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## Topic: Principles of Radar

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# Radar Beam Characteristics

## *Welcome*

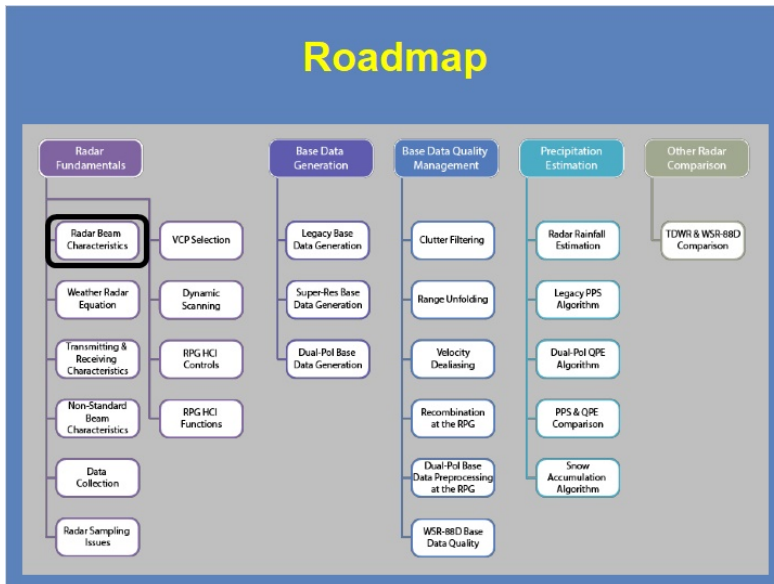


### **Notes:**

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



## 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!

## ***Learning Objectives***

### **Learning Objectives**

1. Identify why the WSR-88D emits discrete pulses
2. Identify how the beam width is determined for radar beams
3. Identify how a radar beam's physical size relates to range from radar
4. Identify how power density relates to transmitted power and range from radar
5. Identify why Rayleigh scattering is important to WSR-88D interpretation
6. Identify the various product resolutions and precisions for WSR-88D products

#### **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.

## ***Radar Beam Characteristics HOME***

*Click a characteristic to learn more*

Discrete Pulses

Beam Width

Physical Size


Power Density

Backscatter Power

Spatial Resolution

Product Resolution

### **Radar Beam Characteristics**

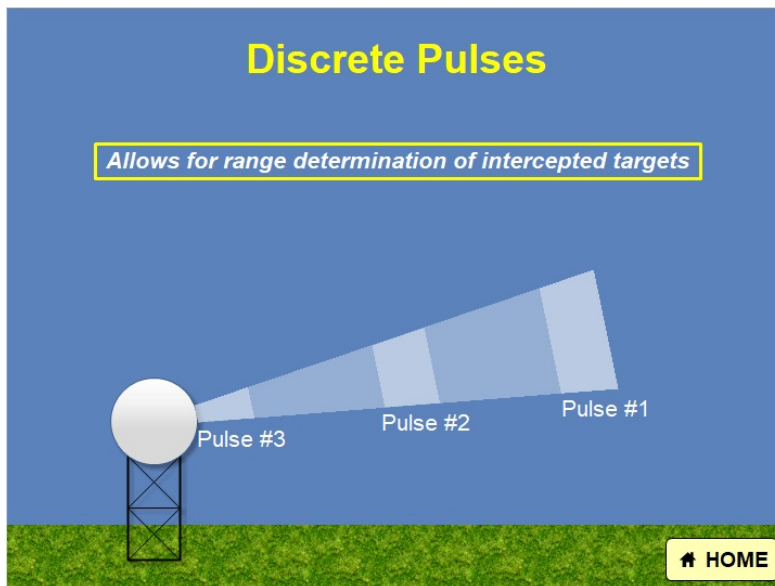


Summary + QUIZ!

### **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.

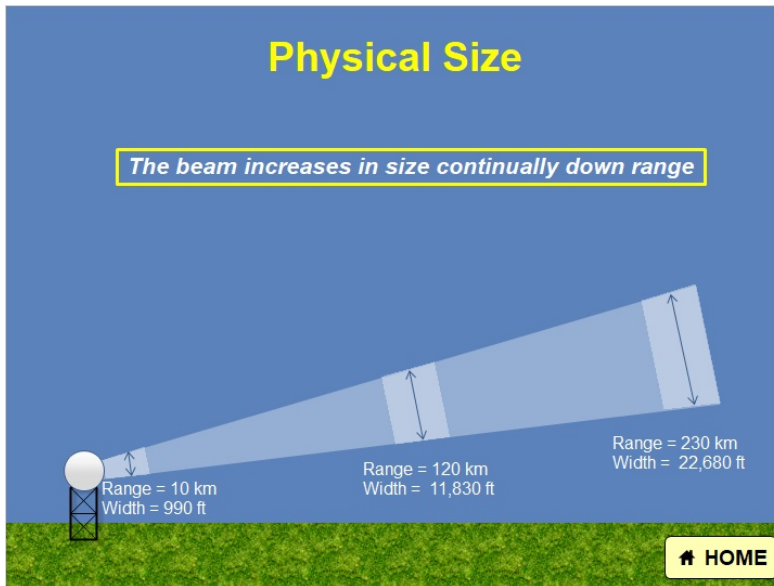
## ***Discrete Pulses***



### **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.

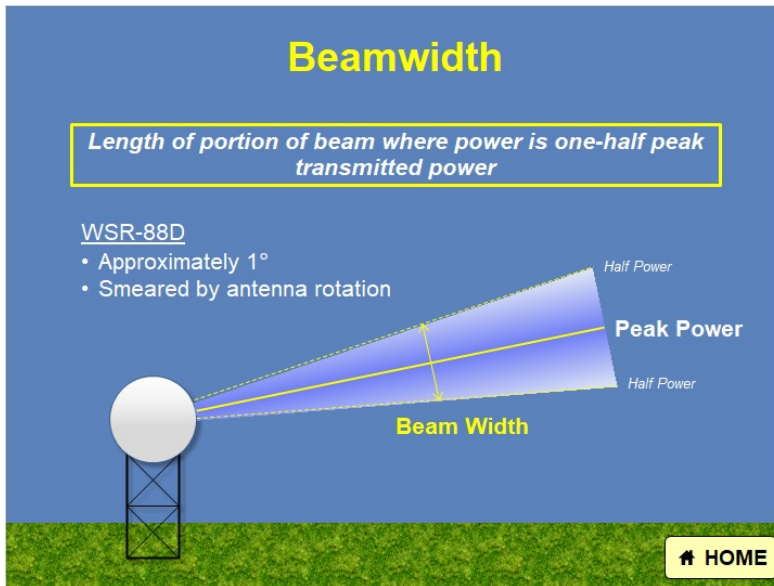
## Physical Size



### 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 the 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.

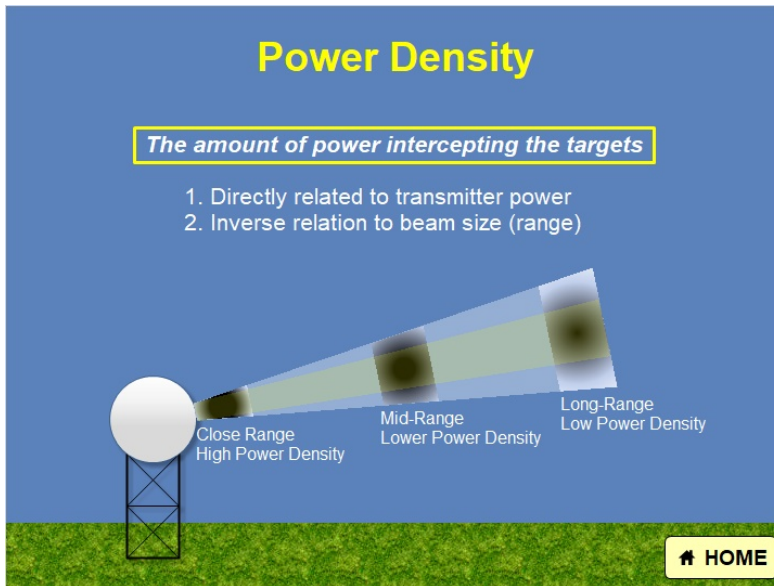
## Beamwidth



### 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 have boundaries, the beamwidth is determined at the point where the power along the beam reaches one-half of the beam's peak transmitted power. This distance is generally measured in degrees and is approximately 1 degree for the WSR-88D. This can be somewhat broader due to the rotation of the antenna while the beam is being transmitted, which is referred to as the effective beam width.

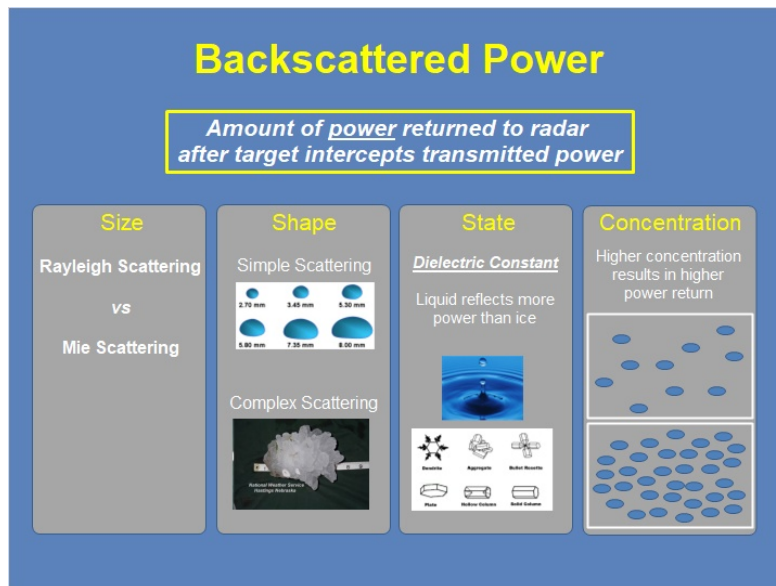
## Power Density



### 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. This way, 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 and the power density actually decreases as the beam goes down range. The power density is not equally distributed across the beam. The beam centerline actually contains most of that power.

## Backscattered Power

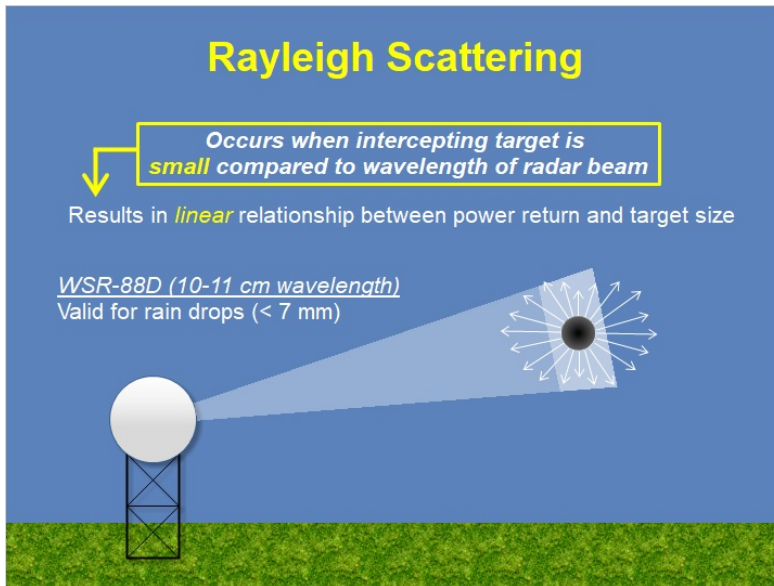


### Notes:

Once the target 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 it is dependent upon 4 characteristics of the weather target. One is 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 ice. Therefore, for the same exact size/shape, water will return a significantly higher amount of power than an ice particle. Finally, we have concentration. Within a given beam, if there only 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 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.



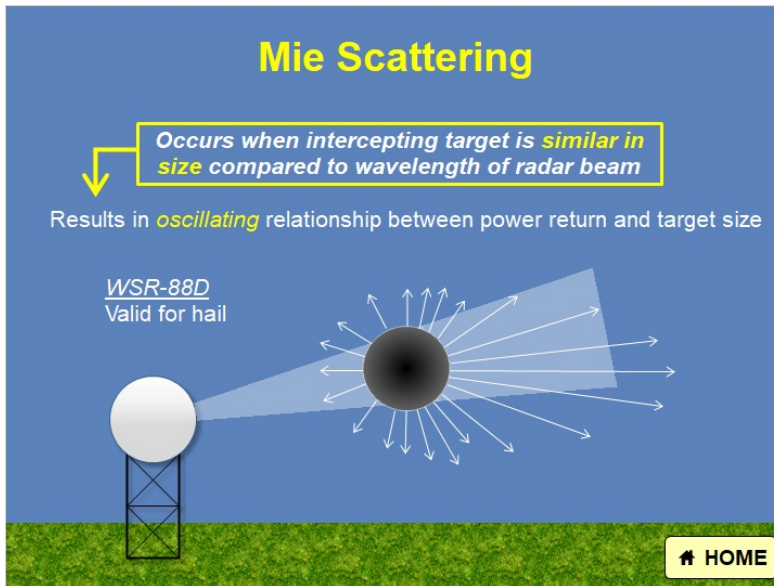
## Rayleigh Scattering



### Notes:

The size of the weather target compared to the wavelength of the radar determines the scattering regime. For targets that are 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 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.

## 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 of the 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.

## Spatial Resolutions

### Spatial Resolutions

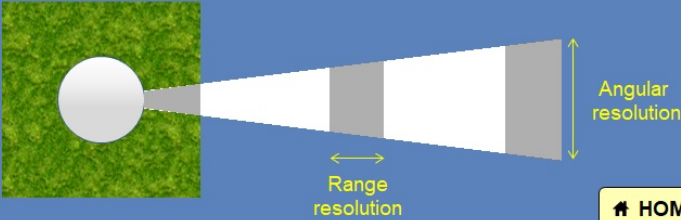
*The amount of detail resolved by the radar - determined by pulse duration and angular beam width*

Angular resolution =  $1^\circ$

- Super-Resolution uses  $0.5^\circ$  using processing techniques

Range resolution = 250 m

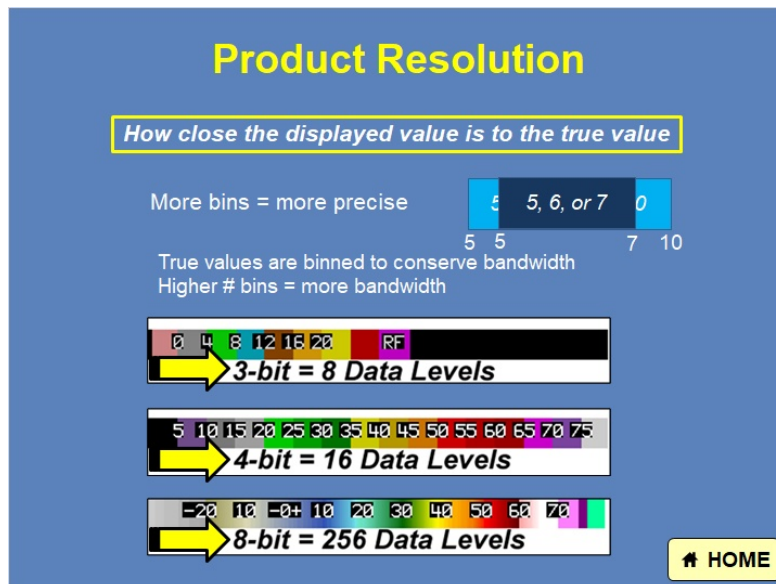
- Lower resolutions of 500 m, 1 km, 2 km, and 4 km available by averaging



### 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.

## 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 it 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.

## Summary

### Summary

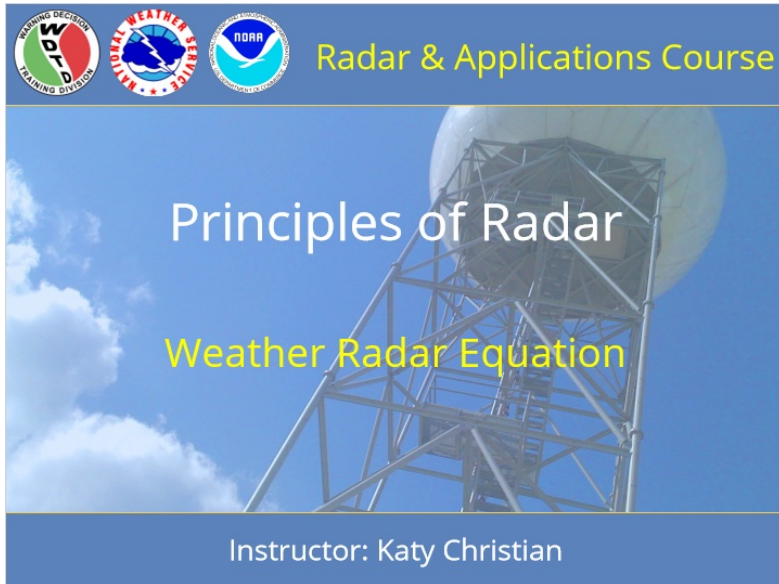
- The 88D emits discrete pulses to determine the range of intercepted targets.
- Beam width is determined at the point at which the power along the beam reaches one-half the peak transmitted power (appx. 1 degree).
- A beam's physical size increases continually down range from the radar.
- Power density is directly related to transmitter power and inversely related to beam size.
- Rayleigh scattering occurs for rain drops with the 88D, resulting in a linear relationship between power return and target size.
- Product resolution determines how close the displayed value is to the true value.

#### Notes:

Let's quickly review what we've learned in this lesson. The 88D emits discrete pulses to determine the range of intercepted targets. Beam width is determined at the point at which the power along the beam reaches one-half the peak transmitted power (appx. 1 degree). A beam's physical size increases continually down range from the radar. Power density is directly related to transmitter power and inversely related to beam size. Rayleigh scattering occurs for rain drops with the WSR-88D, resulting in a linear relationship between power return and target size. And finally, product resolution determines how close the displayed value is to the true value. Click next when you're ready to take the quiz.

# Weather Radar Equation

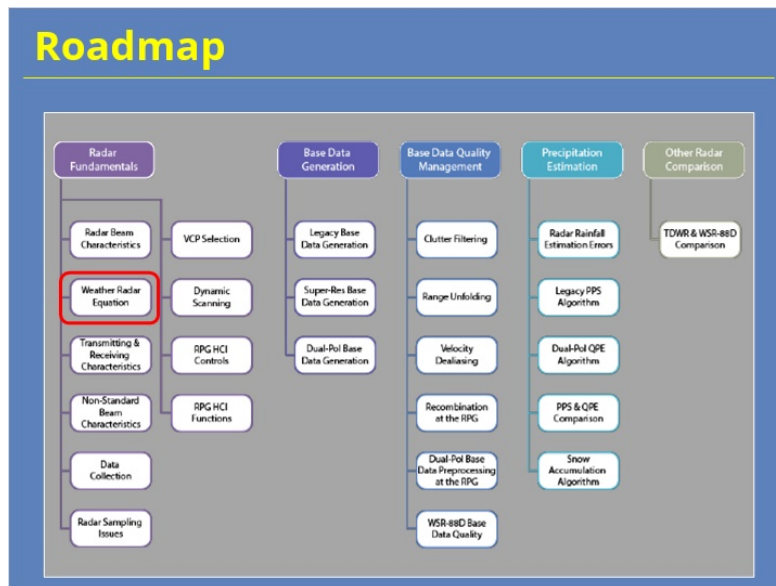
## 1.1 Introduction



### Notes:

Welcome to Principles of Radar! My name is Katy Christian and I'll be your guide through today's lesson over the weather radar equation.

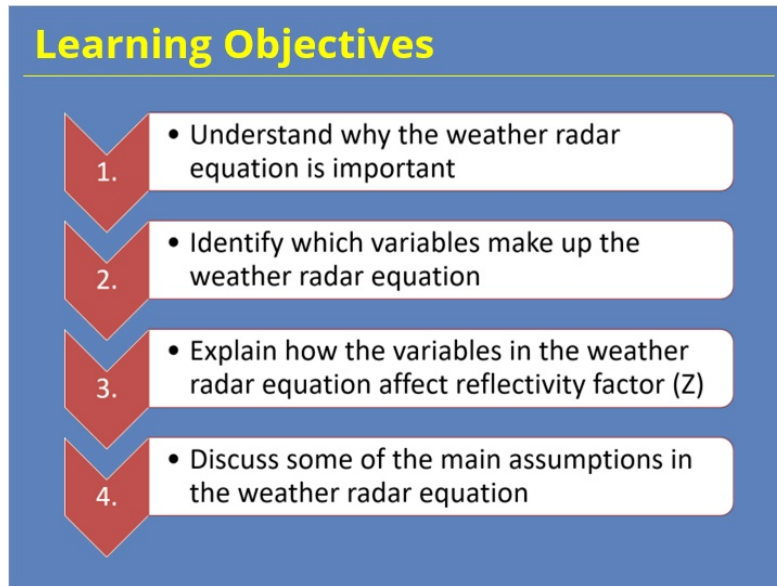
### 1.3 Roadmap



#### Notes:

Just for some context, here is the roadmap for the entire Radar Principles section of RAC - right now, you are here so let's keep moving forward!

## 1.4 Learning Objectives



### Learning Objectives

1. • Understand why the weather radar equation is important
2. • Identify which variables make up the weather radar equation
3. • Explain how the variables in the weather radar equation affect reflectivity factor (Z)
4. • Discuss some of the main assumptions in the weather radar equation

#### Notes:

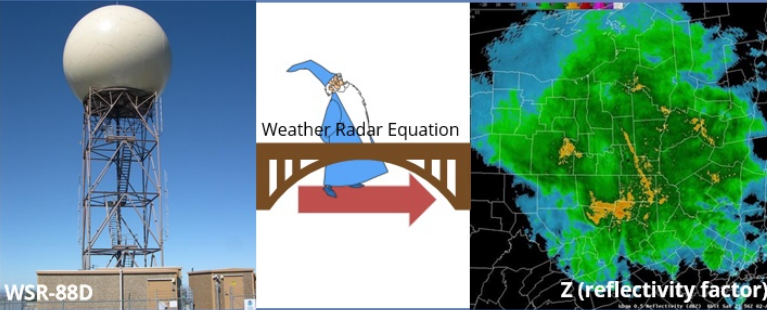
At the end of this lesson, you will be quizzed on the learning objectives shown here. Take a minute to read them so you know what the learning expectations are, and when you're done, click "next" to move on.



## 1.5 Overview

### Overview

Why do we care about the weather radar equation?



WSR-88D

Weather Radar Equation

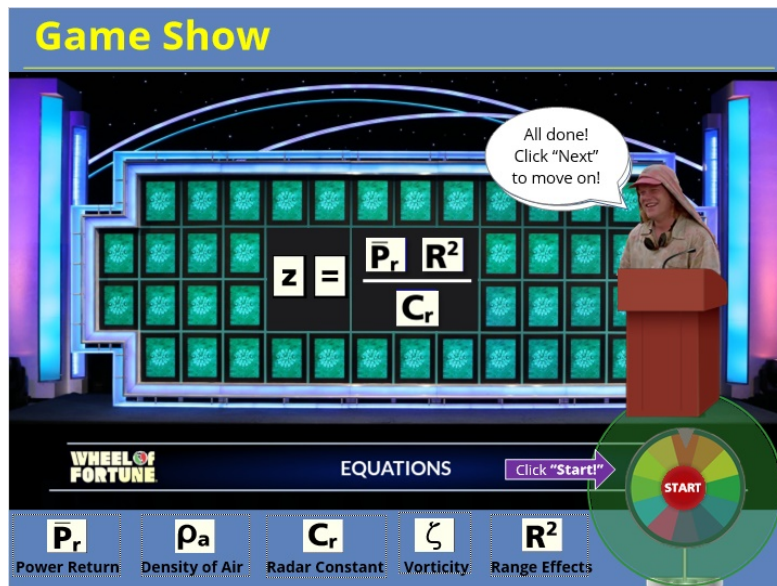
Z (reflectivity factor)

### Notes:

All right, before we go any further, we need to understand why we are devoting an entire module to talking about an equation. Despite popular belief, we aren't going to be burdening you with learning how to derive an entire equation and possibly ruining your day! Instead, we want you to understand why the weather radar equation is important to radar applications.

Take a look at the two pictures shown here. On the left is an image of the WSR-88D radar and on the right is something you're probably very familiar with - radar reflectivity, referred to as Z. Have you ever wondered how we go from just power transmitted by the radar to ending up with something as useful as reflectivity that we use on a daily basis? The jump between the two may seem like magic, but it's actually not. In a very simplified and general sense, the weather radar equation is the means by which we can get from power transmitted by the radar to something as useful as reflectivity. It essentially bridges the gap between the two. Now that we know why the weather radar equation is important, let's spend some time taking a closer look at it!

## 1.6 Game Show

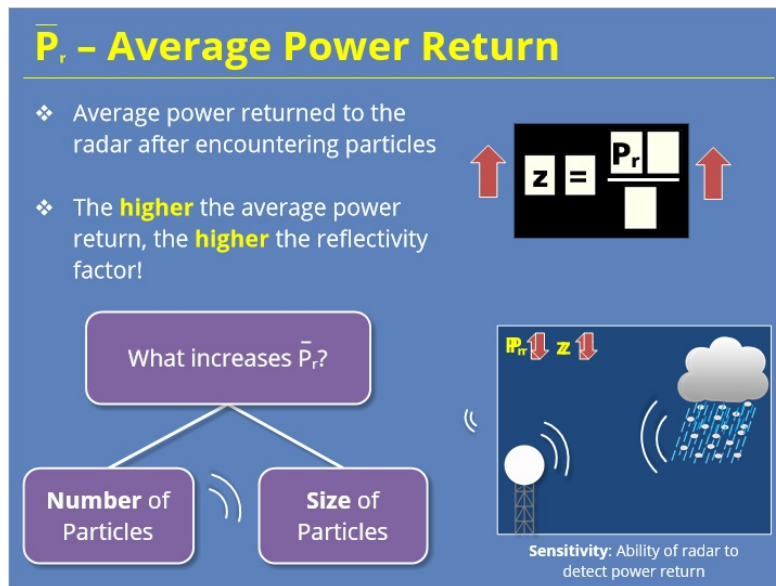


### Notes:

Okay, as I promised earlier, we're NOT going to have you derive the weather radar equation today. However, we ARE going to be piecing it together through means of a little Wheel of Fortune gaming with Dusty from Twister as our game show host! So here is the game plan for this lesson: You have been given the starting point for the weather radar equation, namely solved for the reflectivity factor, or  $z$  on the left since that is what we ultimately care about. After you spin the wheel to receive instructions from Dusty, your job is to complete the equation by guessing which variables are part of the Weather Radar Equation. Your variables to choose from are: Power Return, the Density of Air, the Radar Constant, Vorticity, and Range. Keep in mind that there are only 3 spots - so a couple of these don't belong in the equation. Whenever you select the correct variable, we will talk more specifically about how that variable affects reflectivity factor. You'll then be redirected back to this slide to spin the wheel again. Okay, that's all the instructions I have for you - once you're ready, click on the wheel to spin it and get further instructions from Dusty!

Congrats, you've successfully pieced together the Weather Radar Equation! Now you can go ahead and click "next" to move on.

## 1.7 Average Power Return

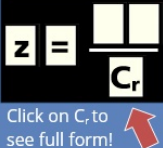


### Notes:

$P_r$  is simply the average amount of power that is returned to the radar after encountering particles in a sample volume. We take the average of the return power as it can vary greatly from pulse to pulse.  $P_r$  is directly proportional to reflectivity factor. In other words, the higher the average return power, the higher the reflectivity factor. So, what things lead to a high average power return? In general,  $P_r$  depends on the number and size of particles in a sample volume. So if there are numerous raindrops or larger targets such as hail in a sample volume, your return power and therefore, reflectivity factor will be much greater. In contrast, if there are only a few small drizzle droplets in a sample volume, the return power and thus reflectivity factor will be much lower. One last thing to quickly note: If you hear the word “radar sensitivity” later on, that just refers to the ability of the radar to detect power return.


## 1.8 Radar Constant

### C<sub>r</sub> – Radar Constant




Click on C<sub>r</sub> to see full form!

"What is this?"



- ❖ The radar constant is a collection of parameters about a specific radar (i.e. fixed characteristics)
- ❖ Calibration keeps these radar constants within acceptable limits
- ❖ |K|<sup>2</sup> is largely dependent on composition of a target (equation assumes **water**: |K|<sup>2</sup> = 0.93)
- ❖ |K|<sup>2</sup> is much lower for ice (0.197) so our equation **UNDERESTIMATES** reflectivity in areas of **snow** and **ice**



\*Not to scale

$$C_r = \frac{\pi^3 p_t g^2 \theta \phi c t |K|^2}{1024 \ln(2) \lambda^2}$$

### Notes:

Okay, let's take a closer look at C<sub>r</sub>, referred to as the radar constant. If you are wondering what exactly this constant is made up of, go ahead click on it to see the fully expanded form. Yikes, I don't know about you, but I much prefer it the way it was before! All jokes aside, a lot of these variables that are wrapped up into the radar constant are just parameters associated with a specific radar. So, things like the wavelength a radar transmits at or the amount of power that is transmitted by the radar. While things are relatively constant, they can actually slowly change over time. To prevent these "constants" from getting too out of line, periodic checks are often performed by the radar operators to make sure they are residing within acceptable limits. This is what is referred to as calibration. Now, I'm not going to go through and talk about each one of these, but if you are curious, you can click on each one and a brief description of what it represents will appear.

However, I do want to briefly draw your attention to the |K| squared term as the assumptions behind it do impact the reflectivity factor. This parameter is referred to as the dielectric constant and its value is largely dependent on the composition of the target that is being sampled. For simplicity, the weather radar equation assumes that the radar is always sampling water droplets, so |K| squared is set to the dielectric constant of water, or 0.93. However, we know that things other than water droplets fall from the sky - such as ice and snow! In those cases, the dielectric constant should actually be much much lower - 0.197 for ice actually! So in regions where ice and snow are occurring, the radar is going to **UNDERESTIMATE** the reflectivity factor there. In other words, the reflectivity factor for snow and ice is generally lower than that of liquid water droplets because of this |K| squared term.

## 1.9 Range

### $R^2$ – Range

- ❖ R represents the range to a target
- ❖ **Power decreases** with increasing distance  
(Decrease in power = distance squared)
- ❖ R is squared to help account for decrease in power for far away targets

$$Z = \frac{R^2}{\quad}$$

After squaring R: Same size target and equal power return



#### Notes:

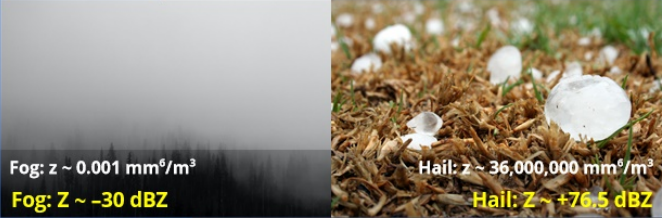
R is essentially the range to a target. As to how it affects the reflectivity factor, let's first discuss it in terms of the actual power transmitted from the radar. When a radar emits a pulse, power return decreases with increasing range for a target of the same size. In fact, this decrease in power is directly proportional to the distance squared. So in the weather radar equation,  $r$  is squared to help account for the decrease in power the further away the target is from the radar. Take a look at the below example:

At 50 km, this precipitating cloud is producing a power return of -16 dB, resulting in a  $Z = 20$  dBZ. At 100 km away, this same precipitating cloud is producing a power return of -22 dB, but because of that  $r^2$  term, it is still producing a reflectivity factor of 20 dBZ. So this variable is designed to help account as best as possible for particles far away from the radar.

## 1.10 Equation Review

**Equation Review**

Largely influenced by number & size of particles

$$z = \frac{\bar{P}_r R^2}{C_r}$$


Fog:  $z \sim 0.001 \text{ mm}^6/\text{m}^3$   
Fog:  $Z \sim -30 \text{ dBZ}$

Hail:  $z \sim 36,000,000 \text{ mm}^6/\text{m}^3$   
Hail:  $Z \sim +76.5 \text{ dBZ}$

Apply logarithmic scale to compress values!

$$Z = 10 \log_{10} \frac{z}{1 \text{ mm}^6 / \text{m}^3}$$

### Notes:

Okay, you've pieced together the Weather Radar Equation and now have a general overview of what each of the terms represent so what else is left? Well, if we were to take reflectivity factor values and directly display them, we'd get a very large range of values. Because the reflectivity factor is largely determined by the number and size of particles in a sample volume, its values can range drastically - from as small as  $.001 \text{ mm}^6/\text{m}^3$  in areas of fog to as large as  $36,000,000 \text{ mm}^6/\text{m}^3$  in areas of hail! Now, this would be pretty bothersome to have to deal with when interpreting reflectivity values on a daily basis so the last step is to take reflectivity factor values from the weather radar equation and compress these values to a smaller range of numbers by using logarithmic values instead of linear values. So capital Z now represents our logarithmic radar reflectivity factor! Using logarithmic reflectivity gives us the advantage of compressing the extreme range of values into much more convenient numbers that we use on a daily basis! For the above example of fog and hail, we are now dealing with a range of  $-30 \text{ dBZ}$  for fog and  $+76.5 \text{ dBZ}$  for large hail on the logarithmic scale - see, much more manageable to say, as well as display on a legend scale!



## 1.11 Assumptions



### Notes:

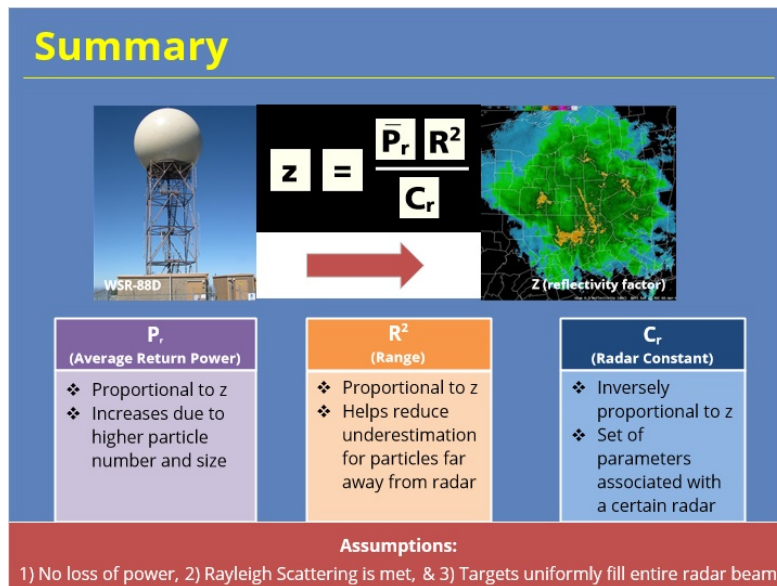
Before we wrap up here, we do need to address several elephants hiding in the room - and by that, I'm referring to several big assumptions that the weather radar equation makes. It's important for us to be aware of these so that we can recognize situations where these assumptions may not be valid and thus where reflectivity data may be off. To see what some of the most major assumptions are, click on each of the elephants in the room to find out.

The weather radar equation assumes that the radar has no loss of power, whether power transmitted or power returned. This loss of power is referred to as "attenuation." However, this is not always a good assumption as there are several situations which can lead to attenuation, including heavy rain, beam blockage, etc.). When attenuation occurs, the returned power signal is significantly weakened resulting in a lower reflectivity factor. So, keep in mind that attenuation can and does occur, even though the weather radar equation assumes that it won't. We'll see some examples of what attenuation looks like in later modules.

For simplicity purposes, the weather radar equation assumes that the diameter of the particles detected are much smaller than the radar wavelength (this is referred to as the "Rayleigh Scattering" assumption). However, when you start to get very large hydrometeors, such as hail, this assumption is no longer true as particles now fall under the "Mie Scattering regime." The end result is that reflectivity values no longer increase linearly with particle diameter. In other words, things get more complicated.

The weather radar equation assumes the ENTIRE radar beam is UNIFORMLY filled with targets. However, we know that this isn't always true, especially at increasing distances from the radar. When this assumption is not true, it can lead to either an over- or under-estimation of Z values as we'll see some examples of later on in another module.

## 1.12 Summary



### Notes:

Before I send you off to take the quiz, let's quickly review the main highlights from today's module. First, you successfully pieced together the weather radar equation as is shown here! Remember that the weather radar equation is the means from which we can go from power transmitted from the radar to getting something as useful as reflectivity! We learned that there are essentially three main variables that affect the reflectivity factor. The average power return is directly proportional to reflectivity factor and things that increase average power return include the number and size of particles in a sample volume. Range, or  $R$  is also directly proportional to  $Z$  and attempts to help minimize lower reflectivities the further away from the radar you are by squaring that  $r$  term. The radar constant, while scary when unpacked, is essentially just a large set of parameters associated with a specific radar. Lastly, we briefly mentioned a few main assumptions that the weather radar equation makes that are important for you to be aware of including:

- Assuming no power loss
- Assuming Rayleigh scattering
- And assuming targets fill the entire radar beam uniformly

Alright, that's all for today's module - when you are ready, click "next" to take the quiz!



# Transmitting & Receiving Characteristics

## 1. Intro to Radar Beam Characteristics

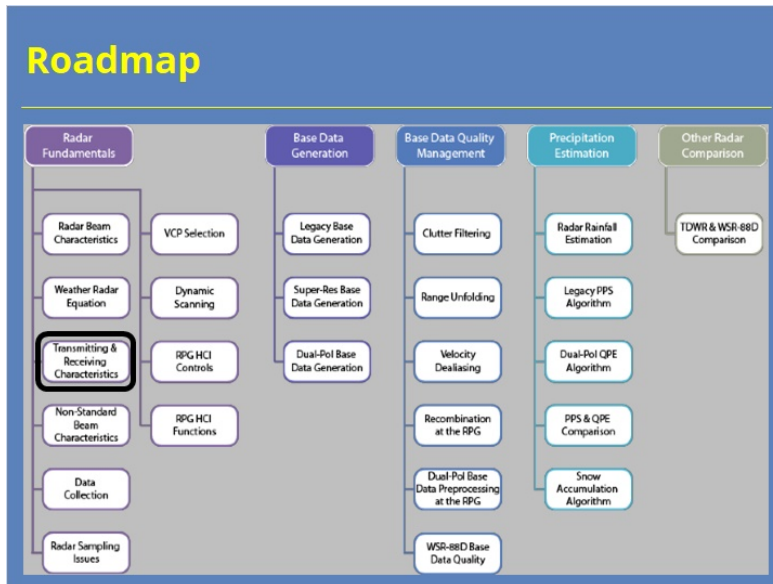
### *Welcome*



### **Notes:**

Welcome to the Radar & Applications Course (RAC) Principles of Doppler Weather Radar. This lesson is on Transmitting and Receiving Characteristics of the WSR-88D radar. Let's get started!

## Roadmap



### Notes:

Here is the complete roadmap for the entire "Principles of Doppler Weather Radar" topic of RAC. You are currently in the Radar Fundamentals section of that topic.

## ***Learning Objectives***

### **Learning Objectives**

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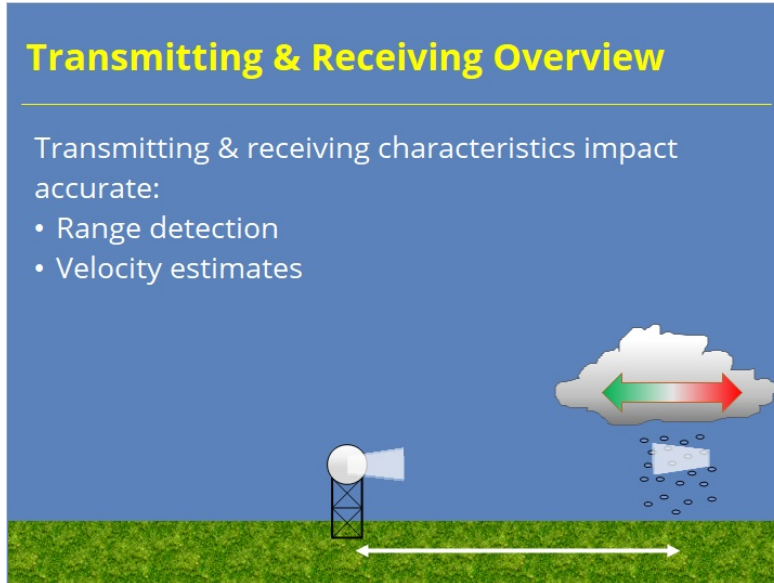
1. Identify the two characteristics determined by the Pulse Repetition Frequency (PRF)
2. Identify the relationship between PRF and Pulse Repetition Time (PRT)
3. Identify the relationships between PRF and maximum unambiguous range and velocity
4. Identify the Doppler Dilemma
5. Identify why the WSR-88D has two pulse duration modes
6. Identify why the target range equation divides by a factor of 2
7. Identify why range folding (RF) occurs with the WSR-88D

#### **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

### *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.

Accurate range detection depends on the transmitting and receiving characteristics of the radar. The WSR-88D also measures velocity which has a similar dependence on those characteristics. This lesson will discuss how range and velocity information are impacted by the radar's transmitting and receiving characteristics and describe what these key characteristics are.

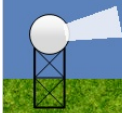
## ***Pulse Repetition Frequency (PRF)***

### **Pulse Repetition Frequency (PRF)**

The number of pulses sent out by the radar per second

**Sample Doppler PRF Set (Set C):**

PRF No.	PRF ( $s^{-1}$ )	PRF No.	PRF ( $s^{-1}$ )
1	446	5	1014
2	802	6	1095
3	857	7	1181
4	926	8	1282



#### **Notes:**

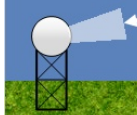
One key transmitting characteristic is pulse repetition frequency (PRF). The PRF determines the number of pulses sent out by the radar every second. The WSR-88D can assign one of eight different PRFs to a pulse depending on the waveform in use. This slide shows a table with a sample set of PRFs that could be implemented. We will explain why the PRF matters in a bit.

## ***Pulse Repetition Time (PRT)***

### **Pulse Repetition Time (PRT)**

The time elapsed between two pulses

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



Time

$$\text{PRT} = 1/\text{PRF}$$

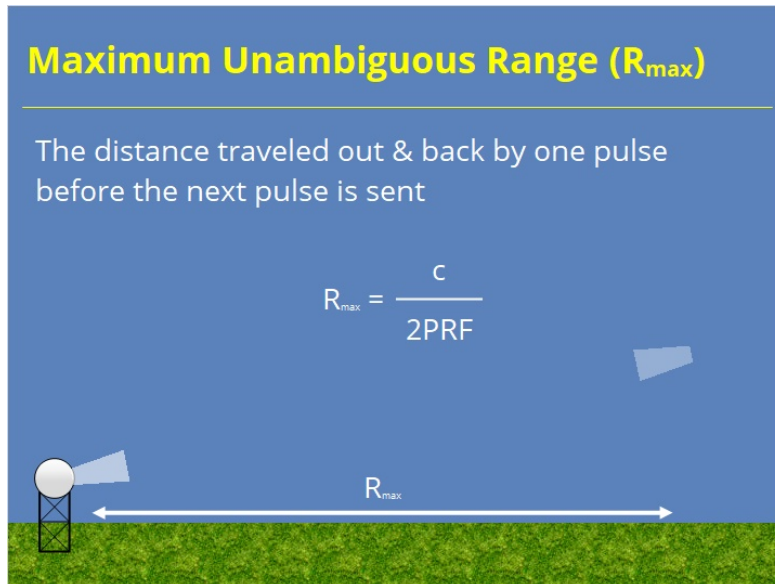
#### **Notes:**

Another way to look at the PRF is the Pulse Repetition Time (PRT). PRT tell you how much time elapses between two consecutive pulses and is simply the reciprocal of the PRF. For the eight PRF options shown on the last slide, we provide their PRTs in this table. PRTs are very short!

## **Maximum Unambiguous Range ( $R_{\max}$ )**

**Maximum Unambiguous Range ( $R_{\max}$ )**

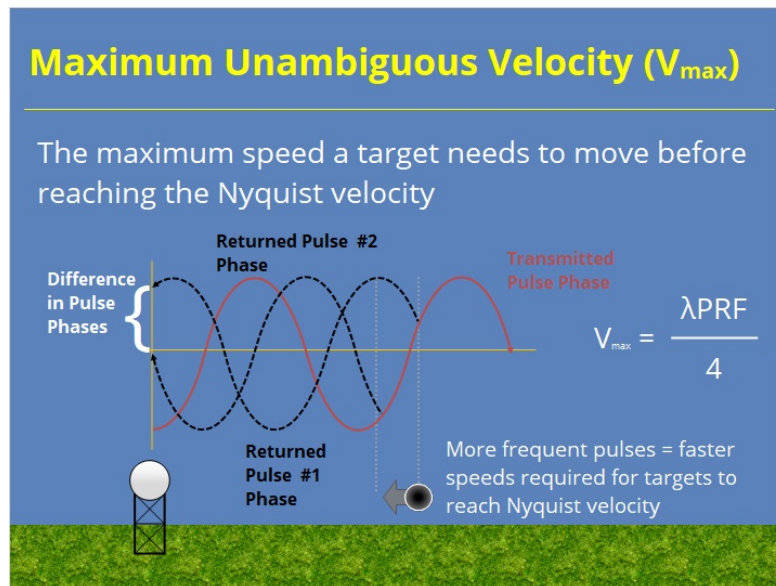
The distance traveled out & back by one pulse before the next pulse is sent

$$R_{\max} = \frac{c}{2\text{PRF}}$$


### **Notes:**

As the WSR-88D emits radiation to determine the range to targets, one might ask if there's a range limit to this process. There is! The maximum unambiguous range (or  $R_{\max}$ ) tells you how far the first pulse travels out and back before the next pulse is transmitted. We determine  $R_{\max}$  by taking the speed of light ( $c$ ) and divide it by two times the PRF. We use two times the PRF because the pulse must travel there and back again. This relationship tells us that the maximum unambiguous range is inversely proportional to PRF. In other words, as the radar sends out more frequent pulses,  $R_{\max}$  decreases and vice versa.

## Maximum Unambiguous Velocity ( $V_{\max}$ )



### 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, the resulting phase difference leads to an ambiguous velocity. For a given sampling rate, the speed limit where this ambiguity is reached is called the Nyquist Velocity, maximum unambiguous velocity, or  $V_{\max}$ . How do we get around this ambiguity? If the radar PRF increases, then scatters don't move as far between pulses which makes ambiguity less likely. So, the higher the PRF, the higher the  $V_{\max}$ .



## Doppler Dilemma

### Doppler Dilemma

Fewer pulses = Long  $R_{\max}$ , but low  $V_{\max}$

More pulses = High  $V_{\max}$ , but short  $R_{\max}$

$$R_{\max} = \frac{c}{2\text{PRF}} \quad V_{\max} = \frac{\lambda \text{PRF}}{4}$$

Scanning strategies have been designed to mitigate the Doppler Dilemma



#### Notes:

At this point, you might think we have a dilemma. You're right we do...the Doppler dilemma! Lower PRFs give us better range detection and higher PRFs reduce velocity ambiguities. It feels like we have to choose one option or the other, hence the dilemma. Fortunately, radar engineers devised a work around when developing scanning strategies for the WSR-88D. We will discuss how scanning strategies can help maximize both  $R_{\max}$  and  $V_{\max}$  in a later lesson. For now, you just need to know that PRF has opposite impacts on  $R_{\max}$  and  $V_{\max}$ .

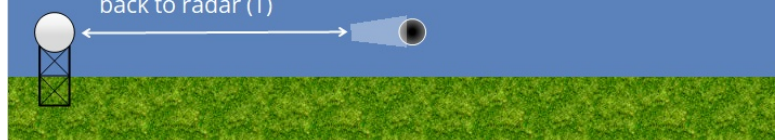
## Target Range Equation

**Target Range Equation**

$$\text{Range} = \frac{cT}{2}$$

Time taken for pulse to reach target and get back to radar (T)

\*\*\*Factor of 2 in denominator because we only want one-way distance



### Notes:


When the pulse returns to the radar, we want to know how far away the echo that reflected the signal was. We can determine the range from our knowledge of the pulse's speed and how long it has been since the pulse was transmitted. If we multiple those two together and divide by two (because the pulse travels there and back again), we get the target's range.

## ***Pulse Duration***

### **Pulse Duration**

The length of time spent transmitting a pulse

Longer pulse duration = more power density (a.k.a. sensitivity)



Short Pulse  
(1.57  $\mu\text{sec}$ )

Long Pulse  
(4.7  $\mu\text{sec}$ )

#### **Notes:**

Pulse duration represents another important transmitting characteristic. It is simply the length of time the radar spends transmitting a pulse. As pulse duration increases, the pulse's power density (and generally its sensitivity) increases. The WSR-88D incorporates two pulse duration modes: short pulse mode and long pulse mode. Short pulses transmit for 1.57 microseconds, and long pulses transmit for 4.7 microseconds. All but one volume coverage pattern uses short pulse mode. We'll explain why that is on the next slide.

## ***Listening Period***

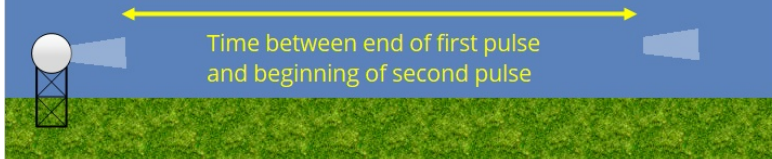
**Listening Period**

---

Length of time spent listening for radar returns

Short Pulse Mode = 99.8%  
Long Pulse Mode = 99.5%

Velocity estimates less reliable in long pulse mode

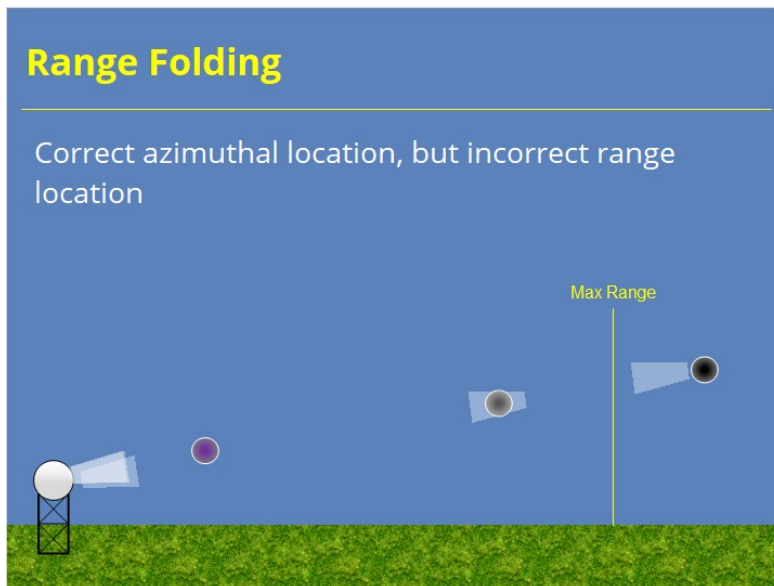


The diagram shows a radar antenna on a green grassy field. A yellow double-headed arrow spans the time between the end of the first pulse and the beginning of the second pulse. The text 'Time between end of first pulse and beginning of second pulse' is written below the arrow.

### **Notes:**

Radars can transmit and listen, but not at the same time. Therefore, longer pulse durations mean less listening for radar echo returns. The listening period refers to the period of time not transmitting a pulse. Specifically, the listening period starts when the first pulse stops transmitting and ends when the second pulse starts. The WSR-88D listens in short pulse mode 99.8% of the time and 99.5% of the time in long pulse mode. In either mode, the radar is a very good listener. However, that small difference between short and long pulse modes does have a significant impact on velocity estimates. Velocity estimates are less reliable in long pulse mode. That's why long pulse mode is only used in one volume coverage pattern.

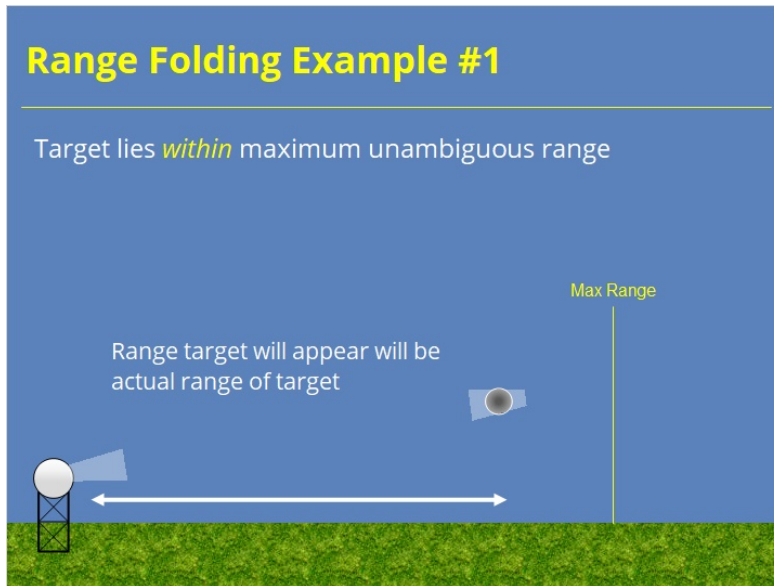
## ***Range Folding***



### **Notes:**

Now that you know the target range equation, let's talk about 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. If the returned pulse arrives after the second pulse is transmitted, the radar will think the data was from the latest pulse, not the first one. The radar will then place the echo closer to the radar than it actually is. This phenomenon is called range folding.

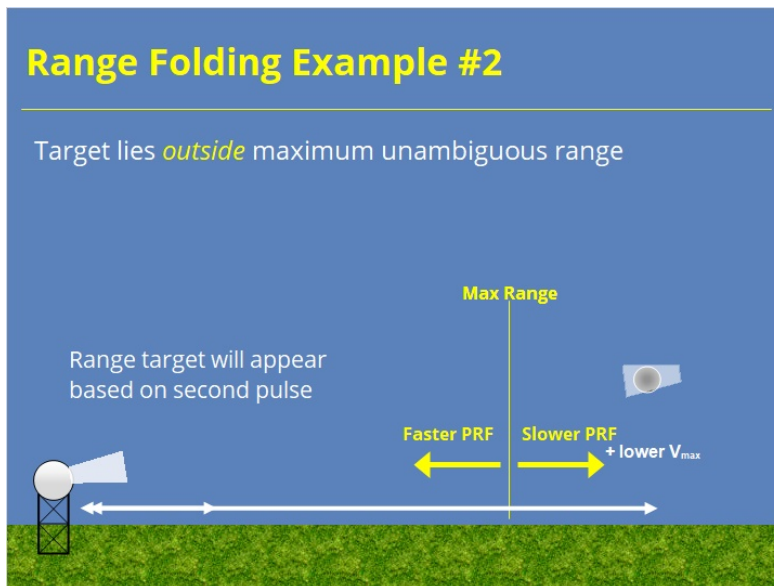
## Range Folding Example #1



### Notes:

This first example shows the normal case where no range folding will occur. The radar sends out the pulse, encounters a target before the maximum unambiguous range (also known as the first trip), and returns an echo to the radar. The returned pulse arrives at the radar before the second pulse is transmitted and therefore gets the correct range applied to it.

## Range Folding Example #2



### Notes:

In this second example, the target lies outside the maximum unambiguous range. When the first pulse encounters the target, the target returns some of the power back towards the radar. However, before that energy can return, a second pulse is transmitted. When the first pulse makes it back to the radar, the radar thinks this power return is from the second pulse, not the first one. Therefore, the radar places the target at a closer range than where it actually resides. It is range folded.

Remember our earlier conversation about how the pulse repetition frequency, or PRF, affected max range? A lower PRF would result in a farther max range since the pulse would have more time to return before a new one is sent. In this way, adjusting the PRF used by the radar can make range folding less of a problem. Remember, though, that there is a cost. Using a lower PRF does result in a lower maximum ambiguous velocity, thanks to the Doppler Dilemma.

### 3. Quiz

#### *Summary*

##### Summary

- Transmitting & receiving characteristics impact:
  - Range estimates
  - Velocity estimates
- PRF/PRT determine the  $R_{\max}$  &  $V_{\max}$  for the pulse (Doppler Dilemma)
- Pulse duration related to  $R_{\max}$
- Targets located beyond the  $R_{\max}$  range folded
  - Appear closer to radar than actuality

#### **Notes:**

In summary, we discussed how certain transmitting and receiving characteristics of the WSR-88D radar pulse impact the range and velocity estimates we can accurately measure. When transmitting the radar pulse, the pulse repetition frequency and time help determine both the maximum unambiguous range and velocity that can be measured. This relationship leads to the Doppler dilemma. The WSR-88D applies different scanning strategies to address this conundrum.

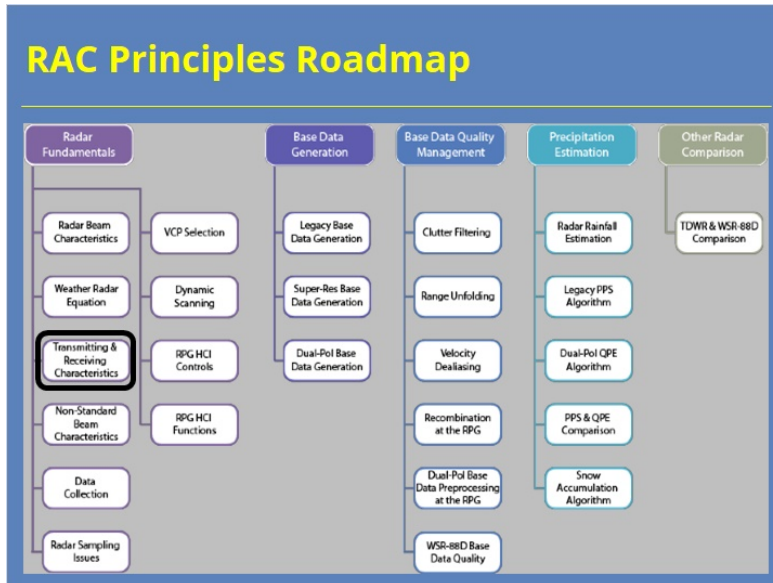
When receiving the radar pulse, the pulse duration becomes significant. This time is related to the maximum unambiguous range and the potential for range folded data. When targets are located beyond that  $R_{\max}$  for a particular PRF, those targets will appear closer to the radar than they actual are. Fortunately, the WSR-88D uses a combination of scanning strategies and algorithms to unfold these data in many situations, but certainly not all.

When you are ready, click the next button to start the quiz.



## 4. Completion

### *RAC Principles Roadmap*



#### **Notes:**

Thank you for completing this lesson. Click the Exit button to complete the lesson, and proceed on to the next lesson in the topic.

# Non-Standard Beam Consequences

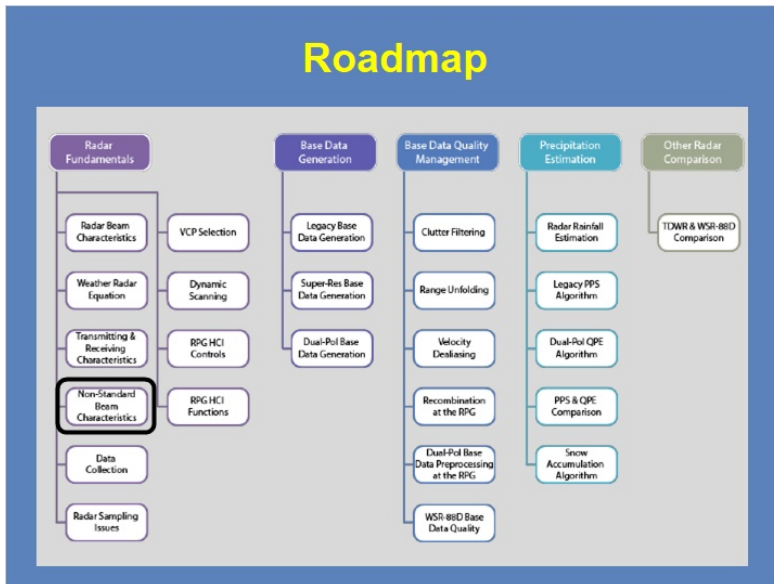
## *Welcome*



### **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).

## Roadmap



### Notes:

Here is the complete roadmap for the “Principles of Doppler Weather Radar” section of RAC. You are currently in the WSR-88D Fundamentals portion of this section.

## ***Learning Objectives***

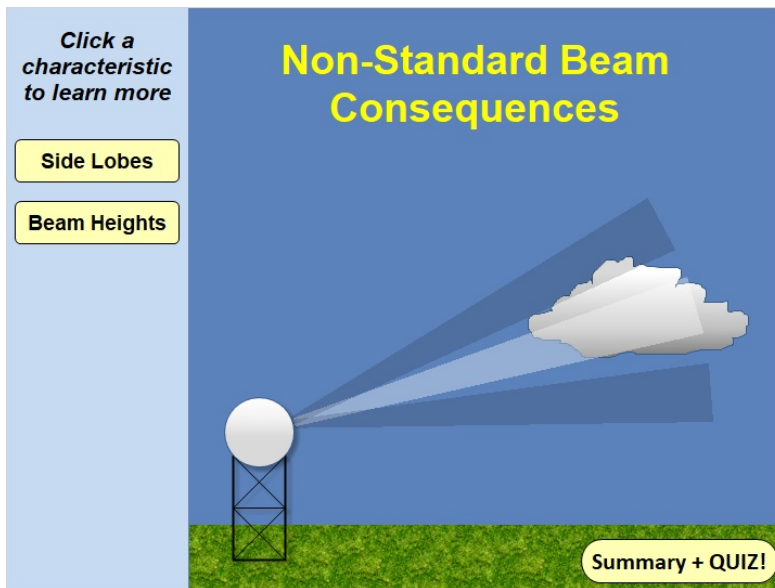
### **Learning Objectives**

1. Identify the definition of side lobe contamination
2. Identify the most likely scenario that will exhibit side lobe contamination
3. Identify why the AWIPS and RPG beam heights may be slightly different
4. Identify the atmospheric conditions which lead to sub-refraction, super-refraction, and ducting
5. Identify how beam height estimations will be affected by sub-refraction and super-refraction

#### **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.

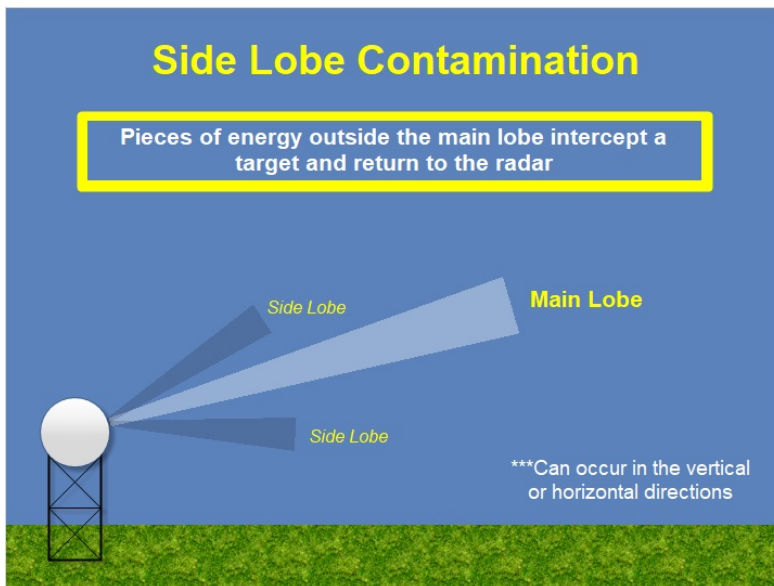
## ***Non-Standard HOME***



### **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.

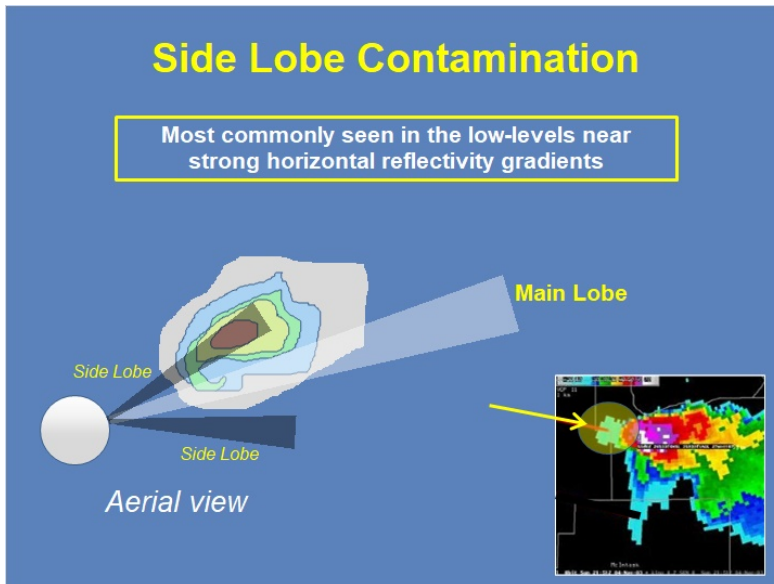
## ***Side Lobe Definition***



### **Notes:**

Recall that the initial energy for the beam is generated by the transmitter and is isotropic in nature, meaning it 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 targets. 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.

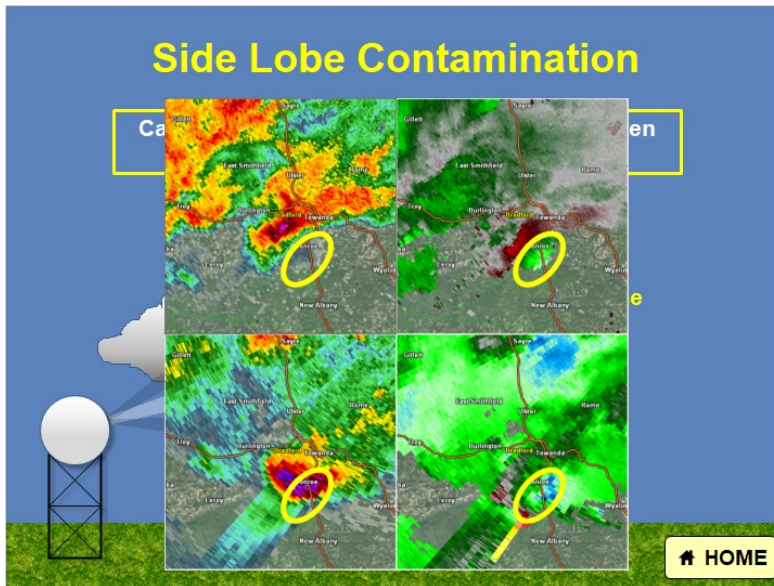
## ***Side Lobe Horizontal***



### **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 the core. Here is an example of side lobe contamination.

## ***Side Lobe Vertical***

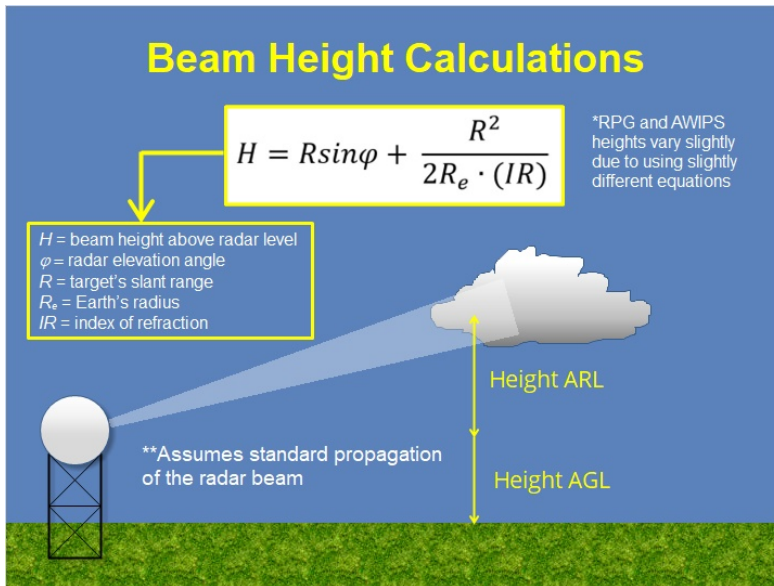


### **Notes:**

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



## Beam Height Calcs

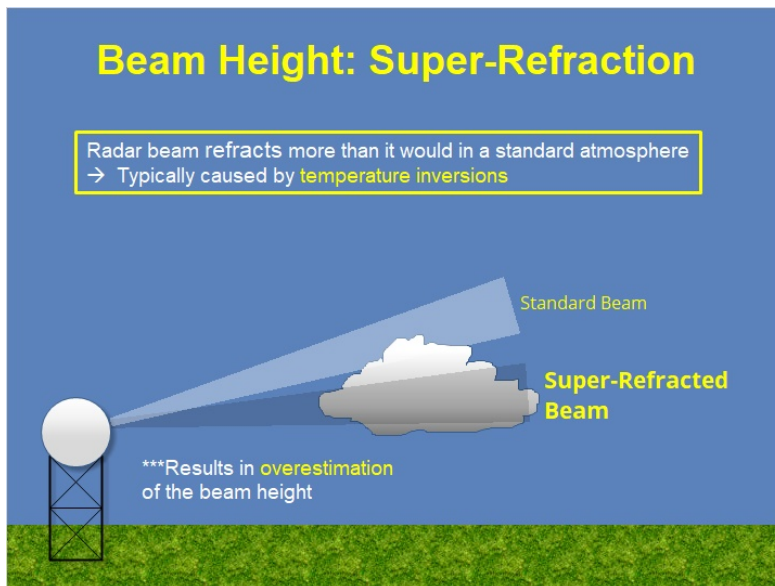


### Notes:

Beam height is one factor that can cause inaccuracies in radar data. Here's the equation which states the beam height. It's not so important to remember the details, but you may want to take a minute to look over what each variable means to orient yourself with this equation before we move on...

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 just slightly off.

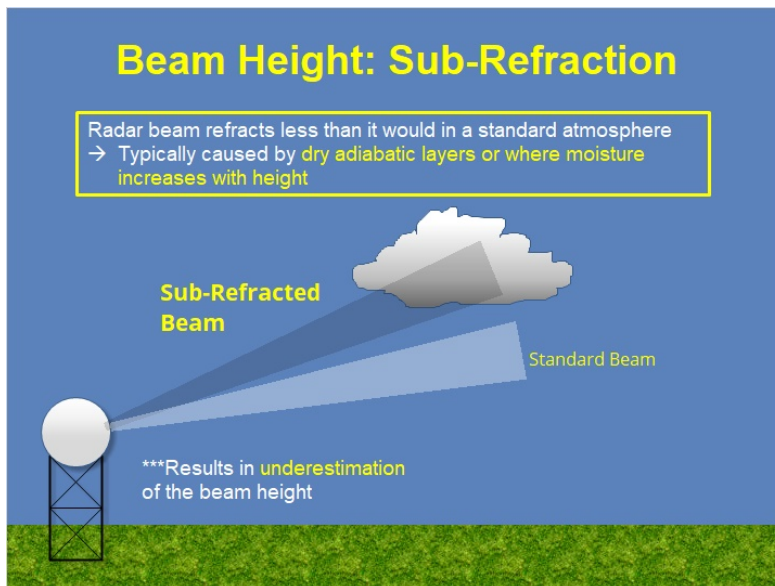
## ***Super-Refraction***



### **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 toward 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 the reported beam height is overestimated. Let's look at the next case... sub-refraction.

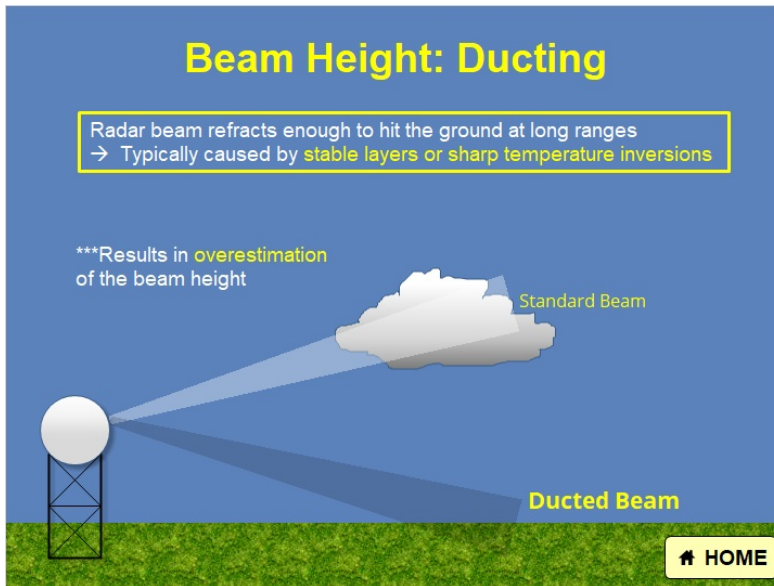
## ***Sub-Refraction***



### **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 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.

## Ducting



### Notes:

A radar beam can sometimes get trapped in a layer and actually bend 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.

## Summary

### Summary

- Side lobe contamination occurs when pieces of energy outside the main lobe intercept a target and return to the radar
  - Most commonly seen in the low-levels near strong horizontal reflectivity gradients
- RPG and AWIPS use slightly different equations to determine beam heights
- Super-refraction typically occurs with temperature inversions
- Sub-refraction typically occurs when moisture increases with height
- Beam height can be over or underestimated if super-refraction or sub-refraction is occurring, respectively

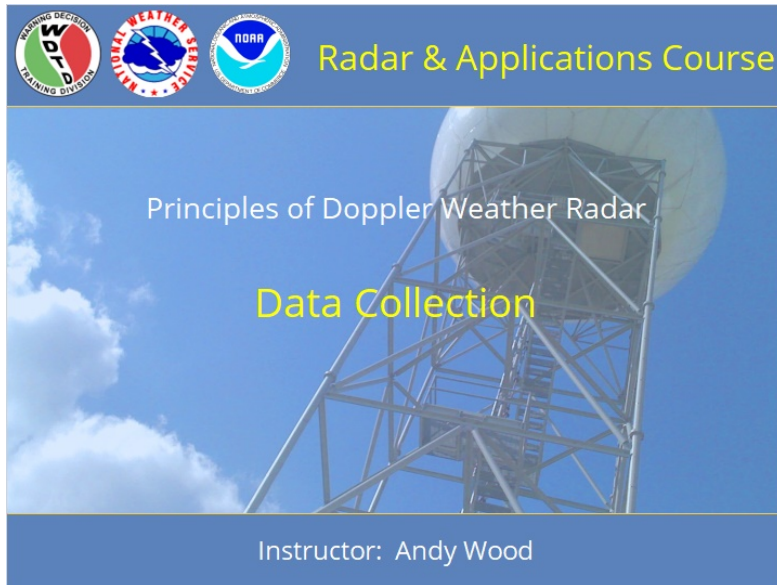
#### Notes:

Let's review what we've learned in this lesson. Side lobe contamination occurs when pieces of energy outside the main lobe intercept a target and return to the radar, and is most commonly seen in low-levels near strong reflectivity gradients. Beam height is another factor that can affect radar estimations, and RPG and AWIPS use slightly different equations to determine beam height. Super-refraction typically occurs with temperature inversions and sub-refraction typically occurs when moisture increases with height. Beam height can be over or underestimated if super-refraction or sub-refraction is occurring, respectively. Click next when you're ready to take the quiz!

# Data Collection

## 1. Intro to Radar Beam Characteristics

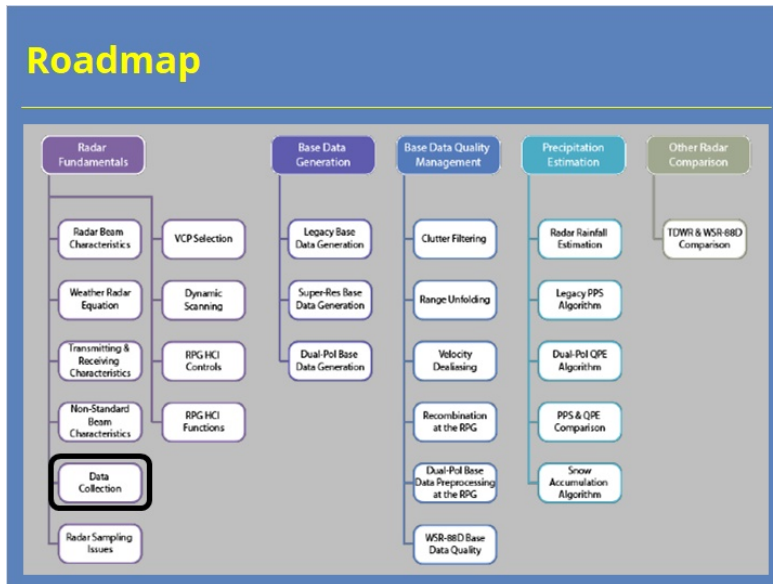
### 1.1 Welcome



#### Notes:

Welcome to the Radar & Applications Course (RAC) Principles of Doppler Weather Radar. This lesson is on Data Collection. Let's get started!

## 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!

## ***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

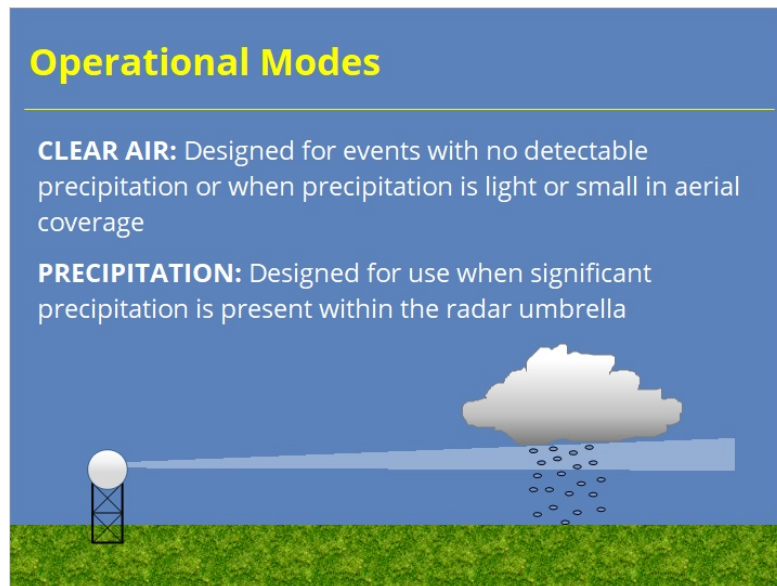
### *Data Collection HOME*



#### **Notes:**

Previous lessons have explained how the radar transmits and receives energy in order to detect meteorological targets. Now we shall build on that knowledge to see how the radar collects data in the most efficient way possible. Every radar implements a scanning strategy to examine a volume of the atmosphere for targets. The WSR-88D is no different. The 88Ds use an operational mode to determine a Volume Coverage Pattern (VCP) that will employ a waveform technique to collect data. VCP specifics will be covered in a later lesson. Here we will focus on operational modes and waveform techniques.

## ***Operational Modes***



### **Notes:**

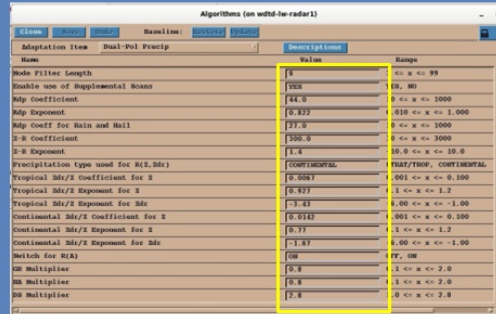
The whole idea of the WSR-88D is to detect precipitation echoes, but the radars run 24/7. So, when weather is not present, the radar is still running. So, it naturally follows there are just two operational modes which are Clear Air and Precipitation. Clear Air mode is primarily used when there are no 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.

The operational mode can be chosen automatically by the radar or manually by the radar operator. We will discuss the automated process over the next several slides.

## Adaptable Parameters

### Adaptable Parameters

- Variables that algorithm rely on to function



Name	Value	Range
Mode Filter Length	1	0 <= x <= 99
Enable use of Supplemental Scans	YES	YES, NO
Adp Coefficient	14.0	0 <= x <= 1000
Adp Exponent	0.133	0.010 <= x <= 1.000
Adp coeff for Rain and Hail	33.0	0 <= x <= 1000
Z-R Coefficient	100.0	0 <= x <= 1000
Z-R Exponent	1.4	10.0 <= x <= 10.0
Precipitation type used for R(Z, Rr)	CONTINENTAL	TROP/TROP, CONTINENTAL
Tropical Rr/Z Coefficient for Z	0.004	0.001 <= x <= 0.100
Tropical Rr/Z Exponent for Z	0.933	0.1 <= x <= 1.2
Tropical Rr/Z Exponent for Rr	-3.43	0.00 <= x <= -1.00
Continental Rr/Z Coefficient for Z	0.014	0.001 <= x <= 0.100
Continental Rr/Z Exponent for Z	0.77	0.1 <= x <= 1.2
Continental Rr/Z Exponent for Rr	-3.87	0.00 <= x <= -1.00
Switch for RRA	ON	ON, OFF
GR Multiplier	0.8	0.1 <= x <= 2.0
RB Multiplier	0.8	0.1 <= x <= 2.0
RS Multiplier	2.8	0.0 <= x <= 2.8

- Changes only w/guidance from radar focal point or lead on duty

#### Notes:

Before discussing how the WSR-88D chooses the operational mode, we should briefly mention adaptable parameters first. Adaptable parameters are key variables the WSR-88D algorithms rely on to function. Although adaptable parameters (as the name suggests) can be changed, most of them should not be without proper guidance from your radar focal point. Radar focal points or lead forecasters on duty will generally be responsible for making any changes that might be needed. However, all forecasters should know these exist and how they might impact certain radar products. We will discuss those specifics periodically throughout the course.

## Clear Air to Precipitation Mode

### Clear Air to Precipitation Mode

Adaptation Item	Mode Selection	Value	Range
Precip Mode dBZ Thresh		30.0	-33.0 <= x <= 95.0, dBZ
Precip Mode dBZ Areal Coverage Thresh		80	0 <= x <= 00000, km^2
Clear Air Mode Selection Time		20	0 <= x <= 60, min
Mode Conflict Duration		8	2 <= x <= 40, hr
Ignore Mode Conflict Duration?		No	No, Yes

Two adaptable parameters significant:

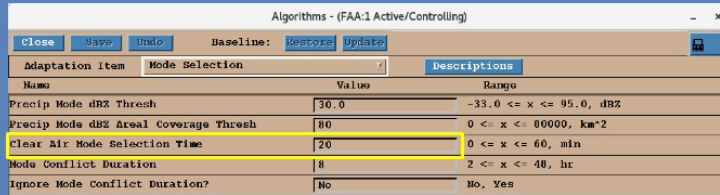
- Precip Mode dBZ Thresh (default = 30 dBZ)
- Precip Mode dBZ Areal Coverage Thresh (default = 80 km<sup>2</sup>)

#### Notes:

There are two adaptable parameters that play a role in this part of operational mode selection (or what is sometimes called the mode selection function). When in clear air mode, the WSR-88D will use a reflectivity threshold to determine if radar echoes capable of accumulating precipitation are present. The default value is 30 dBZ. If reflectivity data exceeding this threshold exists, the radar will then determine if the echo coverage area that meets or exceeds another threshold. That default value is 80 km<sup>2</sup>. If both conditions are met, the WSR-88D will switch to precipitation mode after the current volume scan is complete.

## Precipitation Mode to Clear Air

### Precipitation Mode to Clear Air



Algorithms - (FAA:1 Active/Controlling)		
Close Save Undo Baseline: <b>SPOTORM</b> Update		
Adaptation Item	Mode Selection	Descriptions
Name	Value	Range
Precip Mode dBZ Thresh	30.0	-33.0 <= x <= 95.0, dBZ
Precip Mode dBZ Areal Coverage Thresh	80	0 <= x <= 00000, km^2
Clear Air Mode Selection Time	20	0 <= x <= 60, min
Mode Conflict Duration	8	2 <= x <= 40, hr
Ignore Mode Conflict Duration?	No	No, Yes

One additional parameter to consider:

- Clear Air Mode Selection Time (default = 20 min)

#### Notes:

When in precipitation mode, the reverse process occurs with one additional adaptable parameter to consider. If the reflectivity and areal coverage threshold are not met, a timer starts. Once this threshold has not been met for a particular period of time, then the next volume scan will switch back to clear air mode. By default, this period is 20 minutes.

## Operational Mode Vs. Accumulation

### Operational Mode Vs. Accumulation

Mode Selection:

Name	Value	Range
Precip Mode dBZ Thresh	30.0	-33.0 <= x <= 95.0, dBZ
Precip Mode dBZ Areal Coverage Thresh	80	0 <= x <= 80000, km^2
Clear Air Mode Selection Time	20	0 <= x <= 60, min

Hydromet Preprocessing (Precip Accumulation):

Name	Value	Range
Maximum Allowable Percent Likelihood of Clutter [CLUTTHRESH]	75	0 <= x <= 100
Reflectivity (dBZ) Representing Significant Rain [RAINF]	20.0	10.0 <= x <= 40.0
Area with Reflectivity Exceeding Significant Rain Threshold [RAINF]	100	0 <= x <= 80

These are different parameters & processes!

#### Notes:

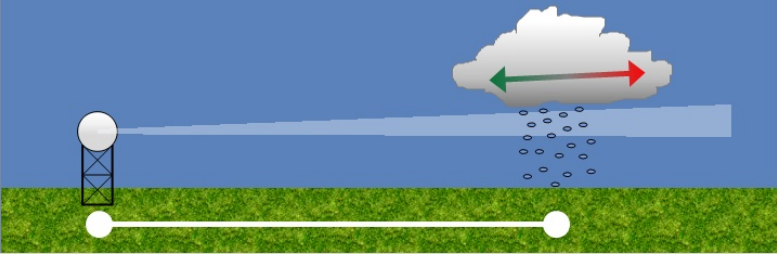
There's one last point I wish to make about operational mode. Later on in this topic, we will discuss the precipitation accumulation algorithms. It's important to know that the radar's mode selection function is a separate process from precipitation accumulation. So, the radar can be in clear air mode and accumulate precipitation. Likewise, the radar can be in precipitation mode and not accumulate precipitation. Forecasters can get stuck on this point, so we will mention it again later.

## Waveforms

**Waveforms**

**CONTIGUOUS SURVEILLANCE (CS):** Use of constant low PRF to get the best maximum unambiguous range ( $R_{\max}$ )

**CONTIGUOUS DOPPLER (CD):** Use of constant high PRF to get the best maximum unambiguous velocity ( $V_{\max}$ )



The diagram illustrates a radar system on a green ground plane. A radar antenna on the left emits a blue beam towards a white cloud target in the distance. The cloud has a green arrow pointing left and a red arrow pointing right, indicating motion. Below the cloud, a series of small circles represent the radar's range gates. A horizontal line with two white dots at its ends is positioned on the ground plane, likely representing the range scale.

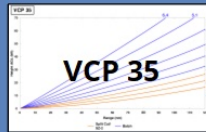
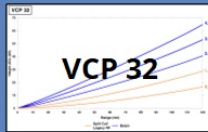
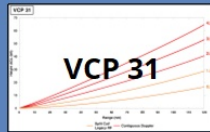
### Notes:

Within each of these operational modes, there is a subset of different scanning strategies. Each WSR-88D radar pulse can employ one of 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...

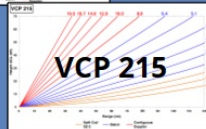
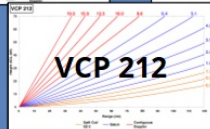
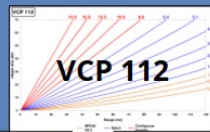
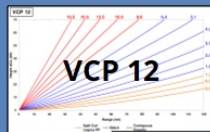
## VCPs

### Volume Coverage Patterns

Clear  
Air:



Precipitation:



#### 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, 112, 212, and 215. In the next couple slides, we'll take a little closer look at the general characteristics of these VCPs...



## Clear Air VCPs

### Clear Air VCPs

Slower antenna rotation rate = improved data accuracy

VCP	Volume Update Time	Scan Characteristics
31	10 min	Long Pulse (60-90 pulses per radial)
32	10 min	Short Pulse (180-300 pulses per radial)
35	8 min	More elevation cuts, tilts similar to VCP 12

#### 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...

## Precip VCPs

### Precipitation VCPs

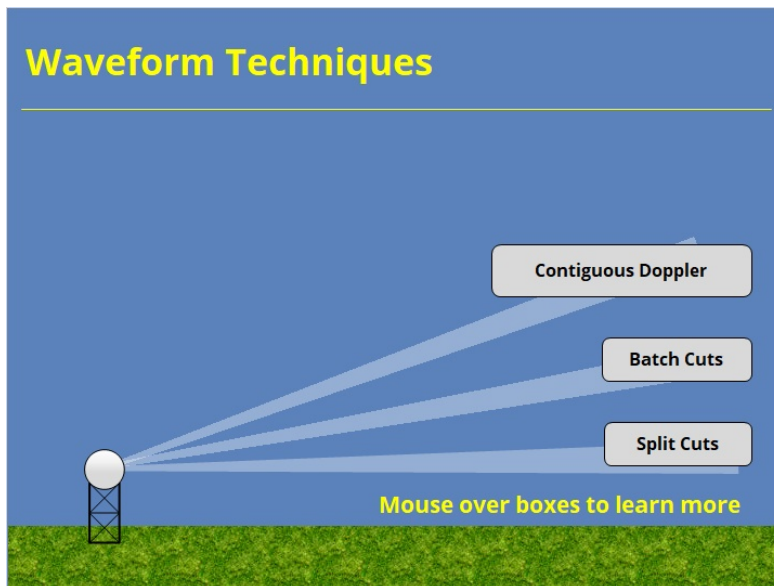
Higher tilts = A more complete view of storms

VCP Goal	VCP Options & Scan Times	Scan Characteristics
Severe Convection	12 & 212 (4-5 min)	Optimized for severe convection
General Surveillance	215 (7 min)	Longer scan times, but better data quality
RF Mitigation	112, 212, & 215 (4-7 min)	MPDA: 112 only SZ-2: 112*, 212, 215 *VCP 112 combines both

#### 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 112, 212, and 215. VCP 112 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.

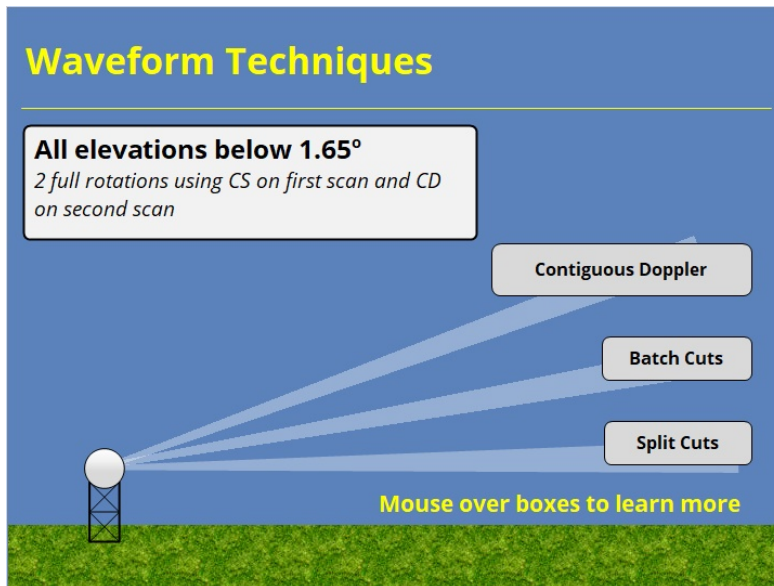
## Waveform Techniques



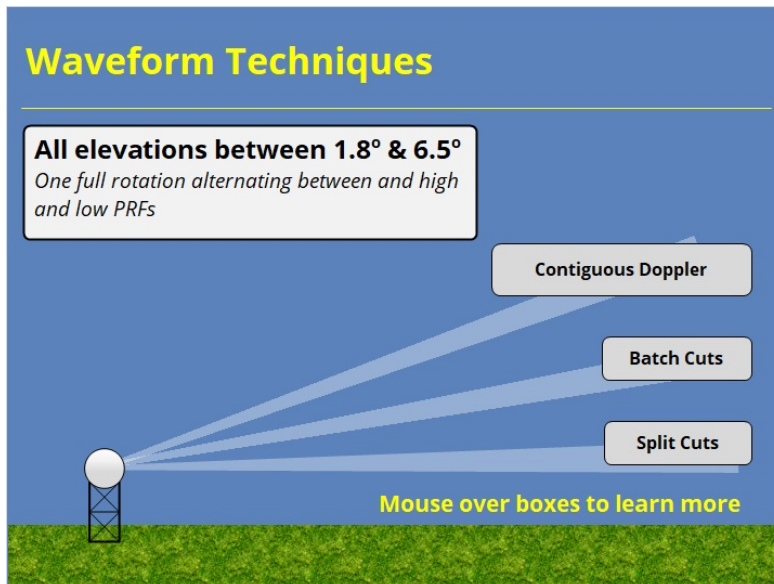
### Notes:

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.

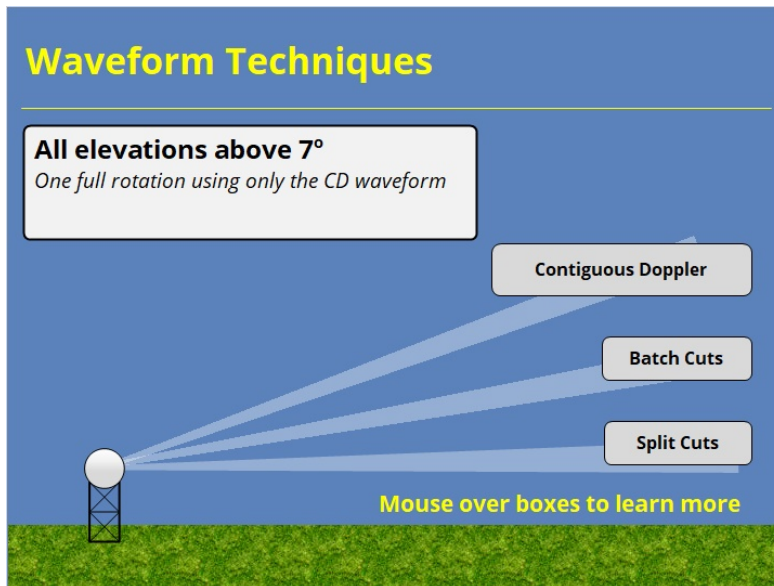
## Split Cuts (Slide Layer)



## Batch Cuts (Slide Layer)



## CD Cuts (Slide Layer)



### 3. Quiz

#### *Summary*

##### Summary

###### Operational Modes:

- Clear Air Mode (VCPs 31, 32, & 35)
- Precipitation Mode (VCPs 12, 112, 212, & 215)

###### Waveforms & Waveform Techniques:

- Contiguous Surveillance (Batch & Split cuts only)
- Contiguous Doppler (Used on all cuts)

#### **Notes:**

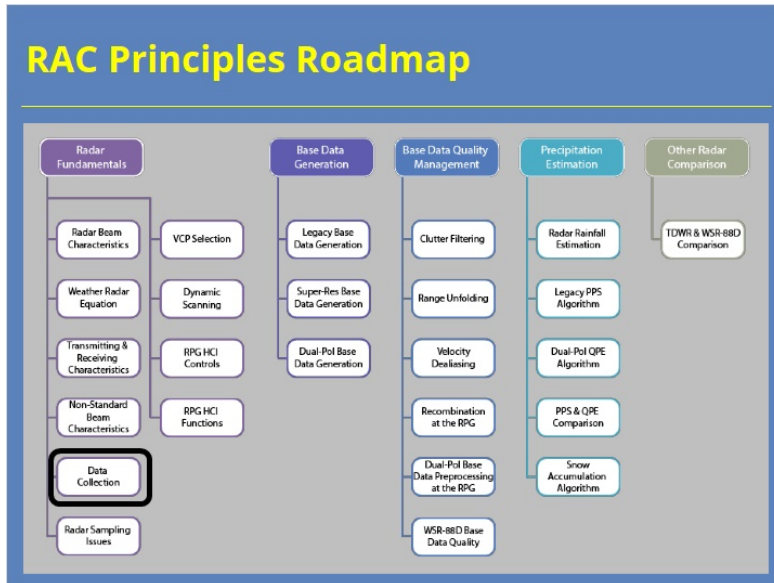
In summary, the WSR-88D uses two operational modes to determine which VCPs are available for use. In Clear Air mode, there are three VCPs. In Precipitation mode, there are four. The VCP Selection lesson will discuss all of these VCPs in more detail.

As the radar scans the atmosphere, it uses two waveforms. Contiguous surveillance waveforms attempt to maximize the unambiguous range while Contiguous Doppler waveforms attempt to maximize the unambiguous velocity. The elevation tilt determines which waveforms are implemented in its waveform techniques. Split cuts perform separate full sweeps of CS or CD waveforms. Batch cuts alternate between CS and CD waveforms throughout the sweep. At higher tilts, the radar uses CD waveforms alone because range folding is much less likely to impact returns.

When you are ready to proceed, click the next button to take the quiz.

## 4. Completion

### *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.

# Radar Sampling Issues

## 1. Intro to Radar Beam Characteristics

### *Welcome*

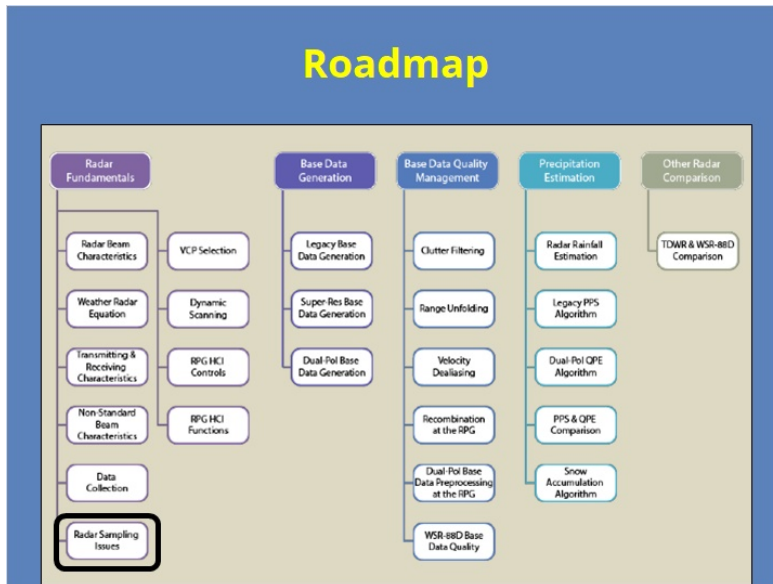


### **Notes:**

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!



## 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!

## ***Learning Objectives***

### **Learning Objectives**

1. Identify the key effect radar sampling issues have on radar-identified features
2. Identify a negative cue
3. Identify the primary factors in radar beam height estimation errors and uncertainty
4. Identify how aspect ratio affects radar signatures
5. Identify how radar horizon affects the parts of the storm radar can see

#### **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.

## ***Learning Objectives***

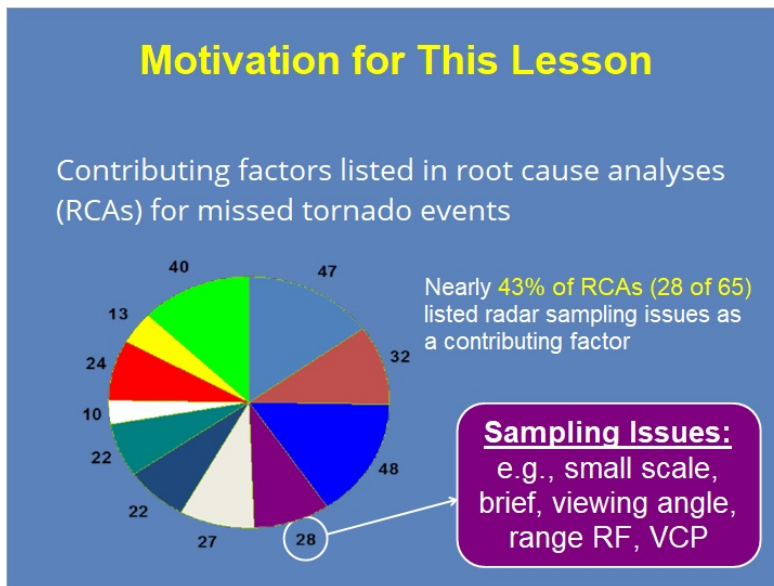
### **Learning Objectives**

6. Identify why buffers should be placed around radar signatures for public warnings
7. Identify how a user can overcome beam blockage issues
8. Identify how viewing angle primarily affects velocity interpretation
9. Identify the most likely scenario to experience noticeable side lobe contamination
10. Identify the products that are directly affected by non-uniform beam filling (NBF) and differential attenuation

#### **Notes:**

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

## Motivation for This Lesson

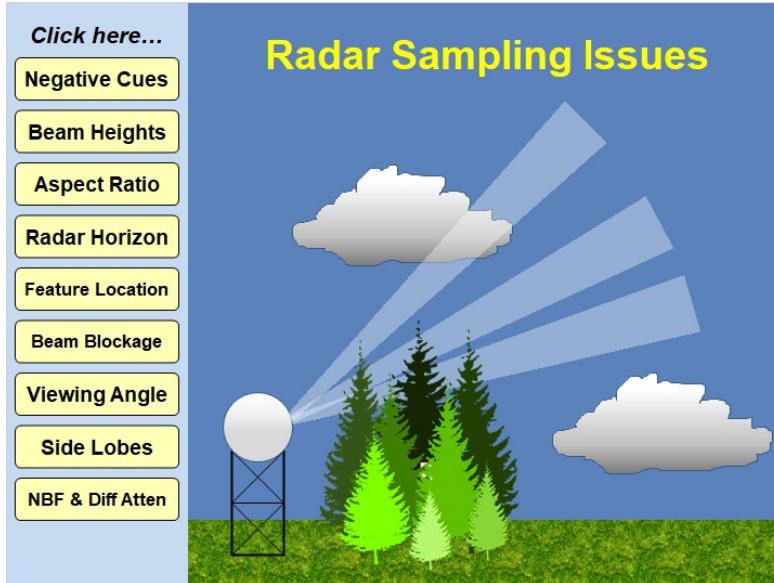


### Notes:

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

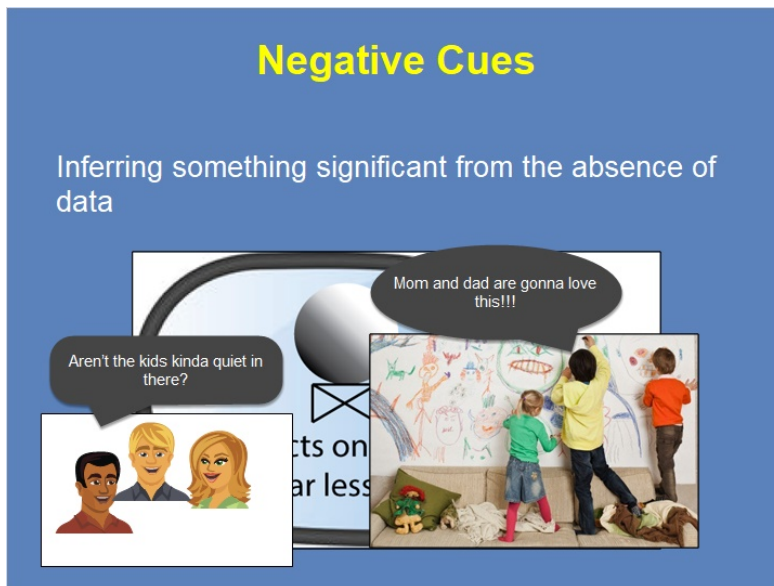
### *Sampling Issues HOME*



#### **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.

## Negative Cues



### Notes:

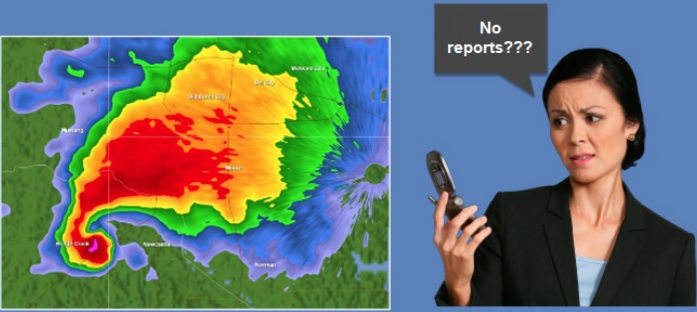
Before we tackle actual sampling limitations, we need to discuss the concept of negative cues. Many of the sampling limitations we'll discuss in this lesson impact forecasters by masking radar signatures and making them appear LESS IMPRESSIVE than they are in actuality. In some situations, the sampling 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.

## ***Negative Cues in Meteorology***

### **Negative Cues in Meteorology**

Major storm moves into major metropolitan area,  
but no reports are received



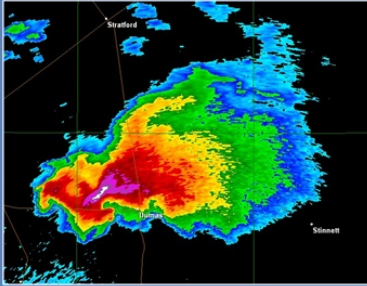
### **Notes:**

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.

## ***Negative Cues in Meteorology***

### **Negative Cues in Meteorology**

Warnings are not being transmitted by NWR or TV



#### **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.



## ***Negative Cues in Meteorology***

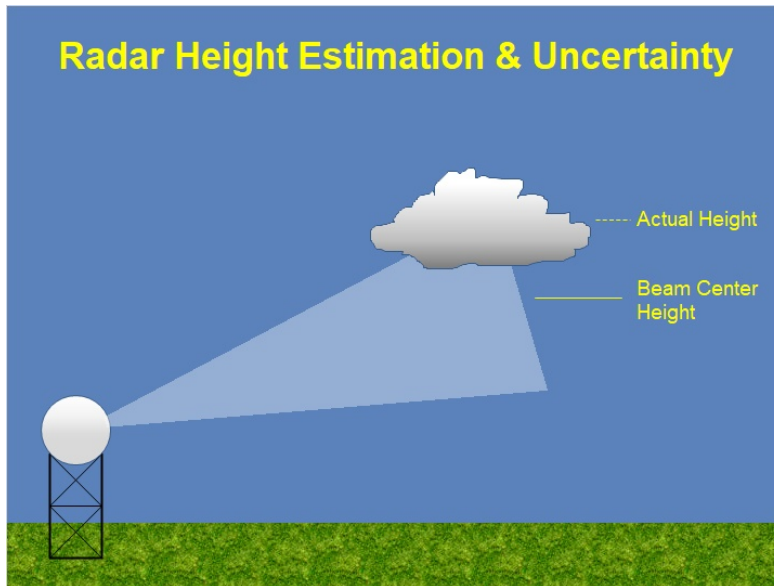
### **Negative Cues in Meteorology**

- Time stamp for radar data stops updating
- Surface observations go missing where there should be information
- Forecaster misses or does not alert office to major radar signature and therefore no warning issued
- Reflectivity suggests a supercell structure, but there is no apparent mesocyclone in velocity
- Lack of sampling by radar due to overshooting low-level features

#### **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.

## ***Beam Heights & Uncertainty***

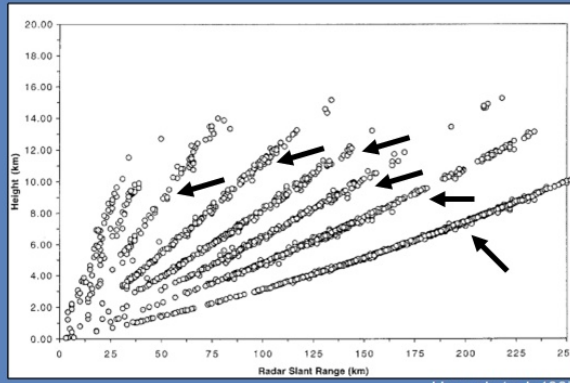


### **Notes:**

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.

## Radar Height Estimates

### Radar Height Estimation & Uncertainty

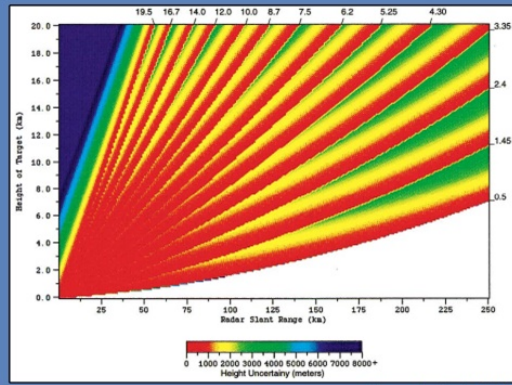


#### Notes:

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.

## Radar Height Uncertainties

### Radar Height Estimation & Uncertainty

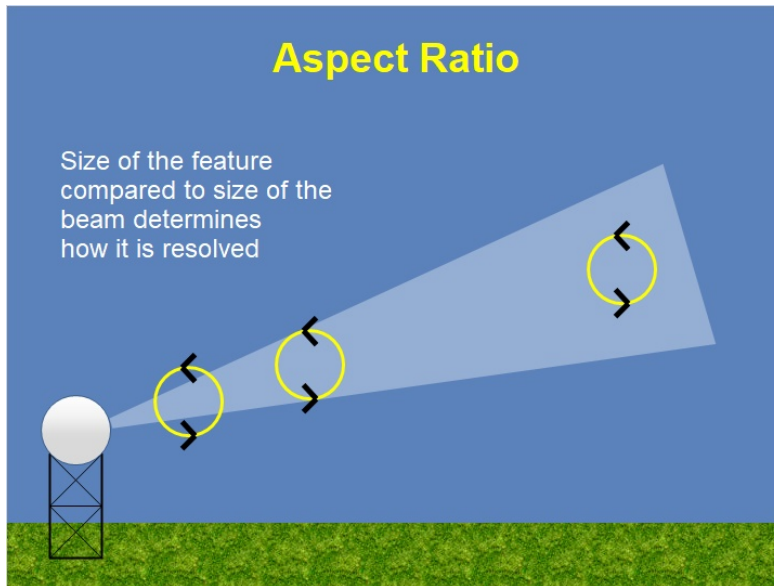


#### Notes:

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.

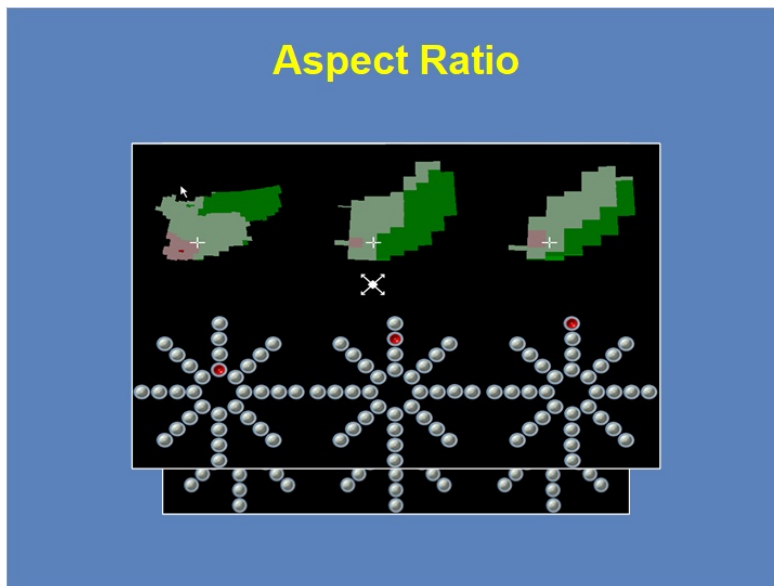
## Aspect Ratio



### Notes:

A target's size compared to the size of the radar beam is called the aspect ratio. Aspect 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.

## ***Aspect Ratio EXAMPLE***

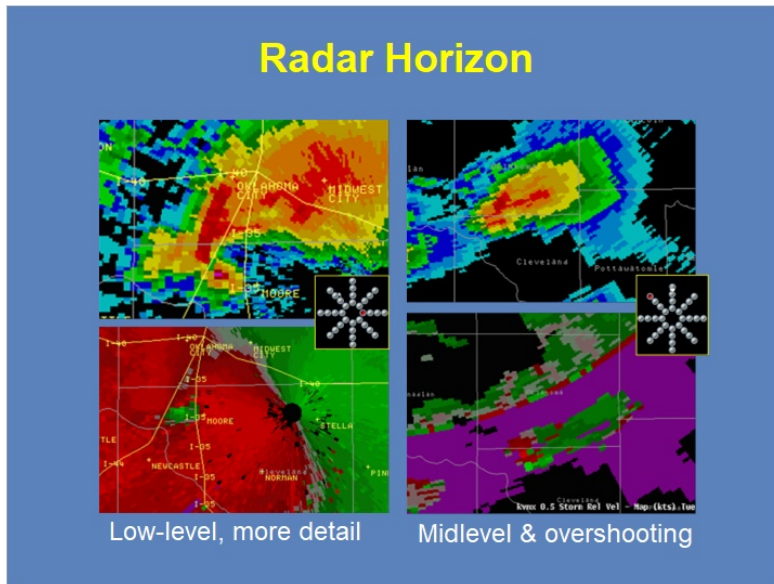


### **Notes:**

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.

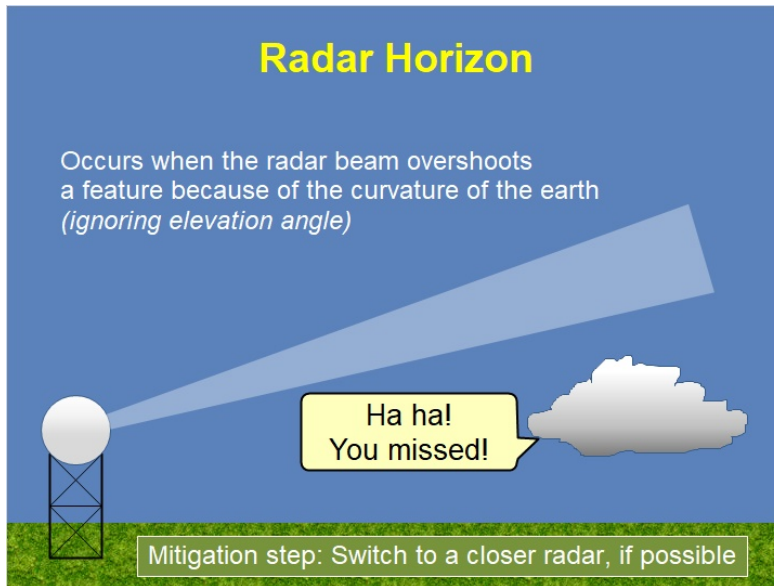
## ***Radar Horizon EXAMPLE***



### **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.

## Radar Horizon

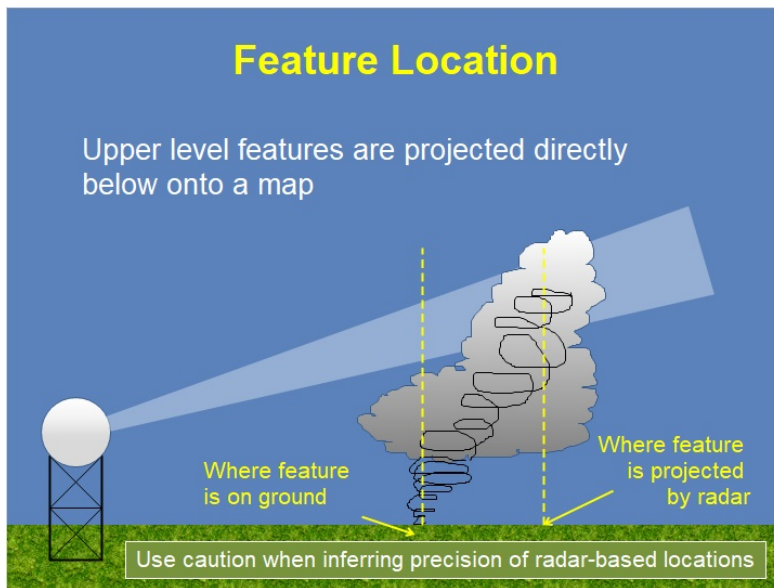


### Notes:

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.



## Feature Location

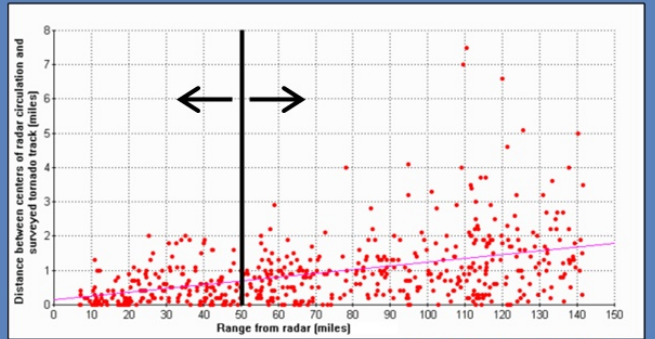


### Notes:

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.

## Feature Location EXAMPLE

### Feature Location

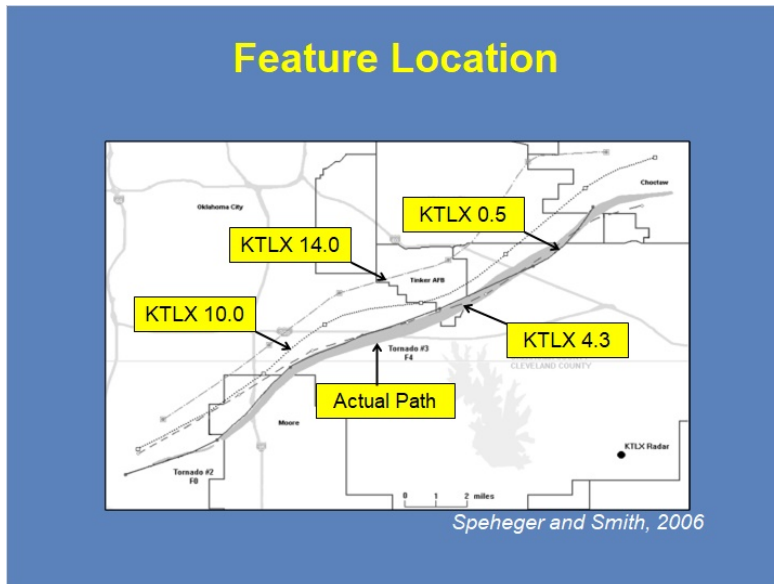


Speheger and Smith, 2006

### 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 noticeable. 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.

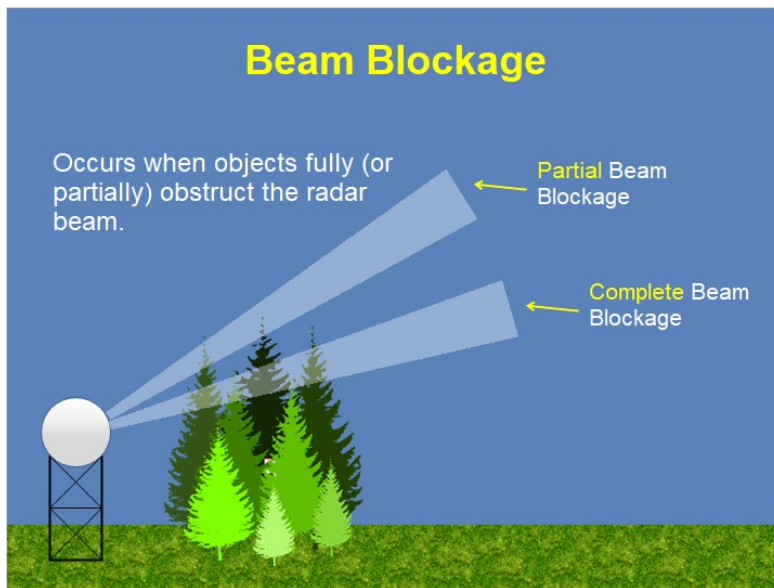
## Feature Location *EXAMPLE 2*



### 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.

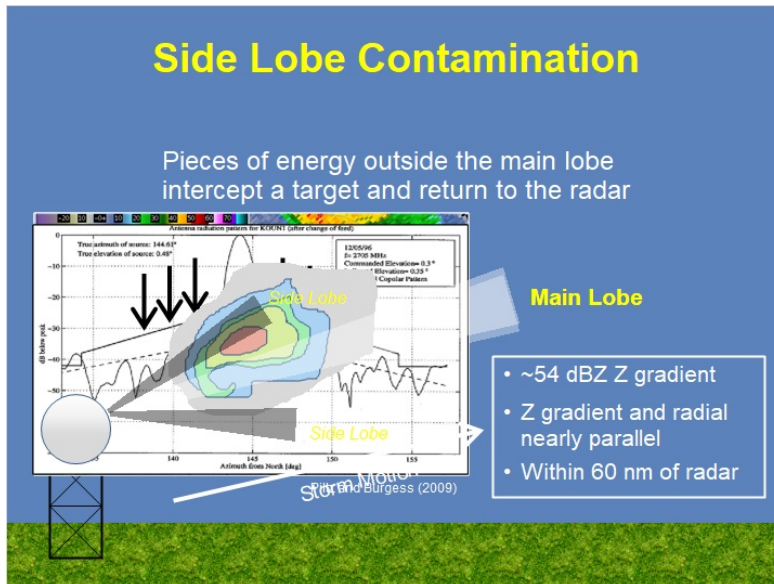
## 2.16 Beam Blockage



### 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.

## Side Lobe Contamination

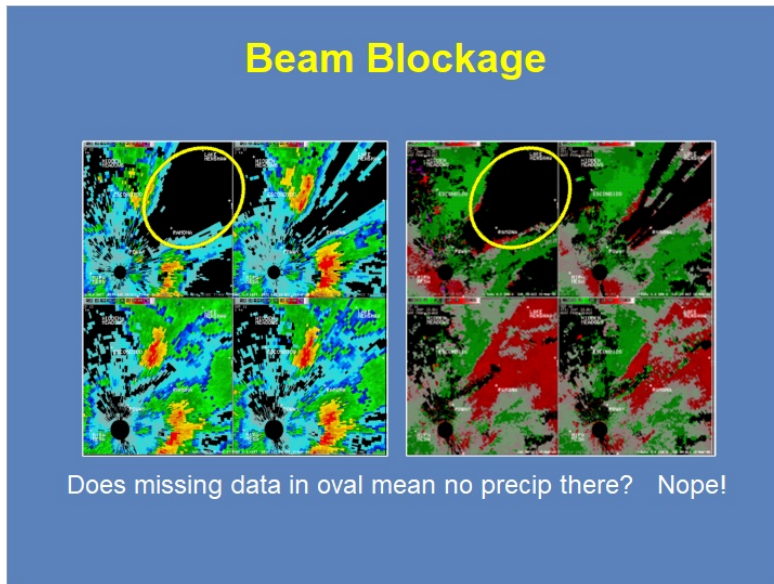


### Notes:

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.

## ***Beam Blockage EXAMPLES***

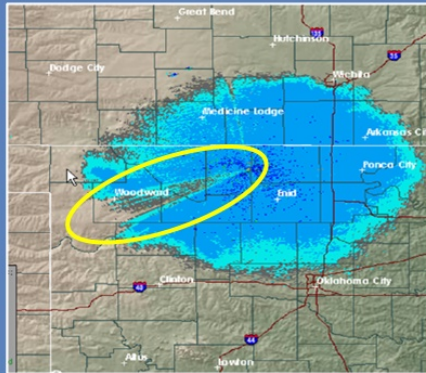


### **Notes:**

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 obstacle 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.

## ***Beam Blockage EXAMPLES***

### **Beam Blockage**

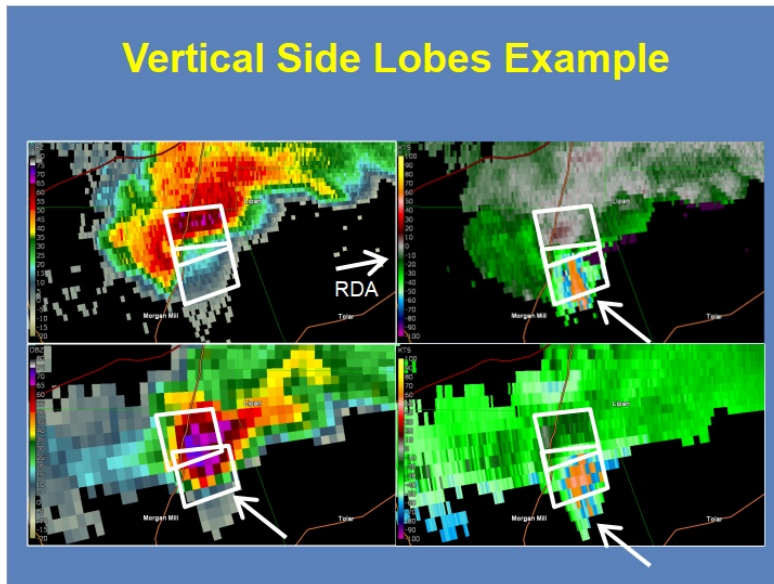


Storms will appear weaker here then they actually are

#### **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.

## Side Lobes EXAMPLE 2



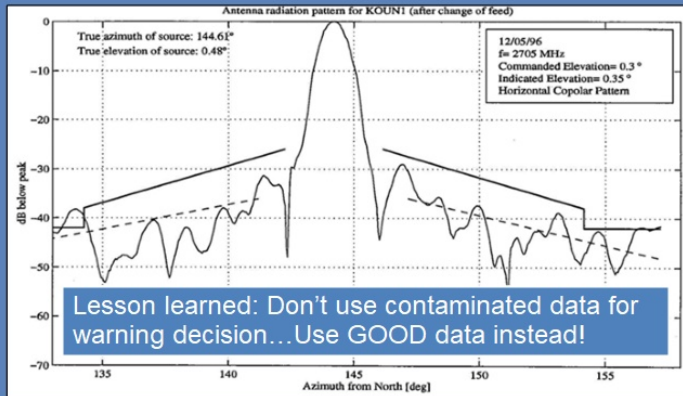
### Notes:

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.



## Final Note on Side Lobes

### Final Note on Side Lobes



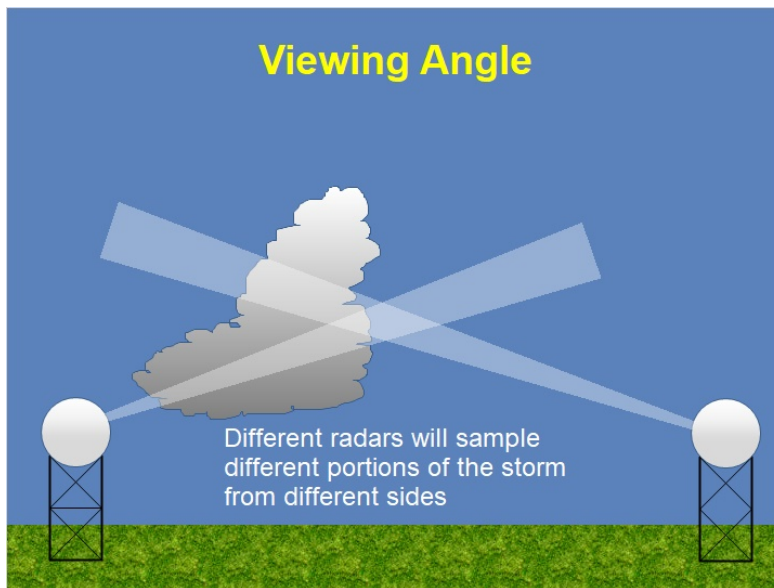
Piltz and Burgess (2009)

### 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.

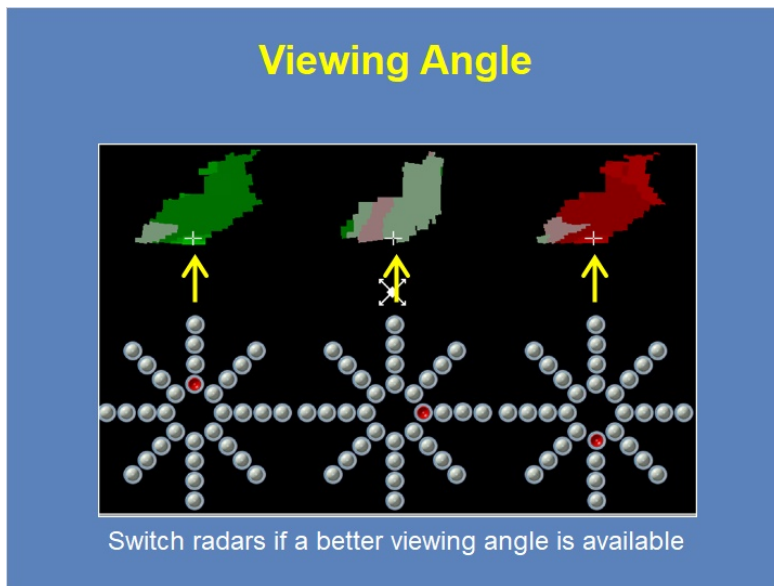
## ***Viewing Angle***



### **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.

## Viewing Angle *EXAMPLE*

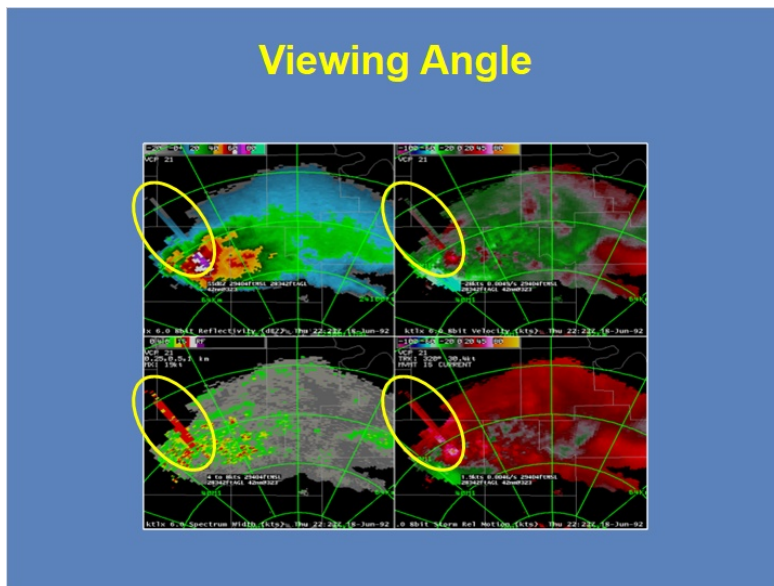


### Notes:

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.

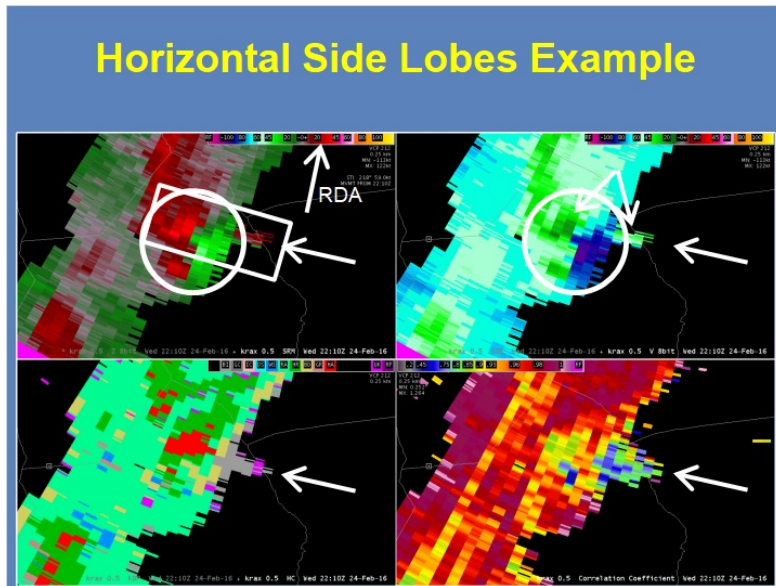
## Viewing Angle EXAMPLE



### 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 shows 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.

## Side Lobes EXAMPLE

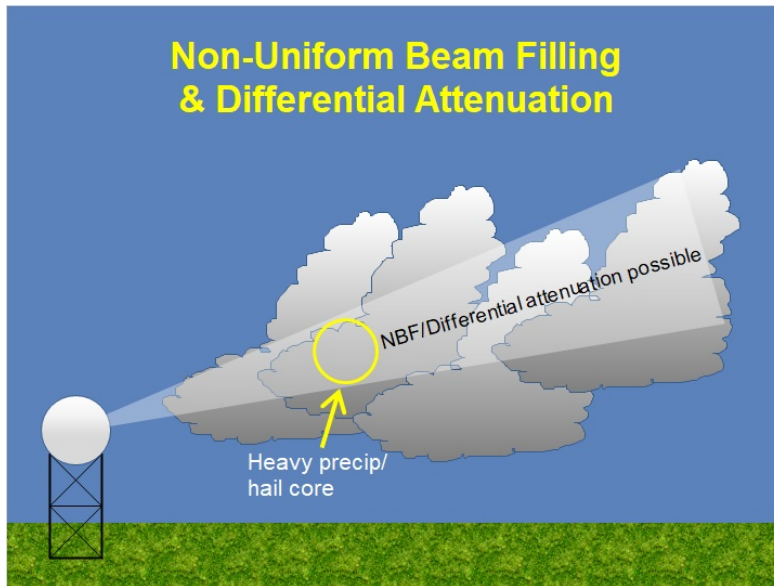


### Notes:

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 than 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.

## ***Non-Uniform Beam Filling & Differential Attenuation***



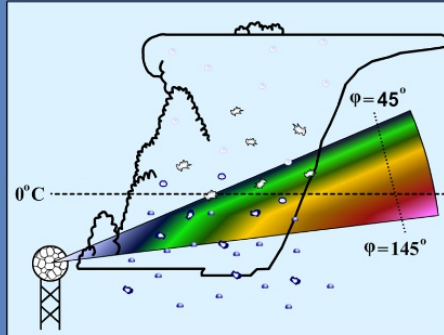
### **Notes:**

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.

## Non-uniform Beam Filling

### Non-Uniform Beam Filling (NBF)

- Gradient of  $\Phi_{DP}$  usually uniform across beam
- Gradient can develop in hail storms at mid ranges or line of storms along radial
- Results in low CC down rest of radial

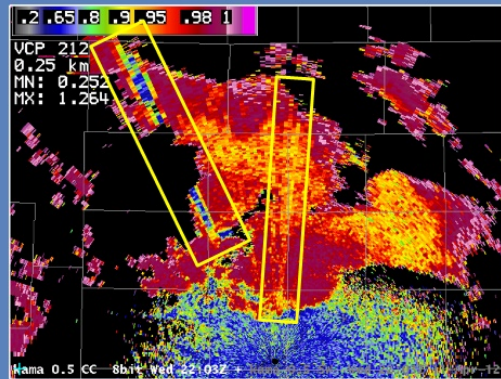


#### Notes:

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.

## ***NBF Example***

### **Non-Uniform Beam Filling (NBF)**

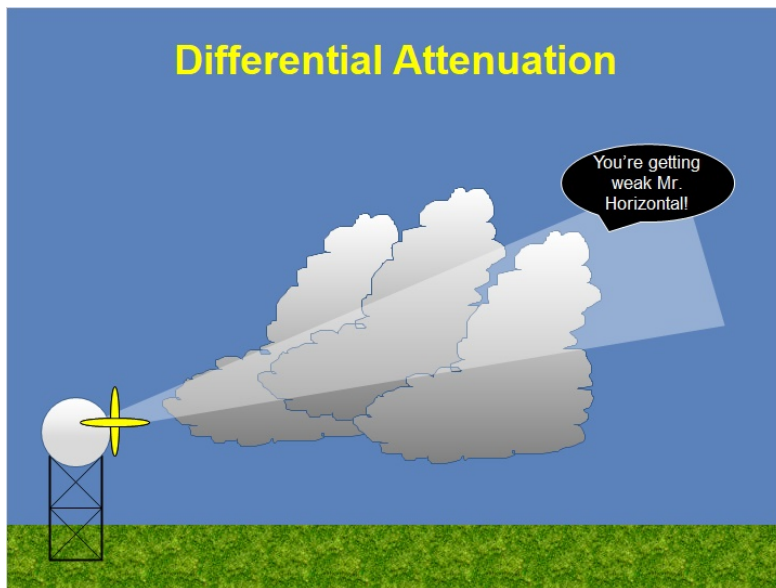


#### **Notes:**

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.



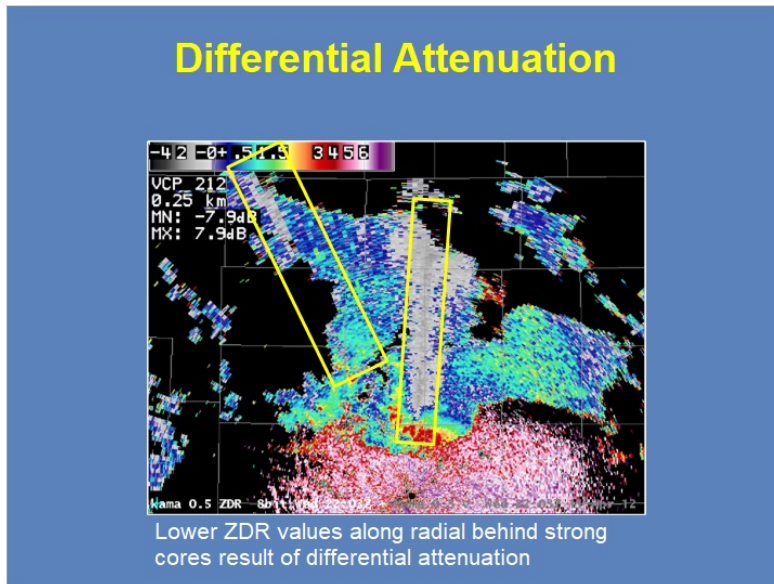
## ***Differential Attenuation***



### **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.

## DA Example

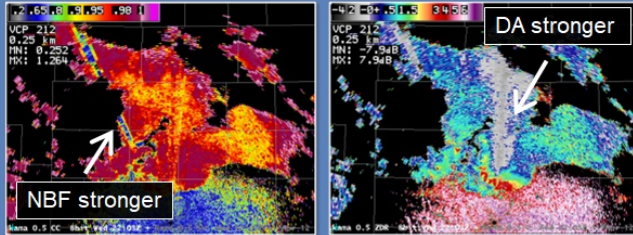


### Notes:

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.

## NBF/DA Differences

### Don't Confuse NBF and DA...



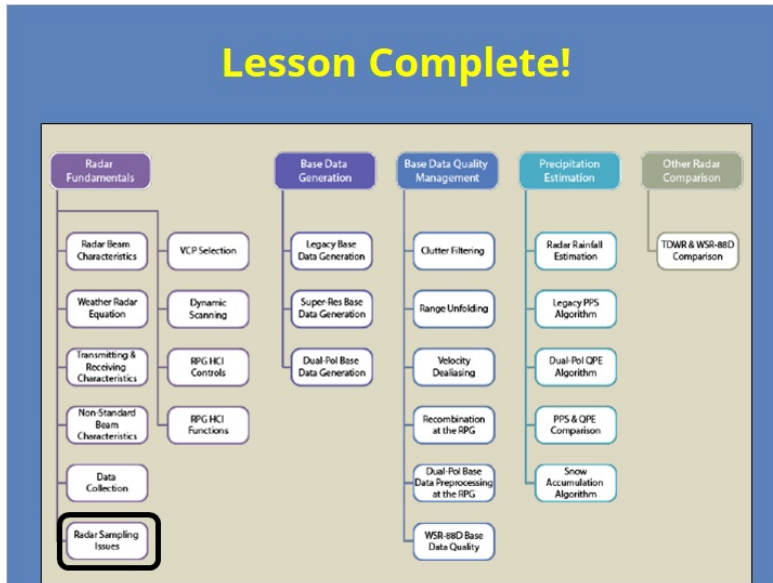
- NBF results from  $\Phi_{DP}$  gradient in beam and lowers CC down radial
- Differential attenuation results from attenuation differences between horizontal and vertical affecting ZDR

#### 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  $\Phi_{DP}$ , 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.

## 4. Completion

**Completion!**



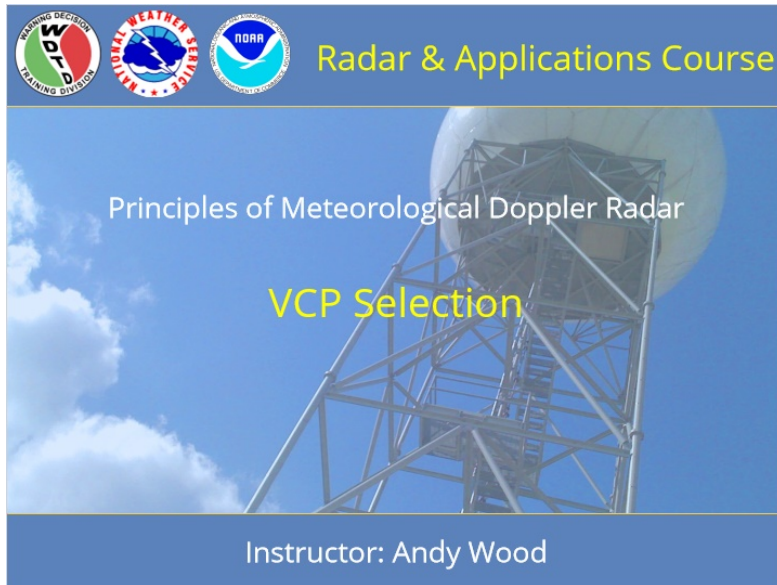
### Notes:

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

# VCP Selection

## 1. Introduction

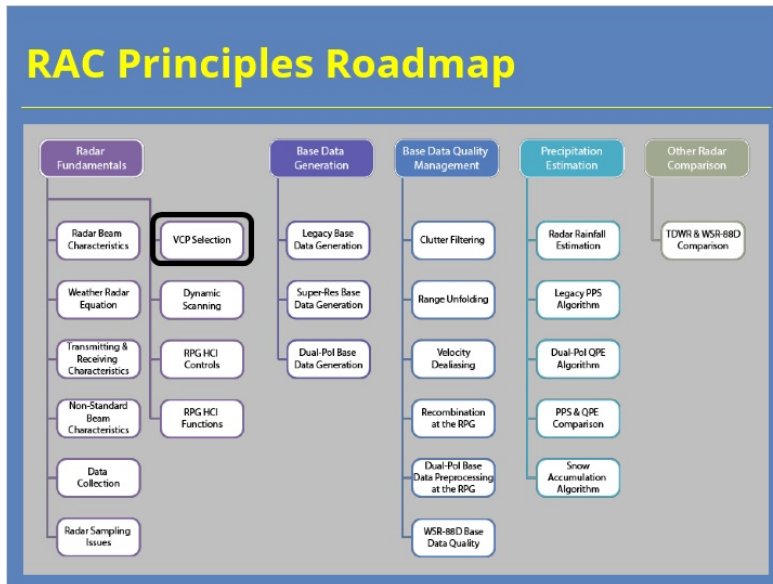
### *Introduction*



### **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.

## 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.

## ***VCP Selection Objectives***

### **VCP Selection Objectives**

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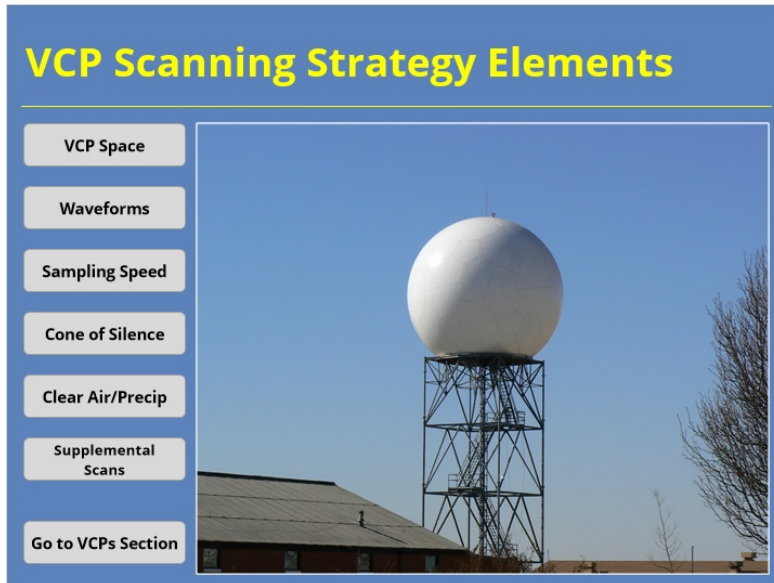
1. Identify the WSR-88D VCPs and the distinguishing characteristics of their scanning strategies
2. Identify the factors that often impact VCP selection, including which one(s) are most relevant
3. Identify how your choice of VCP impacts data quality during clear air & precipitation mode operations
4. Identify which VCPs are appropriate to use in given meteorological or technical situations

#### **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.

## 2. Get to Know Your VCPs

### *VCP Scanning Strategy Elements*

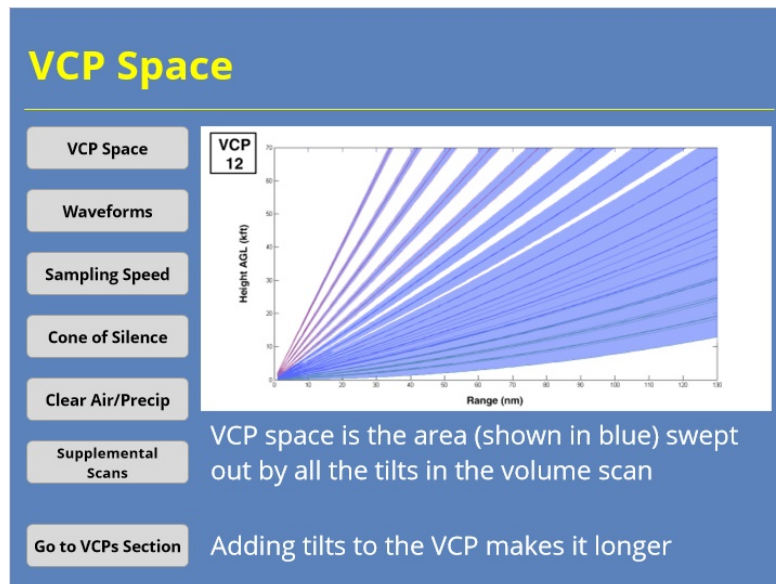


#### **Notes:**

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, whether the VCP was designed for clear air or precipitation, and whether supplemental scans are available for a particular radar site. 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.



## 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 too long, VCPs contain gaps between tilts in certain regions based on the goals of the scanning strategy.

## Waveforms

### Waveforms

VCP Space

Waveforms

Sampling Speed

Cone of Silence

Clear Air/Precip

Supplemental Scans

Go to VCPs Section

WSR-88D has two primary waveforms:

Contiguous Doppler (CD)

Contiguous Surveillance (CS)

- Contiguous Surveillance (CS)
- Contiguous Doppler (CD)

### 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 include both CS and CD scans on some tilts. Split cuts alternate separate, full sweeps of CS and CD pulses, while batch cuts alternate between CS and CD pulses while completing a single sweep. Sometimes even multiple CD scans are used to minimize range unfolding. More on that in the range unfolding lesson.

## ***Sampling Speed***

### Sampling Speed

VCP Space

Waveforms

Sampling Speed

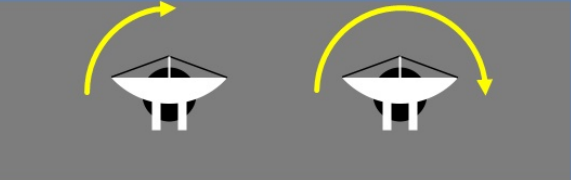
Cone of Silence

Clear Air/Precip

Supplemental Scans

Go to VCPs Section

WSR-88D rotation rate impacts data quality:



Slower rotation:  
Higher data quality

High rotation:  
Lower data quality

### **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.

## ***Clear Air/Precip***

### Clear Air/Precip

VCP Space

Waveforms



Sampling Speed

Cone of Silence

Clear Air/Precip

Supplemental Scans

Go to VCPs Section



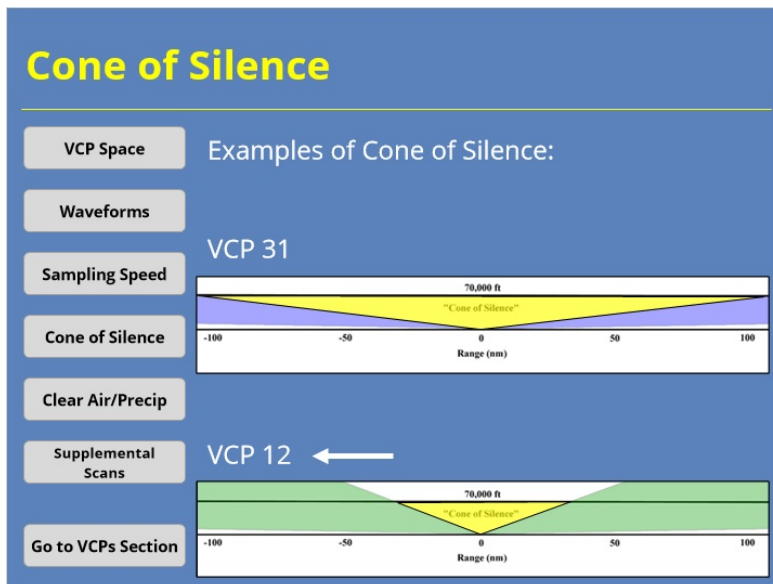
Clear AirPrecip

Precipitation often requires a VCP with a more thorough scan than clear skies

### **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.

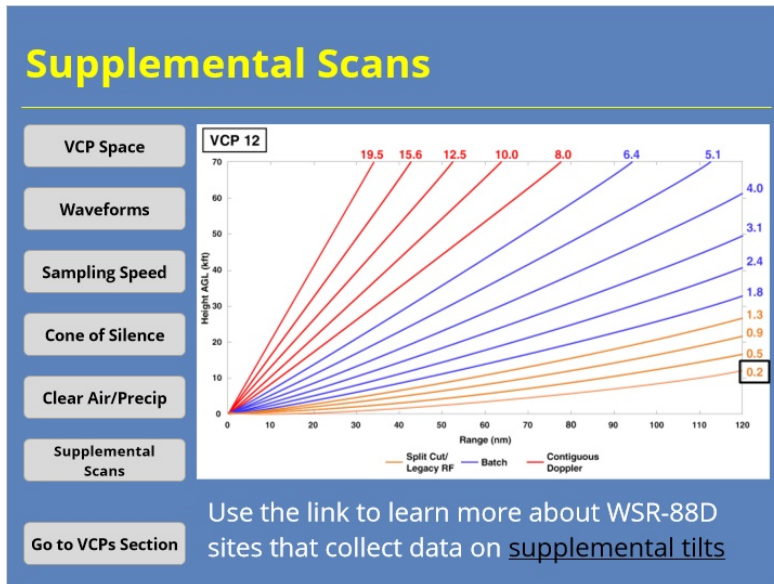
## Cone of Silence



### 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.

## Supplemental Scans

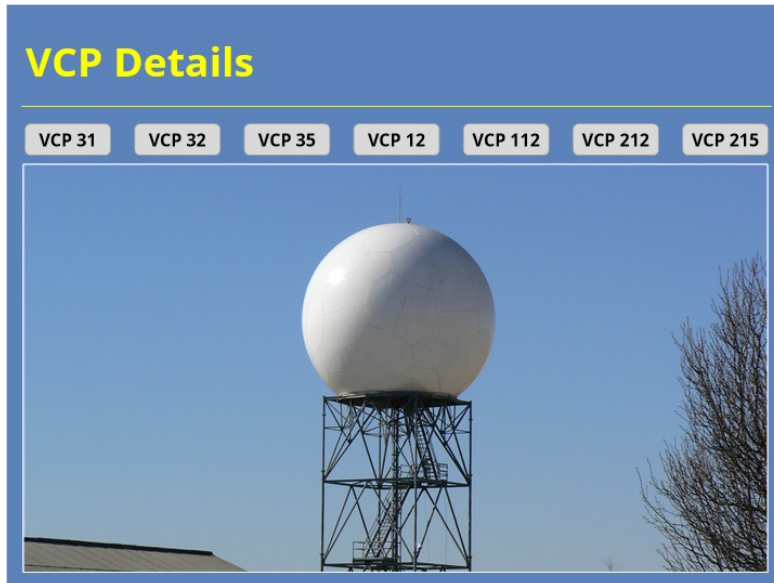


### Notes:

A handful of WSR-88D sites have an additional, supplemental scan available below 0.5 degrees. The exact elevation angle varies from site to site, but the scan is somewhere between -0.2 to 0.4 degrees elevation. A list of the sites with a supplemental scan, and the specific elevation angle of that scan, can be found using the link at the bottom of the slide or by clicking on the resources tab.

### 3. VCP Details

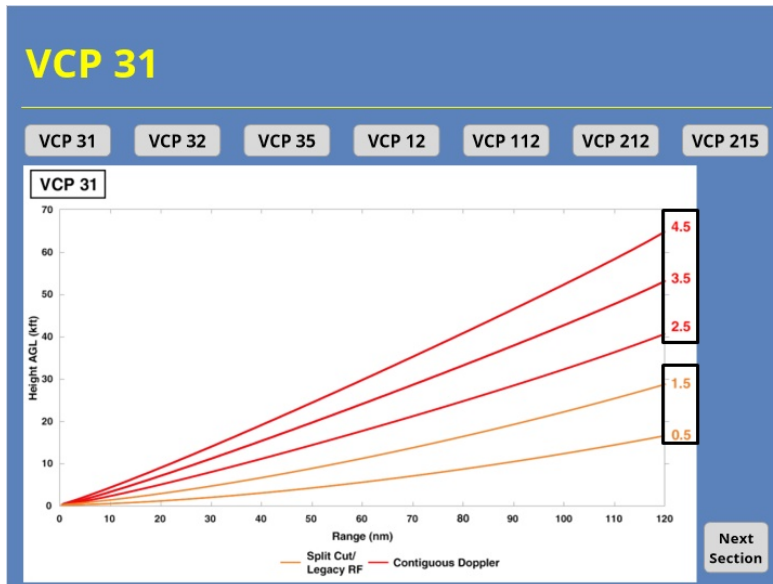
#### *VCP Details*



#### **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.

## VCP 31

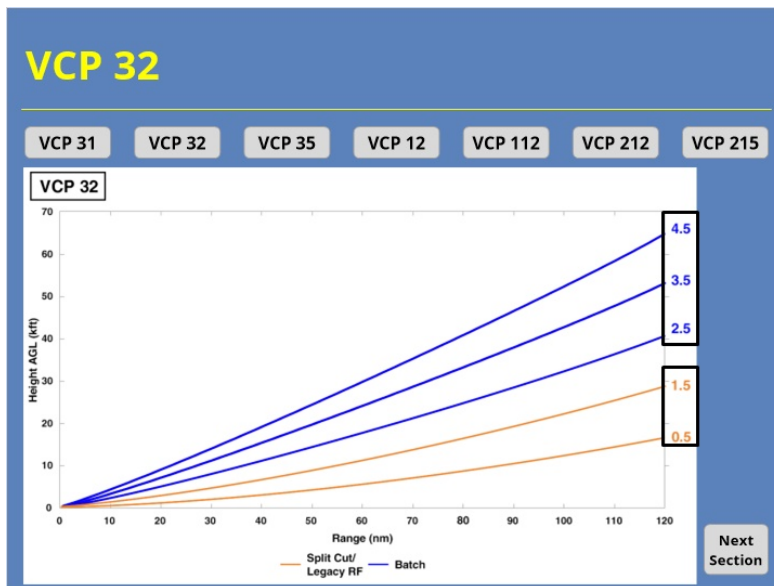


### Notes:

VCP 31 is one of three clear air VCPs. This scanning strategy uses 5 tilts with no gaps. The lowest two tilts use 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.



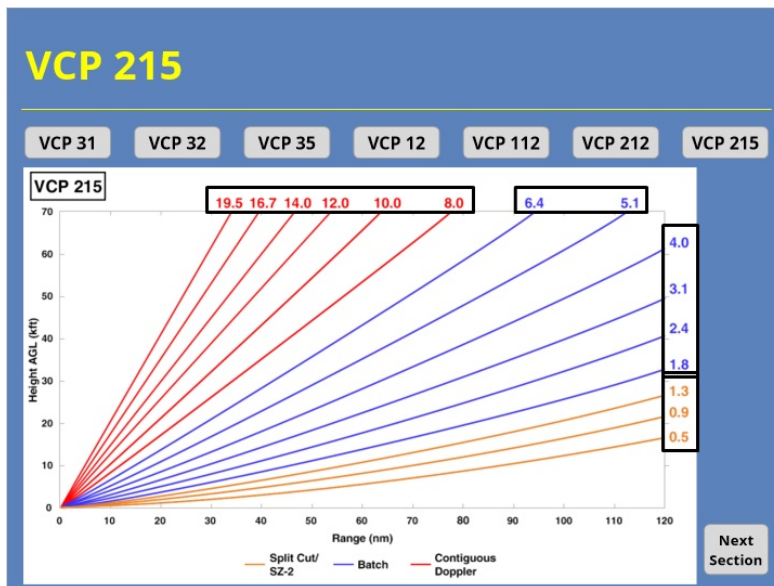
## VCP 32



### Notes:

VCP 32 is one of three clear air VCPs. This scanning strategy uses 5 tilts with no gaps. The lowest two tilts use 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 looks 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.

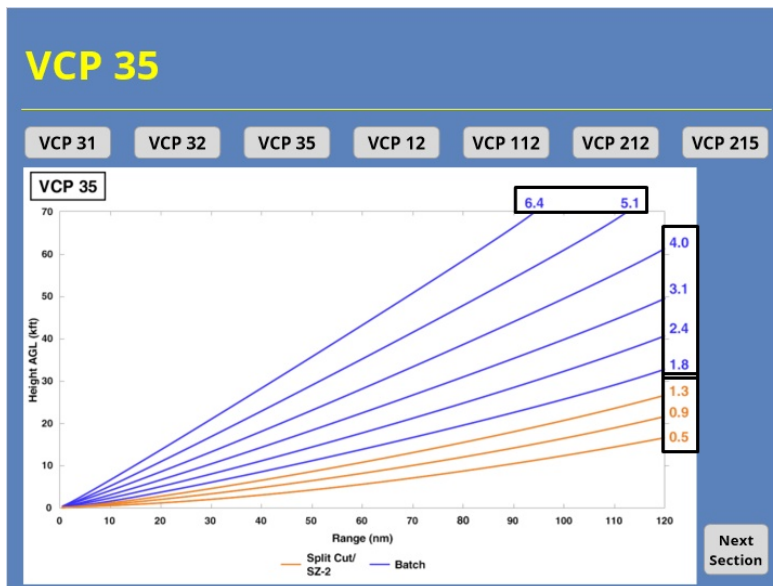
## VCP 215



### 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.

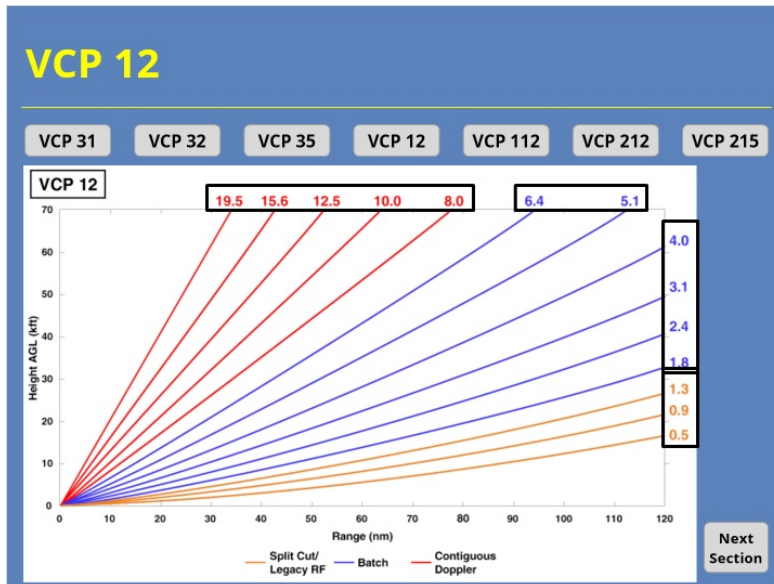
## VCP 35



### 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.

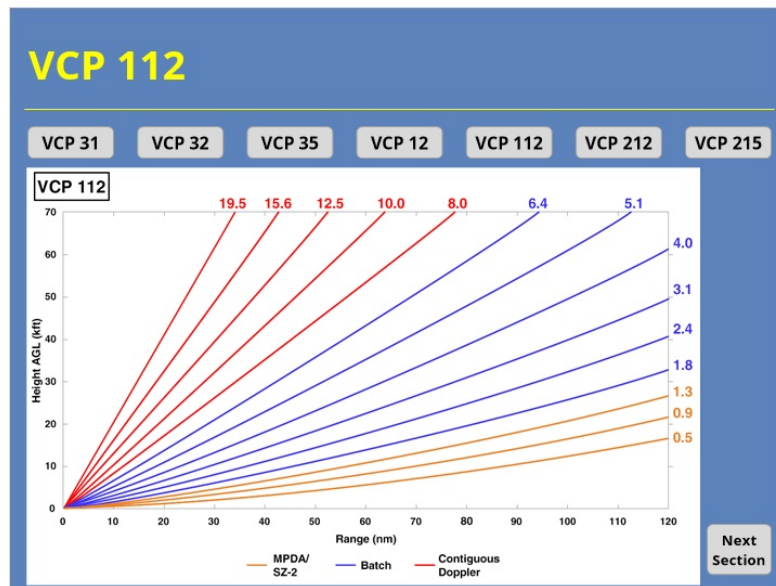
## VCP 12



### 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. 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.

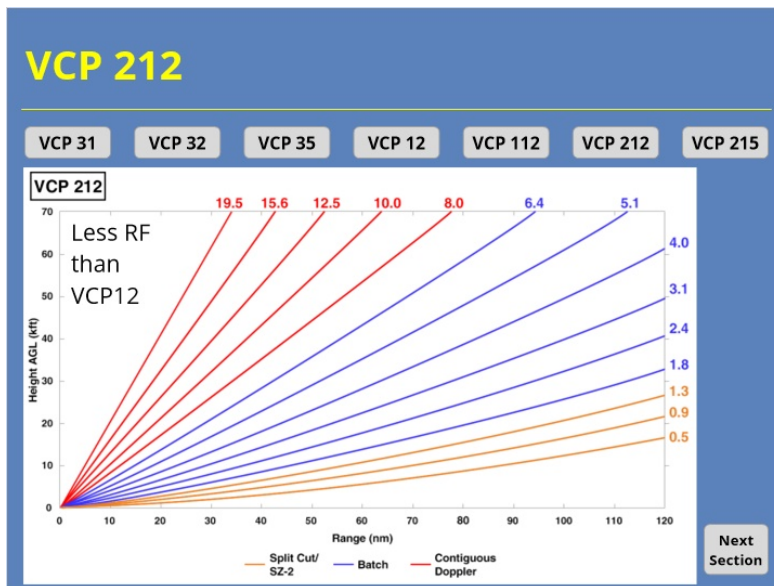
## VCP 112



### Notes:

VCP 112 is a precipitation mode VCP designed for large-scale weather systems or any widespread precipitation where range folding minimization is important. The scanning strategy has 14 tilts and offers the best low level vertical sampling of the atmosphere. Also, one SAILS tilt can be implemented in VCP 112. 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 three tilts. However, the drawback to this technique is that the Doppler pulse PRFs aren't editable for the split cuts where those techniques are used. A complete VCP 112 volume scan without SAILS takes approximately 5.5 minutes to complete.

## VCP 212



### Notes:

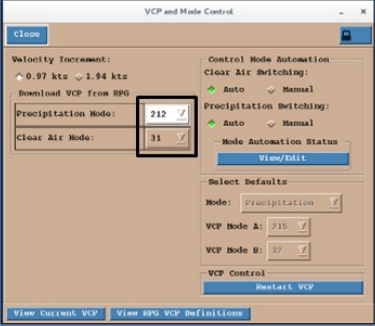
VCP 212 is a precipitation mode VCP designed for convective weather situations and is very similar to VCP 12. This scanning strategy has 14 tilts, and offers good low-level vertical sampling of the atmosphere. Up to 3 SAILS tilts can be included in a single volume scan, also. The primary differences 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. A complete VCP 212 scan without SAILS tilts takes approximately 4.5 minutes.

## 4. Selection & Decision-Making

### *VCP Selection: Science Fact & Fiction*

### VCP Selection: Science Fact & Fiction

In reality, many things may drive VCP selection:

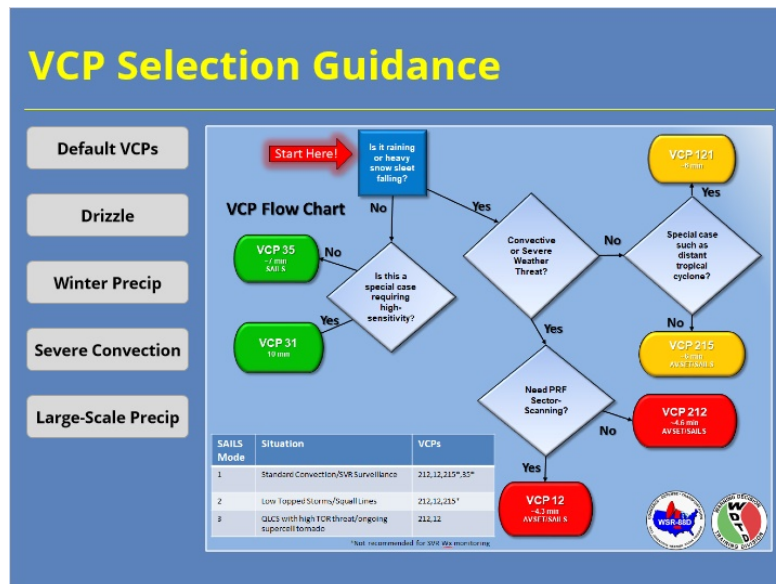


What should drive it: The weather!

#### **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.

## VCP Selection Guidance

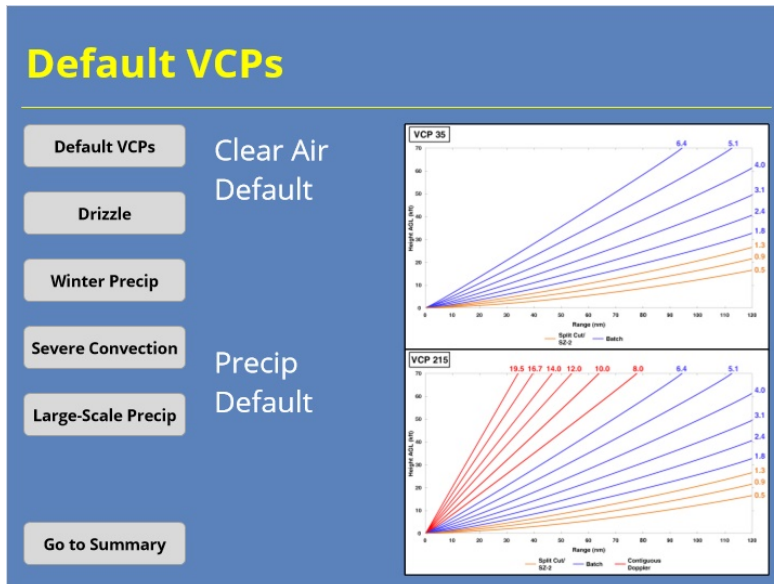


### Notes:

Recent changes to the WSR-88D have helped simplify the VCP selection process. We have created this flowchart to help with this. Choose from the buttons on the left to learn more about VCP selection involving specific weather conditions.



## Default VCPs



### Notes:

The system default volume coverage patterns for the WSR-88D are 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.

## Drizzle

### Drizzle

Default VCPs

Drizzle

Winter Precip

Severe Convection

Large-Scale Precip



Options: VCP 31 (light winds), VCP 35 (everything else)

Go to Summary

### 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.

## Winter Precip

### Winter Precip

Default VCPs


Drizzle

Winter Precip

Severe Convection

Large-Scale Precip

Go to Summary



**Options:** VCP 31 (light winds & precip), VCP 35 (light precip & strong winds), VCP 215 (everything else)

### 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, then 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.

## ***Large-Scale (e.g., Tropical) Systems***

### Large-Scale (e.g., Tropical) Systems

Default VCPs

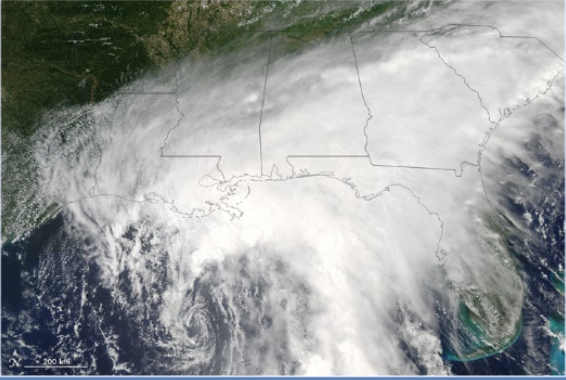
Drizzle

Winter Precip

Severe Convection

Large-Scale Precip

Go to Summary



Options: VCP 112 (general RF mitigation)

### **Notes:**

When a large-scale precipitation system (such as a tropical cyclone) impacts your local area, the best VCP option will be VCP 112. This VCP performs best at mitigating range folding when radar returns cover the area surrounding the radar out to 200 km or more.

## Severe Convection

### Severe Convection


Default VCPs

Drizzle

Winter Precip

**Severe Convection**

Large-Scale Precip



**Options:** VCP 212\* (general use), VCP 12\* (for manual PRF changes)  
\*Be judicious in use of SAILS tilts!

Go to Summary

### 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!

## 5. Quiz

### *VCP Selection Summary*

#### VCP Selection Summary

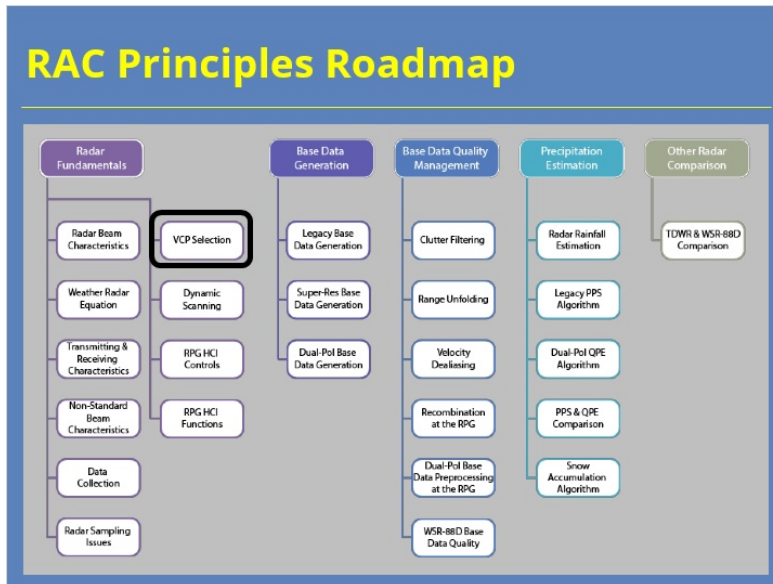
- There are 7 VCPs available:
  - 3 clear air , 4 precipitation mode
  - All 7 use different scanning strategy elements
- Weather should be primary reason behind VCP selection
- When deciding on VCP, remember:
  - VCPs 35 and 215 are standard defaults
  - VCP 31 (Long pulse) for higher sensitivity in light winds
  - VCPs 212 or 12 with severe convection
  - VCP 112 for large scale systems to avoid RF

#### **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 these 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 112 can be beneficial when trying to avoid range folded returns during large scale precipitation systems (like tropical cyclones).

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

## RAC Principles Roadmap



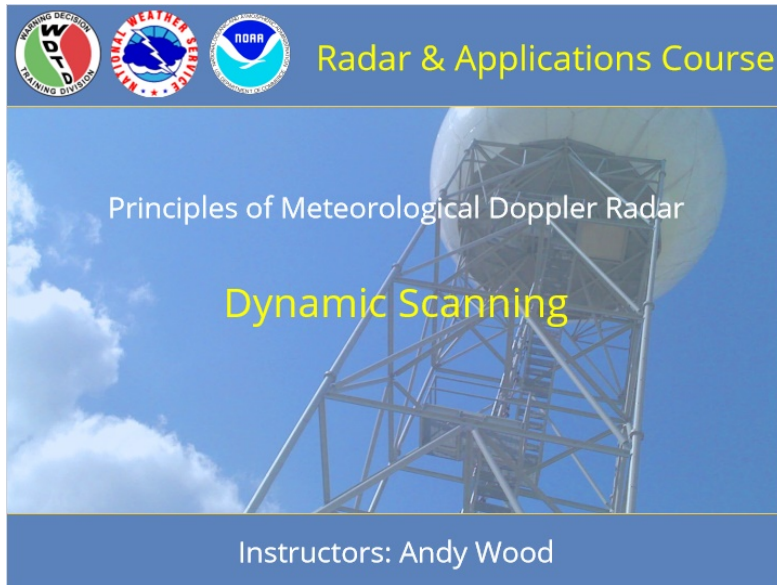
### Notes:

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

### *Title*

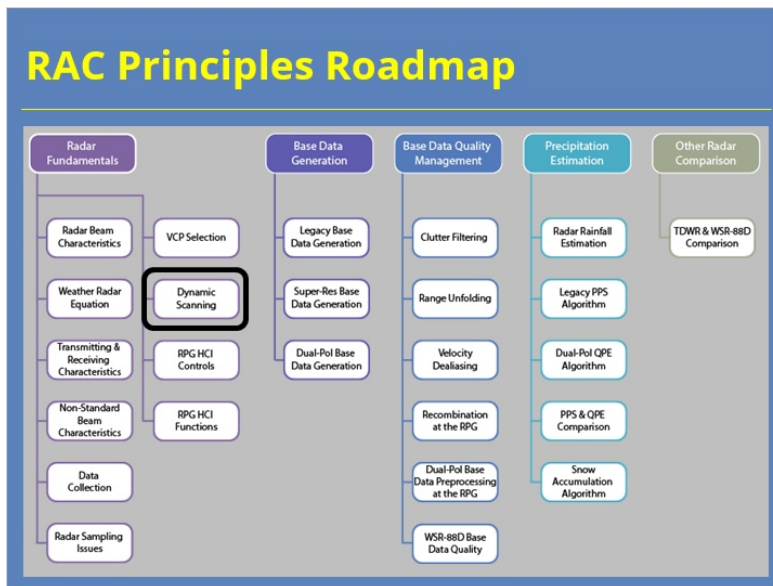


### **Notes:**

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



## 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.

## ***Learning Objectives***

### **Learning Objectives**

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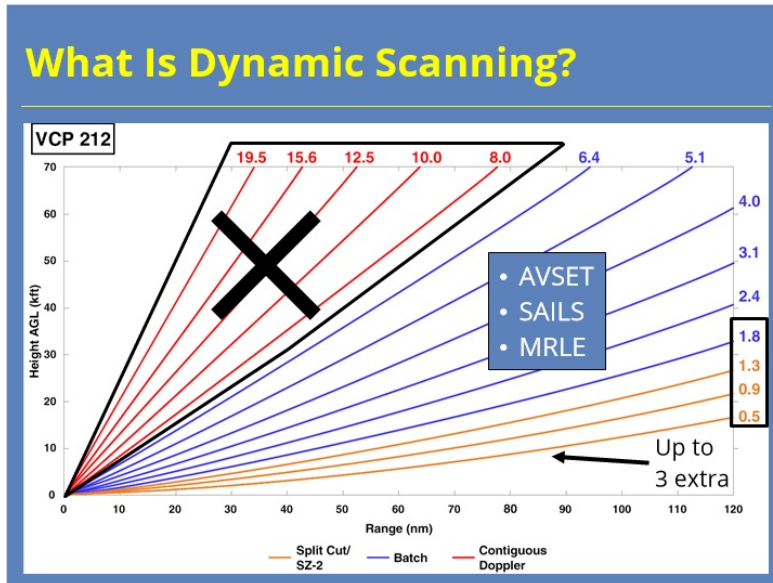
1. Identify what AVSET is, the application's purpose and which volume coverage patterns can use it
2. Identify the steps to take (both by the algorithm & the user) to ensure detection of elevated convection with AVSET
3. Identify what SAILS is, the application's purpose, and which volume coverage patterns can use it
4. Identify the impacts of SAILS use during severe convective events
5. Identify what MRLE is, the application's purpose, and which volume coverage patterns can use it

#### **Notes:**

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

## 2. Dynamic Scanning Basics

### *What Is Dynamic Scanning?*

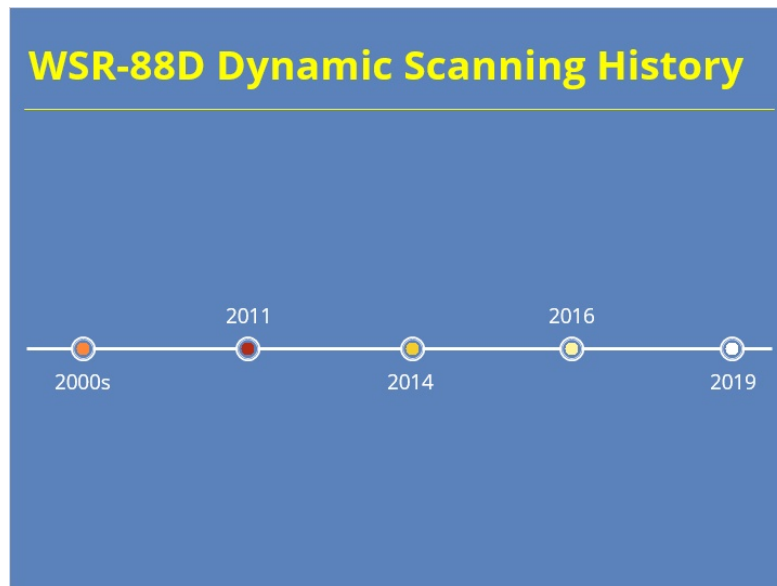


#### **Notes:**

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 MRLE. The SAILS application may occasionally be referred to as MESO-SAILS (or the Multiple Elevation Scan Option of SAILS). However, we will simply refer to this capability as SAILS in this training.

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 up to three supplemental lowest level tilts in each volume scan. The Mid-Volume Rescan of Low-Level Elevations, or MRLE, allows the radar to collect supplemental sweeps for up to the lowest 4 tilts of the volume scan.

## ***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 mission. It didn't take long for WSR-88D users to inquire about getting dynamic scanning capabilities, too.

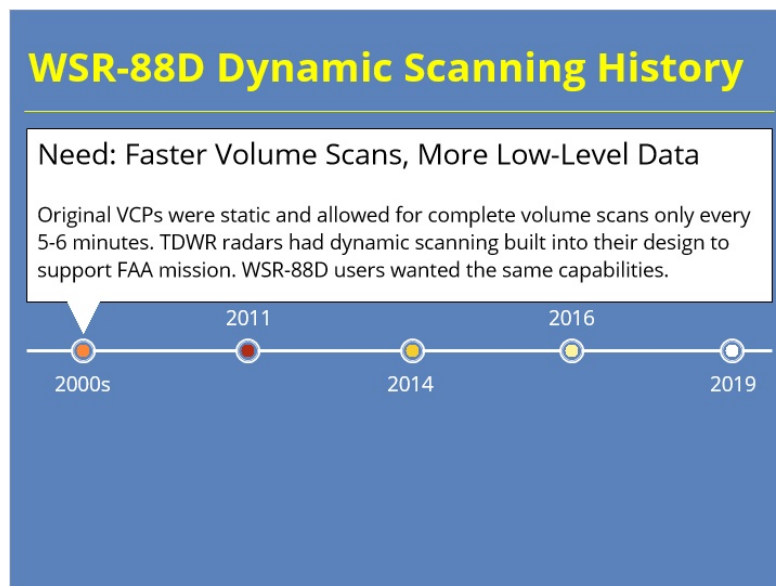
**2011:** With the release of RPG Build 12.3, AVSET was fielded. For the first time, radar operators had the option to terminate volume scans early if little to no detectable precipitation was present aloft. On average, use of AVSET reduced volume scan time during precipitation mode to three-and-a-half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

**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.

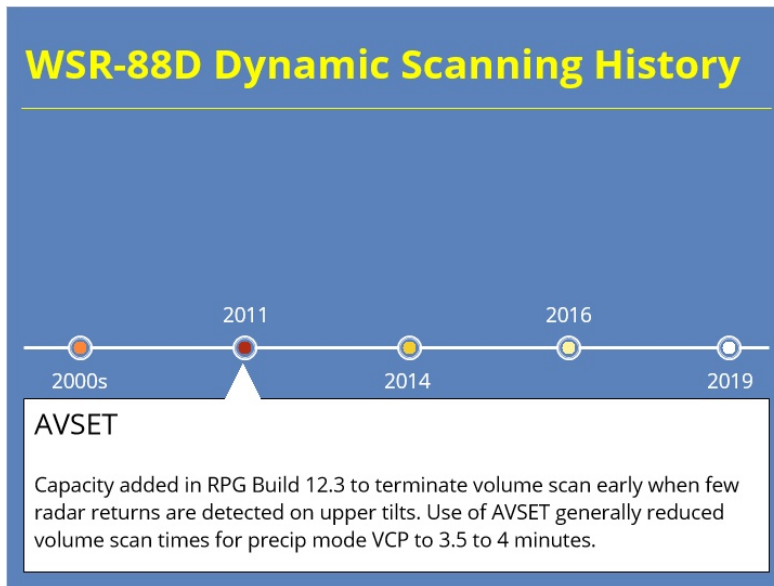
**2016:** Once the SAILS proof of concept was realized, RDA/RPG Build 16 upgraded the capability. Now, up to 3 SAILS scan per volume can be collected. With both SAILSx3 and AVSET enabled, it was now theoretically possible to collect radar data on the lowest tilt approximately every minute.

**2019:** RDA/RPG Build 18.2 adds the capability of collecting an additional scan for tilts other than just 0.5 degrees during a single volume scan. This additional feature allows forecasters to see more frequent data for a deeper region than with just SAILS alone.

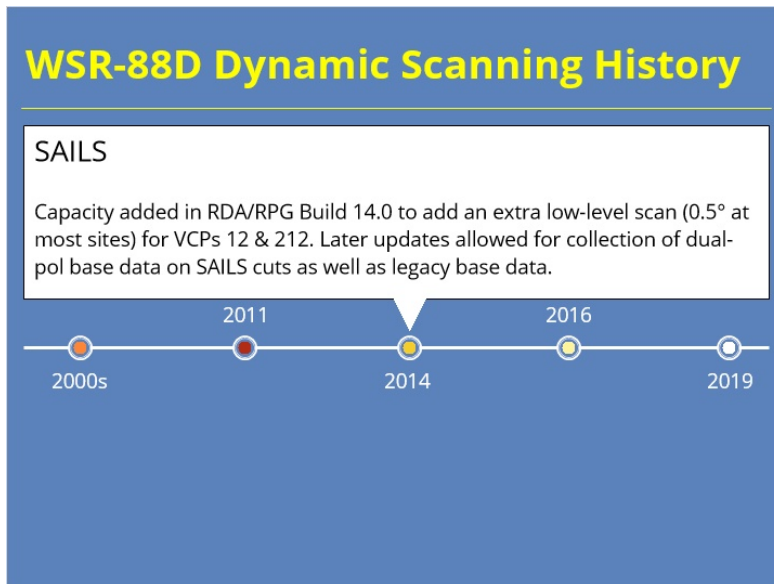
## 2000s (Slide Layer)



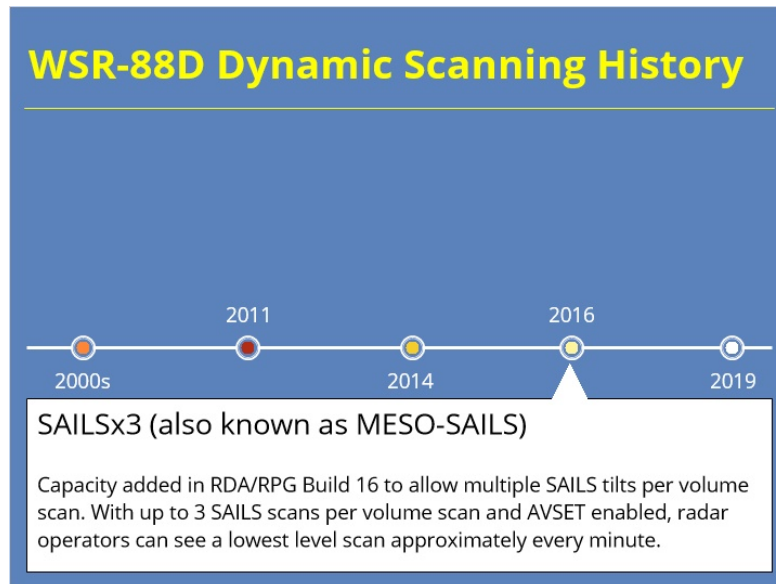
## 2011 (Slide Layer)



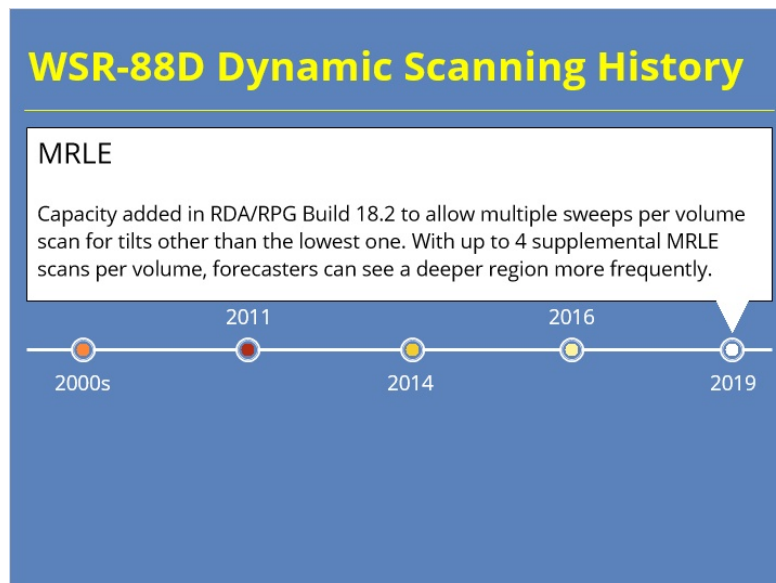
## 2014 (Slide Layer)



## 2016 (Slide Layer)

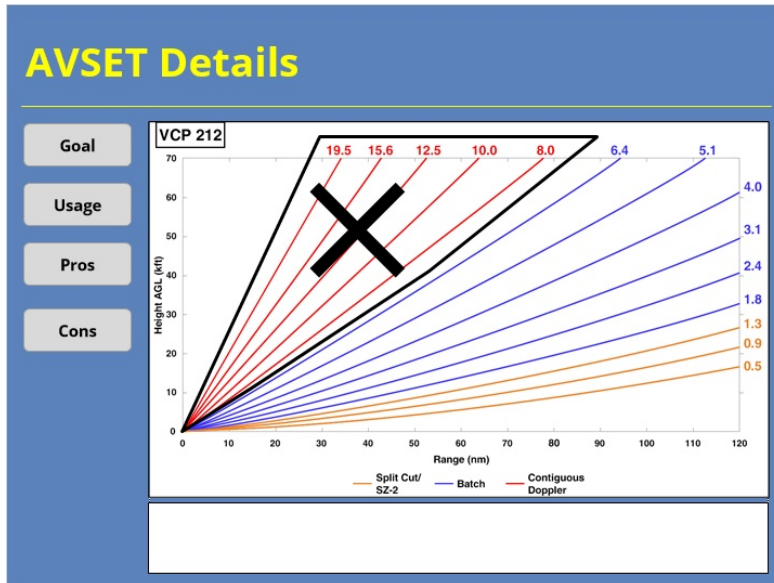


## 2019 (Slide Layer)



### 3. AVSET

#### 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, 112, 212, 215

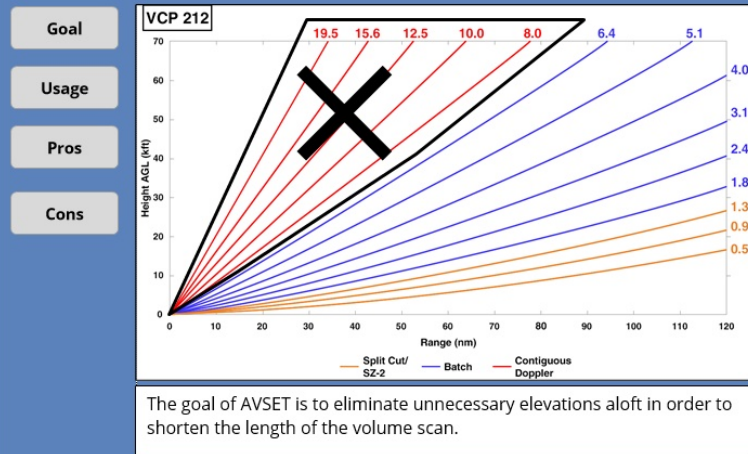
**Pros:** The primary benefit of AVSET is the potential for faster volume scans which can lead to more volume scan over time (up to 1 scan per hour more)

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



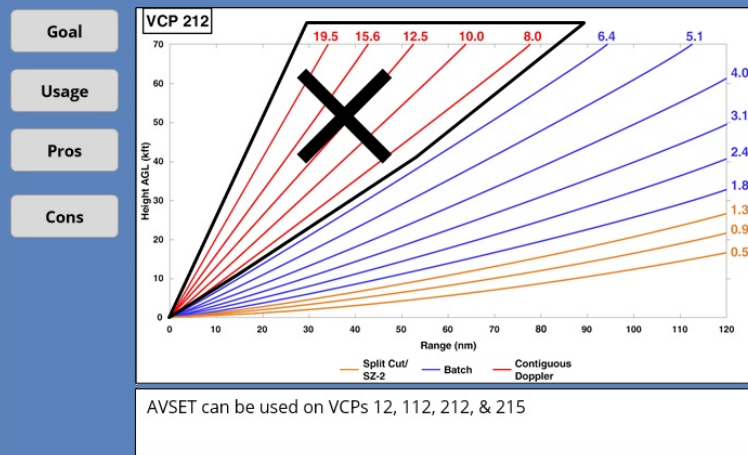
## Goal (Slide Layer)

### AVSET Details



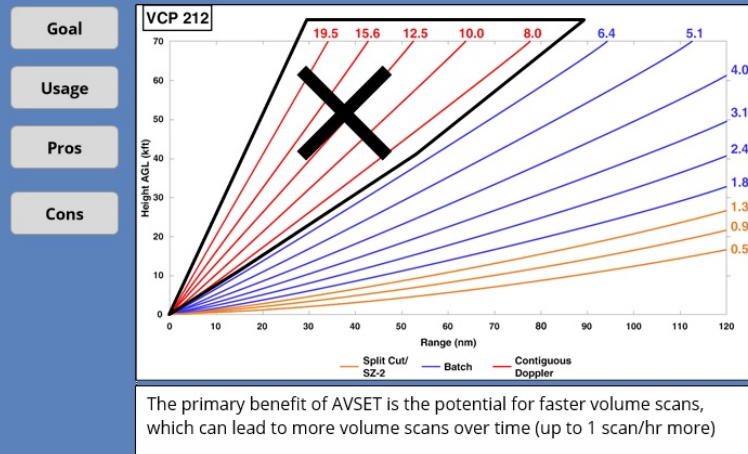
## Usage (Slide Layer)

### AVSET Details



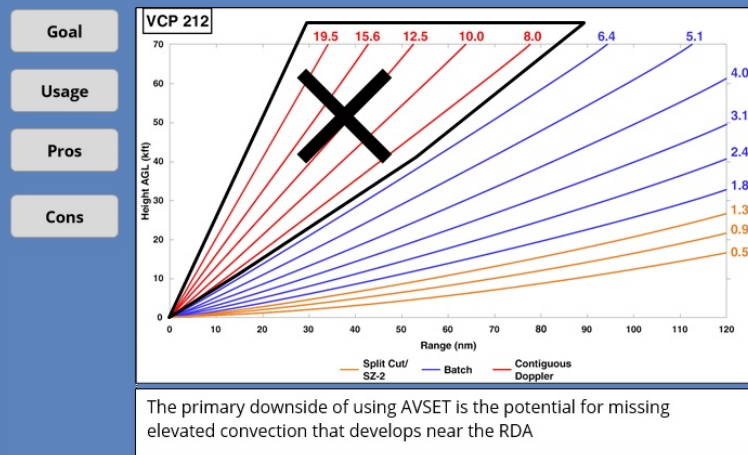
## Pros (Slide Layer)

### AVSET Details

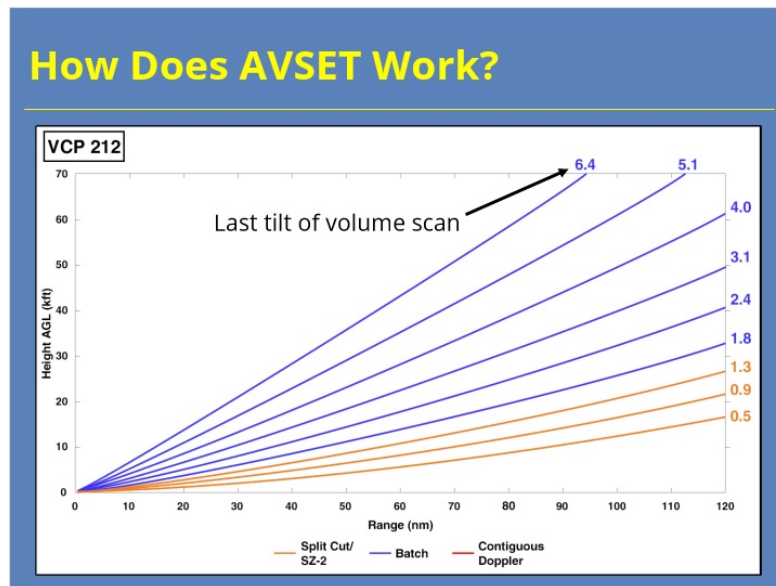


## Cons (Slide Layer)

### AVSET Details



## How Does AVSET Work?



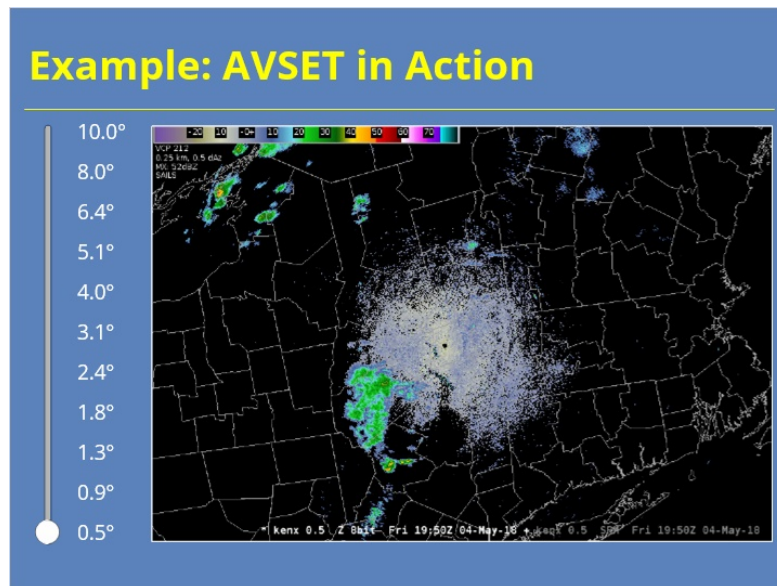
### Notes:

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 km<sup>2</sup>
- The total coverage of 30 dBZ echoes must be less than 30 km<sup>2</sup> and
- The 18dBZ echo coverage area cannot increase by 12 km<sup>2</sup> 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.

### ***Example: AVSET in Action***

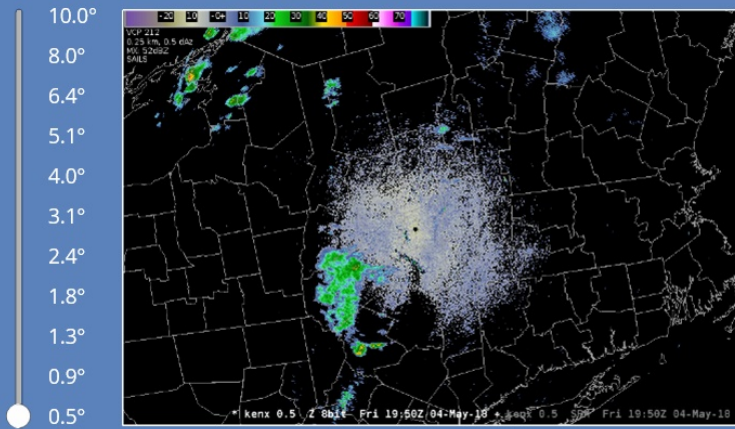


#### **Notes:**

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.

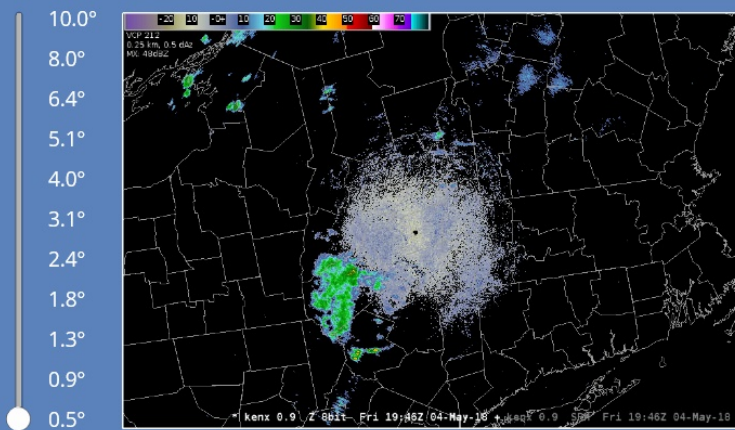
## 0.5 (Slide Layer)

### Example: AVSET in Action



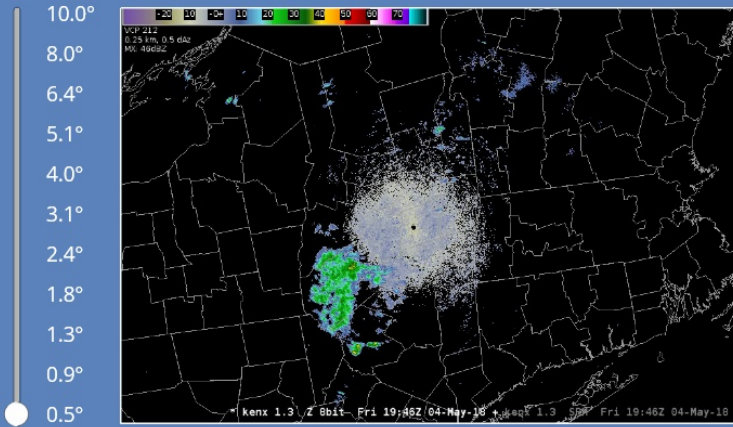
## 0.9 (Slide Layer)

### Example: AVSET in Action



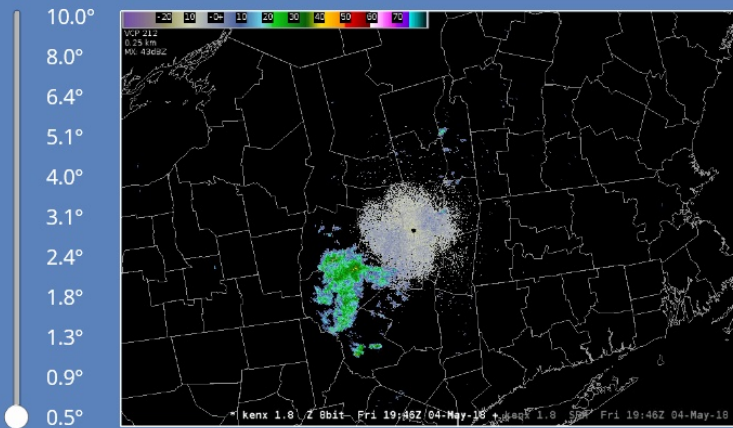
### 1.3 (Slide Layer)

#### Example: AVSET in Action



### 1.8 (Slide Layer)

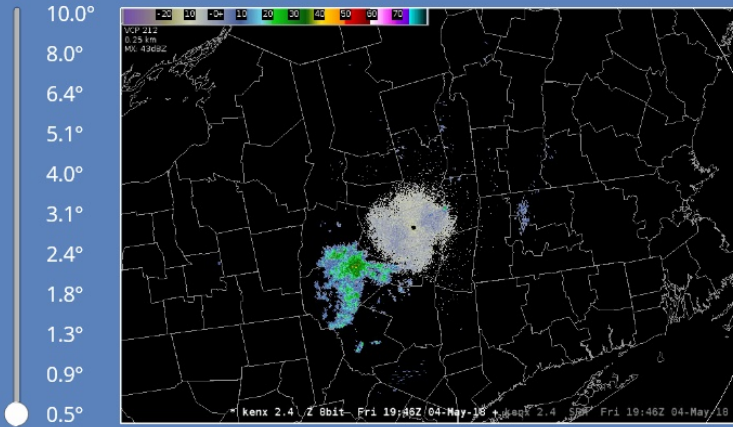
#### Example: AVSET in Action





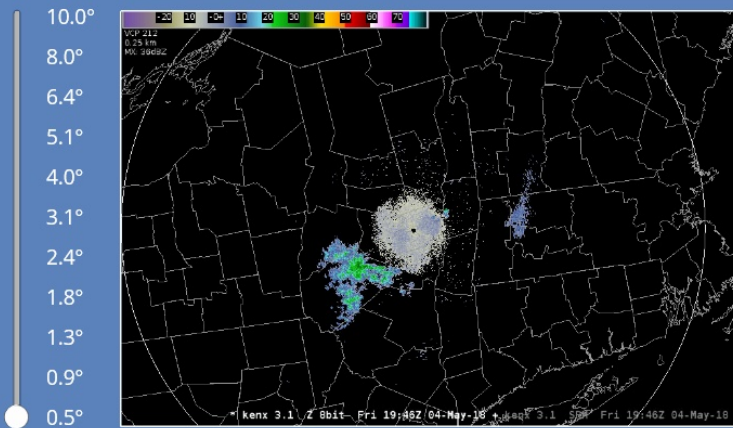
## 2.4 (Slide Layer)

### Example: AVSET in Action



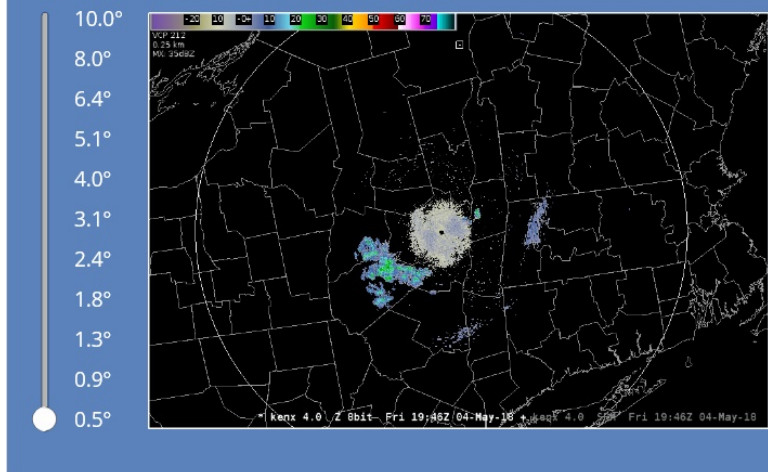
## 3.1 (Slide Layer)

### Example: AVSET in Action



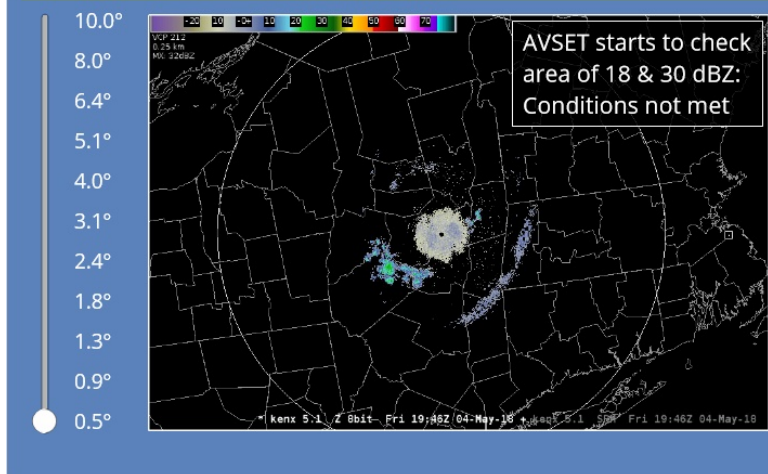
#### 4.0 (Slide Layer)

### Example: AVSET in Action



#### 5.1 (Slide Layer)

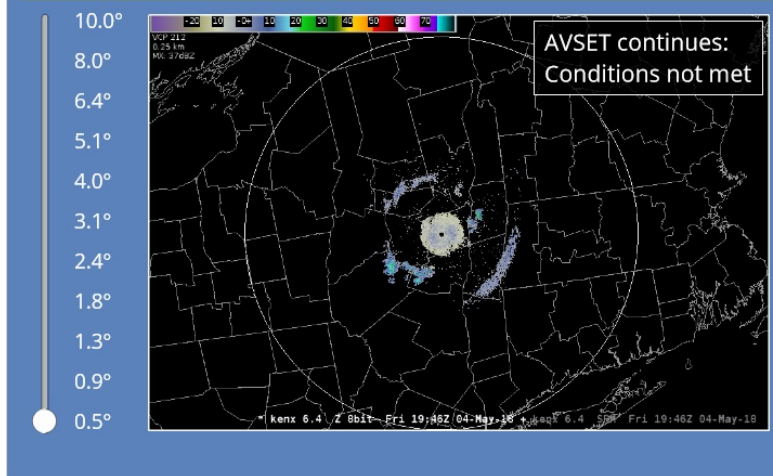
### Example: AVSET in Action





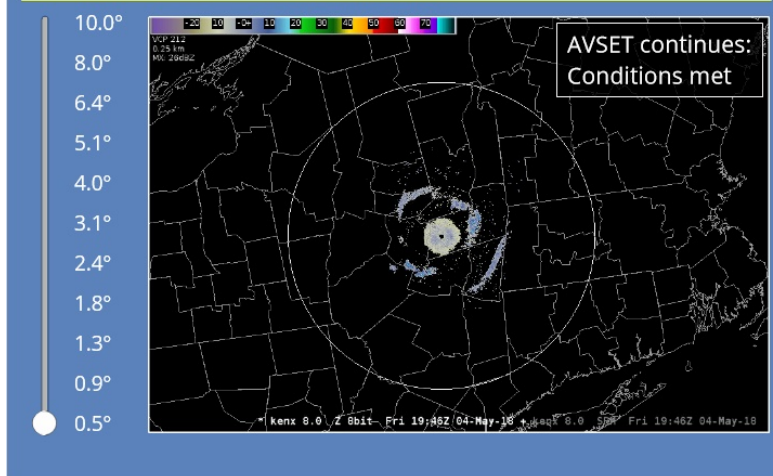
## 6.4 (Slide Layer)

### Example: AVSET in Action



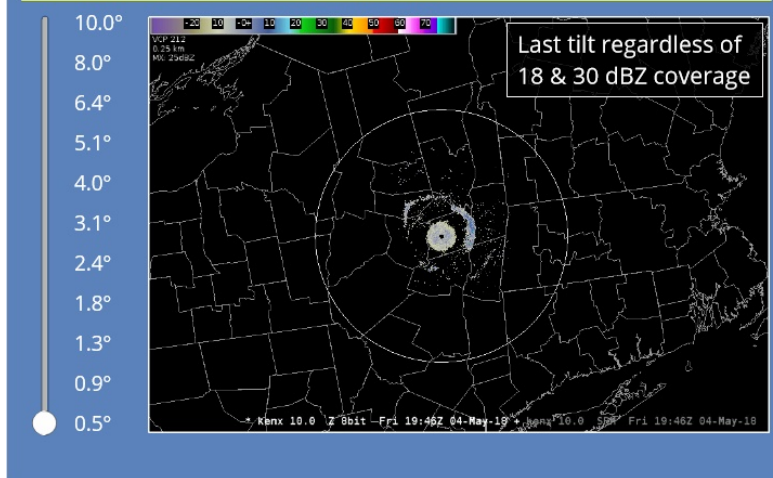
## 8.0 (Slide Layer)

### Example: AVSET in Action

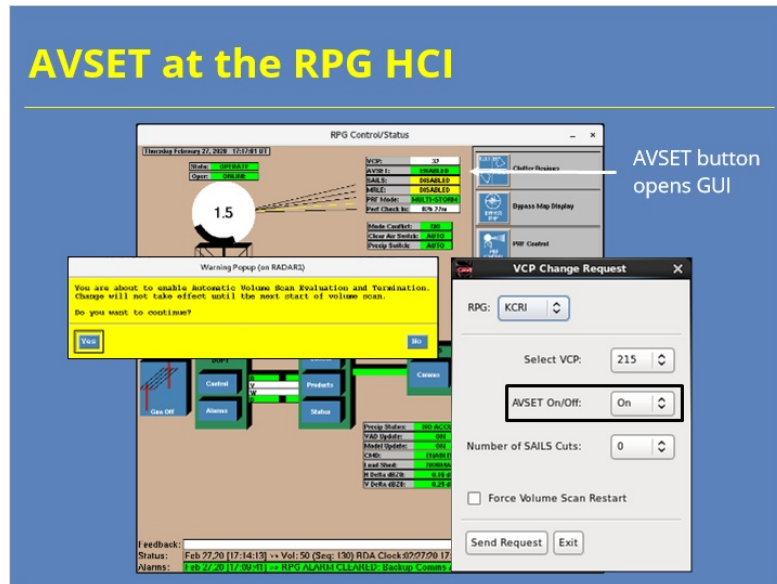


## 10.0 (Slide Layer)

### Example: AVSET in Action



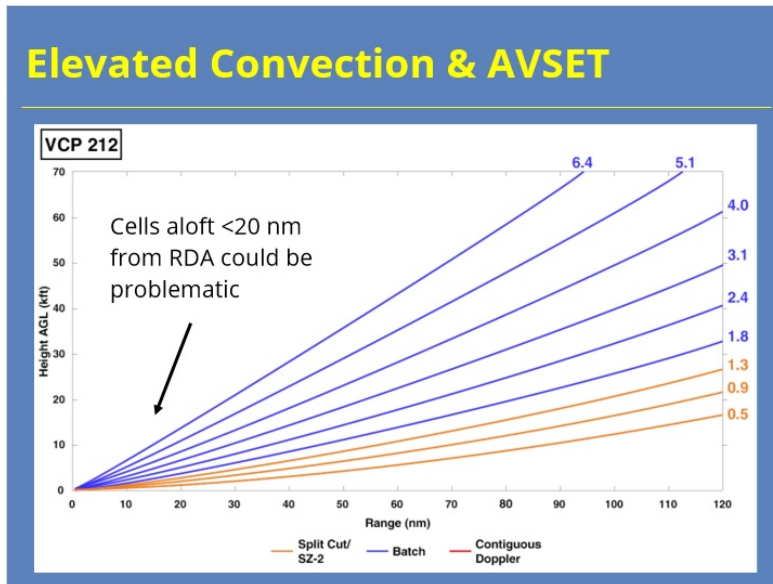
## AVSET at the RPG HCI



### 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.

## ***Elevated Convection & AVSET***

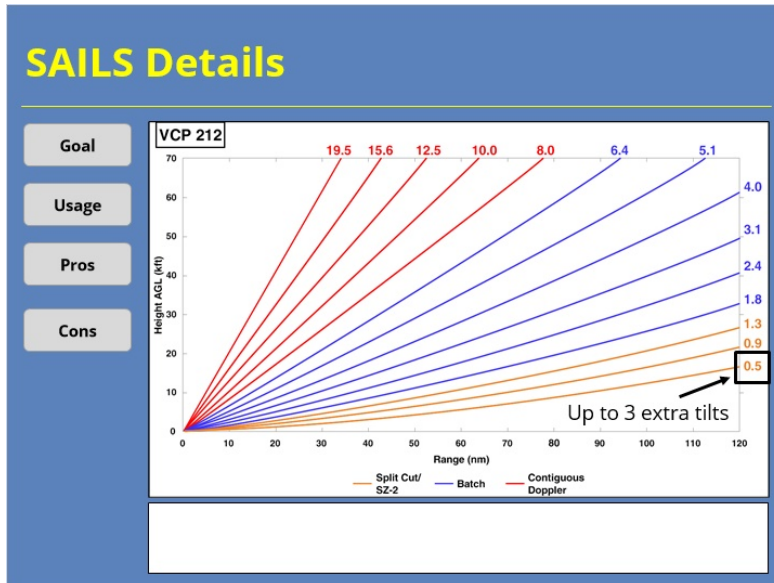


### **Notes:**

The one downside to AVSET involves elevated convection. If elevated convection were to bubble up near the RDA, you could potentially miss cells within the nearest 20 nm of the RDA...at least for a few volume scans. If you suspect that your radar is not detecting elevated cells in your primary radar's cone of silence, 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.

## 4. SAILS

### *SAILS Details*



#### Notes:

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

**Goal:** Provide more frequent low-level tilts

#### Usage:

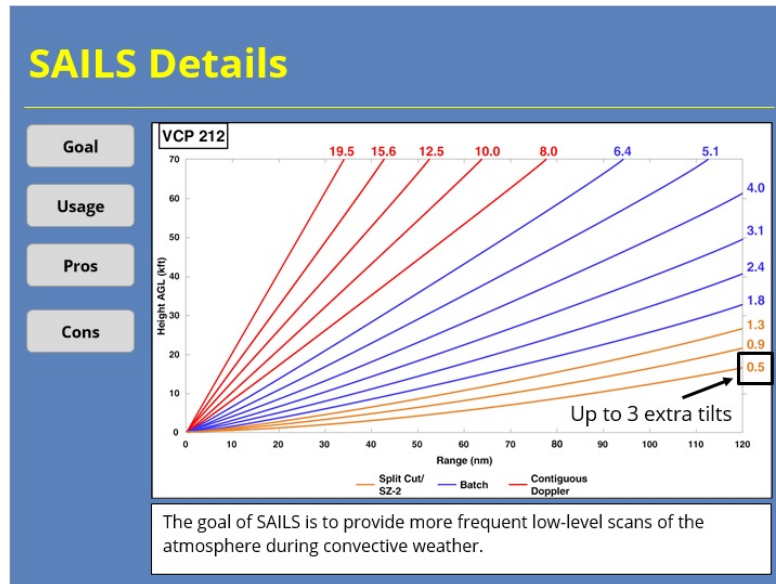
- Up to 3 SAILS tilts: VCPs 12 & 212
- One SAILS tilt: VCPs 35, 112, & 215

**Pros:** Better low-level sampling of atmosphere

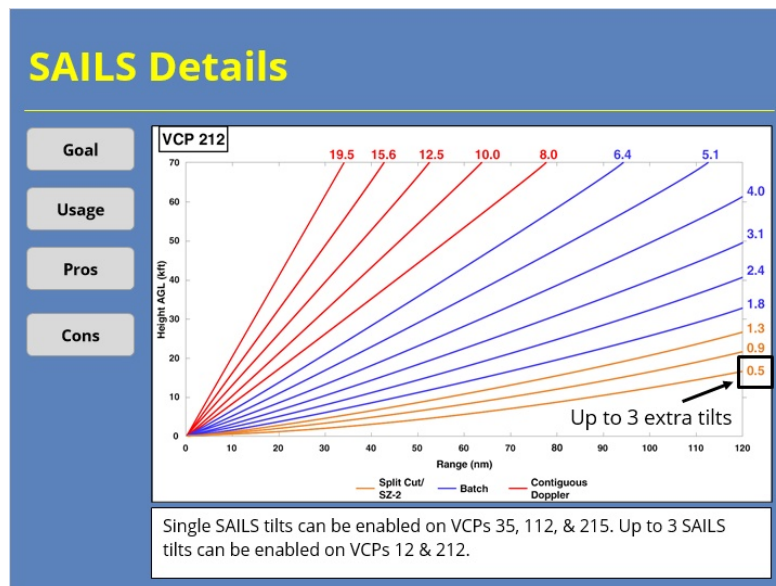
#### Cons:

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

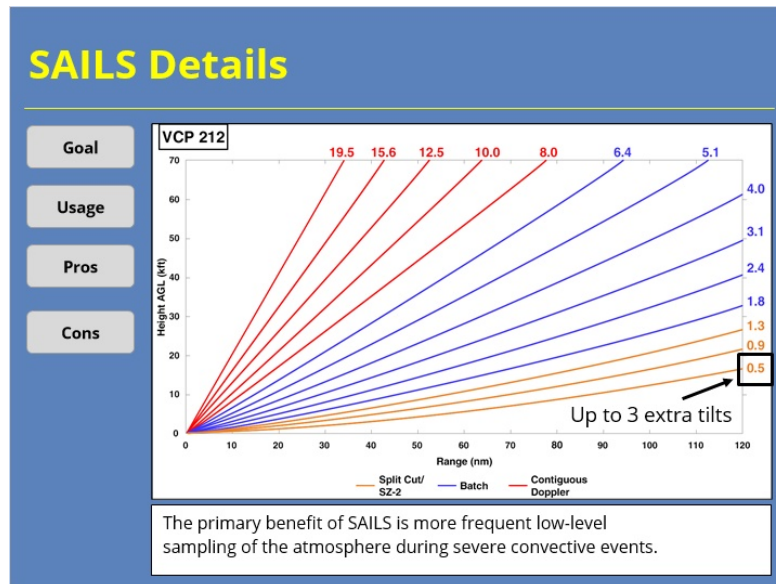
## Goal (Slide Layer)



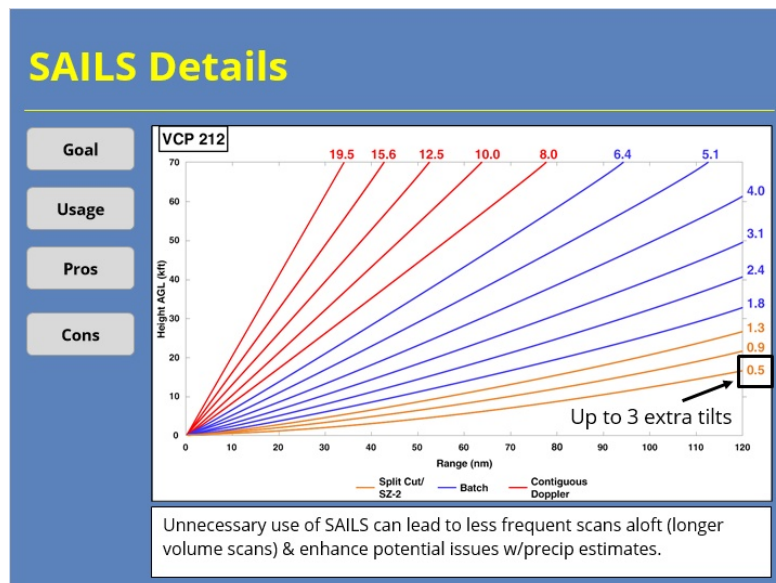
## Usage (Slide Layer)



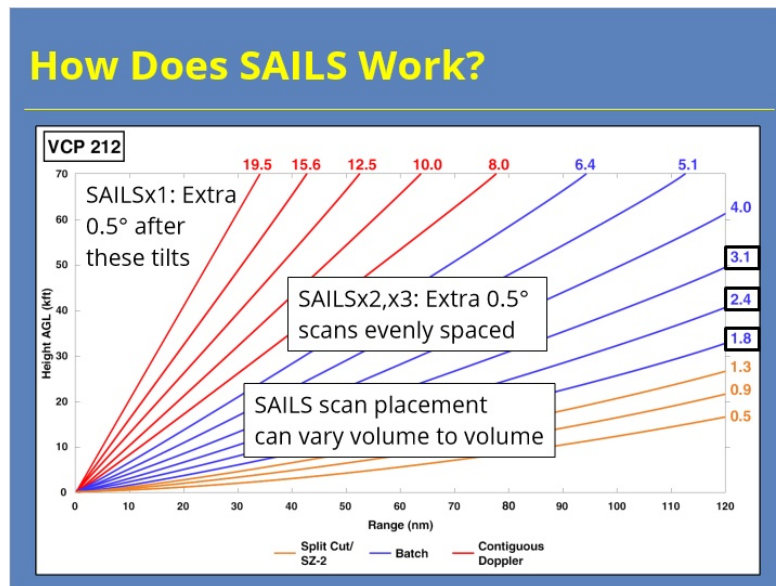
## Pros (Slide Layer)



## Cons (Slide Layer)



## How Does SAILS Work?

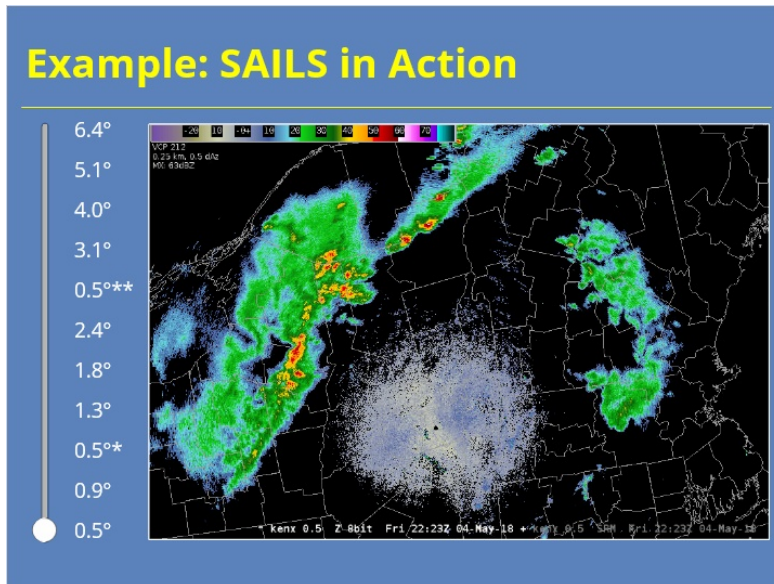


### Notes:

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.



### Example: SAILS in Action

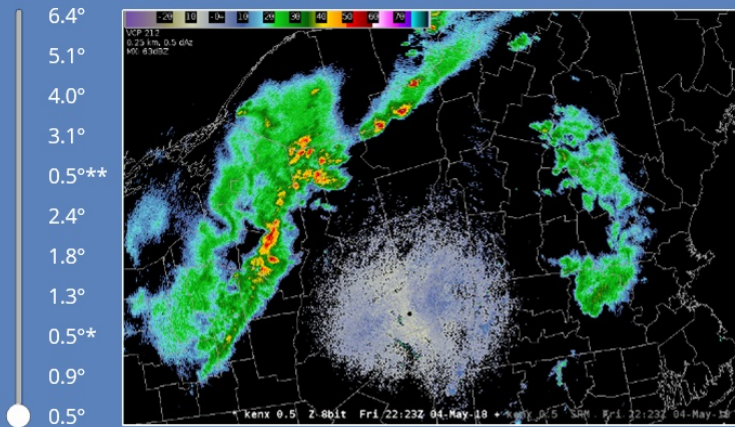


**Notes:**

This interaction shows an actual volume scan where 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.

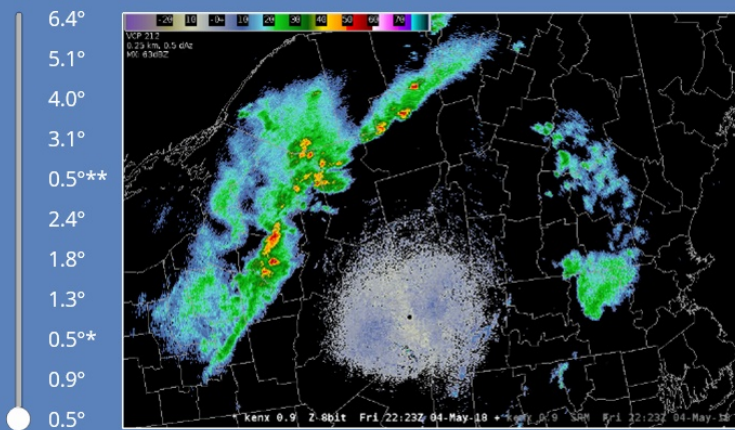
## 0.5 (Slide Layer)

### Example: SAILS in Action



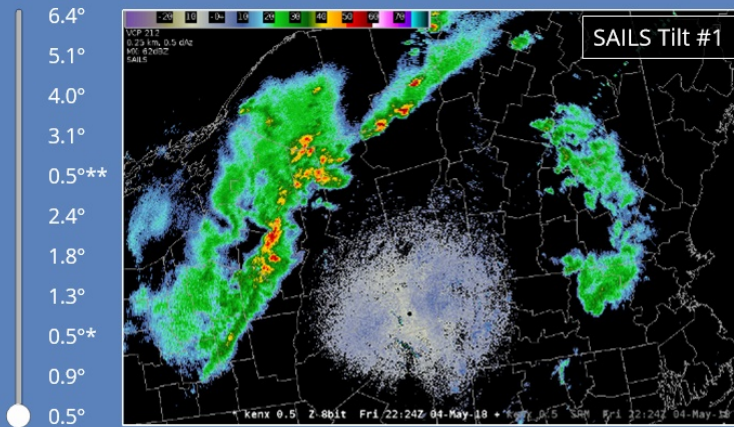
## 0.9 (Slide Layer)

### Example: SAILS in Action



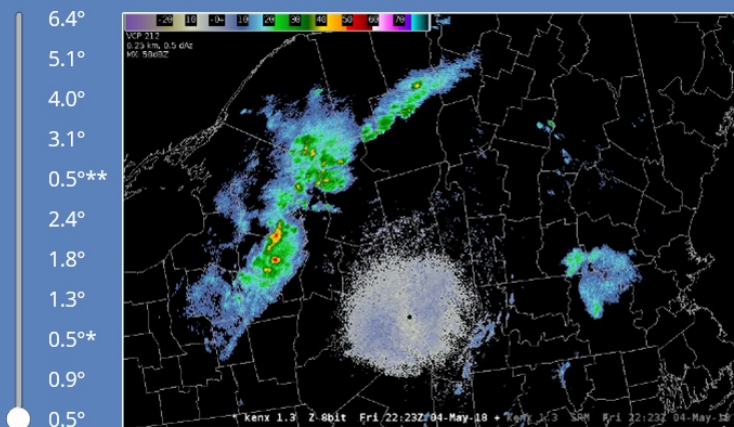
## 0.5 - SAILS 1 (Slide Layer)

### Example: SAILS in Action



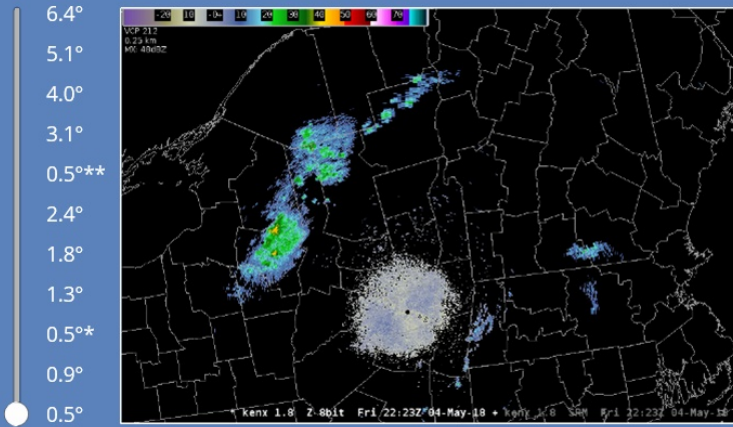
## 1.3 (Slide Layer)

### Example: SAILS in Action



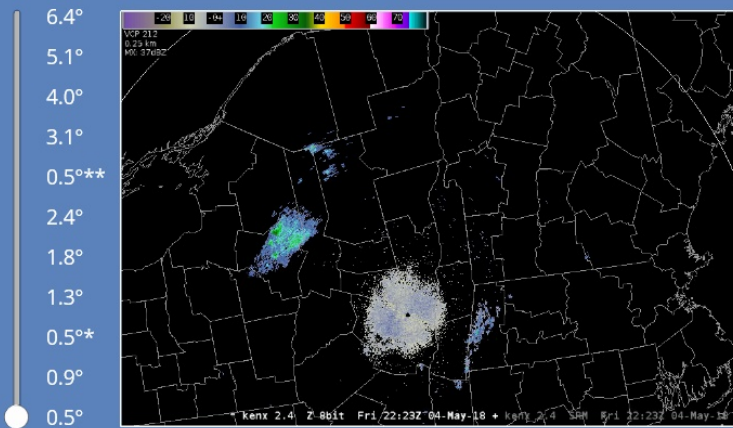
## 1.8 (Slide Layer)

### Example: SAILS in Action



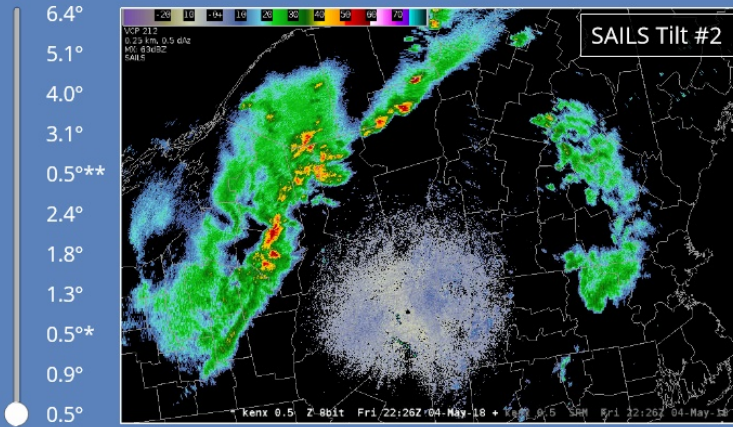
## 2.4 (Slide Layer)

### Example: SAILS in Action



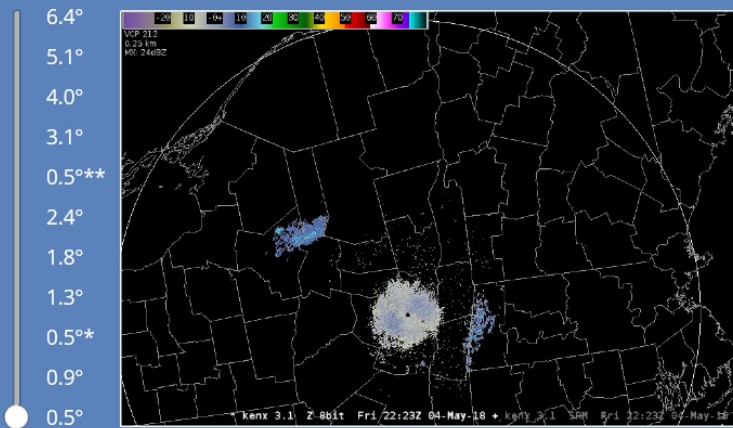
## 0.5 - SAILS 2 (Slide Layer)

### Example: SAILS in Action



## 3.1 (Slide Layer)

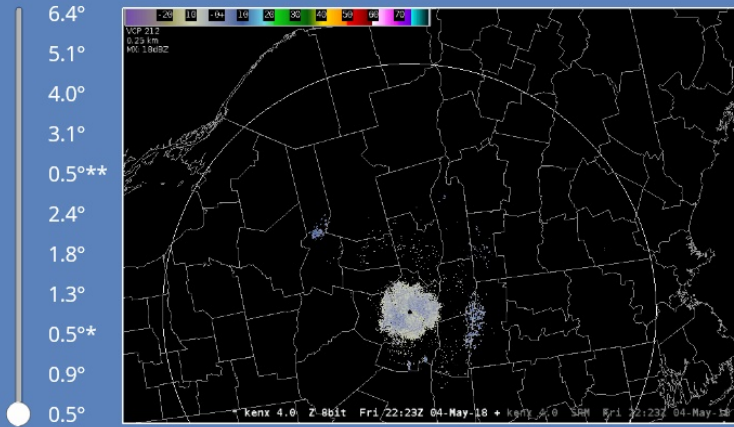
### Example: SAILS in Action





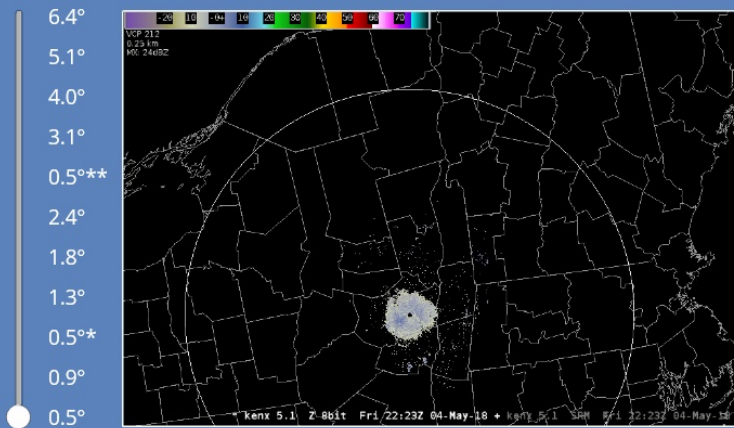
#### 4.0 (Slide Layer)

### Example: SAILS in Action



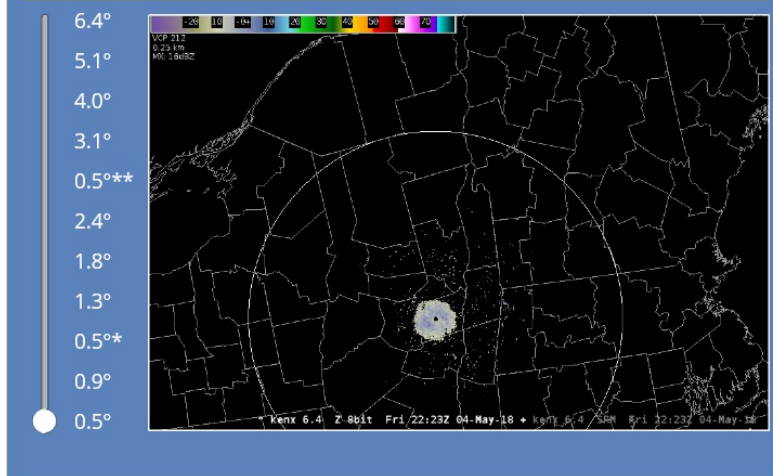
#### 5.1 (Slide Layer)

### Example: SAILS in Action

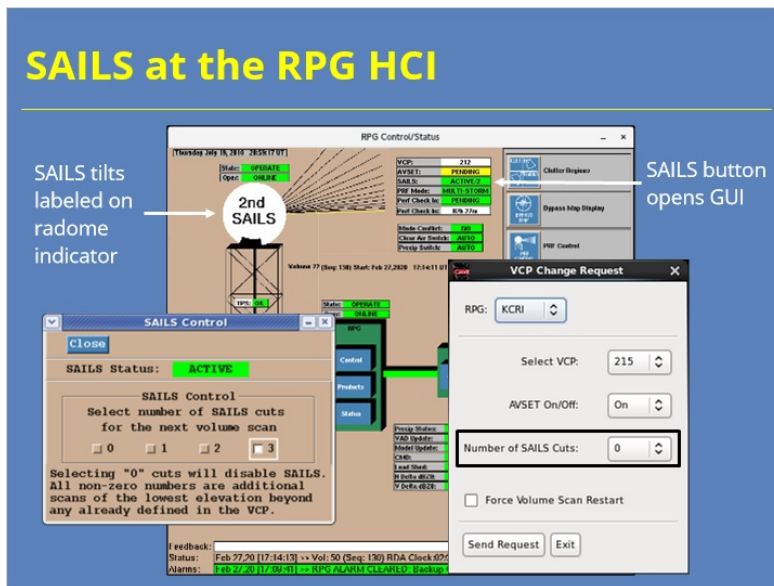


## 6.4 (Slide Layer)

### Example: SAILS in Action



## ***SAILS at the RPG HCI***



### **Notes:**

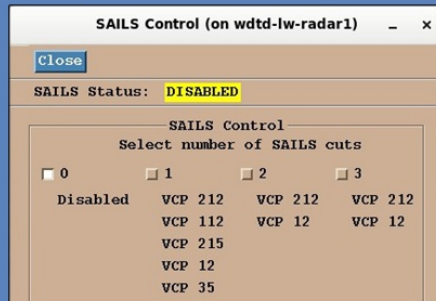
If you need to know when the SAILS tilts are happening, your best bet is to look at the RPG HCI. In the example shown, the RPG is processing the "2nd SAILS" tilt of the volume scan. So, it's the third 0.5 tilt. Remember that you can edit the number of SAILS tilts collected at the RPG by clicking the 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.



## ***SAILS Use: “Food for Thought”***

### **SAILS Use: “Food for Thought”**

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

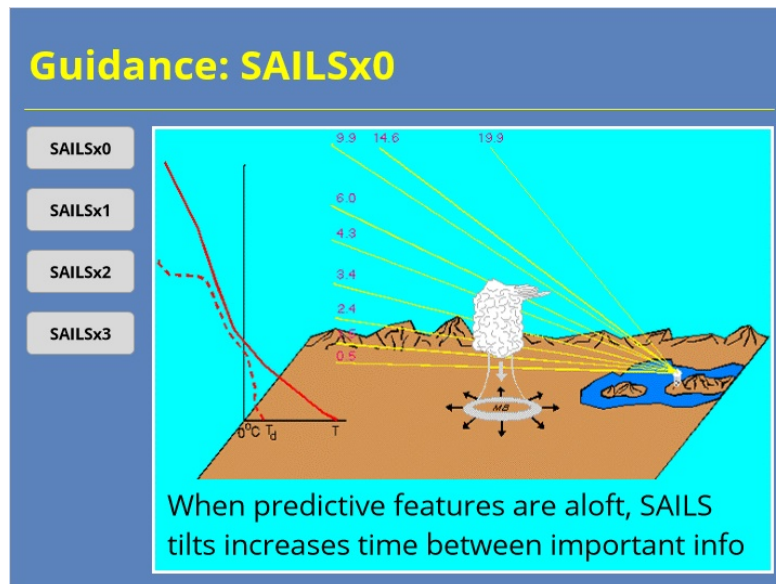


As the need to analyze near surface features increases, the more SAILS tilts you want enabled

#### **Notes:**

Radar operators have multiple SAILS options during severe convection events. If you only remember one thing from these next few slides, it should be that you can’t simply “set and forget” your number of SAILS tilts. You should routinely adjust your SAILS settings based on the needs of the current event. As a general rule, the more analysis focus you want near the surface (and can accept less frequent updates aloft) then the more SAILS tilts you want enabled. Also, there is a chance that MRLE might be a better option for what you want to do than SAILS. We’ll discuss those situations in the next section.

## Guidance: SAILSx0



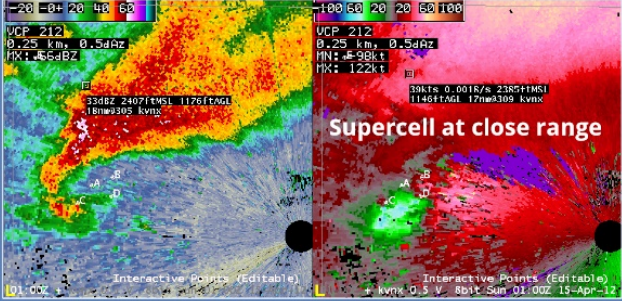
### Notes:

If your primary threat is elevated or pulse storms (like dry microburst storms out west), or if hail is your main concern, you should probably have SAILS disabled. That may seem counter intuitive to some, so let me explain why I recommend that. With elevated or pulse storms, the predictive features that will give you lead time will generally be detected above 0.5 degrees. So, enabling SAILS tilts will just make those important tilts be collected less frequently. That logic also applies to storms where big hail with only marginal or sub-severe winds are expected. Both of these situations may be better served by using MRLE, which we will talk about shortly.

## Guidance: SAILSx1

**Guidance: SAILSx1**

SAILSx0  
SAILSx1  
SAILSx2  
SAILSx3



Good for balancing needs aloft & at surface:

- Severe supercells/multicells (near radar)
- Organized wind events w/MARC

### Notes:

SAILSx1 is a good option when you have competing needs to focus aloft and at the surface. When you have severe supercells and multicells close to the radar or an organized damaging wind event where a potential MARC signature can provide lead time, then SAILSx1 will be a good option.

## Guidance: SAILSx3

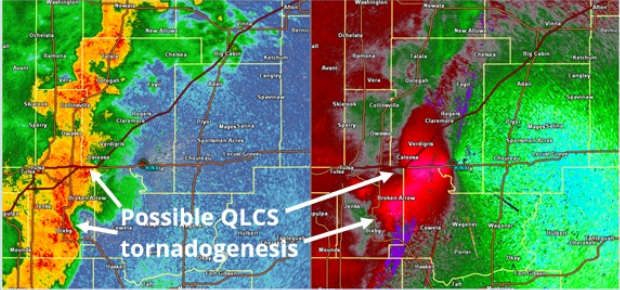
### Guidance: SAILSx3

SAILSx0

SAILSx1

SAILSx2

SAILSx3



Possible QLCS  
tornadogenesis

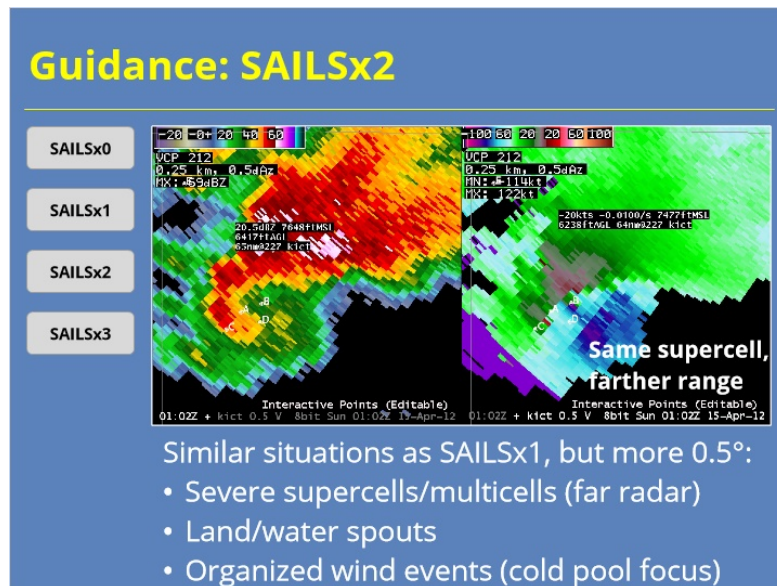
Focus on near surface signatures:

- QLCS tornadoes
- Long-lived supercell (tracking tornado)
- Organized wind events (cold pool focus)

### Notes:

SAILSx3 will be your best option when you need to analyze near surface signatures to provide the best service. For example, QLCS tornado precursors are often visible closer to the surface than supercell tornadoes. So, having the additional lowest level tilts will provide you the best chance to detect the circulation spin up. Likewise, if you have a big, long-lived supercell in an obvious tornado event, then you may want to focus on the lowest level more in order to track the circulation through a metro area or spot a debris signature as soon as possible. This situation would also be good for SAILSx3. So would organized damaging wind events where you need to track the near-surface cold pool.

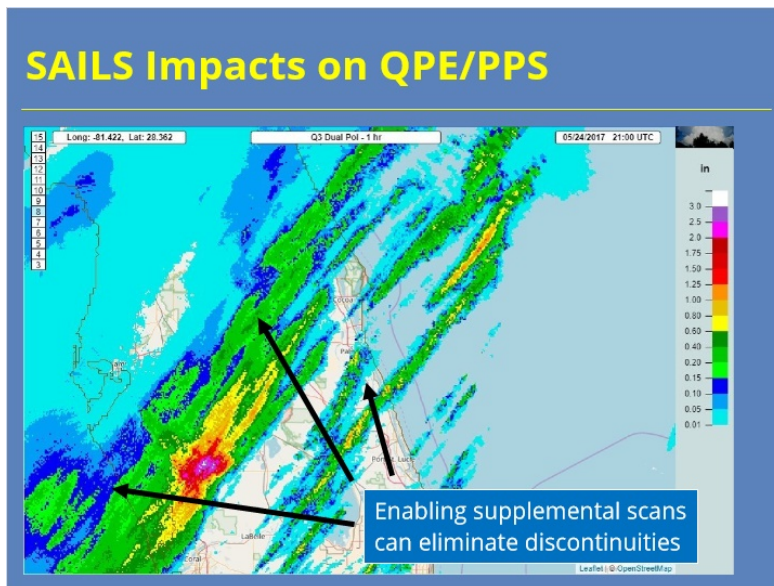
## Guidance: SAILSx2



### Notes:

SAILSx2 will be a good option in many similar situations as SAILSx1. SAILSx2 will be a better choice when your storms of interest are further away from the radar. In these cases, the lowest level tilt will usually be higher above the ground and sampling a larger volume. The additional low-level tilt is more likely to sample the important parts of the storm for severe supercells and multicells, as well as land and water spouts. Additionally, organized damaging wind events where analyzing the near-surface cold pool is important is also a good candidate for SAILSx2.

## ***SAILS Impacts on QPE/PPS***



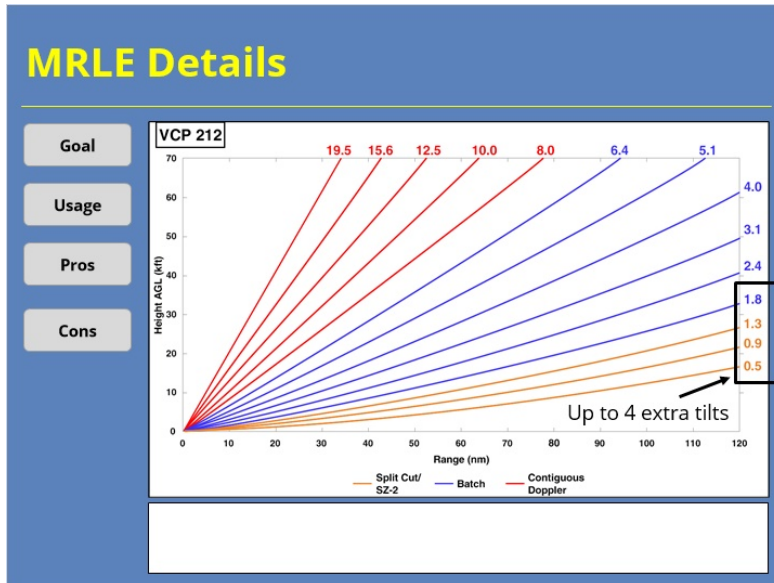
### **Notes:**

Rapidly moving, discrete cells can lead to artifacts in both the QPE and PPS products. An example of one of these artifacts is shown on the slide. Fortunately, the QPE products can address this issue by incorporating data from the SAILS tilts in the estimates. The RPG HCI has an adaptable parameter for the dual-pol algorithms called "Enable use of supplemental scans". Here's how the same data might look when this feature is enabled. This change doesn't impact the legacy PPS products at all. Also, the SAILS data will not help where beam blockage causes the Hybrid Hydrometeor Classification algorithm to use data from a higher elevation angle. So, you will need to balance these two caveats with the desire for smoother dual-pol QPE products.



## 5. MRLE

### MRLE Details



#### Notes:

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

**Goal:** Provide more frequent low-level tilts

#### Usage:

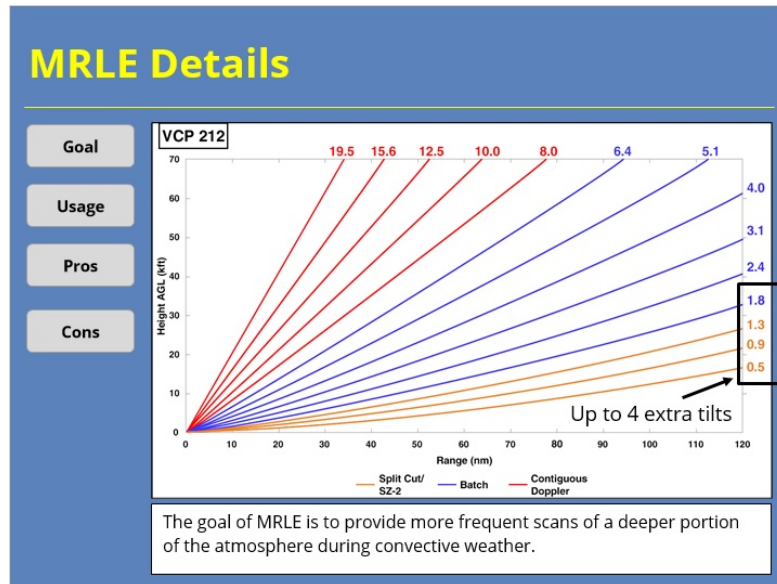
- VCPs 12, 212 & 215

**Pros:** Better low-level sampling of atmosphere during convective events

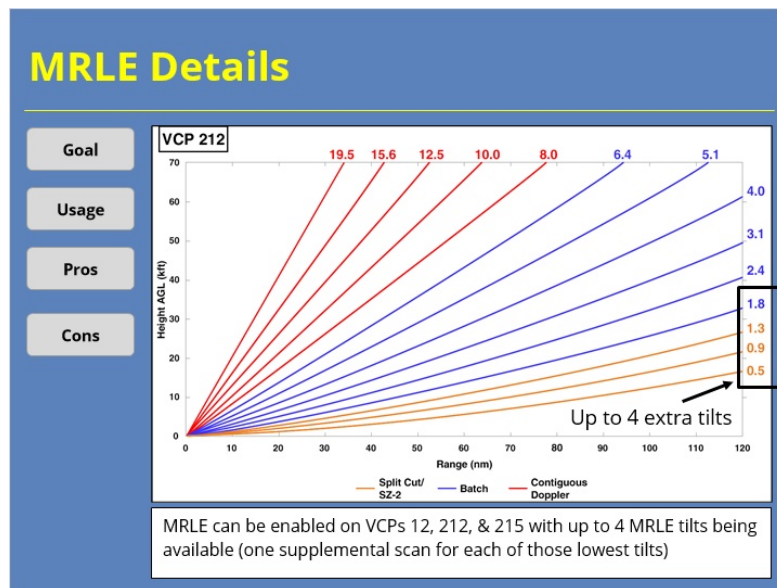
#### Cons:

- Potentially less frequently sampling aloft
- Possibly longer volume scans
- Potential issues with rainfall estimates

## Goal (Slide Layer)

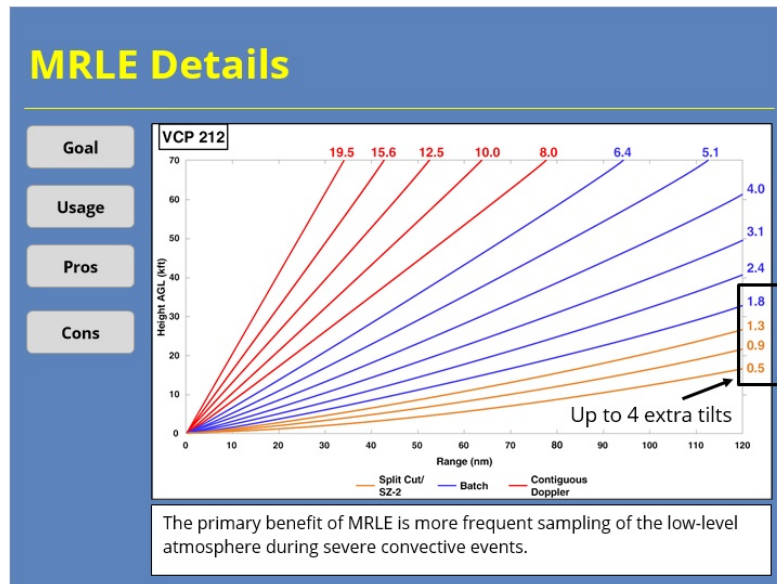


## Usage (Slide Layer)

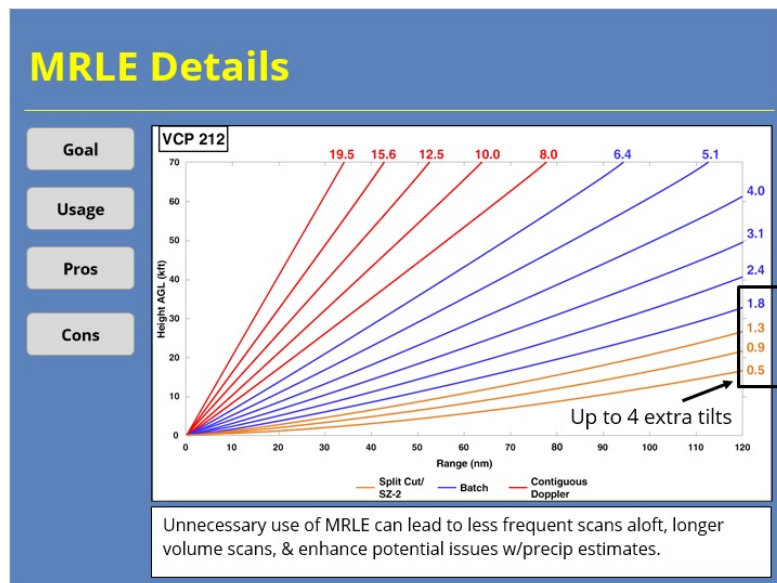




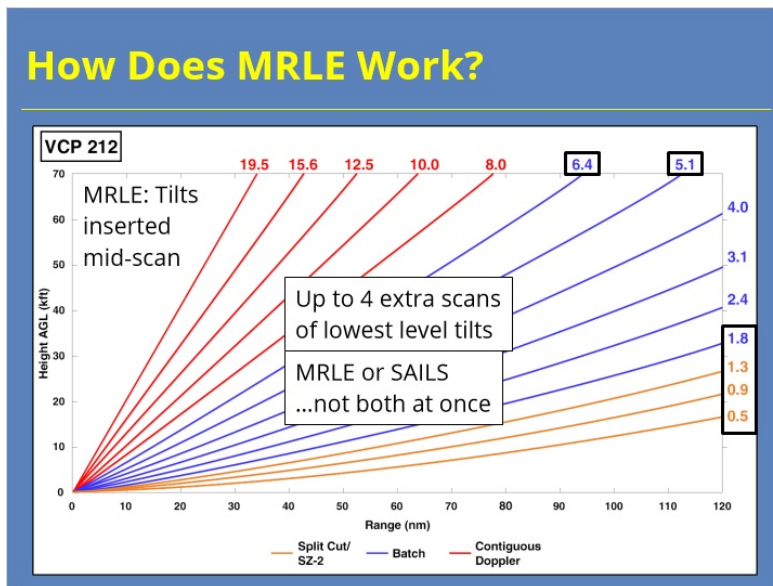
## Pros (Slide Layer)



## Cons (Slide Layer)



## How Does MRLE Work?

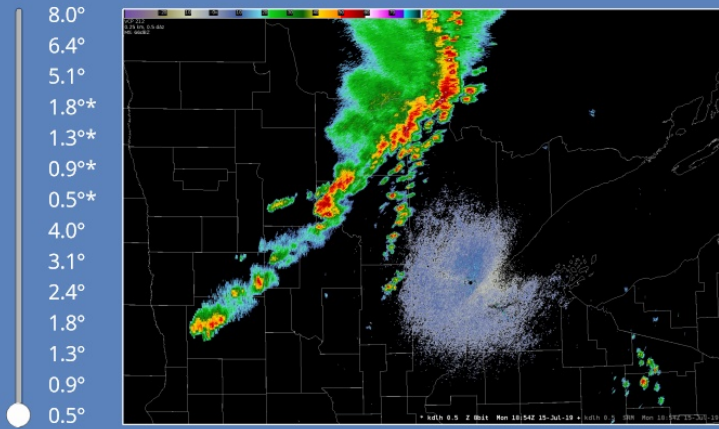


### Notes:

So, how does the radar implement these supplemental scans? Well, the radar works through the volume scan until it's approximately halfway through. Let's use a complete VCP 212 scan as an example to illustrate. The radar scans as normal until it finishes the 5.1 degree tilt. The antenna then drops back down to 0.5 degrees and collects the data for the specified number of MRLE tilts. Then, the antenna rotates back up to 6.4 degrees and completes the volume scan. When AVSET has been enabled, then the radar uses the same logic as SAILS to determine the midpoint of the volume scan to insert the supplemental scans. So, it's possible that the placement of the MRLE scans will vary from volume scan to volume scan in these situations. Remember that you can only have MRLE or SAILS enabled at the same time. You can't do both simultaneously.

## Example: MRLE in Action

### Example: MRLE in Action

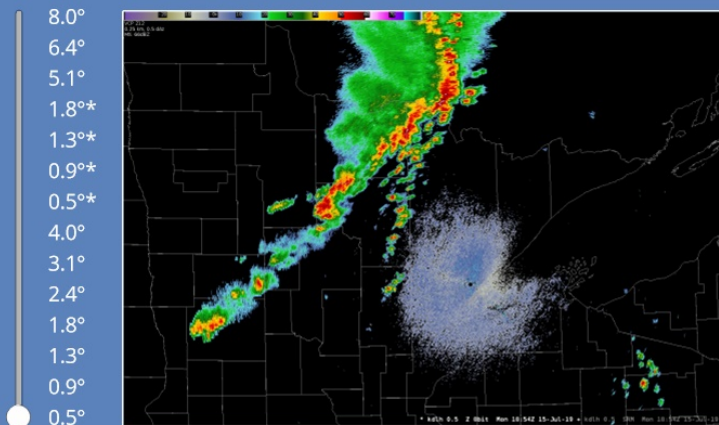


#### Notes:

This interaction shows an actual volume scan where MRLE was enabled. Use the slider bar on the left-hand side of the slide to look at each elevation angle of data. The supplemental MRLE tilts will be annotated with an asterisk in the slider labels.

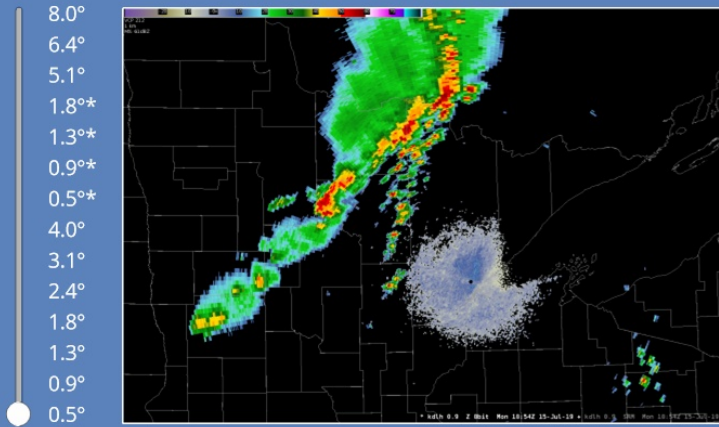
#### 0.5 (Slide Layer)

### Example: MRLE in Action



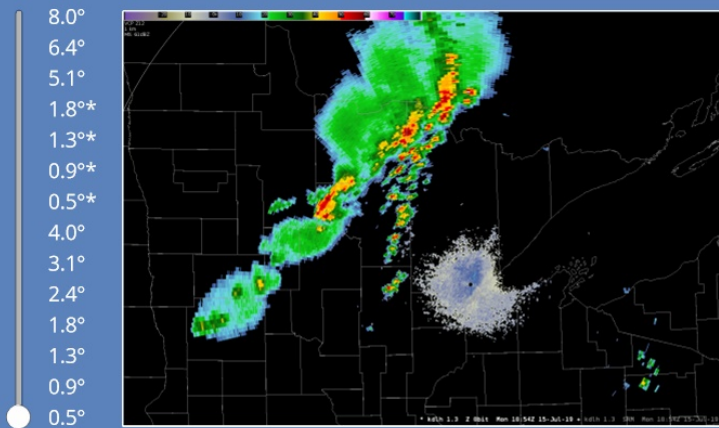
## 0.9 (Slide Layer)

### Example: MRLE in Action



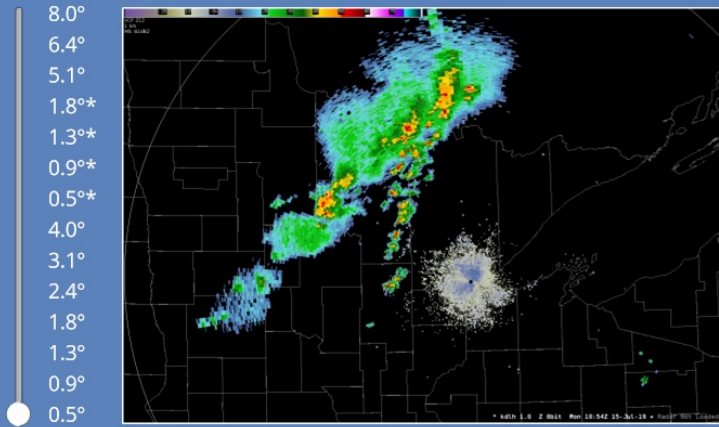
## 1.3 (Slide Layer)

### Example: MRLE in Action



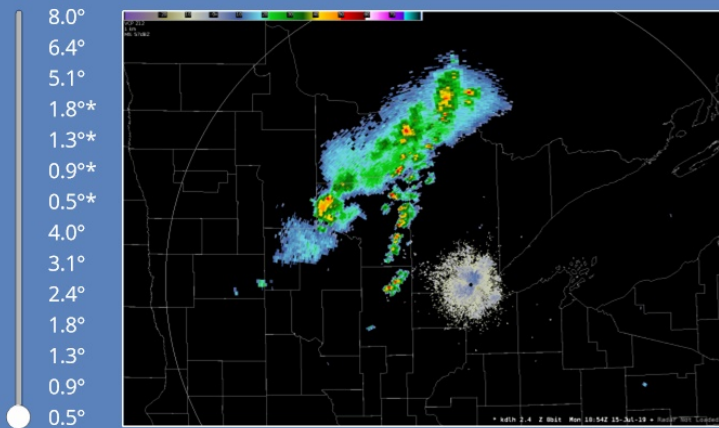
## 1.8 (Slide Layer)

### Example: MRLE in Action



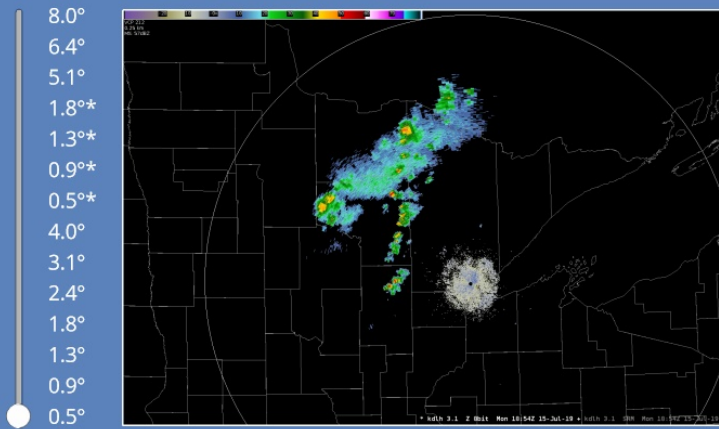
## 2.4 (Slide Layer)

### Example: MRLE in Action



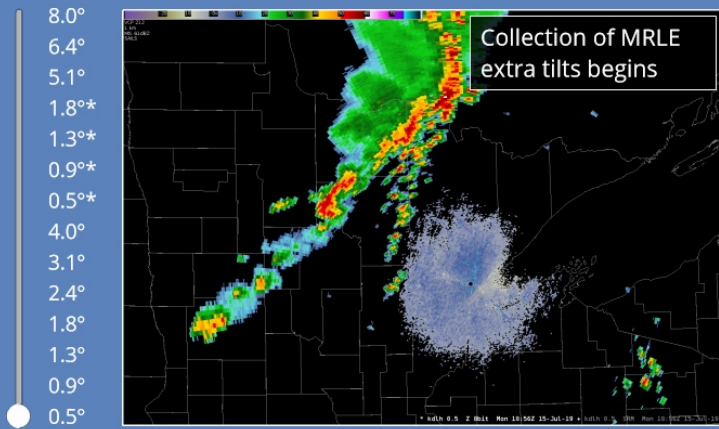
### 3.1 (Slide Layer)

#### Example: MRLE in Action



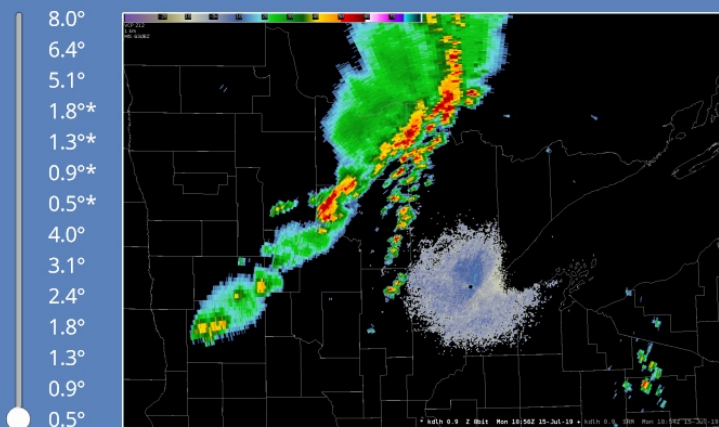
## 0.5-MRLE (Slide Layer)

### Example: MRLE in Action



## 0.9-MRLE (Slide Layer)

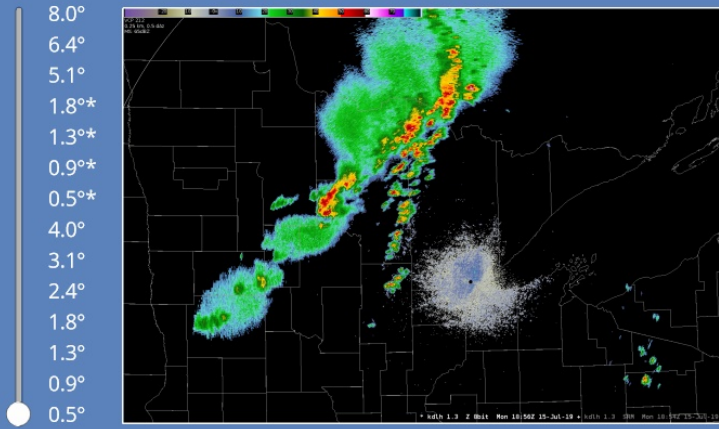
### Example: MRLE in Action





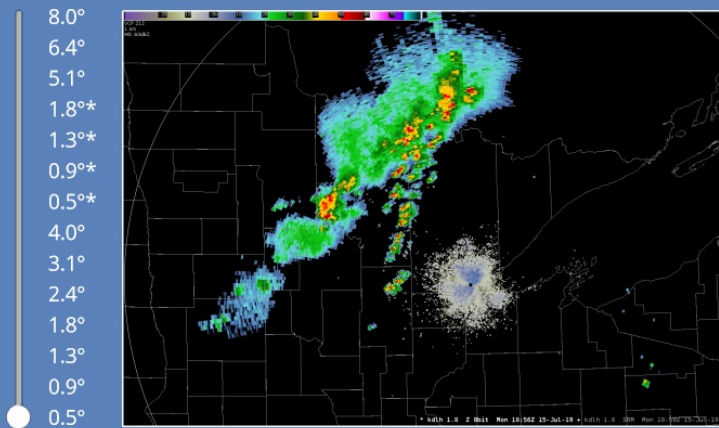
### 1.3-MRLE (Slide Layer)

## Example: MRLE in Action



### 1.8-MRLE (Slide Layer)

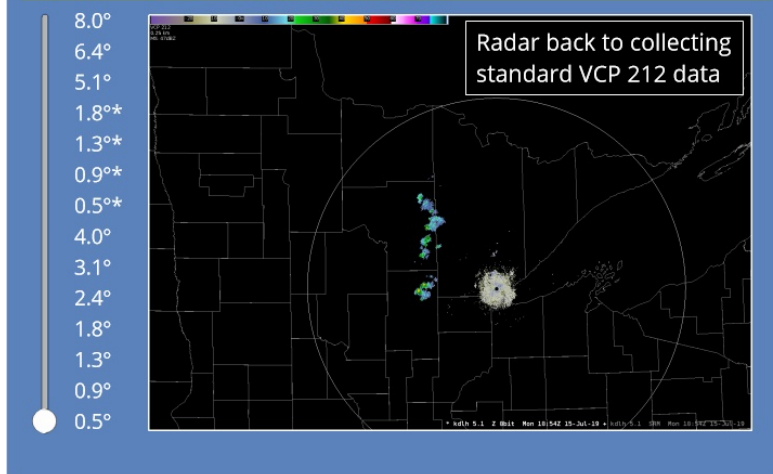
## Example: MRLE in Action





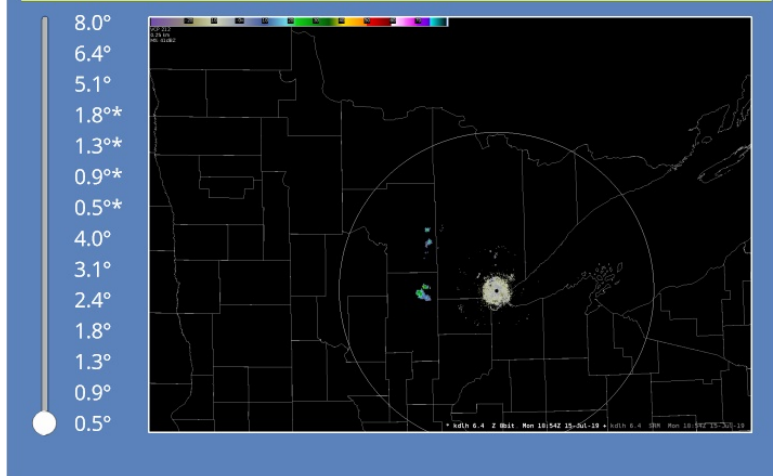
## 5.1 (Slide Layer)

### Example: MRLE in Action



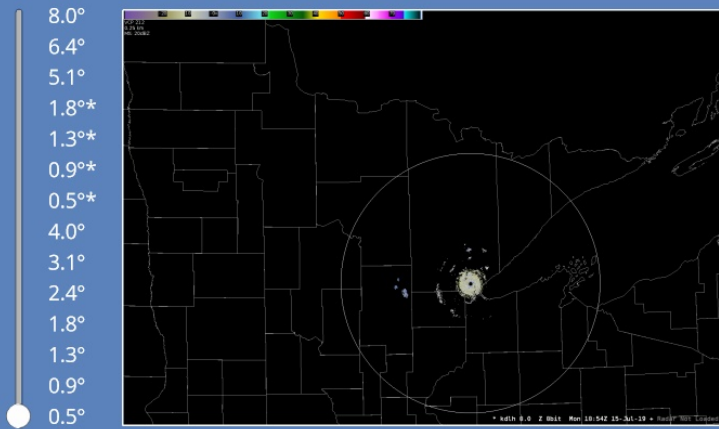
## 6.4 (Slide Layer)

### Example: MRLE in Action

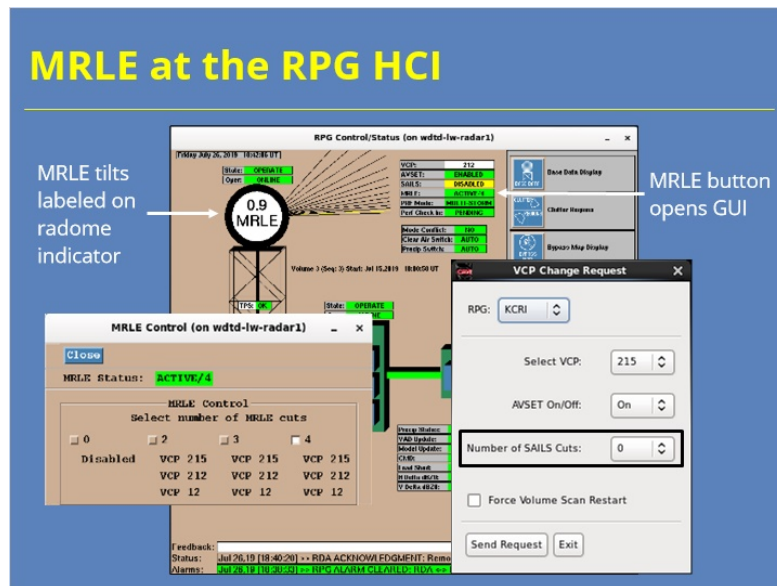


## 8.0 (Slide Layer)

### Example: MRLE in Action



## MRLE at the RPG HCI



### Notes:

If you need to know when the MRLE tilts are happening, your best bet is to look at the RPG HCI. In the example shown, the RPG is processing the "2nd MRLE" tilt of the volume scan. So, it's the supplemental 0.9 tilt. Remember that with Build 18.2, you can edit the number of MRLE tilts collected at the RPG HCI by clicking the MRLE button. In the MRLE Control GUI, you can change the number of MRLE cuts collected. NOTE: You can also make changes at the VCP Change Request GUI on your AWIPS workstation that impact MRLE. For example, if you select a non-zero number of SAILS cuts, MRLE will be deactivated.

## MRLE Use: “Food for Thought”

### MRLE Use: “Food for Thought”

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



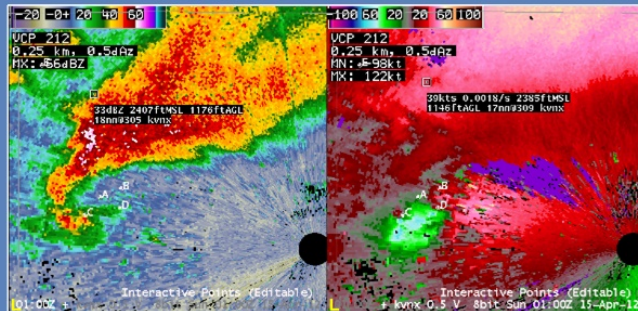
Enable MRLE cuts when feature you want to analyze is best sampled in the lowest 2-4 tilts of the volume

#### Notes:

Just as with SAILS, you can’t simply “set and forget” your number of MRLE tilts. Whether you use MRLE (and how many supplemental scans you include) will depend on your current event. You want to enable MRLE cuts when the storm features you want to analyze are best sampled by the lowest 2-4 tilts of the volume. In these cases, using MRLE will provide you with the most frequent data updates for these features.

## Guidance: MRLE Usage

### Guidance: MRLE Usage

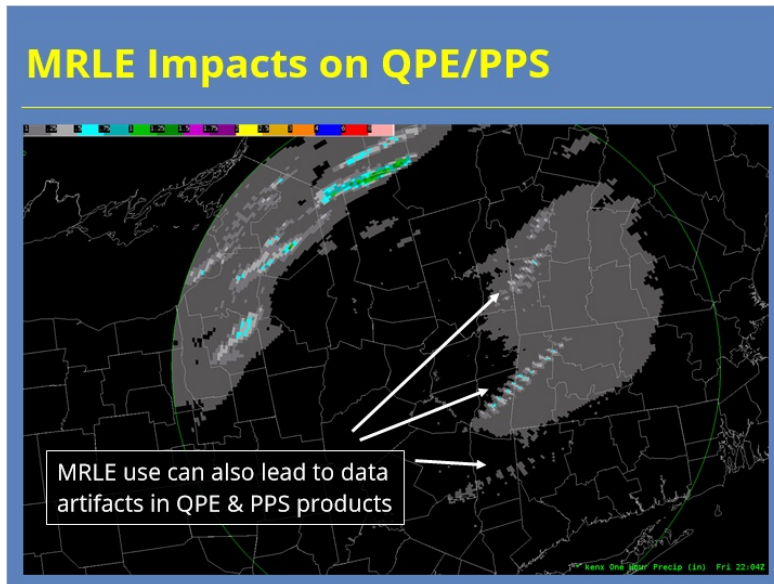


- Tornado genesis (closer ranges)
- Organized damaging wind (rear inflow jet)
- Elevated/pulse storms (far range)

#### Notes:

I can think of a few situations where using MRLE might be your best option. The key word is MIGHT. The first situation would be tornado genesis. For QLCS tornadoes and land/waterspouts, MRLEx4 should sample the lowest 5 km of the storm well in the 10-40 nm range. MRLEx4 may also be the best option for supercellular tornado genesis in the 30-70 nm range...even closer for mini-supercells. Two other situations where MRLE could benefit is analyzing the rear inflow jet of an MCS or an elevated (or pulse) storm at far ranges. And when I say far ranges, I mean 60-100 nm for radar at ground level, and closer for radars located on mountain tops. One last thing I should point out, If you want to look at these same features at longer ranges than what I have listed here, consider using MRLEx2 or x3 instead. Which one you choose will depend on the range of the storms (or features) you want to analyze.

## ***MRLE Impacts on QPE/PPS***



### **Notes:**

Use of MRLE can lead to the same data artifacts in both the QPE and PPS products that are also visible with SAILS. Since up to 4 low-level tilts can be inserted, the issue may be more prominent with MRLE than with SAILS. Toggling on the adaptable parameter “Enable use of supplemental scans” can help reduce (but may not eliminate) these artifacts in the dual-pol precip products.

## 6. Summary & Quiz

### *Summary*

#### Summary

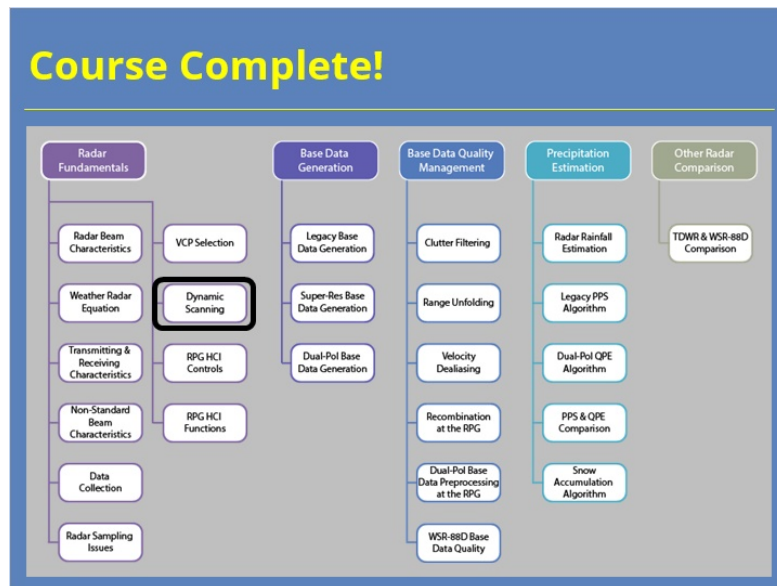
- Dynamic scanning allows the radar operator to adjust their desired VCP to improve data collection
- Key applications: AVSET, SAILS, & MRLE
- AVSET:
  - Helps avoid unnecessary data collection
  - Can result in faster volume scan times
- SAILS:
  - Allows for more frequent lowest-level scans
  - Adjust use as needed (Don't "Set it & forget it!")
- MRLE:
  - More frequent scanning of low-level atmosphere
  - Can't use w/SAILS

#### **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 MRLE. AVSET works to shorten volume scan times by avoiding collection of unnecessary data at higher elevation angles. SAILS allows 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. Lastly, MRLE allows for more frequent scanning of the low-level atmosphere. You can add an extra scan of up to the lowest four tilts per volume scan. However, you can't use MRLE and SAILS together.

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

**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 Controls

## 1. Radar Reflectivity Signatures

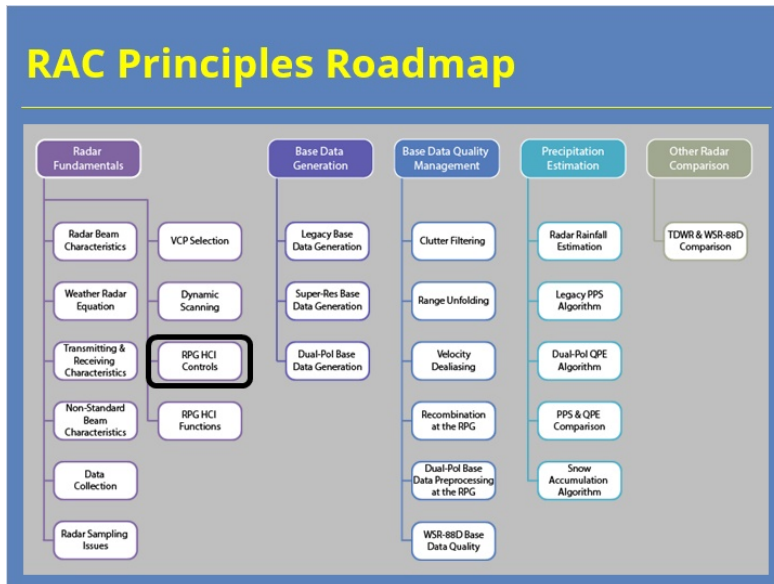
### *Introduction*



### **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!

## 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.

## ***Learning Objectives***

### **Learning Objectives**

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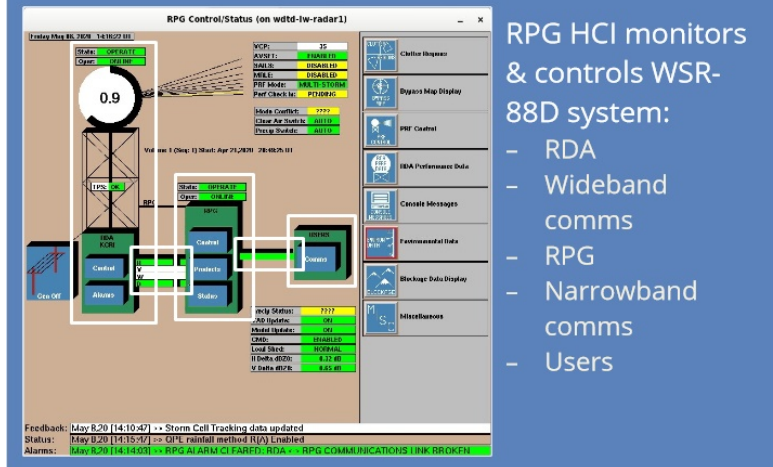
- Identify the WSR-88D system component icons, buttons, & indicators on the RPG HCI
- Identify how to use the RPG HCI to monitor & control the RDA, RPG, & communications line states
- Identify how to perform these basic monitoring & control tasks:
  - Initiate manual system performance check
  - Monitor, filter, and/or triage various alarm messages
  - Send a Free Text Message to other WSR-88D users

#### **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.

## RPG HCI Monitoring & Control

### RPG HCI Monitoring & Control



RPG HCI monitors & controls WSR-88D system:

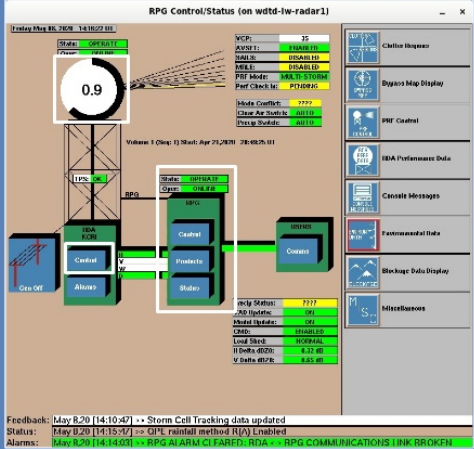
- RDA
- Wideband comms
- RPG
- Narrowband comms
- Users

#### 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.

## RPG HCI Icons, Buttons, & Indicators

### RPG HCI Icons, Buttons, & Indicators



The screenshot displays the 'RPG Control/Status (on wddd-twr-radar1)' window. It features a central radar display with a green radar beam and a target labeled '0.9'. To the left of the radar are buttons for 'Circ Off', 'RDA', 'Control', 'Alarms', and 'Status'. To the right are buttons for 'RPG', 'Control', 'Products', 'Status', and 'Control'. A status bar at the bottom shows feedback, status, and alarms. A sidebar on the right contains a list of icons and buttons for various functions.

RPG HCI provides operator three kinds of tools:

- Icons
- Buttons
- Indicators

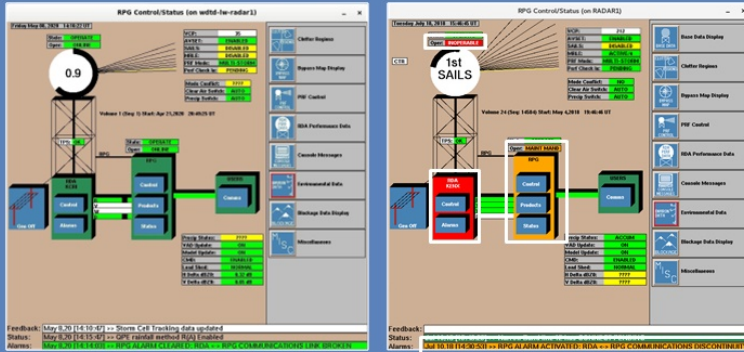
Feedback: May 8, 2014 14:10:47 -> Storm Cell Tracking data updated  
Status: May 8, 2014 14:15:47 -> CIP: rainfall method (R) Enabled  
Alarms: May 8, 2014 14:14:03 -> RPG ALARM C/FART: RDA -> RPG COMMUNICATIONS LINK BROKEN

### 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.

## Lesson Scope

### Lesson Scope



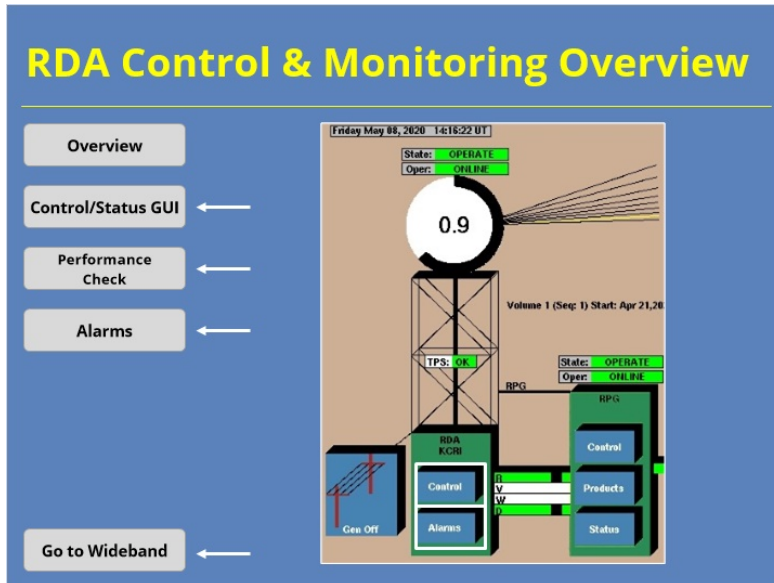
Focus will be on key tasks & “check engine light” alerts that should lead to action

### 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 your car remains drivable.

## 2. RDA Tasks

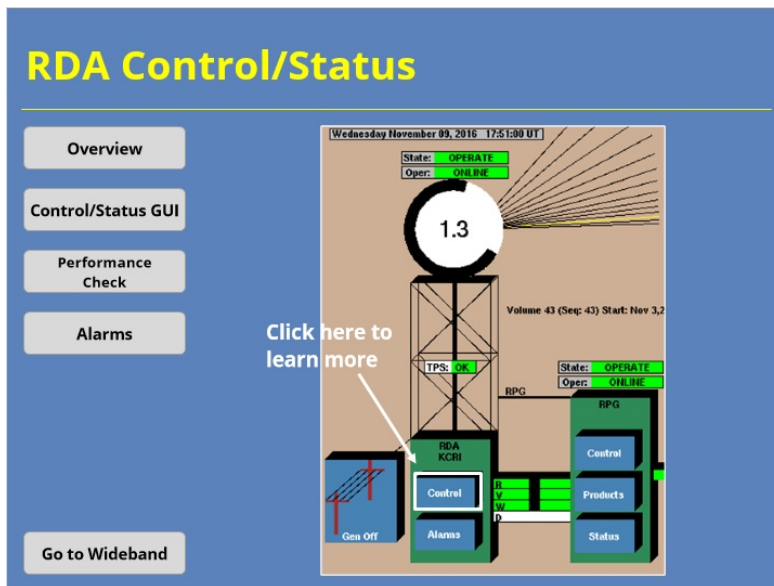
### *RDA Control & Monitoring Overview*



#### 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.

## ***RDA Control/Status***

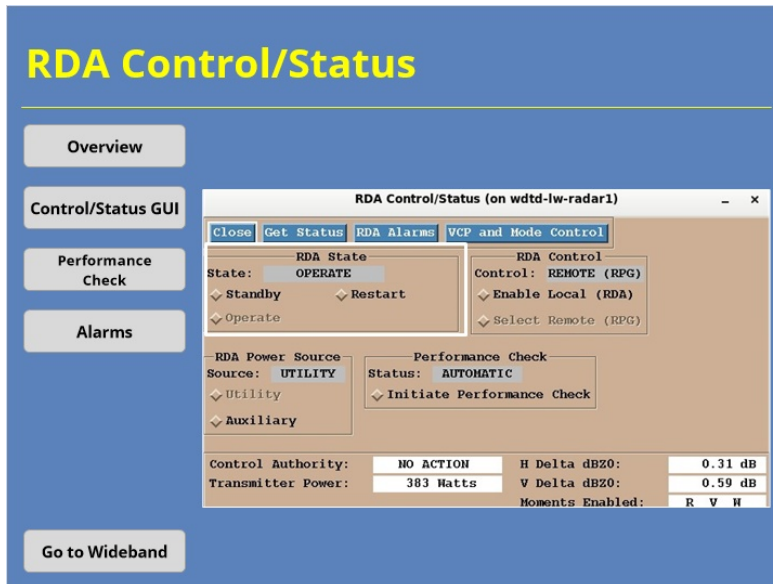


### **Notes:**

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.



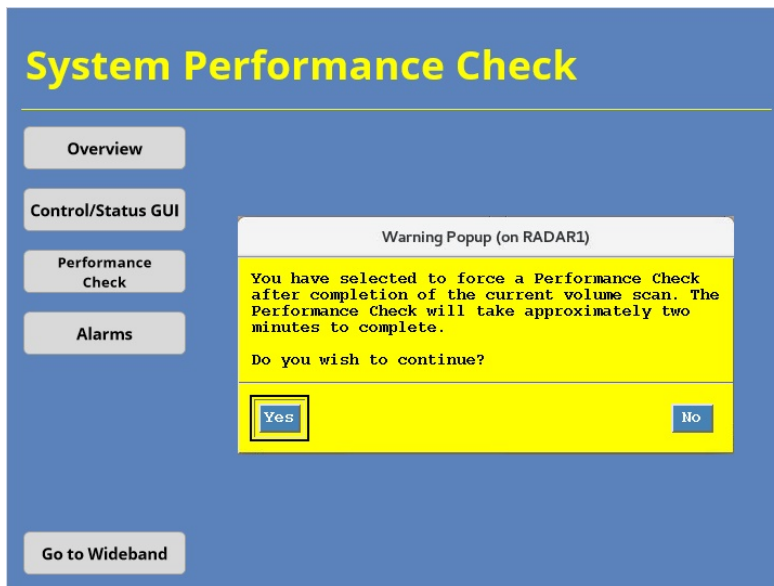
## RDA Control/Status



### 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 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 maintenance being done on the system), you should mention this information to your radar focal point, Electronics (or EI) Tech, or shift supervisor.

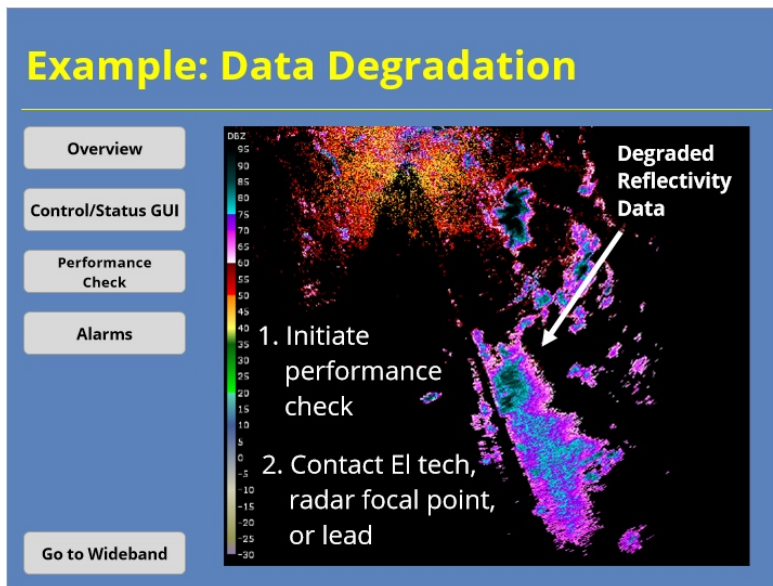
## System Performance Check



### 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.

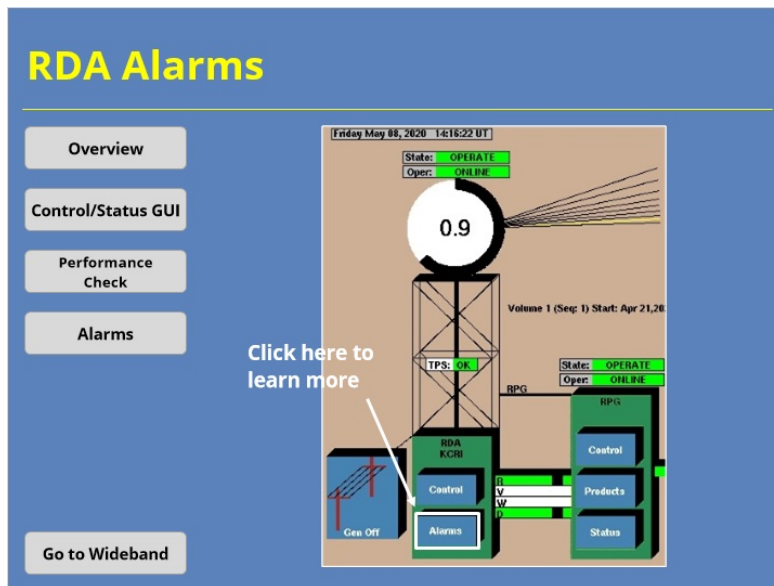
## ***Example: Data Degradation***



### **Notes:**

Let me show you an example of when you might need to manually start a system performance check. Say you notice your radar's Reflectivity has significantly degraded quality like in the example shown. You look at the RPG HCI, and notice that the radar recently completed a system performance check. When this happens, you will want to do two things. First, manually initiate a systems performance check. Second, talk to your El Tech, radar focal point, or lead forecaster on shift. The data degradation may be a result of an underlying maintenance issue with the radar. You can always contact the ROC Hotline staff if you need additional assistance.

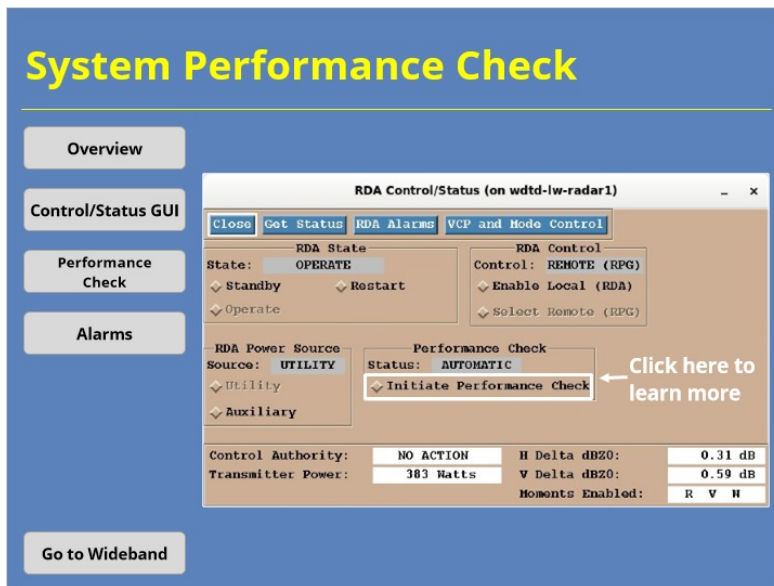
## RDA Alarms



### 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.

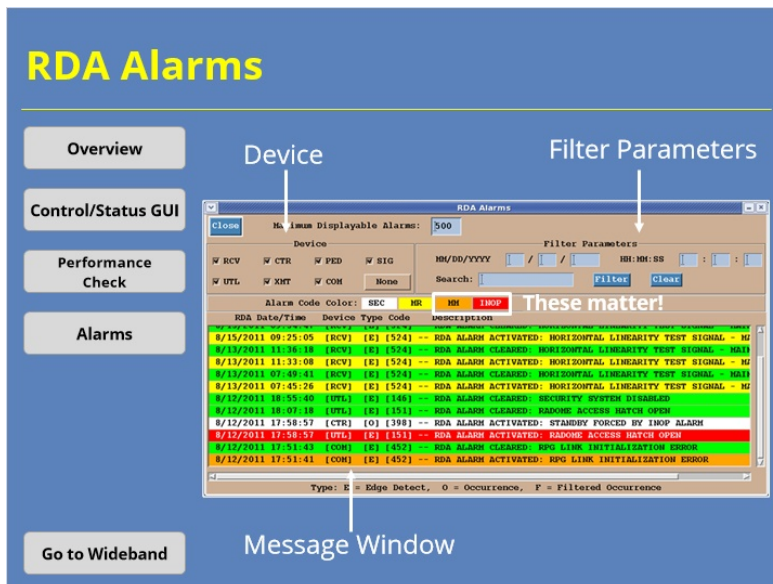
## System Performance Check



### 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.

## RDA Alarms

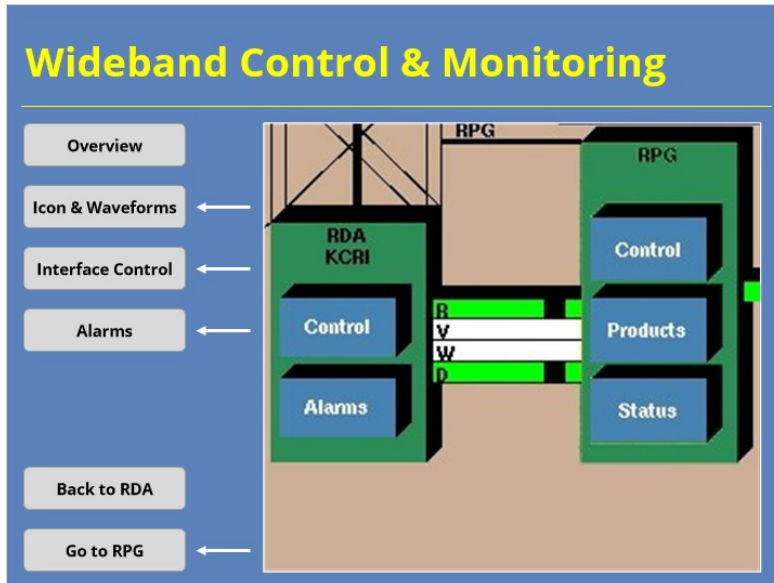


### Notes:

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 EI Tech, radar focal point, or shift supervisor so that they can troubleshoot the issue further.

### 3. Wideband Tasks

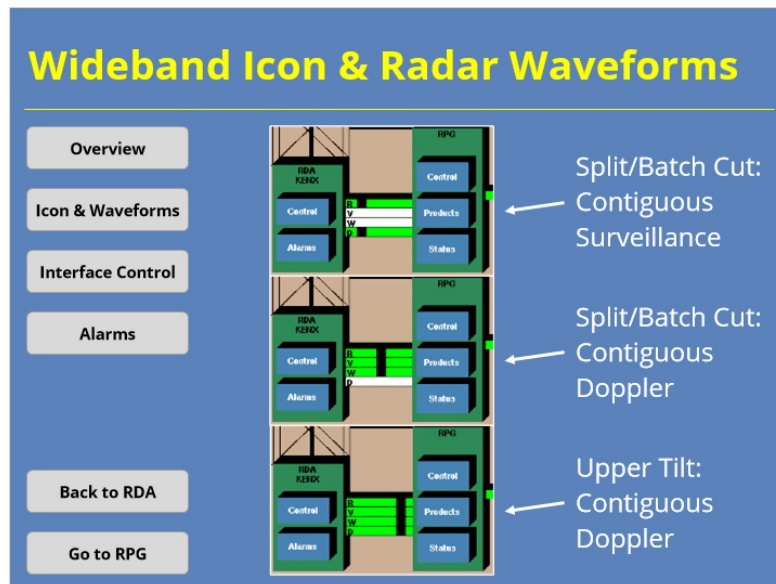
#### *Wideband Control & Monitoring*



#### **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.

## Wideband Icon & Radar Waveforms

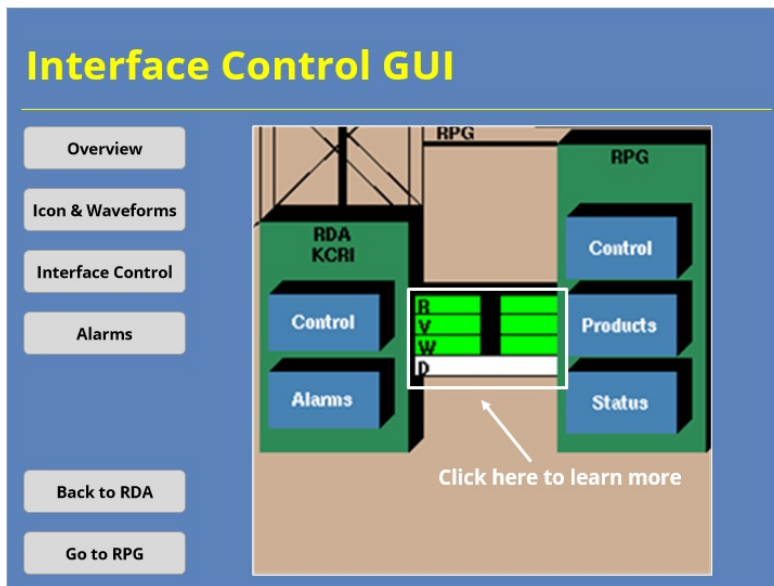


### Notes:

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.



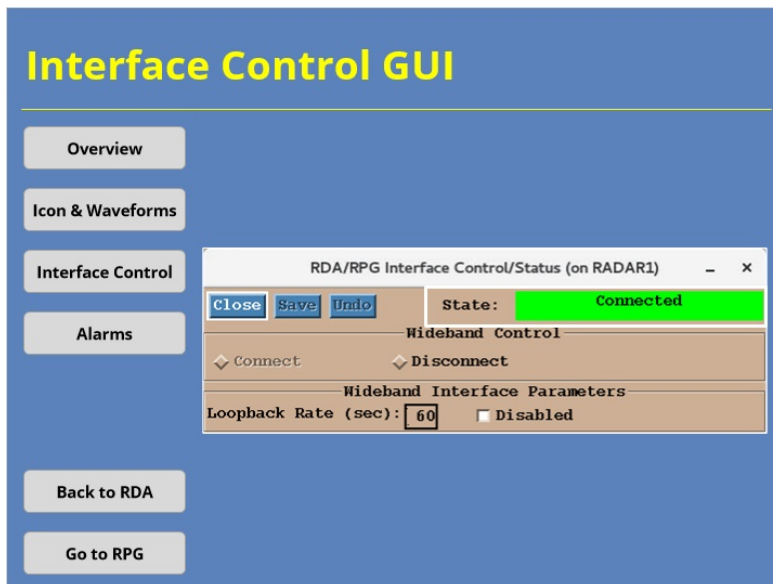
## ***Interface Control GUI***



### **Notes:**

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

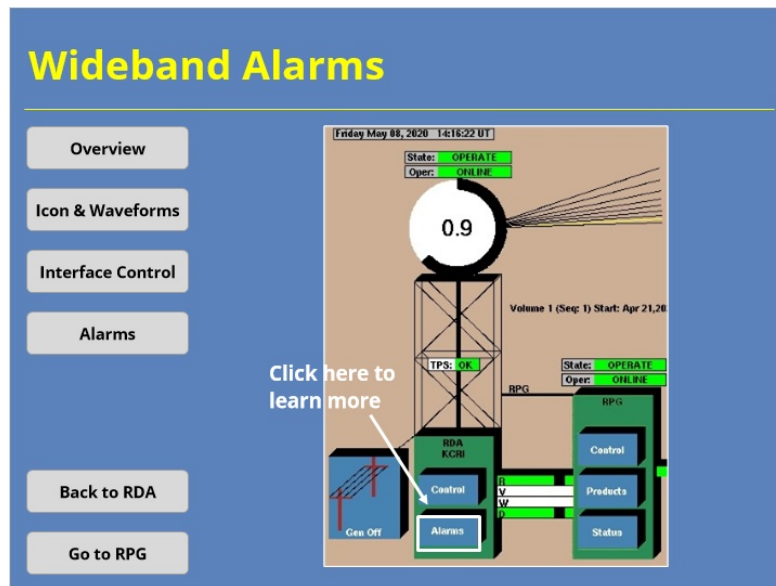
## Interface Control GUI



### 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.

## 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.

## Wideband Alarms

### Wideband Alarms

Overview

Icon & Waveforms

Interface Control

Alarms

Back to RDA

Go to RPG

RDA Alarms

Close

Maximum Displayable Alarms: 500

Filter Parameters

Device: W RCV W CTR W FED W SIG W UTL W XMT W COM None Search: Filter Clear

Alarm Code Color: SEC NR NR LDCR

Comms alarms here

RDA Date/Time	Device	Type	Code	Description
8/15/2011 09:25:05	[RCV]	[E]	[524]	RDA ALARM ACTIVATED: HORIZONTAL LINEARITY TEST SIGNAL - W
8/15/2011 11:18:18	[RCV]	[E]	[524]	RDA ALARM CLEARED: HORIZONTAL LINEARITY TEST SIGNAL - W
8/15/2011 11:33:08	[RCV]	[E]	[524]	RDA ALARM ACTIVATED: HORIZONTAL LINEARITY TEST SIGNAL - W
8/15/2011 07:40:14	[RCV]	[E]	[524]	RDA ALARM CLEARED: HORIZONTAL LINEARITY TEST SIGNAL - W
8/15/2011 07:45:26	[RCV]	[E]	[524]	RDA ALARM ACTIVATED: HORIZONTAL LINEARITY TEST SIGNAL - W
8/15/2011 18:55:46	[UTL]	[E]	[146]	RDA ALARM CLEARED: SECURITY SYSTEM DISABLED
8/15/2011 18:07:18	[UTL]	[E]	[146]	RDA ALARM CLEARED: RADOME ACCESS HATCH OPEN
8/12/2011 17:58:57	[CTR]	[O]	[398]	RDA ALARM ACTIVATED: STANDBY FORCED BY INOP ALARM
8/12/2011 17:59:52	[UTL]	[F]	[451]	RDA ALARM CLEARED: RADOME ACCESS HATCH CLOSED
8/12/2011 17:51:45	[COM]	[E]	[452]	RDA ALARM CLEARED: RPG LINK INITIALIZATION ERROR
8/12/2011 17:51:41	[COM]	[E]	[452]	RDA ALARM ACTIVATED: RPG LINK INITIALIZATION ERROR

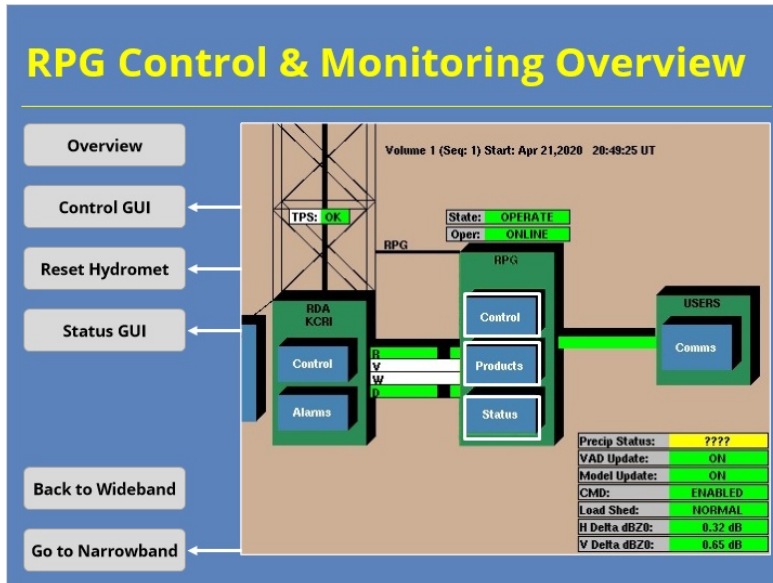
Type: E = Edge Detect, O = Occurrence, F = Filtered Occurrence

### 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.

## 4. RPG Tasks

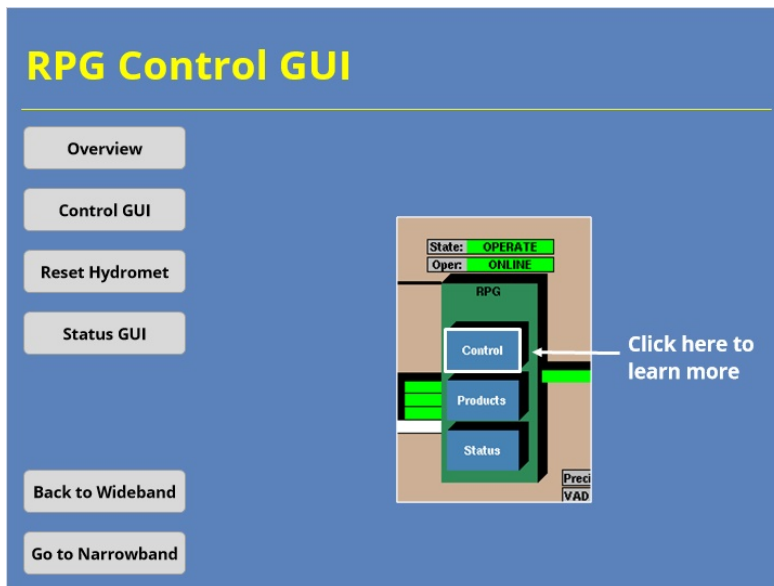
### *RPG Control & Monitoring Overview*



#### 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.

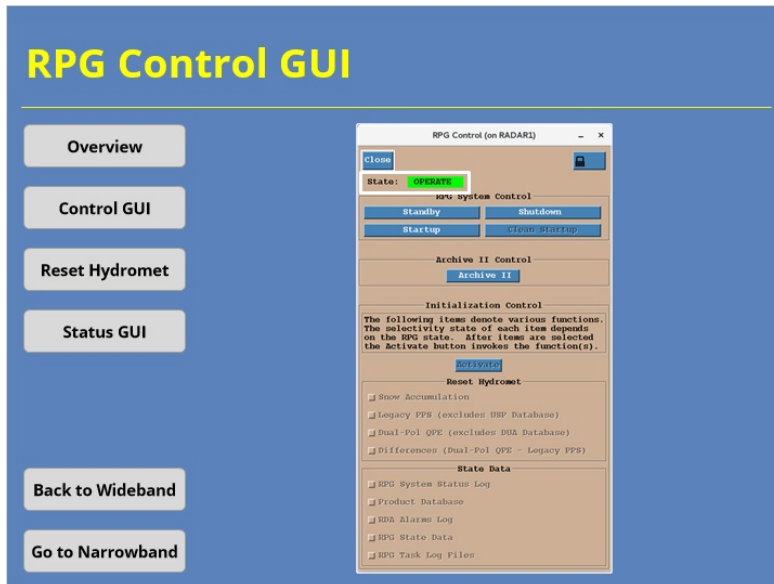
## ***RPG Control GUI***



### **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.

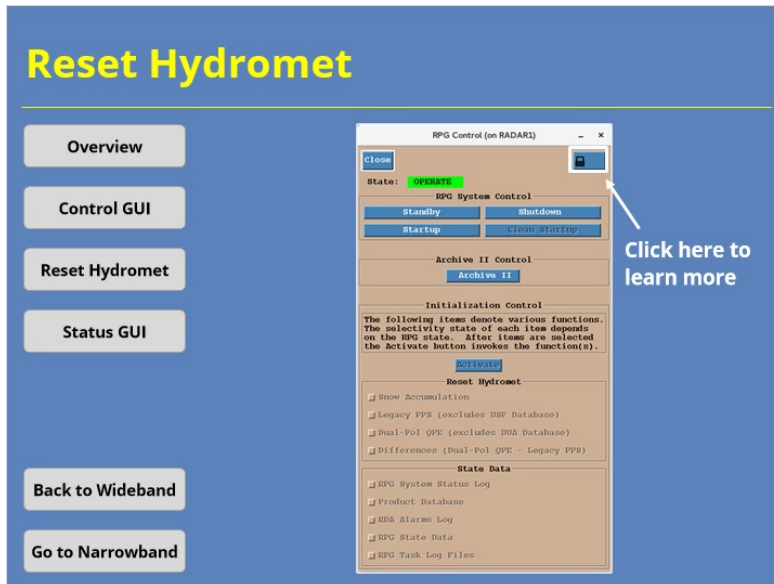
## RPG Control GUI



### 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.

## Reset Hydromet

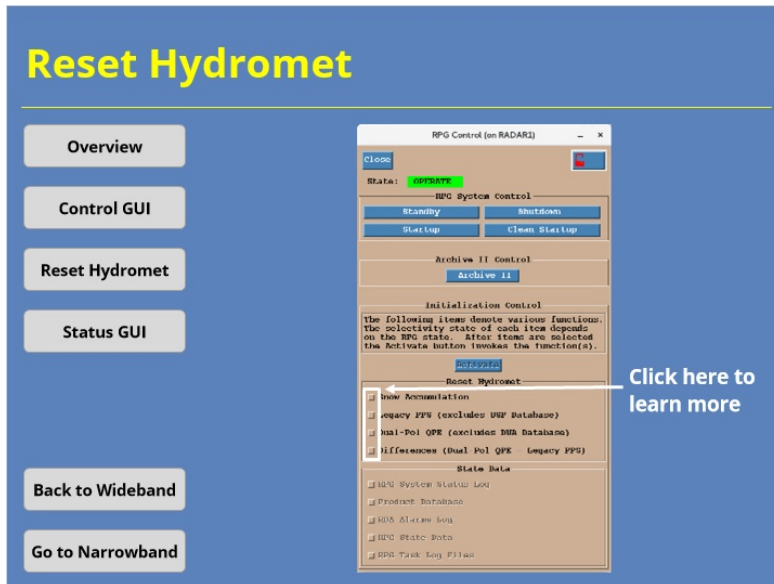


### Notes:

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.



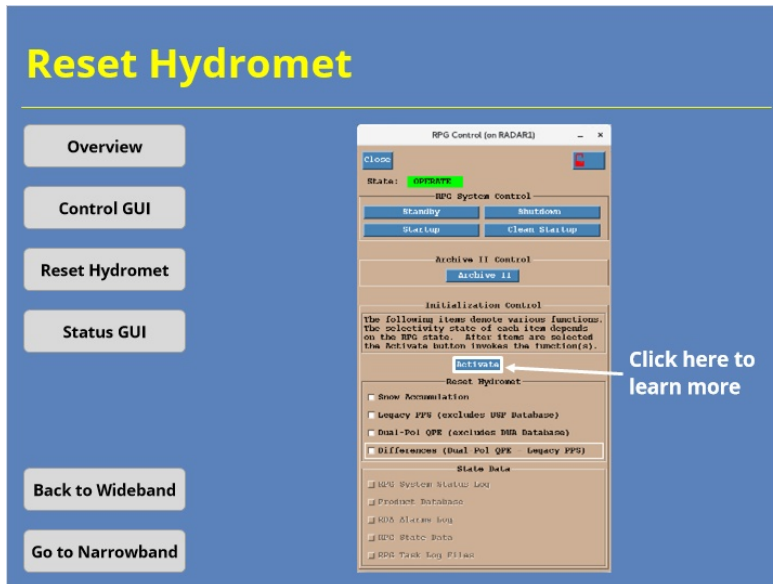
## 4.5 Reset Hydromet



### 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.

## 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.

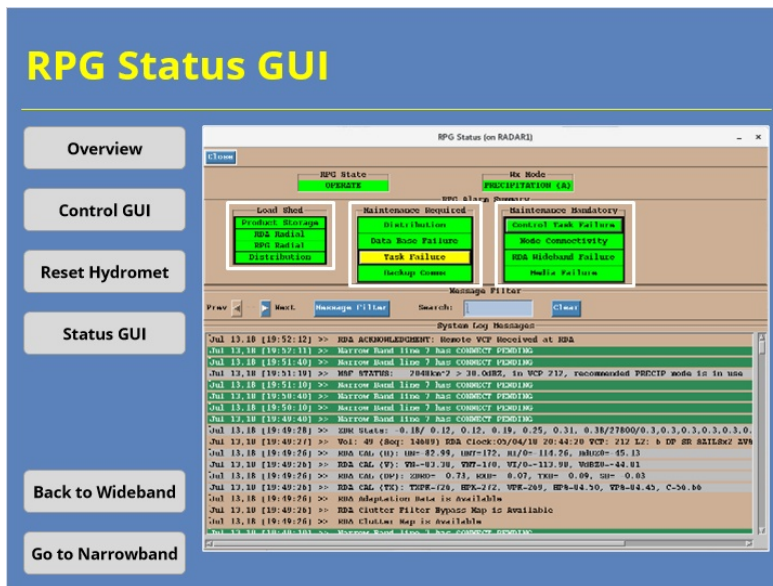
## 4.7 Reset Hydromet



### 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.

## 4.8 RPG Status GUI



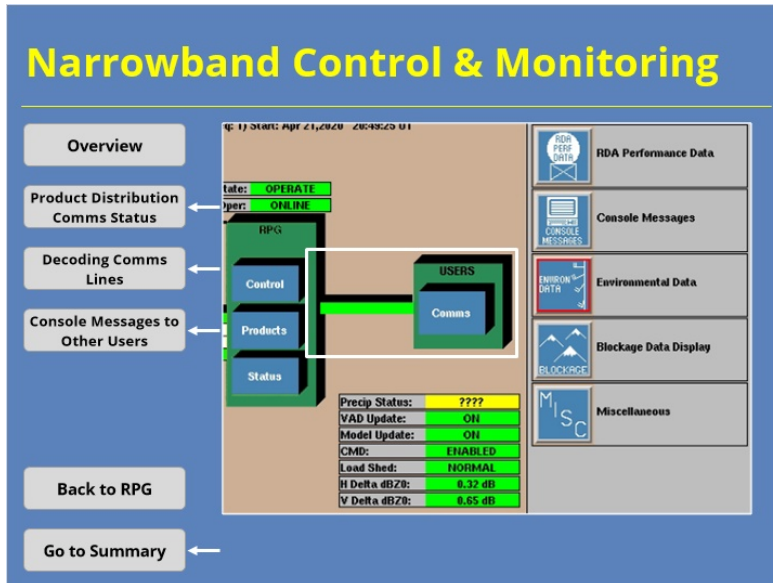
### Notes:

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.

## 5. Narrowband/User Tasks

### *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.

## Product Distribution Comms Status

Product Distribution Comms Status

Overview

Product Distribution Comms Status

Decoding Comms Lines

Console Messages to Other Users

Back to RPG

Go to Summary

Rate: OPERATE  
Type: ONLINE

RPG

Control

Products

Status

USERS

Comms

Precip Status:	????
VAD Update:	ON
Model Update:	ON
CMD:	ENABLED
Load Shed:	NORMAL
H Delta dBZ:	0.32 dB
V Delta dBZ:	0.65 dB

RDA Performance Data

Console Messages

Environmental Data

Blockage Data Display

Miscellaneous

Click here to learn more

### 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.

## Product Distribution Comms Status

### Product Distribution Comms Status

Overview

Product Distribution Comms Status

Decoding Comms Lines

Console Messages to Other Users

Back to RPG

Go to Summary

Product Distribution Comms Status (on RADAR3)

Close

Product Distribution Lines

Line	Type	Enabled	Proto	ID	Host Name	Class	Status	Delay	Rate
1	DEDIC	yes	TCP	110	RPGRP_50	CONNECT	0%	1947K	-
2	DEDIC	yes	TCP		RPGRP_50	COM PEND	0%	-	-
3	DEDIC	yes	TCP		RPGRP_50	COM PEND	0%	-	-
4	DEDIC	yes	TCP		RPGRP_50	COM PEND	0%	-	-
5	DEDIC	yes	TCP		RPGRP_50	COM PEND	0%	-	-
6	DEDIC	yes	TCP		RPGRP_50	COM PEND	0%	-	-
7	DEDIC	yes	TCP		RPGRP_50	DISCON	0%	-	-
8	DEDIC	yes	TCP		RPGRP_50	COM PEND	0%	-	-
9	DEDIC	yes	TCP		RPGRP_50	COM PEND	0%	-	-
10	DEDIC	yes	TCP		RPGRP_50	COM PEND	0%	-	-
11	DEDIC	yes	TCP		RPGRP_50	COM PEND	0%	-	-
12	DEDIC	yes	TCP		RPGRP_50	COM PEND	0%	-	-

Prev --- Next    Sorted By: Line Type Status

Line Control

Reset   Disconnect   Connect   Deselect

General Parameters

Retries 2   Timeout 120   Alarm (%) 100   Warning (%) 95

Line Info

Line 1 (TCP)

Type Dedicated

Port Panel

Band Rate 1536000

Comm Mjr 2

PSever 2

Time Limit 87

Comm Option 80

### 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.

## Decoding Comms Lines

The screenshot shows a software window titled 'Product Distribution Comms Status - (FAA-2 Active/Controlling)'. On the left is a sidebar with buttons: 'Overview', 'Product Distribution Comms Status', 'Decoding Comms Lines', 'Console Messages to Other Users', 'Back to RPG', and 'Go to Summary'. The main area displays a table of communication lines. The table has columns: Line, Type, Enabled, Proto, ID, User Name, Class, Status, Delay, and Rate. The data shows various lines with statuses like 'COM PEND', 'DISCON', and 'CONNECT'. A 'Line Info' panel on the right shows details for the selected line (Line # 1, Type: TCP, Port: 256000, Band Rate: 256000, Comm Msc: 9, PServer: 9, Time Limit: 30, Comms Option: 80).

Line	Type	Enabled	Proto	ID	User Name	Class	Status	Delay	Rate
1	NAM	yes	TCP			2	COM PEND	01	-
2	NAM	yes	TCP			2	COM PEND	01	-
3	DEDIC	yes	TCP			RPQOP_50	COM PEND	01	-
4	DEDIC	yes	TCP			RPQOP_50	COM PEND	01	-
5	DEDIC	yes	TCP	810	opup2_ROC-H	RPQOP_50	CONNECT	01	19K
6	DEDIC	yes	TCP	891	opup4_ROC-H	RPQOP_50	CONNECT	01	21K
7	DEDIC	yes	TCP			RPQOP_50	COM PEND	01	-
8	DEDIC	yes	TCP			RPQOP_50	COM PEND	01	-
9	DEDIC	yes	TCP			RPQOP_50	COM PEND	01	-
10	DEDIC	yes	X25			1	DISCON	01	-
11	DEDIC	yes	X25			1	DISCON	01	-
12	DEDIC	yes	X25			1	DISCON	01	-
13	DEDIC	yes	X25			1	DISCON	01	-
14	DEDIC	yes	X25			1	DISCON	01	-
15	DEDIC	yes	X25			1	DISCON	01	-
16	DEDIC	yes	X25			RPQOP_50	DISCON	01	-
17	DEDIC	yes	X25			RPQOP_50	DISCON	01	-
18	DEDIC	yes	TCP			RPQOP_50	COM PEND	01	-
19	DEDIC	yes	TCP			RPQOP_50	COM PEND	01	-
20	DEDIC	yes	TCP			RPQOP_50	COM PEND	01	-
21	DEDIC	yes	TCP			RPQOP_50	COM PEND	01	-
22	DEDIC	yes	TCP			RPQOP_50	COM PEND	01	-
23	DEDIC	yes	TCP			RPQOP_50	COM PEND	01	-
24	DEDIC	yes	TCP			RPQOP_50	COM PEND	01	-
25	DEDIC	yes	TCP	670	awipsROC	RPQOP_90	CONNECT	01	73K

### 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.



## Console Messages to Other Users

### Console Messages to Other Users

Overview

Product Distribution  
Comms Status

Decoding Comms  
Lines

Console Messages to  
Other Users

Back to RPG

Go to Summary

RPG Control/Status (on wdtb-hw-radar1)

0.9

Gas Off

Alarm

Control

Product

Station

Control

Control

Feedback: May 8, 20 (14:10:47) -- Storm Cell Tracking data updated

Status: May 8, 20 (14:13:47) -- GPL rainfall method (R/A) Loaded

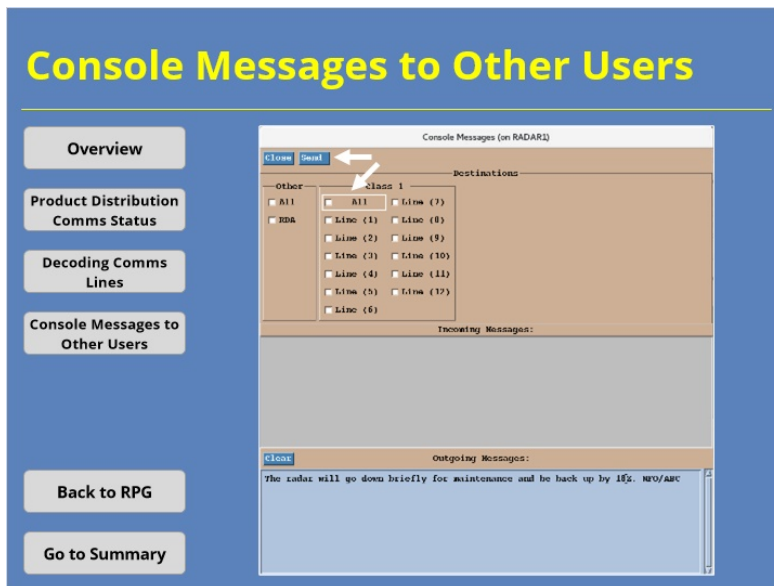
Alarms: May 8, 20 (14:14:00) -- RPG-AI ARM CI FARET: RDA -- RPG COMMUNICATIONS LINK BROKEN

Click here to learn more

### 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.

## 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.

## 6. Summary & Quiz

### *RPG HCI Controls Summary*

#### **RPG HCI Controls Summary**

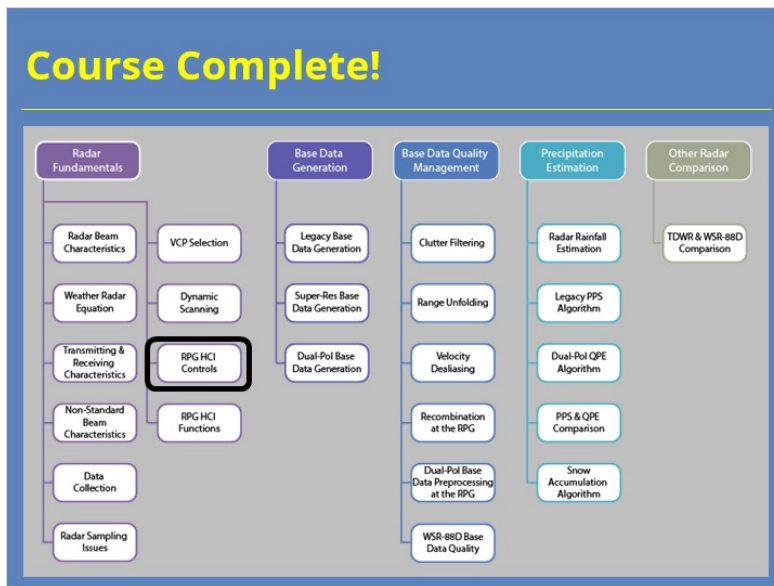
- RPG HCI related components:
  - icons
  - buttons
  - indicators
- Basic control & monitoring at:
  - RDA
  - Wideband
  - RPG
  - Narrowband
- Specific tasks:
  - Manual system performance check
  - Monitor alarm messages
  - Send Free Text Messages

#### **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.

## 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

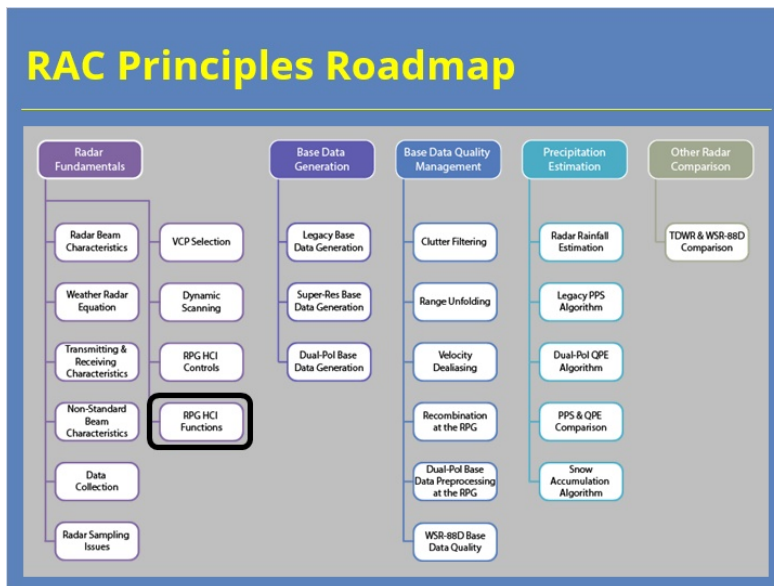
### *Introduction*



### **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!

## 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.

## ***Learning Objectives***

### **Learning Objectives**

---

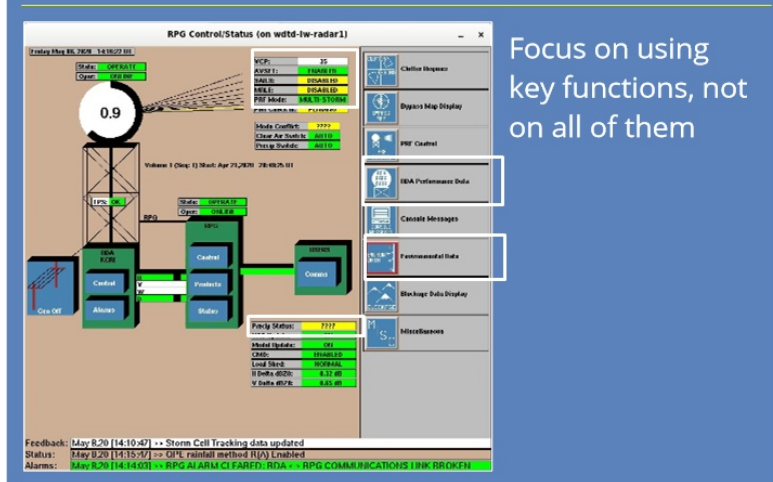
- Identify how to use the following button indicators in order to interact with the radar and control its function:
  - VCP
  - AVSET
  - SAILS
  - MRLE
  - Precip Status
- Identify the three Pulse Repetition Frequency (PRF) Control options, their characteristics, & how to configure them
- Identify the three environmental parameters the RPG uses for product generation & how to manually edit each of them

#### **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.

## Lesson Scope

### Lesson Scope



Focus on using key functions, not on all of them

### 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.

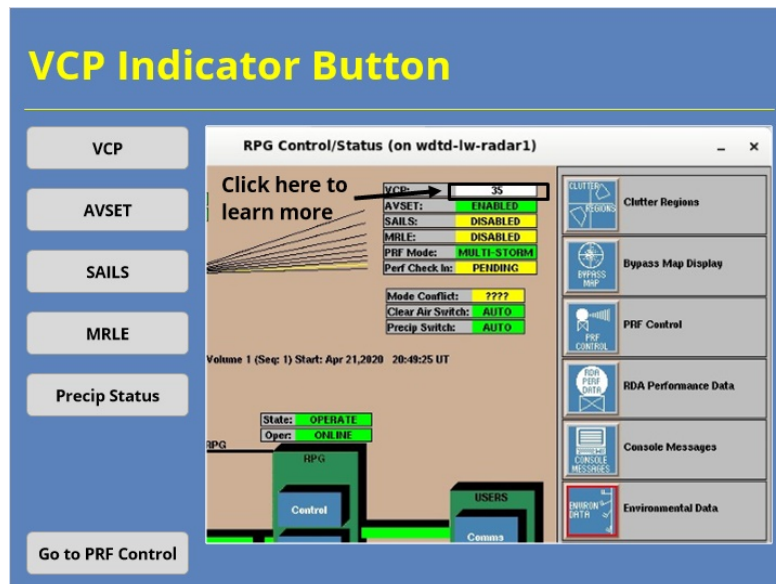


## Button Indicator Overview

[illegible]

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, MRLE 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.

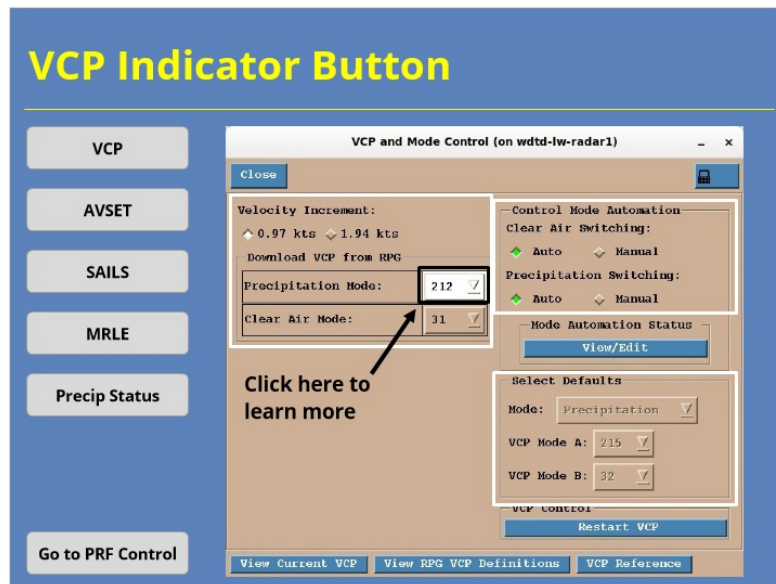
## VCP Indicator Button



### Notes:

The first indicator button we'll discuss is for the current volume coverage pattern (or VCP) in use. 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.

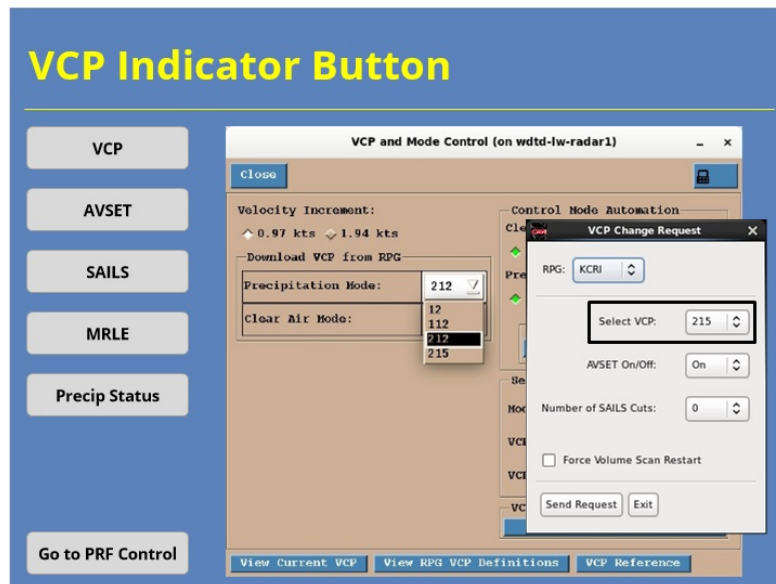
## VCP Indicator Button



### 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.

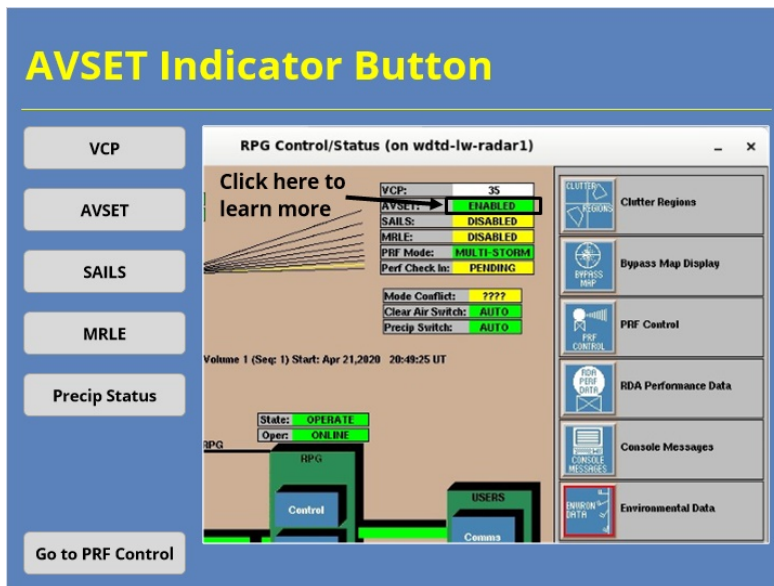
## VCP Indicator Button



### 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.

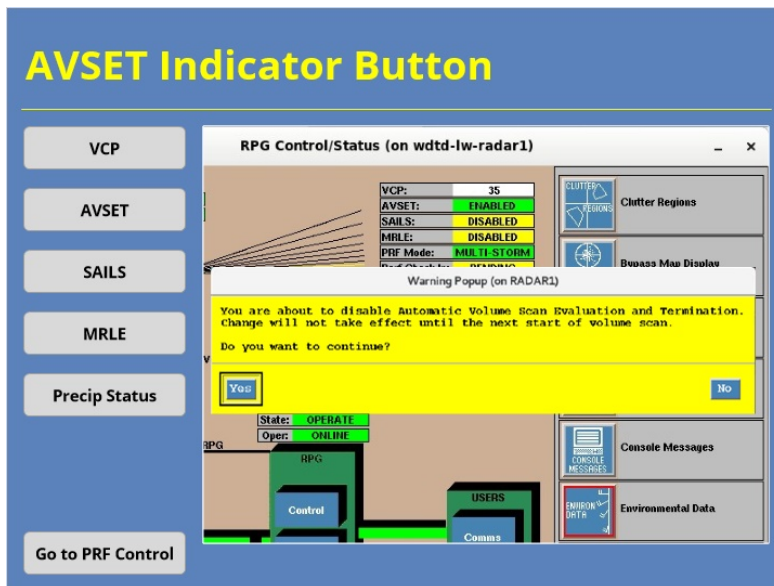
## AVSET Indicator Button



### 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.

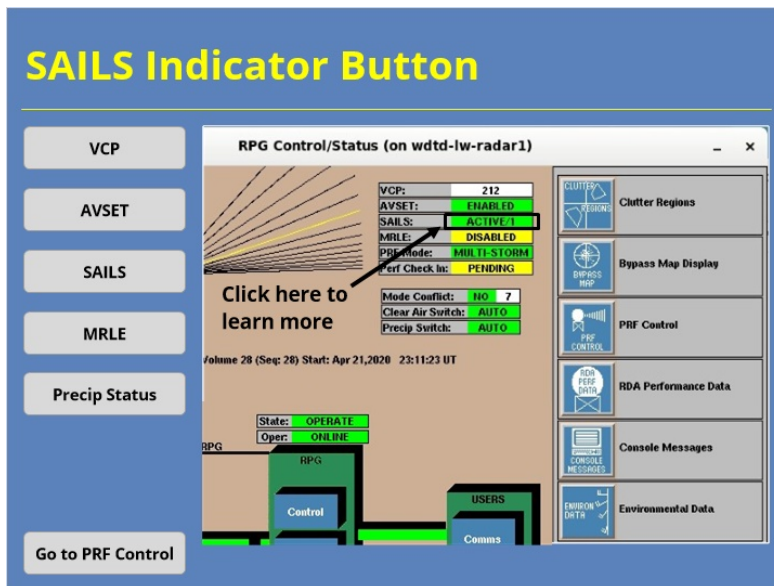
## AVSET Indicator Button



### 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.

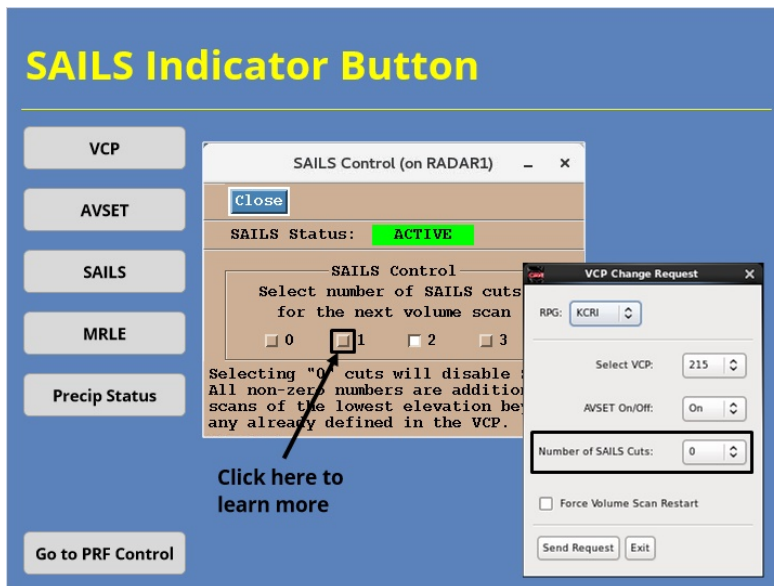
## ***SAILS Indicator Button***



### **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. Clicking on the button brings up the window where you can change the number of SAILS tilts you want included in the next volume scan. Click on the SAILS indicator button to learn more.

## ***SAILS Indicator Button***

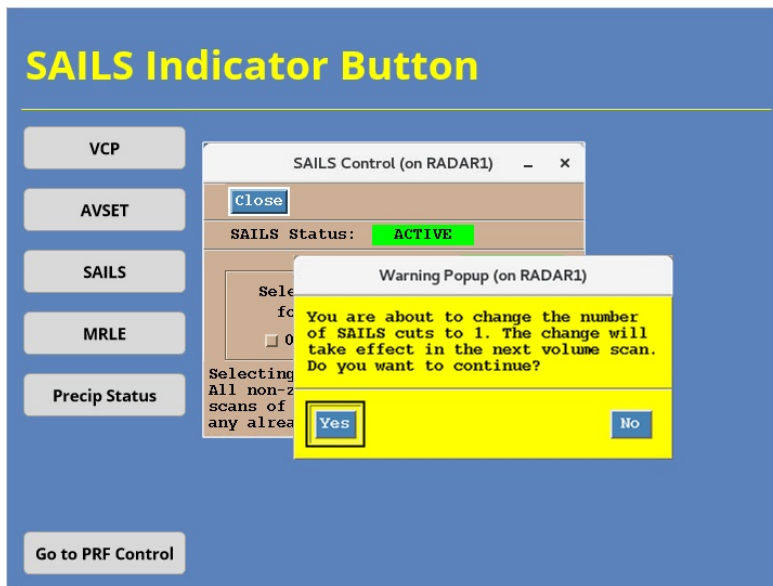


### **Notes:**

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. In the example shown, the current number of SAILS tilts is set to 2. 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.



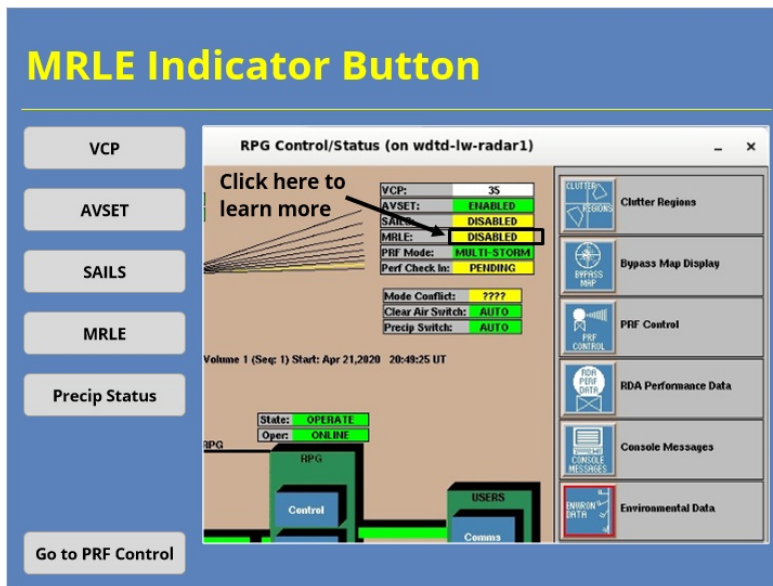
## ***SAILS Indicator Button***



### **Notes:**

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

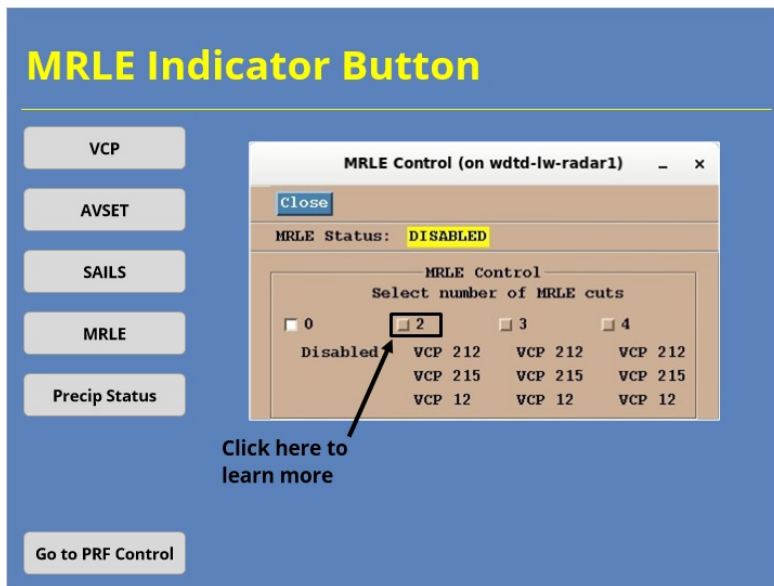
## MRLE Indicator Button



### Notes:

The fourth indicator button we will discuss allows you to enable the Mid-Volume Rescan of Low-Level Elevations (or MRLE). Details on MRLE and how it works can be found in the Dynamic Scanning lesson of this course. Clicking on the button brings up the window where you can choose the number of MRLE tilts you want to include in the next volume scan. Click on the MRLE indicator button to learn more.

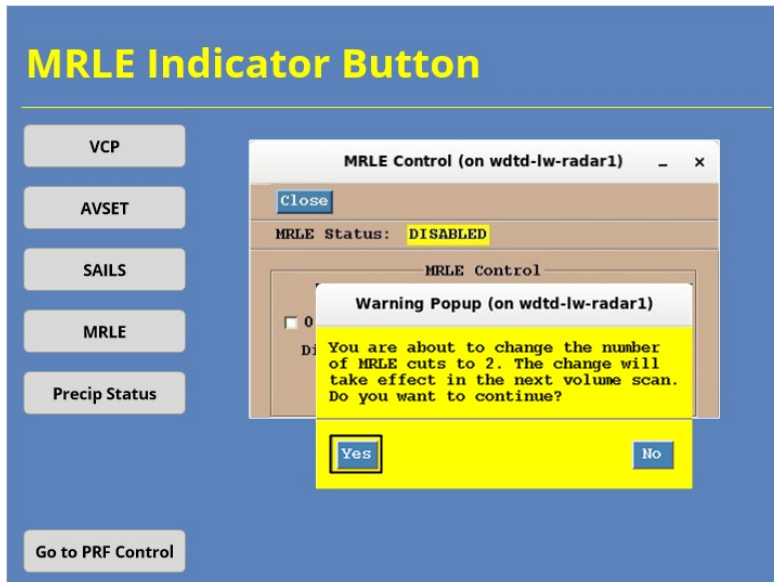
## MRLE Indicator Button



### Notes:

The MRLE Control GUI gives the radar operator the choice between 0, 2, 3 and 4 supplemental cuts that sample the low-level atmosphere. To see what happens if you want to change the number of MRLE tilts to 2, click on the checkbox next to the number 2 in the MRLE Control GUI.

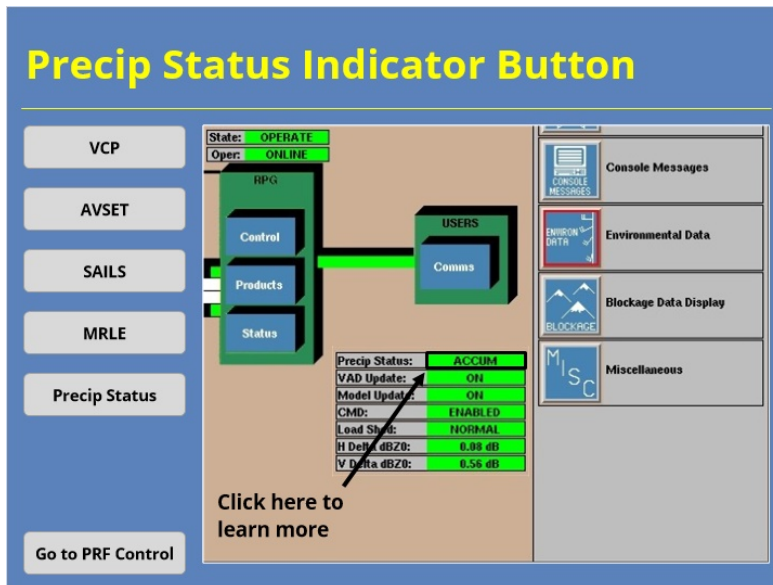
## MRLE Indicator Button



## Notes:

Choosing the “2” checkbox results in the following Warning Popup. Clicking “Yes” will put the change into place on the next volume scan.

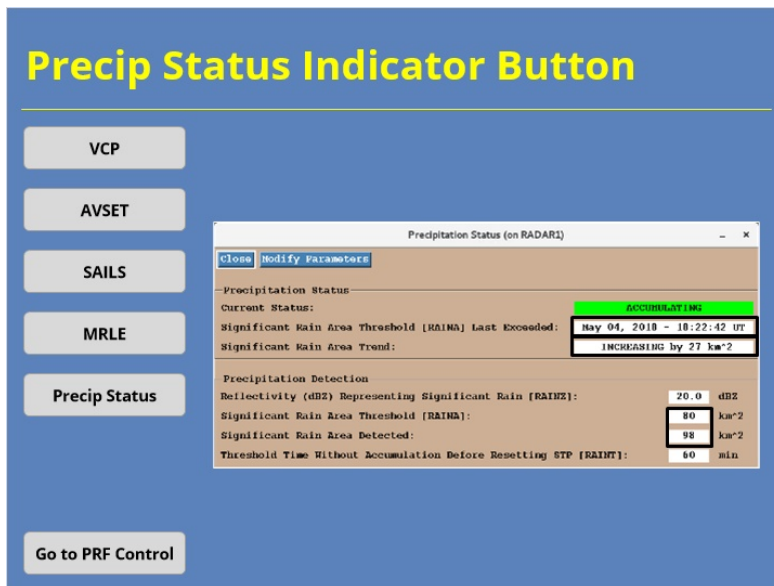
## *Precip Status Indicator Button*



## 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.

## Precip Status Indicator Button

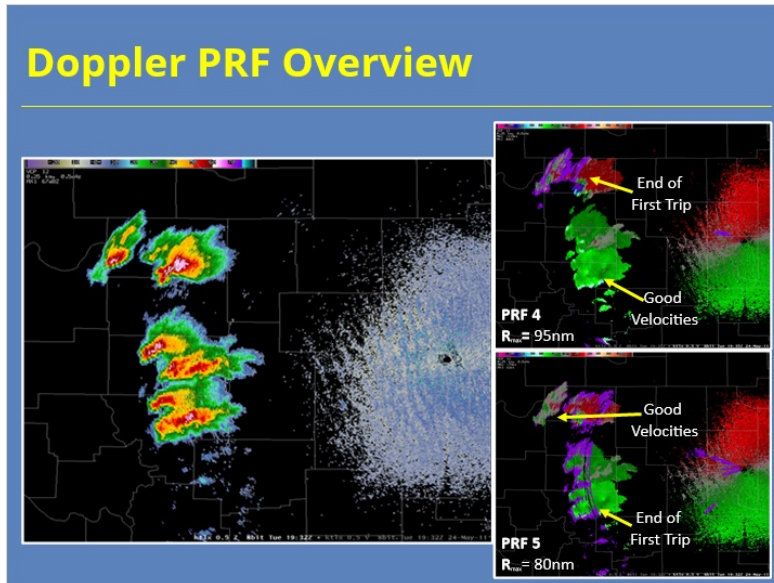


### Notes:

The Precipitation Status GUI provides some important details related to precipitation accumulation. Besides reiterating the accumulation status, you can see 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.

### 3. PRF Control

#### *Doppler PRF Overview*

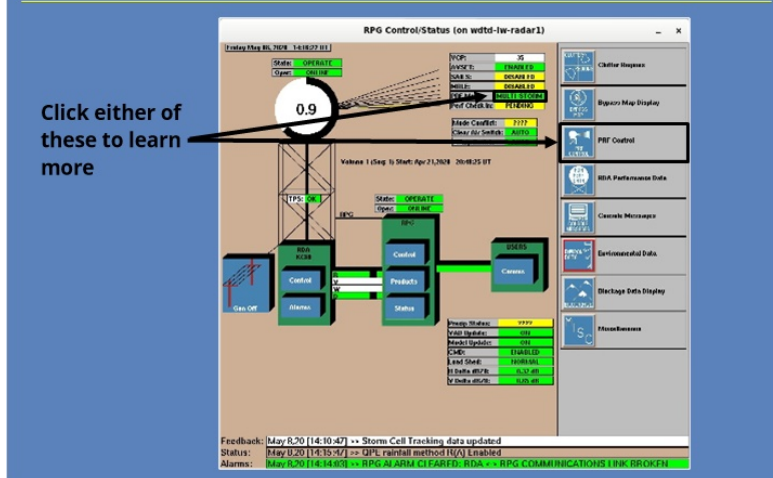


#### **Notes:**

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 several 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 specific 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 112 and 31.

## Accessing the PRF Control Window

### Accessing the PRF Control Window

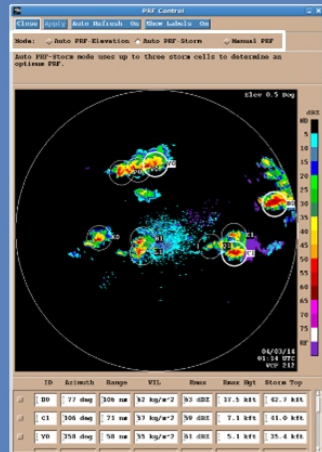


#### Notes:

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.

## Accessing the PRF Control Window

### Accessing the PRF Control Window

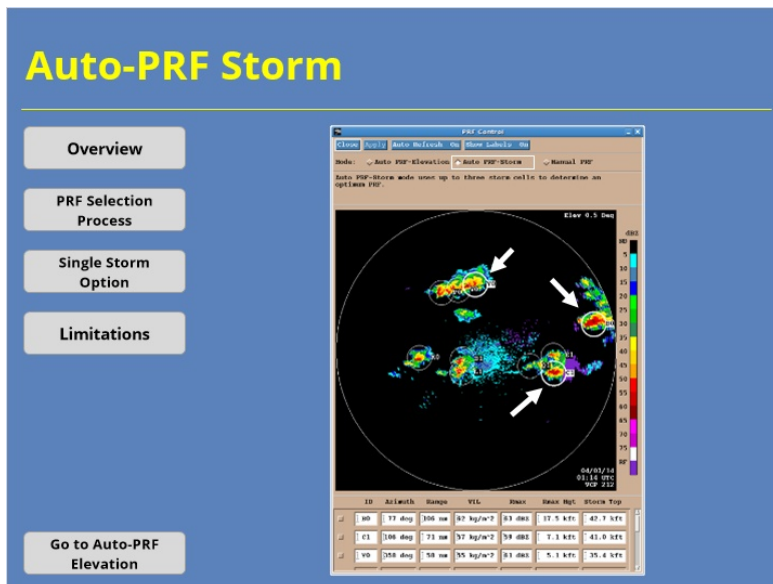


#### Notes:

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.



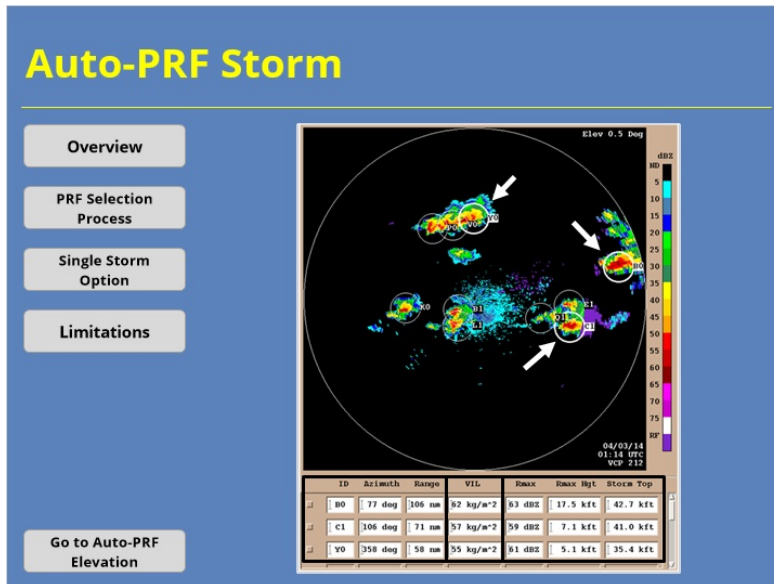
## Auto-PRF Storm



### 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.

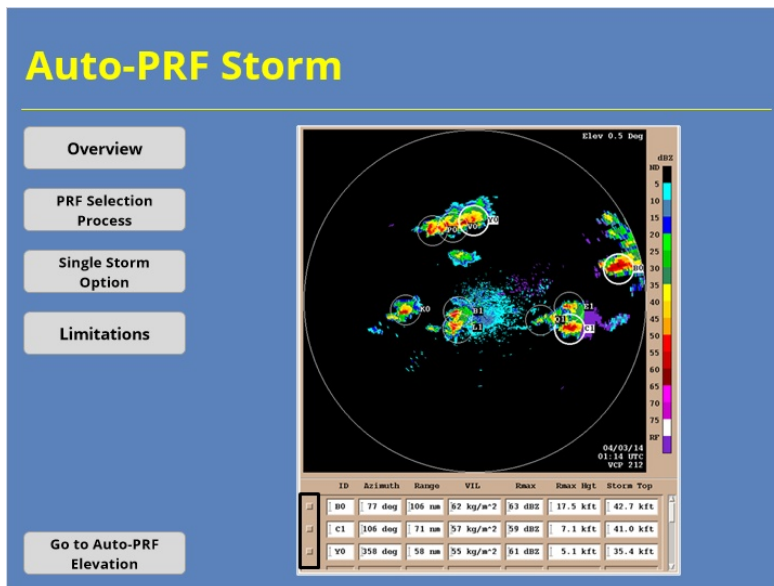
## Auto-PRF Storm



### 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.

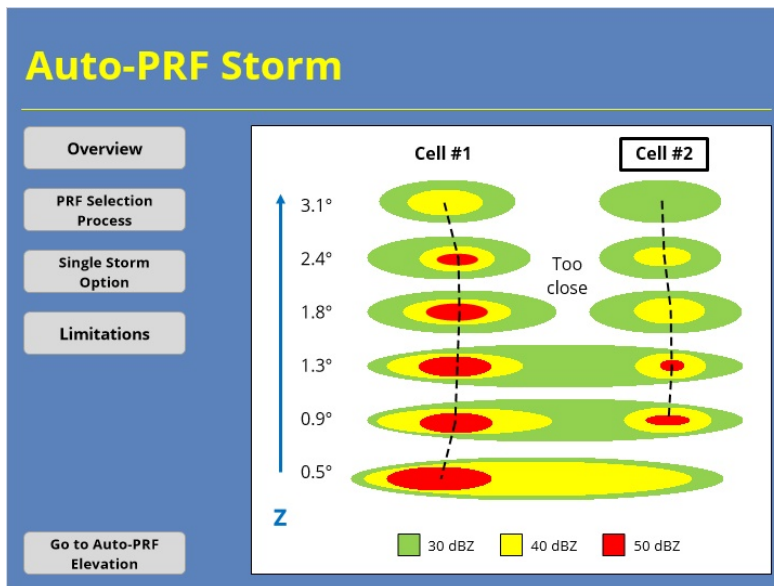
## Auto-PRF Storm



### 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 storm's 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.

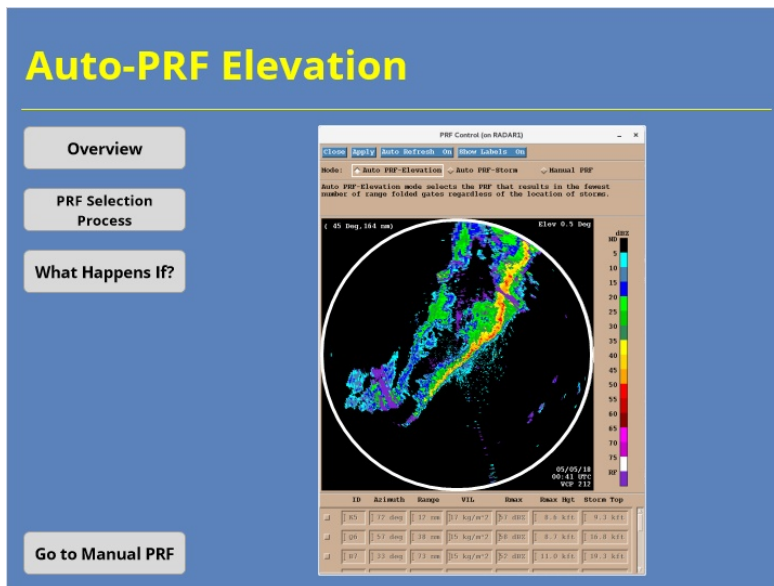
## Auto-PRF Storm



### 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.

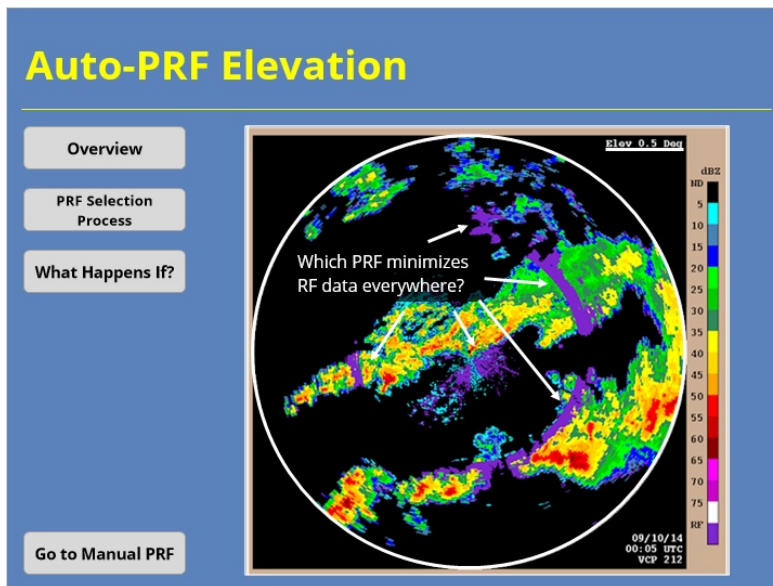
## Auto-PRF Elevation



### 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.

## ***Auto-PRF Elevation***



### **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.

## Auto-PRF Elevation

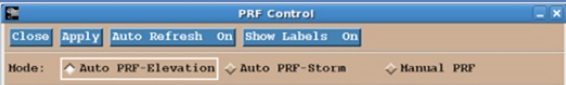
### Auto-PRF Elevation

Overview

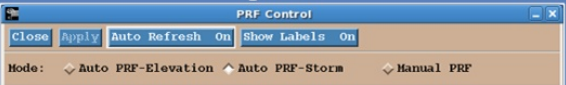
PRF Selection Process

What Happens If?

When storms not identified, Auto PRF – Elevation used:



When storms identified again, Auto PRF – Storm used:



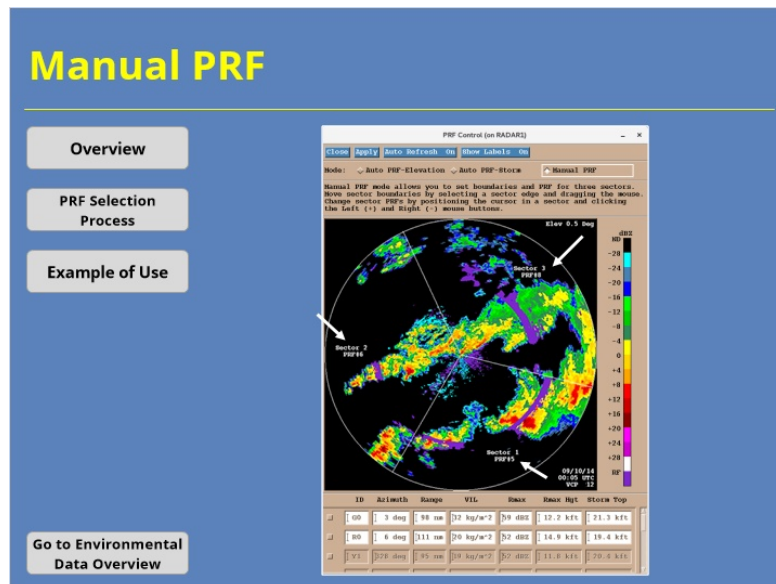
If that's what you want, you're all set!

Go to Manual PRF

### 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.

## Manual PRF

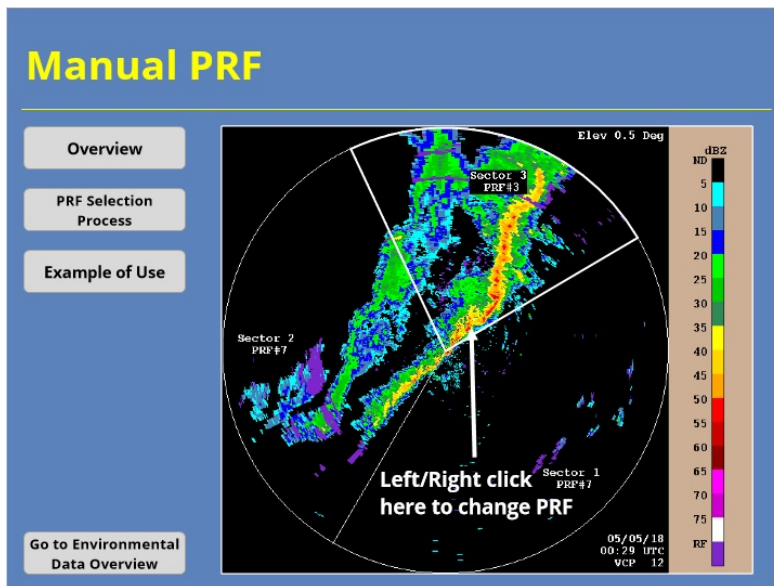


### Notes:

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.



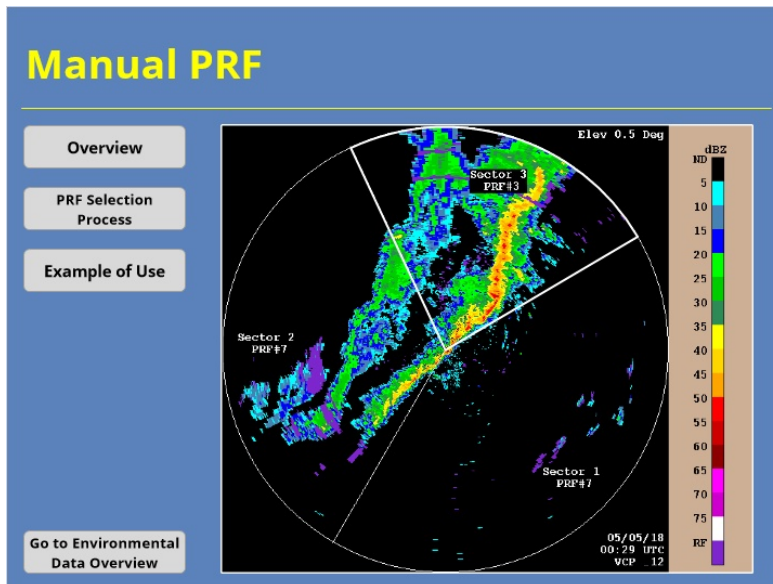
## Manual PRF



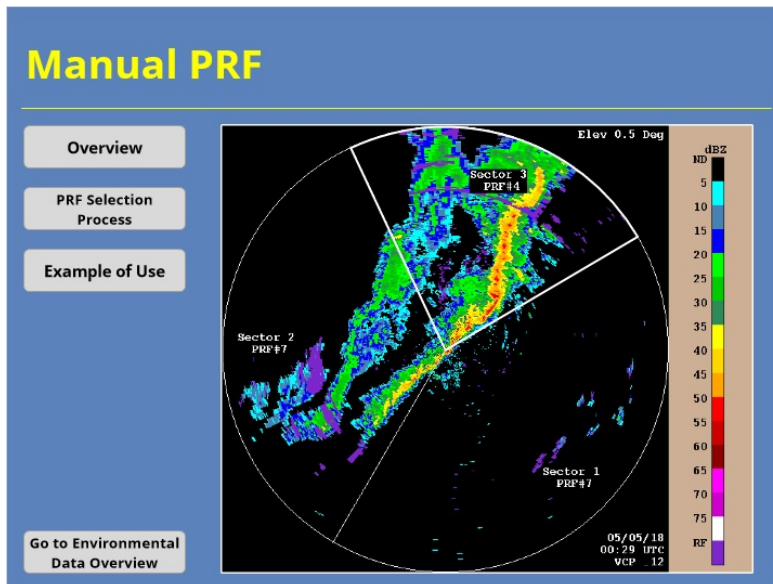
### Notes:

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.

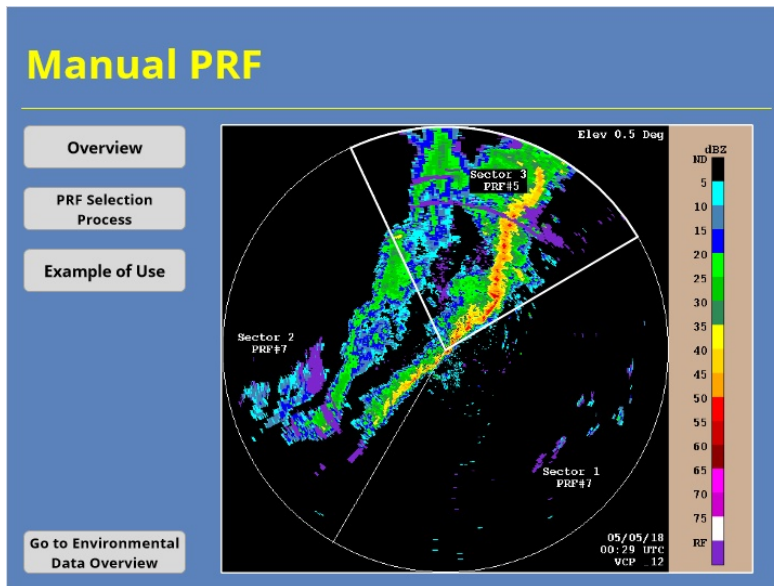
## Process - PRF 3 (Slide Layer)



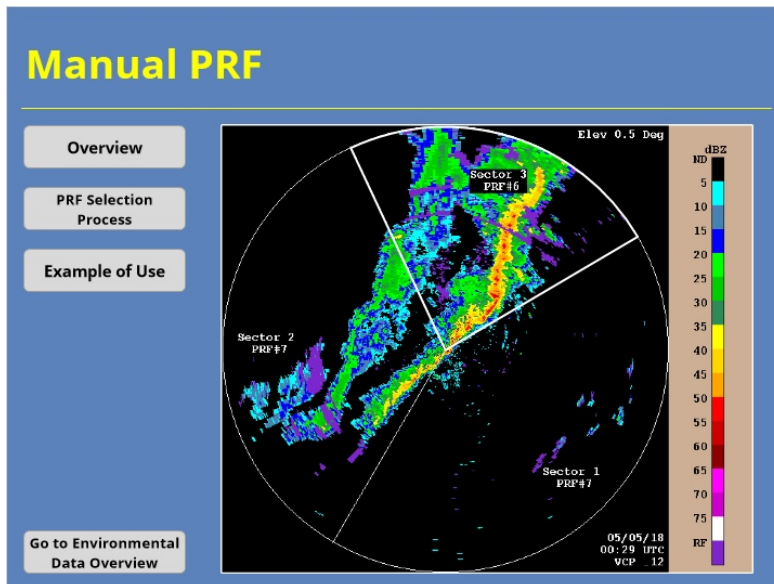
## Process - PRF 4 (Slide Layer)



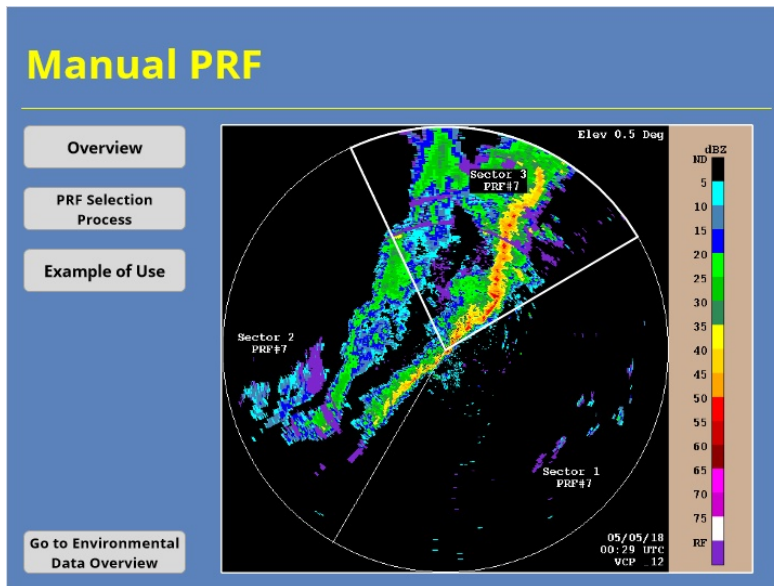
## Process - PRF 5 (Slide Layer)



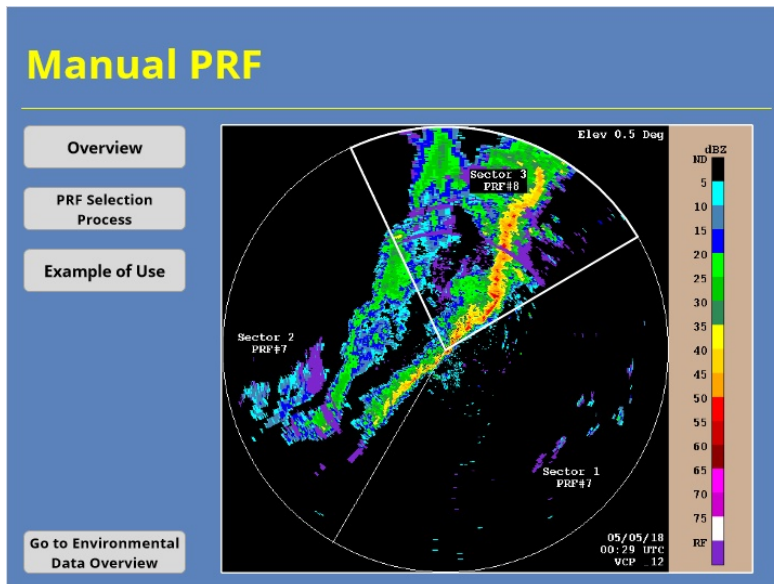
## Process - PRF 6 (Slide Layer)



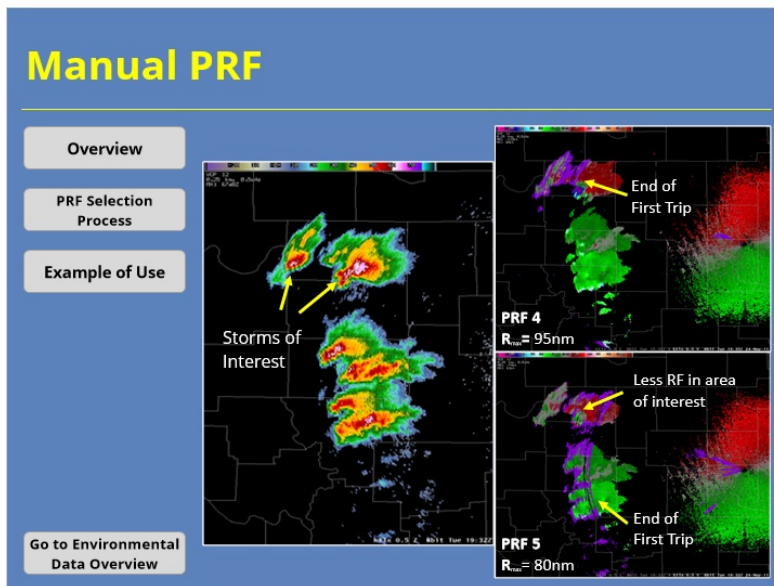
## Process - PRF 7 (Slide Layer)



## Process - PRF 8 (Slide Layer)



## Manual PRF

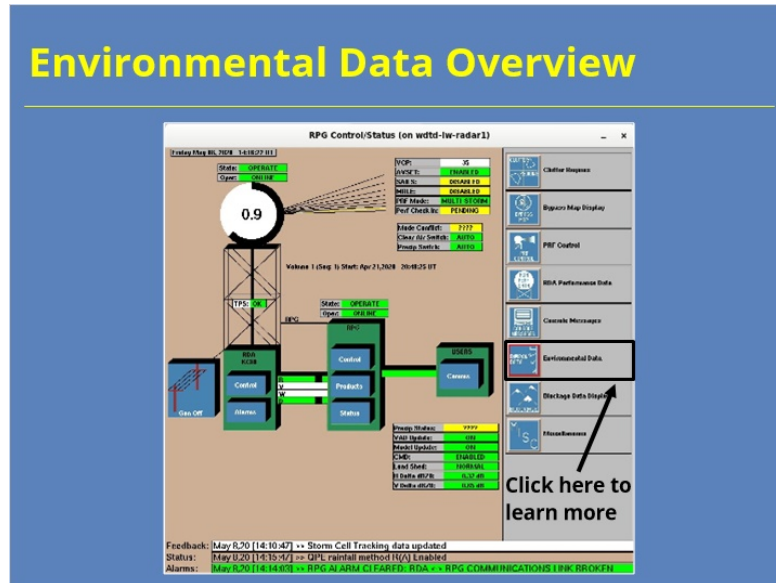


### Notes:

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.

## 4. Environmental Data

### *Environmental Data Overview*

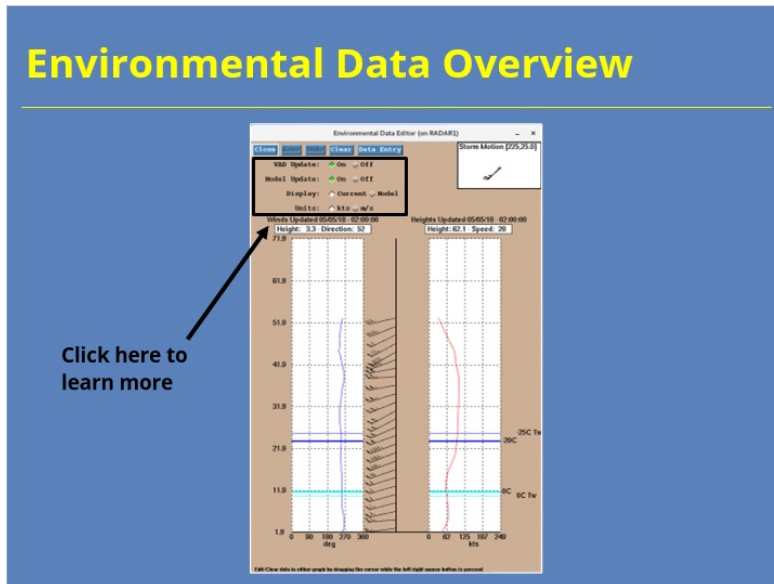


#### **Notes:**

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.

## Environmental Data Overview

### Environmental Data Overview

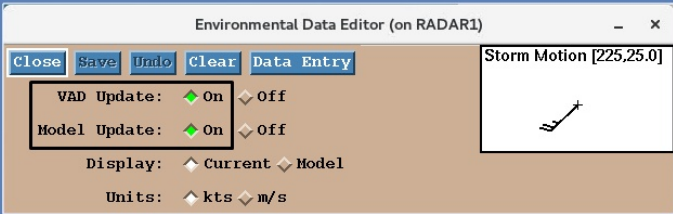


#### Notes:

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.

## Environmental Data Overview

### Environmental Data Overview



These update:

- VAD: Every volume scan
- Model: Every hour

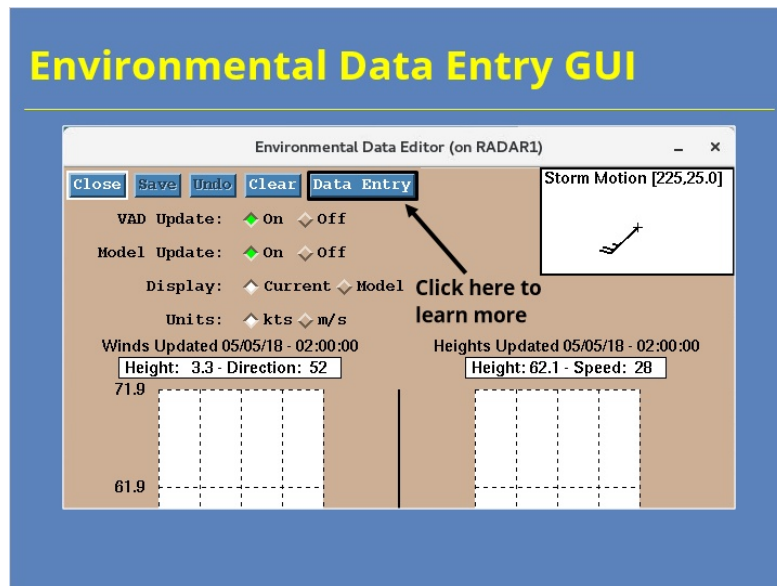
Make sure both are turned on

### 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.



## 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.

## Environmental Data Entry GUI

### Environmental Data Entry GUI

The screenshot shows the 'Environmental Data Entry (on RADAR1)' window. It has a title bar with 'Close', 'Save', 'Info', and 'Clear' buttons. The window is divided into three main sections: 'Environmental Winds Data', 'Temperature Heights', and 'Default Storm Motion'. The 'Environmental Winds Data' section includes a 'Coded Msg (PPHH):' field, an 'Interpolate between levels' checkbox, and a table with columns 'Lvl', 'Dir', and 'Spd'. The 'Temperature Heights' section includes a 'Last Update' timestamp and four height input fields. The 'Default Storm Motion' section includes 'Direction' and 'Speed' input fields. An arrow points from the text 'Click here to learn more' to the 'Info' button.

Lvl	Dir	Spd
kft	deg	kts
1.9	257	43.7
2.9	262	53.5
3.9	265	61.9
4.9	265	67.0
5.9	261	68.1
6.9	257	67.3
7.9	255	66.0
8.9	255	64.5
9.9	254	62.8
10.9	254	61.2
11.9	254	59.9
12.9	253	59.4
13.9	253	59.7
14.9	252	61.4
15.9	251	64.8
16.9	250	69.9

Temperature Heights

Last Update: 05/05/18 - 02:00:00

Height -20 C (0-70 kft MSL) 23.6

Height 0 C (0-70 kft MSL) 11.5

Height -25 C Tw (0-70 kft MSL) 25.5

Height 0 C Tw (0-70 kft MSL) 10.5

Default Storm Motion

Direction (0-360 deg) 225

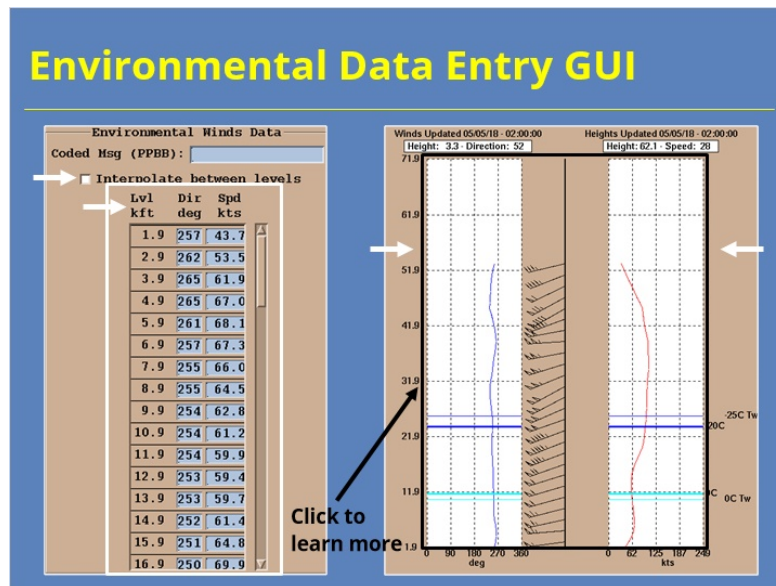
Speed (0-99.9 kts) 25.0

Click here to learn more

#### 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.

## 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 feet 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.

## Environmental Data Entry GUI

**Environmental Data Entry GUI**

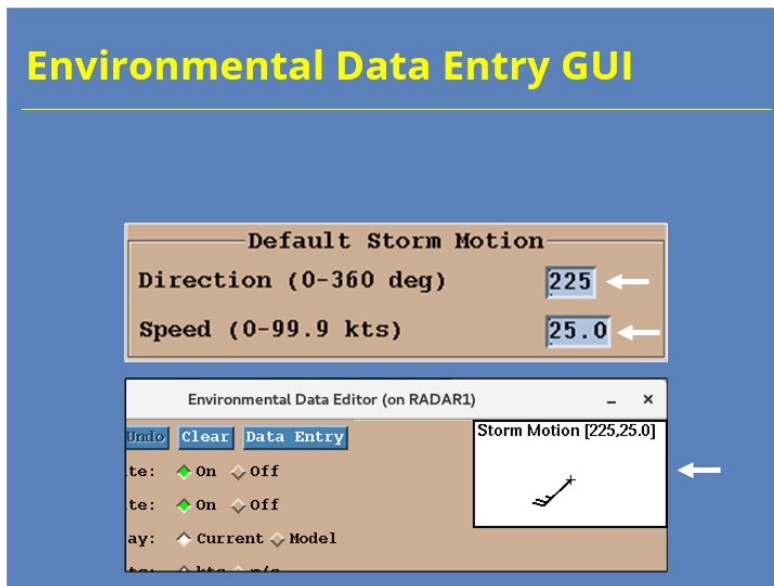
Temperature Heights	
Last Update: 05/05/18 - 02:00:00	
Height -20 C (0-70 kft MSL)	23.6
Height 0 C (0-70 kft MSL)	11.5
Height -25 C Tw (0-70 kft MSL)	25.5
Height 0 C Tw (0-70 kft MSL)	10.5

[Click here to learn more](#)

### 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.

## ***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 can 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.

## 5. Summary & Quiz

### *Summary*

#### Summary

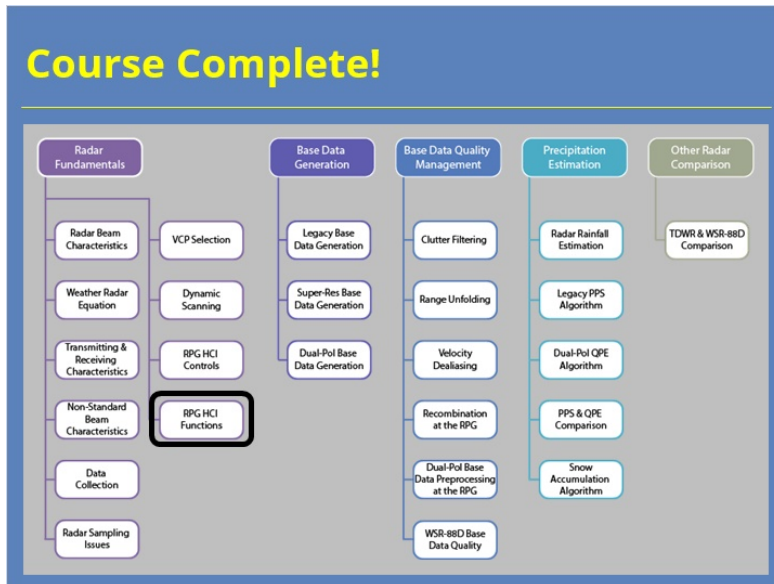
- Discussed five key button indicators on the main RPG HCI:
  - VCP
  - AVSET
  - SAILS
  - MRLE
  - Precip Status
- Discussed 3 options for controlling Doppler PRF selection for velocity base data & how they work
- Presented 3 sets of environmental data required by the RPG for product generation & how to edit their values

#### **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 five important ones you should know how to use: VCP, AVSET, SAILS, MRLE, 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!



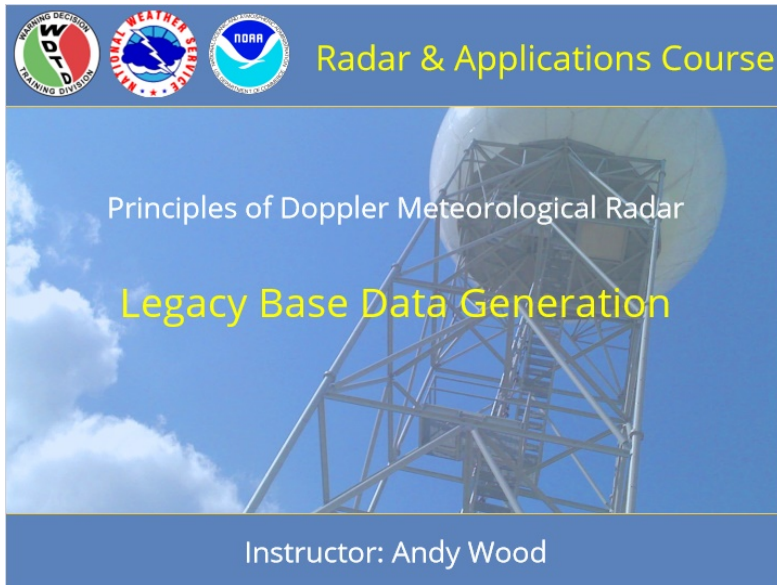
### Notes:

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.

# Legacy Base Data Generation

## 1. Legacy Base Data Generation

### *Introduction*

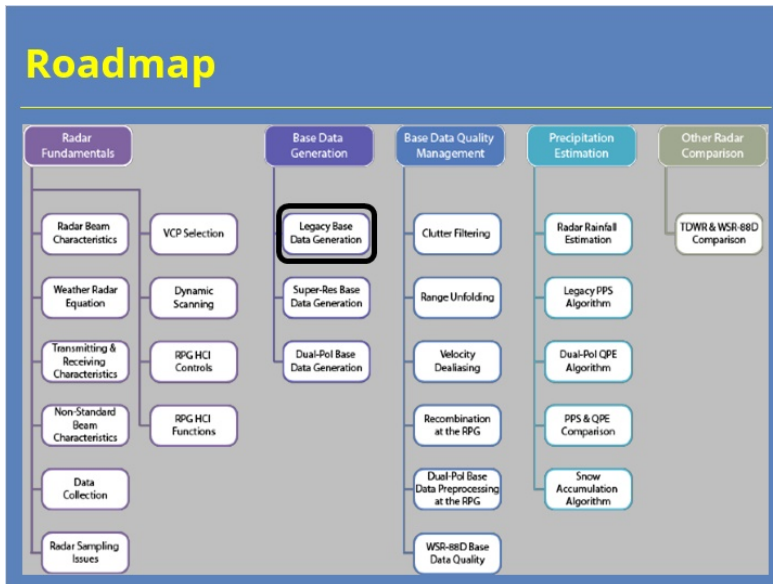


### **Notes:**

Welcome to the Radar & Applications Course, Principles of Doppler Meteorological Radar. This lesson discusses Legacy Base Data Generation. Let's get started!



## Roadmap



### Notes:

Here is the complete roadmap for the entire "Principles of Doppler Weather Radar" topic of RAC. You are currently in the Base Data Generation section of this topic.

## ***Learning Objectives***

### **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)

#### **Notes:**

This lesson has three learning objectives. Please take a moment to read them over and advance to the next slide when you are ready.

## ***Doppler Effect***

### **Doppler Effect**

“The change in frequency with a wave as it reaches a receiver when the receiver and the energy source are in motion relative to each other.”



**What matters:** Frequency shift proportional to target motion

#### **Notes:**

You're likely familiar with the definition of the Doppler Effect. It's the change in frequency with a wave as it reaches a receiver when the receiver and energy source are in motion relative to each other. When applied to weather radar, the radar location is fixed. So, any motion comes from the target. Since the observed frequency change is directly proportional to the target's motion, the radar can determine a target's motion towards or away from the radar.

## Doppler Equation

### Doppler Equation

$$c = f \lambda$$

$c$  = speed of light  
 $f$  = frequency  
 $\lambda$  = wavelength

$$V_r = - (f_{\text{dop}} \lambda) / 2$$

$V_r$  = radial velocity  
 $f_{\text{dop}}$  = Doppler shift  
 $\lambda$  = WSR-88D  
wavelength

- Factor of 2: Propagation & backscatter
- Minus sign: Inbound vs. outbound
  - Inbound motion: Positive Doppler shift
  - Outbound motion: Negative Doppler shift

#### Notes:

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.

## ***Sound Waves & Doppler Shift***

### **Sound Waves & Doppler Shift**

- Sound source moving 50 kts toward or away from receiver
  - Sound frequency = 10,000 Hz
  - Doppler shift =  $\pm 800$  Hz
    - +800 Hz inbound
    - -800 Hz outbound
- Doppler shift ~8% of original frequency
- Detectable by the human ear



#### **Notes:**

The most common example of the Doppler effect involves the change in pitch heard in a train or ambulance moving towards, then away from you. Let's math up this example, shall we? Say an ambulance drives down the road at 50 kts. If the siren has a frequency of 10,000 Hz, the Doppler frequency shift at this speed is 800 Hz. This frequency shift of 8% of the original frequency can be detected by the human ear. The WSR-88D handles Doppler shifts in a different manner because it has to.

## ***WSR-88D & Doppler Shift***

### **WSR-88D & Doppler Shift**

- Target moving 50 kts toward or away from WSR-88D
  - Transmitted frequency = 2850 MHz
  - Doppler shift =  $\pm 487$  Hz
- Doppler shift  $\sim .00002\%$  of original frequency
- WSR-88D does not directly measure such small frequency changes

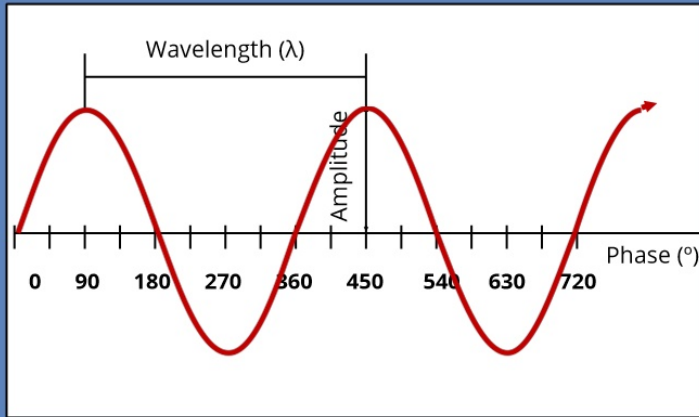


#### **Notes:**

To understand why the WSR-88D handles the Doppler shift differently, let's use a comparable example. Our weather target moves at 50 kts, but we are dealing with electromagnetic waves, not sound waves. The radar transmits a pulse at much higher frequencies than sound waves. As a result, the Doppler frequency shifts a tiny amount compared to the original frequency...too small to measure accurately for our purposes. For radar velocity estimates, we need a different technique.

## ***So What Do We Measure?***

### **So What Do We Measure?**

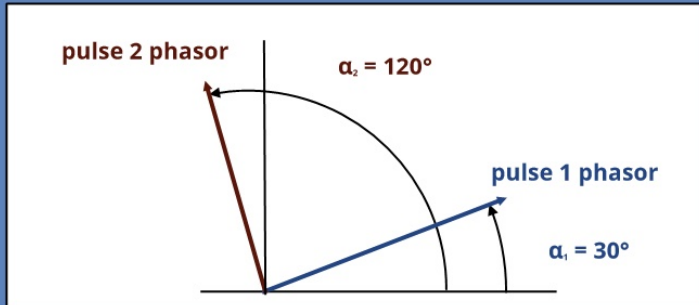


#### **Notes:**

If we don't measure the frequency shift, what else can we do? Let me provide a quick reminder of the various characteristics of wave energy. We measure the wavelength as the distance for the wave to complete one complete cycle, about 10 cm for the WSR-88D. The amplitude describes the signal strength, which can be directly related to reflectivity with a radar pulse. The phase shows a particular point along the wave, which can be used to determine velocity information.

## Pulse-Pair Processing

### Pulse-Pair Processing



Phase of returned pulses key

- Pulse to pulse phase shifts
- pulse pair processing

Knowns:

- Phase on transmit
- Phase on return

#### Notes:

The WSR-88D transmits and receives many pulses. The radar can measure a returned pulse's phase and compare it to the next returned pulses phase. This pulse-to-pulse phase shift relates directly to the radial velocity just like the traditional Doppler shift does. We call this technique pulse pair processing.

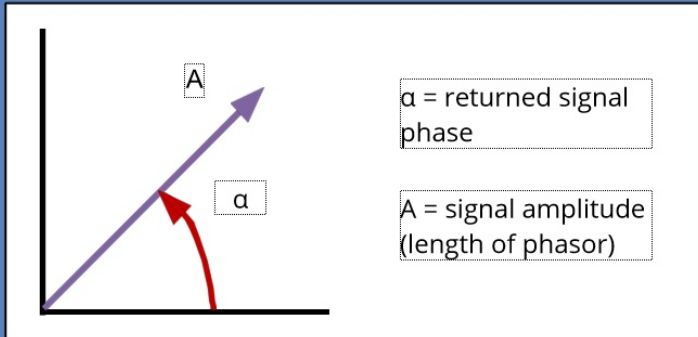
Pulse pair processing works because the initial phase of the transmitted pulse is known as well as the phase of each returned pulse. A phase value gets assigned to each returned pulse, which then is compared to the phase of the next received pulse.



## Signal Phasor

### Signal Phasor

- Snap shot of returned pulse information



- Can also help understand velocity folding/aliasing

#### Notes:

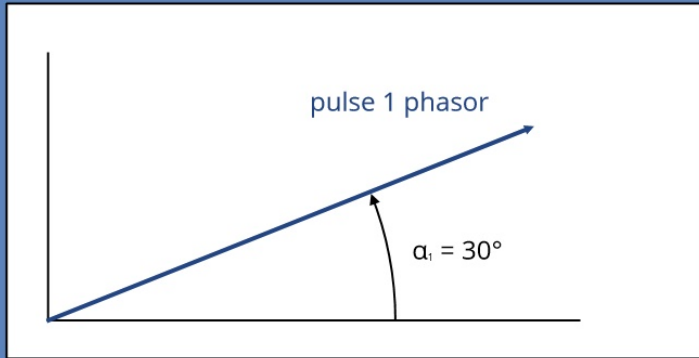
We use phasors to represent the concept of a pulse pair phase shift. A phasor represents the necessary information from each returned pulse. The angle of the phasor from the X-axis depicts the returned pulse's phase. The phasor length indicates the signal's amplitude. If the WSR-88D were continuously transmitting and receiving, you would see the phasor rotate with time. Since pulses need to capture target range and velocity, each phasor is a snapshot instead.

Besides pulse-pair processing, phasors have use in understanding one of the fundamental ambiguities with Doppler weather radar: Velocity folding or aliasing. We'll touch on that topic in a later lesson.

## ***Phasor for Single Pulse***

### **Phasor for Single Pulse**

Phase of returned signal is known

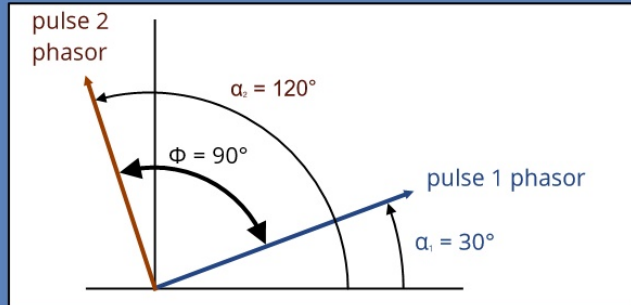


#### **Notes:**

Here's an example showing a phasor for a single pulse. After the transmitting the pulse, it interacted with the target and returned a signal. The phase value for this pulse is  $30^\circ$ .

## Phasors for Two Pulses

### Phasors for Two Pulses



- Measured phase shift directly related to motion
  - Phase shift is distance (up to 10 cm wavelength)
  - PRF tells us our time between pulses

#### Notes:

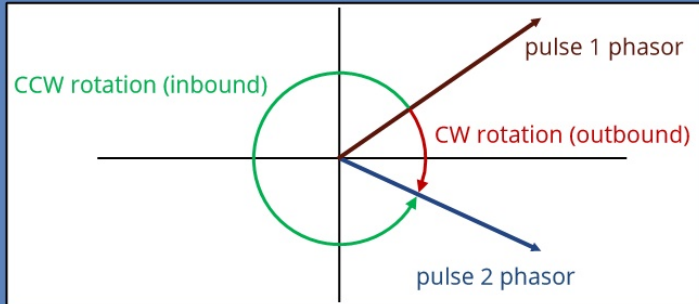
Using the phasor from our previous example, we add a second pulse that returns a phase value of  $120^\circ$ . The pulse pair phase shift corresponds to the angle between the two phasors. That's  $90^\circ$ .

Remember that the phase shift between pulses relates directly to target motion. Our radar wavelength is 10 cm, so we know the phase shift indicates a fraction of that distance. Since the pulse repetition frequency, or PRF, is known, the time between the pulses is also known. We then have both ingredients we need for target speed: distance and time.

## Determining Target Direction

### Determining Target Direction

- Clockwise = outbound
- Counterclockwise = inbound
- "right hand thumb" rule applies

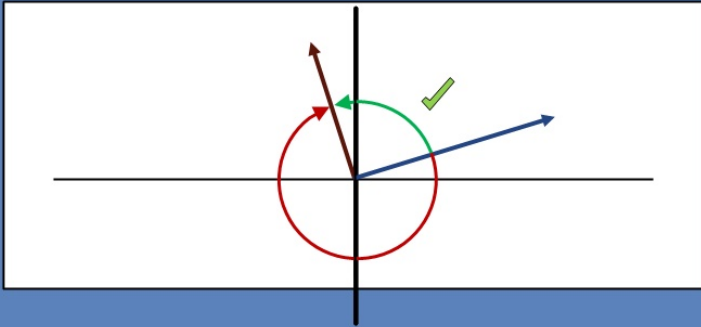


#### Notes:

Phasor rotation from pulse 1 to pulse 2 determines the target direction, or whether it's moving inbound or outbound. If the phasor rotated clockwise, the target moved outbound. If the rotation was counterclockwise, the target moved inbound. The right hand rule for the cross product of two vectors also works. Just remember your thumb points in the direction of motion. In this example, using the angle less than  $180^\circ$  results in clockwise rotation and outbound motion. Using the right hand rule, your thumb points away from you.

## ***Pulse to Pulse Phase Change***

### **Pulse to Pulse Phase Change**



- At least 2 possible angles exist between phasors
- The angle  $< 180^\circ$  always used for first guess

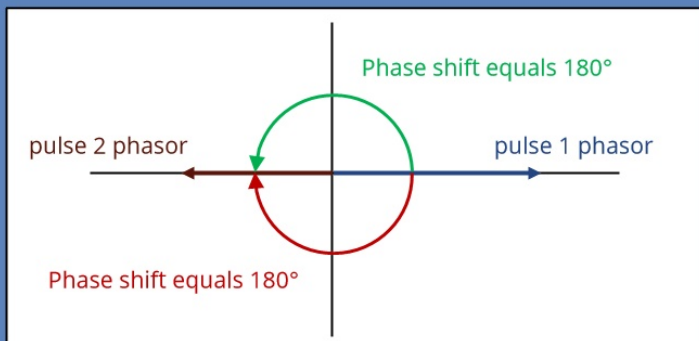
#### **Notes:**

Two phasors represent the information from the different pulses. Since these phasors are snapshots, the radar makes assumptions about what happened between the two pulses. Two possible angles exist between the phasors that represent the returned signals. The radar always uses the angle that is less than  $180^\circ$ .

## Why Less Than 180°?

### Why Less Than 180°?

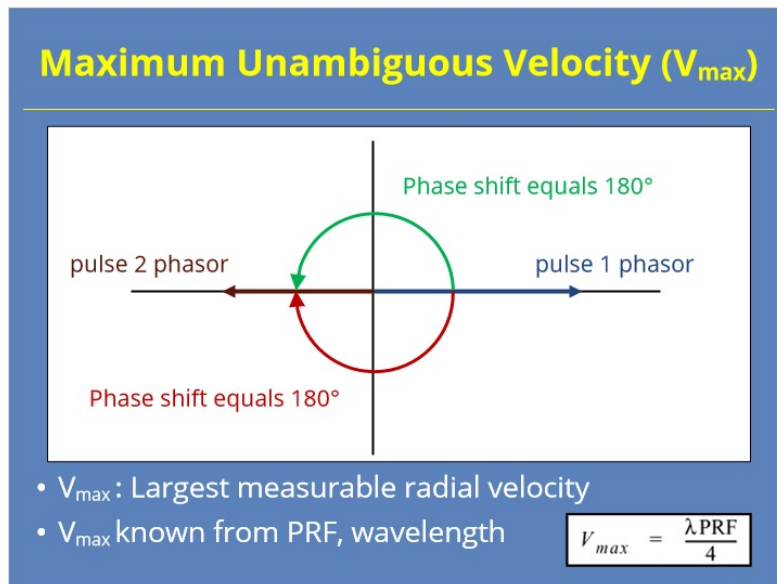
Shifts of  $\geq 180^\circ$  introduces ambiguity



#### Notes:

So, why does the radar use the angle  $< 180^\circ$ ? A phase shift of exactly  $180^\circ$  introduces ambiguity. We can't determine which direction the phasor rotated to get from pulse 1 to pulse 2. If the target moved so fast that its true phase shift is greater than  $180^\circ$ , ambiguity exists in determining the velocity. We will discuss how we deal with that ambiguity later.

## Maximum Unambiguous Velocity ( $V_{max}$ )



### Notes:

We define the maximum unambiguous velocity, or  $V_{max}$ , as the largest velocity that can be measured without ambiguity.  $V_{max}$  corresponds to a pulse pair phase shift of 180° (actually 179.99999...°), and depends on both the PRF used for the pulse and the transmitted wavelength. With the WSR-88D,  $V_{max}$  values range from approximately 16 to 64 kts, and the wavelength is approximately 10 cm.

## Phase Shift-Radial Speed Equation

### Phase Shift-Radial Speed Equation

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

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

#### Notes:

Once we know the pulse-pair phase shift and  $V_{\max}$ , we can compute the first guess radial speed in a straightforward manner. Since the pulse-pair phase shift is a fraction of the maximum phase shift of  $180^\circ$ , the radial speed has that same relationship to  $V_{\max}$ .

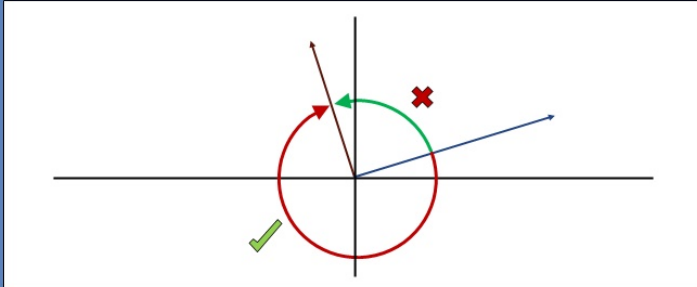
On the next few slides, you will work through some basic calculations of the radial velocity based on this simple relationship.



## ***V<sub>max</sub> and First Guess Velocities***

### **V<sub>max</sub> and First Guess Velocities**

- First guess velocities from phase shift  $< 180^\circ$
- $V_{\max}$  defines interval of first guess velocities
- Every first guess velocity has a set of aliases



#### **Notes:**

Up to this point, we focused on the actual pulse pair phase shift being  $< 180^\circ$ . We call estimates based on this assumption the “first guess velocity”. Since  $V_{\max}$  relates to a phase shift of  $180^\circ$ ,  $V_{\max}$  defines a range of first guess values from  $\pm$  that value. So, if  $V_{\max} = 60$  kts, then the first guess velocities range from -60 kts to +60 kts.

You may ask what happens when the first guess velocity is incorrect? That’s a good question! We determine other possible velocities, or aliases, based on the same equation we used previously if the first guess is wrong. Let’s use another example to see how this works.

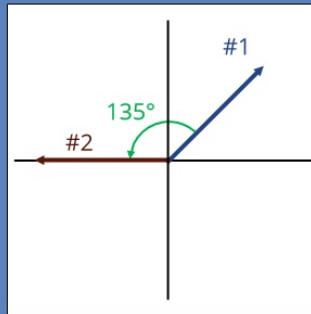
## Putting It Together – Correct 1st Guess

### Putting It Together – Correct 1st Guess

- $V_{\max} = 60$  kts
- First guess phase shift  $135^\circ$

$$\frac{135^\circ}{180^\circ} = \frac{|V|}{60}$$
$$60 \left(\frac{3}{4}\right) = |V| = 45 \text{ kts}$$

- First guess radial velocity: -45 kts
- Counterclockwise rotation



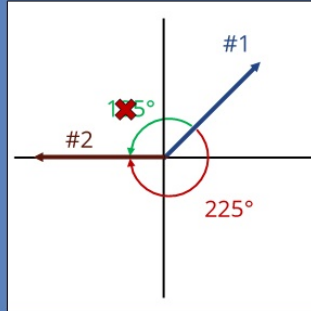
#### Notes:

Let's start our example as our previous ones with the first guess being correct to bring everything together. Our  $V_{\max}$  is 60 knots. From our phasors in the diagram, our pulse-pair phase shift indicates an angle of  $135^\circ$ . Since  $135^\circ$  is three-fourths of  $180^\circ$ , we end up with a first guess velocity of 45 knots. The phasors rotated counterclockwise, so we have an inbound target direction, too.

## Putting It Together – Wrong 1st Guess

### Putting It Together – Wrong 1st Guess

- $V_{\max} = 60$  kts
- First guess phase shift  $135^\circ$  with counterclockwise rotation
  - First guess radial velocity: -45 kts
- Actual phase shift  $225^\circ$  with clockwise rotation
  - Actual radial velocity: +75 kts



#### Notes:

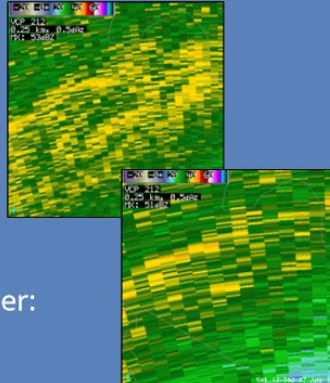
So what happens when the first guess velocity is not correct, or the actual phase shift is  $>180^\circ$ ? Let's flip our previous example to see how this works.

Remember that  $V_{\max}$  is 60 knots, and our first guess velocity was inbound at 45 knots based on a phase shift of  $135^\circ$  in a counterclockwise direction. Say the true phase shift is actually  $225^\circ$  in the clockwise direction. Though our first guess velocity of 45 knots is incorrect, the radar computes +75 knots (which is the actual velocity) as a possible velocity or alias value. How the radar uses alias values to determine a velocity estimate will be discussed in a later lesson.

## ***Base Reflectivity (Z) Generation***

### **Base Reflectivity (Z) Generation**

- Reflectivity generated from multiple pulses
- Average  $P_r$  converted to Z, then converted to dBZ
- Super Res on Split Cuts: 0.5° az x .25 km range
- Legacy Res on Batch & higher: 1.0° az x .25 km range



#### **Notes:**

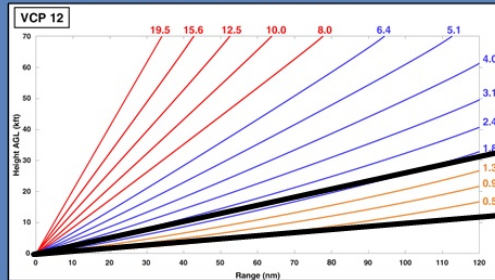
For each range and azimuth, the radar generates reflectivity from multiple pulses. First, the signal processor averages the returned power for these pulses for each 0.25 km range bin. Next, returned power gets converted to reflectivity using the Probert-Jones radar equation. Finally, the radar converts the reflectivity value to dBZ units for transmission to the RPG for product generation.

Remember, Split Cut tilts provide Reflectivity data with 0.5° azimuth by .25 km range resolution. For the Batch and higher elevation tilts, that resolution decreases to 1.0° azimuth by .25 km range.

## Split Cut Data Collection

### Split Cut Data Collection

- Low PRF provides long  $R_{\max}$
- Split Cut approach:
  - 1st rotation CS/low PRF (Z & Dual-pol)
  - 2nd rotation CD/high PRF (V & SW)



#### Notes:

Low pulse repetition frequencies provide for a long maximum unambiguous range for reflectivity data. Split Cut scans collect data using two full sweeps on the lowest two or three elevations for all VCPs except VCP 112. First, the radar collects a full rotation in Contiguous Surveillance (CS) mode, which uses a low PRF. Base Reflectivity and Dual-Pol data come from this scan. A second rotation at the same elevation angle uses a Contiguous Doppler (CD) scan with a higher PRF to collect Base Velocity and Spectrum Width data. This second scan has a much shorter  $R_{\max}$ , and range folded echoes are common. We discuss the range unfolding process more in a later lesson.

## ***Z Generated from PrH***

### **Z Generated from $P_{rH}$**

$$P_r = \left[ \frac{P_t G^2 \theta^2 H \pi^3 K^2 L}{1024 (\ln 2) \lambda^2} \right] \times \frac{Z}{R^2}$$

- P-J radar equation converts  $P_r$  to Z for both horizontal and vertical channels
- Base Reflectivity (Z) calculated from  $P_{rH}$  only

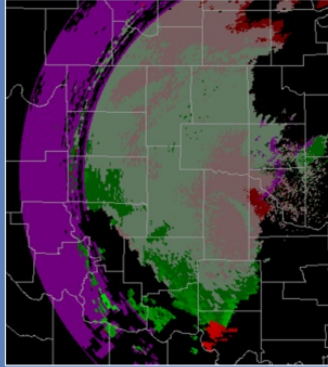
#### **Notes:**

We use the Probert-Jones radar equation to calculate base reflectivity from the average returned power. You can see where the returned power and reflectivity plug into the equation here. This conversion occurs for the returned power in both the horizontal and vertical channels to support the dual-polarization data. However, the radar builds the Base Reflectivity product from the horizontal channel data only.

## ***Base Velocity (V) Generation***

### **Base Velocity (V) Generation**

- Super Res on Split Cuts:  
0.5° az x .25 km
- Legacy Res on Batch & up:  
1.0° az x .25 km
- Max. display range:  
162 nm
- Pulse pair processing:  
Power weighted average  
of pulse velocity estimates



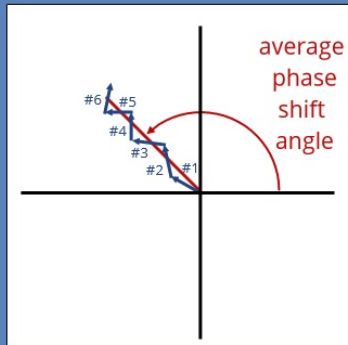
#### **Notes:**

Base Velocity also has a 0.25 km range resolution. Just as with reflectivity, Split Cut tilts collect super resolution data with 0.5° azimuthal resolution. Batch and higher tilts collect standard resolution data with 1.0° azimuthal resolution. Velocity data have a maximum display range of 162 nm. When using pulse pair processing, the radar averages the phase shift between a series of returned pulses to achieve a velocity estimate. However, power weighted (not linear) averaging occurs.

## Power Weighted Average Used for V

### Power Weighted Average Used for V

- Larger scatterers return more power
- These targets have more influence because:
  - More likely to move w/mean flow
  - We want mean flow!
- Vector sum provides weighted average



#### Notes:

What do we mean by power weighted averaging? In a nutshell, larger scatterers tend to return more power. These more reflective targets in the radar volume should have a greater influence on velocity estimates because they are more likely to move with the mean flow, which is what we want to know.

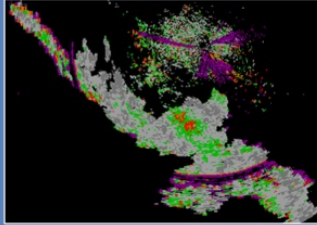
In the graphic shown, each phasor represents the information for one pulse pair. Remember we determine the phase shift between the pulse pairs by measuring the phasor's angle from the positive x-axis. Likewise, the phasor's length relates to the returned powers of the two pulses compared. The vector sum of all the phasors results in a power weighted average of the pulse pair phase shift.



## ***Base Spectrum Width Generation***

### **Base Spectrum Width Generation**

- Super Res on Split Cuts:  
0.5° az x .25 km
- Legacy Res on Batch & up:  
1.0° azimuth x .25 km
- Max. display range: 162 nm
- Proportional to variation in wind speed/direction  
(velocity dispersion)
- Higher values typical with boundaries, high shear,  
& thunderstorms



#### **Notes:**

Like the other legacy base data, Spectrum Width also has a 0.25 km range resolution. Likewise, Split Cuts collect super resolution base data at 0.5° azimuthal resolution. Batch and higher elevation tilts collect standard resolution data with 1.0° azimuthal resolution. As with Base Velocity data, Spectrum Width data has a maximum display range of 162 nm.

Spectrum Width data measure the velocity dispersion or variability among the phasors used to generate velocity data for a range bin. These data are proportional to the variability of both wind speed and direction. Some meteorological phenomenon produce higher spectrum width values. Higher values should be expected with air mass boundaries, high shear environments, and thunderstorms.

## Autocorrelation & Spectrum Width

### Autocorrelation & Spectrum Width

- How successive pulse pair shifts correlate to one another
  - High variation = High Spectrum Width
  - Low variation = Low Spectrum Width



- Visual tool: Doppler Power Spectrum
  - "weather" well approximated by Gaussian curve

#### Notes:

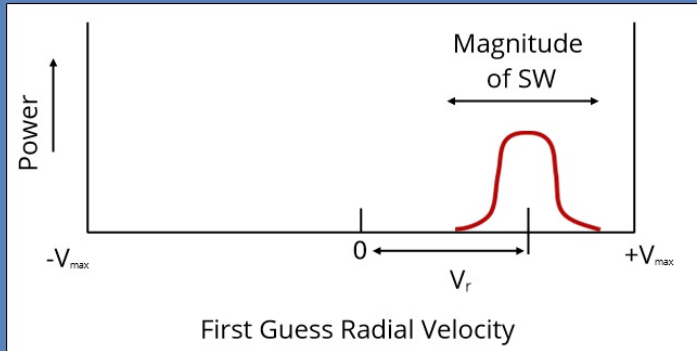
The radar uses a technique called autocorrelation to calculate Spectrum Width. What exactly is being correlated? The technique compares the series of phase shifts from one pulse to the next. If the pulse pair phase shift data for a particular range bin have a lot of variation, Spectrum Width will be high. If little variation exists in these data, Spectrum Width will be low.

It turns out the returned radar "weather" signal can be well approximated by a Gaussian curve called the "Doppler Power Spectrum". The Doppler Power Spectrum represents the base data analysis process in a visual manner.

## ***Doppler Power Spectrum***

### **Doppler Power Spectrum**

- Base data assignment for a single range bin



#### **Notes:**

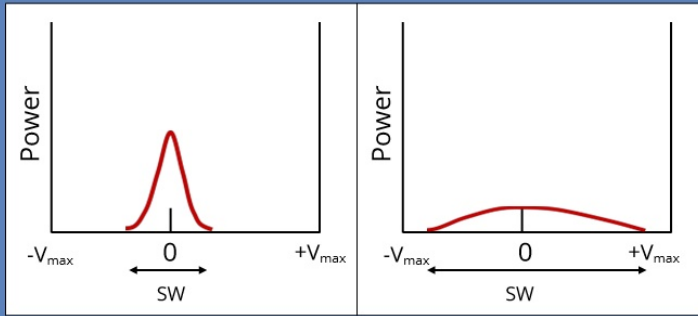
The Doppler Power spectrum represents the base data analysis process for a single range bin. The power and velocity phasors get converted to points known as "spectral coefficients". The radar then fits a curve to these coefficients. The area under the curve represents the average returned power while the midpoint of the curve along the horizontal axis indicates the mean radial velocity. The width of the curve relates proportionally to the magnitude of Spectrum Width. Let's discuss this trait further on the next slide.

## Low vs. High Spectrum Width

### Low vs. High Spectrum Width

Narrow spike (low SW)

Wide & flat (high SW)



#### Notes:

Spectrum Width's magnitude depends on the shape of the power spectrum curve. The example on the left shows returned pulses from ground clutter that have strong power returns and a mean radial velocity near zero. The pulse pair phase shifts vary little, resulting in a Doppler Power Spectrum curve that is narrow and centered near zero velocity (which is a defining trait of most ground clutter). This distribution results in a low Spectrum Width. Our other example contains weather returns with low power, but a wide variety of velocity values. The average radial velocity of the phasors is still near zero, but the width of the Doppler Power Spectrum is much greater than the clutter example. This curve has a high Spectrum Width.

## Summary

### Summary

- Pulse-pair processing used to identify the Doppler velocity estimate of radar targets
- Phase information from returned signal used with  $V_{max}$  to identify the “first guess” velocity estimate
- Base Reflectivity: Average  $P_r$  from returned pulses
- Base Velocity: Phasor vector sum (Power weighted)
- Base Spectrum Width: Dispersion in Doppler Power Spectrum curve
- Split Cuts: Super-resolution data
- Batch Cuts & above: Standard resolution data

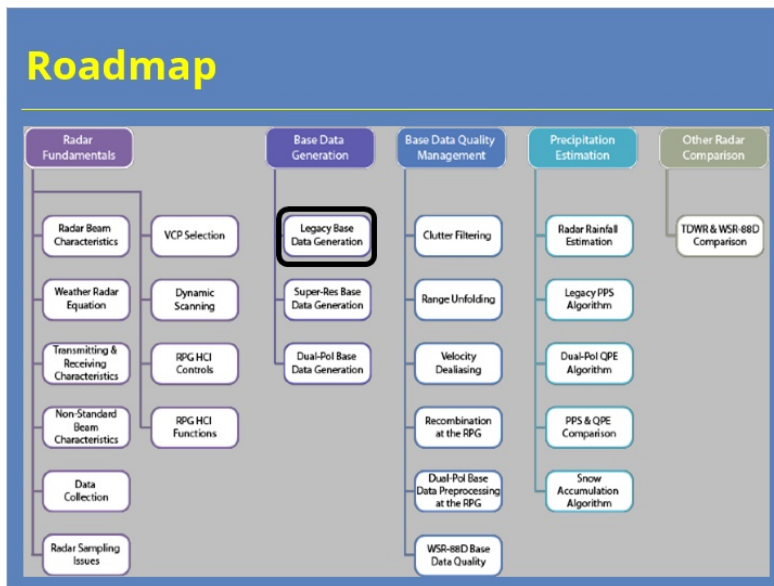
### Notes:

In summary, this lesson discussed several aspects of legacy base data generation. We started by discussing how the WSR-88D uses pulse-pair processing, instead of measuring the phase shift of a single pulse, to identify the Doppler velocity estimate. The radar also uses the PRF of the transmitted signal to determine the maximum unambiguous velocity (or  $V_{max}$ ). The phase shift and  $V_{max}$  allows the radar to calculate the “first guess” velocity estimate.

When calculating the legacy base data, we covered several key points. First, the Base Reflectivity value is computed from an average of the returned power from multiple pulses. The radar calculates Base Velocity from the phasor vector sum, which is a power weighted average, of all the pulses that sample the volume. Lastly, Base Spectrum Width measures the dispersion of the Doppler Power Spectrum curve for the pulses that sample the volume. For all three data moments, the radar calculates super-resolution data on the lower-elevation Split Cuts, while standard resolution data are generated on the Batch Cuts and higher tilts.

When you are ready, proceed to the next slide to take the quiz.

## Roadmap



### Notes:

This lesson is now complete. You can now move on to the next lesson in the course. Thank you for your time!



Welcome to this lesson on super resolution base data generation.



### 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](#)

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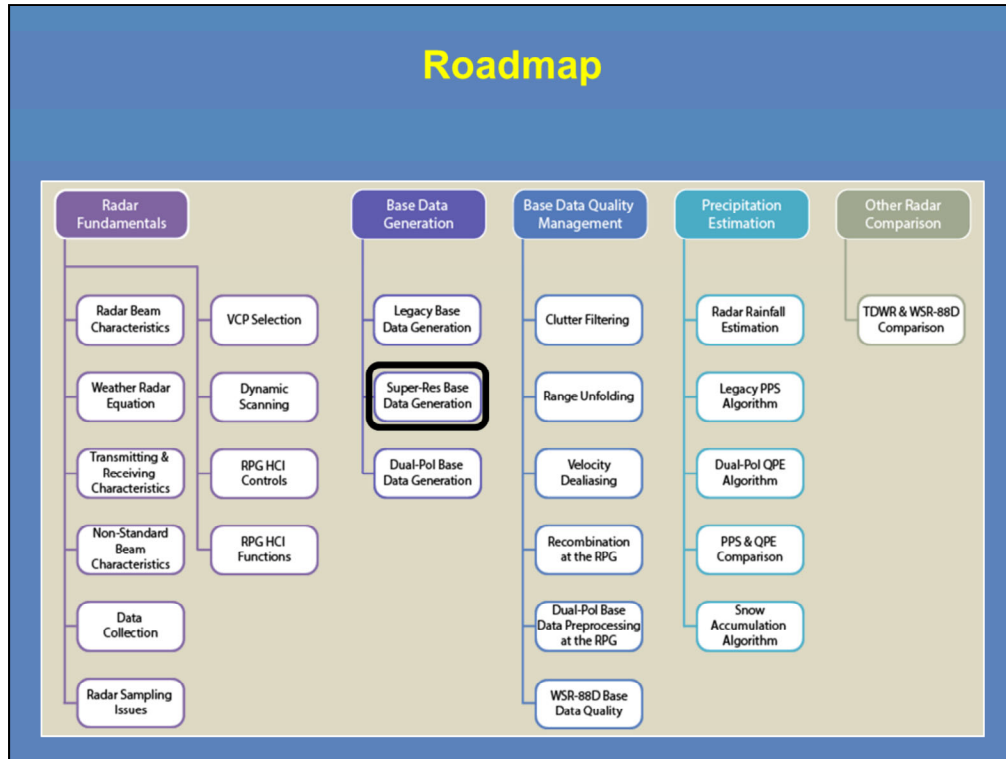


Edit in Engage



Edit Properties





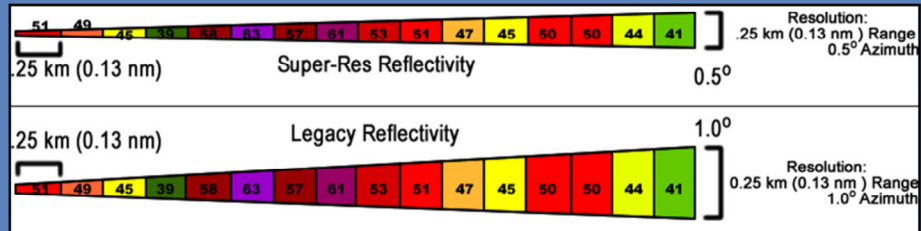
Here is the “roadmap” for this topic in the Radar & Applications Course, with your current location annotated.

## **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.

## Super Resolution Signal Processing



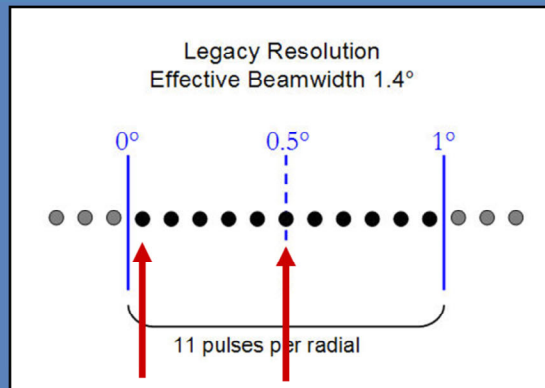
- Super Resolution: 0.5° azimuth for legacy base data on Split Cuts
- How to narrow azimuthal resolution to 0.5°?
  - Overlapping radials
  - Data windowing
- “Effective” beamwidth
  - Physical beamwidth (single pulse) plus the antenna is moving

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.

## Effective Beamwidth

- *Effective* beamwidth is  $\sim 1.4^\circ$ 
  - Beamwidth  $\sim 1^\circ$  for a single pulse



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  $1^\circ$  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  $1^\circ$ . 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  $1.4^\circ$ .

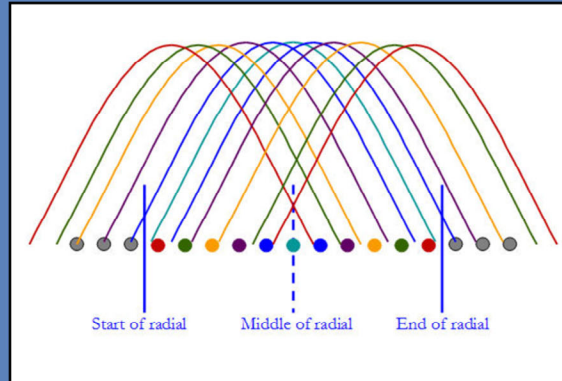
## Overlapping Radials

- Overlapping radials: change defined center of each radial
- Effective beamwidth is *still*  $1.4^\circ$



The overlapping radials technique simply changes the definition of the center of each radial. The radial centers for legacy resolution are  $0.5^\circ$ ,  $1.5^\circ$ ,  $2.5^\circ$ , etc. For super resolution data, the centers change to  $0.25^\circ$ ,  $0.75^\circ$ ,  $1.25^\circ$ ,  $1.75^\circ$ , etc. However, since the number of pulses per radial cannot decrease and the effective beamwidth is still  $1.4^\circ$ , the sampled volume outside of each  $0.5^\circ$  radial continues to be too large. Simply choosing new radial centers is not sufficient. The effective beamwidth must also be narrowed.

## Data Windowing

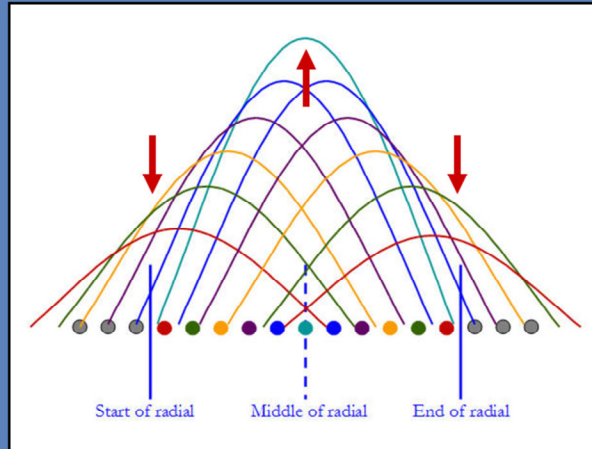


- Data Windowing
  - Apply weighting function to pulses that comprise base data for a radial
- Rectangular window: all pulses have equal weight

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.

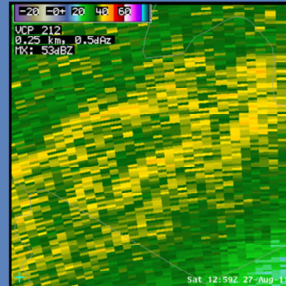
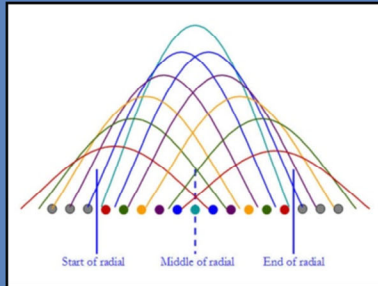
## Data Windowing

- 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.

## Super Resolution Base Data Quality Tradeoffs



- The trade off for narrower effective beamwidth
  - Visual detection of smaller features at longer ranges
  - More error in estimate
- SR base products visually noisier than legacy
- SR base data must be “degraded” for input to algorithms

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.



## Summary

- WSR-88D Specs:
  - Single pulse beamwidth:  $1^{\circ}$
  - Effective beamwidth:  $1.4^{\circ}$
- 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  $0.5^{\circ}$
  - 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.



## Super-Res Data Generation - Final Quiz

Quiz - 2 questions

Last Modified: Aug 23, 2018 at 11:09 AM

### PROPERTIES

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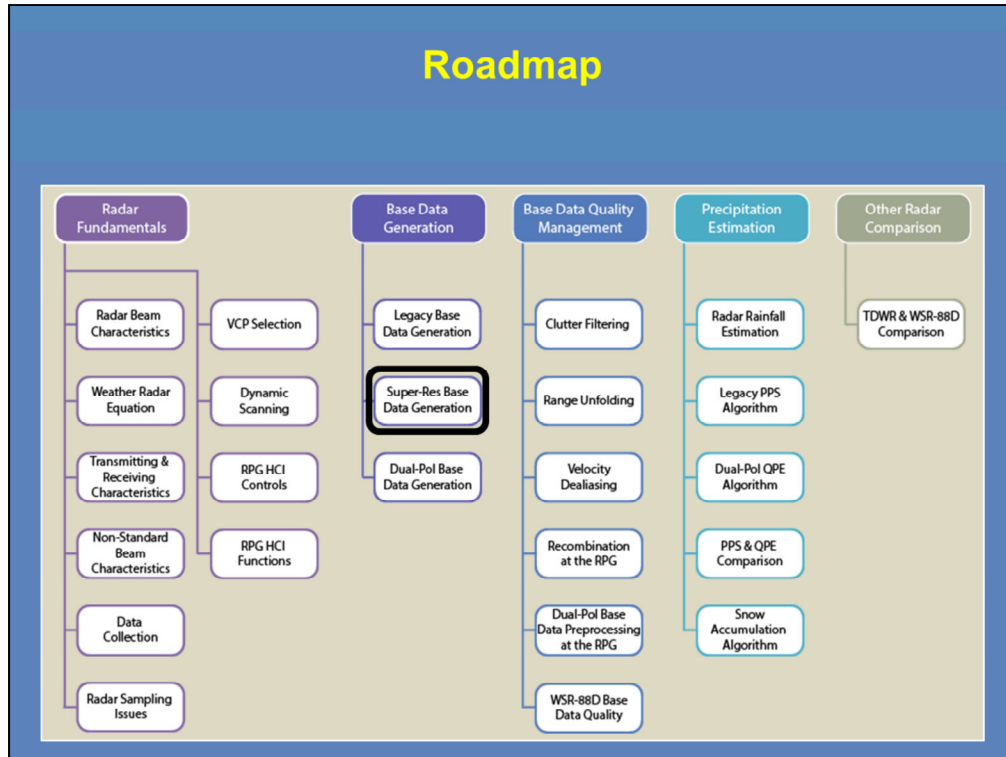
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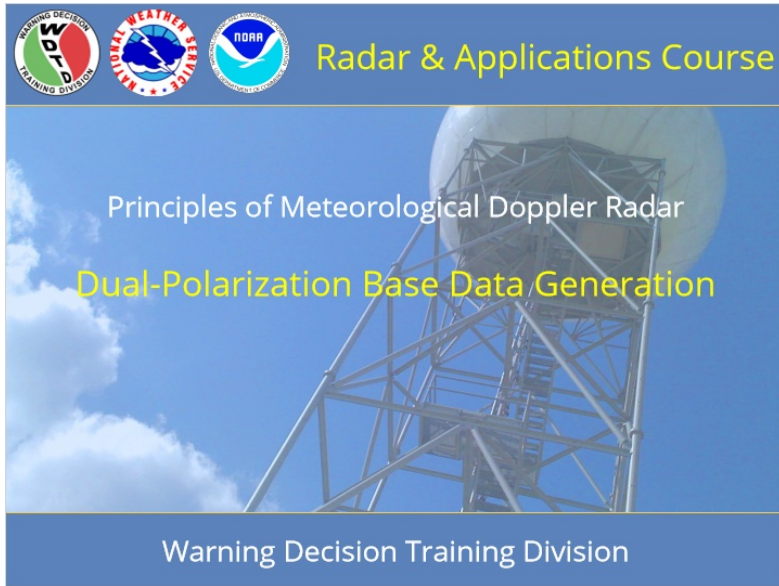
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This concludes this lesson. You can use the roadmap shown to see what topics come next after this lesson. Once you are done, click the exit button to conclude this lesson.

# Dual-Pol Base Data Generation

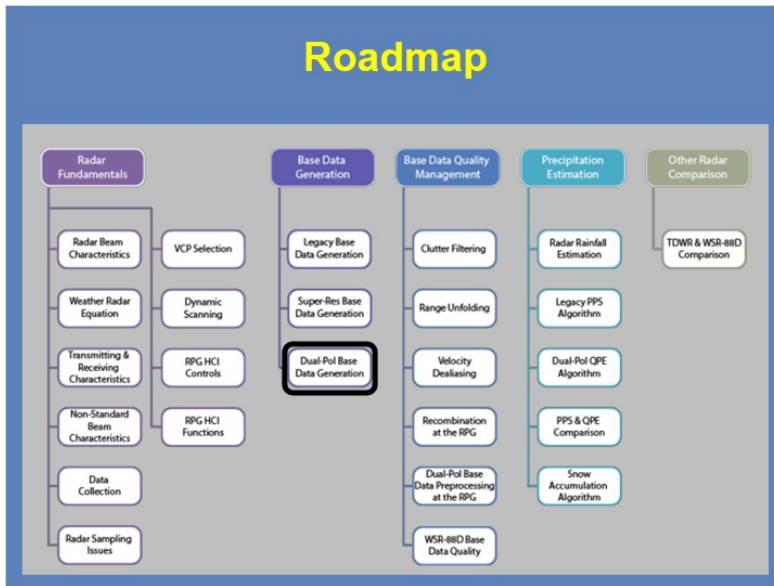
## *Dual-Pol Base Data Generation*



### **Notes:**

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

## Roadmap



### Notes:

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

## ***Learning Objectives***

### **Learning Objectives**

1. Identify how the returned signal is used to generate
  - a) Differential Reflectivity (ZDR)
  - b) Correlation Coefficient (CC)
  - c) Differential Phase ( $\Phi_{DP}$ ), 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

### **Notes:**

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.

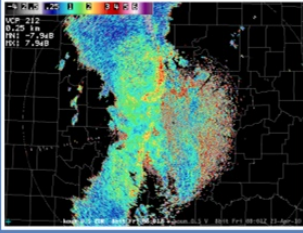
## RDA Generation of ZDR

**RDA Generation of ZDR**

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

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

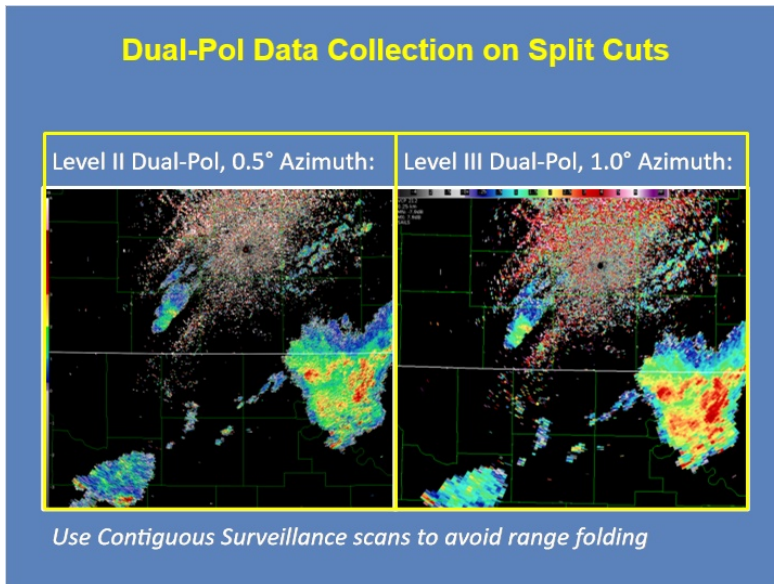
← Calibration of both channels matters!



### Notes:

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.

## Dual-Pol Data Collection on Split Cuts



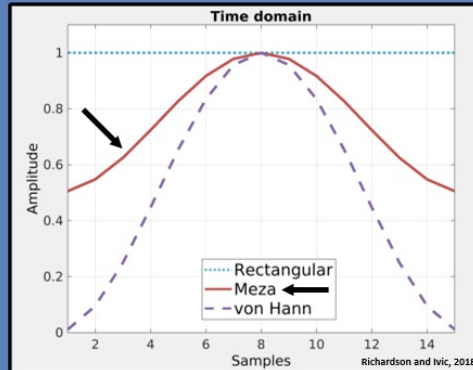
### Notes:

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 left. The same data after recombination for display in AWIPS is shown on the 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.



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

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

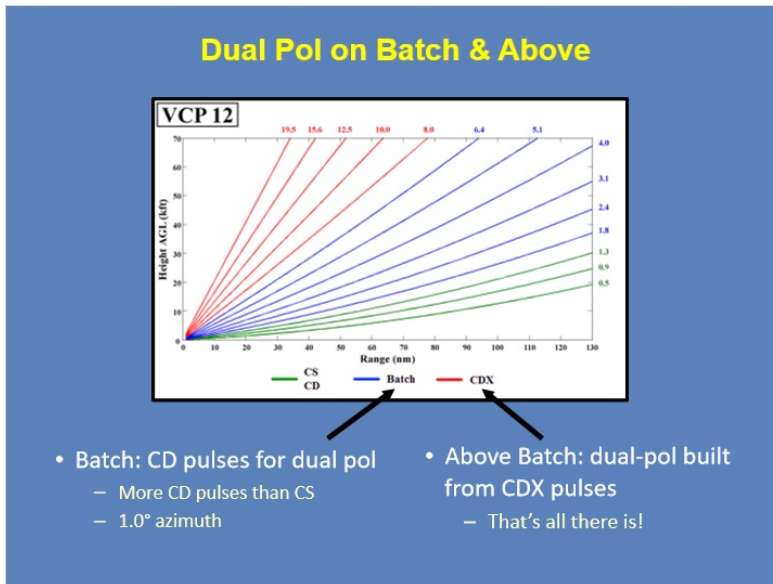


CS pulses use the Meza window to generate Level II dual-pol radials transmitted to the RPG

#### Notes:

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.

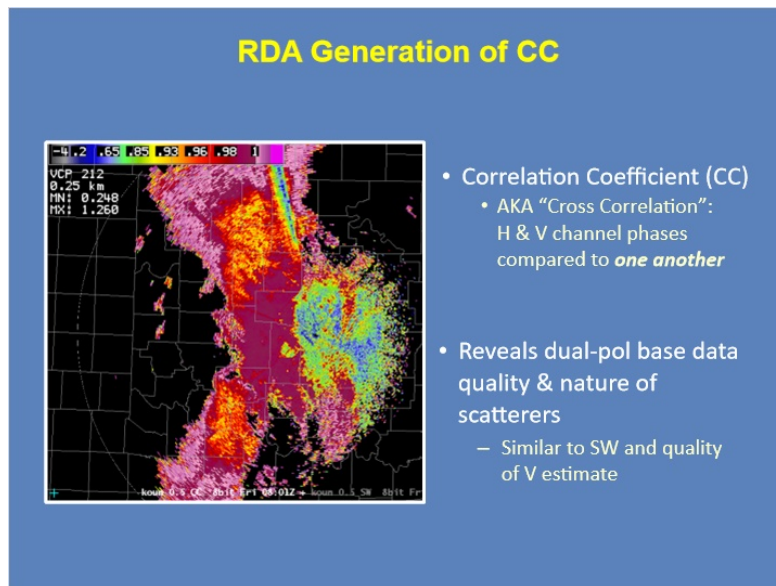
## Dual Pol on Batch & Above



### Notes:

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.

## RDA Generation of CC

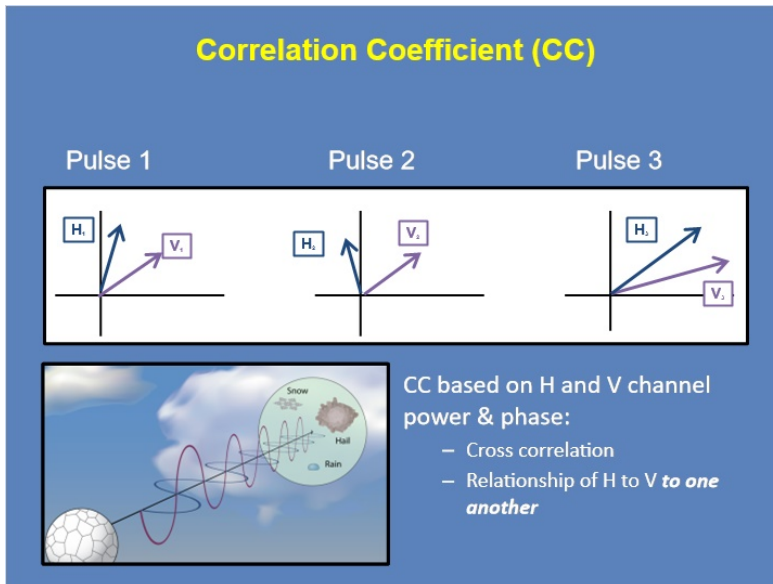


**Notes:**

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.

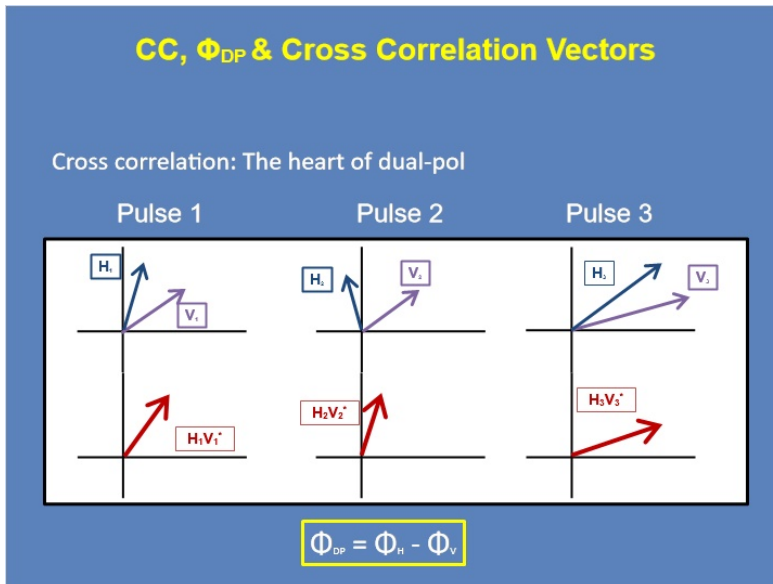
## Correlation Coefficient (CC) Theory



### Notes:

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 known as a cross correlation. The magnitude of and angle between the H and V vectors matter and, fortunately, can be determined by vector multiplication.

## CC, $\Phi_{DP}$ & Cross Correlation Vectors



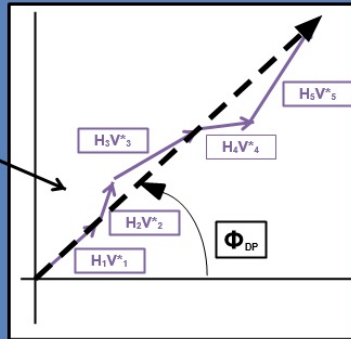
### Notes:

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  $\Phi_{DP}$ . It is the horizontal phase minus the vertical phase:  $\Phi_{DP} = \Phi_H - \Phi_V$ .

## Differential Phase & Other Dual-Pol Variables

### Differential Phase & Other Dual-Pol Variables

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



#### Notes:

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  $\Phi_{DP}$ , is the angle of this vector sum which is included in the base data generated at the RDA for each range bin.

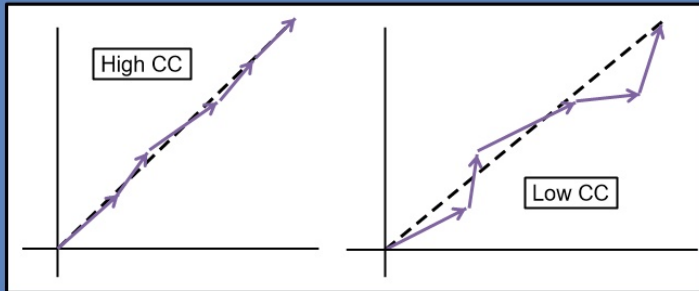
Differential Phase contributes to two dual-pol variables:

1. As we mentioned on the previous slides,  $\Phi_{DP}$  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.

## Correlation Coefficient Is Based on $\Phi_{DP}$

### Correlation Coefficient Is Based on $\Phi_{DP}$

- CC = length of cc vector  $\div$  averaged H & V powers (huh?)
- $0 < CC < 1$ 
  - fraction of “perfect” consistency





#### Notes:

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.

## ***Correlation Coefficient's Utility: Target Type***

**Correlation Coefficient's Utility: Target Type**

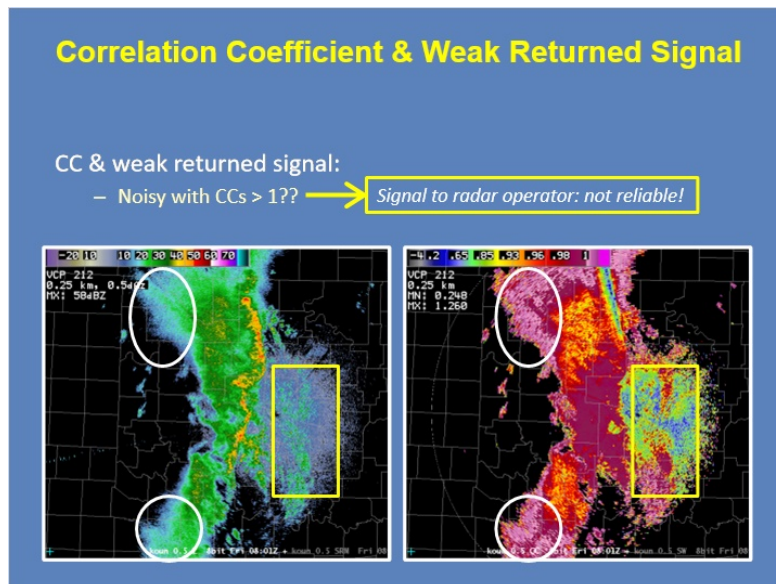
	
<p>Low consistency, low CC (<math>&lt;0.8</math>)</p> <ul style="list-style-type: none"><li>— Scatterers not meteorological</li></ul>	<p>High consistency, high CC (<math>&gt;0.97</math>)</p> <ul style="list-style-type: none"><li>— Scatterers highly uniform (pure rain or snow)</li></ul>

### **Notes:**

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.



## Correlation Coefficient & Weak Returned Signal



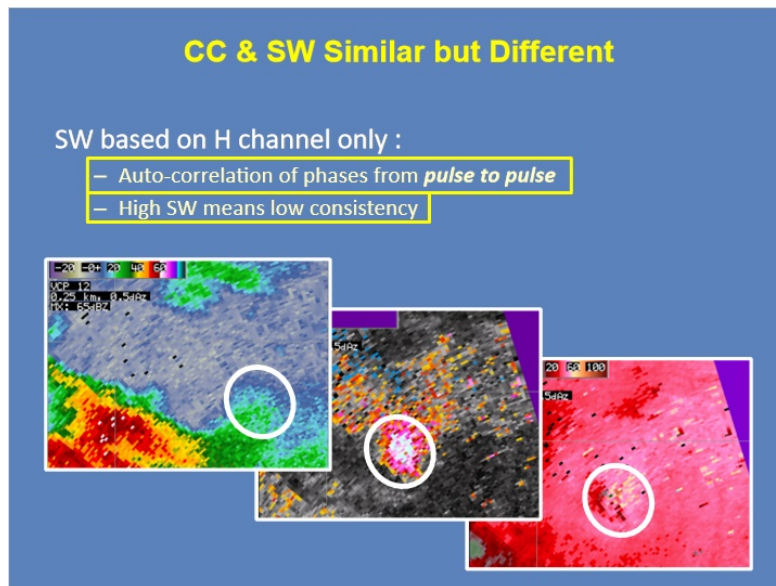
### Notes:

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 return 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.

## CC & SW Similar but Different



### Notes:

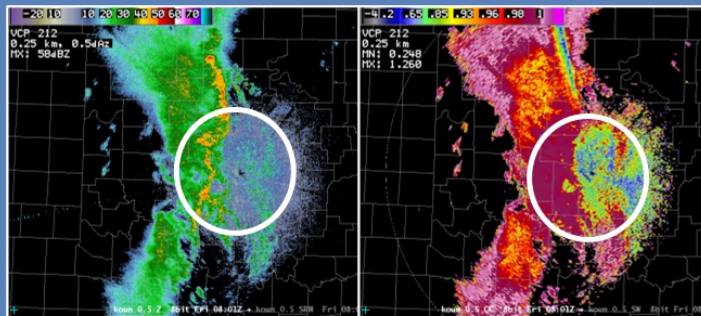
Correlation Coefficient and Spectrum Width are analogous to each other, but they have some important differences. Remember that Spectrum Width uses data from the horizontal channel only and provides a sense of the Base Velocity data quality. Spectrum Width gets calculated from auto-correlation, not cross 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.

## CC & SW Similar, but Different

## CC & SW Similar but Different

## CC based on H & V channels:

- Cross correlation of H & V phases to one another
- High CC means high consistency

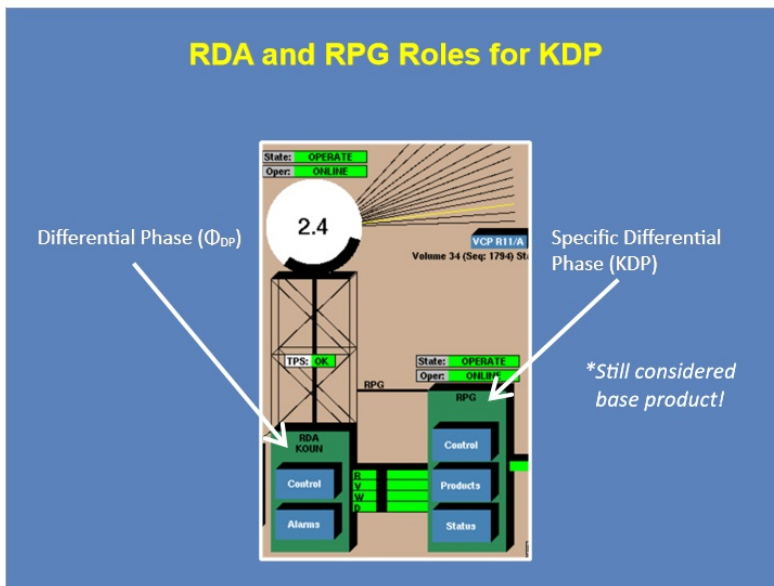


**Notes:**

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.

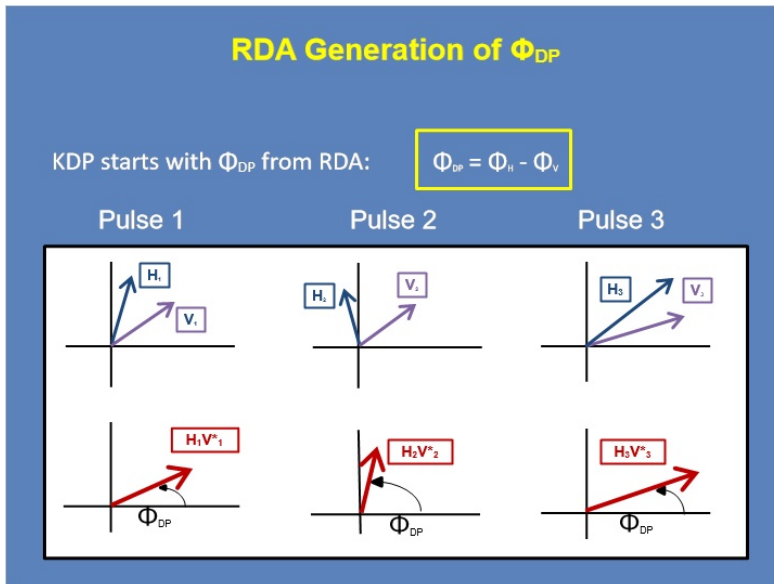
## RDA and RPG Roles for KDP



### Notes:

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.

## RDA Generation of $\Phi_{DP}$



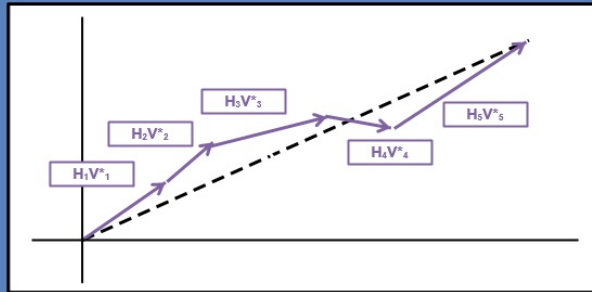
### Notes:

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  $\Phi_{DP}$  is the angle of the cross correlation vector, or horizontal phase minus the vertical phase.

## Differential Phase ( $\Phi_{DP}$ )

### Differential Phase ( $\Phi_{DP}$ )

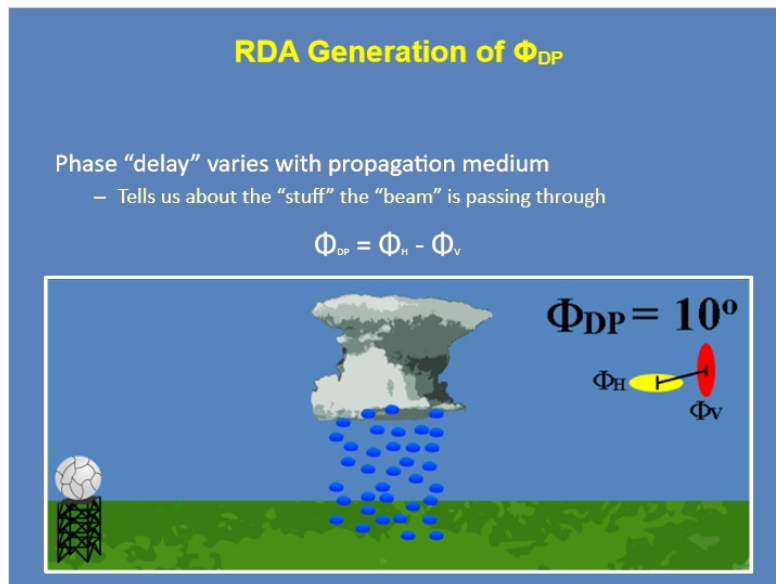
- $(H_n V_n^*)$  vectors for series of pulses...
- Vector sum to average the pulses
- Assigned  $\Phi_{DP}$  is the angle of vector sum



#### Notes:

The differential phase, or  $\Phi_{DP}$ , 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  $\Phi_{DP}$  for that range bin. Since  $\Phi_{DP}$  is an angle, Differential Phase has a unit of degrees.

## Visualization of $\Phi_{DP}$



### Notes:

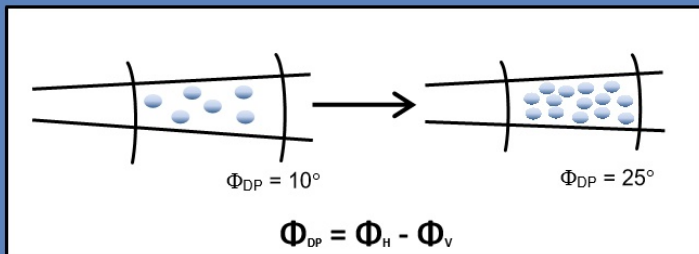
As a radar pulse propagates through the atmosphere, the returned pulse has an apparent delay in its phase. Depending on the atmospheric medium (such as clear skies or precipitation), the extent of the delay changes. The delay also varies between the horizontal and vertical channels. Since we know the 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  $\Phi_{DP}$  positive for that range bin.

## ***$\Phi_{DP}$ Affected by Liquid Water***

### **$\Phi_{DP}$ Affected by Liquid Water**

- Propagation speed affects  $\Phi_{DP}$ 
  - Delays directly related to liquid water content in the volume
- Differences in H & V propagation speeds impacted by:
  1. Particle shape: drizzle or hamburger buns?
  2. Particle concentration: greater liquid water content!



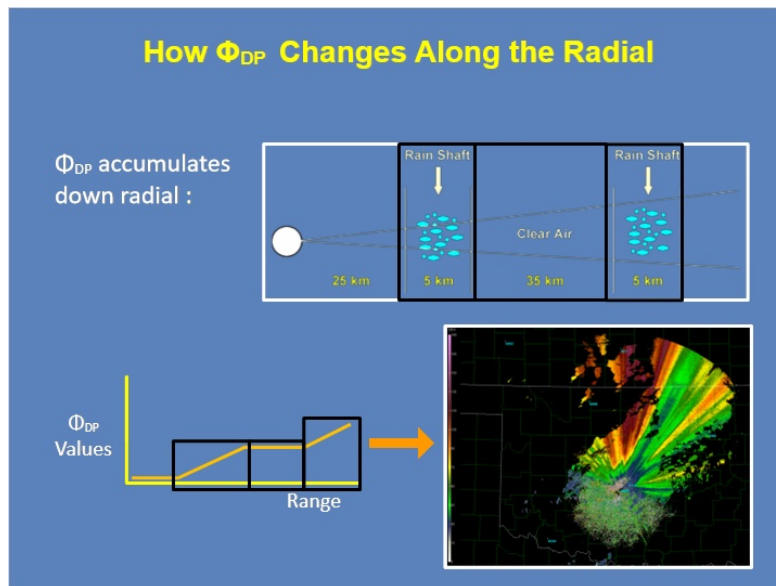
#### **Notes:**

The propagation speed of the horizontal and vertical channels affects the value of  $\Phi_{DP}$ . 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.



## How $\Phi_{DP}$ Changes Along the Radial



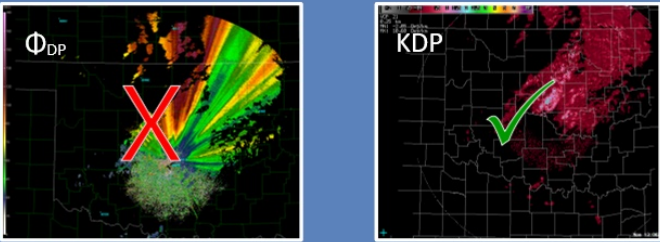
### Notes:

The  $\Phi_{DP}$  value propagates down radial, meaning the propagation delay accumulates with range. There's no way to "reset"  $\Phi_{DP}$  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  $\Phi_{DP}$ . As the pulse encounters a rain shaft,  $\Phi_{DP}$  increases for a series of range bins. Once the pulse is in clear air again, the  $\Phi_{DP}$  value stays constant. Once the pulse encounters precipitation again,  $\Phi_{DP}$  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.

## Why Specific Differential Phase?

**Why Specific Differential Phase?**

- KDP easier to interpret
- Range derivative of  $\Phi_{DP}$ 
  - $\Phi_{DP}$  change in small chunks along radial
  - KDP units  $^{\circ}$  per km

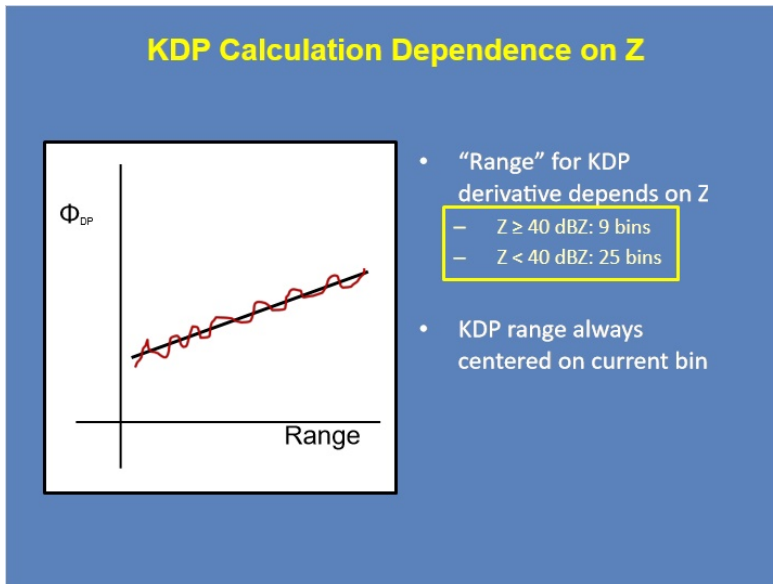
$$KDP = \frac{\phi_{DP}(r_2) - \phi_{DP}(r_1)}{2(r_2 - r_1)}$$


### Notes:

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  $\Phi_{DP}$ . 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  $\Phi_{DP}$ , KDP's units are  $^{\circ}$  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.

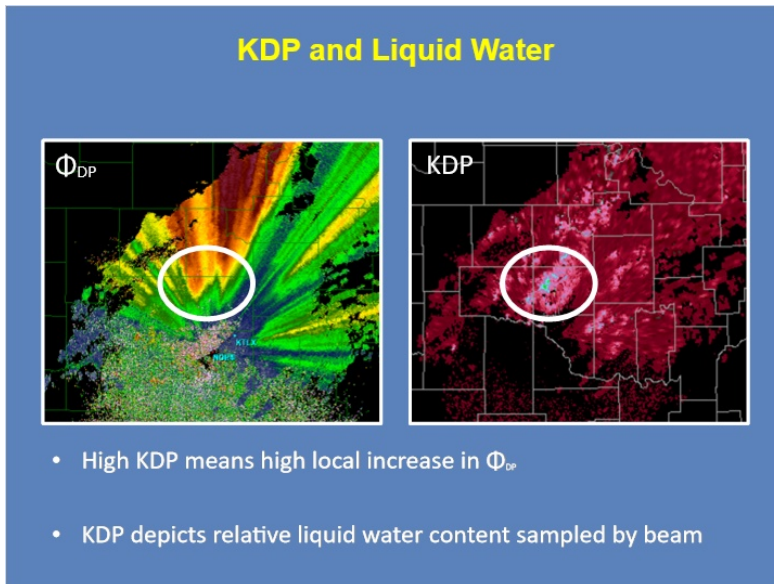
## KDP Calculation Dependence on Z



### Notes:

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.

## ***KDP and Liquid Water***

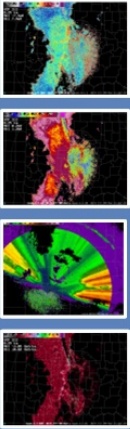


### **Notes:**

KDP 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  $\Phi_{DP}$  gradients along the radial. Notice how the area of greatest significance stands out better in KDP than it does in  $\Phi_{DP}$ .

## Summary of Dual-Pol Base Products

### Summary of Dual-Pol Base Products



- ZDR:
  - Horizontal returned power compared to vertical
  - Average shape
- CC:
  - Fraction of perfect consistency
  - Precip vs. non-precip
- PhiDP:
  - Difficult to interpret for meteorological purposes
- KDP:
  - Relative liquid water content

### Notes:

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  $\Phi_{DP}$ , 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.



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!



### Course Completion Info

*Tabs - 4 Tabs (Including Introduction)*

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

### PROPERTIES

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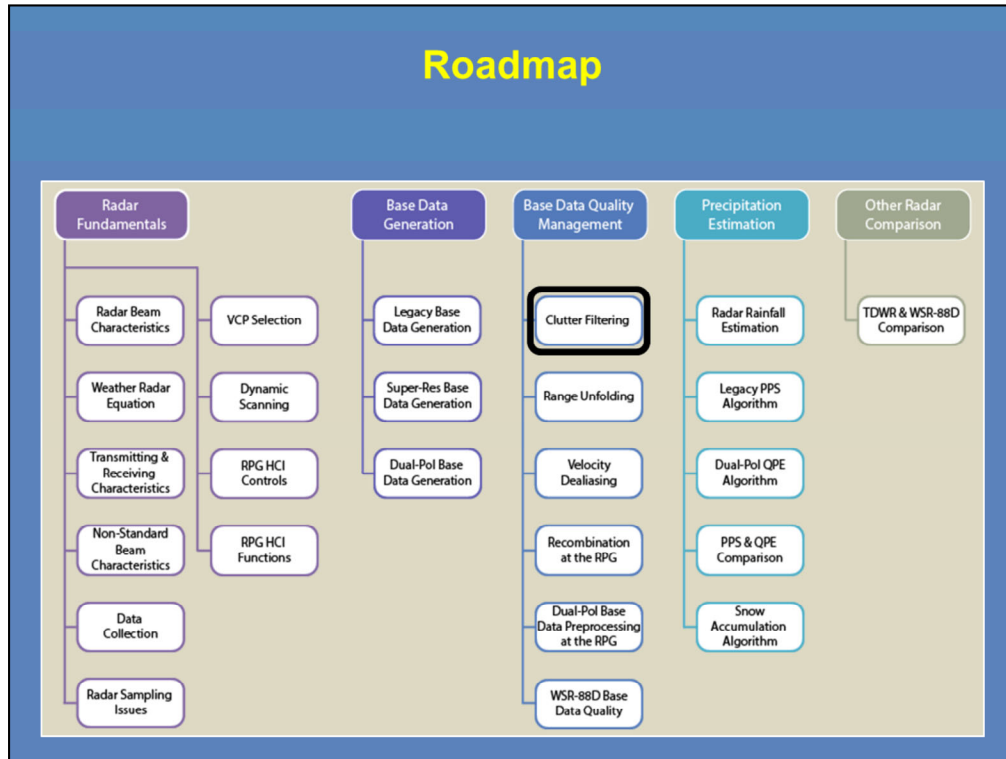
Prev/Next player buttons go to: [Slide in presentation](#)



Edit in Engage



Edit Properties



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

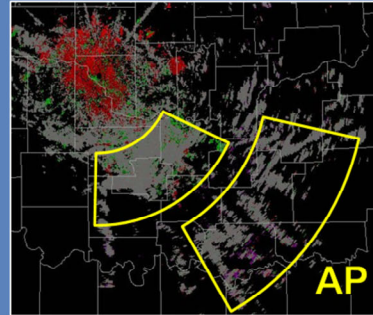
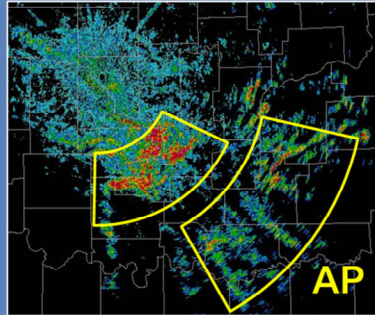


## Clutter Filtering Objectives

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.

## Ground Clutter Contamination



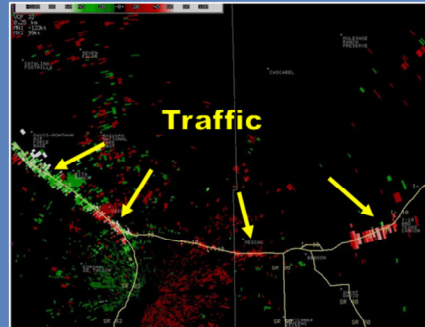
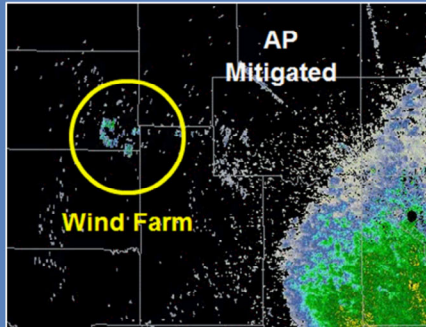
- Returns from non-moving ground targets
  - Affects *all* radar products
- Two types of clutter contamination
  - Normal ground clutter
  - Anomalous propagation clutter

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.

## If It's Moving, It's Not Clutter

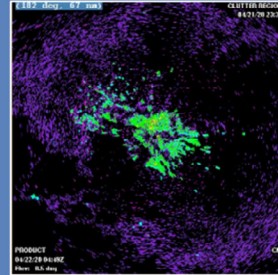
- Returns from wind farms, traffic on roads not identifiable or removable



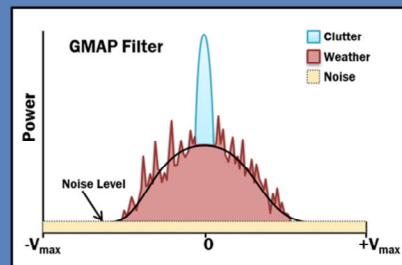
It's important to remember that moving objects are not considered to be ground clutter. The WSR-88D clutter algorithms require clutter echoes to have near zero velocity and spectrum width to be detected. So, anticipate contamination from moving ground targets such as wind farms and traffic on highways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

## Clutter Filtering Algorithms

- Clutter Mitigation Decision (CMD)
  - Clutter identification
- Gaussian Model Adaptive Processing (GMAP)
  - Clutter suppression



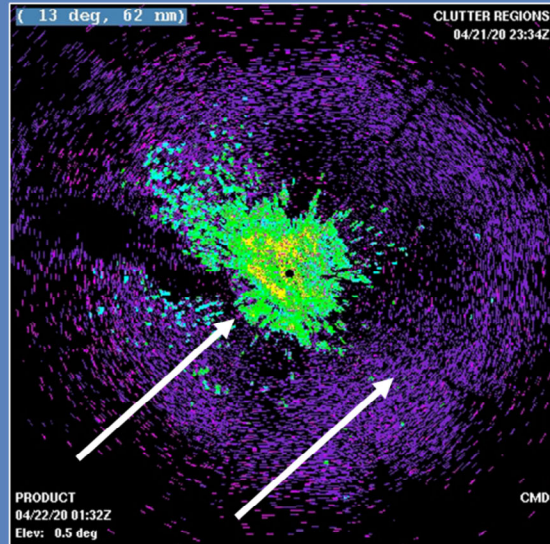
RDA Signal Processor



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 is a literal black box!

## 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

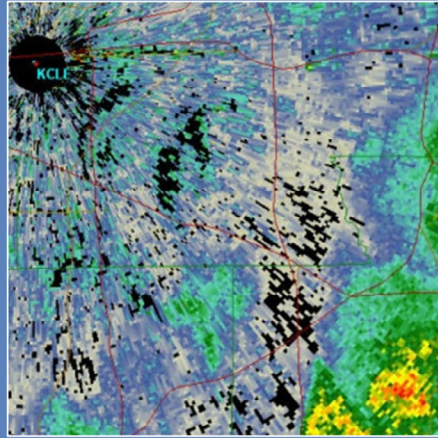


Clutter Mitigation Decision (CMD) offers an automated approach to the management of clutter filtering. CMD can identify both normal and AP clutter every volume scan, which eliminates the need for manually defining and downloading regions files to address AP clutter. The alternative would be to filter 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 areas that have been identified as needing clutter filtering by CMD. The locations labeled in green, yellow, and red are bins where CMD detected clutter and varying degrees of power were ultimately removed from the signal. The purple regions indicate areas where either point clutter was identified or only the dual-pol data were filtered for clutter.

## 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

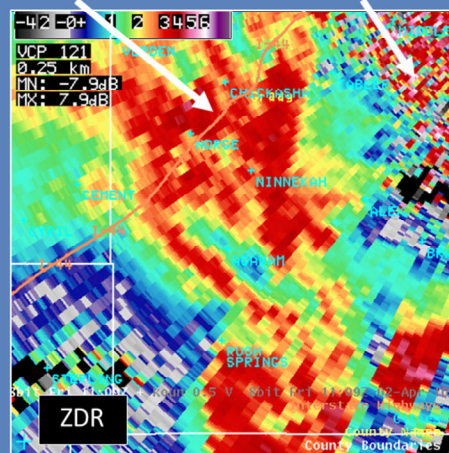


The CMD algorithm uses fuzzy logic with multiple inputs, some of which are based on the Reflectivity base data:

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.

## Standard Deviation of ZDR & CMD

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

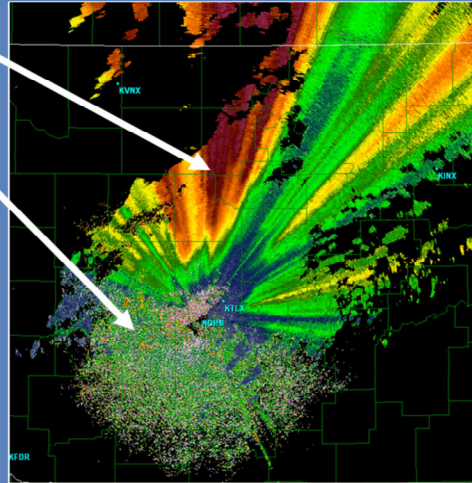


Two inputs to CMD come from the dual-pol base data. The first of these inputs is the standard deviation of Differential Reflectivity (or ZDR). The higher the standard deviation of ZDR in a particular range bin, the greater the likelihood that it contains clutter. In this example, you can likely tell 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.



## Standard Deviation of $\Phi_{DP}$ & CMD

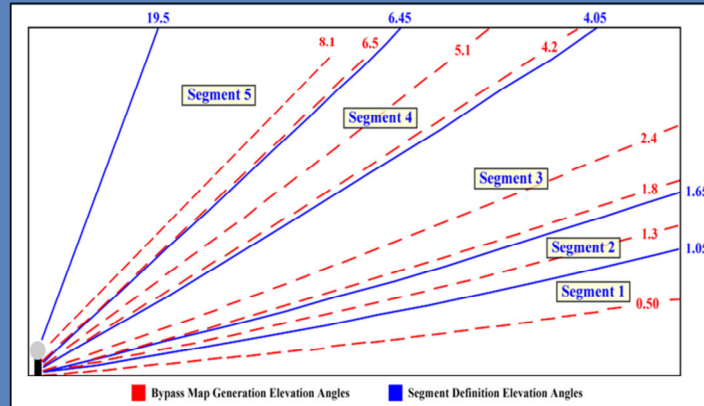
- Standard Deviation of  $\Phi_{DP}$ 
  - Low STDPHI = weather
  - High STDPHI = clutter



The second CMD input based on dual-pol base data is the standard deviation of  $\Phi_{DP}$ . The higher the standard deviation of  $\Phi_{DP}$ , the greater the likelihood that the range bin contains clutter. In this example, compare the noisiness of the  $\Phi_{DP}$  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.



## 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. Segments don't get built for each elevation, thus you cannot see every Bypass Map CMD builds. This process makes CMD troubleshooting efforts challenging.

## Bypass Map Vs. All Bins



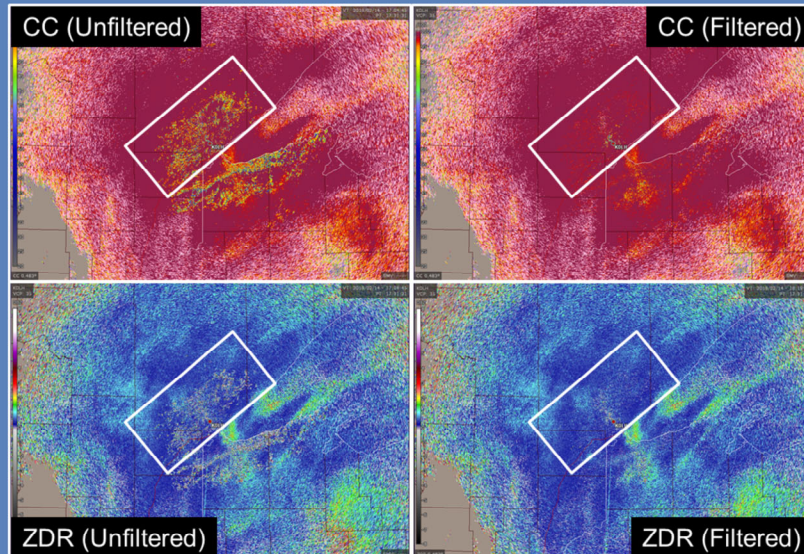
The screenshot shows a window titled "Clutter Region Files" with a menu bar containing "Close", "New", "Save", "Save As", "Delete", and "Open". Below the menu bar is a table with three columns: "Date", "Time", and "Label". The table contains five rows of data, with the second row highlighted in black.

Date	Time	Label
00/00/0000	00:00:00	Default
05/31/2007	17:18:56	SUPPRESSION ONLY W/ BYPASS MAP
05/31/2007	17:20:45	ALL BINS SUPPRESSION SEGMENT 1
06/05/2007	05:16:46	ALL BINS SUPPRESSION SEGMENT1-2
07/03/2009	03:39:34	CMD SEG3 SUPPRESSION

- Keep Bypass Map in control all the time
  - Default clutter regions file
- All Bins suppression rarely needed, only impacts locations
  - Only impacts where filtering occurs, not what GMAP removes

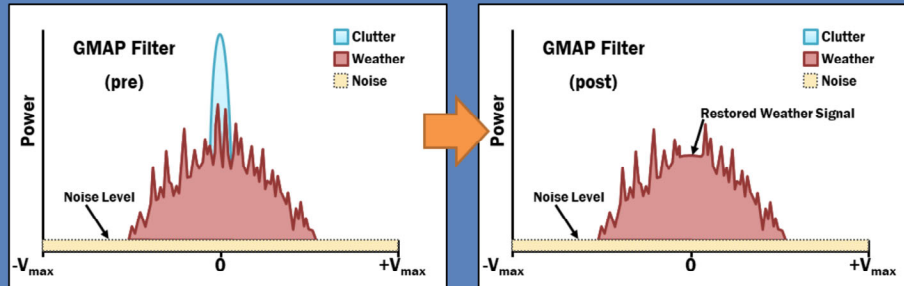
CMD offers “hands off” clutter suppression, though some data quality monitoring may be needed from time to time. In order for CMD to build maps for every elevation, the Bypass Map must be in control for all elevations. The “Default” clutter regions file is designed to do just that. With CMD active, All 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!

## The Clutter Dual-Pol “Footprint”



Differential Phase, Correlation Coefficient, and Differential Reflectivity are all more susceptible to clutter contamination than Velocity and, especially, Reflectivity. As a result, it's possible to notice a clutter “footprint” in the dual-pol products that they wouldn't see in the legacy Doppler products. You can see from the example on the slide, less clutter should be noticeable near the RDA in dual-pol base products on the left. By filtering just the dual-pol data in these areas, we notice a significant improvement in these products. This capability means sites shouldn't turn CMD off to remove the dual-pol clutter footprint near the radar. CMD handles this issue well.

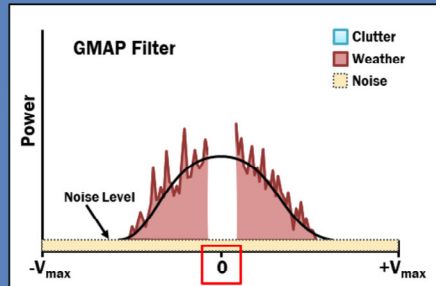
## Clutter Filtering Algorithms



- CMD has *identified* clutter
- For the bins identified by CMD, filtering performed by the GMAP algorithm

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.

## Key Concepts behind GMAP



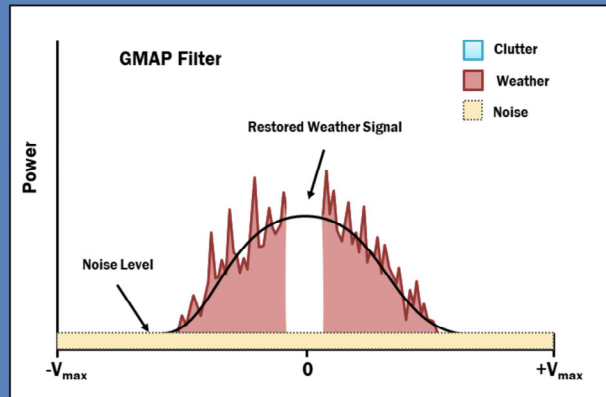
- Weather and clutter signals look different
  - Can be approximated by Gaussian curve
- Remove power from narrow spike near zero velocity
- Once power removed, GMAP attempts to rebuild lost weather signal

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.

## How GMAP Works

- Remove power near zero velocity
- Rebuild lost weather across the gap
  - Need sufficient remaining data points

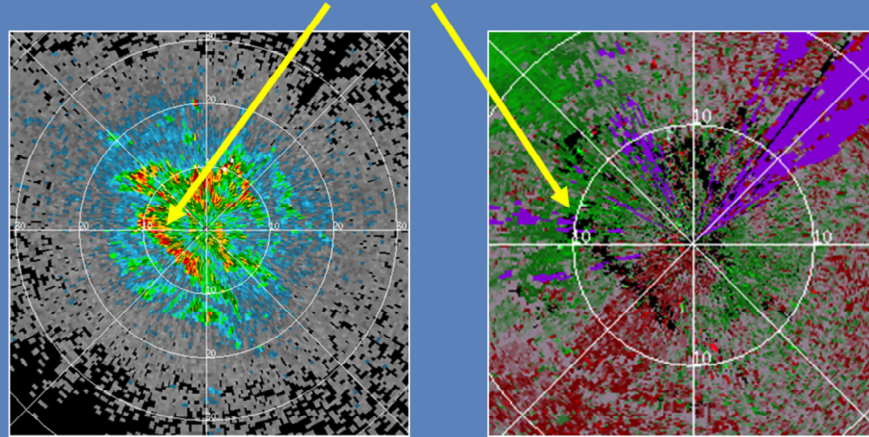


Once the width for signal removal is determined, GMAP applies filtering to all of the signal within that width. In this case, both the clutter and weather signal within this interval will be removed. However, GMAP can rebuild the weather signal that was lost, depending on the availability of data points 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 112. So, you definitely want to use the general surveillance VCP when stratiform, or other slow-moving, non-severe echoes are expected.

## GMAP Radar Example: No Weather Present

Z *without* clutter filtering on left, V *with* clutter filtering on right  
– Note ND gates associated with terrain clutter



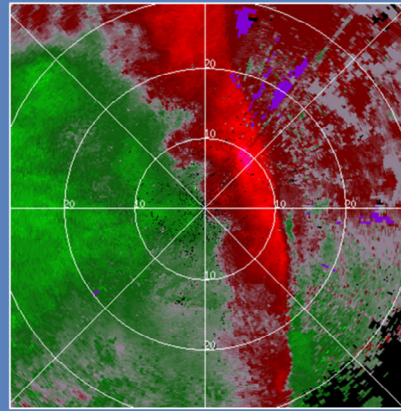
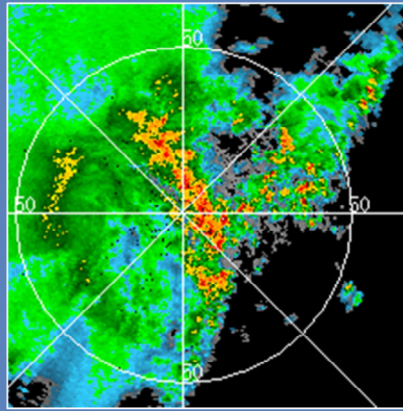
As an example of GMAP performance, we start with a scan where no discernible weather is present. Clutter filtering has been turned off in order to identify the local terrain in the Reflectivity image on the left. Note the ridge line to the southwest. The Velocity image on the right has had clutter filtering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



## GMAP Radar Example: Squall Line Passes Through

Z & V as squall line passes through:

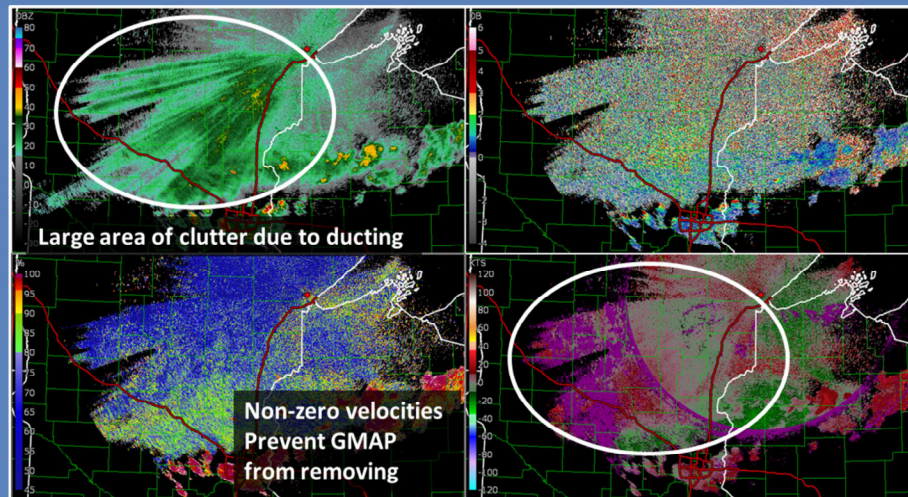
- Clutter has been filled in with data



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.

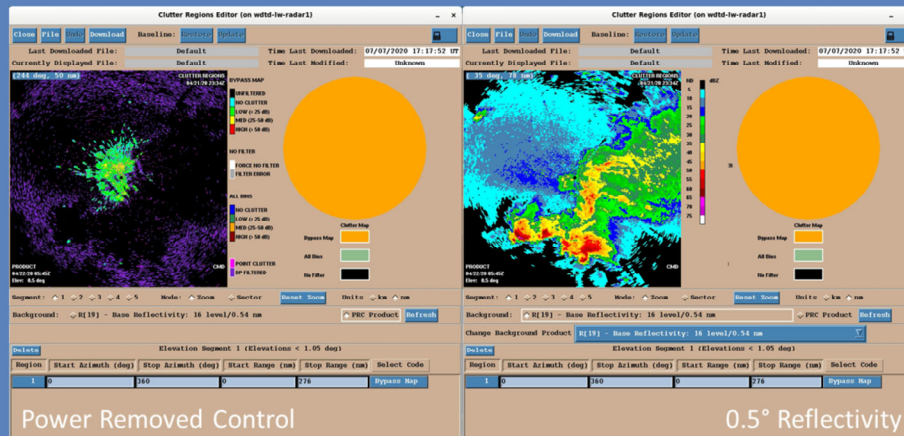


## GMAP Radar Example: Clutter Filtering Failure Due to Ducting



Here's an example where the CMD and GMAP combo didn't do so well. A huge area of reflectivity exists with values exceeding 30 dBZ where we know there's no precipitation. These echoes exist in the outflow area behind a line of storms that has pass through the region in the late evening, early overnight hours. CMD correctly identified these returns (likely due to ducting in that shallow, stable air mass) as clutter. However, look at the velocity data in this region. Too much data occurs at non-zero velocities for GMAP to remove all of the clutter returns. As a result, the clutter remains in the final product.

## Power Removed Control (PRC) Product



- Helps show where filtering applied & what was remove
- Available from RPG (shown) and AWIPS

The RPG now generates the Power Removed Control (PRC) product to help radar operators. The PRC shows where clutter filtering was applied and how much suppression occurred in dB. The product can be found in two locations. On the RPG Human Control Interface, it can be found by clicking on the “Clutter Regions” button in the upper right-hand side of the display. The product can also be accessed from the Radar menu in CAVE under the Data Quality sub-section as PRM.

# Power Removed Control Product

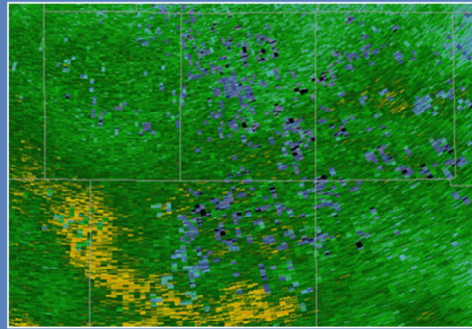
The screenshot shows the 'Clutter Regions Editor' window. The main display is a radar plot with a central bright region and surrounding clutter. A legend on the right shows various filter settings: PASS MAP, FILTERED, NO CLUTTER, DW (< 25 dB), RD (25-50 dB), RCH (> 50 dB), FILTER, ORCE NO FIL, FILTER ERROR, AL BINS, NO CLUTTER, DW (< 25 dB), RD (25-50 dB), RCH (> 50 dB), and CH. A large orange circle is overlaid on the plot. The bottom panel shows a table with columns: Region, Start Azimuth (deg), Stop Azimuth (deg), Start Range (nm), Stop Range (nm), and Select Code. The table contains one row with values: 1, 0, 360, 0, 276, and Bypass Map.

On the left side, you see what interventions were taken. Since the Bypass Map is in control, you use the legend info towards the top of the page. The colors indicate how much power was removed. Additionally, the Point Clutter and DP Filtered legend items apply to range bins that fall into these categories.

## CMD & GMAP Summary

- CMD *identifies* clutter! GMAP *filters* clutter!
- CMD identifies normal & AP clutter
- GMAP only filters bin identified as containing clutter
- VCP 215 better than VCPs 12, 212, & 112 for identifying & removing clutter for general situations

Press "NEXT" to advance to the lesson quiz when ready



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 then handed off to GMAP, which 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 112 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.



## Clutter Filtering - Final Quiz

Quiz - 7 questions

Last modified: Friday, July 17, 2020 at 10:13:21 AM

### Properties

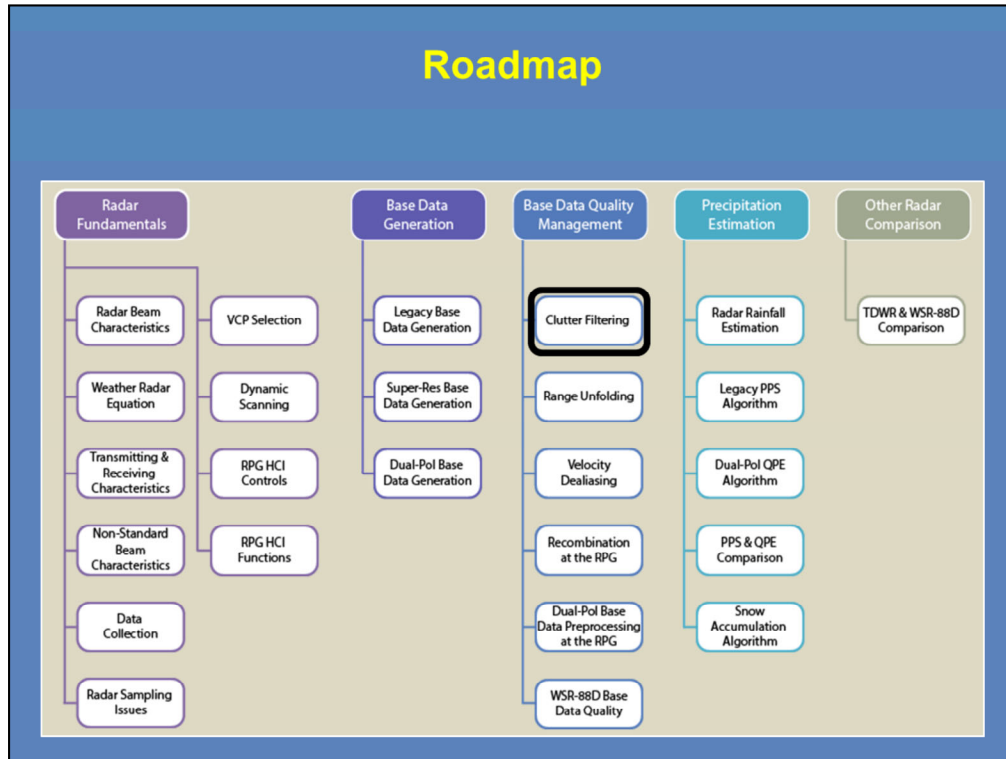
- On passing, 'Finish' button: [Goes to next slide](#)
- On failing, 'Finish' button: [Goes to next slide](#)
- Allow user to leave quiz: [After user has completed quiz](#)
- User may view slides after quiz: [Any time](#)
- Show quiz in menu as: [Single Item](#)



Edit in Quizmaker



Edit Properties



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.

# Range Unfolding

## 1. Lesson

### *Title*

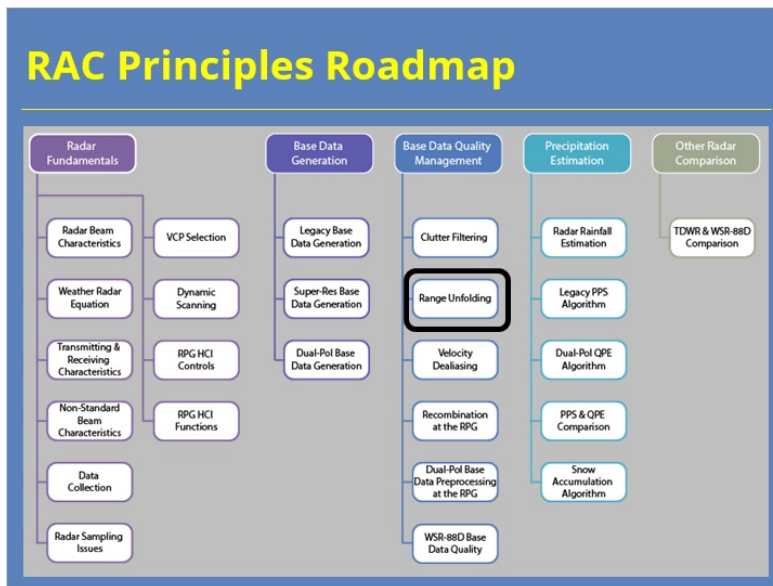


### **Notes:**

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



## 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.



## ***Objective***

### **Objective**

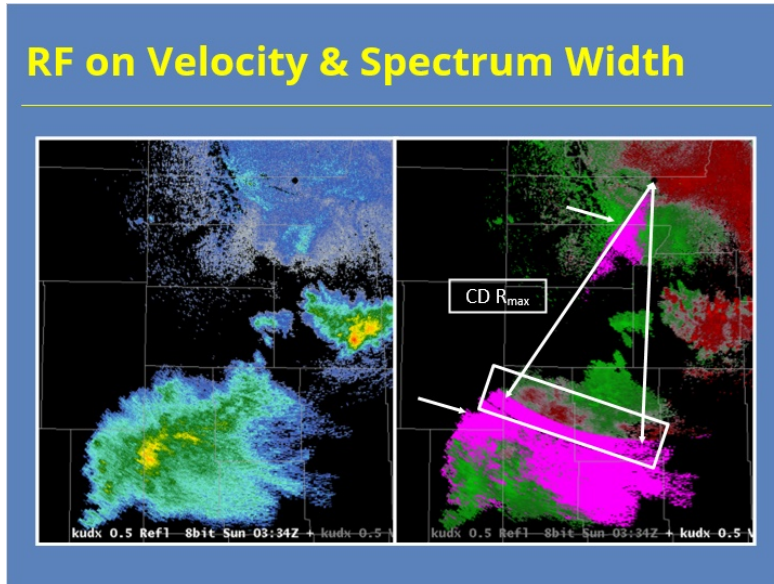
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1. Identify the purpose, strengths and limitations of the following range unfolding algorithms:
  - a) Legacy Range Unfolding
  - b) SZ-2 Range Unfolding

### **Notes:**

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

## ***RF on Velocity & Spectrum Width***

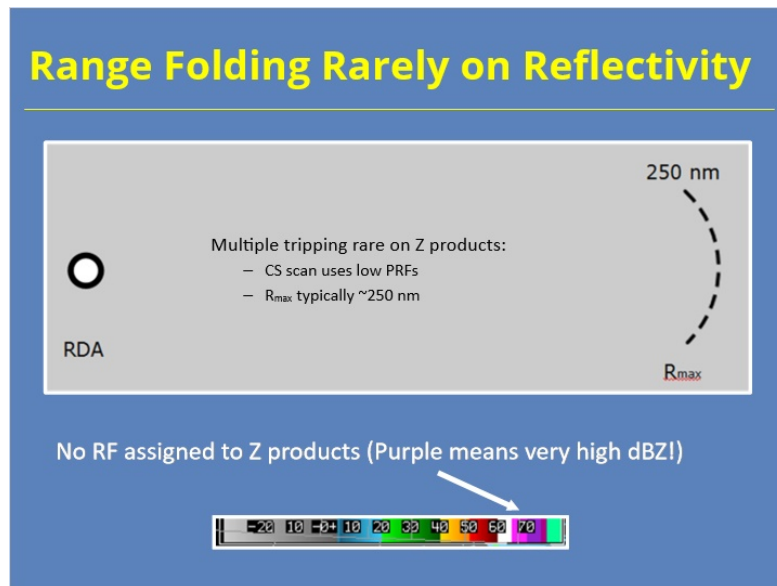


### **Notes:**

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?’”

## ***Range Folding Rarely on Reflectivity***



### **Notes:**

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.

## ***Legacy Range Unfolding Algorithm***

### **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



#### **Notes:**

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 Legacy Unfolding Algorithm***

### **The Legacy Unfolding Algorithm**

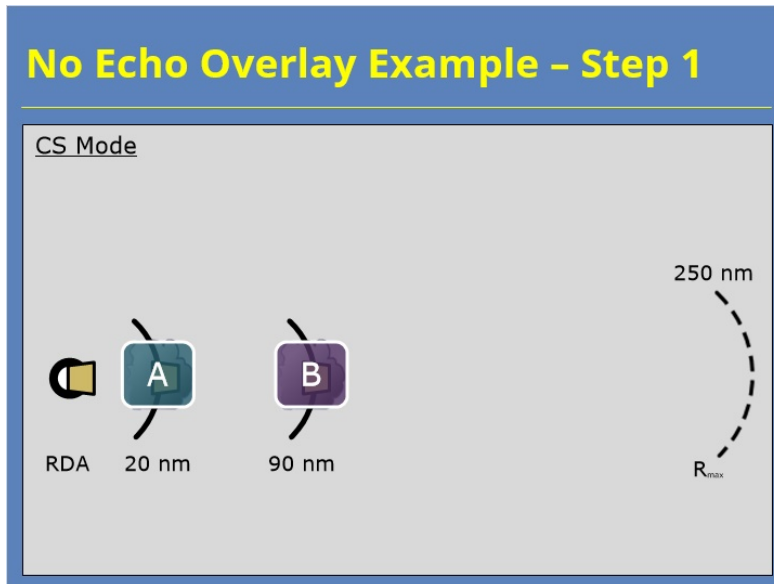
- Two examples provided:
  - Without echo overlay
  - With echo overlay
- Use “in slide animations” (replay as needed)
- Manually advance slides



#### **Notes:**

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. For each of these slides, you will need to manually advance the slide to move to the next step.

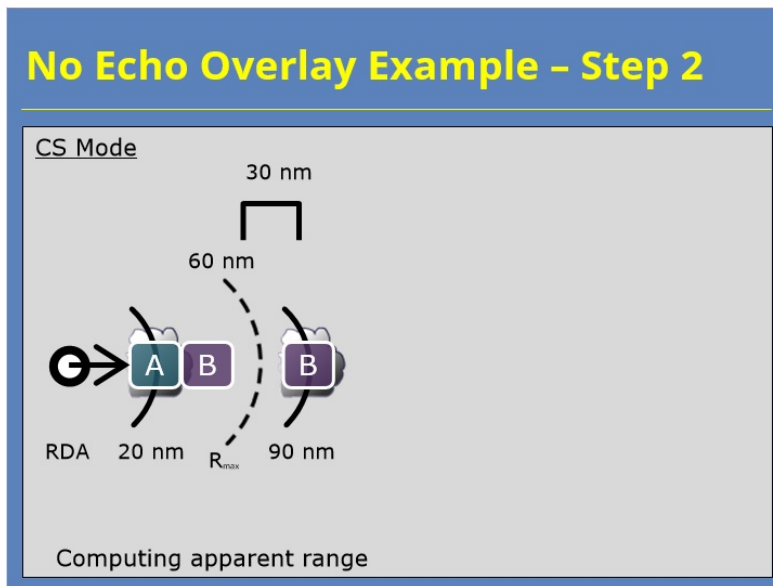
## ***No Echo Overlay Example – Step 1***



### **Notes:**

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.

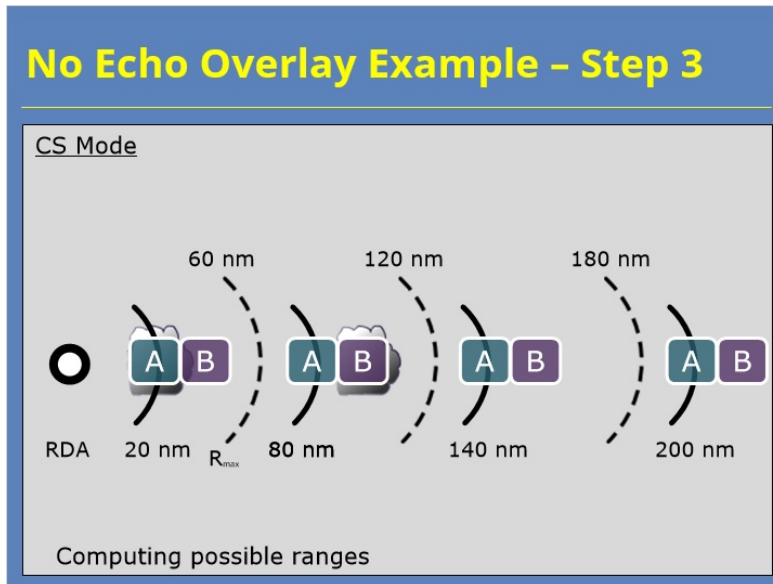
## No Echo Overlay Example – Step 2



### Notes:

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.

### ***No Echo Overlay Example – Step 3***

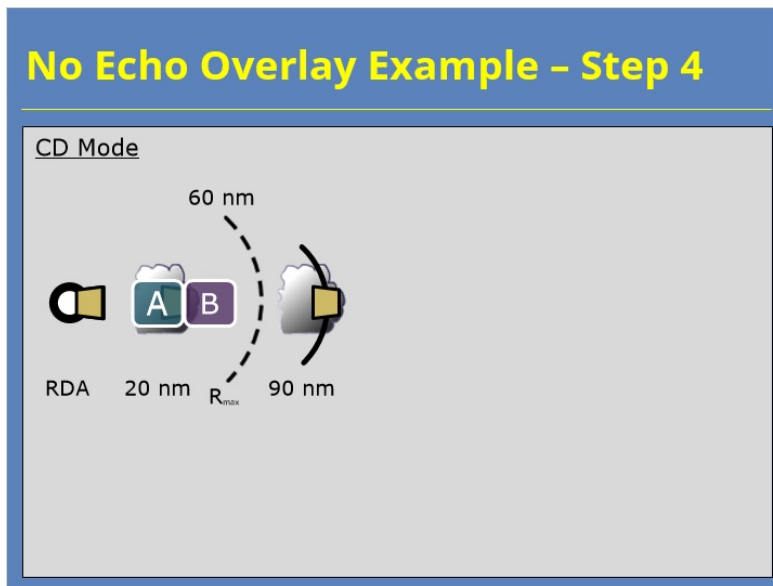


#### **Notes:**

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.



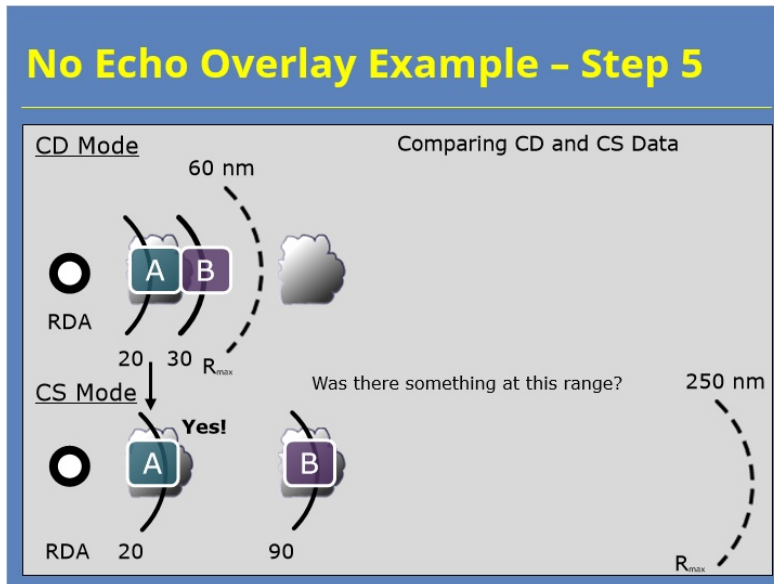
### ***No Echo Overlay Example – Step 4***



#### **Notes:**

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.

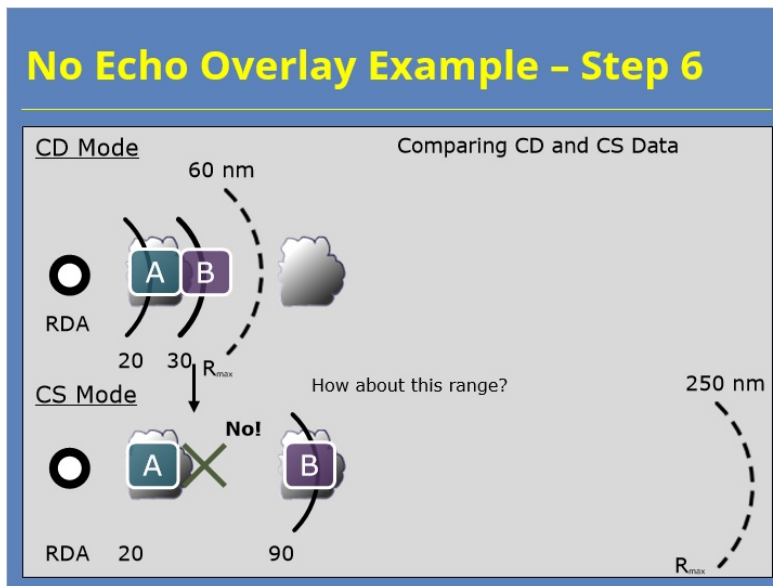
## No Echo Overlay Example – Step 5



### Notes:

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.

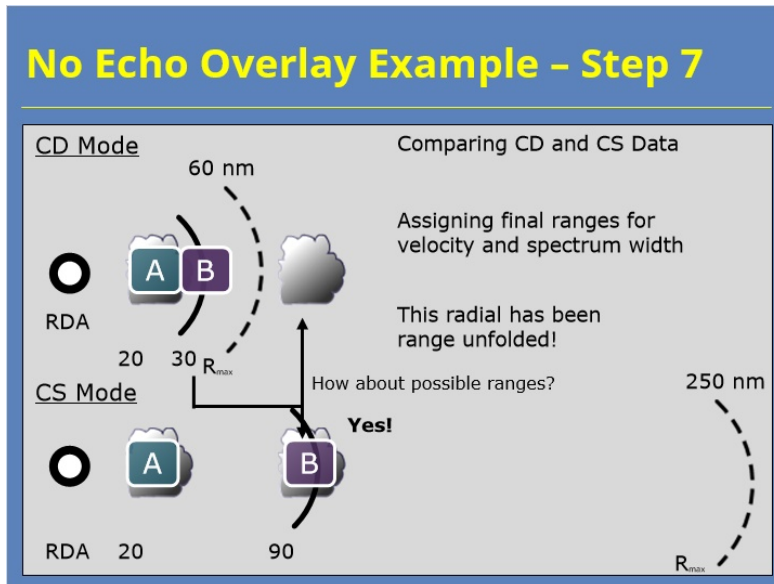
## No Echo Overlay Example – Step 6



### Notes:

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.

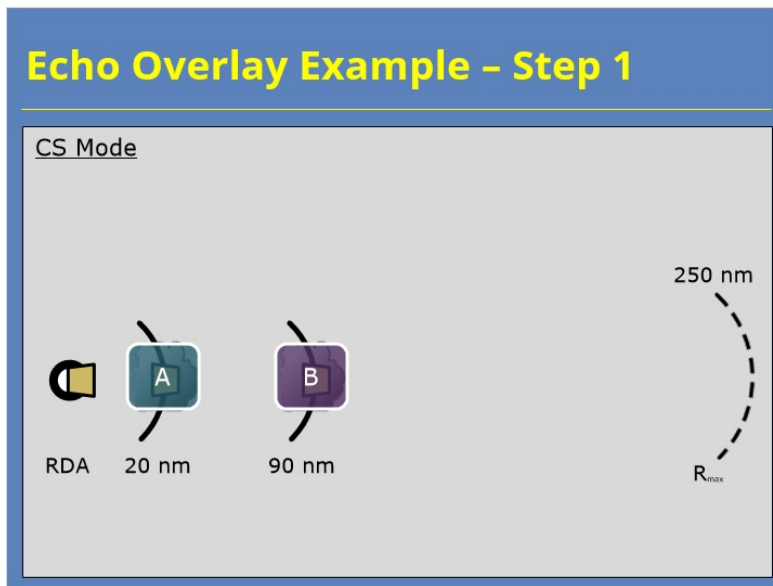
## No Echo Overlay Example – Step 7



### Notes:

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.

## Echo Overlay Example – Step 1

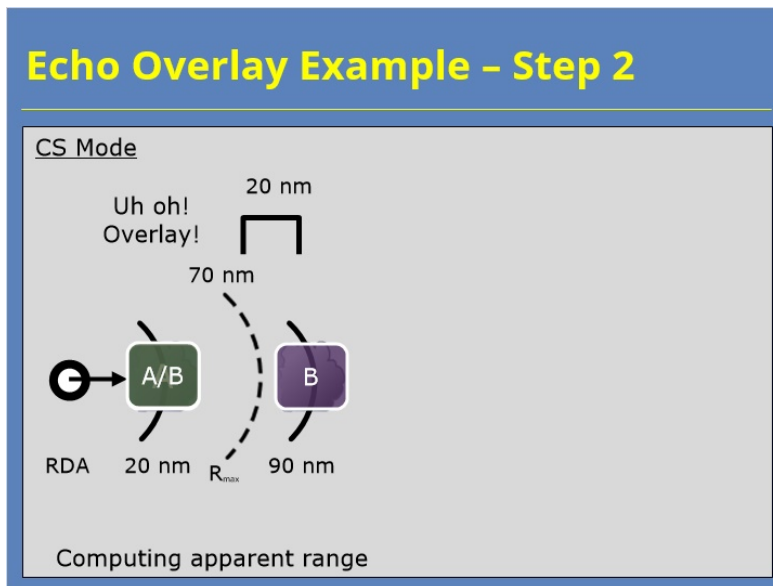


### Notes:

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.

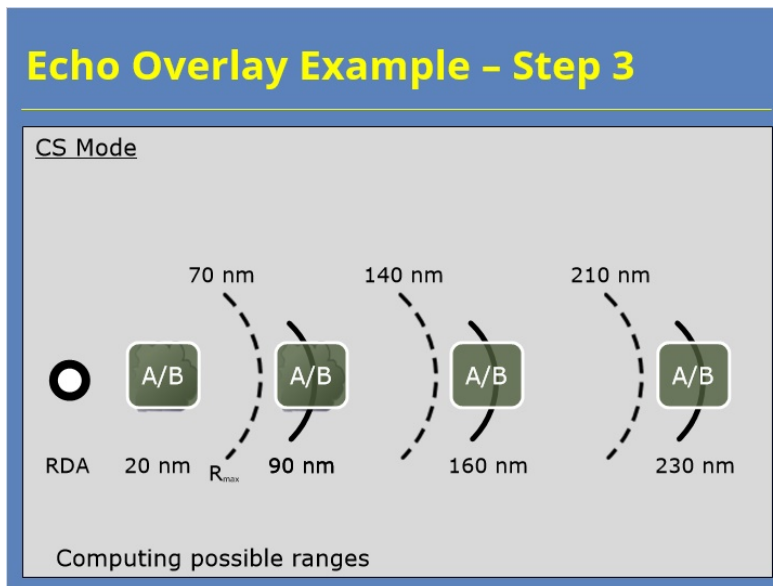
## Echo Overlay Example – Step 2



### Notes:

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.

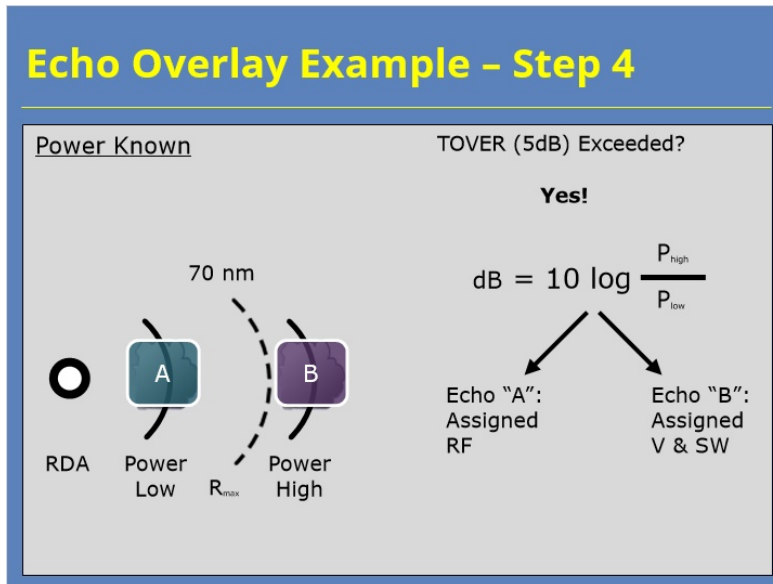
### ***Echo Overlay Example – Step 3***



#### **Notes:**

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

## Echo Overlay Example – Step 4

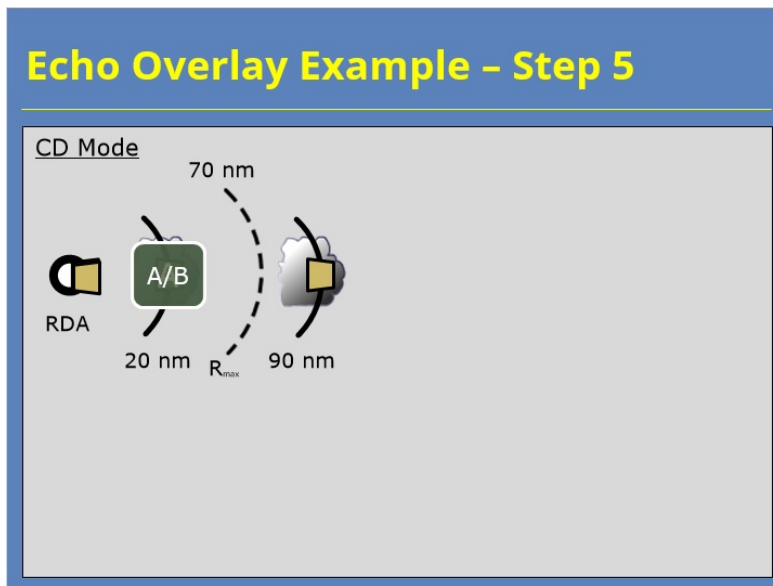


### Notes:

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.



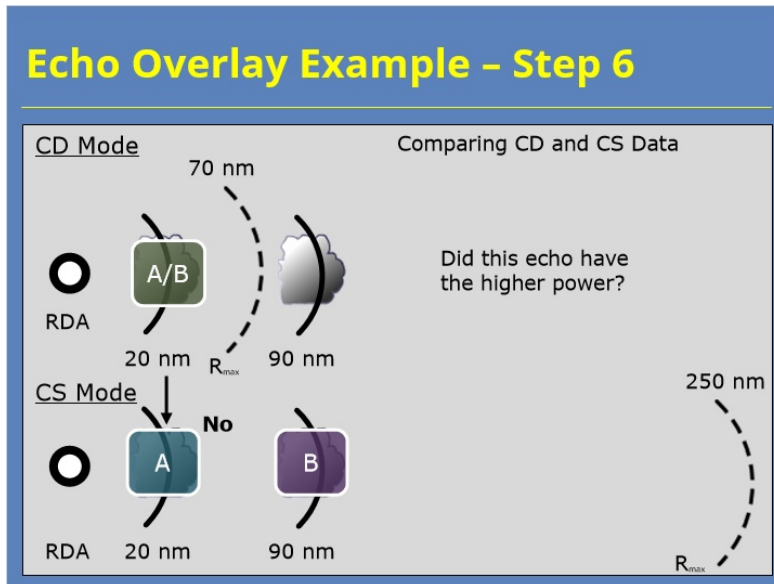
## ***Echo Overlay Example – Step 5***



### **Notes:**

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.

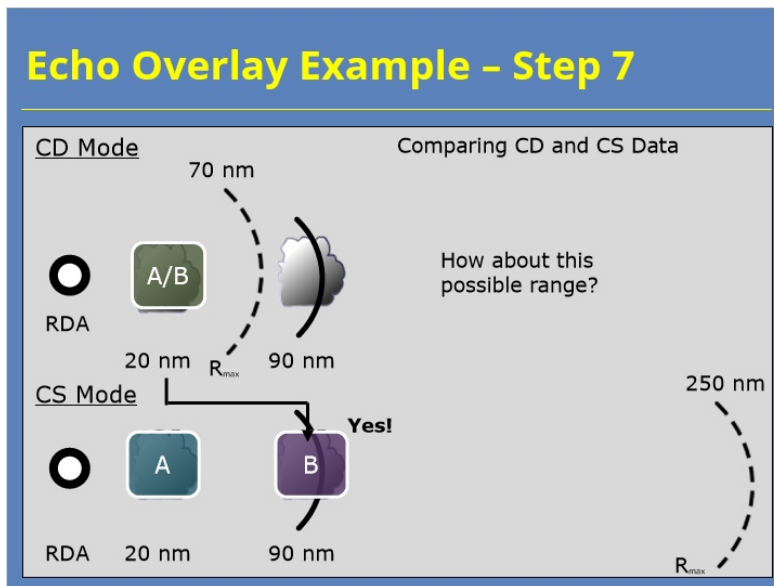
## Echo Overlay Example – Step 6



### Notes:

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, and also determines if that target had the higher returned power. In this particular example, Target A had the lower power, so the answer is “No” at a range of 20 nm.

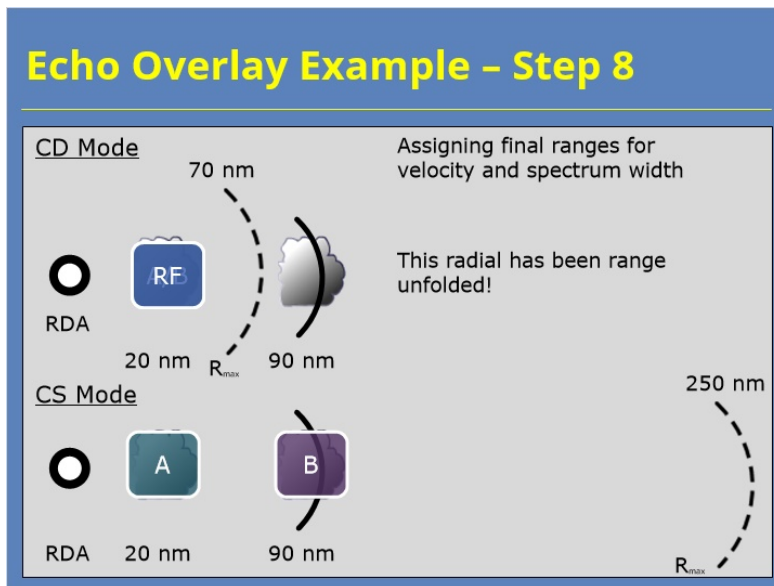
## Echo Overlay Example – Step 7



### Notes:

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.

## Echo Overlay Example – Step 8



### Notes:

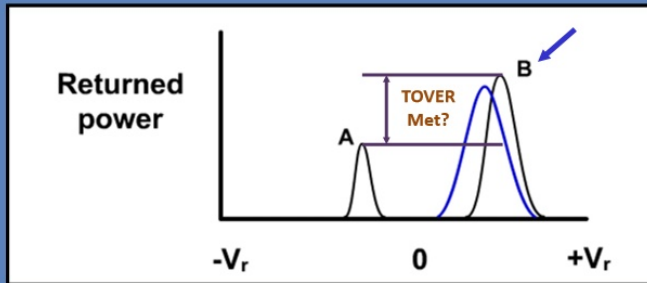
Step 8: Now that we know this velocity and spectrum width data at a range of 20 nm is more representative of the target that was at 90 nm. So, we assign the observed data to the bin at 90 nm, and range folding, or purple, to the echoes at 20 nm.

## More on When Echoes Are Overlaid

### More on When Echoes Are Overlaid

A and B will have same apparent range:

- Pulses returning from both targets at same time
- Is base data representative of either target?



#### Notes:

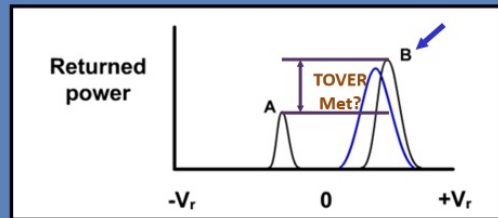
This graphic represents the base data estimation process for a range bin when there is an echo overlay case such as in our previous example. Pulses from two different targets are received and processed at the same time, apparently from 20 nm. If the pulses from these two different targets could be analyzed 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.

## ***Range Unfolding Algorithm: Echoes Are Overlaid***

### **Range Unfolding Algorithm: Echoes Are Overlaid**



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

#### **Notes:**

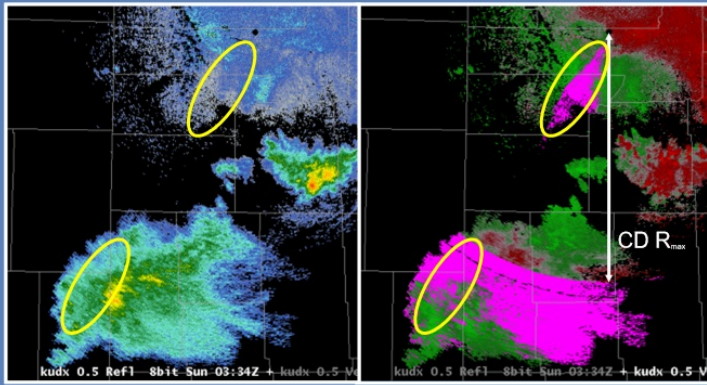
The Range Unfolding Algorithm uses a parameter known as “threshold over”, or TOVER, to determine if the overlaid echoes have a sufficiently high difference in returned power to assign the hybrid velocity to one of them.

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.

## ***Distribution of Range Folded Data***

### **Distribution of Range Folded Data**



#### **Notes:**

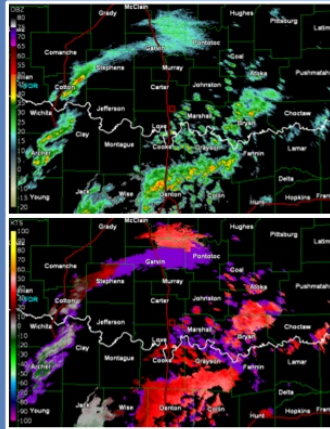
Now for another look at the distribution of RF in Base Velocity, given the location of the echoes in Base Reflectivity. The strongest storms south of the radar are within the first trip, so there is no issue with the availability of the associated velocity data. There is an area of weaker echo to the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

## Legacy Algorithm - Strengths

### Legacy 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. Mitigates “Doppler Dilemma”
  - Low PRF for target range and intensity
  - High PRF for velocity and spectrum width



#### Notes:

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 than the others and can be assigned the velocity and spectrum width values. The other echoes are assigned RF.

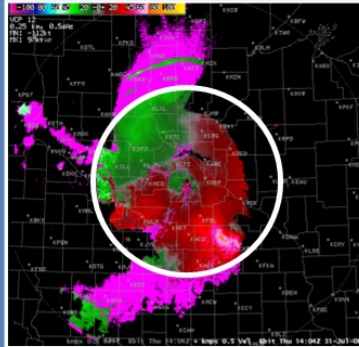
The Legacy Range Unfolding Algorithm mitigates the Doppler Dilemma in this manner. For every radial, the low PRF, Contiguous Surveillance (CS) pulses provide returned power and target range. For that same radial, the high PRF, CD pulses provide more accurate velocity and spectrum width data. Comparing both data sources allows for “unfolding” the velocity and spectrum width to its appropriate range along the radial.



## Legacy Algorithm: Limitations

### Legacy 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



#### Notes:

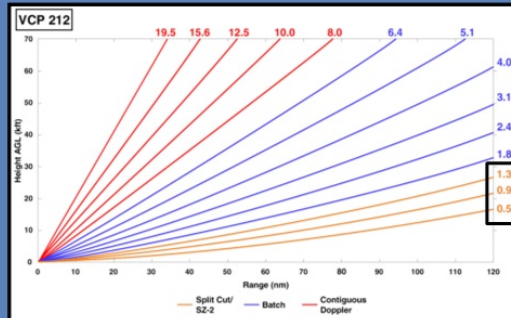
Extensive echo coverage aligned along radials limits the Legacy Range Unfolding Algorithm ability to unambiguous unfold velocity CD data. These situations maximize echo overlay along a radial through the first, second, and third trips. The Legacy Range Unfolding algorithm can only assign overlaid data 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.

## SZ-2 Range Unfolding Algorithm

### SZ-2 Range Unfolding Algorithm

- Run at RDA signal processor



- Applied to Split Cut elevations only on VCPs 35, 212, & 215

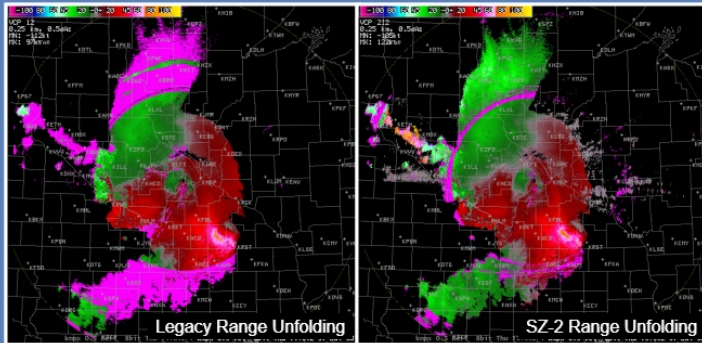
#### Notes:

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.

## Legacy Algorithm Vs. SZ-2

### Legacy Algorithm Vs. SZ-2



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

#### Notes:

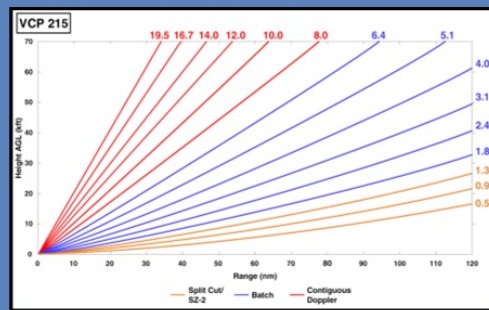
The SZ-2 Range Unfolding algorithm is particularly effective with widespread echo coverage. In this case, the Legacy Range Unfolding algorithm (VCP 12) is used for the data on the left, with SZ-2 (VCP 212) on the right. Use of VCP 212 dramatically improves the availability of velocity and spectrum width.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

## SZ-2 Algorithm Strengths

### SZ-2 Algorithm Strengths

#### 1. SZ-2 Strengths

- Significant increase in availability of velocity data
- Best results with widespread returns



#### Notes:

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.

## ***SZ-2 Algorithm Limitations***

### **SZ-2 Algorithm Limitations**

---

1. All Bins degrades SZ-2 velocity

Procedures in place to address problem:

**CMD:** **ENABLED**

- **CMD enabled:** Default clutter file used with SZ-2 VCP

**CMD:** **DISABLED**

- **CMD disabled:** CMD enabled & default clutter file used with SZ-2 VCP

#### **Notes:**

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.

## ***Conclusion: Range Unfolding***

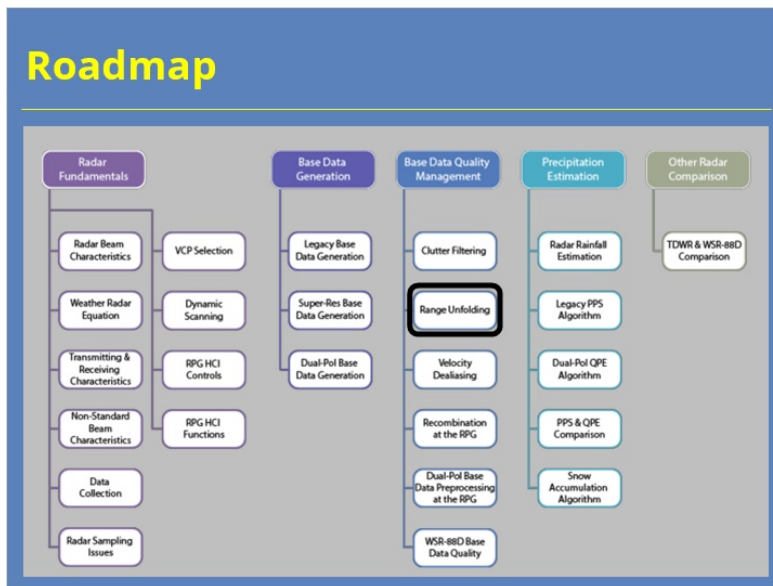
### **Conclusion: Range Unfolding**

- Range unfolding necessary for CD data:
  - Velocity
  - Spectrum Width
- Two algorithms available (run at RDA Signal Processor):
  - Legacy Range Unfolding Algorithm
  - Sachidananda-Zrnic (SZ-2) Range Unfolding Algorithm
- Range Unfolding Algorithm Usage depends on VCP employed:
  - Legacy: 12, 31, 32
  - SZ-2: 35, 212, 215
- SZ-2 Algorithm allows for recovery of more CD data, but All Bins clutter suppression negatively impacts when in use

#### **Notes:**

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.

## Roadmap



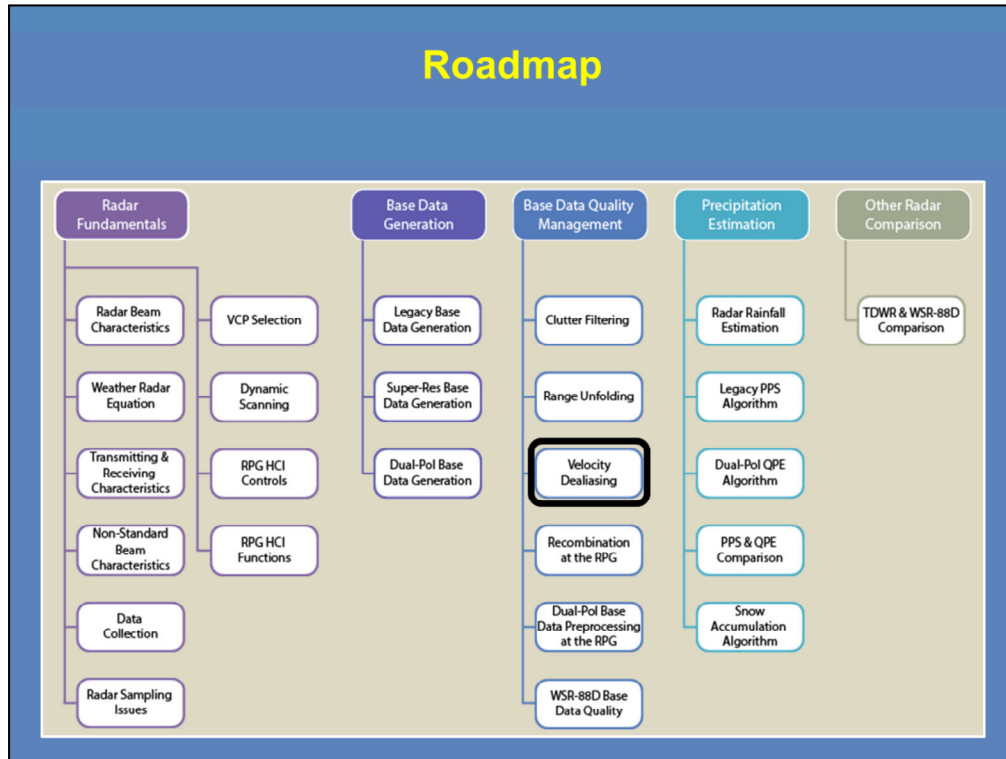
### Notes:

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 in the Radar & Applications Course. This lesson will provide an overview of how the WSR-88D performs velocity dealiasing.





Here is the Principles of Meteorological Doppler Radar “roadmap” with the current lesson highlighted.

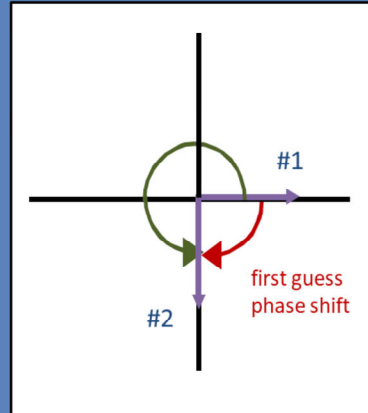
## Objectives

1. Identify the purpose, strengths and limitations of the following techniques to dealias velocity data
  - a) Legacy Velocity Dealiasing Algorithm (VDA)
  - b) 2 Dimensional Velocity Dealiasing Algorithm (2D-VDA)
  - c) VCP 112: Multiple PRF Dealiasing Algorithm

This lesson has one objective. Please take a moment to read through the objective and advance to the next slide when you are ready to proceed.

## Improperly Dealiased Velocities

- V estimated from pulse-to-pulse phase shifts
- First guess V based on shift  $<180^\circ$ 
  - True shift  $<180^\circ$ , first guess correct
- Possible Vs (aliases) based on shift  $>180^\circ$ 
  - True shift  $>180^\circ$ , first guess incorrect

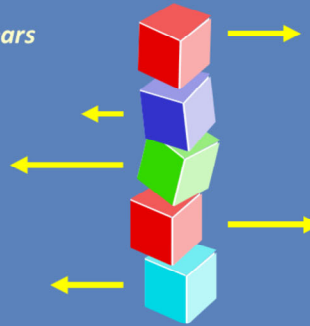


From the Base Data Generation lesson, you learned the process for assigning velocity and spectrum width data to its appropriate range. Remember the WSR-88D determines velocity estimates from pulse-to-pulse phase shifts, with the first guess velocity calculated assuming the phase shift is less than  $180^\circ$ . When the true phase shift exceeds  $180^\circ$ , then the first guess estimate is wrong. These situations result in the radar using one of the other possible velocities, or aliases, that are based on phase shifts  $> 180^\circ$ . The Base Data Generation lesson used such an example where the first guess velocity of +30 kts that was, in actuality, -90 kts.

## Improperly Dealiased Velocities: Product Characteristics

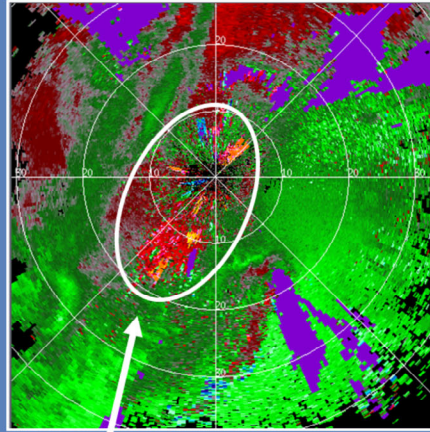
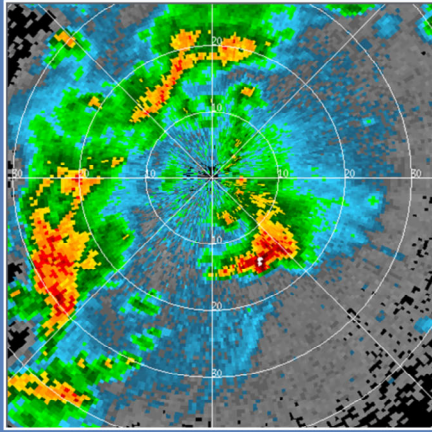
1. Small blocks of Vs in direction opposite from surrounding data
  - Usually at close range
2. Larger blocks or wedges of velocities in direction opposite from surrounding data
  - No zero velocity boundary; *unrealistic shears*

Most likely in areas lacking velocity data continuity



Let's focus first on the impact of improperly dealiased velocities on radar products. Two types of improperly dealiased velocities occur. In the residual ground clutter at close range to the radar, dealiased velocities can occur in small blocks of values with opposite directions from the surrounding data. At further ranges, the other type of dealiased velocities appear. These blocks, or wedges, of poorly dealiased velocities appear larger. A more challenging version of this dealiasing failure occurs when there's significant shear visible along an azimuth. In these cases, forecasters can struggle determining if the azimuthal shears are meteorological in nature or a dealiasing failure. No matter which type you see, they occur most often in areas lacking continuity in the velocity data.

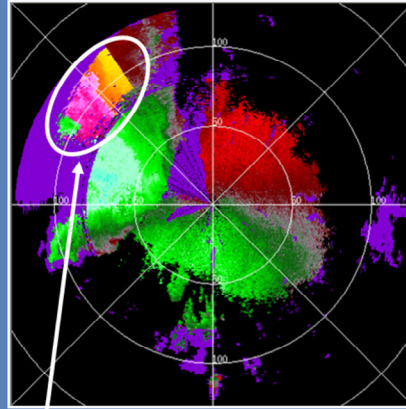
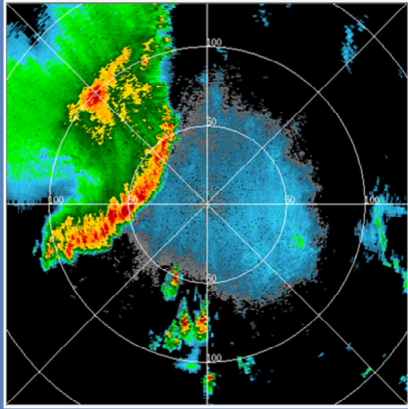
## Improperly Dealiasing Velocities Example



Numerous small blocks at close range

These images show an example of the first type of improperly dealiasing velocities. Notice the numerous small blocks of improperly dealiasing velocities in the clutter region near the RDA. These improperly dealiasing velocities are often operationally insignificant.

## Improperly Dealiasing Velocities Example

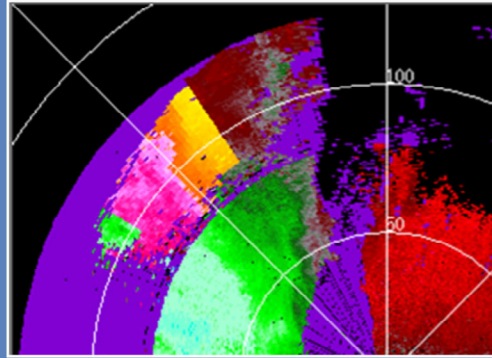


Large block with unrealistic shear along the azimuth

Why would dealiasing failures occur when embedded in RF data?  
Let's find out!

These images show the second type of improperly dealiasing velocities. An area to the northwest of the radar shows two azimuthal shears that are clearly not meteorological in nature. These dealiasing failures occur in a region surrounded by range folded data, which could be significant to the issue.

## Velocity Dealiasing Algorithm



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

Now that we have discussed the impacts of dealiasing failures, now let's discuss how the WSR-88D's velocity dealiasing algorithms work. The first algorithm we will discuss is the Legacy Velocity Dealiasing Algorithm (VDA). The goal of any velocity dealiasing algorithm is to assign the correct radial velocity to each range bin. The VDA starts by identifying "suspect" first guess velocity values. The algorithm then tries the velocity alias values to determine if they would be more appropriate. The algorithm determines what's "appropriate" by comparing the first guess and its aliases to neighboring values. Additional steps in the algorithm search for evidence of real meteorological shears, both azimuthally and radially, to preserve circulations and divergence signatures in the data.

## Velocity Dealiasing Algorithm: “Check Your Neighbor”

- First 3 steps search for V close to each 1<sup>st</sup> guess
  - Compare 1<sup>st</sup> guess against V neighbor
  - Compare 1<sup>st</sup> guess aliases against V neighbor
- Each subsequent step looks a little further away
- Does +59 make sense?
- Last step allows for your input & oversight

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

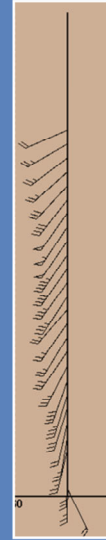
So let's talk about this “check your neighbor” process in a little more detail. The VDA performs this check in three steps. Each step compares the first guess velocity and its associated aliases with a “velocity neighbor”. Each step uses a different “velocity neighbor”, with the comparison velocity values being a little further away from the range bin in question with each subsequent step. In essence, this process determines which possible velocity value makes the most sense with the surrounding velocity field. For example, given the velocity field shown on the slide, does the highlighted outbound 59 knot velocity make sense?

The fourth and final step in this process is the most important because that's where you provide input and oversight to the algorithm.



## Velocity Dealiasing Algorithm: Environmental Winds Table

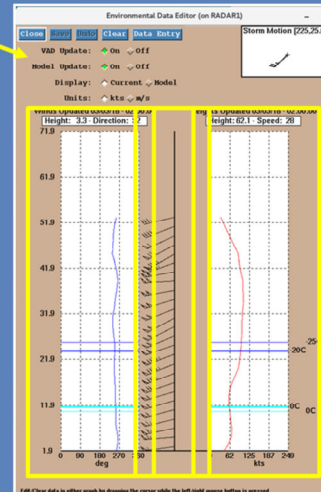
- 1<sup>st</sup> guess and aliases compared to EWT
  - Must be within threshold of EWT velocity
- Important to have representative EWT to support Velocity Dealiasing Algorithm
- EWT interface
  - Environmental Data Editor – graphical
  - Environmental Data Entry - tabular



If steps 1 through 3 don't identify the best velocity estimate for a range gate, then the VDA accesses data from the Environmental Winds Table in step 4 to find a representative velocity for that range bins estimated height above the surface. This situation reinforces why accurate data in this table is so important. You want the Environmental Winds Table to have a realistic picture of the winds aloft. The data can be viewed and edited in both a graphical and tabular format.

## Environmental Data Editor Window

- EWT: Winds aloft from VAD and/or RAP
- Graphs:
  - Wind direction w/height (left)
  - Wind speed w/height (right)
- Wind barb format (middle)



The Environmental Data Editor at the Radar Product Generator (RPG) Human Control Interface (HCI) provides multiple ways to view and edit wind data. The graph on the left shows wind direction with height, while the graph on the right shows the corresponding wind speed with height. In between the two plots are the same information shown in wind barb format. The wind input on this display usually comes from either the Velocity Azimuth Display (VAD) data or the Rapid Refresh (RAP) model. Both sources can be toggled on or off at the top of the GUI. It's not an either or situation, so you can have both toggled on to ensure the best wind data possible.

## Managing the EWT

- VAD Update
  - Ingest of WSR-88D calculated winds each volume scan
- Model Update
  - Ingest of RAP hourly
  - Closest grid point used
- Recommend VAD & RAP Update On
  - Complement one another

Environmental Data Edit

Close Save Undo Clear Data Entry

VAD Update: ☒ On ☐ Off

Model Update: ☒ On ☐ Off

Display: ☒ Current ☐ Model

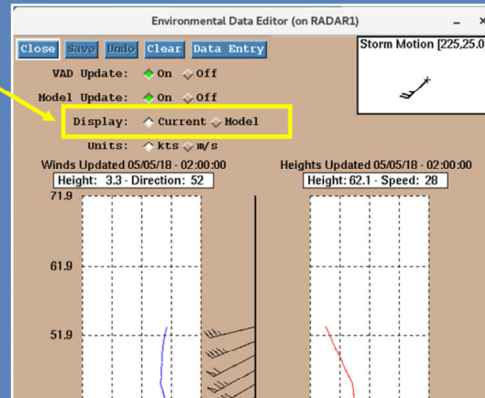
Units: ☒ kts ☐ m/s

Winds Updated 05/05/18 - 02:00:00

Here's a closer look at the controls I was mentioning on the last slide. When "VAD Update" is toggled on, the Environmental Winds Table (or EWT) gets updated every volume scan by the VAD product. Likewise, when "Model Update" is toggled on, the EWT looks hourly for the nearest RAP grid point to update the data. We recommend that both of these controls are set to "On" unless you are experiencing an issue with one or both data sources.

## Managing the EWT

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



If you need to quality control the EWT data, the “Display” options can help. When “Current” is selected, the window will show the current state of the EWT. This option will help you verify if the current data is representative. If you want to check the RAP input, then select “Model”. With this option toggled on, you can view the last hour’s model input. If these data look poor, then you can set Model Update to Off.

## Legacy VDA: Strengths

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

By design, the VDA attempts to provide the best possible velocity data for visual inspection and RPG algorithms that look for velocity-related features such as circulations. The VDA attempts to assign the true radial velocity, even when it exceeds  $V_{\max}$ . The VDA includes some quality control features to preserve significant meteorological shears, such as gust fronts, storm top divergence, mesocyclones, and tornado vortex signatures.

## Legacy VDA: Limitations

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

VDA performance can become degraded when data quality problems reduce the reliability of the first guess velocity. These situations include unfiltered clutter, weak power returns, and (in some cases) a low number of pulses per radial with faster VCPs. When dealiasing failures occur, real shear signatures may become masked. Likewise, RPG algorithm input may be corrupted and lead to issues such as false circulations in the Mesocyclone Detection Algorithm. Dealiasing failures occur most frequently in areas of sparse or mostly range folded data where there are few if any neighboring velocity values for first guess value comparison.

## Legacy VDA: Considerations

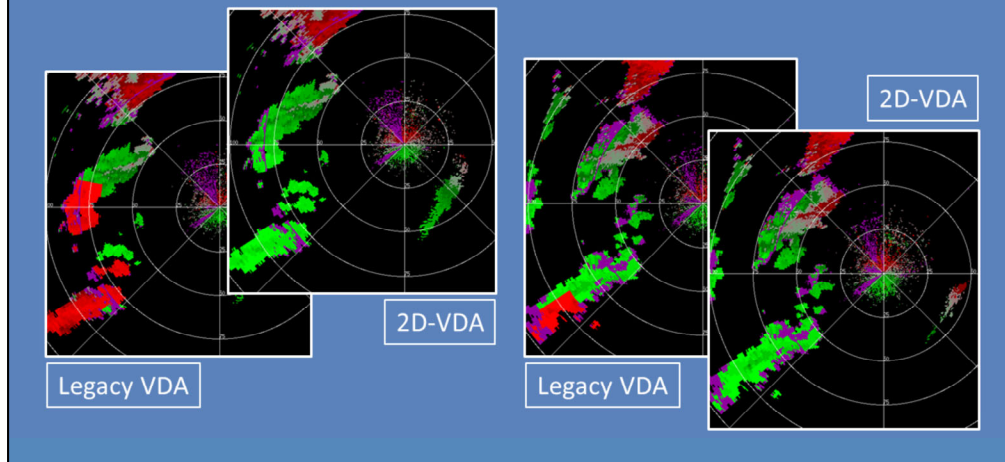
- Suspect improperly dealiased velocities?
  - Change elevation angle
  - Examine previous or later volume scan
  - Anticipate flow based on synoptic conditions
- VCP 31: low PRF (#2) for CD mode
  - Switch to VCP 32 or 35

Dealiasing failures can be subtle, and determining if a shear region is valid can be difficult. If you suspect improperly dealiased velocities, try these techniques. First, dealiased velocities rarely occur from one elevation angle to the next, so try looking above or below the current tilt. Likewise, continuity of dealiased velocities from scan to scan rarely exists, so try looking at the previous or next volume scan. Lastly, when you are looking at synoptic or mesoscale wind features, have knowledge of the expected wind field from other data sources.

If your radar is running in clear air mode, remember that long pulse data (collected by VCP 31) have better sensitivity but poorer velocity estimates. So, dealiasing failures are more likely in VCP 31. If you need higher quality velocity estimates in clear air mode, use VCPs 32 or 35 instead.

## 2-D Velocity Dealiasing Algorithm

- Significant reduction in dealiasing failures
- 2D-VDA is default algorithm; Legacy VDA still plays a role



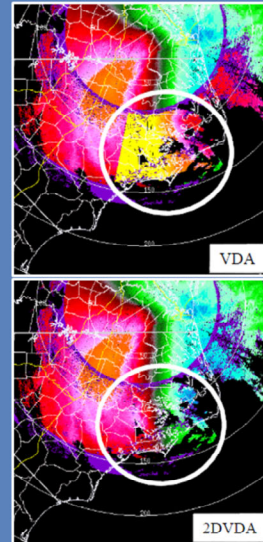
The Two Dimensional Velocity Dealiasing Algorithm (2D-VDA) offers a significant reduction in dealiasing failures when compared to the Legacy VDA. The examples shown come from an event with storms that were moving so fast that the legacy Velocity Dealiasing Algorithm had numerous dealiasing failures,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

While 2D-VDA is the default velocity dealiasing algorithm, the legacy VDA still serves a backup role in the process.



## 2-D Velocity Dealiasing Algorithm

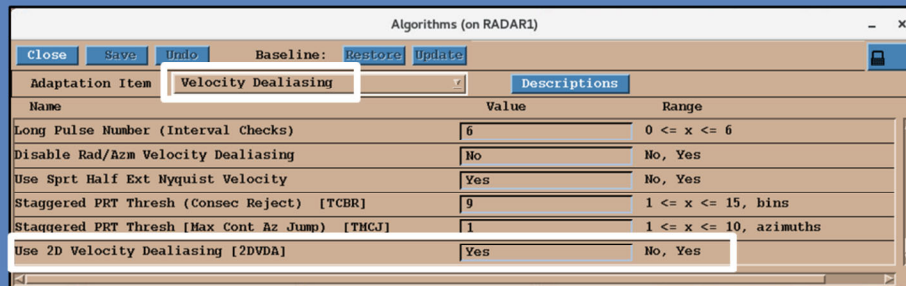
- Dealias entire elevation of V data
  - Azimuth/radial grid built with median V for each grid center
  - V field partitioned to dealias small features
  - Weighting factors reduce data noise



The 2D-VDA provides a more robust velocity dealiasing solution than the Legacy VDA. 2D-VDA's overall approach uses a least squares method to minimize errors in the velocity field. The algorithm builds a two-dimensional grid (in azimuth and range) for each elevation using a median velocity value for each grid center point. This grid serves as a measure of the large scale velocity field. The velocity data then get partitioned so smaller scale features such as mesocyclones, storm top divergence, gust fronts, and tornadic vortex signatures can be properly dealiased. In this process, weighting factors are applied to the velocity data in order to remove noisiness.

## 2D-VDA Implementation

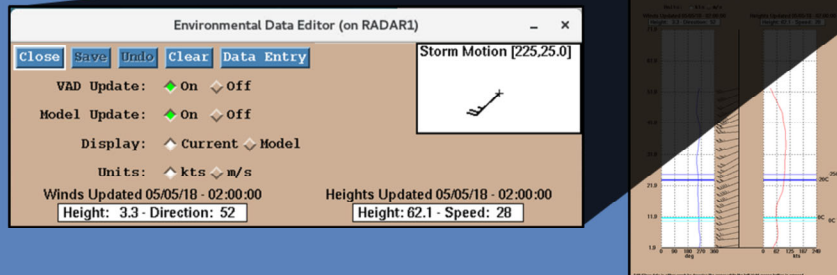
- 2D-VDA is default dealiasing algorithm
- Algorithm has to be disabled to switch back to Legacy VDA



As mentioned previously, the WSR-88D defaults to 2D-VDA for velocity dealiasing. Radar operators must turn off 2D-VDA in the Algorithms window for the Legacy VDA to become the default. Switching 2D-VDA off should not be necessary, but remains an option as a precaution.

## 2D-VDA & the EWT

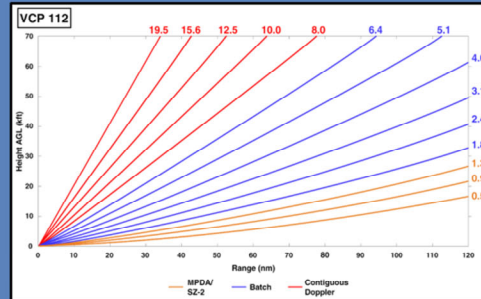
- Environmental Winds Table (EWT)
  - Not used by 2D-VDA (still used by Legacy VDA)
- Need for quality environmental data remains
  - MLDA & 0° C height



While the Environmental Winds Table supports the Legacy VDA, 2D-VDA does not rely on it. However, that doesn't mean that radar operators should not pay attention to the validity of the environmental data when 2D-VDA is in effect. Other RPG algorithms besides Legacy VDA, like the Melting Layer Detection Algorithm, rely on these data to ensure the best quality products possible. Forecasters should double-check these data periodically to ensure they are accurate.

## Multiple PRF Dealiasing Algorithm (MPDA)

- Designed to mitigate range folding *and* improperly dealiased velocities (VCP 112 only)
- Additional CD rotations on lowest 3 elevations
- At 0.5°, 1 CS and 2 CD rotations

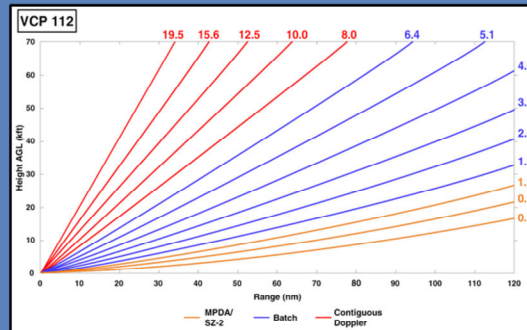


The WSR-88D uses the Multiple PRF Dealiasing Algorithm (MPDA) as a special velocity dealiasing application in VCP 112. This algorithm mitigates both range folding and improperly dealiased velocities, with range folding reductions being most apparent. VCP 112 incorporates additional Doppler rotations for the lower elevations. For example, at 0.5°, there is one CS rotation followed by 2 CD rotations. Each CD rotation uses a different Doppler PRF.

## VCP 112 Considerations

- VCP 12 angles, but *fastest antenna rotations*

- 20 rotations in 5 mins  
30 secs

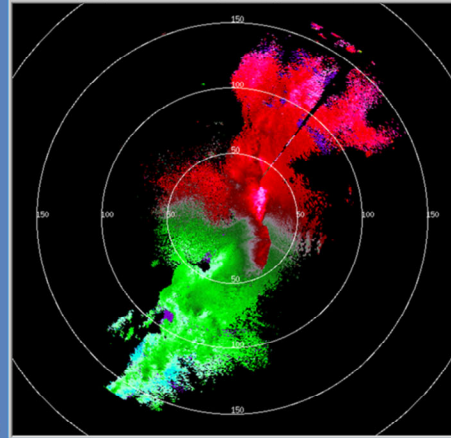


- VCP 112 **NOT** appropriate for fast moving or rapidly evolving storms
  - Use VCP 12 or 212

Since VCP 112 includes additional rotations and has an update rate of about 5.5 minutes, this scanning strategy has both the fastest antenna rotation rates and lowest numbers of pulses per radial of any VCP. As a result, VCP 112 should not be used for fast moving and/or rapidly evolving storms. VCPs 12 or 212 are the appropriate choices instead.

## Strengths of MPDA/VCP 112

- For lowest 3 elevations, VCP 112 recovers nearly **all** velocity data
- Designed for:
  - Hurricanes (no tornadic storms within rainbands)
  - Events with widespread echo coverage

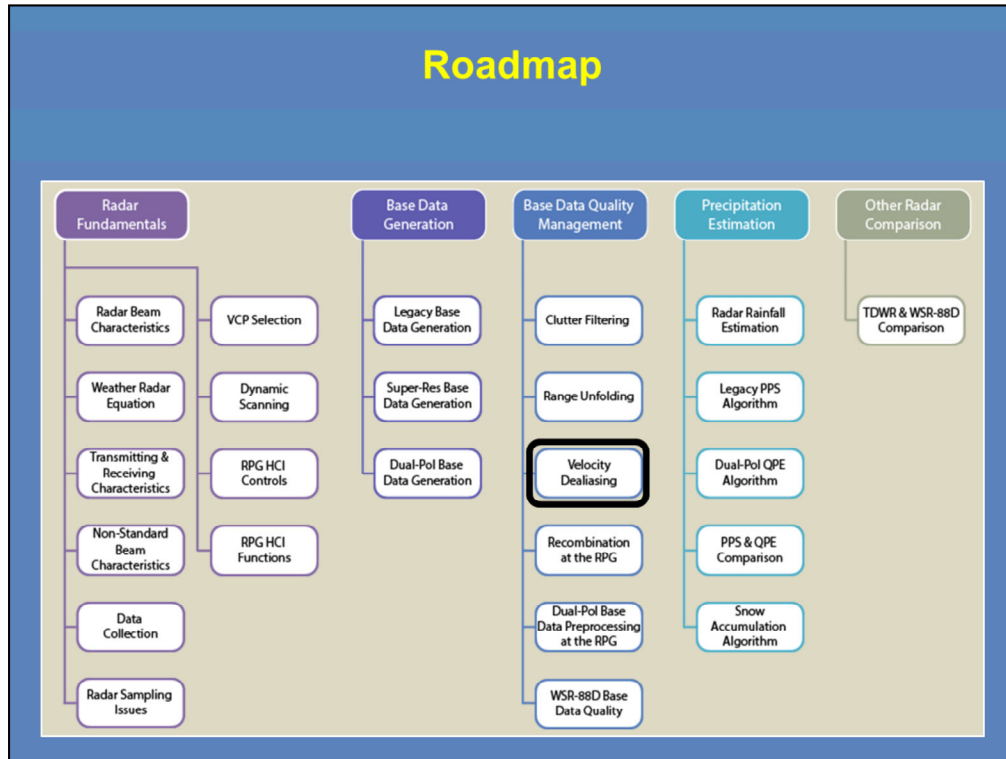


MPDA (aka VCP 112) can recover nearly all velocity data for the lowest three elevations. The Radar Operations Center designed this VCP for sampling hurricanes and other widespread precipitation events. VCP 112 works best while still offshore when large scale velocity structure is the priority. Once operations shift to looking for potentially tornadic storms within the rainbands, VCP 112 should be changed to VCPs 12 or 212.

## Limitations of MPDA/VCP 112

- VCP 112 *not* an appropriate choice for:
  - Tornadoic storms close to the RDA
  - Any situation where fast updates from low elevation base products are a priority
- High antenna rotations + CMD + GMAP + Super Res processing can degrade data quality

VCP 112 should not be used for severe convection. VCP 112 has the highest antenna rotation rates of any VCP while also using the lowest number of pulses per radial. With the application of CMD, GMAP, and super resolution processing, VCP 112 remains susceptible to data quality issues at a higher rate than other VCPs.



Here is the “roadmap” with your current location.



# Data Recombination at the RPG

## 1. Data Recombination at the RPG

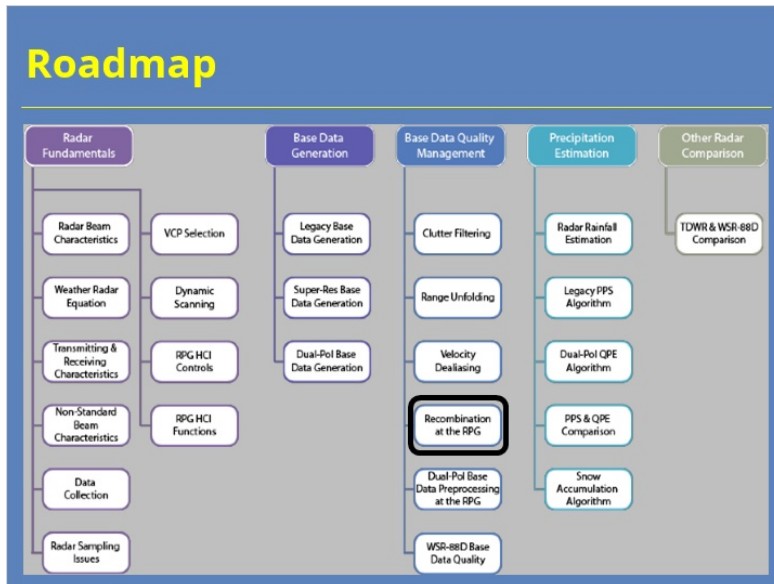
### *Introduction*



### **Notes:**

Welcome to the Radar & Applications Course Principles of Doppler Weather Radar. This lesson discusses base data recombination at the Radar Product Generator or RPG. Let's get started.

## Roadmap



### Notes:

Here is the complete roadmap for the entire "Principles of Doppler Weather Radar" topic of RAC. You are currently in the Base Data Quality Management section of that topic.

## ***Learning Objectives***

### **Learning Objectives**

---

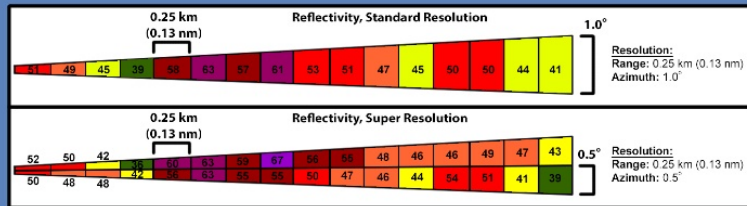
1. Identify the purposes of the different recombination tasks at the RPG

#### **Notes:**

There's one learning objective for this lesson. Please take a moment to review the objective, as the quiz at the end of this lesson is based on it.

## Recombination at the RPG

### Recombination at the RPG



#### Two reasons for Recombination:

1. Split Cut dual-pol base data too noisy  
\* *Exception: Two "Raw" products discussed later*
2. Super-Res base data recombined from 0.5° to 1.0° azimuth for RPG algorithms

#### Notes:

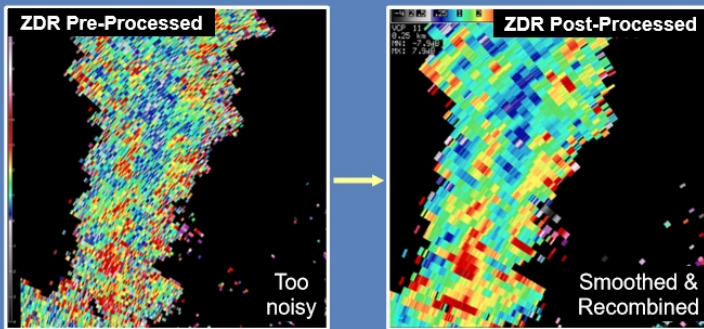
Recombination at the RPG is the process of combining range bins of Level II base data azimuthally, radially, or both. Why might we want to recombine radar data to give ourselves coarser data resolution? There are two reasons for this process at the RPG:

1. The super-res, Level II dual-pol data are very noisy. Too noisy for routine human or algorithm analysis. Recombining the data on the Split cut elevations helps eliminate some of that noise.
2. Likewise, some of the original RPG algorithms were developed using standard resolution radar data as input. Those algorithms have not been updated to input super-resolution data for legacy Doppler products (such as base reflectivity, base velocity, and spectrum width).

## ***Dual-Pol Recombination at RPG***

### **Dual-Pol Recombination at RPG**

1. Split Cut dual-pol data recombined from  $0.5^\circ$  to  $1.0^\circ$  azimuth



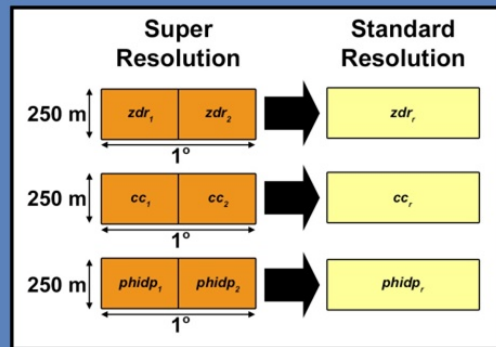
#### **Notes:**

The RDA sends dual-pol base data to the RPG. Those data include Differential Reflectivity, Correlation Coefficient, and Differential Phase. On the Split Cut elevations, these data streams have  $0.5^\circ$  azimuthal resolution. You can see an example of such data on the left. While signals can be seen in this data, the noise present makes it difficult to sample a single range bin and feel that it is representative of the meteorological signal in the data. Recombination (along with radial smoothing at the dual-pol pre-processor which will be discussed in the next lesson) produce the product on the right. These data now have a  $1.0^\circ$  azimuthal resolution and provide a much easier product for meteorological analysis.

## Dual-Pol Azimuthal Recombination

### Dual-Pol Azimuthal Recombination

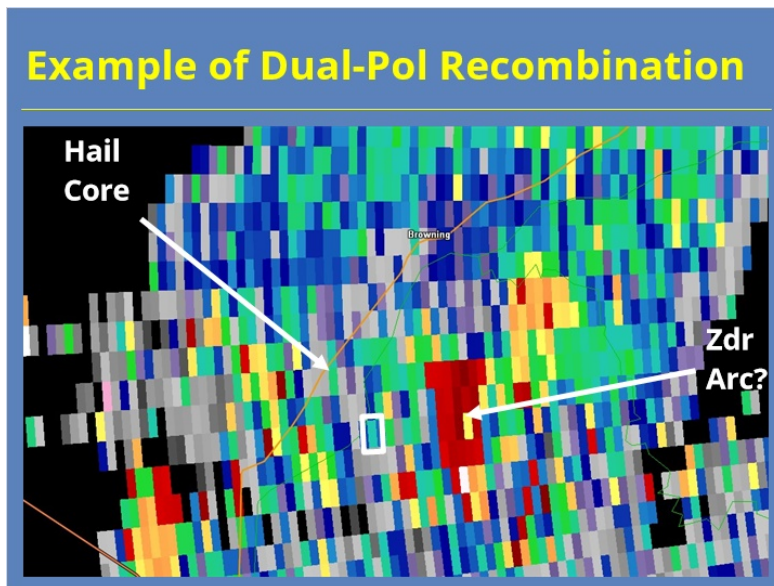
- Combines two  $0.5^\circ$  bins into one  $1.0^\circ$  bin
- No range recombination, but smoothed later



#### Notes:

Dual-pol base data recombination averages the power-weighted values of two adjacent  $0.5^\circ$  range bins into one  $1.0^\circ$  range bin. Since the range resolution stays the same, no range recombination is required. However, more filtering of these data will occur at the dual-pol preprocessor. 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.

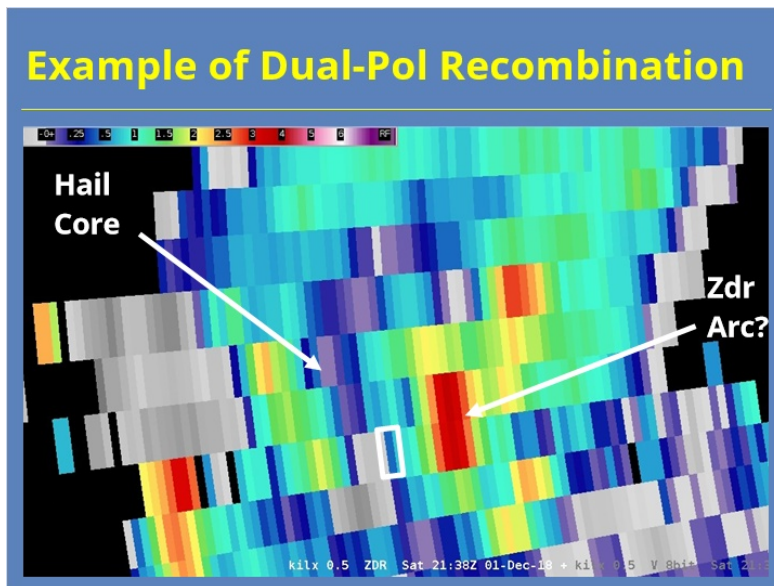
## ***Example of Dual-Pol Recombination***



### **Notes:**

Let's look at an example to see why dual-pol recombination and smoothing (which will be discussed in the next lesson) matters. Here's Differential Reflectivity Level II data. We will focus our attention on this range bin here since it's at the center of the action. To interpret these data properly, you need to look at this image in context to other data. For the sake of time, let me point out some key features present. To the west and northwest of our range bin, there's a hail core. See the generally lower Zdr values there. A few kilometers to the east, we have an area of larger rain drops that might be a developing Zdr arc. Let's see what this same image looks like after recombination and dual-pol preprocessing has occurred.

## ***Example of Dual-Pol Recombination***



### **Notes:**

Here's the Level III data for the same place and time. We have highlighted the same range bin at the center of it all right here. The Zdr values in the hail core are a little higher than in the raw data. The high values in the potential Zdr arc have been smoothed out as well. While these two features would likely be detectable in the raw Level II data, you see the overall patterns in the data much easier in the recombined and smoothed data. Let's look at the numbers in a little more detail to see why that is.



### ***Same Example, But Numeric Data***

#### **Same Example, But Numeric Data**

Original Level II ZDR Values:

0.63	-0.81	-0.19	-0.58	0.44	1.31	2.38	0.06	0.38
0.31	0.31	-0.19	0.56	1.00	0.75	1.69	-1.31	1.13

Recombined Level II ZDR Values:

0.47	-0.25	-0.19	0.00	0.72	1.03	2.04	-0.63	0.76
------	-------	-------	------	------	------	------	-------	------

Level III ZDR (Pre-Processed) Values:

0.44	0.06	0.13	0.19	0.69	0.56	0.75	0.94	0.69
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#### **Notes:**

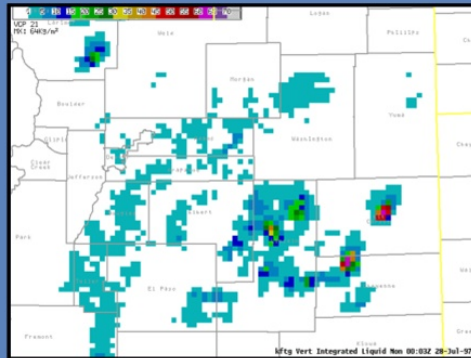
Here are the actual Zdr values from the Level II data. The range bin I pointed out previously is highlighted in orange. I have included several range bins around this one for context as we talk about smoothing the data. So, why not just recombine the data and call it good. Well, here's what you get when you just recombined the super-res data into standard resolution. These data remain very noisy at this point. Now let's look at the recombined AND smoothed data. Even though the value in our range bin barely changed, you can see some major changes in the bins that surround it. Some of these data are 1 dB or more different than the original data for that location. That high amplitude noise for Zdr! We will revisit the significance of this some more in the next lesson.

## ***Legacy Data Recombination at RPG***

### **Legacy Data Recombination at RPG**

2. Original\Early RPG algorithms cannot ingest SR base data

- TDA
- PPS
- VIL



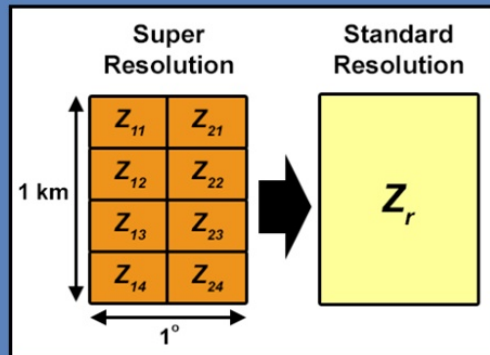
#### **Notes:**

Now let's move on to the second goal of recombination. The original RPG algorithms rely on standard resolution or coarser base data to function. In fact, most algorithms developed prior to super-resolution base data being available fall into that category. In fact, these algorithms were designed for reflectivity input with 1° azimuthal resolution and 1 km range resolution. For Velocity and Spectrum Width, the algorithms require 1° azimuthal resolution and 250 m range resolution. Examples of such algorithms include the Tornado Detection Algorithm, the Legacy Precipitation Processing System algorithm, and Vertically Integrated Liquid (which is shown here on the slide).

## Reflectivity Recombination

### Reflectivity Recombination

- Linear average of 8 bins
- No Data bins: Power estimated & Z used in average



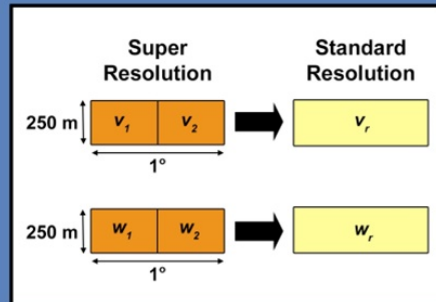
#### Notes:

So, how does Reflectivity recombination work? This image should help. You can see eight super resolution range bins are averaged linearly into one range bin of 1.0° azimuth by 1 km range resolution. For bins assigned No Data, the RPG estimates the associated power, converts that value to Z and included in the average. The RPG does not produce a product that displays Reflectivity at this resolution any more, so the recombined data are only internal to the RPG algorithms.

## Velocity & Spectrum Width Recombination

### Velocity & Spectrum Width Recombination

- Recombination for Velocity & Spectrum Width
  - Power weighted averages
  - SW: Also accounts for velocity estimate variance



#### Notes:

A similar process occurs for the Velocity and Spectrum Width products. For these products, the RPG algorithms require  $1.0^\circ$  azimuth by .25 km range resolution for input. So, the RPG recombines these data azimuthally, only. Recombination performs a power weighted average of the two super resolution bins into the one corresponding standard resolution bin. For Spectrum Width, an additional step accounts for the variance of the two corresponding velocity values in the final spectrum width value. 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 contains data and the other is assigned No Data or RF, then the remaining valid bin is assigned as the legacy resolution value.

## Summary

### Summary

Recombination at the RPG has two goals:

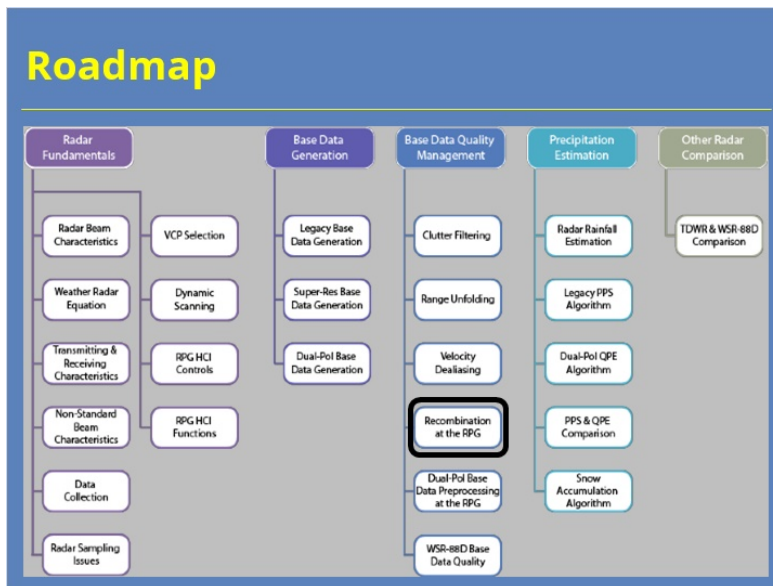
1. Combine dual-pol base data to provide better inputs to forecasters and algorithms
  - Azimuthal recombination only
  - Further noise reduction occurs at dual-pol pre-processor
2. Combine legacy Doppler data for algorithms created prior to super-res implementation
  - Z: azimuthal and range recombination
  - V & SRM: azimuthal recombination only

#### Notes:

In summary, recombination at the RPG has two goals. The first goal of recombination is to combine the dual-pol base data to eliminate noise and make the data more usable for forecasters and algorithms alike. The RPG combines the products azimuthally, but further smoothing to reduce noise occurs at the dual-pol pre-processor. The second goal of recombination involves supporting older RPG algorithms developed prior to super-res data being available. These products require that standard resolution data (or coarser in the case of Reflectivity) be used as input. Reflectivity data are combined azimuthally and by range. Velocity and Spectrum Width data are combined azimuthally, only.

When you are ready, proceed to the next slide to start the quiz.

## Roadmap



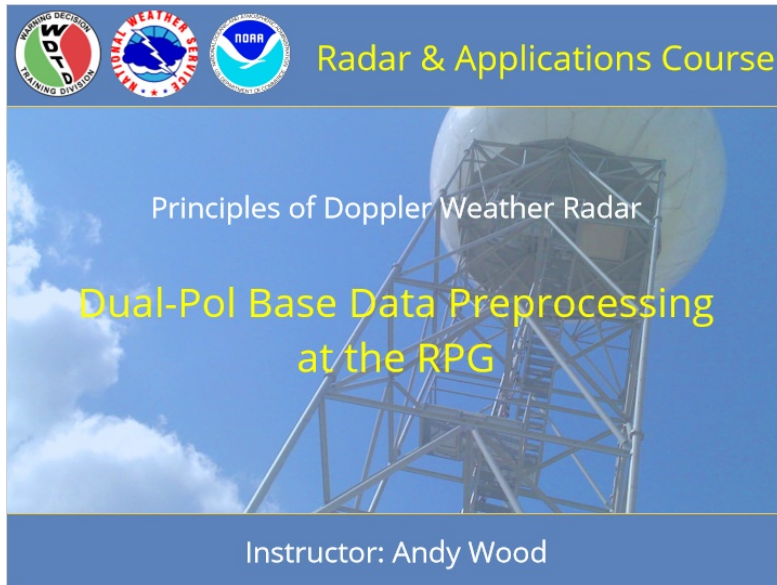
### Notes:

This lesson is now complete. You can now move on to the next lesson in the course. Thank you for your time!

# Dual-Pol Preprocessing at the RPG

## 1. Introduction

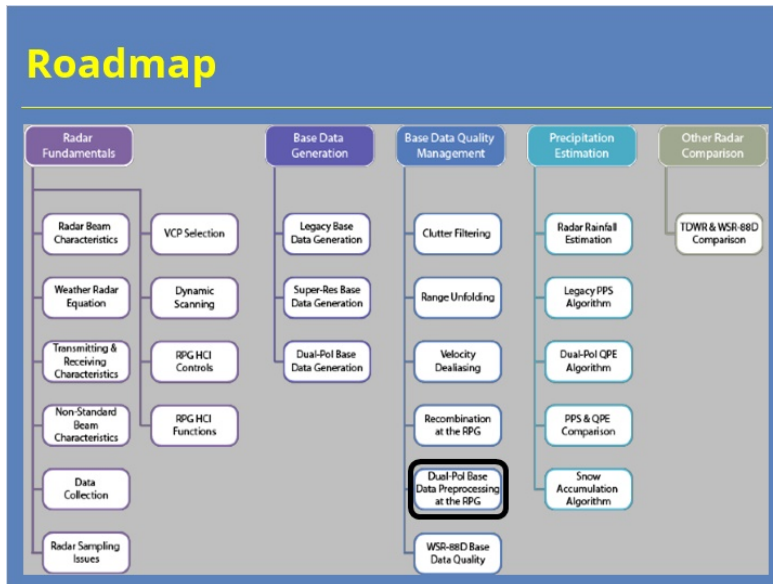
### *Introduction*



### **Notes:**

Welcome to the Radar & Applications Course and this topic, Principles of Doppler Weather Radar. This lesson discusses Dual-Pol Base Data Preprocessing at the RPG. Let's get started!

## Roadmap



### Notes:

Here is the complete roadmap for the entire "Principles of Doppler Weather Radar" topic of RAC. You are currently in the Base Data Quality Management section of that topic.



## ***Learning Objectives***

### **Learning Objectives**

---

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

#### **Notes:**

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

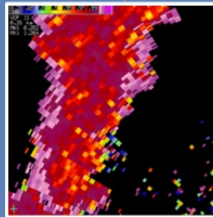
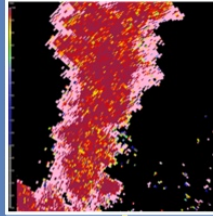
## ***Dual-Pol Preprocessor at the RPG***

### **Dual-Pol Preprocessor at the RPG**

Goal: Prepares base data for base & derived product generation:

1. Smooth base data
2. Compute KDP
3. Calculate data texture
4. Identify data needing further correction

**\*Smoothed Z used *only* for input to Dual-Pol RPG algorithms!**



#### **Notes:**

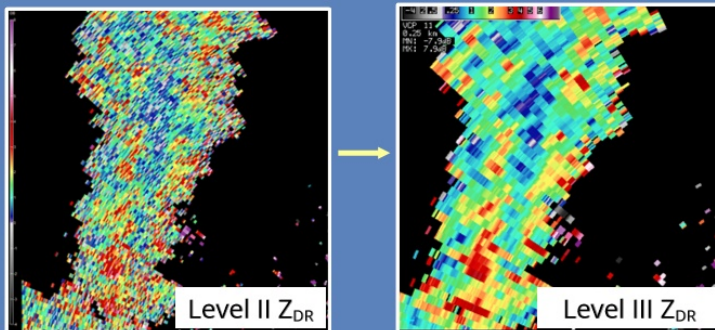
The Dual-Pol Preprocessor is an RPG algorithm that prepares base data from the RDA for both dual-pol base product generation and input to other RPG dual-pol algorithms. The preprocessor prepares these data in several ways. First, the algorithm smooths the dual-pol and reflectivity base data. Other corrections to the data may occur depending on the product. The preprocessor then computes the specific differential phase values for the KDP product from the differential phase base data. The RPG performs two other tasks at the dual-pol preprocessor that are useful for internal purposes of the algorithm: Calculating texture for certain base data and identifying areas of non-uniform beam filling and attenuation.

I should note that the smoothed Reflectivity data mentioned here only gets used as input to the dual-pol RPG algorithms. The actual Base Reflectivity products you analyze have not been smoothed. Now that I have clarified that, let's look at how the dual-pol preprocessor impacts the dual-pol base products.

## Preprocessing for ZDR

### Preprocessing for Z<sub>DR</sub>

1. Smooth recombined data
2. Adjust for precipitation attenuation



#### Notes:

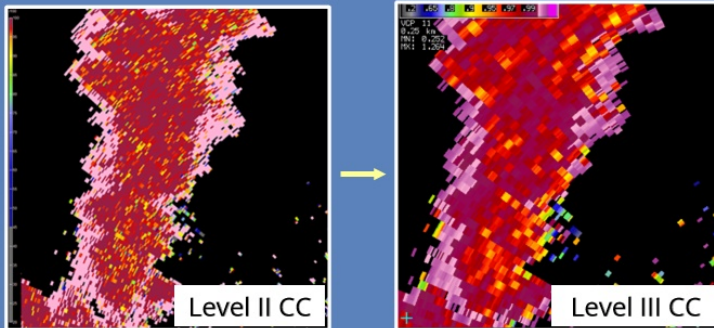
So let's start with Zdr. After data recombination, the dual-pol preprocessor performs two tasks to the differential reflectivity data. First, a five-gate, radial average technique smooths the data. Additionally, a calibration adjustment is applied in areas where precipitation attenuation has been identified.

What does that look like in the actual product. The example on the right is the Level II, super-resolution Differential Reflectivity data. That means 0.5° azimuthal resolution and .25 km range resolution. On the right, we have the smoothed final product you would see in AWIPS. Work by Brandes (2000) shows that the standard error for differential reflectivity along the radial can be reduced from 0.2-0.3 dB to about 0.1 dB by radially smoothing the data. So, smoothing definitely produces more accurate results!

## *Preprocessing for CC*

### Preprocessing for CC

One process: Smooth recombined Correlation Coefficient data



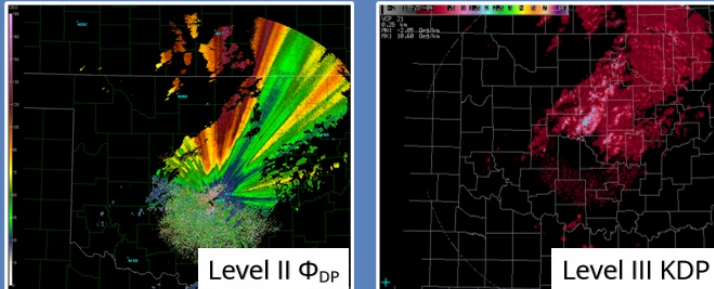
#### **Notes:**

Next let's look at Correlation Coefficient. Like Differential Reflectivity, the recombined CC gets smoothed using a five-bin, radially oriented filter. When we look at the data, once again we have the raw Level II data on the left, and the recombined and smoothed product on the right. The final product has  $1.0^\circ$  azimuthal resolution, .25 km range resolution, and visually smoother data. The data smoothing has even more importance on lower elevations as Correlation Coefficient data are very susceptible to ground clutter contamination (Brandes, 2000).

## *Preprocessor and $\Phi_{DP}$*

### Preprocessor and $\Phi_{DP}$

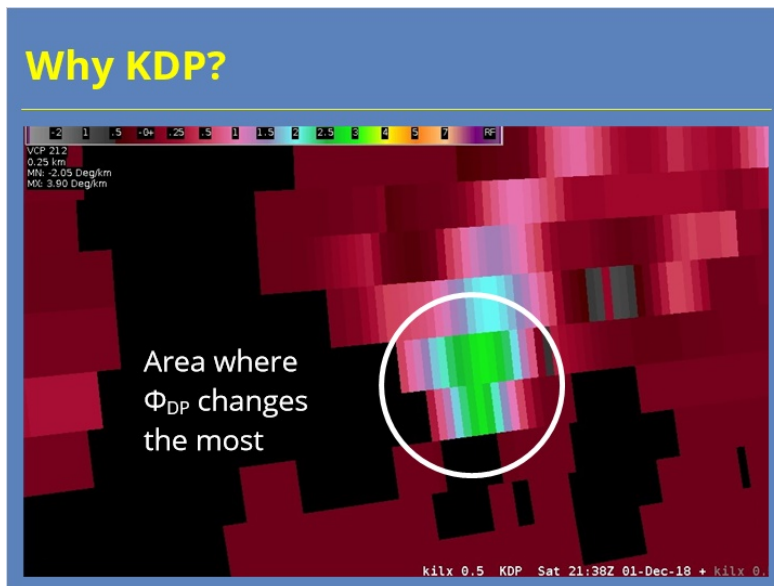
1. Create texture fields for other algorithms
2. Smooth recombined data
3. Calculate KDP values



#### Notes:

Just like the other dual-pol base data, Differential Phase (or  $\Phi_{DP}$ ) is first recombined prior to preprocessing. Prior to smoothing the data, the preprocessor calculates the texture of  $\Phi_{DP}$  for use in other dual-pol algorithms. That's just another way of saying the standard deviation of the data over a nine-gate, radially oriented window. The preprocessor then smooths the  $\Phi_{DP}$  data dependent on the range bins reflectivity value. The radial filter applied in the final data will be nine gates for Reflectivity values at or above 40 dBZ, and 25 gates for weaker returns. Once the data are smoothed, the preprocessor calculates the Specific Differential Phase values, which are just a range derivative applied to the  $\Phi_{DP}$  data. The KDP data are much easier to interpret meteorologically, as you can likely tell when you compare the original Level II data shown on the left with the KDP output on the right. Let's talk about this subject in a little more detail.

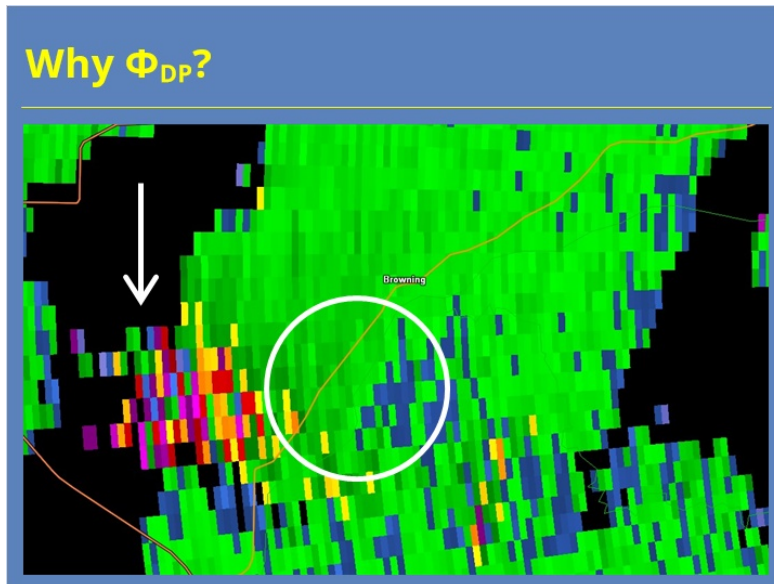
## Why KDP?



### Notes:

So you might ask “Why do we need KDP?” Simply put, applying a range derivative to the Differential Phase data helps users identify the areas of greatest change in phase, and that information is what’s most meteorologically useful. In the example shown, the area in green is where the phase changes the most and corresponds with a convective storm with significant liquid water content. We will talk more about Specific Differential Phase as you go through the course. Now let’s talk a little more about Differential Phase.

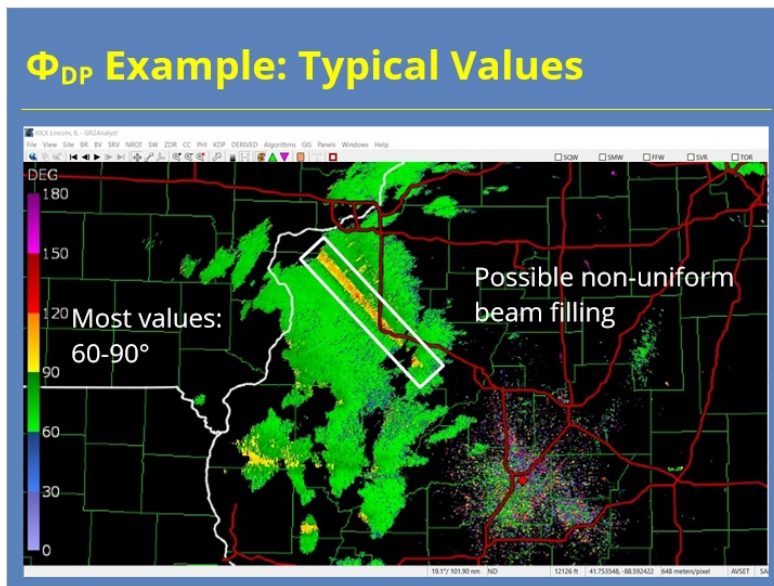
## Why $\Phi_{DP}$ ?



### Notes:

Here's that same storm from the last slide, but showing  $\Phi_{DP}$  instead. The area in the circle is where the highest liquid water content was identified using KDP. It's not nearly as easy to see in  $\Phi_{DP}$ . In fact, our eyes are drawn more to the noisy values in the three-body scatter spike further to the west.

## ***$\Phi_{DP}$ Example: Typical Values***

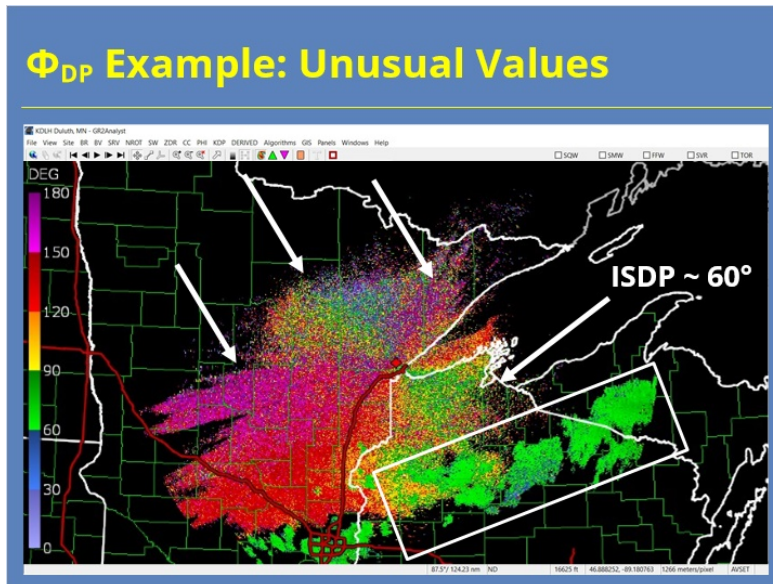


### **Notes:**

Here's another graphic showing a typical example of  $\Phi_{DP}$ . The four panel on the screen shows differential phase on the lower left and KDP on the lower right. In this example, most of the Differential Phase data in the weather returns west and northwest of the radar are in the 60-90° range. These data appear normal except for some possible non-uniform beam filling down radial from a storm northwest of the radar.



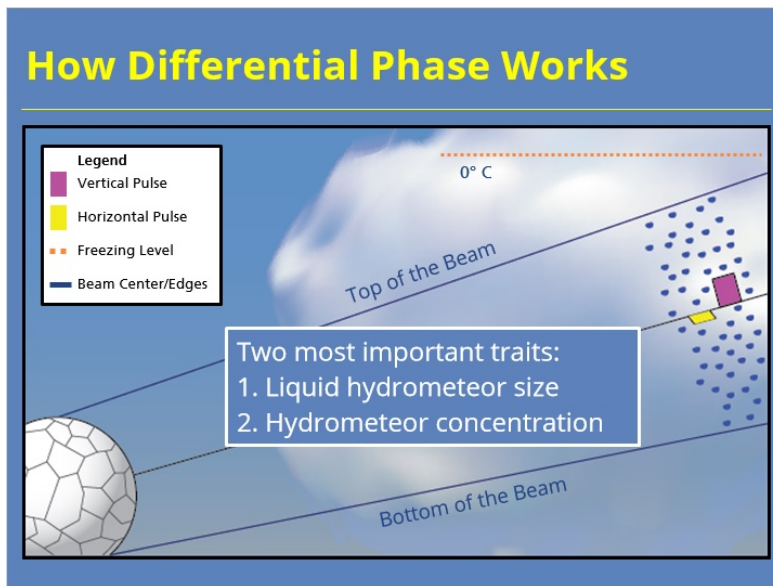
## ***$\Phi_{DP}$ Example: Unusual Values***



### **Notes:**

Here's another example, but this time we see some minor data quality issues. There's a band of precipitation south of the radar, and the  $\Phi_{DP}$  values there are what we expect in the 60-90 degree range for light to moderate precipitation. In the area around the radar, especially to the northeast and southwest, we see a totally different story. The reflectivity data shows evidence of anomalous propagation due to ducting. The  $\Phi_{DP}$  values in these areas are generally in the 120-180 degree range, unlike the 30-90 degree range we see to the northwest and southeast of the radar. When the  $\Phi_{DP}$  data get wrapped away from the typical Initial System Differential Phase values of around 60 degrees, that's usually an indication that something non-meteorological is going on. It could be an anomalous atmospheric phenomenon like we have here, or it could be a system problem, too. Troubleshooting with your local radar focal point, lead forecaster on duty, or even the ROC Hotline can help you get to the bottom of the issue.

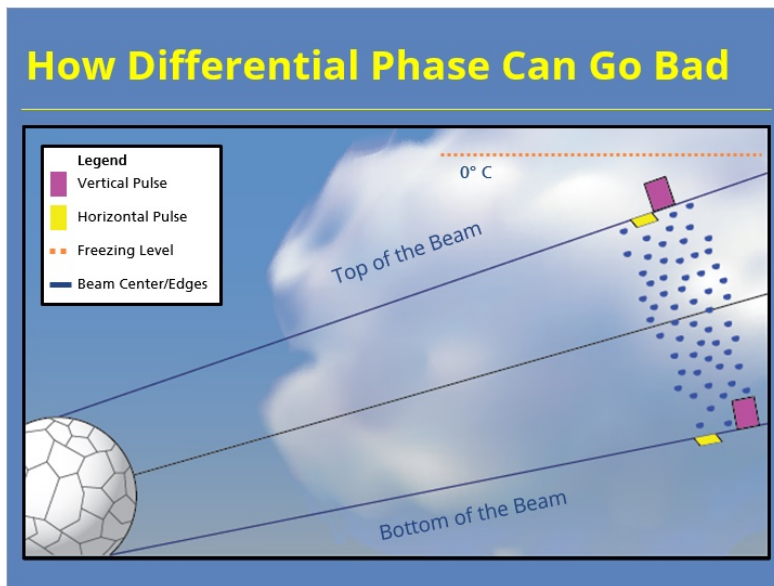
## How Differential Phase Works



### Notes:

Differential Phase provides information on the backscatter properties of targets the radar pulse intercepts. The data measure the difference in phase between the horizontal and vertical returns. These data provide utility because Differential Phase is sensitive to the water liquid content of the targets, but tends to be immune to things like radar calibration, partial beam blockage, and propagation effects. When the pulses leaves the radar,  $\Phi_{DP}$  doesn't equal zero. The initial  $\Phi_{DP}$  value (known as initial system differential phase) gets set to a value around 60 degrees because  $\Phi_{DP}$  can vary highly in ground clutter and clear air near the radar. As the pulse enters precipitation,  $\Phi_{DP}$  increases. This change occurs because the horizontal pulse generally slows more in liquid precipitation than the vertical pulse. Even when precipitation intensity remains constant, the phase difference between the pulses will increase with range. The phase accumulates as the pulse propagates. When spherical targets get intercepted, such as hail, the horizontal and vertical pulses get impacted about the same. The two traits that lead to the biggest increase in  $\Phi_{DP}$  are larger liquid hydrometeor size and increasing hydrometeor concentrations.

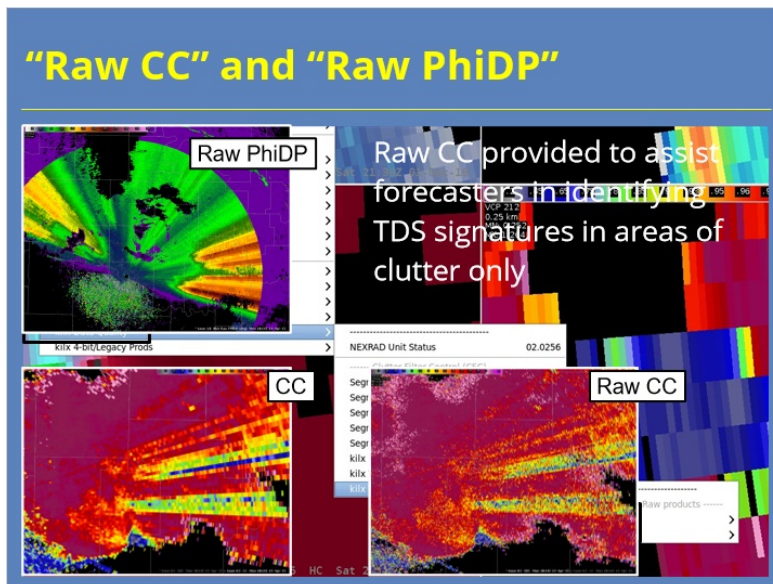
## How Differential Phase Can Go Bad



### Notes:

Now let's show an example where PhiDP can be negatively impacted. In this example, we'll look at PhiDP at the bottom and top of the beam. We start in this area of rain. PhiDP change consistently across the beam in these conditions. Now we move into an area where hail is in the top of the beam, but melts as it falls through the beam, and is liquid at the bottom of the beam. In this situation, PhiDP changes little at the top of the beam due to the frozen, spherical targets present. In the middle and bottom of the beam, PhiDP continues to increase. This situation results in a gradient of PhiDP across the beam. This situation causes a problem because the gradient remains even as the pulse enters all liquid precipitation again. The PhiDP data have become corrupted. This situation describes a process called non-uniform beam filling, which negatively impacts PhiDP and Correlation Coefficient.

## ***“Raw CC” and “Raw PhiDP”***



### **Notes:**

AWIPS allows forecasters to display two dual-pol products that are not recombined or preprocessed in any way. Both products can be found in the Data Quality submenu in AWIPS and contain “raw” in their names: Raw Correlation Coefficient and Raw PhiDP.

Raw PhiDP allows forecasters to view the Differential Phase data in AWIPS. Raw CC has super-resolution data with 0.5° azimuthal resolution, but this product isn’t a substitute for the standard CC product. Remember, the Level II dual-pol base data are considered too noisy for general use. The Raw CC product was added for forecasters to identify potential tornadic debris signatures that might be difficult to see due to ground clutter contamination. Improvements have been made to the Correlation Coefficient data to mitigate this issue to a degree, but forecasters may still desire to use the Raw CC product for this purpose.

## Summary

### Summary

The Dual-Pol Preprocessor performs the following tasks:

- Smooths recombined base data
- Compute the KDP product
- Creates texture fields of some data for algorithms
- Identify non-uniform beam filling & attenuation that require further correction

Also discussed differences between  $\Phi_{DP}$  and KDP, “Raw” products (not on quiz!)

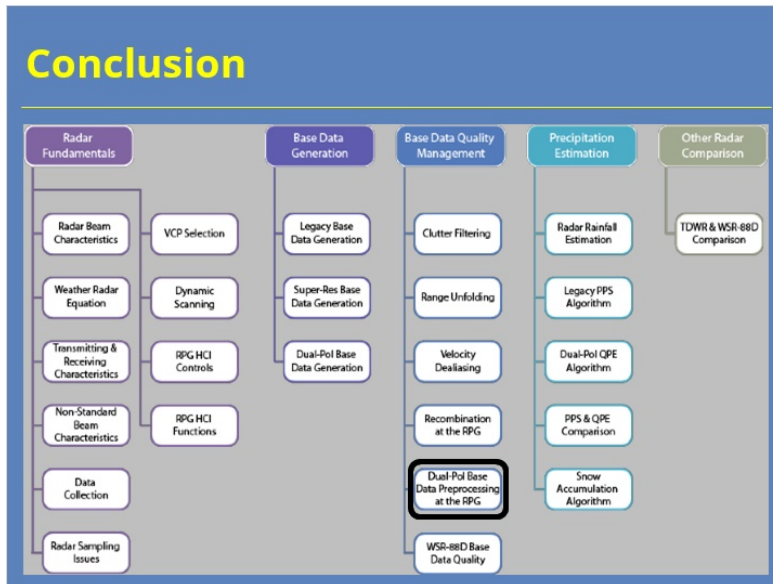
### Notes:

In summary, the dual-pol preprocessor performs several tasks. First, the algorithm smooths the recombined base data for the generation of the dual-pol base products and for input into other algorithms. Second, the preprocessor generates the Specific Differential Phase product. Third, the algorithm creates texture fields of Reflectivity and Differential Phase for use in the other dual-pol algorithms. Lastly, the preprocessor identifies non-uniform beam filling and attenuation that may require further correction in the data.

In addition to these tasks, we discussed two other topics non explicitly covered in the lesson objectives. First, we discussed the differences between  $\Phi_{DP}$  and KDP. Second, we mentioned the “raw” products that can be displayed in AWIPS. Neither of those topics will be covered in the quiz questions, but were included as foundational material for learning objectives covered later in the course.

When you are ready, proceed to the next slide to take the quiz.

## Conclusion



### Notes:

This concludes the lesson. Please feel free to move on to the next lesson in this topic. Thank you for your time!

# Base Data Quality

## 1. Introduction

### *Introduction*

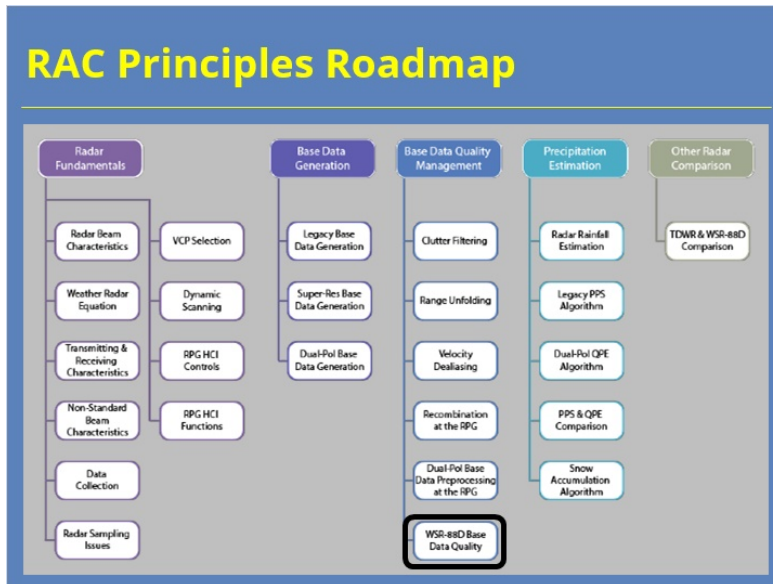


### **Notes:**

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.



## 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.



## ***Base Data Quality Objectives***

### **Base Data Quality Objectives**

---

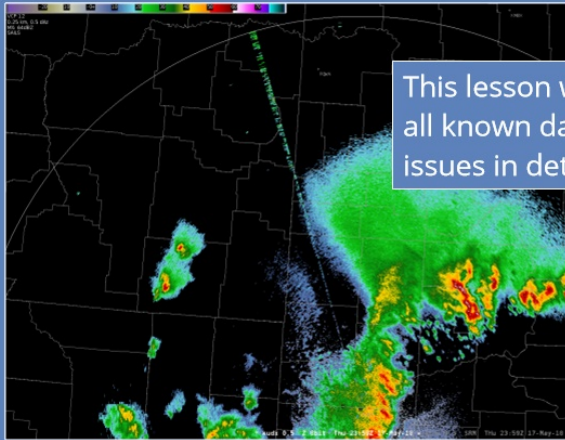
1. Identify the common reflectivity artifacts that impact base data interpretation
2. Identify the common velocity artifacts that impact base data interpretation
3. Identify the common dual-pol artifacts that impact base data interpretation
4. Identify some common practices forecasters can take to mitigate data quality issues, including the additional resources identified in the lesson

#### **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.

## *Lesson Scope*

### Lesson Scope



This lesson will not cover all known data quality issues in detail

#### **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.

## 2. Reflectivity Artifacts

### *Common Base Reflectivity Artifacts*

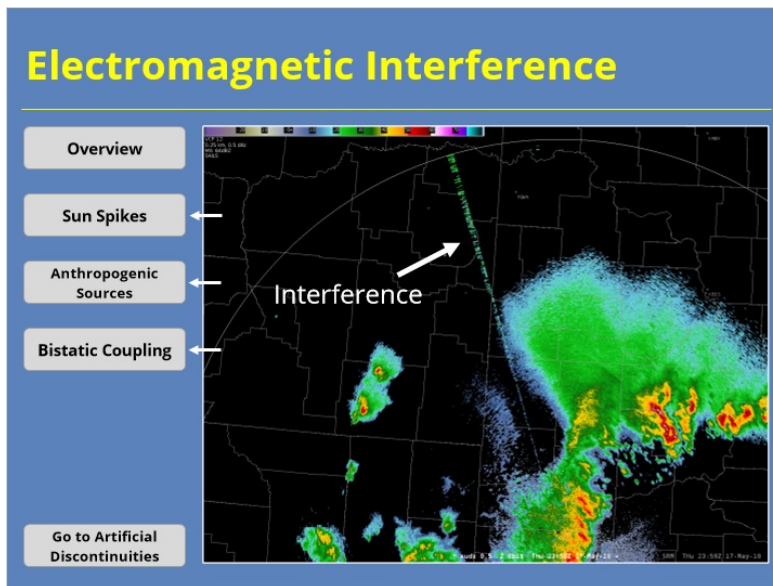
#### Common Base Reflectivity Artifacts

- Electromagnetic interference
- Artificial discontinuities
- Wet radome effect
- Clutter mitigation issues

#### **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.

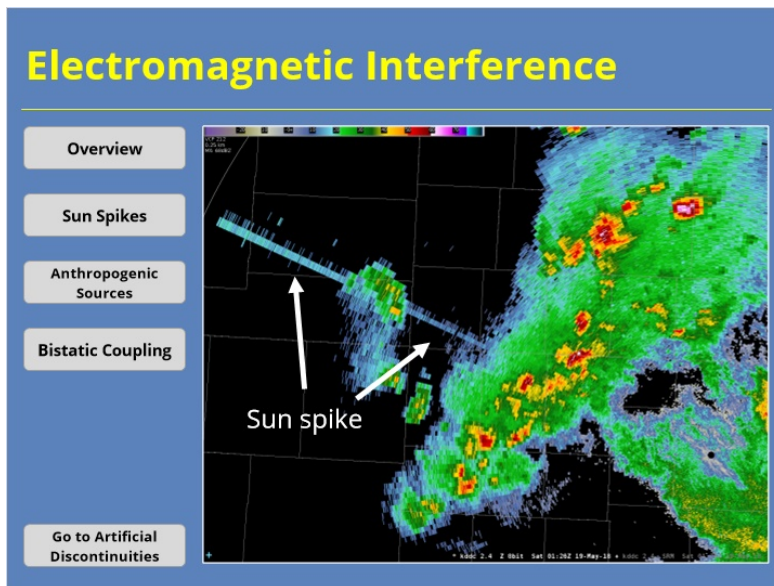
## ***Electromagnetic Interference***



**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.

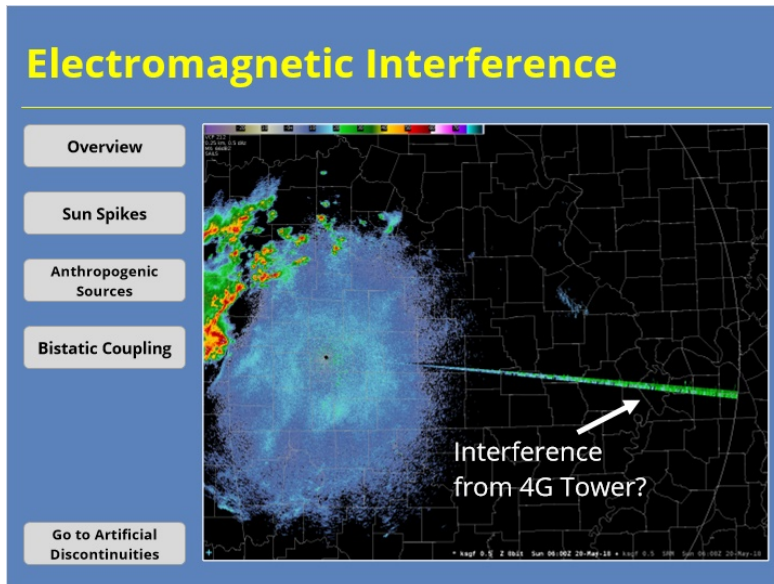
## *Electromagnetic Interference*



### **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.

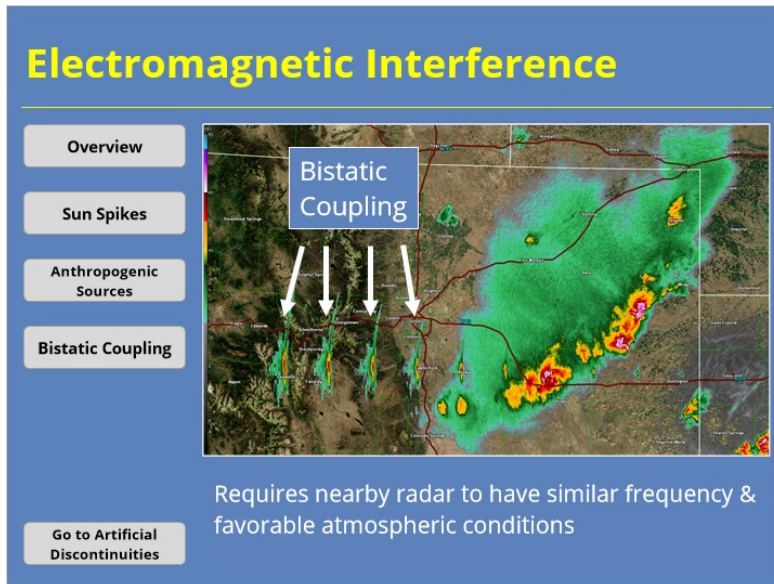
## *Electromagnetic Interference*



### **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.

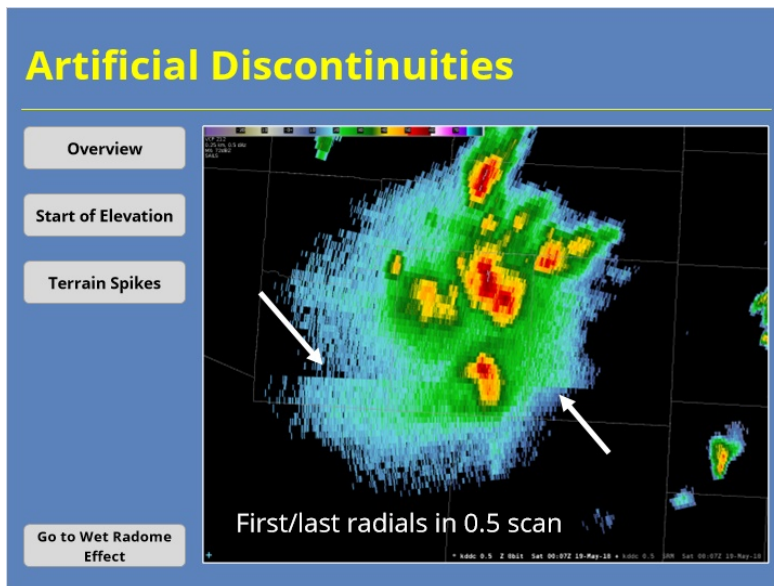
## *Electromagnetic Interference*



### **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.

## *Artificial Discontinuities*

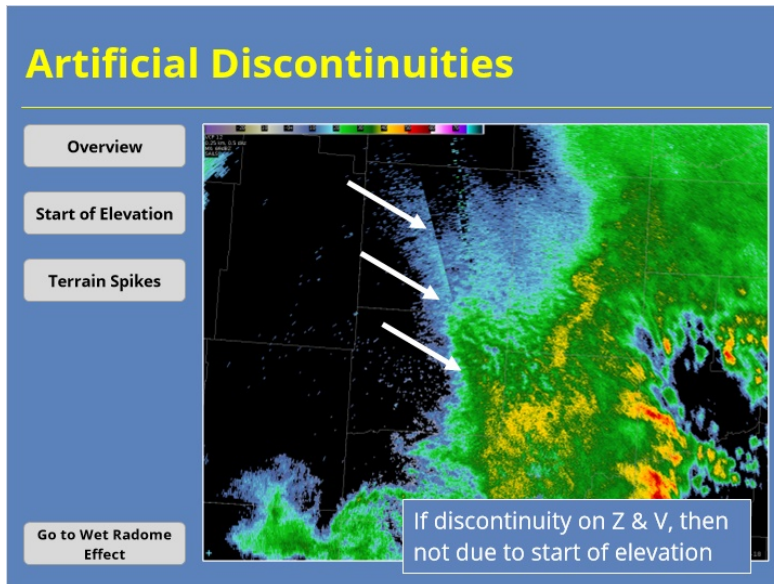


### **Notes:**

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.



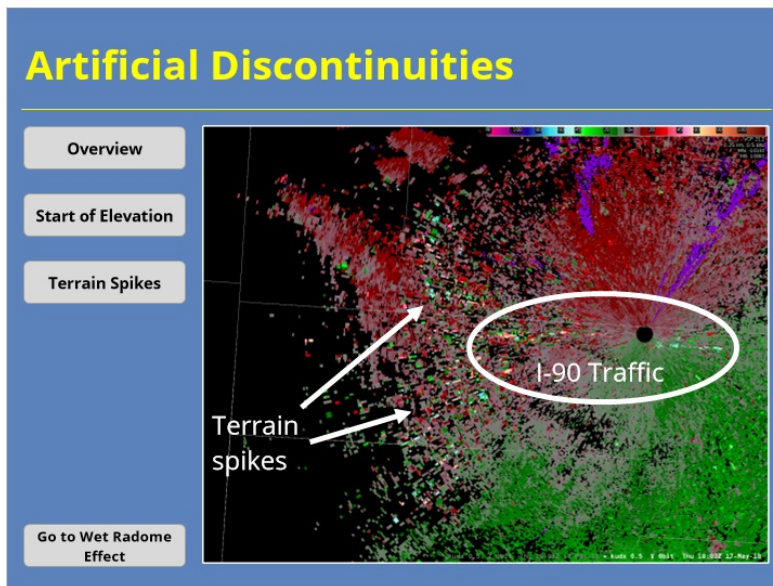
## ***Artificial Discontinuities***



### **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.

## Artificial Discontinuities

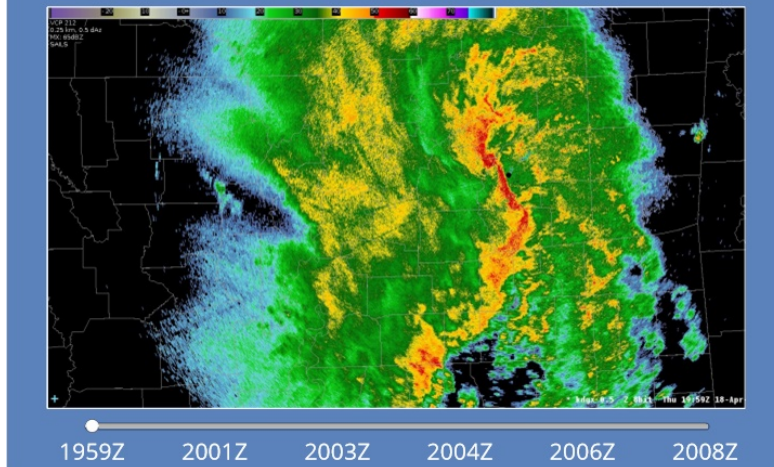


**Notes:**

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 EI) tech if you noticed this issue frequently or for a long duration.

## ***Wet Radome Effect***

### **Wet Radome Effect**

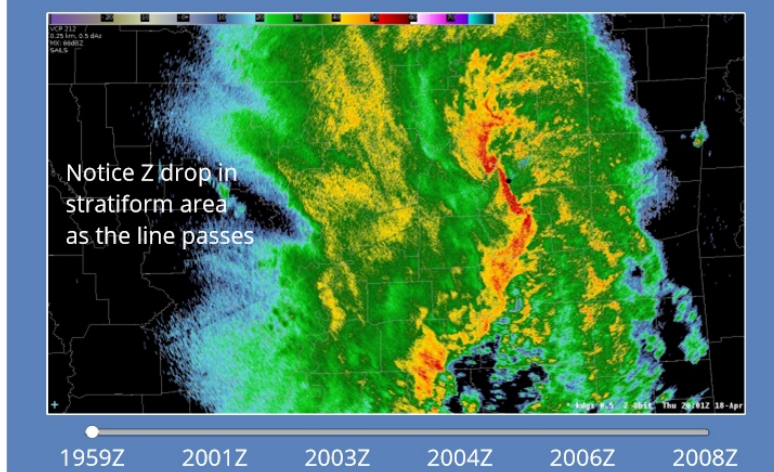


#### **Notes:**

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.

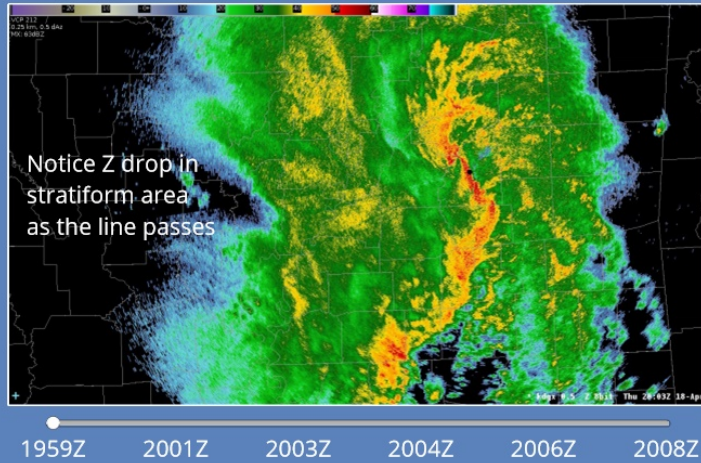
#### **2001 (Slide Layer)**

### **Wet Radome Effect**



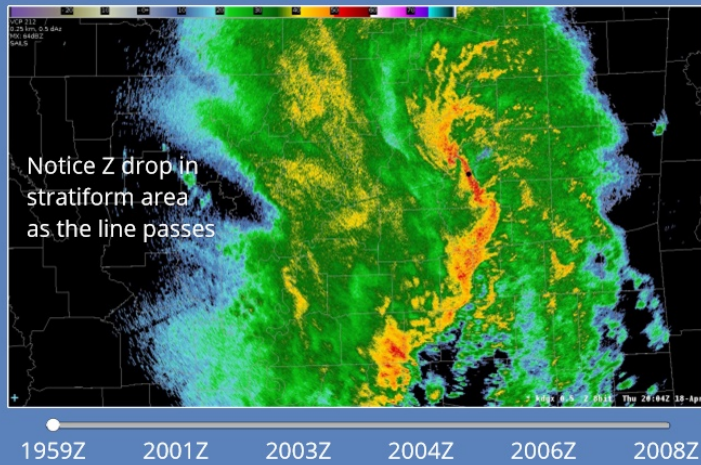
## 2003 (Slide Layer)

### Wet Radome Effect



## 2004 (Slide Layer)

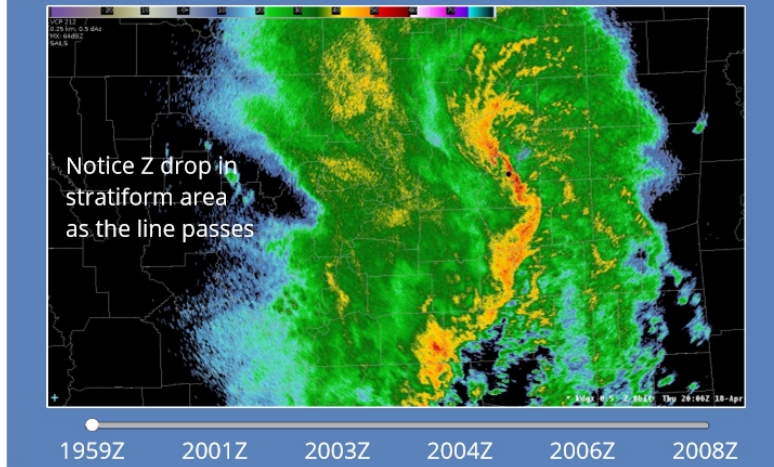
### Wet Radome Effect





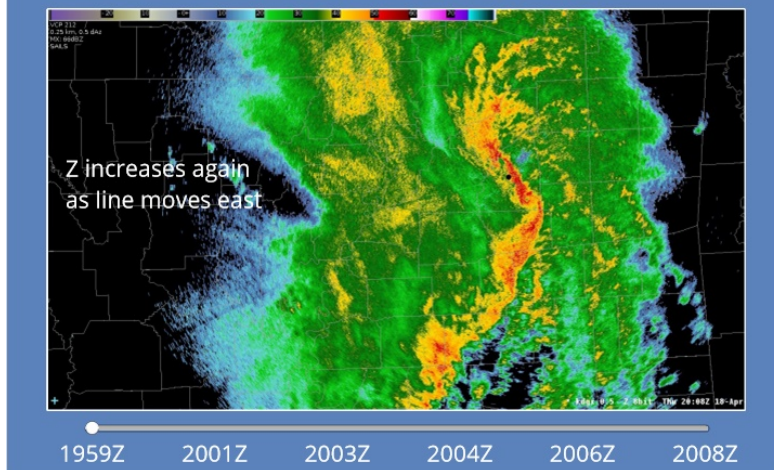
## 2006 (Slide Layer)

### Wet Radome Effect



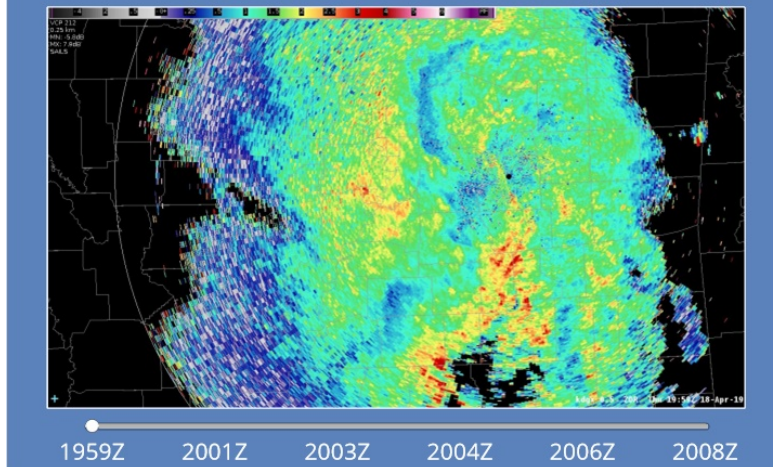
## 2008 (Slide Layer)

### Wet Radome Effect



## ***Wet Radome Effect in ZDR***

### **Wet Radome Effect in ZDR**

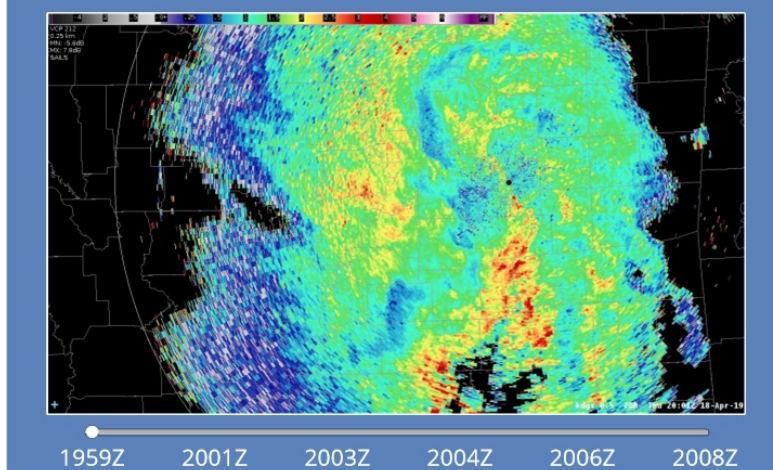


#### **Notes:**

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.

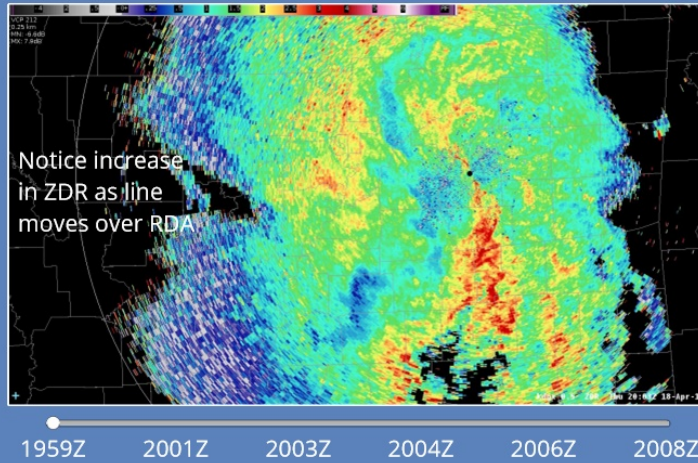
#### **2001 (Slide Layer)**

### **Wet Radome Effect in ZDR**



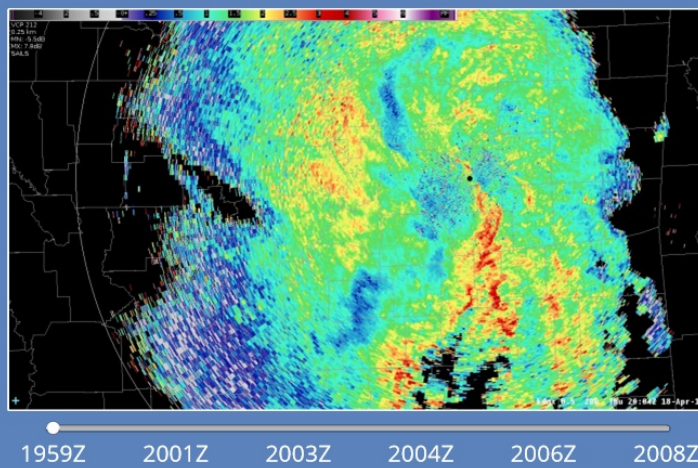
## 2003 (Slide Layer)

## Wet Radome Effect in ZDR



## 2004 (Slide Layer)

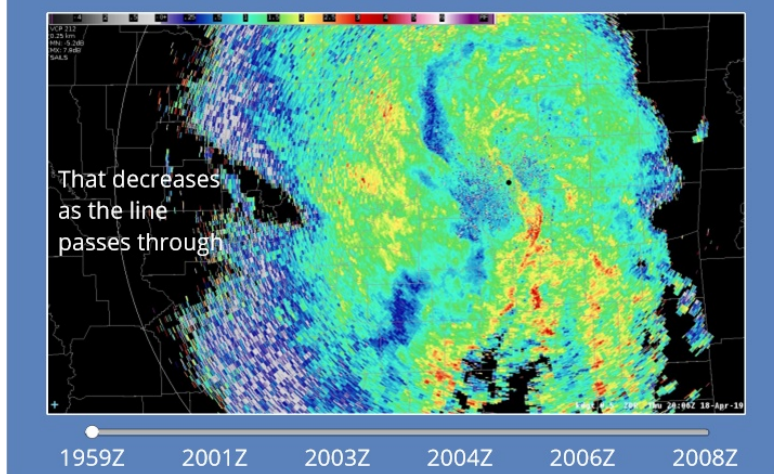
## Wet Radome Effect in ZDR





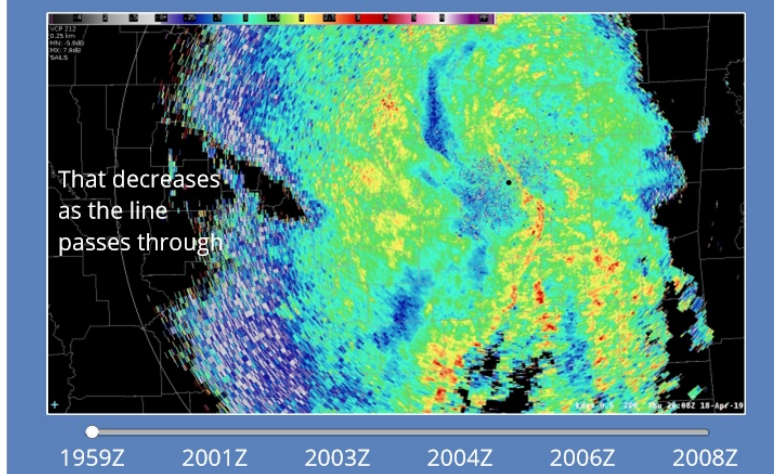
## 2006 (Slide Layer)

### Wet Radome Effect in ZDR



## 2008 (Slide Layer)

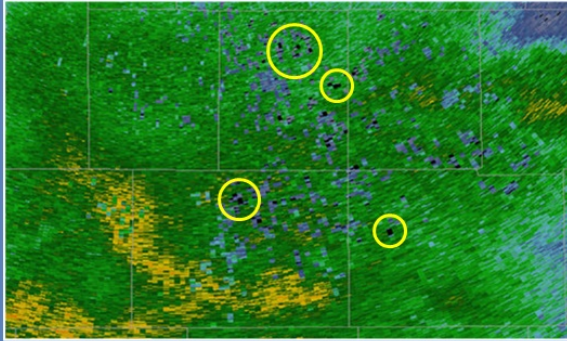
### Wet Radome Effect in ZDR





## ***Clutter Detection & Removal Issues***

### **Clutter Detection & Removal Issues**



Two clutter issues impact data quality:

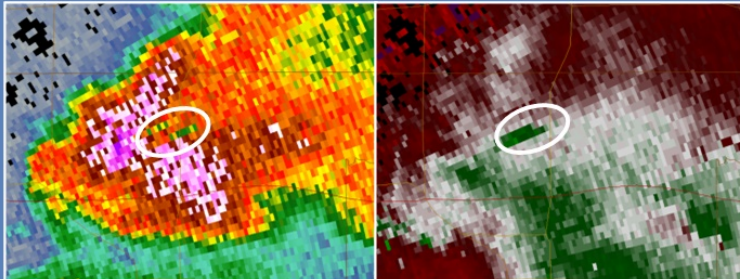
1. Detect and remove clutter where it's not
2. Miss clutter where it is

#### **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.

## ***Clutter “False Positives”***

### **Clutter “False Positives”**



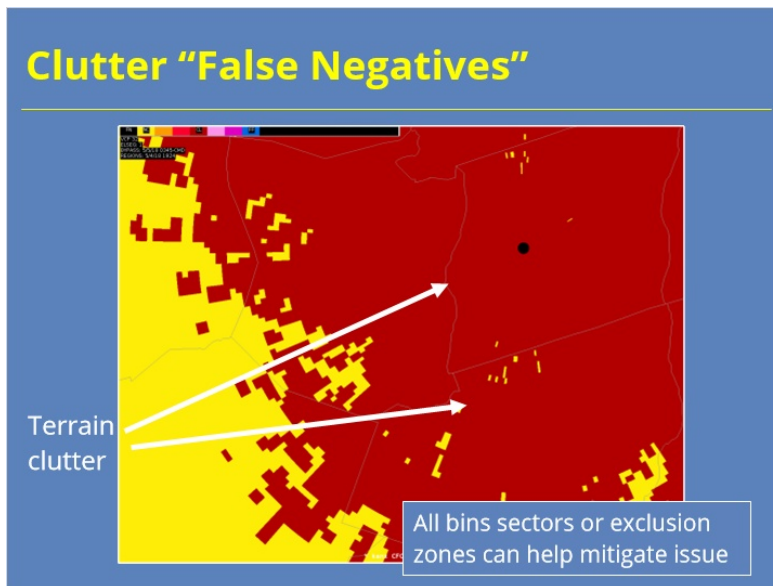
Most likely with weak returns or during fast scans with fewer pulses/radial

#### **Notes:**

The CMD algorithm uses multiple inputs to identify clutter. It performs best when a strong return signal exists and there 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.

## 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 add 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.

### 3. Velocity Artifacts

#### *Common Base Velocity Artifacts*

##### Common Base Velocity Artifacts

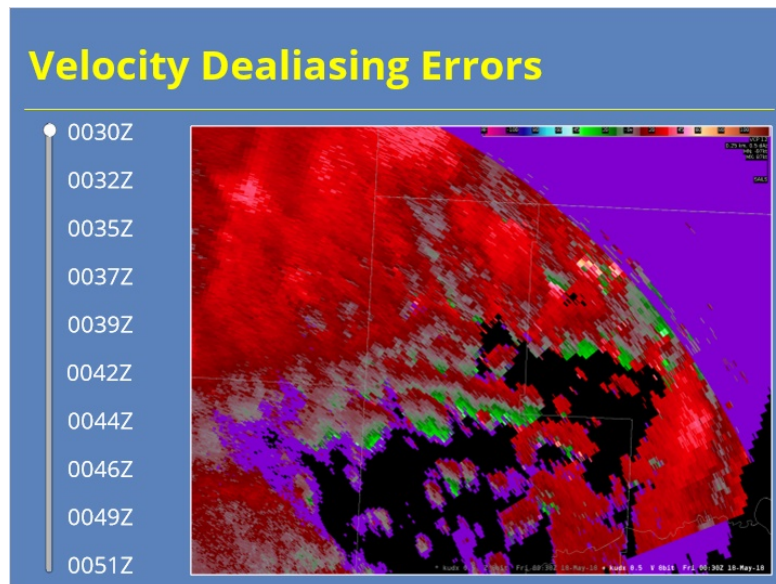
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- Velocity dealiasing errors
- Range folding artifacts

#### **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.

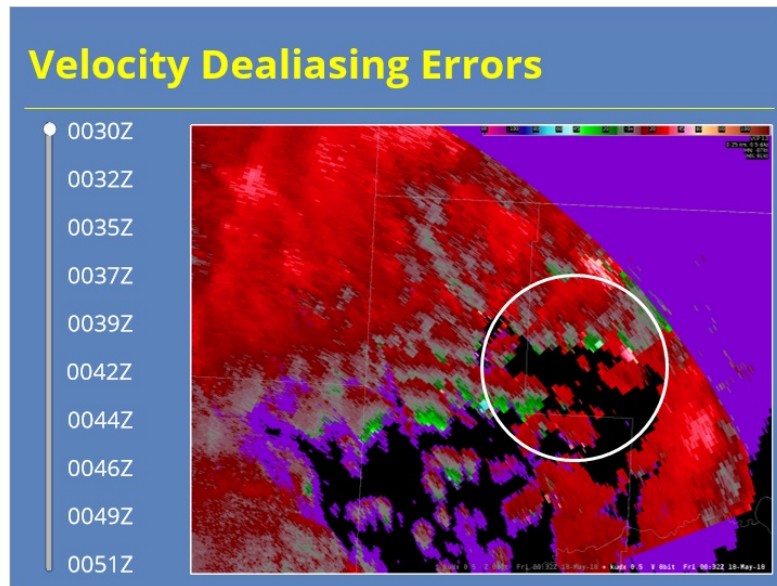
## ***Velocity Dealiasing Errors***



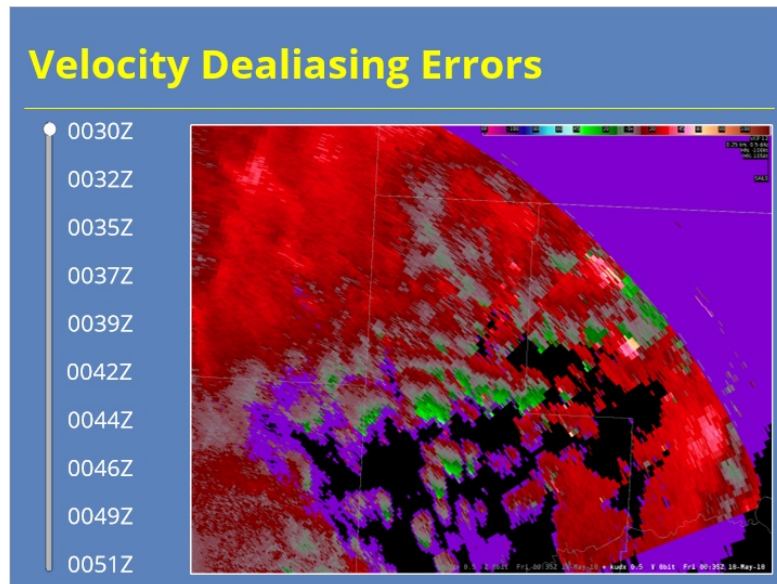
### **Notes:**

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.

## 0032 (Slide Layer)

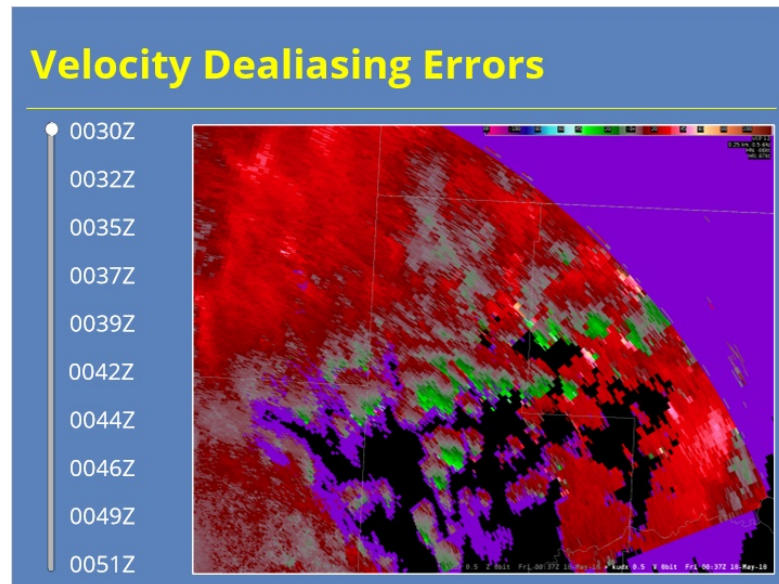


## 0035 (Slide Layer)

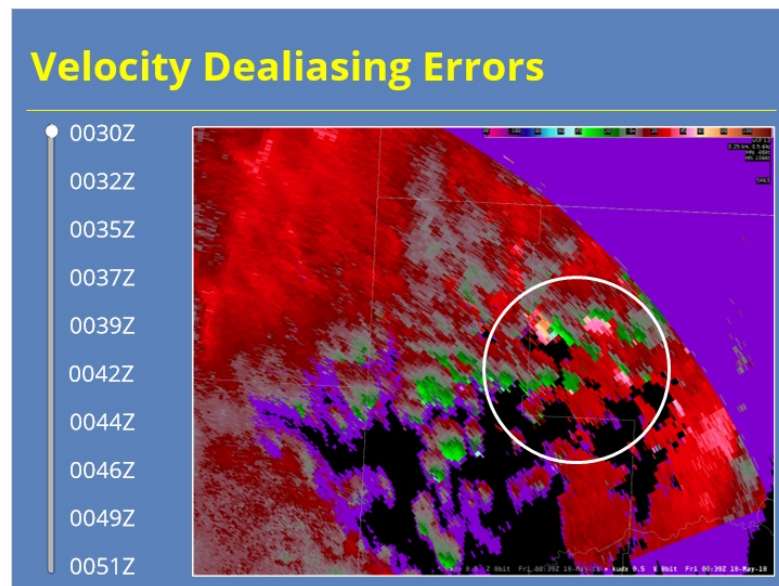




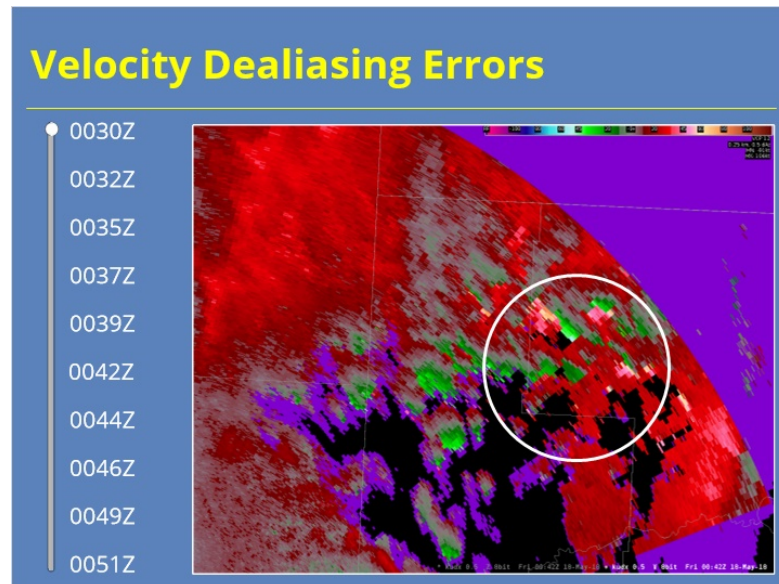
## 0037 (Slide Layer)



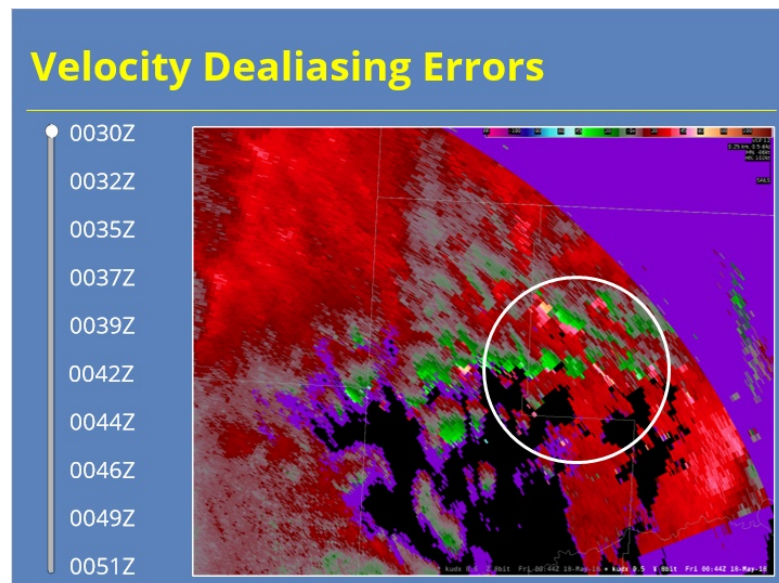
## 0039 (Slide Layer)



## 0042 (Slide Layer)

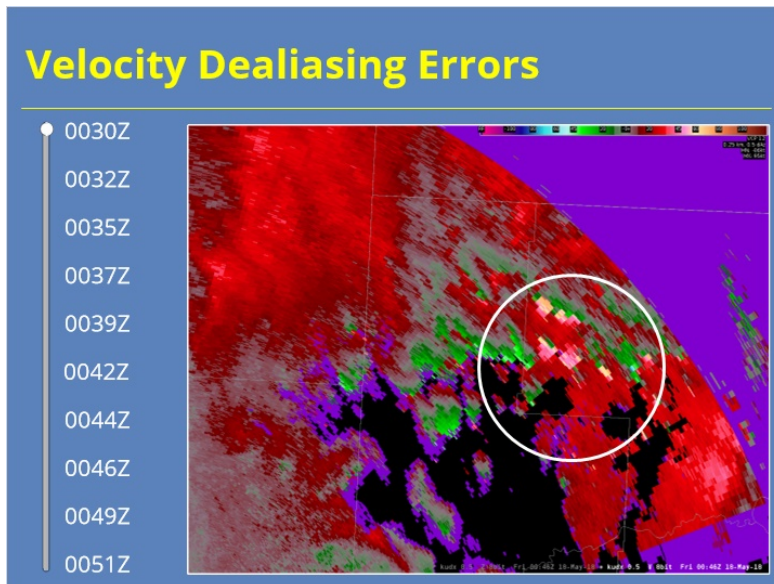


## 0044 (Slide Layer)

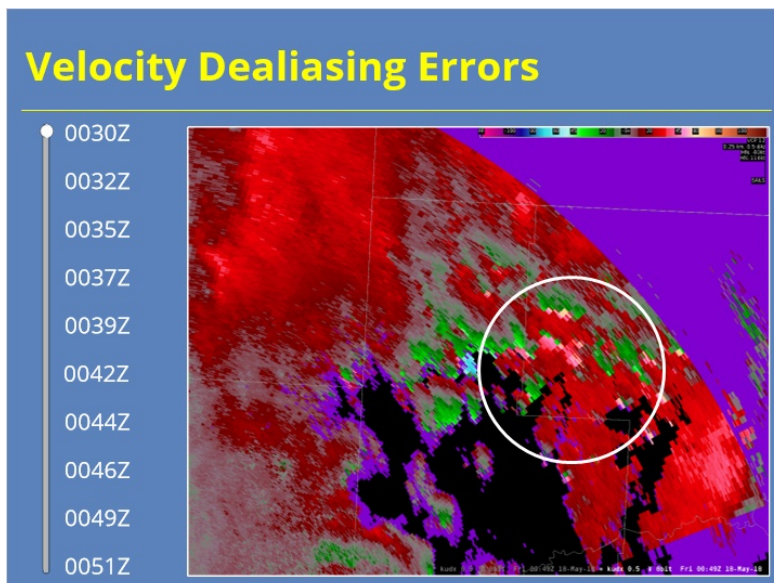




## 0046 (Slide Layer)

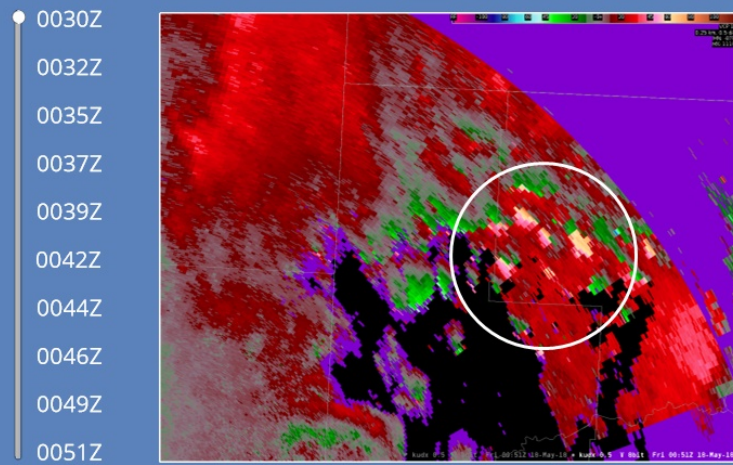


## 0049 (Slide Layer)



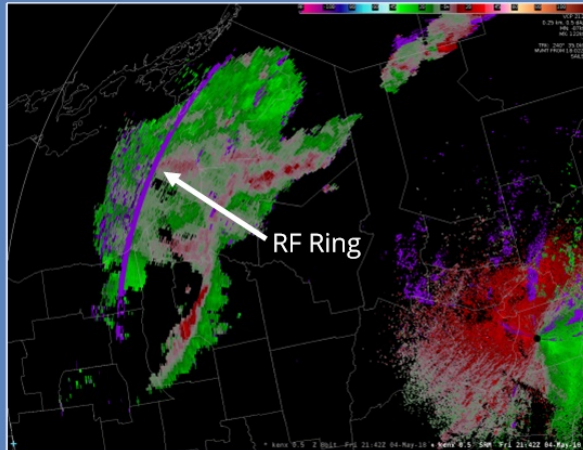
## 0051 (Slide Layer)

## Velocity Dealiasing Errors



## ***Range Folding Mitigation Artifacts***

### **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  $R_{max}$  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.

## 4. Common DP DQ Issues

### *Dual-Pol Data Quality Artifacts*

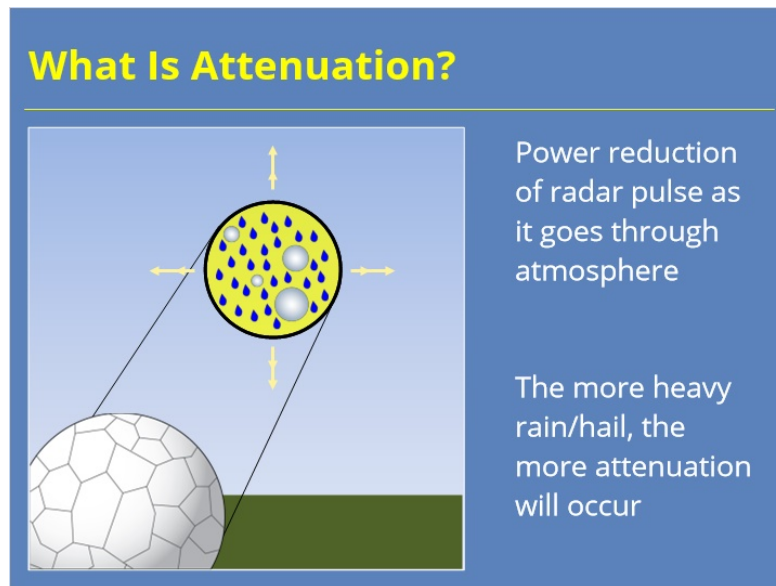
#### Dual-Pol Data Quality Artifacts

- Differential Attenuation
- Non-uniform Beam Filling
- Depolarization Streaks
- Differential Reflectivity Wedges
- Differential Phase Wrapping

#### **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.

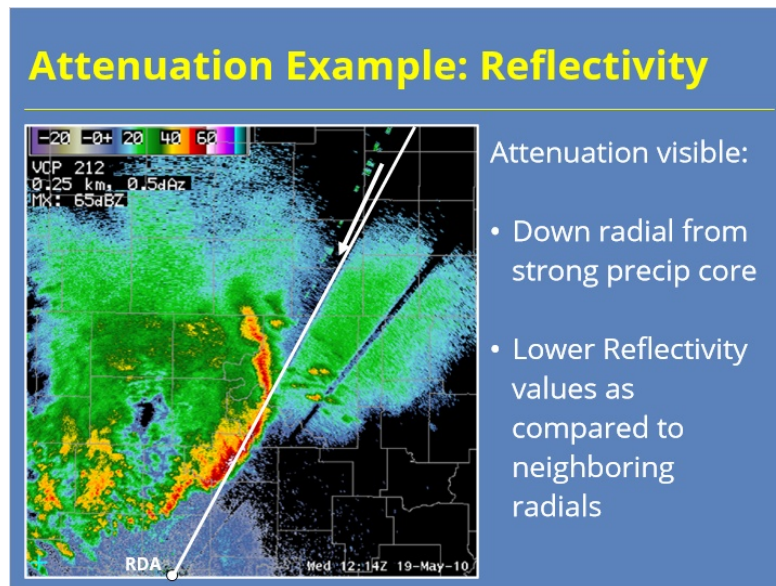
## ***What Is Attenuation?***



### **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.

## ***Attenuation Example: Reflectivity***



### **Notes:**

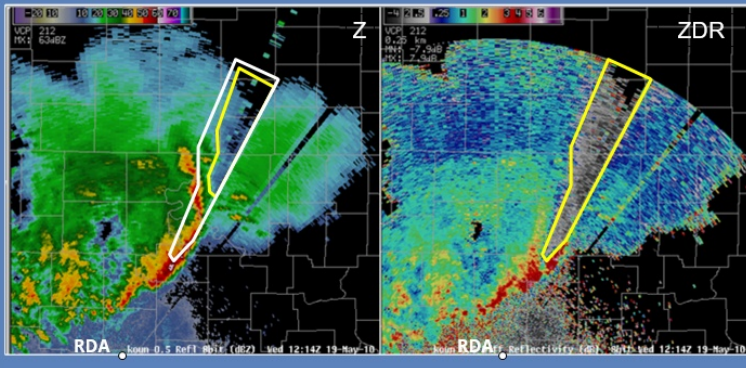
Attenuation impacts Reflectivity more than products like Velocity and Spectrum Width because it reduces the power in the radar pulse. What does a reflectivity product look like when it has been negatively impacted by attenuation? Take a look at the Reflectivity example on the slide. This squall line 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.



## ***What Is Differential Attenuation?***

### **What Is Differential Attenuation?**

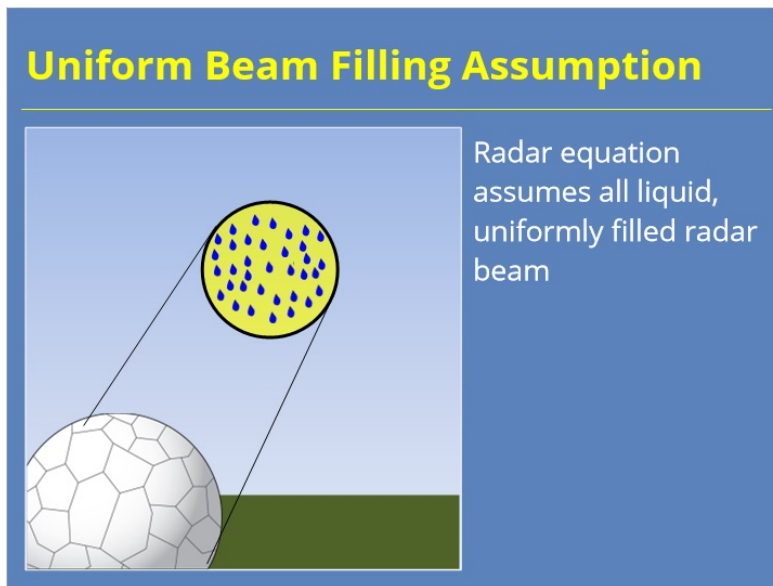
When the horizontal (typically) or vertical channel attenuates more than the other



#### **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.

## ***Uniform Beam Filling Assumption***

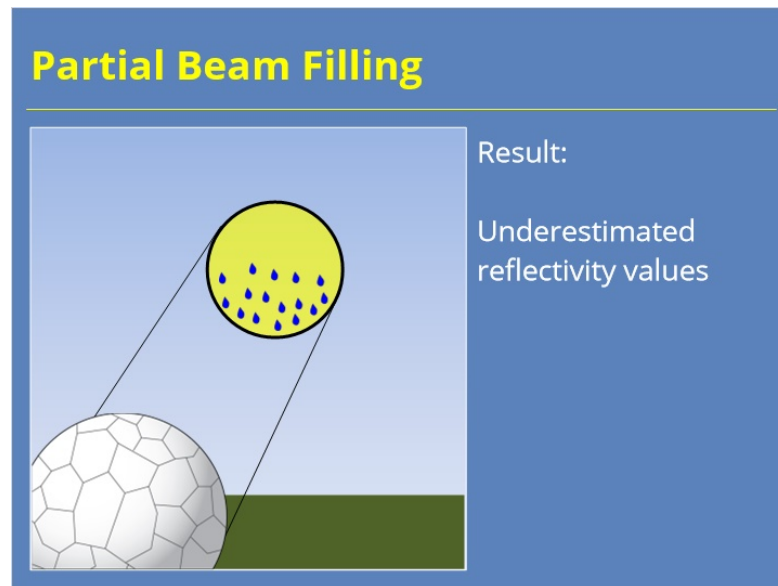


### **Notes:**

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?



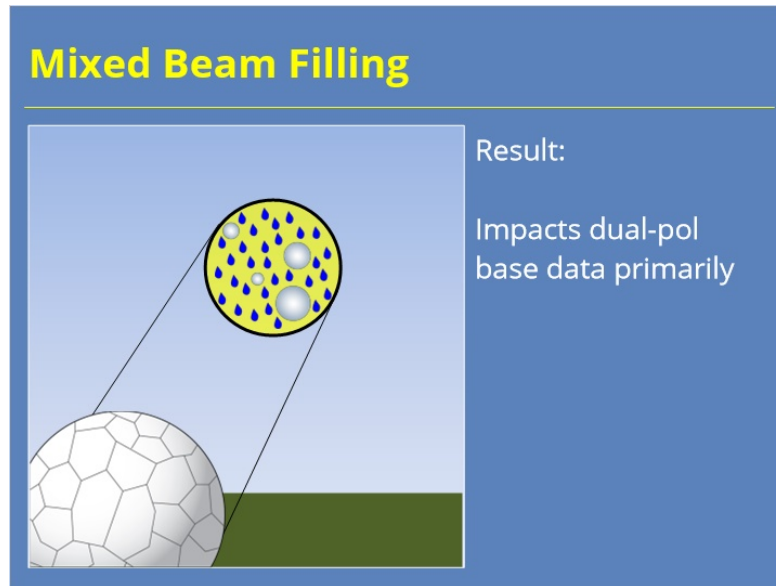
## ***Partial Beam Filling***



### **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.

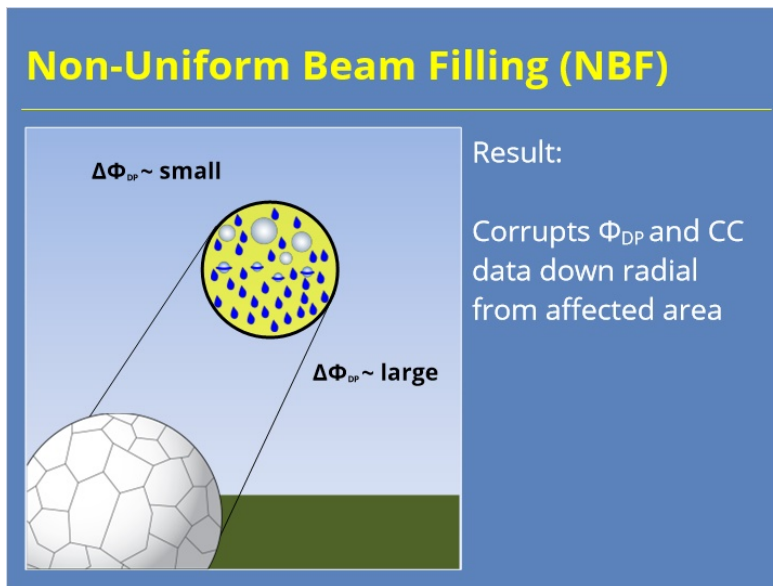
## ***Mixed Beam Filling***



### **Notes:**

When the beam is filled with a mixture of hydrometeor sizes and types, the Probert-Jones uniformity assumption isn't necessarily violated. After all, 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.

## Non-Uniform Beam Filling (NBF)

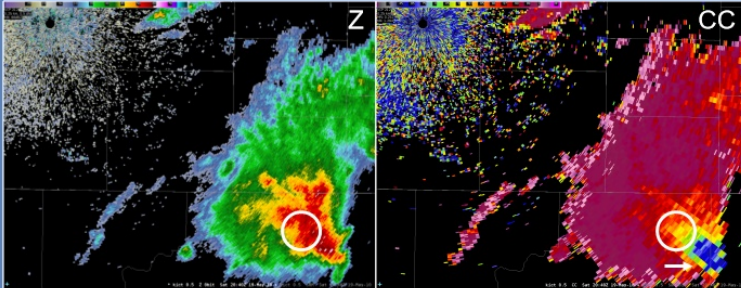


### Notes:

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  $\Phi_{DP}$  gradient across the beam that continues to propagate with the pulse down the radial. This situation results in lower Correlation Coefficient values from there on out than what actually exists in the atmosphere.

## ***Non-Uniform Beam Filling Example***

### **Non-Uniform Beam Filling Example**

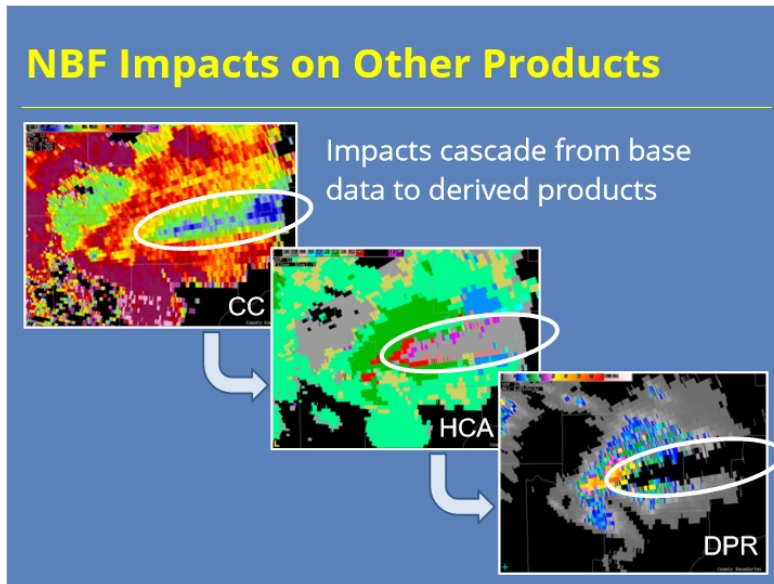


Impacts seen primarily in Correlation Coefficient base data

#### **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.

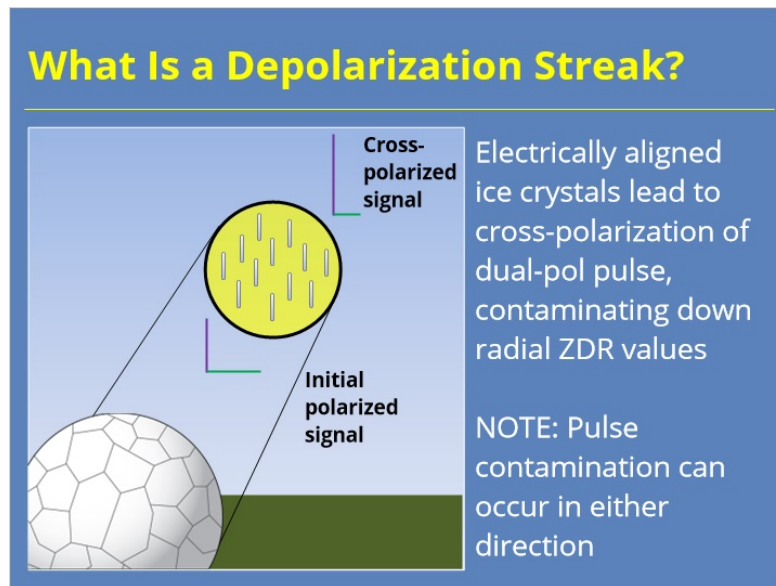
## ***NBF Impacts on Other Products***



### **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.

## ***What Is a Depolarization Streak?***

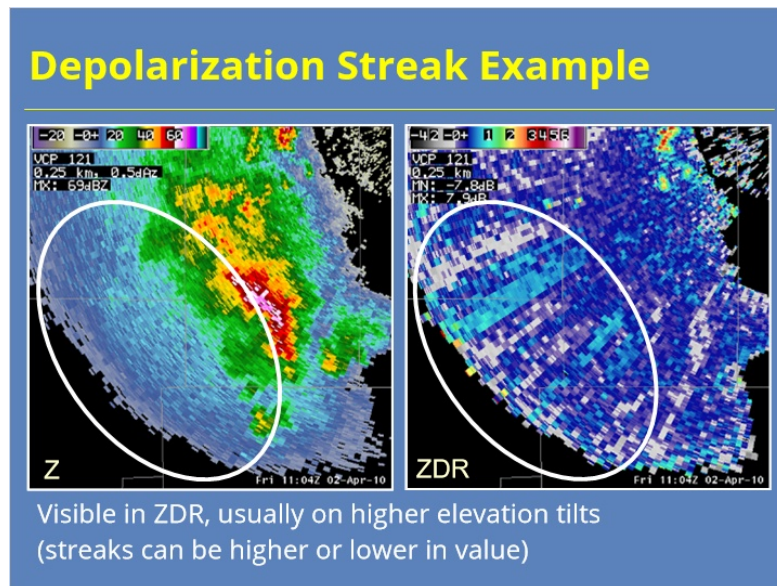


### **Notes:**

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.

## *Depolarization Streak Example*

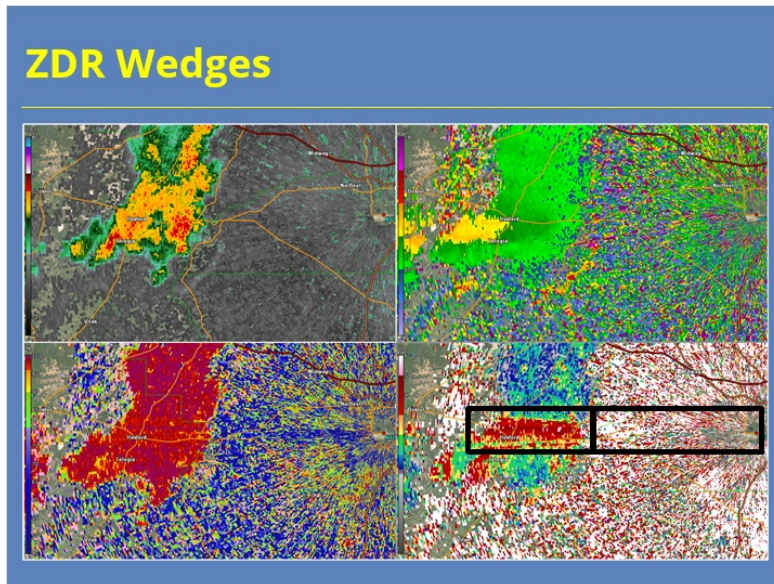


### **Notes:**

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.



## ***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.

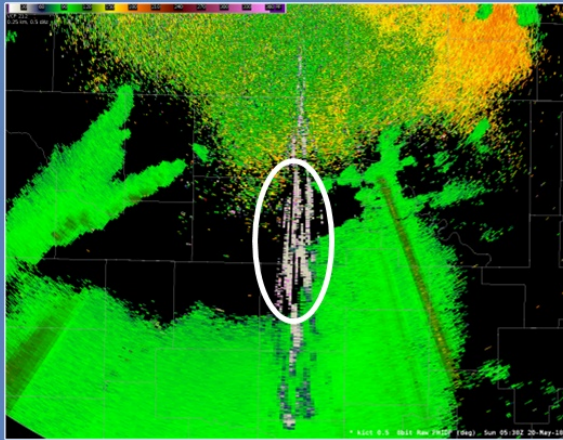


## Differential Phase Wrapping

### Differential Phase Wrapping

$\Phi_{DP}$  Notes:

- ISDP  $\sim 60^\circ$
- ISDP  $\sim 0^\circ$   
can be bad
- Wrapped  $\Phi_{DP}$  values  
impact dual-pol data

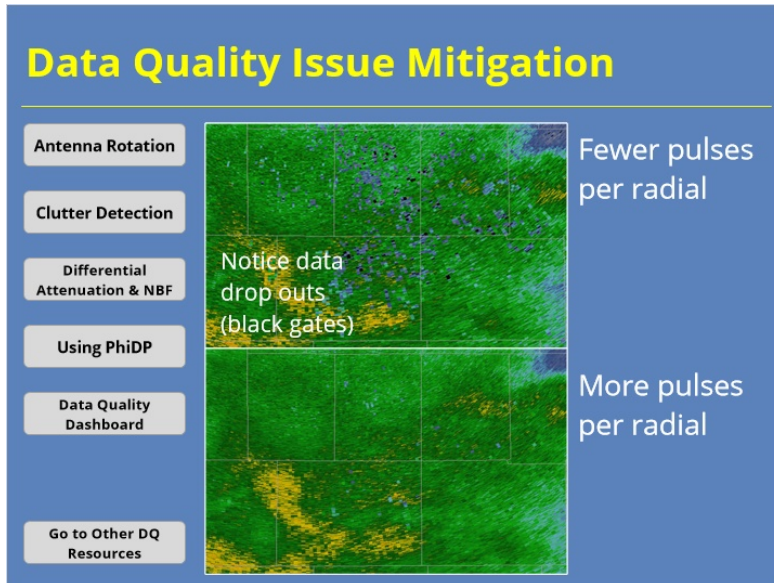


#### Notes:

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.

## 5. DQ Mitigation

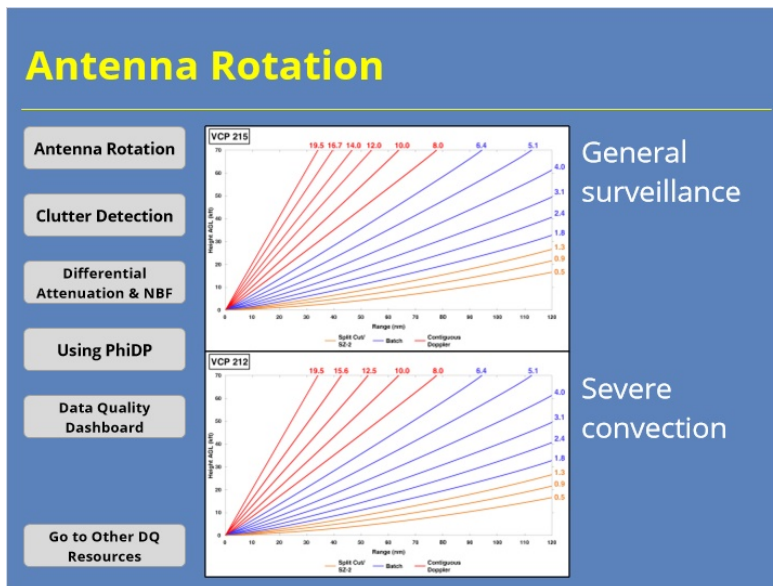
### *Data Quality Issue Mitigation*



#### **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 mitigation 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?

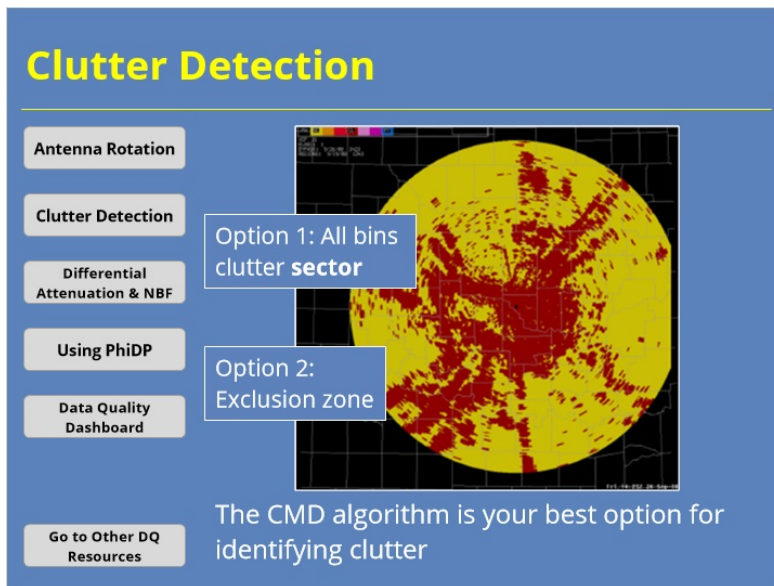
### ***Antenna Rotation***



**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.

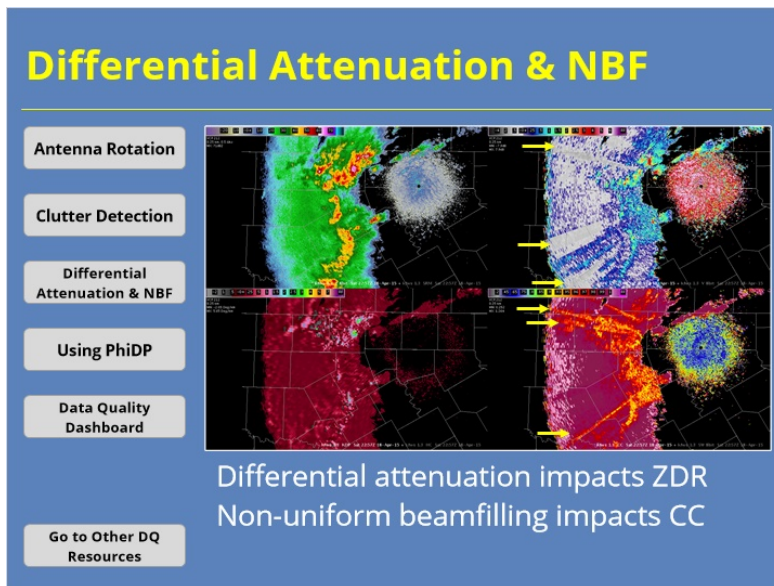
## Clutter Detection



### 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.

## ***Differential Attenuation & NBF***

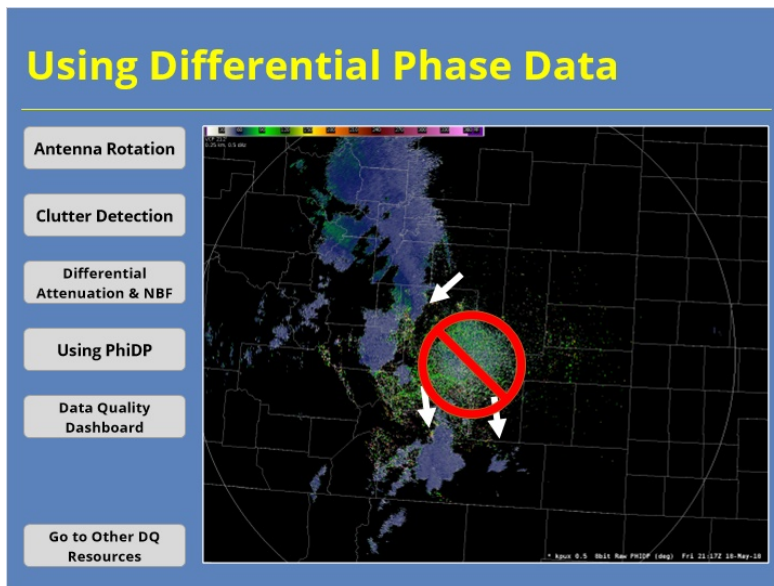


### **Notes:**

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.

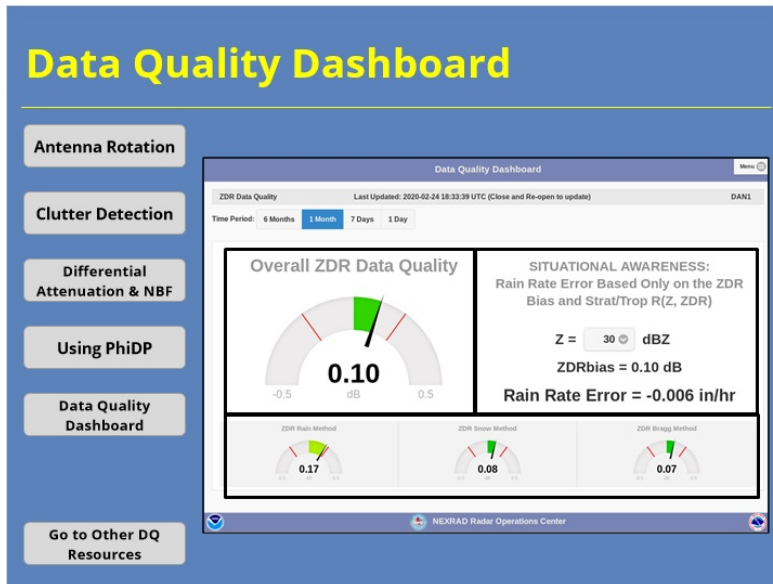
## *Using Differential Phase Data*



### **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.

## Data Quality Dashboard



### Notes:

The Data Quality Dashboard, found on the MSCF, can be another useful mitigation tool. This tool allows radar operators to identify whether the current Differential Reflectivity calibration is within accepted tolerance limits. The dashboard shows not only the overall bias, but also the bias value for the rain, snow, and Bragg bias calculation methods. Likewise, you can also get an estimate of the rain rate error for the R(Z, ZDR) accumulation for different reflectivity values based on the current calibration bias.

## Data Quality Dashboard

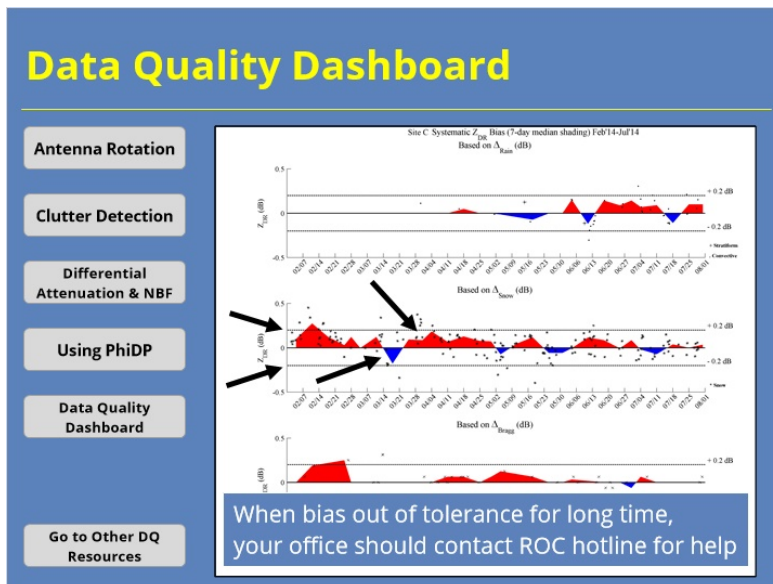


### Notes:

When using the dashboard, you will notice that bias values within tolerance limits will be shaded green. However, once a value exceeds those limits, like the value shown in the lower left, the color will change. In this case, there's a high, or warm, bias that gets shaded orange. If you want to know more about how these values change over time, you can examine that on the "shade" charts.



## Data Quality Dashboard




### Notes:

The “shade” charts show how the ZDR bias values change over time for all three calculation methods. The color scheme on these charts is a little different than on the main dashboard. Here, any positive bias value will appear red while negative bias values appear blue. You then use the two dashed lines in each graph to determine if the values are within the tolerance limits of  $\pm 0.2$  dB. If the calibration is routinely outside of these limits, you should tell your radar focal point and/or EI tech. They can then reach out to the ROC Hotline for further assistance on the issue.

## 6. Other DQ Resources


### *Other DQ Resources for the NWS*

### Other DQ Resources for the NWS



**WDTD:**

- E-mail: [nws.wtdt.rachelp@noaa.gov](mailto:nws.wtdt.rachelp@noaa.gov)
- Web: <https://training.weather.gov/wtdt/>
- Contact WDTD staff directly



**ROC Hotline:**

- Contact info: <https://www.roc.noaa.gov/security/files/pdfs/Hotline.pdf>

**Other:**

- 88D e-mail forum

#### **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.

## ***Shift Change Checklist Product***

### **Shift Change Checklist Product**

Message Date: Jul 28 2018 13:05:44

ICAO: KICT      Date/Time: 07/28/18 13:05:39    Shift Change Checklist  
RDA Status:

RDA Alarm Summary:	No Alarms
RDA Operability Status:	On-Line
RDA Status:	Operate
Control Status:	RPG
Transition Power Source (TPS):	OK
Aux Power Generator State:	Utility Pwr Avail
Super Resolution (SR):	Enabled
Clutter Mitigation Decision (CMD):	Enabled
Horiz./Vert. Delta dBZ0:	-0.26 dB / 0.17 dB
Average Transmitter Power:	1454 W
VCP Number / VMI:	R215 / 0.97 knots (0.5 m/s)
AVSET Status:	Enabled

Product generated once per hour by default

#### **Notes:**

The RPG routinely generates the Shift Change Checklist product with lots of important information about 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.

## Spotting Errors in the Checklist Product

### Spotting Errors in the Checklist Product

```
VAD Update/Model Update:      ON / ON
Temp Heights (0C/-20C):      13.2 / 22.4 Kft
Wetbulb Heights (0C/-25C):    9.7 / 23.6 Kft
Default Storm Motion:        225 @ 25.0 kts
Algorithm Status/Data:
PPS/QPE Precip Status (Area KM^2):  Accum (3448) / Accum (4357)
PPS Z-R Relationship:         CONVECTIVE (Z = 300.0*R^1.4)
PPS RAINA/RAINZ/MXPRA:       80 km^2 / 20.0 dBZ / 200.0 mm/hr
QPE Precipitation Type:       TROPICAL
QPE PAIF Area/Rate/Max Precip Rate: 80 km^2 / 0.5 mm/hr / 200.0 mm/hr
QPE Multis (GR/HA/DS/DS<ML/IC/WS): 0.8/0.8/2.8/1.0/2.8/0.6
```

#### 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.

## 7. Summary & Quiz

### *Summary*

#### Summary

Discussed several topics related to base data quality:

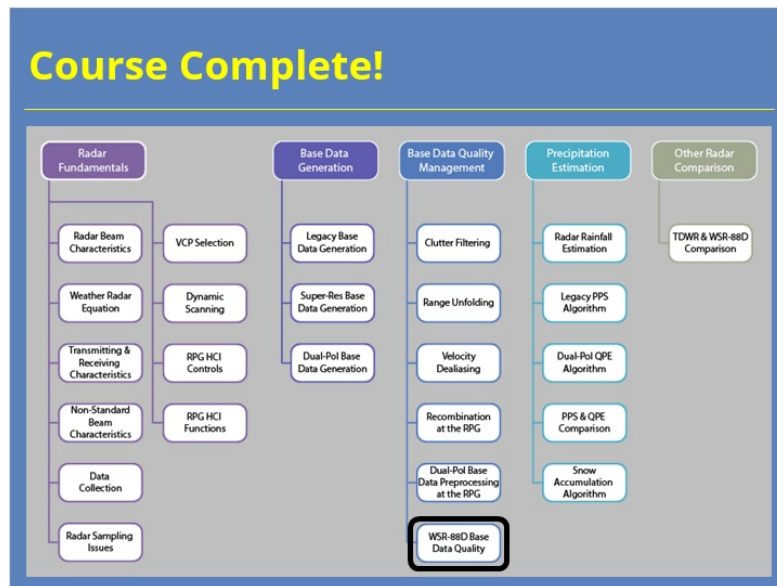
- Data artifacts seen in:
  - Base Reflectivity,
  - Base Velocity, &
  - Dual-pol products
- General ways to mitigate potential data quality issues
- Highlighted other data quality resources available to you & your office

#### **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.

**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.

# Radar Rainfall Estimation Errors

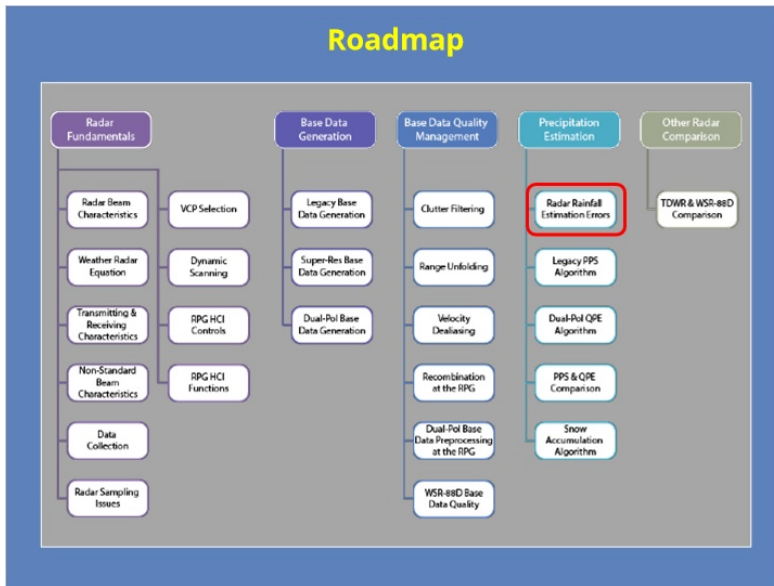
## 1.1 Title Slide



### Notes:

Welcome to Principles of Radar! My name is Katy Christian and I'll be your guide through today's lesson over Rainfall Estimation Errors.

### 1.3 Roadmap



#### Notes:

Just for some context, here is the roadmap for the entire Radar Principles section of RAC - right now, you are here so let's keep moving forward!



## 1.4 Learning Objectives

### Learning Objectives

To **identify** the following about radar rainfall estimation errors:

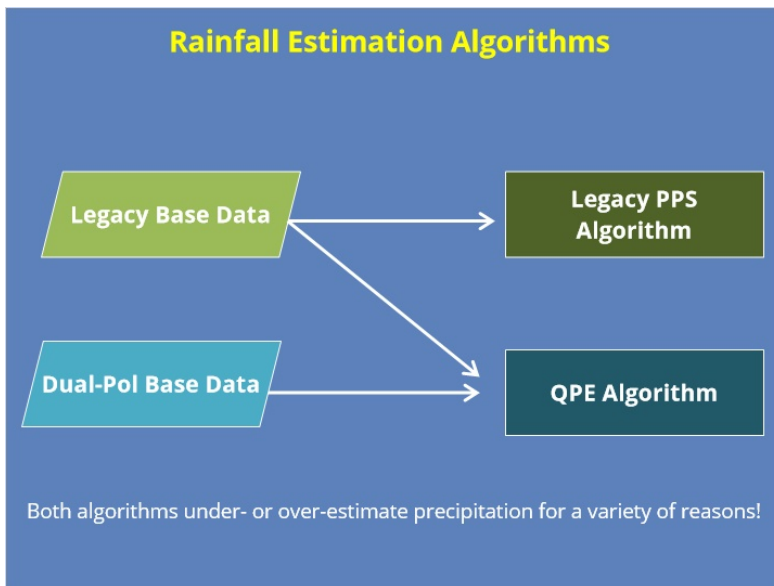
- What algorithms are used to estimate rainfall?
- What are the errors?



### Notes:

The learning objectives for this lesson are to identify: 1) what algorithms are used to estimate rainfall and 2) to identify what are some of the common rainfall estimation errors that we see in these algorithms.

## 1.5 Rainfall Estimation Algorithms

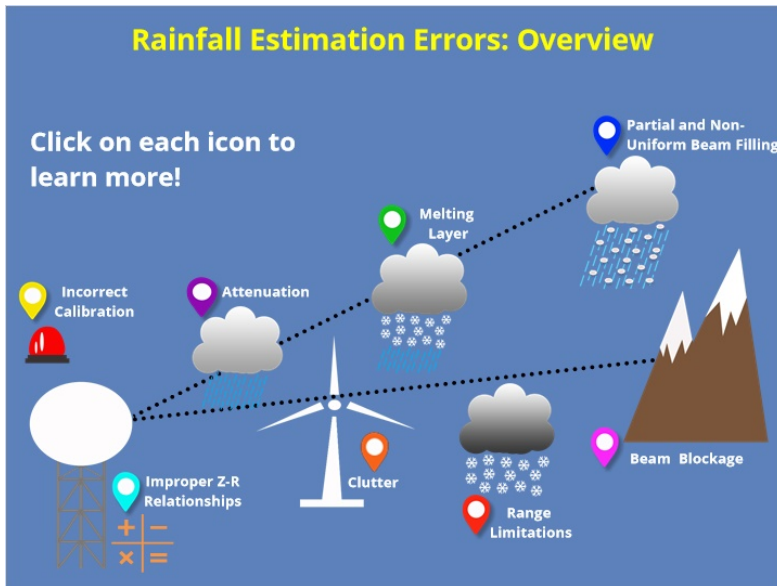


### Notes:

There are two algorithms used in the estimation of rainfall. The first estimates rainfall using the Legacy base data and is referred to as the Legacy Precipitation Processing Subsystem, or Legacy PPS. The second algorithm uses both the legacy and dual-pol base data to estimate rainfall data and is referred to as the QPE algorithm.

Both the Legacy PPS and QPE algorithms can under- or over-estimate rainfall for a variety of reasons we will explore shortly.


## 1.6 Rainfall Estimation Errors: Overview



### Notes:

Alright, let's now take a look at all the things that can cause rainfall estimation errors in both algorithms. Below is a roadmap of the most common sources of rainfall estimation errors. To learn more about each one, simply click on the corresponding icon. When you are done exploring each topic, click next to continue.

## 1.7 Clutter

**Clutter**

**What causes it?**

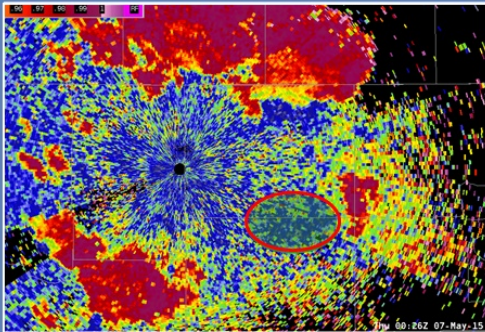
- Clutter algorithm is turned "off" or sources of clutter have a moving component

**What are some common moving sources of clutter?**

- Wind farms, moving cars, insects, birds, airplanes, and superman

**What are its affects?**

- Clutter may be mistaken for real storms!

**Clutter Example**

Click on the image where you think clutter is present!

### Notes:

You probably already have a general idea of what clutter is, but how does it happen? Clutter errors can occur when the clutter filtering algorithm is turned off or when clutter remains after filtering. Remember from an earlier module that the clutter algorithm works only if the clutter echoes are NOT moving. So, clutter will not be filtered out if any of the sources have some movement associated with them. So, what are these? Common moving sources of clutter include wind farms, moving cars, insects, birds, airplanes, and Superman if real.

Take a look at the image below. Multiple storms are ongoing at this time as well as some clutter that did not get filtered out. Can you guess where it is? Click on the image where you think it's occurring and I'll let you know once you've got it. If you guessed this area, you are correct! These stationary high, noisy reflectivities are actually the result of a wind farm here! You can confirm this by toggling over to correlation coefficient and making sure you have low CC values, which we do indeed see we have. You should also see low velocity and spectrum width values.

So, how does clutter impact precipitation estimates? If you're not careful, clutter may be incorrectly interpreted as precipitation echoes, especially when they occur in the midst of ongoing storms as we see in the figure here. Therefore, it's important for you as a forecaster to be aware of what various types of clutter look like and know what types of clutter frequent your CWA.

### 1.8 Improper Z-R Relationships

$+$

$-$

$\times$

$=$

# Improper Z-R Relationships

## What is the issue?

- Z-R relationships are empirically derived and fixed

## What is a common source of error?


- Chosen Z-R relationship does not reflect the environment

## What are its affects?

- Improper Z-R can cause drastic under- or over-estimation of rainfall

### Example: Improper Z-R Relationship

(a) Default Z-R



(b) Tropical Z-R





Image Source: Vitale et al. (2009)

**Notes:**

Remember that the relationships that convert reflectivity to rainfall rate, or Z-R relationships, are empirically derived and fixed. If you are using the Legacy PPS, a few of the most commonly used Z-R relationships are shown in the figure below. Because it is up to the forecaster to choose the appropriate Z-R relationship for a given event, errors in precipitation estimates may creep in if the forecaster is not vigilant in choosing the Z-R relationship that most closely mirrors the precipitation event type.

An example of this is shown in the below images from a study in 2009 over the historic flash flooding in central Kansas in August of 2003. The two images show precipitation estimates for the same event but from using two different Z-R relationships: the convective Z-R relationship on the left and the tropical Z-R relationship on the right. As you can see, the difference in precipitation estimates from Z-R relationships alone is quite drastic - as much as 3 inches in difference! For this historic event, the convective Z-R relationship severely underestimated rainfall amounts while the tropical relationship more closely mirrored local gauge amounts. We'll discuss Z-R relationships more in the next module but just be aware that they can be a source of prescription errors if neglected.

## 1.9 Beam Blockage



### Beam Blockage

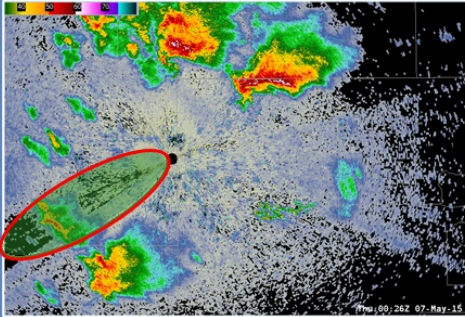
**What is the issue?**

- Radar beam is blocked by trees, terrain, mountains, or buildings

**What are its affects?**

- Precipitation estimates are not calculated or greatly underestimated

**Radar Beam Blockage**



**Dual-Pol offers a workaround for estimating precipitation in areas of beam blockage.**

Click on the image where you think beam blockage is present!


**Stay tuned!**

### Notes:

Another source of precipitation error is when the radar beam is either partially or completely blocked by geographic features or buildings. In the image shown here, can you guess where beam blockage is occurring? Click on the image where you think it's occurring and I'll let you know once you've got it. If you guessed this region, you are correct! Several trees to the southwest of the radar partially block the radar beam. While beam blockage can occur anywhere, it is especially prevalent in the western United States where large mountains often completely block the radar beam.

In cases where the radar beam is partially blocked by terrain, any precipitation that is detected beyond the blockage will be underestimated as the hydrometeors will be sampled by a reduced power beam and will have a diminished return. There is a work around for estimating precipitation in areas of beam blockage using dual-pol but we will discuss that in a later lesson. So, for now just know that beam blockage can cause significant errors in precipitation estimates.

## 1.10 Incorrect Calibration



### Incorrect Calibration

#### What is the issue?


- Radar may not meet calibration standards

#### What are the calibration standards?

- Z: Within +/- 1 dB
- ZDR: Within +/- 0.2 dB

#### What are its affects?

- Precipitation estimates are either under- or over-estimated




### Notes:

Over time and use, a radar may fail to meet certain calibration standards. If you notice that precipitation estimates from your radar routinely do not match with gauge observations and seem unreasonably high or low, you may want to check to see if it is correctly calibrated.

You can do this a couple of ways. To check calibration using reflectivity, you can find this on the RPG Control Status page under the Environmental Tab. The highlighted green box displays calibration values for both the horizontal and vertical channels. For calibration using reflectivity, these values should be within an accuracy of +/-1 dB. So for the example shown here, the reflectivity calibration values are in good shape!

For calibration using differential reflectivity, an easy and quick way to check values is to go to the data quality dashboard page. For differential reflectivity, calibration values should be within +/-0.2 dB. If values fall outside this range, this is a sign your radar may be incorrectly calibrated and should be further investigated by the electronics maintenance staff. Calibration errors can result in large errors in precipitation estimates, whether they be under or overestimation errors.

## 1.11 Melting Layer



### Melting Layer

**What is it?**

- Layer where hydrometeors transition from solid to liquid

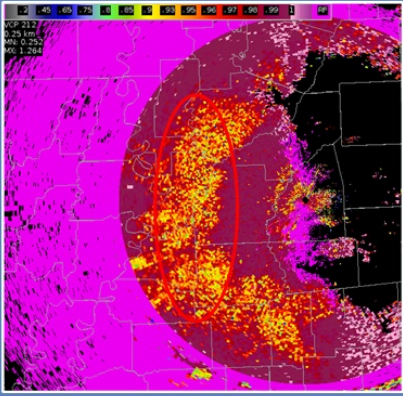
**What causes errors?**

- Radars assume Rayleigh scattering but this is violated in the melting layer!

**What are its affects?**

- Overestimates precipitation (up to 5x)!

Melting Layer/Bright Band



\* Know the level of the 0 degree isotherm!


### Notes:

The melting layer, or “bright band”, is a layer within the atmosphere where hydrometeors transition from solid to liquid. To understand why the melting layer creates a precipitation estimate issue, remember from earlier that radars assume Rayleigh scattering where the particles detected are assumed to be much smaller than the radiation emitted. However, in the layer, Rayleigh scattering is violated because very large hydrometeors exist. This acts to greatly enhance reflectivities and results in a large overestimation of precipitation, sometimes up to five times more than they should be!

In the example below, you can see a band of enhanced reflectivities surrounding the radar and if you toggle over to correlation coefficient, you can see that in this same band, CC values around 0.9 indicating mixed phase precipitation within the melting layer. One way to prevent incorrectly identifying the bright band as a measure of surface rainfall is to know at what level the 0 degree isotherm exists



## 1.12 Range Limitations



### Range Limitations

#### What is the issue?

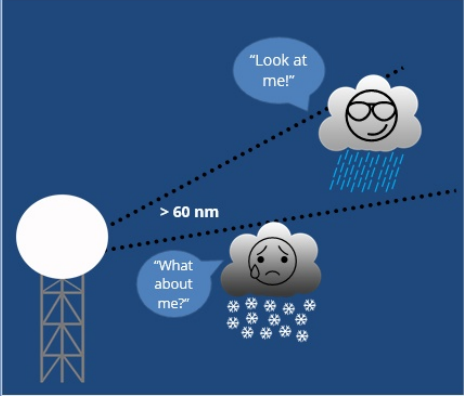
- Radar beam overshoots precipitation
- Radar beam undershoots precipitation

#### Where is this common?

- **Overshooting:** Low cloud base environments (cool season)
- **Undershooting:** Dry sub-cloud environments (western U.S.)

#### What are its affects?

- **Overshooting:** Underestimation of rainfall
- **Undershooting:** Overestimation of rainfall




### Notes:

The effects of range are a fundamental challenge when using radar to estimate rainfall. One of the biggest estimation errors is when the radar beam overshoots precipitation, resulting in a gross underestimation or the radar not even sensing the precipitation. Overshooting is particularly a problem during the cool season when low cloud bases with shallow precipitation are common. For most radars, overshooting becomes a major issue at long ranges, so anything > 60 nautical miles.

Another artifact of range is the reverse where instead of overshooting the precipitation, the radar beam detects rain aloft but due to evaporation below, all the rain is evaporated before it reaches the ground so the radar is grossly overestimating precipitation. This is often the case in dry desert environments in the West where deep, dry sub-cloud layers evaporate any falling precipitation. So, just be aware that the further you are from the radar, the greater the chance the radar could be overshooting precipitation or indicating rain even though it never makes it to the surface.

## 1.13 Attenuation



### Attenuation

#### What is attenuation?

- Reduction in power transmitted and returned by the radar

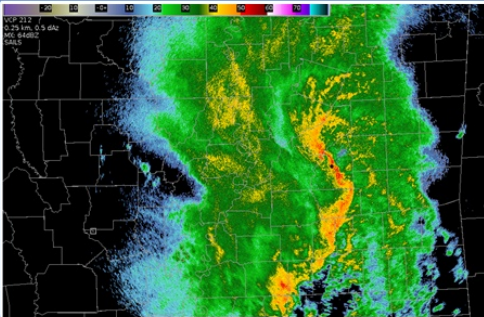
#### What causes it?

- Heavy rain, large hail cores, and a wet radome

#### What are its affects?

- Underestimation of precipitation

#### Attenuation from Wet Radome



Click on the image where you think attenuation is present!

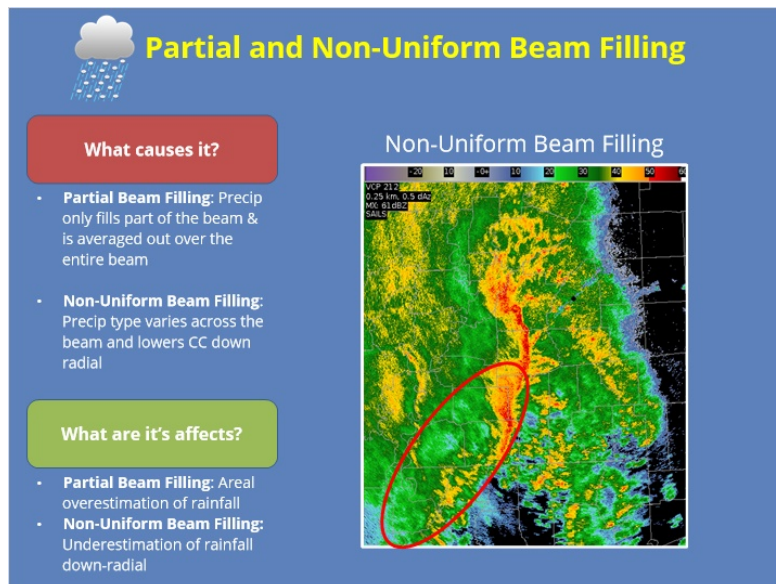
### Notes:

Alright, so what is attenuation? Attenuation simply refers to a reduction in power transmitted and returned from the radar. There are a few things that can cause attenuation including heavy rain, large hail cores, and when the radar is covered by a thin film of water, referred to as a wet radome. In the case of heavy rain, when a radar beam encounters large concentrations of hydrometeors, the returned power signal is weakened and the radar has a hard time seeing very far into the heavy rain. As such, attenuation due to heavy rainfall results in an underestimation of precipitation.

In the below example, can you guess where attenuation is occurring? Click on the image where you think it's occurring and I'll let you know once you've got it. If you guessed to the northwest of the radar, you are correct! Both heavy rain and a hail core are causing a reduction in power down radial resulting in an underestimation of the actual amount of precipitation that is falling in this area. If this persists over several radar scans, precipitation estimates here will suffer from underestimation.

As for the case of a wet radome, under certain circumstances a thin film of water can coat the radar and act to reduce the power transmitted and returned from the radar. This results in an underestimation of rainfall over the entire radar field. In the below example a squall line is approaching the radar. In the next image, you can see a visible reduction in the magnitude of reflectivities across the entire radar field of view.

## 1.14 Partial and Non-Uniform Beam Filling



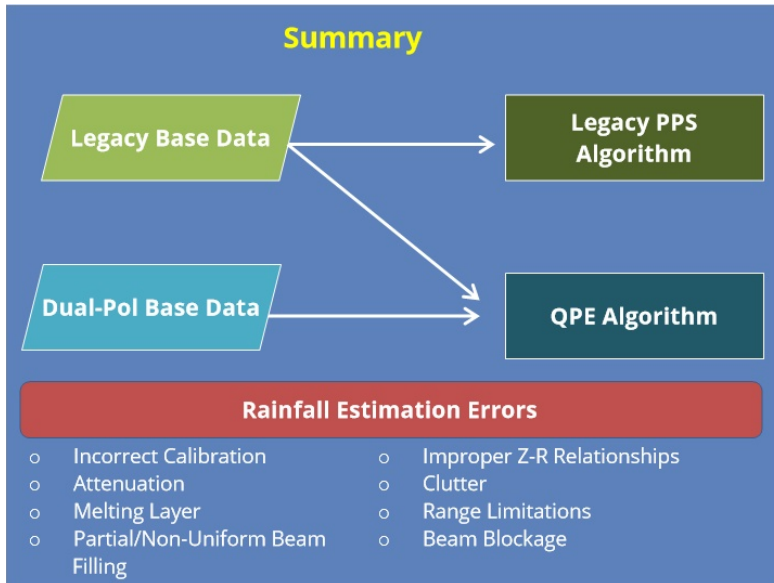
### Notes:

Alright, let's talk about what causes both partial and non-uniform beam filling. Partial-beam filling occurs at long ranges from the radar when precipitation only fills a small fraction of the beam. Since the radar equation averages the reflectivity over the pulse volume, the resulting reflectivity will yield lower values than what is actually occurring in that fraction of the beam. However, here's the catch: since the radar beam widens at increasing distances, this underestimation will be spread over a much wider area and will result in an areal overestimation of precipitation.

Non-uniform beam filling occurs when a gradient in precipitation type exists across the beam which is more common at increasing distances due to a larger beam width. The change in differential phase due to different hydrometeor types largely affects correlation coefficient and results in an underestimation of CC values down radial of where this gradient exists. An example of this is shown here - notice the radials of dampened CC values to the southwest of the radar. When CC is underestimated down radial, active precipitation areas down that same radial may not be converted to rainfall.

## 2. Summary

### 2.1 Summary

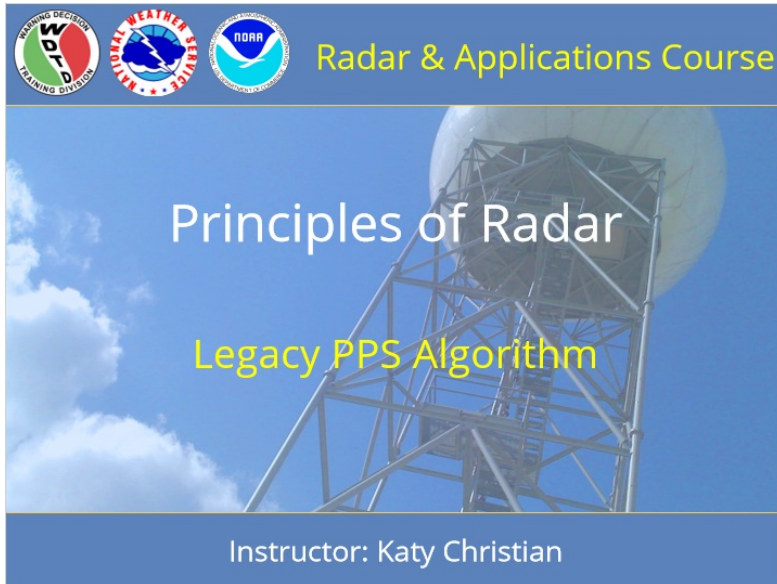


#### Notes:

Let's now recap very quickly what we've learned so far: there are two types of rainfall estimation algorithms - the Legacy PPS is based solely on Legacy base data whereas QPE is based on both Legacy and Dual-Pol base data. Both these rainfall estimation algorithms suffer from numerous errors that we discussed and are listed below. Alright, you are now finished with the lesson portion of this module. Whenever you're ready, please click next to move on to take the quiz.

# Legacy PPS

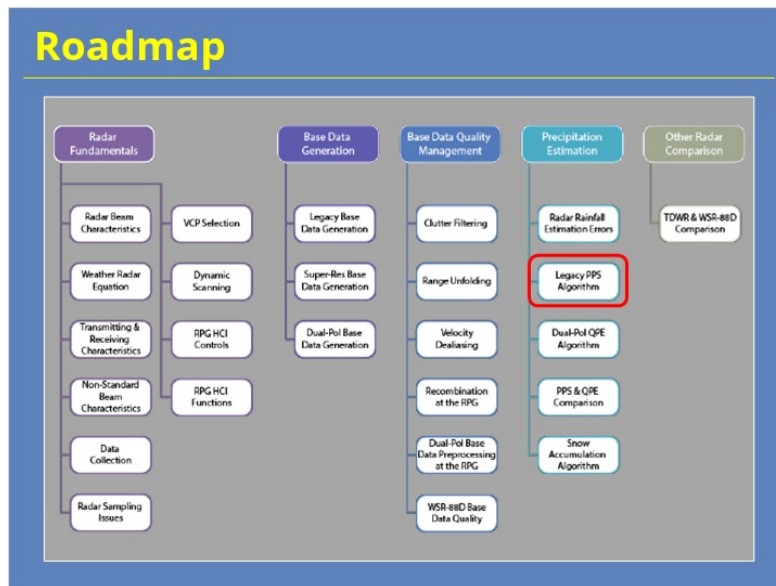
## 1.1 Title Slide



### Notes:

Welcome to Principles of Radar! My name is Katy Christian and I'll be your guide through today's lesson over the Legacy Precipitation Processing Subsystem algorithm, referred to as the Legacy PPS.

### 1.3 Roadmap



#### Notes:

Just for some context, here is the roadmap for the entire Radar Principles section of RAC - right now, you are here so let's keep moving forward!

## 1.4 Learning Objectives

### Learning Objectives

---

To **understand** the following about the Legacy PPS Algorithm:

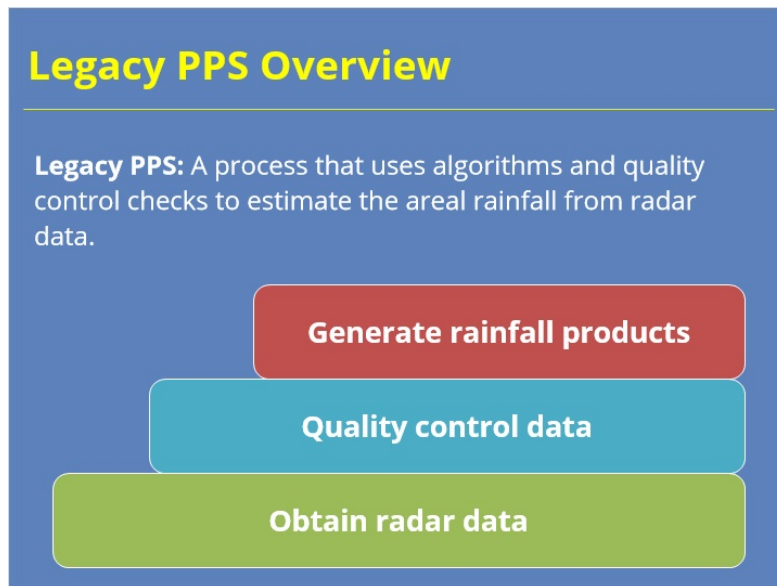
- What is it?
- How does it work?



#### Notes:

The learning objectives for this lesson are short and sweet: to understand what the Legacy PPS algorithm is and how it works. Let's get started!

## 1.5 Legacy PPS Overview



### Notes:

So what is the Legacy PPS? It is essentially a process that uses multiple algorithms and quality control checks to estimate the areal rainfall from radar data. As a broad overview, the Legacy PPS can be broken up into three steps. It first obtains the necessary radar data from the RDA. It will then quality control this data. Lastly, it will generate multiple different rainfall products for your use. Now I know it might be nice if we could just stop there but we need to go into more detail as there are several adaptable parameters that you as a forecaster need to know about if you're to use and understand this rainfall algorithm. So, without further ado, let's dive into more details about how it works!



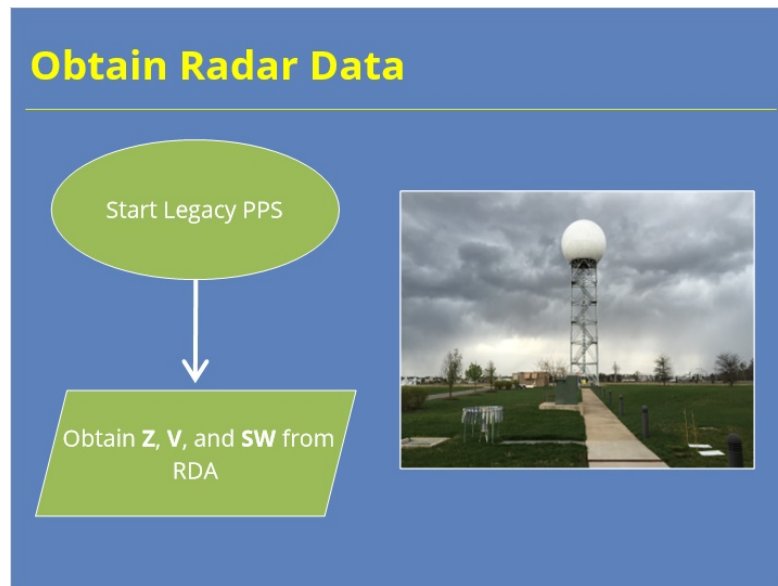
## 1.6 Lesson Roadmap



### Notes:

Okay, from the looks of this slide, I bet you're thinking, "Wait a minute, I thought this was supposed to be a lesson over the Legacy rainfall algorithm?" You are correct but who says we can't have a little fun while we're at it! So here is the game plan for today's lesson. Your goal as the learner, or PacMan in this case, is to make it through the maze without being caught by common enemies of RAC distance learning - these include "fatigue", "distractions", "boredom", or the ultimate nemesis, "no caffeine." When you arrive at each sign post, click on it to learn more and when you are done, you'll be quickly tested so see if you've retained the material. Beware that if you do not succeed, you may overrun by the enemies shown within the maze. So, good luck to you and to get started, click on PacMan to begin your journey!

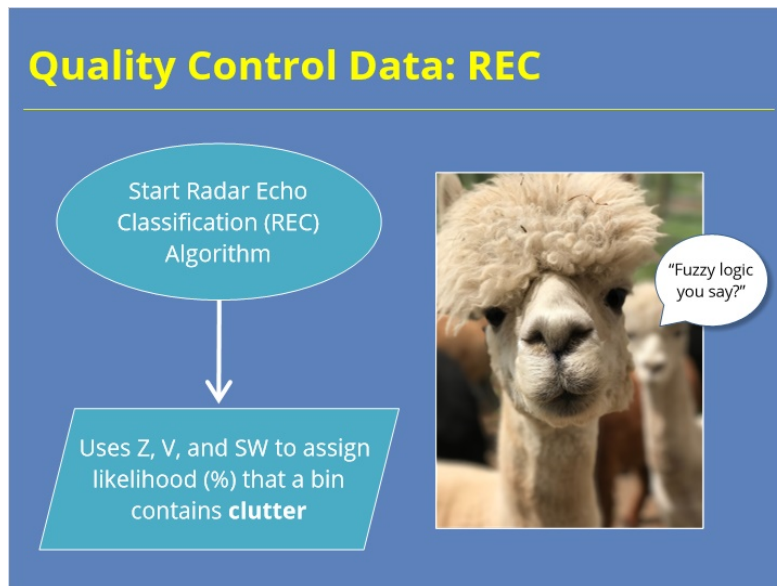
## 1.7 Obtain Radar Data



### Notes:

The first step in the Legacy PPS Algorithm is to obtain reflectivity, velocity, and spectrum width from the Radar Data Acquisition Unit, or RDA. The Legacy PPS will then use this base data as input for several different algorithms and quality checks that we will discuss shortly.

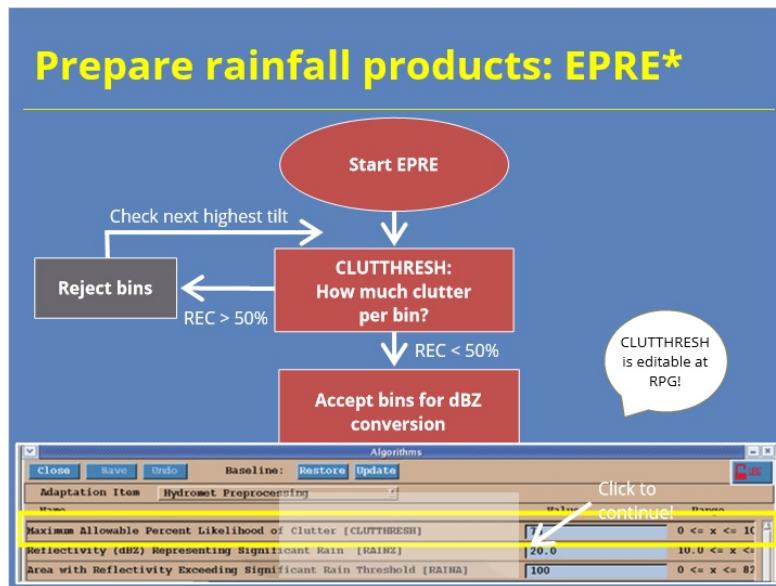
## 1.10 Quality Control Data: REC



### Notes:

The Radar Echo Classification algorithm is essentially a fuzzy logic algorithm that quality controls the data. It works by using Z, V, and SW values to assign a percentage likelihood that a particular bin contains clutter. This percentage value will also be used later on as we will see.

### 1.13 Prepare Rainfall Products: EPRE

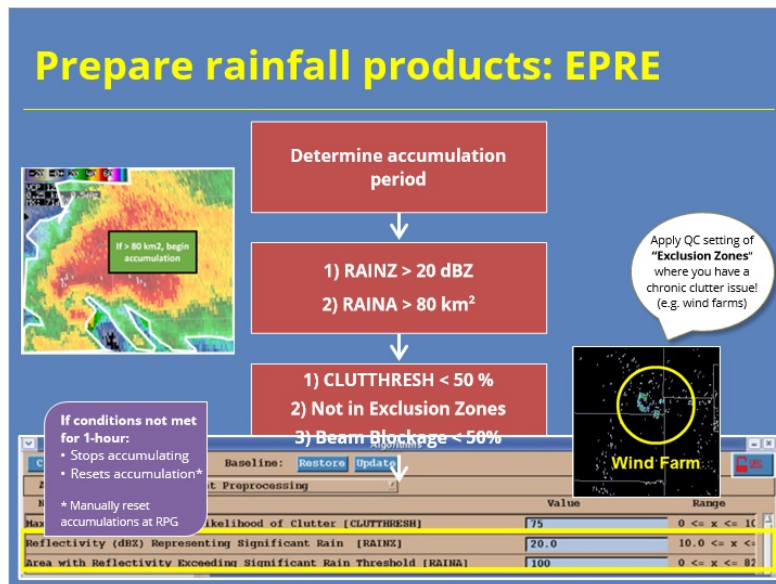


#### Notes:

EPRE, or the Enhanced Precipitation Preprocessing algorithm, essentially prepares the data for rainfall product generation. This algorithm is composed of several steps so we will work them one by one. To start, EPRE begins with a parameter called CLUTTHRESH. CLUTTHRESH looks at the clutter likelihood percentage that was designated by REC, or Radar Echo Classifier, earlier. If REC designates a bin as having less than or equal to 50% clutter, CLUTTHRESH allows the dBZ associated with this bin to be converted to rainfall. If a bin is designated as having > 50% clutter, CLUTTHRESH rejects this bin for conversion to rainfall and it will then check the next highest tilt to see if this condition is met.

One thing for you to know is that CLUTTHRESH is editable at the RPG! Although the default value is set to 50%, you can change this. Here's an example where CLUTTHRESH was increased to 75% in an area of very little terrain clutter. Before changing any parameters, just be sure to always talk it over with your radar focal point or the lead forecaster on duty. Once this condition is met, EPRE will then determine the start and end period over which to accumulate rainfall. Click on the highlighted box to continue the flowchart!

## 1.14 EPRE Continued



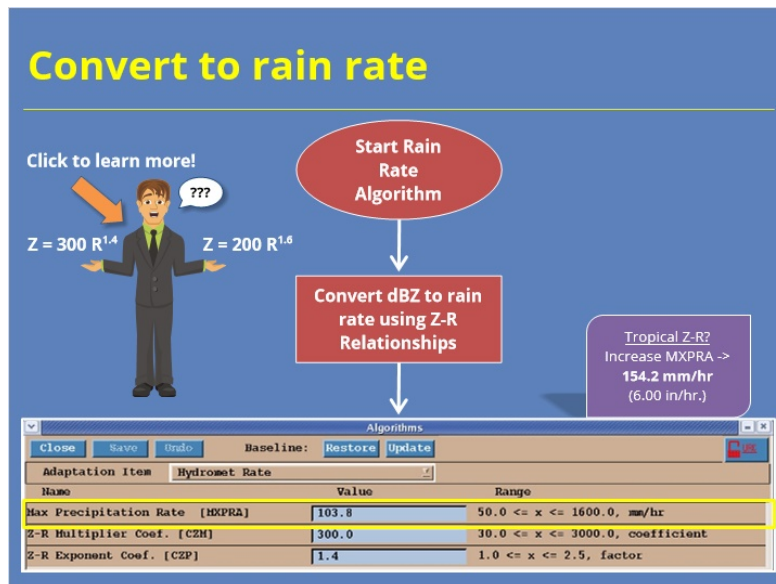
### Notes:

To determine the rainfall accumulation period, two conditions must be met. First, a parameter called RAINZ represents the minimum dBZ that must be met in order for EPRE to start accumulating rainfall. As a default, RAINZ must exceed 20 dBZ in order for bins to count as precipitation returns. Next, RAINA represents the areal coverage of RAINZ that must be met in order for EPRE to start accumulating rainfall. By default, RAINA must exceed 80 km<sup>2</sup>. To the left is an example where both these conditions are satisfied. It's important for you to know that both RAINZ and RAINA are editable at the RPG and the below figure shows an example of this where RAINA was increased to 100 km<sup>2</sup>. This is often done if the minimum area set by RAINA is too small and is accumulating clutter instead of precipitation. Once precipitation returns of at or > 20 dBZ are detected over 80 km<sup>2</sup>, the Legacy PPS begins accumulating rainfall and will continue to do so as long as thresholds are satisfied. If conditions are not met for one hour, rainfall accumulations will reset. You can also manually reset rainfall accumulations in the RPG Control window.

I quickly want to mention that within EPRE, there is a quality control caveat referred to as "Exclusion Zones" that prevents reflectivity from residual clutter from terrain or moving sources of clutter from being converted to rainfall. You will want to make use of this quality control option if you have a chronic clutter problem. Exclusion Zones can be defined at the RPG.

The final step of the EPRE algorithm is to build both the Hybrid Scan Reflectivity and the Digital Hybrid Scan Reflectivity products. In order to do this, dBZ bins must meet the following conditions: 1) CLUTTHRESH < 50%, 2) must not fall within an exclusion zone, and 3) beam blockage must be < 50%. Once these 3 conditions are met, the EPRE algorithm is done!

## 1.17 Convert to Rain Rate



### Notes:

The Rain Rate algorithm works by taking the dBZ values from the earlier step and converting them to rain rate using whatever Z-R relationship is set at the RPG. The rain rate algorithm also applies a parameter called Max Precipitation Rate that caps high rain rates that are a result of hail contamination. The default rain rate cap is 103.8 mm/hr, or 4.09 in/hr as shown in the below image. If you are using the tropical Z-R relationship, it is recommended that you increase the hail cap to 154.2 mm/hr, or 6.00 in/hr. Speaking of Z-R relationships, it can often be confusing to know which Z-R relationship to choose leading up to a given event. With that in mind, click on the following icon to learn more. Once you're done, you'll be redirected to the next slide.

## 1.18 Z-R Relationships Available in the Legacy PPS

### Z-R Relationships Available in the Legacy PPS

Relationship:

$$Z = \alpha R^{\beta}$$

Convective

Tropical

Marshall-Palmer

Cool Stratiform (East/West)

The PPS relies on Reflectivity (Z) for estimating rainfall (R) by applying a Z-R relationship to estimate **liquid** precipitation at the surface. There are five Z-R relationships that have been developed over the years that are available for use with the PPS on the WSR-88D. Each relationship involves using different coefficients (alpha and beta) to adjust the relationship accordingly. The optimum relationship is a function of season, geographic location, and expected weather type.

Click on the buttons to see what these equations are, when they should be used and learn more about when to use it (and why)? Once finished, click "Next."

**Notes:**

## Convective (Slide Layer)

### Z-R Relationships Available in the Legacy PPS

Relationship: **Convective**

$$Z = 300R^{1.4}$$

☒ Convective ☐ Tropical ☐ Marshall-Palmer

☐ Cool Stratiform (East/West)

The "Convective" Z-R relationship was used as the original, default NEXRAD rainfall equation. It works best with deep, or non-tropical, summertime convection.

## Tropical (Slide Layer)

### Z-R Relationships Available in the Legacy PPS

Relationship: **Rosenfeld-Tropical**

$$Z = 250R^{1.2}$$

☐ Convective ☒ Tropical ☐ Marshall-Palmer

☐ Cool Stratiform (East/West)

The Rosenfeld-Tropical Z-R relationship (Rosenfeld et al., 1993) was developed to improve PPS rainfall estimation in tropical convective systems, particularly during land-falling hurricanes and tropical storms.

The lower alpha and beta values in the equation mean that R will be higher with this equation than when compared to the default relationship. Tropical (i.e., warm rain) convective systems tend to have a higher concentration of smaller drops than continental (i.e., cold rain) systems for the same liquid water content.



## Marshall-Palmer (Slide Layer)

### Z-R Relationships Available in the Legacy PPS

Relationship: **Marshall-Palmer**

$$Z = 200R^{1.6}$$

**Convective** **Tropical** **Marshall-Palmer**

**Cool Stratiform (East/West)**

The Marshall-Palmer relationship (Marshall et al., 1955) should provide the best PPS estimates during general stratiform rainfall events. If mixed precipitation types are present (i.e., stratiform and convective), select the Marshall-Palmer relationship only if stratiform is the most significant and/or most widespread precipitation regime present.

## Cool Stratiform (East/West) (Slide Layer)

### Z-R Relationships Available in the Legacy PPS

Relationship: **East Cool Stratiform** **West Cool Stratiform**

$$Z = 170R^{2.0} \quad Z = 75R^{2.0}$$

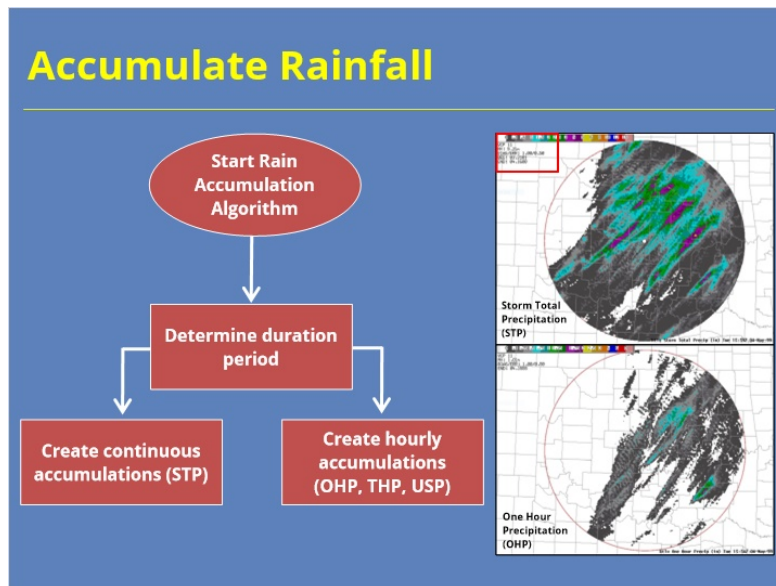
**Convective** **Tropical** **Marshall-Palmer**

**Cool Stratiform (East/West)**

Studies of cool season stratiform rain events (Super and Holroyd, 1998; Cairns et al., 1998; Huggins and Kingsmill, 1998; and Quinlan and Sinsabaugh, 1999) have shown that the best Z-R relationship depends significantly on geographic location. The Radar Operations Center recommends separate Z-R relationships for Eastern and Western U.S. locations.

Cool season stratiform Z-R relationships enhance rainfall estimates from lower Reflectivity values, so clutter contamination may appear more prominently during these events.

## 1.21 Accumulate Rainfall



### Notes:

The rain accumulation algorithm takes the rain rates previously calculated and accumulates them over different durations. There are two different durations over which it accumulates. The first is a continuous accumulation where as long as RAINZ and RAINA are satisfied, it will continue to accumulate rainfall. An example of a continuous accumulation is the Storm Total Precipitation, or STP, as shown on the right. The accumulation start time for this product can be found in the upper left hand corner.

The next type of accumulation is hourly accumulations where the hourly end time is either the current volume scan or the top of each hour. Some examples of hourly accumulations include the one-hour precipitation as shown in the figure to the right, three hour precipitation, or user selectable precipitation.

## 1.24 Apply Bias (Optional)

### Apply Bias (optional)

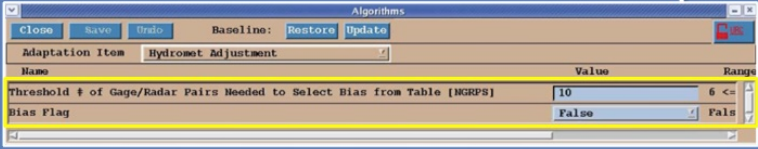
**Multi-Sensor Precipitation Estimator (MPE):** Compares radar rainfall estimates to gauge data and sends bias table to RPG once an hour.

Rain gauge values can be inaccurate!

Local biases aren't QC'd!

Beware of bias!!

History of configuration issues in AWIPS!



Adaptation Item	Hydromet Adjustment	Value	Range
Threshold # of Gauge/Radar Pairs Needed to Select Bias from Table [MGRPS]		10	6 <=
Bias Flag		False	False

### Notes:

The adjustment bias algorithm is optional and gives users the ability to apply a bias multiplier to the rainfall accumulations. In AWIPS, the Multi-Sensor Precipitation Estimator (MPE) compares radar rainfall estimates to gauge data and sends a bias table to the RPG every hour. A parameter known as the Bias Flag controls the ability to apply the bias and by default, it is set to false. Setting the Bias flag to true will apply the bias generated by the MPE out to a range of 124 nm. However, a word of caution: the MPE bias output is NOT perfect due to some of the issues shown on the slide. With those in mind, it is recommended that you do not mess with changing the default bias flag as doing so can potentially create more issues. If you're interested in learning more about biases, please take the WDTD lesson titled "Interpreting QPE Bias Information in AWIPS."

## Completion Layer (Slide Layer)

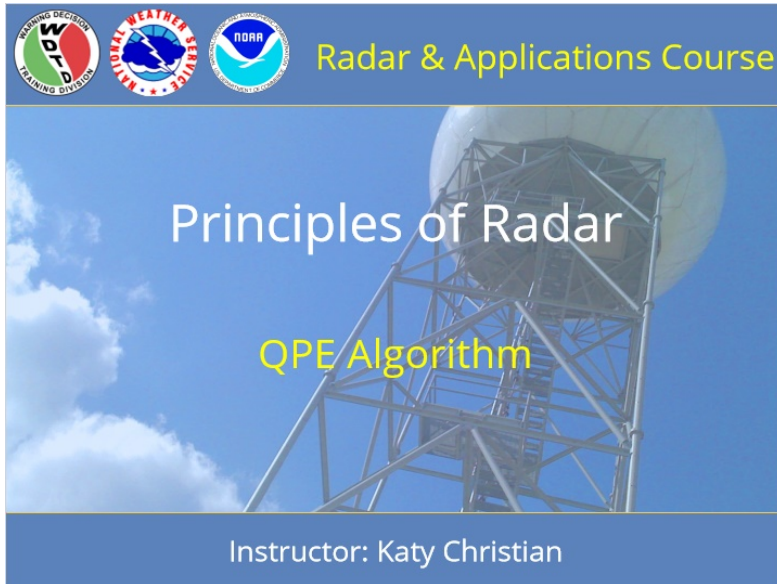
### Your roadmap to success!



**Congratulations! You're finished!**  
**Click "Next" to take the quiz!**

# Dual-Pol QPE Algorithm

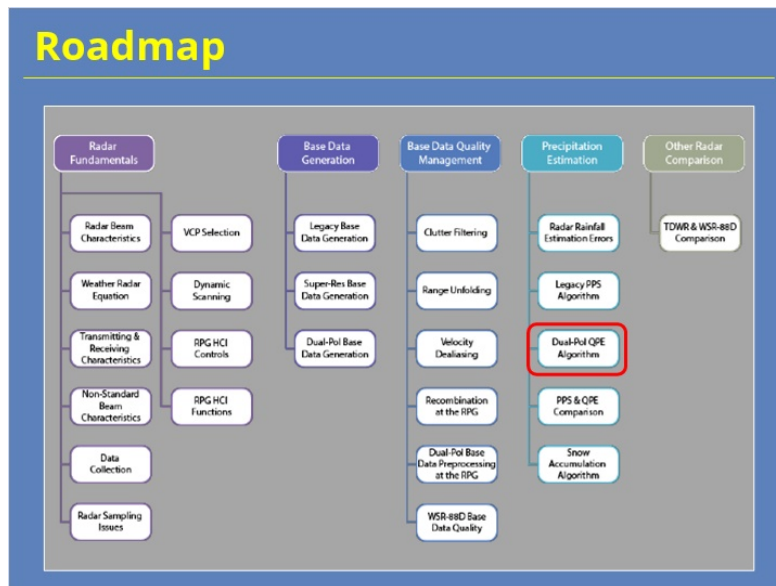
## 1.1 Introduction



### Notes:

Welcome to Principles of Radar! My name is Katy Christian and I'll be your guide through today's lesson over the Dual-Pol QPE Algorithm.

## 1.3 Roadmap



### Notes:

Just for some context, here is the roadmap for the entire Radar Principles section of RAC - right now, you are here so let's keep moving forward!

## 1.4 Learning Objectives

### Learning Objectives

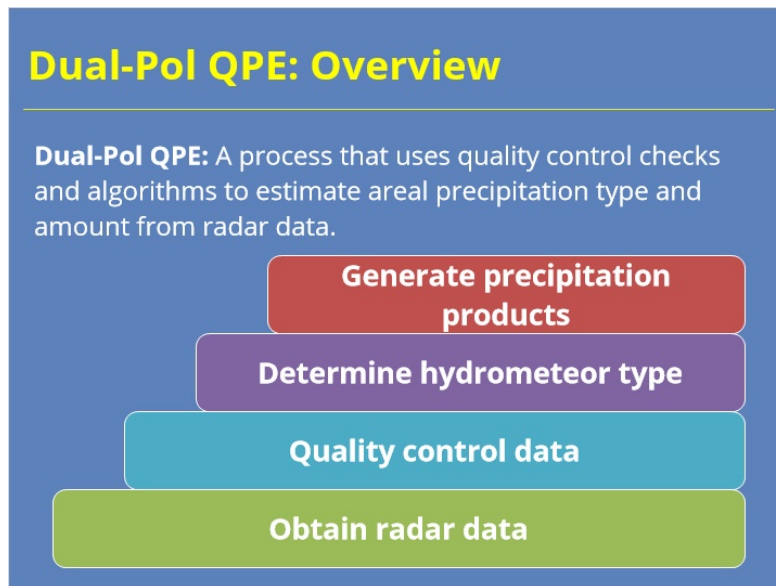
- **Identify** the QPE algorithm, it's inputs, & processing steps (including when rain rates are used)
- **Identify** some best practices when using the QPE algorithm



#### Notes:

The learning objectives for this lesson are 1) to identify the QPE algorithm, it's inputs, and processing steps, including when certain rain rates are used, and 2) to identify some best practices when using the QPE algorithm. Let's get started!

## 1.5 Dual-Pol QPE: Overview



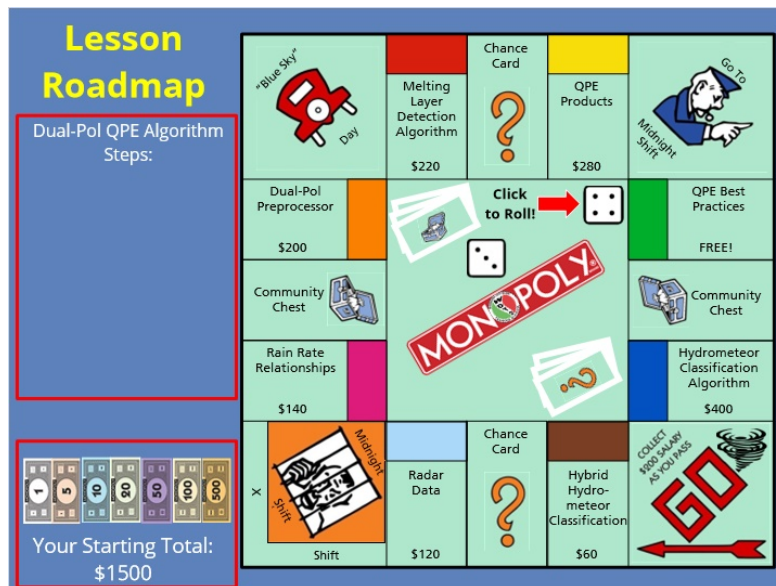
### Notes:

So what is the Dual-Pol QPE? It is essentially a process that uses multiple quality control checks and algorithms to estimate both the areal precipitation type and amount from radar data. In general, the Dual-Pol QPE can be broken up into four steps. It first obtains the necessary radar data from the RDA. It will then quality control this data. Next, it will determine hydrometeor types before generating multiple different precipitation products for your use.

If you remember from the previous lesson, this generally looks similar to the Legacy PPS with the exception of the 2nd to last step - determining hydrometeor type. It turns out that this difference is very important as to how the Dual-Pol QPE generates precipitation products. So, without further ado, let's dive into more details about how this algorithm works, starting with obtaining radar data.



## 1.6 Lesson Overview



### Notes:

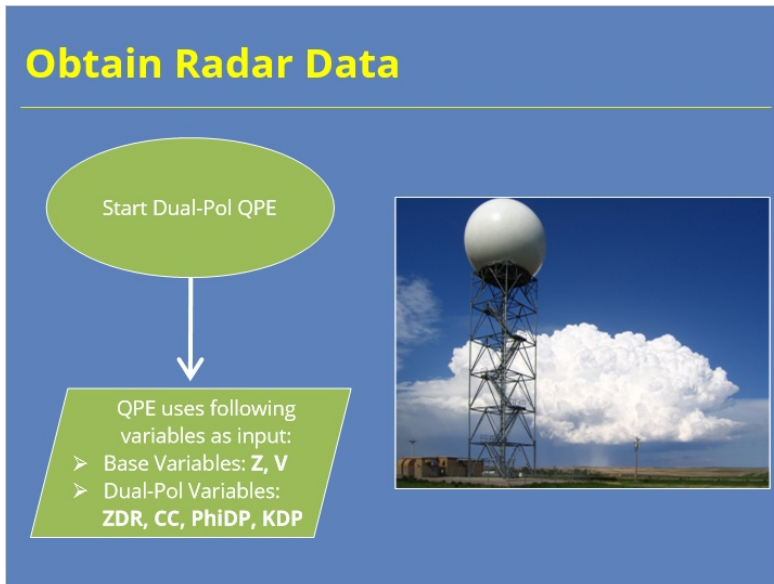
Allright, as with the Legacy PPS module before this, we are gonna shake things up a bit in terms of the lesson game plan! After all, if you're going to have to learn about a rainfall algorithm, you might as well make it fun!

So, here's the game plan for this lesson - we are gonna play some WDTD Monopoly. Your goal as the learner is to buy up each property, or in this case, each component that makes up the Dual-Pol QPE Algorithm. When you land on each property, you will be redirected to another slide to learn more about it and once done, you will have purchased that property. The goal is to buy up all the pieces and your available balance will be updated in the bottom left hand corner of the screen so you can keep tabs on it throughout.

As you make your way through the board, the QPE Algorithm steps will also be listed on the left hand side so you can keep the overall order of the algorithm in mind. I've taken the liberty of assigning you a tornado game piece. Allright, that's all for rules: to get started, click on the dice to roll and get on your way!

## 1.7 Radar Data

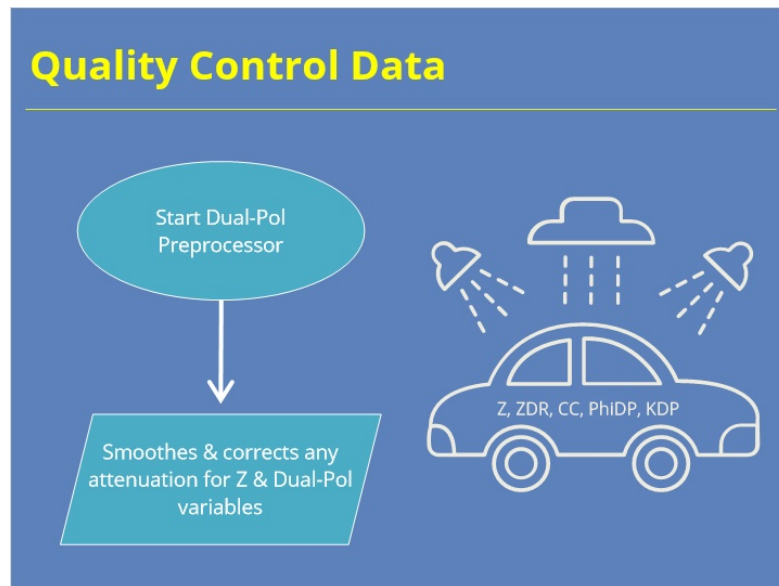
### Obtain Radar Data



#### Notes:

The Dual-Pol QPE Algorithm starts by variables being retrieved by the RDA and then processed at the RPG. The QPE Algorithm uses the base variables, Z and V, as well as the dual-pol variables, which include Differential Reflectivity (ZDR), Correlation Coefficient (CC), Differential Phase (PhiDP), and Specific Differential Phase (KDP). The QPE Algorithm will then use both the base and dual-pol variables as input into several different quality control checks and algorithms we will discuss shortly.

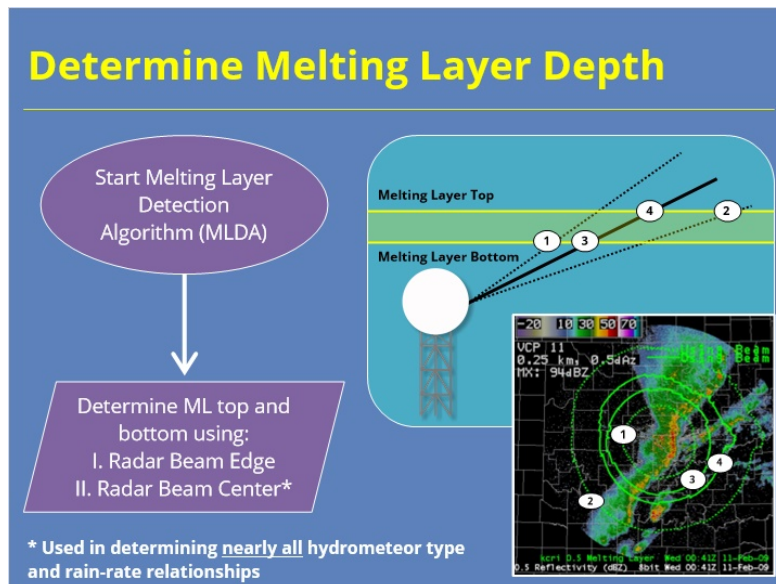
## 1.9 Dual-Pol Preprocessor



### Notes:

The Dual-Pol Preprocessor can be thought of as the car wash for Z and the Dual-Pol variables. It will smooth the data and if there is any attenuation present, it will also correct for this.

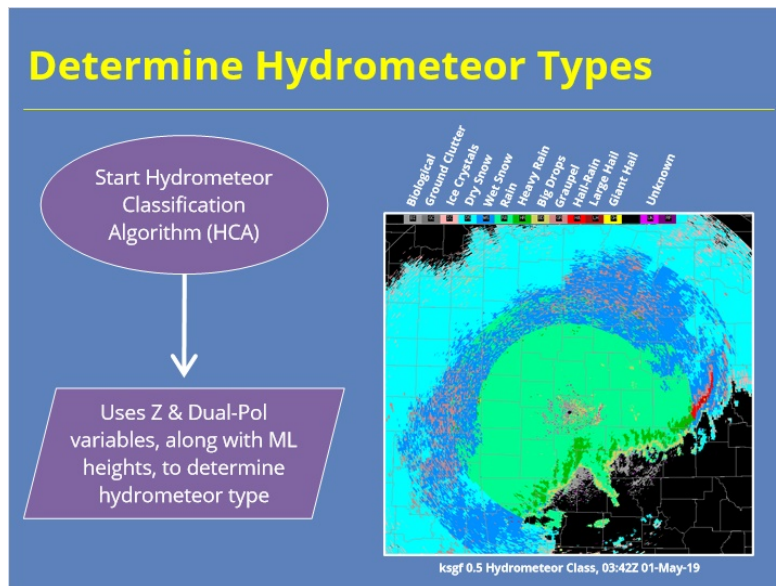
## 1.11 Melting Layer Detection Algorithm (MLDA)



### Notes:

The purpose of the Melting Layer Detection Algorithm, or MLDA, is to determine the depth of the melting layer. This information is needed to properly classify hydrometeor types as we'll discuss later on. For each elevation angle, the MLDA works by detecting four different heights as illustrated in the figure to the right. The first set of heights represent where the radar beam edges encounter the bottom and top of the melting layer. In AWIPS, the melting layer heights as seen by the radar beam edges are displayed as the dotted green lines. The second set of heights represents where the radar beam center encounters the bottom and top of the melting layer. In AWIPS, these heights are displayed as the solid green lines. The melting layer as defined by the CENTER of the radar beam is ultimately what is used by nearly all algorithms when determining precipitation type and the appropriate rain-rate relationships to use.

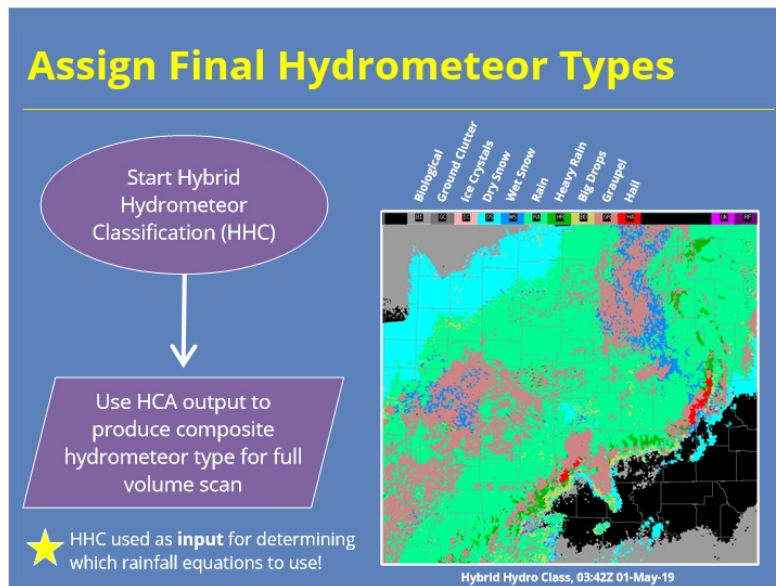
### 1.13 Hydrometeor Classification Algorithm (HCA)



#### Notes:

The Hydrometeor Classification Algorithm, or HCA, uses the base and dual-pol data, alongside the melting layer heights previously calculated, to estimate the hydrometeor type at the height of the radar beam for every elevation angle. To the right is an example of what the HCA looks like along with the hydrometeor types that it classifies radar bins as. You will go into more detail over the HCA in another module but for now, just know that it classifies the hydrometeor type at the height of the radar beam.

## 1.15 Hybrid Hydrometeor Classification (HHC)



### Notes:

The Hybrid Hydrometeor Classification, or HHC, uses output from the HCA to provide a cumulative, or composite, hydrometeor type for the full volume scan. In other words, the HHC determines the final cumulative hydrometeor type.

The figure to the right is an example of the HHC output for the same time as the HCA output that was shown on the previous slide. You'll see a big difference in final hydrometeor type as well as a reduction in the speckling look of the data. This is because the HHC uses a smoothing technique to reduce the speckling appearance. The HHC product is important because values from it will be used as input into determining what rain rate equation to use for precipitation estimates as we'll see shortly.

## 1.17 Rain Rates: Overview

### Assign Rain Rates: Overview

Non-Precipitation Classification	Equation	Rain Classification With R(A) Enabled (Default)	Equation
Ground Clutter (GC) or Unknown (UK)	Not Computed	Light/Moderate Rain (RA), Big Drops (BD), or Heavy Rain (HR) and $Z \leq 50$ dBZ and blockage $\leq 95\%$ and echo is below the bottom of the ML	R(A)
No Echo (ND) or Biological (BI)	0	Light/Moderate Rain (RA) or Big Drops (BD) and echo is below the bottom of the ML and R(A) cannot be computed	R(Z,Zdr)
Hail and Ice Classification	Equation		
Rain/Hail (HA) and blockage $\geq 5\%$	R(Kdp)	Heavy Rain (HR) and $Z > 50$ dBZ and echo is below the bottom of the ML	R(Kdp)
Rain/Hail (HA) and echo is at or below the top of the melting layer (ML) and blockage $< 5\%$	R(Kdp)	Light/Moderate Rain (RA) or Big Drops (BD) and echo is at or above the bottom of the ML	R(Z,Zdr)
Rain/Hail (HA) and echo is above the top of the ML and blockage $< 5\%$	$0.8 * R(Z)$	Heavy Rain (HR) and blockage $< 20\%$ and $Z \leq 45$ dBZ and echo is at or above the bottom of the ML	R(Z,Zdr)
Graupel (GR)	$0.8 * R(Z)$	Heavy Rain (HR) and blockage $> 20\%$ or $Z > 45$ dBZ and echo is at or above the bottom of the ML	R(Kdp)
Wet Snow (WS)	$0.6 * R(Z)$		
Dry Snow (DS) and echo is at or below the top of the ML	$1.0 * R(Z)$	Rain Classification With R(A) Disabled	Equation
Dry Snow (DS) and echo is above the top of the ML	$2.8 * R(Z)$	Light/Moderate Rain (RA) or Big Drops (BD)	R(Z,Zdr)
Ice Crystals (IC)	$2.8 * R(Z)$	Heavy Rain (HR) and blockage $< 20\%$ and $Z \leq 45$ dBZ	R(Z,Zdr)
		Heavy Rain (HR) and blockage $> 20\%$ or $Z > 45$ dBZ	R(Kdp)

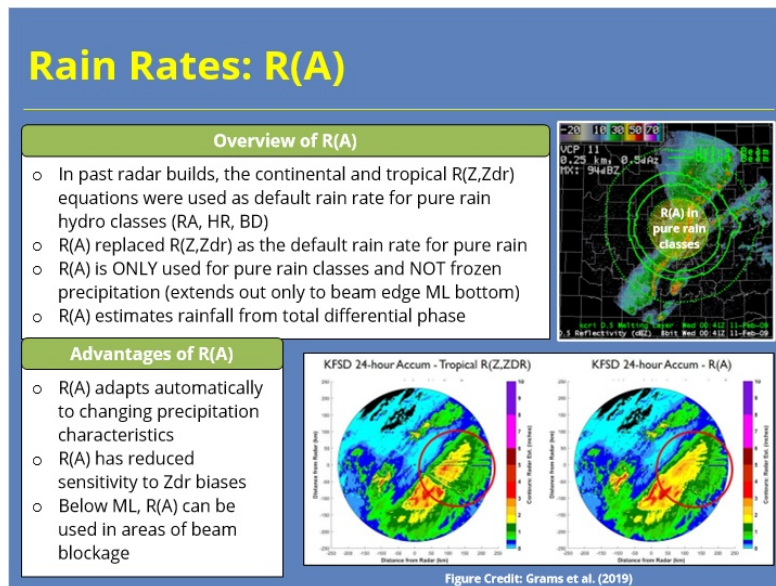
#### Notes:

For each radar range bin, the Dual-Pol QPE algorithm determines which rain-rate relationship to use based on the Hydroclass value designated earlier, position relative to the melting layer, and the percentage of beam blockage that is occurring.

For non-precipitation classes, such as ground clutter or biological, the radar range bins are either assigned a value of zero or the rain rate is just not computed. For Hail, Snow, and Ice classifications, here are the conditions that must be met for the corresponding equations to be used. For Rain classifications with the Specific Attenuation Rain Rate method, or R(A) enabled, here are the following conditions that must be met for various equations to be used. And lastly, if R(A) is NOT enabled, here are the following classifications and equations used. This table is also available in the "Resources" tab.

Now, I know at first glance, this looks very complicated and confusing, kind of like a W2 form. However, don't worry: you do not need to know every single condition that constitutes a specific rain-rate relationship to be used. Further, while this does look like a lot, there are really just four different rain-rate relationships used throughout: R(KDP), variations of R(Z), R(A), and R(Z,Zdr). With that in mind, let's just briefly talk through the utility of each of these relationships, beginning with R(A) that is used for pure rain.

## 1.18 Rain Rates: $R(A)$



### Notes:

Before we talk about  $R(A)$ , we need to give a quick background. In past radar builds, the continental and tropical  $R(Z,Zdr)$  equations were used as the default equations for pure rain, where pure rain is any of the following hybrid hydrometeor classes: rain, heavy rain, or big drops. However,  $R(Z,Zdr)$  was found to underestimate precipitation, especially during heavy rainfall events. Because of this, the specific attenuation rain rate method, or  $R(A)$  was created to replace  $R(Z,Zdr)$  and is now the default equation used for pure rain classes. Because  $R(A)$  is VERY sensitive to ice contamination and is ONLY valid for pure rain, it can only be applied up to the bottom of the melting layer as defined by the radar beam EDGE. So this would be up to the first dotted green line in AWIPS as shown in the figure here.  $R(A)$  will not be used anywhere beyond that first dotted green line due to possible ice contamination.

As for how it works,  $R(A)$  estimates rainfall from the total differential phase. Some advantages of this include being able to adapt automatically to changing precipitation characteristics, reduced sensitivity to  $Zdr$  biases, and reduced impacts from partial beam blockage. Being able to estimate rainfall in areas of beam blockage is one major advantage of this method. Take a look at the figures below: to the left is the 24-hour rainfall accumulations using the Tropical  $R(Z,Zdr)$  relationship. The red circle highlights the impact of tree blockage on the overall precipitation amounts. To the right shows the same 24-hour rainfall accumulation period but for the  $R(A)$  method. Within the same area, you can see a substantial reduction in beam blockage on the precipitation field. Notice that once you get beyond the bottom of the melting layer as defined by the beam edge,  $R(A)$  can no longer be used so the blocked radials look the same in both.



### 1.19 Rain Rates: $R(Z)$ , $R(K_{dp})$ , $R(Z, Z_{dr})$

#### Rain Rates: $R(Z)$ , $R(K_{dp})$ , and $R(Z, Z_{dr})$

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

- ❖ Used at or above the ML for hail, snow, & ice
- ❖ Site-specific coefficients improve precipitation estimates in the ML

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

- ❖ Used for pure rain classes (rain, heavy rain, or big drops) when  $R(A)$  cannot be computed or is not enabled
- ❖ Used primarily at or above the bottom of the ML

1)  $R(K_{dp}) = 44 |K_{dp}|^{0.822} \text{sign}(K_{dp})$

2)  $R(K_{dp}) = 27 |K_{dp}|^{0.822} \text{sign}(K_{dp})$

- ❖ Used primarily below the ML
- ❖ Version 2) is used if Hydroclass is Rain/Hail AND  $CC < 0.97$  to reduce overestimation due to melting hail

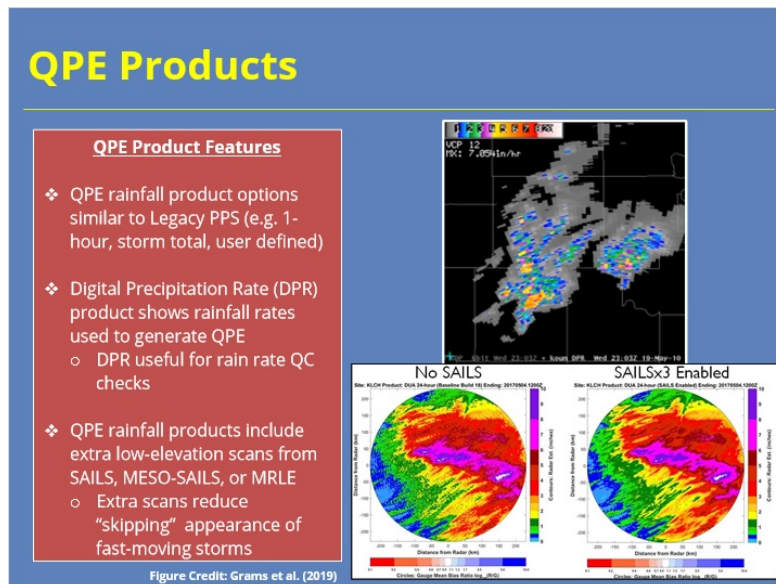
#### Notes:

The last three equations that are used to determine rain rate within the Dual-Pol QPE algorithm are  $R(Z)$ ,  $R(K_{dp})$ , and  $R(Z, Z_{dr})$ . The equation for  $R(Z)$  is shown here.  $R(Z)$  is used at or above the melting layer for hail, snow, ice classifications as shown in the table below. The varying coefficients in front of each  $R(Z)$  relationship is largely due to a field experiment back in 2014 that found improvement in precipitation estimates within the melting layer by using site-specific coefficients.

The  $R(K_{dp})$  equation is shown here and is primarily used below the melting layer. One thing to note is that in regions of melting hail, KDP can be very high, which will ultimately drive rain rates unreasonably high. With that in mind, the  $R(K_{dp})$  equation was altered to have a lower multiplier out front. If the Hydroclass is designated as Rain/Hail AND has a correlation coefficient  $< 0.97$ , the  $R(K_{dp})$  equation with the lower multiplier out front is used to reduce unreasonably high rain rates. Remember, this is only the case for rain/hail mixture. The default  $R(K_{dp})$  equation is used for all other situations listed in the table shown earlier.

As we stated earlier, the specific attenuation rainfall method, or  $R(A)$  replaced  $R(Z, Z_{dr})$  for hydro classes representing pure rain, so rain, heavy rain, or big drops. However, this doesn't mean that  $R(Z, Z_{dr})$  is never used. If  $R(A)$  cannot be computed or is not enabled as the default option on the dual-pol precip menu,  $R(Z, Z_{dr})$  is used instead.  $R(Z, Z_{dr})$  is also used for narrow small areas above the melting layer where  $R(A)$  cannot be used due to the presence of frozen precipitation.

## 1.21 QPE Products



### Notes:

The final Dual-Pol QPE rainfall products are very similar to Legacy PPS rainfall products, in terms of available options to choose from. However, there is one product that has no PPS equivalent - that is the Digital Precipitation Rate, or DPR, product. This product shows the rainfall rates that were used to generate QPE rainfall products. One advantage of this product is that it can bring your attention to any areas where rainfall rates seem unreasonably high and you can cross check those areas with dual-pol variables to see if they physically make sense or not.

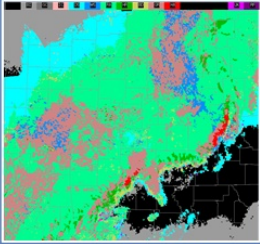
Another unique feature about QPE rainfall products that you should be aware of is that when either SAILS, MESO-SAILS, or MRLE is enabled, the extra low-elevation scans will be incorporated into the output of the QPE rainfall products. The temporal frequency of QPE products will remain the same. So for the case of DPR, one DPR product will still be produced per volume scan. However, the final accumulation product will now have more frequent rain rate updates where the lowest angle was used in the hybrid scan. While the addition of SAILS or MRLE scans do not improve the accuracy of QPE rainfall products, they help produce a much smoother overall precipitation field, particularly in the case of fast-moving storms where a skipping pattern can often be seen. The figure to the right shows an example of the addition of SAILS to dual-pol accumulation products. While precipitation amounts are similar for both, you can see an overall much smoother and coherent precipitation spread across the radar field of view when SAILS was enabled.

## 1.23 QPE Best Practices

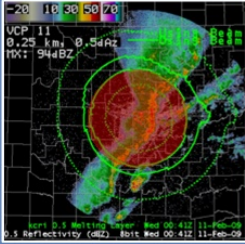
### QPE Best Practices

QPE Best Practices

- ❖ Trust QPE performance BELOW the ML
- ❖ Regularly monitor output from MLDA and HHC to make sure values make physical sense



Hybrid Hydro Class (HHC)



MLDA

### Notes:

As a best practice, you can generally trust QPE performance BELOW the melting layer. Above the melting, QPE performance will be negatively impacted by frozen hydrometeors so be leery of trusting QPE values here.

Lastly, since QPE products rely on the output of several algorithms, such as the MLDA, HCA, and HCC, remember that issues can arise and that you can't always trust QPE products as ground truth. As a best practice, you should monitor output from the MLDA and HHC to make sure the ML heights and Hydroclass values make physical sense as those ultimately feed into determining the final QPE products.

## Completion Layer (Slide Layer)

Dual-Pol QPE Algorithm Steps

1. Obtain Radar Data
2. Quality Control Data
3. Determine ML Depth
4. Determine Hydrometeor Types
5. Assign Final Hydrometeor Types
6. Assign Rain Rates
7. Produce QPE Products

Your Ending Total:  
\$180

MONOPOLY

**Congrats, you won!!**

Click "Next" to take the quiz.

# PPS and QPE Comparison

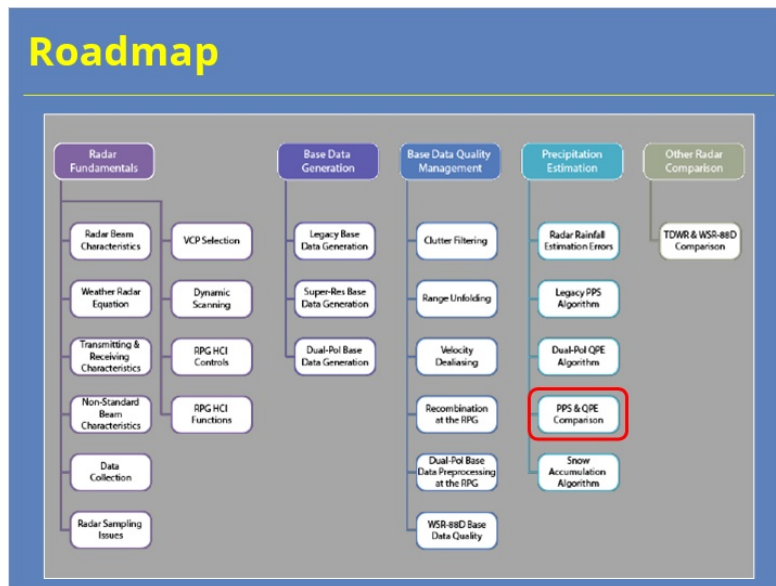
## 1.1 Title Slide



### Notes:

Welcome to Principles of Radar! My name is Katy Christian and I'll be your guide through today's lesson where we'll discuss how the Legacy PPS and Dual-Pol QPE algorithms compare to each other.

### 1.3 Roadmap



#### Notes:

Just for some context, here is the roadmap for the entire Radar Principles section of RAC - right now, you are here so let's keep moving forward!

## 1.4 Learning Objectives

### Learning Objectives

- **Identify** similarities between the PPS and QPE, including rainfall generation methods and quality control procedures
- **Identify** differences between the PPS and QPE, including input sources and rainfall products




#### Notes:

The learning objectives for this lesson are to identify similarities between the PPS and QPE, including rainfall generation methods and quality control procedures as well as identify some differences, which include input sources and rainfall products.

## 1.5 PPS and QPE: Similarities Overview

### PPS and QPE: Similarities Overview

Similarities
• Common Rain Rate Equation
• Start/Stop Accumulations
• Manual Reset at RPG
• Exclusion Zones
• QC for Hail Contamination



### Notes:

Let's start by discussing some of the similarities between the Legacy PPS and Dual-Pol QPE rainfall algorithms which are shown here. This list is by no means exhaustive but we'll cover some of the more important ones for you to be aware of. Let's get started by looking at how both the PPS and QPE algorithms share a common rain rate equation.



## 1.6 Rain Rate Equation

### Similarities: Rain Rate Equation

1. The Legacy PPS and Dual-Pol QPE share one equation in common:  
**Convective Z-R in PPS =  $R(Z)$  in QPE**

#### Z-R Relationships Available in the Legacy PPS

Relationship: Convective

$$Z = 300R^{1.4}$$

Convective Tropical Marshall-Palouse

Cool Stratiform (East/West)

The "Convective" Z-R relationship was used as the original, default NEXRAD rainfall equation. It works best with deep, or non-tropical, summertime convection.

#### Rain Rates: $R(Z)$ , $R(K_{dp})$ , and $R(Z, Z_{hyd})$

$$R(Z) = (0.0175) Z^{0.714}$$

- Used at or above the ML for hail, snow, & ice
- Site-specific coefficients improve precipitation estimates in the ML

$$R(Z, Z_{hyd}) = (0.0142) Z^{0.77} Z_{hyd}^{-1.49}$$

- Used for pure rain classes (rain, heavy rain, or big drops) when  $R(K)$  cannot be computed or is not enabled
- Used primarily at or above the bottom of the ML

$$1) R(K_{dp}) = 44 \left( \frac{K_{dp}}{K_{dp0}} \right)^{0.833} \text{sign}(K_{dp})$$
$$2) R(K_{dp}) = 27 \left( \frac{K_{dp}}{K_{dp0}} \right)^{0.833} \text{sign}(K_{dp})$$

- Used primarily below the ML
- Version 2) is used if Hydroclass is Rain/Hail AND CC < 0.97 to reduce overestimation due to melting hail

#### Notes:

While both PPS and QPE use multiple different equations to determine rain rate, one of these equations appears in both PPS and QPE. In the Legacy PPS algorithm, it is the convective Z-R relationship. In the QPE algorithm, this same equation shows up as the  $R(Z)$  relationship that is used for hail, ice, and snow classifications.

While these two equations look different, they are actually the same. The PPS form is the more familiar format, solved for Z, while the QPE form is just rewritten solved for R, which is more useful to the QPE algorithm. This is the only equation that PPS and QPE have in common.

## 1.7 Accumulation Rules

### Similarities: Accumulation Rules

2. Both the PPS and QPE have related thresholds for when to start or stop rainfall accumulations.

The image displays two screenshots of software interfaces for different algorithms. The top screenshot is for the 'Legacy PPS' algorithm, showing a table with two rows of parameters: 'Reflectivity (dBZ) Representing Significant Rain [RAINZ]' with a value of 20.0 and a range of 10.0 <=, and 'Area with Reflectivity Exceeding Significant Rain Threshold [RAINA]' with a value of 80 and a range of 0 <= x <. The bottom screenshot is for the 'Dual-Pol QPE' algorithm, showing a table with three rows of parameters: 'PAIF Area Threshold' with a value of 80 and a range of 0 <= x <= 82800, km^2; 'PAIF Rate Threshold' with a value of 0.5 and a range of 0.0 <= x <= 50.0, mm/hr; and 'Number of Exclusion Zones' with a value of 0 and a range of 0 <= x <= 20.

Adaptation Item	Value	Range
Reflectivity (dBZ) Representing Significant Rain [RAINZ]	20.0	10.0 <=
Area with Reflectivity Exceeding Significant Rain Threshold [RAINA]	80	0 <= x <

Adaptation Item	Value	Range
PAIF Area Threshold	80	0 <= x <= 82800, km^2
PAIF Rate Threshold	0.5	0.0 <= x <= 50.0, mm/hr
Number of Exclusion Zones	0	0 <= x <= 20

#### Notes:

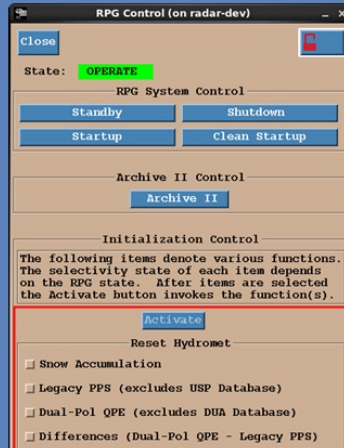
Both the PPS and QPE use comparable rules for when to start or stop rainfall accumulations. Remember from the Legacy PPS lesson that a minimum reflectivity threshold, referred to as RAINZ, must be met over a minimum area, referred to as RAINA, in order to start accumulating precipitation.

In the QPE algorithm, this similar concept applies but is just renamed under the Precipitation Accumulation Initiation Function, or PAIF. The minimum area that must be met is the same in both PPS and QPE. In the QPE algorithm, a minimum rainfall rate must be met. This is analogous to RAINZ in PPS, where a minimum reflectivity must be met. So, similar accumulation rules apply to both the PPS and QPE algorithms.

## 1.8 Storm Total Reset

### Similarities: Storm Total Reset

3. Both algorithms reset storm total accumulations after 1 hour if their respective thresholds are not met.



#### Notes:

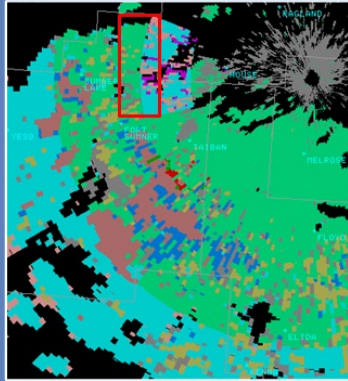
Both the PPS and QPE algorithms reset storm total accumulations in the same manner. If accumulations fall below their respective thresholds after one hour, storm total accumulations will reset. You can also reset them both manually in the RPG Control Panel window under the "Reset Hydromet" option.

## 1.9 Exclusion Zones

### Similarities: Exclusion Zones

4. Both the PPS and QPE algorithms have the option of applying exclusion zones.

**Remember:**  
Use "Exclusion Zones" for persistent or chronic clutter areas!



#### Notes:

Remember from the Legacy PPS lesson that in areas of persistent clutter, you have the option of setting up an exclusion zone over that area that will prevent reflectivities there from being converted to rainfall. The good news is that you also have this option in the Dual-Pol QPE algorithm as well.

Both PPS and QPE handle this the same way, where if a range bin falls within an exclusion zone, both algorithms will use the next tilt above the exclusion zone to estimate rainfall. Sometimes you can actually see the effect of the next highest tilt apparent in the Hybrid Hydrometeor Classification product where snow or ice classifications from the next highest tilt appear surrounded by lower tilts that have non-frozen precipitation classification types.

## 1.10 Hail Quality Control

### Similarities: Hail Quality Control

5. Both algorithms quality control for hail.

**Legacy: Applies precipitation rate cap.**

Adaptation Item	Hydromet Rate
Max Precipitation Rate [HSPRA]	103.8
Z-R Multiplier Coef. [CZH]	100.0
Z-R Exponent Coef. [CZP]	1.4

**QPE: Adjusts rain rate equation used.**

	Hail Classification	Equation
$R(Z) = (0.017) Z^{0.714}$	Rain/Hail (HA) and blockage $\geq 5\%$	$R(Kdp)$
1) $R(K_{dp}) = 44  K_{dp} ^{0.822} \text{sign}(K_{dp})$ 2) $R(K_{dp}) = 27  K_{dp} ^{0.822} \text{sign}(K_{dp})$	Rain/Hail (HA) and echo is at or below the top of the melting layer (ML) and blockage $< 5\%$	$R(Kdp)$
	Rain/Hail (HA) and echo is above the top of the ML and blockage $< 5\%$	$0.8 * R(Z)$
	Graupel (GR)	$0.8 * R(Z)$

#### Notes:


Both the PPS and QPE have built in quality control checks for hail. The way Legacy does this is by capping rain rates at 103.8 mm per hour, or 4.09 inches per hour. The way QPE does this is by applying variations of  $R(Z)$  or  $R(KDP)$  to whatever bins the Hybrid Hydrometeor Classification designates as having hail or graupel, along with certain melting layer and beam blockage thresholds. So, both the PPS and QPE have their respective ways of mitigating precipitation overestimates due to hail.

## 1.11 PPS and QPE: Differences Overview

### PPS and QPE: Difference Overview

Differences

- Input Data
- Rain Rate Equations
- Bright Banding
- Bias Application
- Rain Rate Product
- Hourly Accumulations



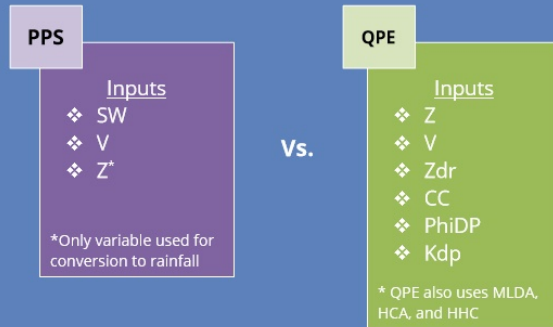
### Notes:

Now that we've talked about several commonalities between the PPS and QPE, let's take a look at several areas in which these two algorithms differ from each other. We'll start by taking a look at how the input data into these two algorithms differ.

## 1.12 Data Input

### Differences: Data Input

1. The QPE algorithm uses considerably more data inputs into its algorithm than the PPS.



#### Notes:

Both the PPS and QPE algorithms rely on different inputs to produce rainfall estimates. If you remember from earlier, PPS relies on the following base data: SW, V, and Z. All three are used by the Radar Echo Classifier to identify bins that likely contain clutter while Z is just used for conversion to rainfall.

QPE uses considerably more variables as input: Z, V, and the Dual-Pol base variables which include Zdr, CC, PhiDP, and Kdp. The QPE algorithm uses these variables, as well as output from the MLDA, HCA, and HHC to assign the appropriate rain rate equation for each radar range bin.

## 1.13 Rain Rate Equations

### Differences: Rain Rate Equations

2. Legacy uses 1 Z-R relationship with editable parameters while QPE uses 4 different rain rate equations under certain conditions

#### Z-R Relationships Available in the Legacy PPS

Relationship:

$$Z = \alpha R^\beta$$

Convective Tropical Marshall-Palmer

Cool Stratiform (East/West)

#### QPE Rain Rate Classifications

Non-Precipitation Classification	Equation	Rain Classification With R(A) Enabled (Default)	Equation
Ground Clutter (GC) or Unknown (UK)	Not Computed	Light/Moderate Rain (RA), Big Drops (BD), or Heavy Rain (HR) and Z < 50 dBZ and blockage > 10% and echo is below the bottom of the ML	R(A)
No Echo (NE) or Biological (BI)	0	Light/Moderate Rain (RA) or Big Drops (BD) and echo is below the bottom of the ML and R(A) cannot be computed	R(Z,Zdr)
Trail and Ice Classification	Equation		
Rain/Hail (RH) and blockage > 5%	R(Kdp)	Heavy Rain (HR) and Z > 50 dBZ and echo is below the bottom of the ML	R(Kdp)
Rain/Hail (RH) and echo is at or below the top of the melting layer (ML) and blockage > 5%	R(Kdp)	Light/Moderate Rain (RA) or Big Drops (BD) and echo is at or above the bottom of the ML	R(Z,Zdr)
Rain/Hail (RH) and echo is above the top of the ML and blockage > 5%	0.8* $R(Z)$	Heavy Rain (HR) and blockage > 10% and Z < 45 dBZ and echo is at or above the bottom of the ML	R(Z,Zdr)
Grainy (GR)	0.8* $R(Z)$	Heavy Rain (HR) and blockage > 10% or Z < 45 dBZ and echo is at or above the bottom of the ML	R(Kdp)
Wet Snow (WS)	0.8* $R(Z)$		
Dry Snow (DS) and echo is at or below the top of the ML	1.0* $R(Z)$	Light/Moderate Rain (RA) or Big Drops (BD)	R(Z,Zdr)
Dry Snow (DS) and echo is above the top of the ML	2.0* $R(Z)$	Heavy Rain (HR) and blockage > 10% and Z < 45 dBZ	R(Z,Zdr)
Ice Crystals (IC)	2.0* $R(Z)$	Heavy Rain (HR) and blockage > 10% or Z < 45 dBZ	R(Kdp)

#### Notes:

As we mentioned earlier, PPS and QPE only share 1 rain-rate equation in common. The remaining are very different from each other. While PPS just relies on one Z-R relationship with editable parameters, QPE utilizes four different rain-rate equations based on different input variables:  $R(Z)$ ,  $R(Z,Zdr)$ ,  $R(Kdp)$ , and  $R(A)$ .

The QPE algorithm determines which rain-rate relationship to use based on the Hydroclass value designated earlier, position relative to the melting layer, and the percentage of beam blockage that is occurring. So, the process that goes into what determines which rain rate relationship is used for the QPE algorithm is considerably more intricate than that of the PPS.



## 1.14 Bright Banding

### Differences: Bright Banding

3. Bright banding is more pronounced in PPS than QPE.

Remember:  
QPE reducing bright  
banding depends on  
correct identification  
by the HHC!

Bright Banding



QPE Rain Rate Classifications

Hail and Ice Classification	Equation
Rain/Hail (HA) and blockage $\geq 5\%$	$R(Kdp)$
Rain/Hail (HA) and echo is at or below the top of the melting layer (ML) and blockage $< 5\%$	$R(Kdp)$
Rain/Hail (HA) and echo is above the top of the ML and blockage $< 5\%$	$0.8 * R(Z)$
Graupel (GR)	$0.8 * R(Z)$
Wet Snow (WS)	$0.6 * R(Z)$
Dry Snow (DS) and echo is at or below the top of the ML	$1.0 * R(Z)$
Dry Snow (DS) and echo is above the top of the ML	$2.8 * R(Z)$
Ice Crystals (IC)	$2.8 * R(Z)$

#### Notes:

If you remember from the rainfall estimation errors lesson, we learned that the presence of the melting layer, or bright band, greatly enhances reflectivities and results in a large overestimation of precipitation. One big difference between the two rainfall algorithms is that while the PPS algorithm cannot quality control for bright banding, the QPE algorithm can!

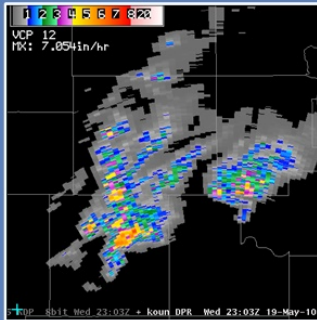
It does so by automatically adjusting the rain rate equation used for water coated frozen hydrometeors, such as wet snow, that are typically found within the melting layer. However, keep in mind that the ability of the QPE algorithm to QC for bright-banding is only as good as the ability of the Hybrid Hydrometeor Classification product to correctly identify frozen hydrometeor types.

## 1.15 Rain Rate Product

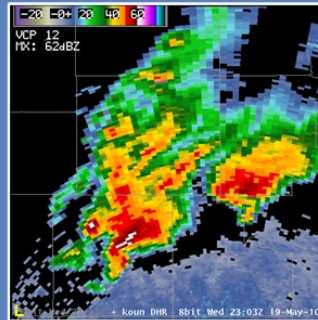
### Differences: Rain Rate Product

4. Instantaneous rain rates are available to view in QPE but not PPS.

**QPE:** Digital Precipitation Rate (DPR) shows instantaneous rain rate for each radar range bin.



**PPS:** Digital Hybrid Reflectivity (DHR) shows dBZ value for each radar range bin.



#### Notes:

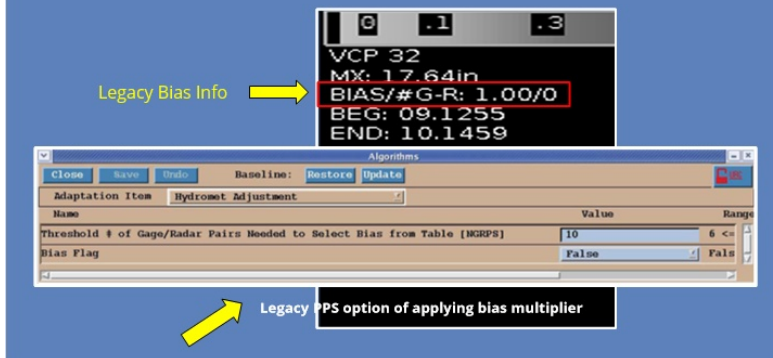
Remember from the QPE module that there is one Dual-Pol precipitation product that has no PPS counterpart: the Digital Precipitation Rate, or DPR product. Remember that this product shows the instantaneous rain rate for each radar range bin that is used in accumulation products.

Unlike QPE, the Legacy PPS does not show the instantaneous rates that feed into producing the final accumulation products. The closest counterpart it has is the Digital Hybrid Scan Reflectivity, or DHR, which just gives the dBZ value for each radar range bin before converting it to rainfall rate.

## 1.16 Bias Adjustment

### Differences: Bias Adjustment

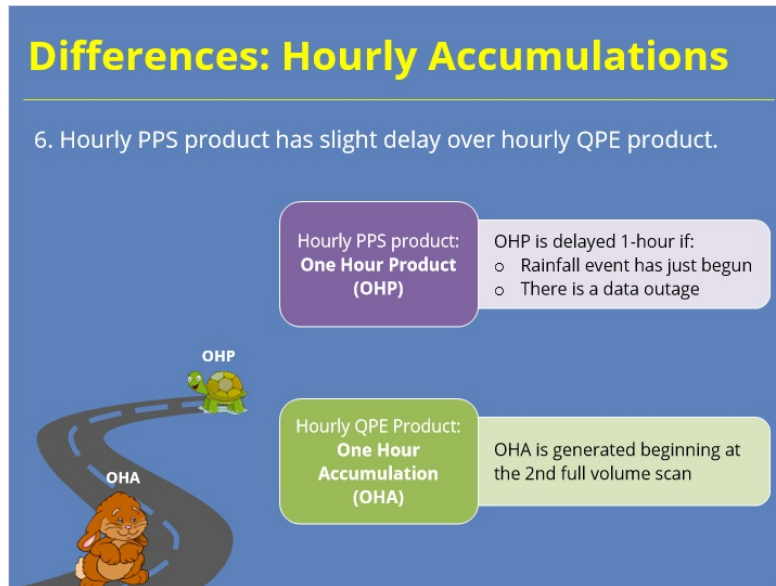
5. The Legacy PPS gives you the ability to apply a bias multiplier to precipitation estimates but QPE does **NOT**.



#### Notes:

Remember from the Legacy PPS module that, while not recommended, you do have the option of applying a bias adjustment to the precipitation field. Unlike PPS, you do NOT have this option within the QPE algorithm. All of the dual-pol QPE products lack a bias adjustment. You can see this reflected in the legend information of QPE precipitation products. In this example, bias information is reported for Legacy while bias information for QPE is displayed as "N/A."

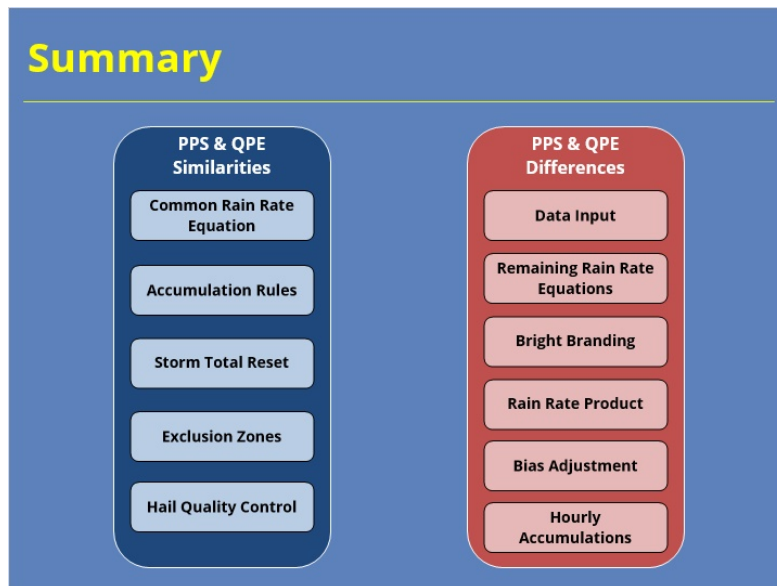
## 1.17 Hourly Precipitation Accumulations



### Notes:

While both the PPS and QPE have their respective one hour precipitation products, that is the One Hour Product for PPS and One Hour Accumulation for QPE, there is a difference when these hourly products are generated under certain circumstances. If a rainfall event has just begun or there is an outage, PPS will have a slight delay where it will not generate its hourly precipitation product for nearly one hour. In contrast, the hourly QPE product is generated more quickly and is available beginning at the 2nd full volume scan.

## 1.18 Summary



### Notes:

To recap, some similarities between the PPS and QPE include sharing a common rain rate equation, similar start/stop accumulation rules and ability to reset accumulations, the option of applying exclusion zones, and quality control methods to reduce hail contamination.

Some differences include what variables are used as input into the algorithms, the number of rain-rate relationships used, the ability to mitigate bright banding effects, the ability to view instantaneous rain rates, the ability to apply a bias adjustment, and differences related to updates to hourly precipitation products. All right, that's all for this lesson - when you're ready, go ahead and click "next" to take the quiz.



Welcome to the lesson on the Snow Accumulation Algorithm.



### 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](#)

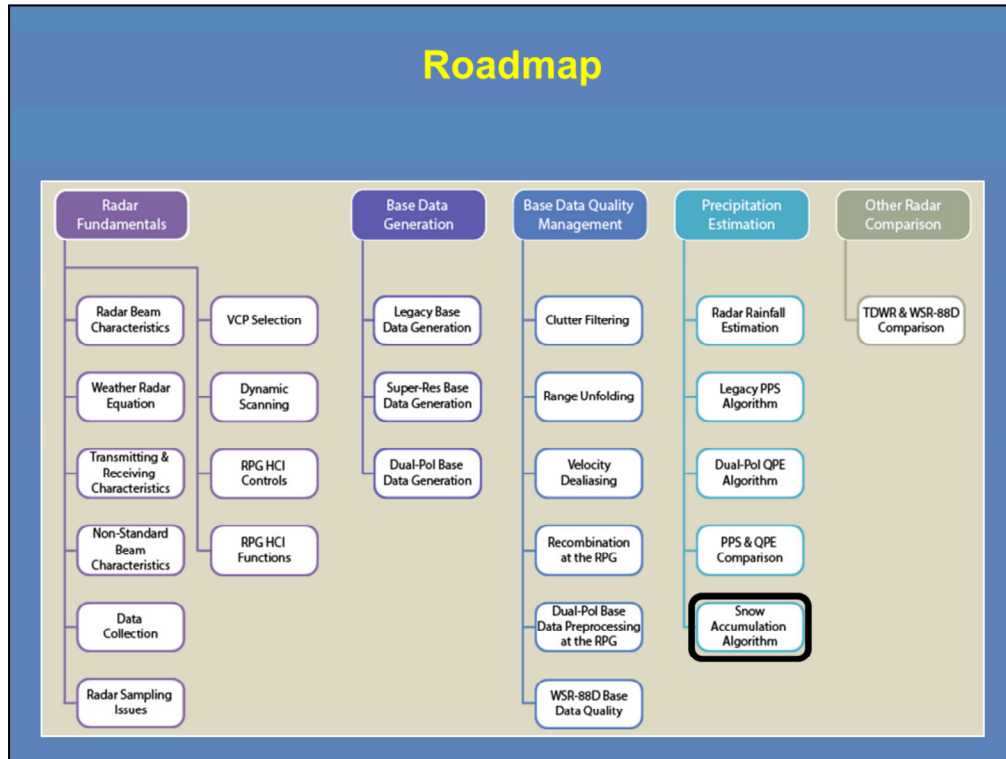
Prev/Next player buttons go to: [Slide in presentation](#)



Edit in Engage



Edit Properties



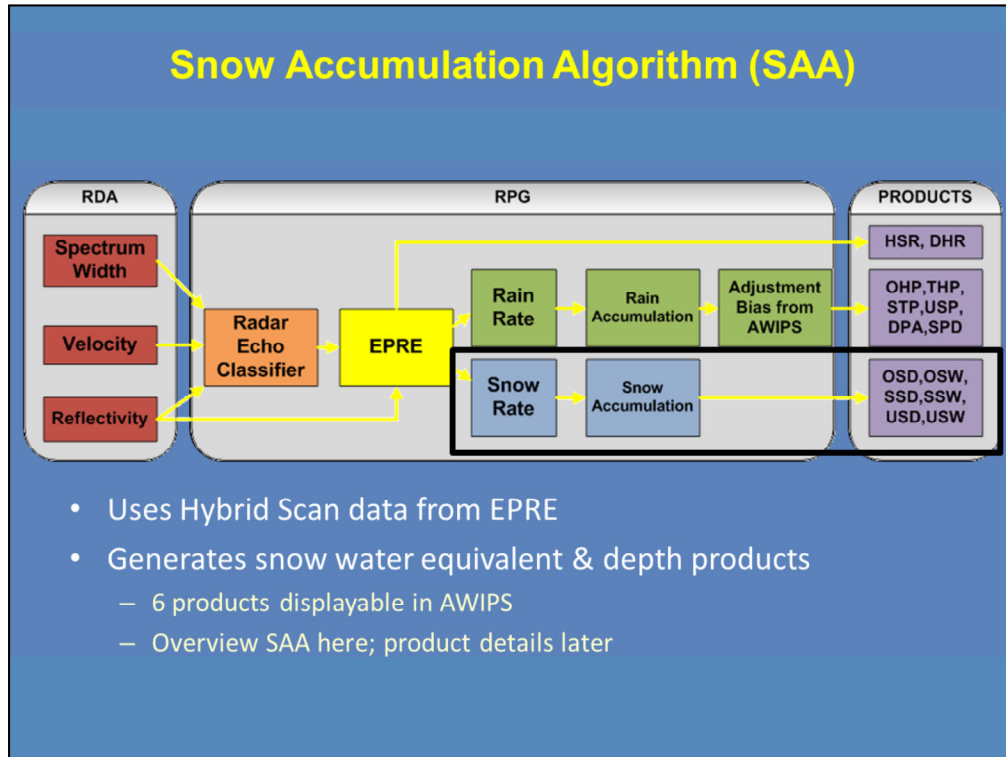
Here is the Roadmap with your current location.



## Learning Objectives

1. Identify strengths & limitations of the Snow Accumulation Algorithm

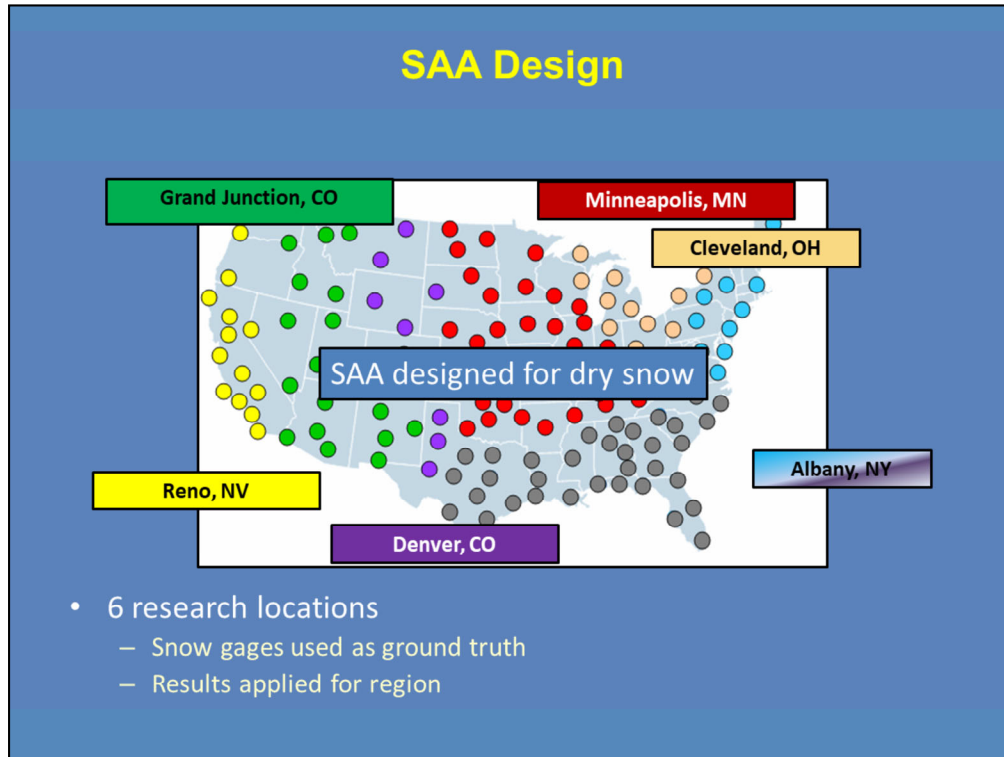
There is one objective for this lesson.



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

After data processing, this algorithm produces 6 total products in AWIPS that represents values for snow water equivalent and depth over various time ranges.

Currently 6 products in AWIPS and more information on the products will be presented in a later lesson.

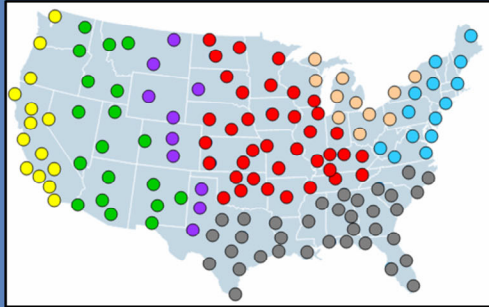


The SAA was developed from data collected at 6 different research locations. At each of these locations, a network of high quality snow gages was used as ground truth against the radar snowfall estimates. The output of this research provided default adaptable parameters that are used at each of the regions on the map. Note that there was not a research site selected in the southern United States. The data for Albany was selected for use in both the Northeast and Southern United States.

One of the most important assumptions with the SAA is that it was designed for dry snow events.

## Z-S Relationships

- Reflectivity (Z) to rate of snow water equivalent (S)
- Same default Z-S relationship for each region



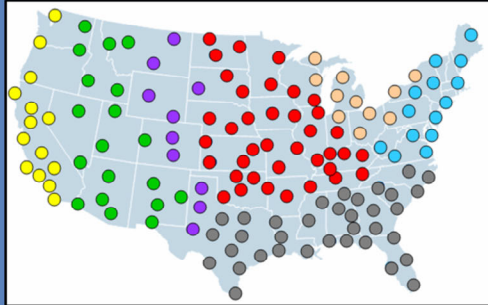
Research Location	Relationship
Albany, NY	$Z = 120 S^2$
Cleveland, OH	$Z = 180 S^2$
Minneapolis, MN	$Z = 180 S^2$
Denver, CO	$Z = 130 S^2$
Grand Junction, CO	$Z = 40 S^2$
Reno, NV	$Z = 222 S^2$

Similar to how there are Z-R relationships to estimate rainfall rates from reflectivity, there are Z-S relationships developed to estimate snow water equivalent from reflectivity. Using the EPRE Hybrid Scan data as input, the returned power is plugged into a Z-S relationship using coefficients developed from one of the regional research locations.

This table lists the default Z-S relationships for each research location.

## SAA and Snow Ratio

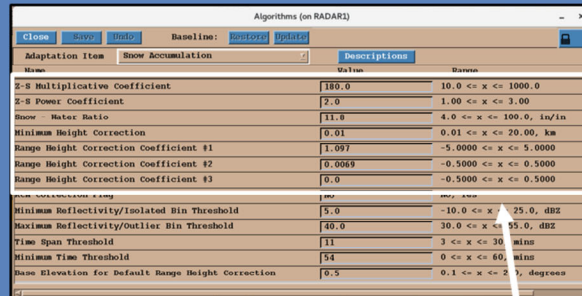
- Snow ratio
  - Water equivalent to snow depth
- Same default Snow Ratio for each region



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

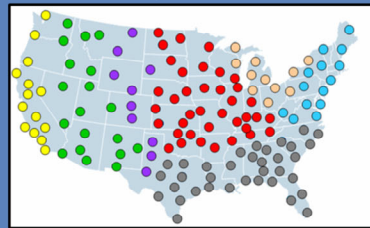
The snow ratio used for converting snow water equivalent to snow depth is another adaptable parameter and the default values for each region are listed here. Even within a given region, it is expected that the appropriate ratio will vary from event to event.

## SAA Adaptable Parameters



Adaptation Item	Value	Range
Z-S Multiplicative Coefficient	180.0	10.0 <= X <= 1000.0
Z-S Power Coefficient	2.0	1.00 <= X <= 3.00
Snow - Water Ratio	11.8	4.0 <= X <= 100.0, in/in
Minimum Height Correction	0.01	0.01 <= X <= 20.00, km
Range Height Correction Coefficient #1	1.097	-5.0000 <= X <= 5.0000
Range Height Correction Coefficient #2	0.0069	-0.5000 <= X <= 0.5000
Range Height Correction Coefficient #3	0.0	-0.5000 <= X <= 0.5000
Minimum Reflectivity/Isolated Bin Threshold	5.0	-10.0 <= X <= 25.0, dBZ
Maximum Reflectivity/Outlier Bin Threshold	40.0	30.0 <= X <= 55.0, dBZ
Time Span Threshold	11	3 <= X <= 30, mins
Minimum Time Threshold	54	0 <= X <= 60, mins
Base Elevation for Default Range Height Correction	0.5	0.1 <= X <= 2.0, degrees

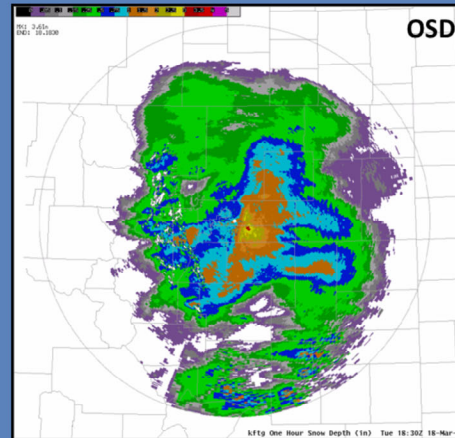
- Default values based on region
- Seven URC adaptable parameters:
  - Z-S,
  - Snow Ratio,
  - Height Correction



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.

## SAA Products

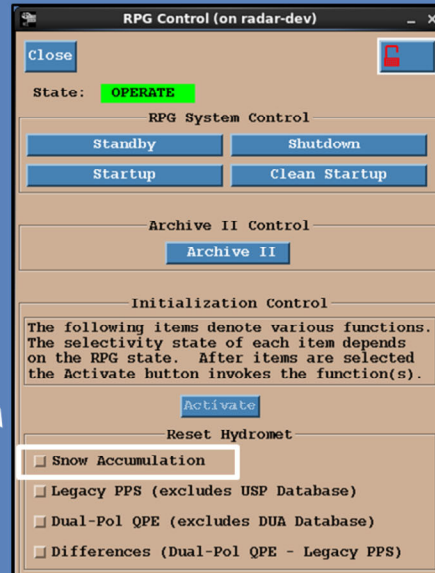
- 1km x 1°; 16 data levels; range of 124 nm
  - **OSW**: One Hour Snow Water Equivalent
  - **OSD**: One Hour Snow Depth
  - **SSW**: Storm Total Snow Water Equivalent
  - **SSD**: Storm Total Snow Depth
  - **USW**: User Selectable Snow Water Equivalent
  - **USD**: User Selectable Snow Depth



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.

## Begin and End of Snowfall Accumulations

- **No** automatic reset of snow accumulations
- Must be *manually* reset prior to event



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.



## SAA Strengths

- Only source of real time high resolution snowfall accumulations
- Uses best possible reflectivity (close to ground) to convert to snowfall
- Accumulations can be reset to zero as needed
- Available Z-S relationships and snow ratios are editable

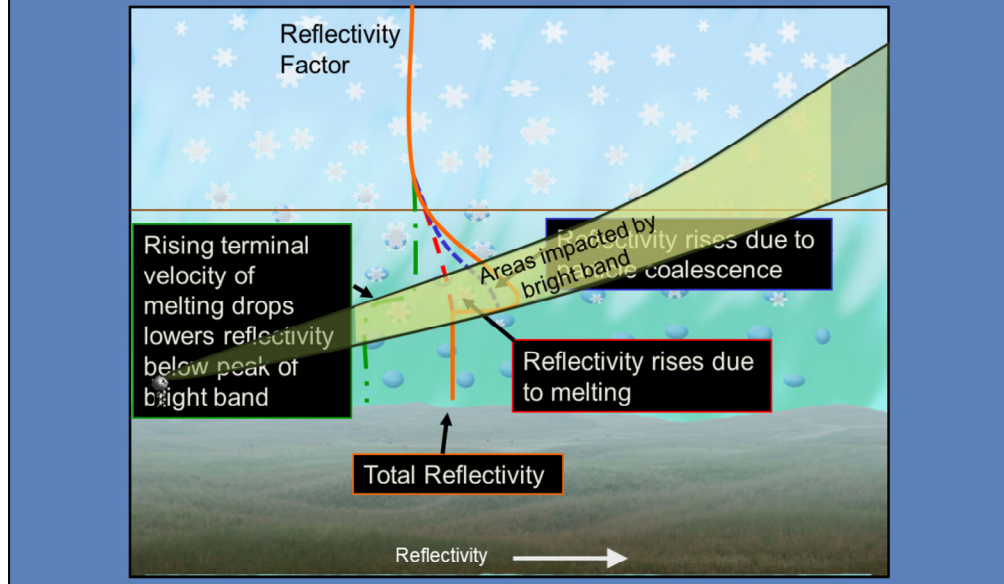
The first strength of the SAA is that it is the only source for real time high resolution snowfall accumulations. Since the SAA also uses EPRE as input, the SAA uses a reflectivity value closest to the ground that is not from clutter and is not blocked by the beam. At the RPG, snow accumulations can be reset to zero as needed. The Z-S relationships and snow ratios are editable.

## SAA Limitations

- SAA designed for dry snow
- Ground truth likely needed:
  - to verify precipitation type
  - to determine onset of accumulation
- No automatic reset of accumulations; must be done manually
- Available Z-S relationships and snow ratios may not be representative

Perhaps the most important thing to remember about the SAA is that it designed for dry snow, snow that does not melt as it falls or when it hits the ground. Ground truth will likely be needed to verify precipitation type and to determine the onset of snow accumulation. The onset must be known in order to reset the snow accumulations, which must be done manually. Finally, the default Z-S relationship were developed at specific locations and applied across an entire region. So both the Z-S relationship and the snow ratio may not be representative for your CWA and may require adjusting.

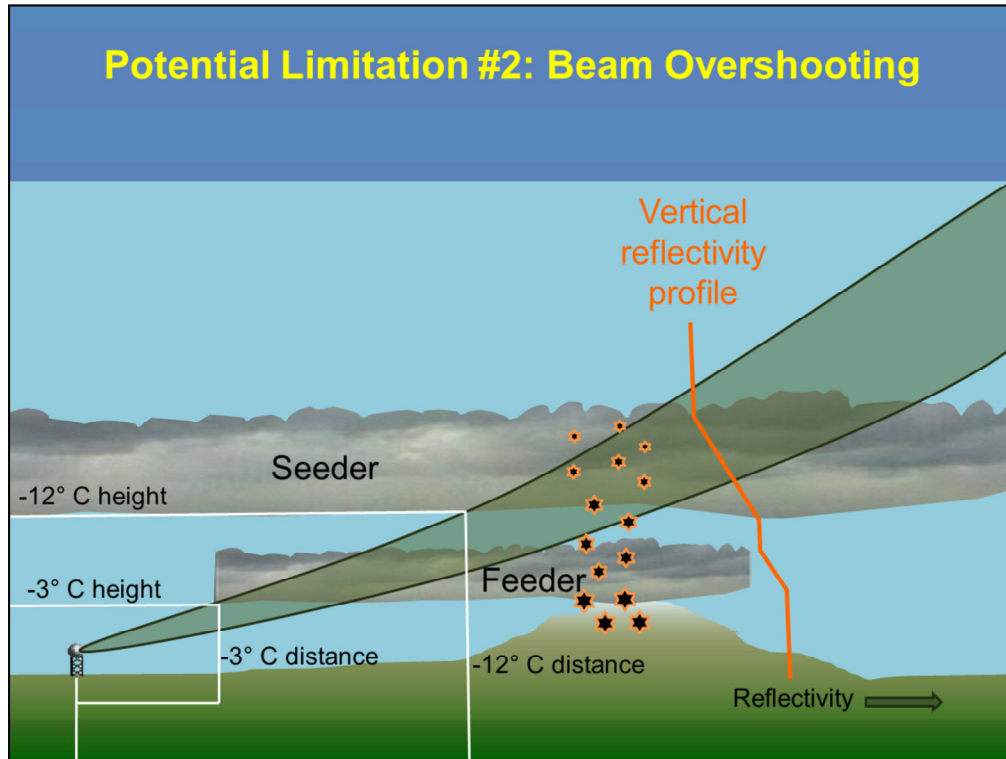
## Potential Limitation #1: Assumption of Dry Snow



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.

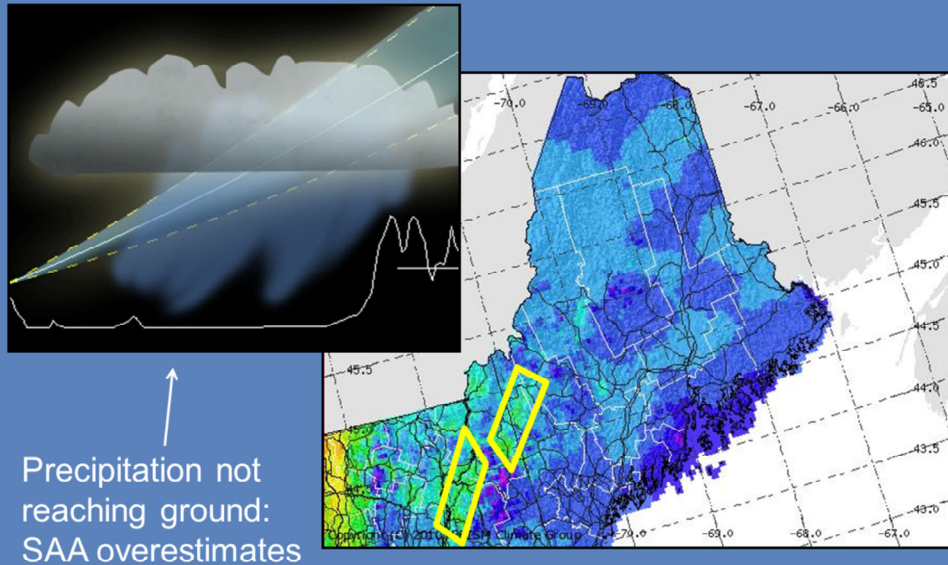


Assume we have a cloud pictured here actively generating precipitation so the intensity increases from top to bottom. Reflectivity begins to degrade once the top of the radar beam is above this precipitation production layer, and the signal is lost once the bottom of the beam is above the cloud.

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.

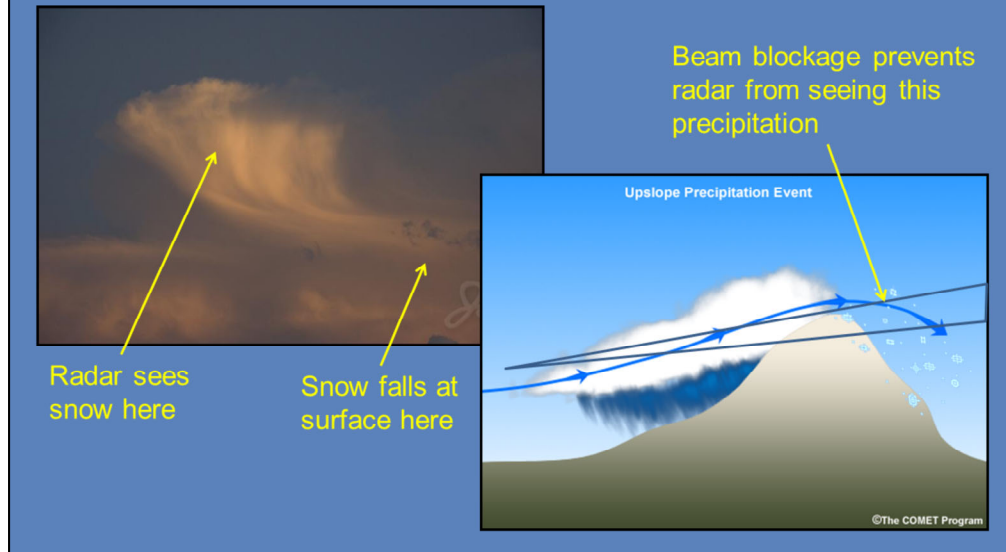
A particularly acute example of this problem is with orographic precipitation. With precipitation very close to upslope terrain, it's difficult to separate ground returns from real precipitation. So, even when the beam does sample the precipitation generation regions, reflectivity can be degraded.

### Potential Limitation #3: Sub-Beam Evaporation/Sublimation



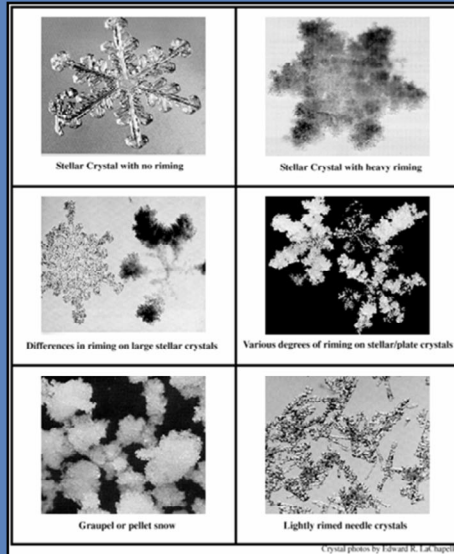
Another data quality issue to consider is sub-beam evaporation (or sublimation). When sub-beam evaporation/sublimation occurs, expect the Snow Accumulation Algorithm to overestimate the liquid equivalent precipitation at the surface. The problem is most common when the near-surface air mass is dry (such 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.

## Potential Limitation #4: Horizontal Displacement of Falling Precipitation



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.

## Potential Limitation #5: Unusual Precipitation Particle Shapes



- Changes in shape, size can impact Z, LE differently
- Events can contain mix of stratiform, convective elements
- Variations can be difficult to detect, let alone predict
  - SAA doesn't account for these variations

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

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Allow user to leave quiz: [After user has completed quiz](#)

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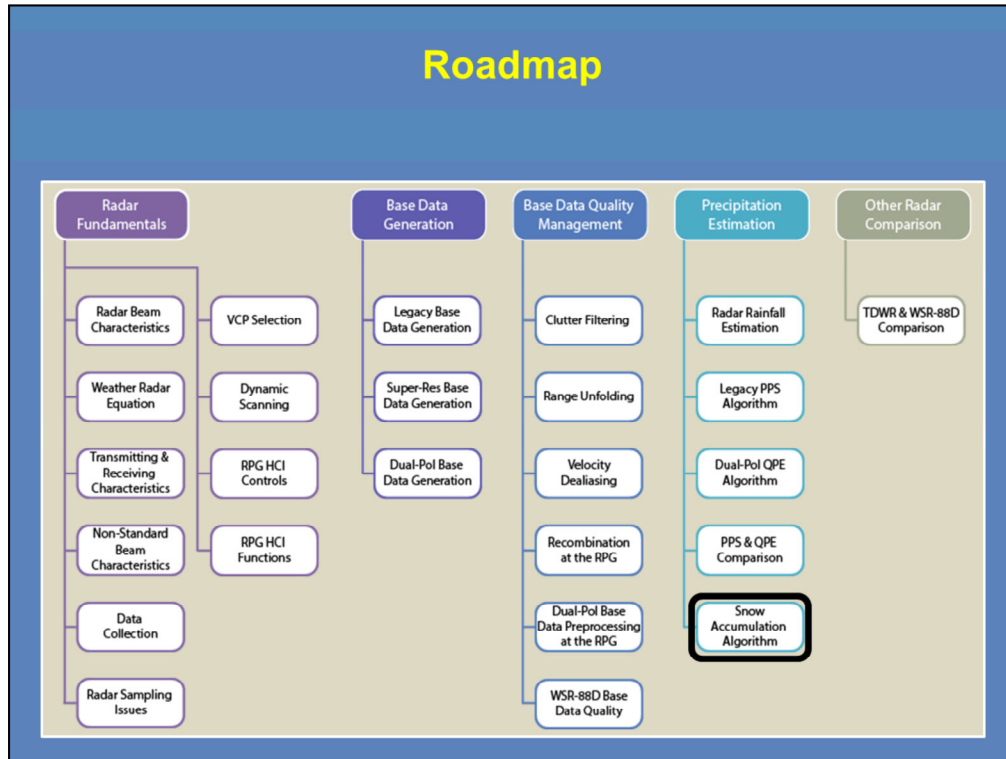


Edit in Quizmaker



Edit Properties

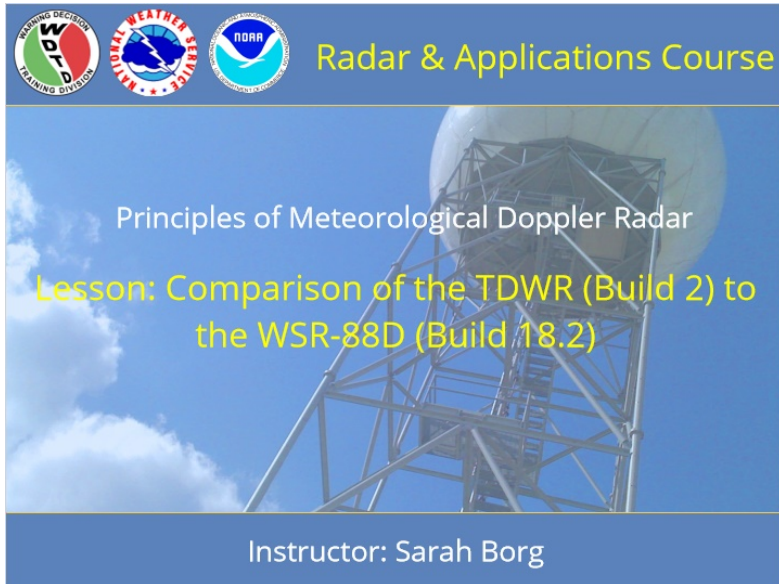




This concludes the lesson and here is the Roadmap with your current location.

## TDWR vs. WSR-88D

### *Title Slide*



**WFO** TRAINING DIVISION  
NATIONAL WEATHER SERVICE  
NOAA

**Radar & Applications Course**

Principles of Meteorological Doppler Radar

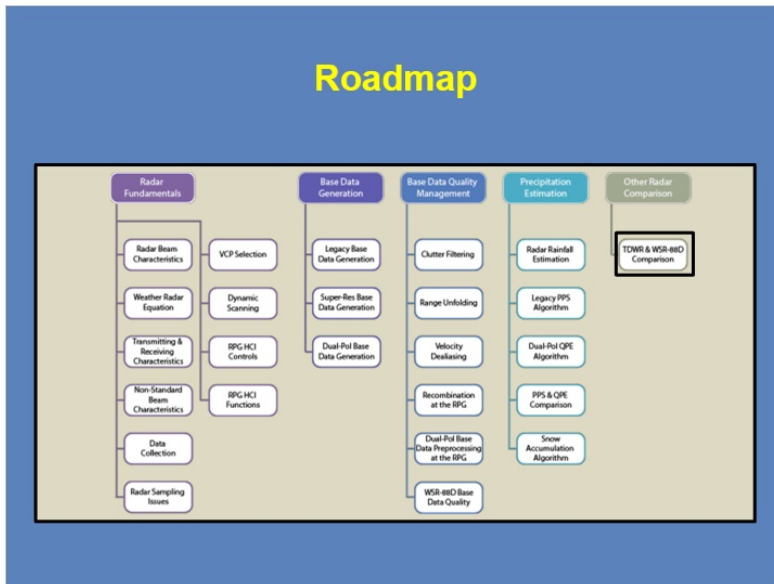
**Lesson: Comparison of the TDWR (Build 2) to the WSR-88D (Build 18.2)**

Instructor: Sarah Borg

### **Notes:**

Welcome to the Radar and Applications Course: Principles of Meteorological Doppler Radar. This lesson compares TDWR Build 2 to WSR-88D Build 18. Let's get started!

## Roadmap



### Notes:

Here is the complete roadmap for the entire "Principles of Doppler Weather Radar" section of RAC. You are currently in the TDWR and WSR-88D Comparison lesson.

## ***Learning Objectives***

### **Learning Objectives**

- Identify the key specification differences between the TDWR and WSR-88D radars including wavelength, half-power beamwidth, pulse length, VCPs, dual-polarization technology, clutter filtering, and velocity dealiasing.
- Identify the strengths and weaknesses of using TDWR products in NWS operations.

#### **Notes:**

Please review the two listed learning objectives for this lesson, and when you are ready, advance to the next slide.

## ***TDWR Background Information***

### **TDWR Background Information**

*TDWR = Terminal Doppler Weather Radar*

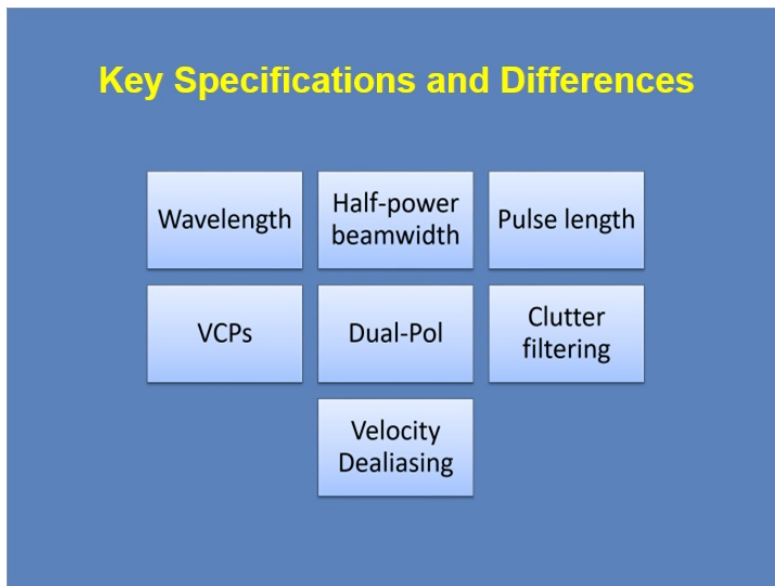
- Designed by FAA to scan near major airports for hazardous aviation conditions
  - Wind shear, gust fronts, downbursts, etc.
  - Specific for short range analysis
- Can sometimes provide critical support to NWS mission



#### **Notes:**

We'll begin with a brief overview of the origin of the TDWR. TDWR stands for "Terminal Doppler Weather Radar". These radars were designed by the Federal Aviation Administration to monitor the weather near airports for hazardous aviation conditions, such as wind shear, gust fronts, downbursts, and more. They were created specifically for short range analysis, however they can sometimes provide critical support to the NWS mission to protect life and property.

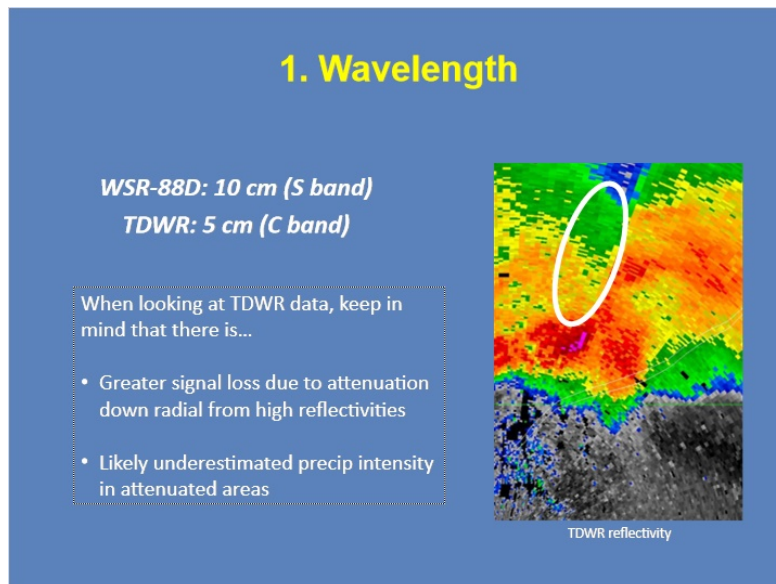
## ***Key Specifications and Differences***



### **Notes:**

There are a variety of differences between the WSR-88D and the TDWR systems. The seven listed here will be the focus of this lesson. Let's go ahead and get started with the first item on the list, wavelength.

## Wavelength

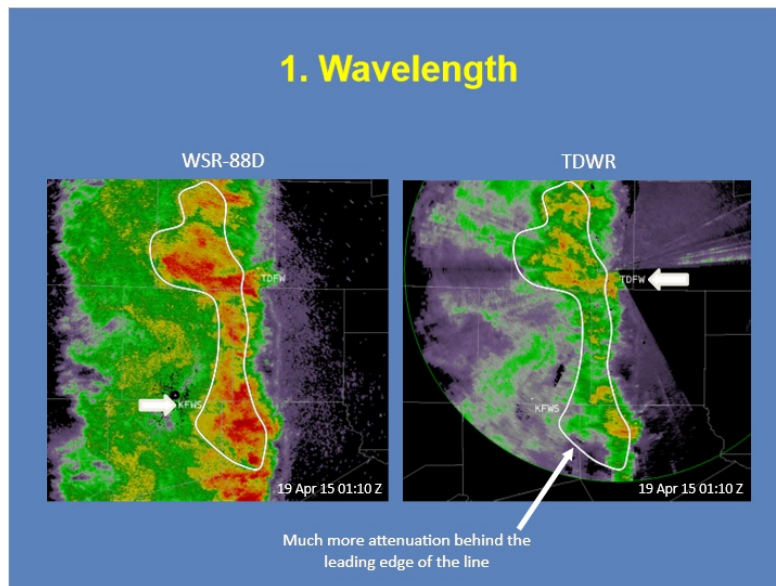


### Notes:

The WSR-88D wavelength is 10 cm (S band), compared to the TDWR wavelength of 5 cm (C band). The most significant consequence of using a C band radar is attenuation.

Attenuation will result in signal loss down radial from strong returns. The stronger the return, the greater the signal loss down radial. Hail and heavy rain will have the greatest impact. In this example, signal loss down radial from a small storm core results in an unrealistic gradient from one azimuth to the next. Hail and heavy rain will produce the most dramatic attenuation, but keep in mind that there is some signal loss even with weak to moderate returns. This will result in underestimates of precipitation as well, even in areas down radial from moderate reflectivities.

## Wavelength Example

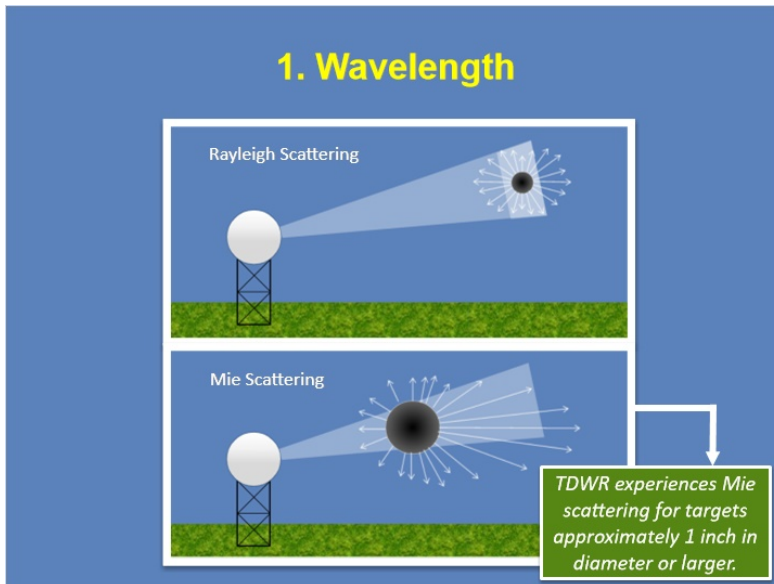


### Notes:

This example shows the difference in reflectivity due to attenuation between a WSR-88D and a TDWR. The area outlined is the same for both images, at the same time. We can see that attenuation from the TDWR side is much greater than the WSR-88D, minimizing the severity of the line.



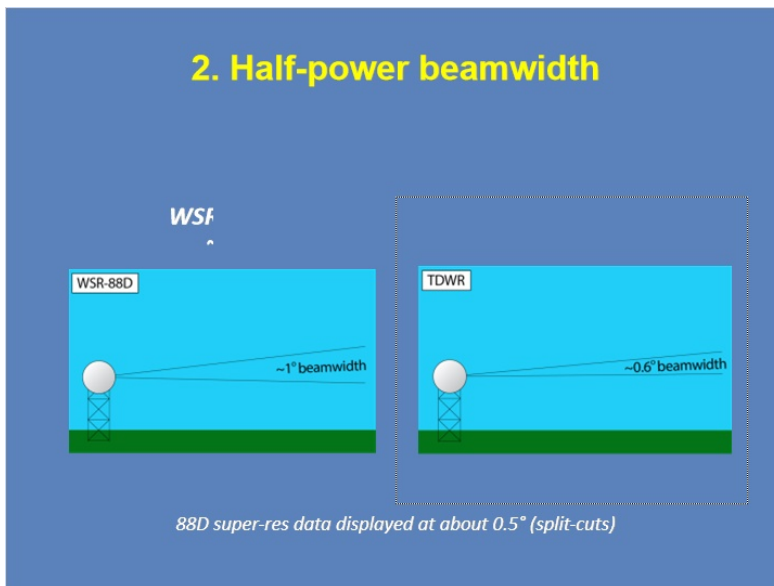
## Scattering Review



### Notes:

While scattering effects were discussed in an earlier lesson on Radar Beam Characteristics, let's quickly review how Rayleigh and Mie scattering work to better understand the scattering regimes that are likely for each radar. Weather radars work best in Rayleigh scattering, where targets are much smaller than the transmitted wavelength, because returned power is directly related to the target's size. When targets are similar in size to the wavelength, Mie scattering occurs. In Mie scattering, the relationship between returned power and target size isn't linear, but is more oscillating in nature. The TDWR radars experience Mie scattering when targets are approximately 1 inch in diameter. The attenuation and Mie scattering issues with TDWR returns results in poor data quality when looking at echoes located down radial from severe hail cores (or even intense rainfall). Mie scattering is much more common with TDWR data since the wavelength is shorter and therefore objects are more likely to be closer in size to the wavelength.

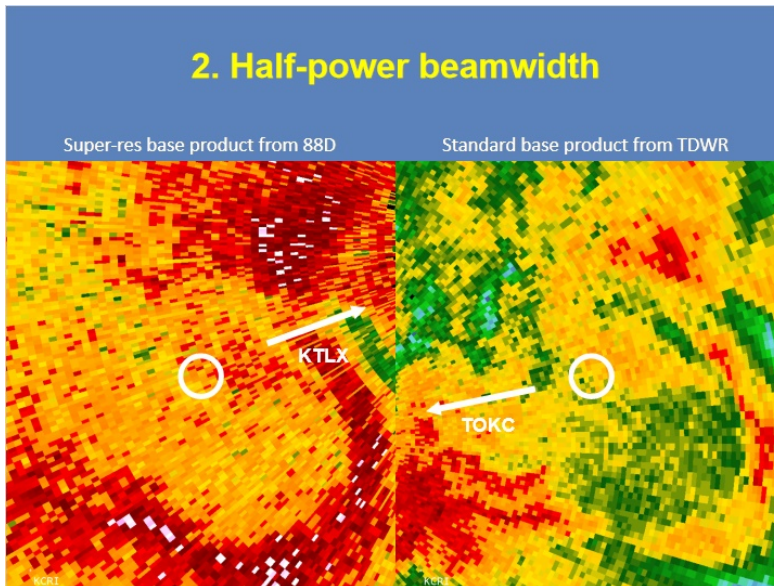
## Half-power beamwidth



### Notes:

The physical beamwidths for a single pulse are different. The WSR-88D has a physical beamwidth of about 1 degree at half-power, while the TDWR has a beamwidth of about 0.55 degrees at half-power. For the split-cut elevations of the WSR-88D, super resolution data are available and displayed in nearly the same resolution as the TDWR data. However, above the split-cuts, super-resolution products are not available for the WSR-88D, and azimuthal resolution is about 1 degree.

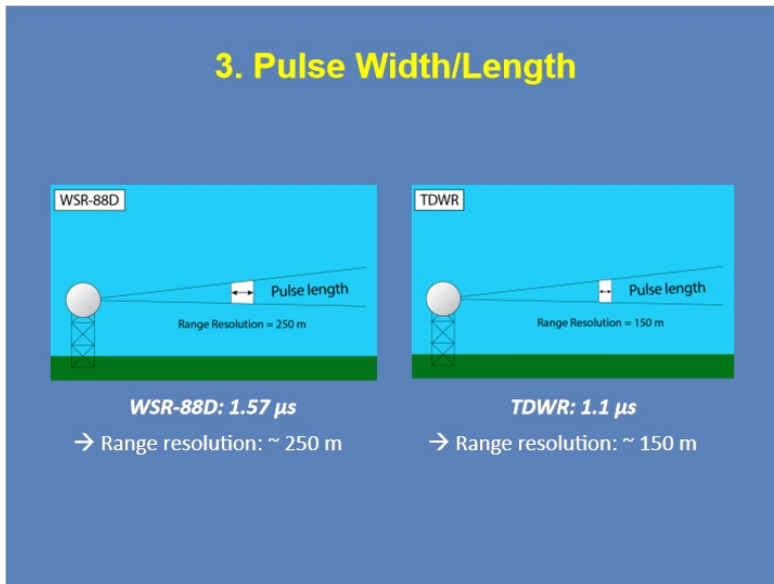
## ***Beamwidth Example***



### **Notes:**

The example on this slide is used to show how super-res base products and the TDWR have approximately the same azimuthal resolution. In other words, for some tilts, the product resolution is similar between the two. This example shows data from KTLX and TOKC at approximately the same time and distance from the respective radars. The direction to each radar site is pointed out to better see differences between azimuthal resolution, which is mostly vertical, versus range resolution, which is mostly horizontal. Azimuthal resolution between the two is fairly similar.

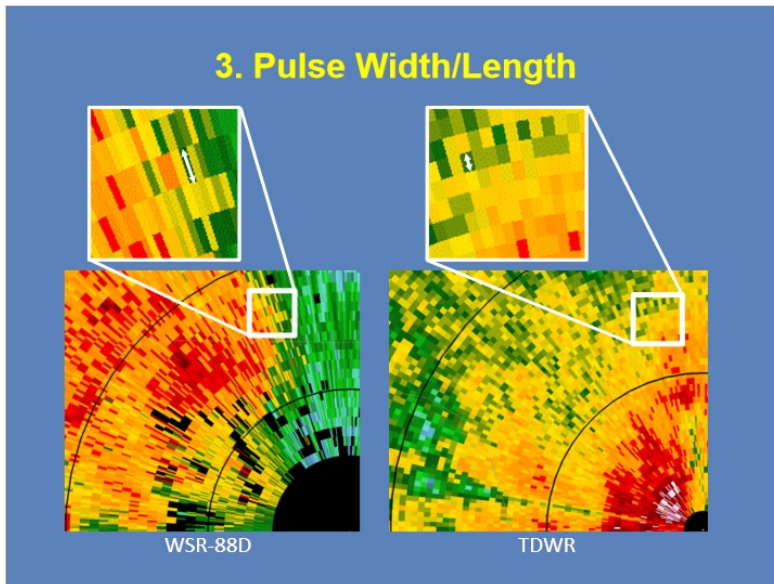
## ***Pulse Width***



### **Notes:**

The pulse length determines the minimum necessary distance between targets for them to be resolved. For WSR-88D systems with a pulse length of 1.57 microseconds, the range resolution is about 250 meters. For TDWR systems, the range resolution is smaller, about 150 meters. This means that TDWRs can “see” features that are closer together, or in other words, for features to be identified they only need to be larger than  $\frac{1}{2}$  of the pulse length, which is smaller for the TDWR than the 88D.

### ***Pulse Width Example***



#### **Notes:**

By looking closely at the two images, we can see the differences in the range bins. For the WSR-88D, the range bins are larger than those of the TDWR. The range bin differences are due to the differences in pulse length between these systems. The TDWR has a shorter pulse length, allowing for greater range resolution than the WSR-88D. Don't forget, however, that while the range resolution is greater, attenuation also happens more easily with the TDWR. So while targets may more likely be resolved, the reflectivity echo is also likely weaker in the TDWR data.

## VCPs

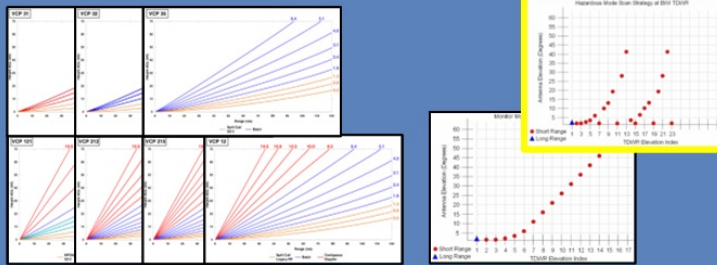
### 4. VCPs

#### WSR-88D: 7 total VCPs

- 3 clear air modes
- 4 precip modes

#### TDWR: 2 VCPs

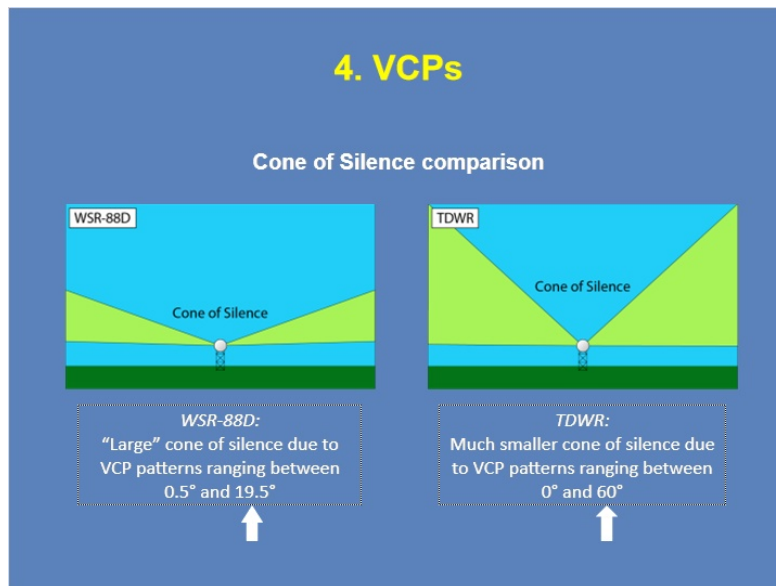
- 1 monitor mode (clear air)
- 1 hazardous mode (precipitation mode)



#### Notes:

VCPs are *volume coverage patterns*. The WSR-88D has 7 different VCPs, all designed for different environmental regimes and can be selected by the radar operator. While the TDWR only has a single precipitation mode (or “hazardous” mode”), this mode is significant because it provides lowest elevation reflectivity and velocity scans every minute, which is greater temporal resolution than any of the WSR-88D VCPs. The caveats, however, are that there is no radar operator control over which VCP to use and options are not set up to fit specific weather regimes.

## VCPs - Cone of Silence

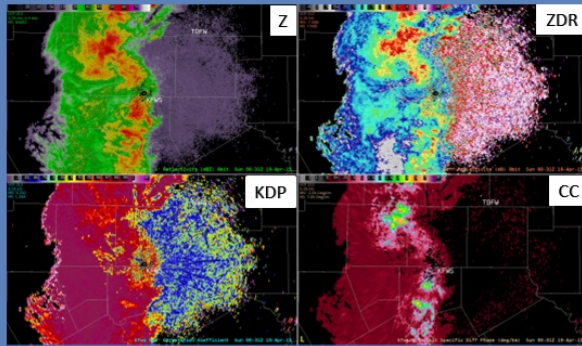


### Notes:

In addition, the TDWR has a smaller cone of silence than the 88D due to the fact that the TDWR volume coverage patterns reach much higher elevations. The TDWR reaches elevations up to 60 degrees as compared to the WSR-88D's highest elevation scan of 19.5 degrees.

## Dual-Pol

### 5. Dual-Pol



WSR-88D Dual-Pol Products

**WSR-88D:**  
All dual-pol  
products are  
available

**TDWR:**  
No dual-pol  
availability

#### Notes:

Dual-pol products are very beneficial to forecasters for many reasons, one of them being hail threat analysis. Unfortunately, TDWRs do not have dual-pol capabilities. So when it comes to analyzing hydrometeor composition, your local TDWR will not be as useful as the nearby 88D!



## Clutter Filtering

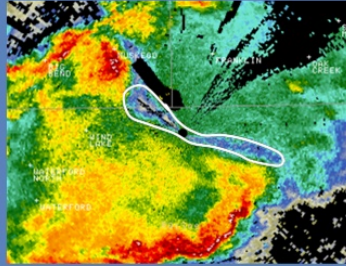
### 6. Clutter Filtering

#### **WSR-88D:**

- CMD algorithm, static bypass map and/or all-bins for clutter identification
- GMAP algorithm for clutter removal

#### **TDWR:**

- All-bins like algorithm for clutter identification
- Modified GMAP clutter removal
- Often see zero-isodop data loss



TDWR Reflectivity

#### **Notes:**

When it comes to clutter filtering, the options available with the 88D data offer much more control than those of the TDWR. For the WSR-88D, the primary tool for clutter filtering is the Clutter Mitigation Detection (CMD) algorithm, however other options are available to use for backup or specific situations. The TDWR, however, uses an all-bins approach no matter what, which often results in data loss along the zero-isodop.

## Velocity Dealiasing

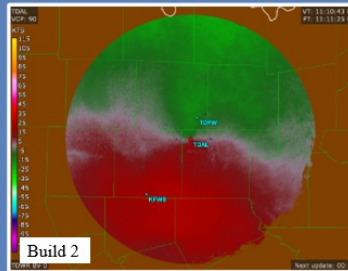
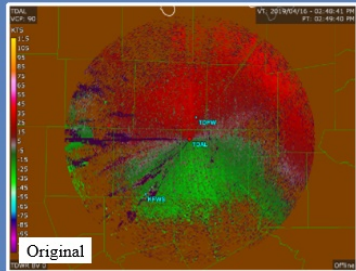
### 7. Velocity Dealiasing

#### WSR-88D:

- 2-D VDA
- Legacy VDA
- Multiple PRF available with VCP 121

#### TDWR:

- Multiple PRF techniques used based on elevation tilt of collected data



#### Notes:

The SPG has a new technique for dealiasing TDWR velocity data. Unlike the WSR-88D that offers different techniques based upon RPG configuration and VCP in use, the TDWR takes care of dealiasing without interaction from forecasters. Take a look at the example on the slide. The figure on the left shows the original TDWR dealiasing algorithm while the image on the right shows the current technique.

## Differences Table

### Summary of Key Differences

	WSR-88D	TDWR
Wavelength	10 cm (S Band)	5 cm (C band)
Half-power Beamwidth	~ 1°	~ 0.6°
Pulse Length	1.57 $\mu$ s	1.1 $\mu$ s
Range Resolution	~ 250 m	~ 150 m
VCPs	3 clear air 4 precip	1 clear air ("monitor") 1 precip ("hazardous")
Dual-Pol Availability	Yes	No
Clutter Filtering	Various methods, little data loss	"All-bins" algorithm, more aggressive, signal loss on zero isodop
Velocity Dealiasing	Primarily uses 2-D or legacy VDA	Primarily uses MPRF

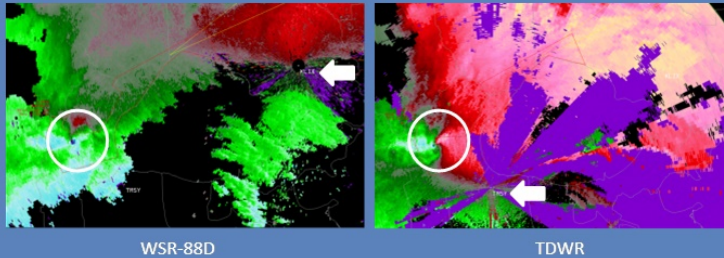
#### Notes:

Here is a table providing a summary of the key differences discussed. This will also be available in the resources tab for a closer look. Feel free to click "Next" to advance to the next slide when you are ready.

## ***Pros of using TDWR data with WSR-88D data***

### **Pros of using TDWR data with WSR-88D data**

1. May provide better viewing angle of important velocity features
2. Better range resolution than WSR-88D
3. 1 minute lowest level scans
4. May overcome WSR-88D cone of silence



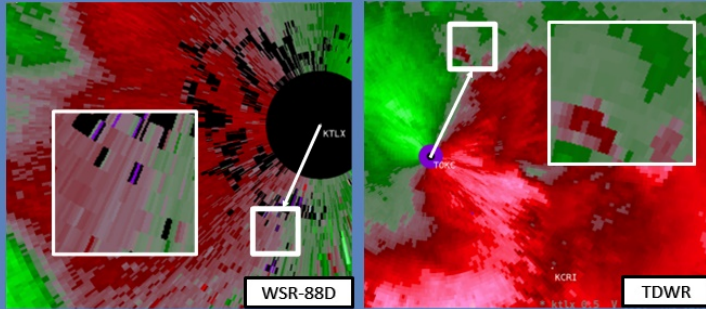
### **Notes:**

Now that we have gone over the specification differences, let's take a look at how these differences play into analysis with the WSR-88D. There are several important "pros" to using TDWR data when available, in conjunction with the WSR-88D Data. The first is the possibility that a TDWR may provide a better viewing angle for important velocity features, as shown in the example here. Both radars detect the rotation, however since the TDWR is much closer it detects a much tighter and more detailed rotation couplet.

## Pro #2

### Pros of using TDWR data with WSR-88D data

1. May provide better viewing angle of important velocity features
2. **Better range resolution than WSR-88D**
3. 1 minute lowest level scans
4. May overcome WSR-88D cone of silence



#### Notes:

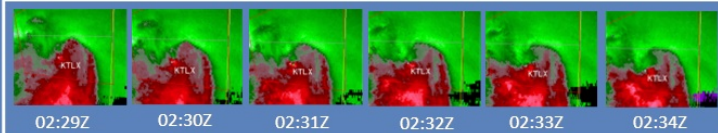
The next “pro” is the better range resolution with the TDWR. As discussed previously, the shorter pulse length of the TDWR allows targets that are closer together to be resolved.

### Pro #3

#### Pros of using TDWR data with WSR-88D data

1. May provide better viewing angle of important velocity features
2. Better range resolution than WSR-88D
3. **1 minute lowest level scans (!!!)**
4. May overcome WSR-88D cone of silence

TDWR:



WSR-88D:



#### Notes:

Perhaps the most important features of TDWR data for NWS operations is the availability of high resolution, low elevation radar data in 1 minute intervals. This example shows a small circulation close to both a TDWR and a WSR-88D. The evolution of this feature in the TDWR data is viewable in 1 minute intervals, while we can see the same time period in WSR-88D data is missing many intermediate time steps.

## Pro #4

### Pros of using TDWR data with WSR-88D data

1. May provide better viewing angle of important velocity features
2. Better range resolution than WSR-88D
3. 1 minute lowest level scans
4. **May overcome WSR-88D cone of silence**



WSR-88D at 02:26 Z



TDWR at 02:26 Z

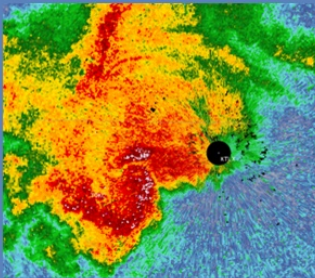
### Notes:

And finally, another pro of the TDWR is the ability to overcome the WSR-88D cone of silence. This example is great to show how a significant circulation is hidden by the WSR-88D cone of silence in the left image, but clearly visible when switching to the nearby TDWR shown in the right image.

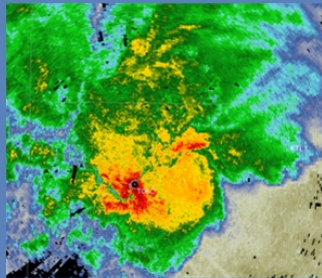
## ***Cons of using TDWR data***

### **Cons of using TDWR data**

1. More susceptible to attenuation & Mie scattering effects



WSR-88D Z at 2:04Z



TDWR Z at 2:04Z

### **Notes:**

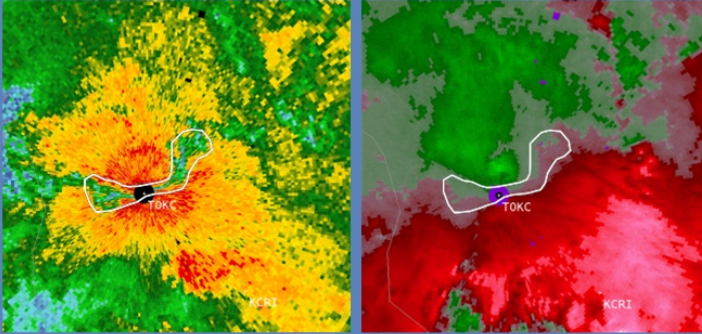
Along with the pros of course comes cons to using the TDWR data. One of the major cons is the susceptibility of TDWR data to attenuation and Mie scattering effects due to its shorter wavelength, an example of which is shown here, where both images show reflectivity at the same time.



## Con #2

### Cons of using TDWR data

#### 2. Clutter filtering too aggressive (Zero isodop data loss)



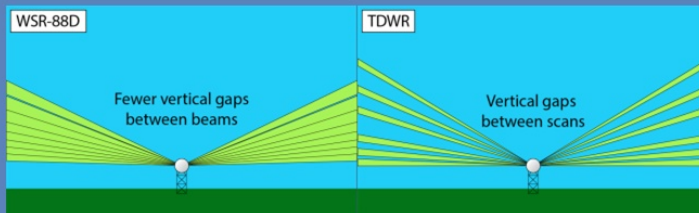
#### Notes:

As mentioned, TDWR data often contains zero-isodop data loss due to its “more aggressive” clutter filtering technique, compared to the WSR-88D. The example here shows the TDWR’s reduced reflectivity values within the area of the zero isodop on velocity.

### Con #3

#### Cons of using TDWR data

##### 3. More gaps in vertical scans



#### Notes:

While the TDWR has the benefit of reaching higher elevations, it has the caveat that there are more gaps in between the vertical scans as well. The figures on the slide show an example of this.

## Con #4

### Cons of using TDWR data

#### 4. Less control of VCPs



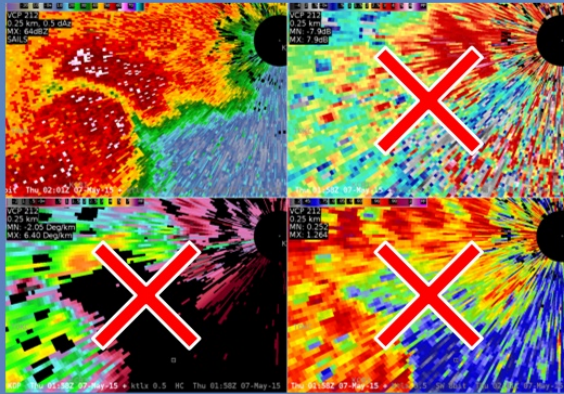
#### Notes:

With the WSR-88D systems, the operator has the ability to change VCPs whenever necessary to best fit the meteorological situation. For TDWRs, there is actually NO freedom for the operator to control VCPs, as the changes are completely automated, and you get only the single precip mode and single clear air mode.

## Con #5

### Cons of using TDWR data

#### 5. No dual-pol data



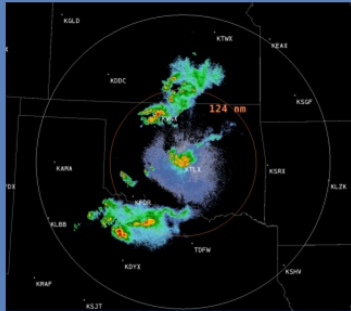
#### Notes:

As mentioned, the TDWR also does not have dual-pol products like the WSR-88D. When using the TDWR, you will have to stick with the legacy base products or the limited suite of derived products offered for the TDWR.

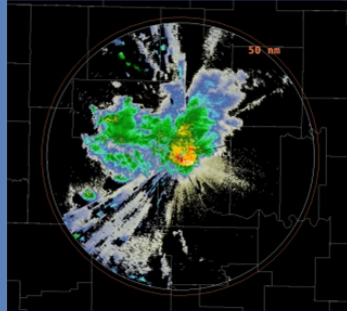
## Con #6

### Cons of using TDWR data

#### 6. Shorter $R_{\max}$



WSR-88D (short range):  
124 nm (~ 230 km)



TDWR (short range):  
50 nm (~ 90 km)

#### Notes:

The range of each system differs greatly. The TDWR has a much shorter range, which is not always a bad thing, however it does make the WSR-88D more versatile when analyzing storms far from the radar. It is worth noting, however, that the TDWR does have a long range reflectivity product which extends out to approximately 300 km, but all other products are shorter range.

## **Conclusion**

### **Conclusion**

- Many specification differences exist between the TDWR and WSR-88D systems such as wavelength, half-power beamwidth, pulse length, and others.
  - Differences allow for unique analysis of data through multiple sources.
- TDWRs offer many strengths to add to the utility of the WSR-88D, with some caveats.
  - Better range resolution, lowest-level 1-minute scans, and other benefits come alongside greater attenuation and aggressive clutter filtering.

#### **Notes:**

In conclusion, let's review what we learned in this lesson. We reviewed many specification differences between the TDWR and WSR-88D systems, with a few of the most important being wavelength, half-power beamwidth, and pulse length. These differences provide forecasters an additional analysis technique when interrogating storms.

In addition, we discussed the many strengths of the TDWR which add to the utility of the WSR-88D system. Those don't come without caveats though. For example, better range resolution and lowest-level 1-minute scans are great benefits of the TDWR, however the TDWR also comes with greater attenuation and more aggressive clutter filtering.

## Lesson Completion



### Notes:

Congratulations on completing this lesson! You are now ready to proceed to the next part of this course. If you are taking this lesson in the CLC, please click on the Exit button to close the lesson and record your completion.