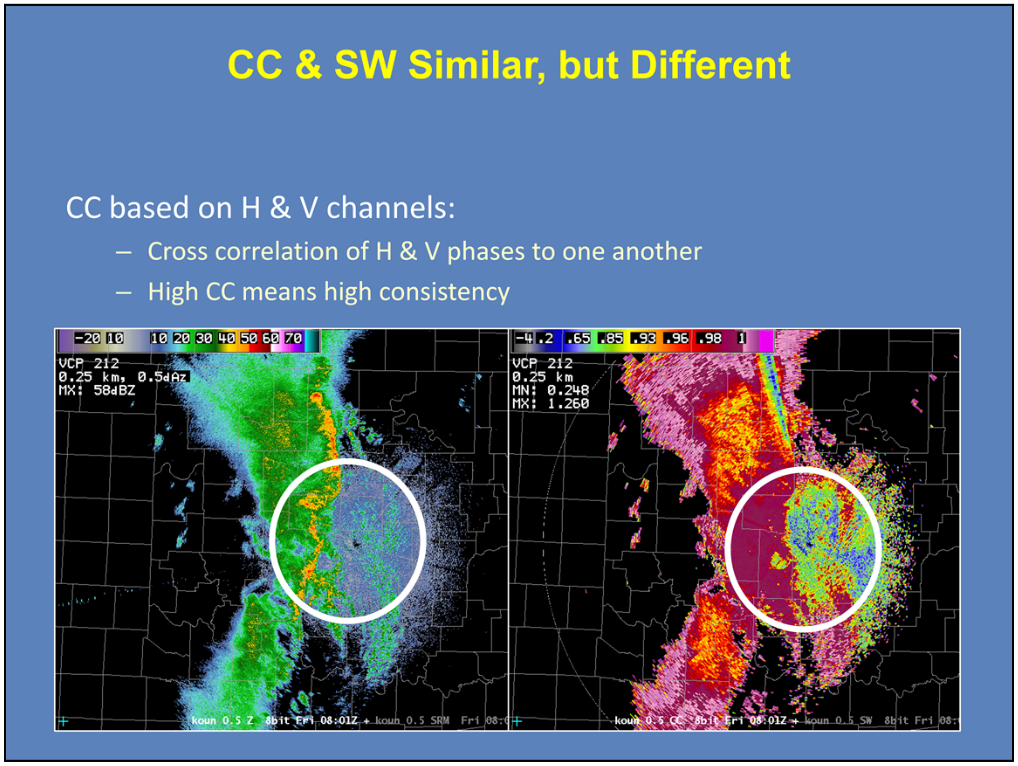

Unlike Spectrum Width, CC gets calculated from both the horizontal and vertical channels and tells us about the consistency of the sampled scatterers. Correlation Coefficient calculations derive from cross-correlation, not auto-correlation, which compares phases from the horizontal and vertical channels from the same pulse. The greater the consistency between the channels in strong signal, the values increase to 1.0. So, consistency and CC have a direct relationship.

The circled areas in the two graphics capture both precipitation and clutter near the radar. The CC values associated with precipitation is higher than that compared to the clutter and biological returns to the east of it.

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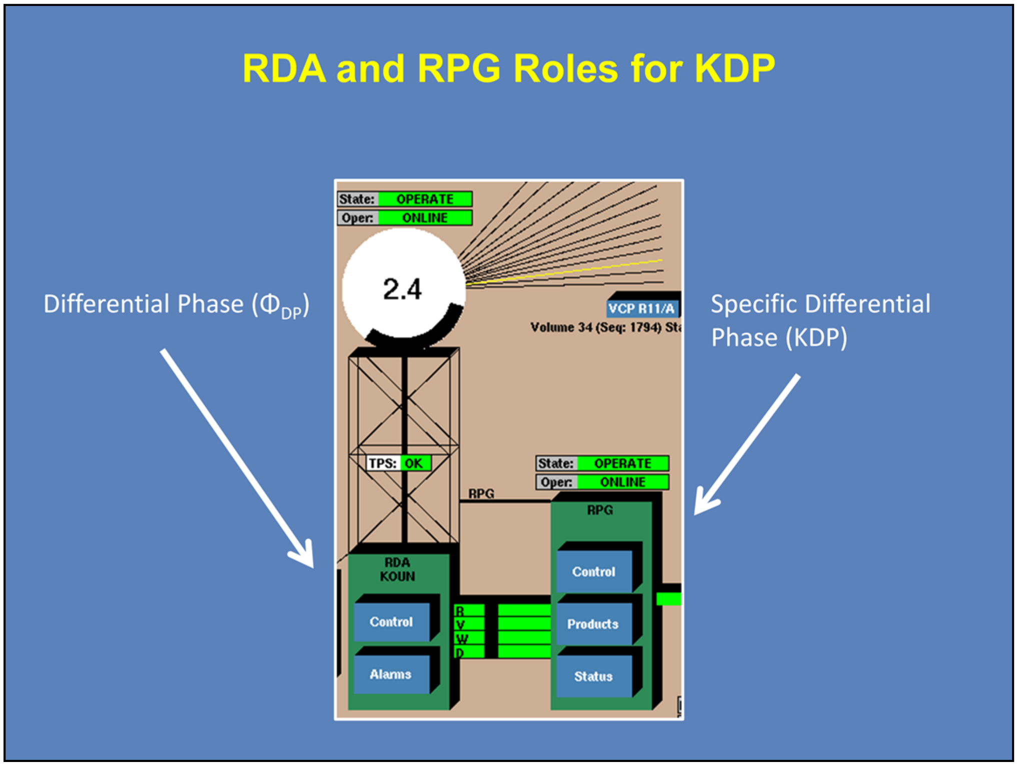

Another dual-pol base product is Specific Differential Phase, or KDP. While KDP is technically derived from the Differential Phase, or $\Phi_{DP,}$ base data collected at the RDA, it is the most fundamental form of that data which are meteorologically useful to operational forecasters. So, even though Specific Differential Phase is generated at the RPG, it is considered a base product in terms of meteorological interpretation.

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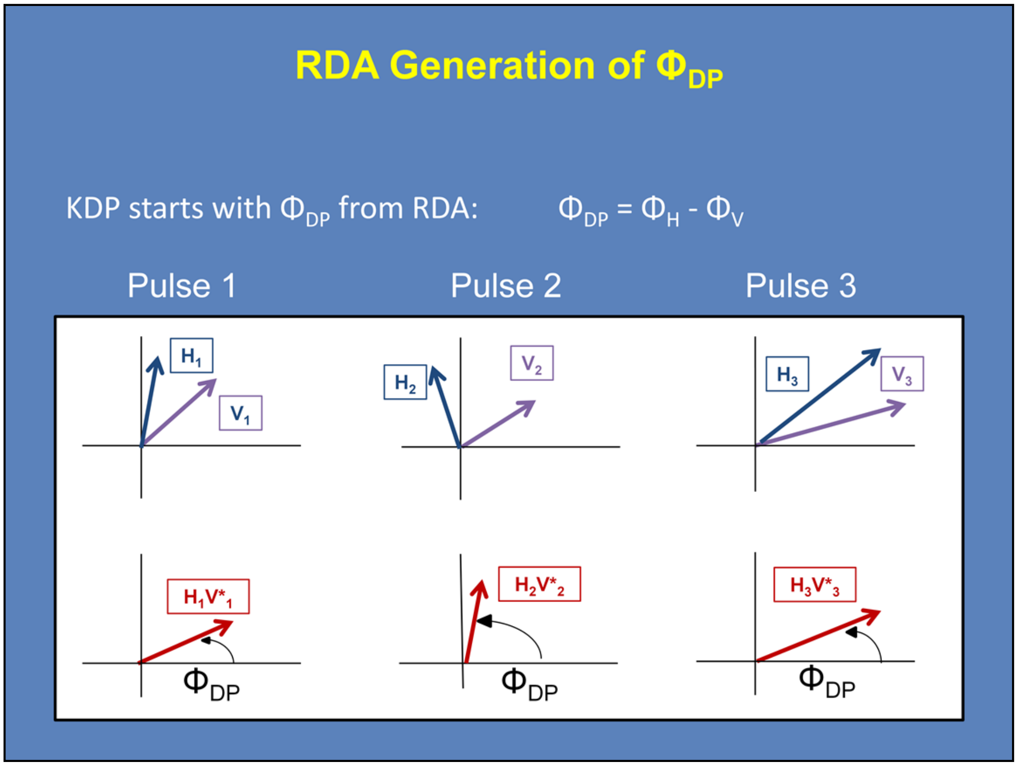

Specific Differential Phase benefits meteorologists because it tells us something about the medium that the beam is propagating through. To understand KDP, let's go back to Differential Phase. Recall that Φ_{DP} is the angle of the cross correlation vector, or horizontal phase minus the vertical phase.

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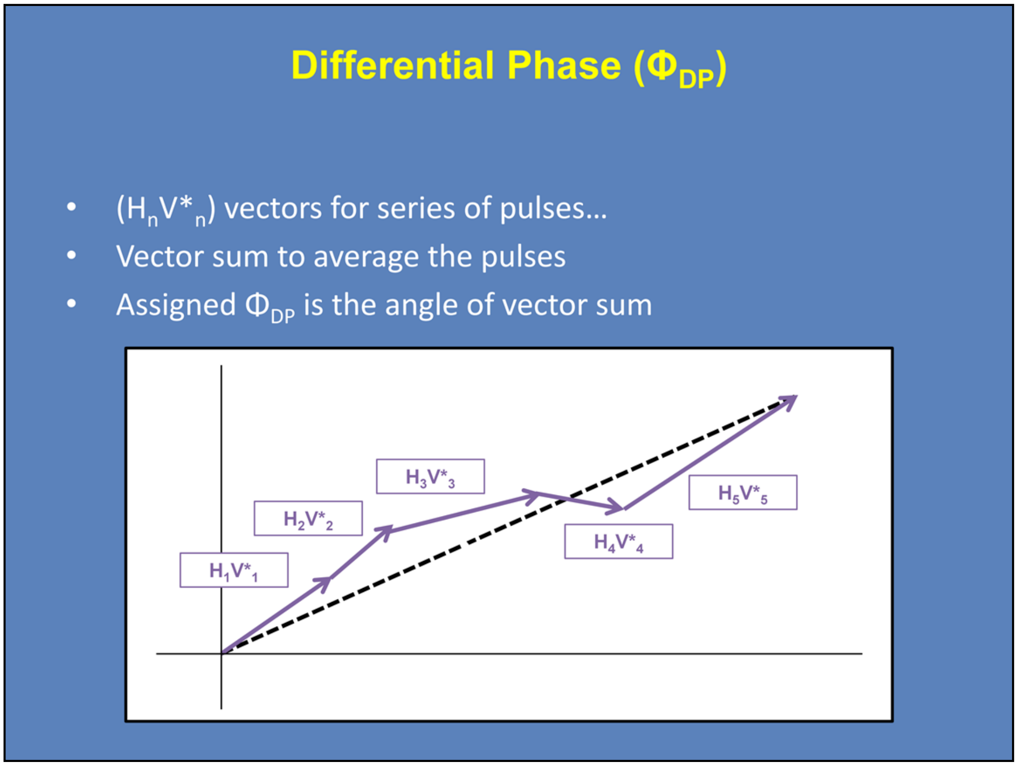

The differential phase, or Φ_{DP}, value assigned as base data comes from the vector sum of the individual pulse cross correlation vectors in the radial. The angle of this vector sum is the assigned Φ_{DP} for that range bin. Since Φ_{DP} is an angle, Differential Phase has a unit of degrees.

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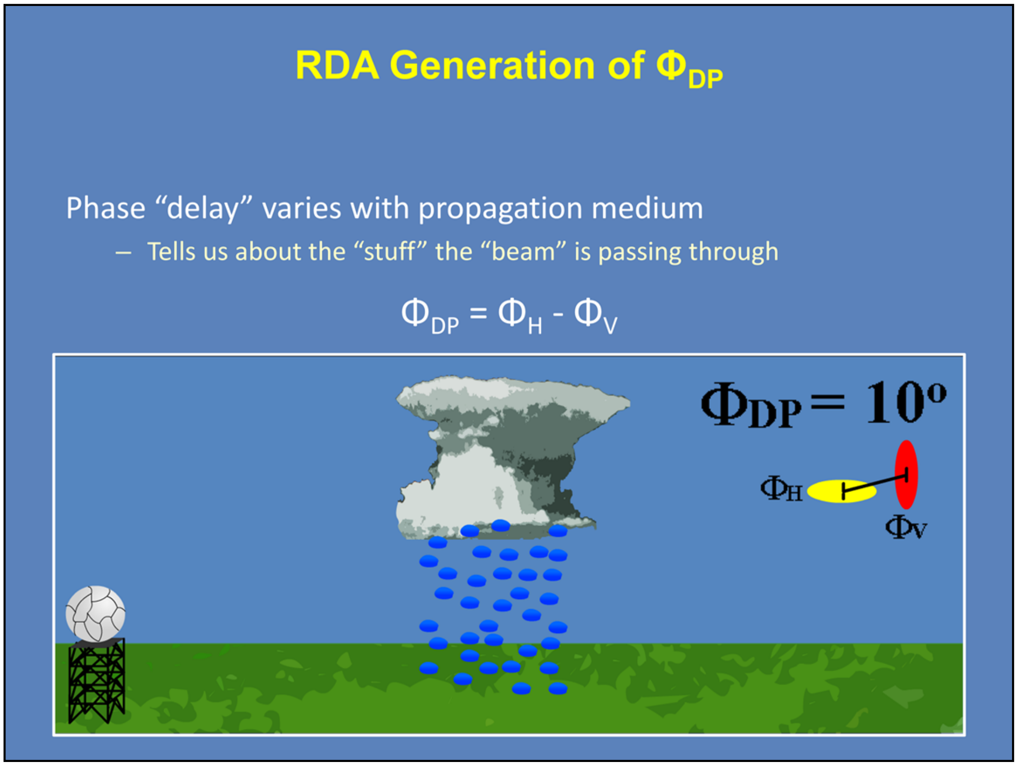

As a radar pulse propagates through the atmosphere, the returned pulse has an apparent delay in its phase. Depending on the atmospheric medium (such as clear skies or precipitation), the extent of the delay changes. The delay also varies between the horizontal and vertical channels. Since we know the delays for both channels, this data gives us valuable information on the nature of the medium the radar pulse passes through.

Liquid water provides more "resistance" to the outgoing pulse than clear air. The graphic on the slide shows what happens to the pulse delay in both the horizontal and vertical channel as it propagates. Raindrops have a larger horizontal extent, so there's more resistance apparent in that channel as the pulse passes through rain. As a result, the returned phase for the horizontal will be greater than the vertical, making Φ_{DP} positive for that range bin.

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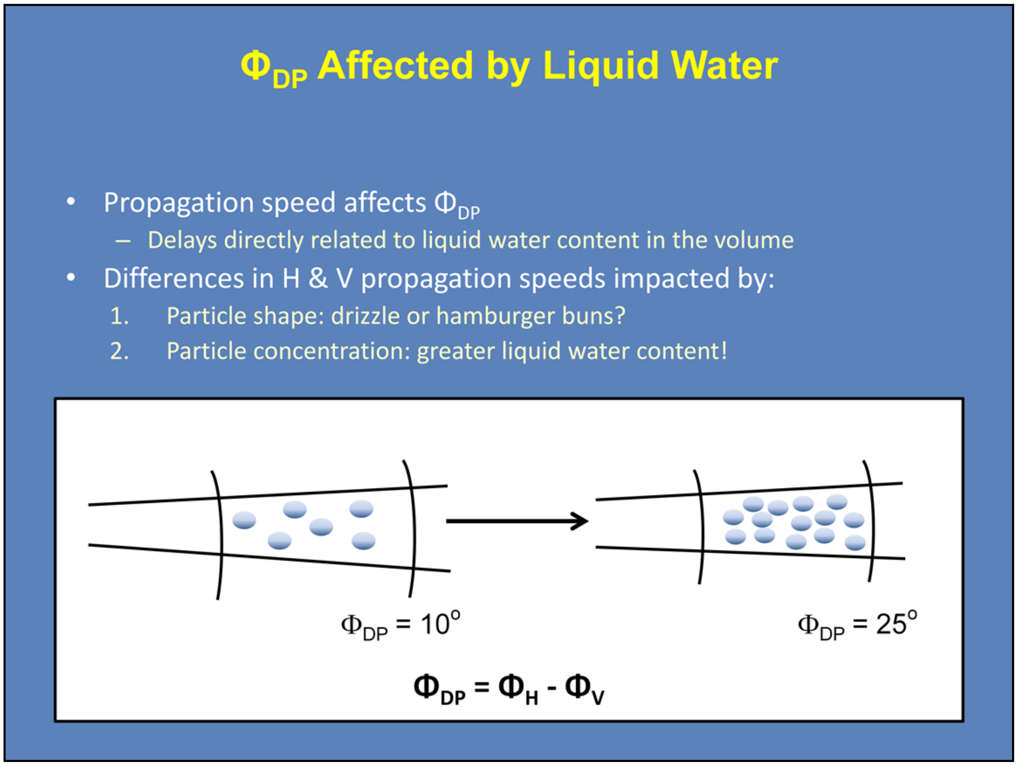
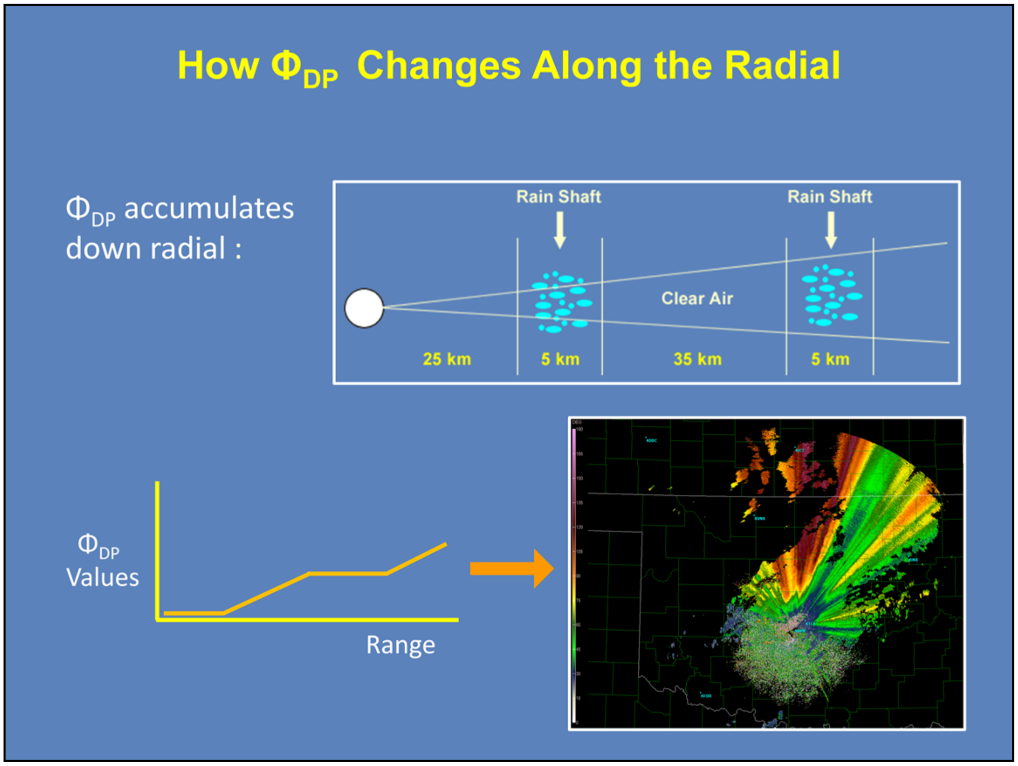
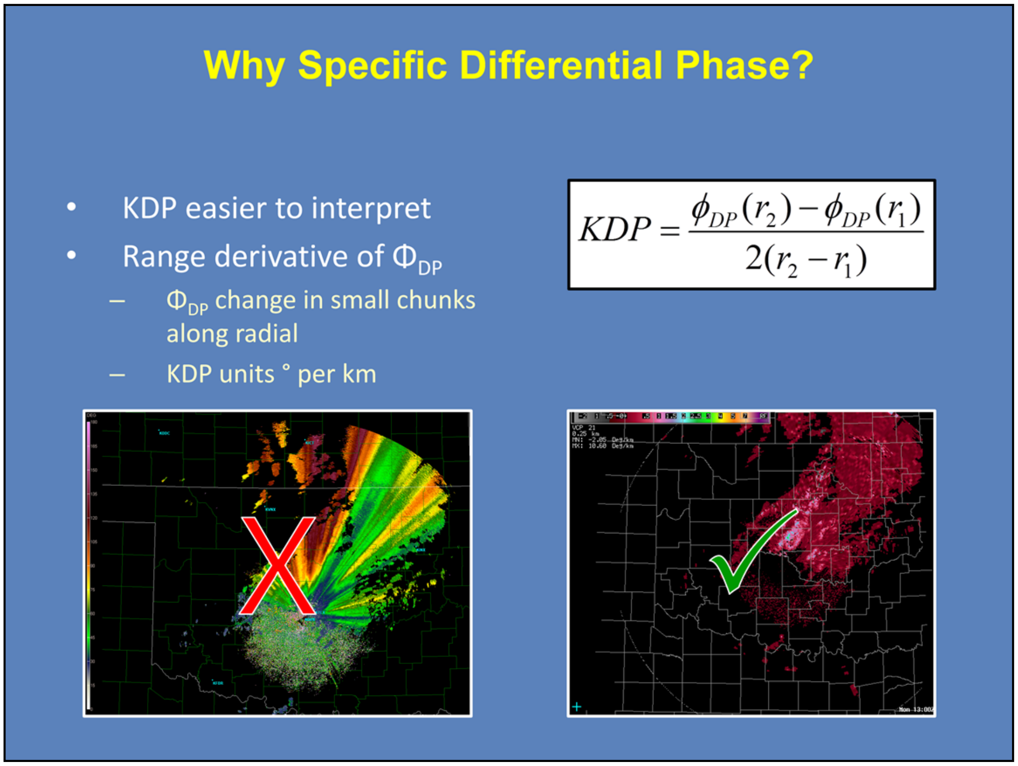


The propagation speed of the horizontal and vertical channels affects the value of Φ_{DP}. Propagation speeds can be slowed due to scatter shape and/or concentration. The larger the scatterer, the greater the delay in the propagation. Likewise, the greater the scatterer concentration, the greater the propagation delay. In both cases, the increased delay in propagation is directly proportional to the liquid water content in the volume. This direct relationship is what makes KDP so valuable!

Here are 2 example atmospheric volumes. The size and shape of the rain drops are the same in both volumes. However, the volume on the right has a larger concentration of drops. The greater concentration of drops will result in a larger propagation delay and larger Differential Phase for that range bin.

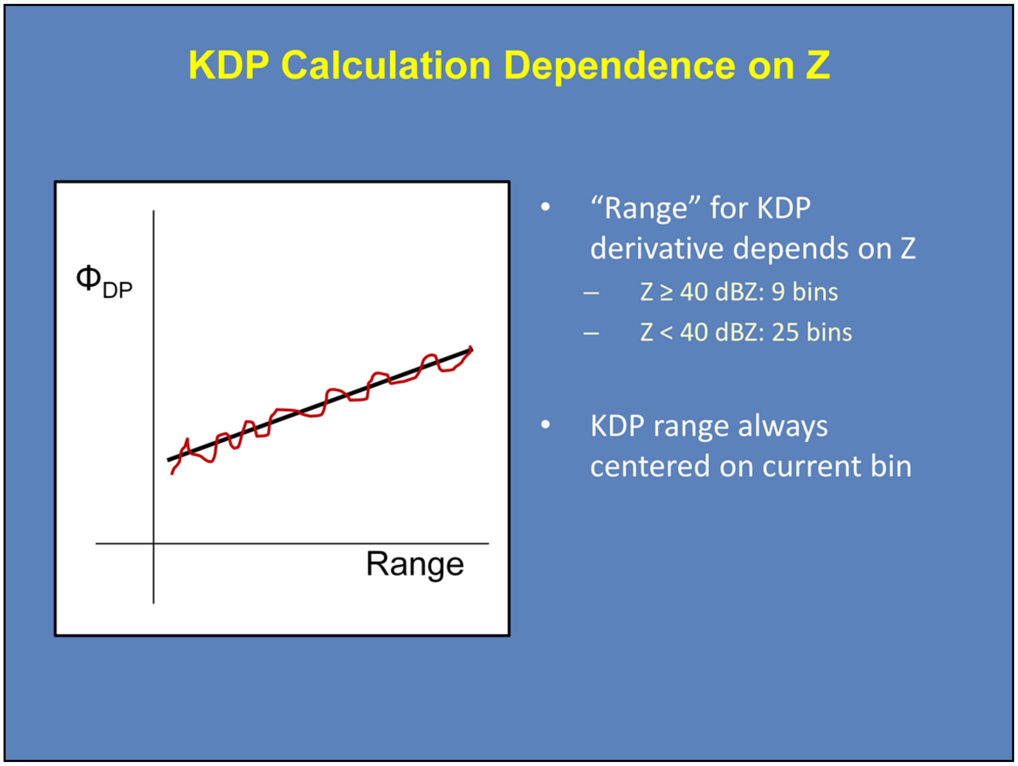


The Φ_{DP} value propagates down radial, meaning the propagation delay accumulates with range. There's no way to "reset" Φ_{DP} as the pulse travels outbound and passes through one or more areas of precipitation. Using the simplified example on the slide, the pulse first passes through clear air which doesn't impact Φ_{DP}. As the pulse encounters a rain shaft, Φ_{DP} increases for a series of range bins. Once the pulse is in clear air again, the Φ_{DP} value stays constant. Once the pulse encounters precipitation again, Φ_{DP} increases as the pulse propagates down radial. Never does the phase reset to 0 as seen in the example product in the lower right. You can see from this display how the data may be difficult to interpret meteorologically.



As mentioned previously, the RDA sends Differential Phase data to the RPG. Though both Specific Differential Phase and Differential Phase are available in AWIPS, KDP is easier to interpret. KDP is defined as the range derivative of Φ_{DP}. Specific Differential Phase allows the radar operator to see how Differential Phase changes over very short ranges, which is the information they want to know. Because KDP is a range derivative of Φ_{DP}, KDP's units are ° per km.

This equation on the slide does not represent the actual calculation of Specific Differential Phase. This version represents the concept of the change in Differential Phase over a range interval. The actual calculation involves a least squares fit of multiple differences along the radial, centered at the range bin.



Since the quality of dual-pol data depends on signal strength, the span of range bins used for KDP calculation depends on the Reflectivity value. When Z is at or above 40 dBZ, only 9 bins are used versus the 25 bins when Z is lower. Using more bins at weaker signals allows for more smoothing in the data that is inherently more noisy. In either case, the span of bins is centered on the current range bin.

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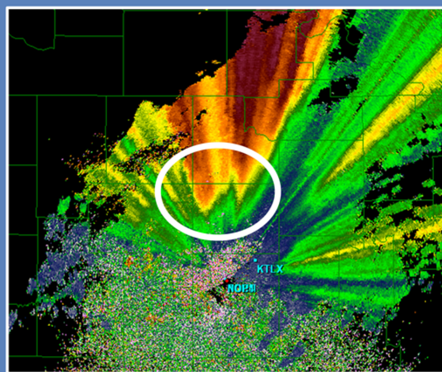
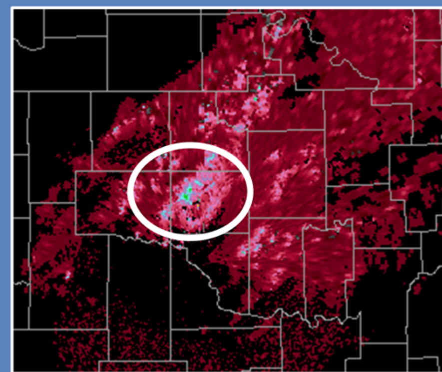
KDP and Liquid Water





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

KDP's provides a method to estimate the liquid water content sampled by the pulse since the phase change directly correlates to the liquid in the beam. The graphic on the left shows Differential Phase while the graphic on the right shows Specific Differential Phase. Since KDP is a derivative, the higher KDP values annotated on the graphic equate to the highest Φ_{DP} gradients along the radial. Notice how the area of greatest significance stands out better in KDP than it does in Φ_{DP}.

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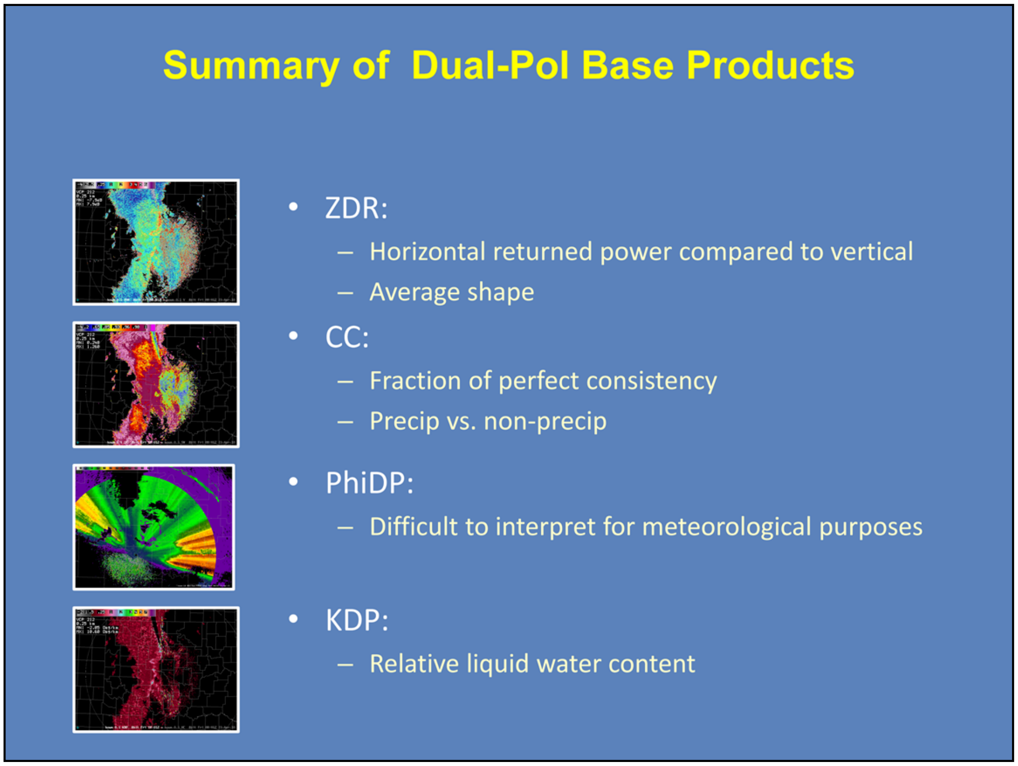

During this lesson, we discussed four dual-pol products. Differential Reflectivity (or ZDR) shows how the returned power between the horizontal and vertical channels compare to each other. These data tell us about the average shape of the scatterers in the volume. The data doesn't contain any phase information. Correlation Coefficient, or CC, uses both the returned power and phase from both channels to determine the consistency between them. CC values are a unitless value between 0 and 1 that reveals information about the nature of the scatters in the radial. Meteorological targets have high CC values while biologic and anthropomorphic targets have low CC values. Differential Phase, or Φ_{DP}, uses phase information to determine how the pulse is being delayed as it propagates. Differential Phase has limited meteorological use because its difficult to interpret. However, Specific Differential Phase, or KDP, has much more benefit because it conveys the locations where Differential Phase changes rapidly. Increasing in phase change is directly correlated to how much liquid water the pulse encounters as it propagates.

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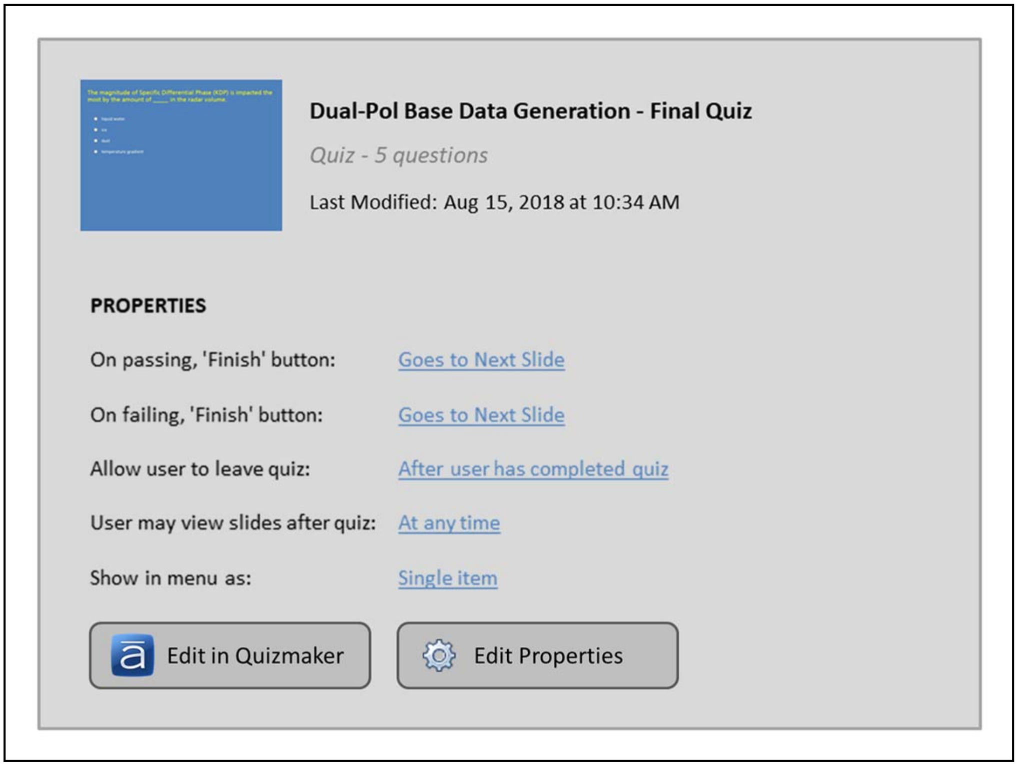
Dual-Pol Base Data Generation - Final Quiz
Quiz - 5 questions
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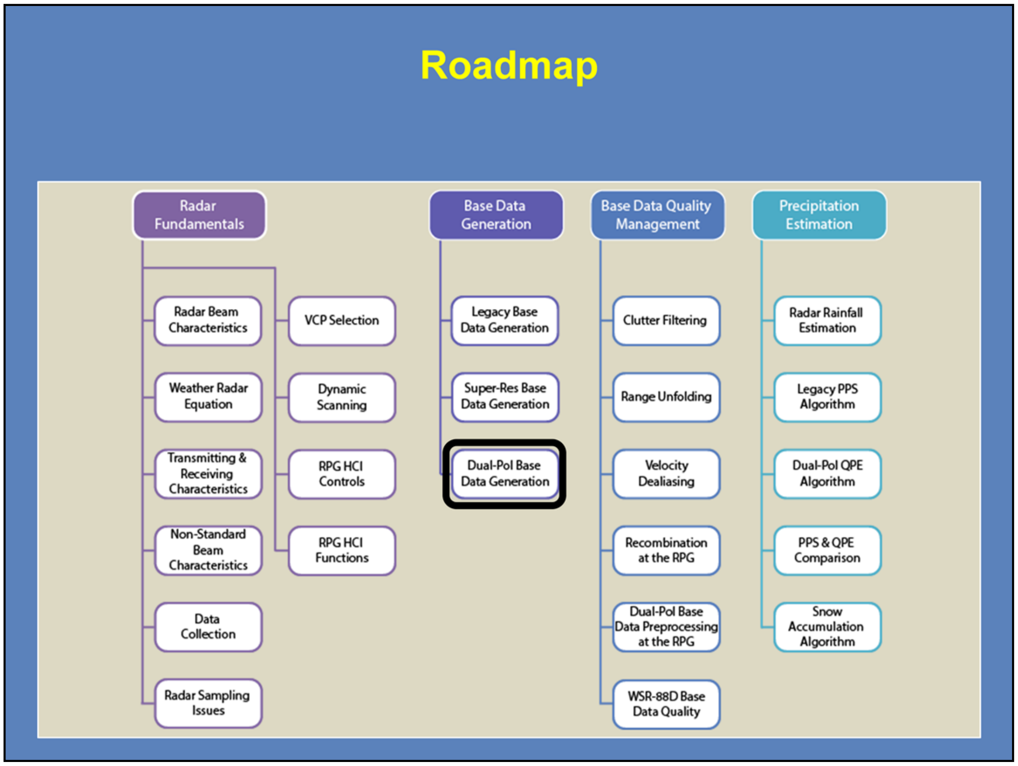

Congratulations on passing the quiz. You have now completed this lesson. You can use the “roadmap” to see what comes next, then click the “Exit” button to leave the course.

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Welcome to this lesson on Clutter Filtering. This lesson is part of the Radar & Applications Course Principles of Meteorological Doppler Radar topic. Let's get started!

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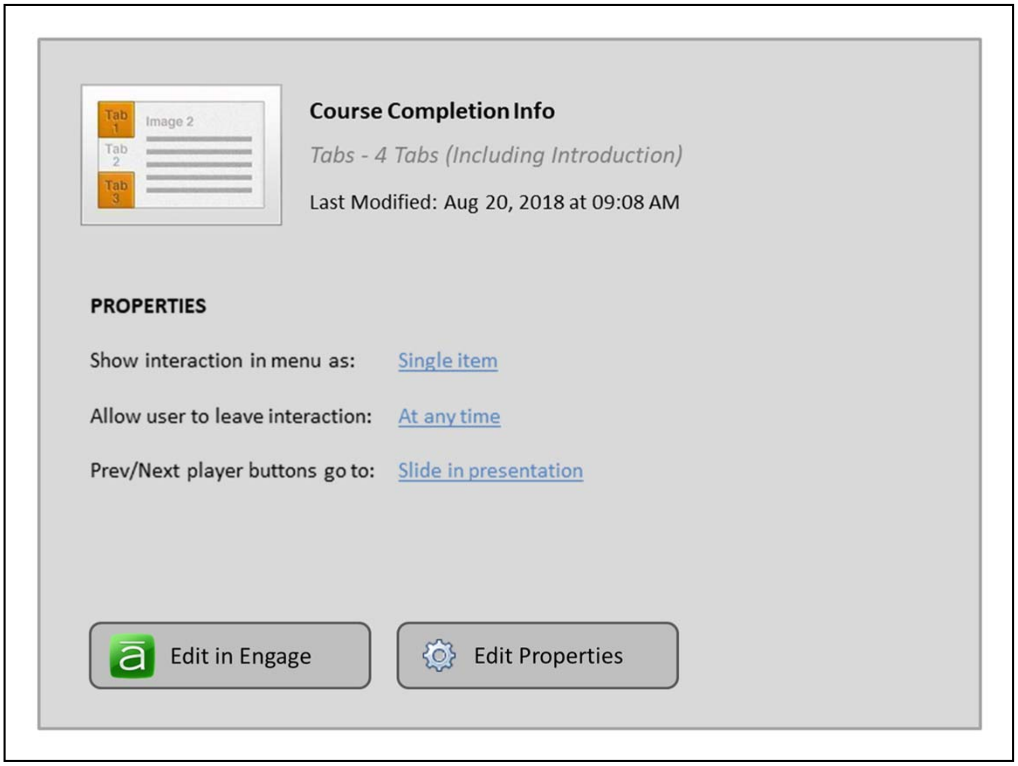
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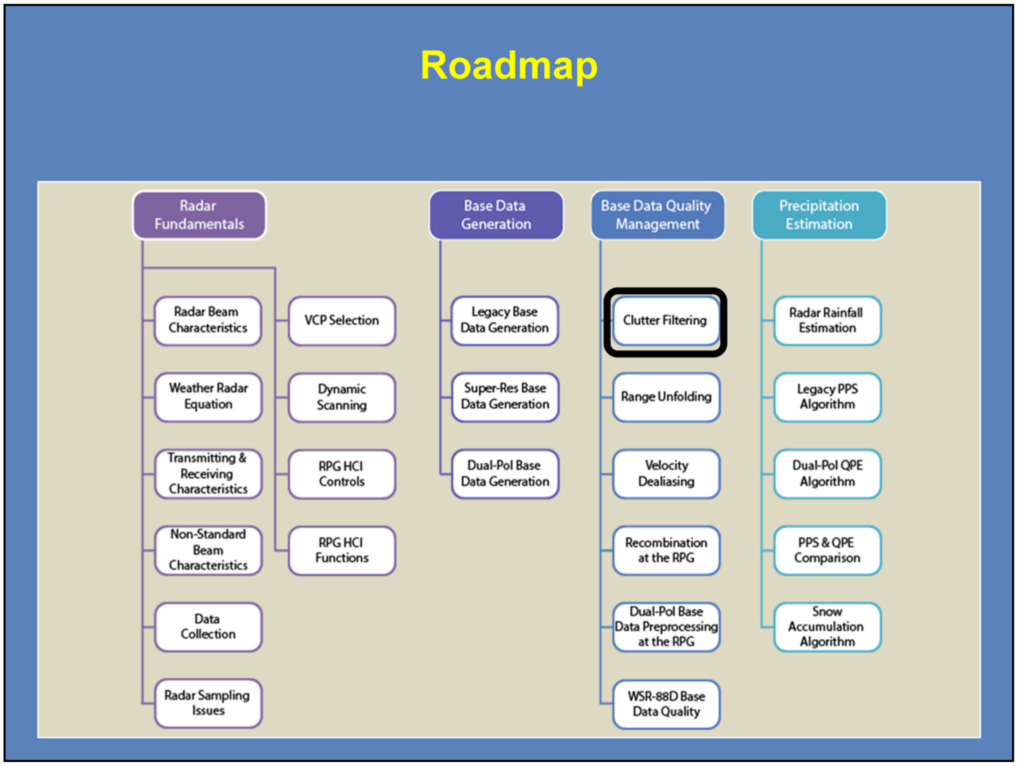

Here is the “roadmap” for this topic with your current location highlighted.

Clutter Filtering Objectives

1. Identify the purpose, strengths and limitations of the following clutter suppression algorithms:
   a) Clutter Mitigation Decision (CMD)
   b) Gaussian Model Adaptive Processing (GMAP)
2. Identify examples of moving ground-based targets that cannot be identified by CMD

There are the two objectives for this lesson. Take a moment to read them over and advance to the next slide when you are ready.

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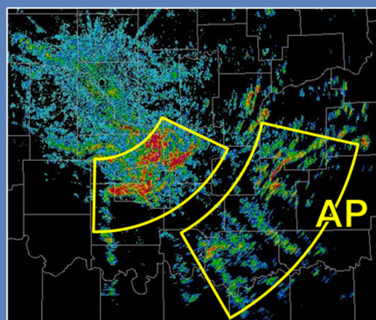
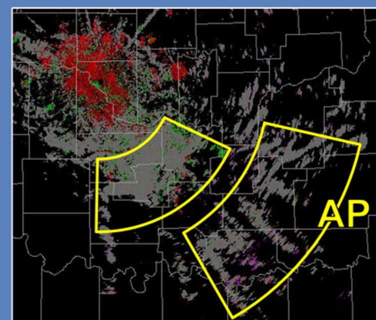
Ground Clutter Contamination





- Returns from non-moving ground targets
  - Affects ***all*** radar products
- Two types of clutter contamination
  - Normal ground clutter
  - Anomalous propagation clutter

In general, ground clutter occurs on WSR-88D radar products because returns from stationary or nearly stationary ground targets weren't filtered out. Clutter suppression gets applied at the signal processor just before the base data are built. So, unfiltered clutter negatively impacts all radar products. There are two types of clutter contamination. The first type, which you can call normal ground clutter, exists all the time because it results from elevated terrain, buildings, etc. The second type, which is more transient, depends on atmospheric conditions and is known as anomalous propagation clutter.

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

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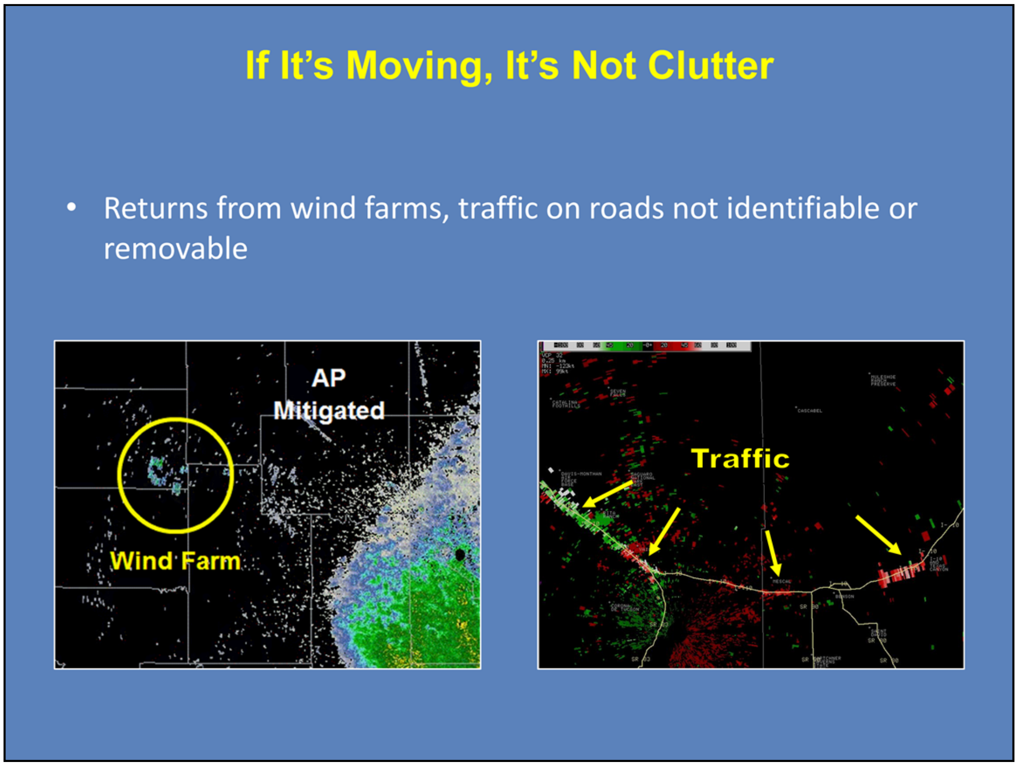

It's important to remember that moving objects are not considered to be ground clutter. The WSR-88D clutter algorithms require clutter echoes to have near zero velocity and spectrum width to be detected. So, anticipate contamination from moving ground targets such as wind farms and traffic on highways when the proper conditions exist to detect them.

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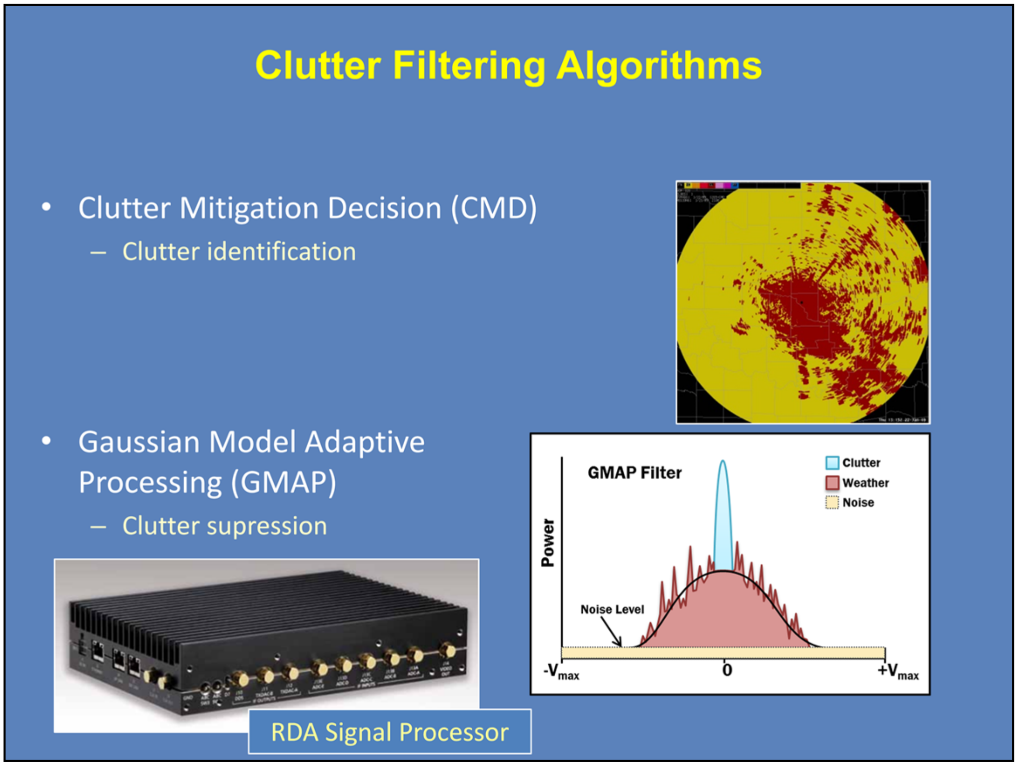

The clutter filtering process relies on two different algorithms. First, the Clutter Mitigation Decision (CMD) algorithm identifies where clutter exists on a bin by bin basis. Then, for each bin identified by CMD, the Gaussian Model Adaptive Processing (GMAP) algorithm applies a signal reduction, or a suppression, to the clutter signal. Both CMD and GMAP are run at the RDA signal processor which a literal black box!

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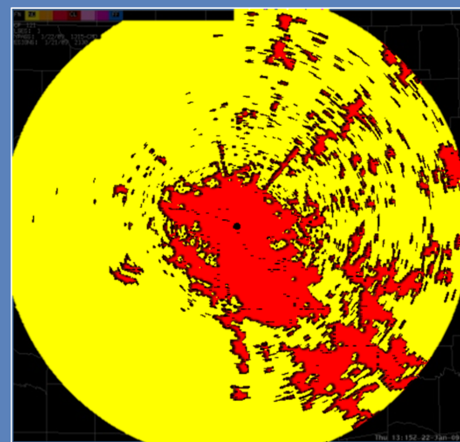
CMD in a Nutshell

- 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. The alternative would be to filter for clutter in every bin, which introduces other issues that we will discuss later. CMD builds what's known as a dynamic Bypass Map that shows each bins that the algorithm identifies as containing clutter. GMAP then suppresses clutter only in the those bins identified in the Bypass Map.

The image on the right shows a visualization of a CMD generated Bypass Map. It's called the Clutter Filter Control (CFC) product. The red bins represent clutter identified bins. The yellow bins do not contain clutter, based on CMD's analysis.

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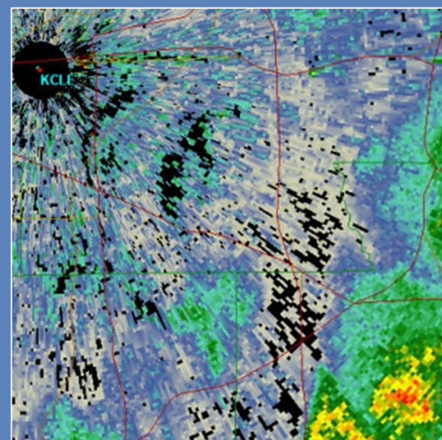
Reflectivity Based Inputs to CMD

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



The CMD algorithm uses fuzzy logic with multiple inputs, some of which are based on the Reflectivity base data:

1. The first input is Reflectivity (or Z) texture. Weather signals tend to have a smoother Reflectivity texture than clutter.

2. Another input is called Reflectivity spin. This input provides information on how the reflectivity gradient changes sign as you move along the radial.

3. A third input is called the Clutter Phase Alignment (CPA). This variable captures the variance of pulse to pulse phase changes. When CPA is high, the phasors have good alignment which means the returns have a higher likelihood of containing clutter.

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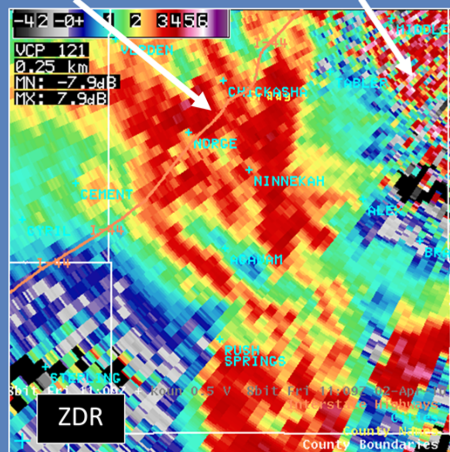
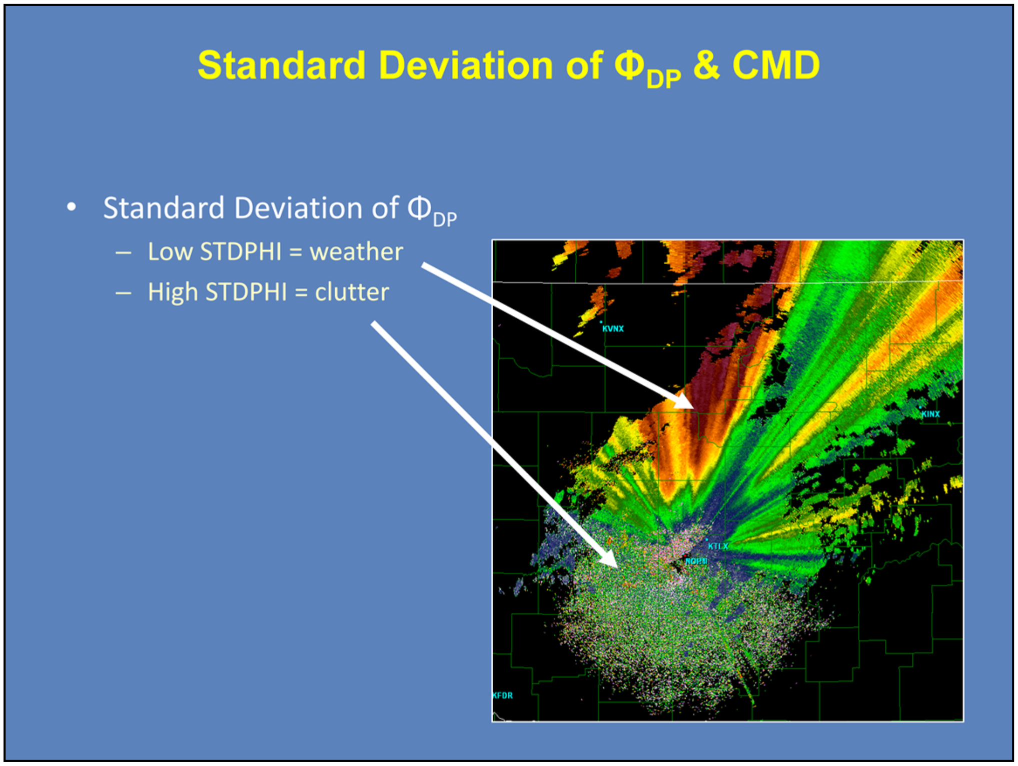
Standard Deviation of ZDR & CMD

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



Two inputs to CMD come from the dual-pol base data. The first of these inputs is the standard deviation of Differential Reflectivity (or ZDR). The higher the standard deviation of ZDR in a particular range bin, the greater the likelihood that it contains clutter. In this example, you can likely tell a difference in ZDR appearance between the two areas pointed out by the arrows. The weather signal dominates the smoother area visible towards the middle of the image. The upper right-hand corner, where the ZDR returns are more variable, likely contain significantly more clutter signal.



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 greater the likelihood that the range bin contains clutter. In this example, compare the noisiness of the Φ_{DP} data surrounding the radar to the south and west with the areas of to the north through the east that contain weather signal (you'll just have to trust me that precipitation was occurring there). The standard deviation data captures that variation (or lack of it), which can be very useful for the CMD algorithm.

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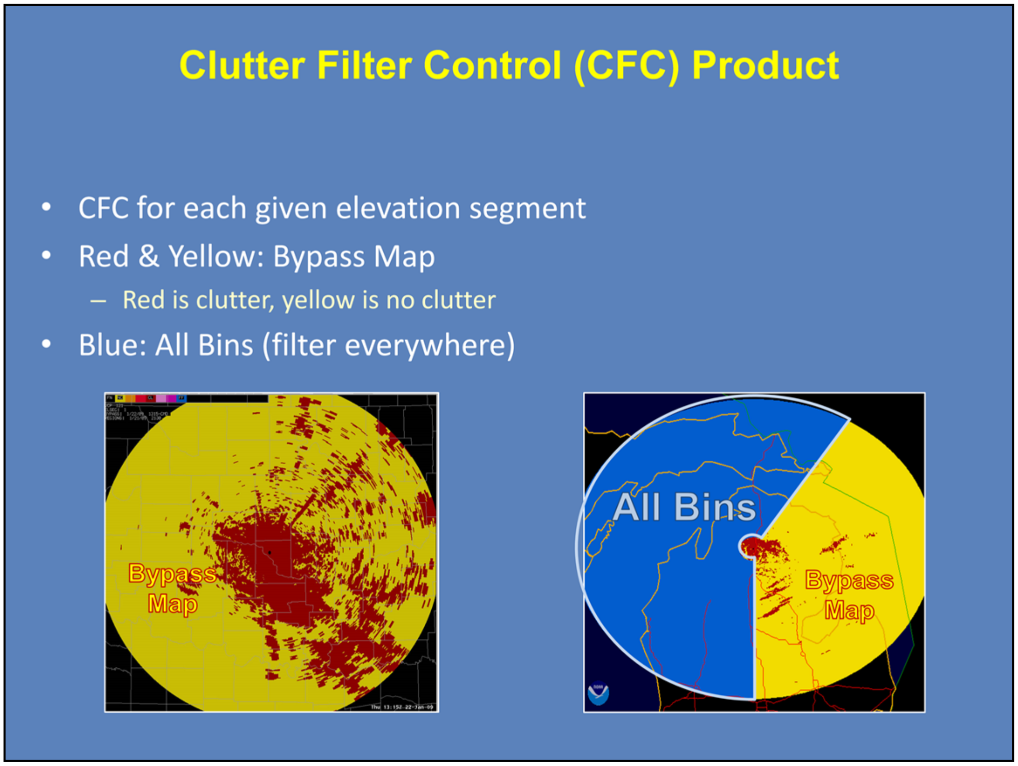

For each elevation segment (which can be generated from the Bypass Maps from one or more tilts), the CFC product displays the type of clutter filtering that has been invoked for the lowest elevation in that segment. Where the Bypass Map is in control of clutter identification, the bins will be colored red or yellow. As a reminder, red bins will be filtered for clutter and yelow bins will not. When you see blue on the CFC product, that’s where All Bins filtering has been manually implemented. All Bins filtering means you filter every single bin in that area.

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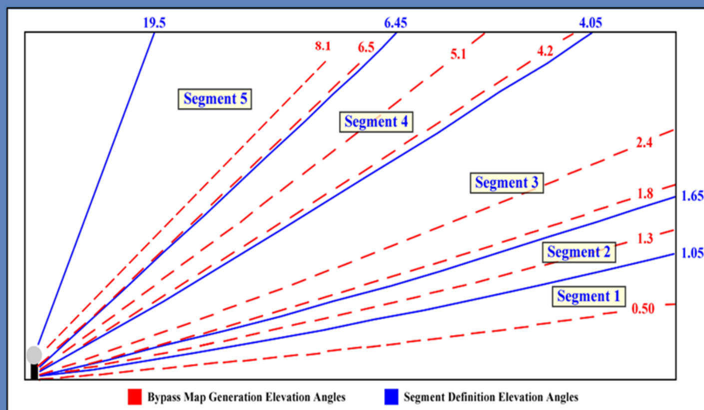
CMD Implementation



- 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 builds a bypass map for every elevation and rotation. For the Split Cuts, that means separate Bypass maps get built for both the Contiguous Surveillance (CS) and Contiguous Doppler (CD) scans. For the remaining elevations in the volume scan, CMD builds a new map for each tilt. Clutter Filter Control products don't get built for each elevation, thus you cannot see every Bypass Map CMD builds. This process makes CMD troubleshooting efforts challenging.

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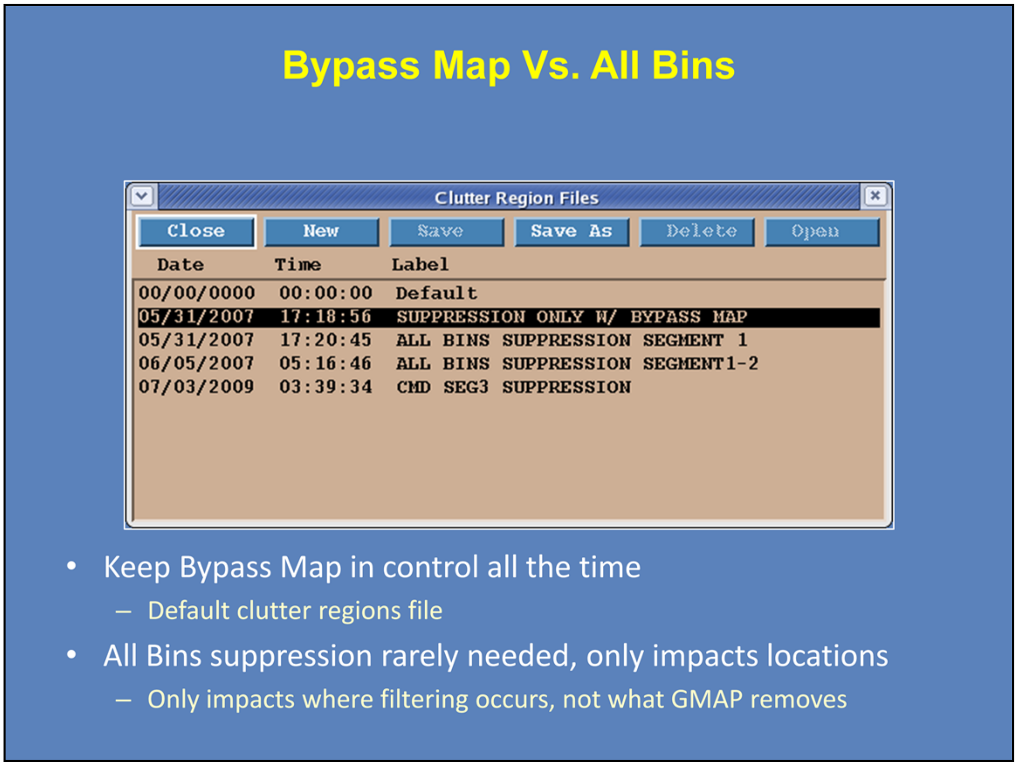

CMD offers “hands off” clutter suppression, though some data quality monitoring may be needed from time to time. In order for CMD to build maps for every elevation, the Bypass Map must be in control for all elevations. The “Default” clutter regions file is designed to do just that. With CMD active, All Bins suppressions is rarely needed. However, some offices may choose to implement All Bins suppression in certain areas to ensure clutter filtering occurs in area where it is needed. Just remember that All Bins only defines WHERE suppression occurs. GMAP determines how much power gets removed when the suppression is performed. If you routinely see returns that you believe to be clutter, remember to check the Velocity and Spectrum Width data to see if the values are near zero!

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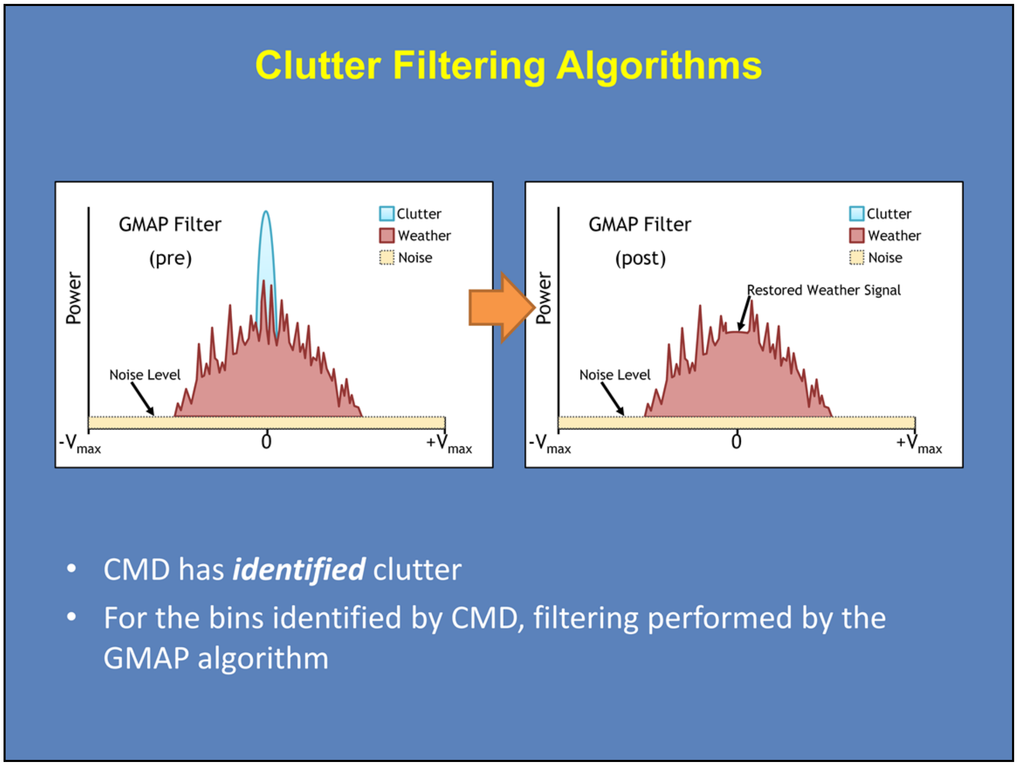

Now that CMD has identified where clutter exists, the filtering (or removal) of the clutter from the returned signal can occur. The GMAP algorithm applies filtering only to those bins identified on the Clutter Filter Control product. Let's see how that works.

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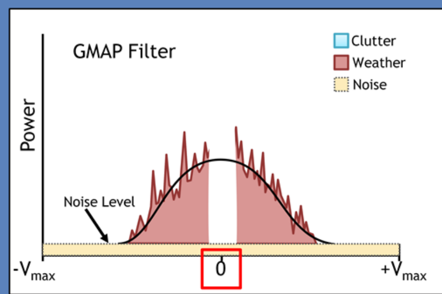
Key Concepts behind GMAP



- 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 (like the blue green spike in the graphic) contains high power centered at zero Velocity with a narrow Spectrum Width. A weather signal (the broader pink curve) will have varying power returns, Velocity. and Spectrum Width. This difference between clutter signals and weather signals can be used to remove the clutter signal with minimal damage to the weather signal. A key principle in GMAP's design suggests that both clutter and weather signals can often be well represented by Gaussian curves. We've done just that in this simplified example. Another important concept to remember is that weather signals are not usually centered at zero velocity.

So, keeping these points in mind, GMAP first removes power from the returned signal near zero velocity. Hopefully, as much of the "spike" as possible gets suppressed. If enough of the weather signal remains, GMAP rebuilds the weather signal that was lost.

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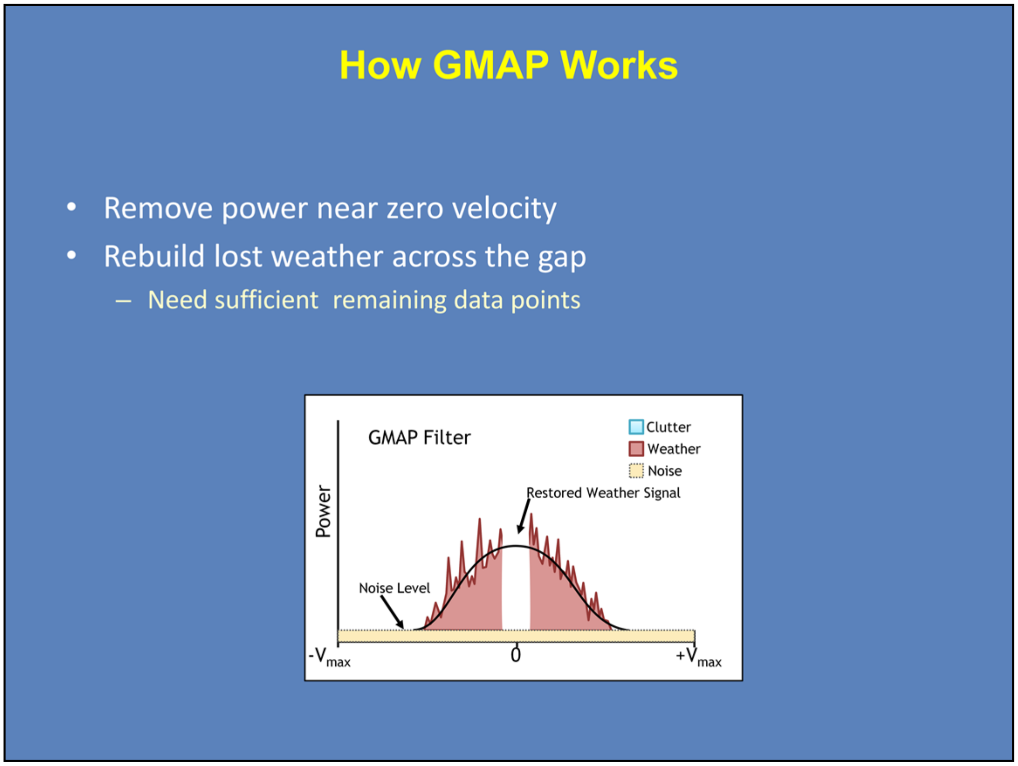
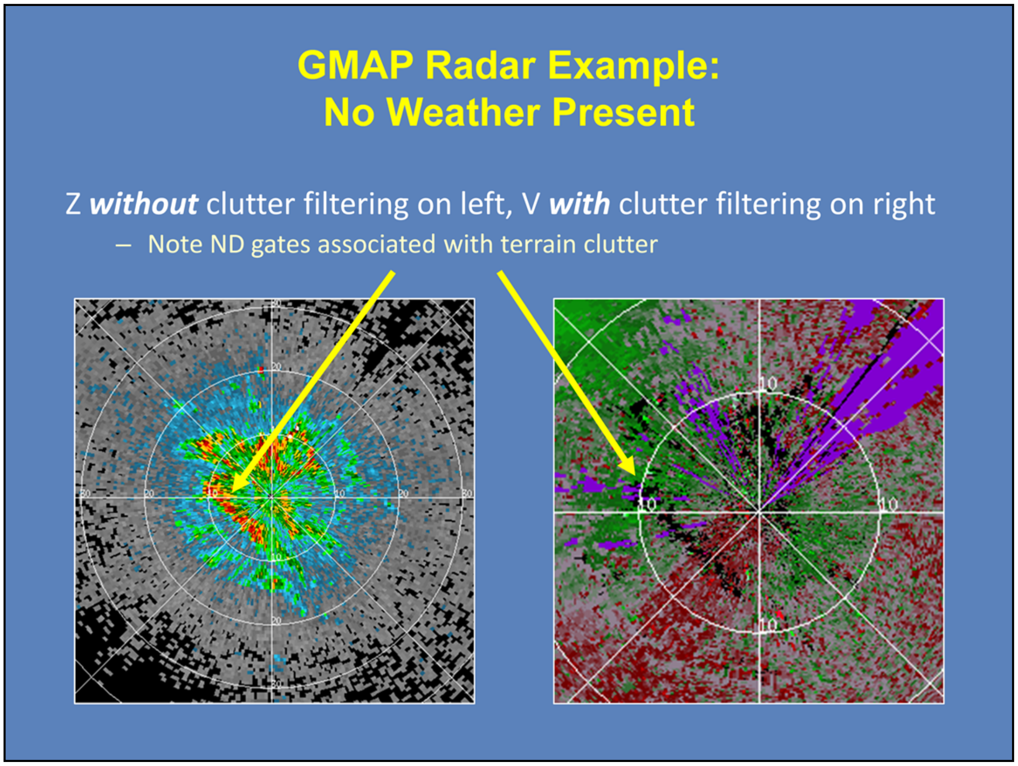


Once the width for signal removal is determined, GMAP applies filtering to all of the signal within that width. In this case, both the clutter and weather signal within this interval will be removed. However, GMAP can rebuild the weather signal that was lost, depending on the availability of data points outside of the gap. When sufficient weather signal data outside the gap exists, GMAP rebuilds the weather signal across the gap using the Gaussian estimate.

The available number of pulses per radial impacts GMAP's performance, especially with respect to the rebuilding of the signal. GMAP performs better rebuilding the signal with data collected in VCP 215 versus VCPs, 12, 212, and 121. So, you definitely want to use the general surveillance VCP when stratiform, or other slow-moving, non-severe echoes are expected.



As an example of GMAP performance, we start with a scan where no discernible weather is present. Clutter filtering has been turned off in order to identify the local terrain in the Reflectivity image on the left. Note the ridge line to the southwest. The Velocity image on the right has had clutter filtering applied. A second step, known as clutter censoring, has occurred 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 in the area associated with the ridge line to the southwest.

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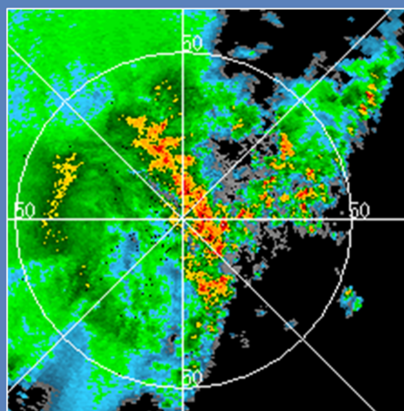
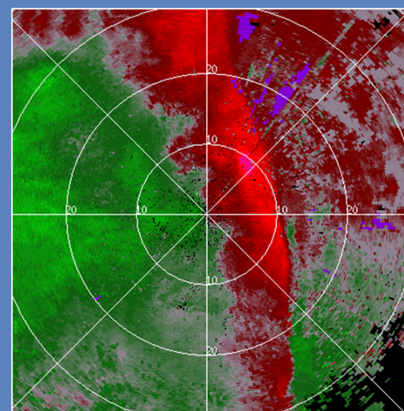
GMAP Radar Example: Squall Line Passes Through

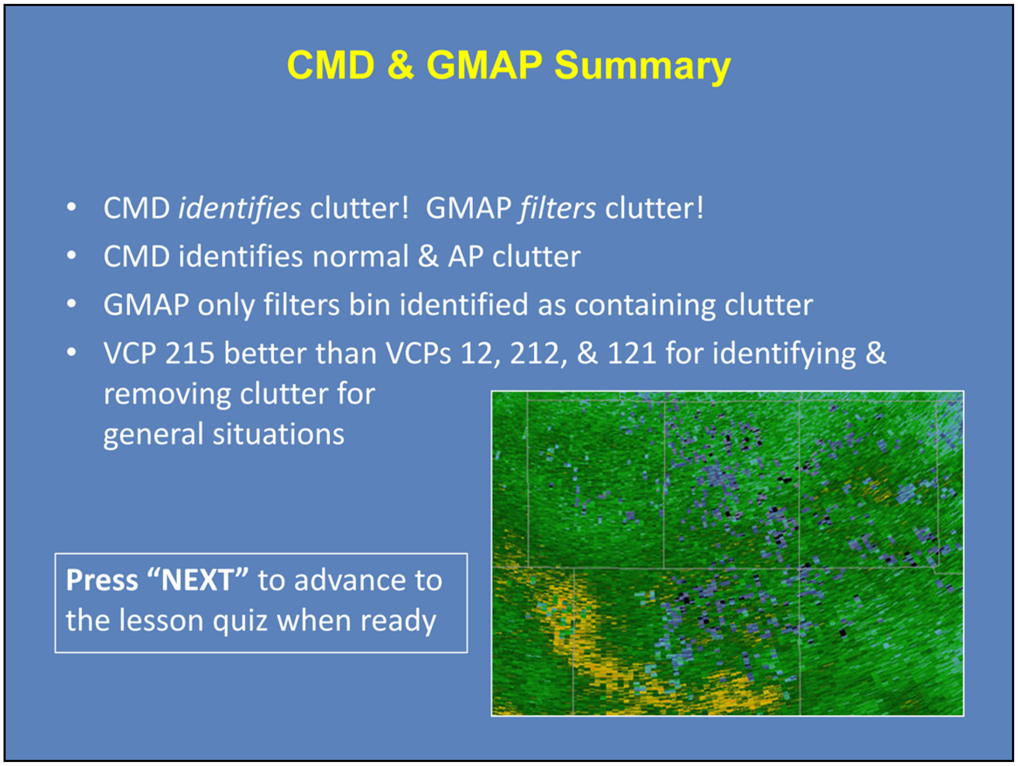
Z & V as squall line passes through:

- Clutter has been filled in with data





At a later time, a squall line passes through the area with clutter filtering turned on for both products. The squall line appears in both the Reflectivity image on the left and the Velocity product on the right, but the Velocity product has been zoomed in compared to the Reflectivity. Note that, in both products, the ridge and other terrain clutter areas are no longer apparent. The weather signal was strong enough (and enough pulses were available), for GMAP to rebuild the weather for the bins that contained clutter.



In summary, Clutter Mitigation Decision (CMD) and Gaussian Model Adaptive Processing (GMAP) work together to identify and suppress clutter, respectively. CMD identifies both normal and AP clutter on a bin by bin basis for every rotation and every elevation tilt in a VCP. These Bypass Maps are used to generate the Clutter Filter Control product that gets handed off to GMAP. GMAP performs the suppression by applying filtering only to the bins identified by CMD (or for regions defined as All Bins) and removing power from the signal near zero velocity. GMAP can also rebuild the weather signal in the filtered area if sufficient data points remain outside the gap.

The performance of both CMD and GMAP are impacted by the number of pulses per radial. Both algorithms work better using VCP 215 than on VCPs 12, 212, and 121 because more pulses are available per radial for the general surveillance VCP. This fact is one of several reasons to use VCP 215 for general surveillance situations, like stratiform rain.

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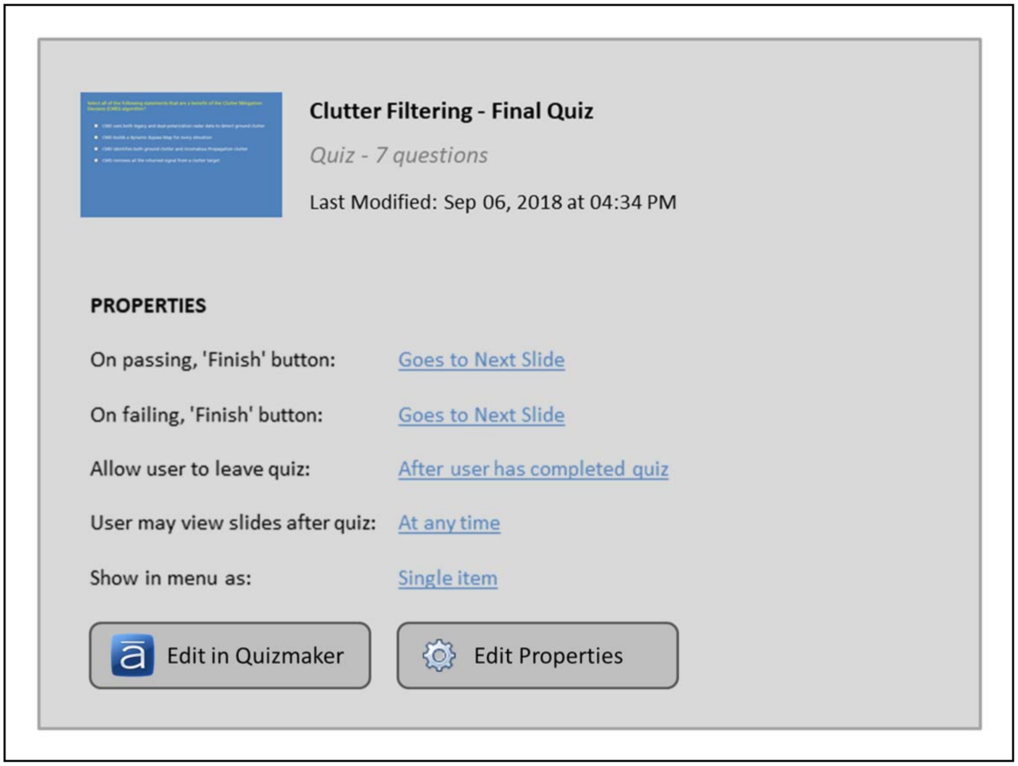
Clutter Filtering - Final Quiz
Quiz - 7 questions
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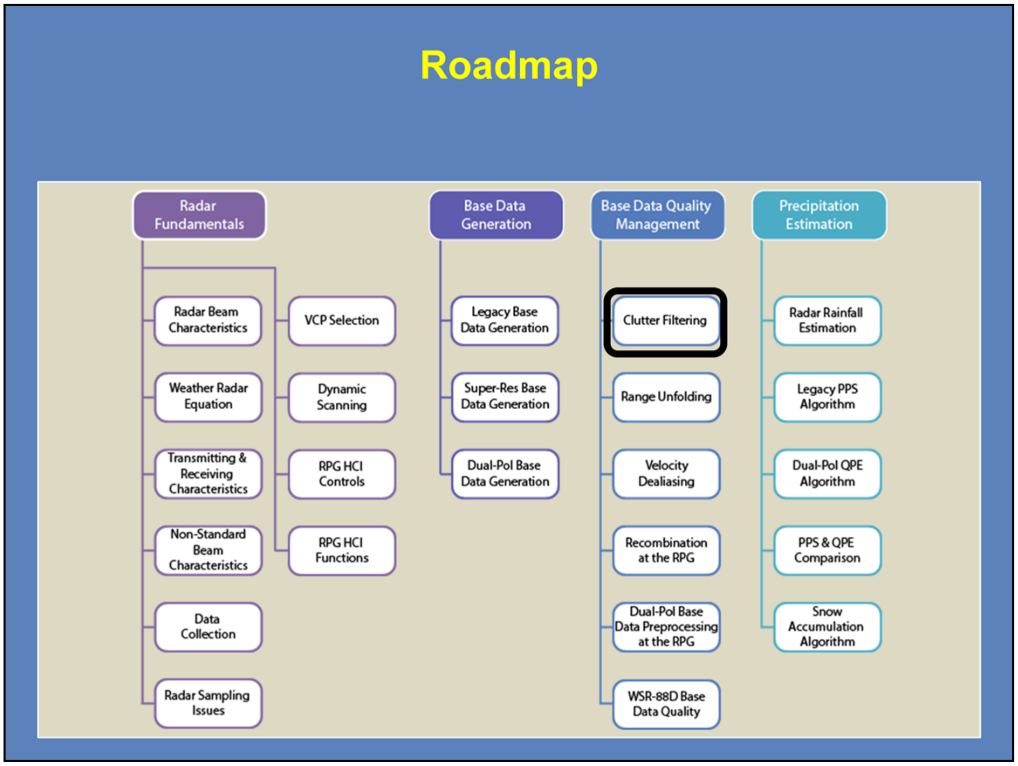

Congratulations on passing the quiz. You are now complete for this lesson. Here is the “roadmap” again so you can see what lessons come next. Click the Exit button to close this window when you are done.

Welcome to this lesson on the Principles of Meteorological Doppler Radar. This lesson will discuss range unfolding of precipitation echoes.

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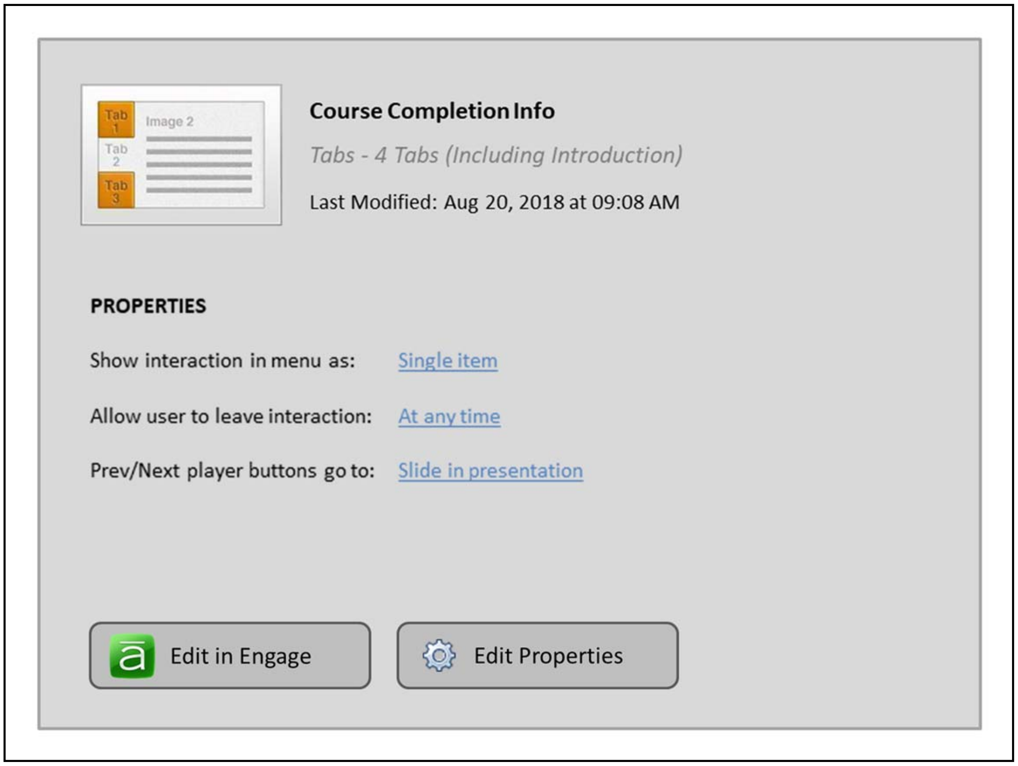
Tab 1
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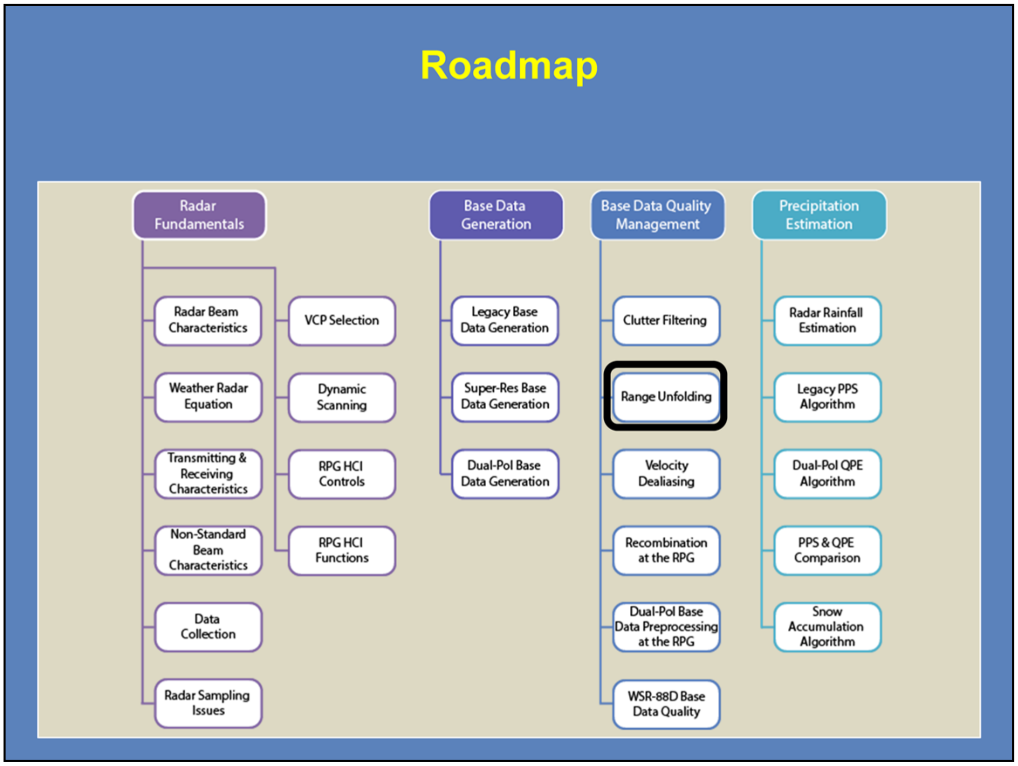

Here is the “roadmap” for this topic with your current lesson highlighted.

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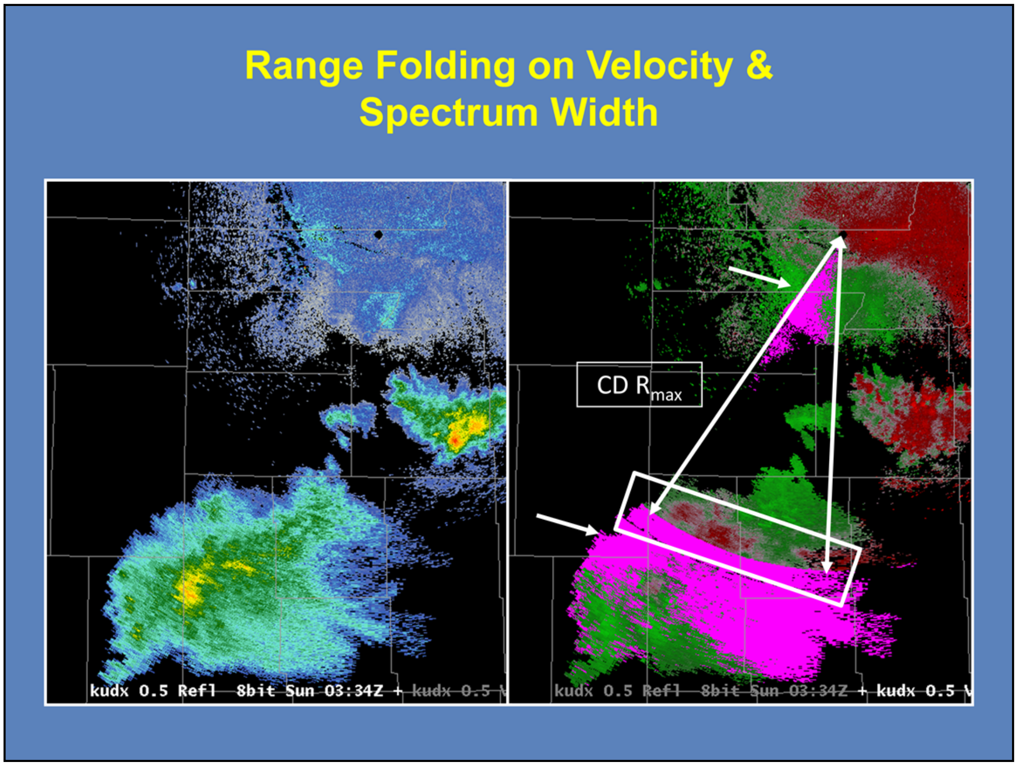
Objective

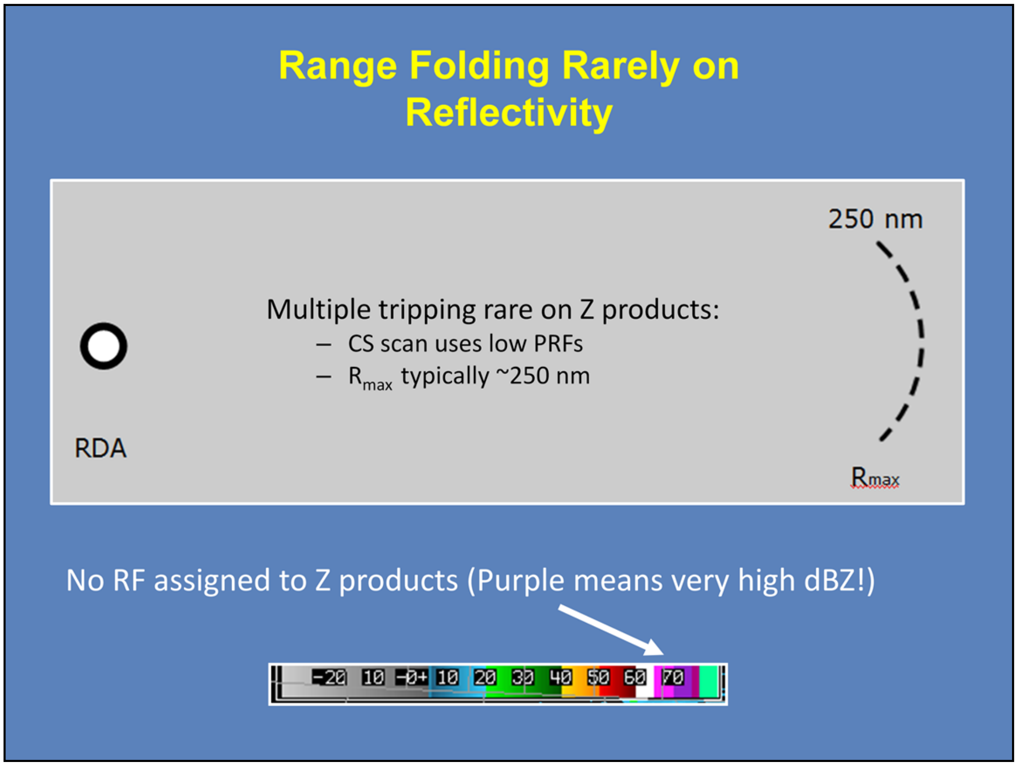
1. Identify the purpose, strengths and limitations of the following range unfolding algorithms:
   a) Legacy Range Unfolding
   b) SZ-2 Range Unfolding

There is one objective for this lesson. Please read it over and advance to the next slide when you are ready.



Recall from our discussions of the Doppler dilemma that high PRFs are needed to allow for high Nyquist velocities, but also result in short maximum unambiguous ranges (or R_{max}). When precipitation echoes are detected past the first “trip”, it is necessary to unfold the data to its appropriate range.

Through the next several slides, we will explain how the data are unfolded and the purple “RF” data areas are assigned on the Radial Velocity and Spectrum Width products. An important feature to notice in these products is the discontinuity in the velocity data at a fixed range as seen in the example shown here. You will often see this discontinuity in velocity and spectrum width data as long as there is sufficient areal coverage of echo over multiple trips. This discontinuity occurs at the range for R_{max} on the Contiguous Doppler (or high PRF) cut used for velocity data collection. The two important questions to ask are: “how did any velocity data end up being assigned beyond the first trip?” and “why does the radar assign some of those regions with valid velocity data and others with the RF ‘purple haze’?”



Remember that the Continuous Surveillance scans (where reflectivity data are collected) use low PRFs that result in long maximum unambiguous ranges. So, these cuts produce reflectivity data with a R_{max} of ~250 nm and very little data that gets collected outside of the first trip. As a result, the color purple on Reflectivity products indicates very high dBZ values, not range folding.

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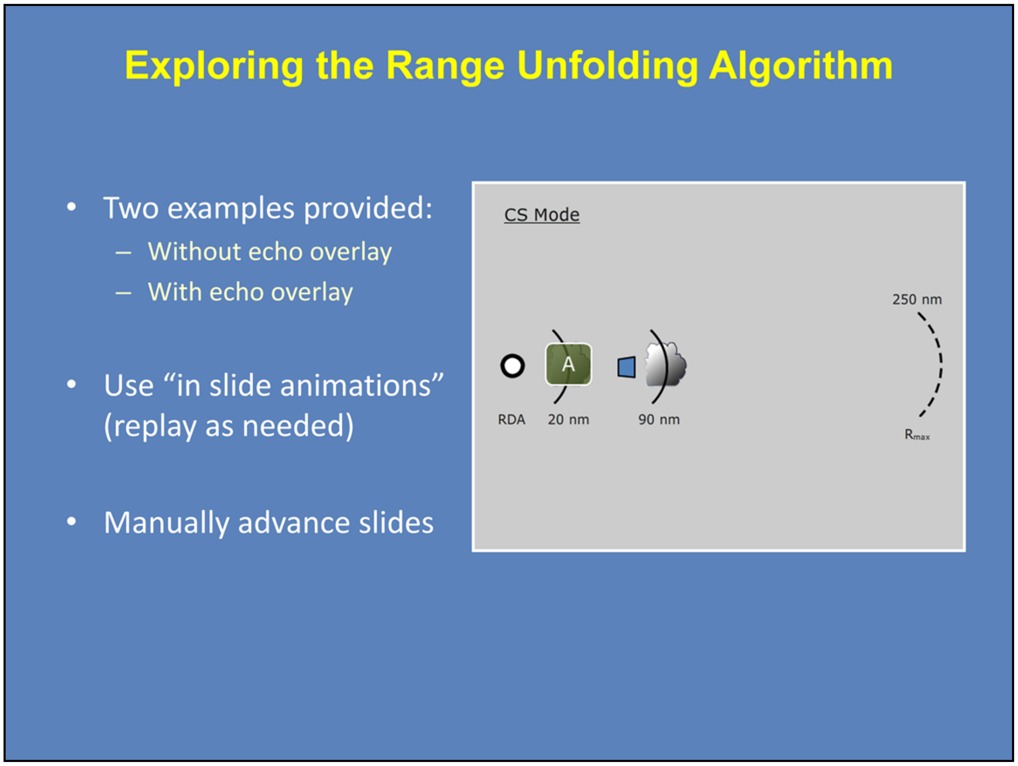
Legacy Range Unfolding Algorithm

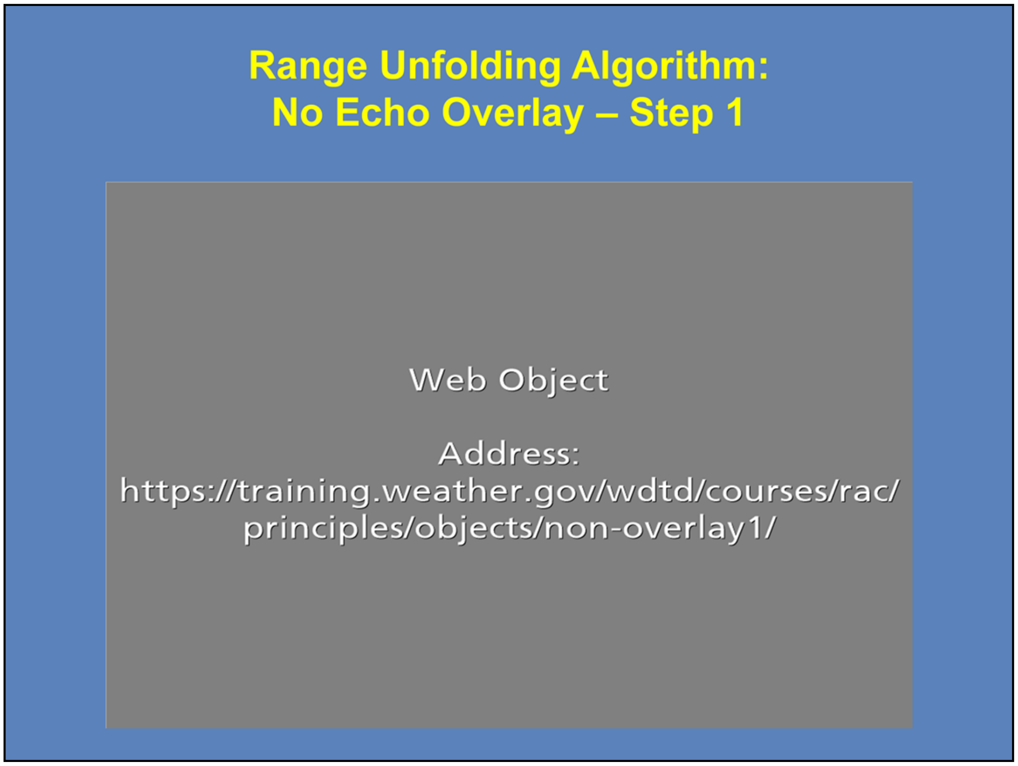
- In action since WSR-88D original deployment
- Assigns V & SW to proper range
  - May be beyond CD R_{max}
- Run at RDA signal processor for several VCPs:
  - VCPs 12, 31, & 32

We will discuss two range unfolding techniques in this lesson, the first of which is the technique released initially with the WSR-88D. We will refer to this range unfolding algorithm as the Legacy Range Unfolding Algorithm.

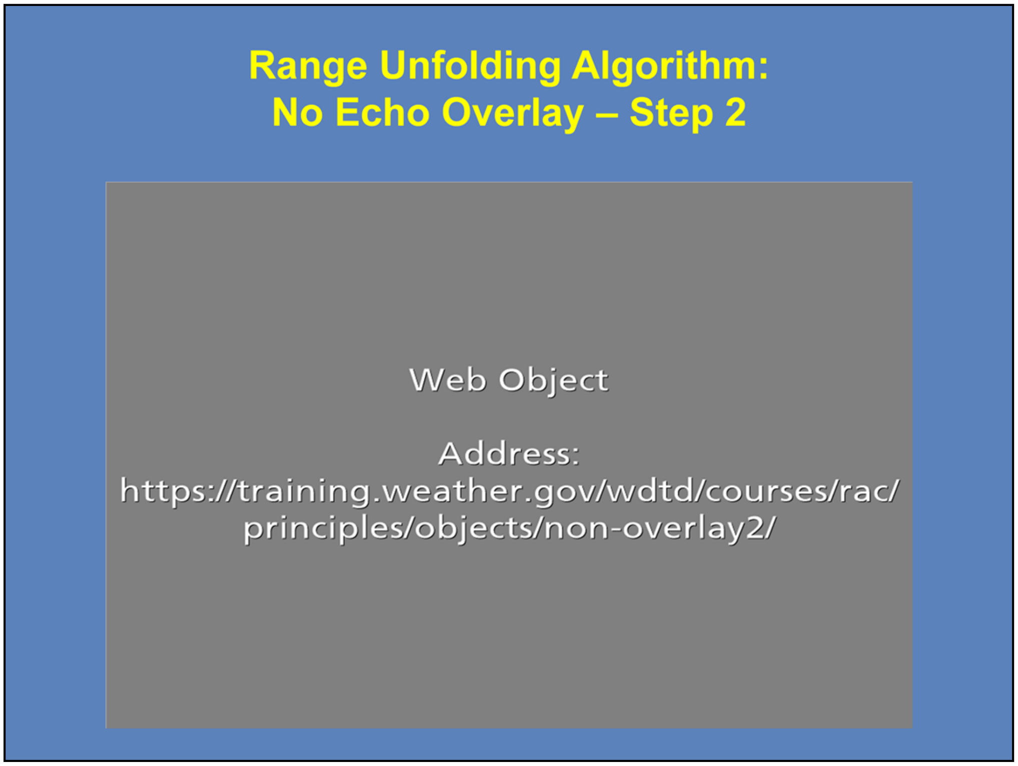
The goal of the Legacy Range Unfolding Algorithm is to assign velocity and spectrum width data to its appropriate range. That range can be beyond the maximum unambiguous range for the Continuous Doppler scans. So, the precipitation echoes might be in the first trip, the second trip, or (in rare cases) even the third trip. This algorithm runs at the RDA signal processor, which is literally a black box, for VCPs 12, 31, and 32.



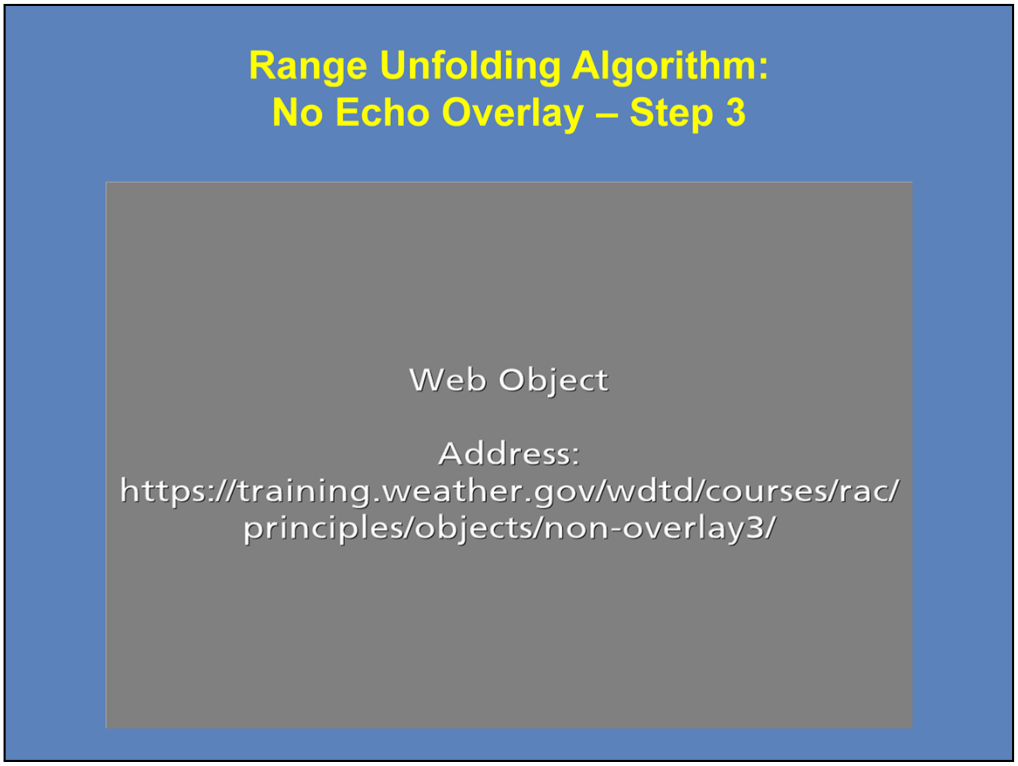
The next several slides will demonstrate two examples of how the Range Unfolding algorithm works: One with no echo overlay and one with overlay. We will walk through each example using numerous steps. The steps will be shown using in slide animations that you can replay as many times as you like, if needed. For each of these slides, you will need to manually advance the slide to move to the next step. We also provide some troubleshooting steps on the next slide in case the animations do not work initially for you.



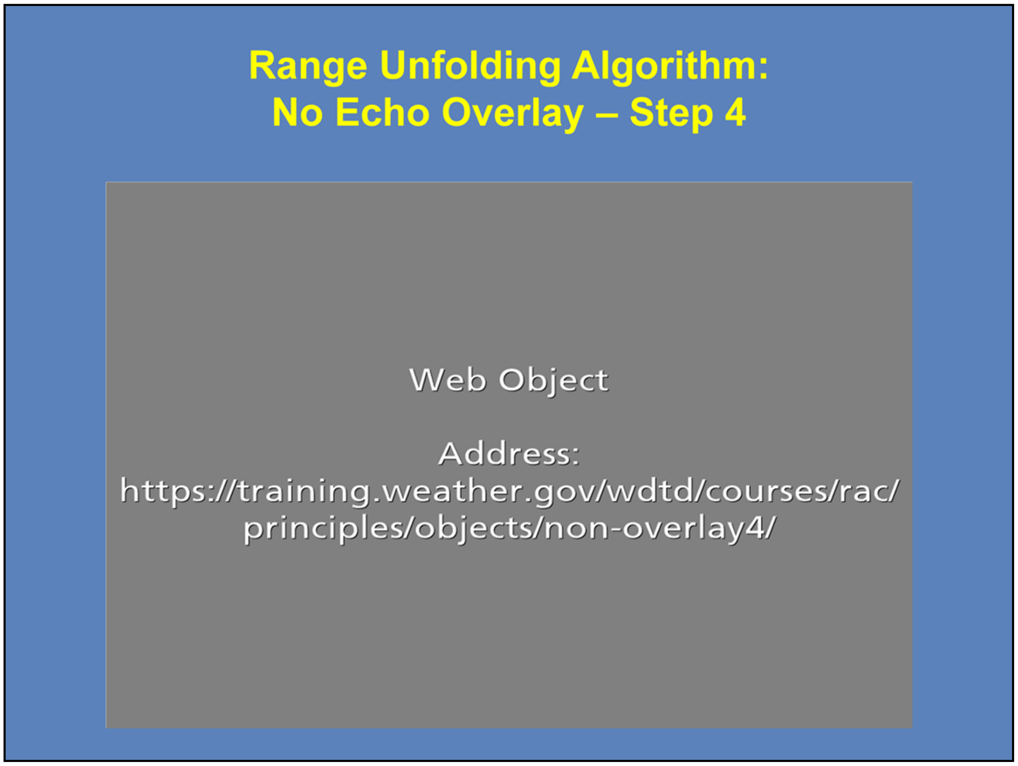
Step 1: We look down a single radial in surveillance mode. That means we have a nice long unambiguous range. We have two targets along this radial. The first one is at 20 nm, and the second one is at 90 nm. Since both of these targets are within the first trip, we know their true range and we know their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



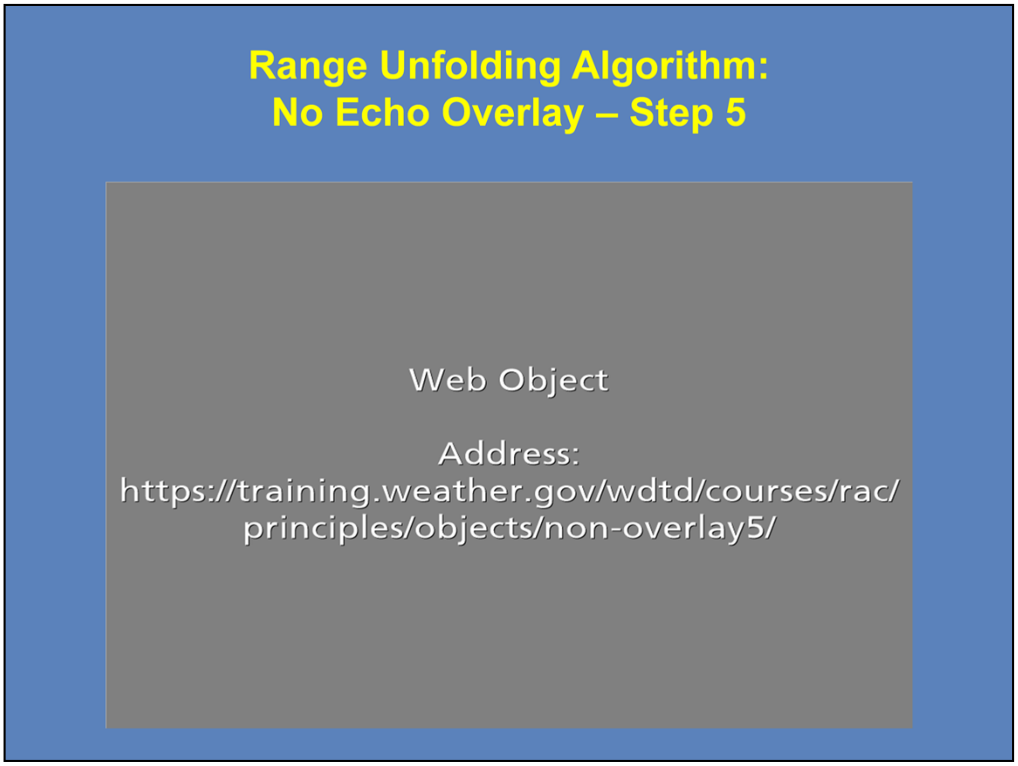
Step 2. Prior to the switch to Doppler mode on the next rotation, the algorithm computes what the apparent ranges of these two targets will be. In this case, Our R_{max} of 60 nm in CD mode results in target A staying at 20 nm while target B will be folded into an apparent range of 30 nm.



Step 3: We know target B has an apparent range of 30 nm. At this step, the algorithm computes all the possible ranges for each target that shows up in the CD mode first trip, and these possible range go out into the second and third trips.



Step 4. With those calculations out of the way, the radar can collect data in Doppler mode. The energy from pulse 1 for target B (which was at 90 nm) propagates back to the RDA, 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 in CD mode.



Step 5: Now that the RDA can begin the actual down radial comparison of the CS and CD data. The algorithm checks to see wherever there is a target in the CD data if there was something at that same range in CS data. So, when we get to target A, the algorithm checks if there was something at 20 nm in the CS 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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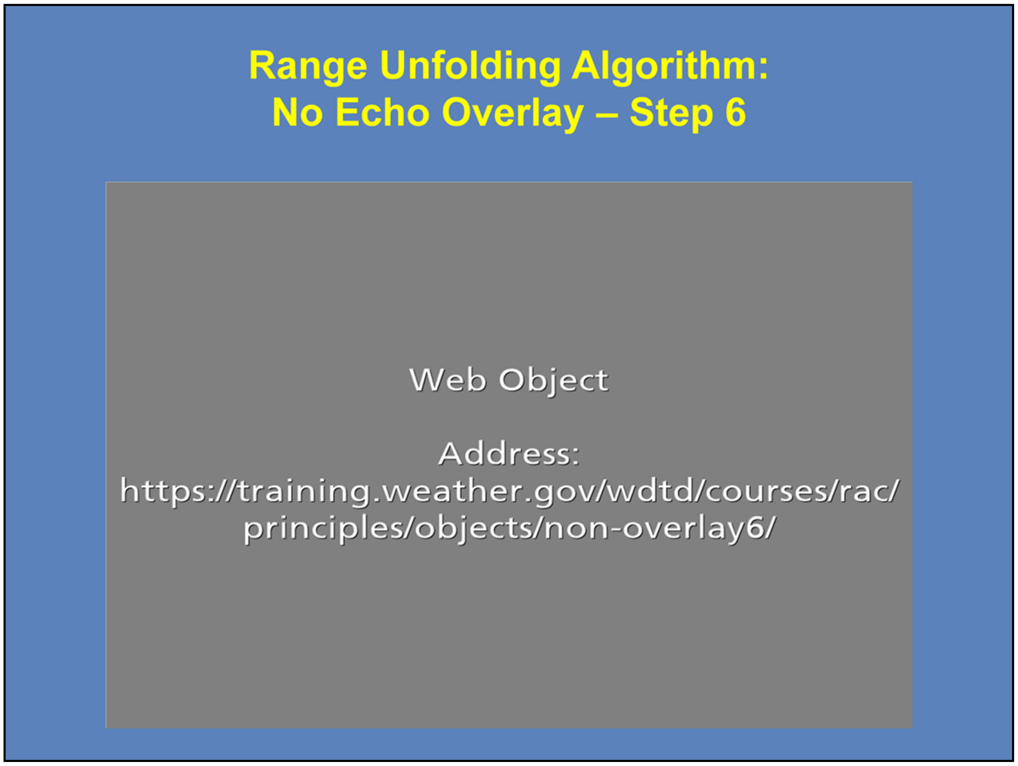

Step 6: When the algorithm gets to target B at an apparent range of 30 nm, it compares that location to the CS data. In this case, no there wasn’t a target at 30 nm in the CS data.

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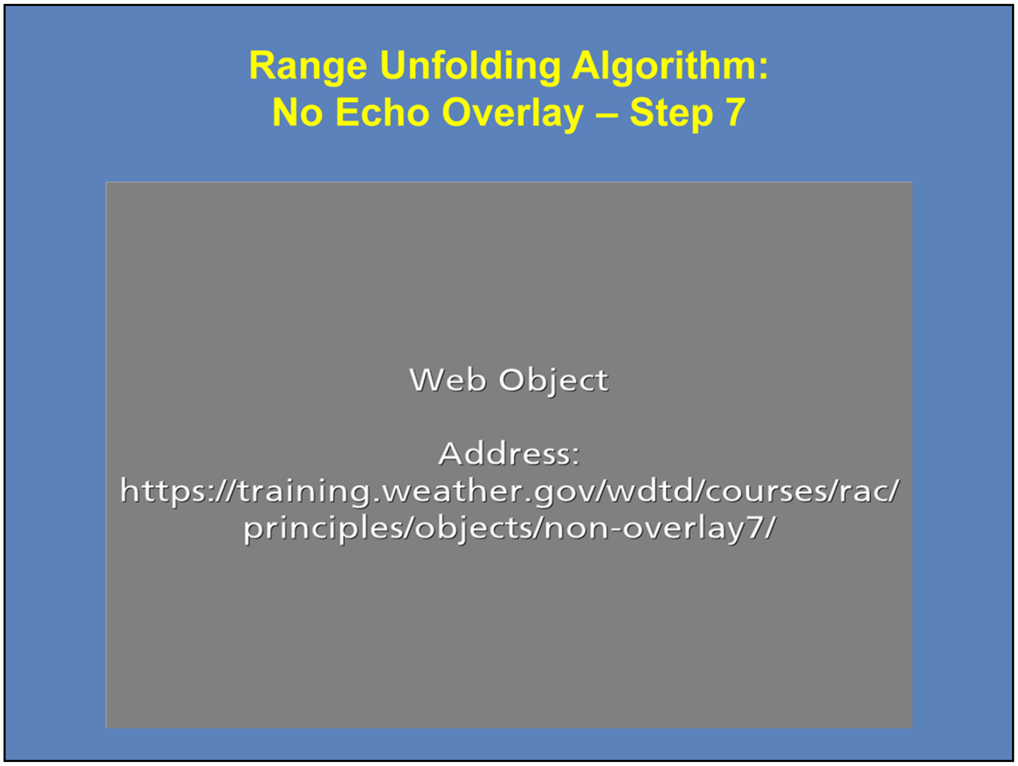

Step 7: Since no targets were detected at 30 nm in the CS data, the algorithm checks the next possible range which is 90 nm. And, yes, a target was detected in the Surveillance data at that range. That’s how we know that the velocity value that appears to be coming from 30 nm actually belongs at 90 nm.

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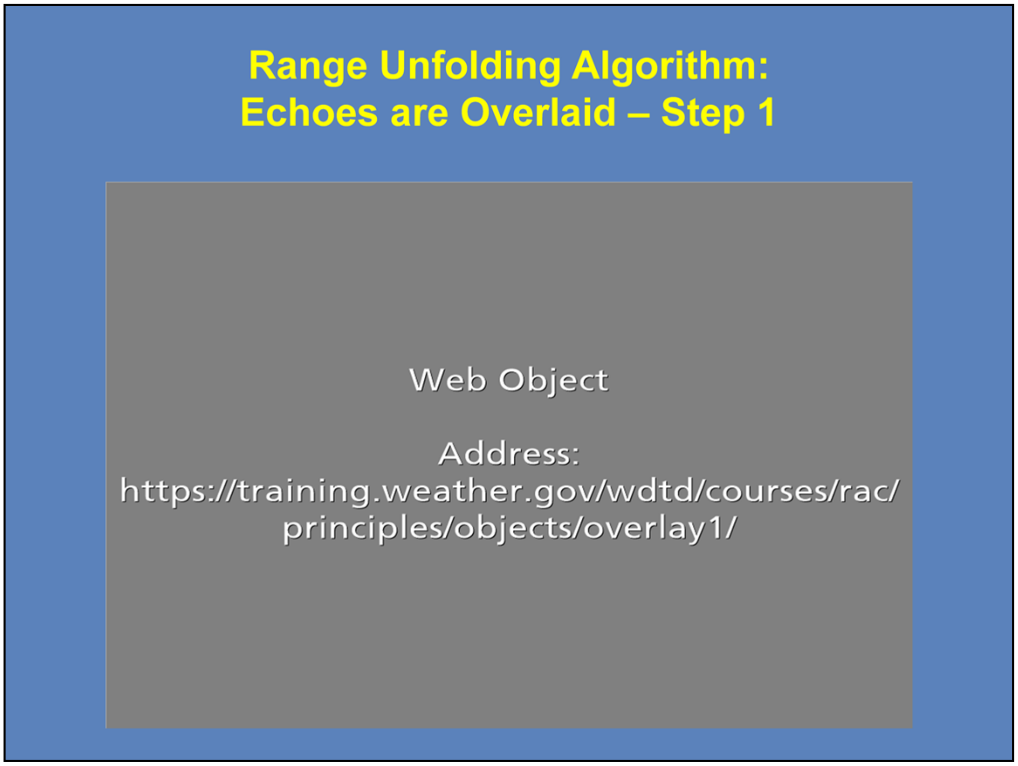
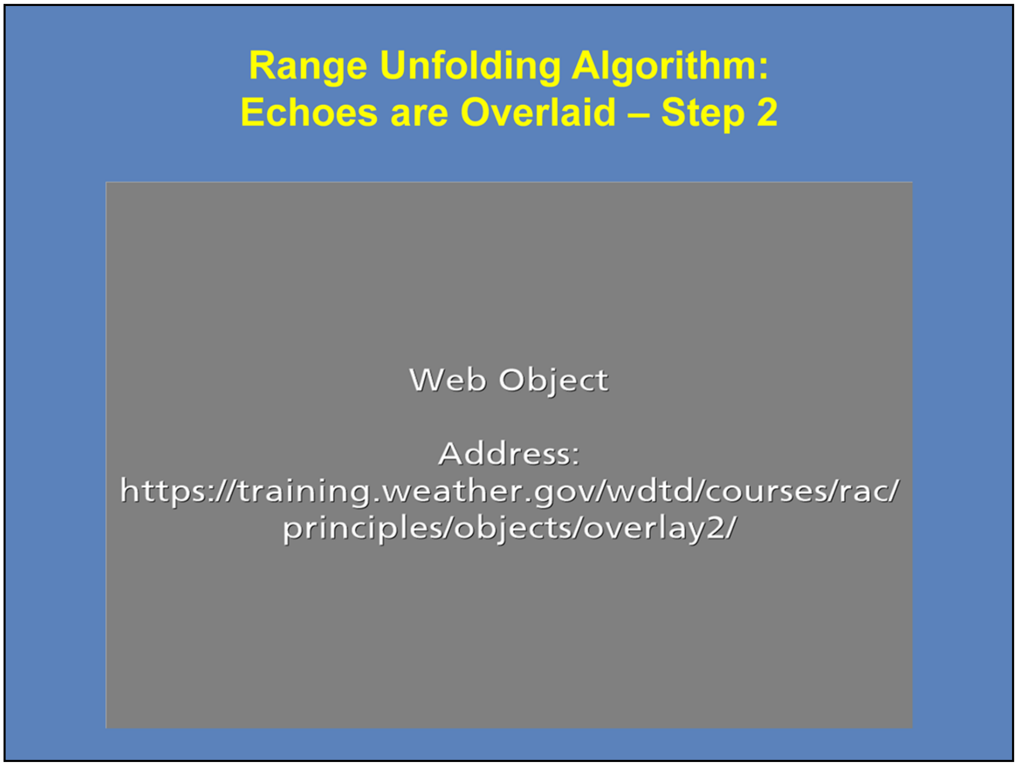
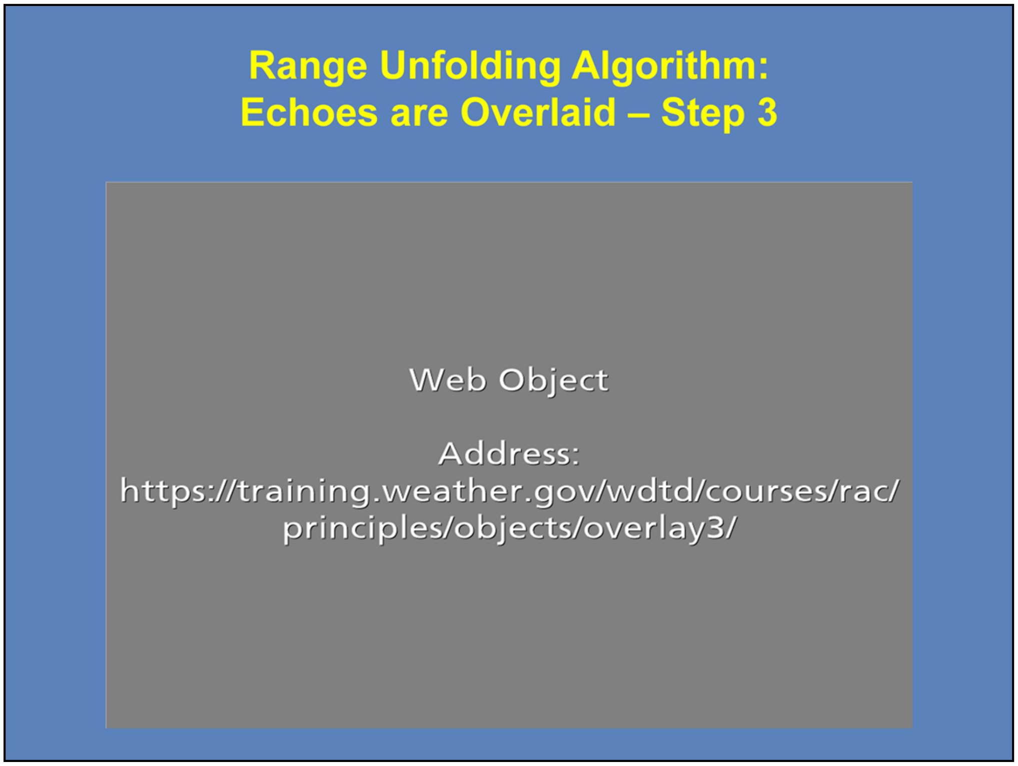


Now let’s look at our second example where echoes are overlaid on top of each other.

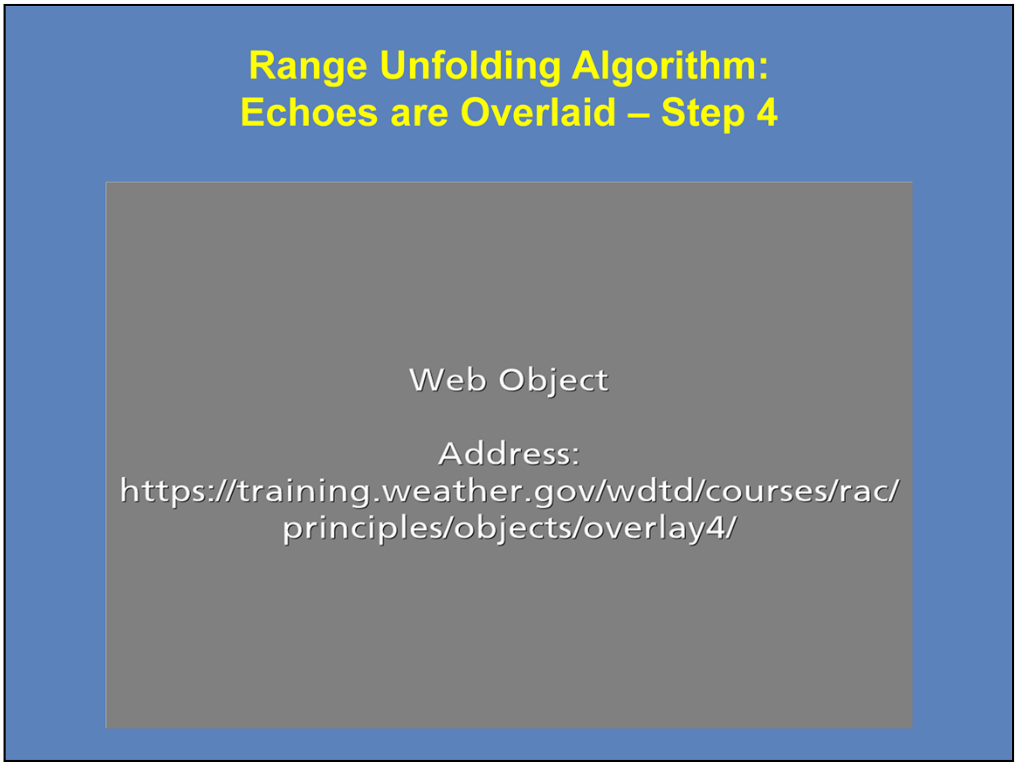
Step 1: We start off with the same initial conditions. In Surveillance mode, the RDA detects targets at 20 and 90 nm. The maximum unambiguous range is 250 nm, so we know the returned power and range for each of these targets.



Step 2: This time, when the radar switches to Doppler mode, the maximum unambiguous range will be 70 nm. That means both of the targets will have an apparent range of 20 nm. It also means that pulses are returning back to the RDA at the same time, so this is an overlay situation.



Step 3: Just as before, the algorithm accounts for the apparent ranges of the targets across the first, second and third trips.



Step 4: Here's where the algorithm takes advantage of the fact that it knows the returned power for each of these two targets and their original range. The algorithm compares those returned powers to each other, and it computes a threshold (called TOVER) to determine whether the velocity and spectrum width data are assigned to one of these two targets. So, the higher powered target is compared to the lower power target, and if difference reaches this threshold, the algorithm can assign the velocity and spectrum width values to one of these overlaid targets.

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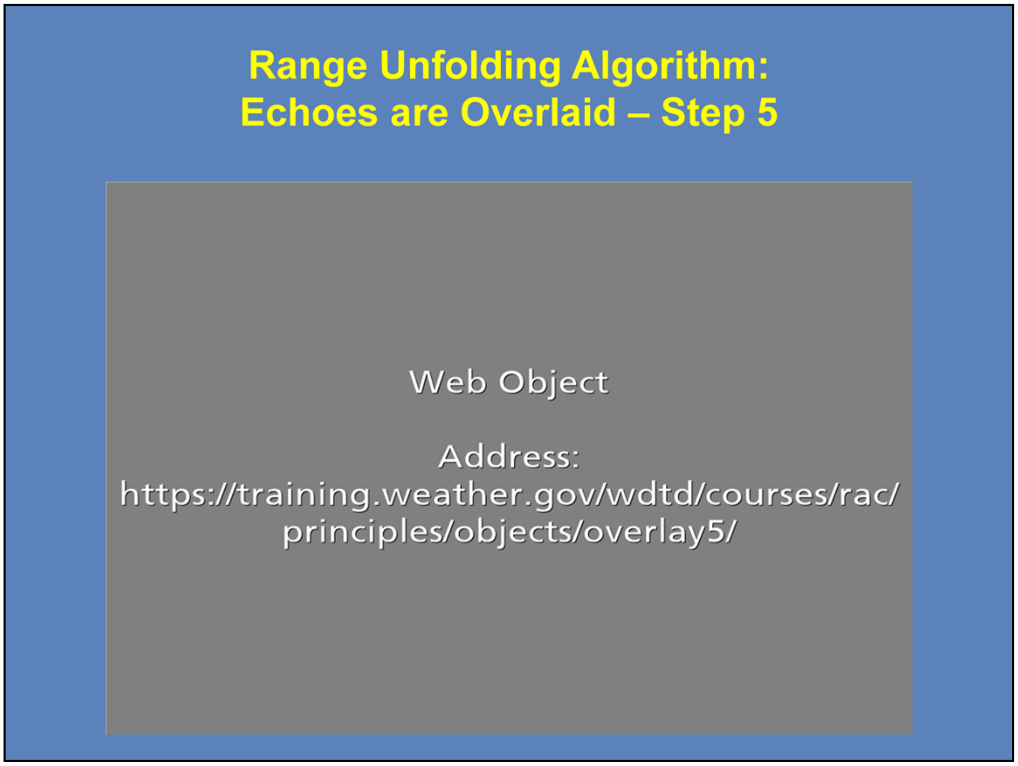
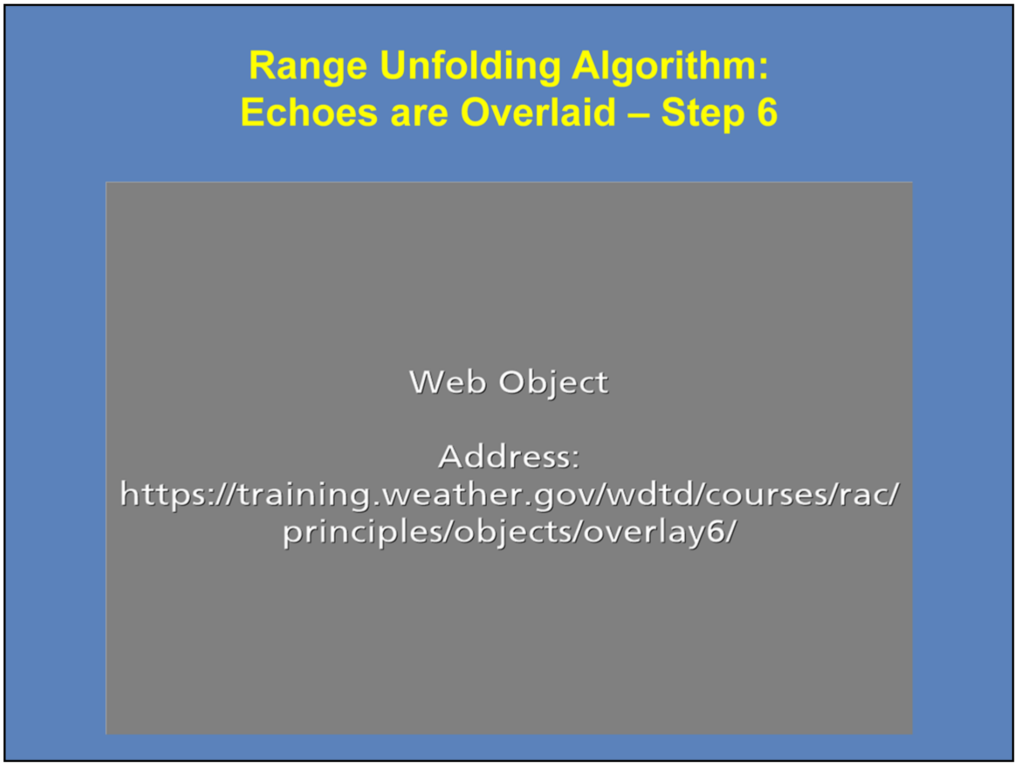


Step 5: Now the actual Doppler data collection begins, and notice that information from pulses 1 and 2 come back to the radar at the same time. So the velocity and spectrum width values have an apparent range of 20 nm, that is composed of data from returned pulses for both targets A and B.



Step 6: Now the algorithm begins the comparison of the Doppler to the Surveillance data. The algorithm answers the question whether a target was at a specific range, but also determines if that target that had the higher returned power. 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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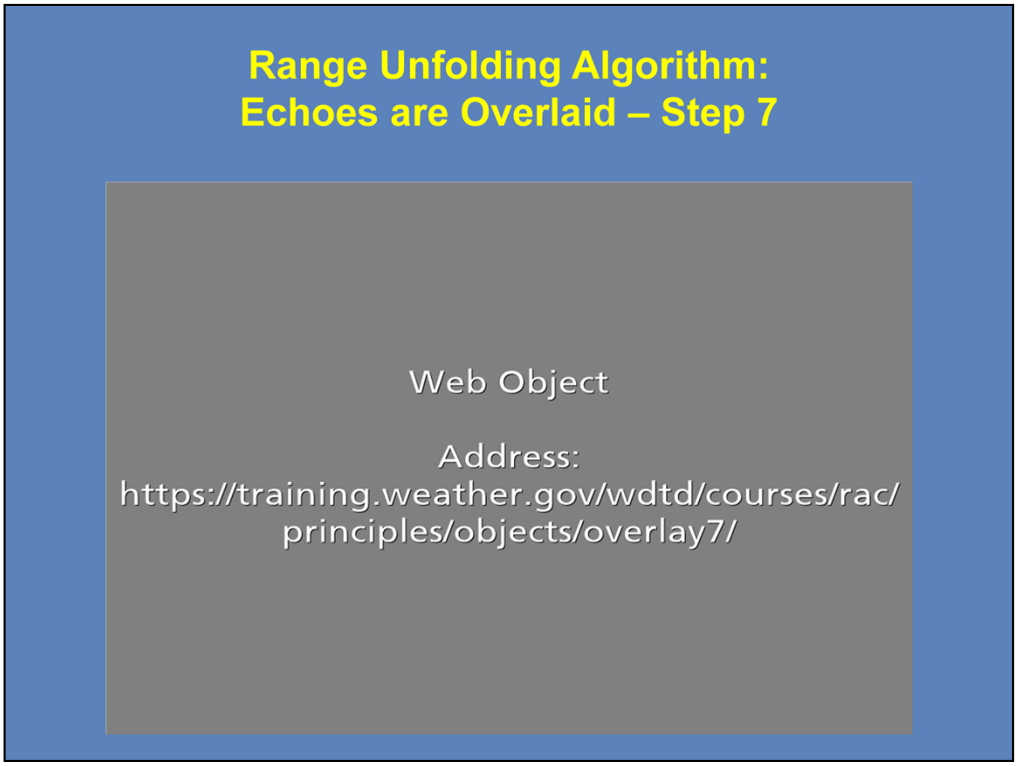

Step 7: Since the answer was no the first time, the algorithm looks at other possible ranges for this target. Was there something in the CS data at 90 nm? Yes. And was this the higher power target? Yes.

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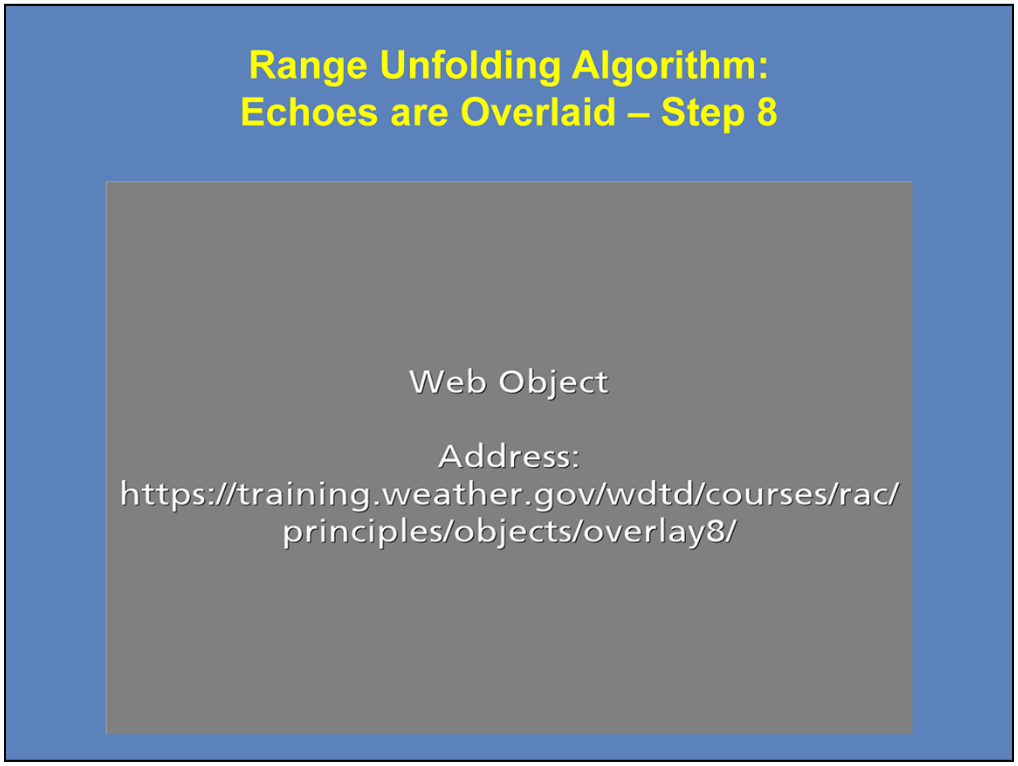

Step 8: Now that we know this velocity and spectrum width data at a range of 20 nm is more representative of the target that was at 90 nm. So, we assign the observed data to the bin at 90 nm, and range folding, or purple, to the echoes at 20 nm.

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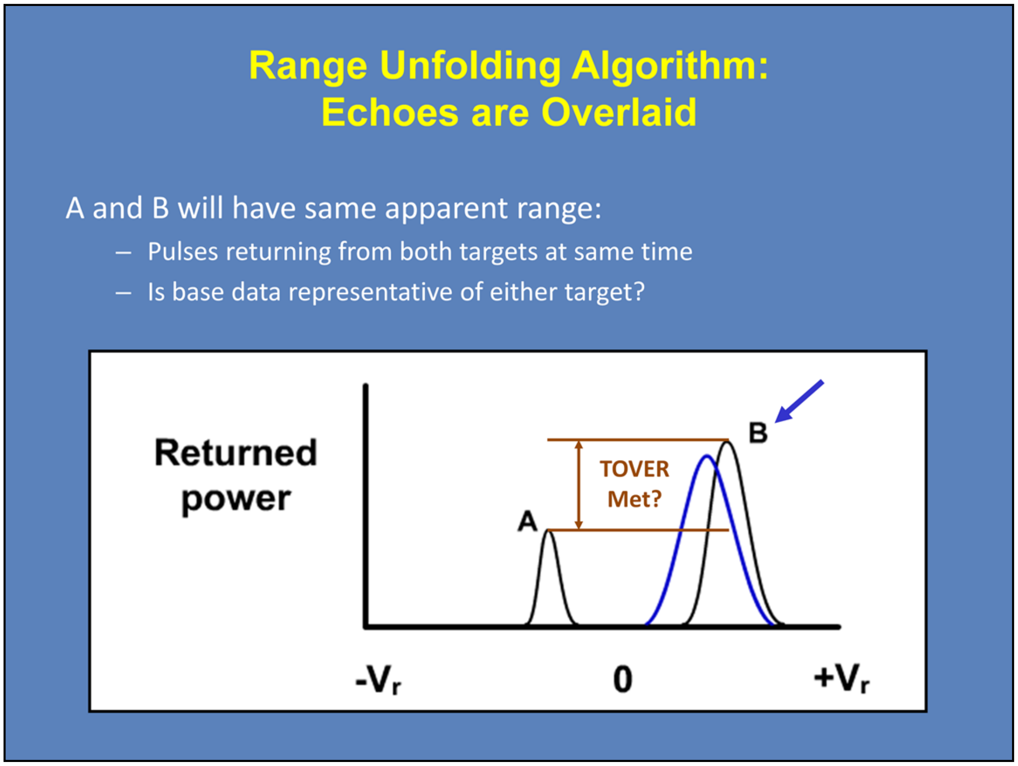
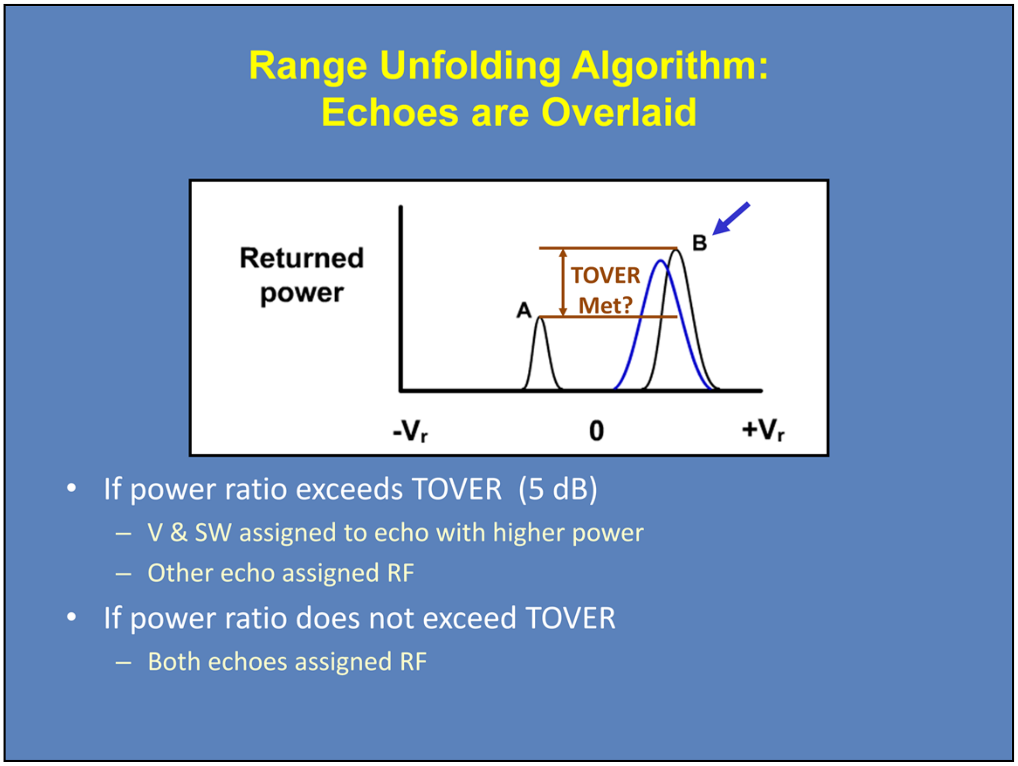


This graphic represents the base data estimation process for a range bin when there is an echo overlay case such as in our previous example. Pulses from two different targets are received and processed at the same time, apparently from 20 nm. If the pulses from these two different targets could be analyzed separately, the result would be the black bell curves for targets A and B. However, the returned pulses 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 since it is returning significantly more power than target A. Recall that velocity estimates are power weighted, so this “hybrid” velocity estimate will more closely resemble the more “powerful” target B.

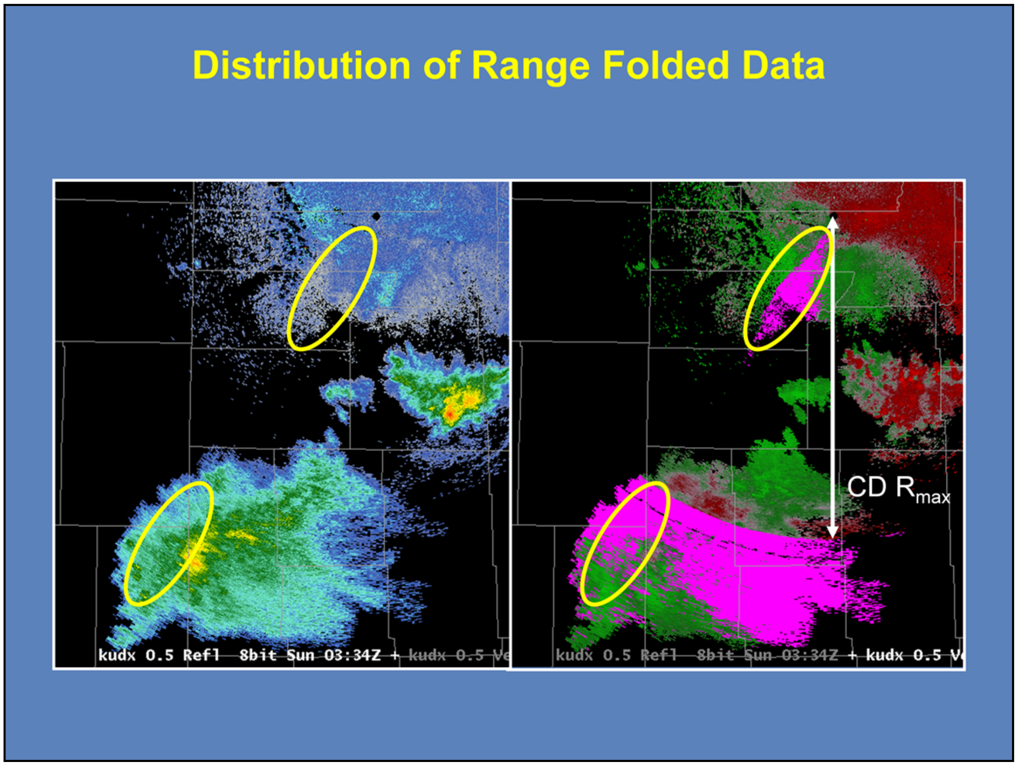
Lastly, the algorithm needs to determine if the power returned by B is sufficiently greater than A for the “hybrid” velocity to be assigned to target B.



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

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

If the power ratio does not exceed TOVER, the algorithm assigns RF to both of the overlaid echoes.



Now for another look at the distribution of RF in Base Velocity, given the location of the echoes in Base Reflectivity. The strongest storms south of the radar are within the first trip, so there is no issue with the availability of the associated velocity data. There is an area of weaker echo to the south and southwest of the radar, some of which falls within both the first and second trip of the Contiguous Doppler scan data.

The yellow ovals highlight a group of gates in the same relative positions in the first and second trips, with purple assigned to both of the bins in most cases. In general, 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.

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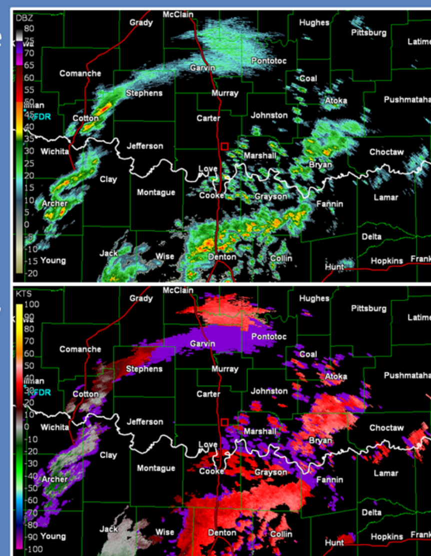
Legacy Range Unfolding Algorithm: Strengths

1. Places V & SW at proper range
   - May be beyond CD R_{max}
   - Echoes overlaid and TOVER exceeded:
     - One assigned V and SW
     - Other assigned RF
2. Mitigating “Doppler Dilemma”
   - Low PRF for target range and intensity
   - High PRF for velocity and spectrum width



Now for a summation of Legacy Range Unfolding Algorithms strengths. In most instances, this algorithm achieves its objective of assigning velocity and spectrum width data to the appropriate range, which may be beyond the R_{max} of the Contiguous Doppler (CD) scan. When echoes are overlaid, the Legacy Range Unfolding Algorithm can, at best, assign velocity and spectrum width to one of the overlaid echoes. The algorithm decides whether to assign the values based on the returned power of the separate echoes that contribute to the overlay. If TOVER is exceeded, then one of the echoes has returned sufficiently more power that the others and can be assigned the velocity and spectrum width values. The other echoes are assigned RF.

The Legacy Range Unfolding Algorithm mitigates the Doppler Dilemma in this manner. 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 more accurate velocity and spectrum width data. Comparing both data sources allows for “unfolding” the velocity and spectrum width to its appropriate range along the radial.

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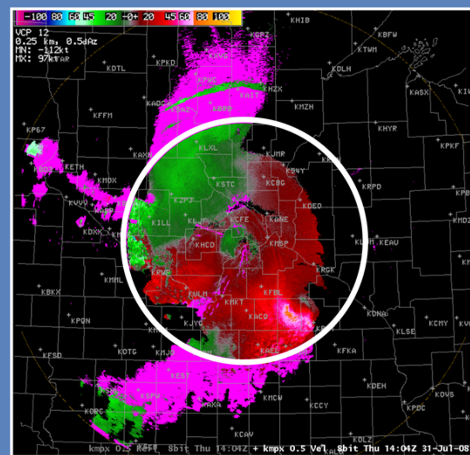
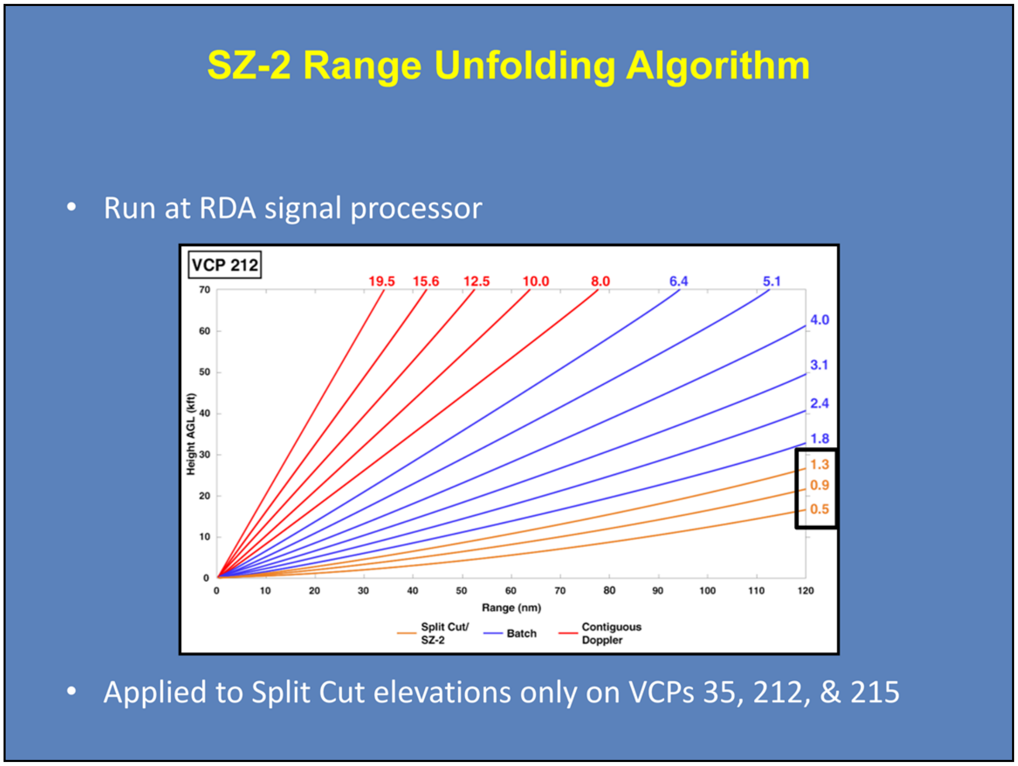
Legacy Range Unfolding Algorithm: Limitations

1. Extensive echo coverage with echoes extended along radials
   – Echo overlay maximized
2. V & SW unavailable for overlaid echoes if power ratio does not exceed TOVER



Extensive echo coverage aligned along radials limits the Legacy Range Unfolding Algorithm ability to unambiguous unfold velocity CD data. These situations maximize echo overlay along a radial through the first, second, and third trips. The Legacy Range Unfolding algorithm can only assign overlaid data to one of the echoes, so the result of these situations is extensive range folded data. If the returned power from the overlaid echoes is too similar, than both echoes will be assigned RF values.

This example shows a case where the TOVER requirement was met for most of the echoes in the first trip.



The second range unfolding technique for the velocity and spectrum width data is known as SZ-2 Range Unfolding and was fielded in 2007. This technique is named for the two research scientists who developed it: Mangalore Sachidananda and Dusan Zrnic. This algorithm runs at the RDA signal processor, the literal black box, just like the Legacy Range Unfolding Algorithm.

The SZ-2 algorithm is available only for the Split Cut elevations of VCPs: 35, 212, 215.

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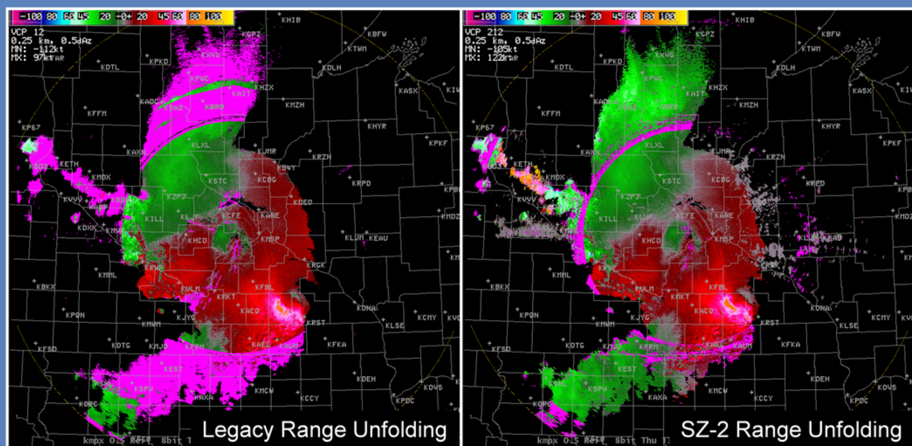
Legacy Range Unfolding vs. SZ-2



- Legacy Range Unfolding recovers velocity from ***one*** of the echoes
- SZ-2 usually recovers velocity from ***both*** echoes

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. Use of VCP 212 dramatically improves the availability of velocity and spectrum width. Notice from the data that Continuous Doppler data are available from multiple trips over large areas, resulting in extensive echo overlay. Where there is echo overlay, the Legacy Range Unfolding Algorithm can recover, at best, one of the echoes. On the other hand, the SZ-2 technique usually recovers both overlaid echoes.

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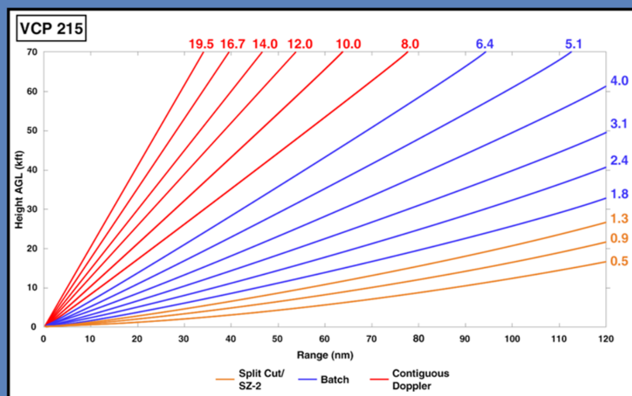
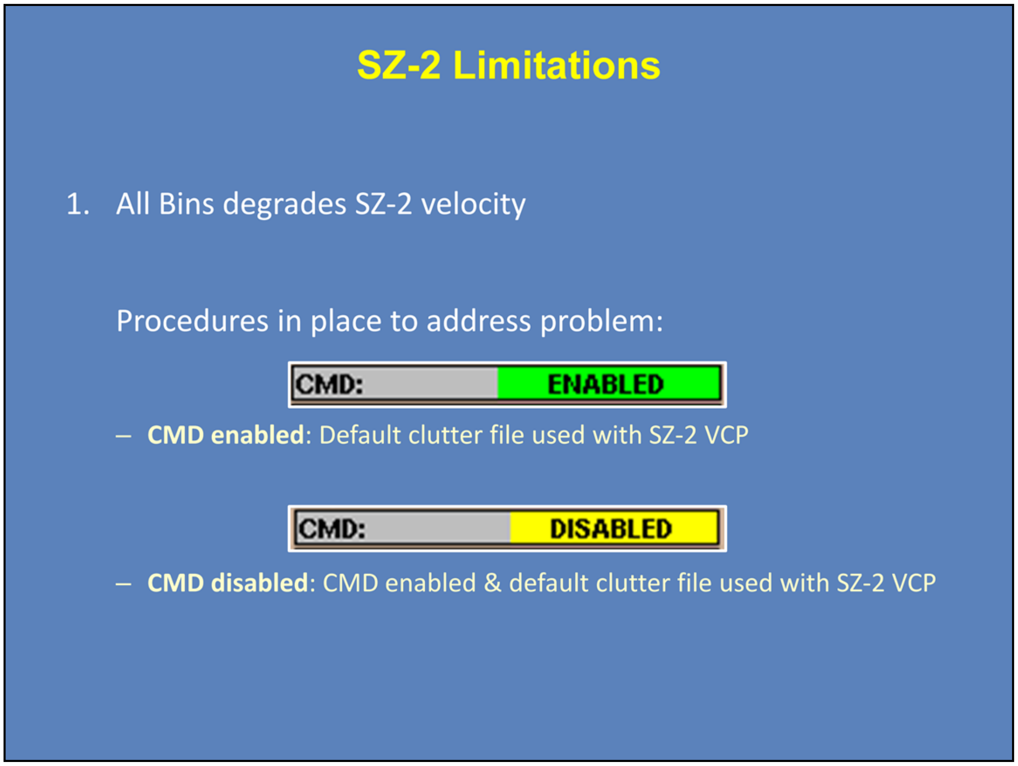
SZ-2 Strengths

1. SZ-2 Strengths
   - Significant increase in availability of velocity data
   - Best results with widespread returns



The SZ-2 Range Unfolding Algorithm's strength results from its increased availability of velocity data for multiple trips. The best results come with events with widespread echo coverage.



With the Clutter Mitigation Detection algorithm active, the radar almost never needs All Bins clutter suppression. SZ-2 usage adds another reason to avoid All Bins suppression, as All Bins suppression can degrade the velocity data when SZ-2 is applied. In fact, the RPG software has built in procedures to avoid having All Bins and SZ-2 active at the same time.

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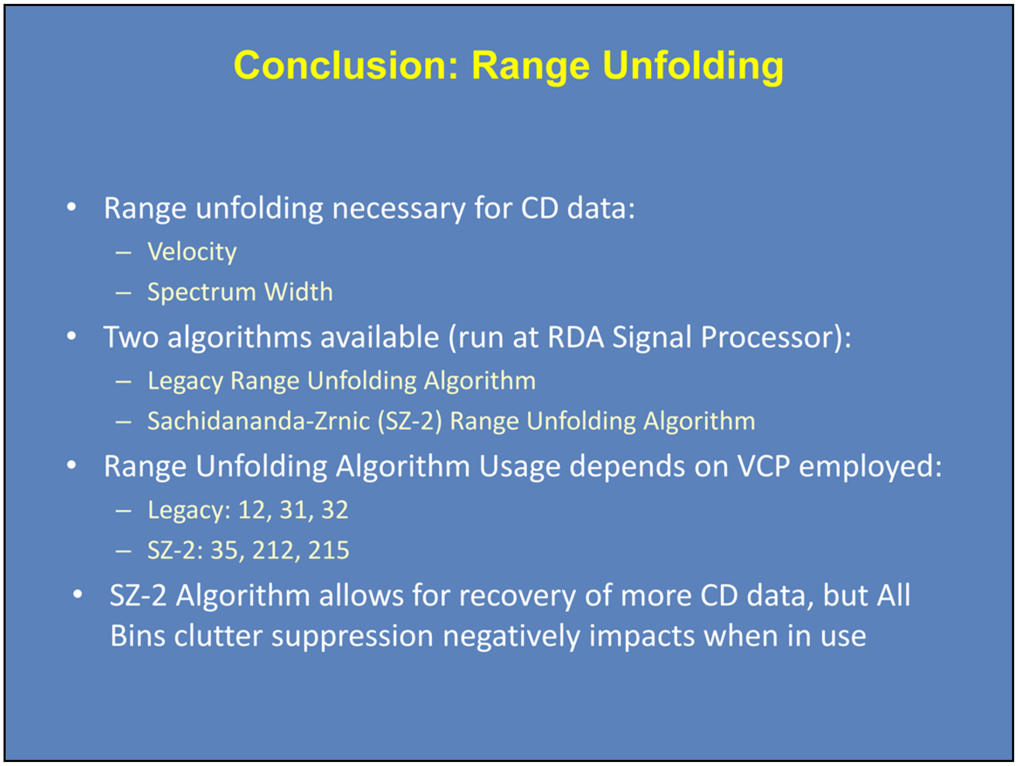

To wrap things up, the higher PRFs used during the Contiguous Doppler scan makes range unfolding of velocity and spectrum width data necessary because of the short maximum unambiguous ranges. The WSR-88D uses two different range unfolding algorithms at the signal processor to handle this process. The Legacy Range Unfolding Algorithm addresses the issue for VCPs 12, 31, and 32. The Sachidananda-Zrnic (or SZ-2) algorithm unfolds the CD scan data for VCPs 35, 212, and 215. The SZ-2 Algorithm generally outperforms the Legacy algorithm because it allows for the recovery of more CD velocity and spectrum width data during overlay situations. However, the downside to the SZ-2 Algorithm is All Bins clutter suppression negatively impacts data quality when SZ-2 is in use.

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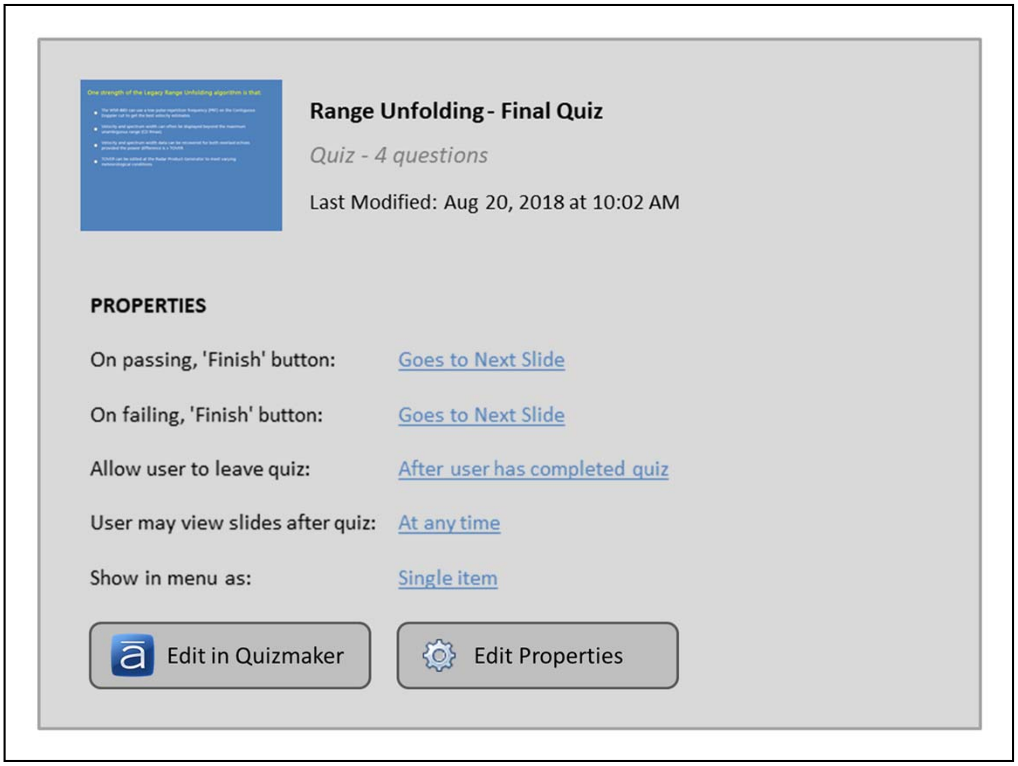
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Quiz - 4 questions
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User may view slides after quiz: At any time
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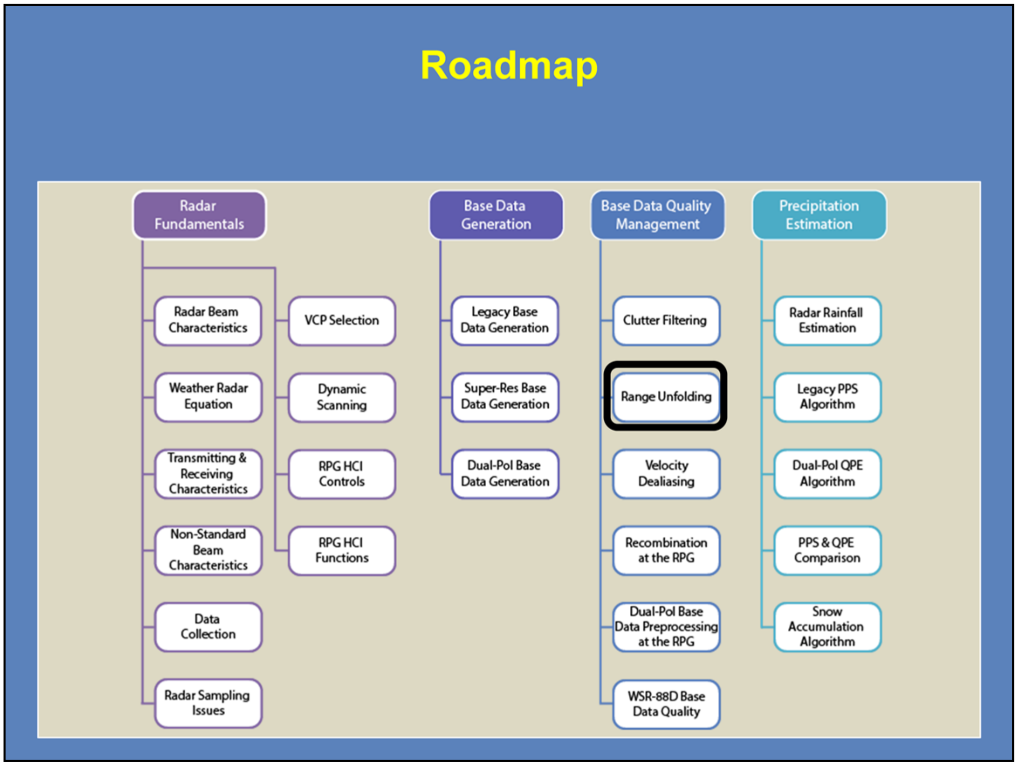

You have now completed this lesson on the range unfolding of velocity data. You are ready to proceed to the next lesson.

Welcome to this lesson on Velocity Dealiasing.

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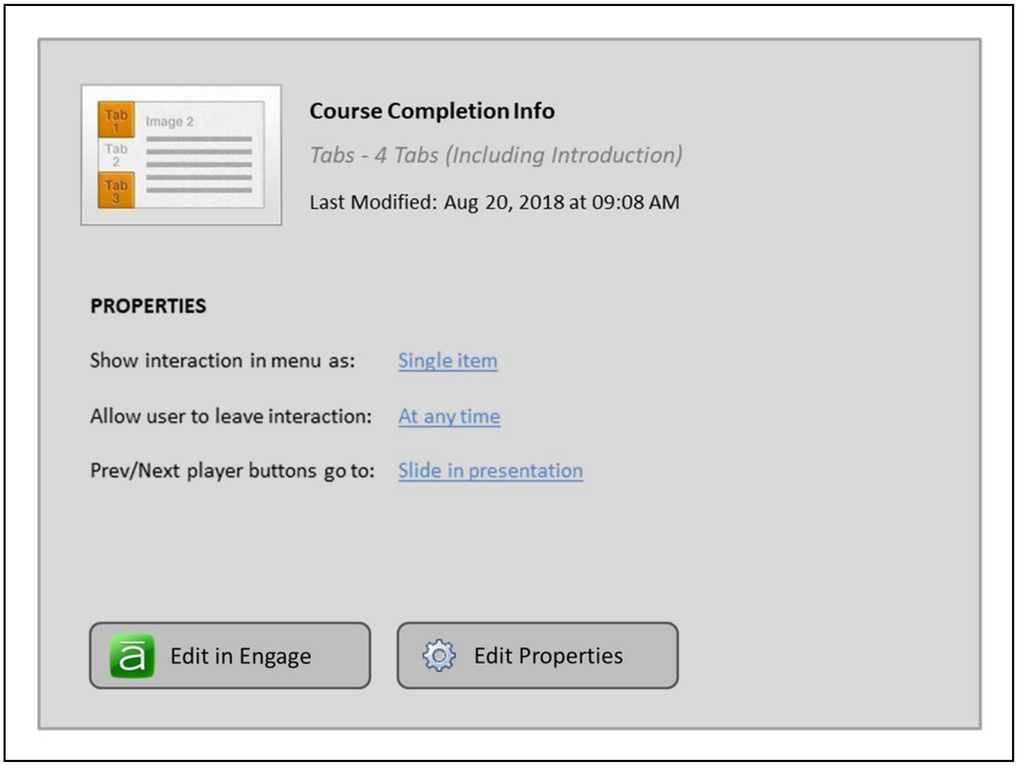
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Last Modified: Aug 20, 2018 at 09:08 AM
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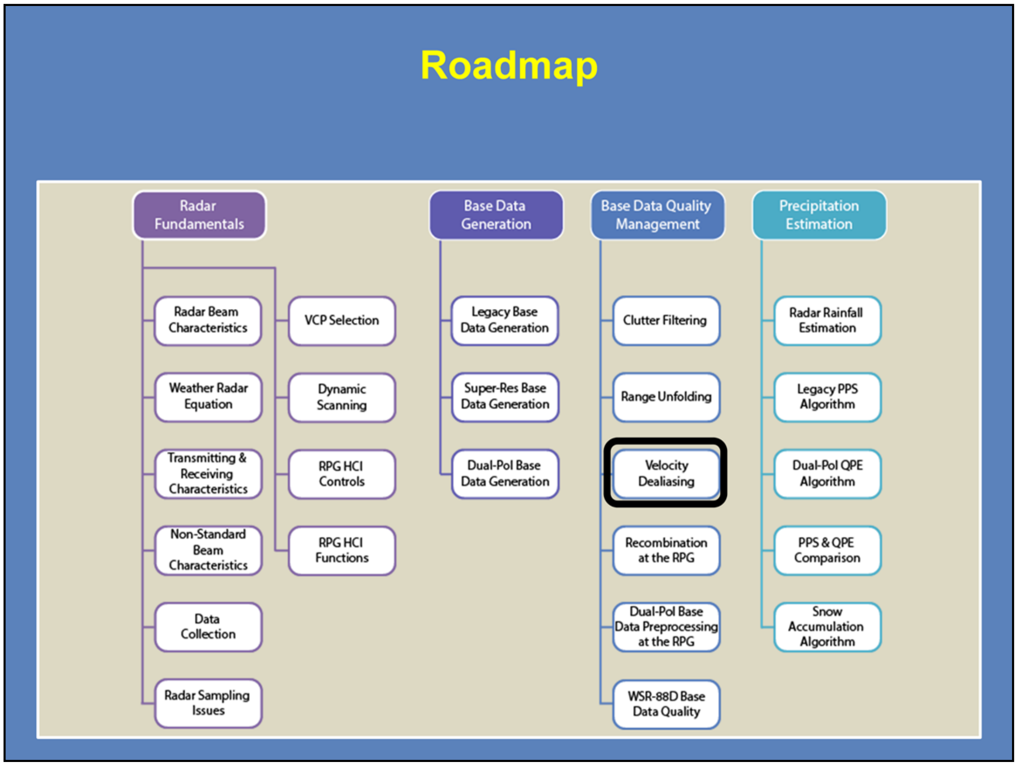
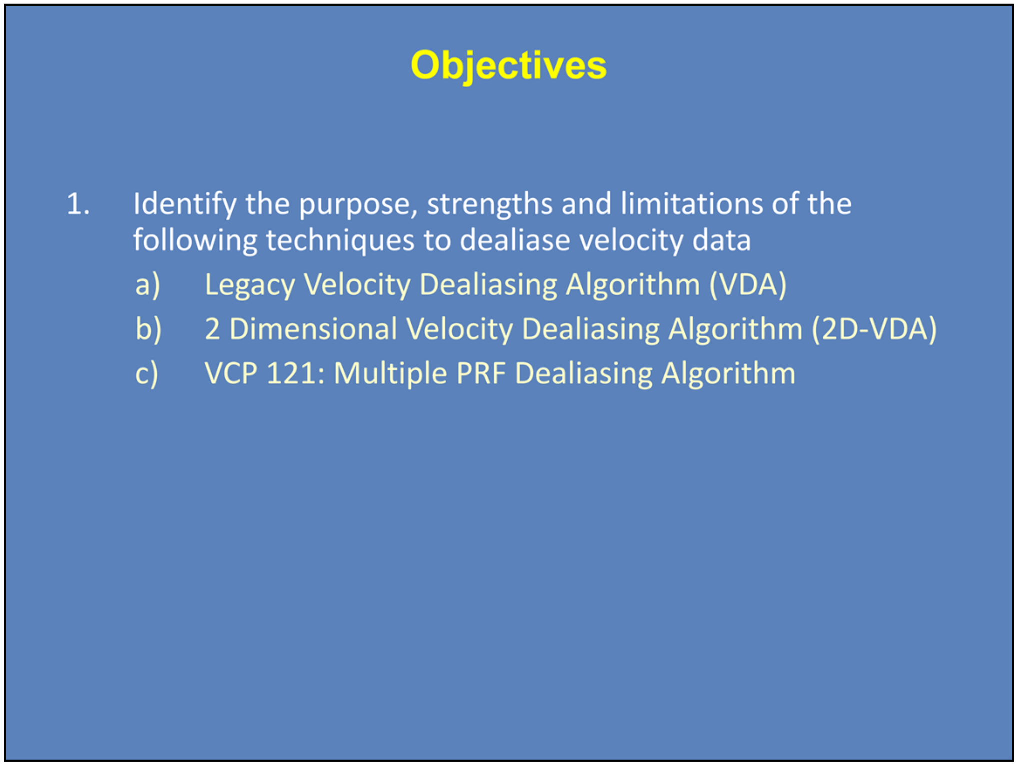
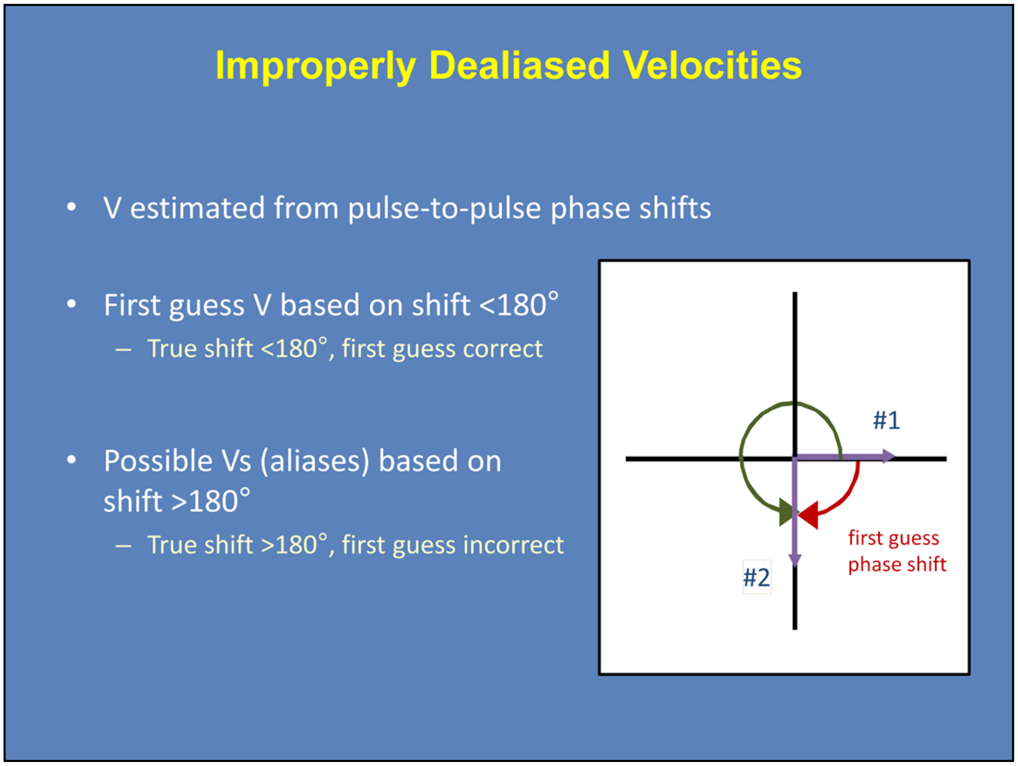


Here is the “roadmap” with your current location.



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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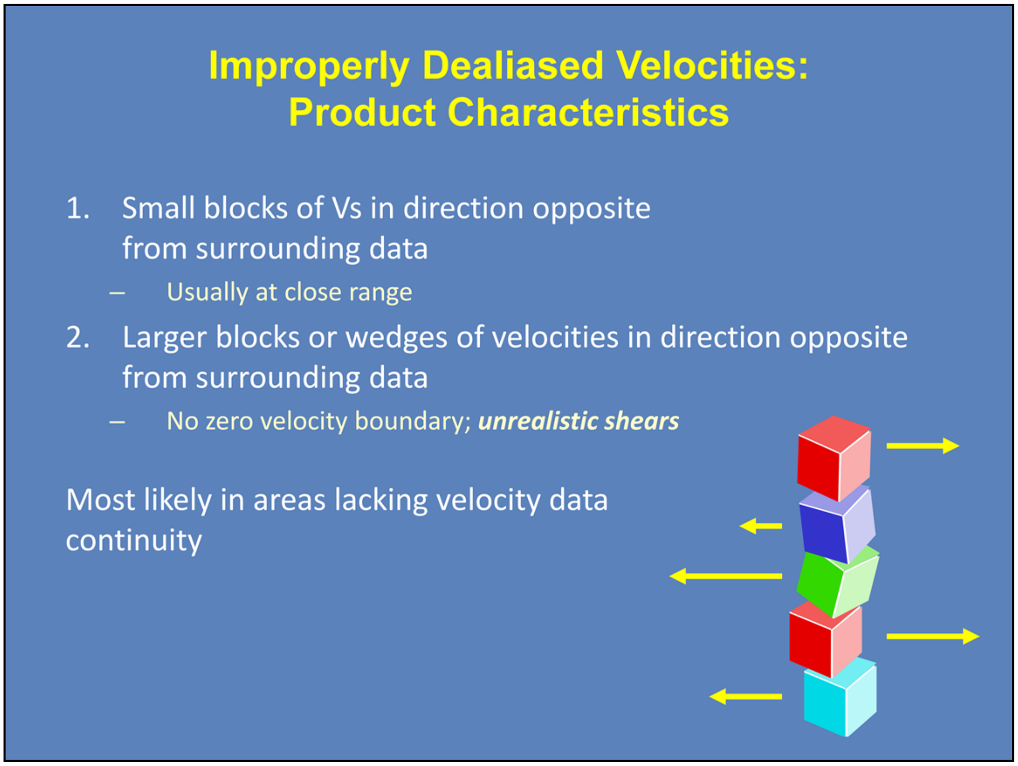
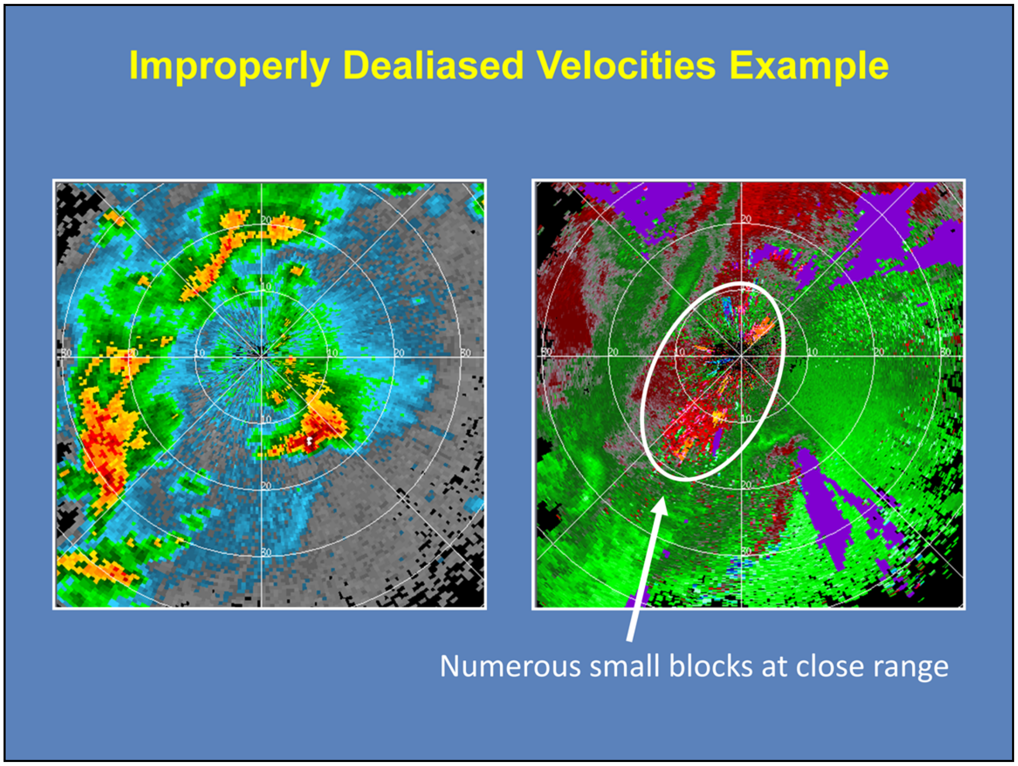


Before looking at the algorithm that “de-aliases” velocities, we first look at the impact of improperly dealiased velocities on the radar products. There are two types of improperly dealiased velocities. At close range, especially in residual ground clutter, small blocks of velocity values opposite in 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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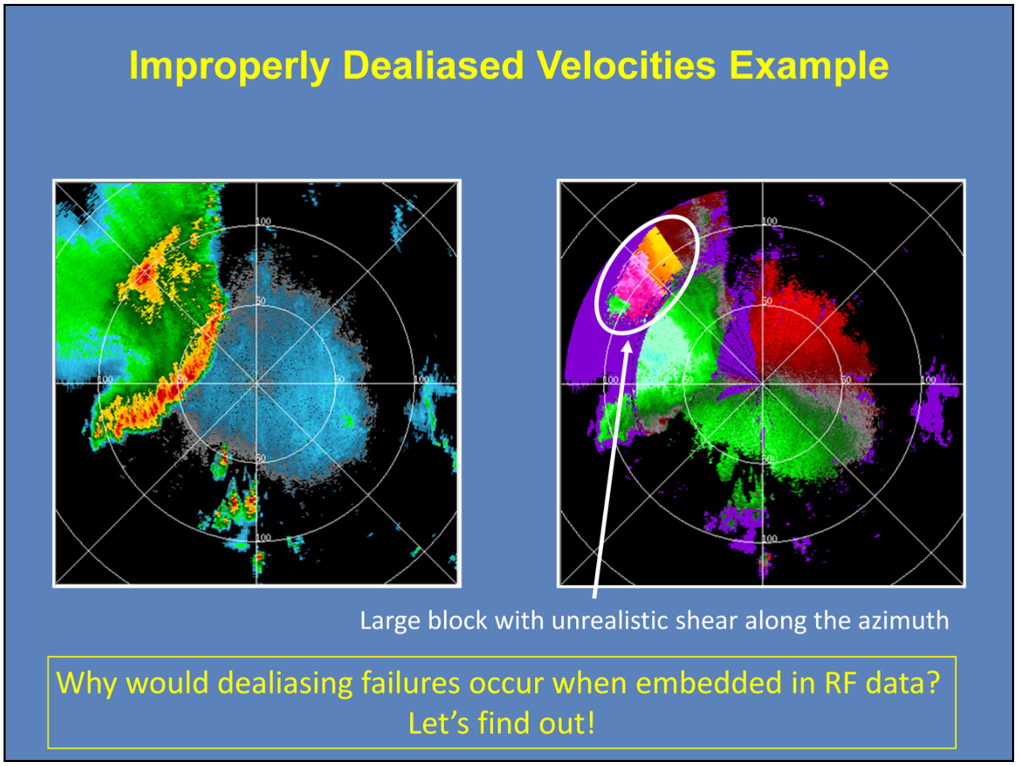
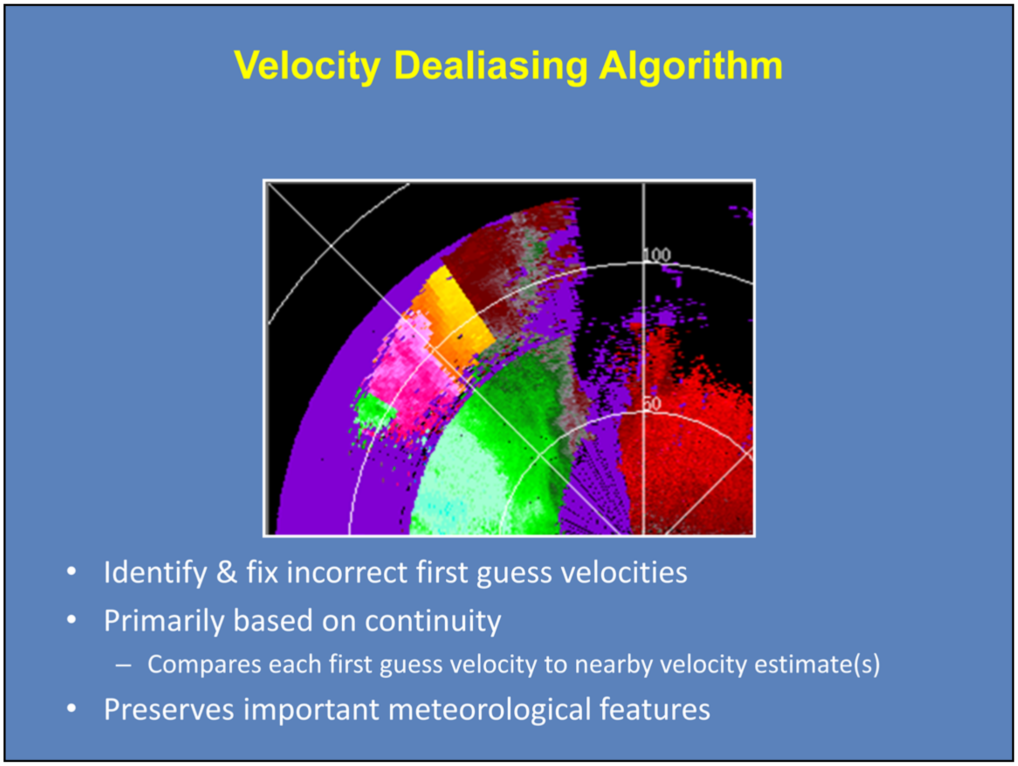


This is an example of improperly dealiased velocities resulting in two azimuthal shears that are clearly not meteorological. Another term for this data artifact is dealiasing failures. The fact that these failures occur while embedded in an area where RF has been assigned is related to how the dealiasing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



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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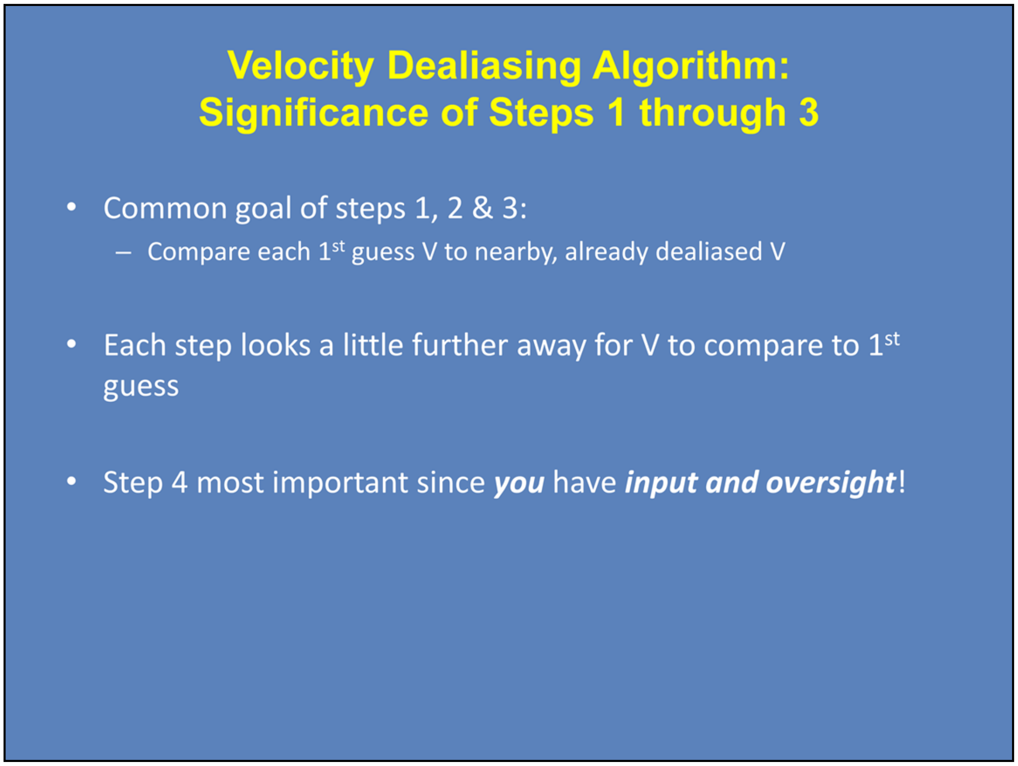
Velocity Dealiasing Algorithm: "Check Your Neighbor"

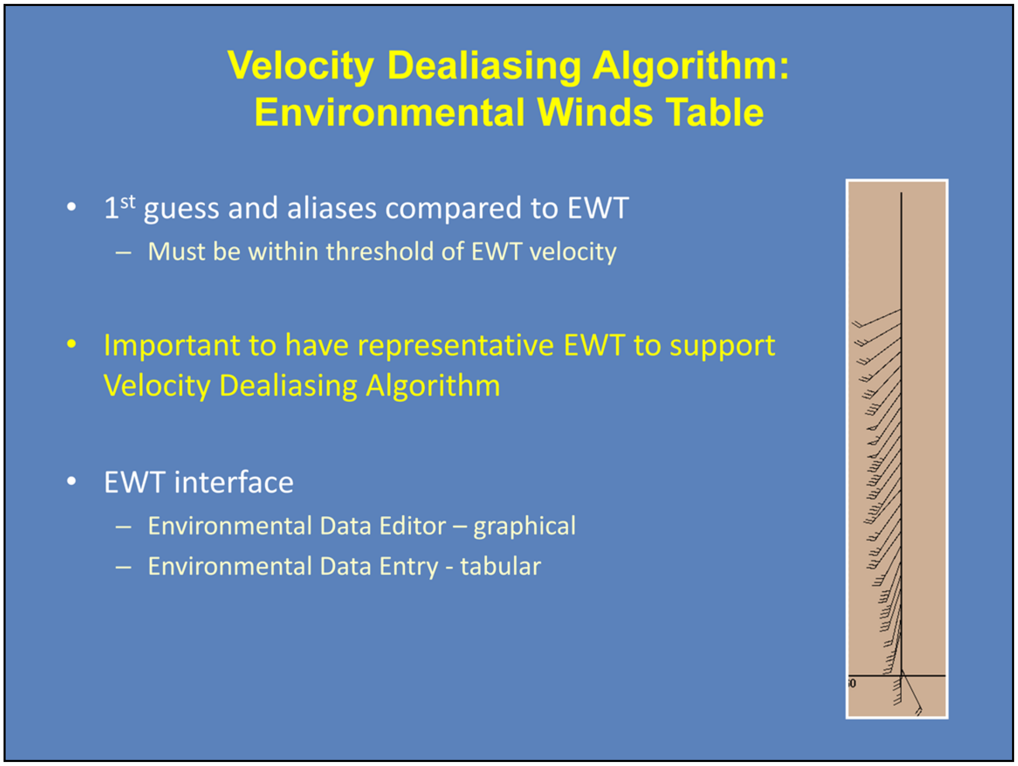
- First 3 steps search for V close to each 1st guess
  - Compare 1st guess against V neighbor
  - Compare 1st guess aliases against V neighbor
- Does +59 make sense?

-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.

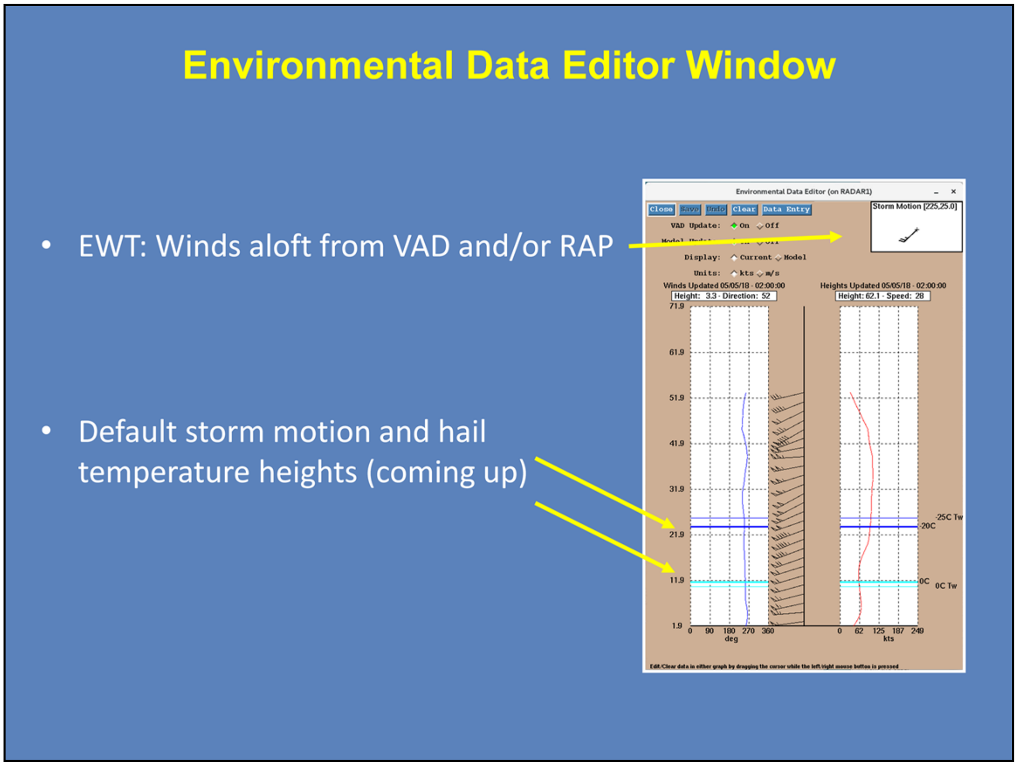


The first three steps of the Velocity Dealiasing algorithm have the common goal of comparing each first guess velocity to a “velocity neighbor”. That “velocity neighbor” varies with each step, getting a little further away from the first guess velocity. With respect to everyday operations, the most important 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.



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.

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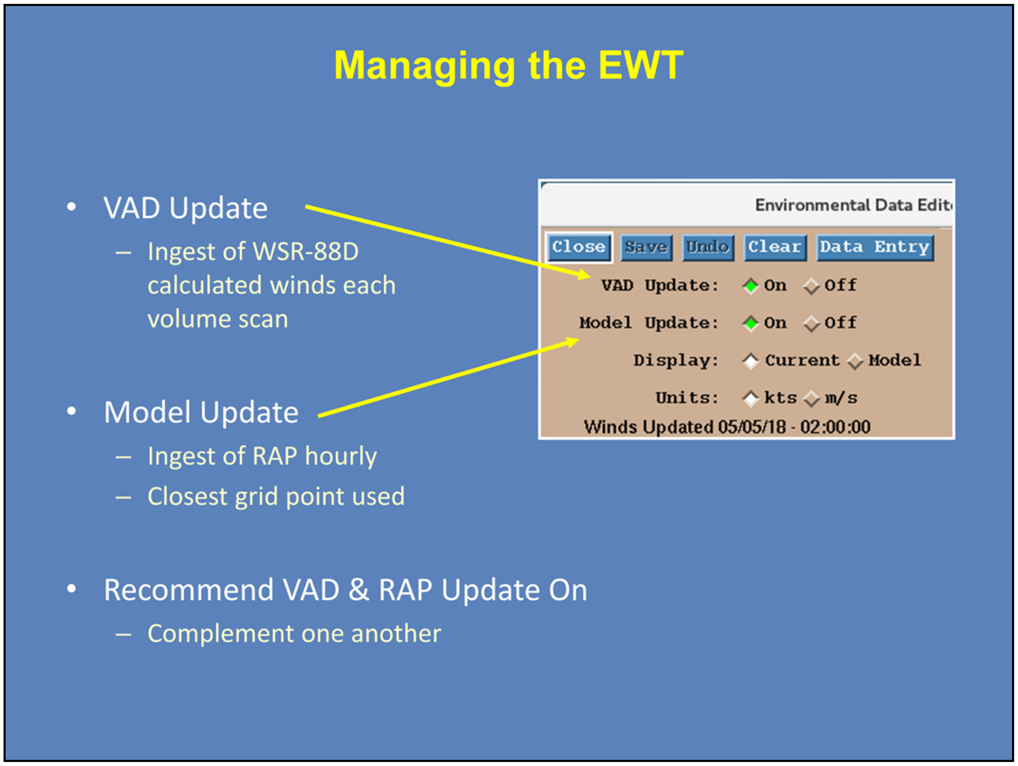

Here's a closer look at the buttons that control inputs to the Environmental Winds Table. When VAD Update is set to On, the EWT is updated every volume scan by VAD-generated winds aloft. When Model Update is set to On, the RAP data for the closest grid point are used hourly to update the EWT.

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.

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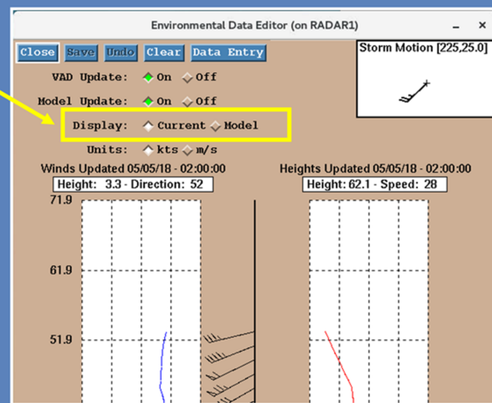
Managing the EWT

- Use Display for quality control
  - Current: EWT
  - Model: latest RAP data
- RAP data poor?
  - Set Model Update to Off



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.

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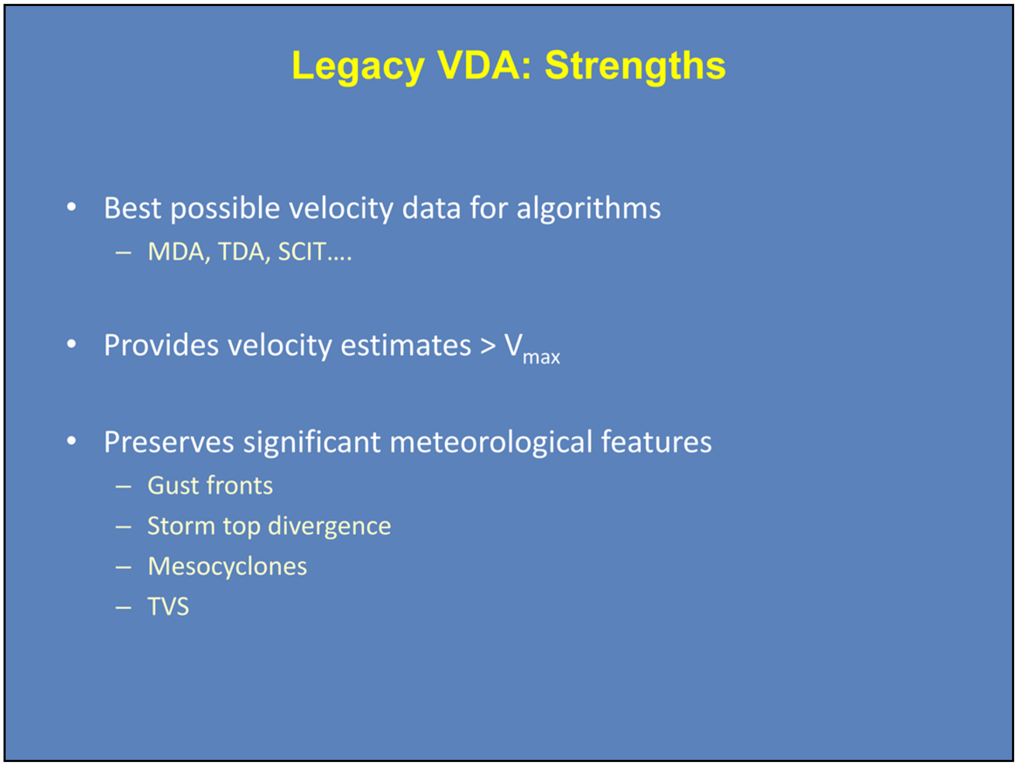

The Velocity Dealiasing algorithm is designed to provide the best possible velocity data, primary to support the RPG algorithms that look for significant features such as circulations. The Velocity Dealiasing algorithm attempts to assign the true radial velocity, even when it exceeds V_{max}. There are 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.

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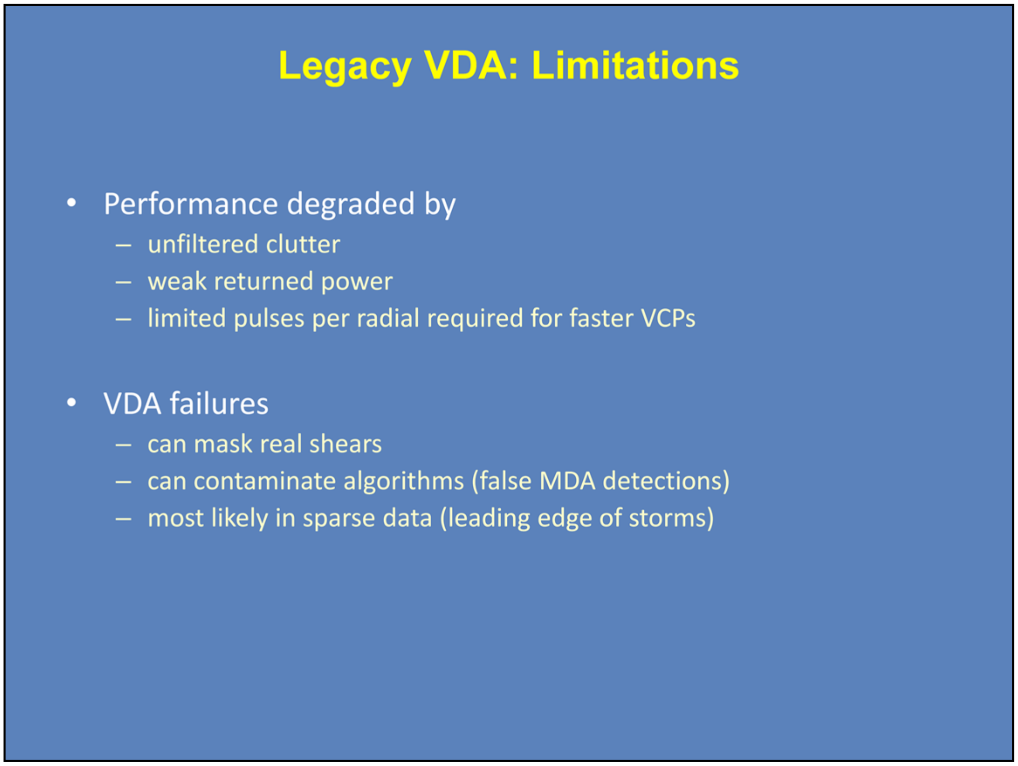

The performance of the Velocity Dealiasing algorithm is degraded by data quality problems that reduce the reliability of the first guess velocity. This includes unfiltered clutter, weak returned power, and in some cases, the low number of pulses per radial with the faster VCPs. When dealiasing failures 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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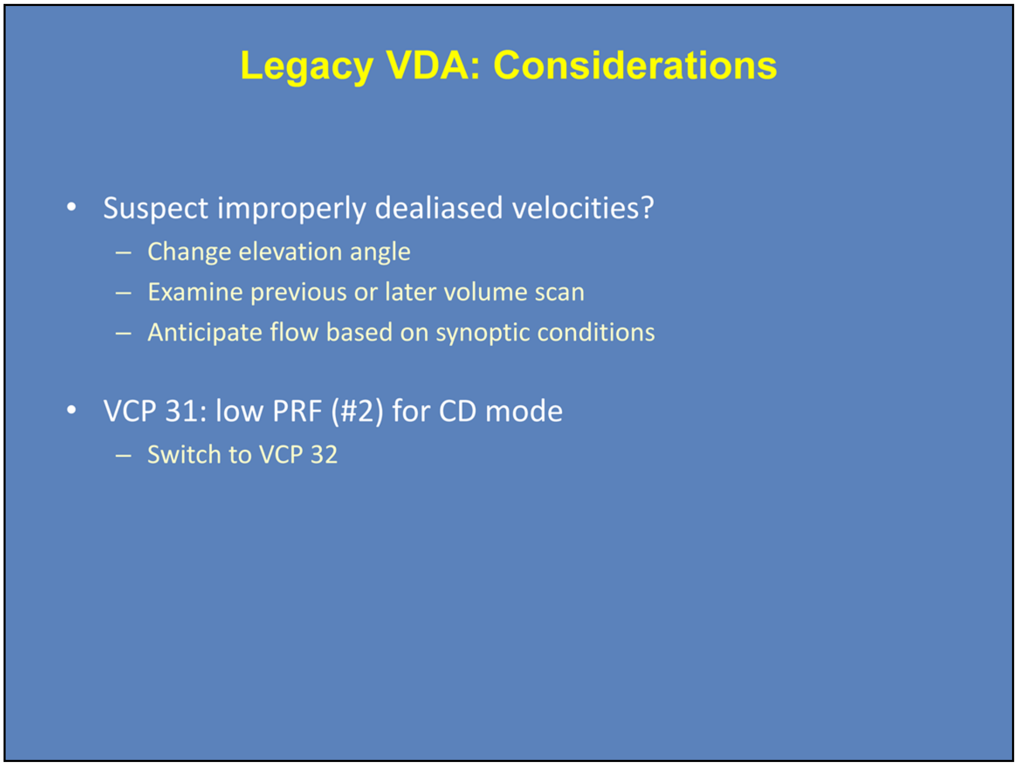
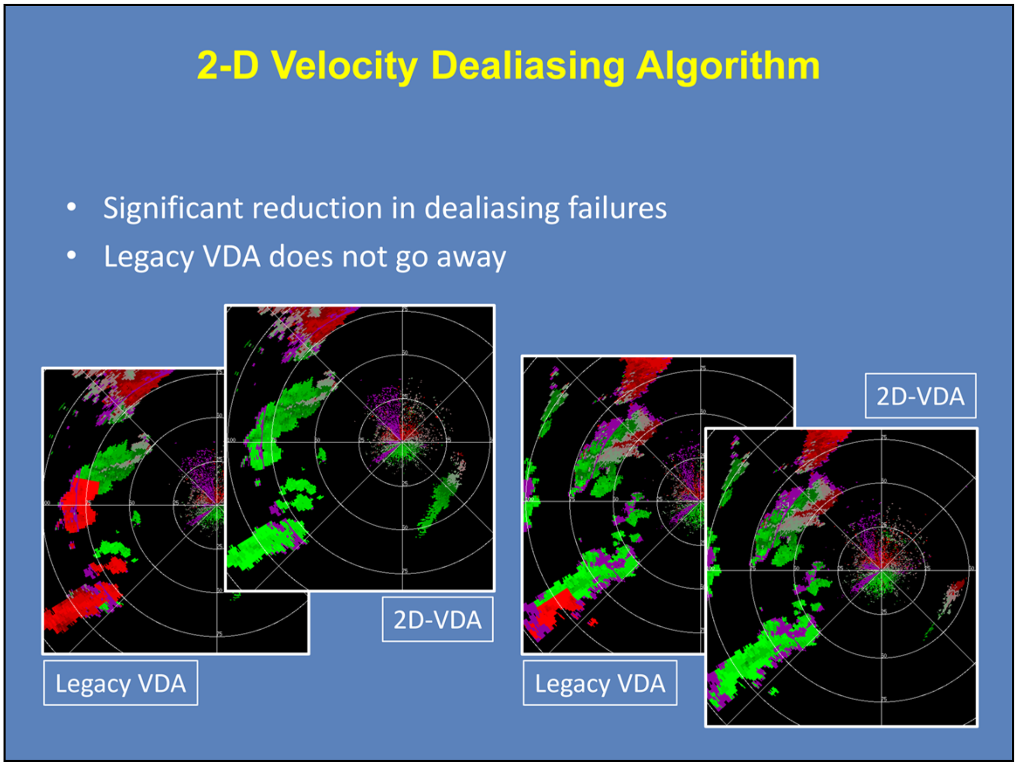


Sometimes dealiasing failures are subtle, and it can be hard to determine if you are seeing a valid shear. It is helpful to be aware that improperly dealiased velocities are not usually preserved from one elevation angle to the next, or from one volume scan to the next. For synoptic or mesoscale flow,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



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.

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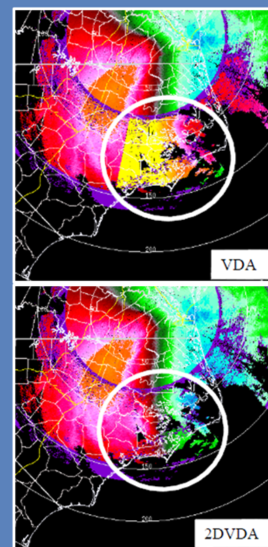
2-D Velocity Dealiasing Algorithm

- Dealias entire elevation of V data
  - Azimuth/radial grid built with median V for each grid center
  - V field partitioned to dealias small features
  - Weighting factors reduce data noise
  - Low weighting where spectrum width is high



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.

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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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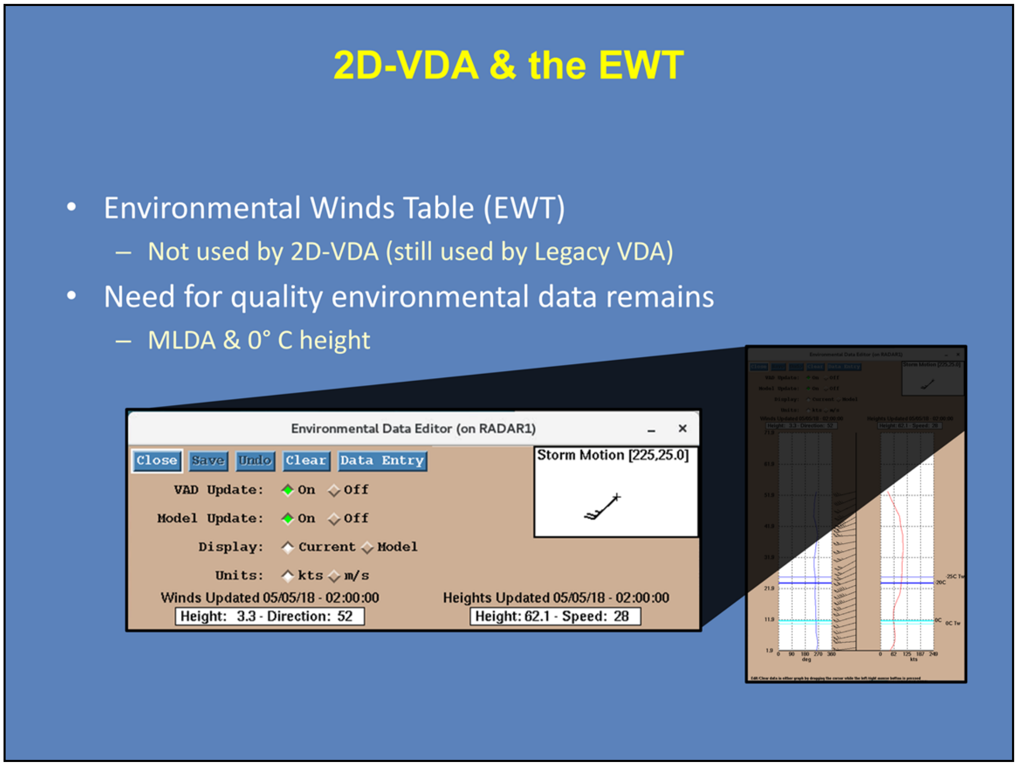
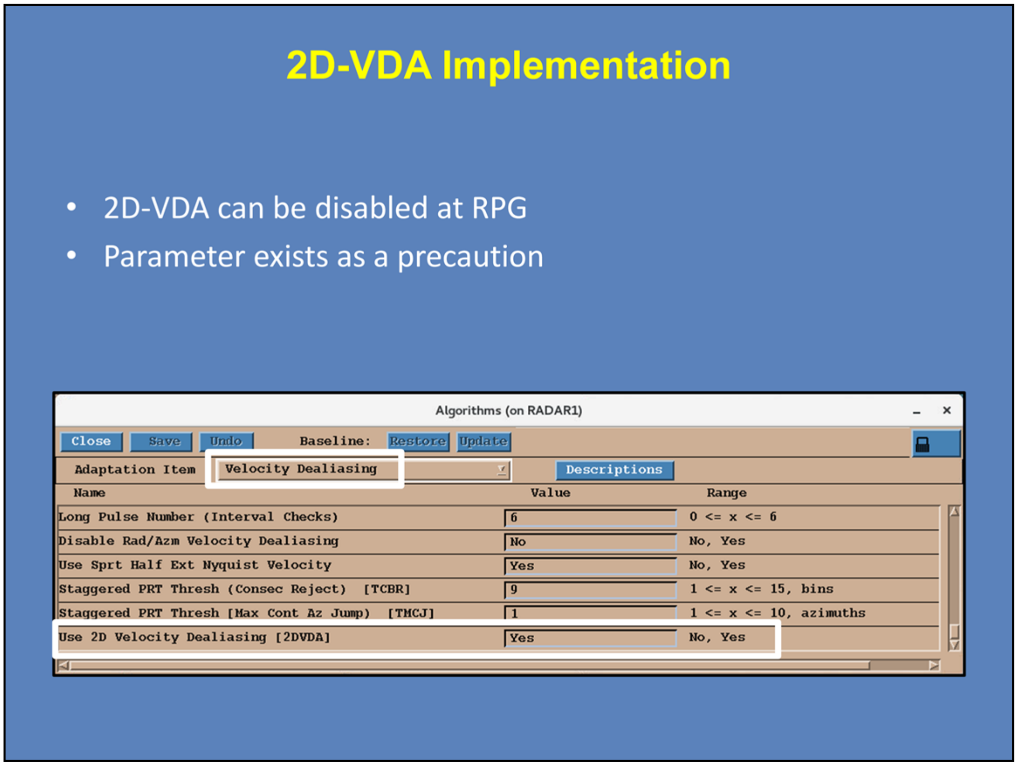


The Environmental Winds Table (EWT) supports the performance of the Legacy VDA, and will continue to do so whenever the Legacy VDA is running. The 2D-VDA does not rely on the EWT.

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.

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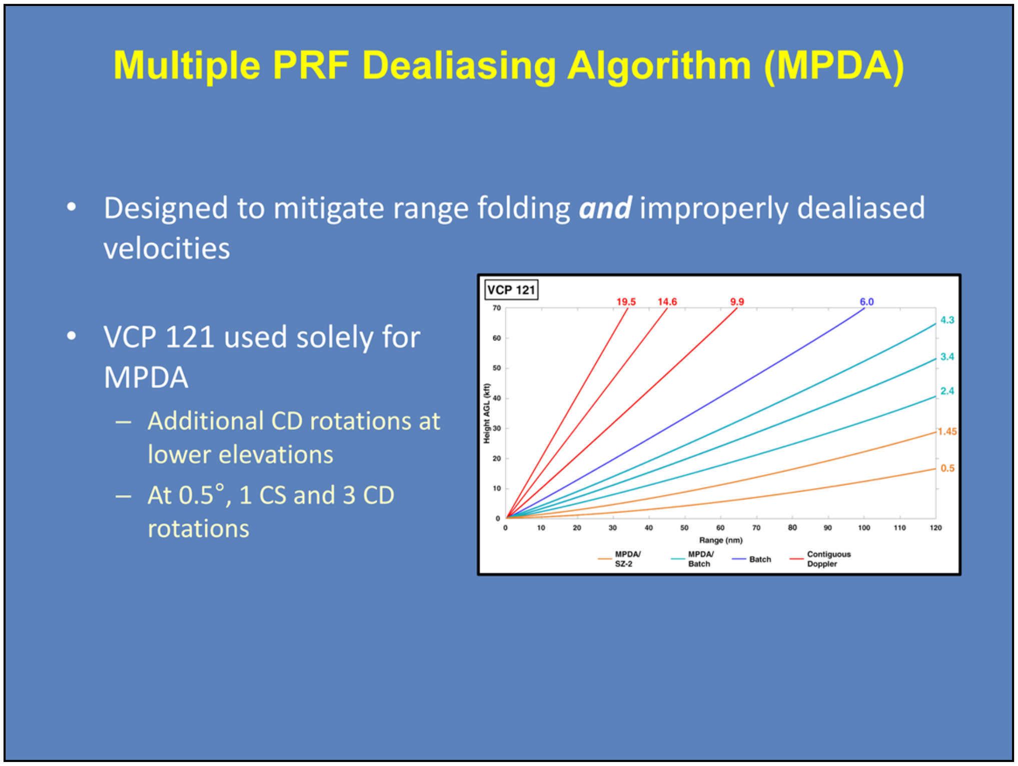
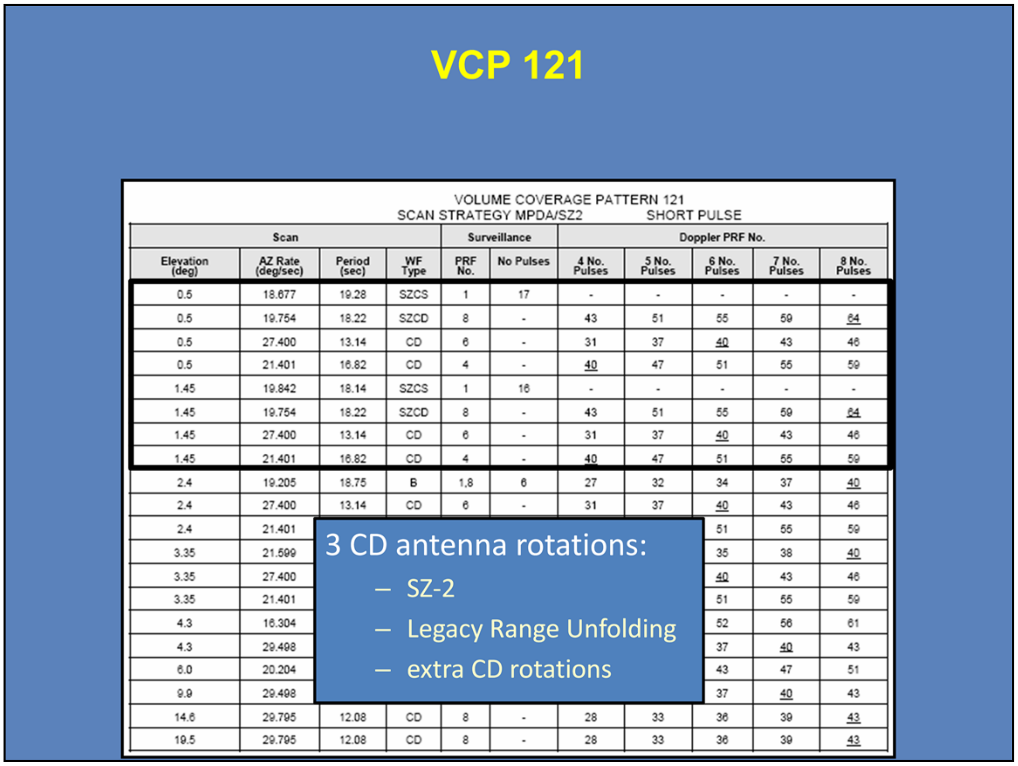


The Multiple PRF Dealiasing Algorithm (MPDA) is a special application uniquely used for VCP 121. It is designed to mitigate both range folding and improperly dealiased velocities, with range folding mitigation the most apparent. VCP 121 has additional Doppler rotations for the lower elevations. For example,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



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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51	55	59
3.35	21.599	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35	38	40
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3.35	21.401	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51	55	59
4.3	16.304	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	52	56	61
4.3	29.498	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37	40	43
6.0	20.204	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43	47	51
9.9	29.498	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	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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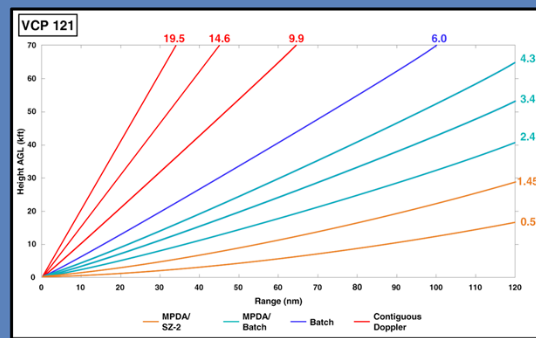
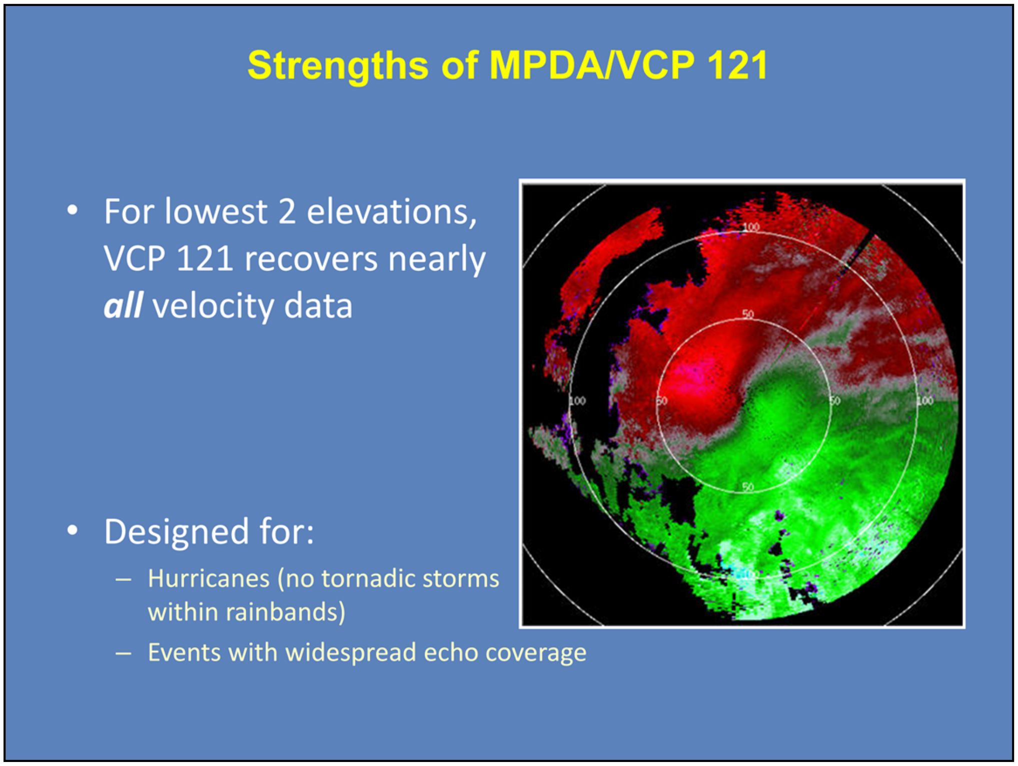
VCP 121 Considerations

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

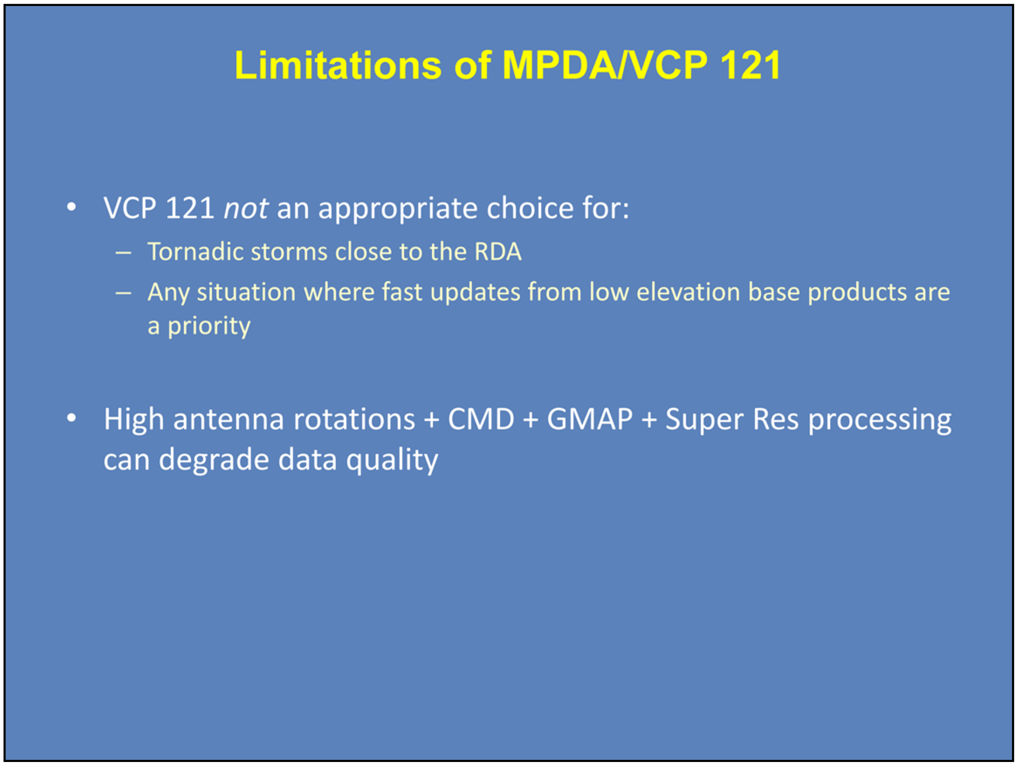


- VCP 121 **NOT** appropriate for fast moving or rapidly evolving storms
  - Use VCP 12 or 212
  - Better vertical sampling & faster updates

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.

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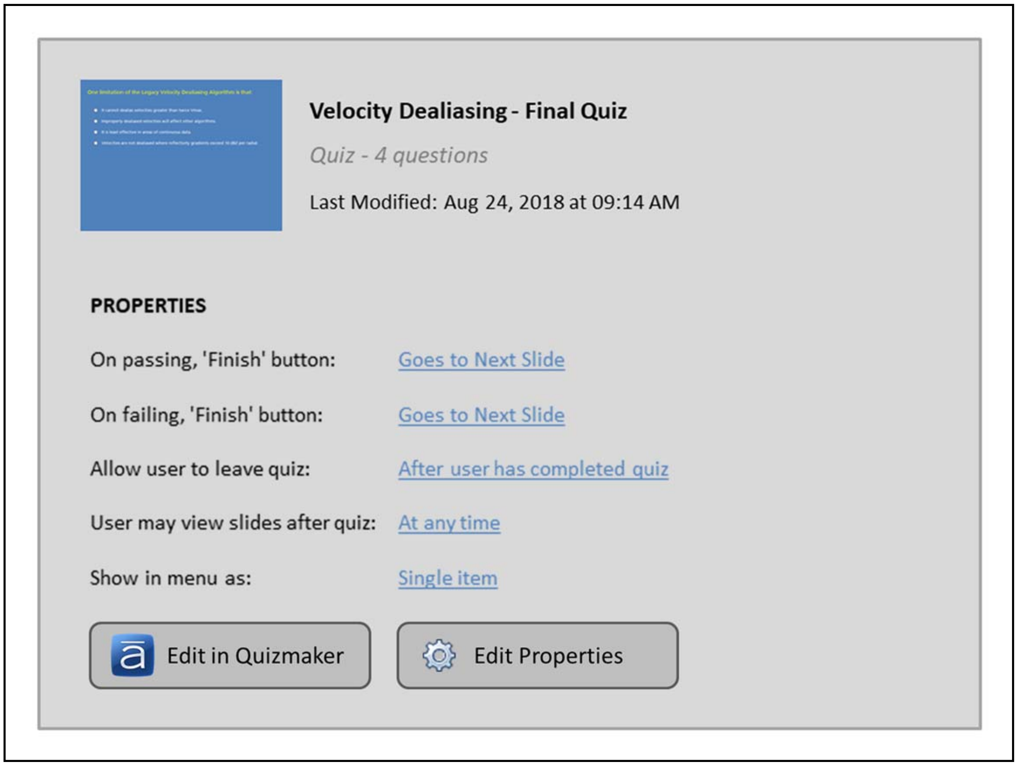
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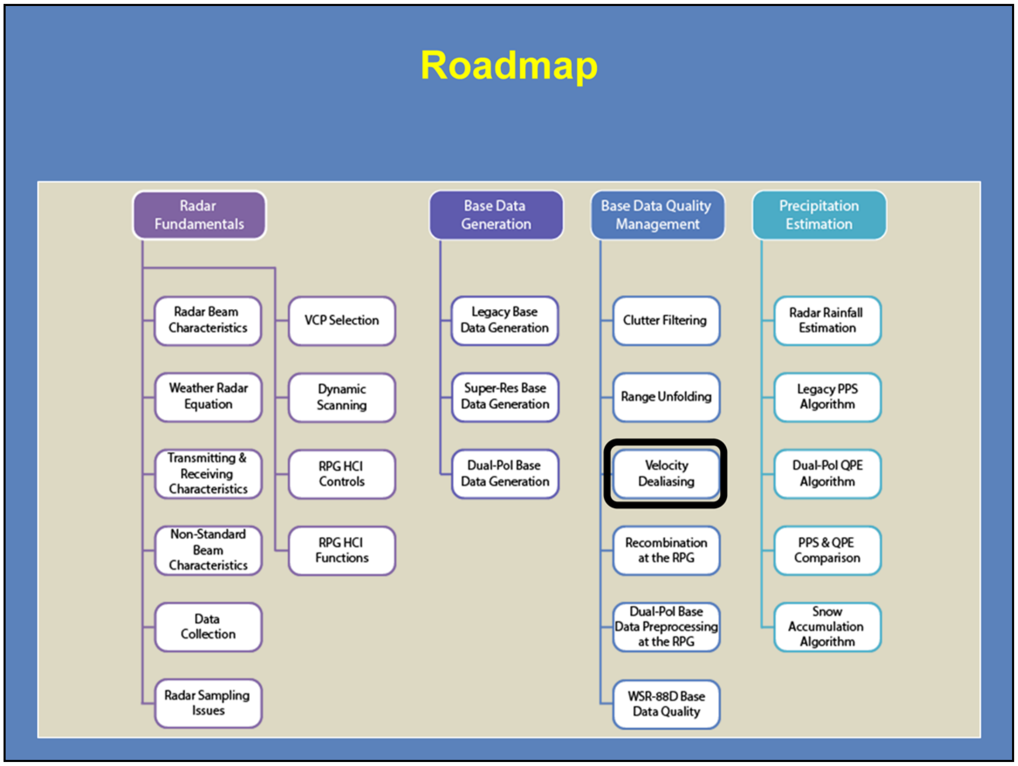
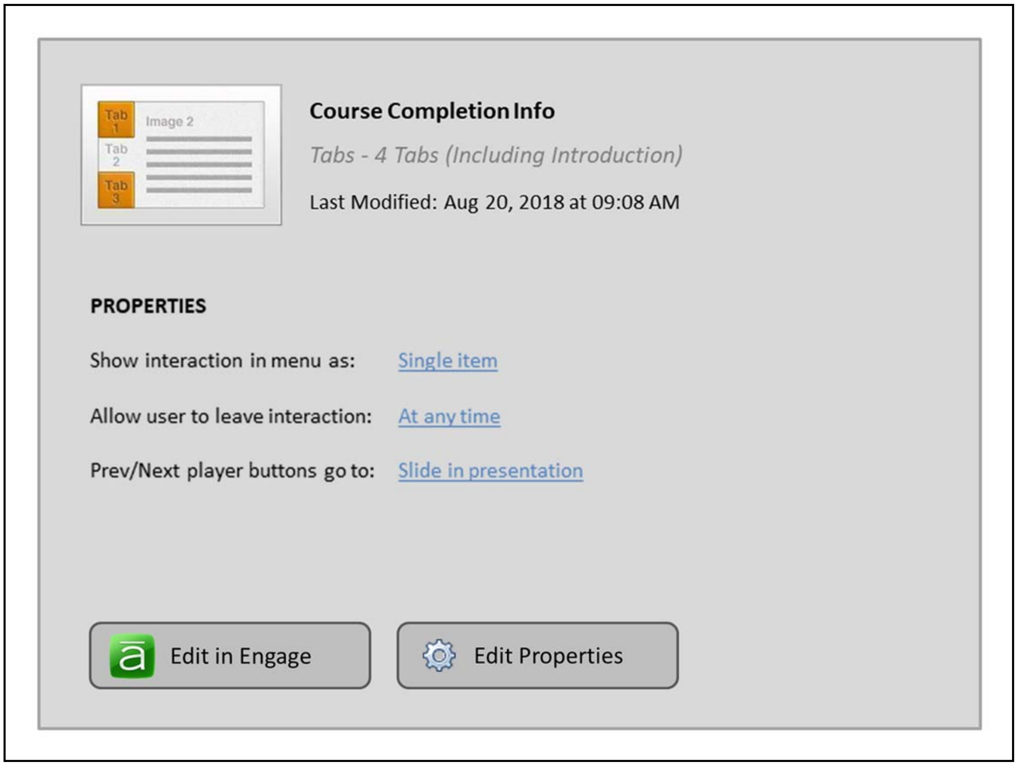


Here is the “roadmap” with your current location.

Welcome to the lesson on Data Recombination at the RPG.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Tab 3
Image 2
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Edit Properties

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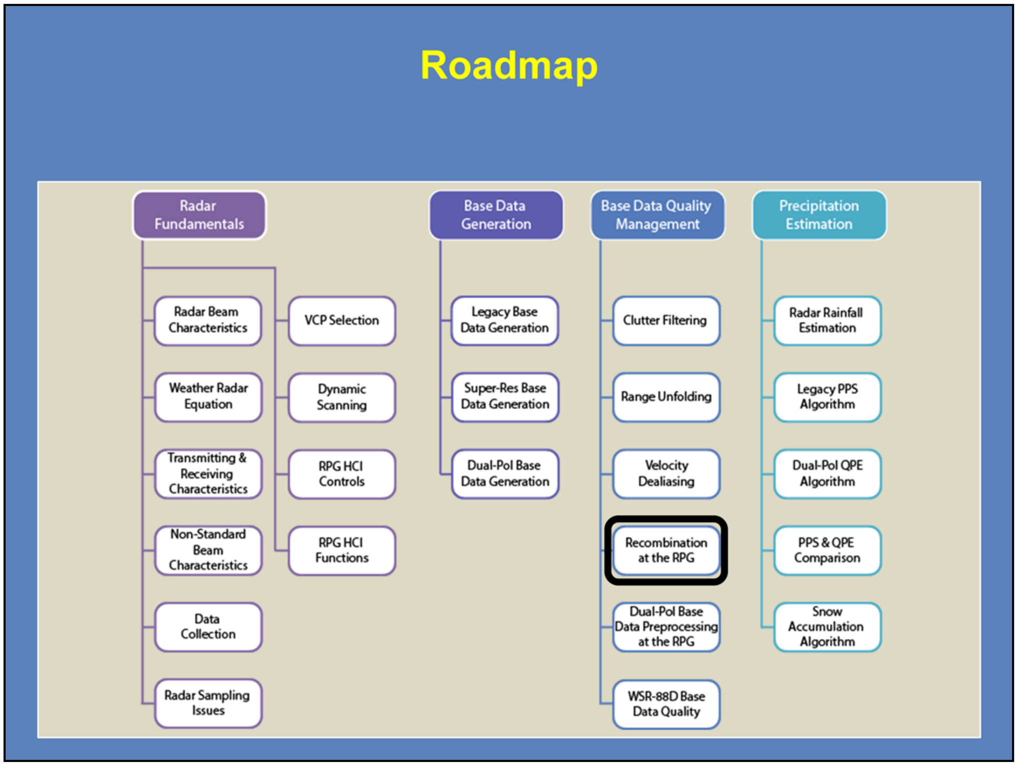

Here is the “roadmap” with your current location.

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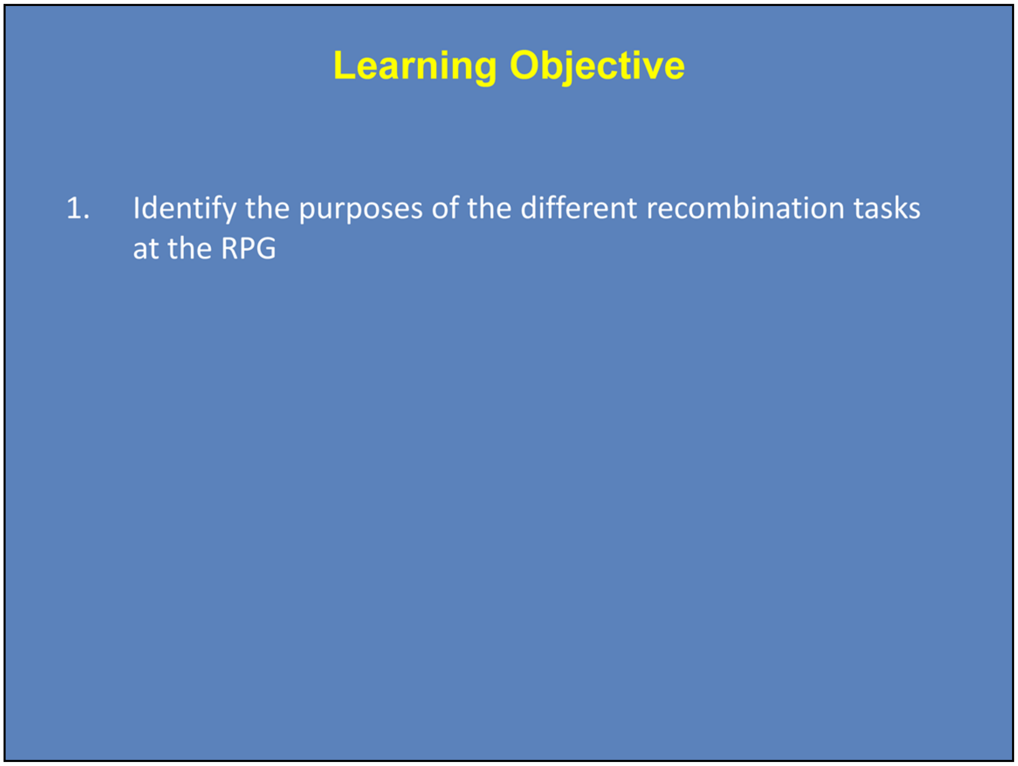
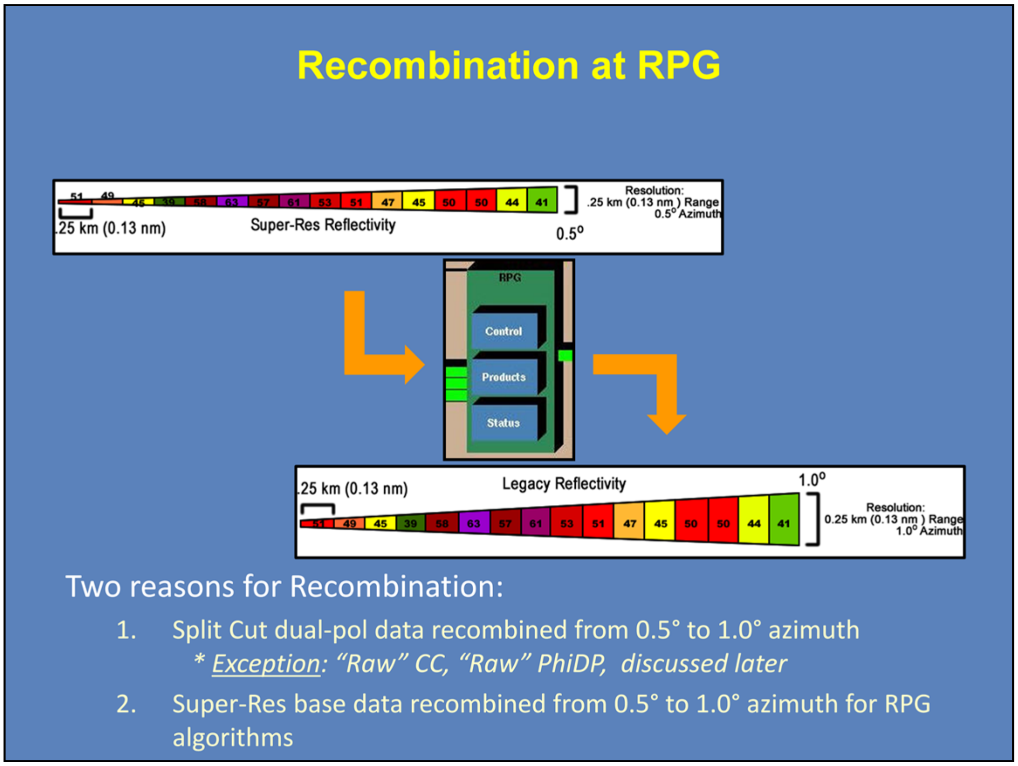


There is one objective in Recombination at the RPG.



Now for recombination at the RPG, which is a process that is needed for two reasons, to generate products themselves or for input into algorithms.

1. For the Split Cut elevations, the dual-pol base data are processed at the RDA with an azimuthal resolution of 0.5°, and that is simply too noisy. The dual pol base data are recombined to a 1.0° azimuth before the products are built.

2. Also for the Split Cut elevations, the super res base data (reflectivity, velocity and spectrum width) are recombined from 0.5° to 1.0° to support some of the RPG algorithms which cannot ingest a resolution that is that high.

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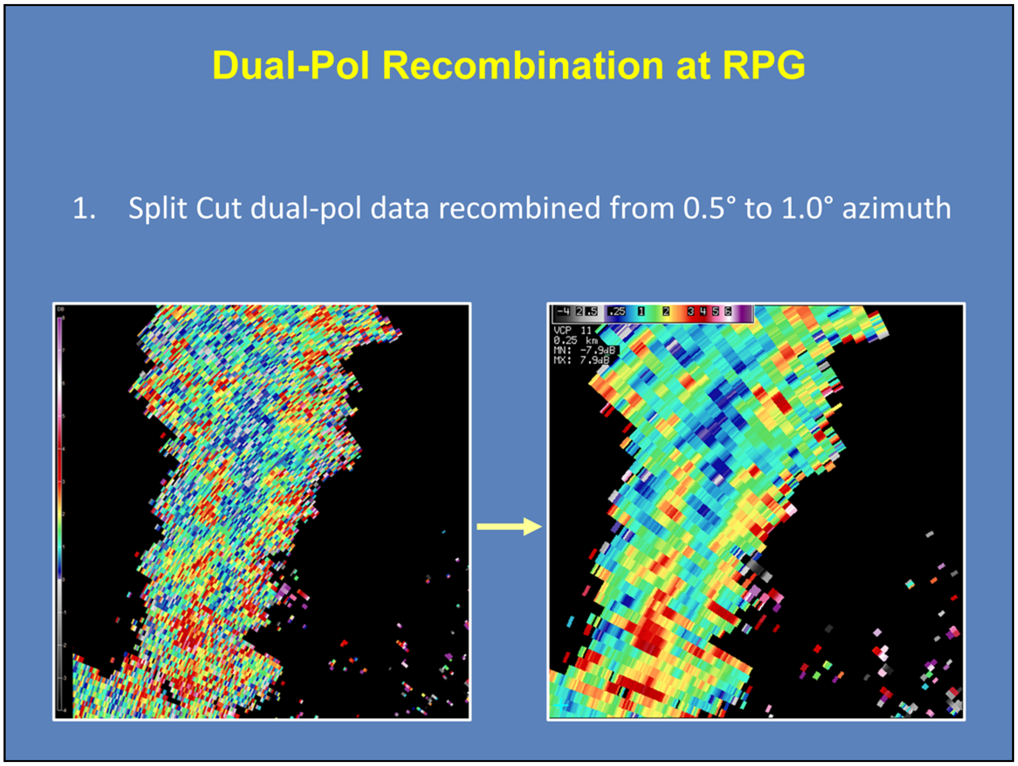

The dual-pol base data arriving from the RDA are ZDR, CC, and Φ_{DP}. For the Split Cuts, all of these data have an azimuthal resolution of 0.5°, and are too visually noisy for direct product generation. These data are recombined to an azimuth of 1.0°.

The dual-pol base data are also “preprocessed”, and this involves smoothing as well as 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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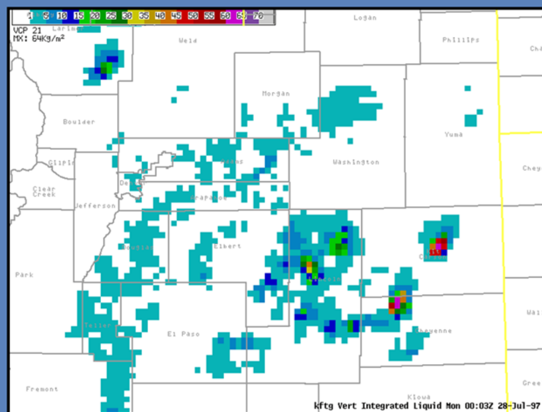
Recombination at RPG



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, the legacy 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.

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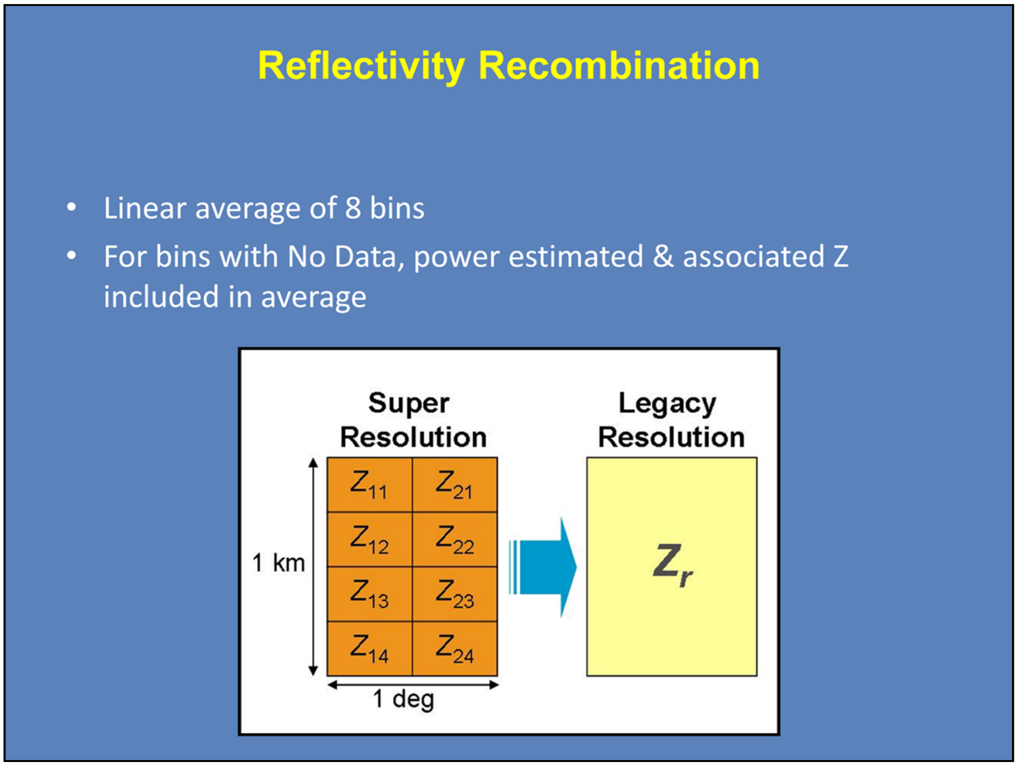

What you see here is to support the RPG algorithms that require 1.0° azimuth by 1 km range resolution for reflectivity input.

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.

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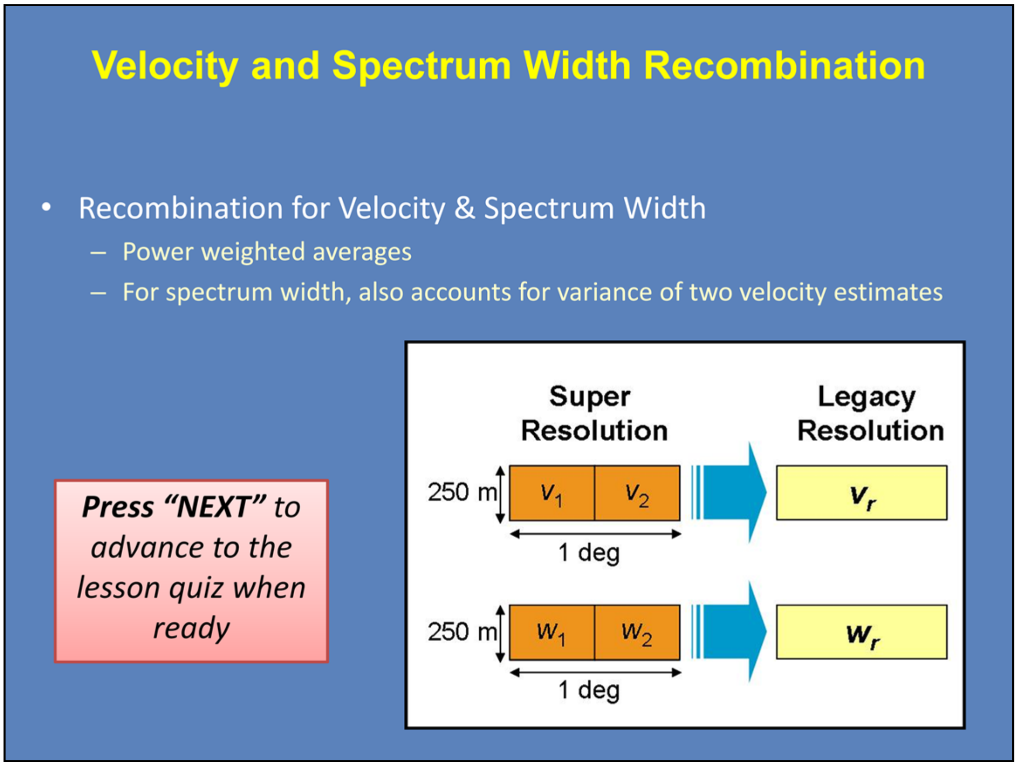

This step is for RPG algorithms that require 1.0° azimuth by .25 km range resolution for velocity and spectrum width input.

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 range-folded, then the legacy bin is also assigned No Data or range-folded (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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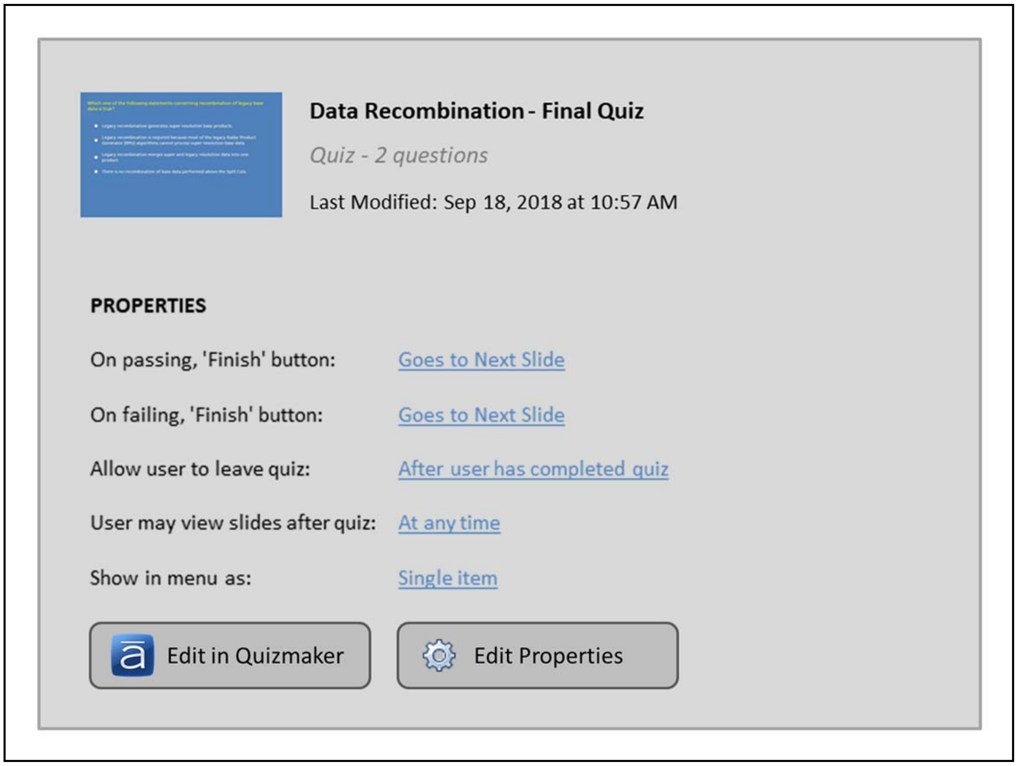
Data Recombination - Final Quiz
Quiz - 2 questions
Last Modified: Sep 18, 2018 at 10:57 AM
PROPERTIES
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Goes to Next Slide
On failing, 'Finish' button:
Goes to Next Slide
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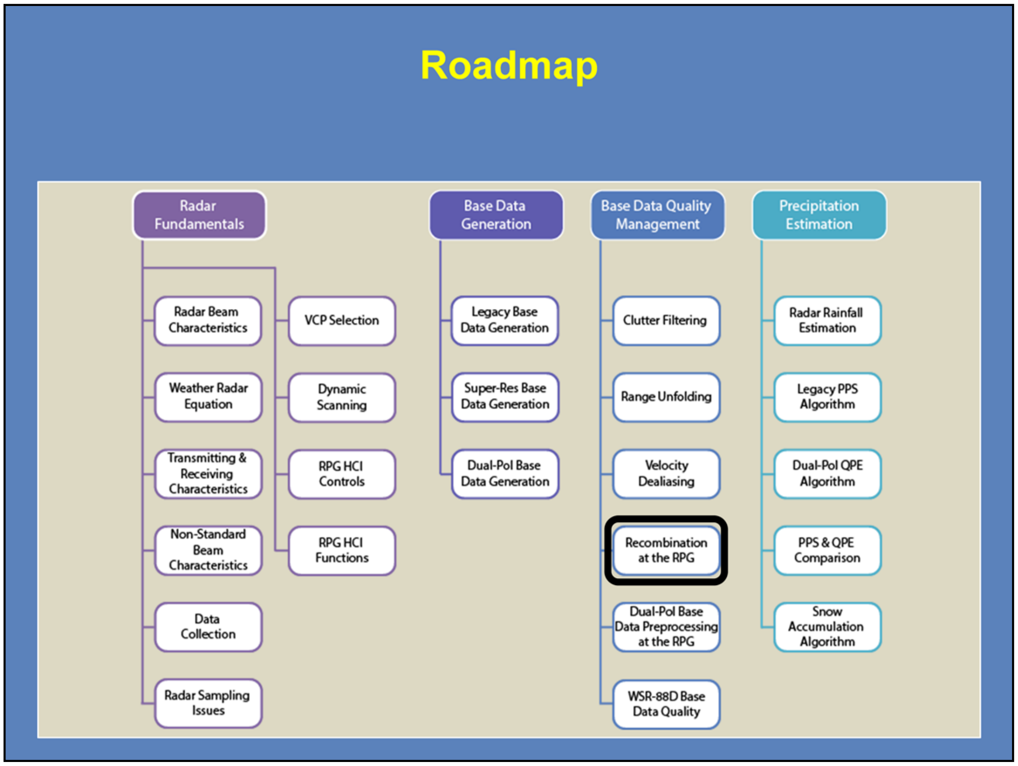
After user has completed quiz
User may view slides after quiz:
At any time
Show in menu as:
Single item
Edit in Quizmaker
Edit Properties



This concludes the lesson, and here is the “roadmap” with your current location.

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Welcome to Dual-Pol Base Data Preprocessing at the RPG

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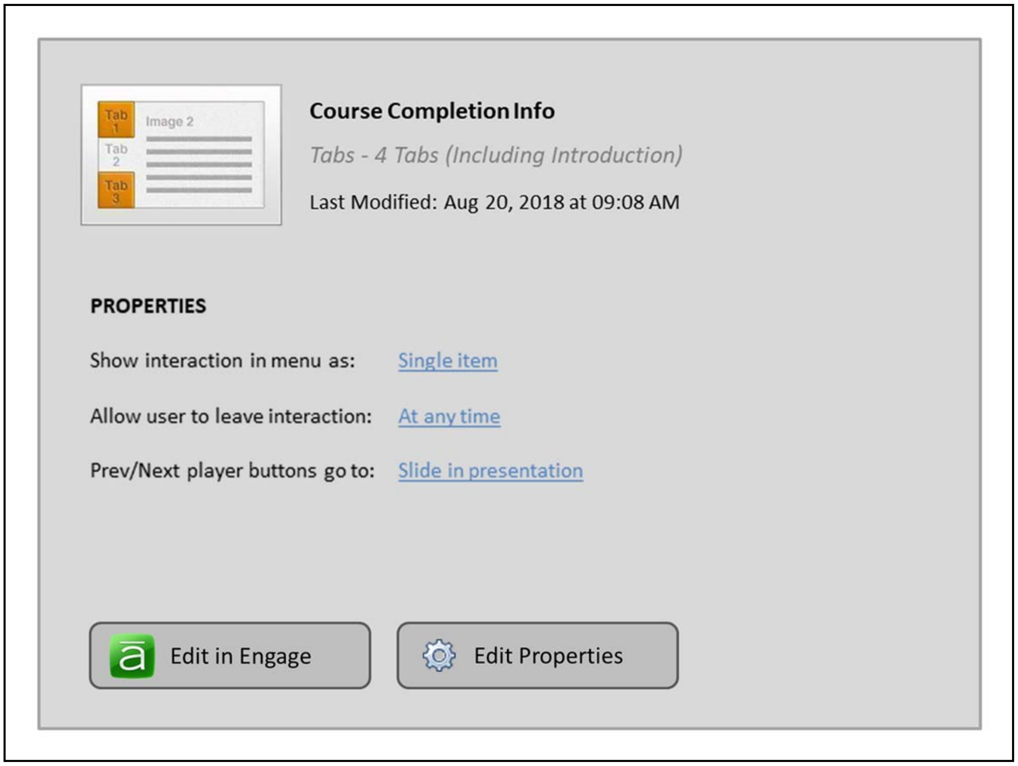
Tab 1
Image 2
Tab 2
Tab 3
Course Completion Info
Tabs - 4 Tabs (Including Introduction)
Last Modified: Aug 20, 2018 at 09:08 AM
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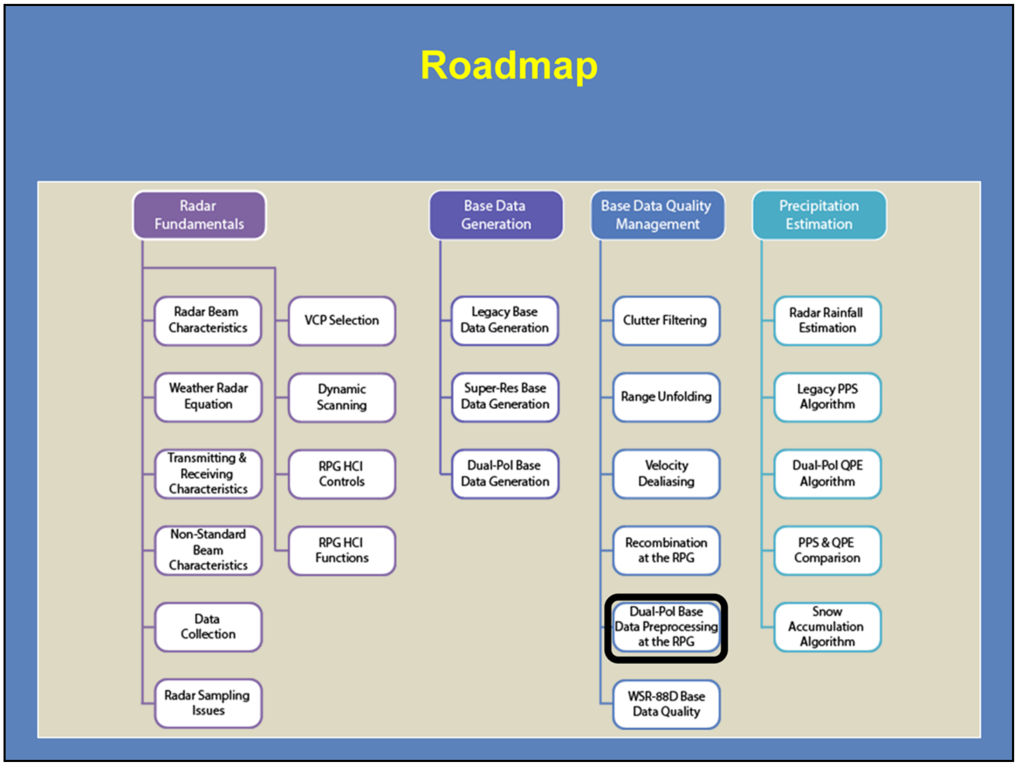
Allow user to leave interaction: At any time
Prev/Next player buttons go to: Slide in presentation
Edit in Engage
Edit Properties



Here is the “roadmap” with your current location.

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Learning Objective

1. Identify the primary tasks of the Dual-Pol Preprocessor at the RPG.

There is one objective for Dual Pol Preprocessing.

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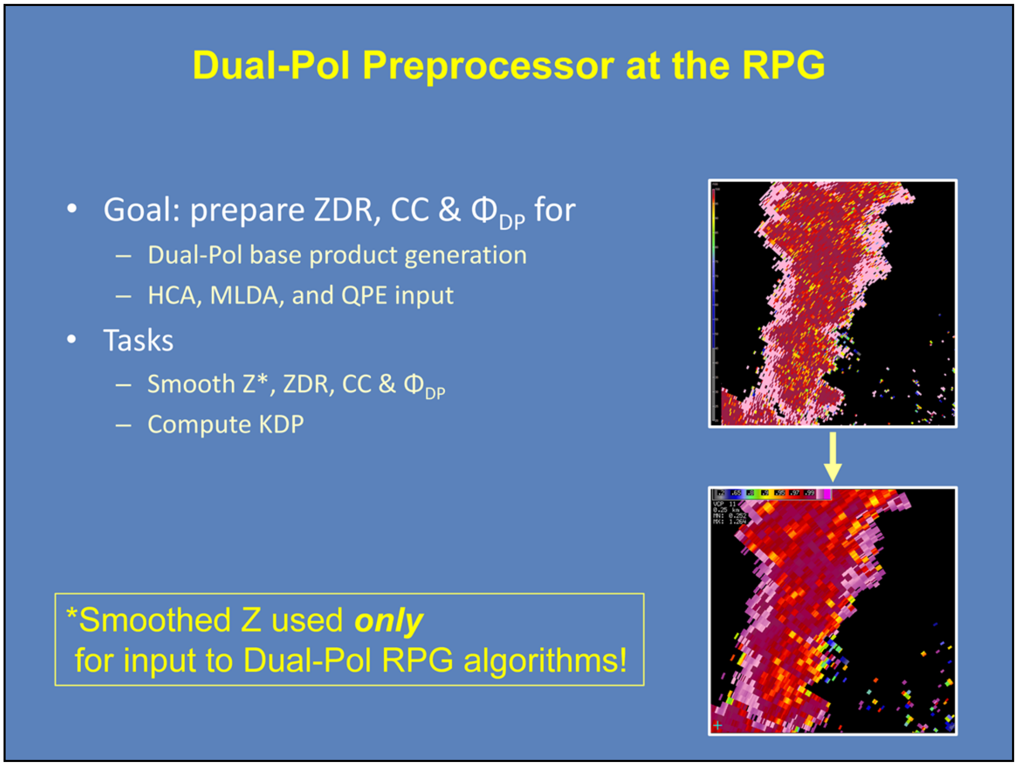

The Dual-Pol Preprocessor is an RPG algorithm. It's purpose is to prepare the Dual-Pol base data for two things: base product generation for the Dual-Pol products, as well as input into the RPG Dual-Pol algorithms, i.e. Hydrometeor Classification Algorithm (HCA), the Melting Layer Detection Algorithm (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 generally too noisy for human interpretation and certainly for 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 the legacy base products that you are familiar with.

The remaining task for the Preprocessor is to compute the Specific Differential Phase (KDP) values, before we generate the KDP product.

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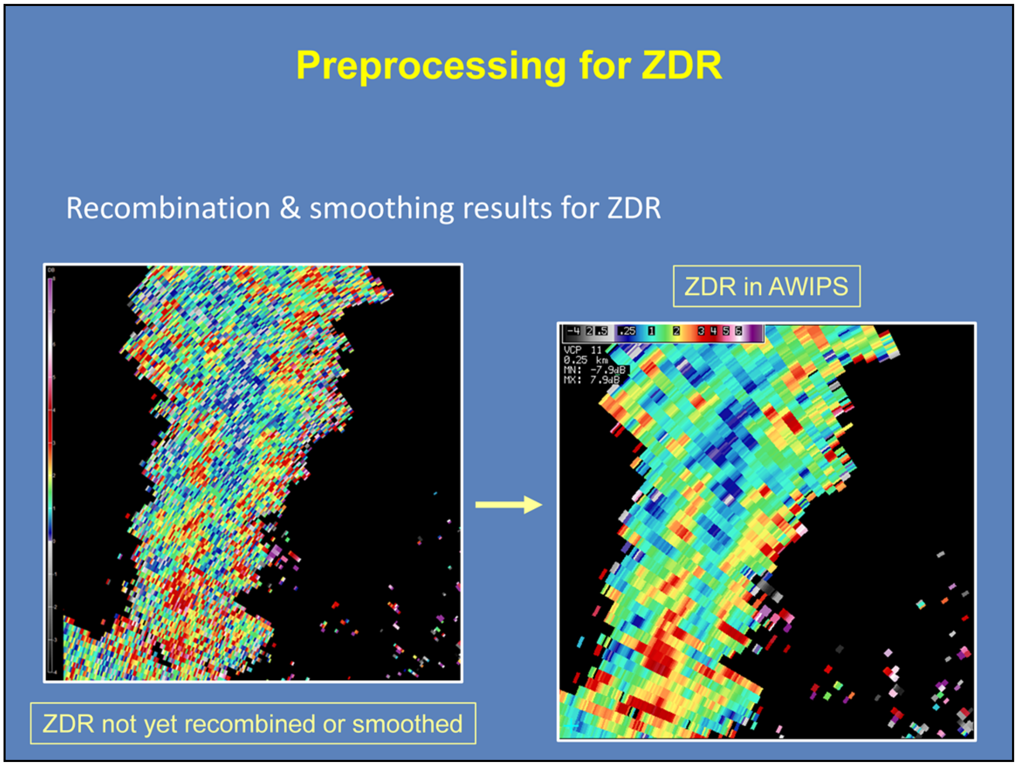
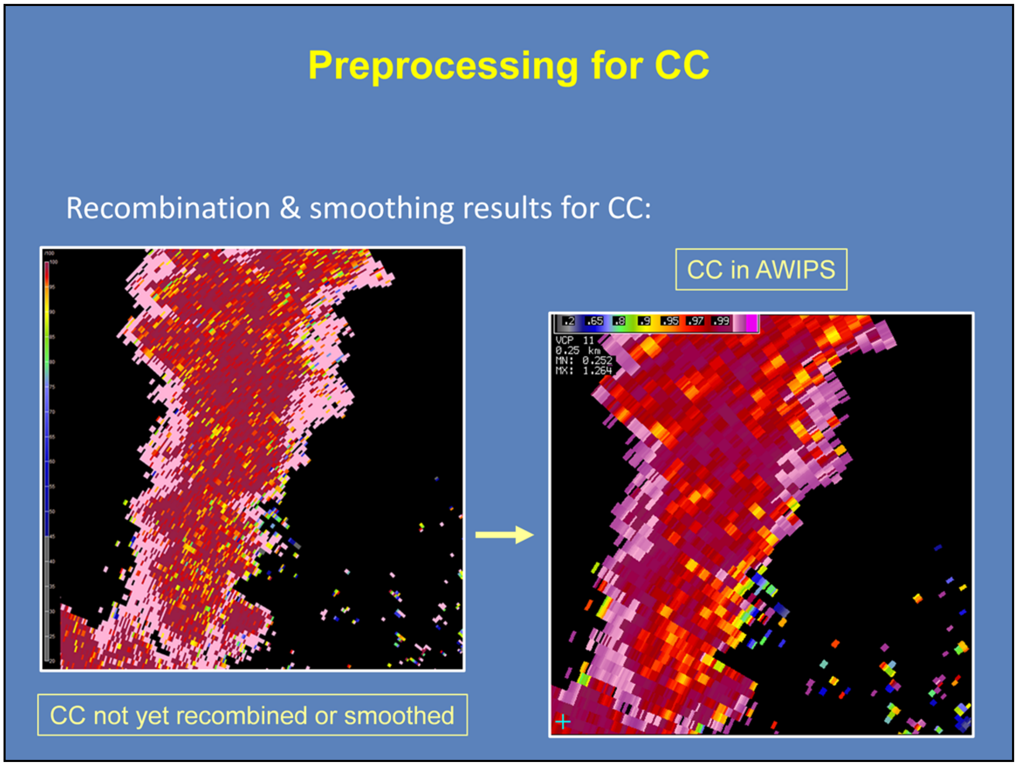


The example on the left is raw Differential Reflectivity, ZDR, from the RDA, at 0.5° azimuthal resolution and .25 km range resolution. It has not yet been recombined or smoothed. It is pretty noisy for even human interpretation. The image on the right is the same data displayed in AWIPS after recombination 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.



Here’s a similar comparison for Correlation Coefficient, CC. We have raw CC on the left and the recombined and smoothed CC on the right. As with ZDR, the same smoothing technique is applied. It’s a linear average to a segment (of varying length) along the radial. That average value is then assigned to the original range bin at the center of the segment.

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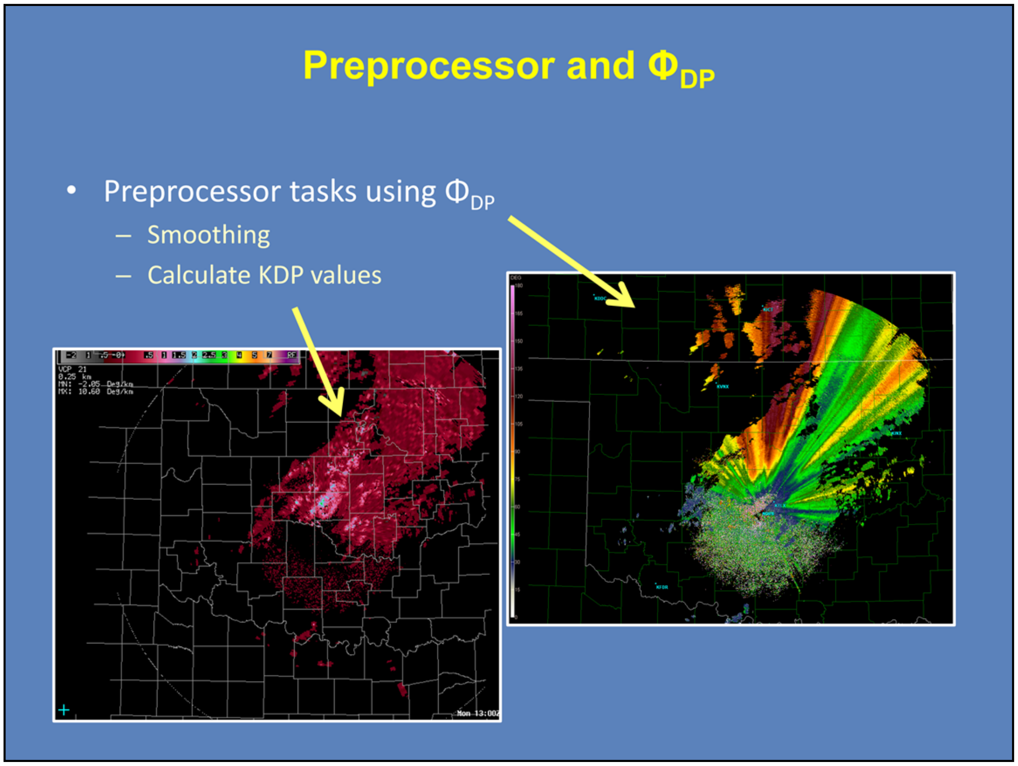
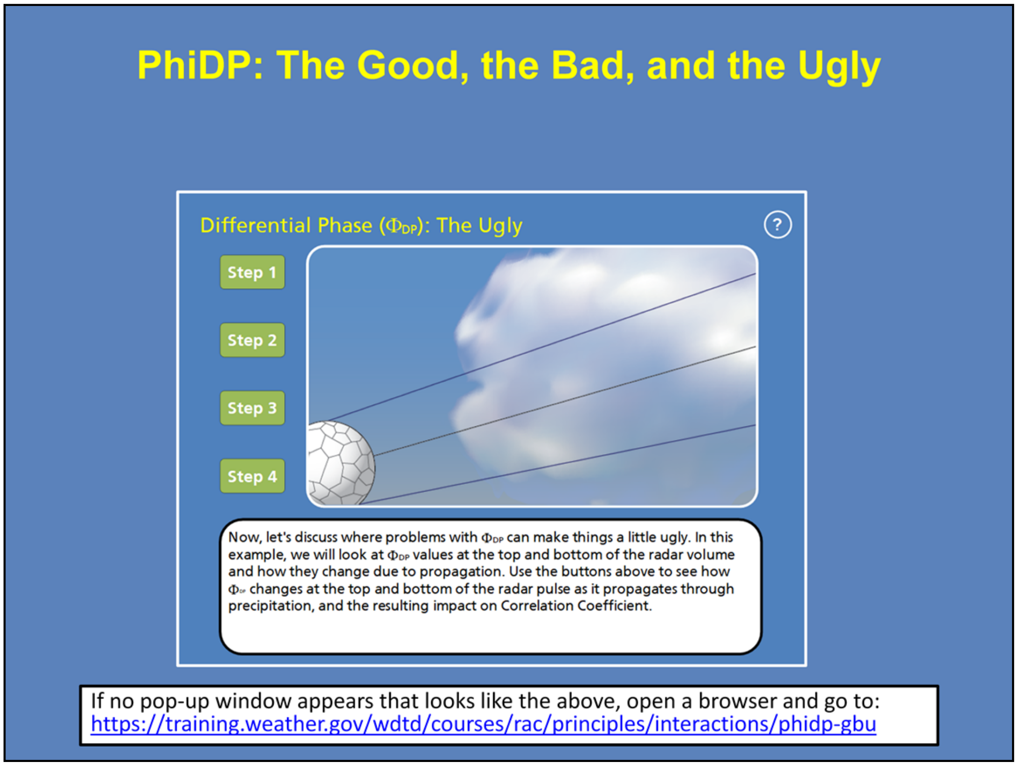


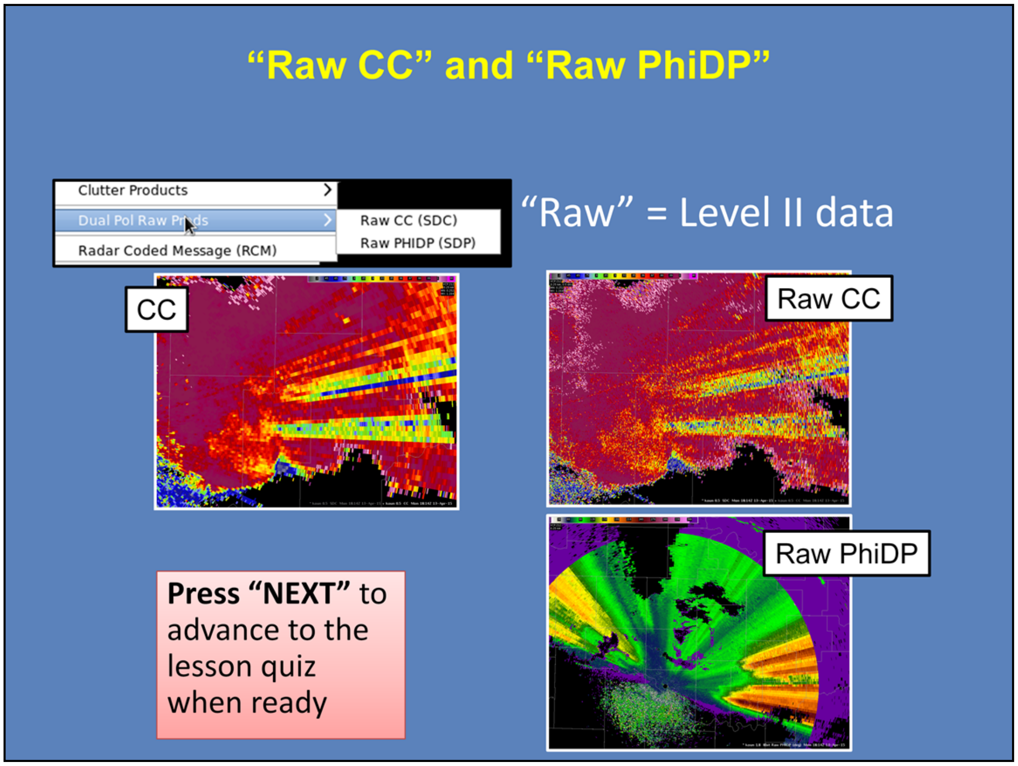
As with ZDR and CC, the Differential Phase, Φ_{DP}, base data are first recombined, then smoothed. On the right is an example of Φ_{DP} base data, not yet recombined or smoothed. This image is from GR Analyst, showing the raw Level II data.

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.



(Click to be linked to sub-lesson on PhiDP)



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 to the RPG.

The Raw CC has higher azimuthal resolution (0.5°), however it is not a substitute for the regular CC product. 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). That's why this product was made available.

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

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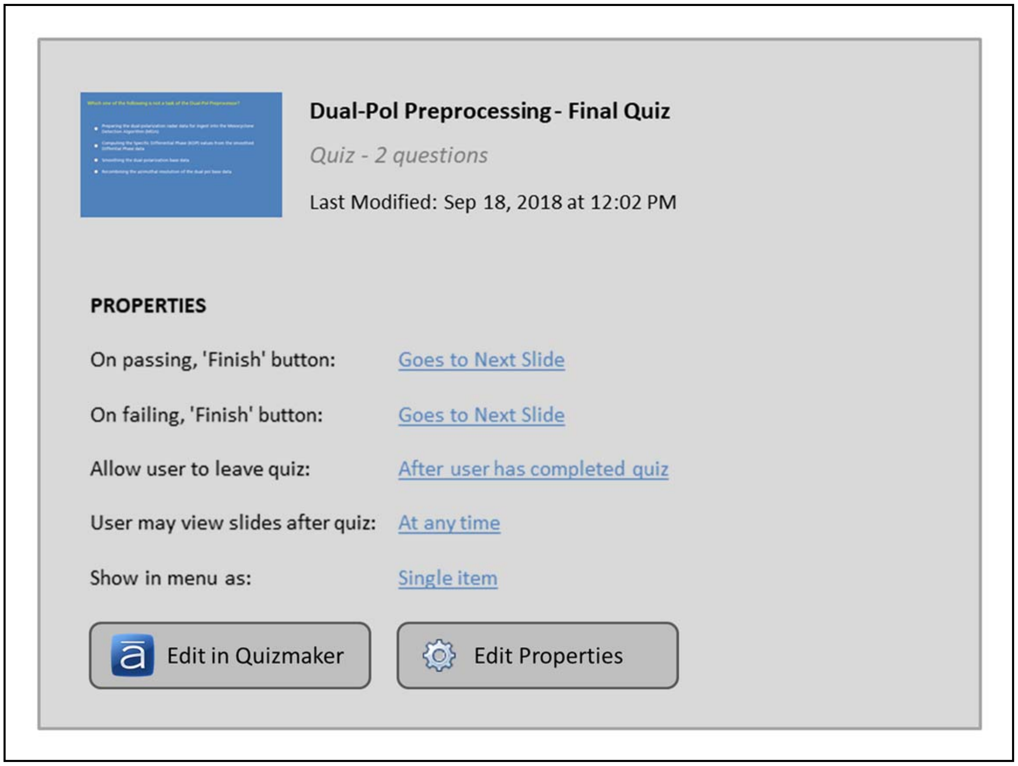
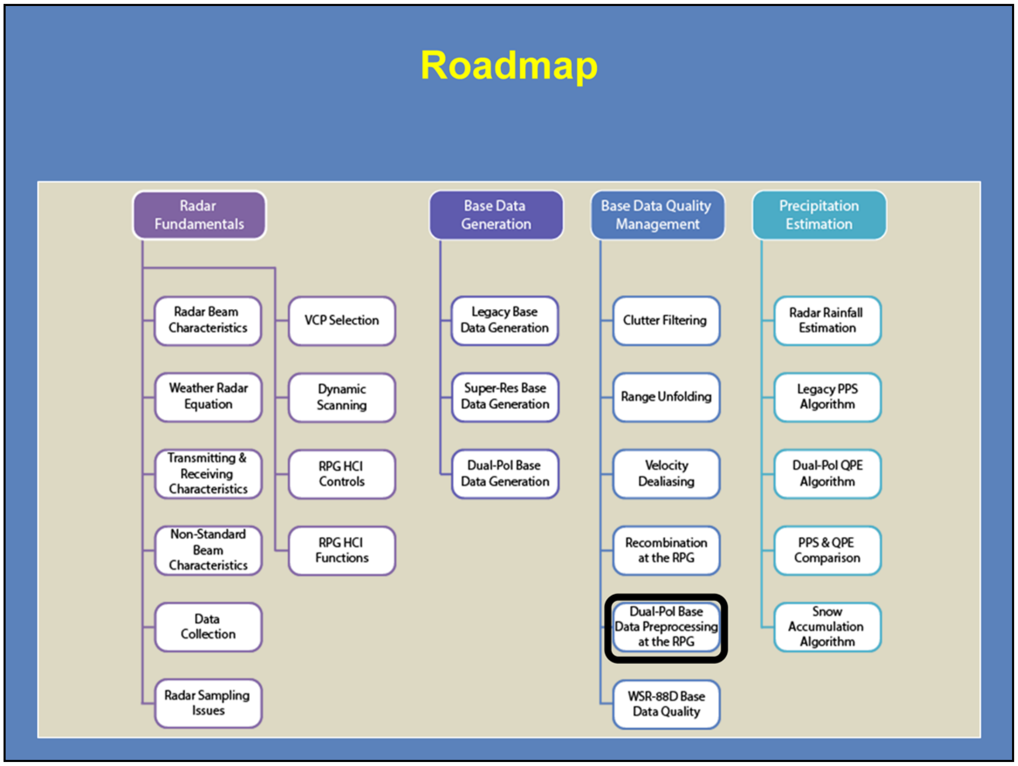

Dual-Pol Preprocessing - Final Quiz
Quiz - 2 questions
Last Modified: Sep 18, 2018 at 12:02 PM
PROPERTIES
On passing, 'Finish' button:
Goes to Next Slide
On failing, 'Finish' button:
Goes to Next Slide
Allow user to leave quiz:
After user has completed quiz
User may view slides after quiz:
At any time
Show in menu as:
Single item
Edit in Quizmaker
Edit Properties



This concludes the lesson, and here is the “roadmap” with your current location.

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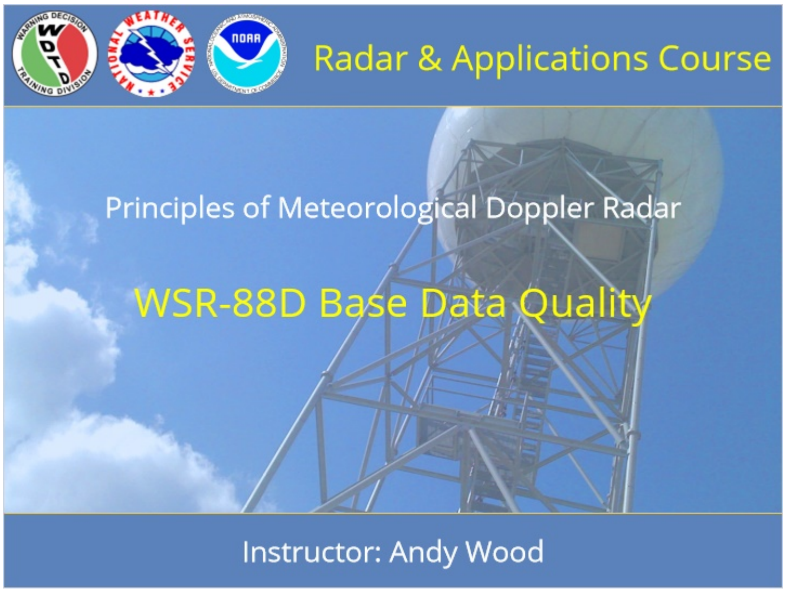
Base Data Quality

1. Introduction

1.1 Introduction



Notes:

Welcome to this lesson on WSR-88D Base Data Quality. This lesson is part of the Principles of Meteorological Doppler Radar topic in the Radar & Applications Course.

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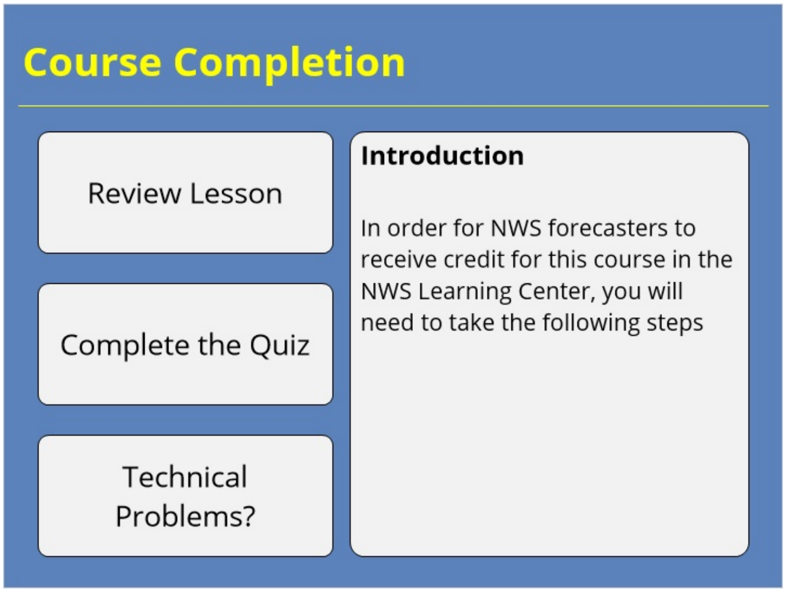
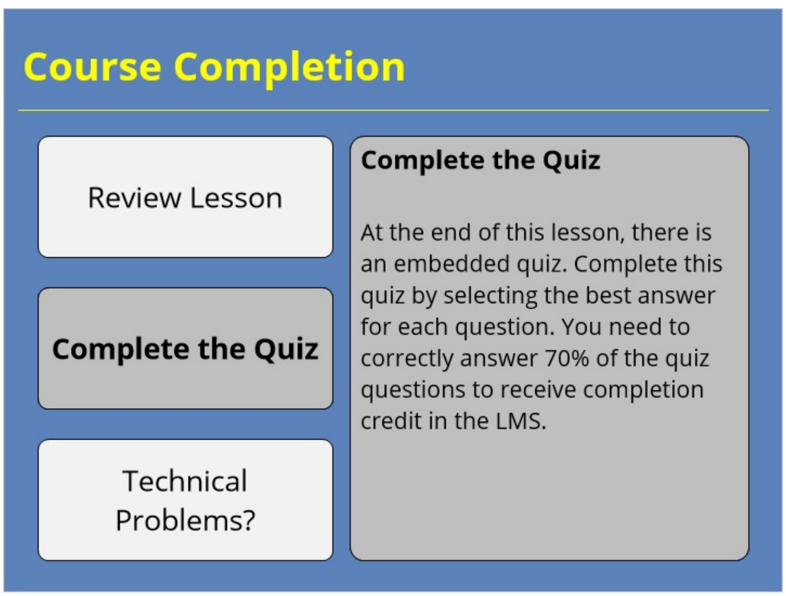
1.2 Course Completion



Complete the Quiz (Slide Layer)



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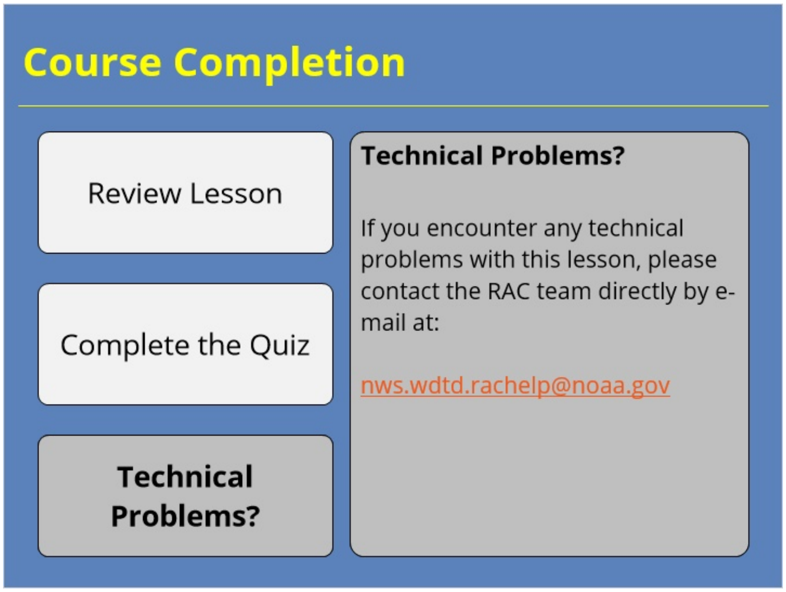
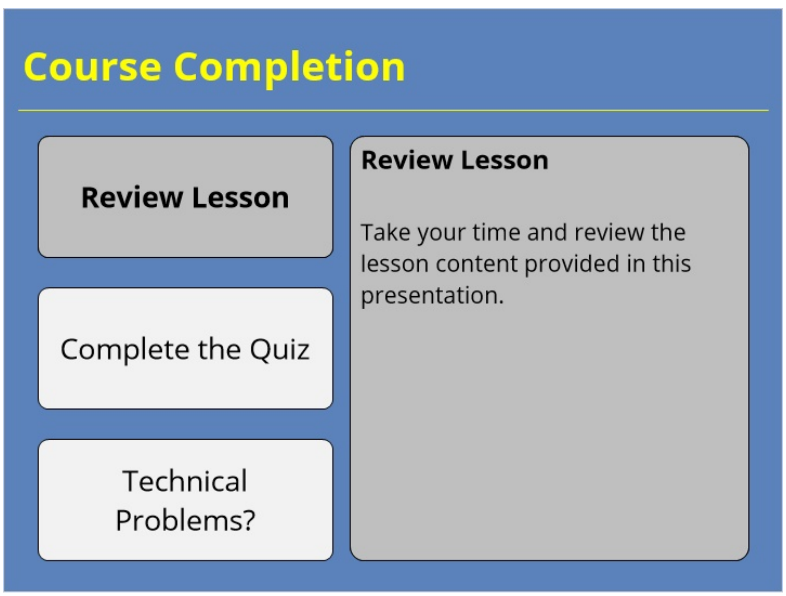
Technical Problems (Slide Layer)



Review Lesson (Slide Layer)



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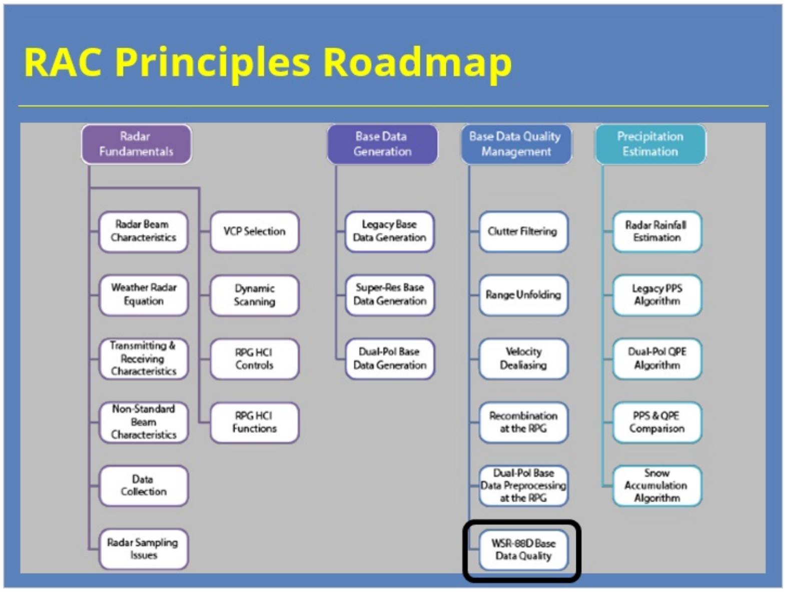
1.3 RAC Principles Roadmap



Notes:

Here is a roadmap for the RAC Principles topic. This lesson, which is part of the Base Data Quality Management section, is highlighted. Once you have had a chance to look over the roadmap, advance to the next slide.

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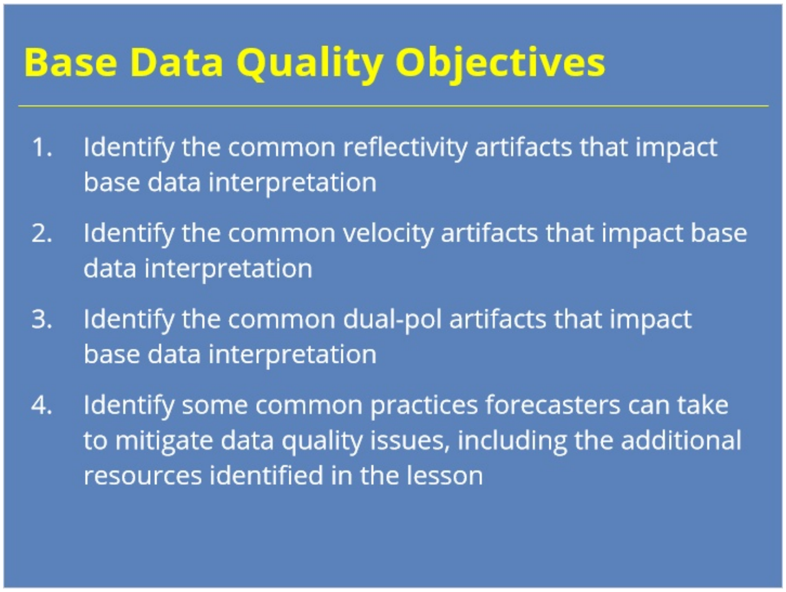
1.4 Base Data Quality Objectives



Notes:

This lesson has four learning objectives. Please take a moment to review them, and advance to the next slide when you are ready to proceed.

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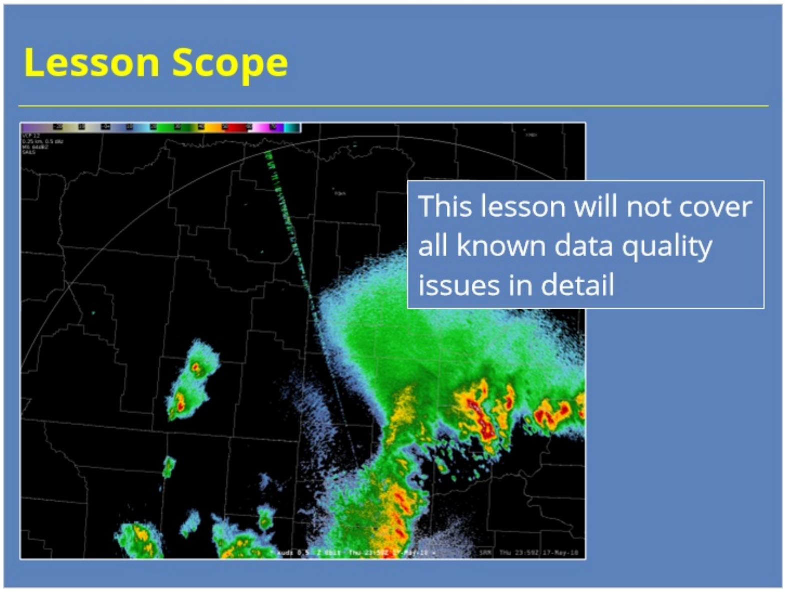
1.5 Lesson Scope



Notes:

I just want to take a moment to discuss the scope of this lesson. There are dozens of known base data quality oddities and anomalies from the WSR-88D that have been documented in some form over the last 25 year. We will not cover all of them here. Some of these data artifacts, such as side lobe contamination, have already been discussed multiple times in previous lessons. So, we will let that content stand for itself. Other anomalies will either be discussed in subsequent lessons, happen too infrequently to document and discuss properly, or were simply cut for the sake of time.

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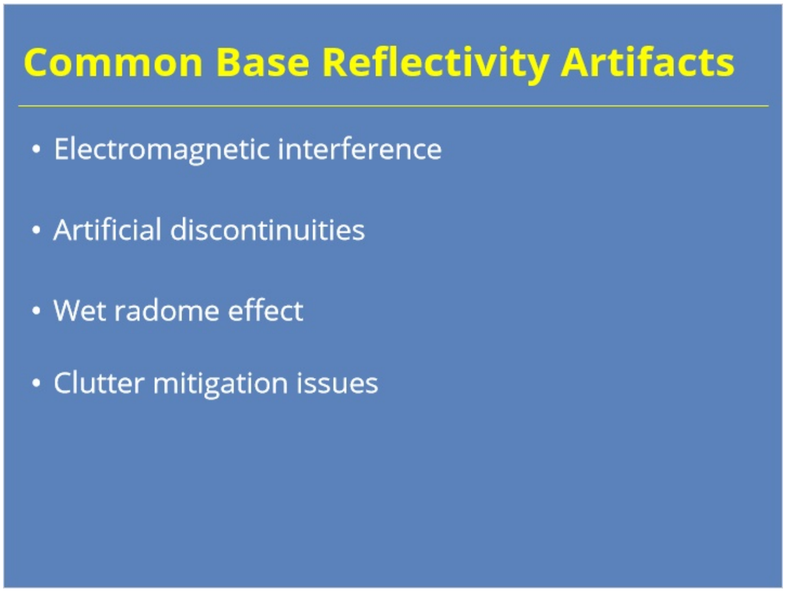
2. Reflectivity Artifacts

2.1 Common Base Reflectivity Artifacts



Notes:

In this first section, we will discuss some common data quality issues that impact base reflectivity. The issues we'll discuss include electromagnetic interference, artificial discontinuities, the wet radome effect, and clutter mitigation issues. Some of these artifacts can impact other data, too, but we will discuss them here since we are starting with Reflectivity.

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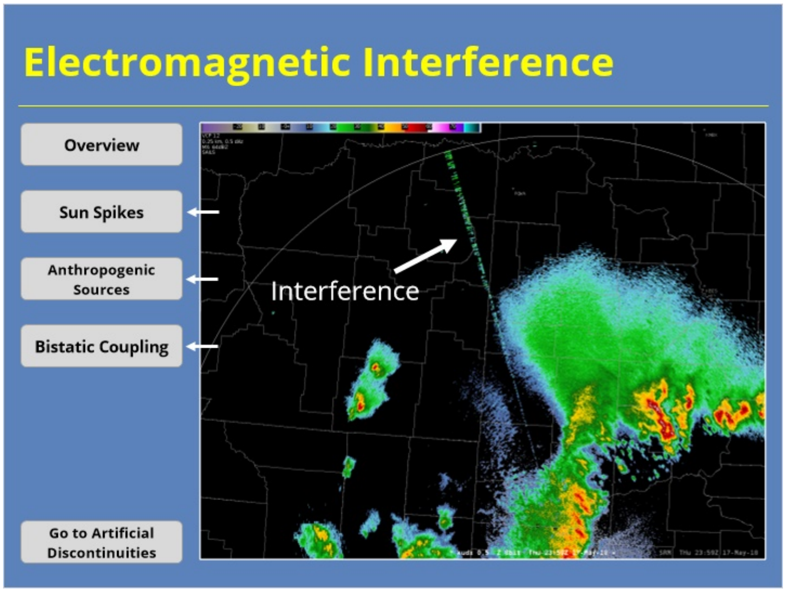
2.2 Electromagnetic Interference



Notes:

Electromagnetic interference occurs when an external source of electromagnetic energy interferes with the radar's data collection design. The source of electromagnetic interference can be from any number of things. Click on the buttons to the left to see different examples of electromagnetic interference.

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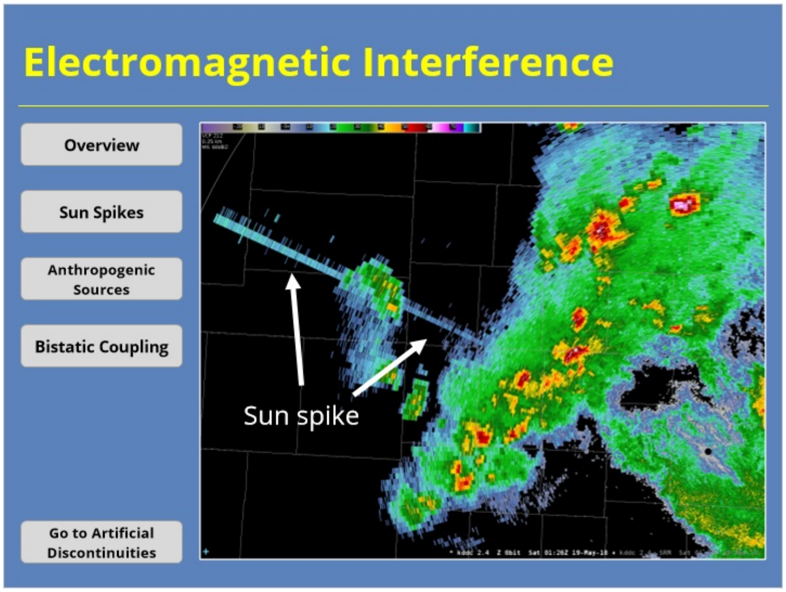
2.3 Electromagnetic Interference



Notes:

One common form of electromagnetic interference is a sun spike. These show up on the radar before sunset or after sunrise, when the sun just happens to be at the same elevation that radar is scanning. Sun spikes occur at predictable times, so their impacts tend to be minimal.

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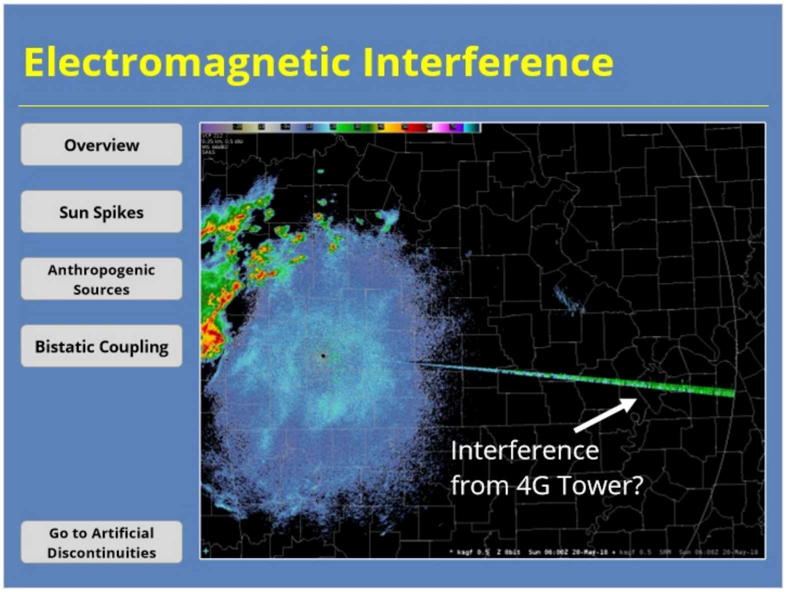
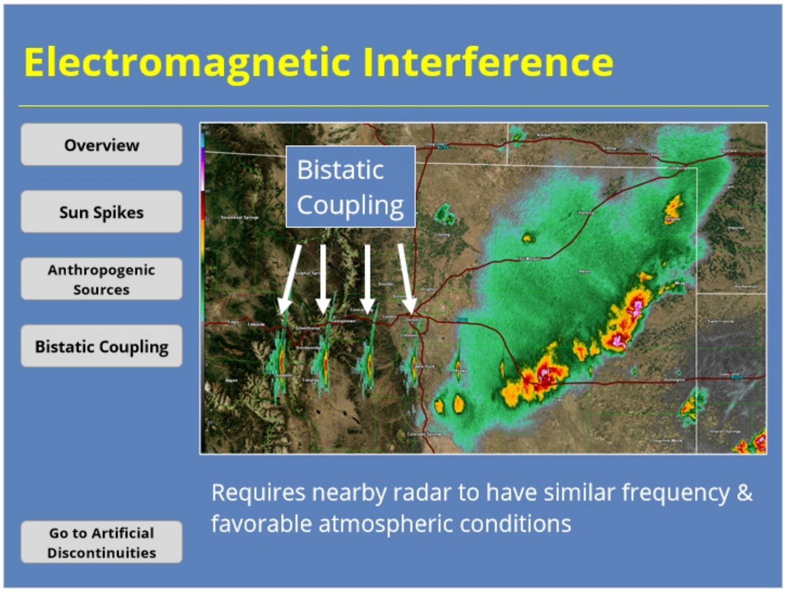
2.4 Electromagnetic Interference



Notes:

Frequencies near S-band are in high demand for telecommunications and other applications. So, Another form of electromagnetic interference you may see is interference from 4G comms towers and other private industry sources. This interference can be transient or persist for several volume scans. If the interference persists, work with the Radar Operations Center to identify the point source location and work with the owner to fix the issue.

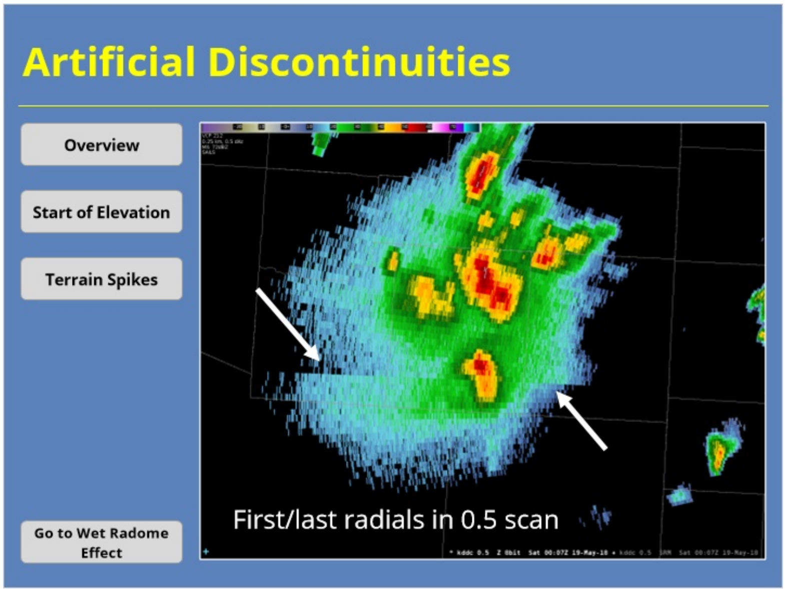
2.5 Electromagnetic Interference



Notes:

Sometimes the interference isn’t from an external source at all. Bistatic coupling occurs when two nearby WSR-88D sites have similar transmitter frequencies and their antennas are able to detect the other sites transmitted pulse. This type of interference, like in the example shown, may also be called running rabbits. This interference requires the transmitted pulse to be ducted or super-refracted in a way that it will travel an atypical path to the nearby radar.

2.6 Artificial Discontinuities



Notes:

Occasionally, radial discontinuities may be apparent in the base data. Click the buttons on the left to see a couple of examples of these discontinuities and where and when you might see them.

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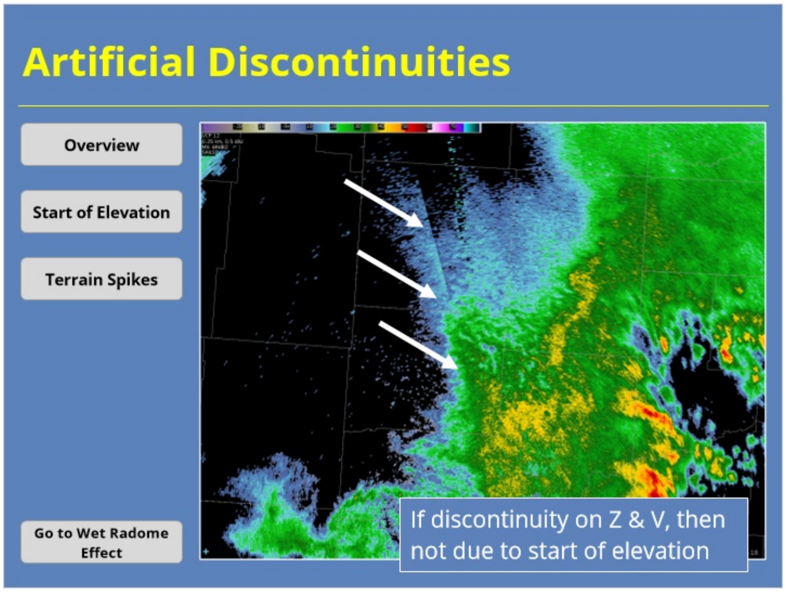
2.7 Artificial Discontinuities



Notes:

Occasionally, the 0.5 tilt will have a noticeable discontinuity at the beginning of the scan. The cause for this discontinuity can be many. Sometimes the radar antenna has a wobble as it starts the 0.5 Contiguous Surveillance scan that goes away after a few radials. If the wobble occurs frequently or throughout the scan, it can signal an issue with the radar. I should note that if the same discontinuity is seen on the Contiguous Doppler cut, it's not due to the start of the volume scan. Similar artifacts can be seen during super refractive conditions or at sites near significant bodies of water.

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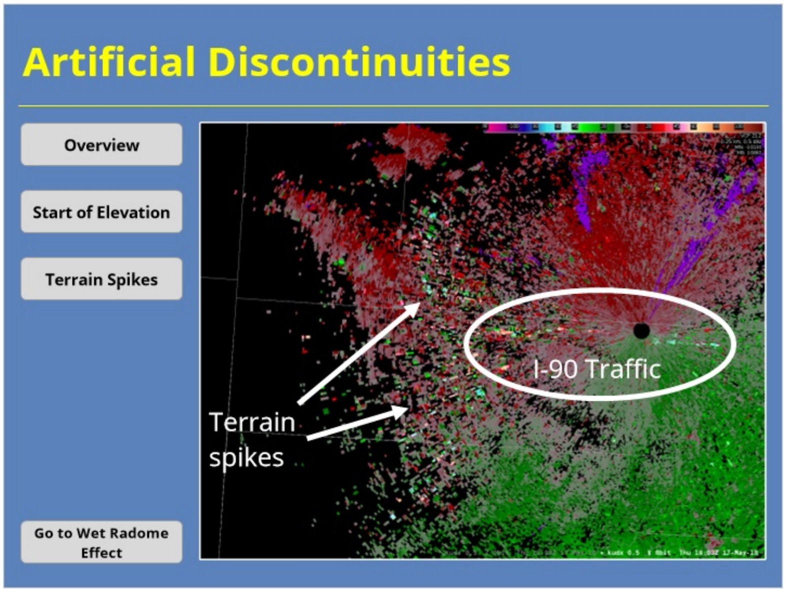
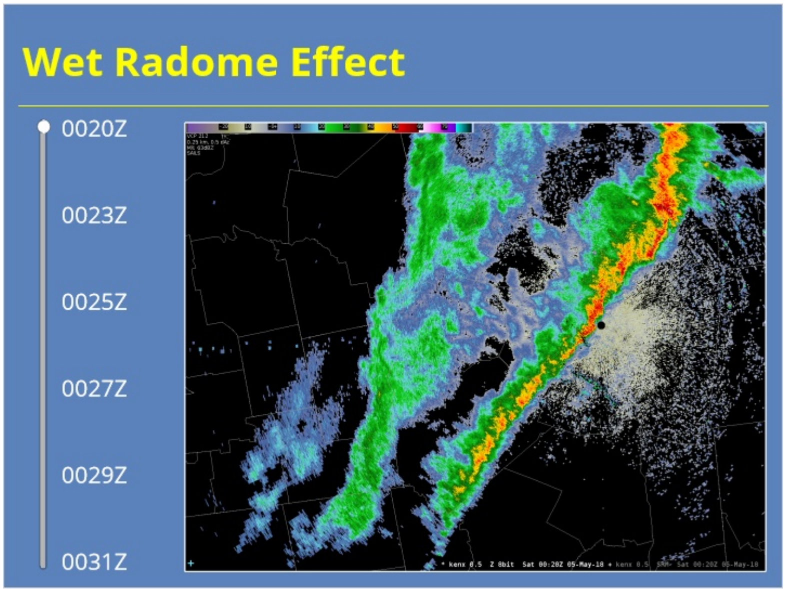
2.8 Artificial Discontinuities



Notes:

Radials of higher reflectivity may be visible across hills or mountains. These spikes exist regardless of the form of clutter filtering used. Sometimes the data artifact will look like a large cluster of echoes instead of a series of spikes. The spikes may be more apparent when you switch to other base products like Velocity. Weather signals do not appear to be impacted when these artifacts are present, and no known fix exists for them. However, you should talk with your radar focal point and electronics (or El) tech if you noticed this issue frequently or for a long duration.

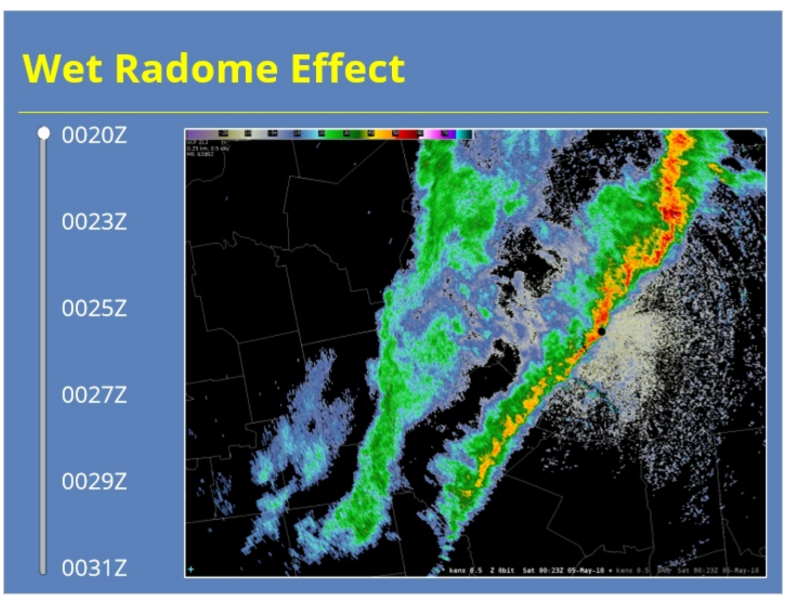
2.9 Wet Radome Effect



Notes:

When precipitation falls on the radome, reflectivity data may experience some subtle attenuation effects where values dip. Use the controls on the slide to see how Reflectivity is impacted as this line moves over the radome.

0023 (Slide Layer)



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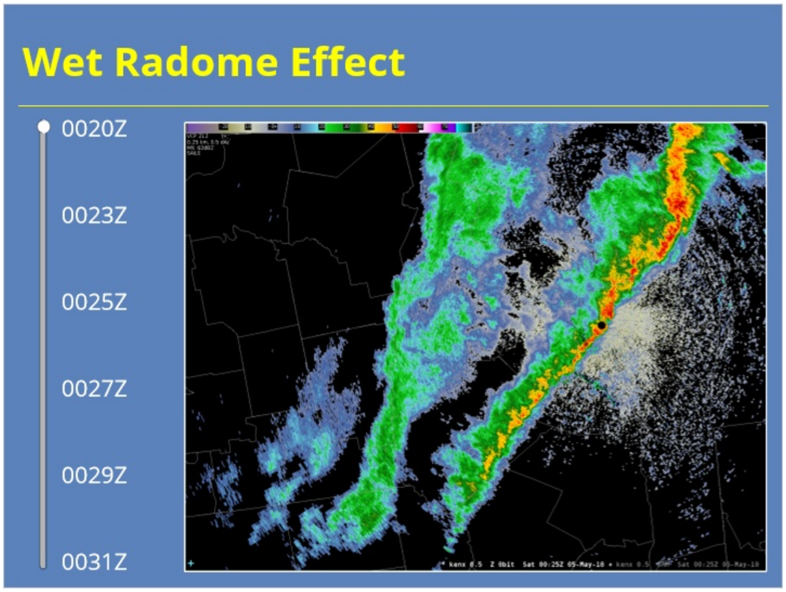
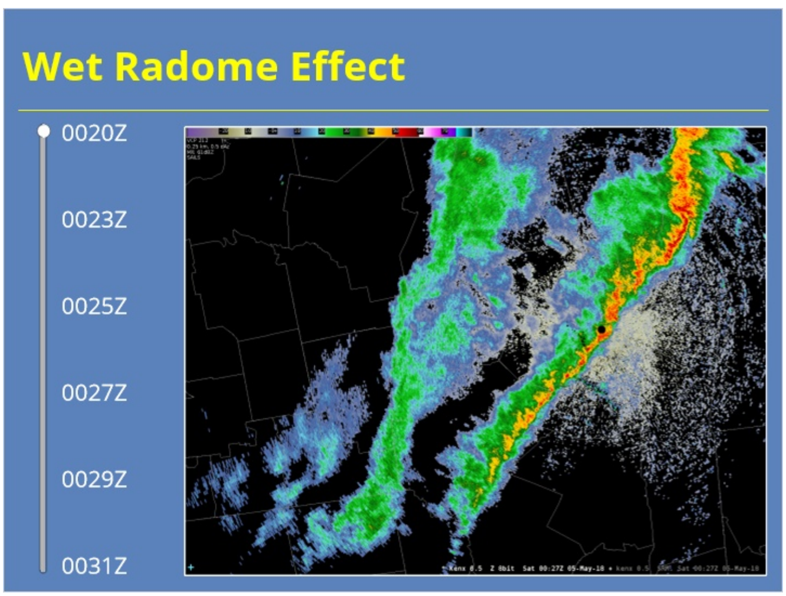
0025 (Slide Layer)



0027 (Slide Layer)



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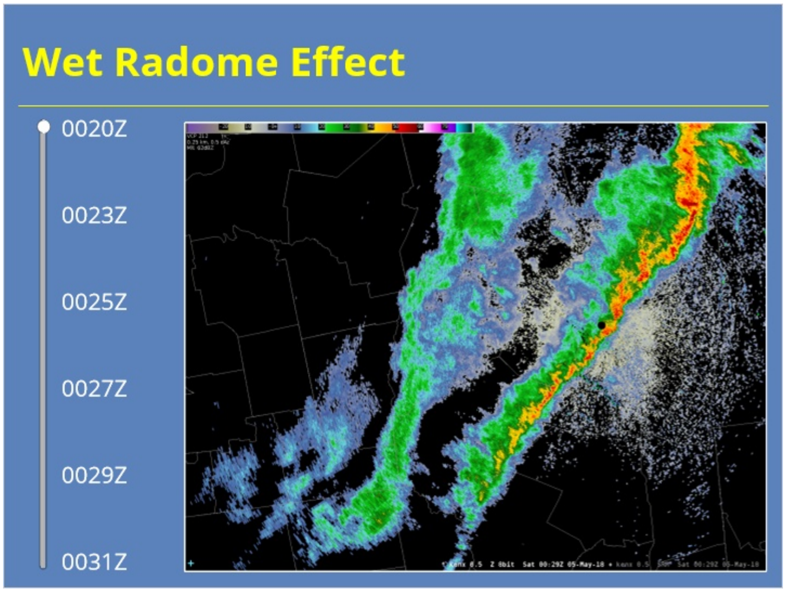
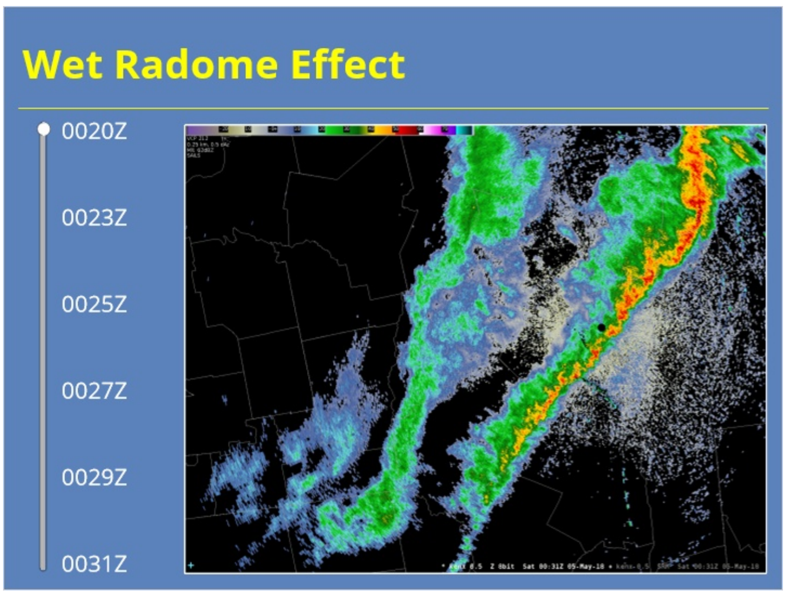
0029 (Slide Layer)



0031 (Slide Layer)



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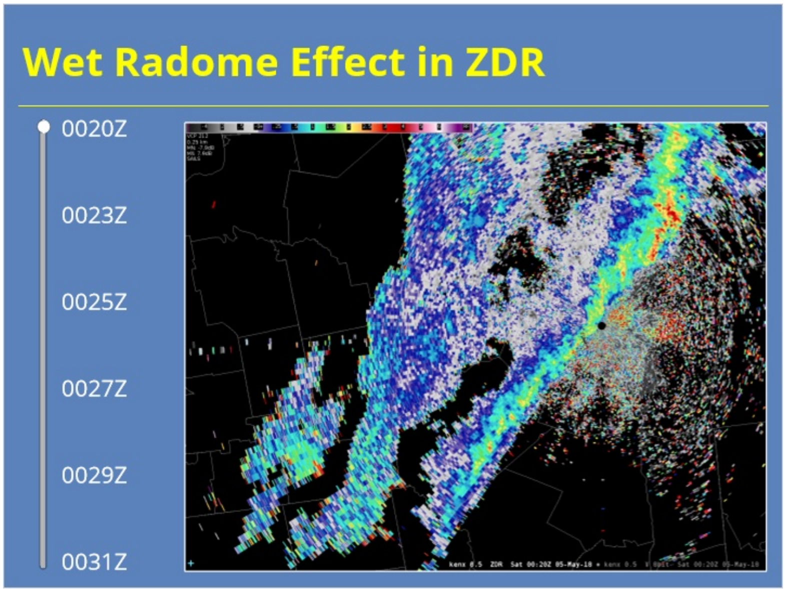
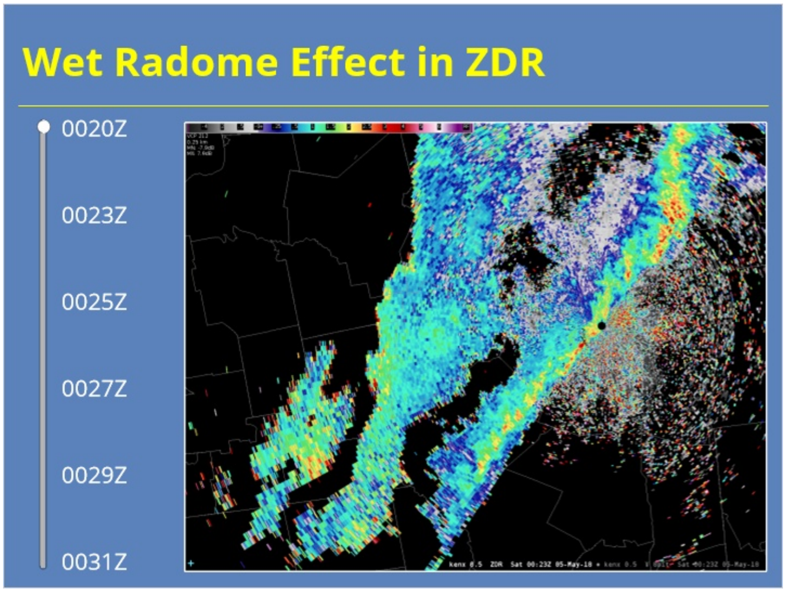
2.10 Wet Radome Effect in ZDR



Notes:

This artifact often appears more conspicuously in Differential Reflectivity, although the values tend to increase when the radome is wet. Use the controls on the slide to see how a wet radome effect impacts ZDR.

0023 (Slide Layer)



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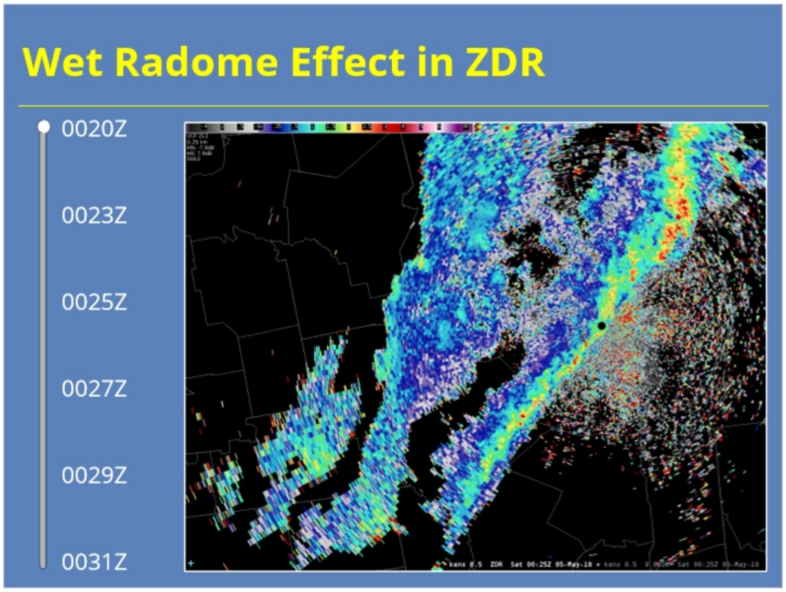
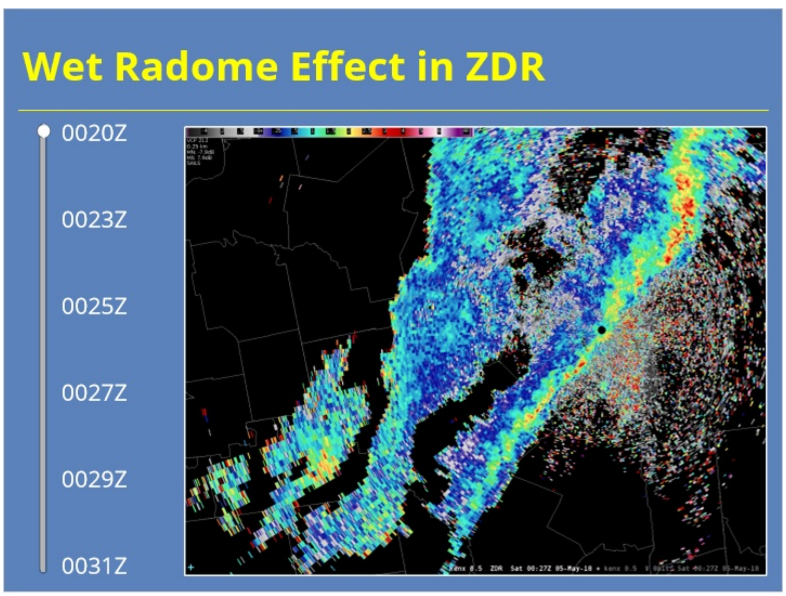
0025 (Slide Layer)



0027 (Slide Layer)



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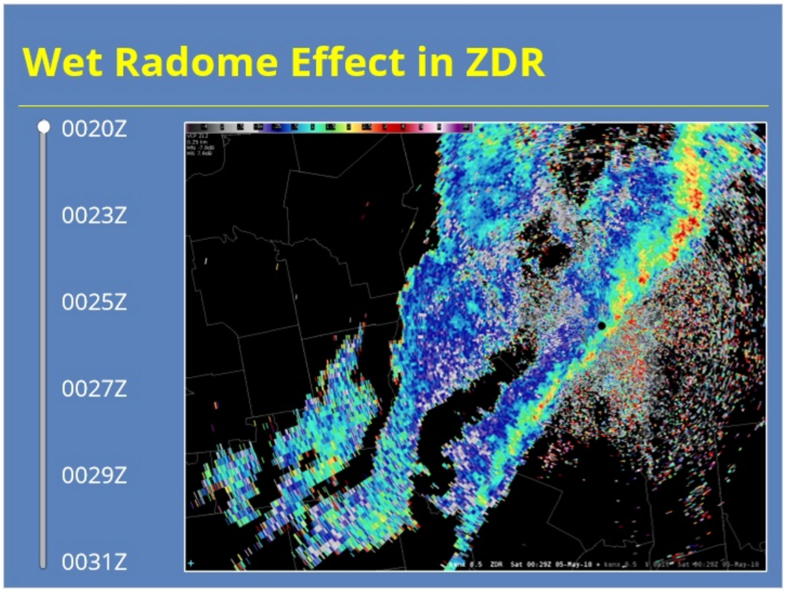
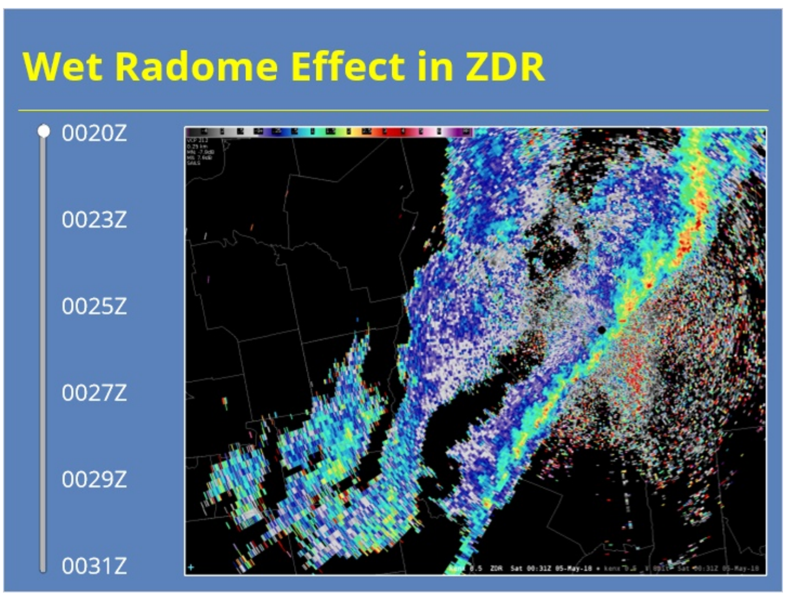
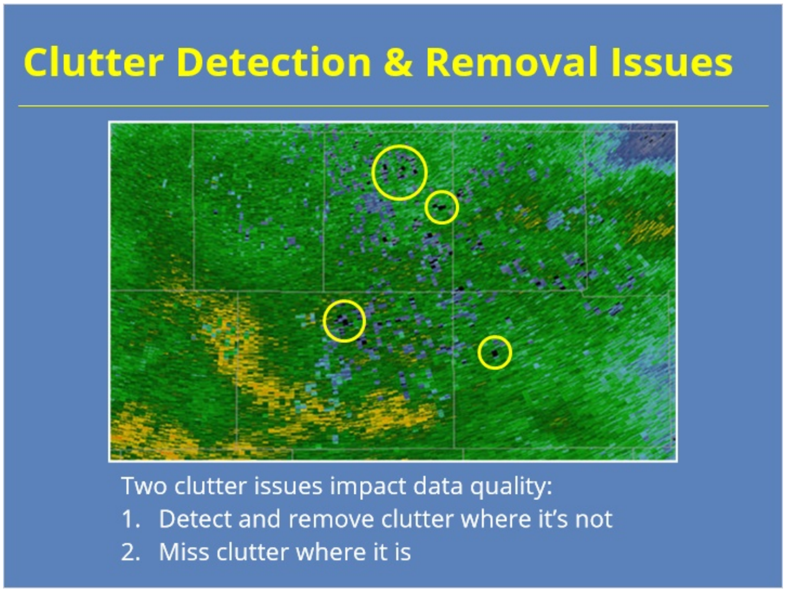
0029 (Slide Layer)



0031 (Slide Layer)



2.11 Clutter Detection & Removal Issues



Notes:

The Clutter Mitigation Detection (or CMD) algorithm is the preferred means for the WSR-88D to identify range bins contaminated with ground clutter. However, the algorithm is not perfect. CMD (along with the GMAP algorithm) can fail and impact base data quality in two ways: It can misidentify clutter where it isn't present (aka: false positive) or it can miss clutter where it is present (aka: false negative). This section will discuss the ramifications of both situations.

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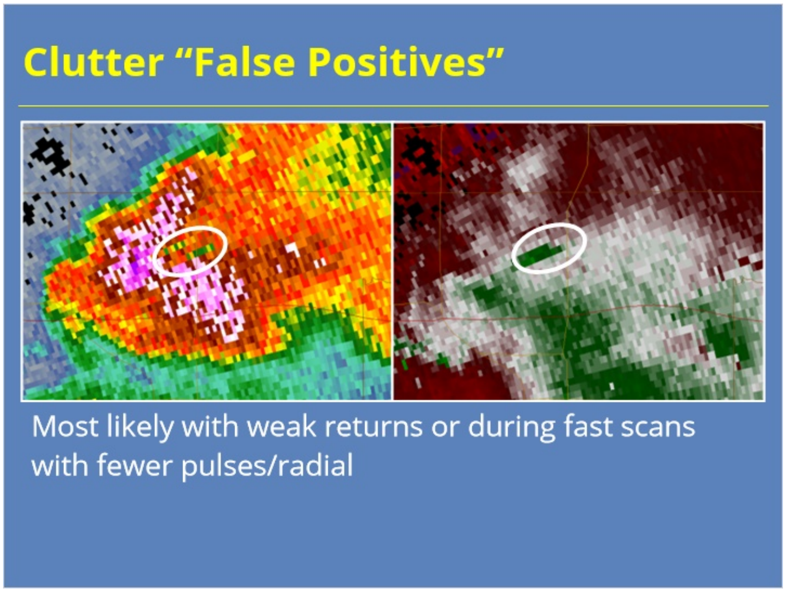
2.12 Clutter "False Positives"

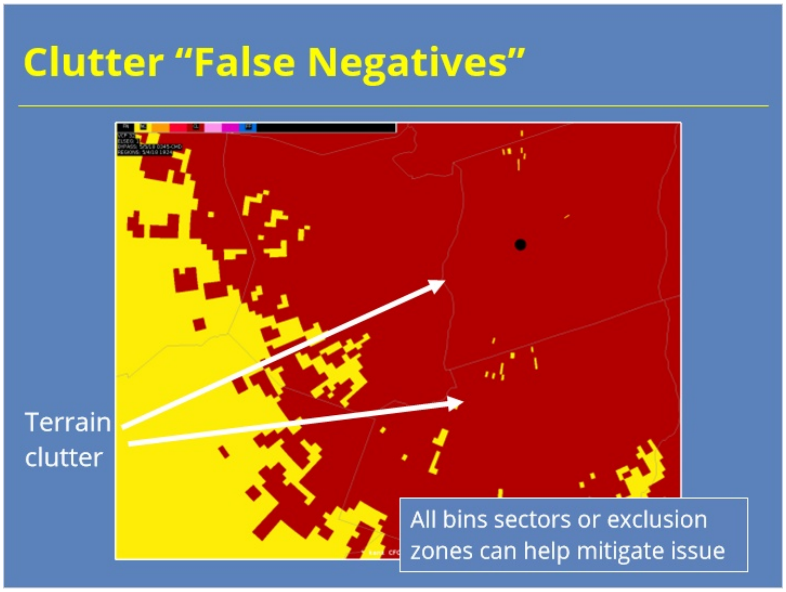


Notes:

The CMD algorithm uses multiple inputs to identify clutter. It performs best when a strong return signal exists and their are lots of pulses per radial. When the radar detects weak returns (such as weak stratiform precipitation) using a faster VCP (with fewer pulses per radial), performance issues can occur. One way the algorithm can perform poorly is by falsely identifying clutter in a given bin. These false positive detections can result in noisy data with sporadic gates of signal removed that didn't contain clutter.

This issue can impact convective storms such as in the example shown. See how several bins appear to be missing data in this area of high reflectivity? Anytime severe convection is anticipated, the need for VCP 12 or 212 outweighs the desire for perfect clutter suppression. However, use of VCP 215 during stratiform events will improve CMD performance.

2.13 Clutter "False Negatives"



Notes:

A similar problem happens when the clutter algorithms fail to detect clutter. In the example shown, some of the clutter from terrain has been identified and removed, but not all of it. These artifacts often occur because some aspect of the return doesn't look like clutter. See, if I pull up the bypass map data for this area, you can see some form of clutter filtering occurred. So, it's not like the CMD algorithm didn't detect the clutter. Often the problem occurs because the velocities associated with the clutter has a significant non-zero component.

To address this issue, radar operators can adds sectors for all bins filtering or create an exclusion zone for routine clutter areas like this one. These options are both preferable to turning off the CMD algorithm and relying on all bins clutter suppression throughout the entire scan.

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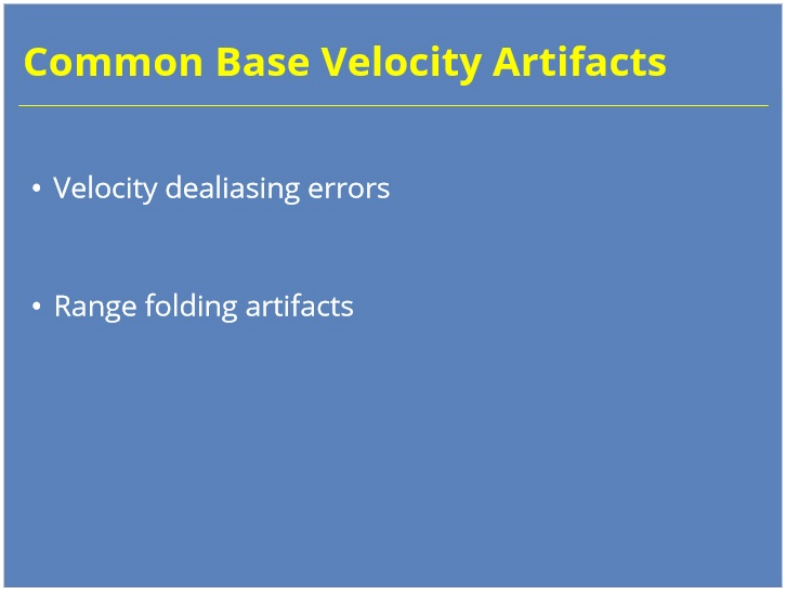
3. Velocity Artifacts

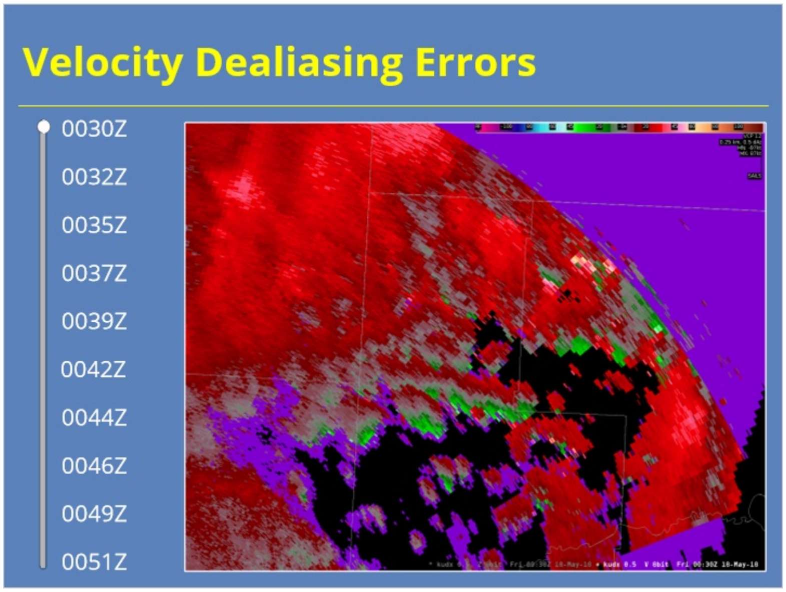
3.1 Common Base Velocity Artifacts



Notes:

Most base velocity data quality artifacts tend to fall into two categories: Issues with velocity data being improperly dealiased and range folded data artifacts.

3.2 Velocity Dealiasing Errors



Notes:

A whole lesson discusses velocity dealiasing and how it works, so a lot could be said and shown on this subject. Even with the velocity dealiasing algorithms in place at the RPG, sometimes errors occur. VCP 31 is most susceptible to dealiasing errors because of its low Nyquist Velocity. However, all VCPs can potentially be impacted. If you suspect velocities may be improperly dealiased, check for temporal and vertical continuity of the signature as dealiasing errors tend to be transient in nature.

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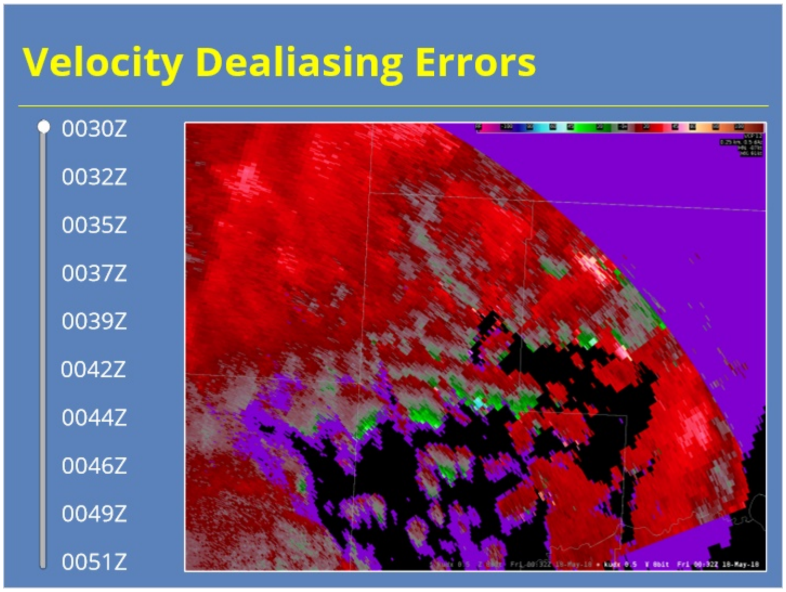
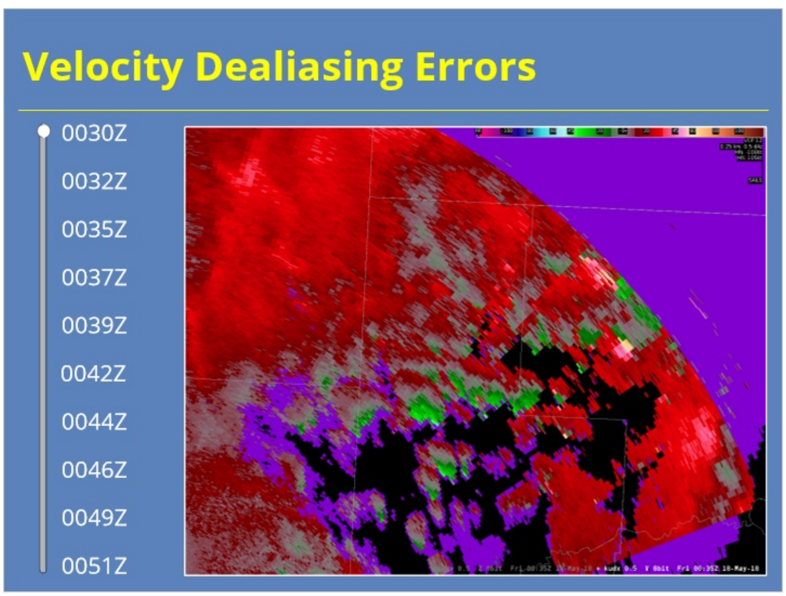
0032 (Slide Layer)



0035 (Slide Layer)



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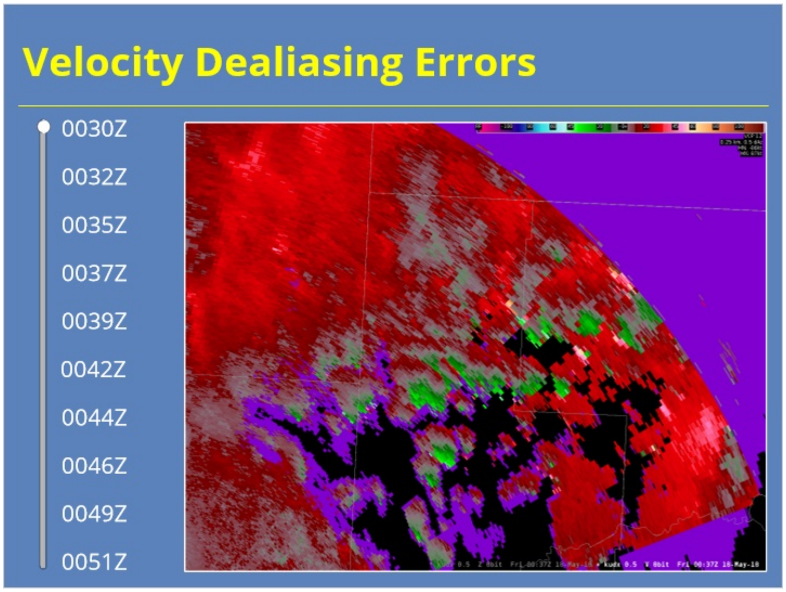
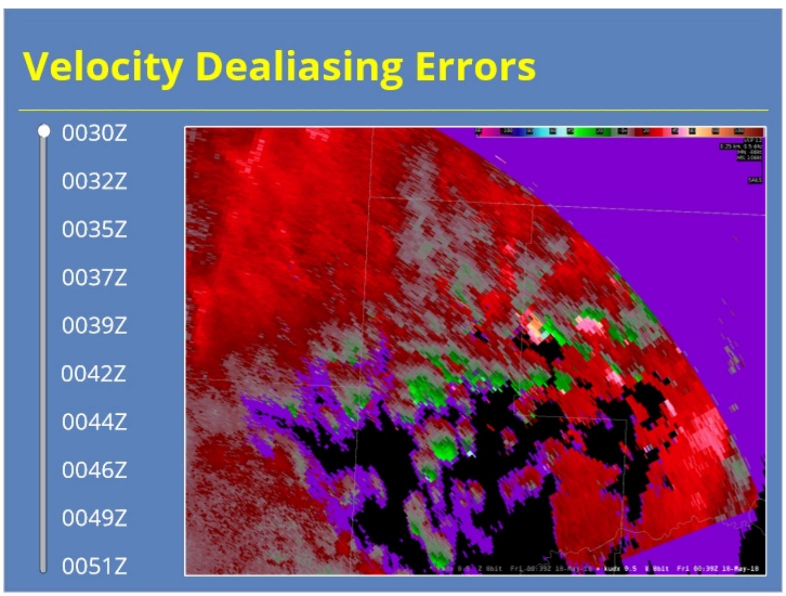
0037 (Slide Layer)



0039 (Slide Layer)



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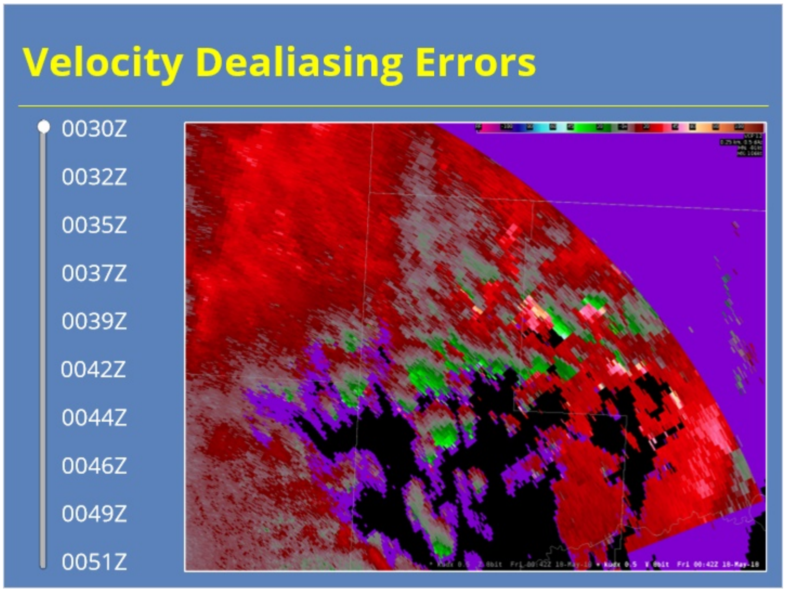
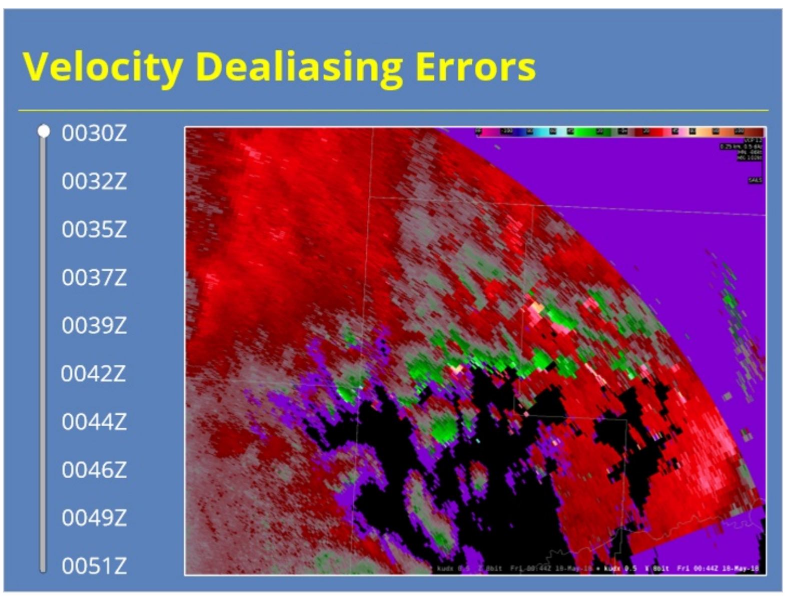
0042 (Slide Layer)



0044 (Slide Layer)



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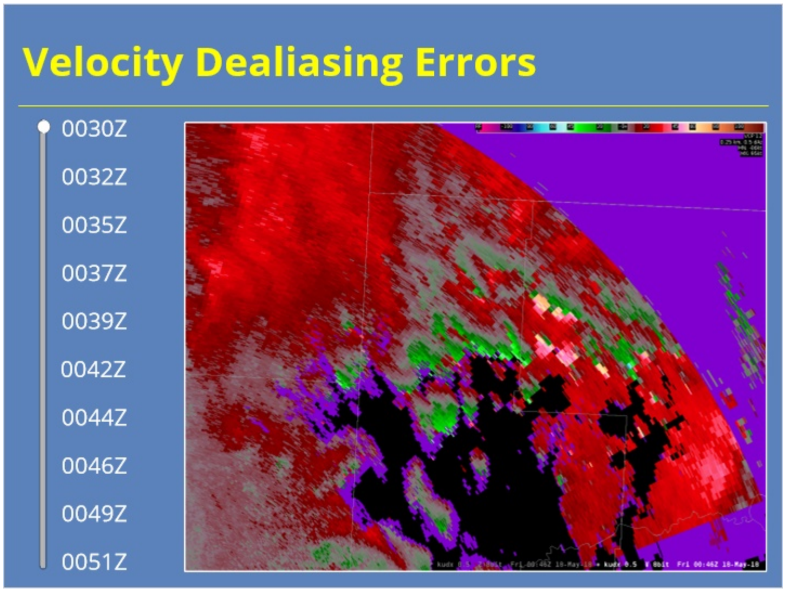
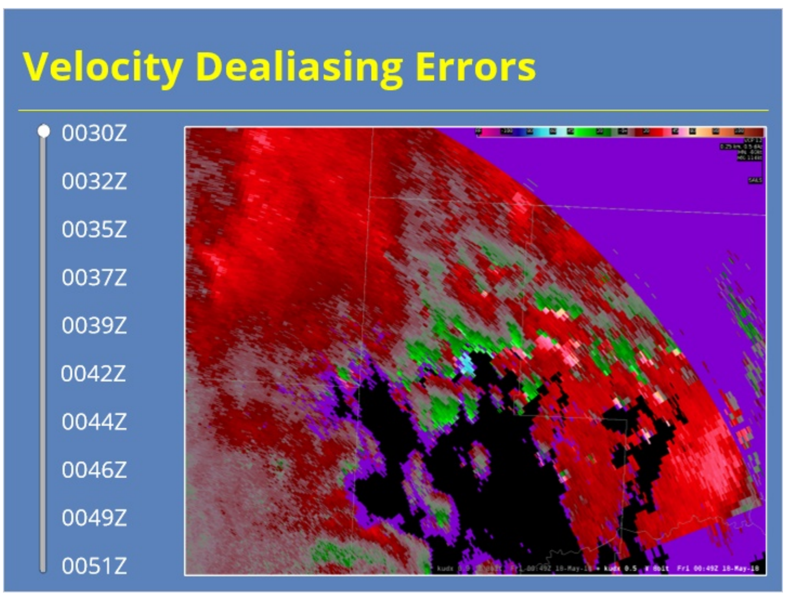
0046 (Slide Layer)



0049 (Slide Layer)



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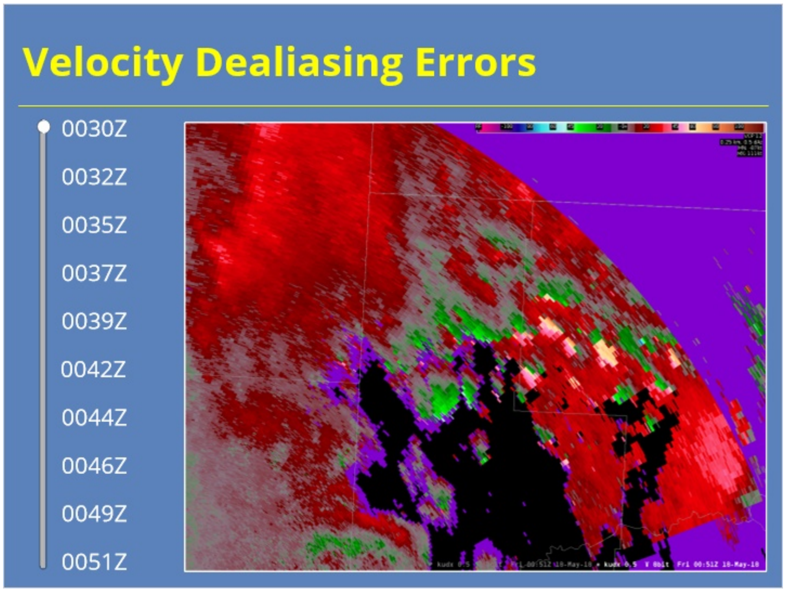
0051 (Slide Layer)



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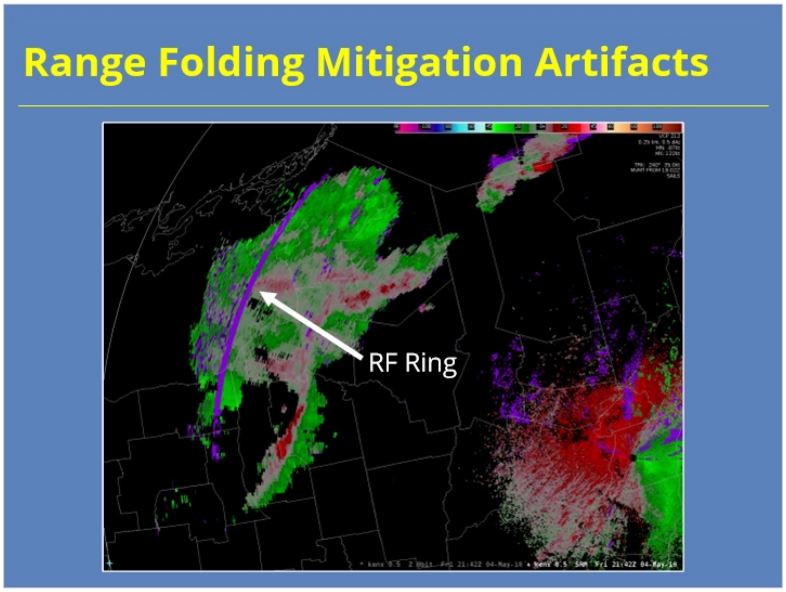
3.3 Range Folding Mitigation Artifacts



Notes:

At this point, you have likely taken the lesson on range unfolding of velocity data. So, you should realize that range folded velocity data happens. That's just life. However, RF data happens more frequently in certain situations. For instance, range gates just beyond the first trip (or Rmax distance) are often impacted by range folded velocities. Even when you use a SZ-2 VCP, you will likely get a ring of RF data at the end of the first trip distance of the Contiguous Surveillance or Doppler scans. While you can mitigate this issue to a degree by changing to VCP 12, you will often end up with more RF data that way. So, you just need to pick your poison in these situations.

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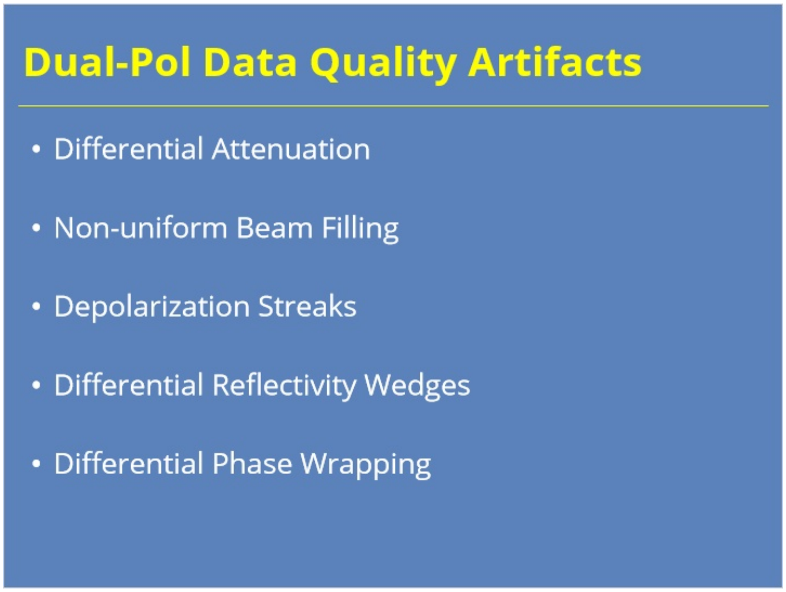
4. Common DP DQ Issues

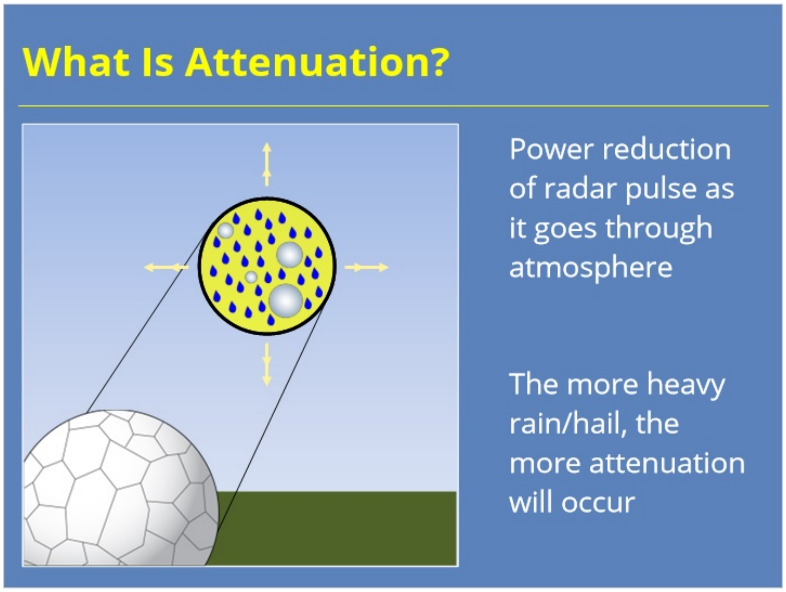
4.1 Dual-Pol Data Quality Artifacts



Notes:

There are numerous dual-pol related data quality issues that can be visible on radar products. This section will focus on five of these artifacts that impact dual-pol base data: Differential attenuation, non-uniform beam filling, de-polarization streaks, Differential Reflectivity wedges, and Differential Phase wrapping.

4.2 What Is Attenuation?



Notes:

Attenuation of the radar pulse has always been an issue with weather radar. Anytime electromagnetic energy is transmitted through a medium, some of the energy will be attenuated. The more dense the medium (such as a volume of heavy rain or hail), the more attenuation will occur. The attenuated portion of radar pulse is lost and cannot be recovered. Fortunately, the WSR-88D transmits a 10 cm wavelength pulse, which attenuates much less than shorter wavelength radar.

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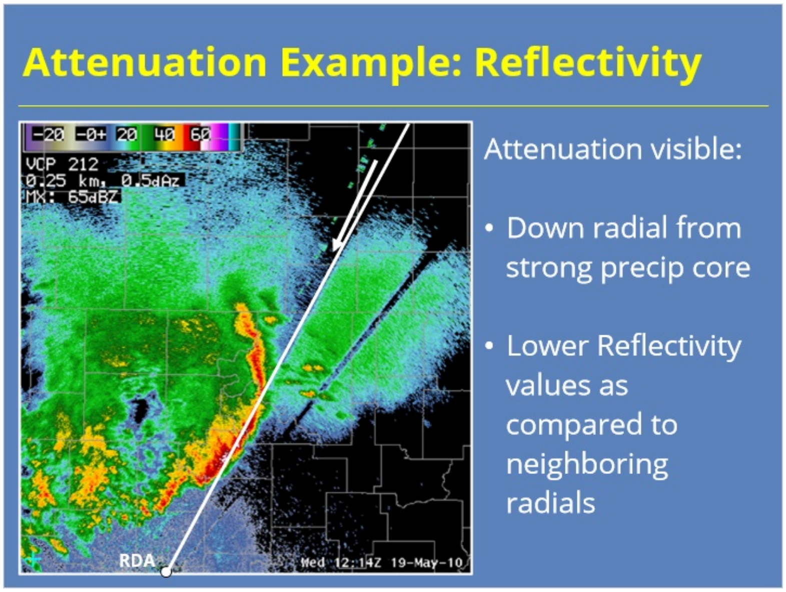
4.3 Attenuation Example: Reflectivity



Notes:

Attenuation impacts Reflectivity more than products like Velocity and Spectrum Width because it reduces the power in the radar pulse. What does a reflectivity product look like when it has been negatively impacted by attenuation? Take a look at the Reflectivity example on the slide. This squall line is oriented directly along a radial. This line should help you visualize the radial orientation better. I will leave it for a second or two more, now let’s look at the data. See how the reflectivity values are significantly lower down radial from the storm core compared to other nearby radials? That difference is due to attenuation.

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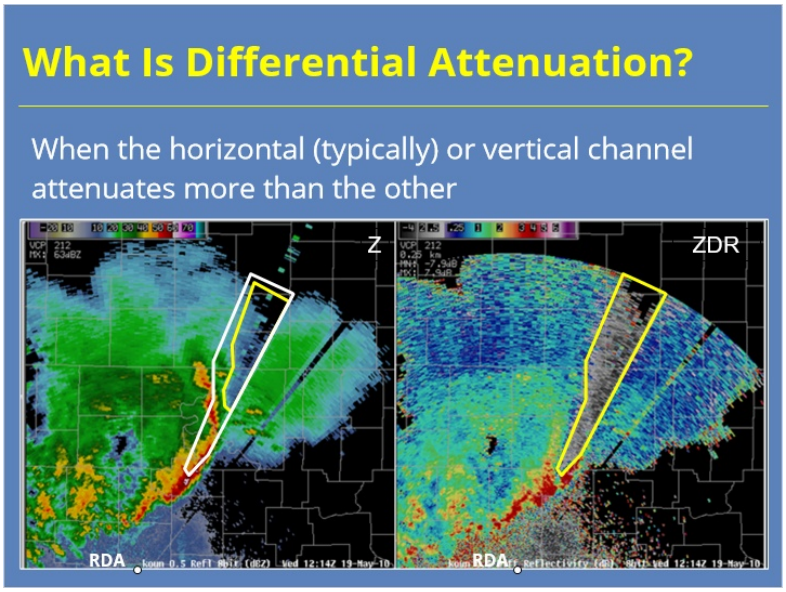
4.4 What Is Differential Attenuation?



Notes:

So, what is differential attenuation? Well differential attenuation occurs when one component of the polarized pulse's signal (usually the horizontal channel) get attenuated more than the other one. I've added the Differential Reflectivity product from the same time as the previous example to demonstrate. I have highlighted the area in Base Reflectivity that appears to be attenuated. The same region appears to be experiencing differential attenuation as well. In fact, if I move the area from ZDR over to Z, you can see the attenuation in the horizontal channel is noticeable closer to the RDA in ZDR than it is in Z. Any products derived from this ZDR data will inaccurately represent the actual atmospheric conditions.

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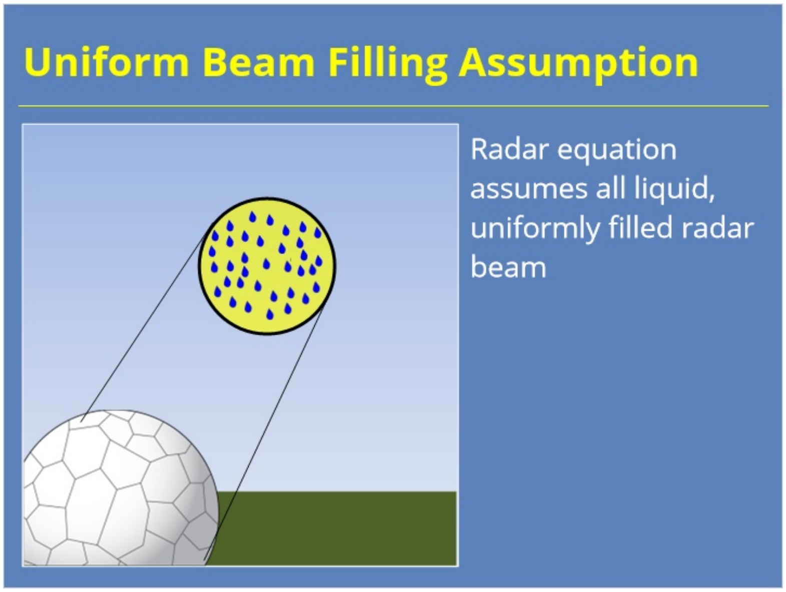
4.5 Uniform Beam Filling Assumption



Notes:

Before we discuss non-uniform beam filling, we need to provide some context as to why that condition is significant. Remember that the Probert-Jones radar equation assumes that the radar beam is filled uniformly with liquid precipitation. In reality, both of those conditions are frequently not met. So, what are the impacts when that happens?

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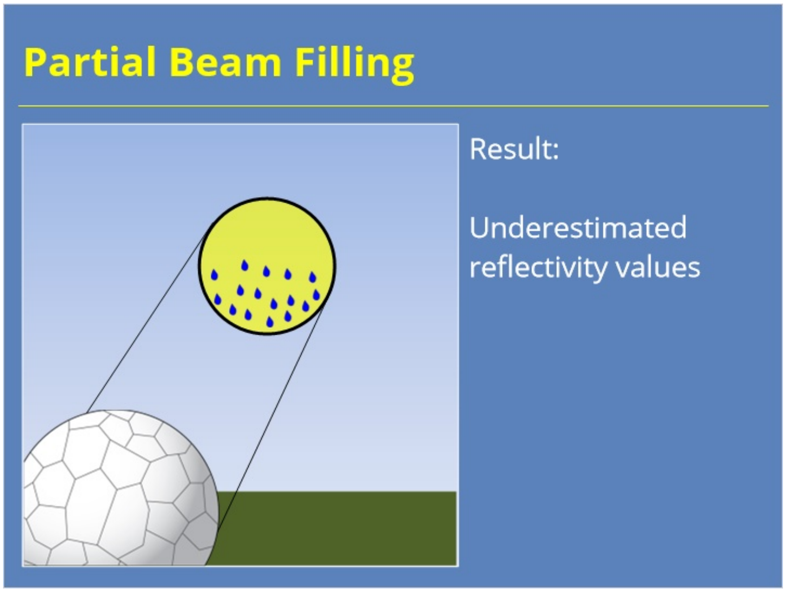
4.6 Partial Beam Filling



Notes:

When the beam is only partially filled with precipitation, the end result is Reflectivity will be underestimated. Differential Reflectivity usually isn't impacted because it relies on the ratio between the two channels which are often impacted comparably by partial beam filling.

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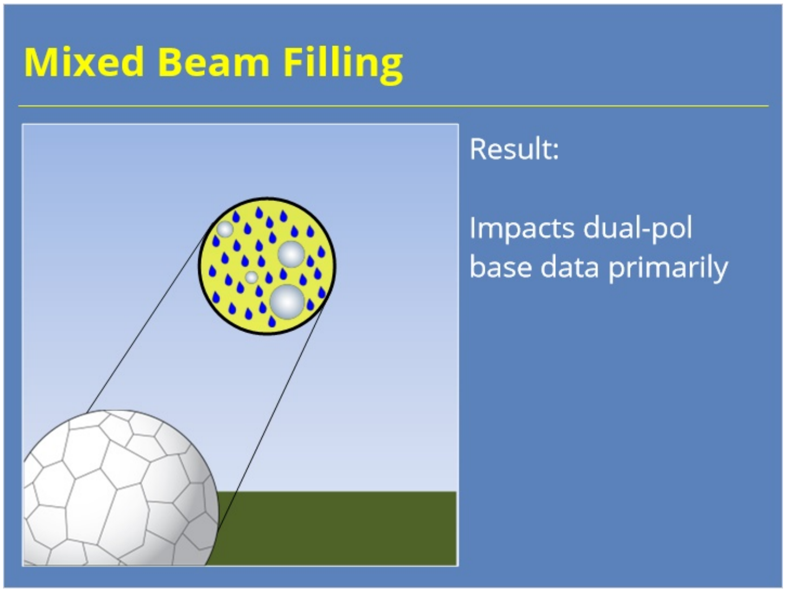
4.7 Mixed Beam Filling



Notes:

When the beam is filled with a mixture of hydrometeor sizes and types, the Probert-Jones uniformity assumption isn't necessarily violated. Afterall, as long as the different sizes are uniformly distributed throughout the beam, the assumption is still valid. However, that mixture of hydrometeors still impacts the base data. The dual-pol data, in particular, are more noticeably impacted than the legacy base products.

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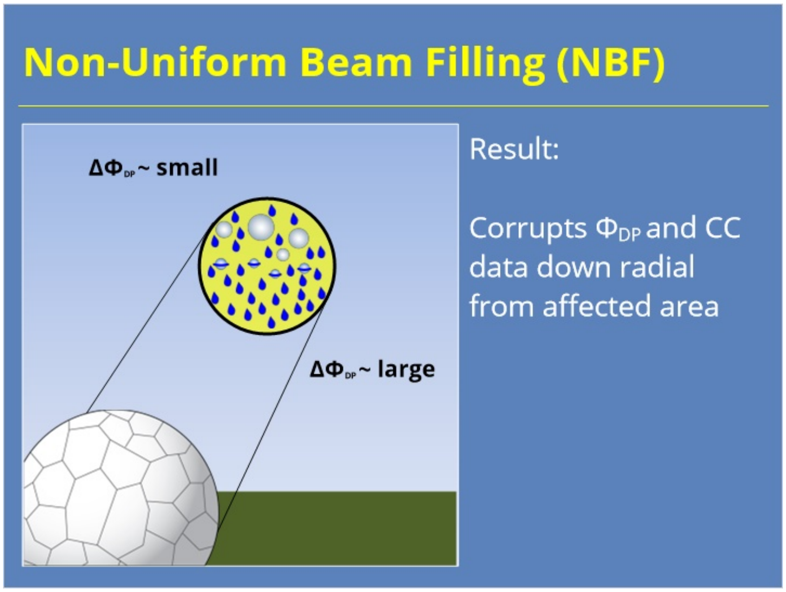
4.8 Non-Uniform Beam Filling (NBF)



Notes:

While both partial and mixed beam filling can impact your base data, non-uniform beam filling differs from both of these situations in that it creates artifacts in the data that impact both the radar bins in question, but all bins down radial from that bin. The problem is related to the combination of mixed precipitation types that are not uniformly distributed. At the top of the beam, Differential Phase changes marginally because the hail stones dominate the returned power. At the bottom of the beam, Differential Phase changes significantly because it is passing through all liquid precipitation. This configuration results in a PhiDP gradient across the beam that continues to propagate with the pulse down the radial. This situation results in lower Correlation Coefficent values from there on out than what actually exists in the atmosphere.

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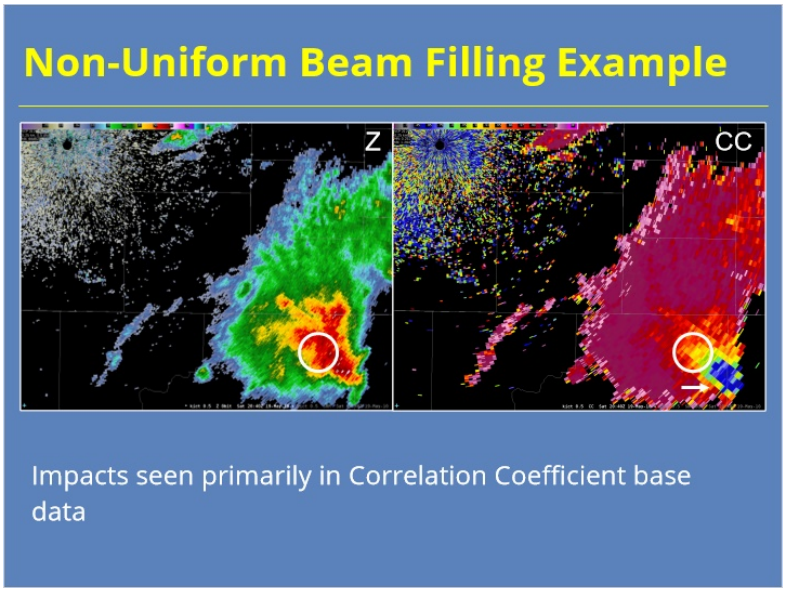
4.9 Non-Uniform Beam Filling Example



Notes:

So, what does a Correlation Coefficient product look like when it has been impacted by non-uniform beam filling? Here’s an example. The circled area in the Reflectivity and CC products shows where the non-uniform beam filling is actually occurring. Notice how the down radial CC values are significantly lower than the values from nearby radials. We don’t see a similar artifact in the Reflectivity data.

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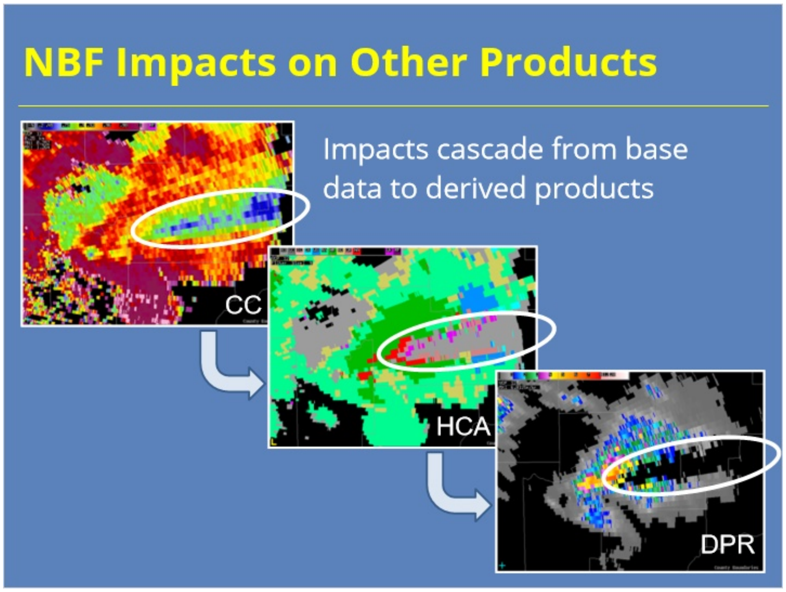
4.10 NBF Impacts on Other Products



Notes:

So, how does this data artifact impact other products? Well, the easiest way to see the impact is by looking at the dual-pol precipitation products. The low CC values cause a large swatch of bins to be classified as biological targets that are actually precipitation. When this information gets used to generate the instantaneous rate product, the bins labeled as biological returns have no accumulated precipitation. So, you can see how this artifact can be a problem and why forecasters need to be mindful of these signatures in the base data.

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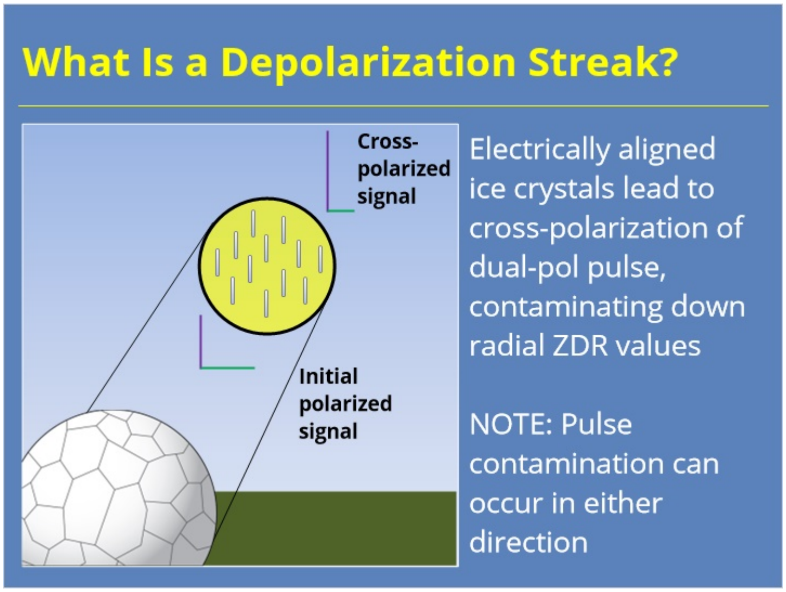
4.11 What Is a Depolarization Streak?



Notes:

The next data quality artifact in this section is depolarization streaks. Depolarization streaks occur along a radial when the pulse passes through a electrified region of a storm populated with ice crystals. The electric field in the storm, if it's strong enough, can cause the ice crystals to cant in a preferred direction. When the radar pulse hits these canted crystals, some of the energy in the radar pulse cross-polarizes. So, you start off with an initial polarized signal that is equally strong in both the vertical and horizontal. After passing through the electrified area, one of the orthogonal components is stronger than the other.

I should note that, in this example, I show some of the horizontal pulse switching to vertical. Well, the opposite can happen, too. In fact, it's common to see alternating streaks of anomalously high and low ZDR values in these electrified regions.

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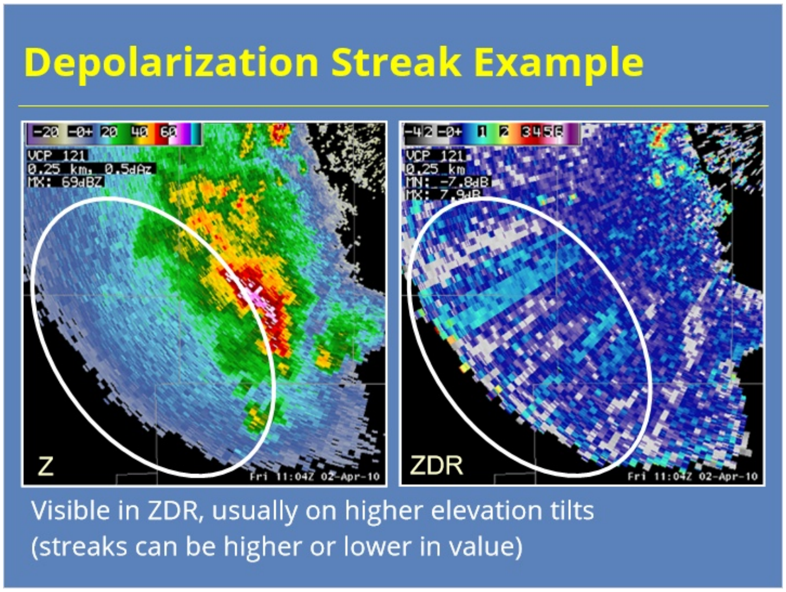
4.12 Depolarization Streak Example



Notes:

So, what do these depolarization streaks look like in the base radar data? You can see that Base Reflectivity really isn't impacted at all. However, In ZDR you can see radially oriented streaks of higher or lower values when compared to adjacent radials. These streaks will be transient in nature as the electric field fluctuates. They will be more noticeable on higher elevation tilts where ice crystals are more likely in convection. The good news, these data artifacts have minimal operational impact. But, it's still good to know what they are so you can recognize them.

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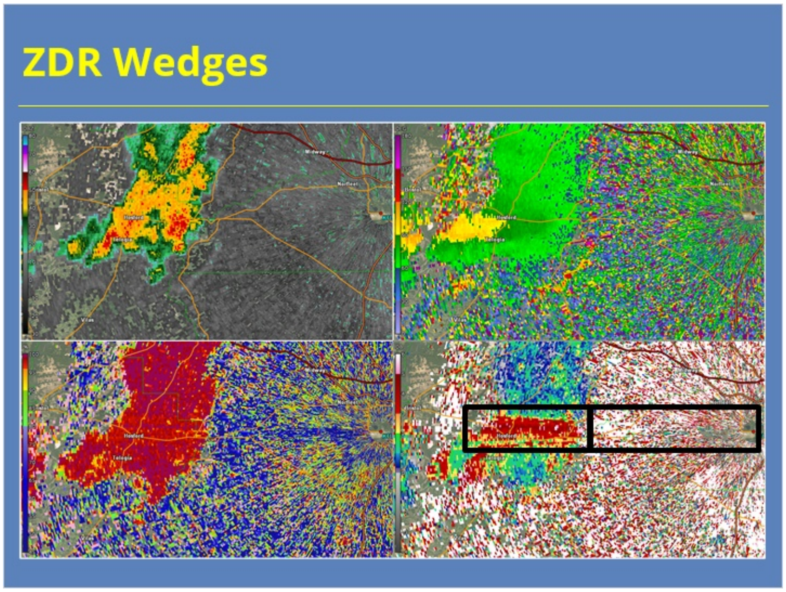
4.13 ZDR Wedges



Notes:

Occasionally, wedges (or spikes) will appear in Differential Reflectivity data. These artifacts can appear for several different reasons. In some cases, like this example, there may be some ground object that blocks more of the vertical pulse than the horizontal pulse. The clear air returns are so highly positive that the wedge isn't apparent there. However, once you enter into weather returns, you can see the values are out of whack. Sometimes, ZDR wedges can be due to hardware issues, so you want to tell your radar focal point or el tech about these kinds of signatures when you notice them.

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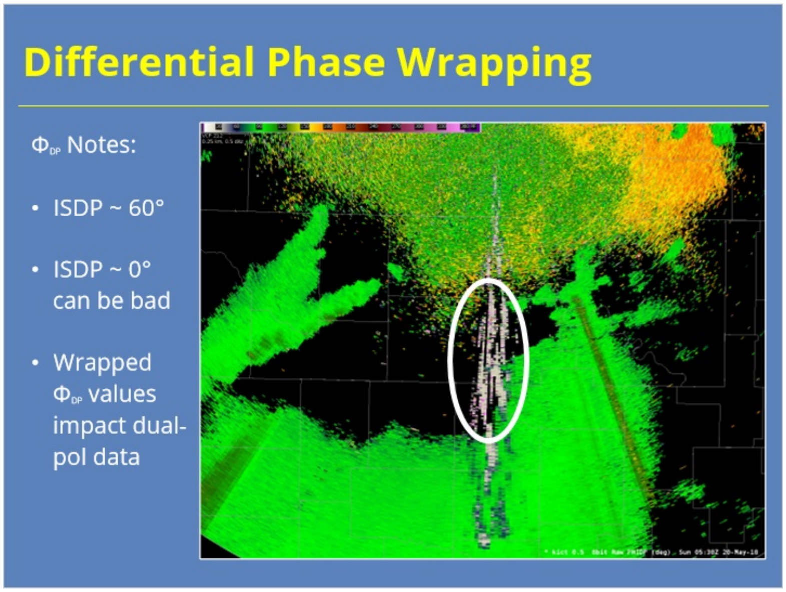
4.14 Differential Phase Wrapping



Notes:

We don't spend a whole lot of time in the RAC on Differential Phase (or Phi), but it can be a useful product for quality controlling issues with the radar. If you know one thing about Differential Phase, it should be that (when calibrated properly) Phi values should be around 60 degrees when entering the first precipitation returns on the radial. This value is known as Initial System Differential Phase. In this example, the ISDP is a little higher than that and is closer to 90 degrees. If ISDP is a little high, that's not a big problem. If ISDP is low, like near 0 degrees, then you can run into issues. This example has a few radials where ISDP is low due to some interference. It may be a little hard to see, but some of the values are pink, meaning the values have wrapped around to the high 300s. Since this is interference, we know the data is bad. If it happens in areas you know is precip, your CC and other dual-pol data can be negatively impacted.

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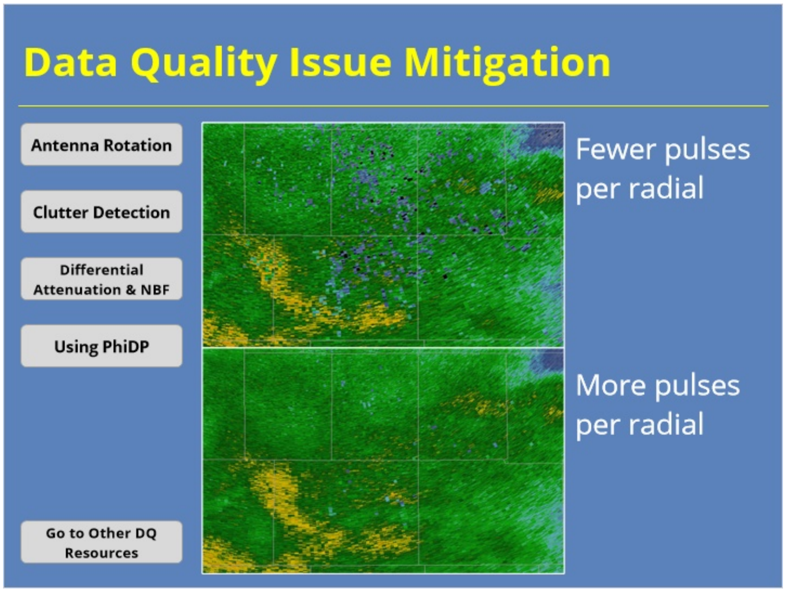
5. DQ Mitigation

5.1 Data Quality Issue Mitigation



Notes:

Our discussions up to this point identified a variety of base data quality issues, what may cause them, and possibly even some mitigation steps. Here are some additional mitgation step you can take to help get the best quality data possible. After all, if a few simple steps could change your radar displays from the image on the top to the image on the bottom, then would you not want to take those actions?

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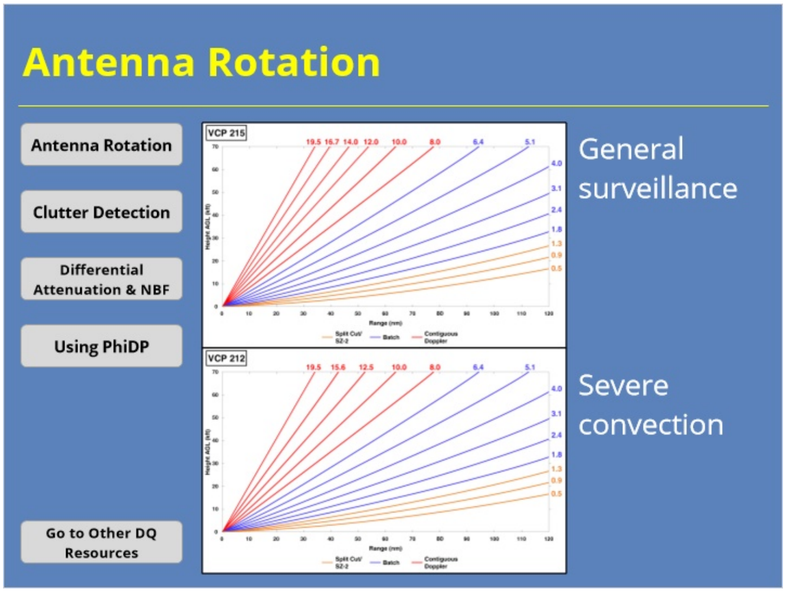
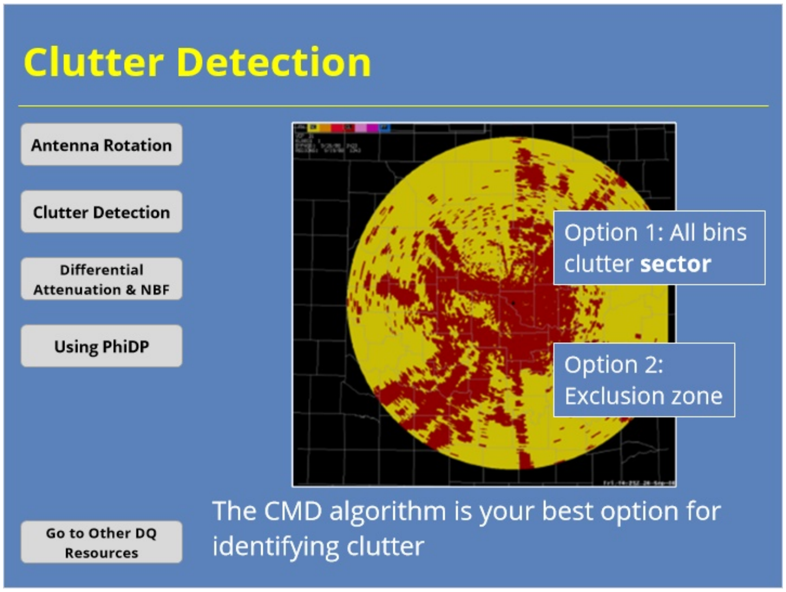
5.2 Antenna Rotation



Notes:

Antenna rotation rates can impact data quality. The best way to mitigate data quality issues due to radar rotation rates is use the available VCPs in the situations they were designed for. For example, VCP 215 is a great choice for many types of precipitation events as it was designed for general surveillance. If severe convection is a threat, switch to VCP 212. Just remember to switch back to VCP 215 if severe convection ceases to be a threat during the event.

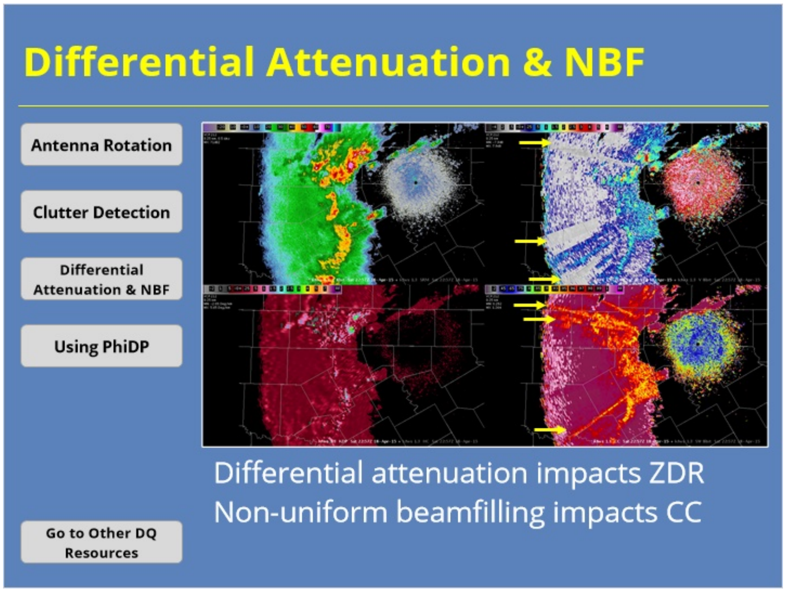
5.3 Clutter Detection



Notes:

The CMD algorithm is your best option for identifying clutter and getting the highest quality radar base data. If you notice false positive detections where data is dropping out where it should not, make sure you are using the best VCP for the current weather situation. If you notice false negative detections where clutter isn't being removed, then you have two options. First, you can create a sector where all bins clutter filter occurs. You will want to make this sector as small as possible because filtering every bin will definitely impact your base data. If that doesn't work, probably because the returns have a non-zero velocity, then you will need to use an exclusion zone. Exclusion zones are your tool of last resort, so you definitely want to use them judiciously.

5.4 Differential Attenuation & NBF

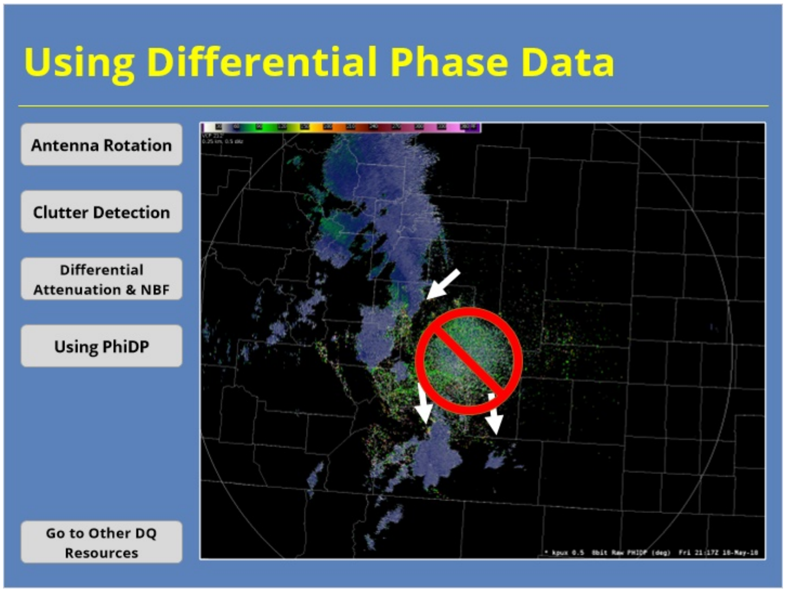


Notes:

While differential attenuation and non-uniform beam filling often occur in similar conditions, their physical causes are different. Differential attenuation impacts the Differential Reflectivity product while non-uniform beam filling will impact the Correlation Coefficient product. In the example shown, see how the radial spikes don't always match up between ZDR and CC.

If you notice either artifact in your base data, then it's likely that your hydroclassification and dual-pol precipitation products will be negatively impacted, too. You will need to make adjustments for QPE rainfall totals for these areas if the conditions linger over the same locations for more than a volume scan or two.

5.5 Using Differential Phase Data



Notes:

Differential Phase can be a very useful tool for diagnosing data quality issues. Look at PhiDP values in areas you know are precipitation close to the radar to ensure that your initial system differential phase values are around 60 degrees…especially if your radar has had maintenance recently! Also, check those ISDP values if you suspect widespread attenuation in Z or ZDR. Just don't get hung up on the noisy PhiDP values in clear air or clutter returns. Those will not tell you much. You need returns from actual precipitation to know if your radar has a problem.

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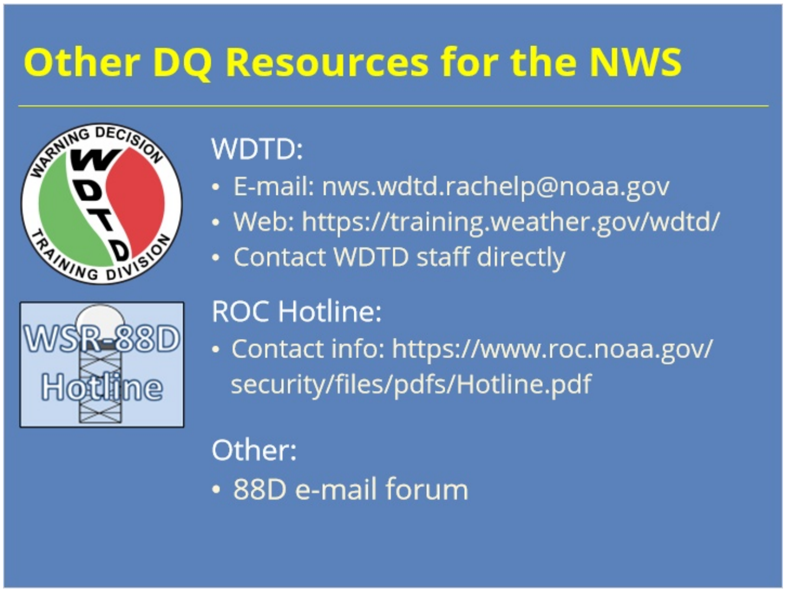
6. Other DQ Resources

6.1 Other DQ Resources for the NWS



Notes:

There are several different radar data quality resources available to NWS forecasters. For starters, feel free to contact the Warning Decision Training Division staff with any radar related questions you have. Even when we don't know the answer, we can usually connect you with someone who can. Speaking of people who know the answers, don't forget about the Radar Operations Center (ROC) Hotline staff. If you notice something unusual (or problematic) going on with your WSR-88D, you will definitely want to give them a call. Just remember that the ROC Hotline is only available to National Weather Service, Air Force, and Federal Aviation Administration personnel since they are the tri-agency radar operators. Lastly, there is a e-mail forum for the WSR-88D. All you need to do is subscribe to that forum on the NWS list server, and you will be included in the conversation.

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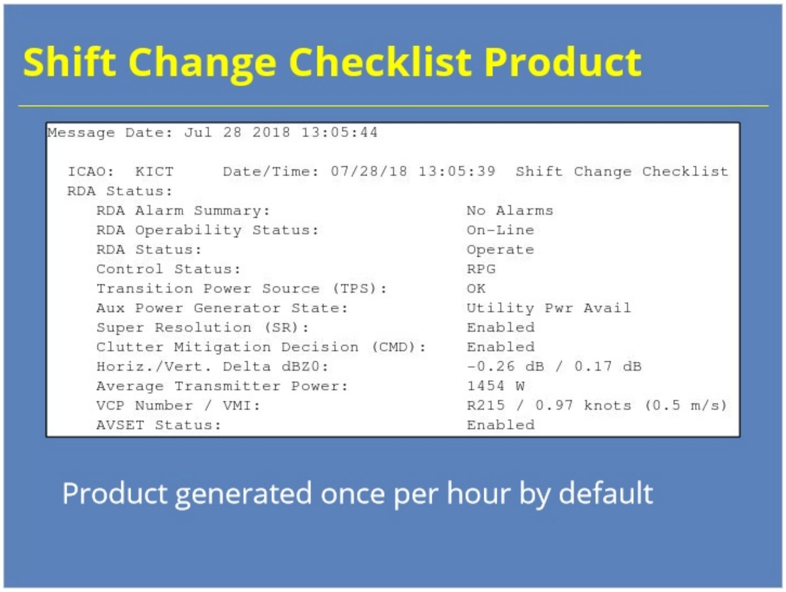
6.2 Shift Change Checklist Product



Notes:

A new product in RPG Build 18 is the Shift Change Checklist product. The RPG generates this text product routinely (in fact, once an hour is the default) with lots of important information about the how the WSR-88D system is operating. What's nice about this product is you can pull it up on AWIPS. So, that radar checklist that you are supposed to do once a shift? Well, now you can do it from AWIPS instead of going over to the MSCF.

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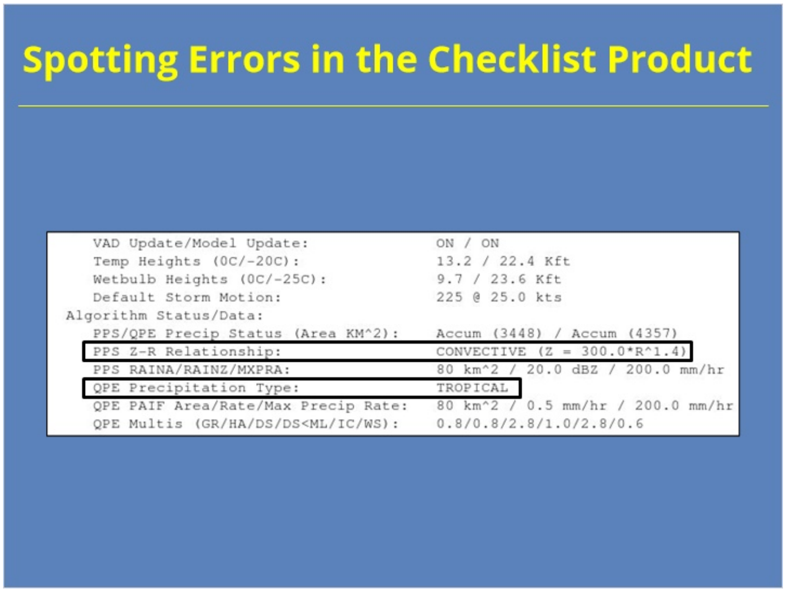
6.3 Spotting Errors in the Checklist Product



Notes:

So, let me show you an easy example of how you can use the Shift Change Checklist product to QC your radar. In the example on the slide, we have a mismatch going on between the PPS and QPE algorithms. The PPS algorithm is using a convective Z-R relationship. However, the dual-pol QPE algorithm has been switched over to a tropical R(Z,ZDR) relationship. This kind of mismatch can lead to problems when comparing the output of the two algorithms.

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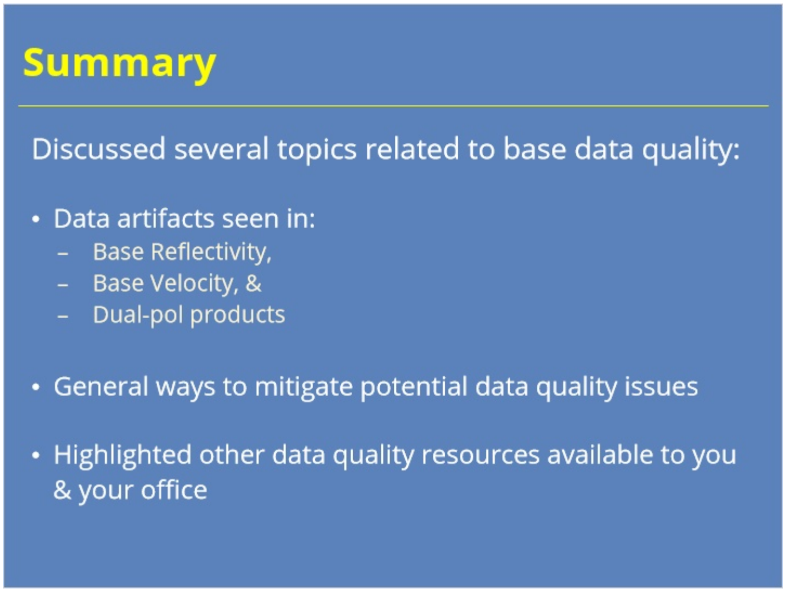
7. Summary & Quiz

7.1 Summary

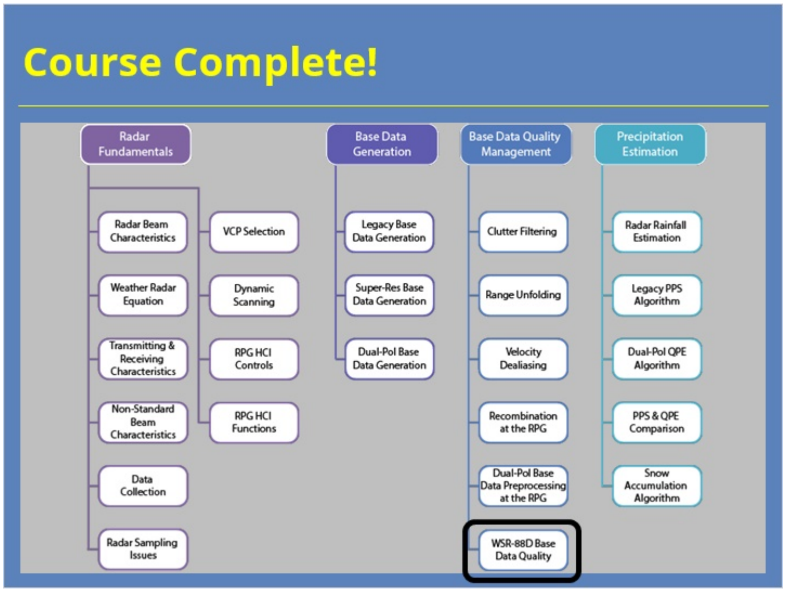


Notes:

This lesson discussed several common data quality issues. These topics included some common data artifacts seen in Base Reflectivity, Base Velocity, and dual-pol products. Several general mitigation steps forecasters can take to get the best data quality possible were presented. We also discussed some additional data quality resources at your disposal.

The next slide will start the lesson quiz. Click the next button when you are ready to proceed.

7.11 Course Complete!



Notes:

You have successfully completed this course. You can look over the roadmap on the slide to see what courses remain in this topic or you can click the Exit button to close the window and record your completion.

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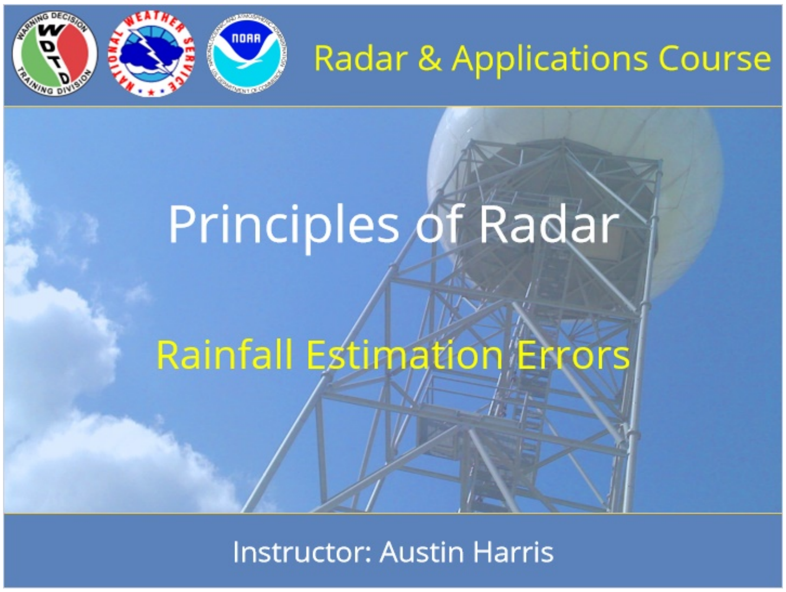
Rainfall Estimation Errors

1. Introduction

1.1 Title Slide



Notes:

Welcome to the Principles of Radar lesson on Rainfall Estimation Errors.

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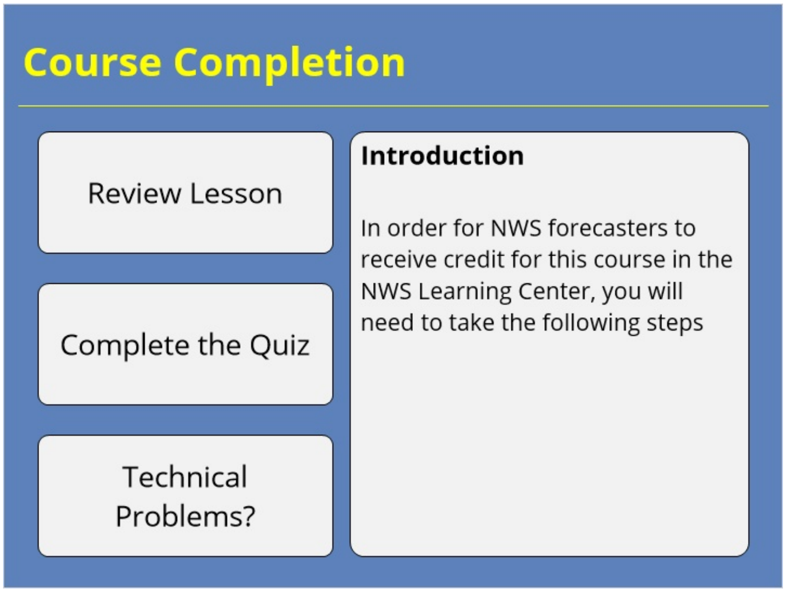
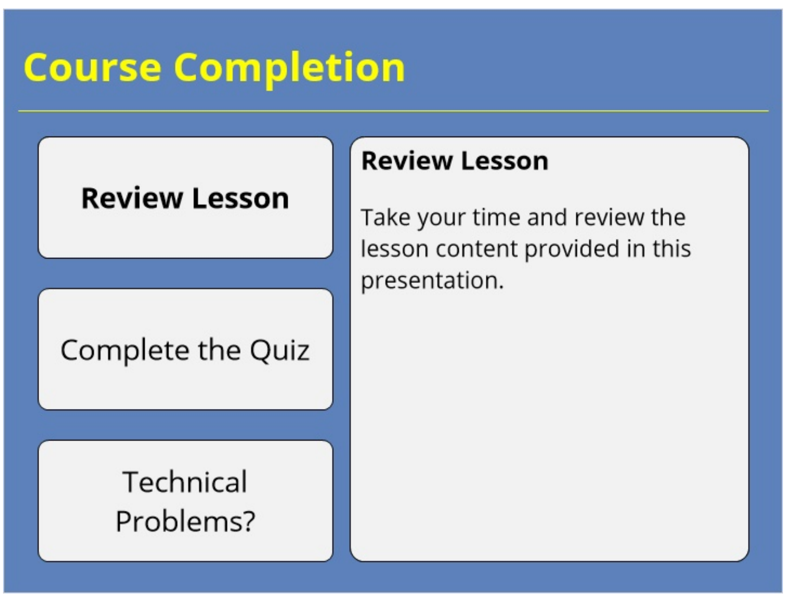
1.2 Course Completion Info



Notes:

If you are completing this course for credit, please review this interaction on how to complete this course within the NWS Learning Center. After viewing all the slides, click "Next" to continue.

Review Lesson (Slide Layer)



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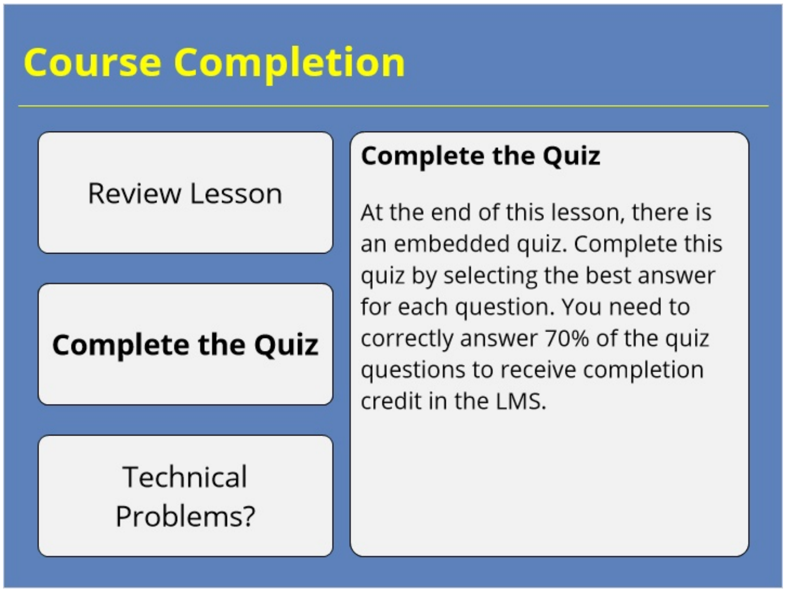
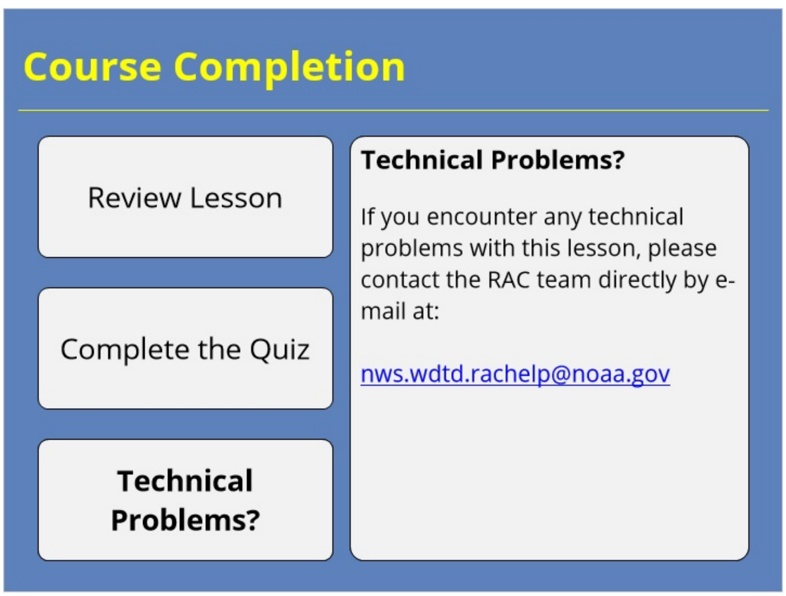
Complete the Quiz (Slide Layer)



Technical Problems (Slide Layer)



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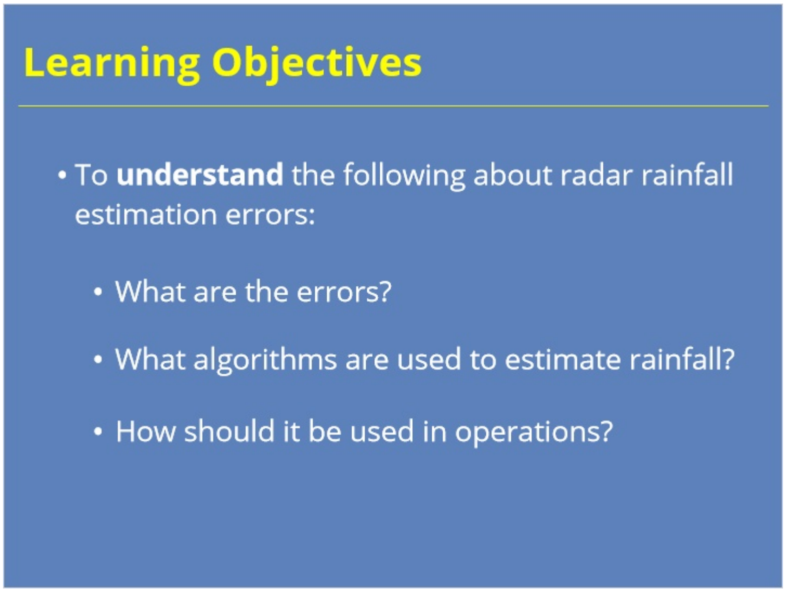
1.3 Learning Objectives



Notes:

The learning objective for this lesson is to understand the following about rainfall estimation errors:

What are the errors?

What algorithms do we used to estimate rainfall?

How should it be used in operations?

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2. Homepage

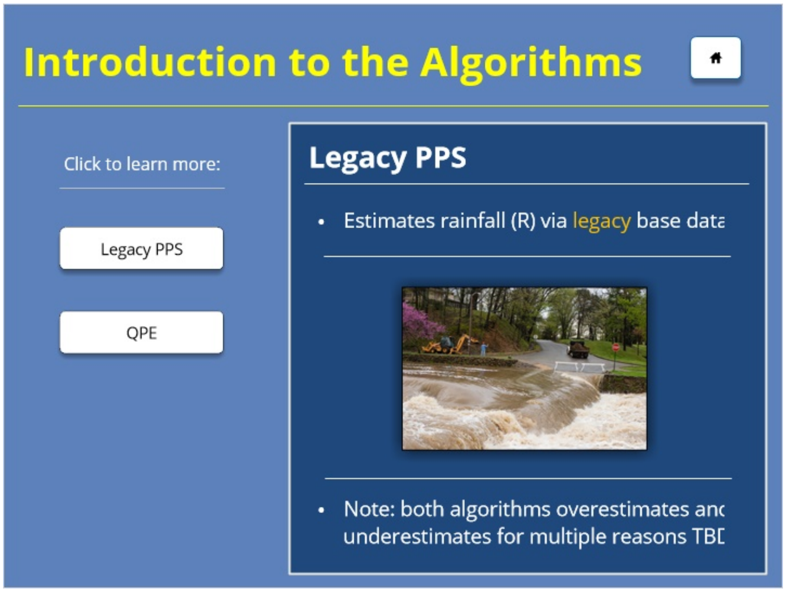
2.1 Homepage: Rainfall Estimation Errors

Notes:

Welcome to the homepage for this lesson on Rainfall Estimation Errors. From here, you can click on these three buttons to get an Introduction to the algorithms used to estimate rainfall, the types of errors that are associated with them, and some of the operational context you need to know when using these products. Once you feel comfortable with these materials, take the quiz by clicking at the bottom right of the screen.

3. Introduction to the Algorithms

3.1 Introduction to the Algorithms



Notes:

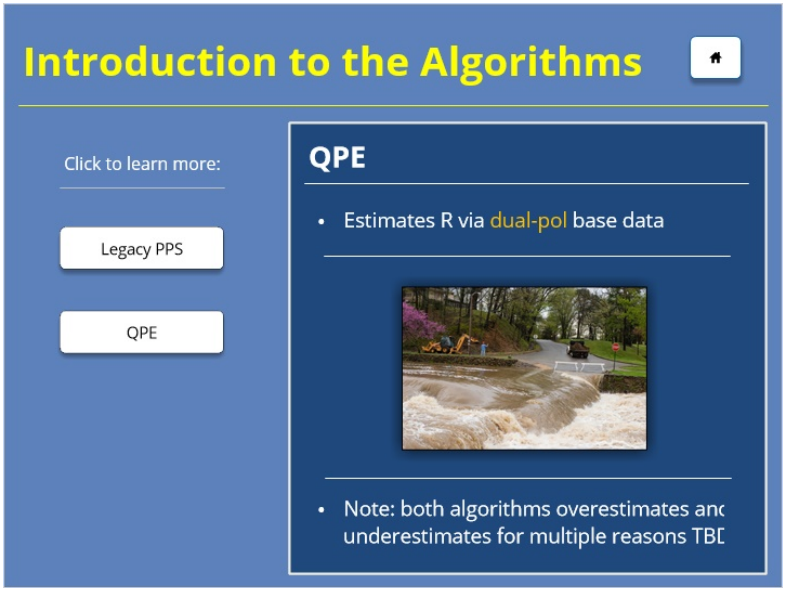
PPS:

There are two algorithms used in the estimation of rainfall. This first algorithm, the Legacy PPS, estimates rainfall using the legacy base data only. This algorithm, just like the other, will overestimate and underestimate rainfall for multiple reasons which will be discussed in the next section.

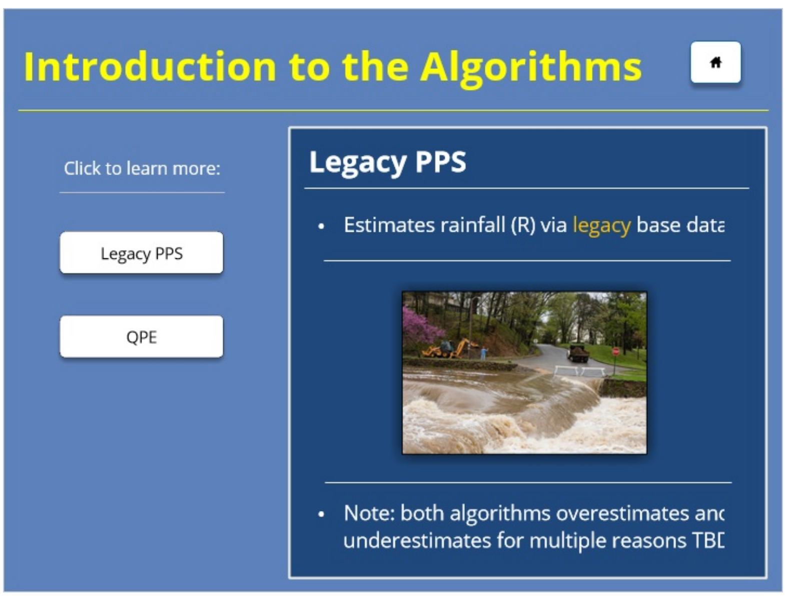
QPE:

The QPE algorithm estimates rainfall using BOTH the legacy and the dual-pol base data, and like the other algorithm, will overestimate and underestimate rainfall for multiple reasons to be discussed in the next section.

QPE Algorithm (Slide Layer)



Legacy PPS Algorithm (Slide Layer)



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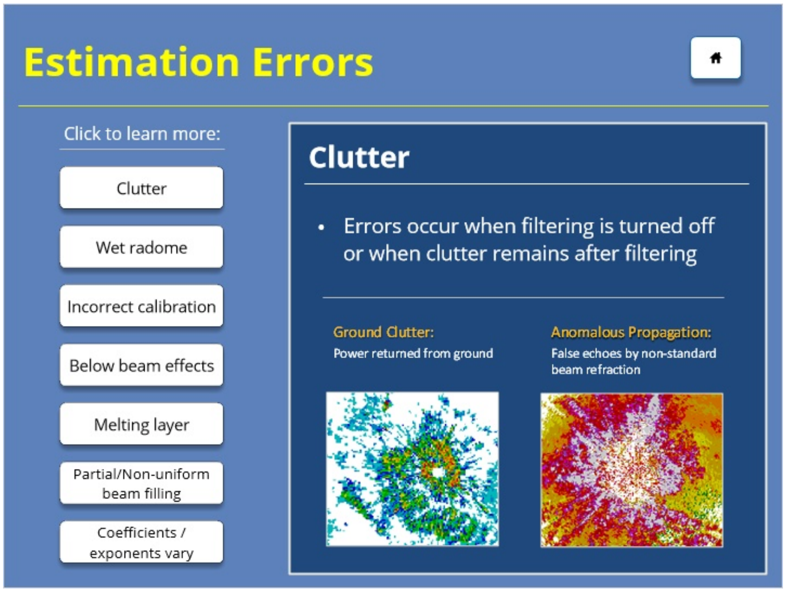
4. Typical Errors

4.1 Typical Errors



Notes:

CLUTTER

Clutter errors can occur when clutter filtering is turned off or when clutter remains after filtering.

WET RADOME

The radome surface is hydrophobic, meaning that it's designed to repel water. However water can still coat the radar, and when it does it typically reduces the power transmitited and returned from the radar, which in turn decreases the reflectivity and the estimation of rainfall.

INCORRECT CALIBRATION

Incorrect calibration can lead to large errors in estimations of rainfall. These errors can be both an under or an over-estimate of rainfall.

BELOW BEAM EFFECTS

Below beam effects are a fundamental challenge when using a radar to estimate rainfall.

Evaporation below the beam can occur in the presence of a deep, dry sub-cloud layer. This layer will evaporate some (or even all) of the rain leaving the cloud, causing an overestimation of rainfall by the algorithm.

Coalescence below the beam occurs primarily in subtropical or tropical areas and at long distances from the radar. Here, 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, and as a result, underestimates by the radar are likely.

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MELTING LAYER

Our rainfall algorithms are designed to estimate LIQUID rainfall. Therefore algorithm performance is much more reliable where the radar beam is intercepting liquid hydrometeors below the melting layer. Within the melting layer and above, rainfall estimation is much less accurate.

Partial/ NUBF

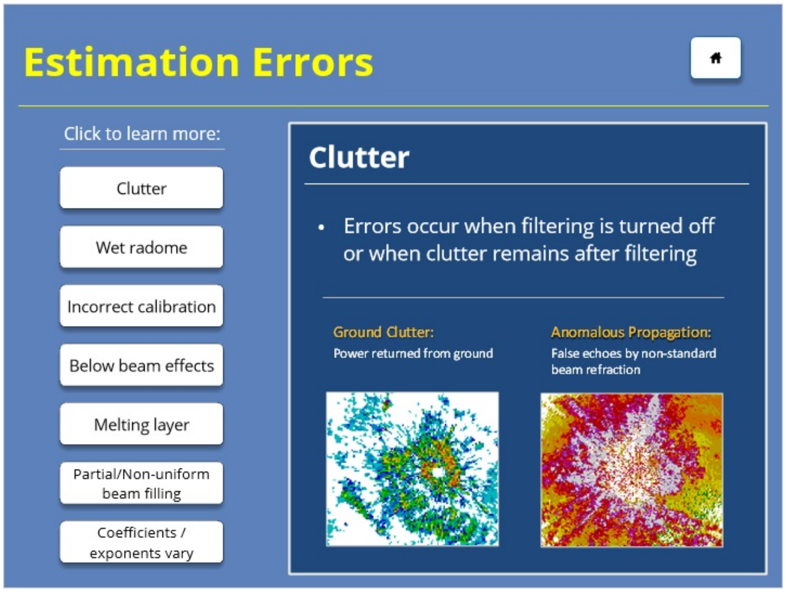
In partial beam filling, only a portion of the beam is sampling precipitation, which is something that's pretty common far from the radar. When this happens, the reflectivity and rainfall rates are both underestimated, and since the beam volume is greater than the actual precipitation volume, the areal coverage is overestimated too.

For non-uniform beam filling, when a gradient of precipitation types exists across the beam, CC can be underestimated down the radial, and active precipitation areas down that radial may not be converted to rainfall.

COEFFICIENTS/EXPONENTS MAY VARY

No need to memorize the equations, just know that the equations that are used to convert radar products into estimations of rainfall are empirical and imperfect.

Clutter (Slide Layer)



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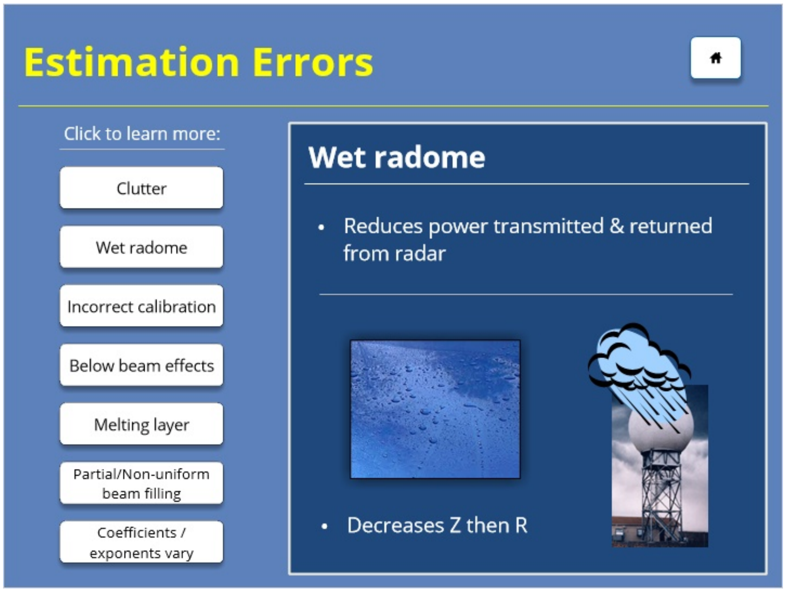
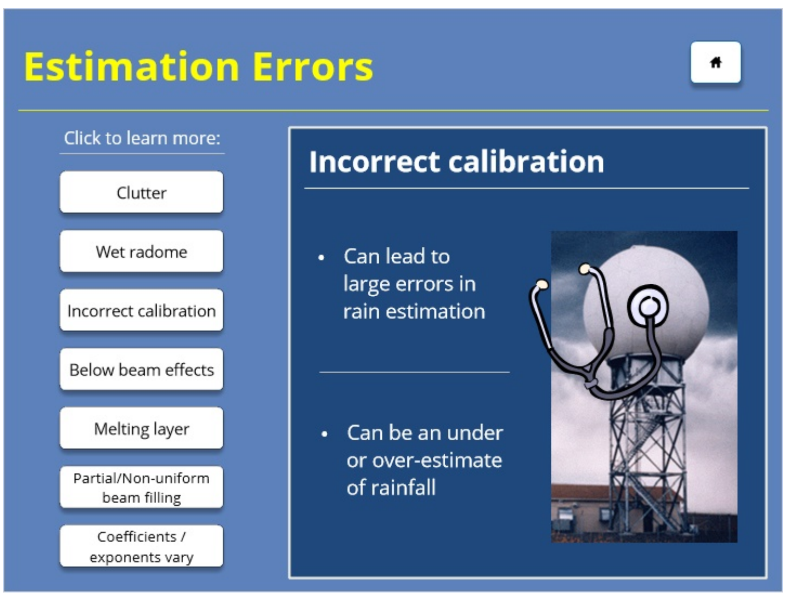
Wet Radome (Slide Layer)



Incorrect z calibration (Slide Layer)



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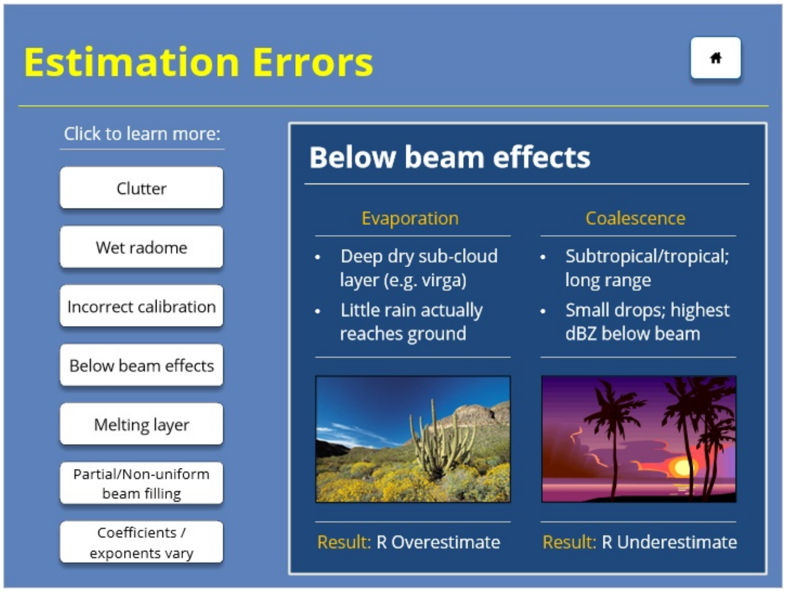
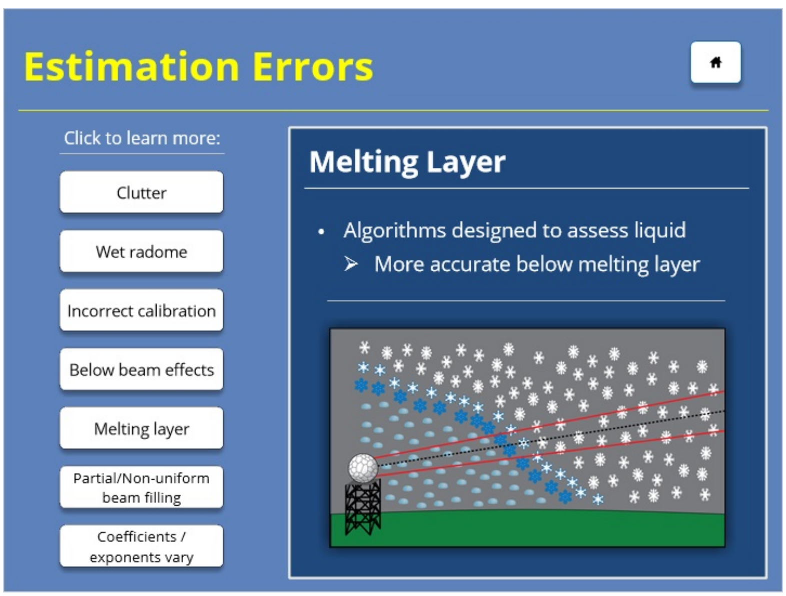
Below beam effects (Slide Layer)



Melting layer (Slide Layer)



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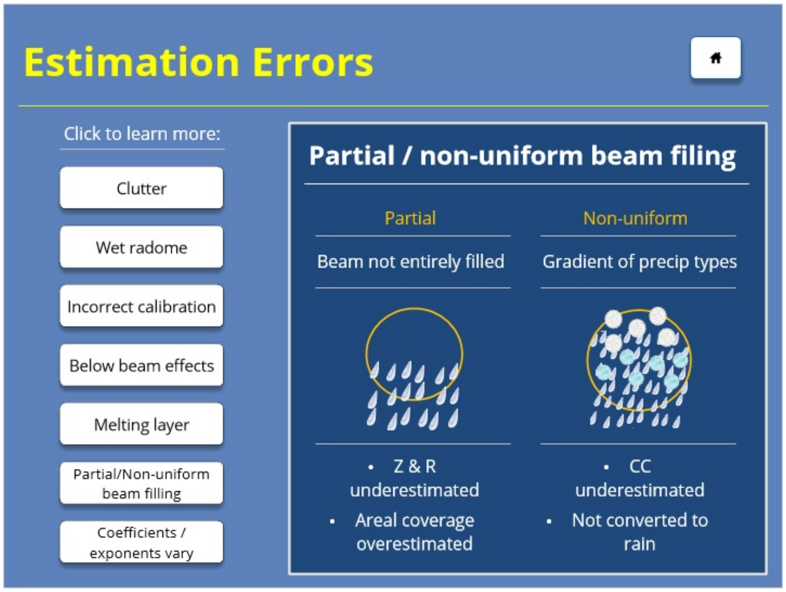
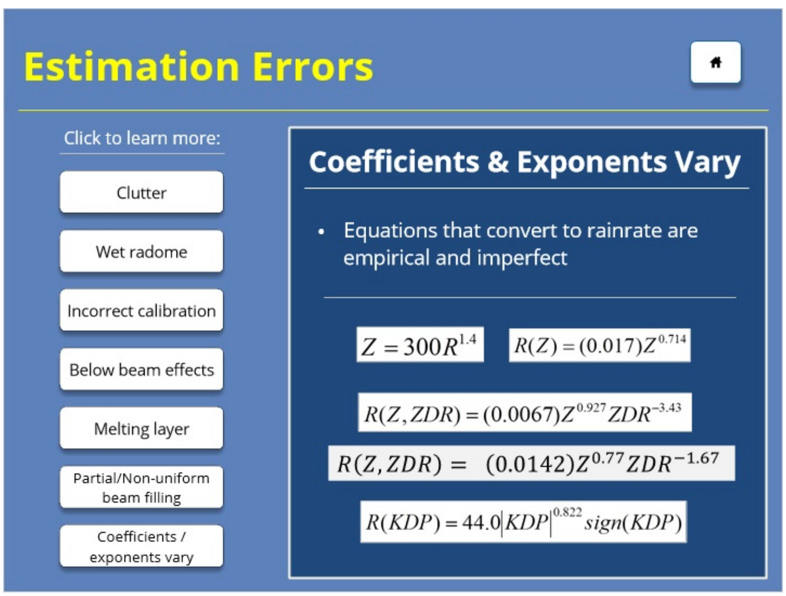
NUBF (Slide Layer)

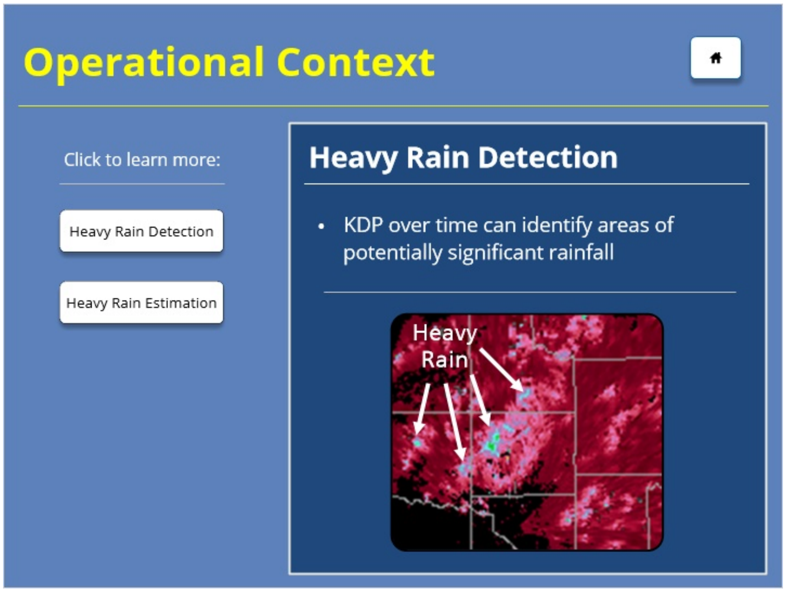


Coefficients / exponents vary (Slide Layer)



5. Operational Context

5.1 Operational Context



Notes:

HEAVY RAIN DETECTION

It's important to distinguish between using base products to identify areas of heavy rain vs. using the output from an algorithm to estimate rainfall amounts. On the detection side, KDP is a dual-pol product that can help us identify areas of heavy rainfall alongside reflectivity. While useful at spotting where the heavy rain occurs, you do not get an absolute sense of how much rain has fallen with this method.

ESTIMATION

The rainfall estimation algorithms give us a sense of how much rain has fallen over time. However given all of their errors, using them requires some situational awareness. Ask yourself, do these locations of heavy rain make sense? In this way, using KDP to quality control the algorithms will yield the best results for operations.

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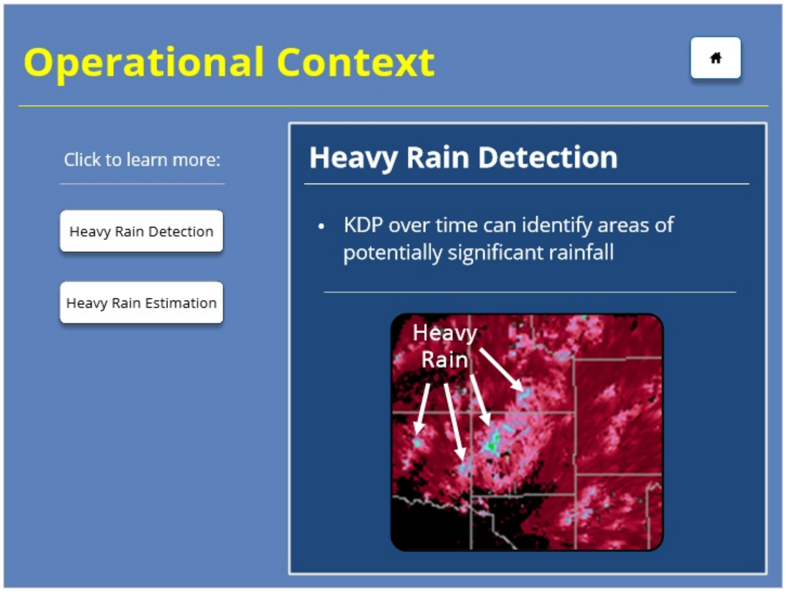
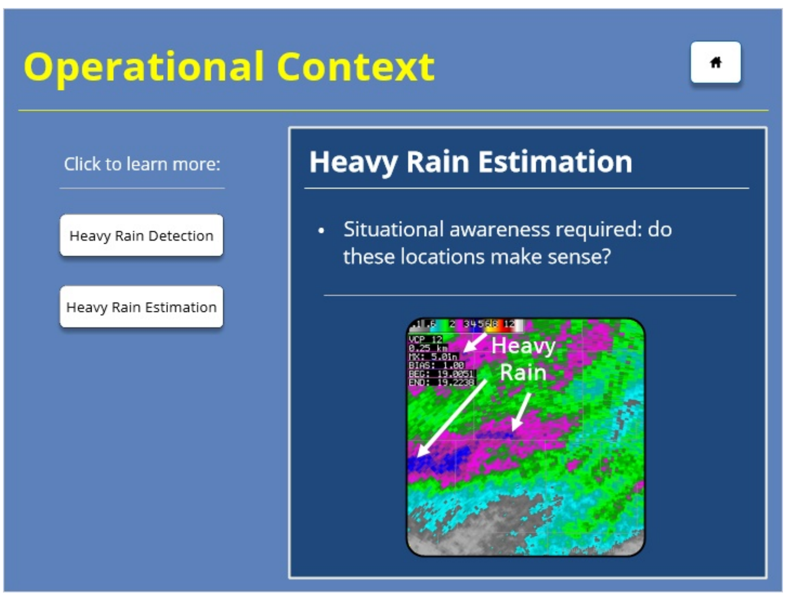
Detection (Slide Layer)



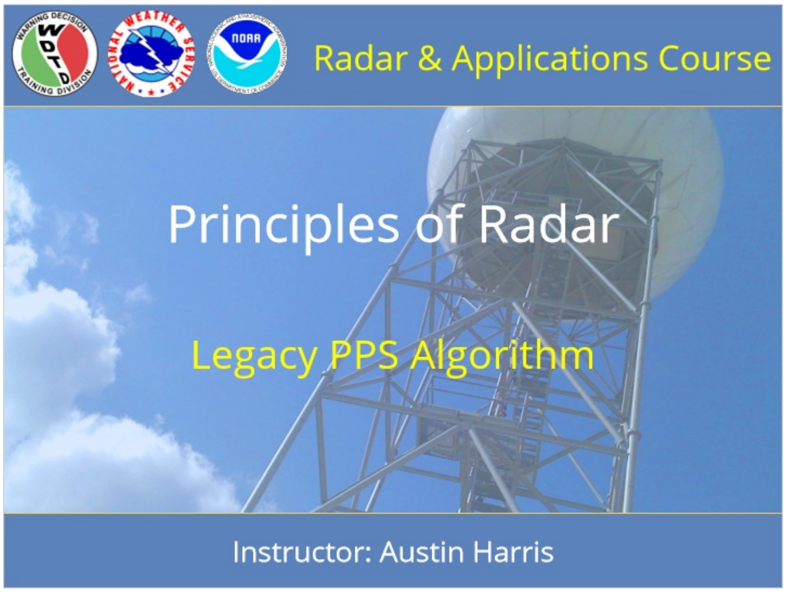
Estimation (Slide Layer)



Legacy PPS Algorithm

1. Introduction

1.1 Title Slide



Notes:

Welcome to the Principles of Radar lesson on the Legacy PPS Algorithm for rainfall estimation.

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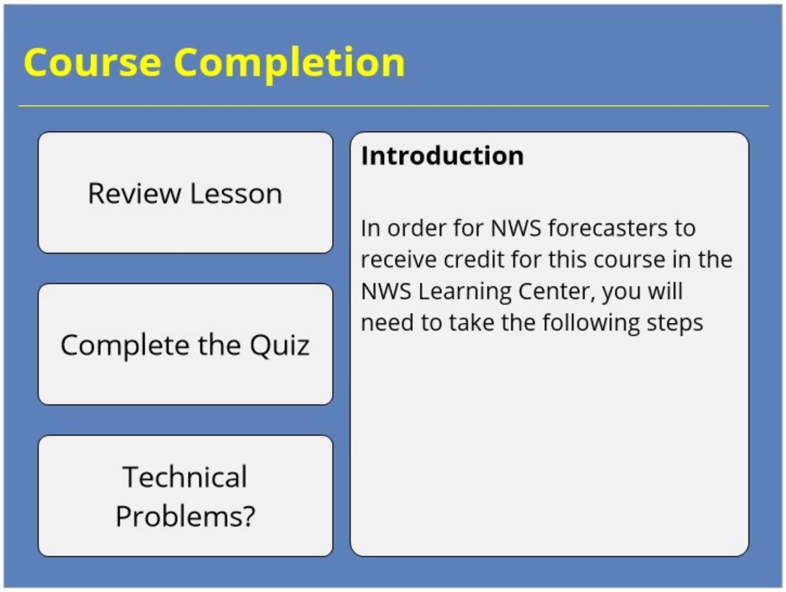
1.2 Course Completion Info



Notes:

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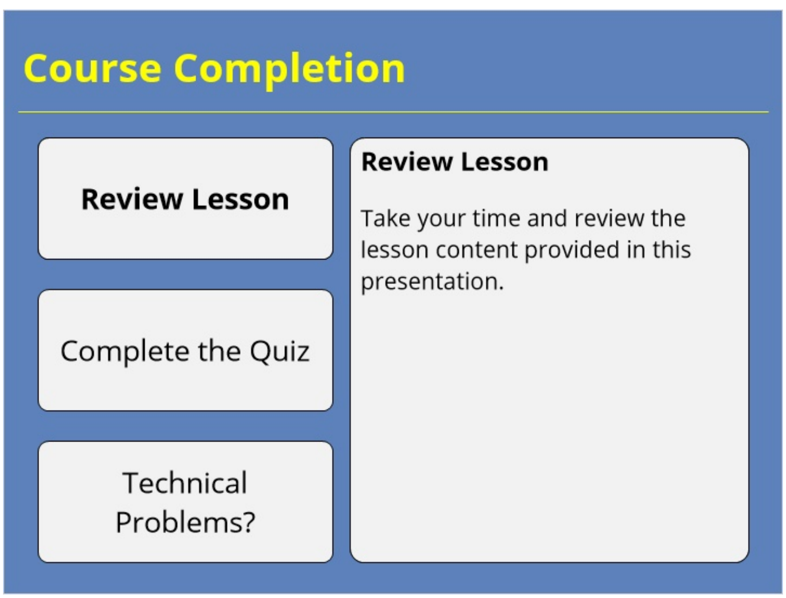
Review Lesson (Slide Layer)



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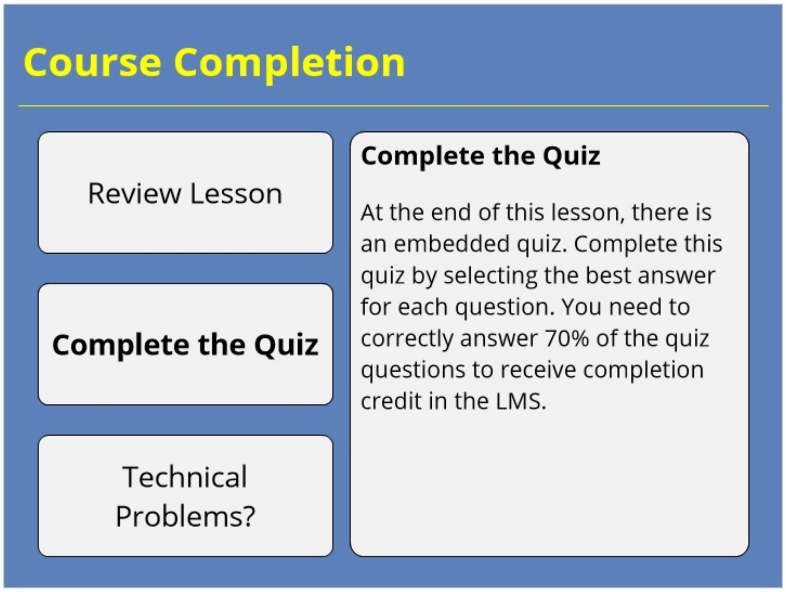
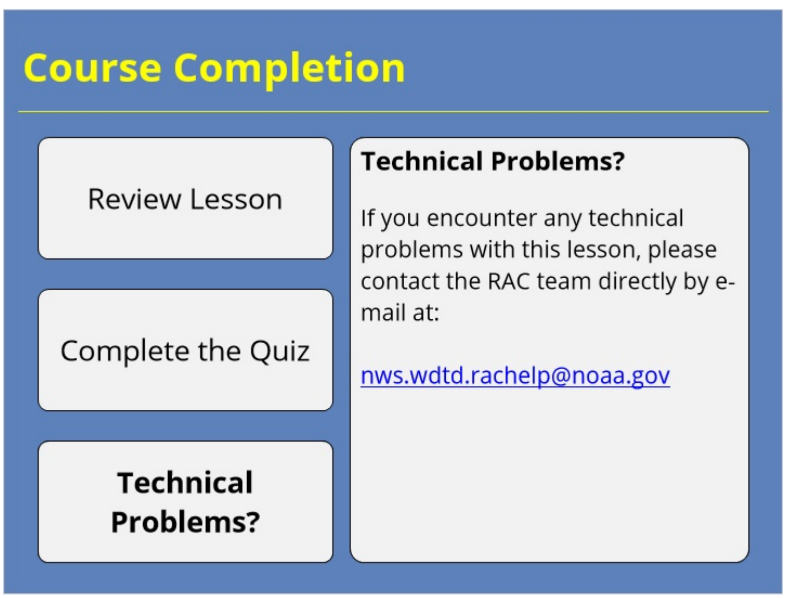
Complete the Quiz (Slide Layer)



Technical Problems (Slide Layer)



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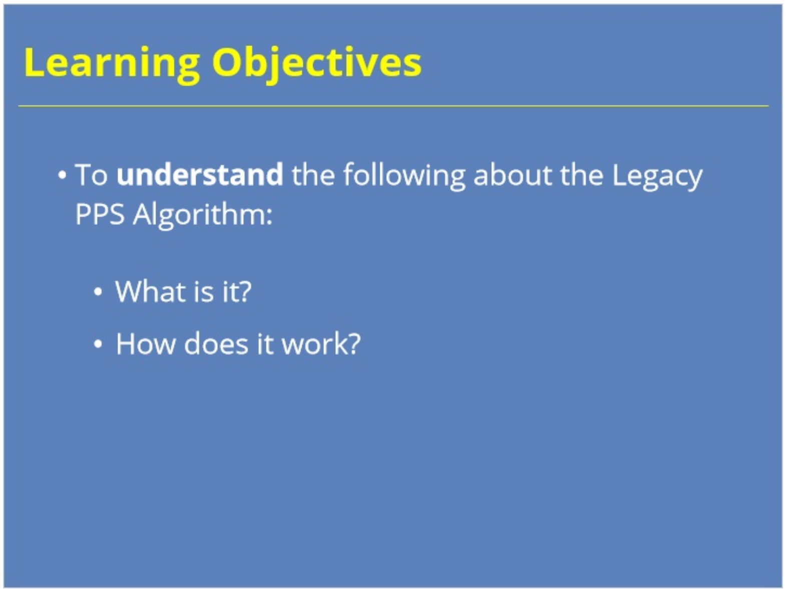
1.3 Learning Objectives



Notes:

The learning objective for this lesson is to understand the following about the Legacy PPS Algorithm:

What is it?

How does it work?

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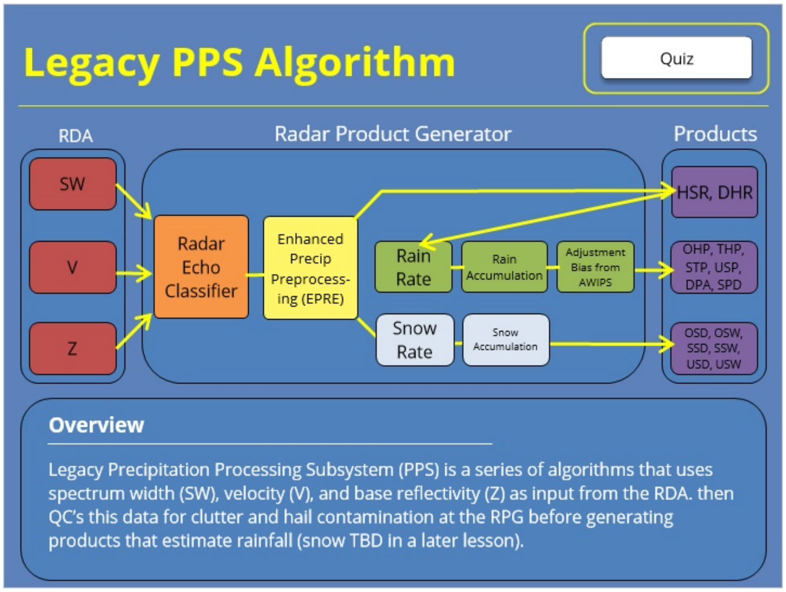
2. Homepage: Legacy PPS Flowchart

2.1 Overview



Notes:

HOMEPAGE

Welcome to the homepage for this lesson on the Legacy PPS Rainfall Estimation Algorithm. Details about how the algorithm works can be found by clicking on the buttons in the flow chart, and once you feel comfortable with these details, take the quiz at the top right of the screen.

OVERVIEW

In general, the Legacy PPS is a series of algorithms that uses spectrum width, velocity, and base reflectivity as input from the RDA, then quality controls this data for clutter and hail contamination at the RPG, before generating products that estimate rainfall.

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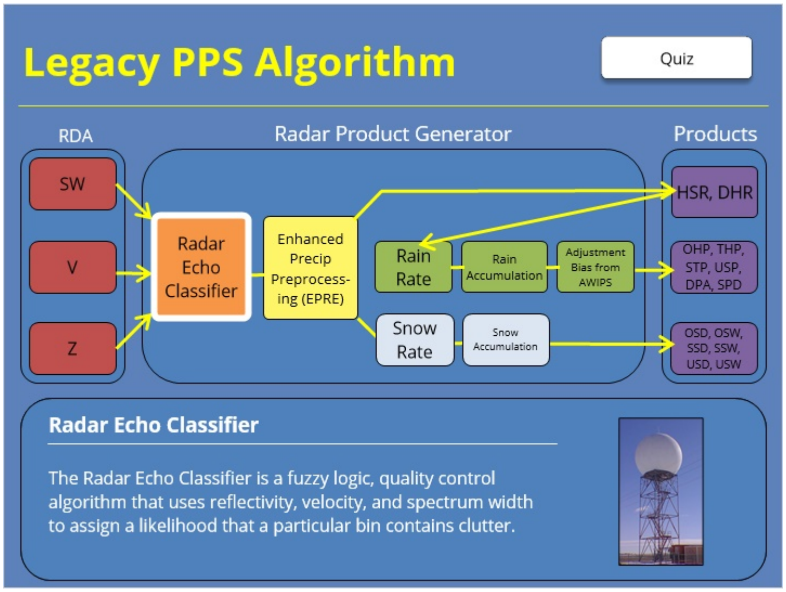
2.2 Radar Echo Classifier



Notes:

REC

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

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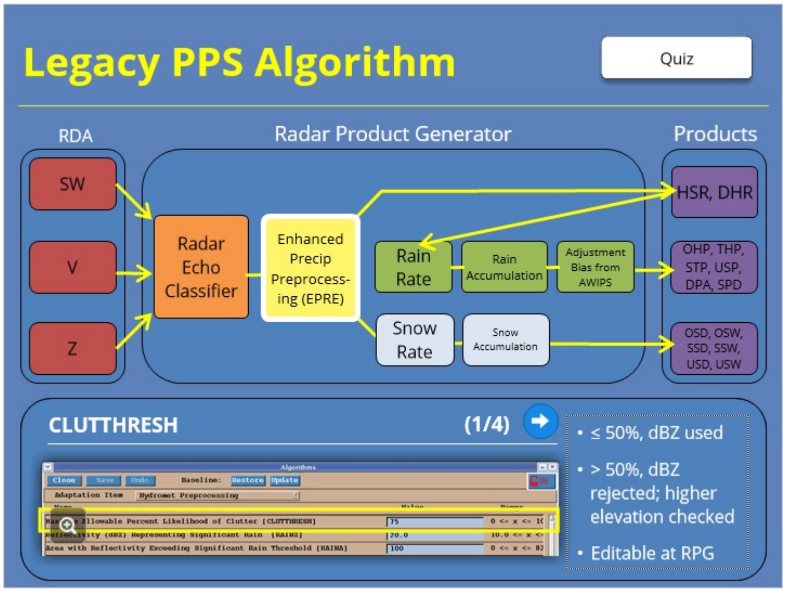
2.3 EPRE: CLUTTHRESH



Notes:

CLUTTHRESH

EPRE ingests this guidance for comparison against a parameter called CLUTTHRESH which determines whether or not a dBZ is used in rainfall product generation. The default setting 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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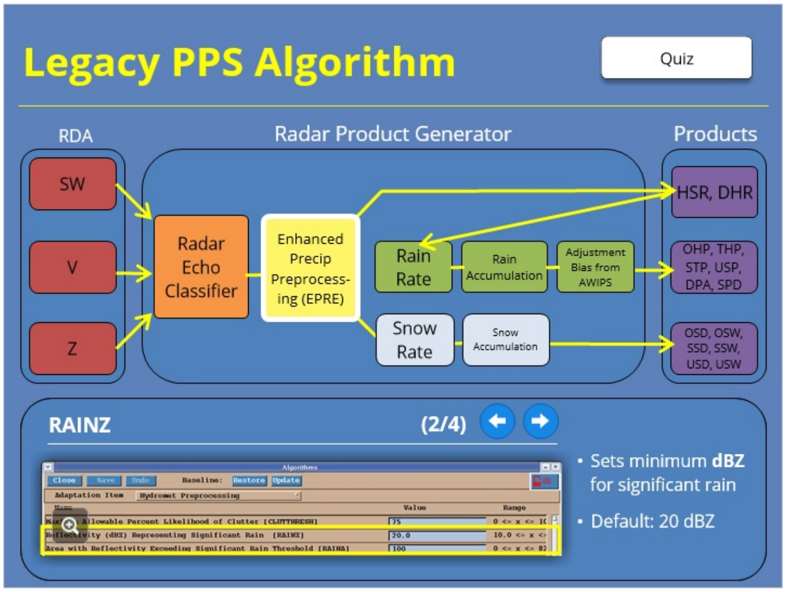
2.4 EPRE: RAINZ



Notes:

RAINZ

EPRE determines when accumulations begin and when they end. 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, but that can be changed.

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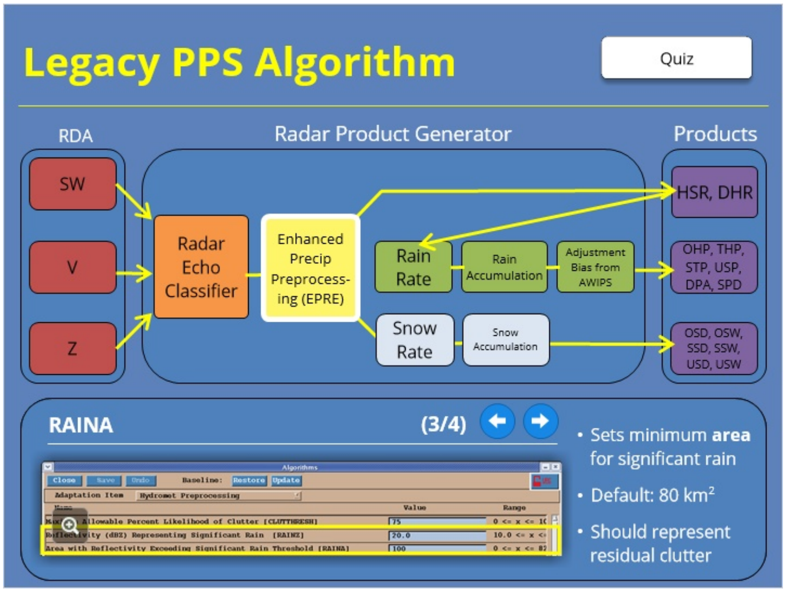
2.5 EPRE: RAINA



Notes:

RAINA

Again, EPRE determines when accumulations begin and when they end. RAINA represents the area component of this, and in particular it is the minimum areal coverage of returns at or above RAINZ to be considered rain. The default value for RAINA is 80 km2. Also, 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.

Quick side note here too: 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 second is a manual reset of the storm total accumulation available at the RPG, specifically the RPG Control window.

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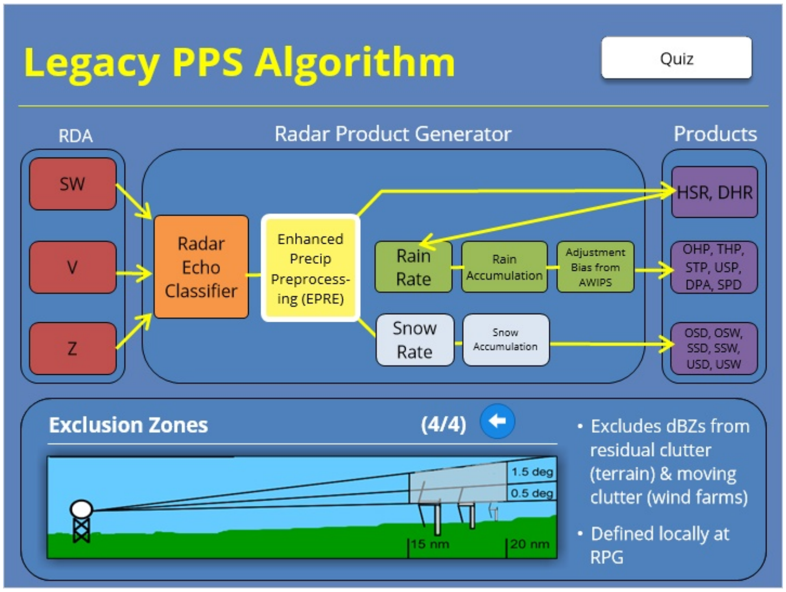
2.6 EPRE: Exlusion Zones



Notes:

EXCLUSION ZONES

Another quality control option that is part of EPRE is the application of Exclusion Zones, which are used to prevent reflectivity from mountains or wind farms 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, and are defined locally at the RPG.

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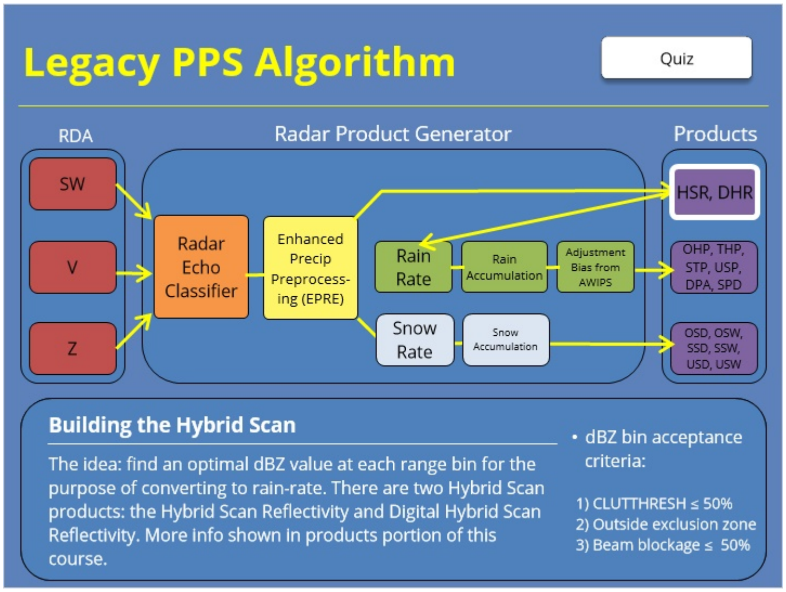
2.7 HSR, DHR



Notes:

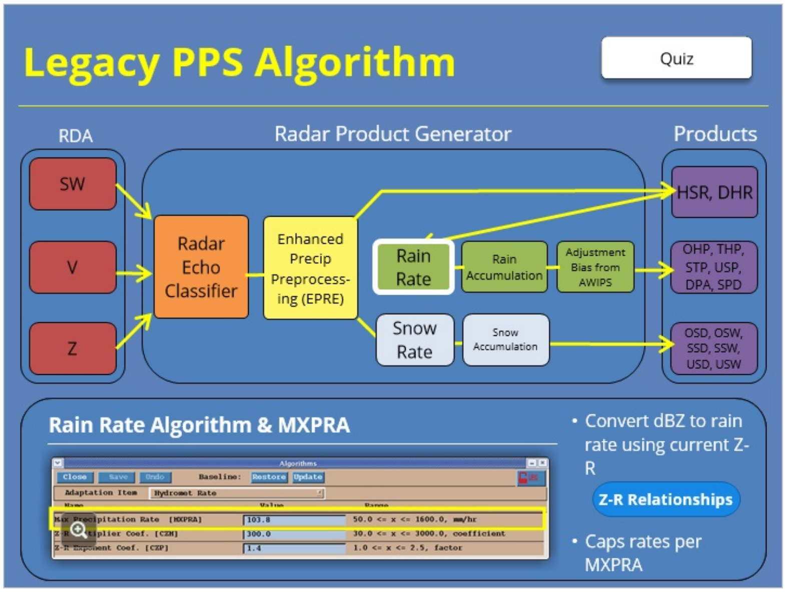
BUILDING THE HYBRID SCAN

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:

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

2.8 Rain Rate



Notes:

RAIN RATE

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). which 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 this parameter be adjusted to 6in/h.

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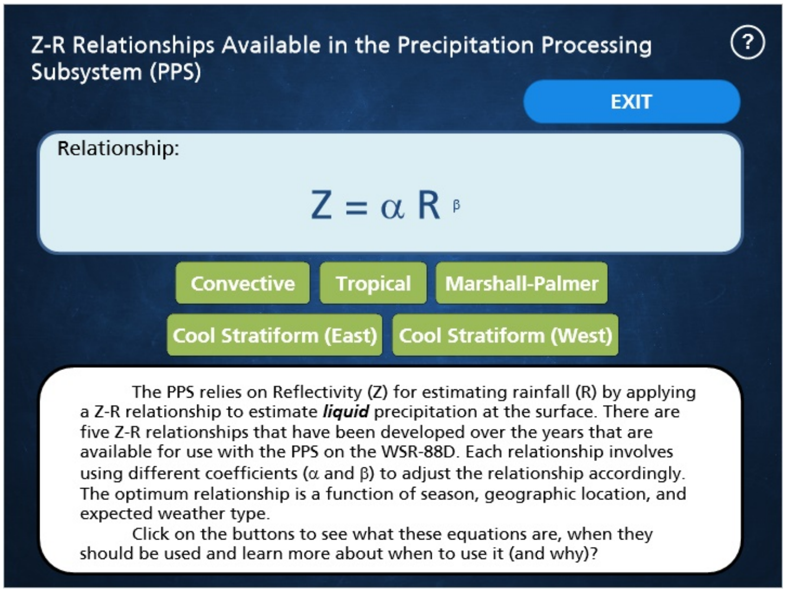
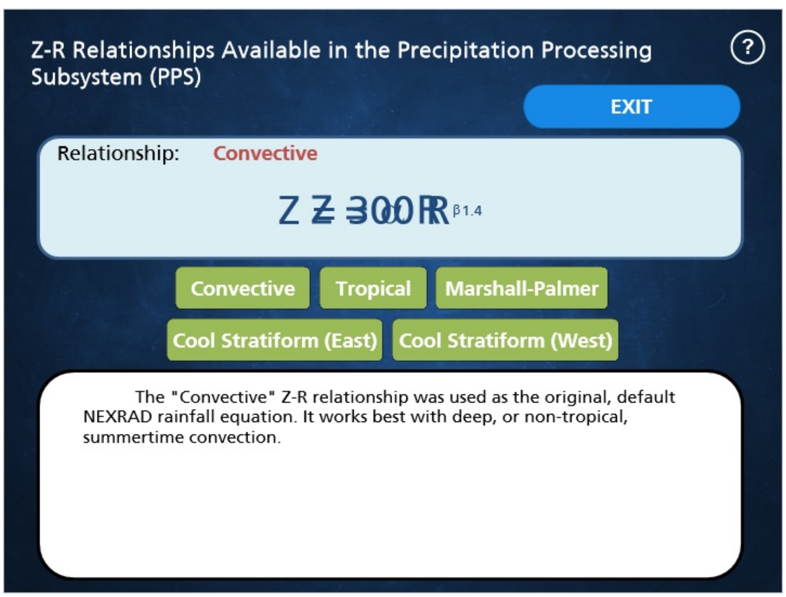
2.9 Z-R Relationships Available in the Precipitation Processing Subsystem (PPS)



Convective (Slide Layer)



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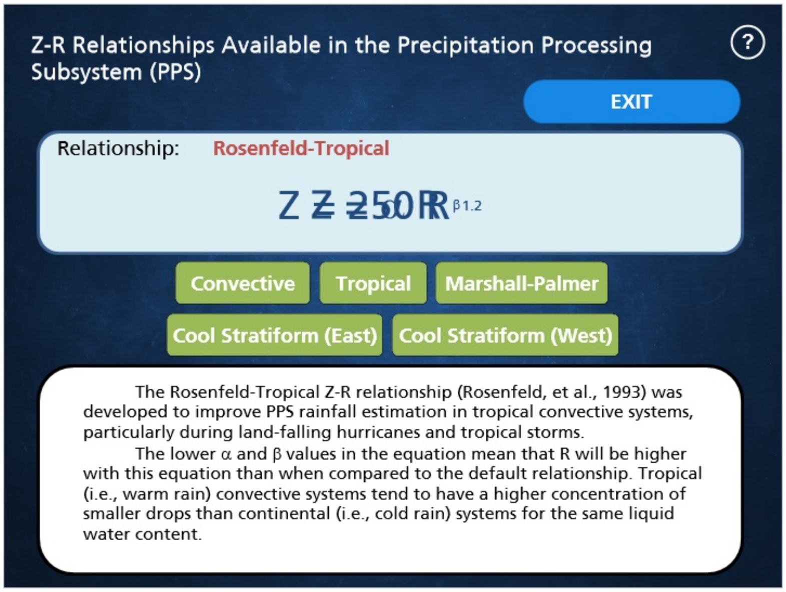
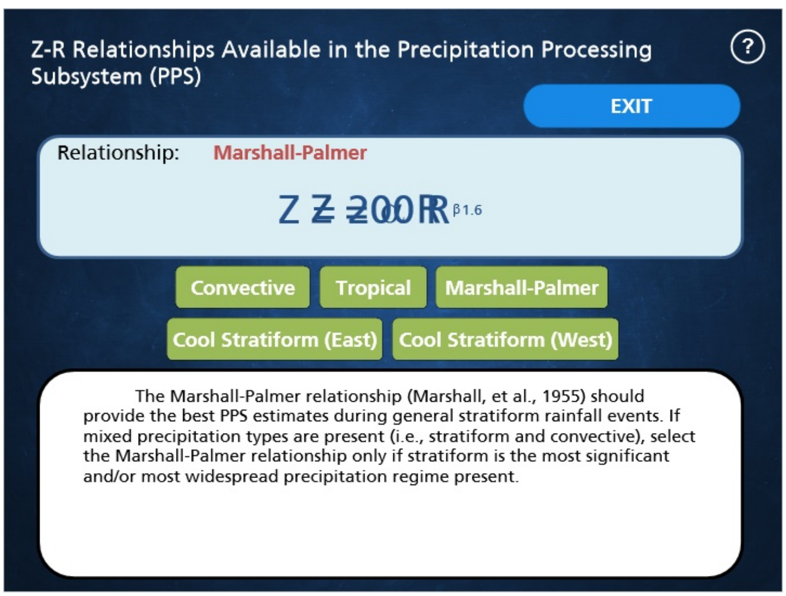
Tropical (Slide Layer)



Marshall-Palmer (Slide Layer)



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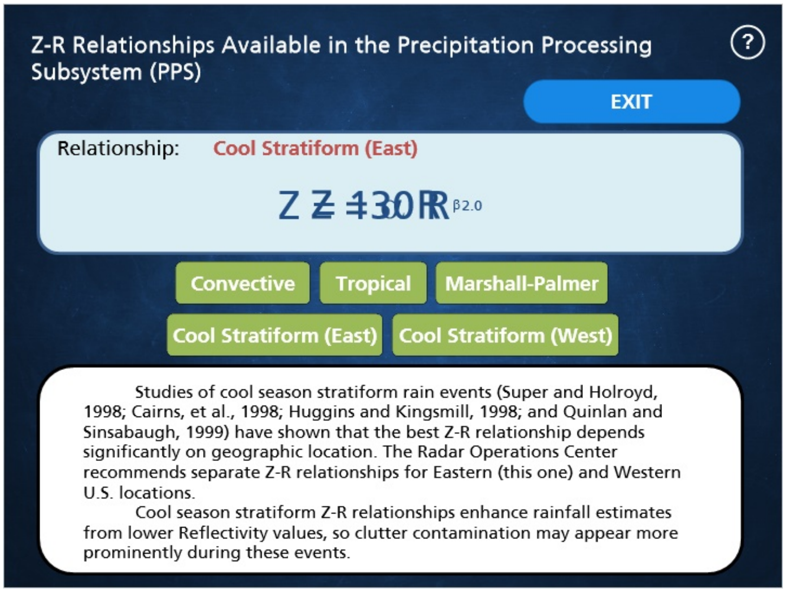
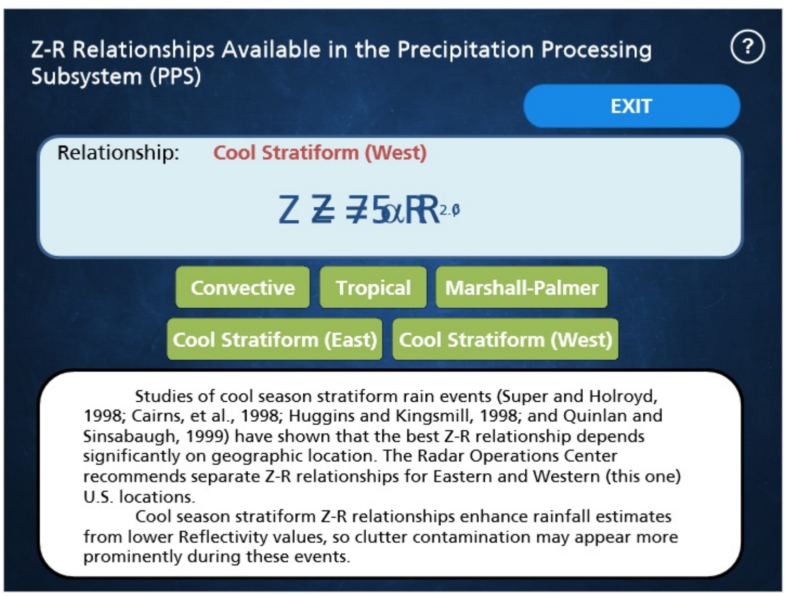
East-Cool Stratiform (Slide Layer)



West-Cool Stratiform (Slide Layer)



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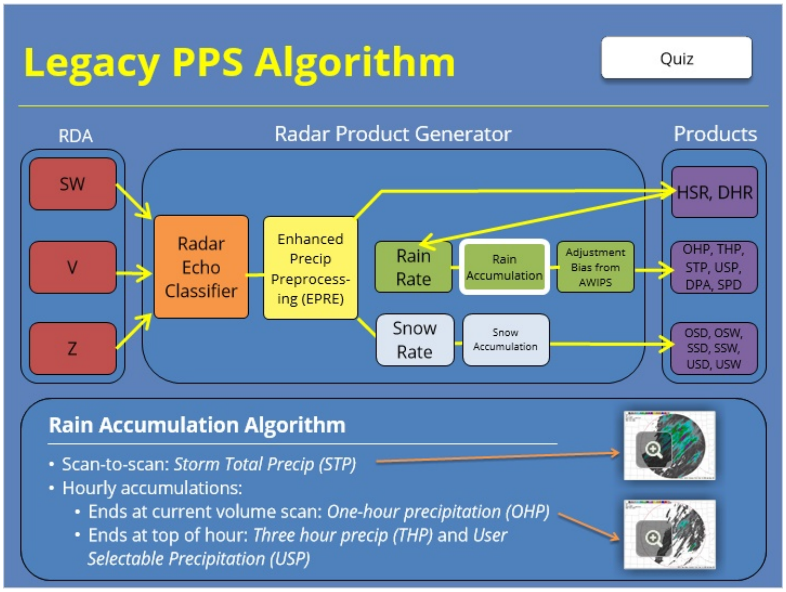
2.10 Rain Accumulation

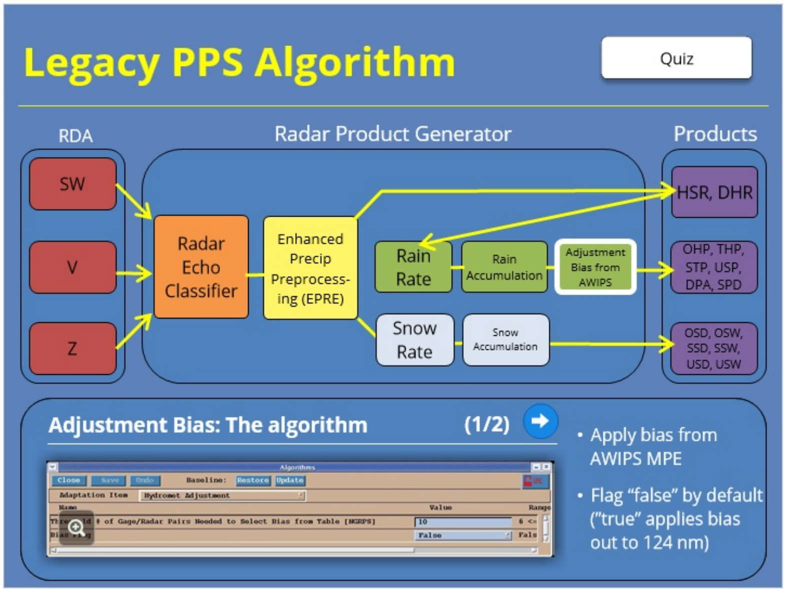


Notes:

RAIN ACCUMULATION ALGORITHM

The Rain Accumulation Algorithm uses the calculated rain rates and differing durations to accumulate rainfall. There are two different types of accumulations. 1) Scan to scan accumulations continue every volume scan as long as RAINZ and RAINA are exceeded. The Storm Total Precipitation (STP) product is one example of this. 2) The second type of accumulation is hourly. There is a one hour accumulation ending at the current volume scan time, the OHP product. There is also a one hour accumulation that ends at the top of each hour. These are used to build the Three Hour Precipitation (THP) and User Selectable Precipitation (USP) products.

2.11 Adjustment Bias: The Algorithm



Notes:

THE ALGORITHM

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.

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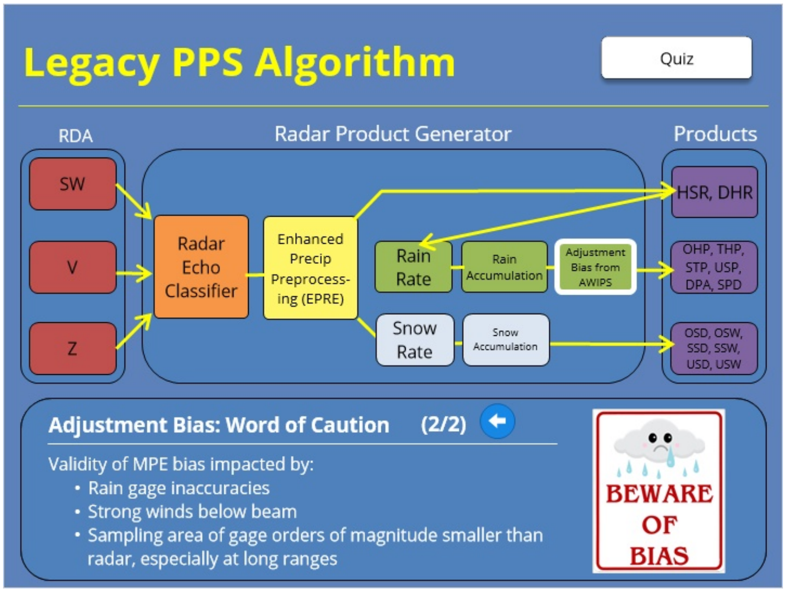
2.12 Adjustment Bias: Word of Caution



Notes:

BIAS WORD OF CAUTION

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 than the radar.

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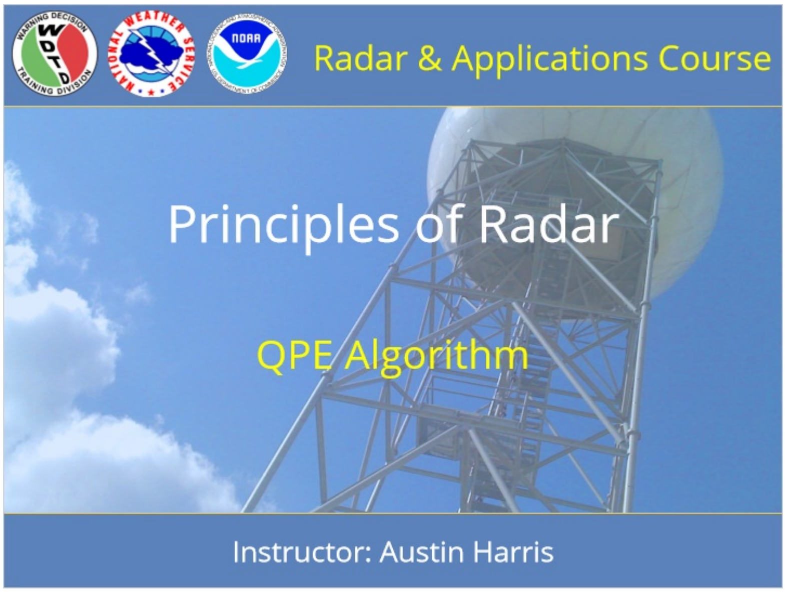
QPE Algorithm

1. Introduction

1.1 Title Slide



Notes:

Welcome to the Principles of Radar lesson on the QPE Algorithm for rainfall estimation.

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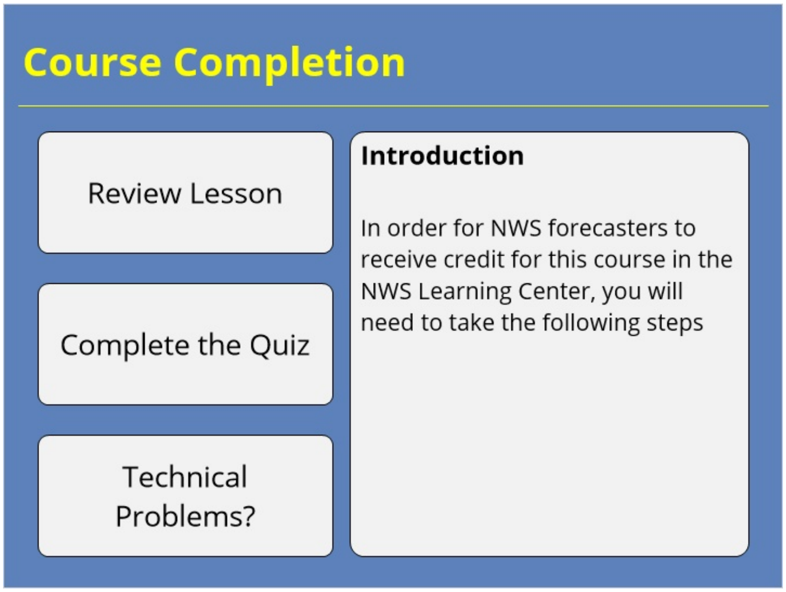
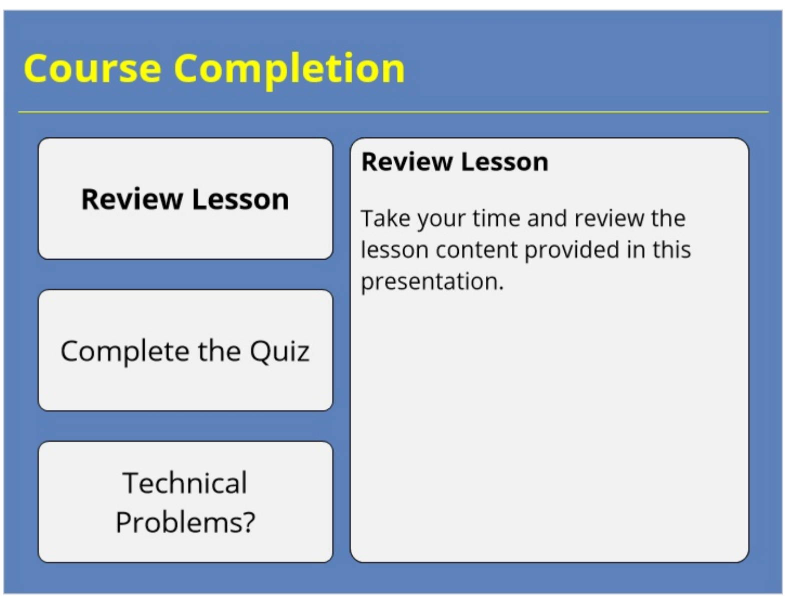
1.2 Course Completion Info



Notes:

If you are completing this course for credit, please review this interaction on how to complete this course within the NWS Learning Center. After viewing all the slides, click "Next" to continue.

Review Lesson (Slide Layer)



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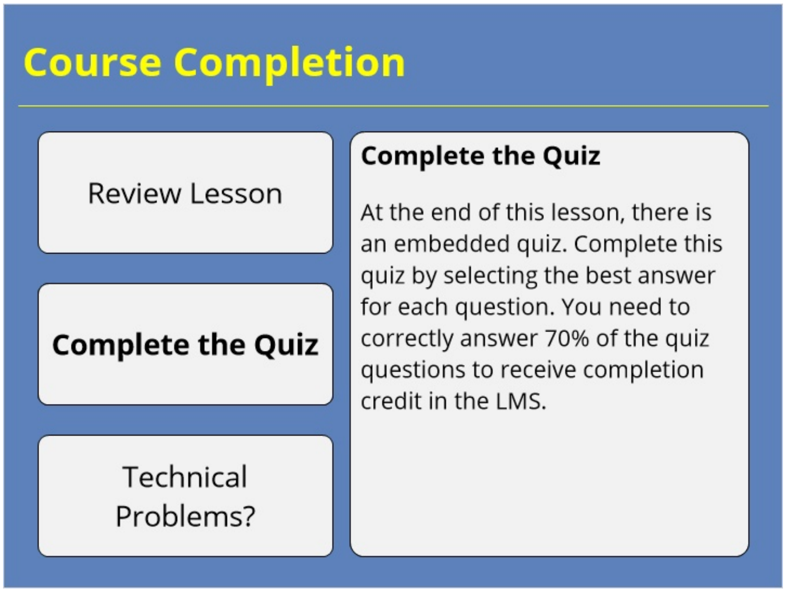
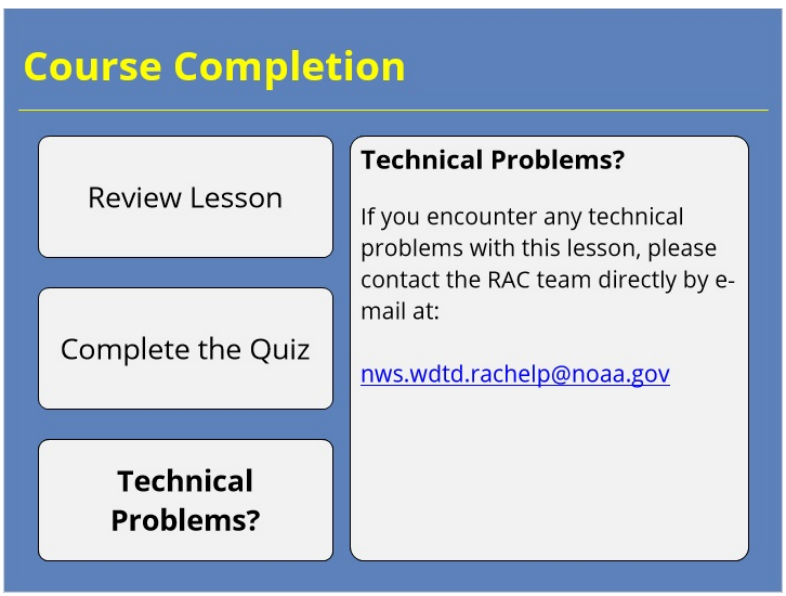
Complete the Quiz (Slide Layer)



Technical Problems (Slide Layer)



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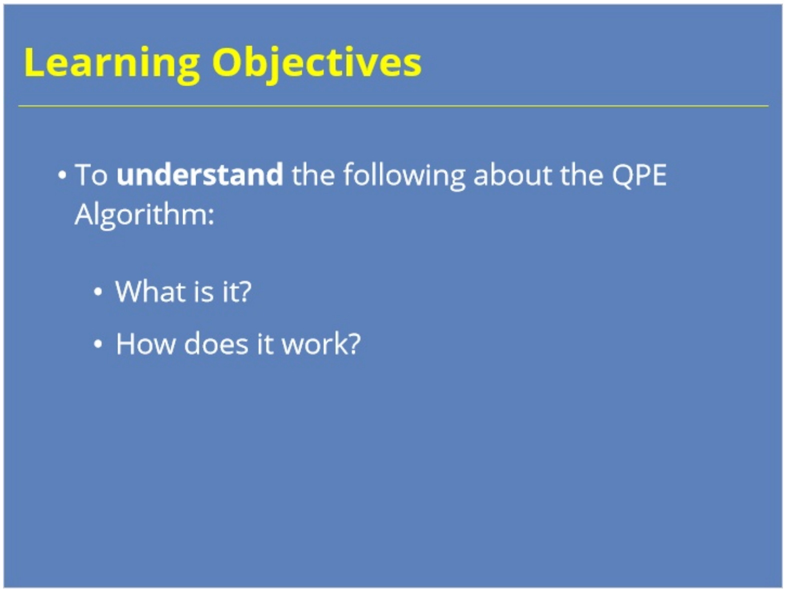
1.3 Learning Objectives



Notes:

The learning objective for this lesson is to understand the following about the QPE Algorithm:

What is it?

How does it work?

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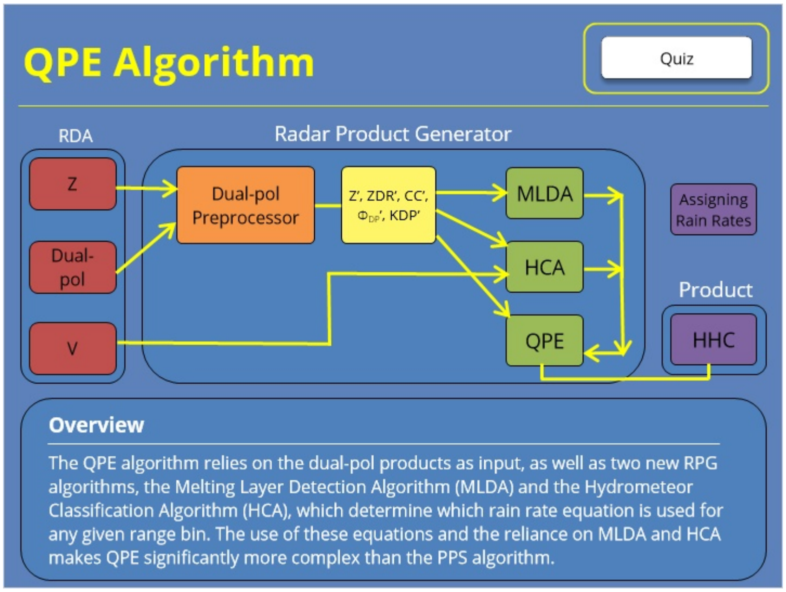
2. QPE Algorithm

2.1 Homepage: QPE Flow of Data



Notes:

HOMEPAGE

Welcome to the homepage for this lesson on the Quantitative Precipitation Estimation (QPE) Rainfall Estimation Algorithm. Details about how the algorithm works can be found by clicking on the buttons in the flow chart, and once you feel comfortable with these details, take the quiz at the top right of the screen.

OVERVIEW

The QPE algorithm relies on the dual-pol products as input, as well as two new RPG algorithms, the Melting Layer Detection Algorithm (MLDA) and the Hydrometeor Classification Algorithm (HCA), which determine which rain rate equation is used for any given range bin. The use of these equations and the reliance on MLDA and HCA makes QPE significantly more complex than the PPS algorithm.

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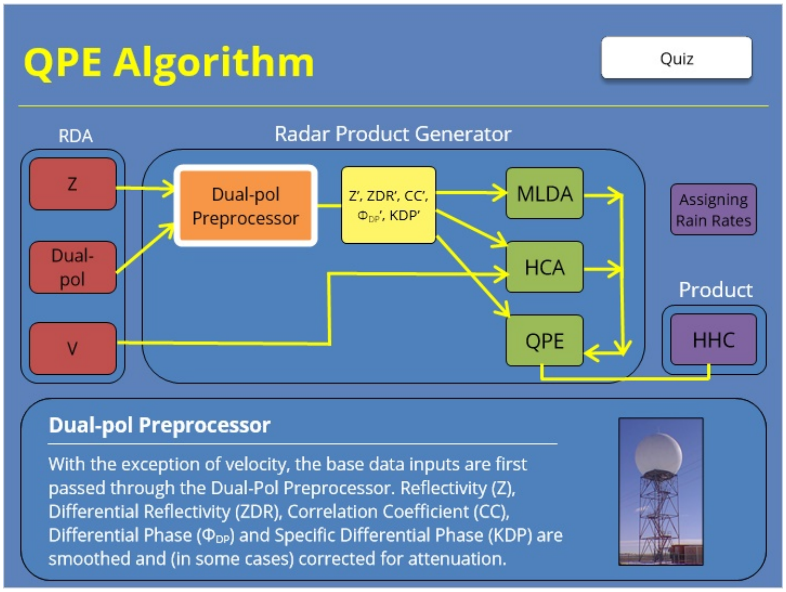
2.2 Dual-pol preprocessor



Notes:

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), Differential Phase (Φ_{DP}) and Specific Differential Phase (KDP) are smoothed and (in some cases) corrected for attenuation.

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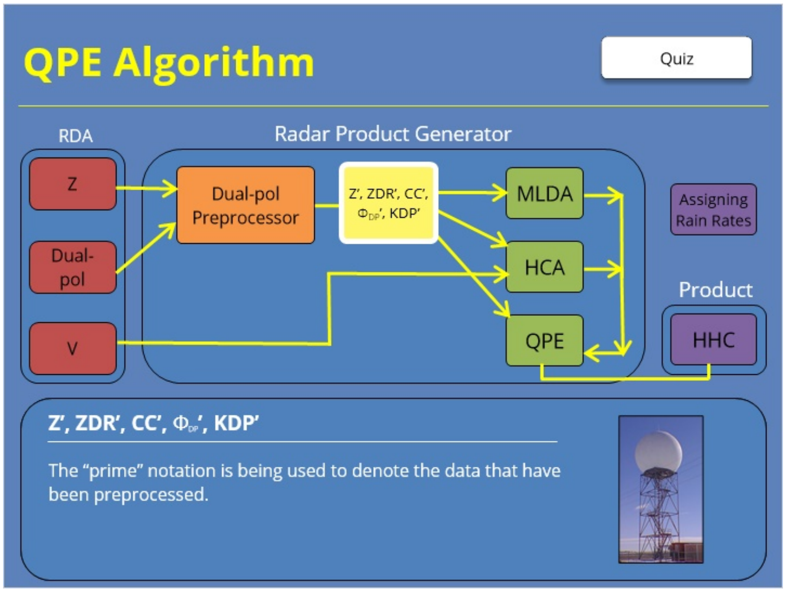
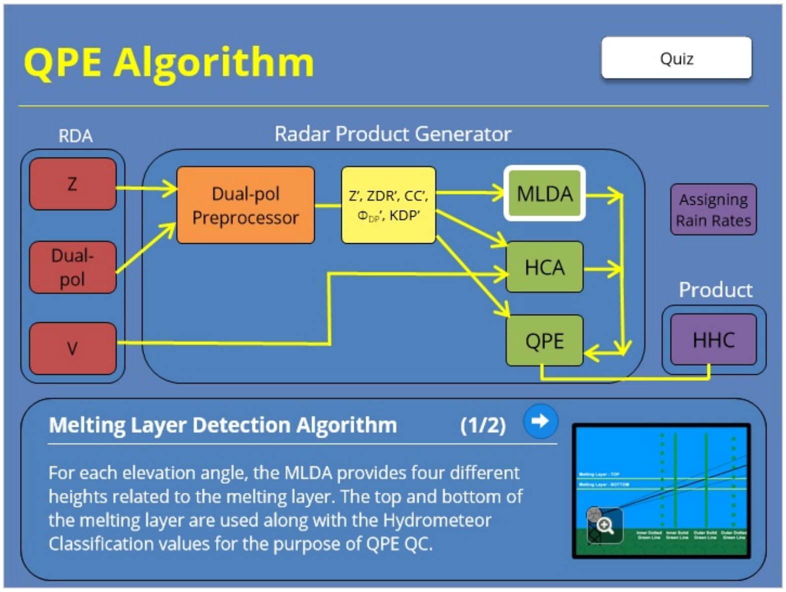
2.3 Primes



Notes:

The “prime” notation is being used to denote the data that have been preprocessed.

2.4 MLDA Part I



Notes:

For each elevation angle, the MLDA calculates four different heights related to the melting layer, as shown in the graphic to the right. The top and bottom of the melting layer are used to estimate precipitation type along with the Hydrometeor Classification values, which can be used to QC the rainfall output.

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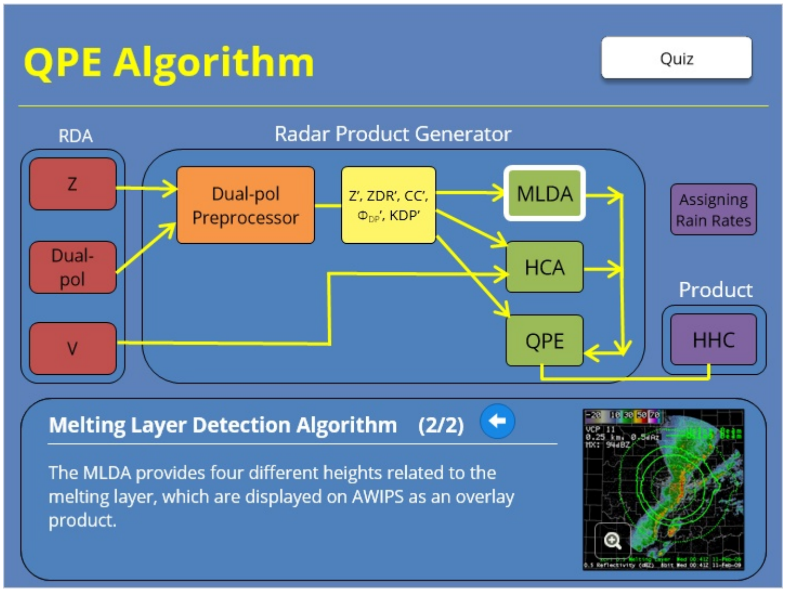
2.5 MLDA Part II



Notes:

The MLDA provides four different heights related to the melting layer, which are displayed on AWIPS as an overlay product.

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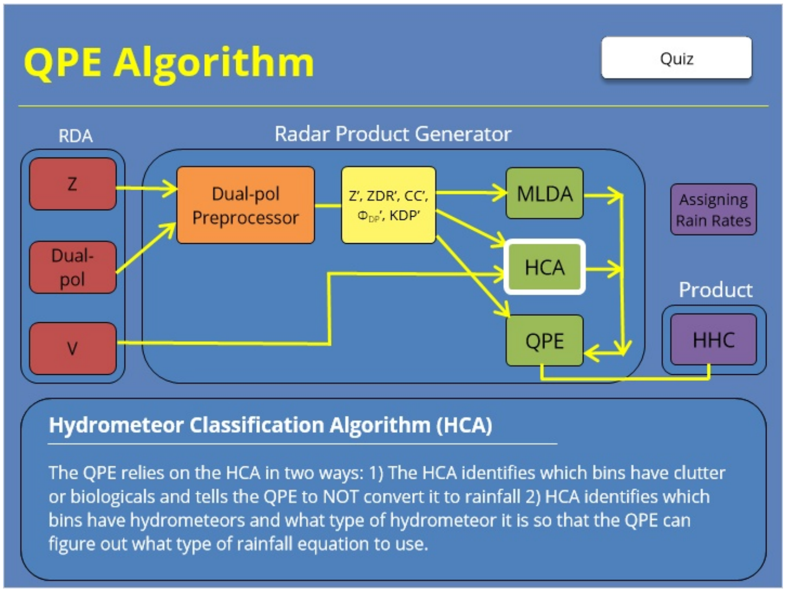
2.6 HCA



Notes:

HOMEPAGE

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The QPE algorithm relies on the dual-pol products as input, as well as two new RPG algorithms, the Melting Layer Detection Algorithm (MLDA) and the Hydrometeor Classification Algorithm (HCA), which determine which rain rate equation is used for any given range bin. The use of these equations and the reliance on MLDA and HCA makes QPE significantly more complex than the PPS algorithm.

DUAL-POL PRE-PROCESSOR

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), Differential Phase (Φ_{DP}) and Specific Differential Phase (KDP) are smoothed and (in some cases) corrected for attenuation.

PRIMES

The "prime" notation is being used to denote the data that have been preprocessed.

MLDA-1

For each elevation angle, the MLDA calculates four different heights related to the melting layer, as shown in the graphic to the right. The top and bottom of the melting layer are used to estimate precipitation type along with the Hydrometeor Classification values, which can be used to QC the rainfall output.

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MLDA-2

The MLDA provides four different heights related to the melting layer, which are displayed on AWIPS as an overlay product.

HCA

The QPE algorithm relies on the HCA in two ways: 1) The HCA identifies which bins have clutter or biologicals and tells the QPE to NOT convert it to rainfall and 2) The HCA identifies which bins have hydrometeors and what type of hydrometeor it is so that the QPE can figure out what type of rainfall equation to use.

HHC-1

The 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. This can be very useful as a QC check for the QPE rainfall products.

HHC-2

HHC can be used for an overall QC check, but be cautious about checking every single bin. The data here are smoothed via a technique called a 9 bin filter, which has the effect of reducing speckling on the product.

•

ASSIGNING RAIN RATES-1

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. 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).

ASSIGNING RAIN RATES-2

This table is a summary of the hydroclass values and position relative to the ML that determines which rain rate equation is used by the QPE.

QPE-1

QPE has one product that has no PPS counterpart: the Digital Precipitation Rate (DPR). It presents the rain rates (in/hr) used to generate the suite of QPE rainfall accumulation products. The DPR can be used as a QC check to determine if the precipitation rates seem reasonable.

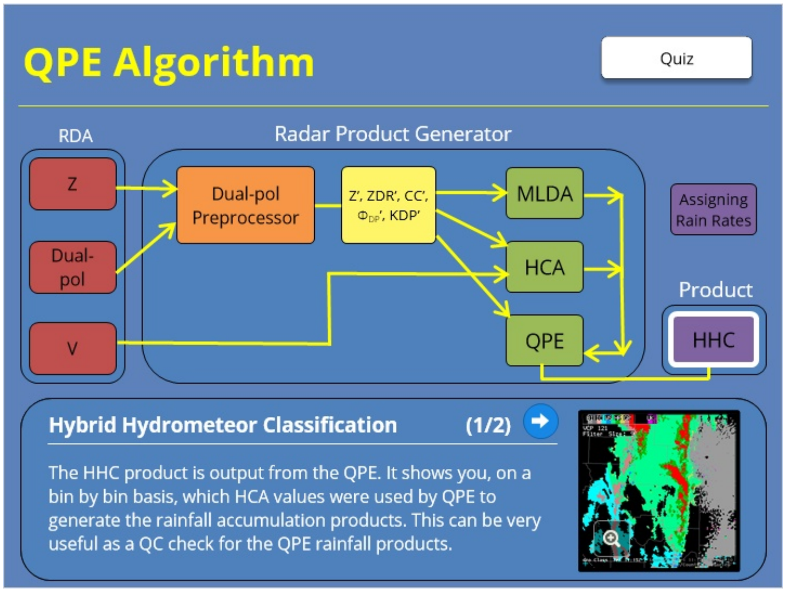
QPE-2

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.

QPE-3

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.

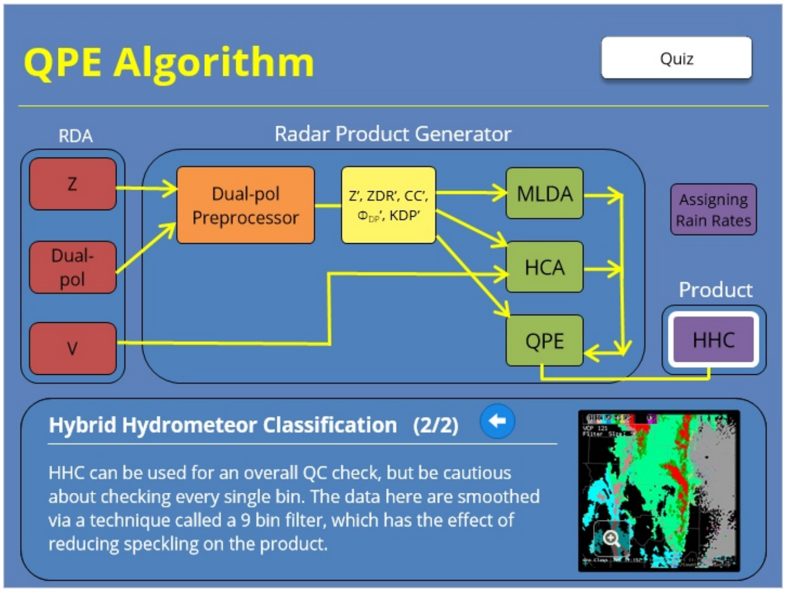
2.7 HHC Part I



Notes:

The 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. This can be very useful as a QC check for the QPE rainfall products.

2.8 HHC Part II



Notes:

HHC can be used for an overall QC check, but be cautious about checking every single bin. The data here are smoothed via a technique called a 9 bin filter, which has the effect of reducing speckling on the product.

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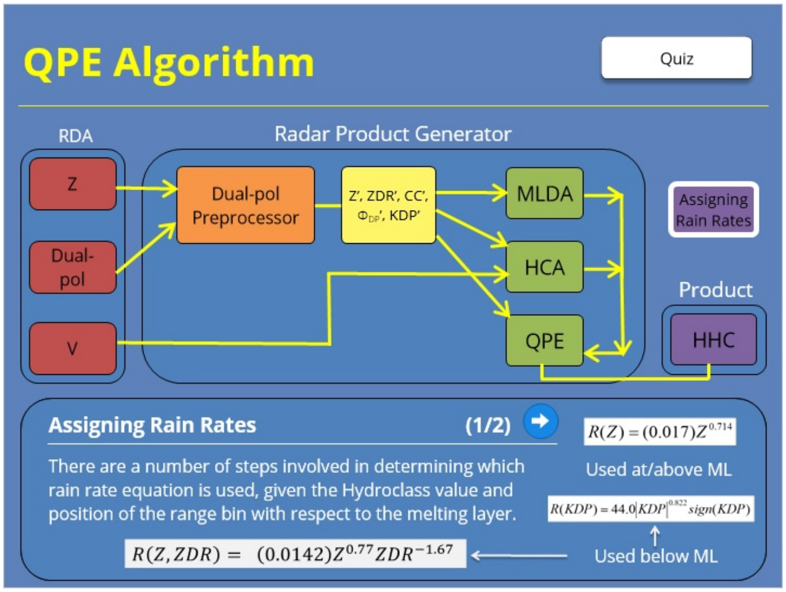
2.9 Rain Rates Part I



Notes:

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. 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).

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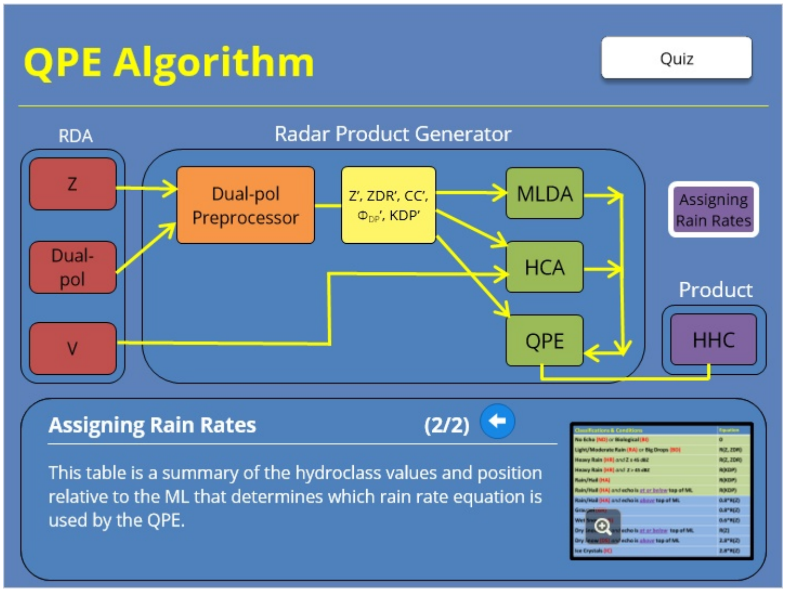
2.10 Rain Rates Part II



Notes:

This table is a summary of the hydroclass values and position relative to the ML that determines which rain rate equation is used by the QPE.

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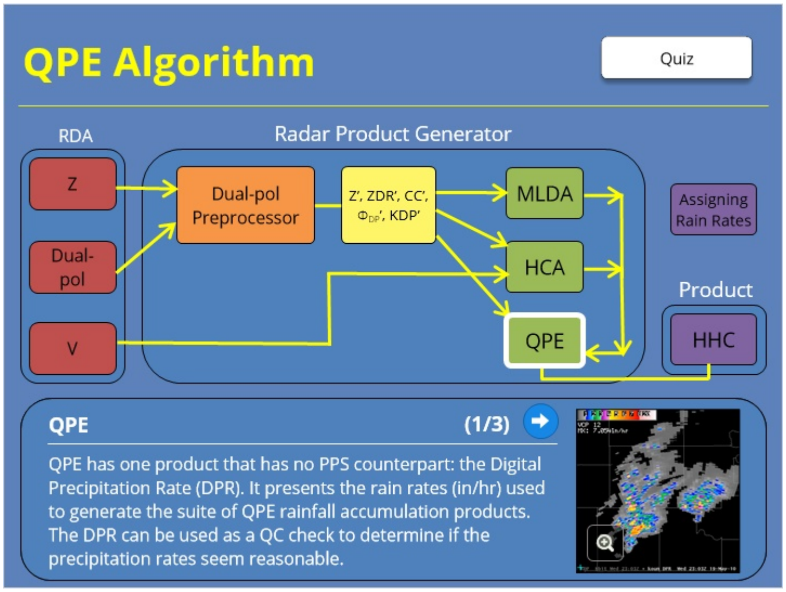
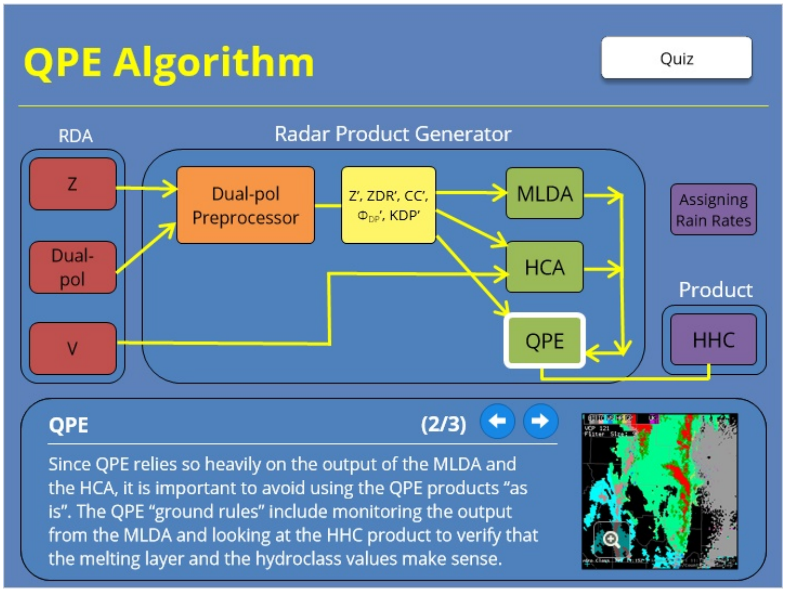
2.11 QPE Part I



Notes:

QPE has one product that has no PPS counterpart: the Digital Precipitation Rate (DPR). It presents the rain rates (in/hr) used to generate the suite of QPE rainfall accumulation products. The DPR can be used as a QC check to determine if the precipitation rates seem reasonable.

2.12 QPE Part II



Notes:

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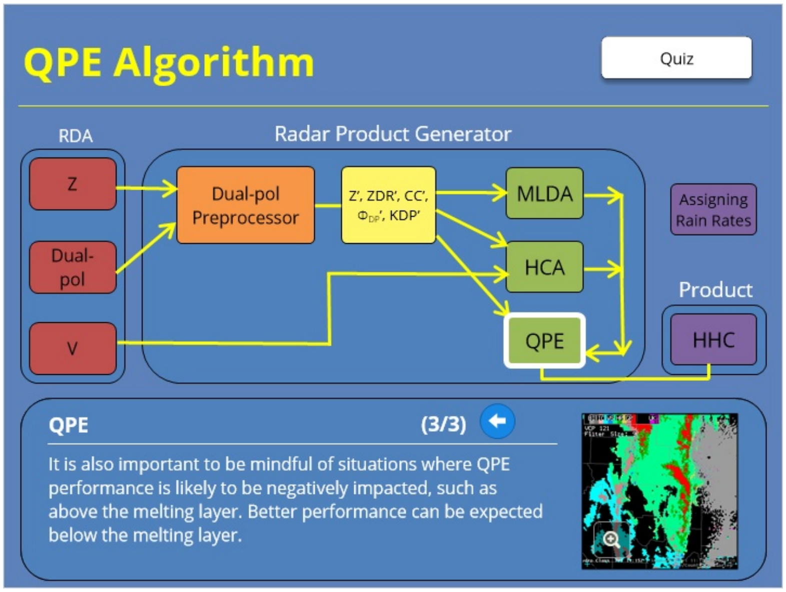
2.13 QPE Part III



Notes:

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.

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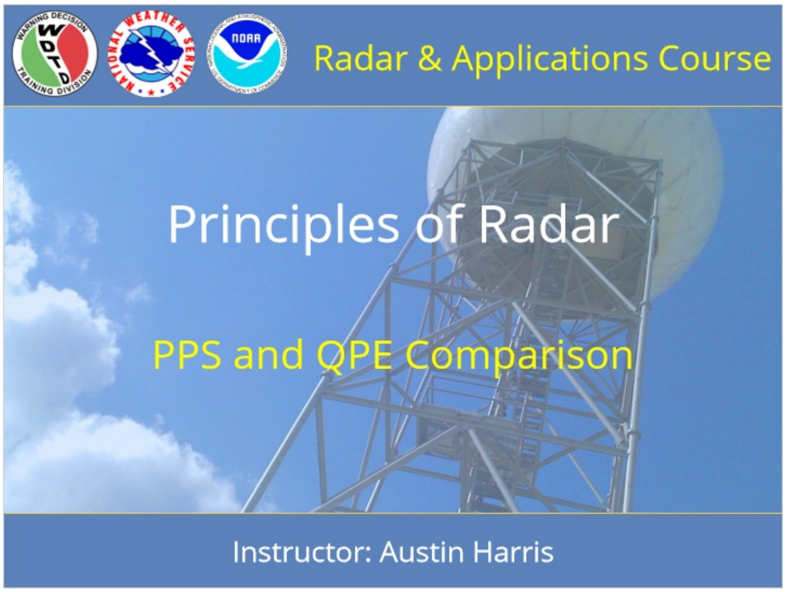
PPS and QPE Comparison

1. Introduction

1.1 Title Slide



Notes:

Welcome to the Principles of Radar lesson comparing PPS and QPE algorithms.

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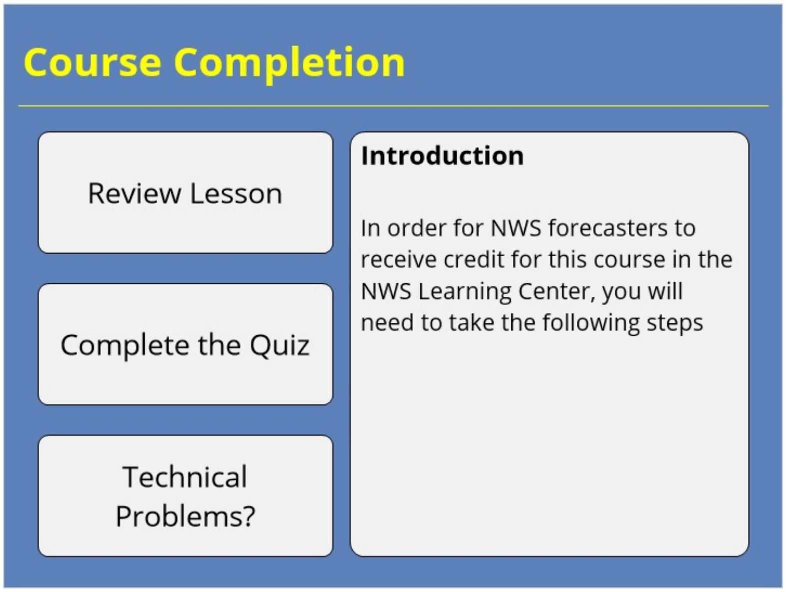
1.2 Course Completion Info



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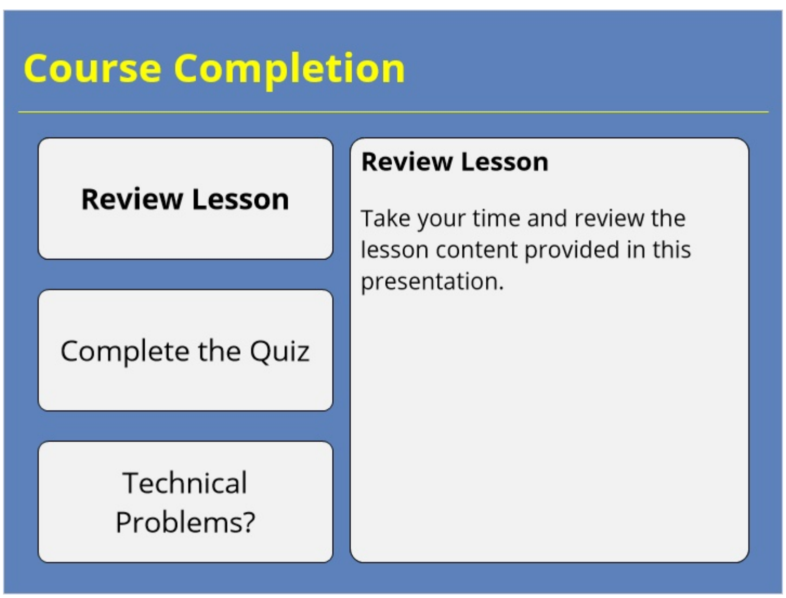
Review Lesson (Slide Layer)



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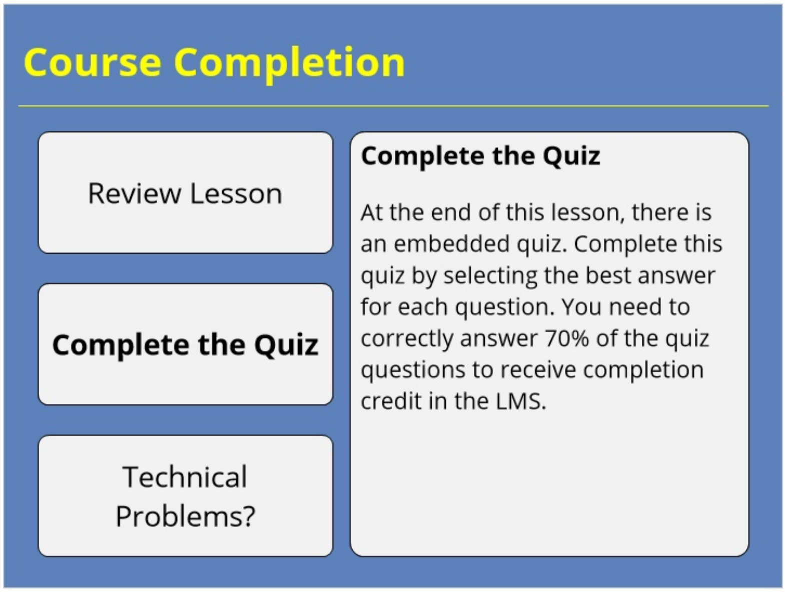
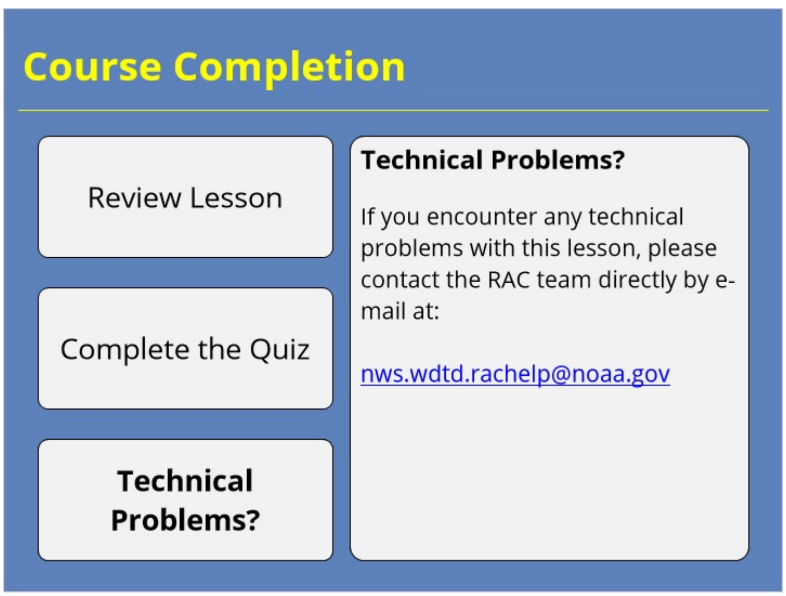
Complete the Quiz (Slide Layer)



Technical Problems (Slide Layer)



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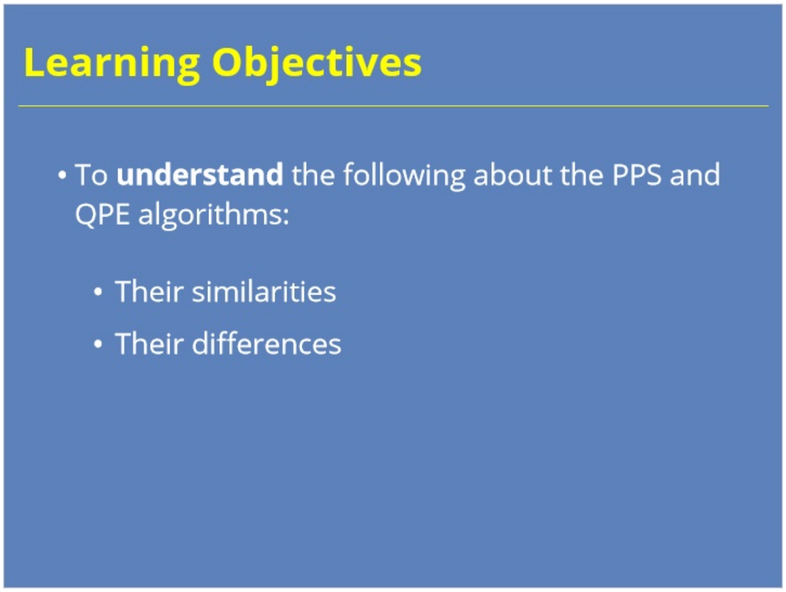
1.3 Learning Objectives



Notes:

The learning objectives for this lesson are to understand the following about the PPS and QPE algorithms:

1. Their similarities

2. Their differences

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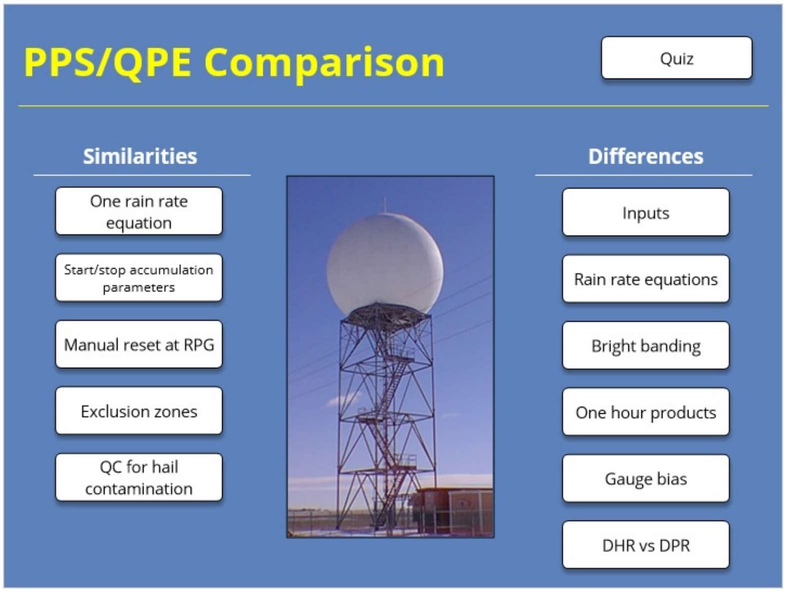
1.4 Homepage



Notes:

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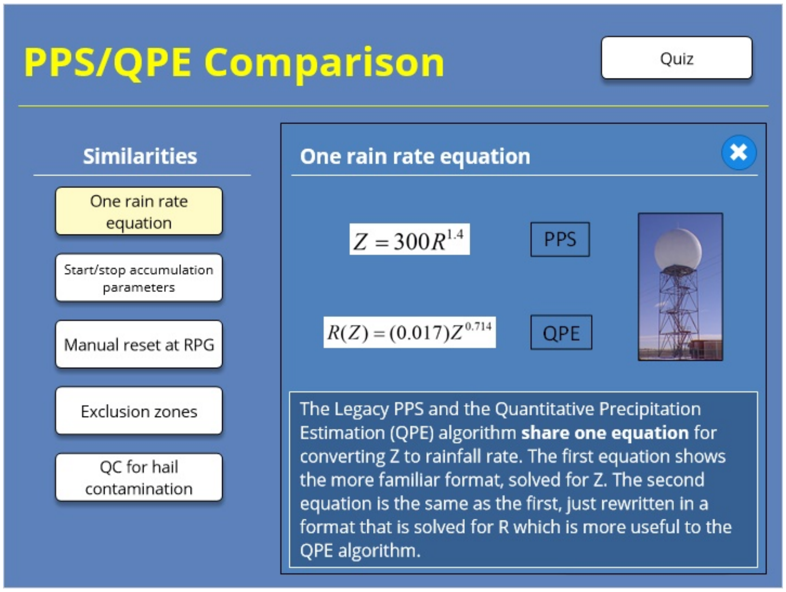
2. Similarities

2.1 One rain rate equation



Notes:

The PPS and the QPE algorithms 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 which is more useful to the QPE algorithm. Note, this is the only equation they have in common, with the majority of them being different.

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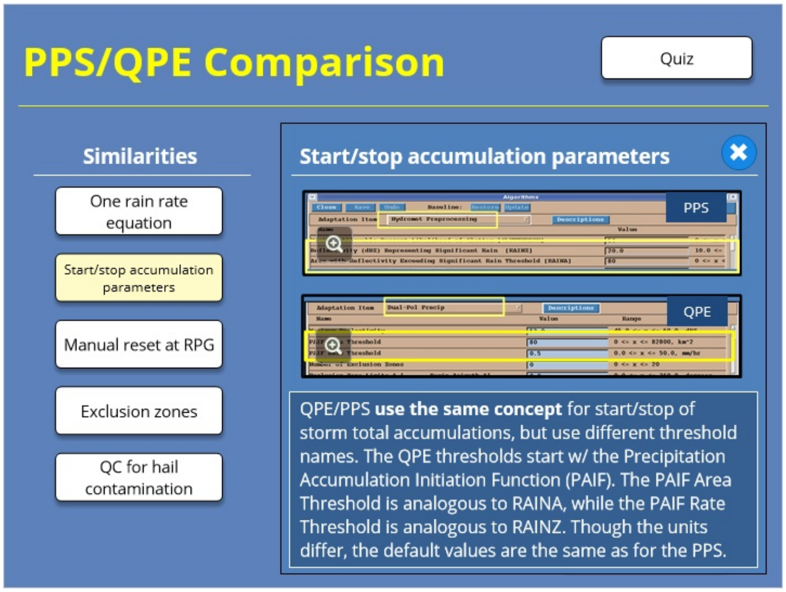
2.2 Start/stop accumulation parameters



Notes:

QPE/PPS use the same concept for start/stop of storm total accumulations, but use different threshold names. The QPE thresholds start w/ 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.

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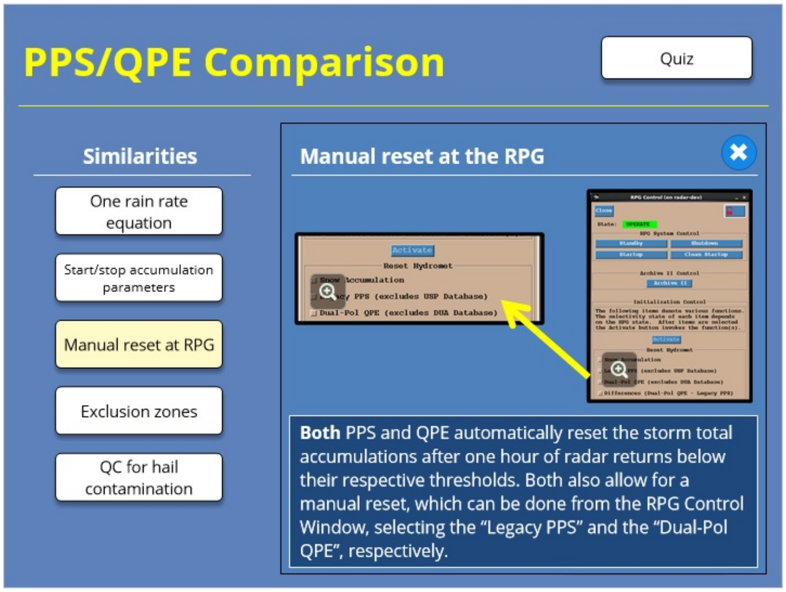
2.3 Manually reset at RPG



Notes:

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

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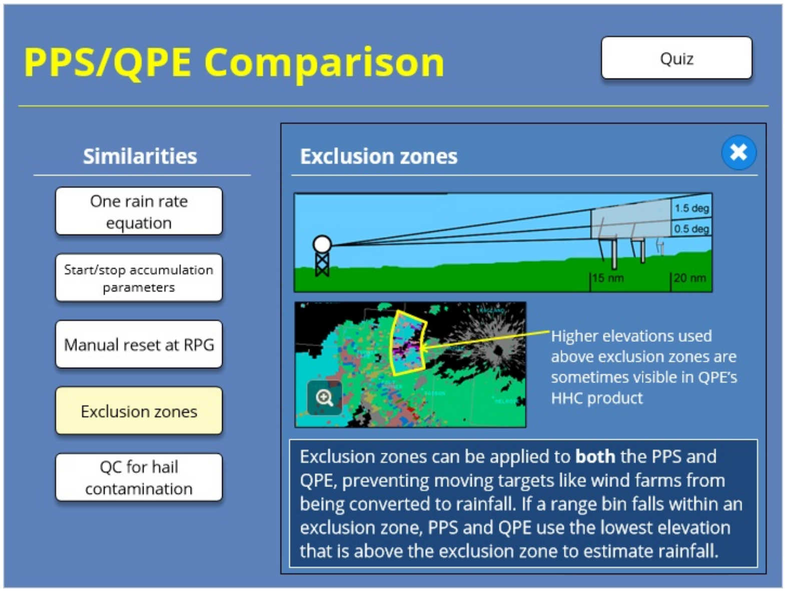
2.4 Exclusion Zones



Notes:

Exclusion zones can be applied to both the PPS and QPE, preventing moving targets like wind farms from being converted to rainfall. 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 of where the use of that next highest tilt can become evident in the HHC hyrdroclass product, as this block above the exclusion zone was changed to frozen precipitation as it intersected the melting layer. Keep that in mind when using this product.

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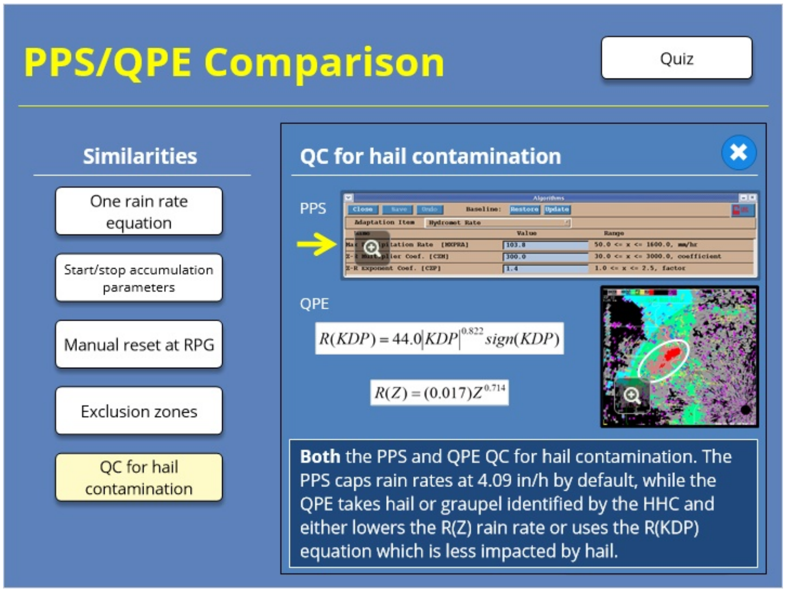
2.5 QC for hail contamination



Notes:

Both the PPS and QPE QC check for hail contamination. The PPS caps rain rates at 4.09 in/h by default, while the QPE takes hail or graupel identified by the HHC and either lowers the R(Z) rain rate or uses the KDP equation which is less impacted by hail.

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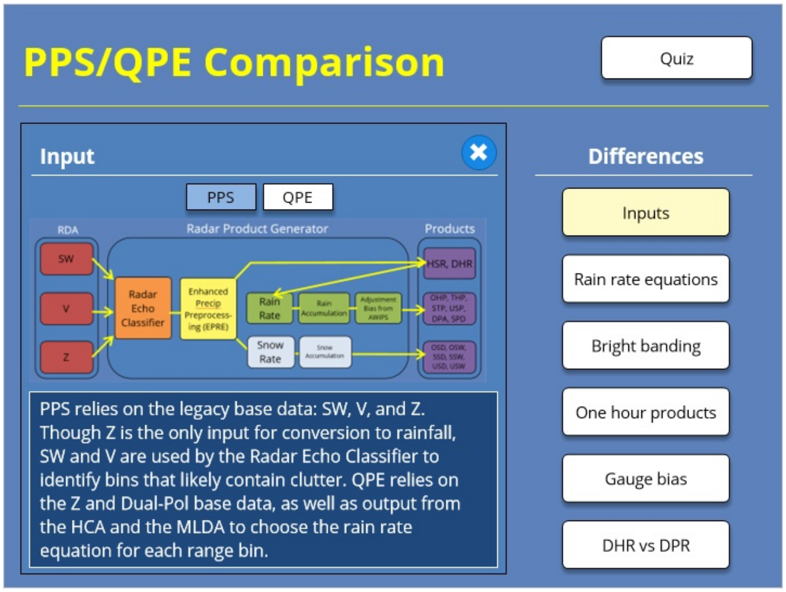
3. Differences

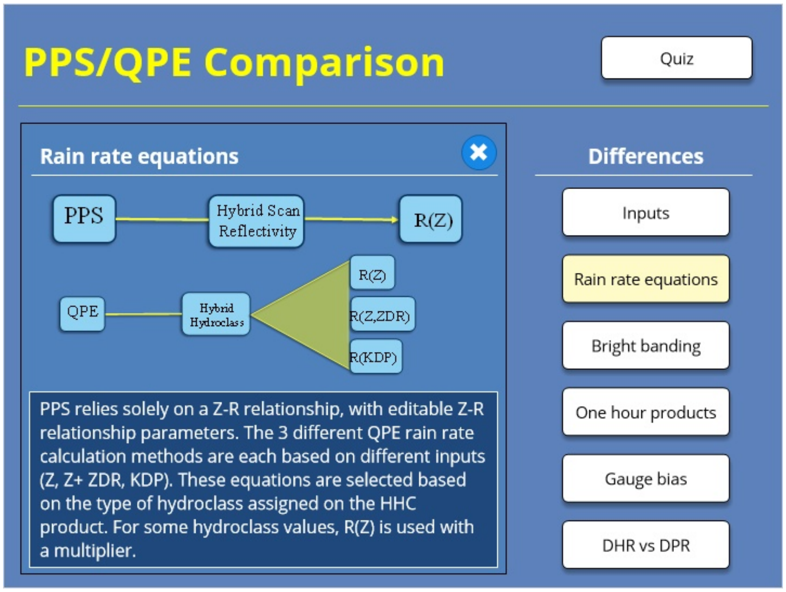
3.1 Inputs



Notes:

The Legacy PPS relies on the legacy base data: SW, V, and Z. Though Z is the only input for conversion to rainfall, SW and V are used by the Radar Echo Classifier to identify bins that likely contain clutter. QPE relies on the Z and Dual-Pol base data, as well as output from the HCA and the MLDA to choose the rain rate equation for each range bin.

3.2 Rain rate equations



Notes:

The PPS relies solely on a Z-R relationship, with editable Z-R relationship parameters. The 3 different QPE rain rate calculation methods are each based on different inputs (Z, Z+ ZDR, KDP). 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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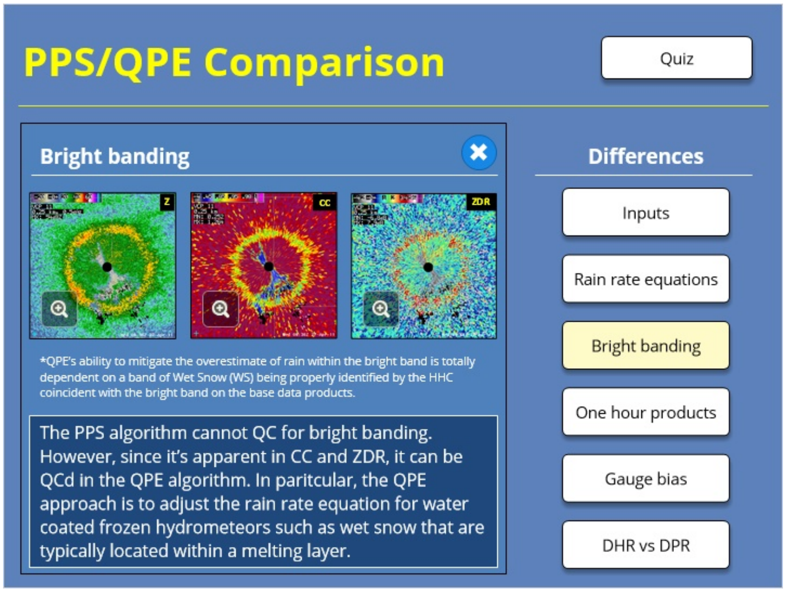
3.3 Bright banding



Notes:

Unfortunately the PPS algorithm cannot QC for bright banding. However, since it's apparent in CC and ZDR, it can be QCd in the QPE algorithm. In paritcular, 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 melting layer. 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.

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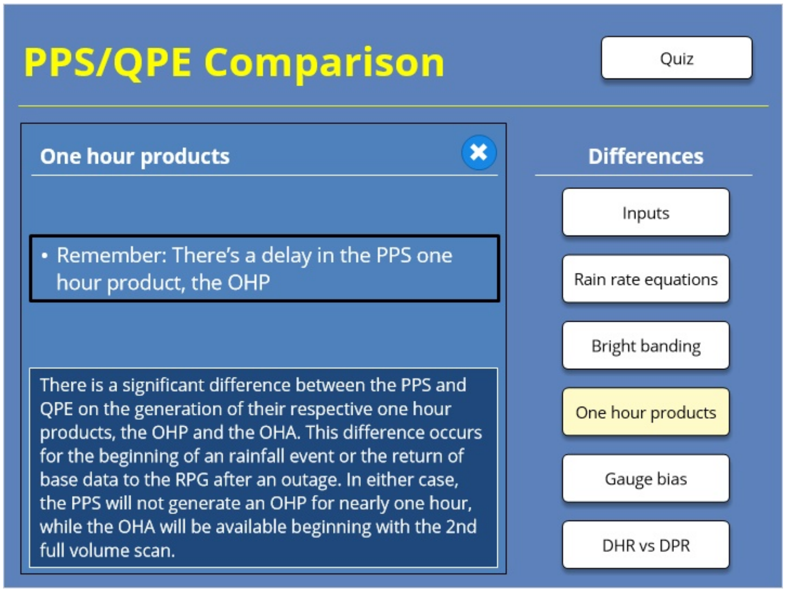
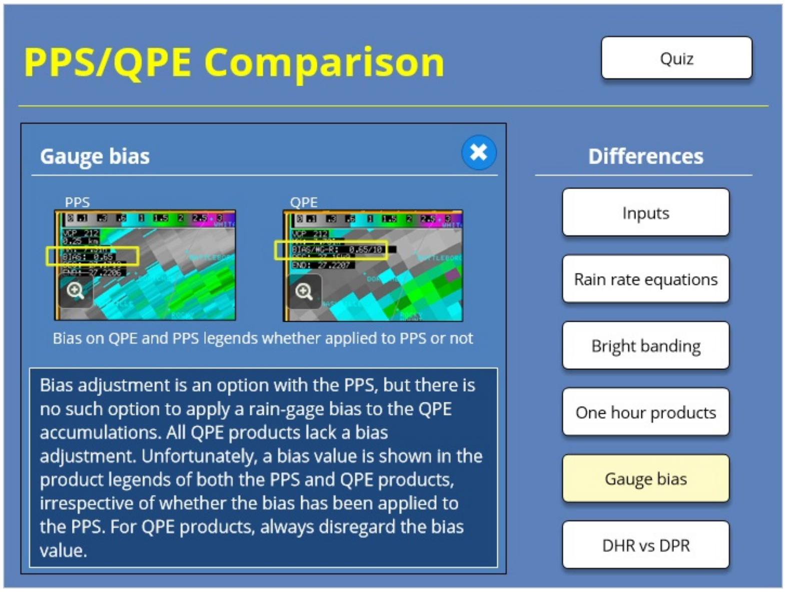
3.4 One hour products



Notes:

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. 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.

3.5 Gauge bias



Notes:

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 the QPE products lack a bias adjustment. 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.

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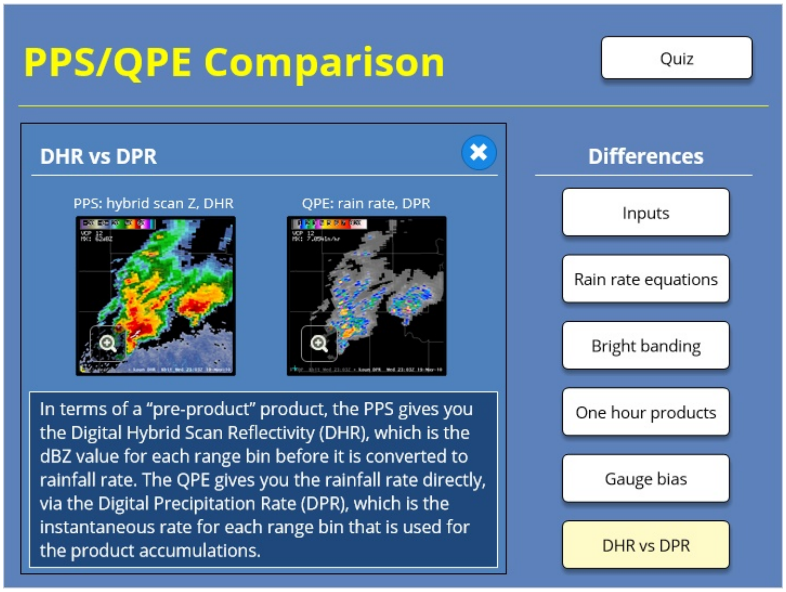
3.6 DHR vs DPR



Notes:

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. 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.

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Welcome to the lesson on the Snow Accumulation Algorithm.

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Course Completion Info

Tabs - 4 Tabs (Including Introduction)

Last Modified: Aug 20, 2018 at 09:08 AM

PROPERTIES

Show interaction in menu as: Single item

Allow user to leave interaction: At any time

Prev/Next player buttons go to: Slide in presentation

Edit in Engage

Edit Properties

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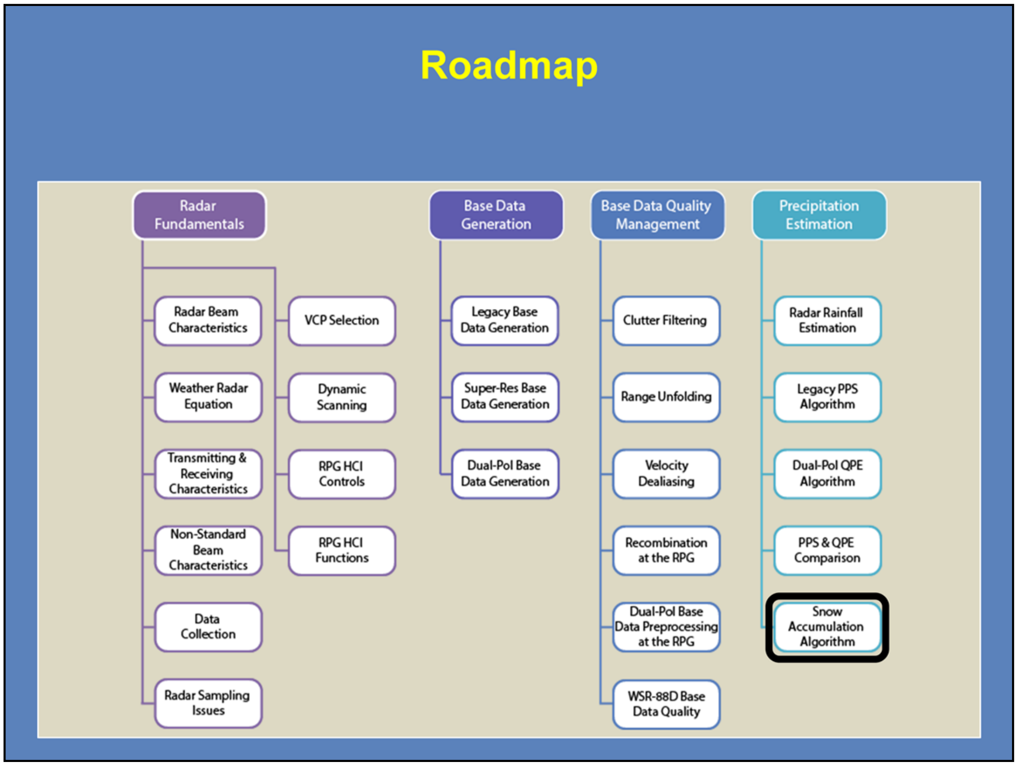
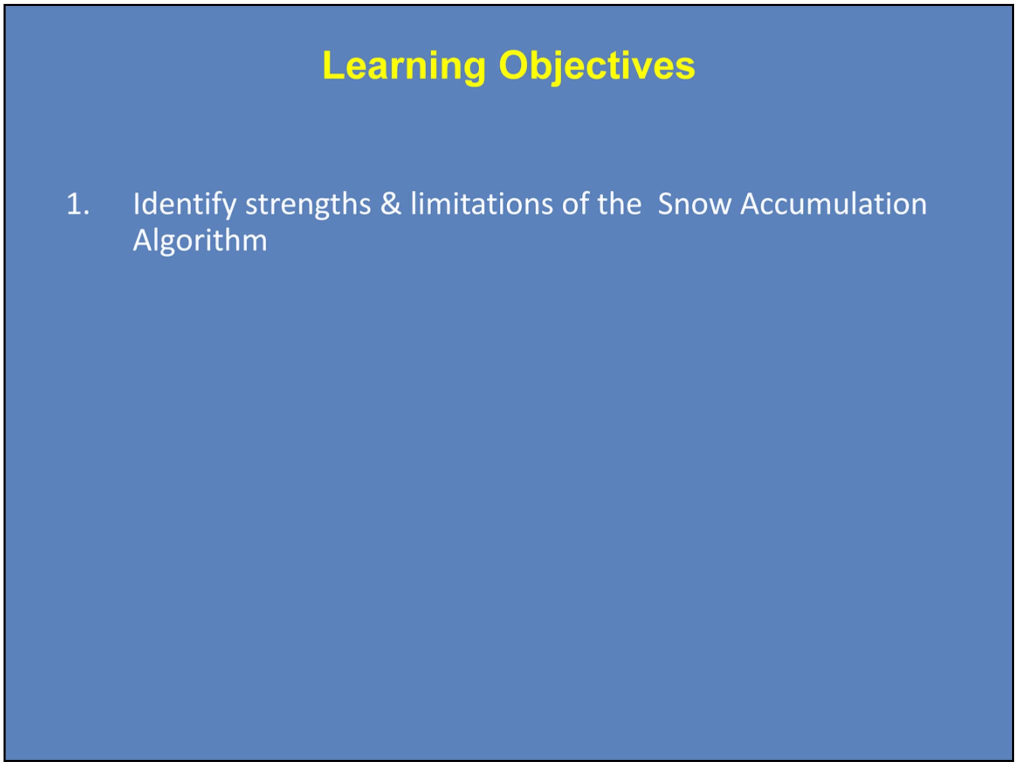


Here is the Roadmap with your current location.



There is one objective for this lesson.

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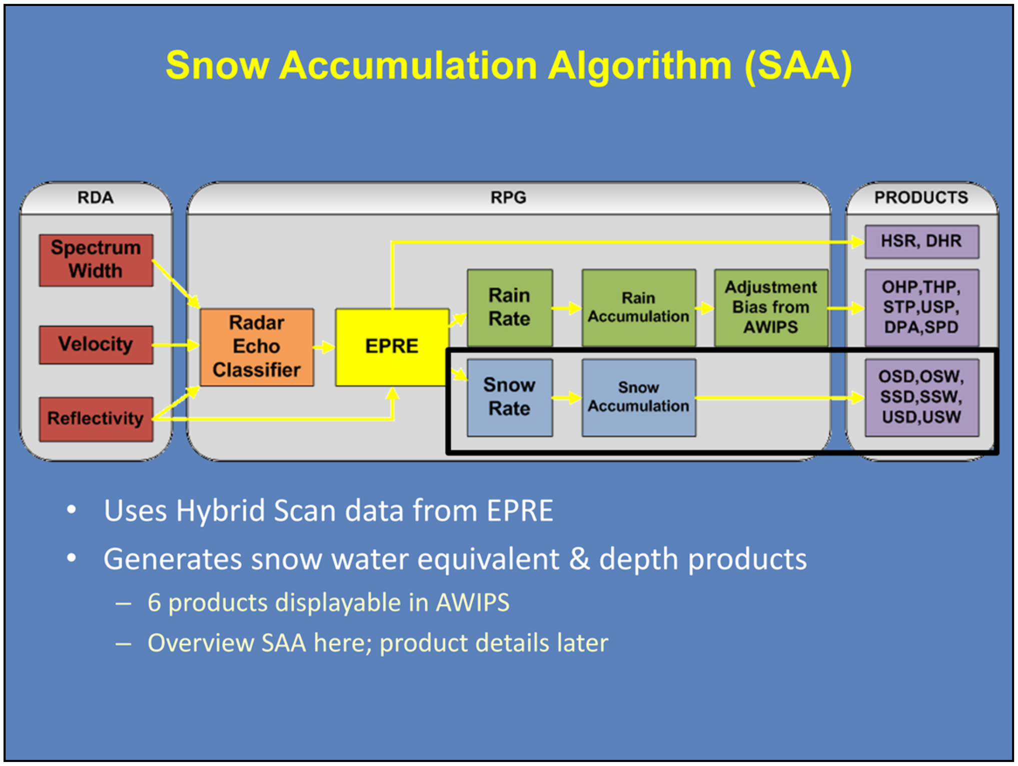
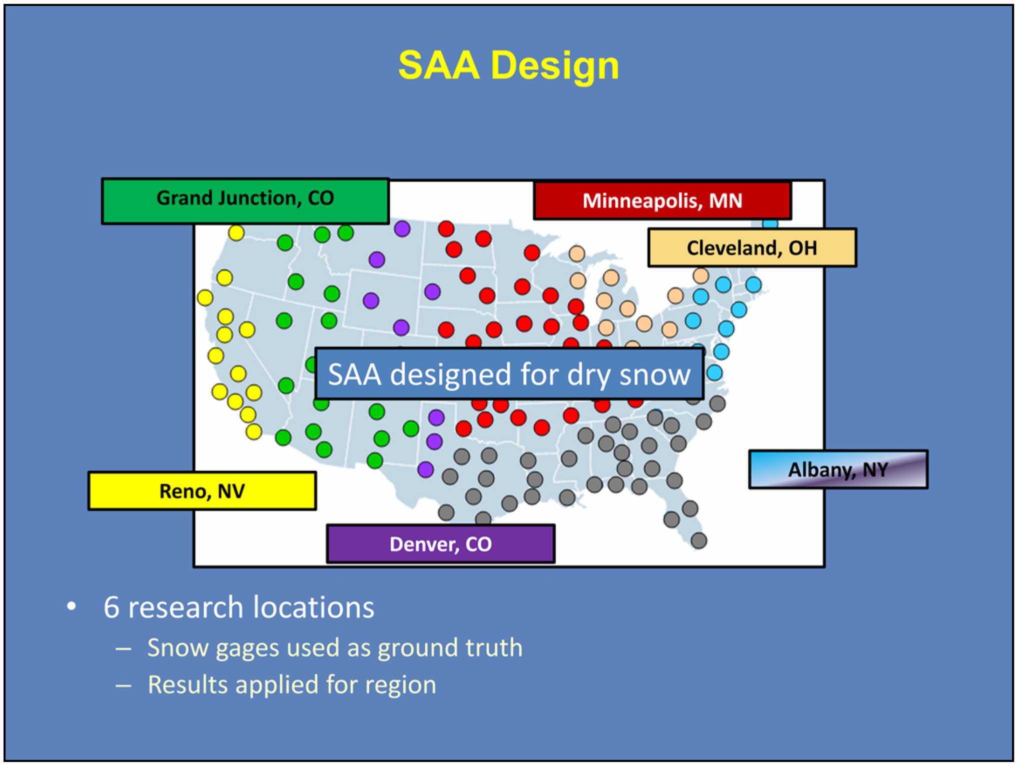


We now focus on the generation of snow water equivalent and snow depth products from the Snow Accumulation Algorithm (or SAA). The SAA uses hybrid scan data from the Enhance Preprocessing Algorithm (EPRE)

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.



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.

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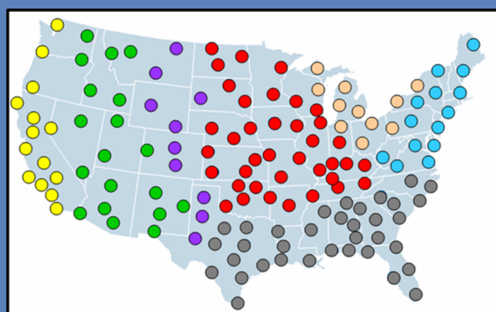
Z-S Relationships

- 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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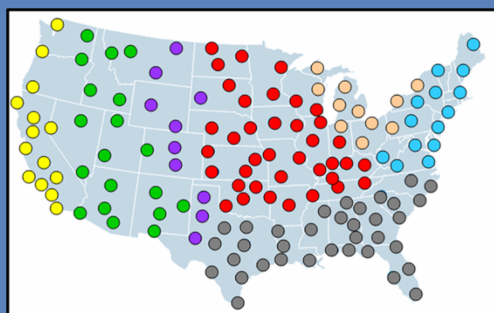
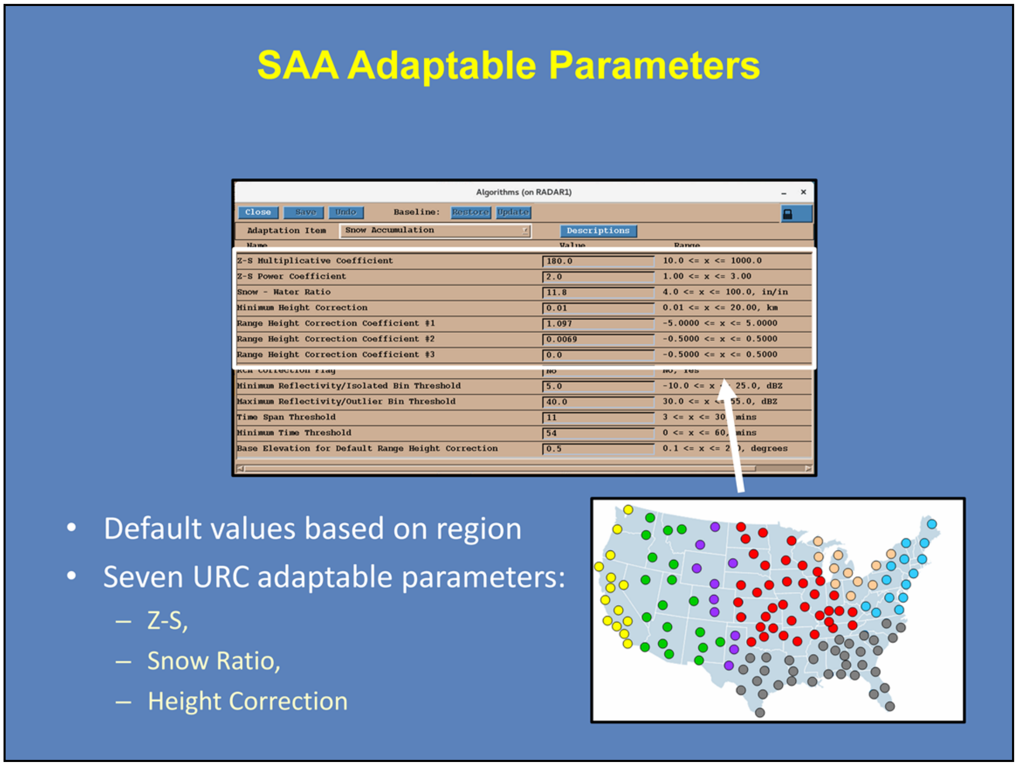
SAA and Snow Ratio

- 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.

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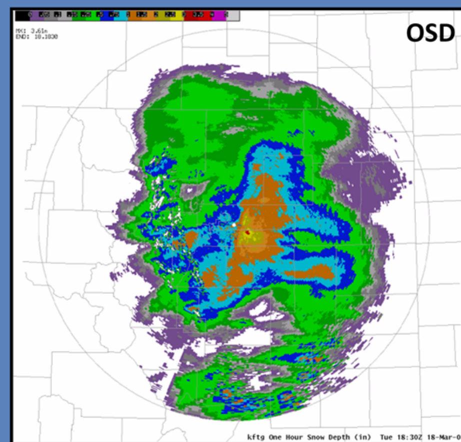
SAA Products

- 1km x 1°; 16 data levels; range of 124 nm
  - OSW: One Hour Snow Water Equivalent
  - OSD: One Hour Snow Depth
  - SSW: Storm Total Snow Water Equivalent
  - SSD: Storm Total Snow Depth
  - USW: User Selectable Snow Water Equivalent
  - USD: User Selectable Snow Depth



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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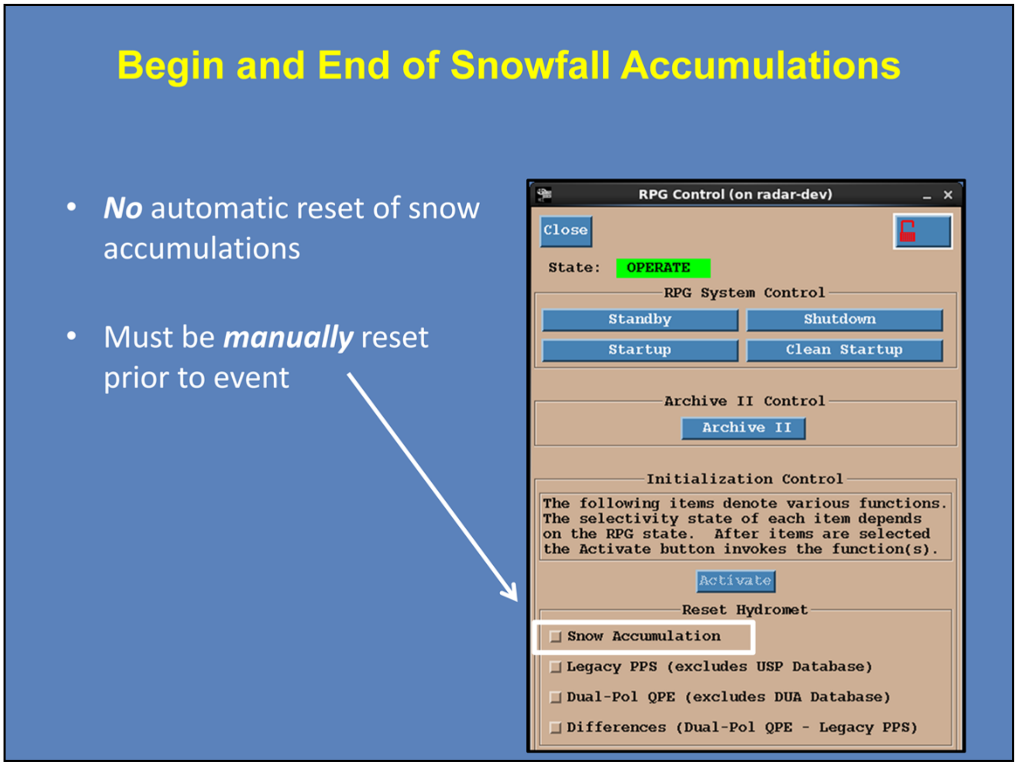
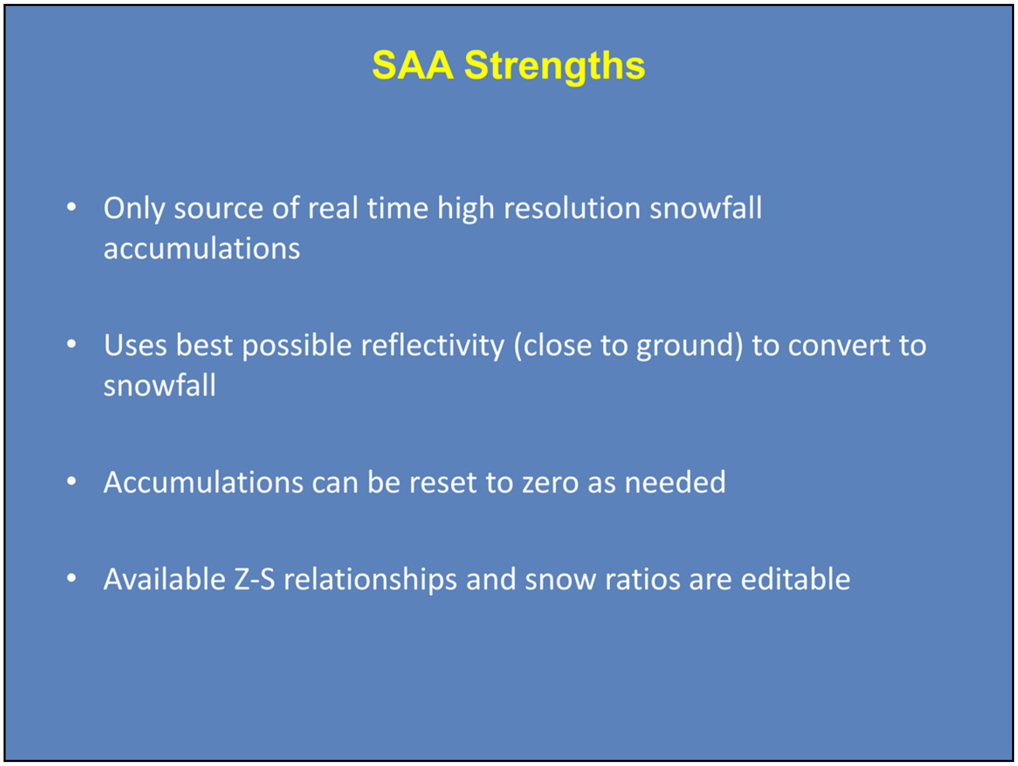


The SAA is designed to be event driven, and there is no automatic reset of the accumulations. This means the snow accumulations must be reset to zero at the beginning of an event. Resetting is done at the RPG Control window, just as with a reset of the PPS or QPE storm total accumulations.



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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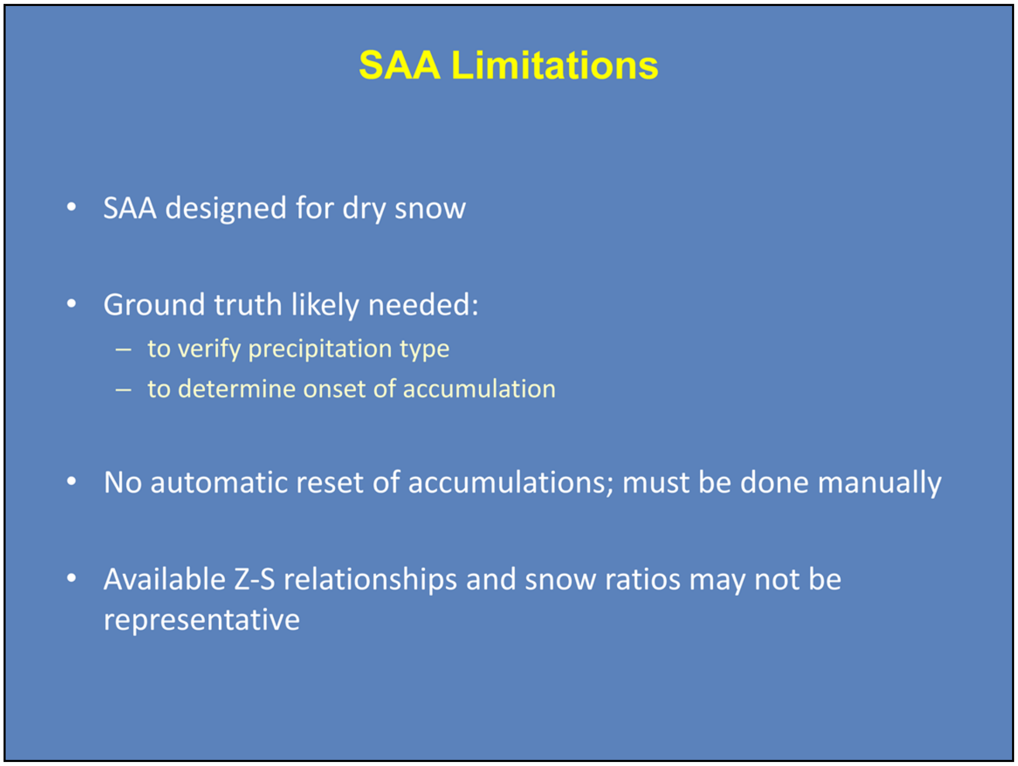
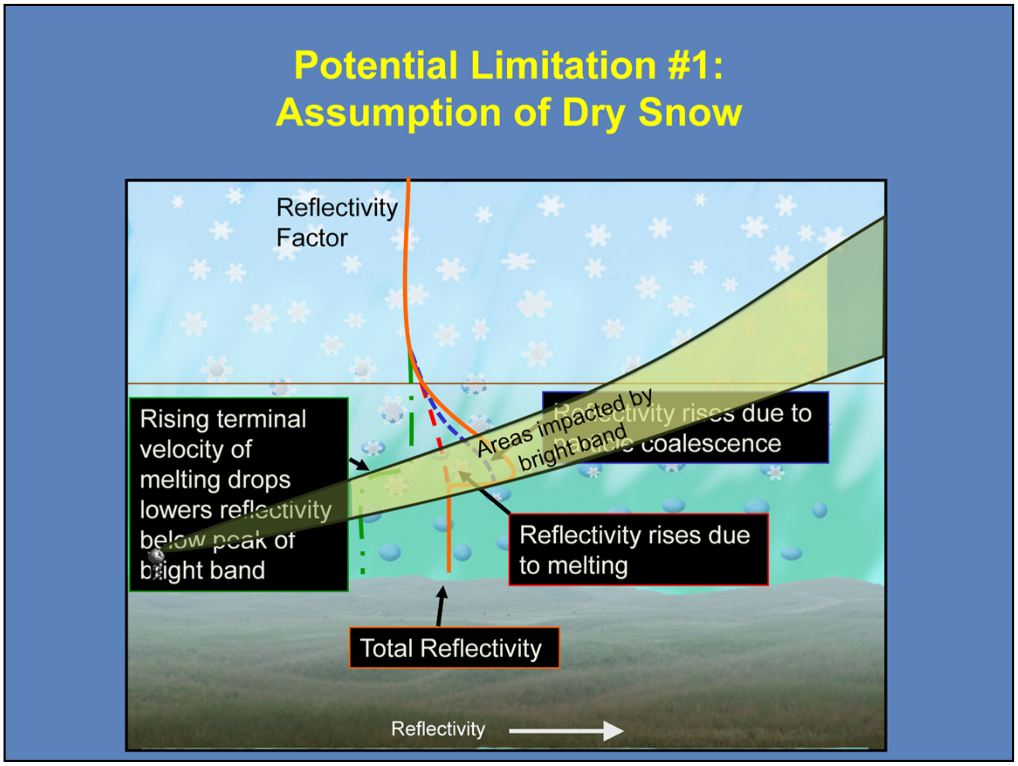


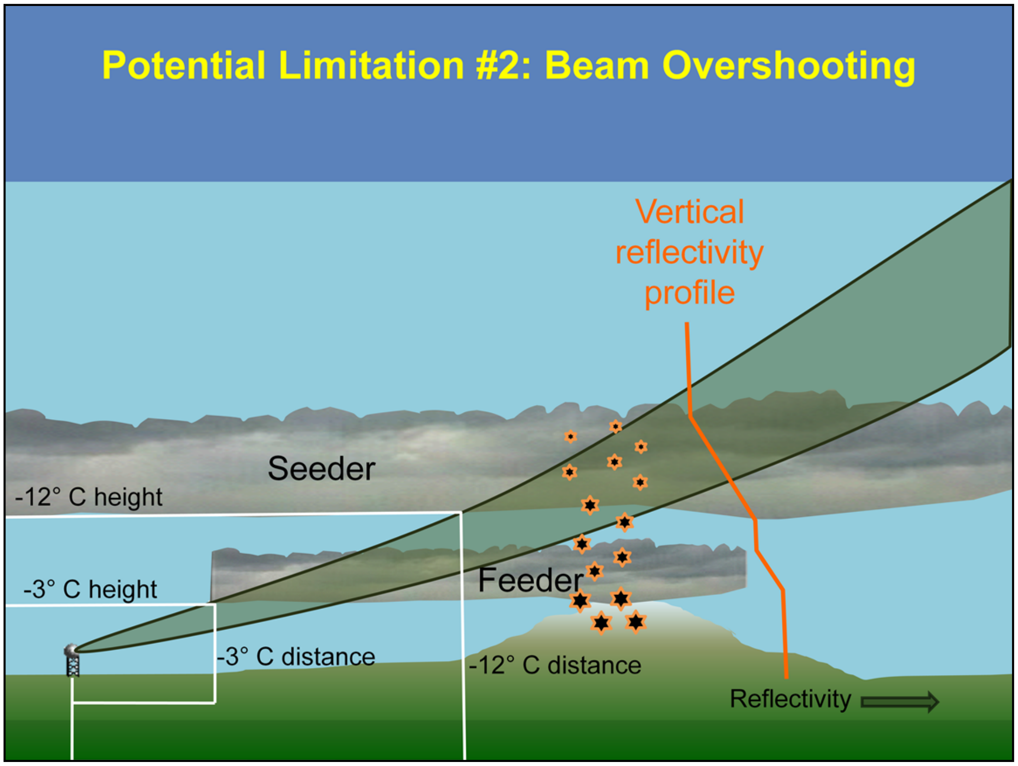
Perhaps the most important thing to remember about the SAA is that it designed for dry snow, snow that does not melt as it falls or when it hits the ground. Ground truth will likely be needed to verify precipitation type and to determine the onset of snow accumulation. The onset must be known in order 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.

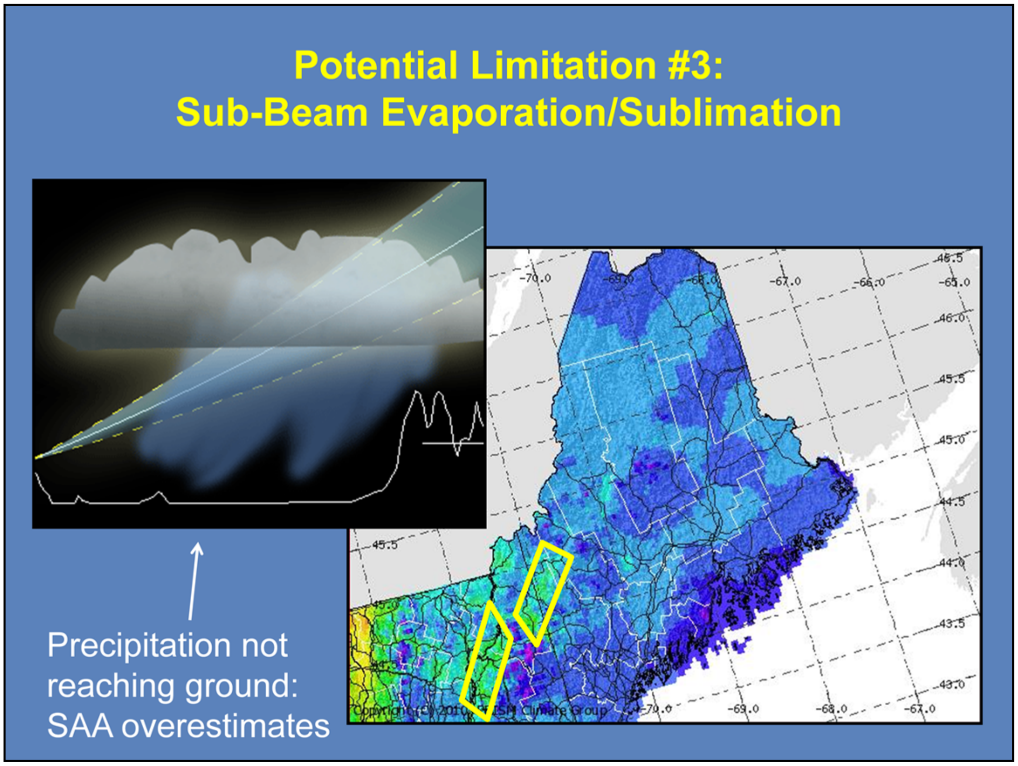
Due to these mechanisms, overestimation can occur in areas where the radar samples the bright band because wet snow has a higher reflectivity than dry snow. This overestimation can occur even when only portions of the beam (i.e., the top or bottom) are sampling the bright band.



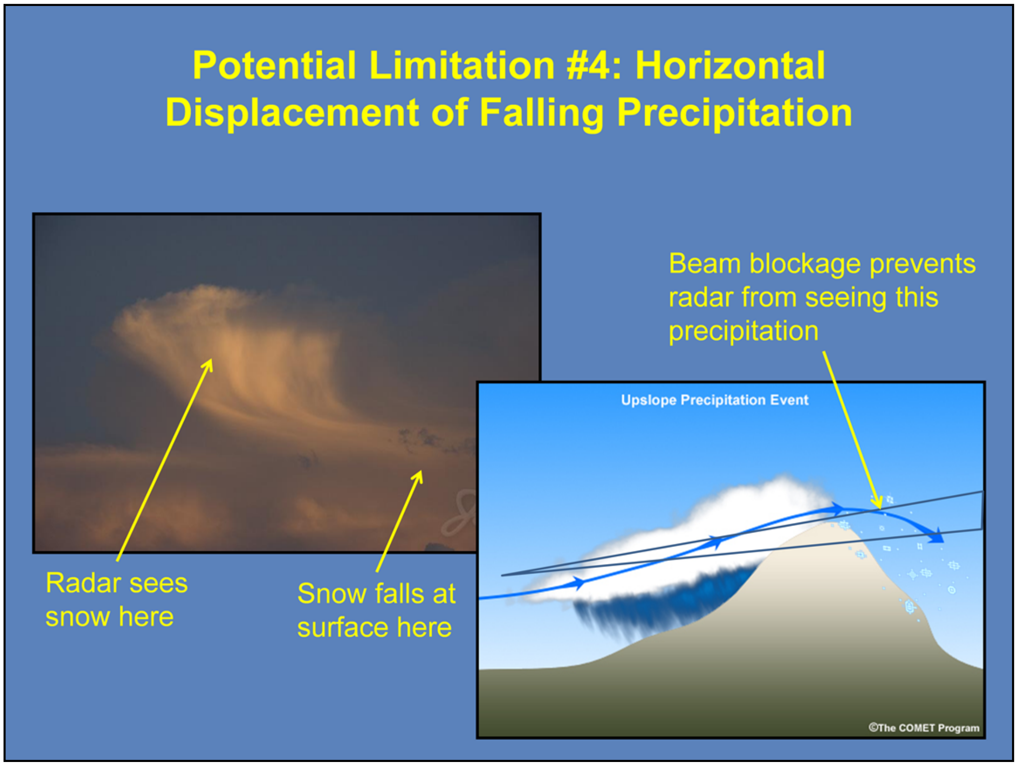
Assume we have a cloud pictured here actively generating precipitation so the intensity increases from top to bottom. Reflectivity begins to degrade once the top of the radar beam is above this precipitation production layer, and the signal is lost once the bottom of the beam is above the cloud.

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.



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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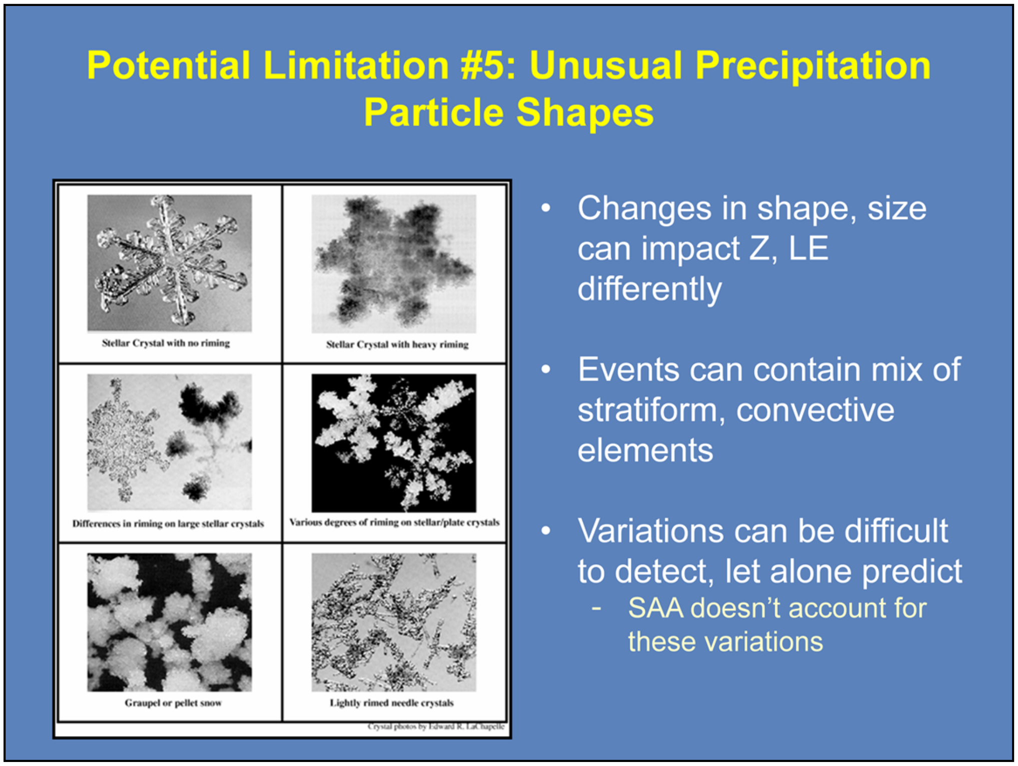
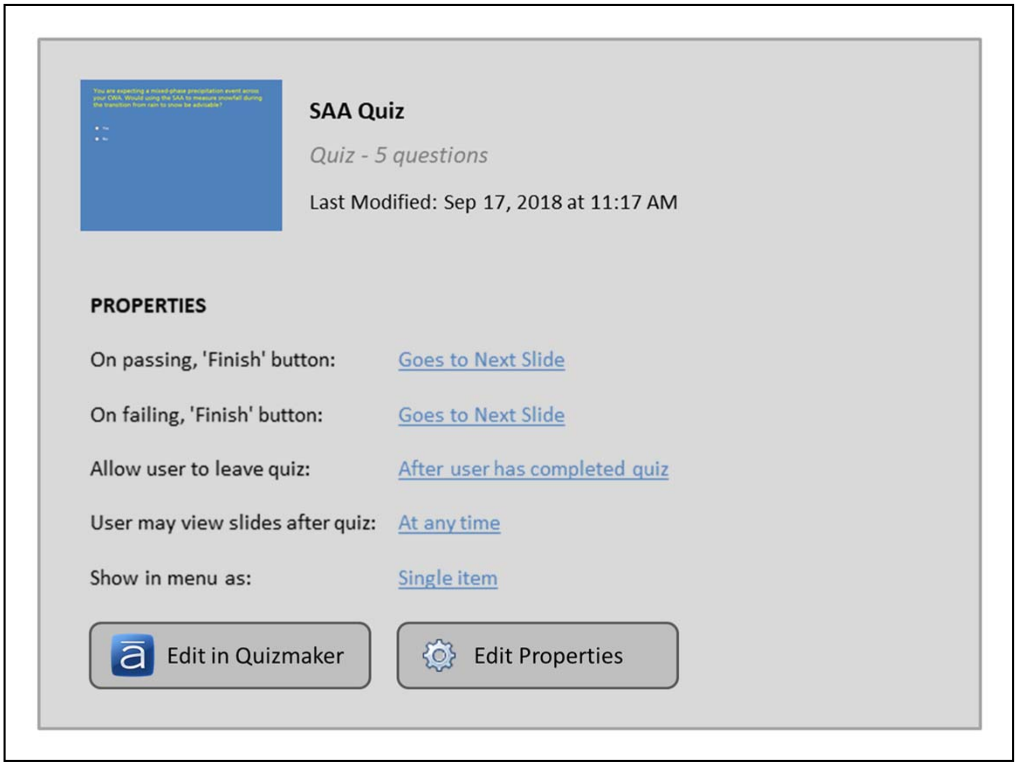


Precipitation particle shape and size can significantly alter reflectivity without a corresponding change in the liquid equivalent precipitation rate. If you experience snow events, take a look at how the shapes and sizes of the snowflakes change over short periods of time.

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.


SAA Quiz
Quiz - 5 questions
Last Modified: Sep 17, 2018 at 11:17 AM
PROPERTIES
On passing, 'Finish' button:
Goes to Next Slide
On failing, 'Finish' button:
Goes to Next Slide
Allow user to leave quiz:
After user has completed quiz
User may view slides after quiz:
At any time
Show in menu as:
Single item
Edit in Quizmaker
Edit Properties

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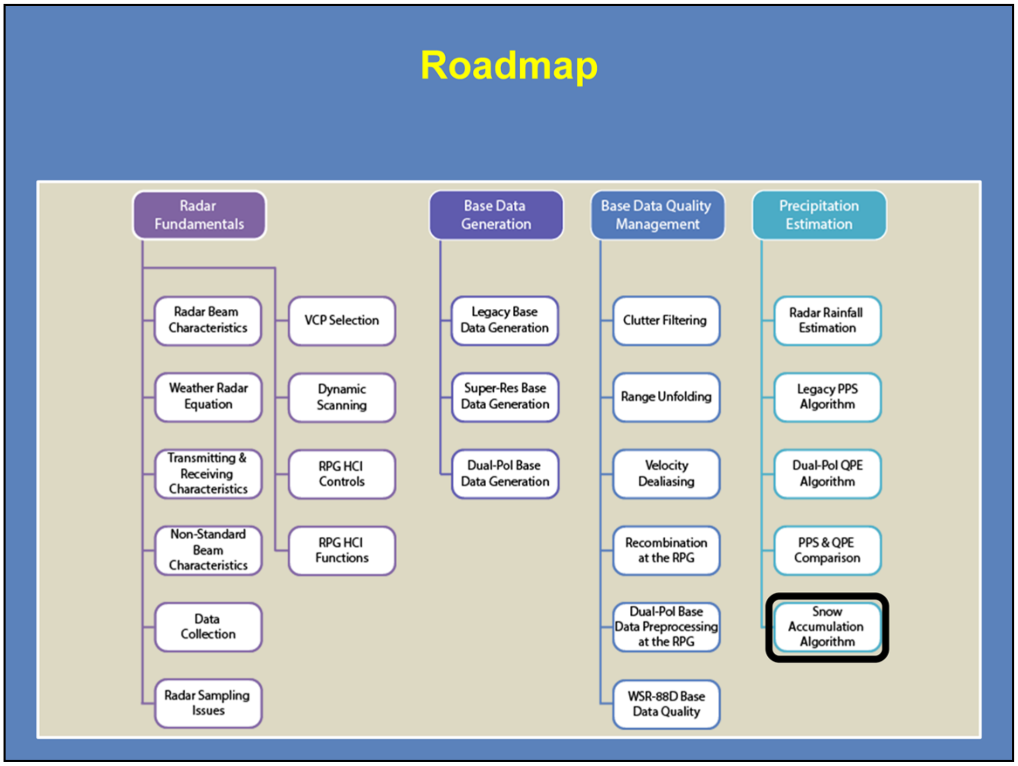

This concludes the lesson and here is the Roadmap with your current location.