NWS WSR-88D Radar Fundamentals

Meteorology 432 Instrumentation and Measurements

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Topic List

- History of Radar
- Radar Basics
- NWS Radar Products
- Signatures on Radar
- Sources for Radar Data
- New and Future Radar Upgrades

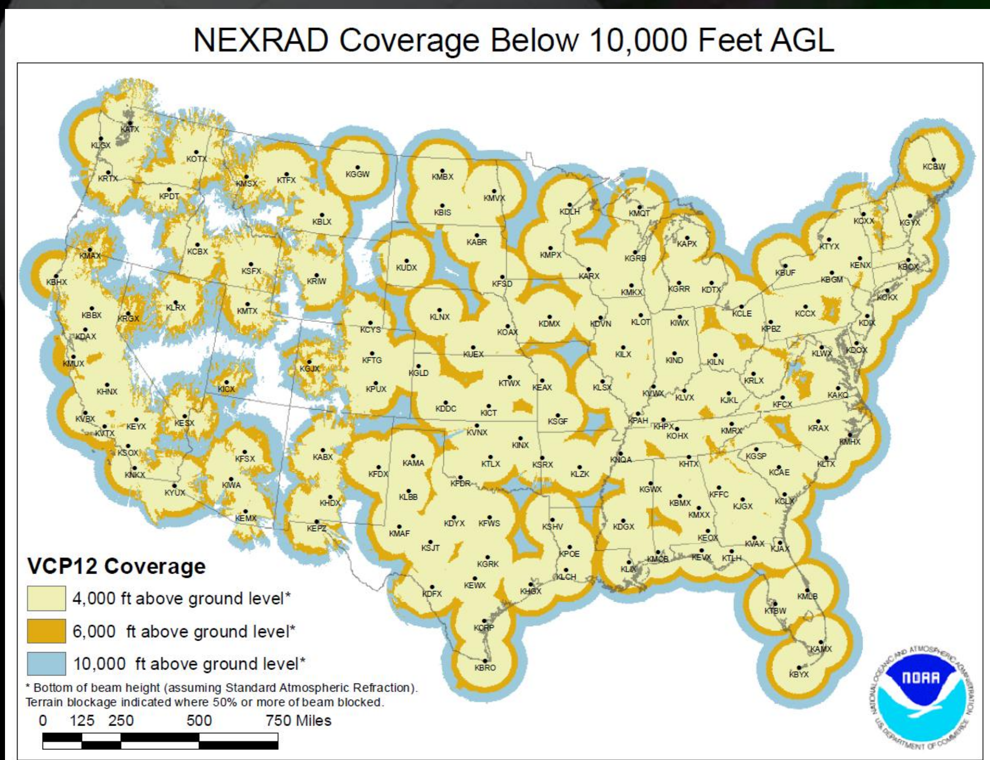
History of Radar

- History of Weather Radar
  - Radar invented during WWII
    - Many surplus radars given to Weather Bureau after the war
  - WSR-57 and WSR-74 were the first radars built specifically for weather detection (reflectivity only)

  - WSR-88D was the first radar able to detect particle motion. Deployed across the county in the mid to late 1990s.

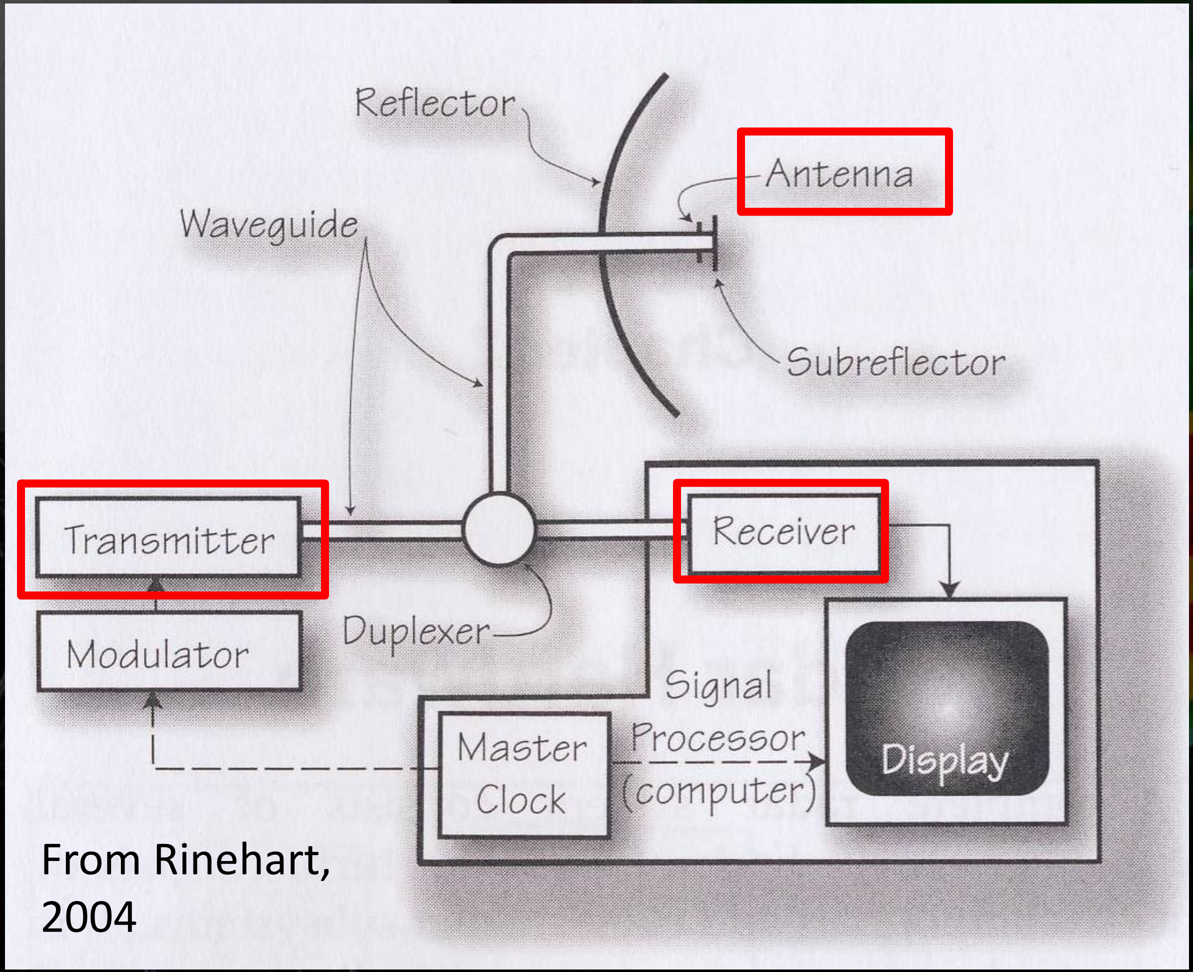
History of Radar

- Current WSR-88D Network – 160 Radars



Radar Basics
Radar Hardware

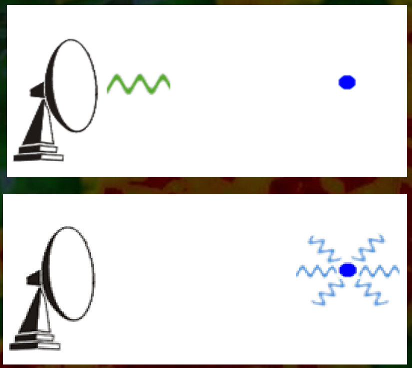
- Schematic Diagram



Radar Basics

How Radar Works

- Radar is an acronym that stands for RAdio Detection And Ranging
- How it Works:
  - The radar transmits a burst of radio waves in a certain direction
  - These waves bounce off whatever they hit (raindrop, bird, dust, etc) and some of this energy is scattered back to the radar's receiver.



  - Because radio waves travel at the speed of light, we can calculate the distance of the object from the radar! (Speed of Light x Time from Transmit to Received)/2

Radar Basics

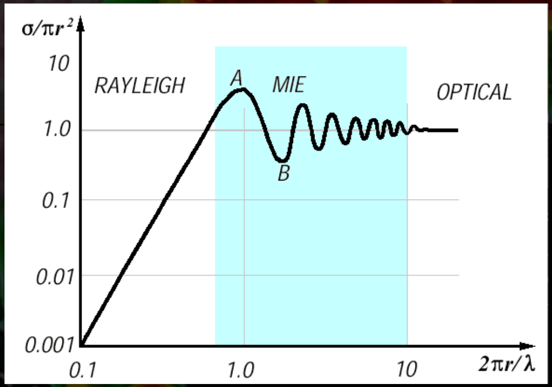
Reflectivity

- The amount of radio wave energy scattered back to the radar determines the object’s intensity, or *reflectivity*
- Reflectivity is a function of:
  - Size (radar cross section)
  - Shape (round, oblate, flat, etc.)
  - State (liquid, frozen, mixed, dry, wet)
  - Concentration (# of particles in a volume)

Radar Basics

Reflectivity

- **Some Notes on Backscattering**
  - Two types of scattering, Rayleigh and Mie
  - ***Rayleigh**:* Backscattering is proportional to target radius **(Easy to Calculate Reflectivity!)**
  - Rayleigh scattering: Target Diameter (D) is much smaller than the wavelength of the transmitted E-M (radio wave) energy (D < λ/16)
  - The WSR-88D's wavelength is approximately 10.7 cm, so Rayleigh scattering occurs with targets whose diameters are ≤ 7 mm or ≈0.4 inch
  - Raindrops seldom exceed 7 mm so all liquid drops are Rayleigh scatters!



Radar Basics

How to Calculate Reflectivity: The Radar Equation!

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

(Also known as the Probert-Jones Radar Equation)

Pr = power returned to the radar from a target (watts)
Pt = peak transmitted power (watts)
G = antenna gain
θ = angular beamwidth
H = pulse length
π = pi (3.141592654)
K = physical constant (target character)
L = signal loss factors associated with attenuation and receiver detection
Z = target reflectivity
λ = transmitted energy wavelength
R = target range

$$P_r = \frac{C_r Z L_a}{R^2}$$

$$Z = \frac{P_r R^2}{C_r L_a}$$

Simplified Radar Equation

Reflectivity (Z) is a function of power returned and range from radar

Radar Basics

Reflectivity Units

- However, reflectivity units (Z) increase exponentially with target size.
- To make the scale more manageable, we apply a logarithmic conversion to reflectivity units, and we get dbZ.

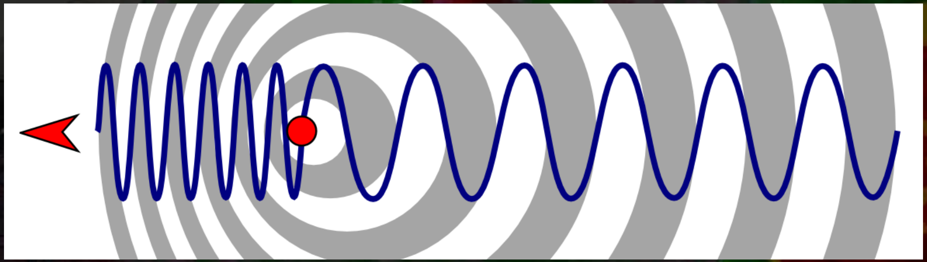
$$dBZ = 10 \log_{10} Z$$

dBZ	Z(mm^6m^{-3})	dBZ	Z(mm^6m^{-3})
-32	0.000631	30	1,000
-28	0.001585	41	12,589
-10	0.1	46	39,810
0	1	50	100,000
5	3.162	57	501.187
18	63.1	95	3,162,277,660

Radar Basics

Measuring Velocity

- The WSR-88D can also detect whether particles are moving towards or away from the radar, using the Doppler Shift principle
  - Commonly observed with sound waves emitted from a moving object
    - Object Moves Towards You: Sound waves are compressed (have a higher frequency) and have a higher pitch. Also known as a positive phase shift.
    - Object Moves Away You: Sound waves are stretched (have a lower frequency) and have a lower pitch. Also known as a negative phase shift.

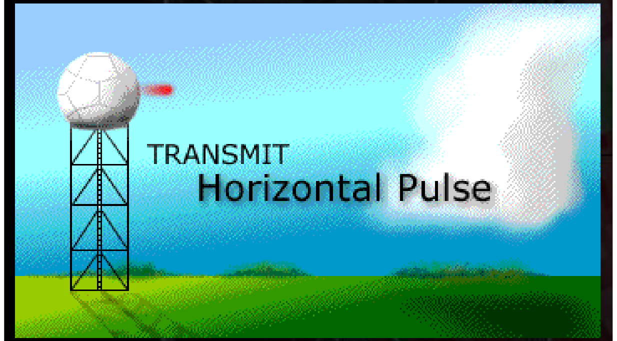


- Radar measures change in wave phase and determines whether the target is moving towards or away from the radar.
- The larger the phase shift, the higher the target's radial velocity.

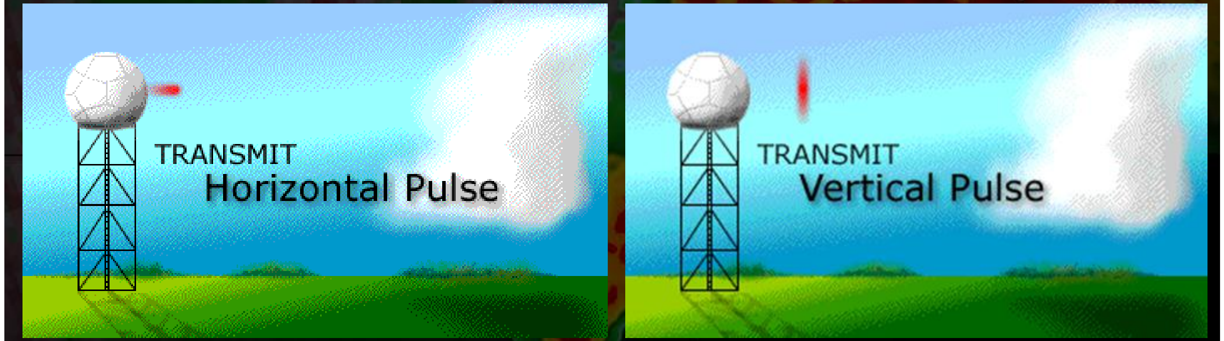
Radar Basics

Dual Polarization

- Dual-polarimetric (dual-pol) radars transmit radio wave pulses oriented in both the horizontal and vertical direction.
- Allows the radar to take a cross section through sample target.
- NWS radars upgraded to dual-pol from 2011-2013.
- Allows for better precipitation type and amount estimations, as well as differentiating between precip and non-precip echoes.



Non-Dual Pol Radars



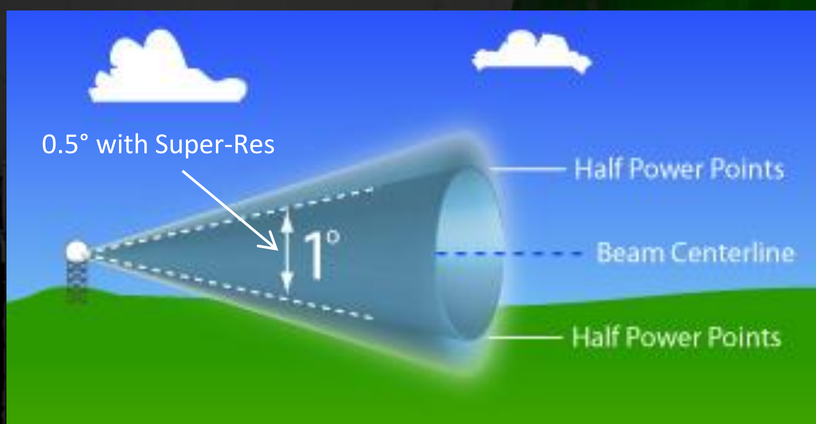
Dual-Pol Radars

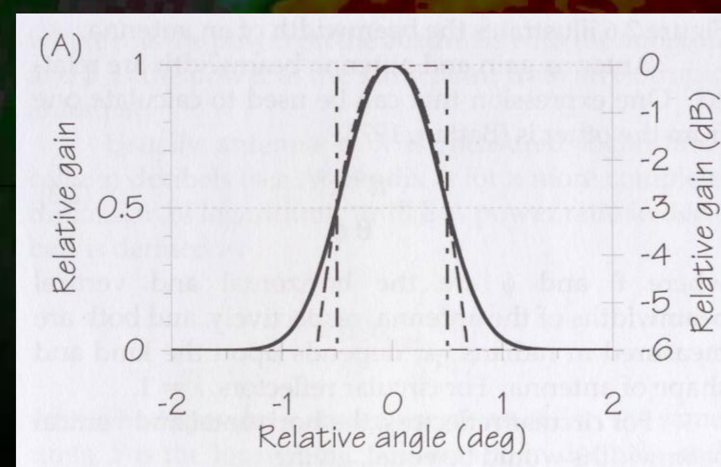
Radar Basics

Beam Characteristics

- Think of the radar beam like a flashlight, with more intense light in the center and less on the edges of the beam
- The beam becomes wider by nearly 1000 feet for every 10 miles in distance

The angular width of the radar beam is defined as that region of transmitted energy that is bounded by one-half (-3 dB) the maximum power. The maximum power lies along the beam centerline and decreases outward.





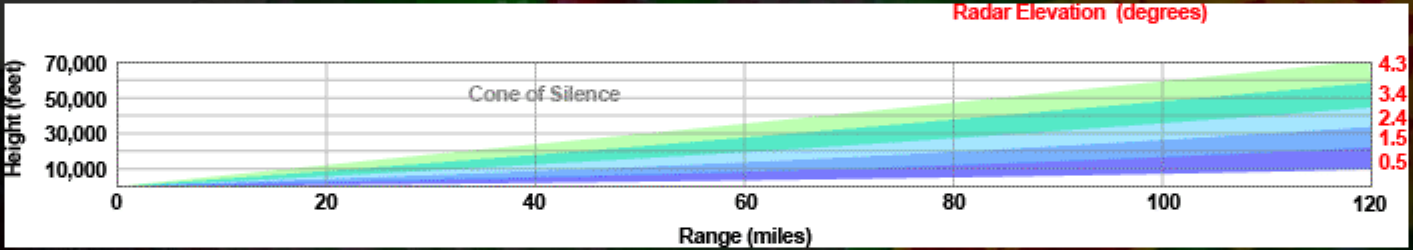
Radar Basics

Volume Coverage Patterns (VCPs)

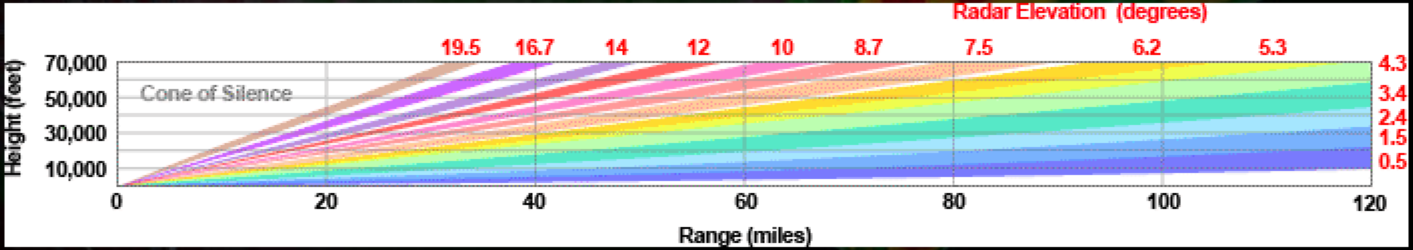
- The radar continuously scans the atmosphere by completing Volume Coverage Patterns (VCP).
- A VCP consists of the radar making multiple 360° scans of the atmosphere, sampling a set of increasing elevation angles.

There are two main operating states of the WSR-88D; Clear Air Mode and Precipitation Mode.

Clear Air Mode



Precipitation Mode



Radar Basics

Volume Coverage Patterns (VCPs)

1. Convection Group -- VCPs 11 and 12
2. Shallow Precipitation Group -- VCP 21
3. Clear Air Group -- VCPs 31 and 32
4. Range Folding Mitigation Group -- VCPs 121^, 211*, 212*, and 221*

VCPs 12 and 212 are the primary VCPs used in severe weather, completing one rotation every 4.5 minutes

^The Multiple PRF Dealiasing Algorithm (MPDA) is part of VCP 121 processing. MPDA reduced range folding by processing additional Doppler rotations at lower elevation angles.

* The Sachinananda-Zrnic (SZ-2) technique is implemented for the lower two or three elevations for VCPs 211, 221, and 212. When echoes are overlaid, SZ-2 can usually recover velocity data for two of the overlaid range bins. SZ-2 is also used for one of the Doppler rotations at 0.5 and 1.5 degrees with VCP 121.

Radar Basics

Limitations

- Non-Uniform Beam Filling
  - As the beam widens with increasing distance from the radar, more detail will be lost and storms may appear weaker.

More radar energy will be focused on Storm 1 and the radar will display a higher reflectivity

Radar Basics

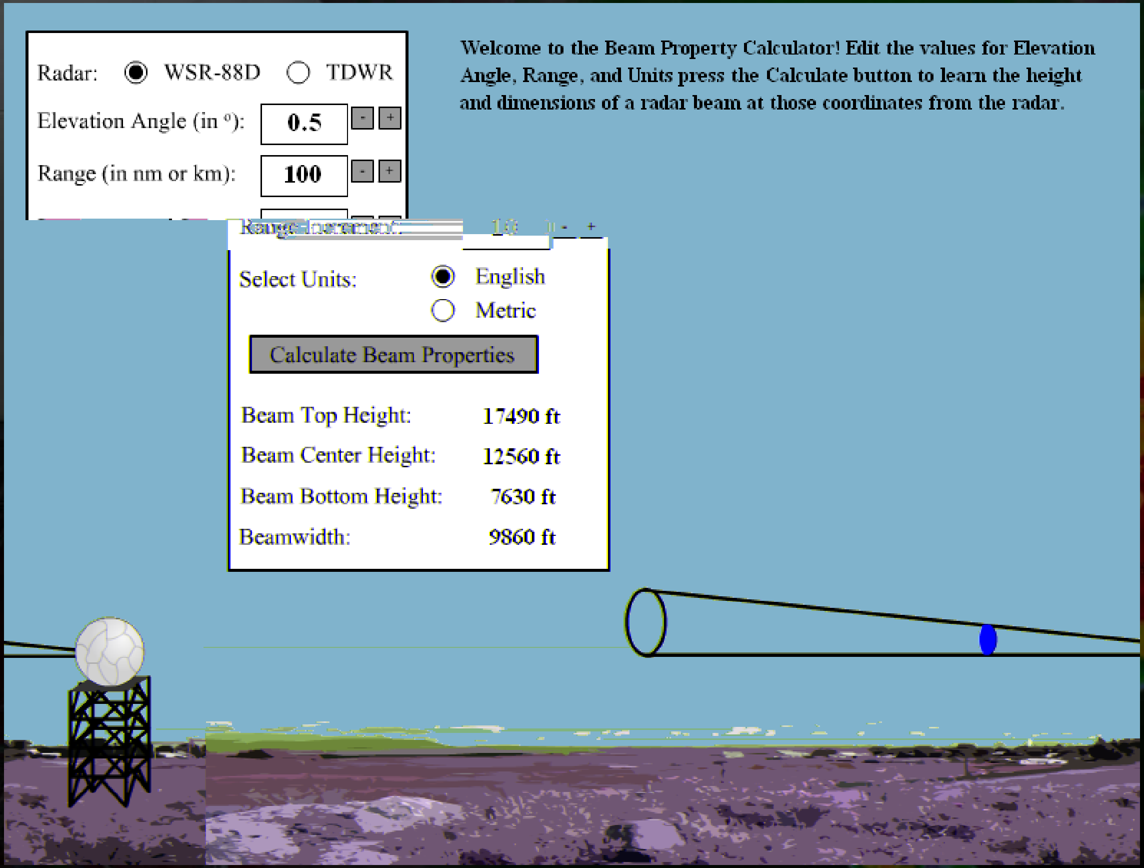
Limitations

- Beam Height
  - Due to the curvature of the Earth, height of the radar beam above ground increases exponentially the further one is from the radar.
    - Will overshoot developing storms far from the radar and even low stratiform precipitation within 40-50 miles of the radar
    - Unable to see rotation in the lowest levels of distant storms

Radar Basics

Limitations

- Beam Height



Radar Basics

Limitations

- Refraction
  - The beam actually travels in a slightly curved path due to differences in atmospheric density caused by variations in temperature, humidity, and pressure.
  - The amount of curvature depends on the magnitude of the density differences.
  - Can lead to erroneous beam height estimates!

Radar Basics

Limitations

- Attenuation
  - Occurs when large objects scatter most of the radio energy back to the radar, leaving little to travel downradial to distant storms.
  - Makes downradial storms appear weaker.
  - Attenuation is fairly minimal with the WSR-88D, but can happen under circumstances
    - Large Hail Cores
    - Long line of storms oriented along the beam path

Radar Basics

Limitations

- The Doppler Dilemma
  - Ideally, you would like the radar to sample at far ranges (R_{max}) and detect high velocities (V_{max}). *But we can't have the best of both worlds!!*
  - Why????
  - It all has to do with the radar's PRF, or pulse repetition frequency
    - PRF is the number of pulses transmitted each second by the radar
    - Both R_{max} and V_{max} are dependant on the PRF
    - *However, R_{max} has an inverse dependence on the PRF, while V_{max} has a direct dependence*

$$V_{max} = \frac{\lambda \mathrm{PRF}}{4}$$

$$R_{max} = \frac{c}{2\,\mathrm{PRF}}$$

Radar Basics

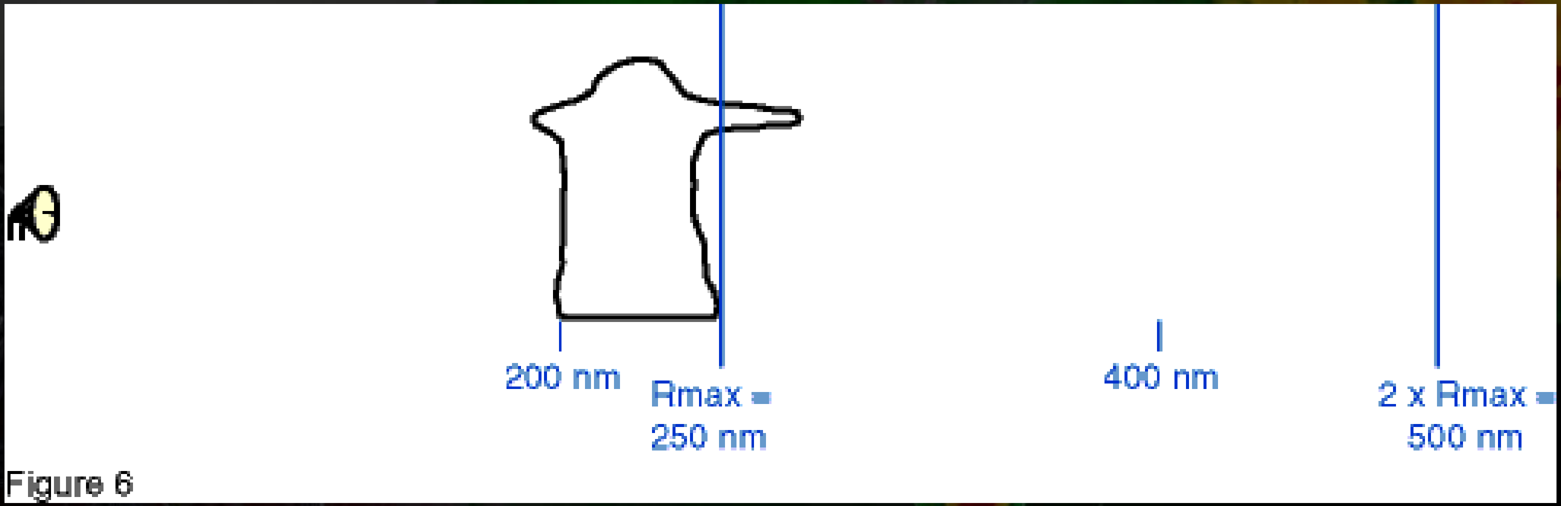
Limitations

- The Doppler Dilemma
  - High PRF: Desirable for obtaining high quality Doppler velocity information. The high PRF results in a short R_{max} and increases the chance for multiple trip echoes/range folding.
  - Low PRF: Desirable for greater target range and power, but when velocities exceed the relatively low V_{max}, they become aliased/fold over.
  - So what do we do?!?!?
    - **Flexible PRFs:** We have the ability to change the PRF at the radar depending on the situation and distance the storms are from the radar.
    - **Multiple Scans at Each Elevation Angle:** One optimized for R_{max} and the other optimized for V_{max}

Radar Basics

Limitations

- Range Folding
  - Range folding is the placement of an echo by the radar in a location whose azimuth is correct, but whose range is erroneous (but in a predictable manner).
  - This phenomenon occurs when a target lies beyond the maximum unambiguous range of the radar (R_{max}).



Storm Within R_{max}

Radar Basics

Limitations

- Range Folding
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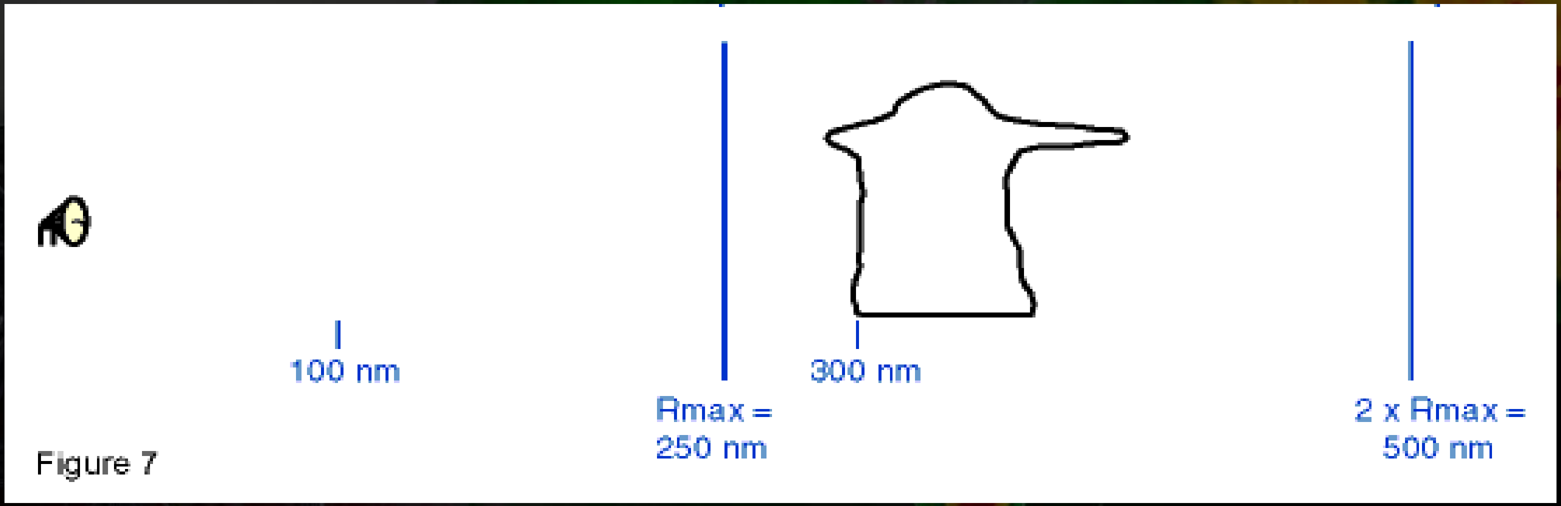


Storm Outside of R_{max}

Radar Basics

Limitations

- Range Folding
  - Range folding is the placement of an echo by the radar in a location whose azimuth is correct, but whose range is erroneous (but in a predictable manner).
  - This phenomenon occurs when a target lies beyond the maximum unambiguous range of the radar (R_{max}).

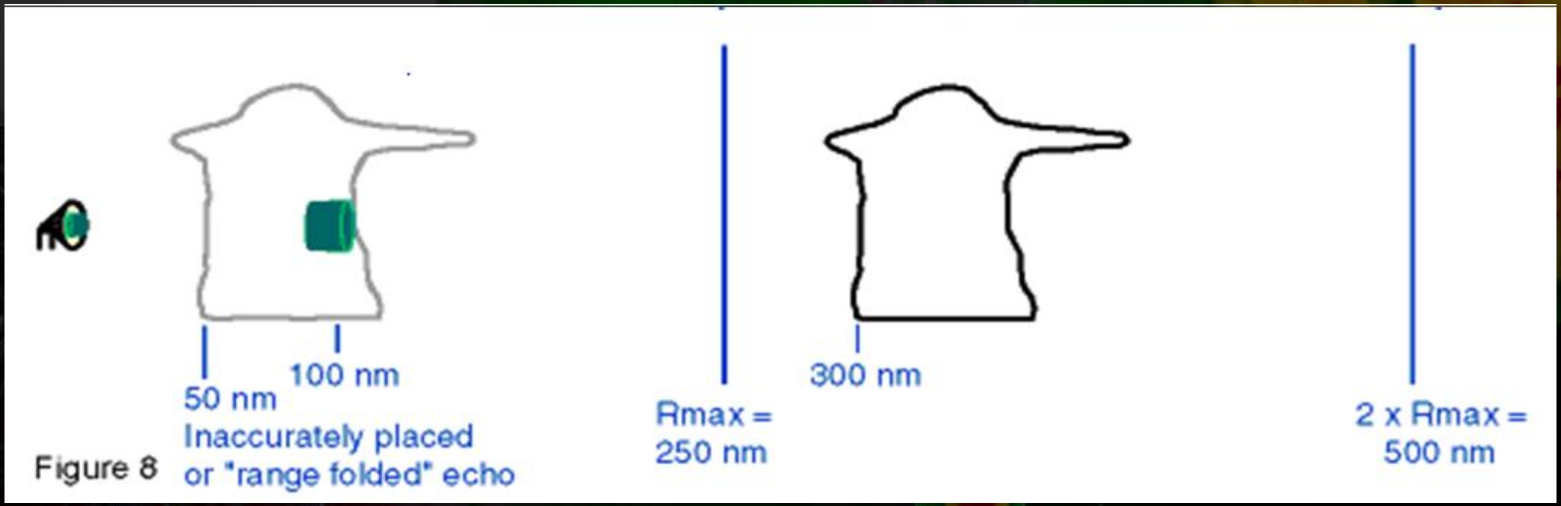


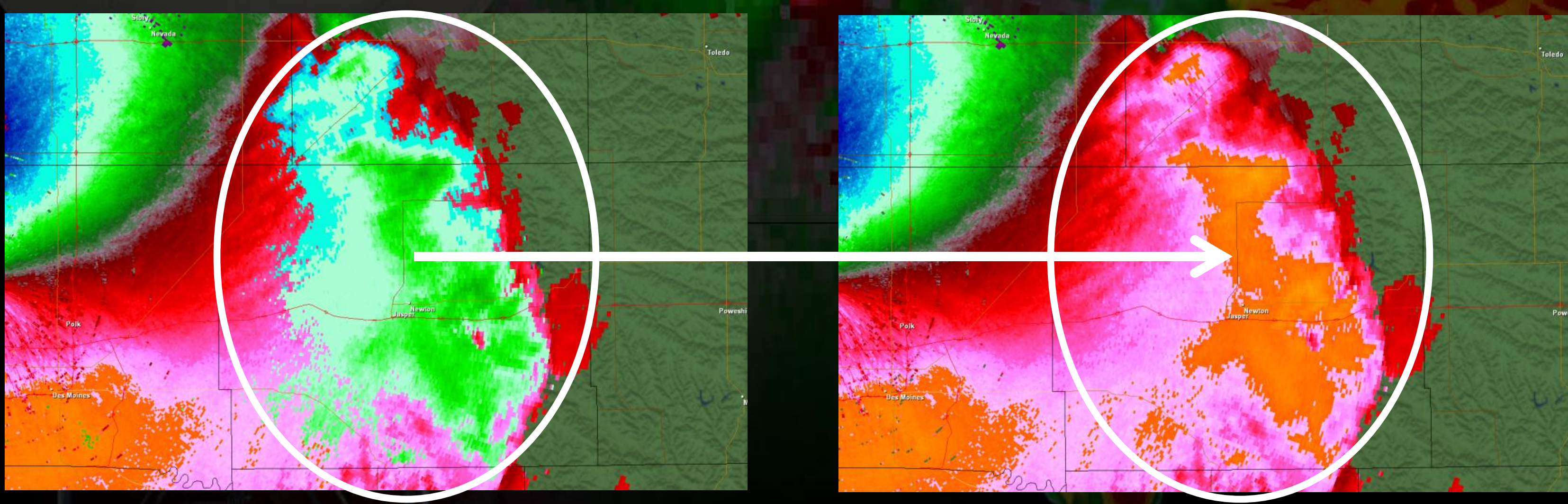
Figure 8

Storm Incorrectly Placed

Radar Basics

Limitations

- Velocity Aliasing/Folding
  - Occurs when the radio wave has been shifted so far from its original position that the radar cannot tell if it is inbound or outbound.
  - Can be corrected/mitigated with software (called dealiasing)



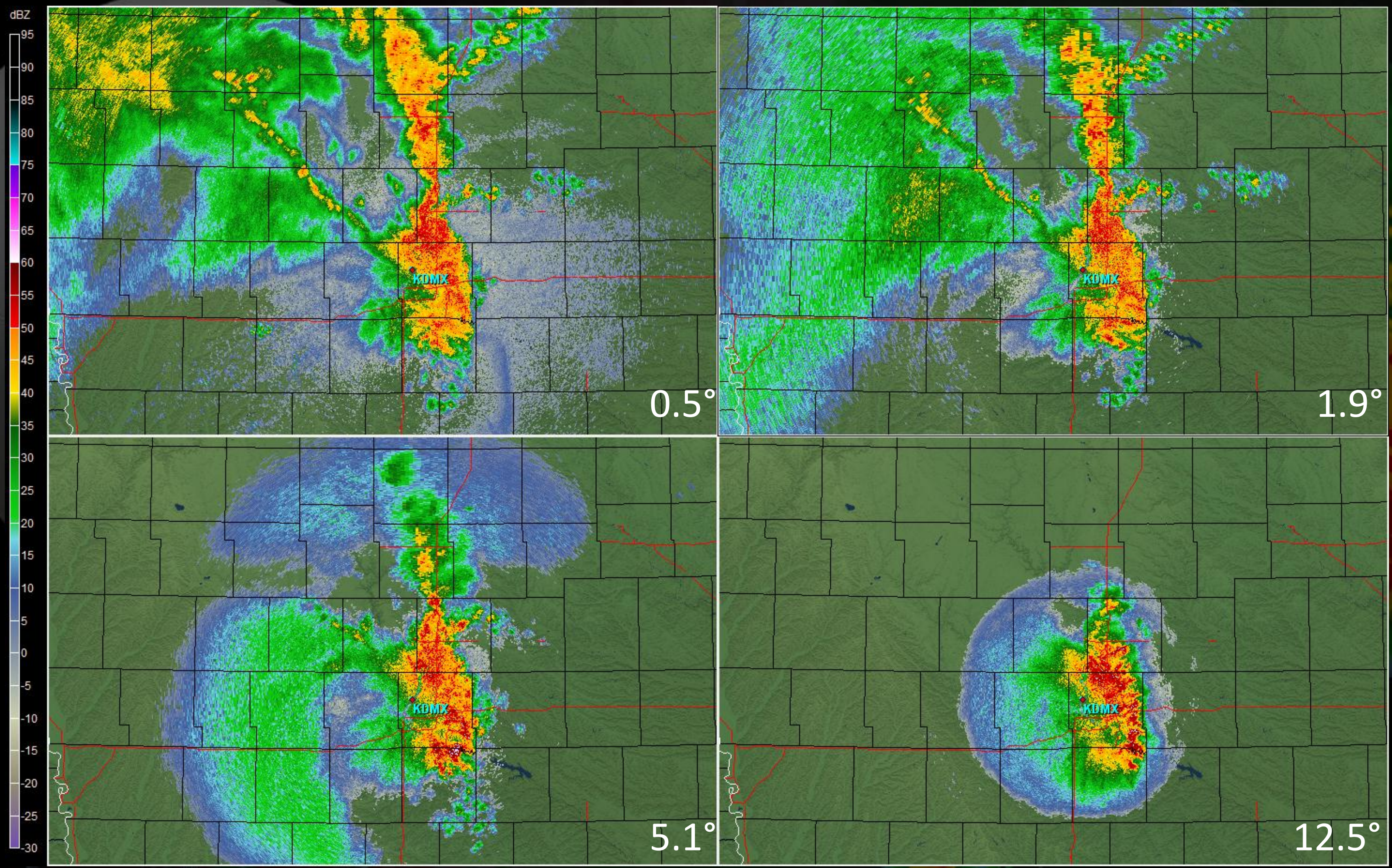
NWS Radar Products

Product Levels

Level II (Base) Products	Level III (Derived) Products
• Base Reflectivity • Base/Storm-Relative Velocity • Spectrum Width • Differential Reflectivity (ZDR) • Correlation Coefficient (CC) • Differential Phase Shift (KDP)	• Composite Reflectivity • Echo Tops • Vertically Integrated Liquid (VIL) • 1 hr, 3hr, and Storm Total Precipitation • Hydrometeor Classification Algorithm (HCA) • TVS, MD, and Hail Size Algorithms

NWS Radar Products

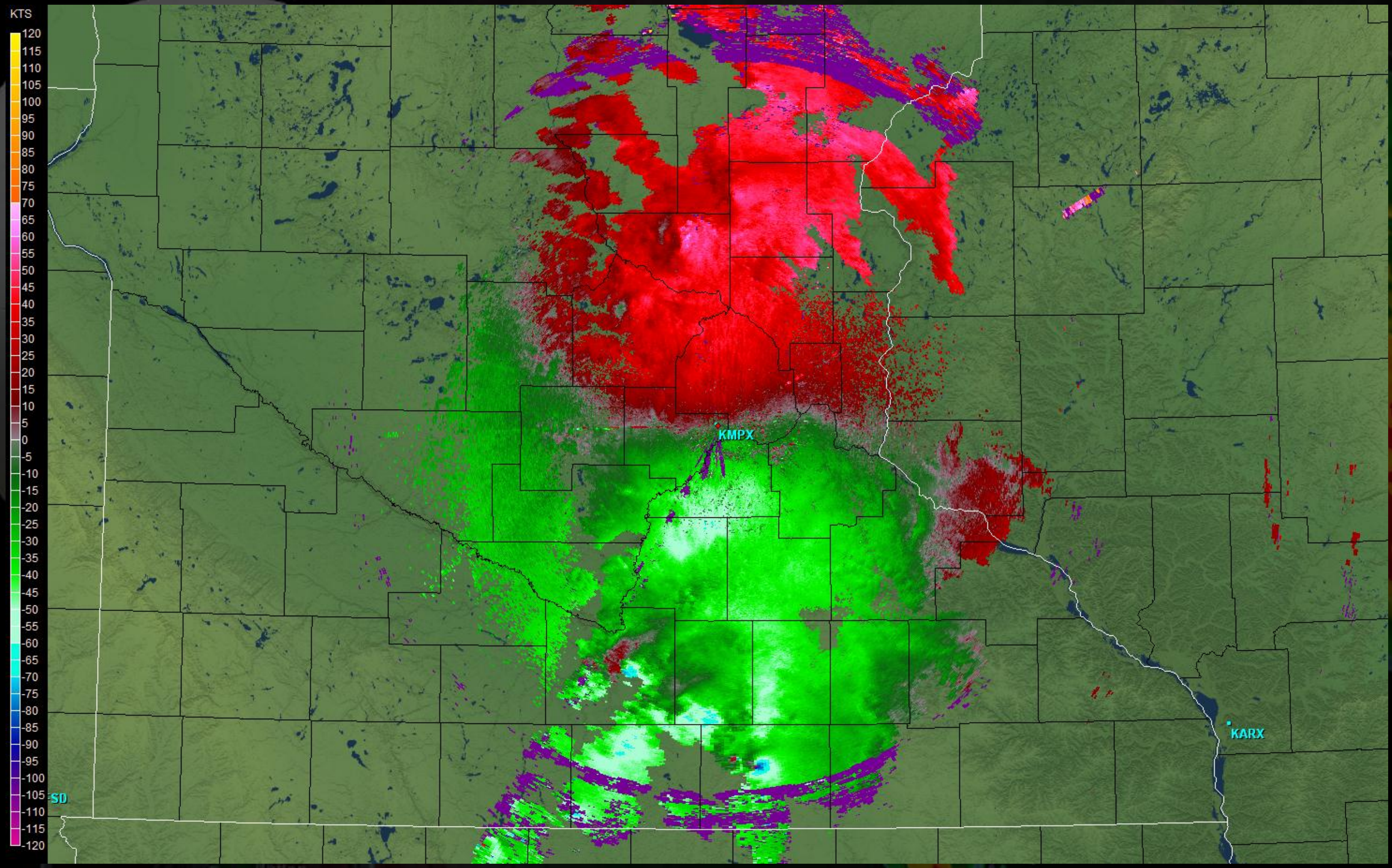
Base Reflectivity



Resolution: 0.5 Degrees x 0.25 km (0.5° to 1.5°), 1.0 Degree x 0.25 km above 1.5°

NWS Radar Products

Base Velocity

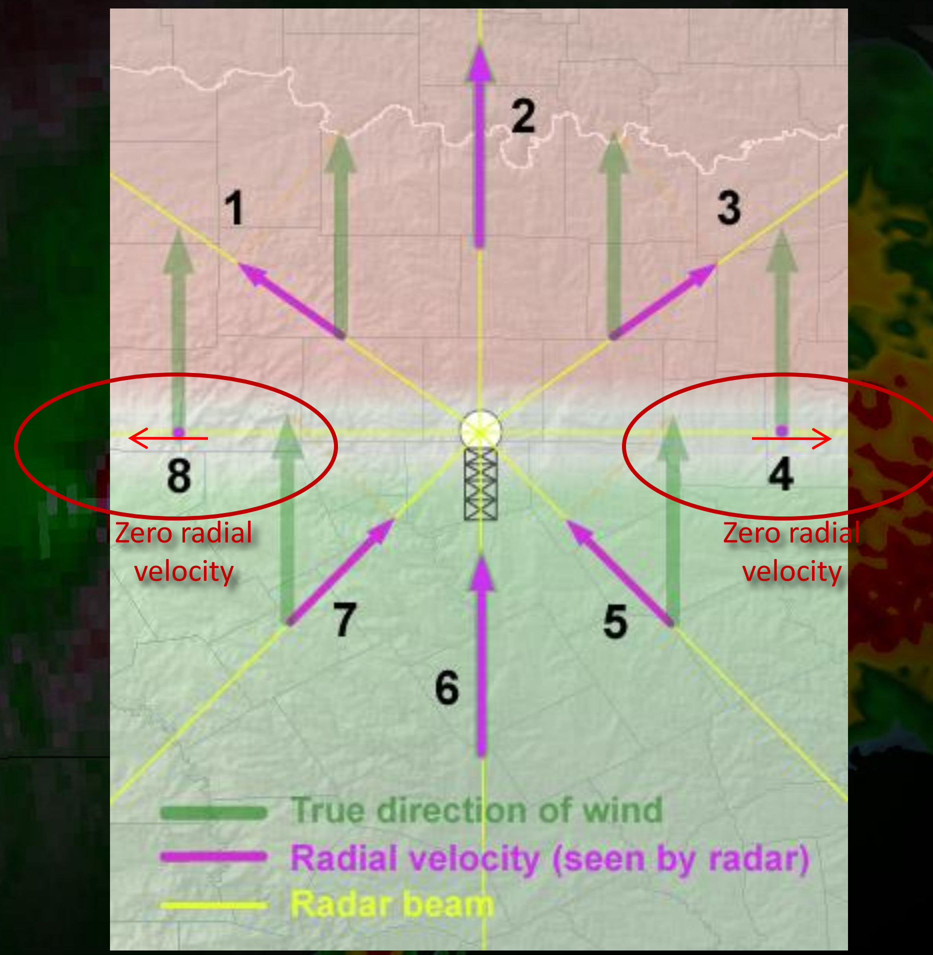


Resolution: 0.5 Degrees x 0.25 km (0.5° to 1.5°), 1.0 Degree x 0.25 km above 1.5°

NWS Radar Products

Velocity Interpretation

Remember: A radar can only measure the component of the wind that is moving **towards** or **away** from it.



Cool Values (Green/Blue):
Winds are moving towards the radar (inbound)

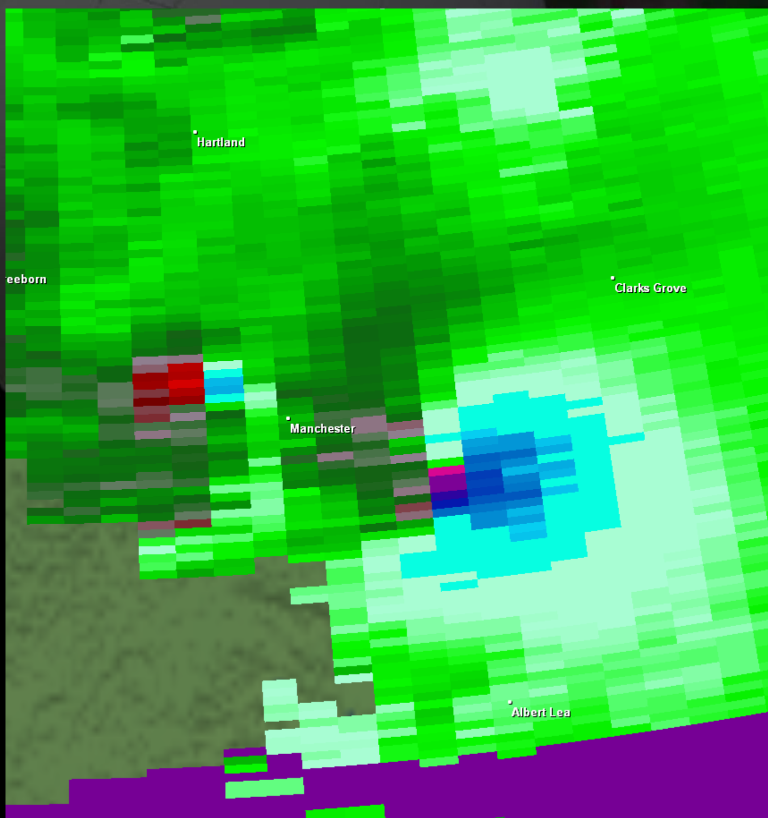
Warm Values (Red/Orange):
Winds are moving away from the radar (outbound)

NWS Radar Products

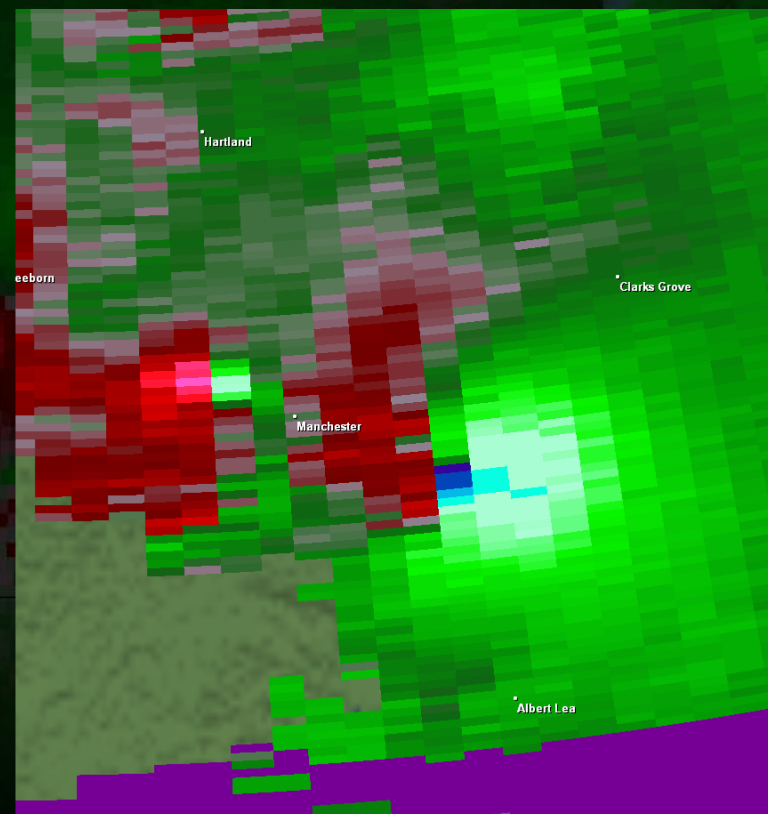
Storm-Relative Velocity

Storm-Relative Velocity: Storm motion is subtracted from base velocity

-Easier to spot rotation in storms



Base Velocity



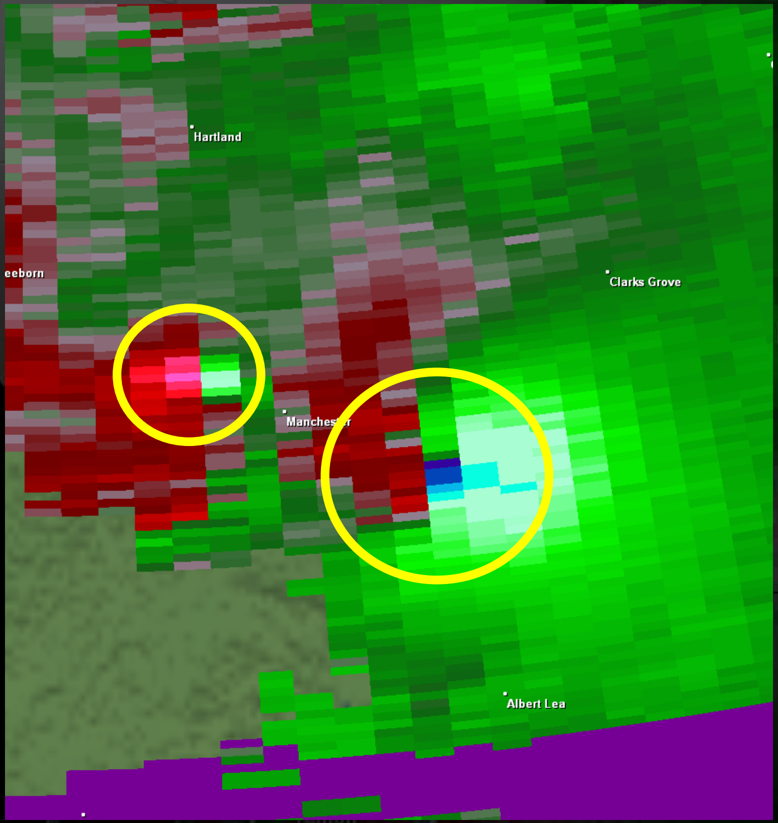
Storm-Relative Velocity

NWS Radar Products

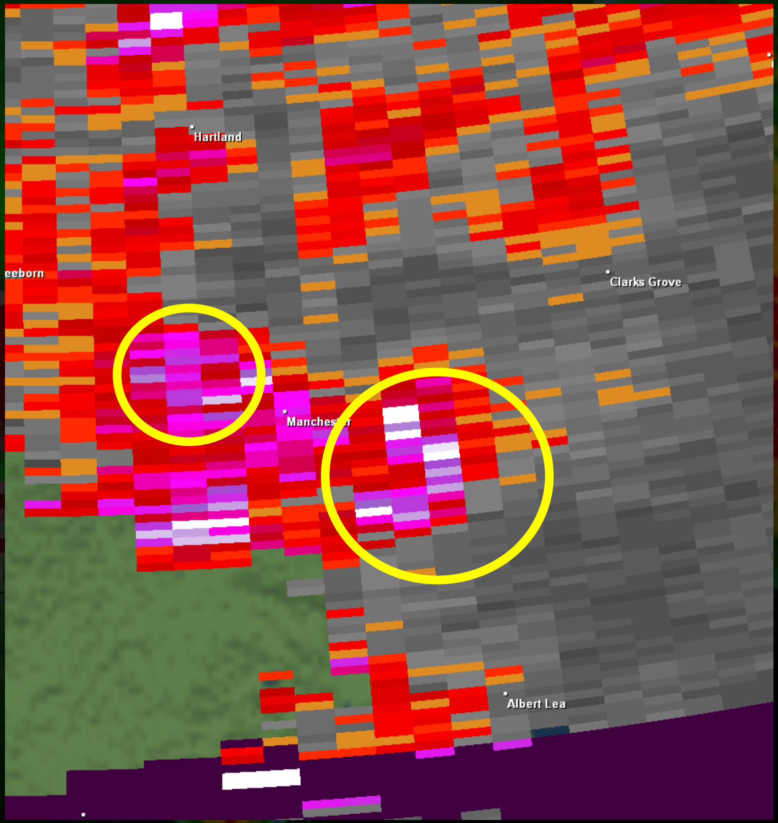
Spectrum Width

Measures the variability of the winds in each velocity gate.

-Also useful for finding rotation. (Units: Knots)



Storm-Relative Velocity

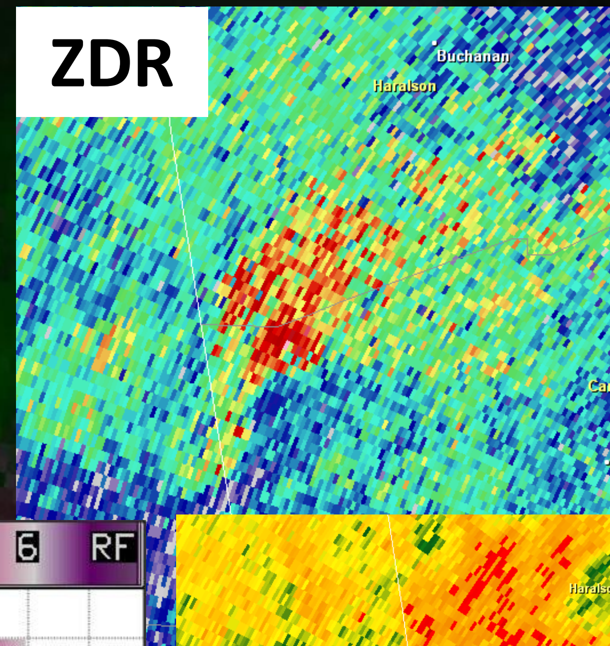


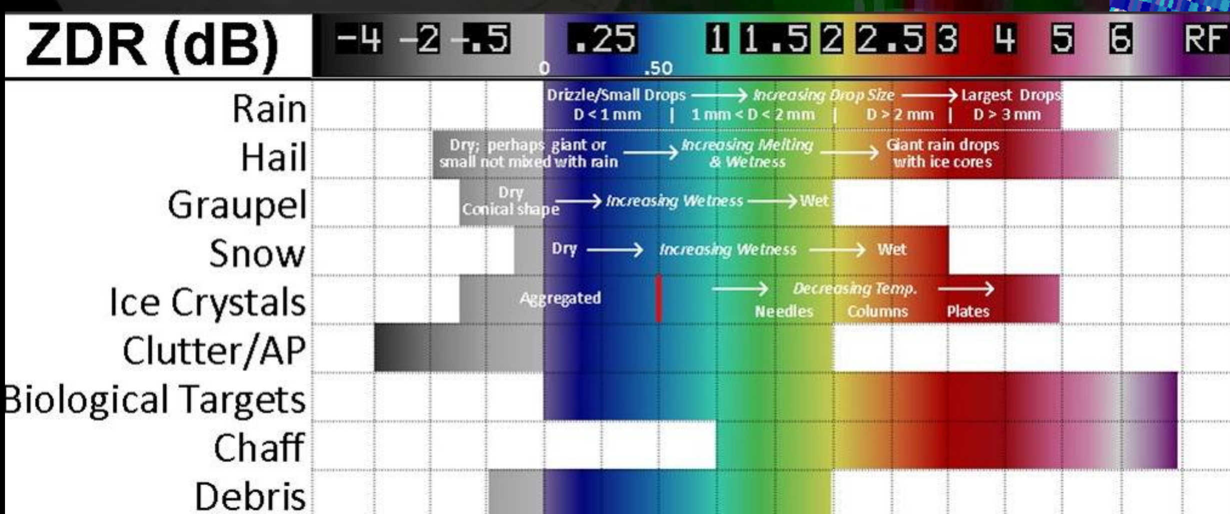
Spectrum Width

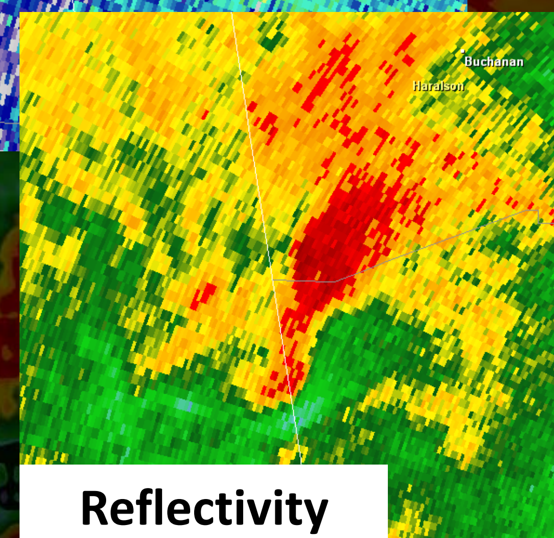
NWS Radar Products

Differential Reflectivity (ZDR)

- **Measures the difference between the horizontal and vertical reflectivity values.**
- Near zero ZDR indicates spherical targets.
- Positive ZDR indicates oblate or flat objects oriented in the horizontal.
- Negative ZDR values denote vertically oriented targets (typically ice or big hail).



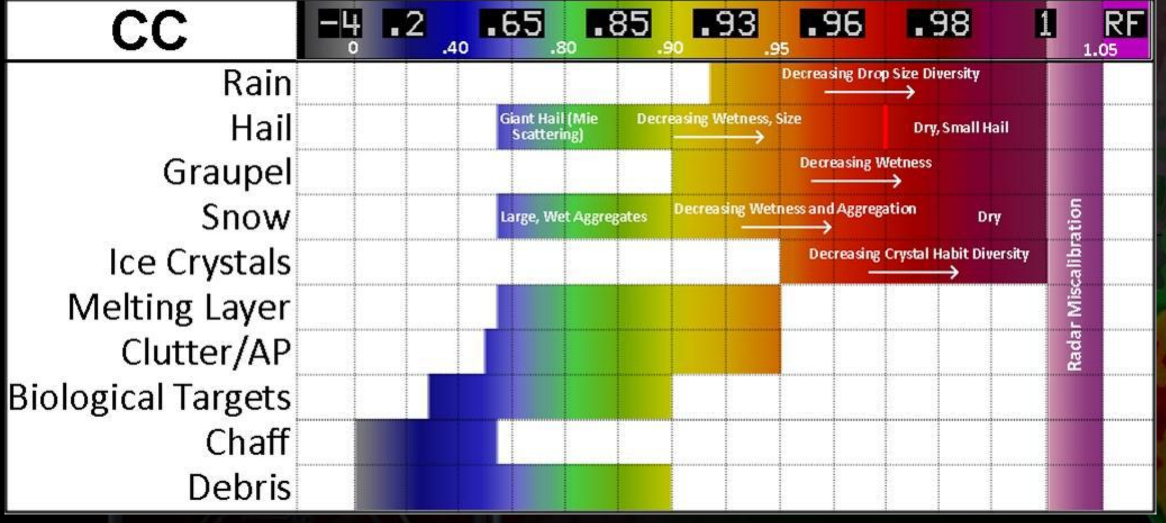


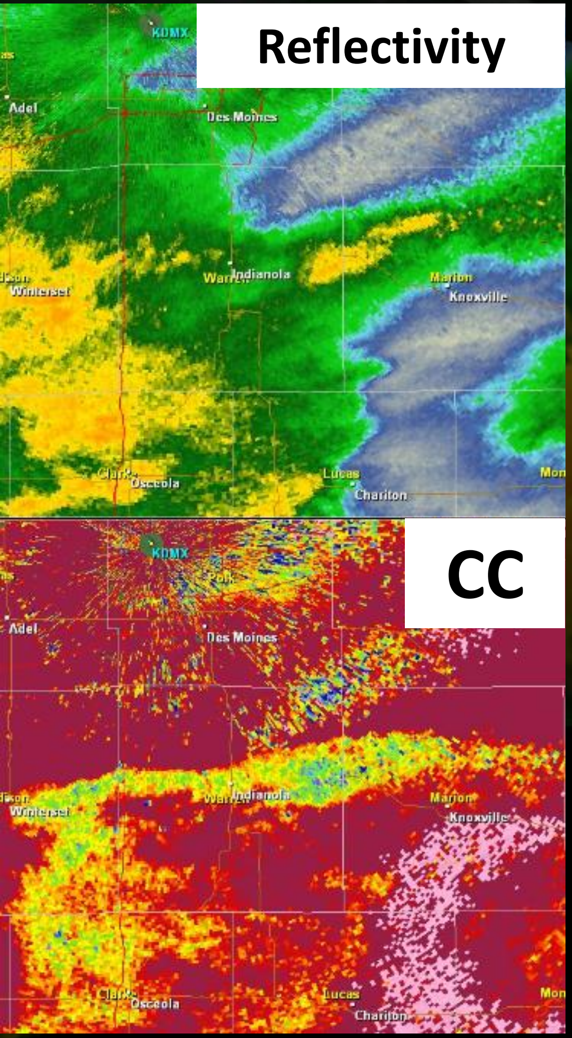


NWS Radar Products

Correlation Coefficient (CC)

- **Measures how similar the vertical and horizontal pulses behave from pulse to pulse. Ranges from 0 to 1 (unit less)**
- CC of near 1.00 = sample volume contains objects of the same shape and size
- CC less than 1 denotes a mixture of different sized particles

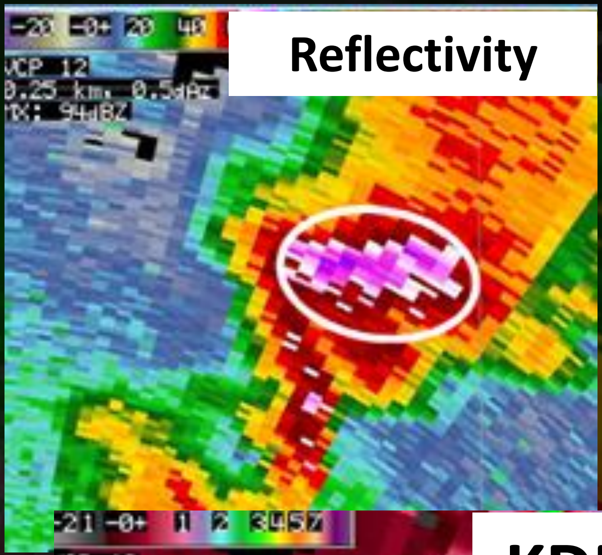


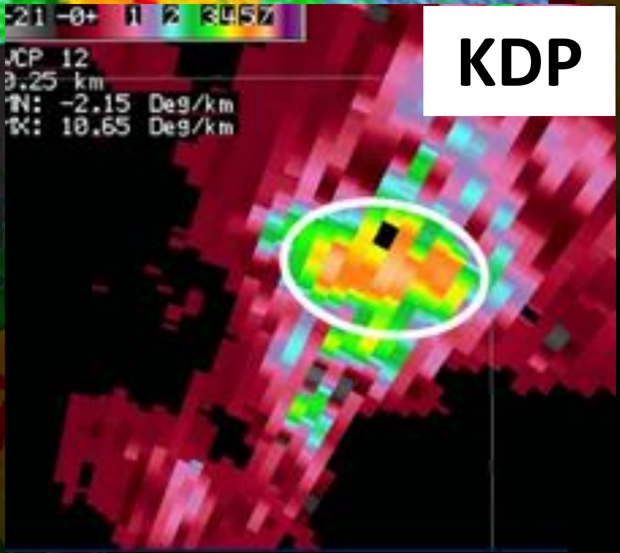


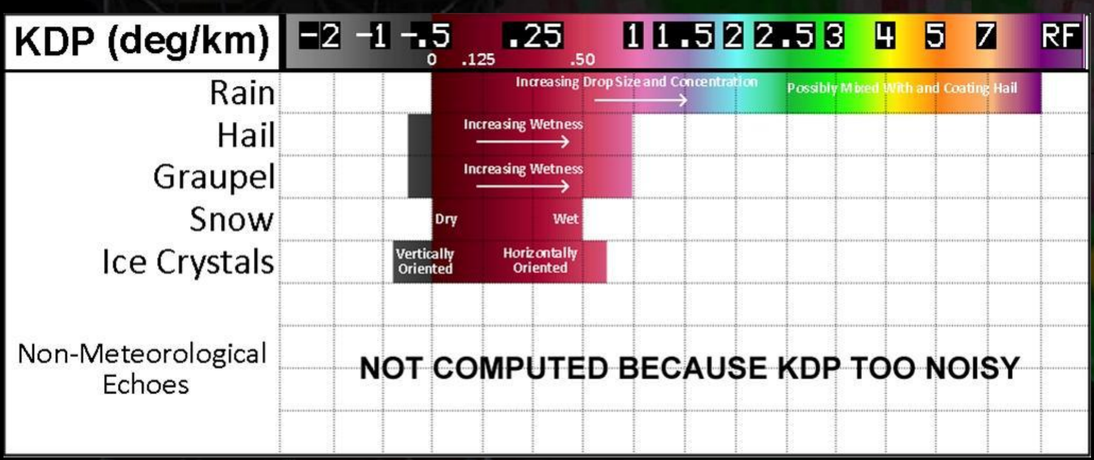
NWS Radar Products

Specific Differential Phase (KDP)

- **Measures the difference in phase shift between the horizontal and vertical pulses (range derived).**
- Radio waves travel more slowly through water than air
- Essentially measures the liquid content of the sample volume
- Very useful for determining areas of heavy precipitation.





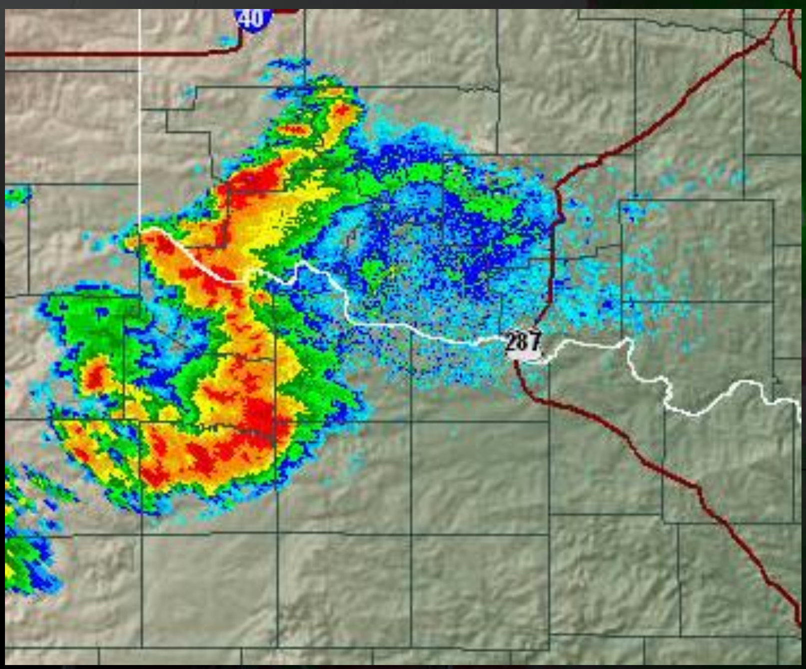


NWS Radar Products

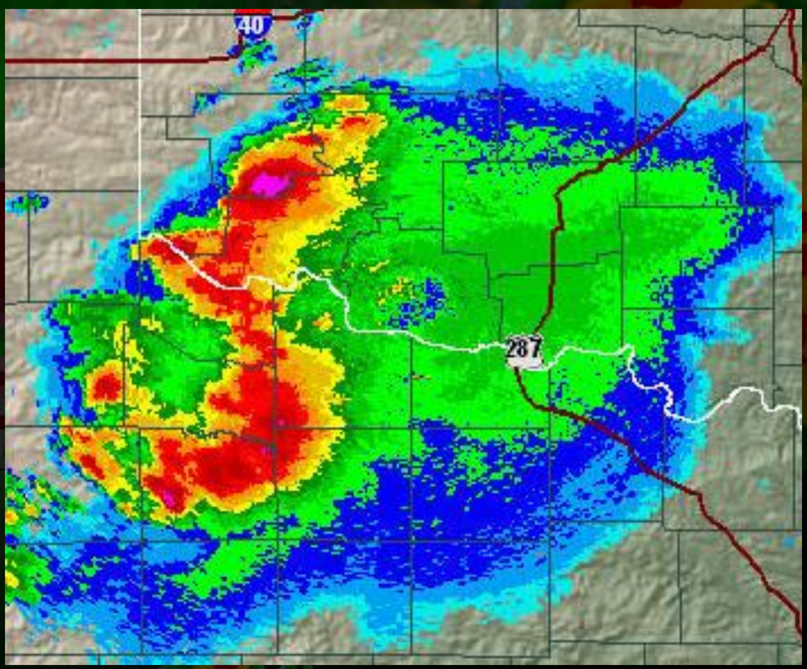
Composite Reflectivity

Takes the highest reflectivity value over a given point, throughout each VCP, and plots it on a two dimensional map

-Is useful for quickly locating hail cores aloft and determining the size and shape of the anvil.



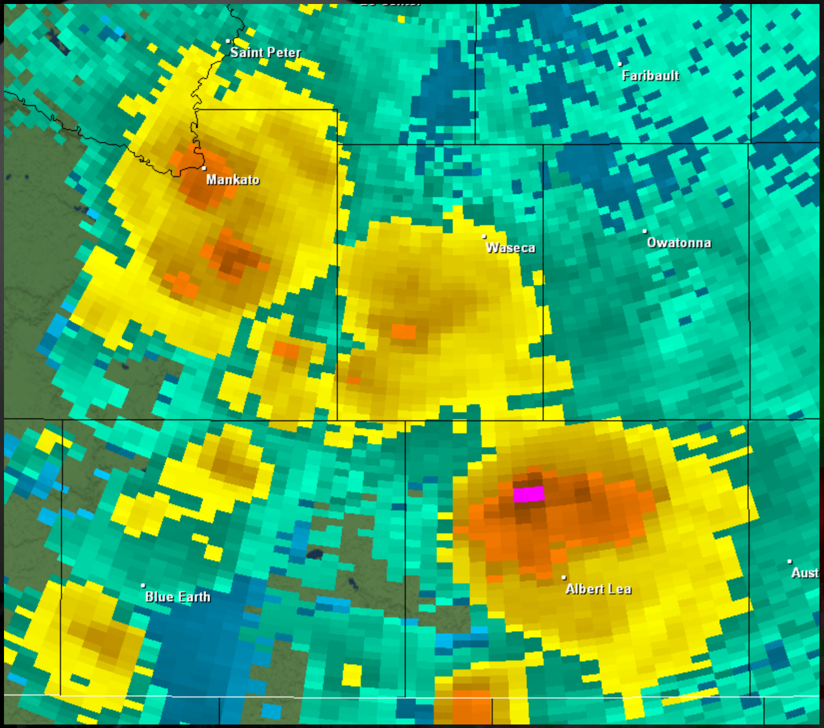
Base Reflectivity

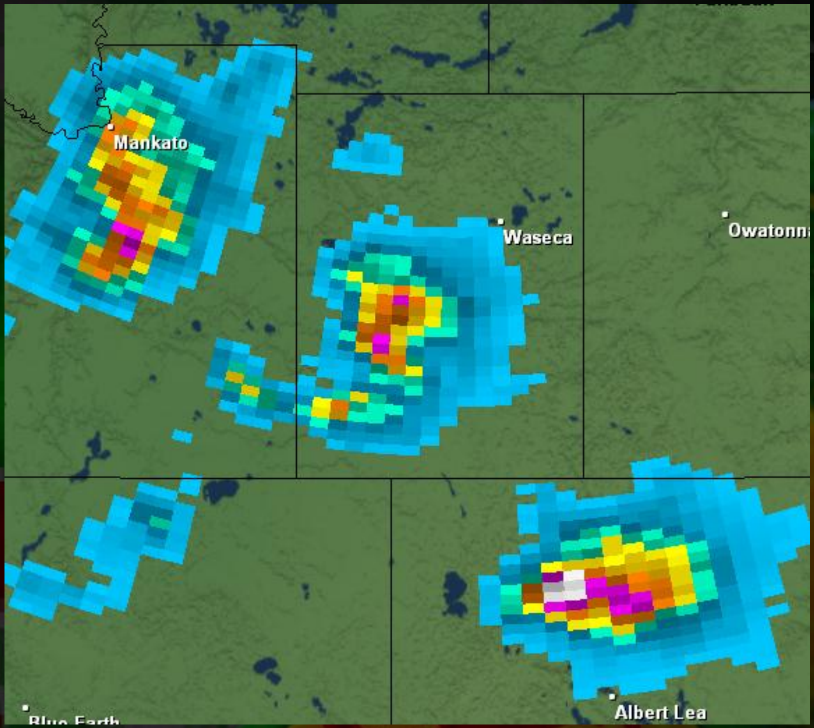


Composite Reflectivity

NWS Radar Products

Echo Tops and VIL



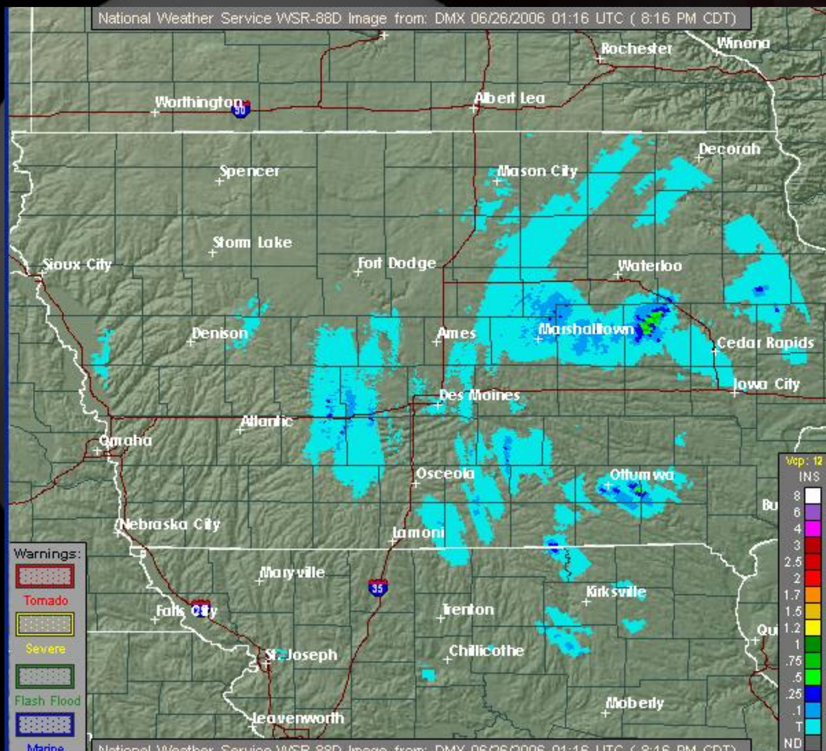


Echo Tops: Maximum height of the radar echoes. Useful for determining the tops of storm anvils.

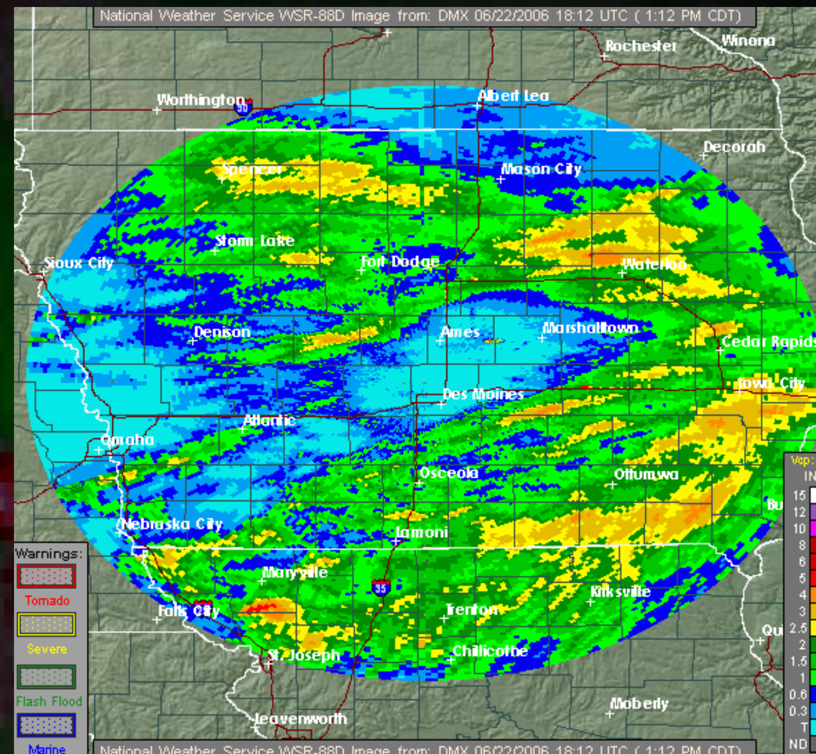
VIL (Vertically Integrated Liquid): Liquid content of a storm—a useful first guess at which storms might be producing hail.

NWS Radar Products

1 hr, 3 hr, Storm Total Precipitation Accumulation



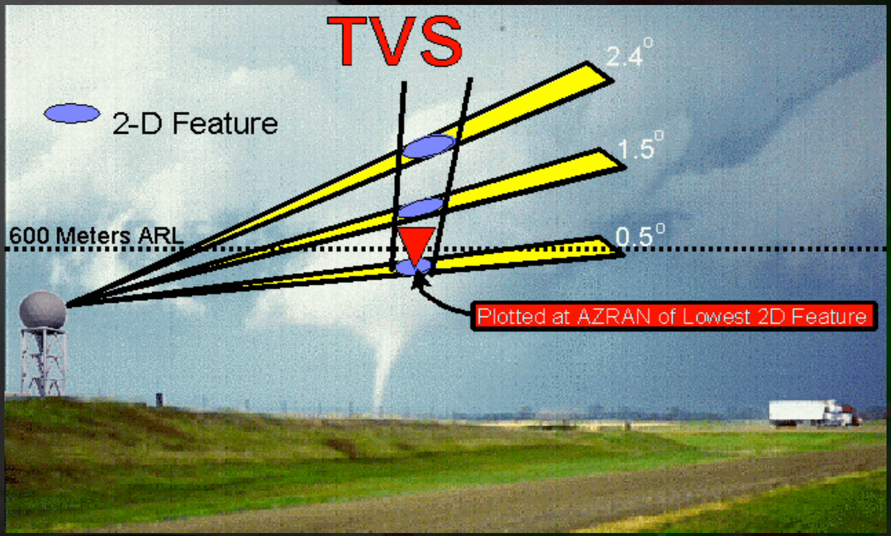
One Hour Precipitation



Storm Total Precipitation

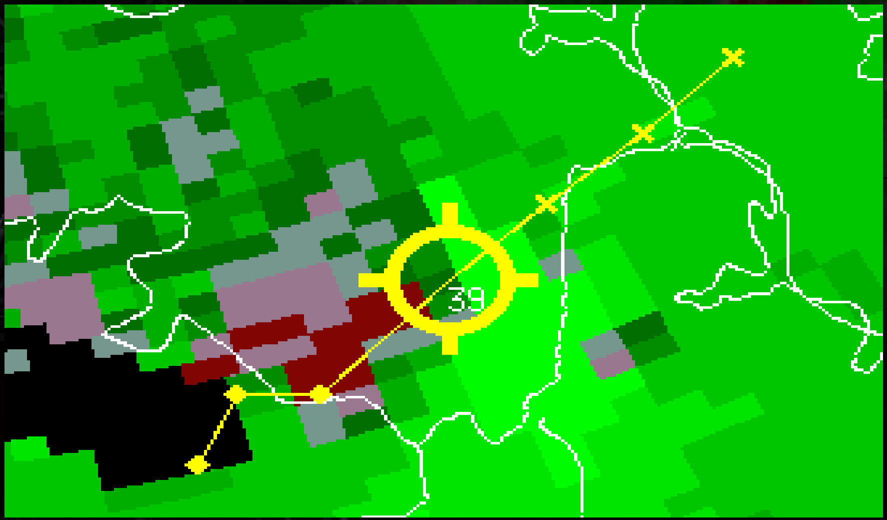
NWS Radar Products

TVS, MD, and Hail Size Algorithms



Tornado Vortex Signature (TVS)

An intense gate-to-gate azimuthal shear associated with tornadic-scale rotation

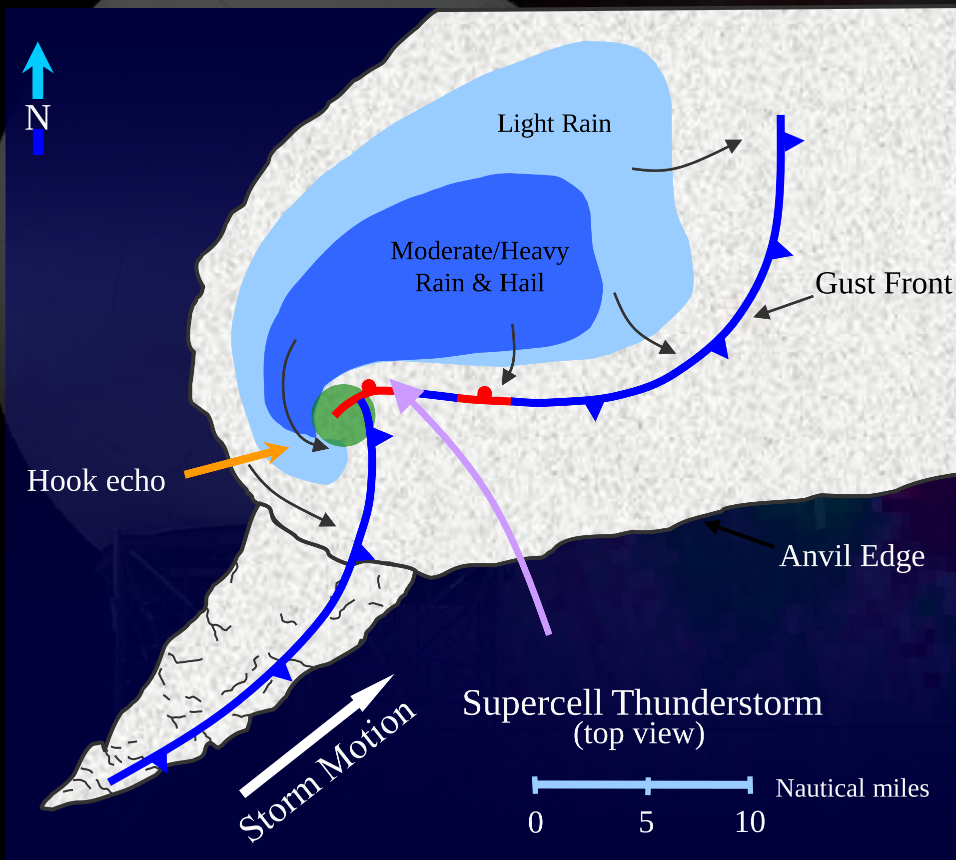


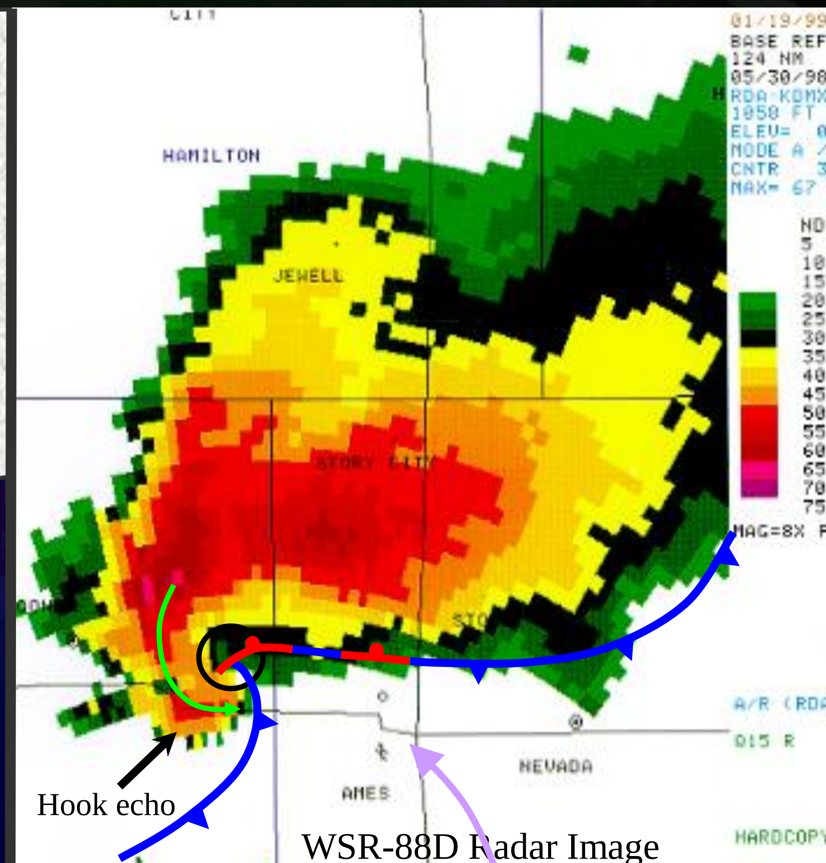
Mesocyclone Detection (MD)

A storm-scale region of rotation, typically around 2 to 6 miles in diameter, which typically covers an area much larger than the tornado that may develop within it

Signatures on Radar

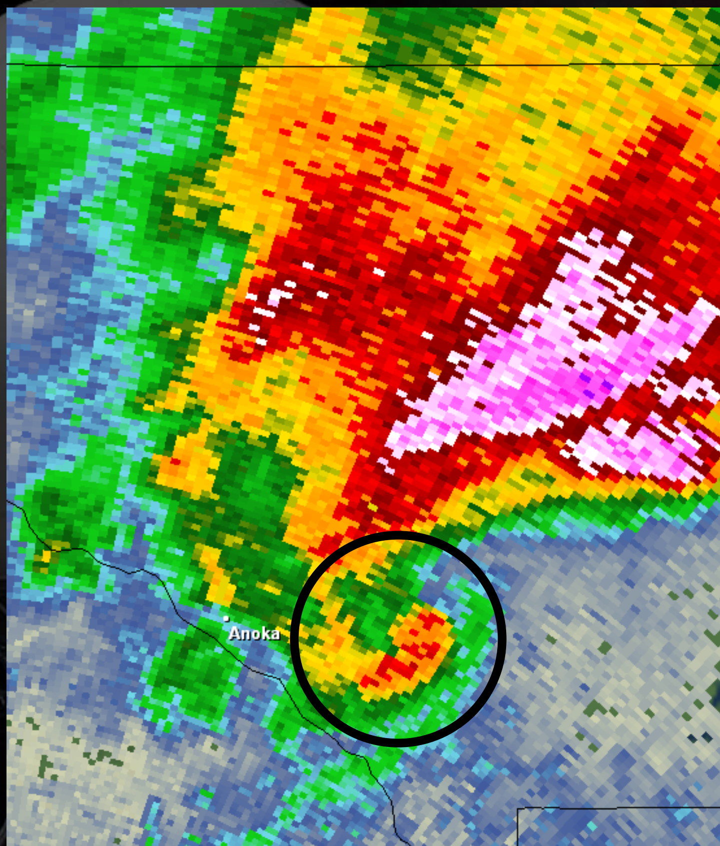
Classic Supercell



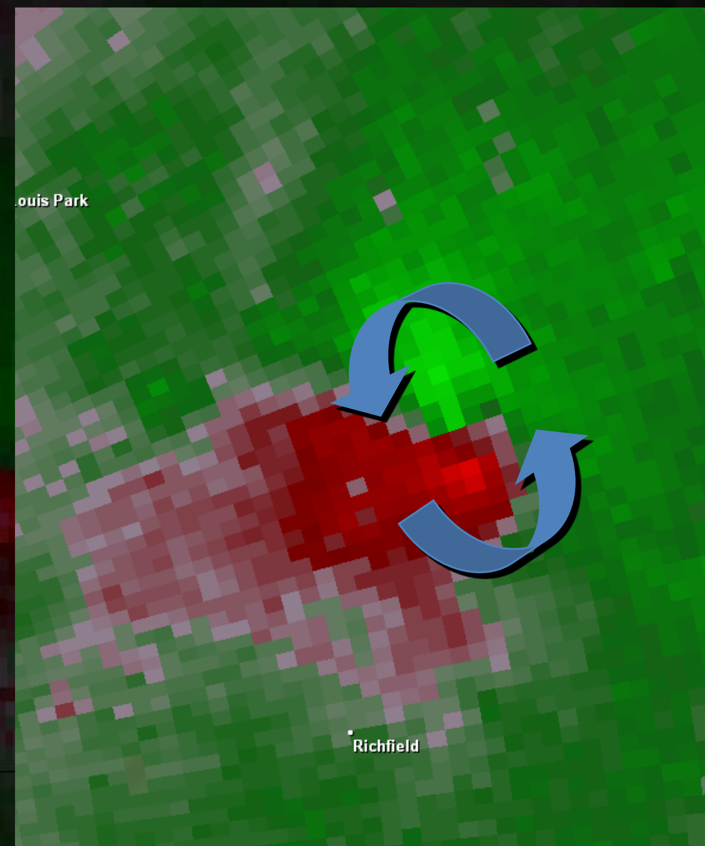


Signatures on Radar

TVS (Tornado Vortex Signature)



Hook Shape on Reflectivity

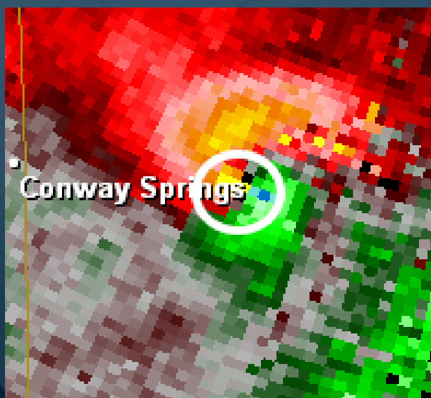


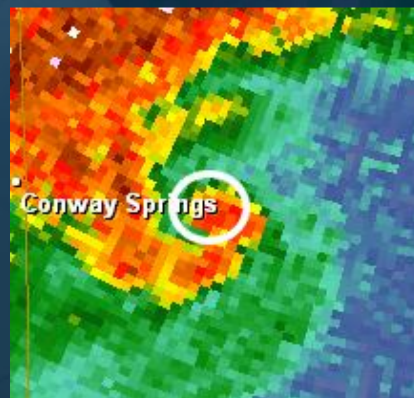
Tight Couplet on Velocity

Signatures on Radar

TDS (Tornadic Debris Signature)

Requirements

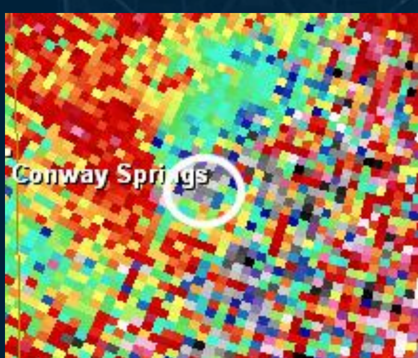


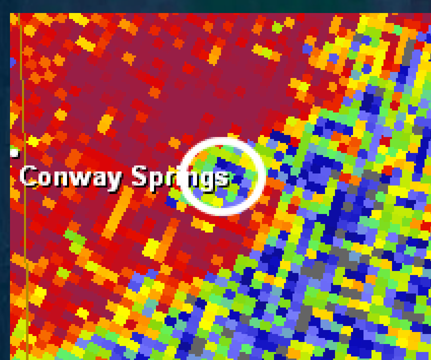


Tornadic Vortex Signature

- Strong gate-to-gate shear on storm relative velocity
- Prominent hook shape on reflectivity (not required)

PLUS



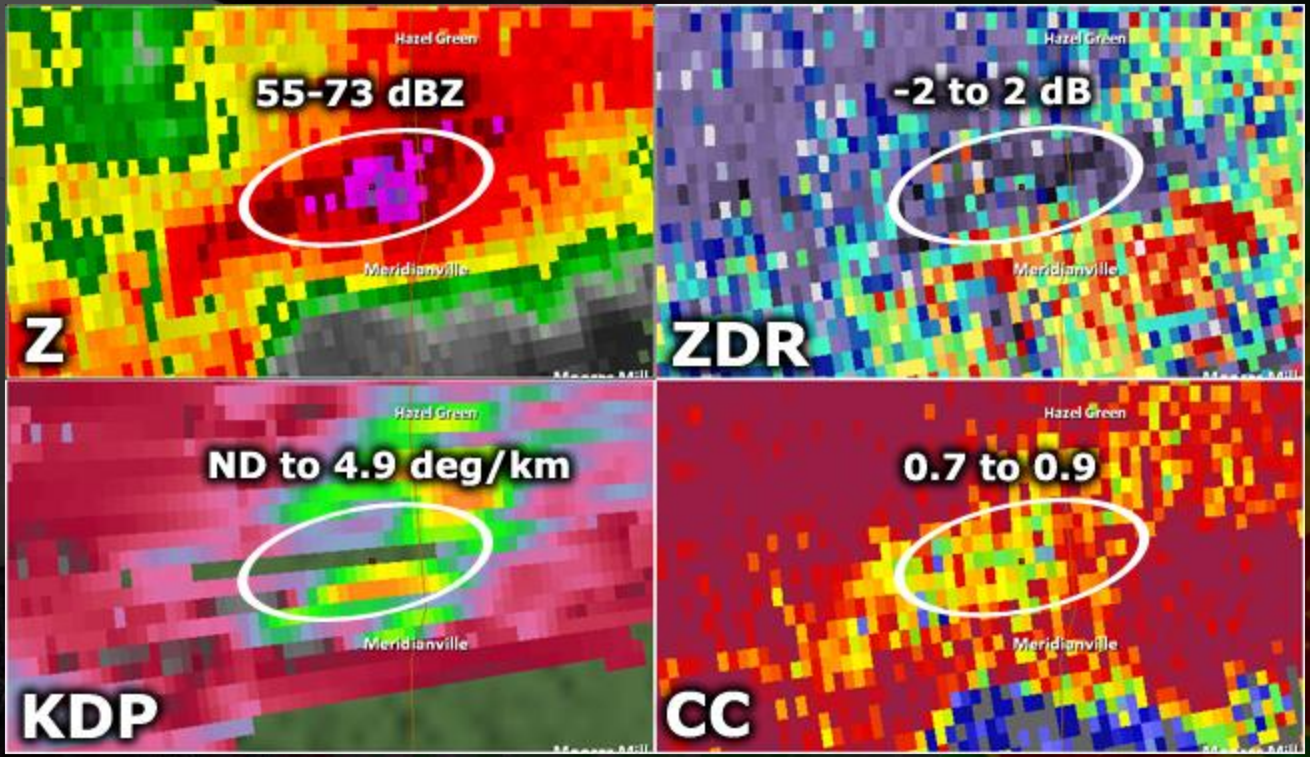


- Very Low ZDR
  - Tumbling of objects
- Reduction in CC
  - Debris of different sizes

All Collocated Together

Signatures on Radar

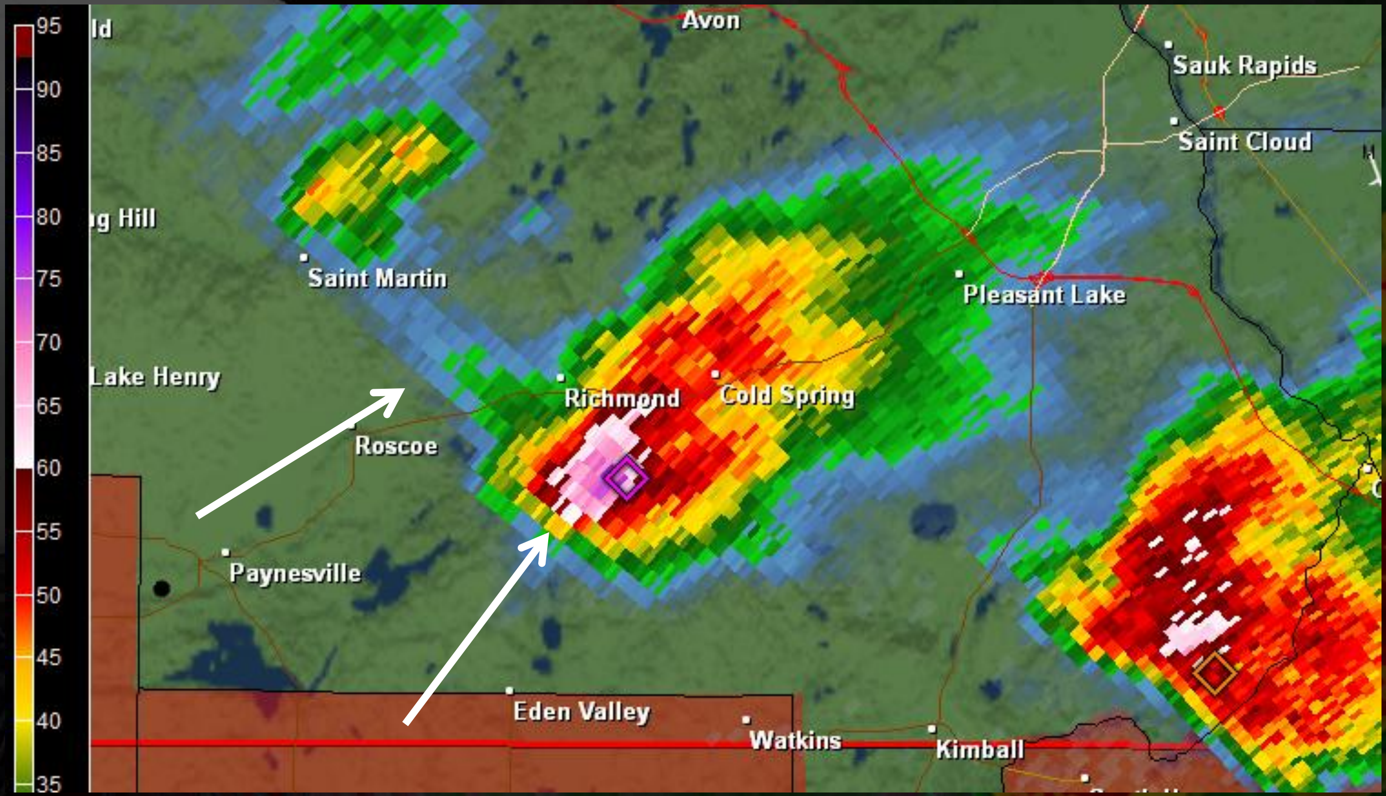
Hail Core



- Strong Reflectivities (+55 dbZ) in a Thunderstorm
- Near Zero ZDR values (tumbling hailstone appears as a circular object)
- Reduced CC values (rain and hail mixed/different sized hailstones)
- KDP values can vary widely depending if the hail is mixed with rain.

Signatures on Radar

Hail Core

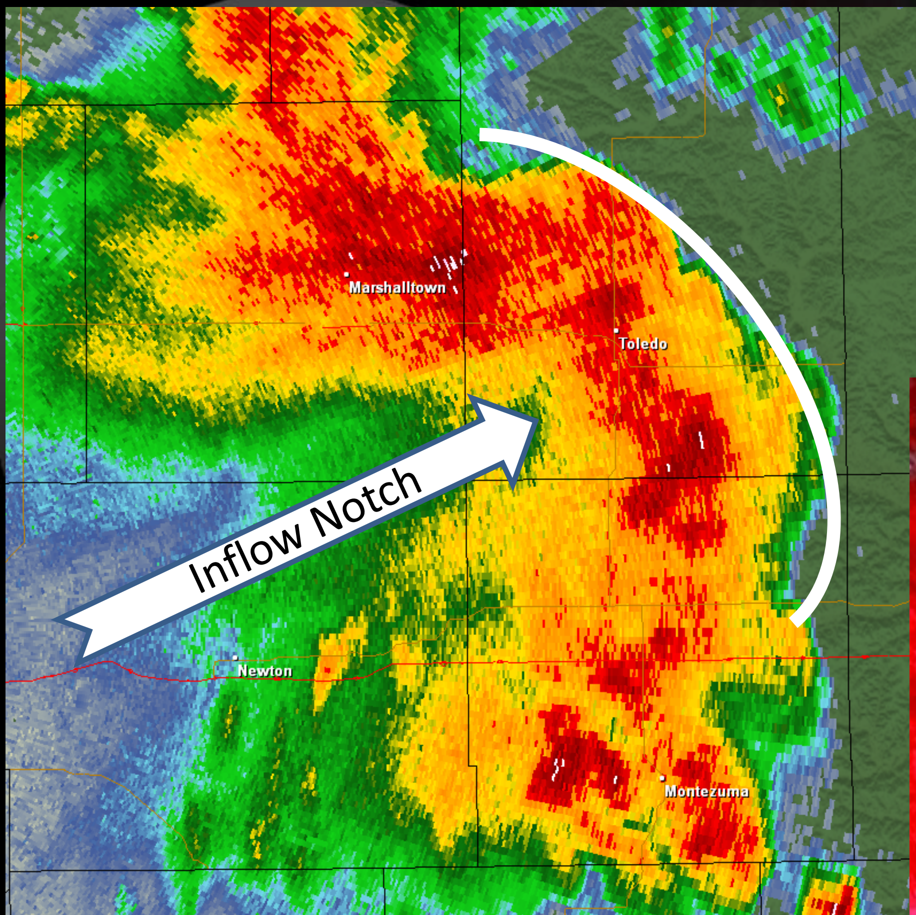


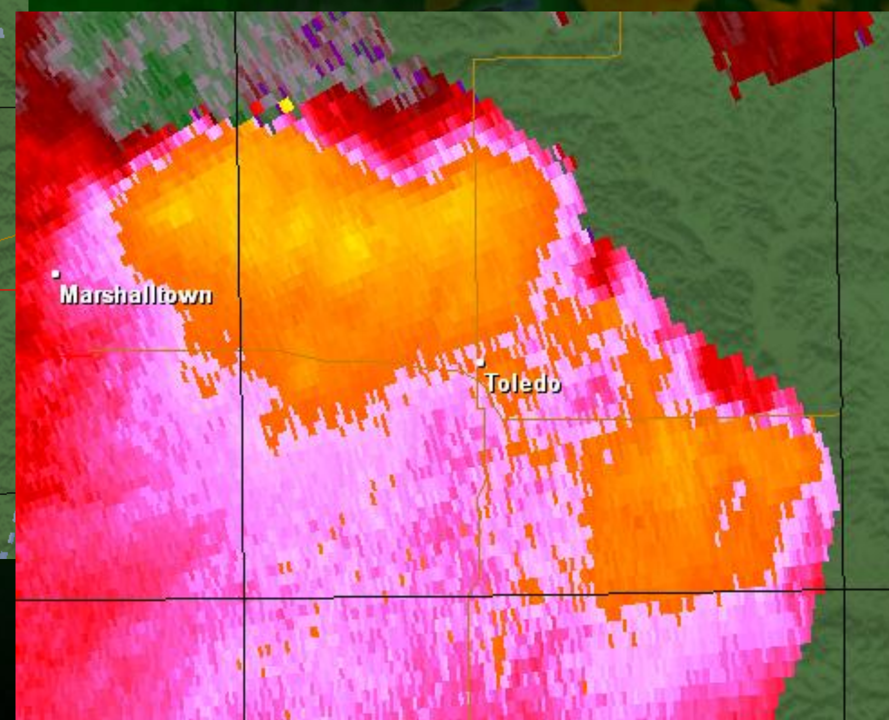
Other Notable Features

Occasionally a Three Body Scatter Spike (TBSS) down radial of the core.
TBSS shows up very nicely on CC

Signatures on Radar

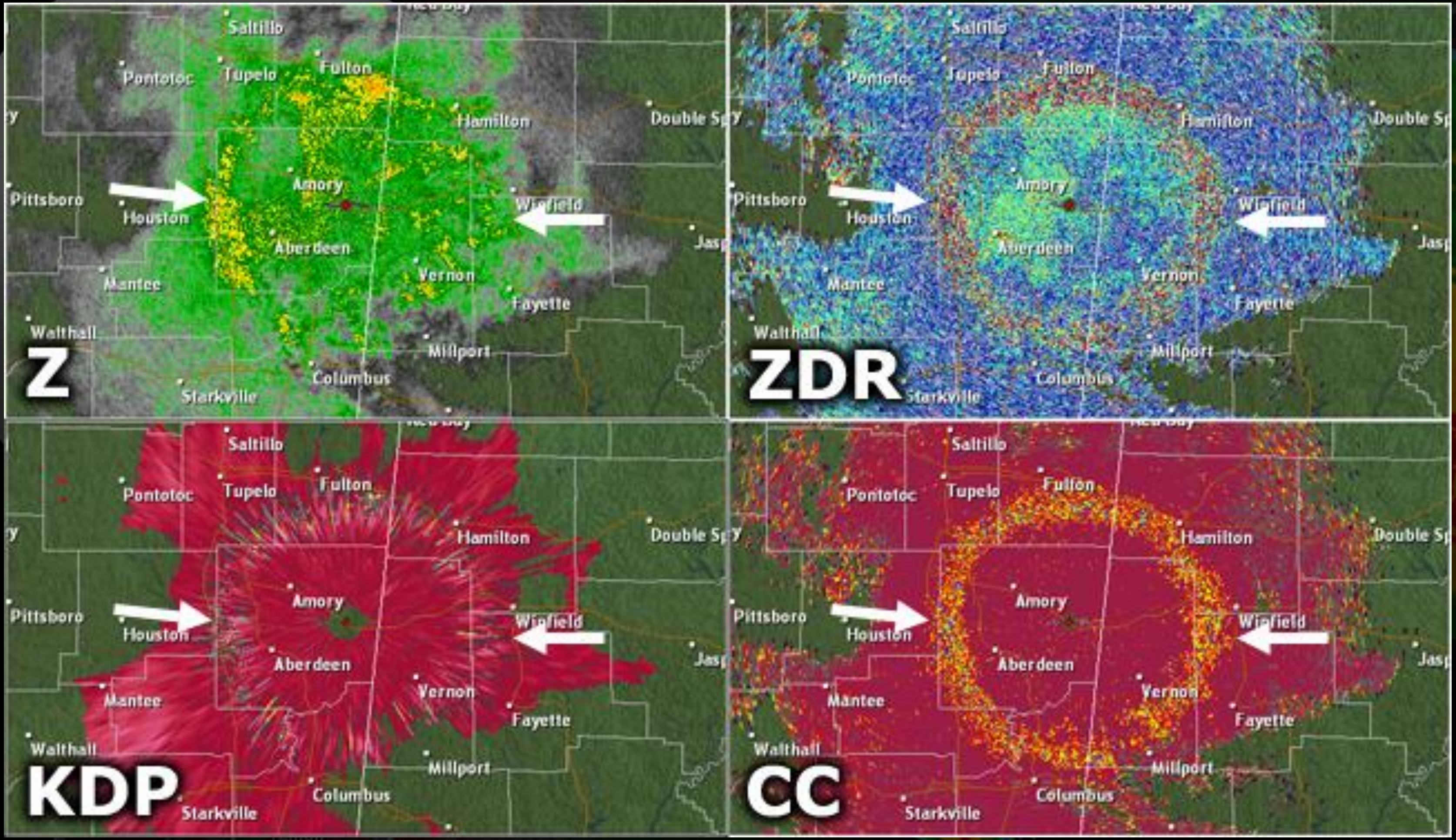
Damaging Winds





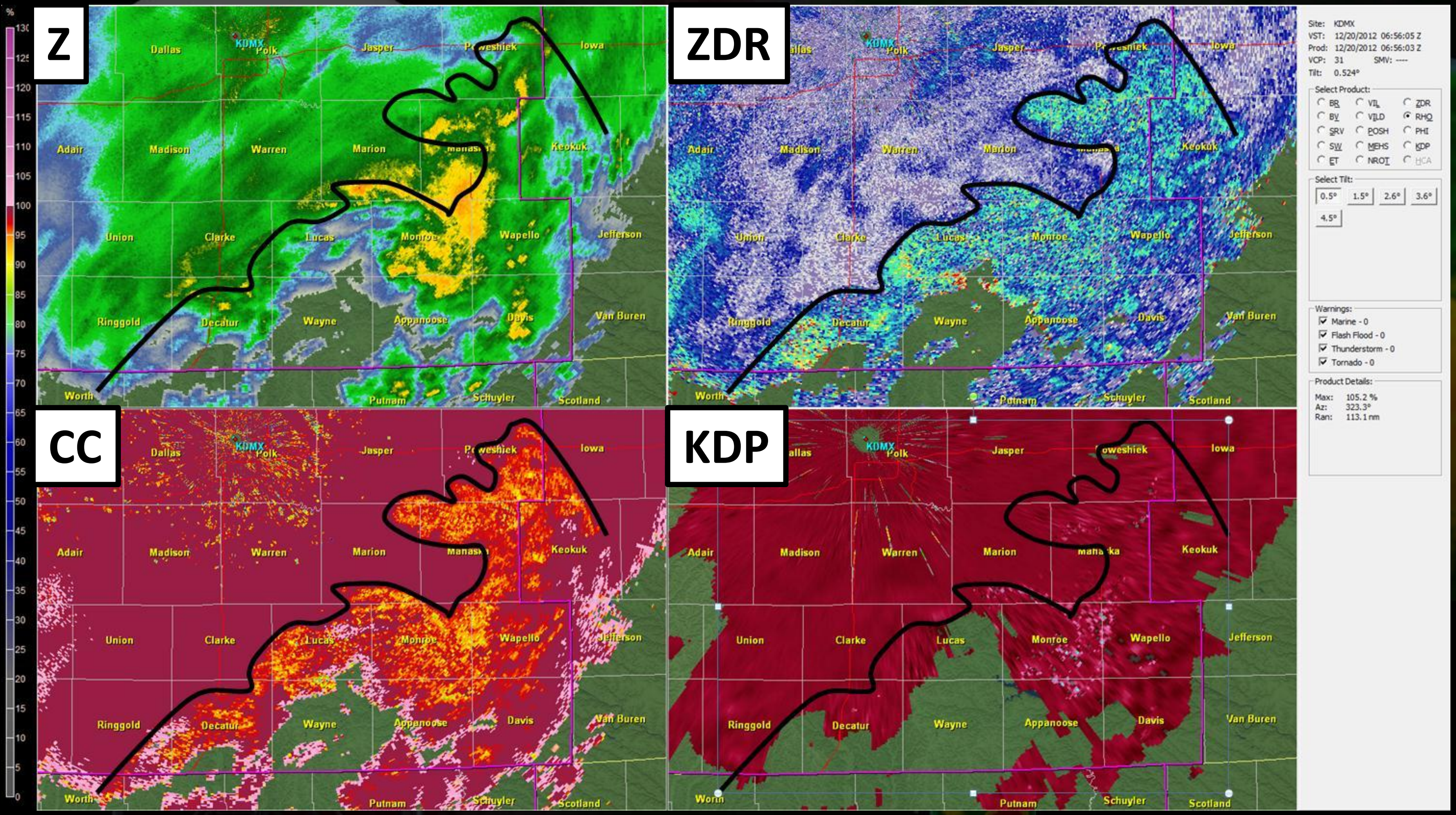
Signatures on Radar

Bright Band



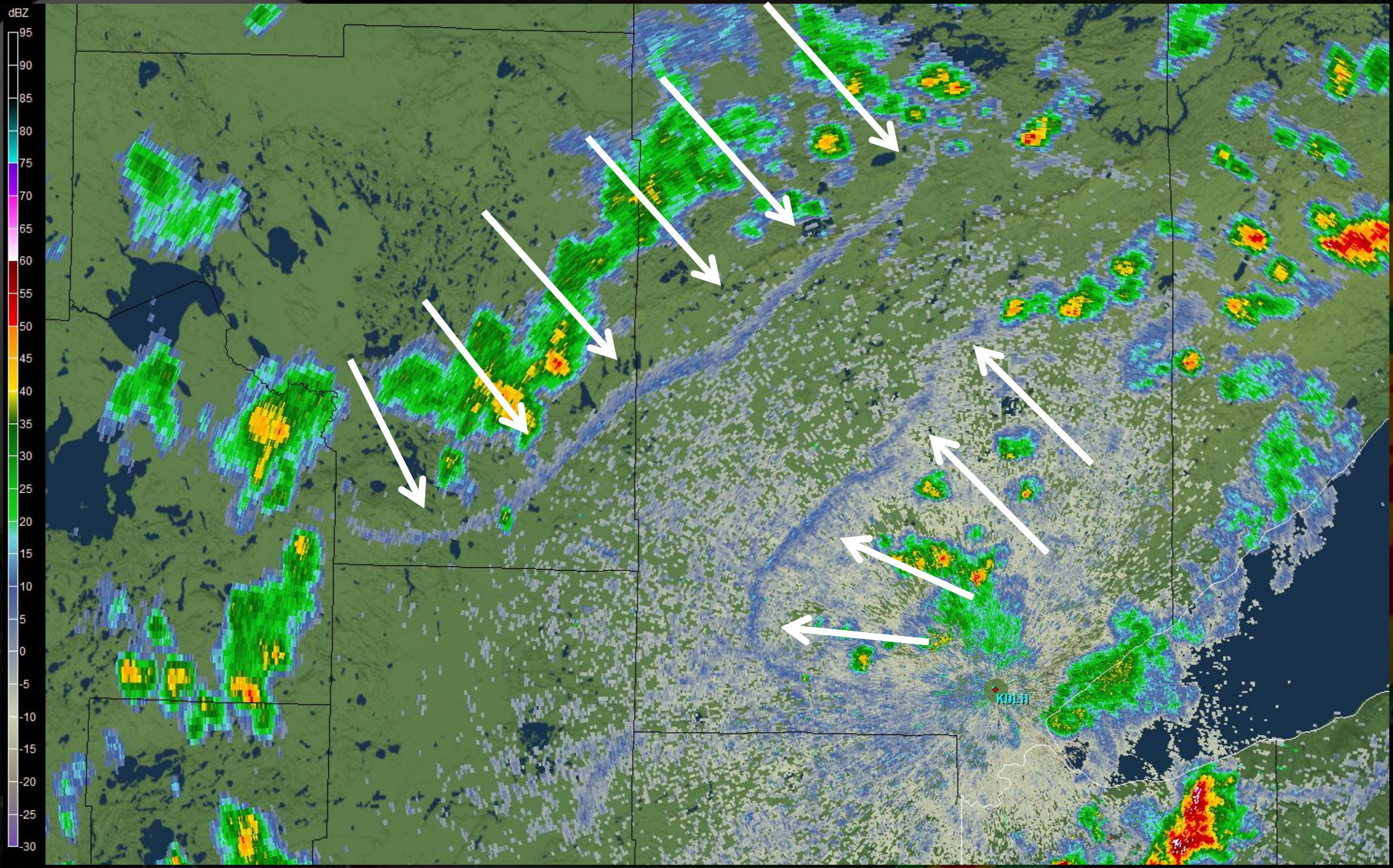
Signatures on Radar

Mixed Precipitation



Signatures on Radar

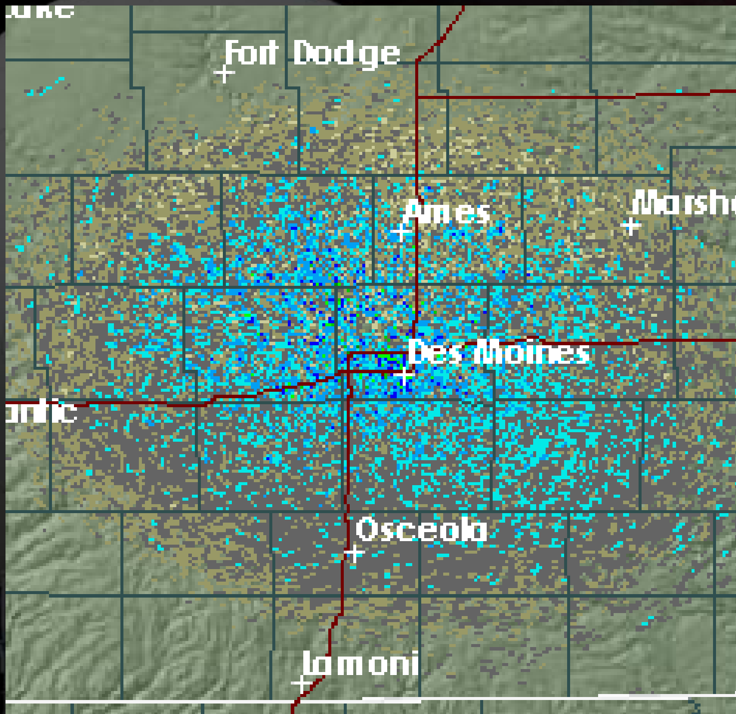
Boundaries



Outflow Boundaries, Cold/Warm Fronts, Sea Breezes, Etc.

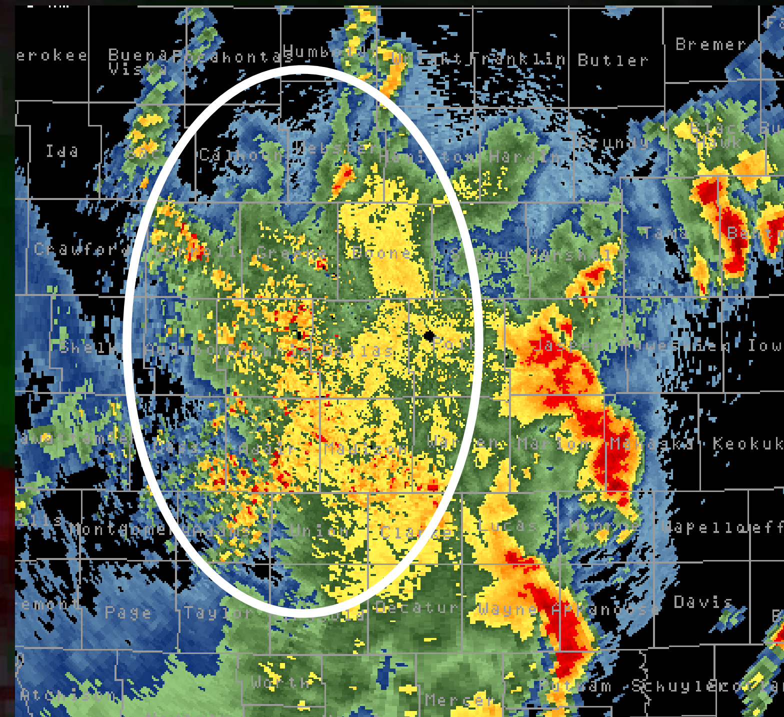
Signatures on Radar

Ground Clutter/AP



Ground Clutter

Dust, Insects, Birds, Wind Farms, Etc.

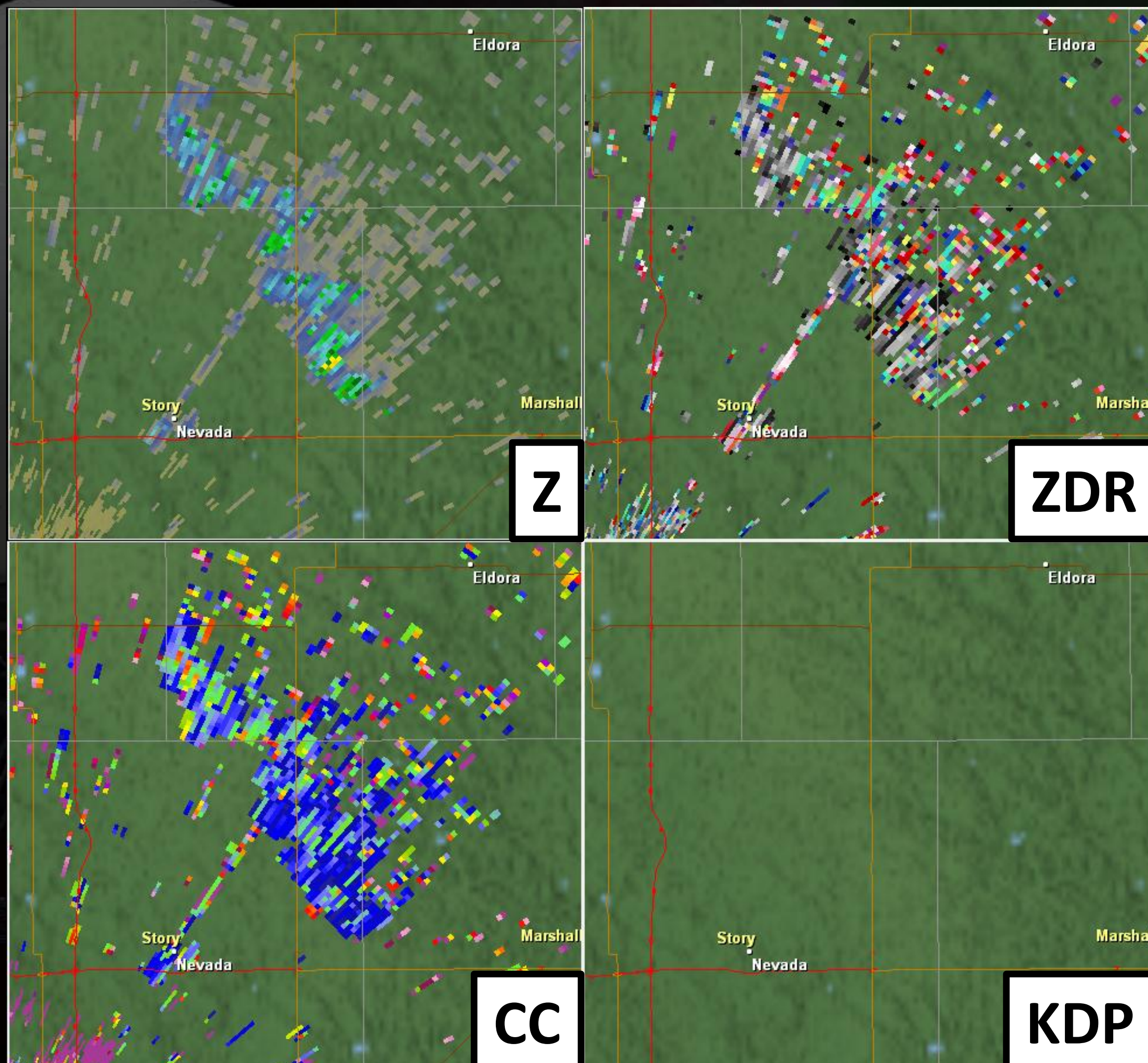


AP (Anomalous Propagation)

Beam Striking the Ground

Signatures on Radar

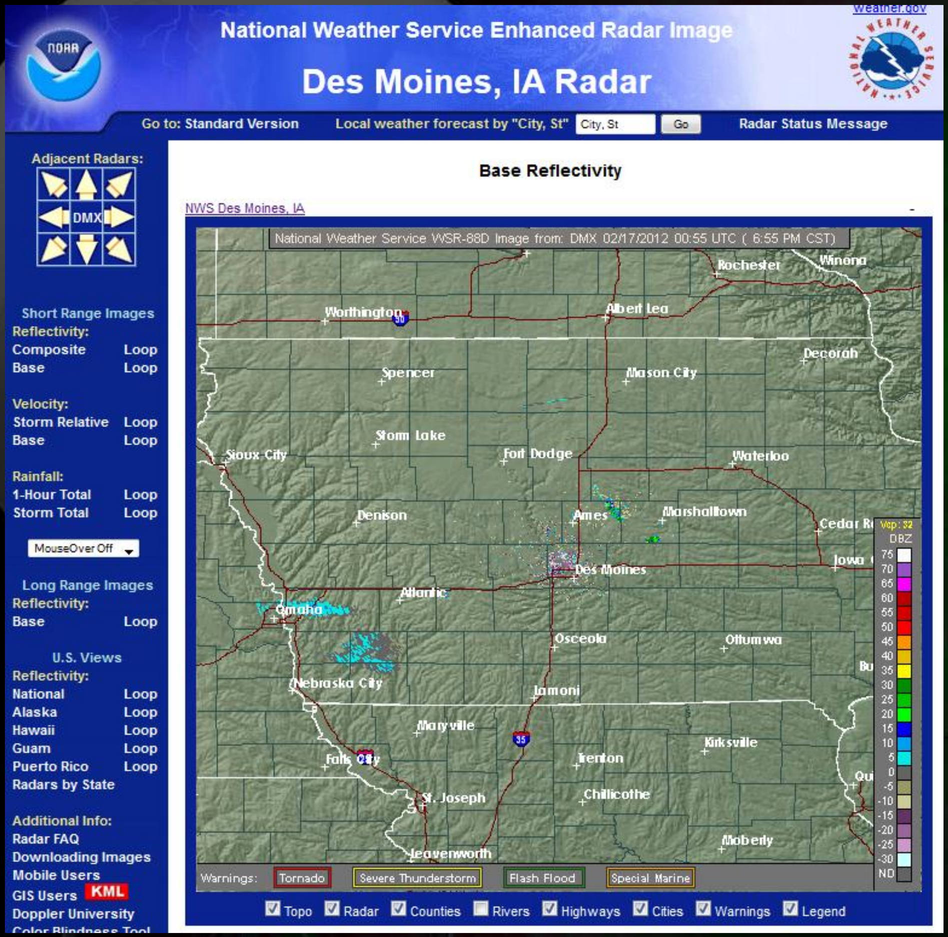
Ground Clutter/AP



Wind Farm Example from KDMX

Sources for Radar Data

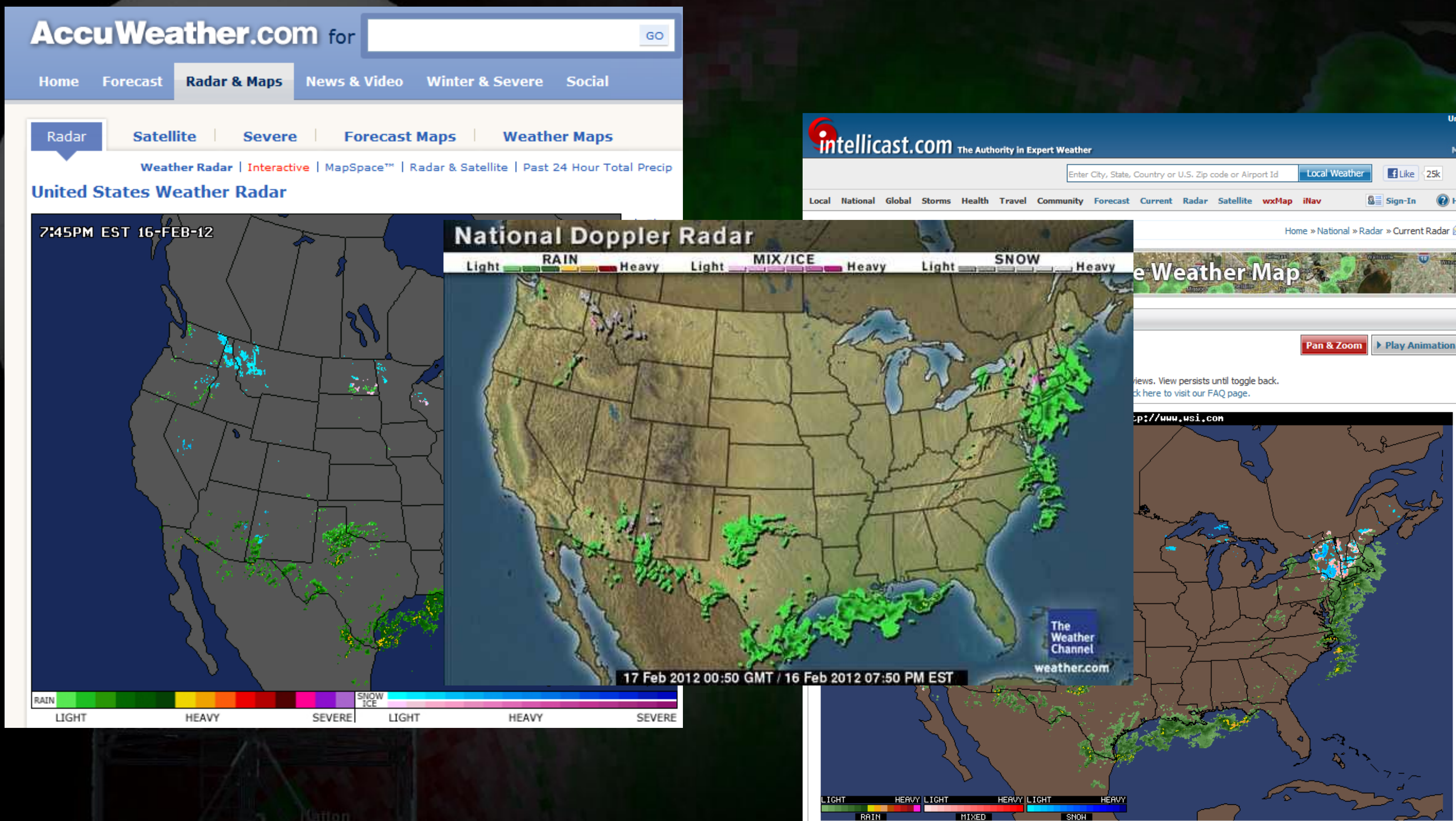
NWS Web Page



- Numerous products available in normal and loop mode
- Warning polygons make it easy to track severe storms at a glance
- Standardized format throughout the NWS
- Quick links to surrounding radars
- Links to radar FAQ's and instructions

Sources for Radar Data

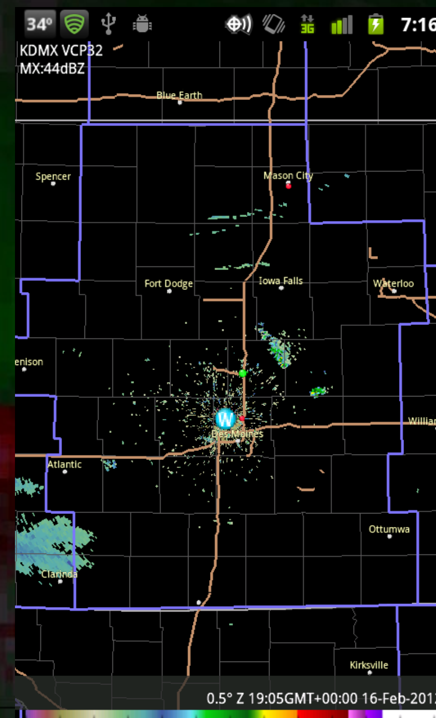
Other Commercial Web Pages

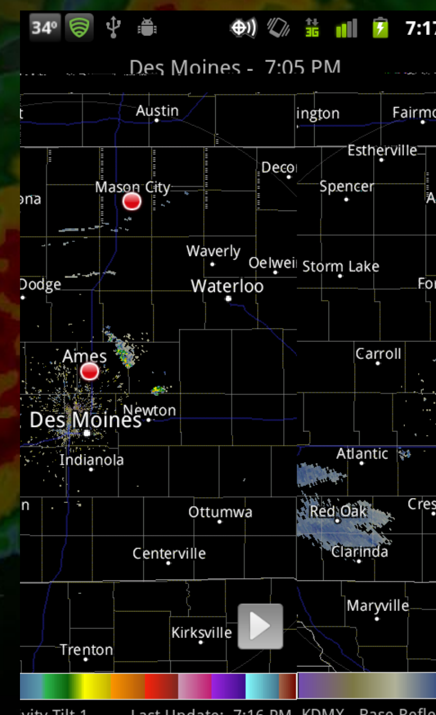


Sources for Radar Data

Cell Phone Applications

- A number of radar apps for smartphones and tablets have appeared in recent years
- Mixture of free and paid apps
- Two of the more robust radar apps are PYKL3 Radar and Radarscope
- Many other radar apps and weather apps that bundle in radar data.

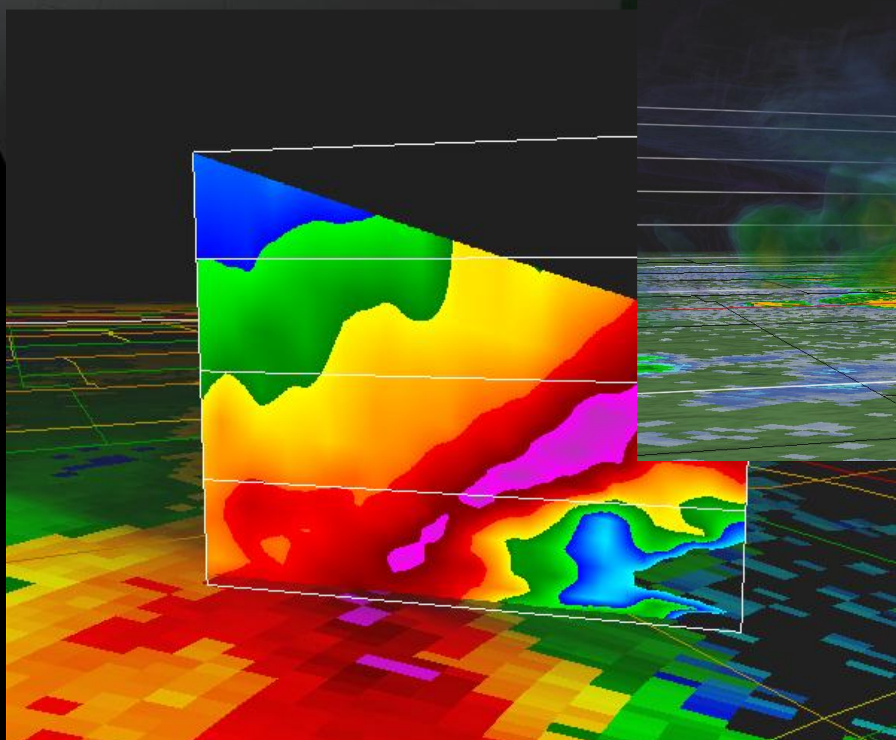


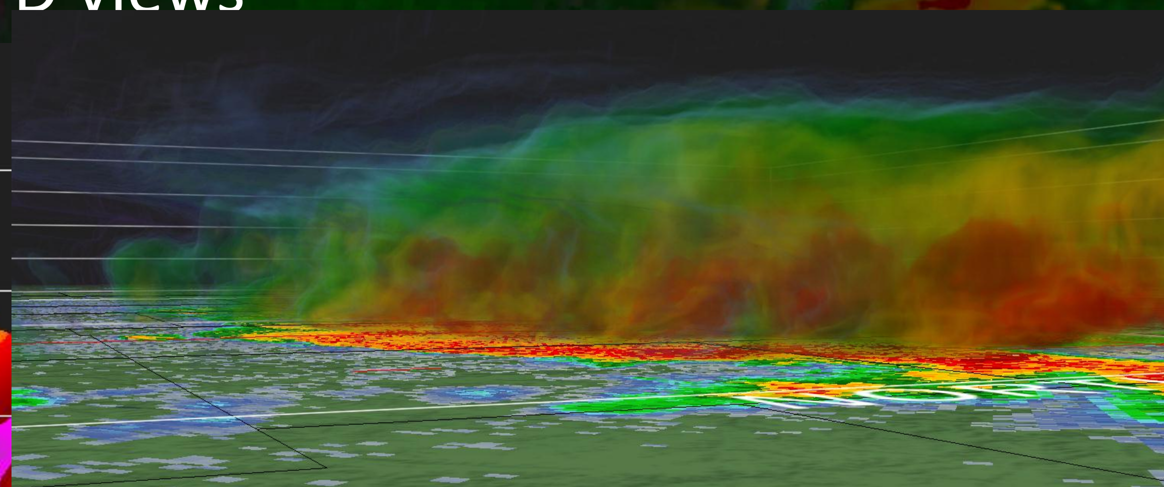


Sources for Radar Data

Gibson Ridge Software

- GR Level 2, GR Level 2 AE, GR Level 3
  - Can view and manipulate radar data, take cross sections and 3-D views

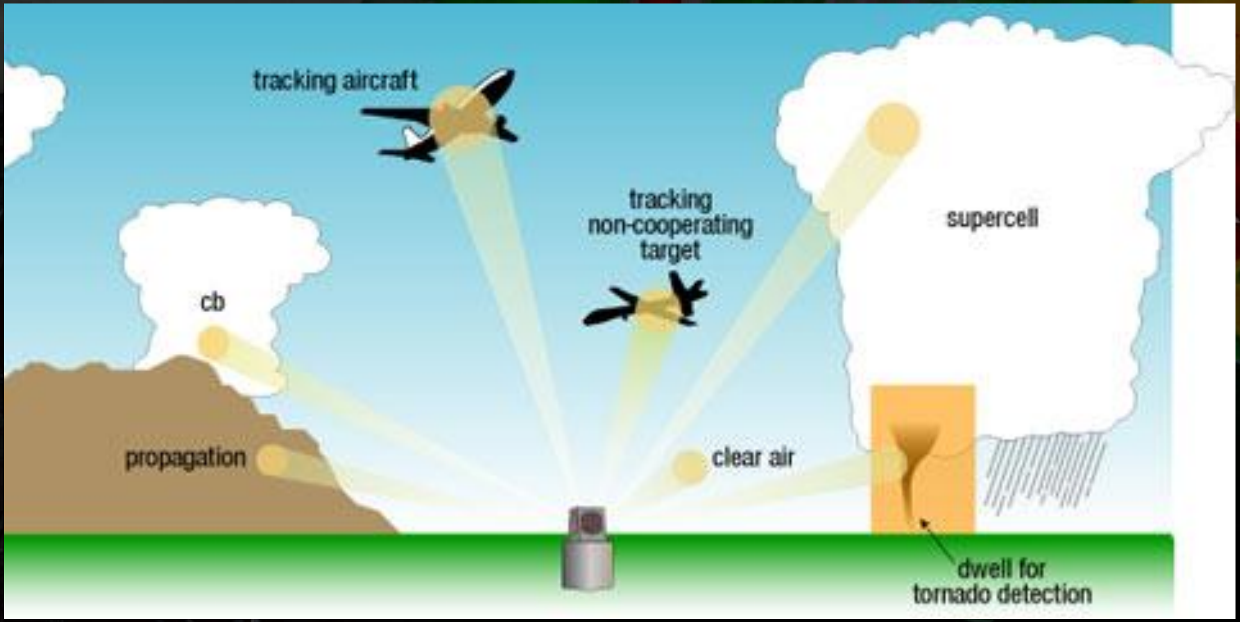




New and Future Radar Upgrades

Phased Array

- Consists of four stationary panels pointing in the cardinal directions
- The rapid scanning ability of phased array radar gives it the potential to be a multi-use, adaptively scanning radar.
- Using multiple beams and frequencies that are controlled electronically, phased array radar reduces the scan time of severe weather from slightly more than 4 minutes for NEXRAD radar to only 1 minute.



New and Future Radar Upgrades

Phased Array

Only Current Phased Array Radar—Norman, OK

Questions?

Other Helpful Radar Web Pages

http://www.srh.noaa.gov/jetstream/doppler/doppler_intro.htm

http://www.wdtb.noaa.gov/courses/dloc/topic3/lesson1/index.html

http://www.weather.gov/DesMoines

Kevin.Skow@noaa.gov