The Radar

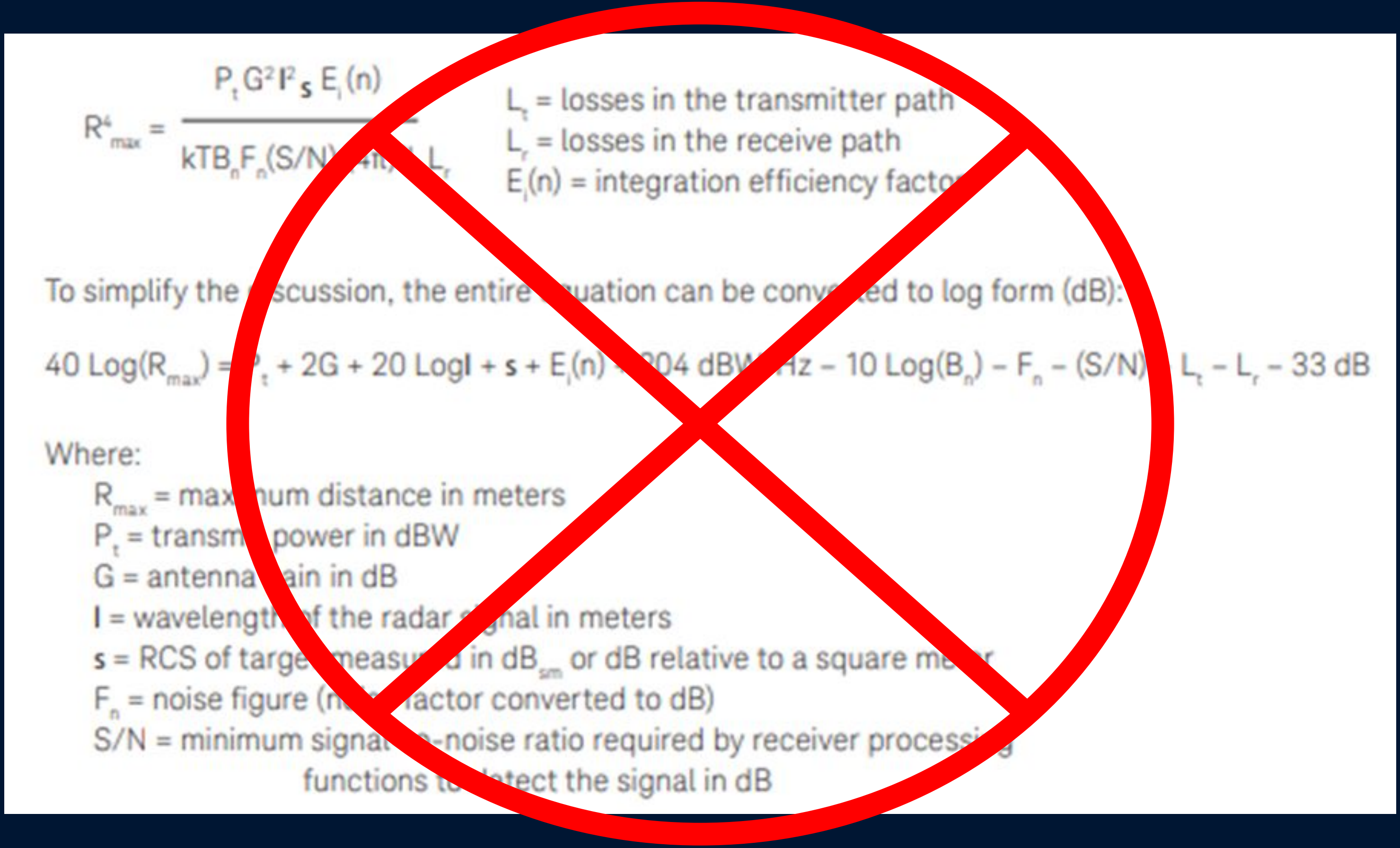
Meteorologist Caleb Cravens

NWS Nashville, TN


RADAR
NOAA
NWS Nashville, TN

In this lesson

- Background and History
  - What is radar?
  - How does it work?
  - Limitations and advantages
  - Advancements in radar
- Radar products and applications
  - Base (Z, V, SW) and Dual-Polarization



$$R^4_{max} = \frac{P_t G^2 l^2 s\, E_i(n)}{kTB_nF_n(S/N) \ldots L_r}$$

L_t = losses in the transmitter path
L_r = losses in the receive path
$E_i(n)$ = integration efficiency facto…

To simplify the …scussion, the entire …uation can be conv…ed to log form (dB):

$$40\,Log(R_{max}) = …_t + 2G + 20\,Log\,l + s + E_i(n) … 04\,dBW … Hz - 10\,Log(B_n) - F_n - (S/N) … L_t - L_r - 33\,dB$$

Where:

- R_{max} = max…num distance in meters
- P_t = transm… power in dBW
- G = antenna …ain in dB
- l = wavelengt… f the radar … nal in meters
- s = RCS of targe… measu… in dB_{sm} or dB relative to a square me…r
- F_n = noise figure (n… actor converted to dB)
- S/N = minimum signa… -noise ratio required by receiver processi…
  functions t… etect the signal in dB

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War…What Is It Good For?

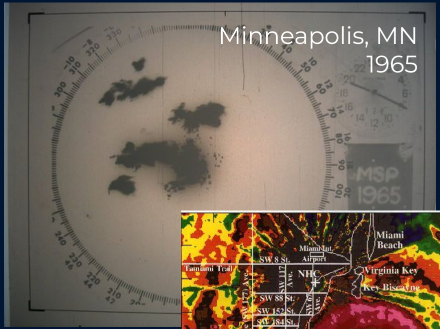
- Radar began as a way to detect enemy aircraft and ships
- During World War II (1939-1945), operators noticed “weather noise”
- WSR-1 entered service in 1947
- Since then…
  WSR-1A, WSR-3, WSR-4, WSR-57, WSR-74, WSR-88D*

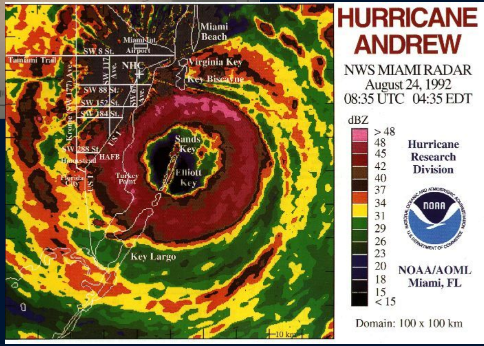
* In operation today.

[Check out “Operational Use of Weather Radar by U.S. Weather Services”...]

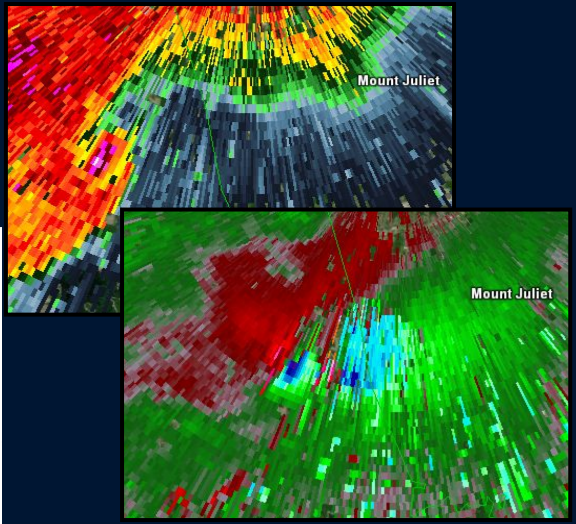
WSR Iterations

WSR-3 (retired 1978)
Surplus from Navy, 3 cm





WSR-57
“Modern”, no velocity



WSR-88D
Doppler, velocity

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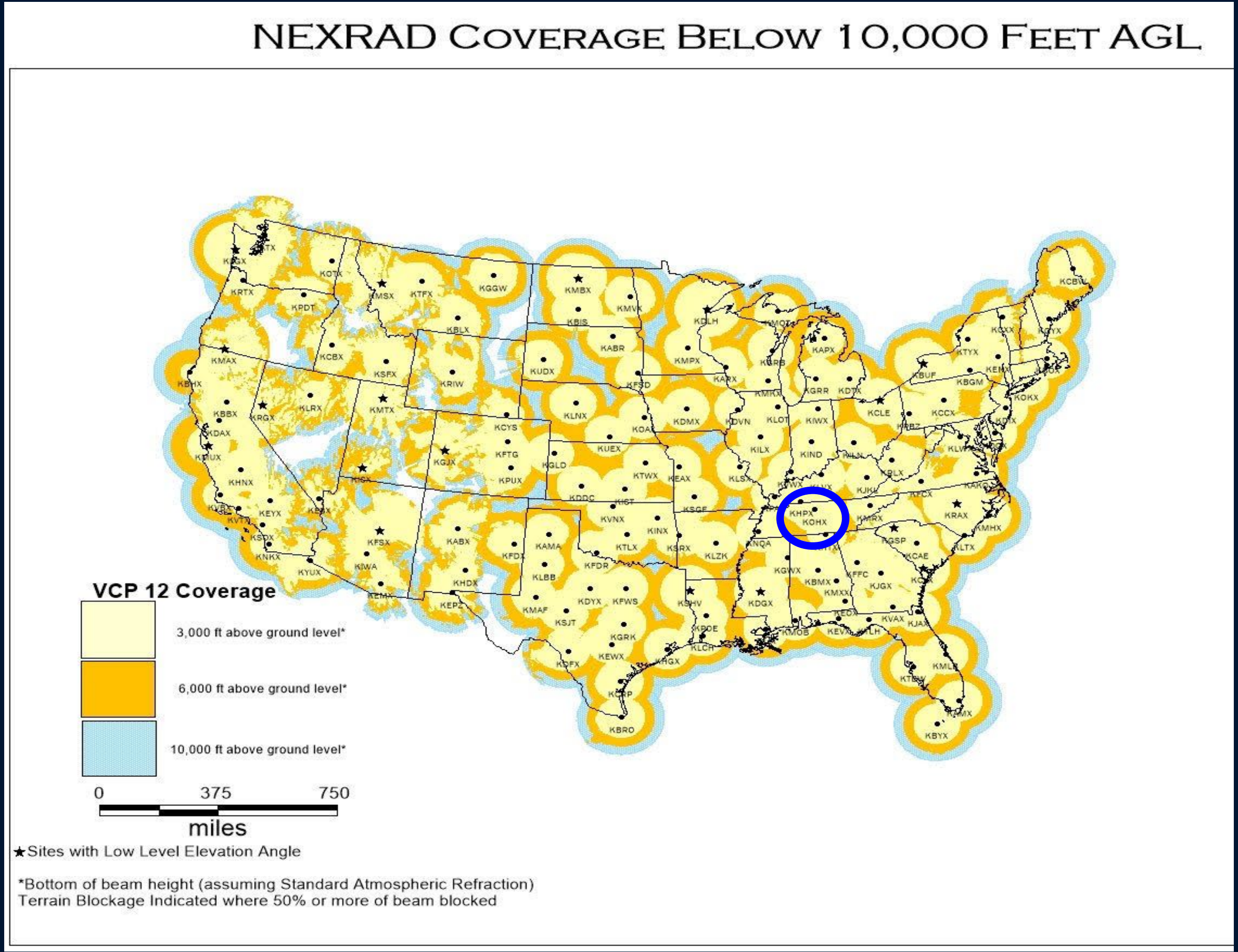
Sources: https://www.weather.gov/dtx/beecherradar | https://military-history.fandom.com/wiki/WSR-57



- **Radars each have a 4-letter callsign**

- **Nashville's radar is KOHX**

How Radar Works

- Antenna dish spins 360 degrees and can tilt up to 19.5 degrees
- Brief pulse of energy is sent
    - Pulses used to display target distance/range from the antenna
- Radar “listens” for energy to travel back from a target

Question Time

Limitations of Radar

- Refraction of radar beam
- Curvature of Earth's surface
- "Cone of silence" and proximity to radar
- Beam spreading and storm location (more ambiguity)

Limitations of Radar

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Refraction of Radar Beam

- Refraction
  - As the radar beam propagates through the atmosphere, the top of the beam travels faster than the bottom. This causes bending or refraction of the beam.
- Causes may include:
  - Pressure
  - Temperature
  - Moisture

Causes of Radar Beam Refraction

- Pressure (main cause of refraction)
  - Decreases with height, causing beam to bend downward
- Temperature
  - Generally decreases with height, causing beam to bend upward. Higher lapse rates increase upward bending.
    - **A temperature inversion will cause the beam to bend downward.*
- Moisture
  - Typically, vapor pressure decreases with height, causing beam to bend downward. A more rapid decrease in vapor pressure increases downward bending (and vice versa).
    - **Increases in vapor pressure with height will cause beam to bend upward.*

https://www.weather.gov/jetstream/beam_max

Normal refraction

Beam bends
more than normal

Beam bends **less than** normal

Beam **really bends more than** normal

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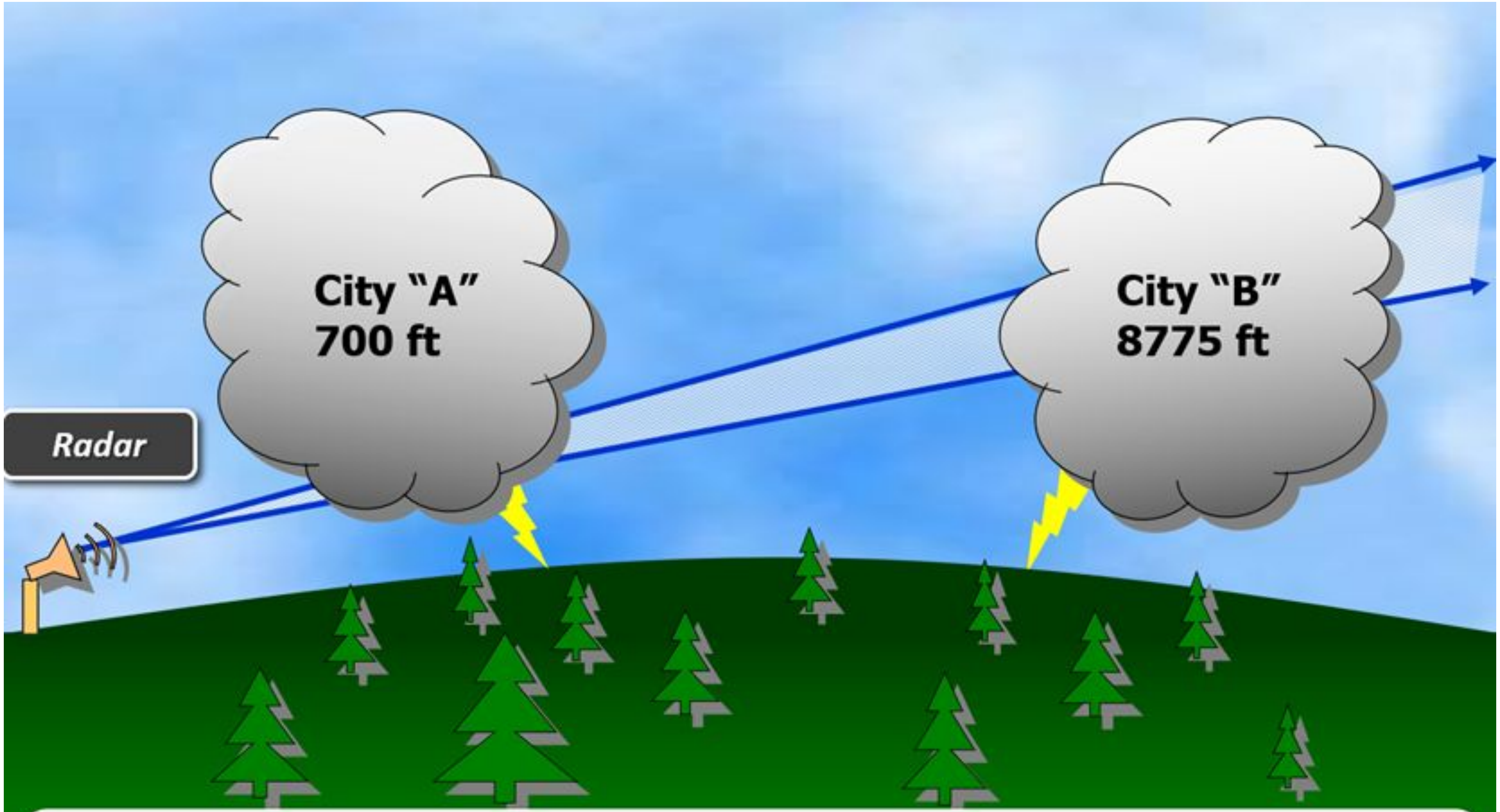

Because the Earth is curved, the radar beam gets higher further away from the radar site

Limitations of Radar

- Refraction of radar beam
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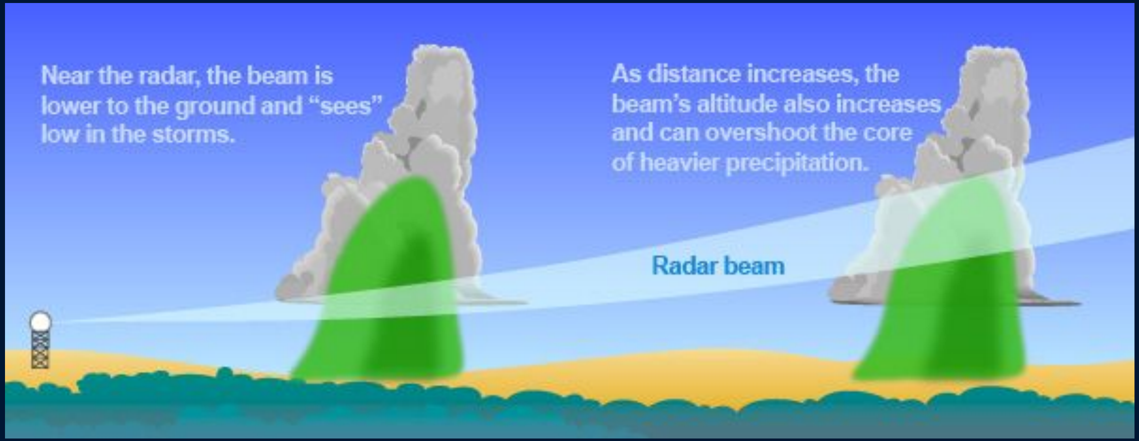
Cone of Silence and Proximity to Radar

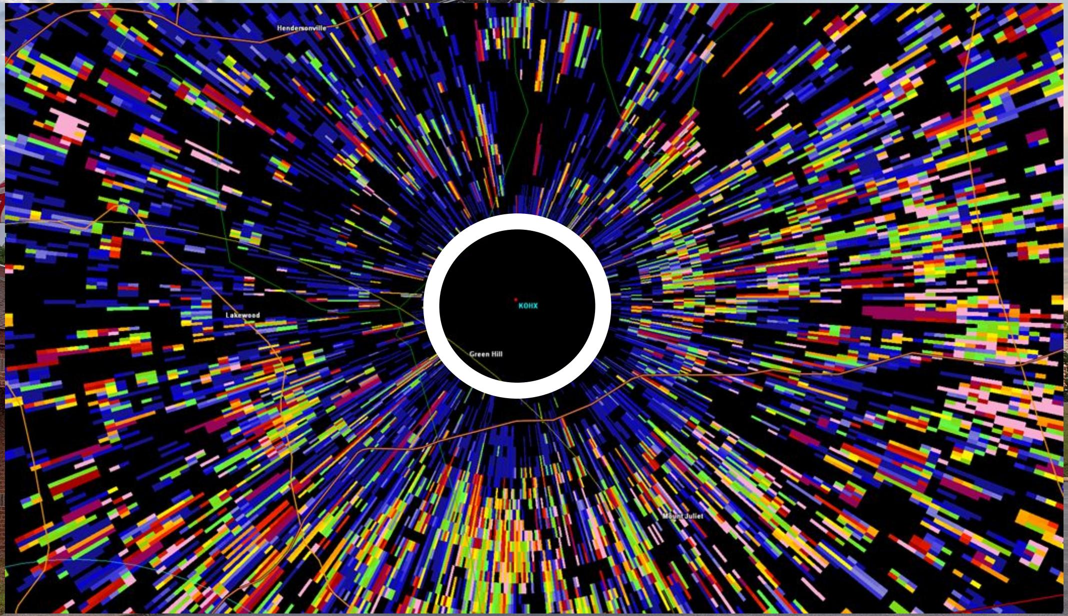
- "Cone of silence" is the area where radar is limited in its ability to scan directly overhead.
- Cone of silence radius: ~ 1 nautical mile
- Storms closer to the radar are being scanned at lower levels than storms farther away



CONE OF SILENCE

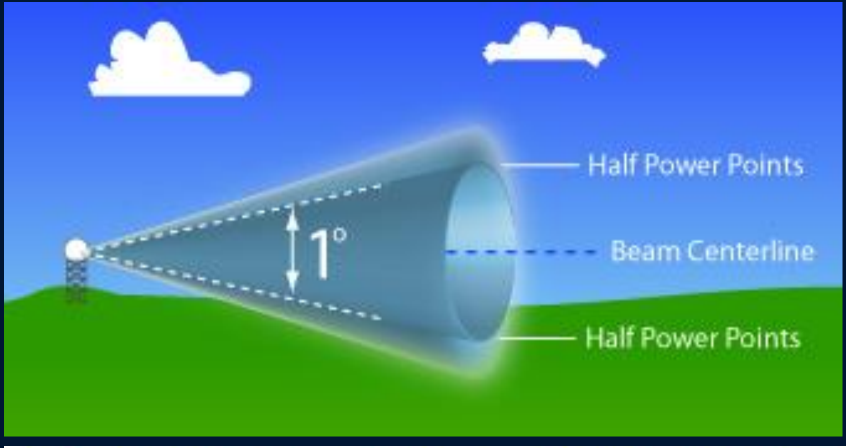
19.5 degree tilt (highest radar tilt)

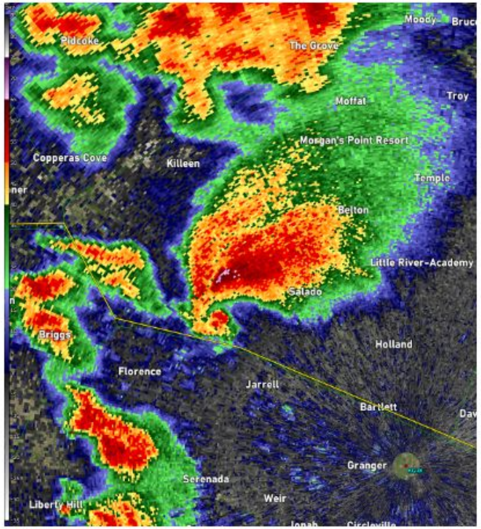
Cone of Silence Demonstration



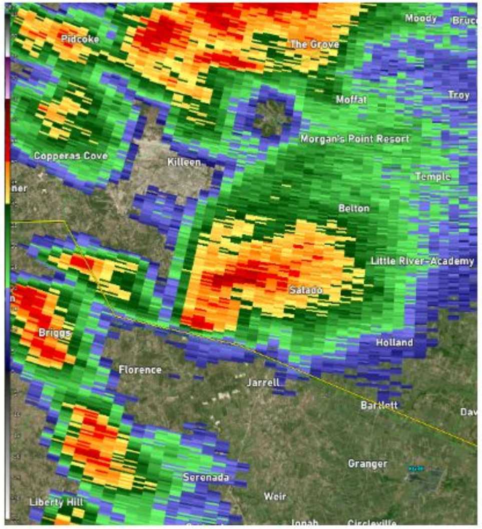
Limitations of Radar

- Refraction of radar beam
- Curvature of Earth’s surface
- “Cone of silence” and proximity to radar
- **Beam spreading and storm location (more ambiguity)**





20 mi



98 mi

- Beam spreads out approximately 1,000 feet for every 10 miles of travel, so at 120 miles from the radar, the beam is over 2 miles wide.

- Impacts the resolution of the returned data. Small storm scale features that are easily seen close to the radar are often masked at long distances.

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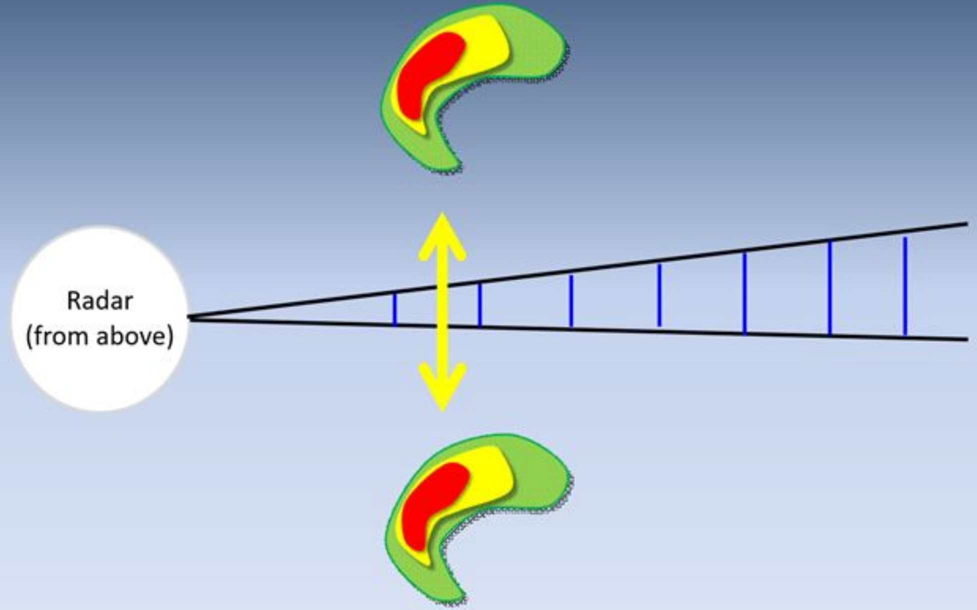
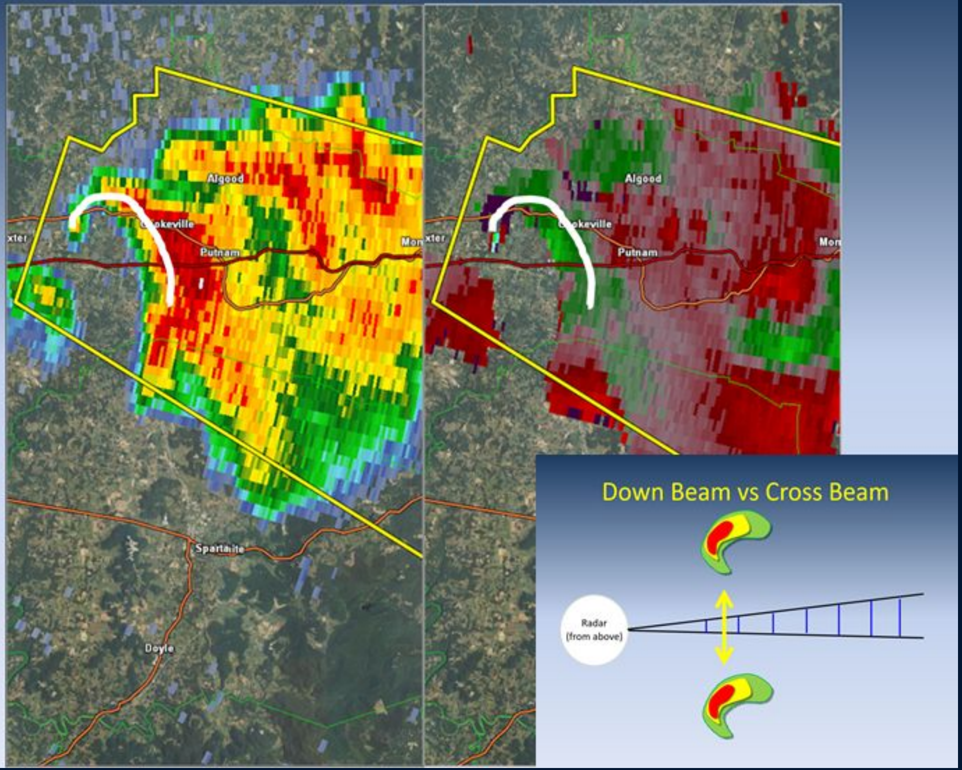
Can multiple radars be used at once to help with their individual limitations?

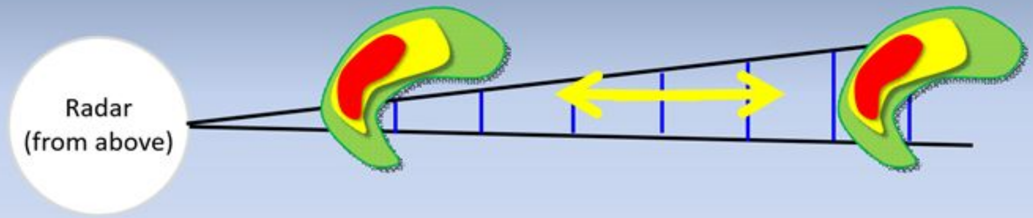
Down Beam vs Cross Beam



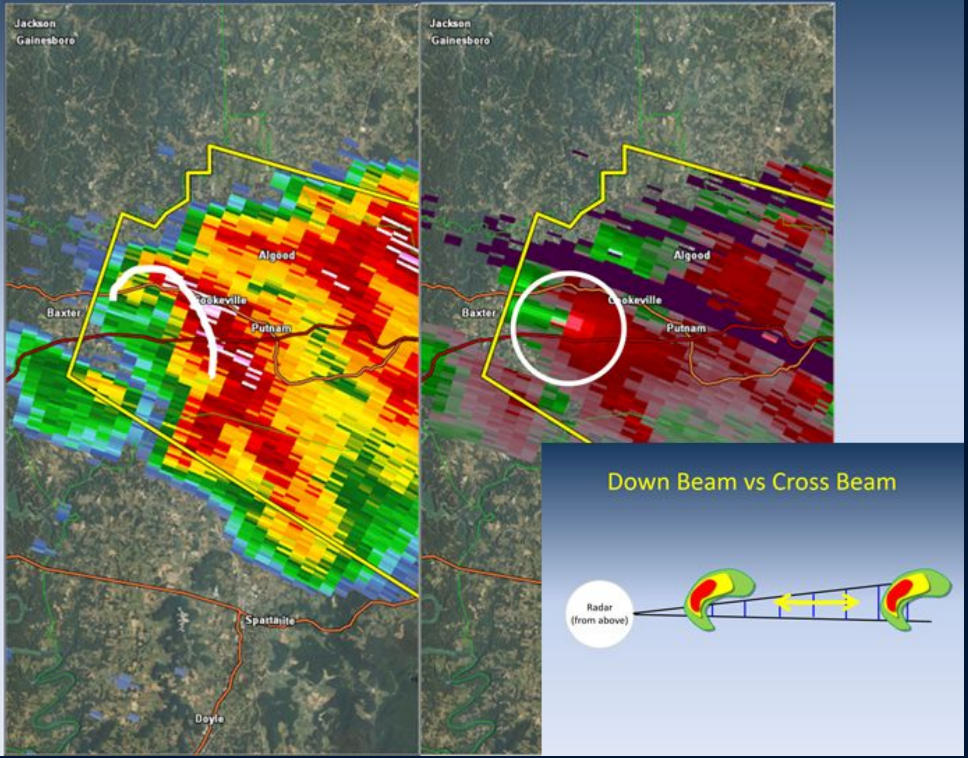
From OHX on July 14, 2015



Down Beam vs Cross Beam



From HTX on July 14, 2015



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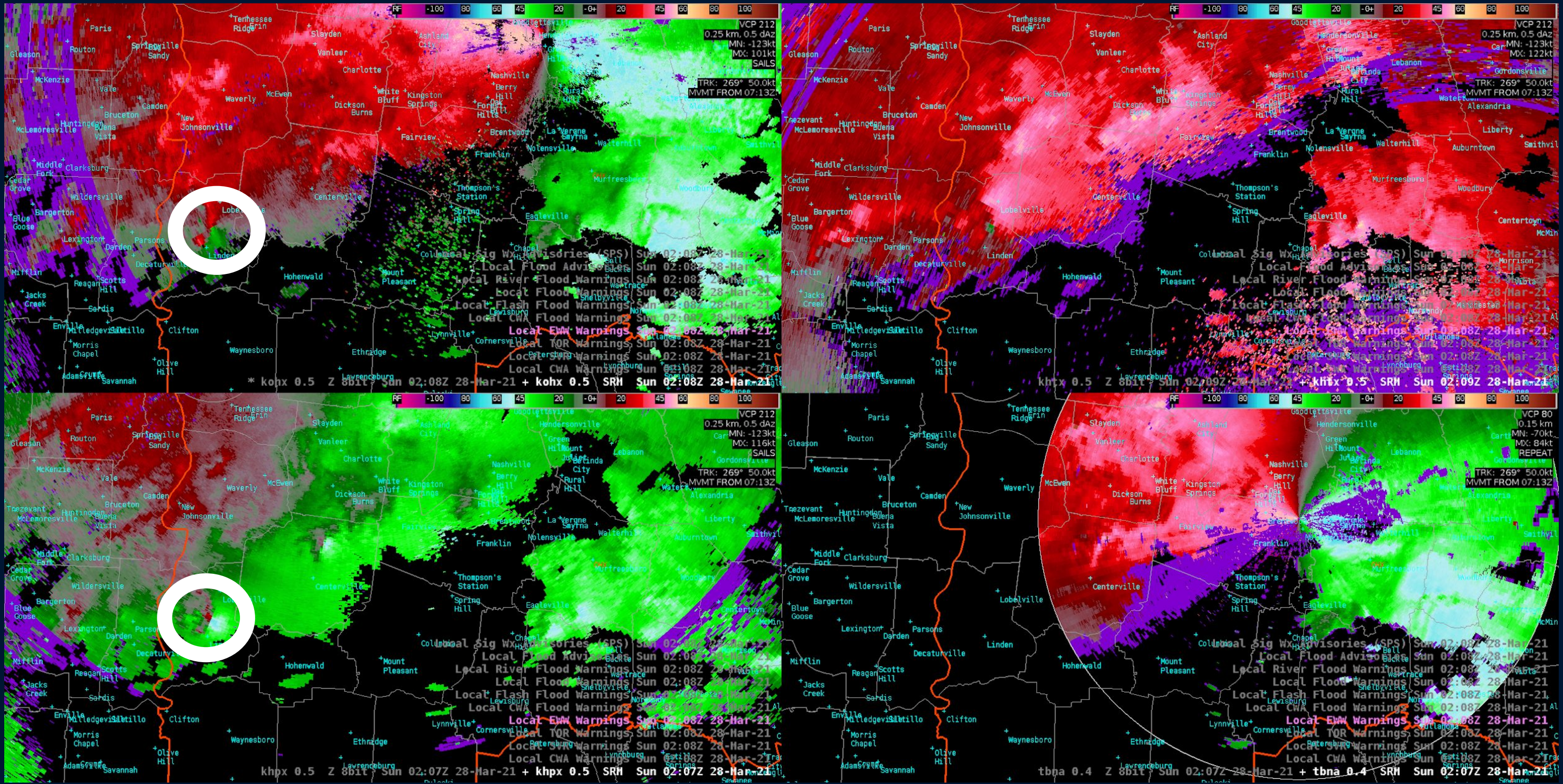

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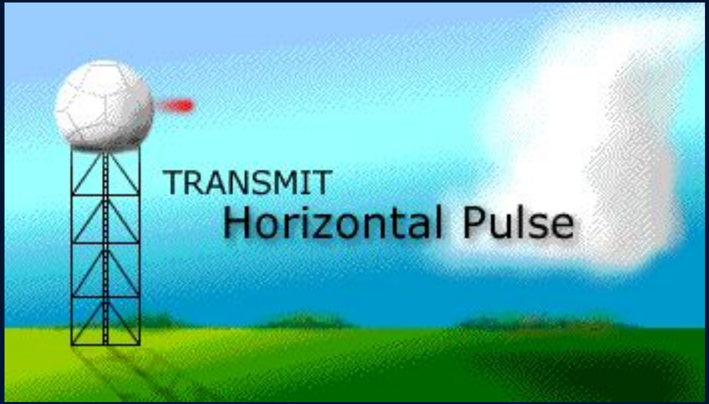
Question Time

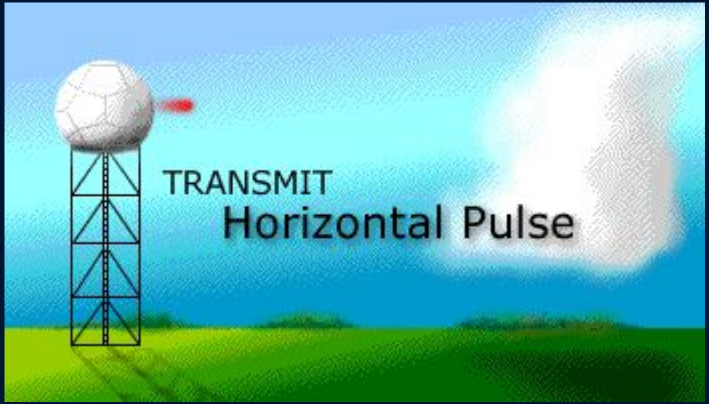
Conventional v. Dual-Pol Radar

- Conventional: standard horizontal pulse
- Detects targets, “listens” for energy to return

versus

- Dual-pol: upgrades completed in 2013
- Standard horizontal pulse *plus* a vertical pulse
- Hail detection, raindrop size, improved rainfall estimates, non-meteorological targets
- Detection of chaff, debris, and melting layer (CC)


TRANSMIT
Horizontal Pulse


TRANSMIT
Horizontal Pulse

Volume Coverage Patterns (VCP)

Clear Air Mode

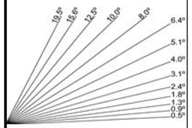
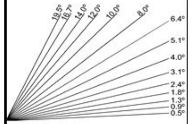
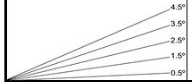
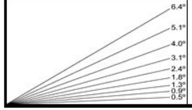
31 - Complete volume scan using five elevation angles in 10 minutes

35 - Adds overlapping low elevation angles to help show light precipitation and non-precipitation targets (~7 minutes)

Precipitation Mode

12 - 14 slices, 17 360° scans in ~4 minutes
212 - Similar to 12, best for distant severe weather
215 - General precip surveillance (~6 minutes)
121 - Tropical systems, enhances velocity data (~5.5 minutes)

Quick Reference VCP Comparison Table for RPG Operators as of RPG Build 22

Slices	Tilts	VCP	Time*	Algs.	Usage	Limitations
	14	12	4.3 mins	AVSET	Fastest VCP. Rapidly evolving, severe convective events (e.g., squall line, MCS).	High antenna rotation rate decreases the effectiveness of clutter filtering and decreases the accuracy of the base data estimates.
		212	4.6† mins	SAILS MRLE	Rapidly evolving, severe convective events (e.g., supercells, squall line, MCS). Uses SZ-2 to significantly reduce range-obscured V/SW data compared to VCP 12.	All Bins clutter suppression is not recommended. High antenna rotation rate decreases the effectiveness of clutter filtering and decreases the accuracy of the base data estimates. PRF sectors not allowed.
		112	5.5† mins	AVSET SAILS	Large-scale systems with widespread high velocity (e.g., long squall lines, hurricanes). Significantly reduces range-obscured V/SW data within 230km compared to other VCPs.	PRFs are not editable for Split Cuts. RF only mitigated for Split Cuts. Limited to a single SAILS scan.
	15	215	6† mins	AVSET SAILS MRLE	VCP of choice for general surveillance of precipitation. Best vertical coverage. Lower SNR than VCPs 12/212. Uses SZ-2 to reduce range-obscured V/SW data. Lower low-level antenna rotation rates increase the accuracy of base data estimates. Shares common lower elevations with VCPs 12/212 and 35.	All Bins clutter suppression is not recommended. Slower low-level updates than VCP 12/212. Limited to a single SAILS scan. PRF sectors not allowed.
	5	31	10 mins	None	Clear-air, snow, and light stratiform precipitation. Best sensitivity. Only long pulse VCP.	Susceptible to velocity dealiasing failures. No coverage above 5°. Rapidly developing convective echoes aloft might be missed.
	9	35	7† mins	SAILS	Clear-air, snow, and light stratiform precipitation. Shares common lower elevations with VCPs 12/212 and 215. Overlapping low-level coverage. Uses SZ-2 to significantly reduce range-obscured V/SW data compared to VCP 31.	All Bins clutter suppression is not recommended. No coverage above 6.4°. Rapidly developing convective echoes aloft might be missed. Limited to a single SAILS scan. PRF sectors not allowed.

* VCP Update times are approximate and subject to variation with use of dynamic scanning algorithms. † VCP update times will vary based on Active PRF.

Lowest to highest elevation
19.5°
15.6°
12.5°
10.0°
8.0°
6.4°
5.1°
4.0°
3.1°
2.4°
1.8°
1.3°
0.9°
0.5°
Radar slices or tilts
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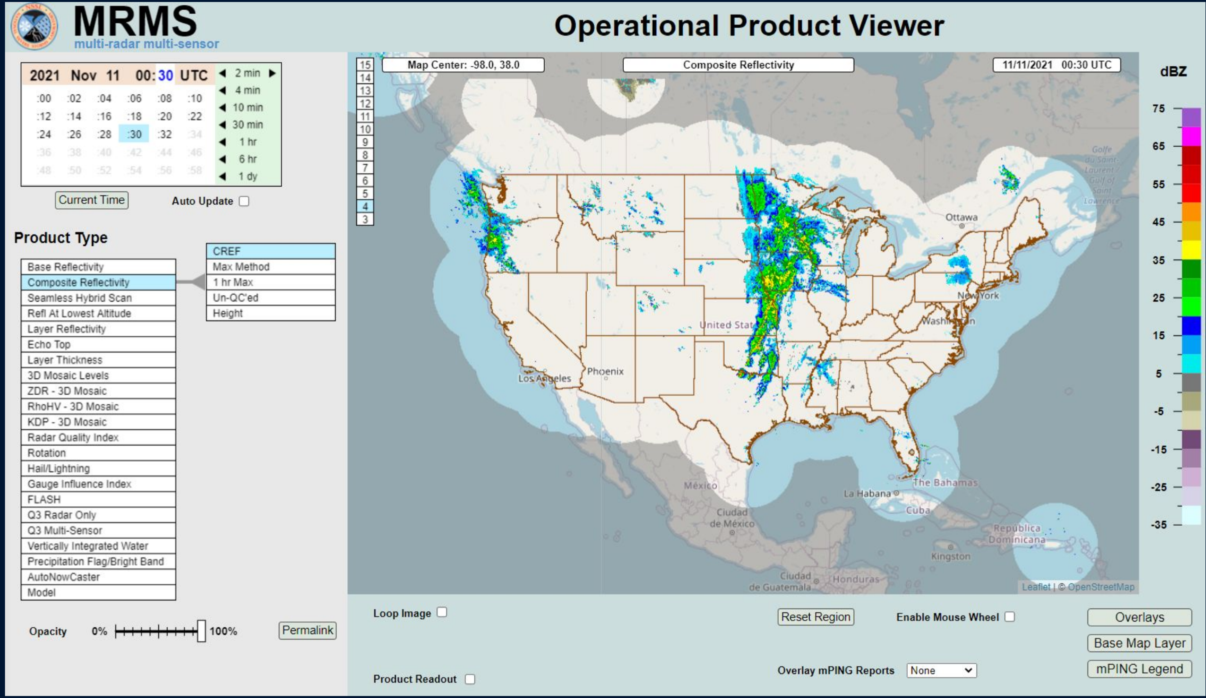
NATIONAL WEATHER SERVICE

MRMS - What is it?

- **Multi-radar/Multi-sensor System**
- Integrates the following:
  - Data from multiple radars
  - Surface/upper-air observations
  - Lightning detection systems
  - Satellite observations
  - Forecast models
- Attempts to increase accuracy of interpretation, especially where radar performance is degraded
- Provides additional derived products of operational interest



Screen capture, [MRMS Operational Product Viewer](), November 10, 2021 (6:35 PM CST).

Radar Products

- Conventional
  - Reflectivity
  - Velocity
  - Spectrum width
- Dual-pol
  - Reflectivity
  - Velocity
  - Spectrum width

  ...plus

  - Differential reflectivity
  - Correlation coefficient
  - Specific differential phase

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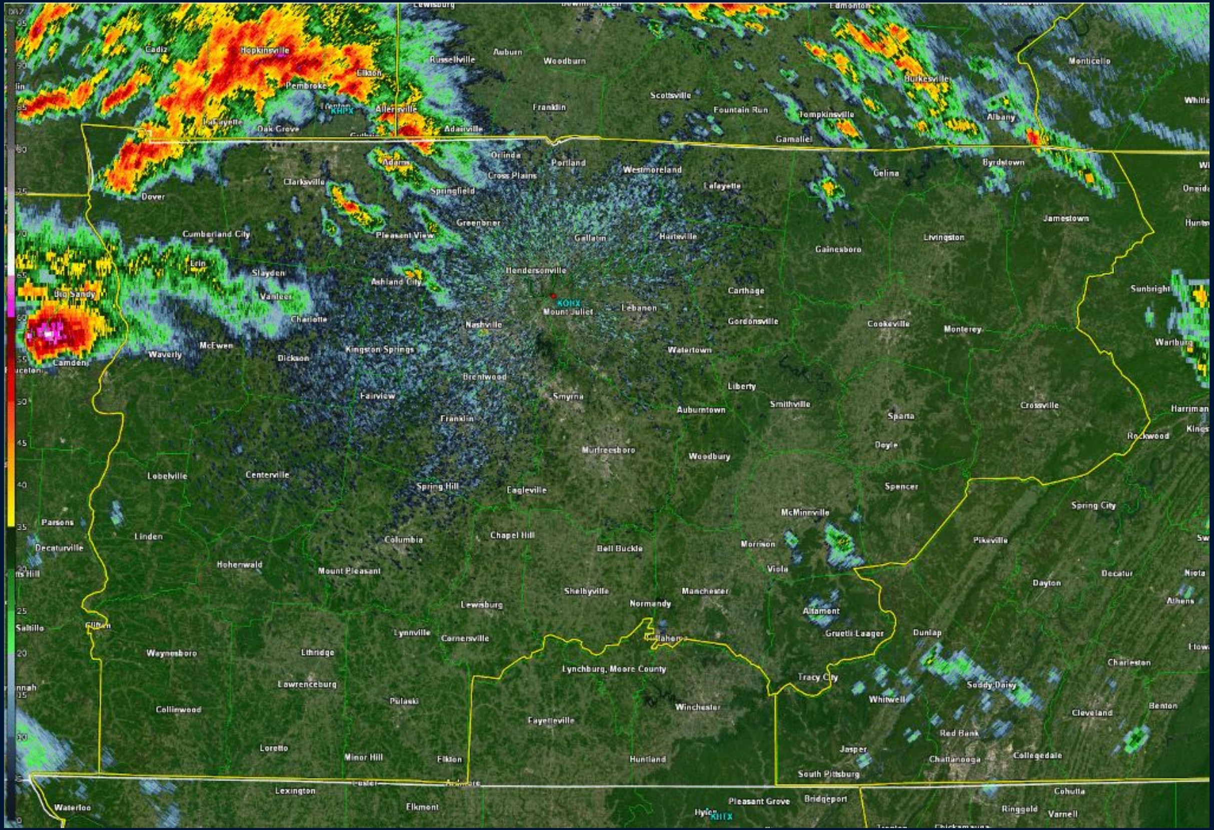

Reflectivity - March 3, 2020

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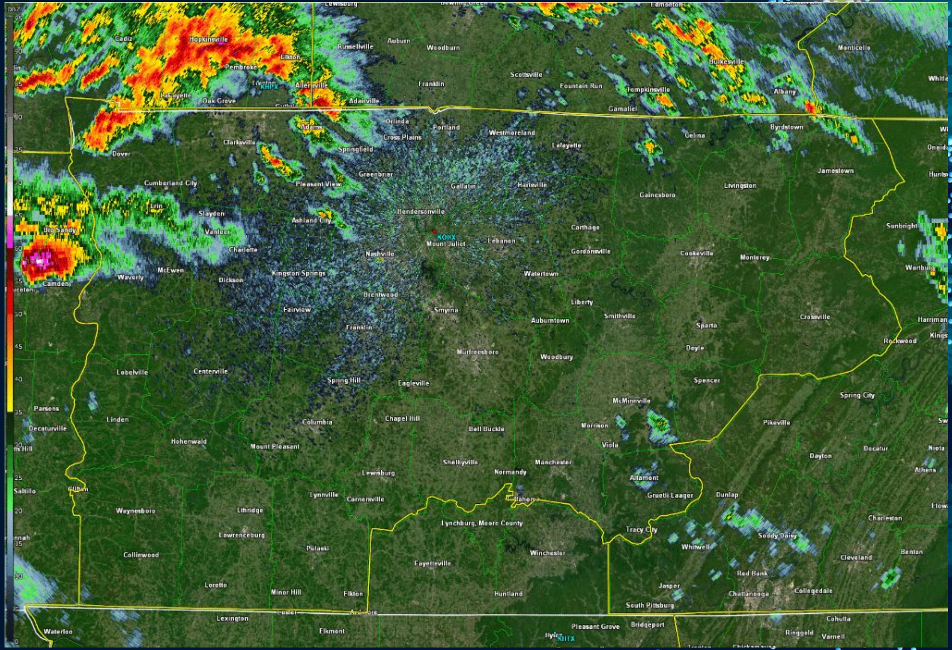
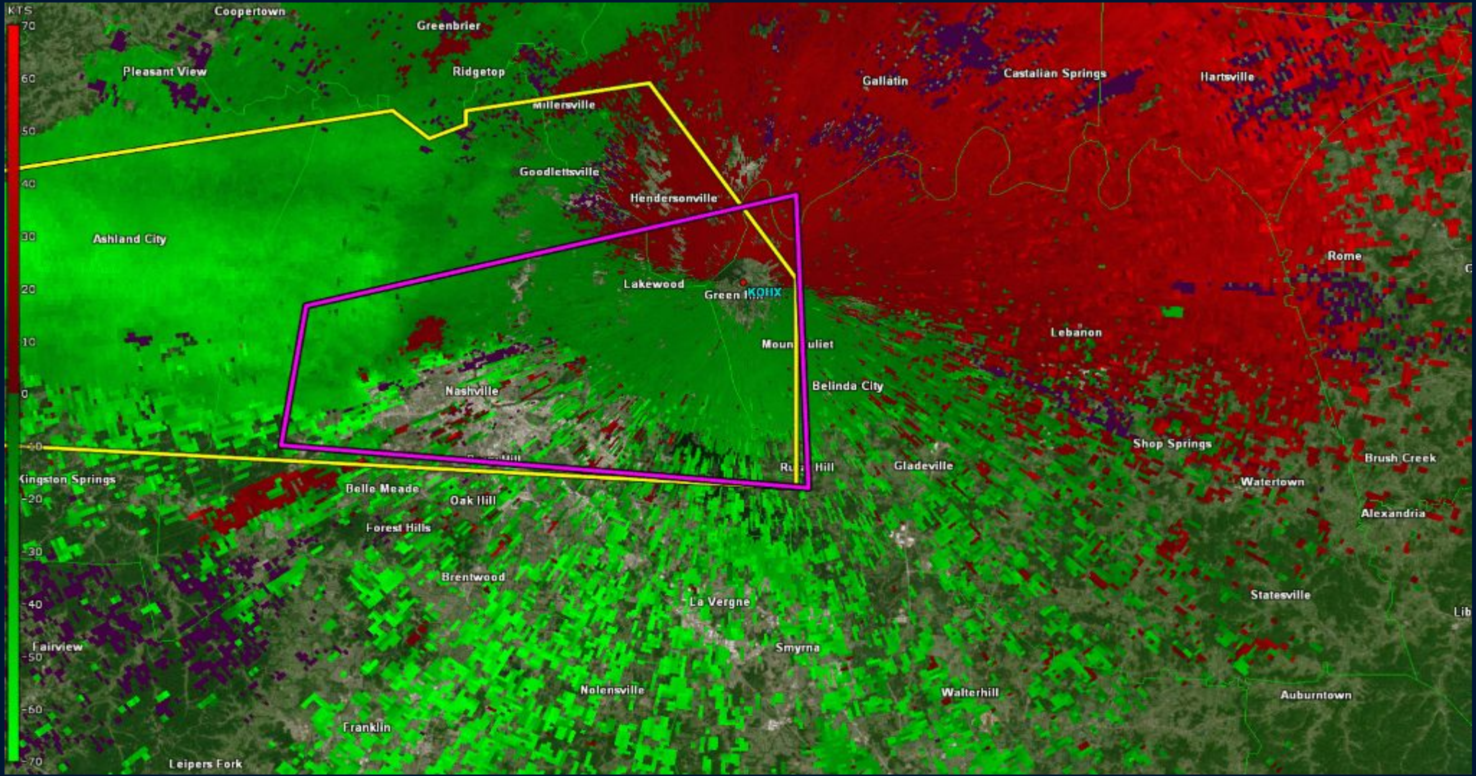
Reflectivity (Z)

- Estimated returned power converted to an equivalent value
    - Measured in dBZ
- Most commonly used/seen product
    - Helps to identify precipitation and some non-meteorological targets





Velocity - March 3, 2020

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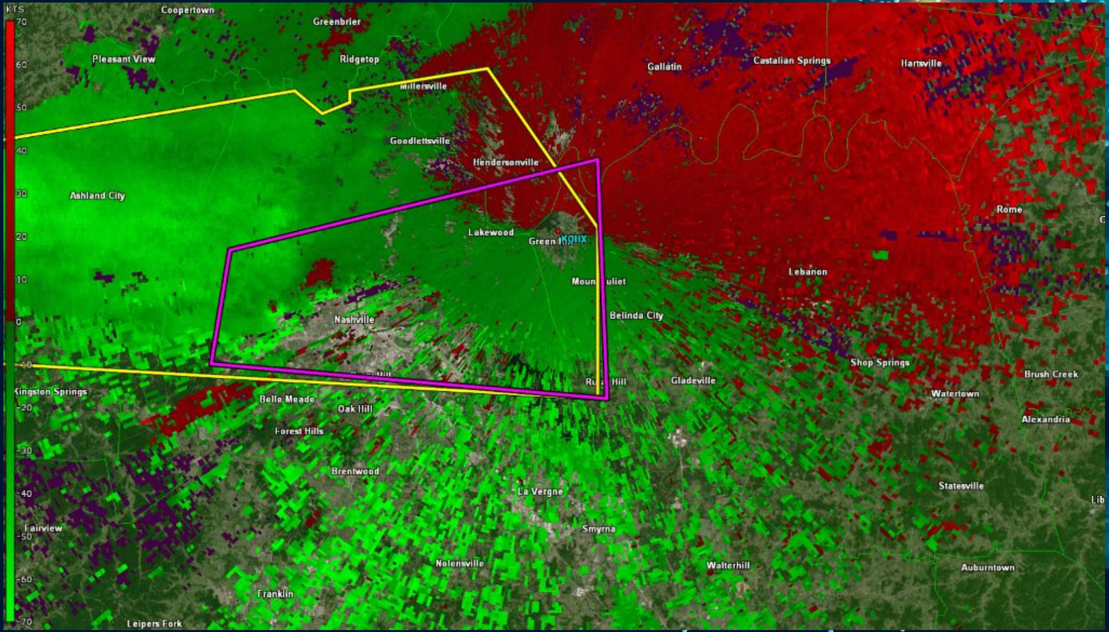
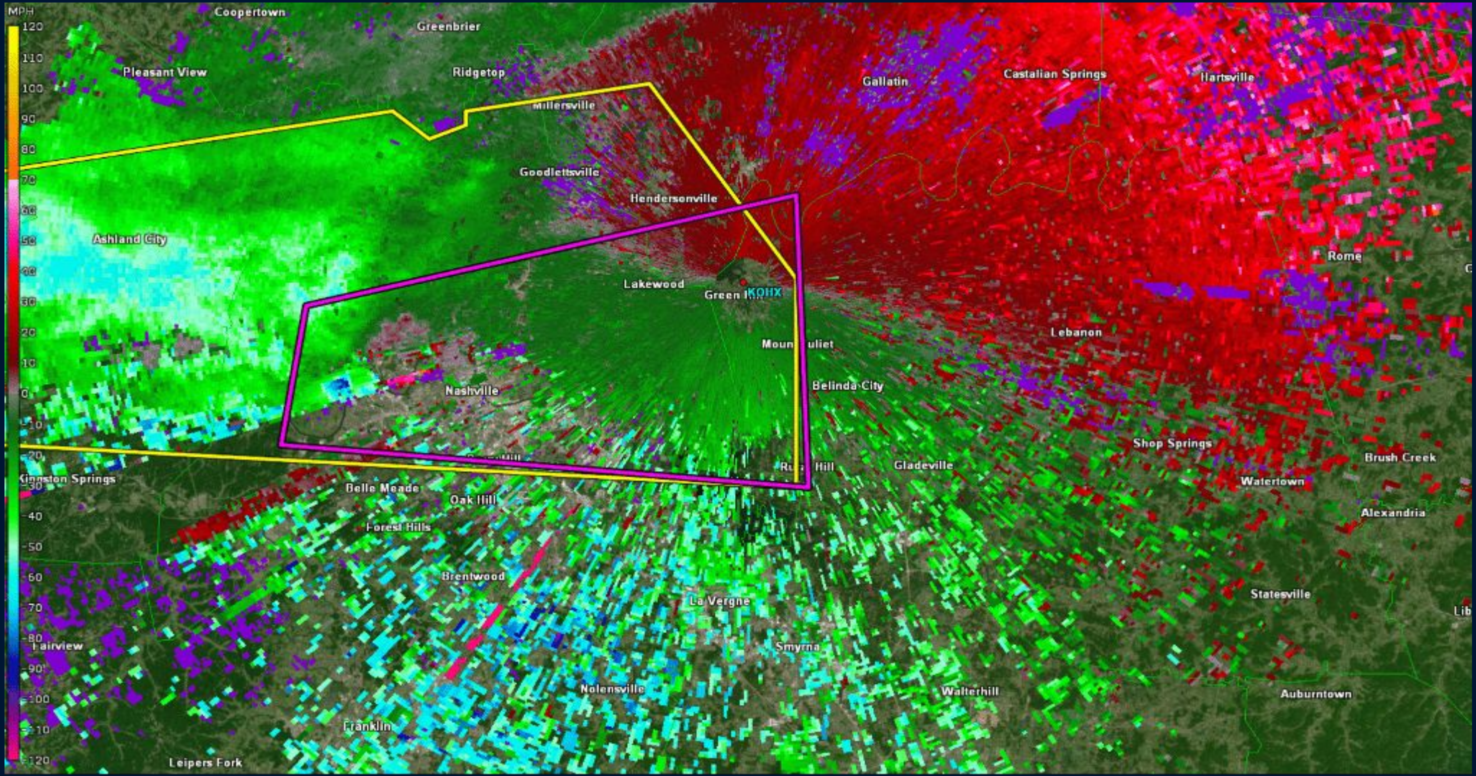
Velocity (V)

- Motion of a target detected, either toward or away from the radar
  - Measured in knots (kts)
- Commonly used to detect damaging winds and tornadoes

**Need to enough targets for accurate reading*





Storm-relative velocity - March 3, 2020

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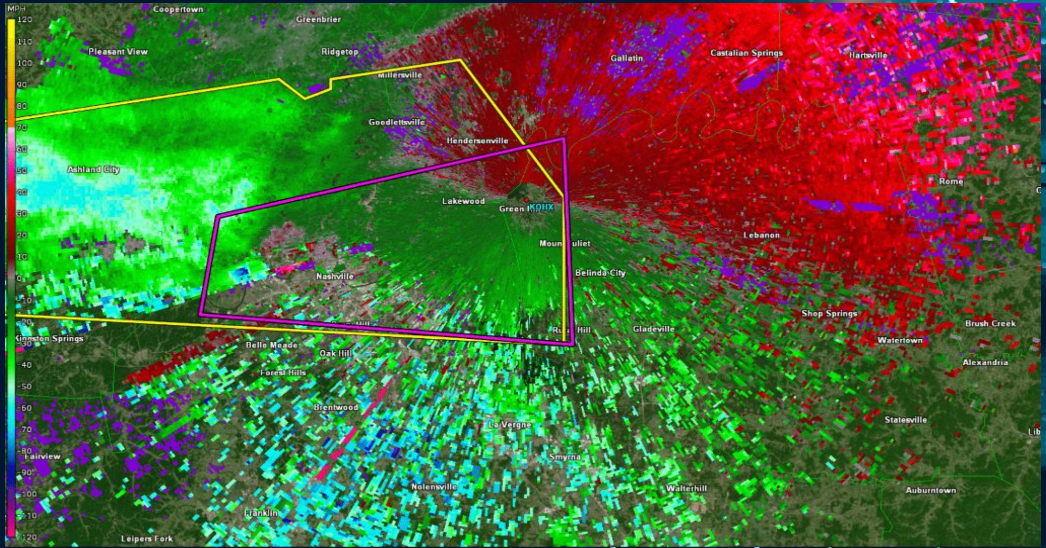
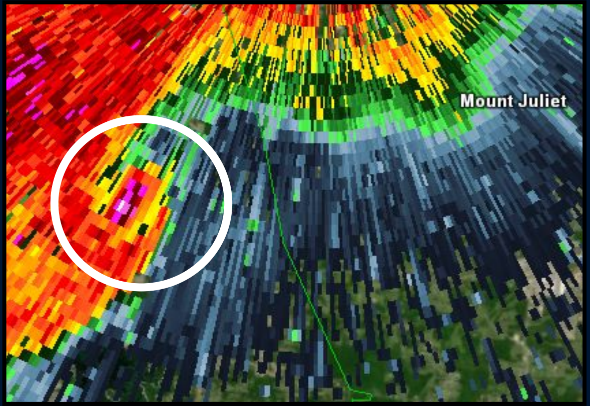
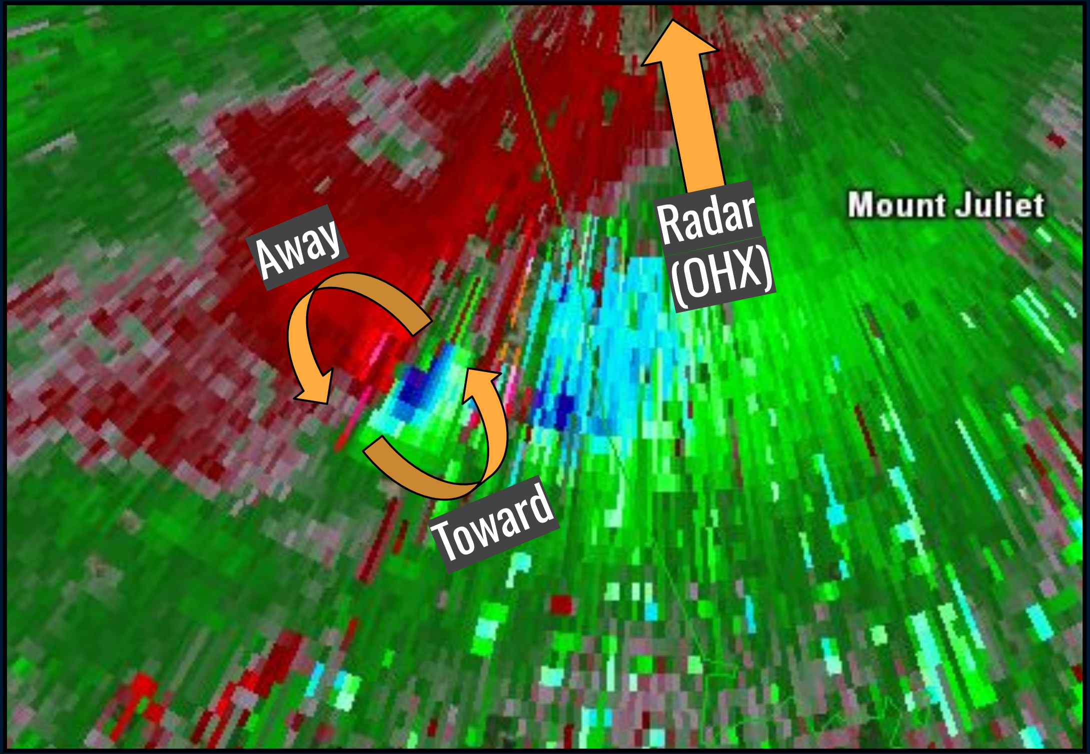
Storm-Relative Velocity (SRM)

- Motion of a storm subtracted out to help better identify rotation
    - Measured in knots (kts), converted to miles per hour (mph)
- Storm motion (speed and direction) can be manually adjusted in some radar software



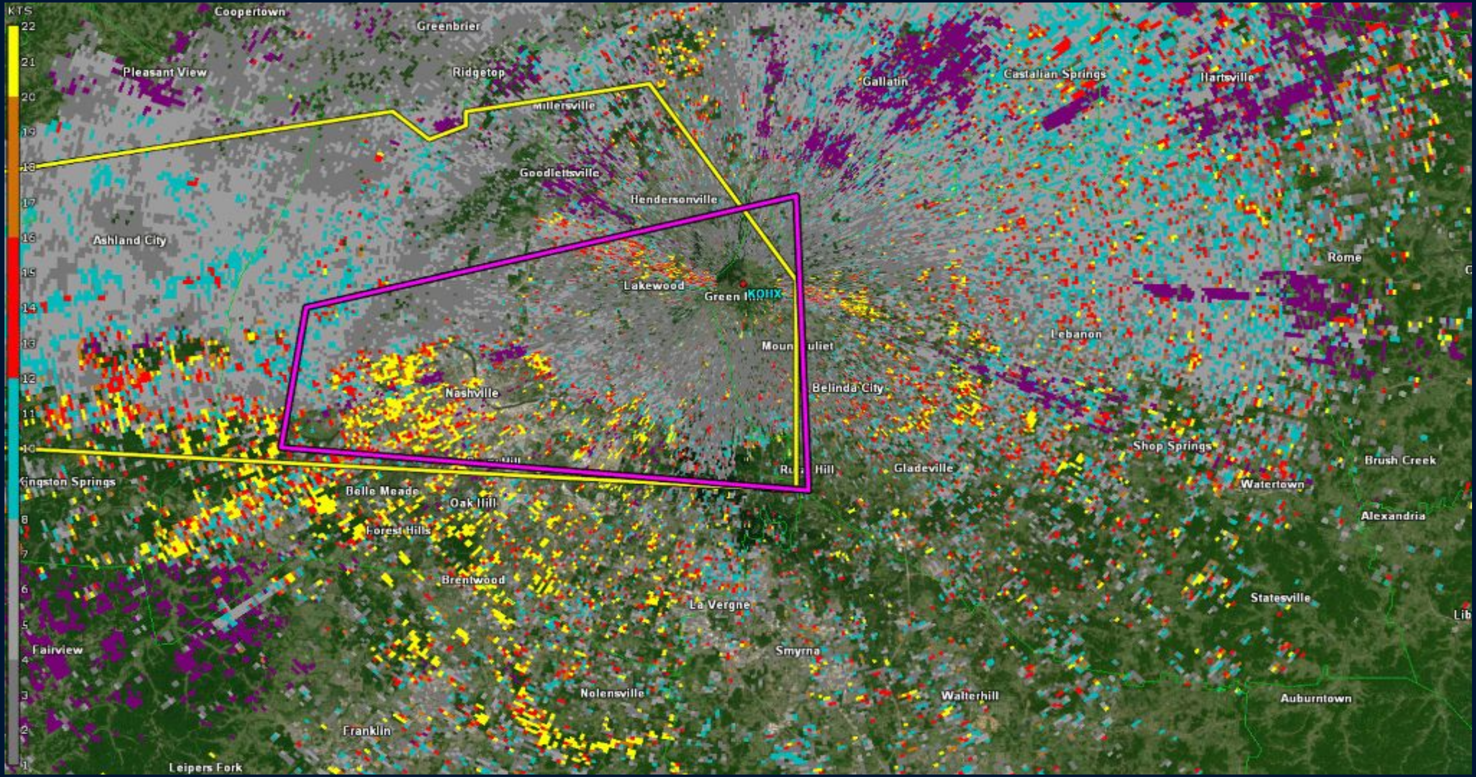
**Need to enough targets for accurate reading*





- Look for gate-to-gate winds (typically shades of red and green on velocity images)
  - Strong winds, adjacent on radar, usually indicate rotation

**Reflectivity must be co-located with velocity*



Spectrum width - March 3, 2020

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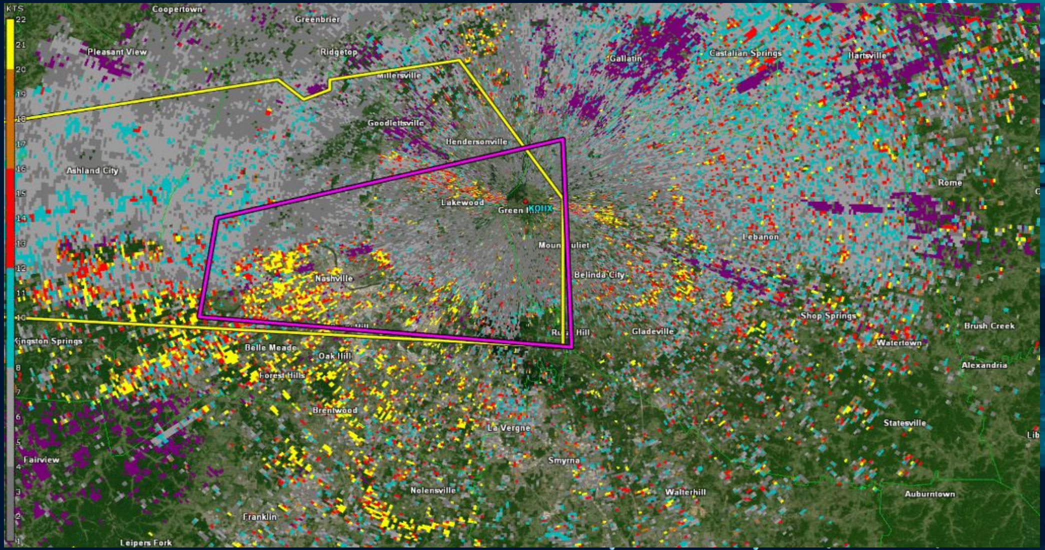
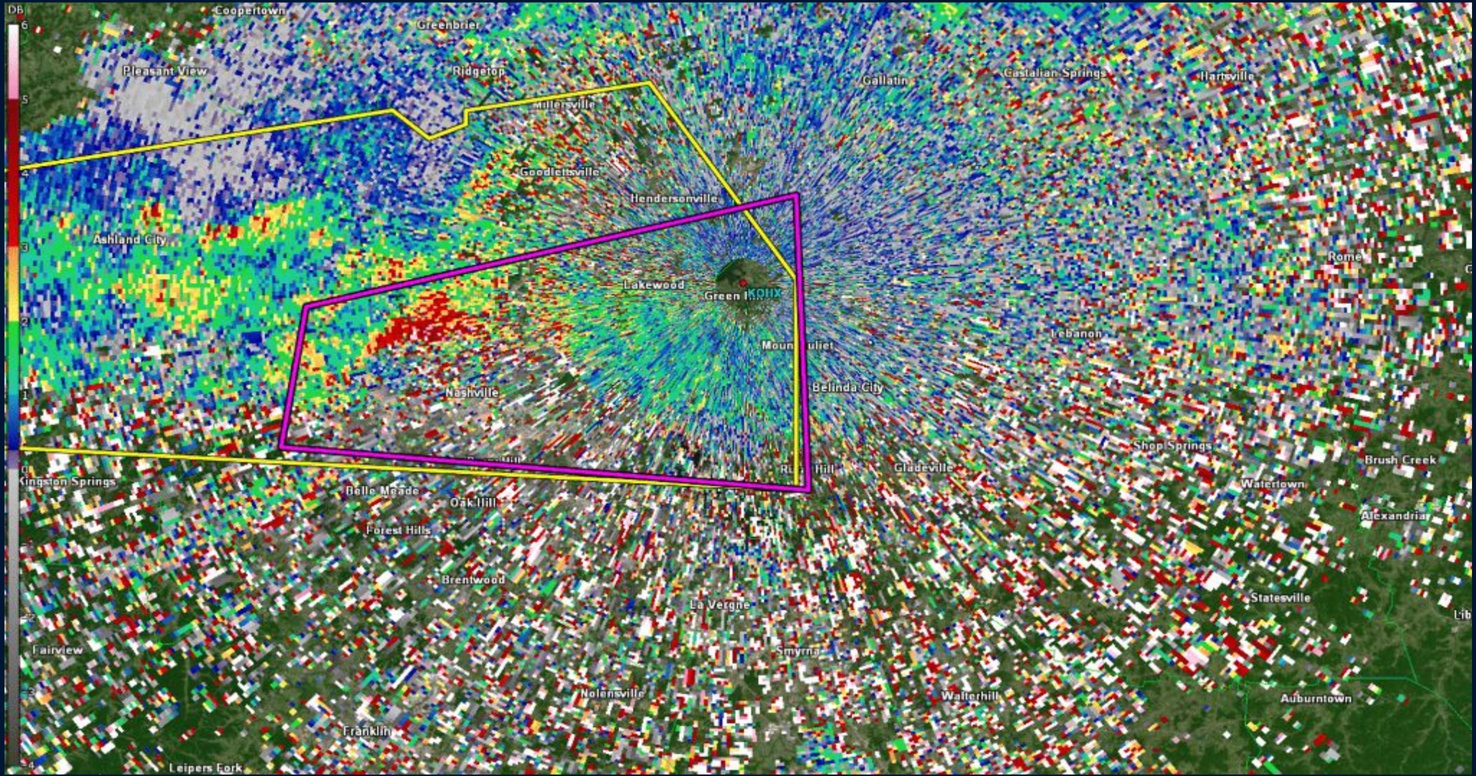
Spectrum Width (SW)

- Detects order/disorder in radar velocities
  - Measured in knots (kts)
- Helps to identify turbulence/wind shear (i.e. gust fronts, center of greatest rotation)
- Higher values = turbulent
- Lower values = less turbulent

**Need to enough targets for accurate reading*





Differential reflectivity - March 3, 2020

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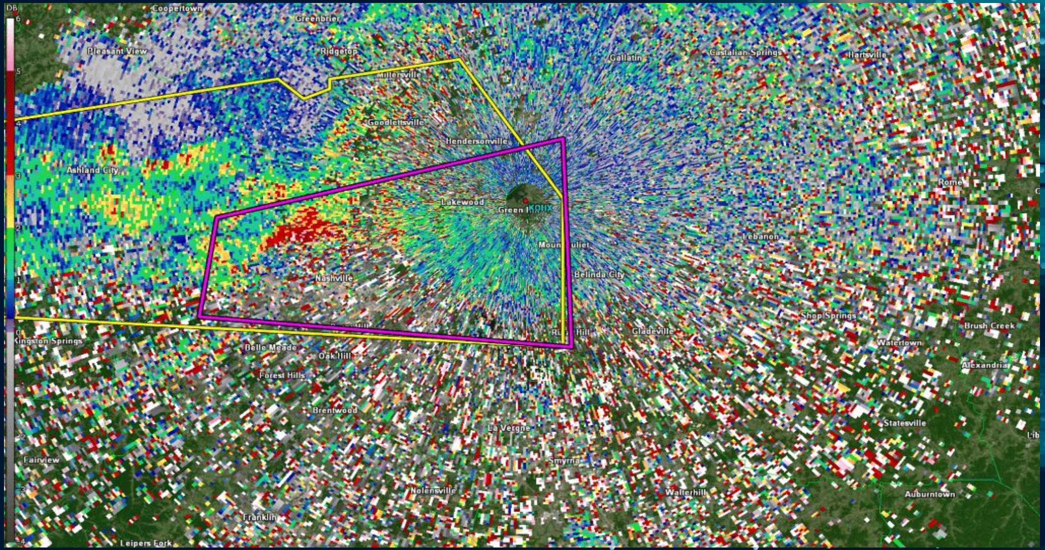
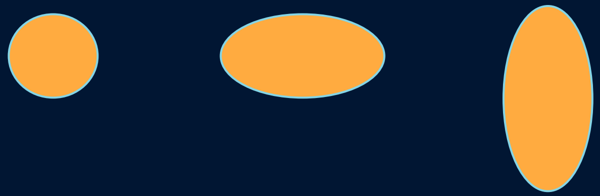
Differential Reflectivity (ZDR)

- Difference in horizontal and vertical reflectivity
    - Measured in dBZ
- Near 0 dBZ: <u>spherical</u> targets
- > 0 dBZ: <u>horizontally-oriented</u> targets
- < 0 dBZ: <u>vertically-oriented</u> targets



**Need to enough targets for accurate reading*

~ 0 dBZ > 0 dBZ < 0 dBZ

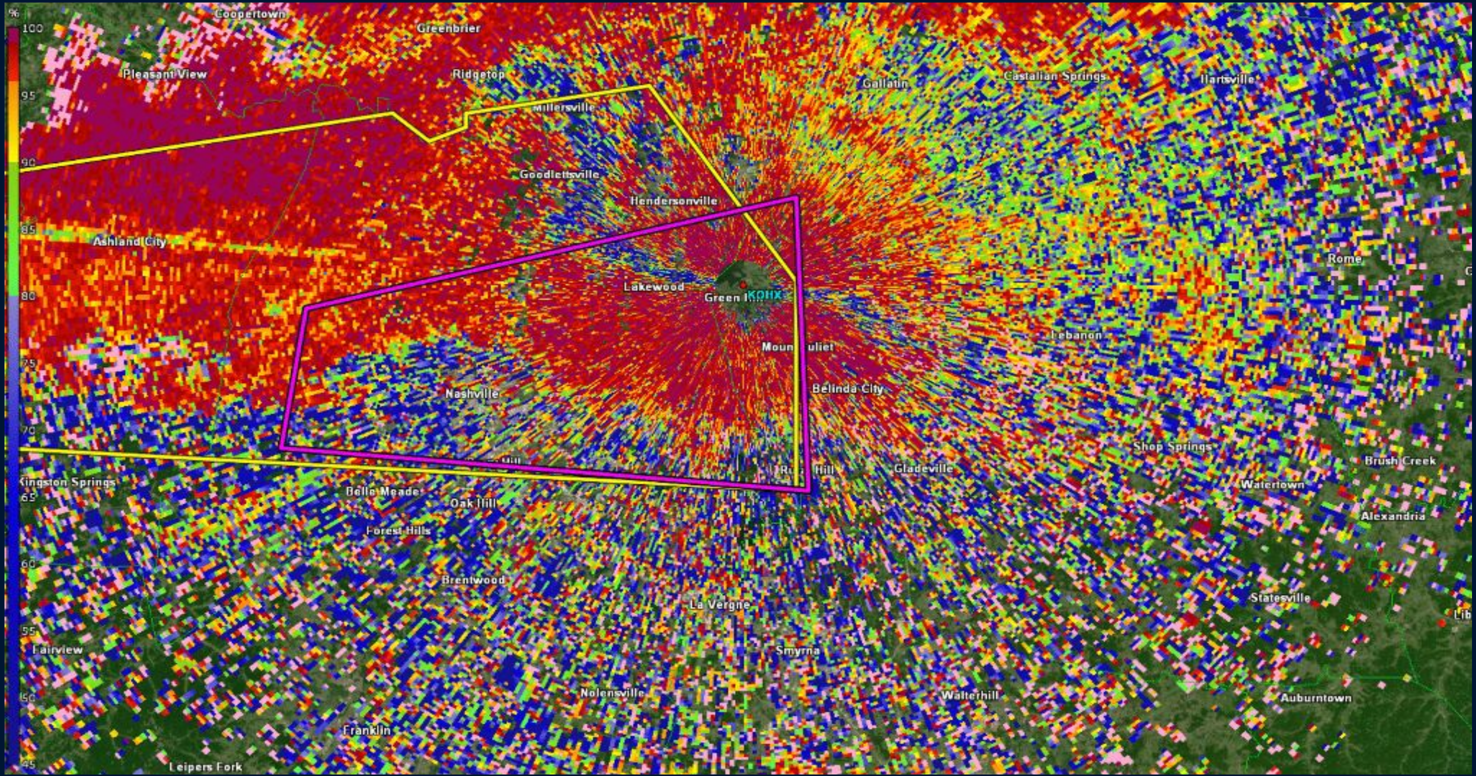


Differential Reflectivity (ZDR)

- Raindrops
  - The larger the drop, the more horizontal/oblate its shape
  - Larger drops = higher ZDR

- Hail
  - Tumbles as it falls, making it appear spherical
  - ZDR values near zero

- Debris
  - Does not have preferred orientation
  - Values near or slightly below zero on ZDR



Correlation coefficient - March 3, 2020

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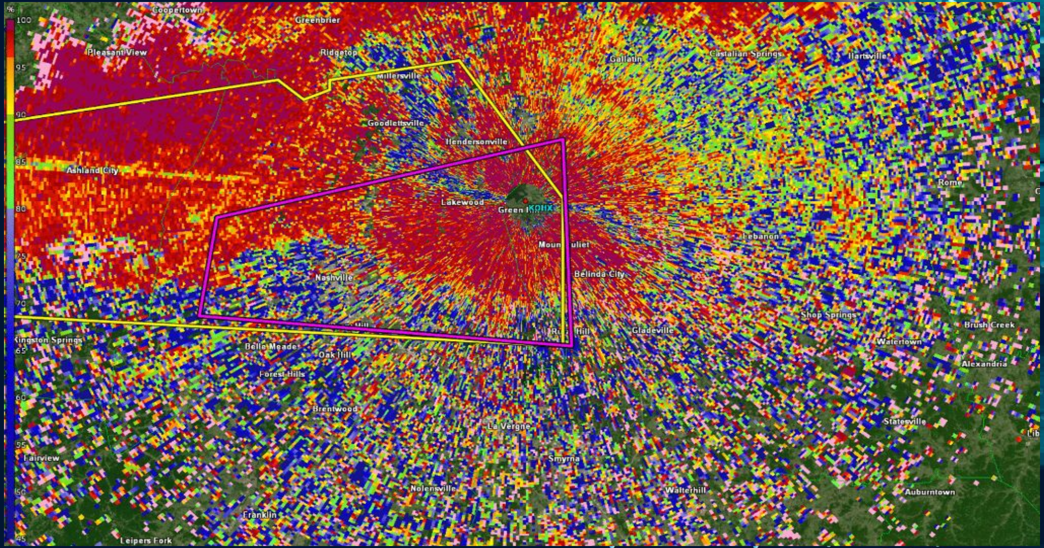
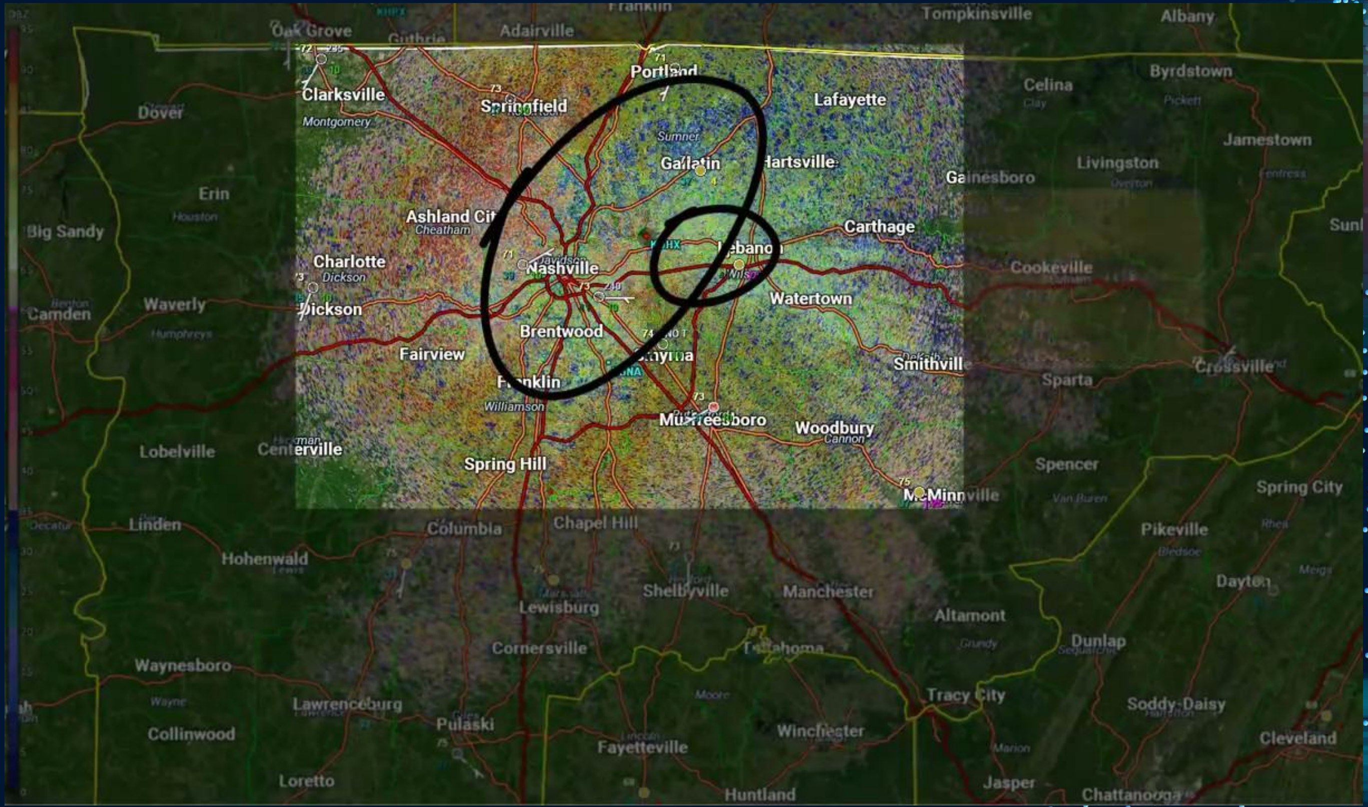
Correlation Coefficient (CC)

- Helps to detect similarities or differences in target shapes
- <u>Higher values</u> = similar targets
    - Rain and some snow
- <u>Lower values</u> = varying targets
    - Wet ice/snow or non-meteorological targets such as debris
    - Can also help detect a melting layer



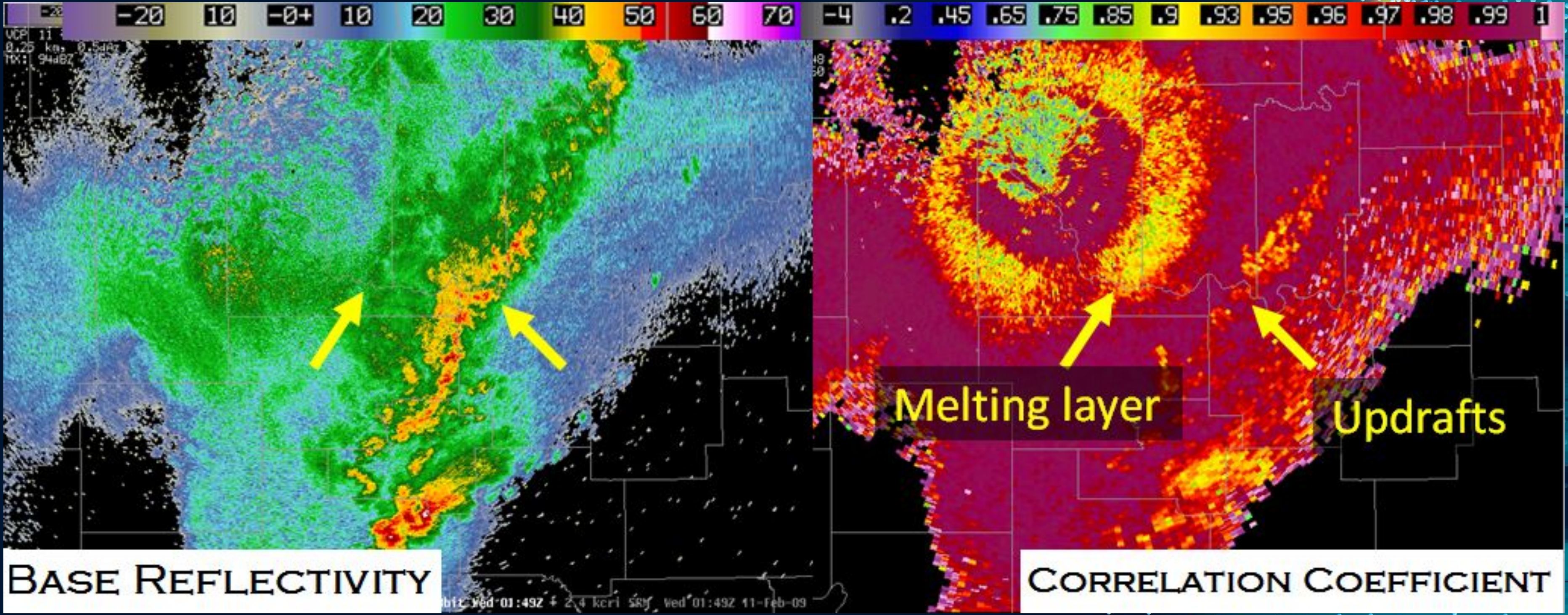
**Need to enough targets for accurate reading*

Correlation Coefficient (CC) - Example



From Monday, November 8, 2021

Correlation Coefficient (CC) - Example



https://images.app.goo.gl/xXo7n3VG87oZzz5P6

Applying radar techniques

How warnings are issued…

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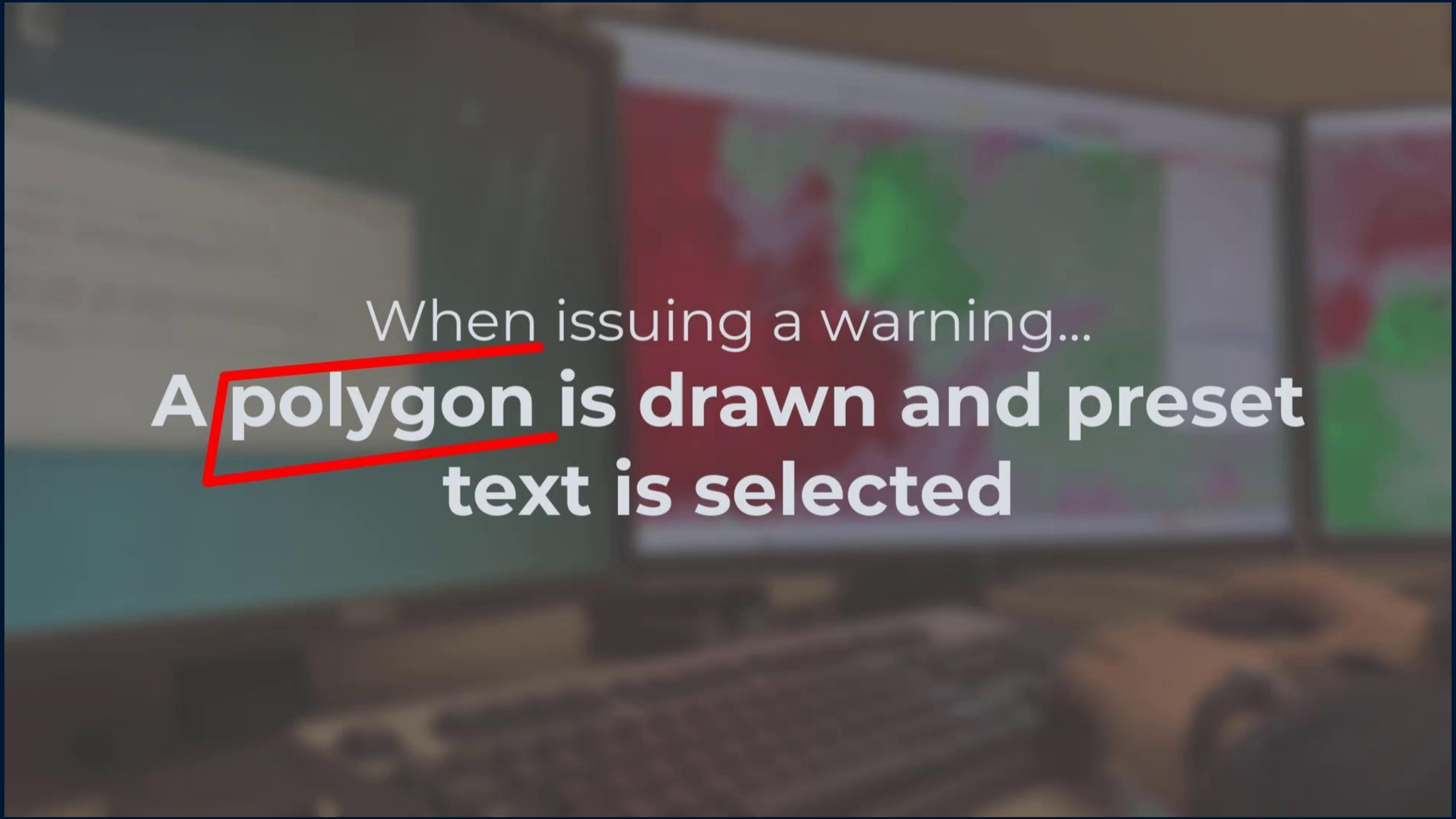

Applying radar analysis to real-life scenarios

Real-life scenarios

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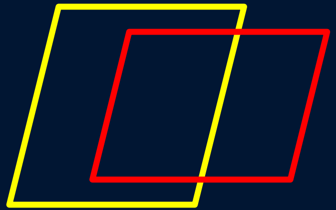
Rules

- Select from these options:
  - Warning needed (severe thunderstorm or tornado warning)
  - No warning (includes early cancellation)

Warning needed



No Warning

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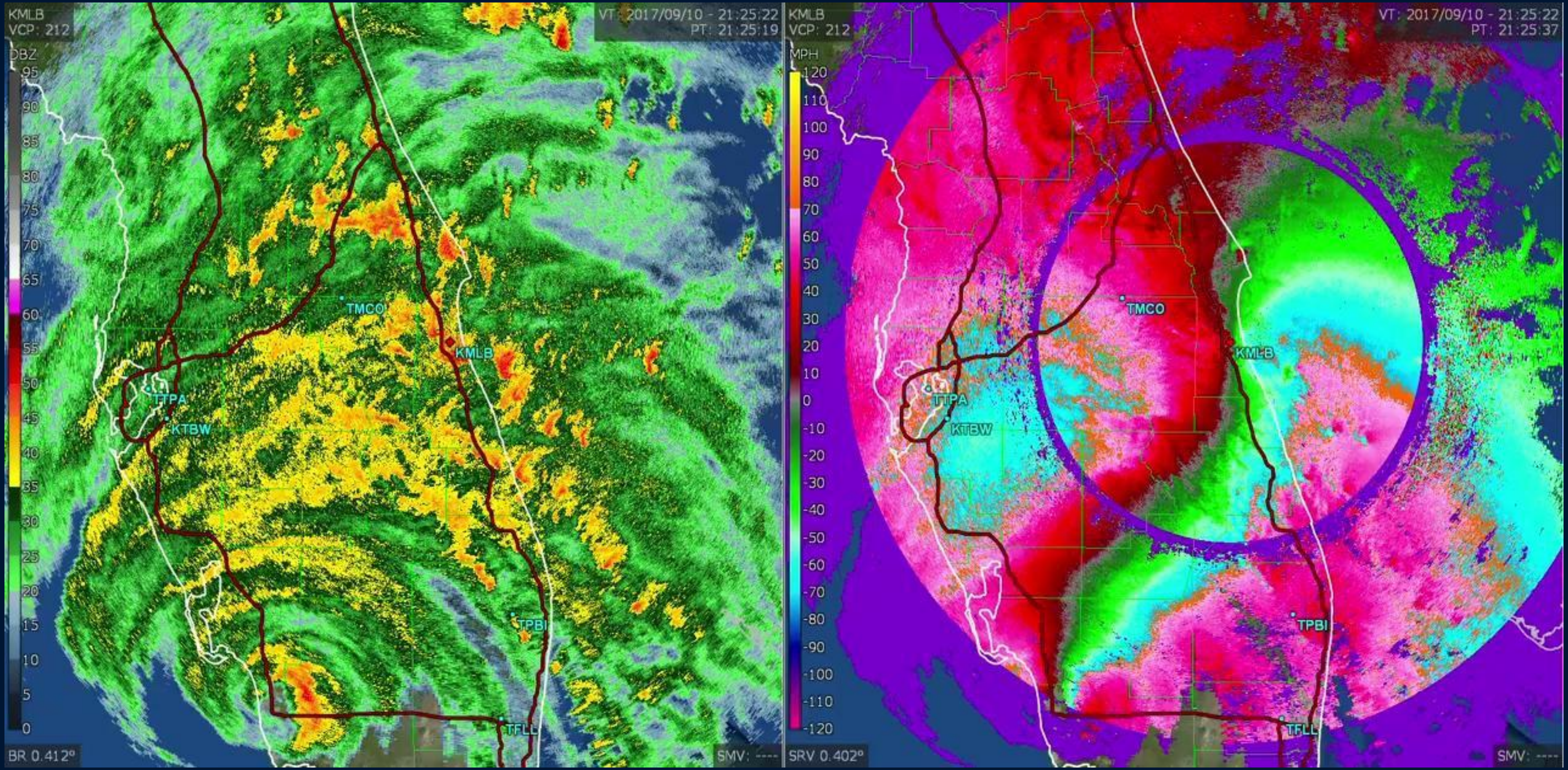
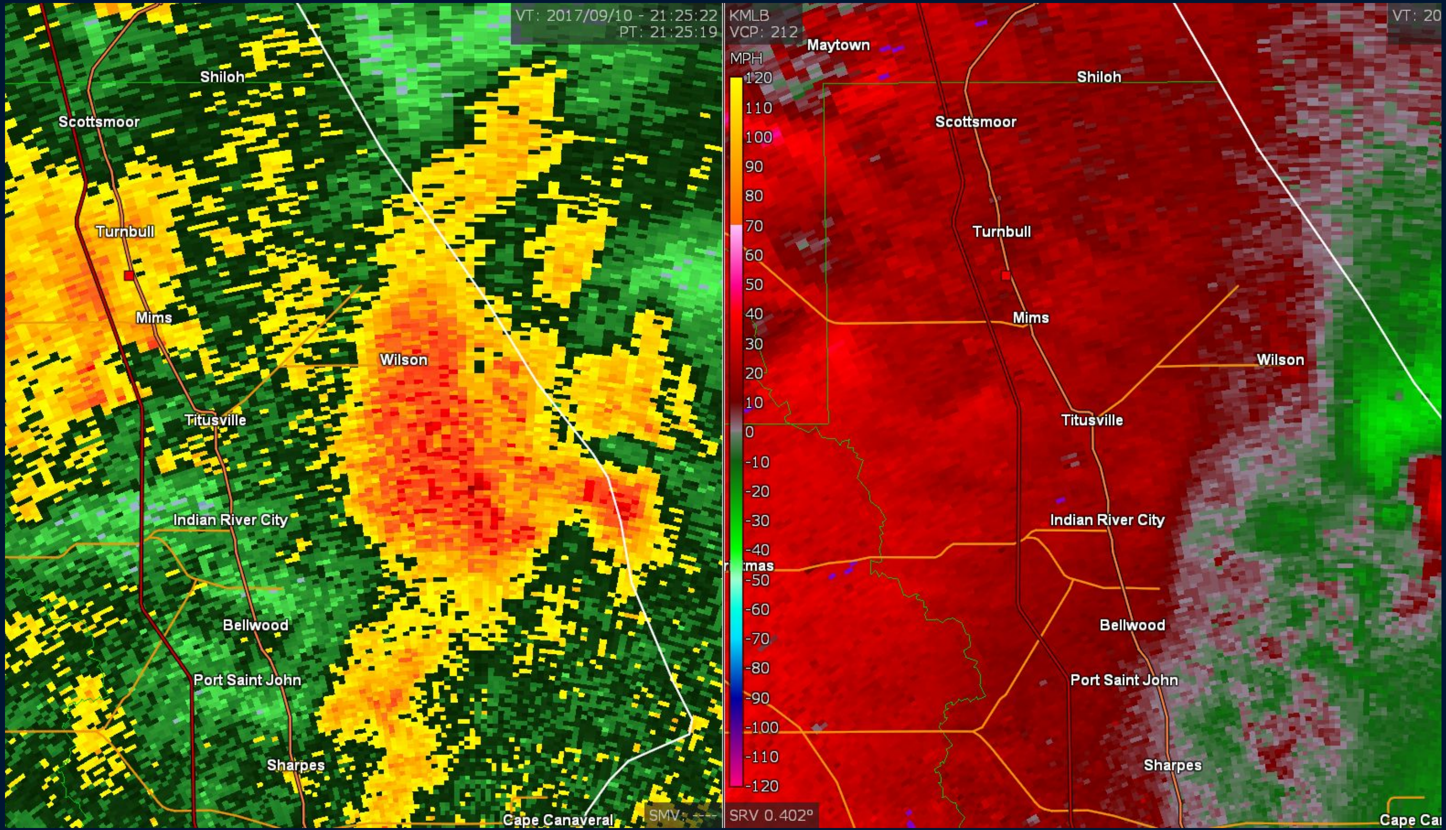


Hurricane Irma (FL) - 09/10/2017 5:25 PM to 6:40 PM EDT

NWS Nashville, TN



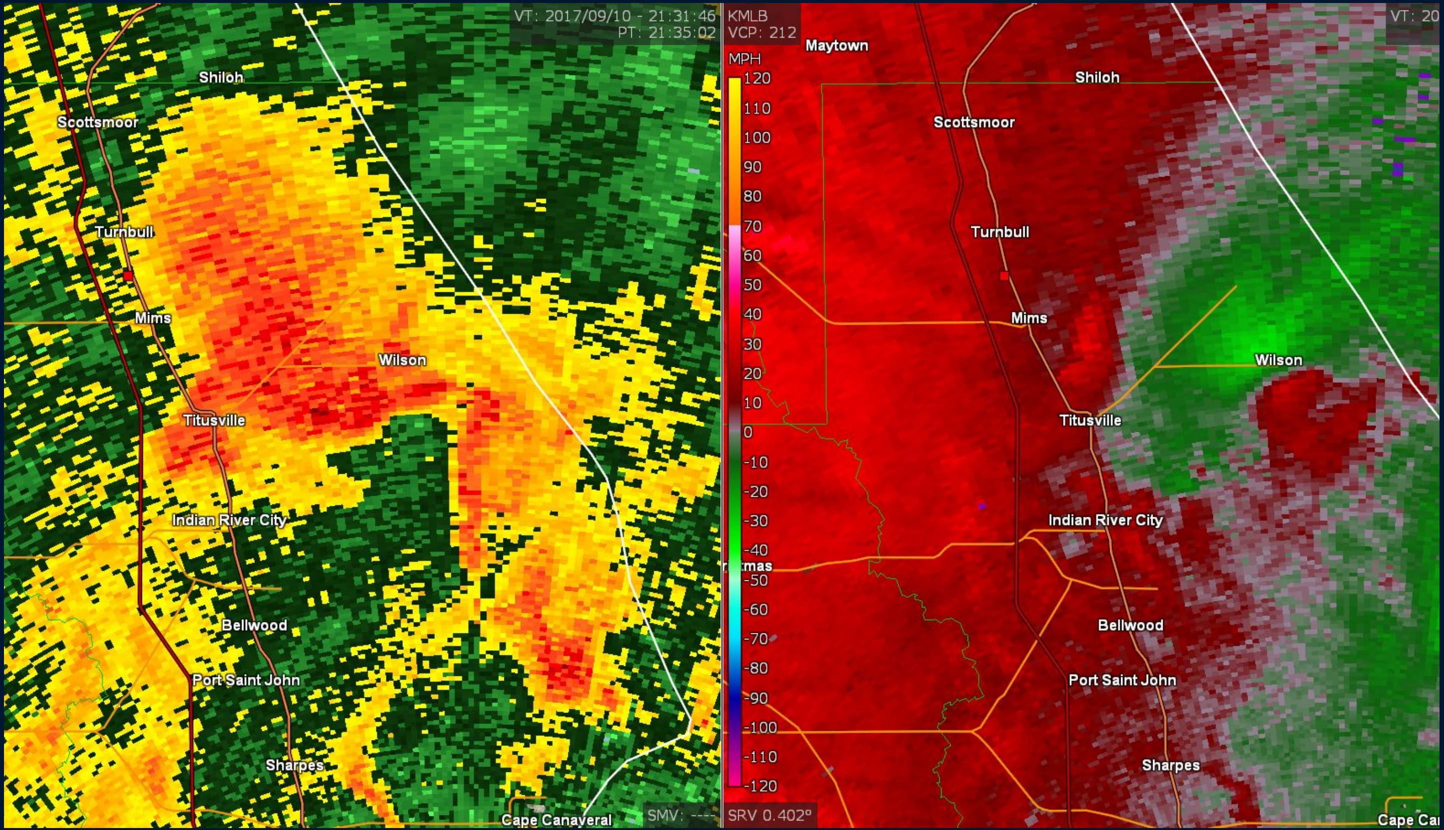
CHOOSE:

Warning needed

No warning

5:25 PM - Warning or no warning?

NWS Nashville, TN



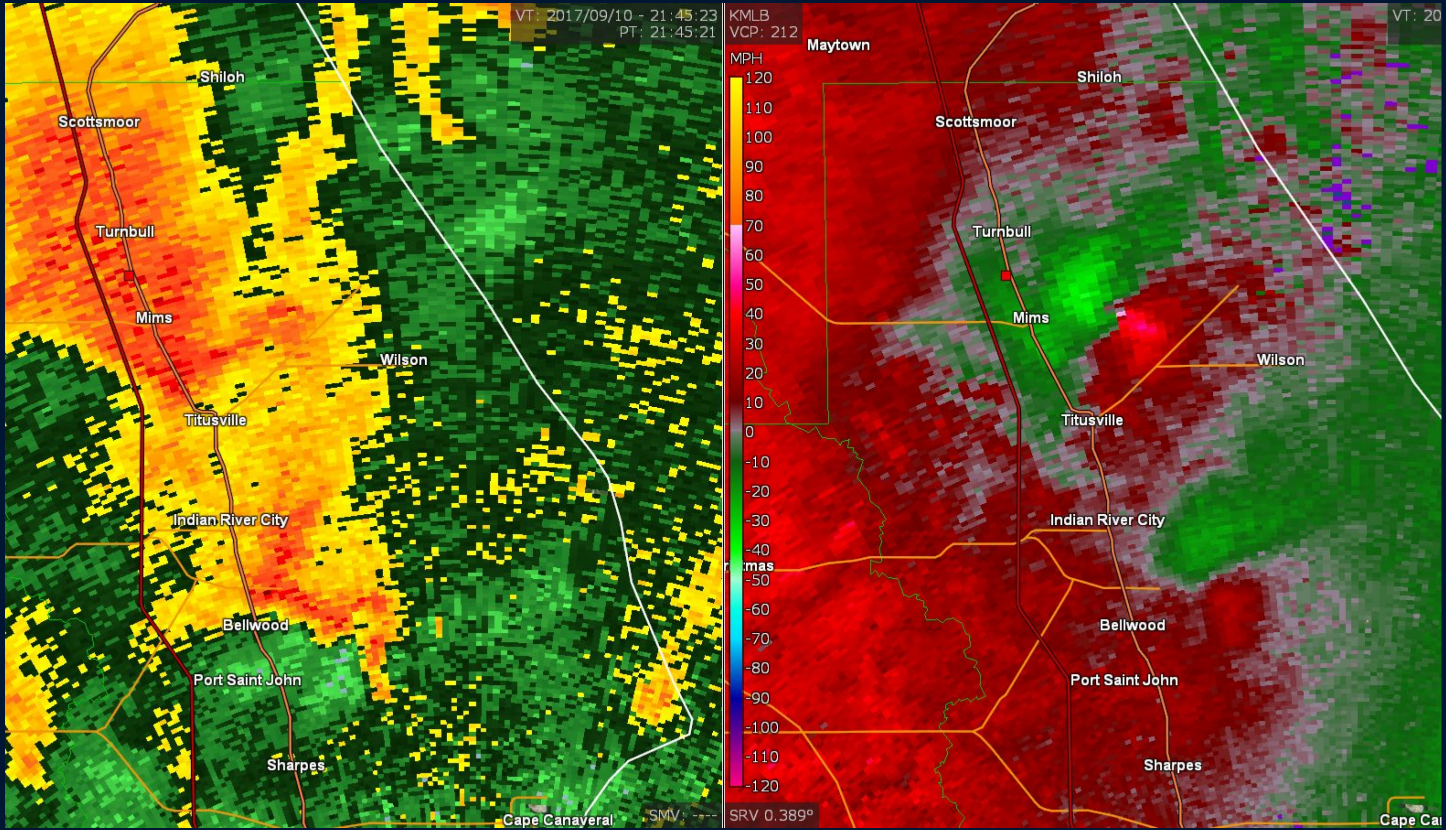
CHOOSE:

Warning needed

No warning

5:35 PM - Warning or no warning?

NWS Nashville, TN



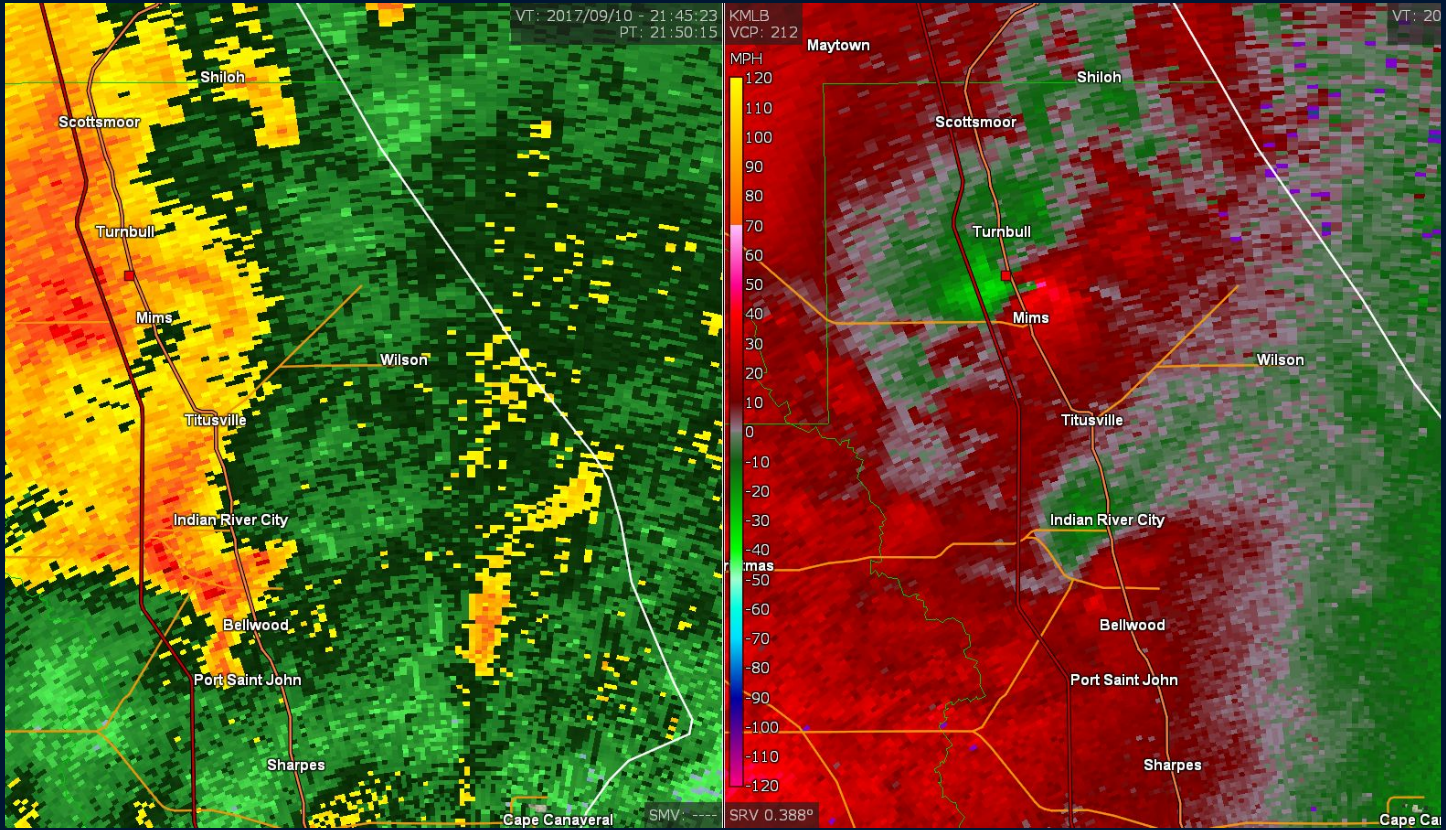
CHOOSE:

Warning needed

No warning

5:45 PM - Warning or no warning?

NWS Nashville, TN



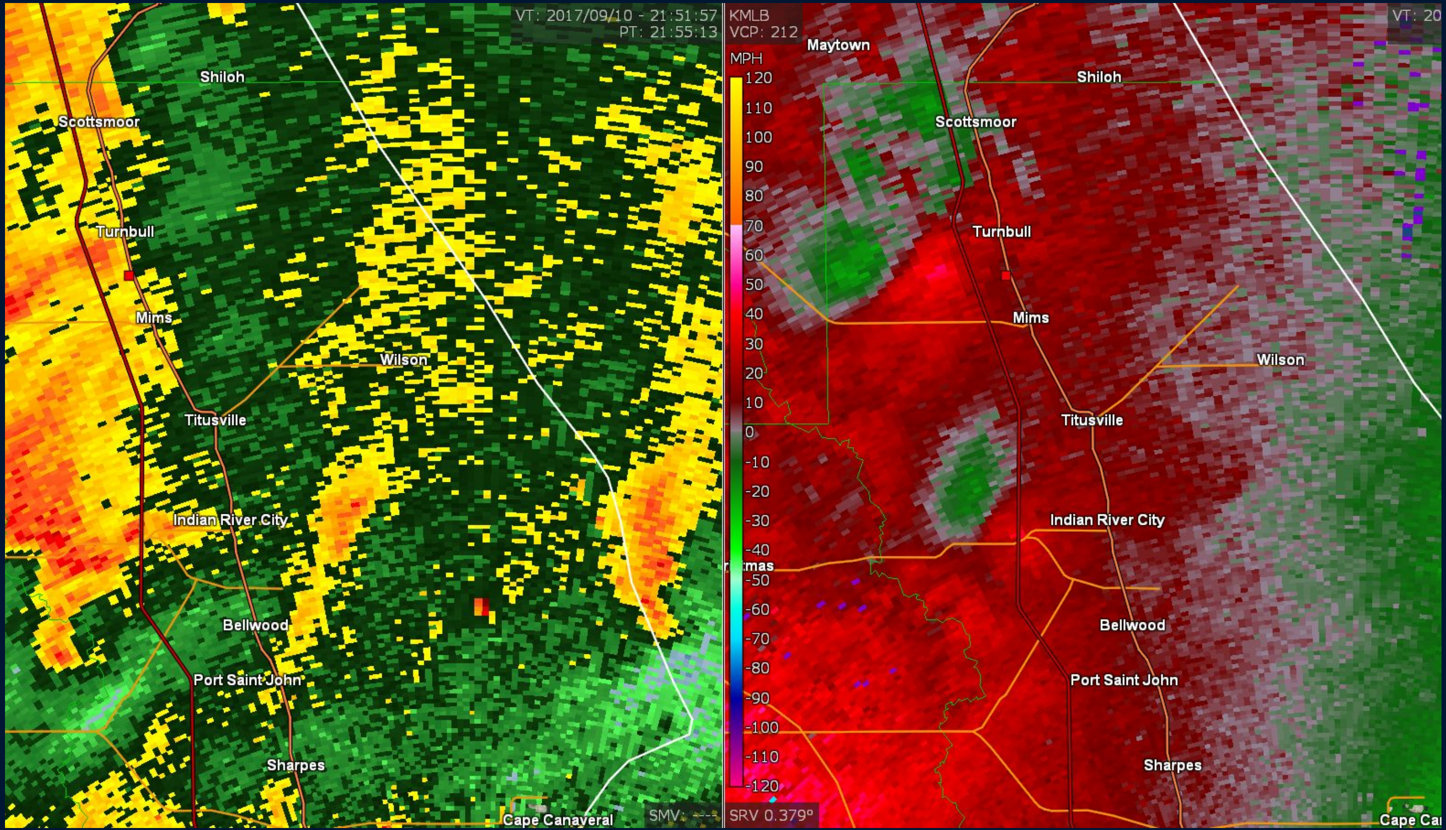
CHOOSE:

Warning needed

No warning

5:50 PM - Warning or no warning?

NWS Nashville, TN



CHOOSE:

Warning needed

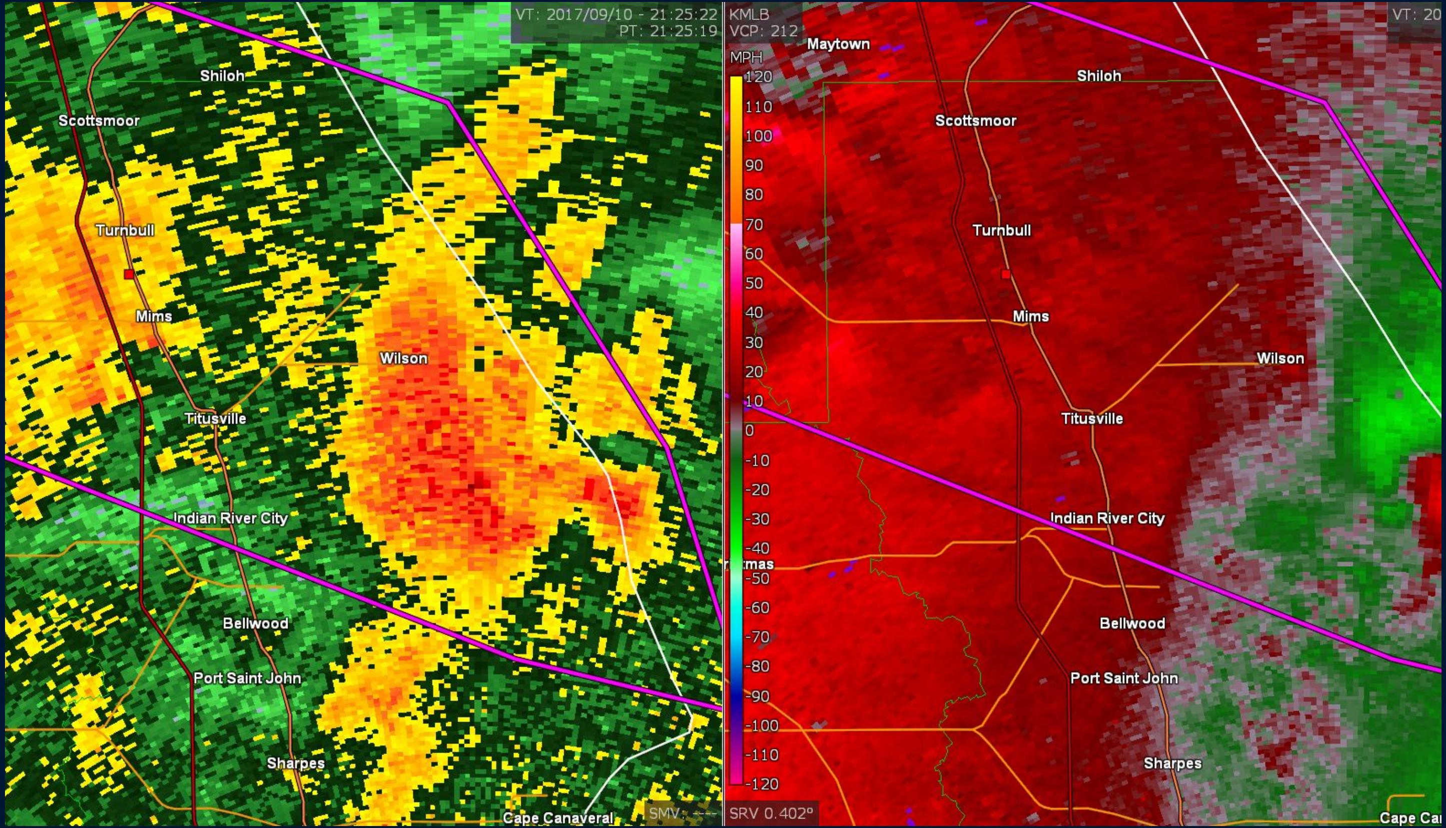
No warning

5:55 PM - Warning or no warning?

NWS Nashville, TN

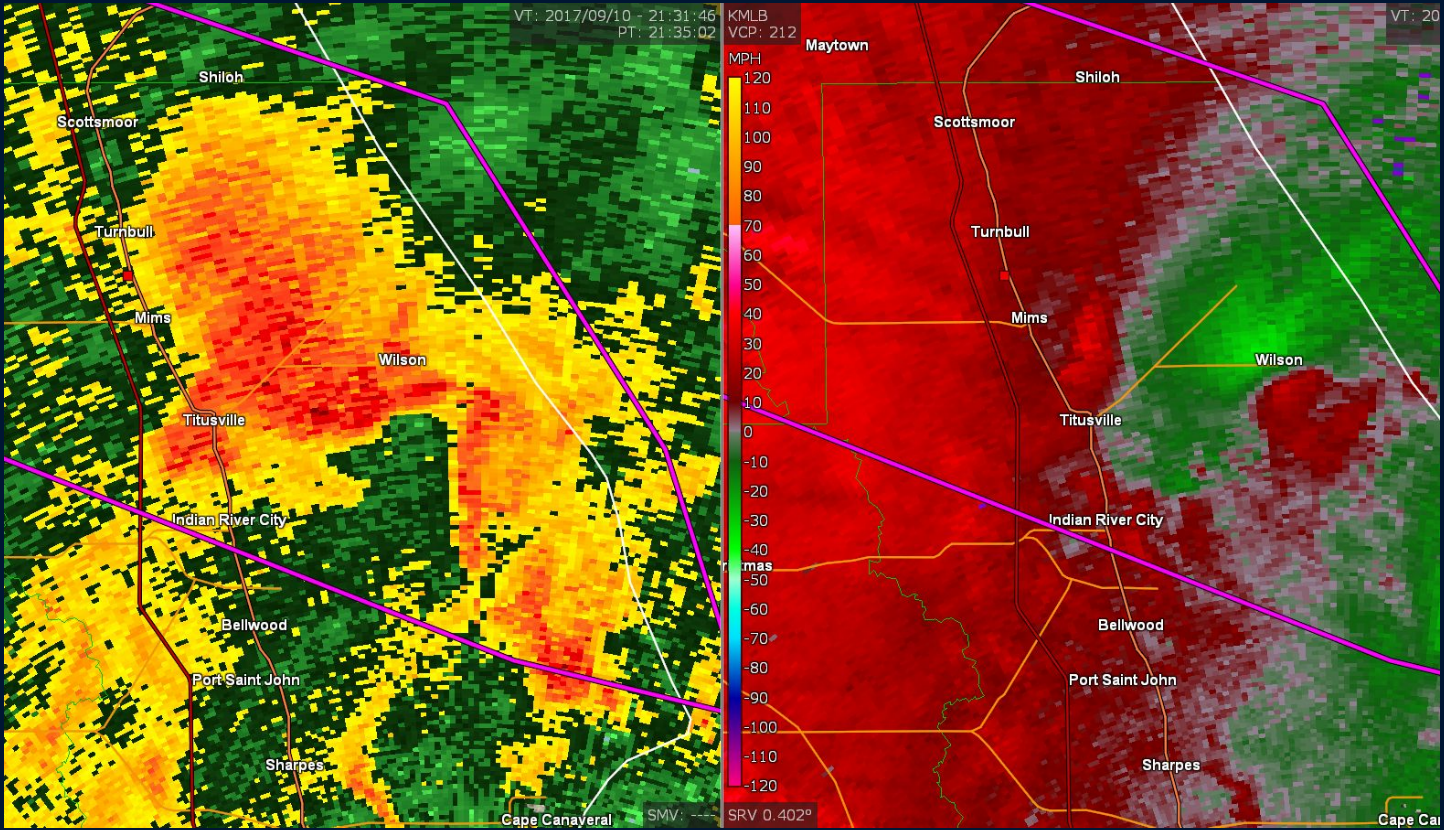
Results

Check your work...



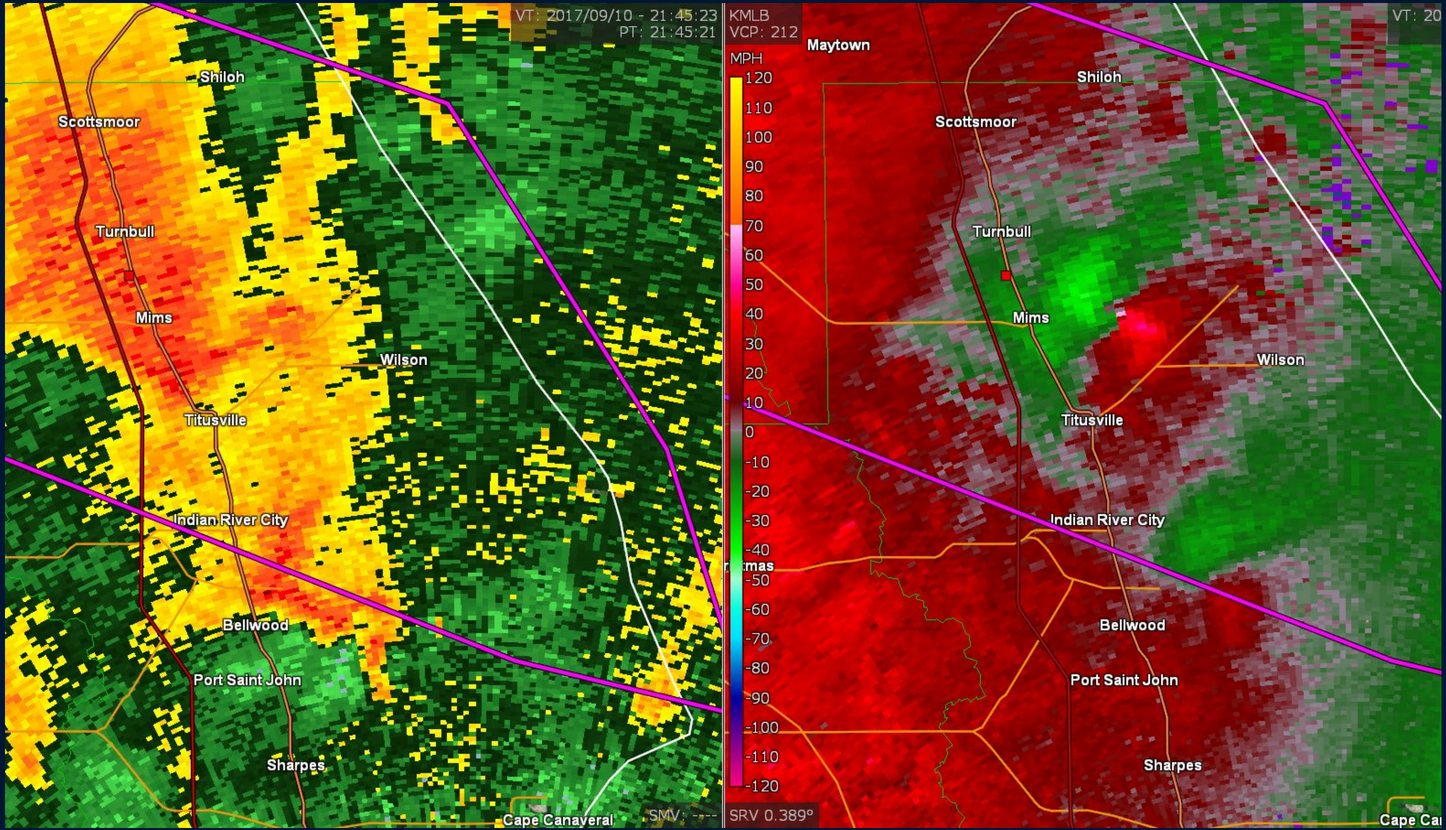
5:25 PM - Actual warnings

NWS Nashville, TN



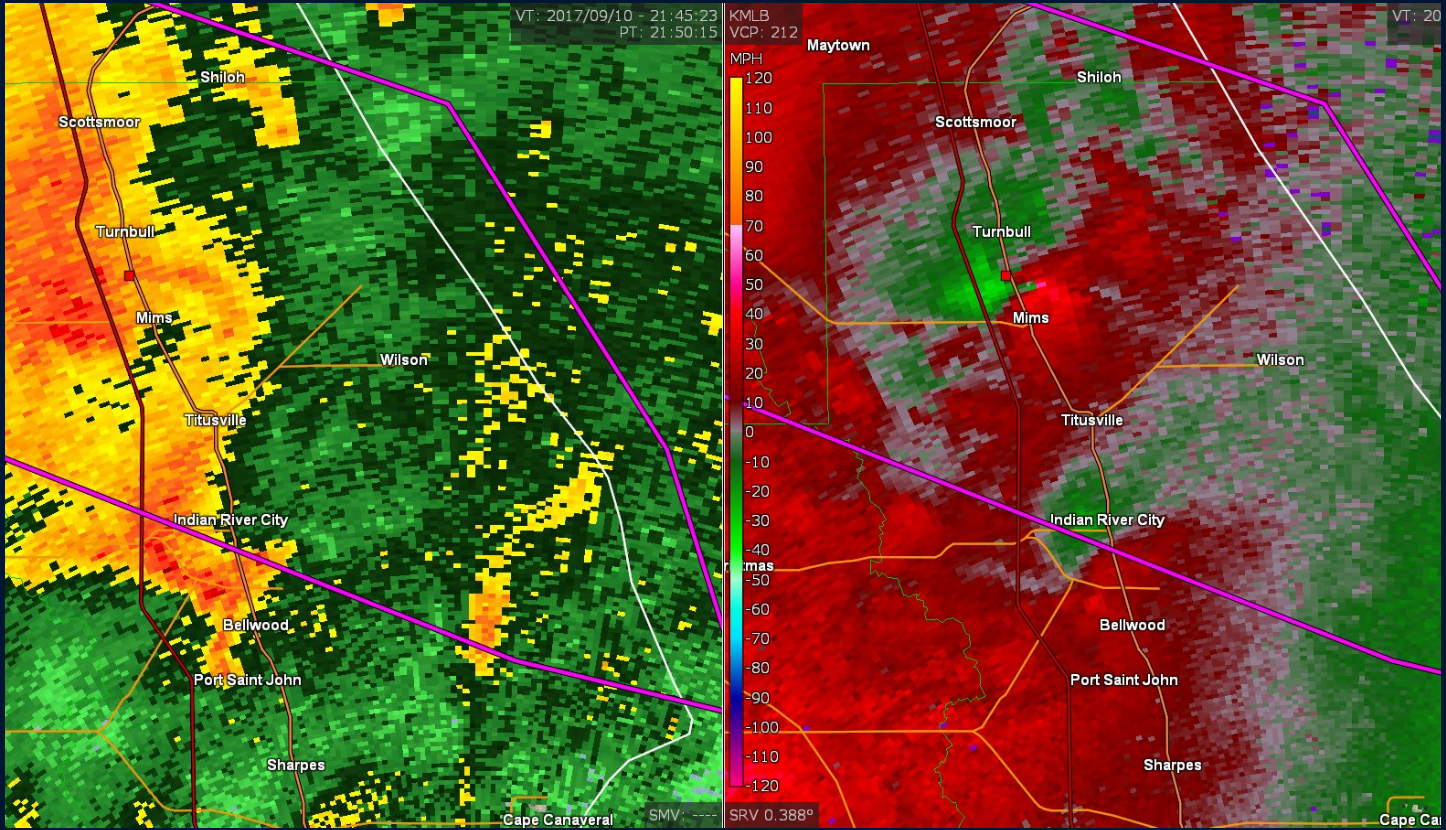
5:35 PM - Actual warnings

NWS Nashville, TN

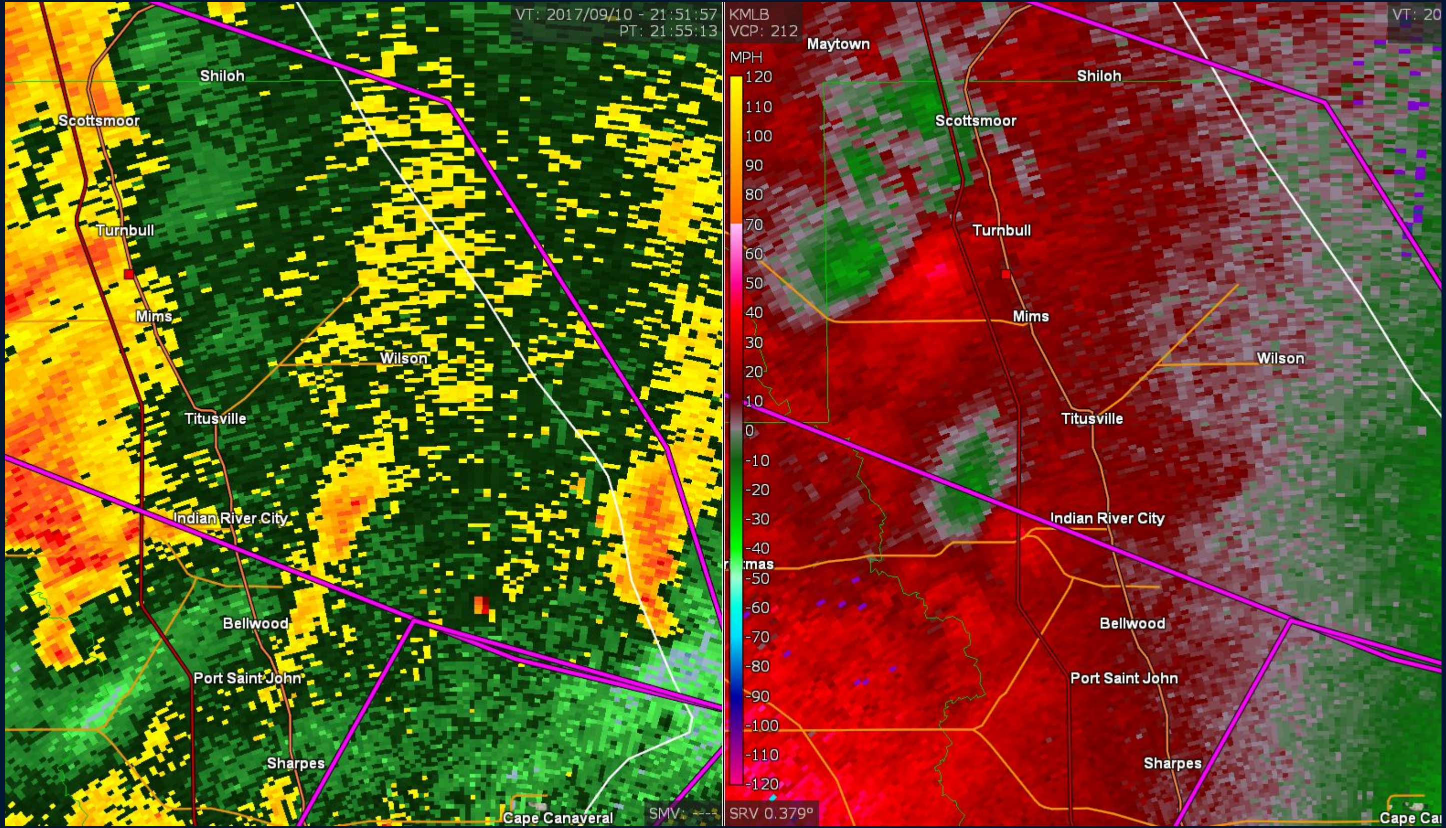


5:45 PM - Actual warnings

NWS Nashville, TN



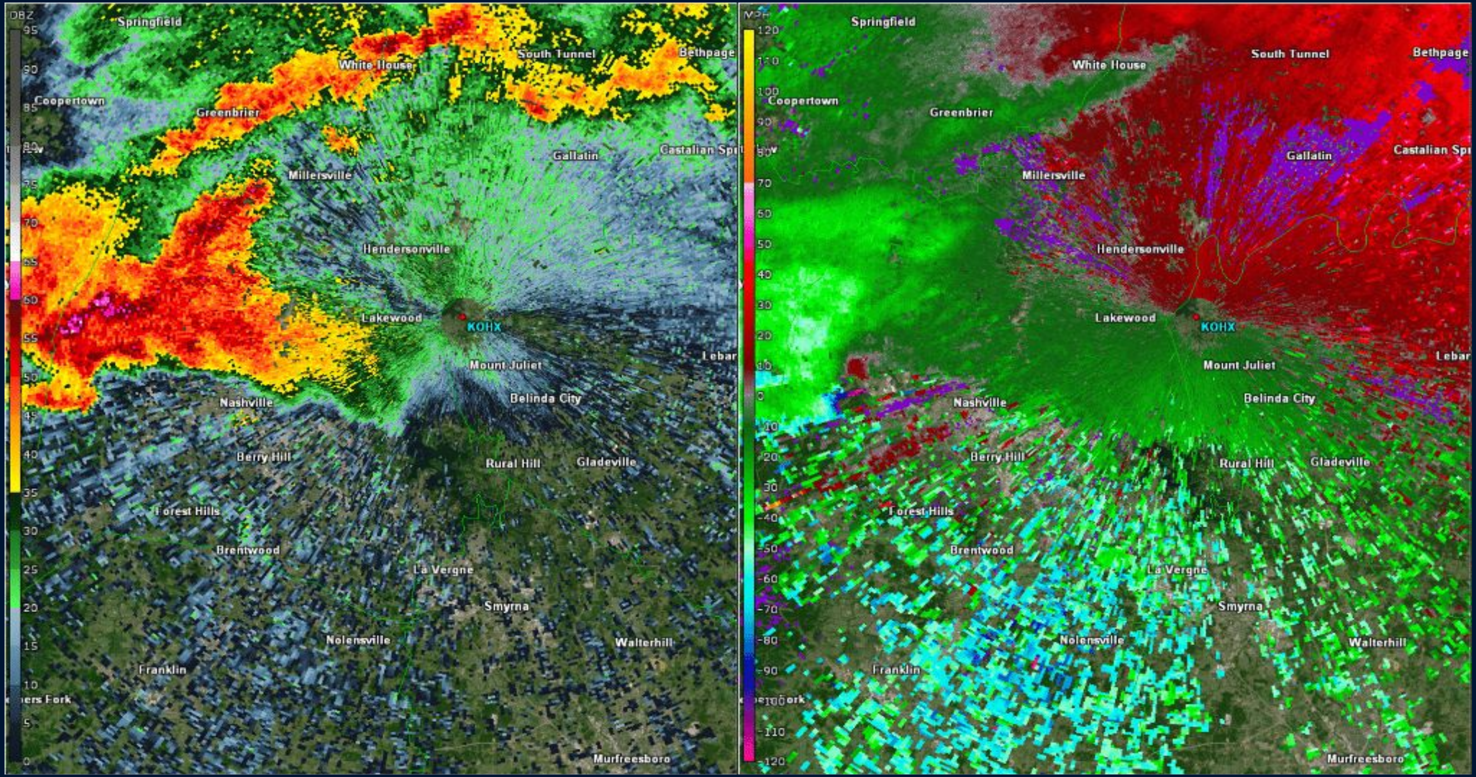
5:50 PM - Actual warnings



5:55 PM - Actual warnings

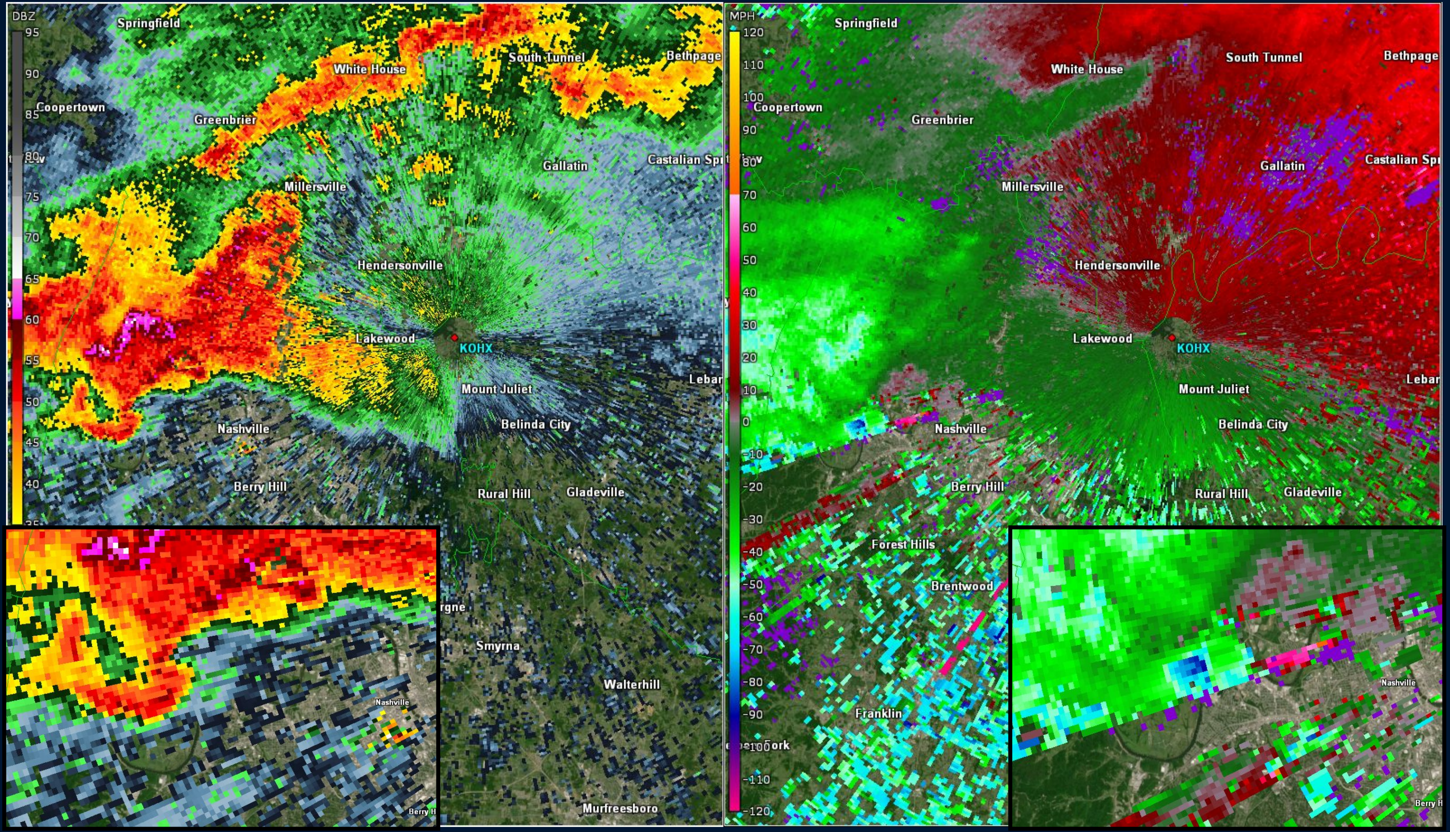
NWS Nashville, TN

Next Scenario



Davidson, Sumner, Wilson Counties, TN - 12:32 AM to 1:12 AM CST

NWS Nashville, TN



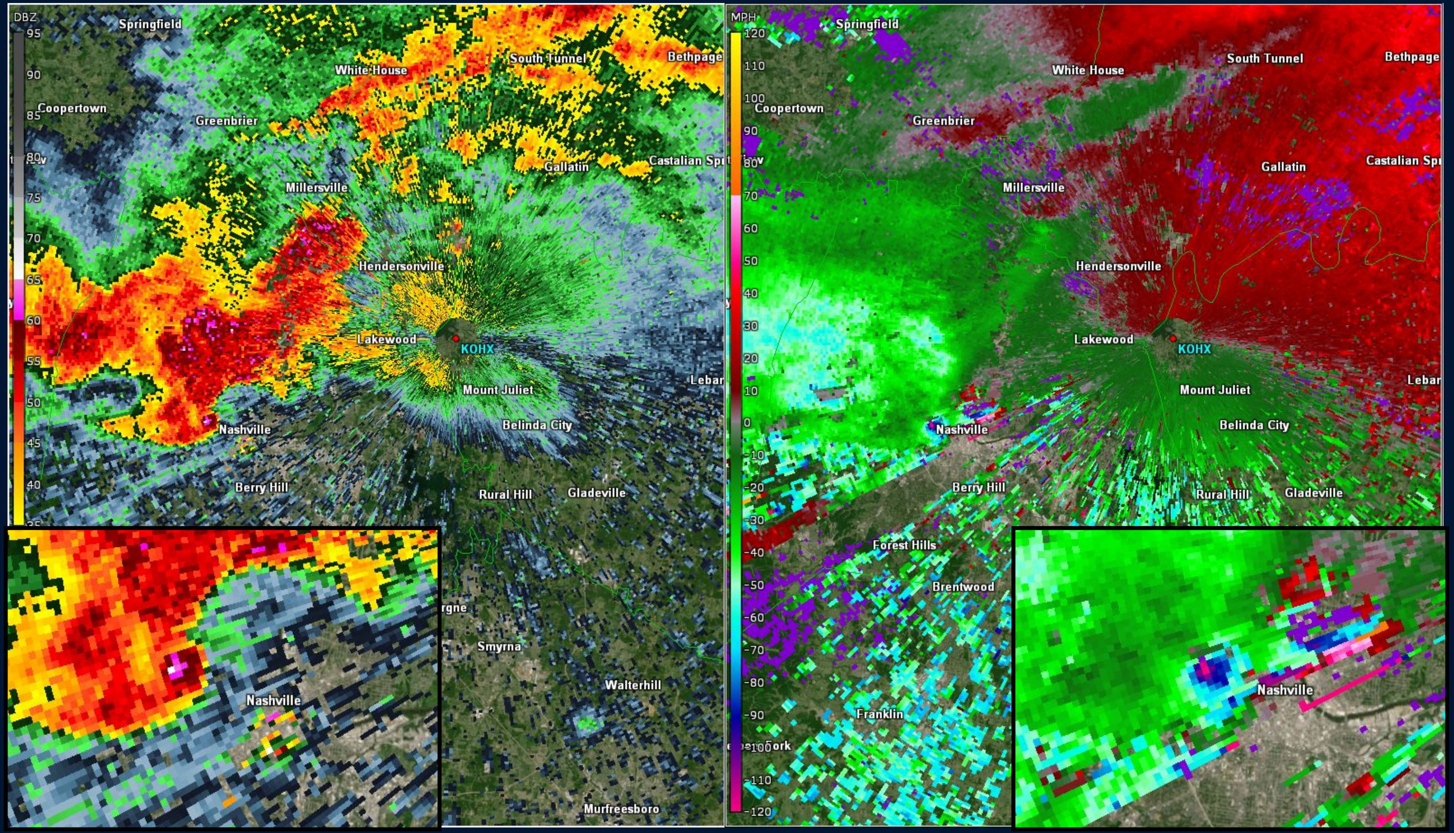
CHOOSE:

Warning needed

No warning

12:35 AM - Warning or no warning?

NWS Nashville, TN



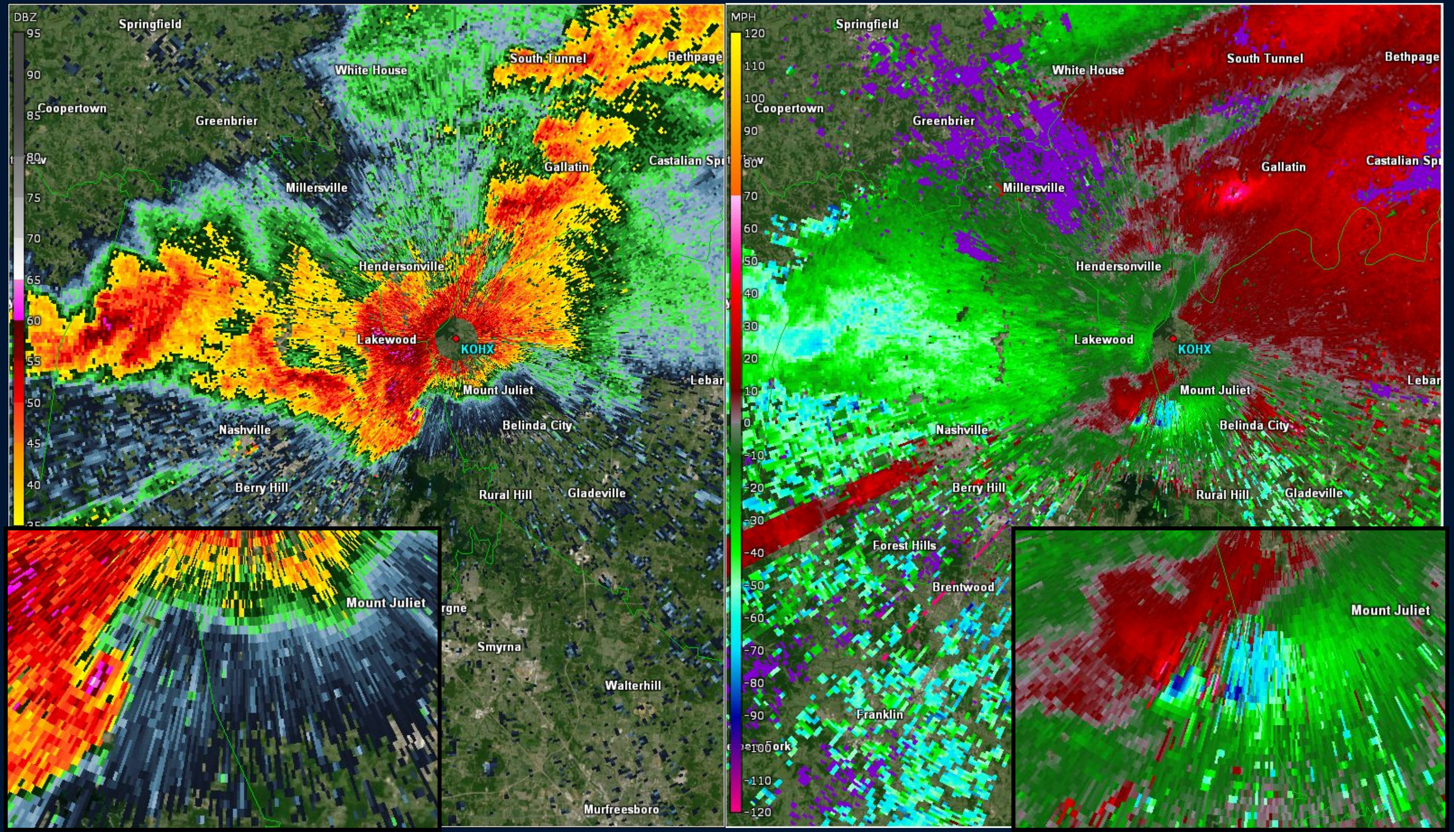
CHOOSE

Warning needed

No warning

12:40 AM - Warning or no warning?

NWS Nashville, TN



CHOOSE:

Warning needed

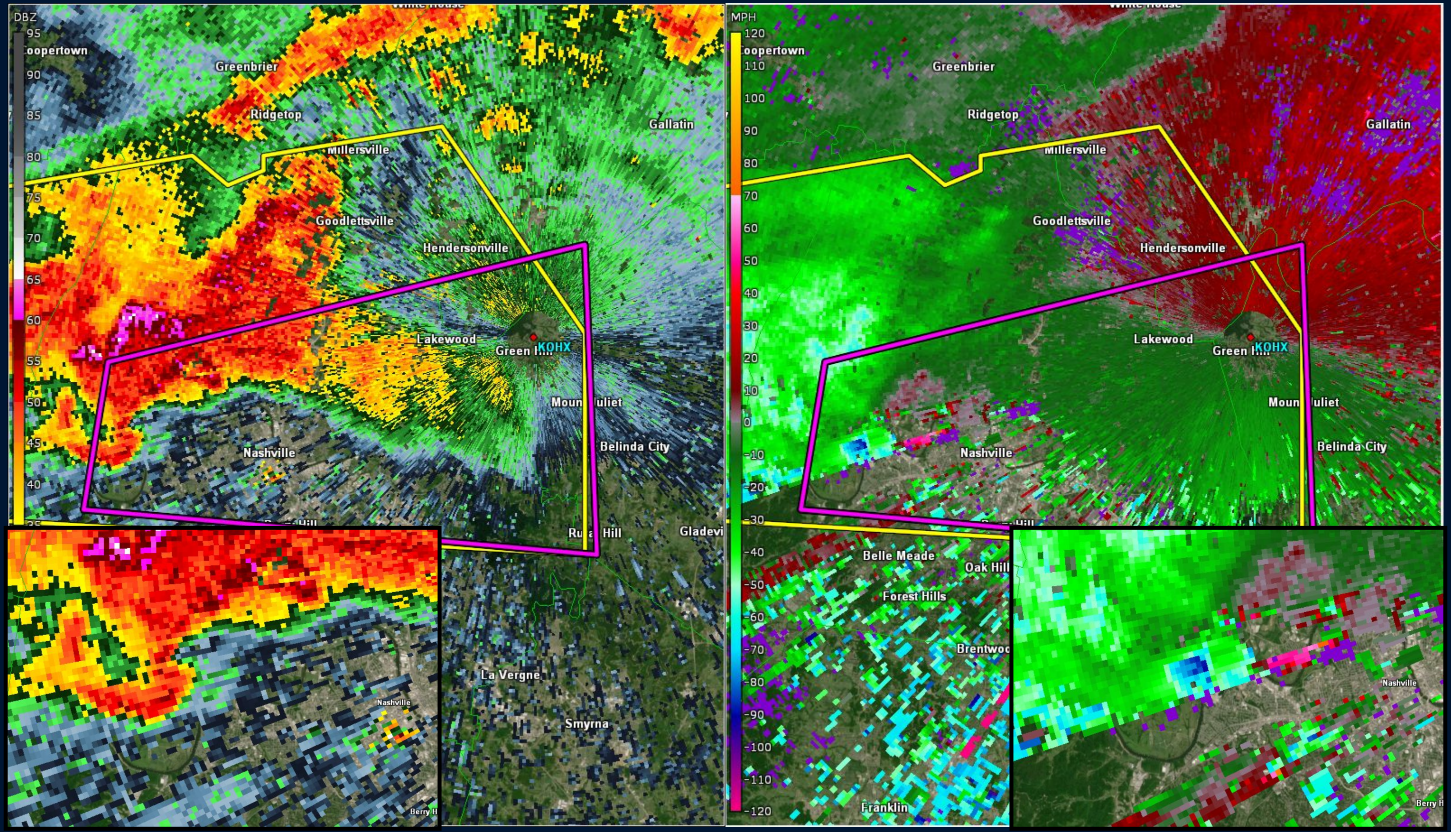
No warning

12:52 AM - Warning or no warning?

NWS Nashville, TN

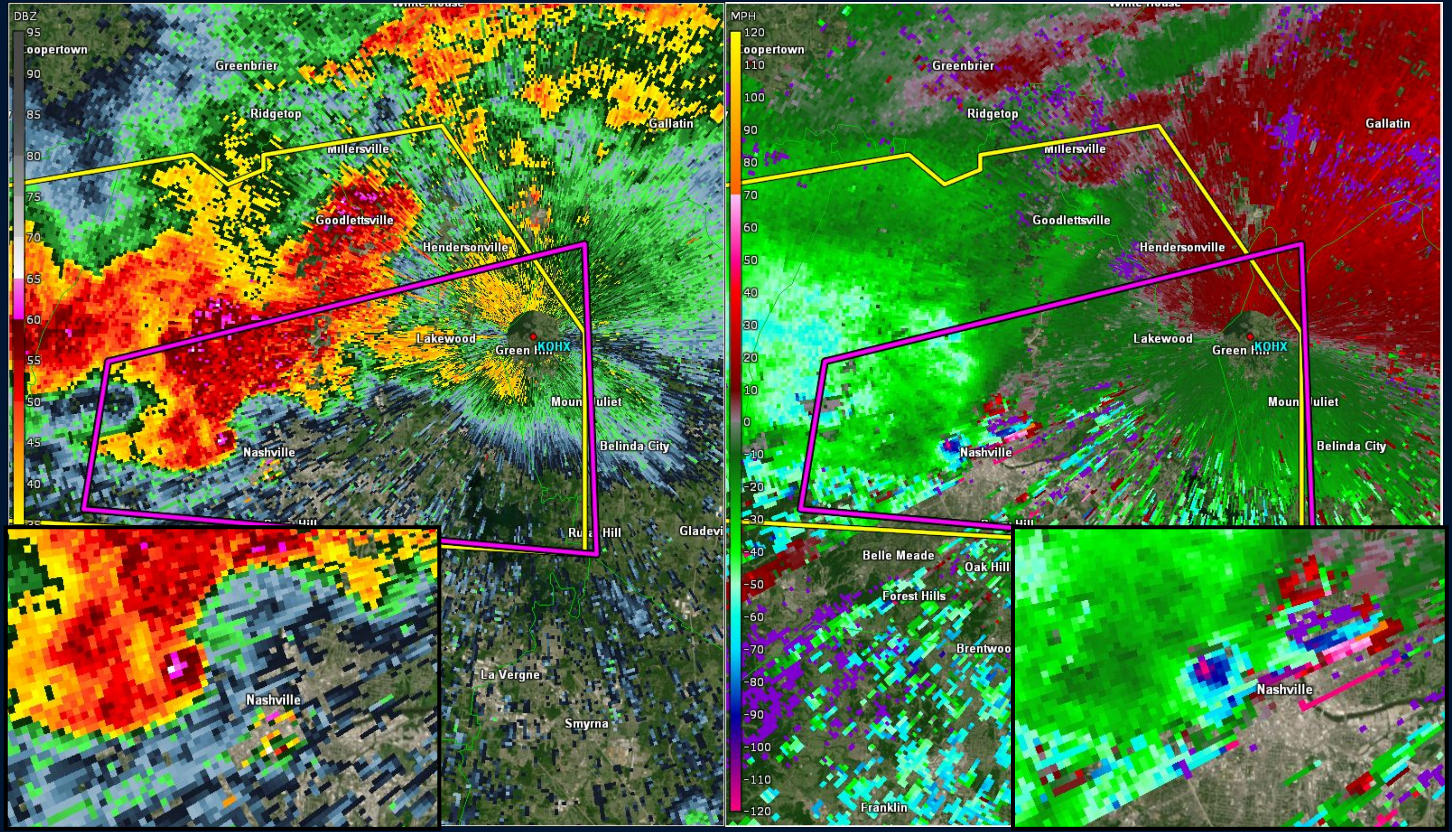
Results

Check your work...



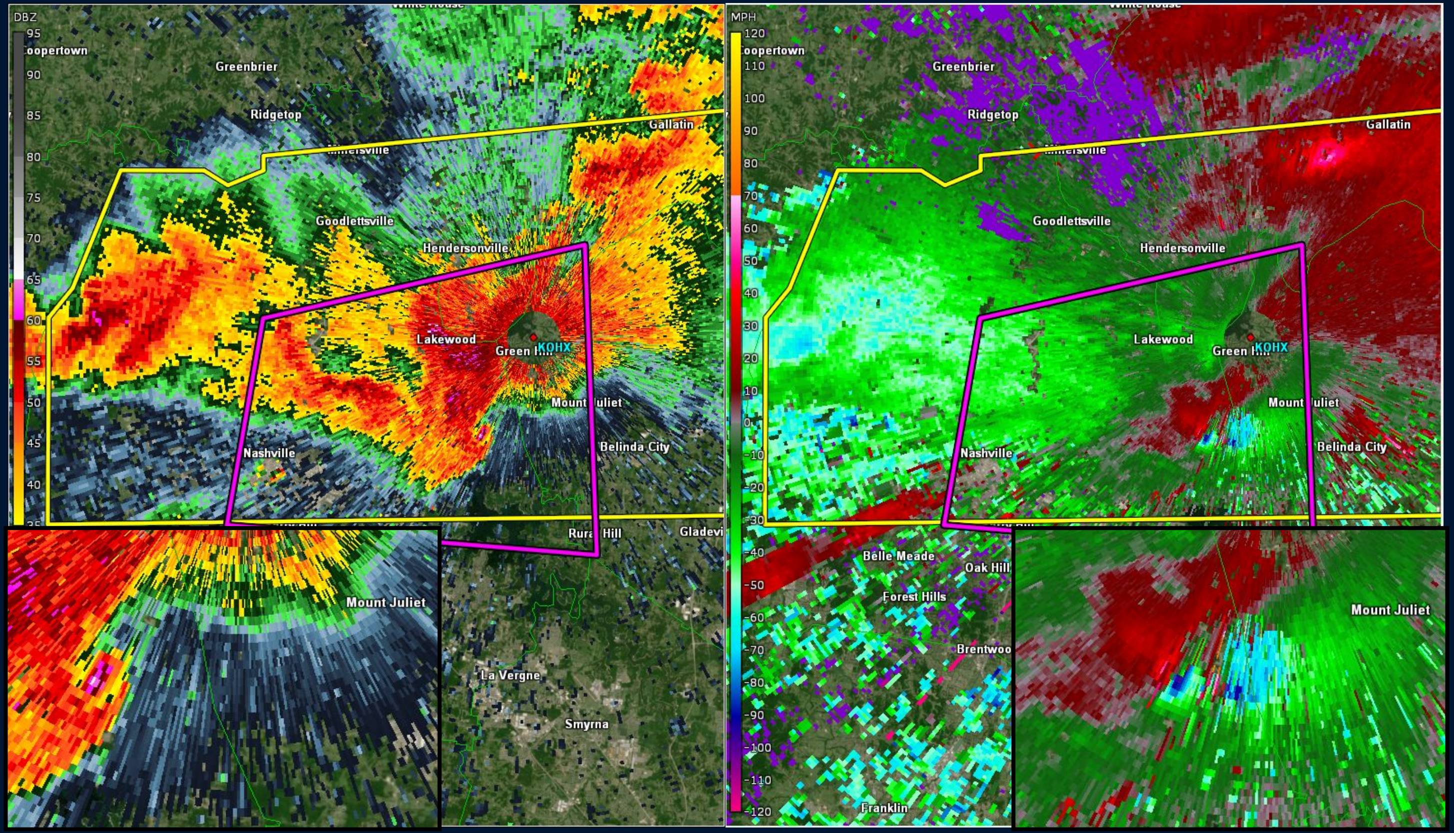
12:35 AM - Actual warnings

NWS Nashville, TN



12:40 AM - Actual warnings

NWS Nashville, TN



12:52 AM - Actual warnings

NWS Nashville, TN


Lowest to highest elevation
19.5°
15.6°
12.5°
10.0°
8.0°
6.4°
5.1°
4.0°
3.1°
2.4°
1.8°
1.3°
0.9°
0.5°
NOAA
Remember...radar images are available for many heights in the atmosphere!
NATIONAL WEATHER SERVICE

More information

For more on the March 2-3, 2020 tornadoes, visit weather.gov/ohx/20200303.

Today’s attendance

Were multiple people watching from one screen?

Let us know!

caleb.cravens@noaa.gov

Next classes:

Rip Current, November 20 at 7 PM
Hurricanes, November 21 at 10 AM
Radar, November 25 at 10 AM

Questions?

caleb.cravens@noaa.gov