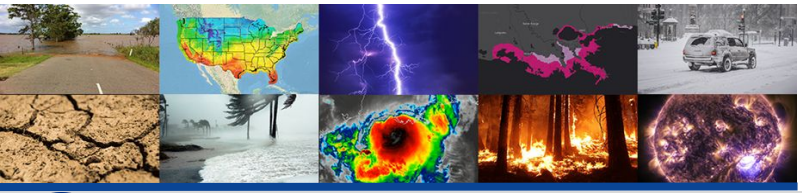
National Weather Service Burlington Weather Forecast Office

Advanced Skywarn Course - Severe Weather Operations

Robert Haynes - NWS Burlington

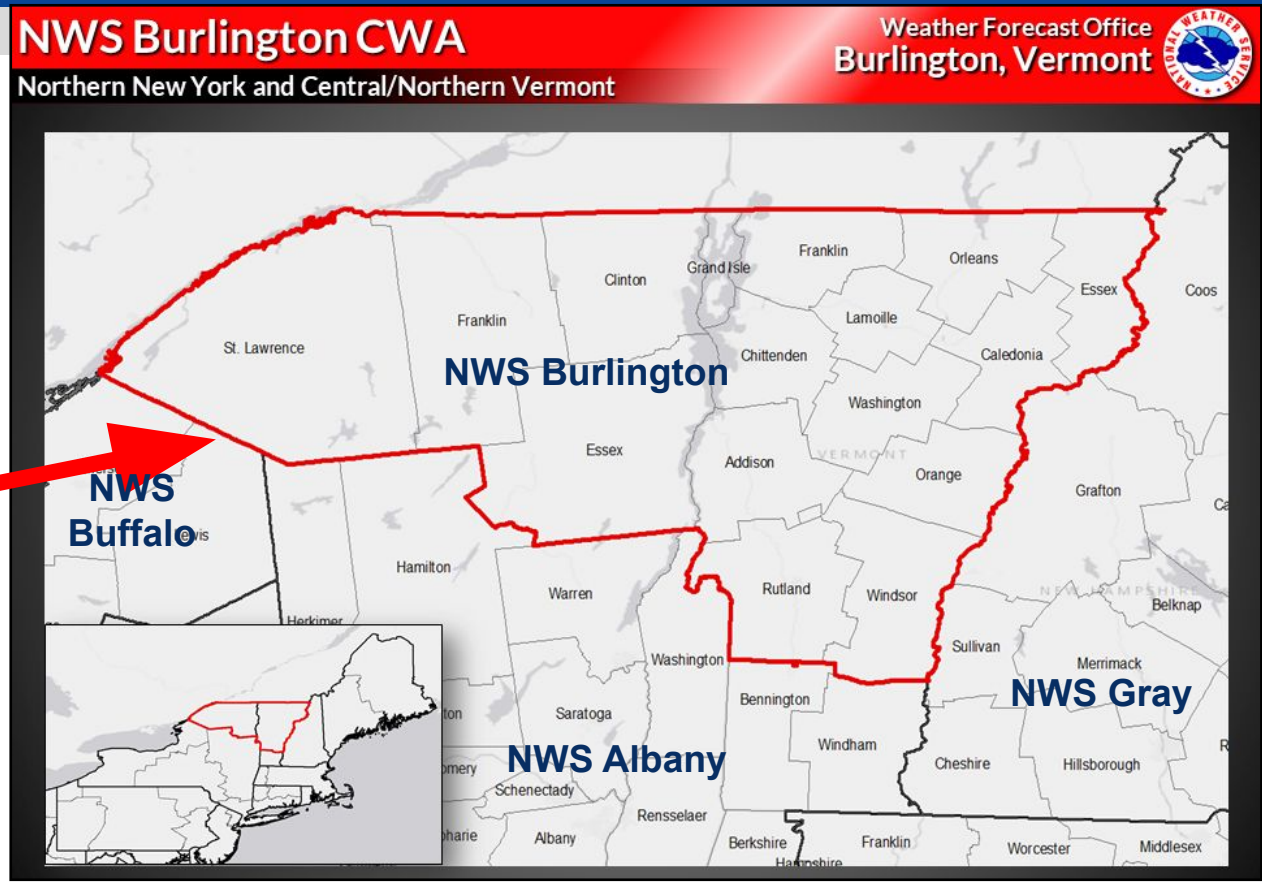


Presentation Layout

- ❑ Review What's in the Toolkit
- ❑ Look at the functions of Dual Pol and MRMS
- ❑ Forecasting Thunderstorm Evolution
- ❑ The Function of Satellites
- ❑ Case Reviews

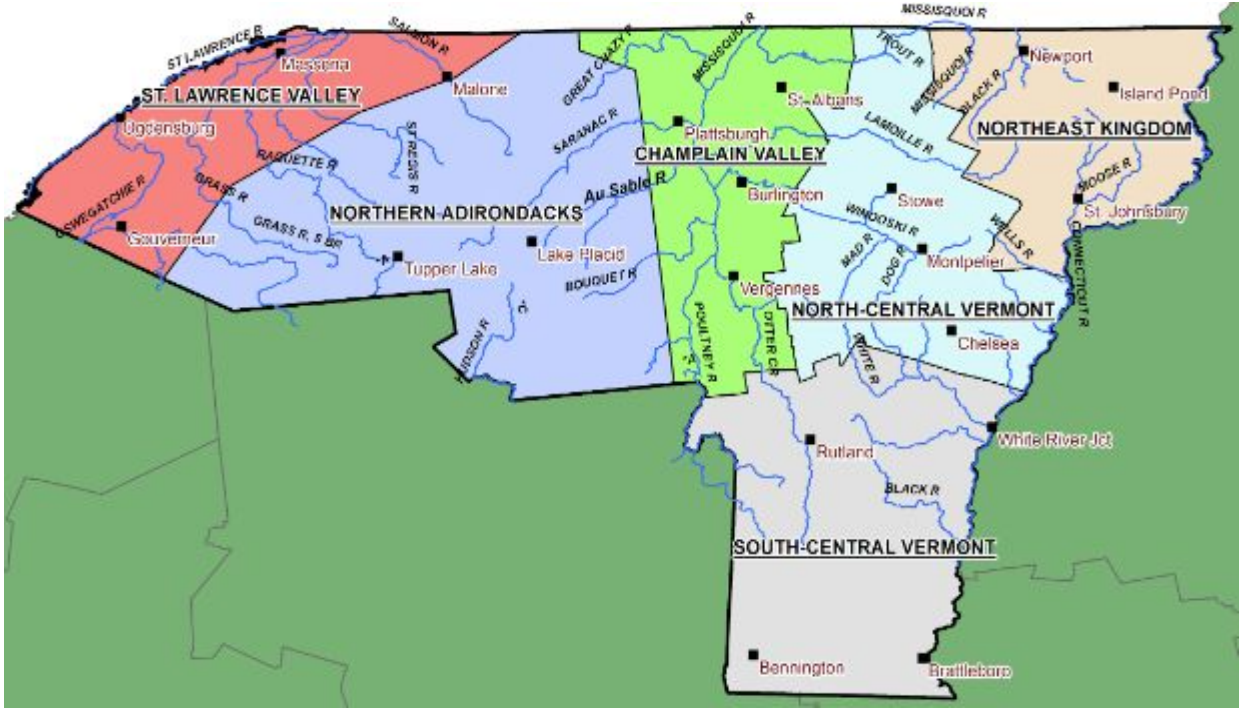
Where Do We Service?

- We service all of Vermont, except Bennington and Windham Counties and the 4 northernmost counties of New York.



Where Do We Service?

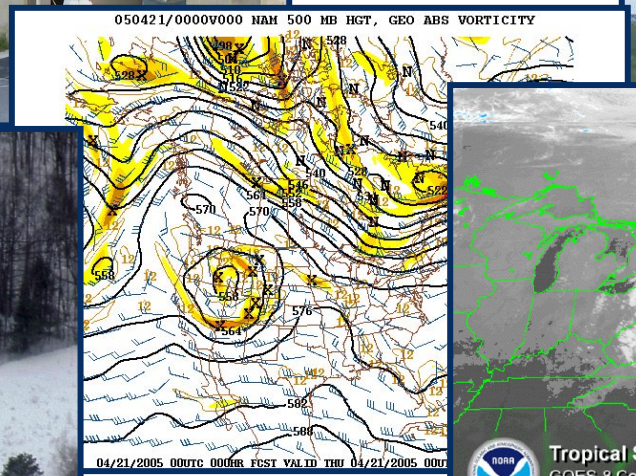
- Variable terrain features make for challenging weather forecasting and observations.

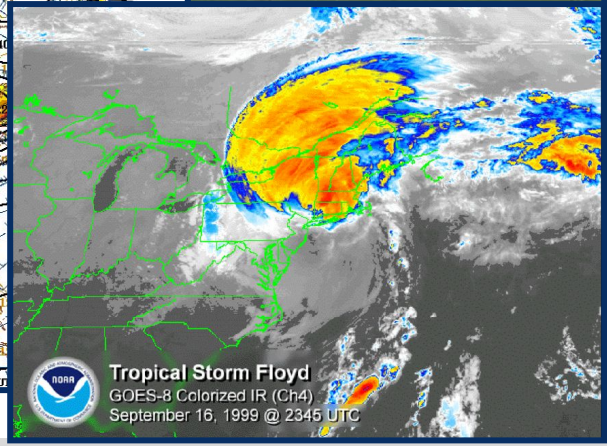


We've got many screens to employ!

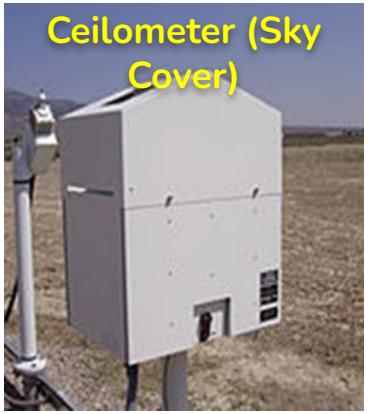
Working With All We Have

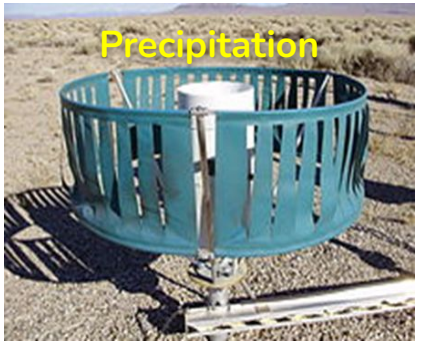
- ✔ We use all kinds of methods to make weather observations.
  - ✔ *Surface Observations*
  - ✔ *Upper Air Observations*
  - ✔ *Computer Models*
  - ✔ *Satellite Imagery*
  - ✔ *Radar*



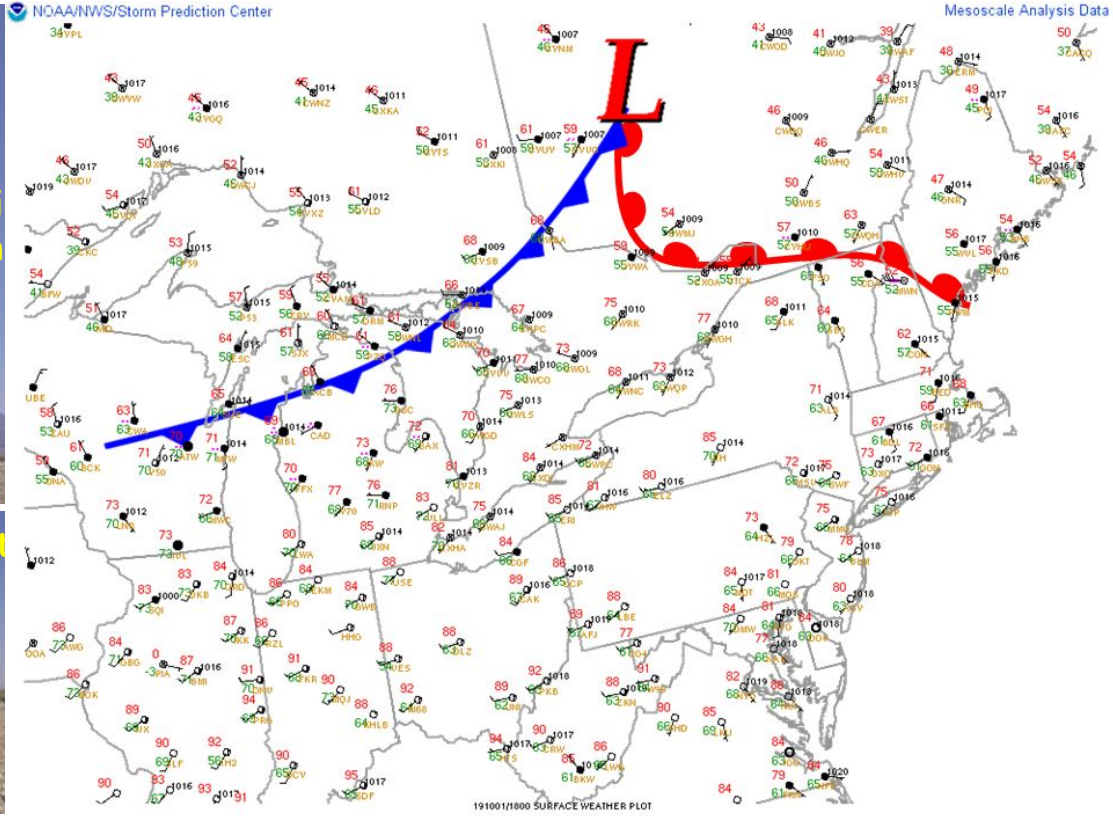


Surface Observations



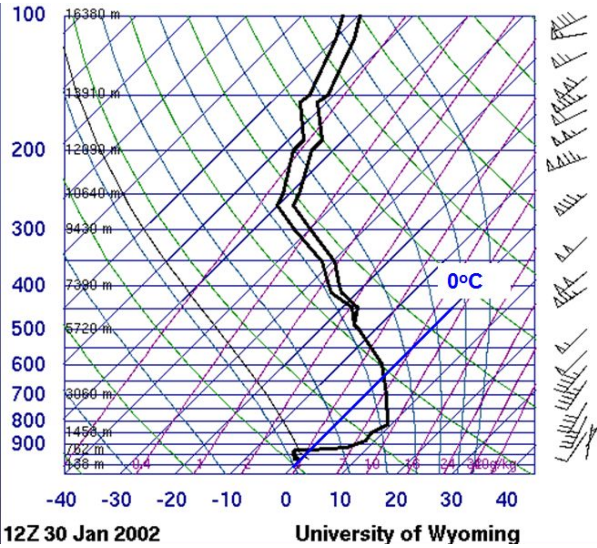


Surface Stations Make Many Maps



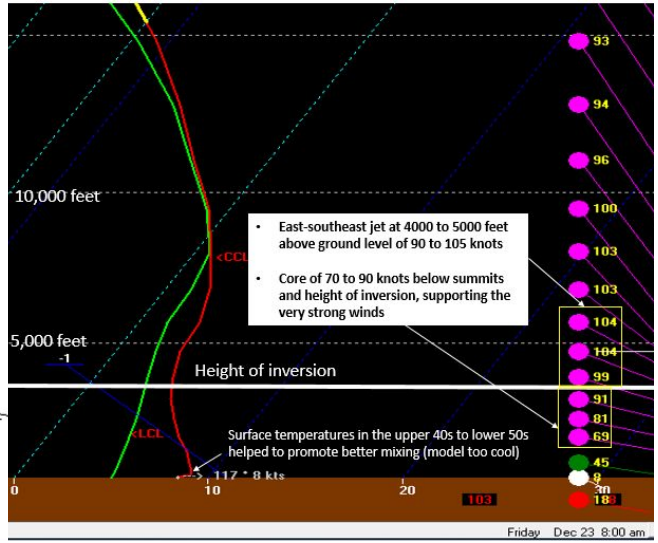
How We Use Weather Balloons

Determining whether it will be snow or be freezing rain



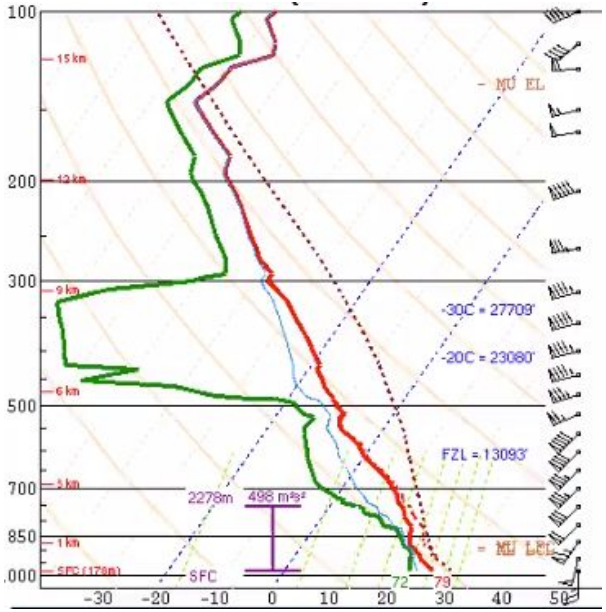
From one of Oklahoma's most devastating freezing rain events.

Whether we observe damaging downslope or gap winds



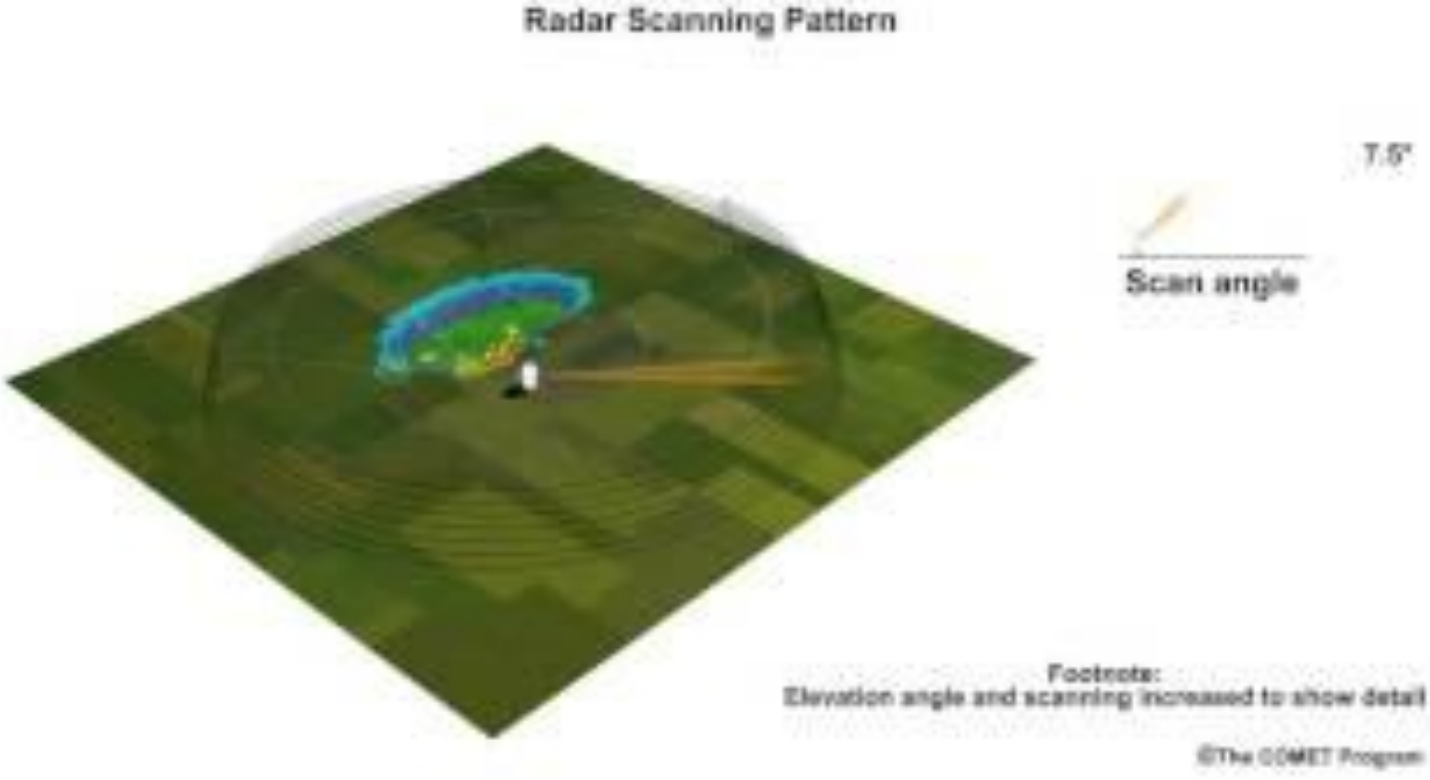
A 71 mph wind gust reported where I work Dec 23rd, 2022

Whether or not thunderstorms are possible



April 27, 2011 Super-Outbreak

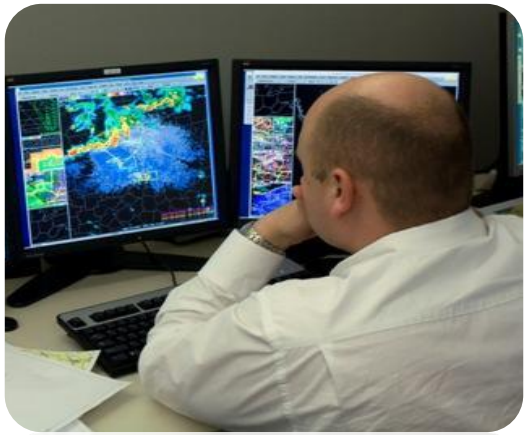
The Most Relevant Severe Wx Tool



https://youtu.be/Yrq2TVdM8HI

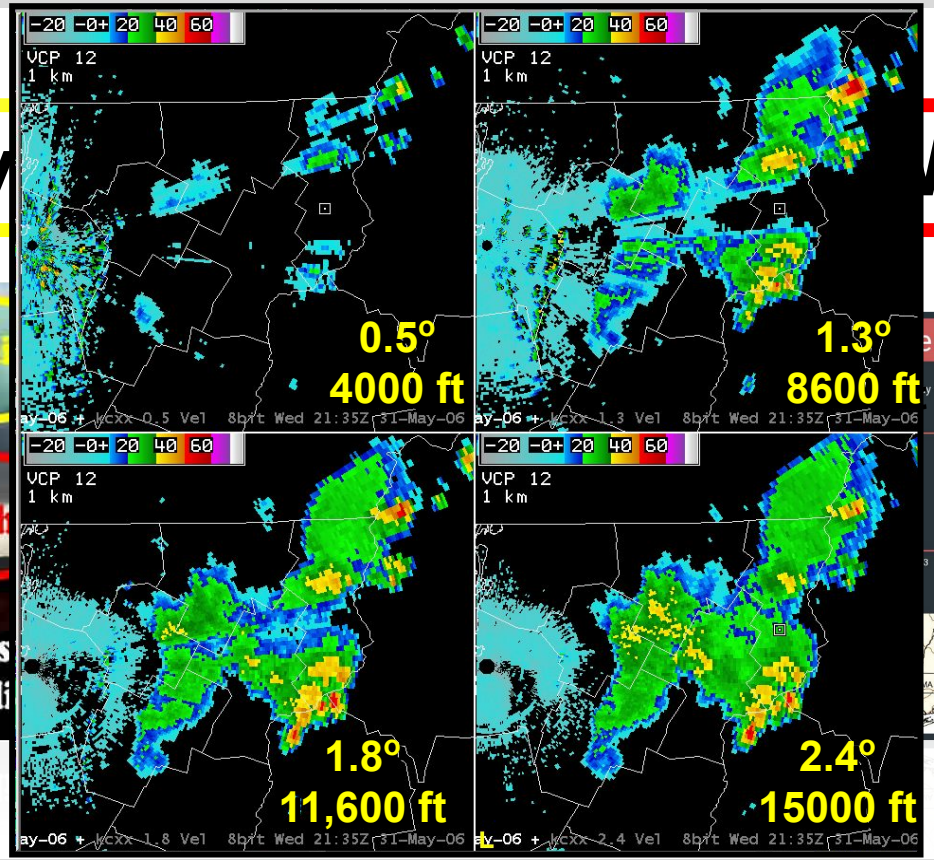
Why Do We Need spotters?

Observe → **Report** → **Warning**



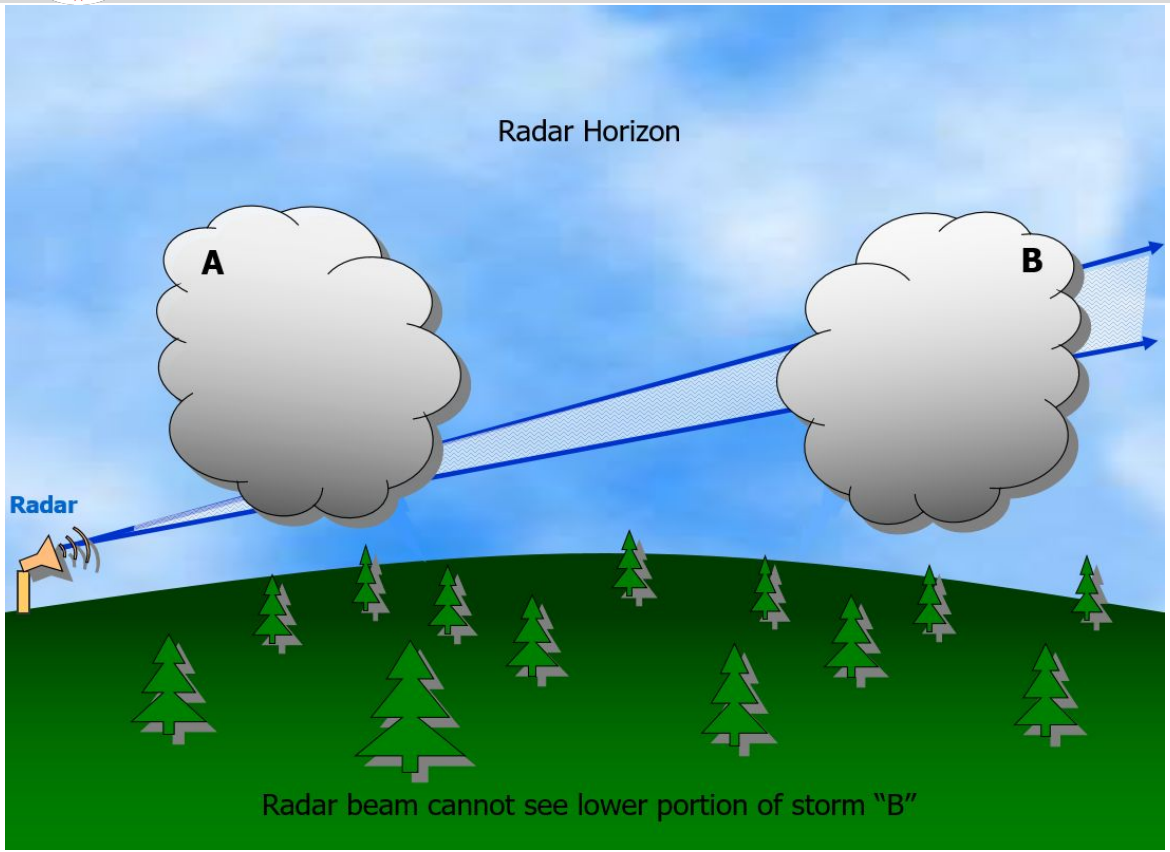
Why Do We Need spotters?

Observ



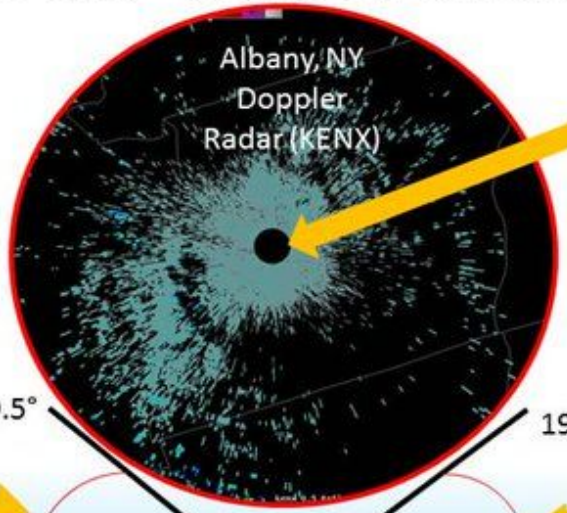
Warning

Loss of Vision Far Out



- Radar emitted at an angle to avoid Earth's curvature
- So it moves up the atmosphere and also widens (decreasing resolution)
- It's a lot easier to warn for the Burlington area than it is for Springfield, Vermont.

What is the "Cone of Silence"??



1 The "Cone of Silence" is a spherical image on the Doppler Radar that is unable to measure Meteorological and/or non-Meteorological data.

2 The Doppler Radar radar goes through a series of scans or tilts of the atmosphere ranging from 0.5° to as high as 19.5° when thunderstorms are present.

3 Once the radar completes one revolution of scans ending at a certain tilt, the scans return to a tilt of 0.5° and the cycle begins again.

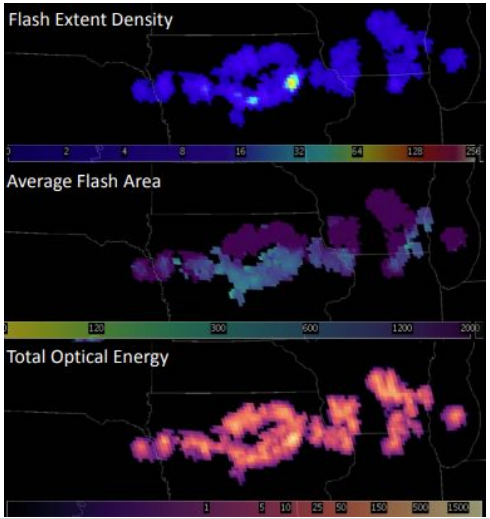
4 Areas above the highest tilt cannot be seen by the radar itself and hence we have the "Cone of Silence"

www.weather.gov/albany | NWSAlbany | @NWSAlbany | YouTube NWSAlbany

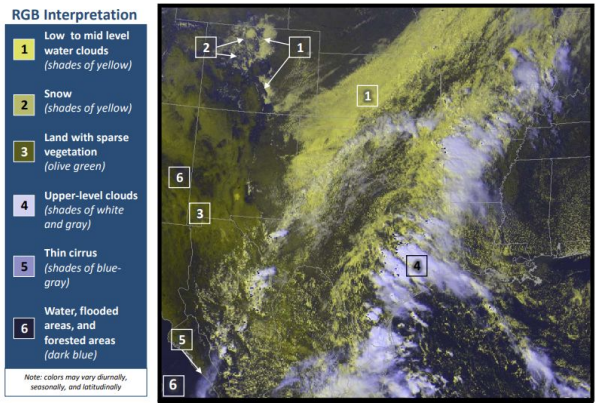
Satellites Help Screen Severe Storms

Satellite informs how a storm is evolving sometimes before you see those changes on radar: More or less lightning, are cloud tops warming, etc.

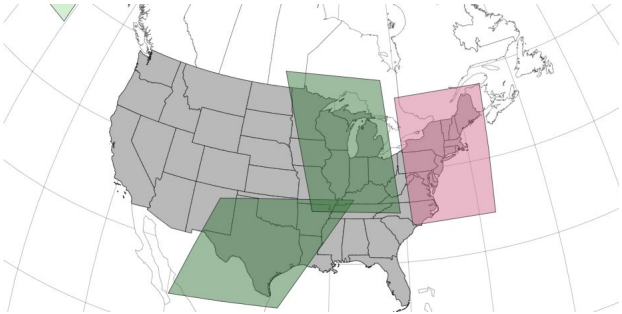
Global Lightning Mapper



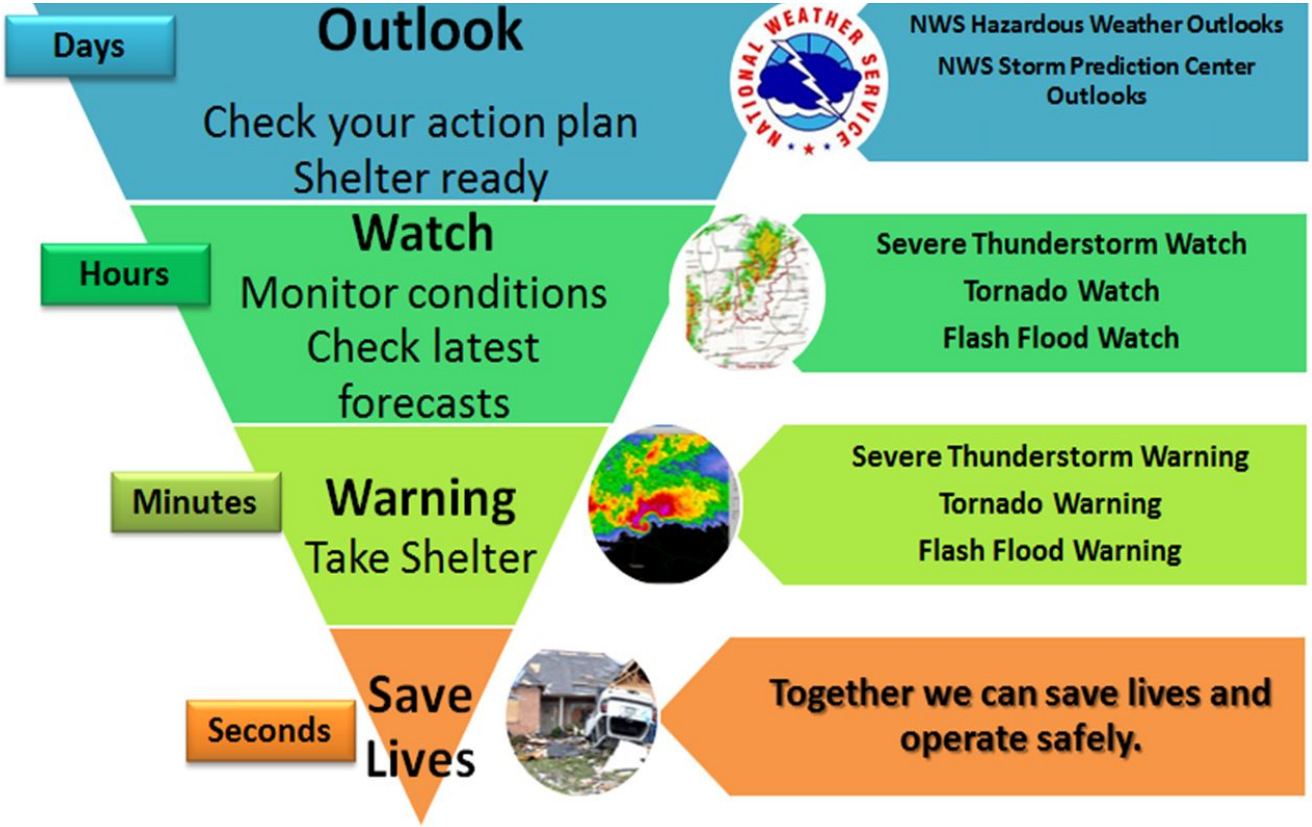
Distinguish Details About Storms



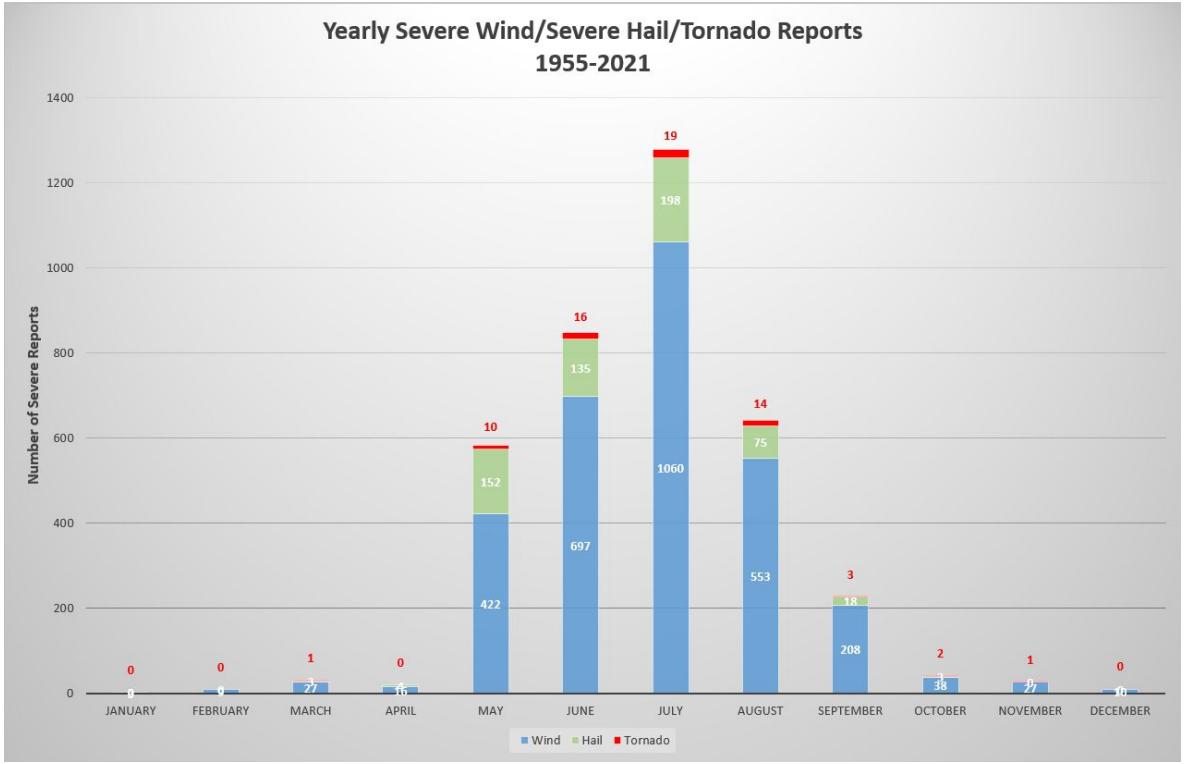
Minute-by-minute change



Messaging Evolves As We Get Closer to Severe Storms



Brief Overview of Thunderstorm Types and Hazards

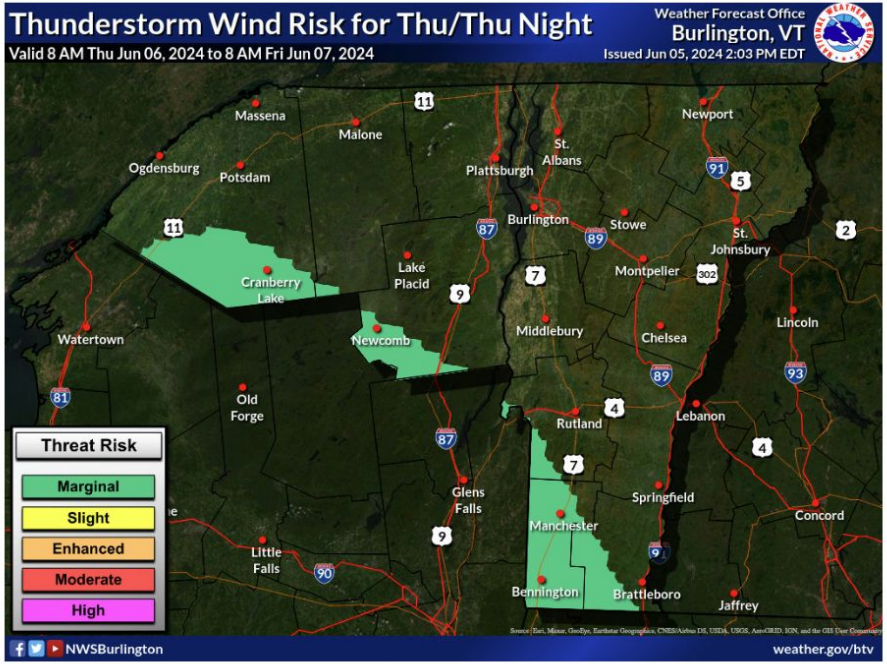


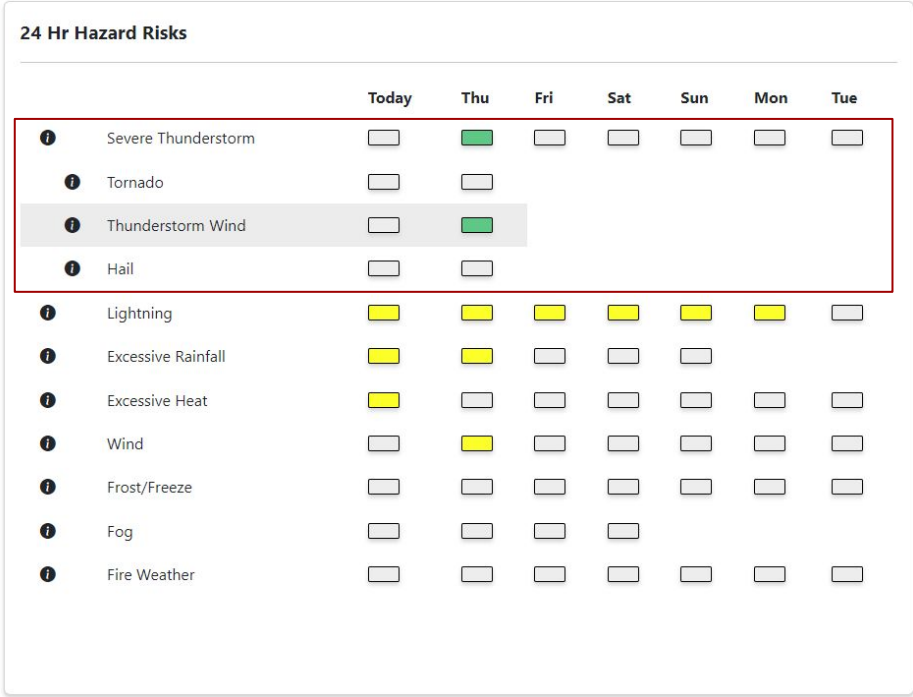
Climatological period of Severe Weather is the height of summer

Why is this so?

- More daytime heating – greater atmospheric instability
- Bermuda high usually allows moisture from the Gulf of Mexico advance northwards.
- While areas like Florida don't get fronts in the summer, we can still get weak frontal boundaries that help storms develop.

Graphical Hazardous Weather Outlook (GHWO)





https://www.weather.gov/erh/ghwo?wfo=btv

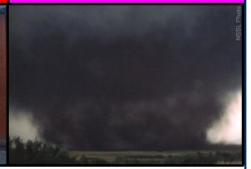
Storm Prediction Center Outlooks

Understanding Severe Thunderstorm Risk Categories

THUNDERSTORMS (no label)	1 - MARGINAL (MRGL)	2 - SLIGHT (SLGT)	3 - ENHANCED (ENH)	4 - MODERATE (MDT)	5 - HIGH (HIGH)
No severe* thunderstorms expected	**Isolated severe thunderstorms possible**	**Scattered severe storms possible**	**Numerous severe storms possible**	**Widespread severe storms likely**	**Widespread severe storms expected**
Lightning/flooding threats exist with <u>all</u> thunderstorms	Limited in duration and/or coverage and/or intensity	Short-lived and/or not widespread, isolated intense storms possible	More persistent and/or widespread, a few intense	Long-lived, widespread and intense	Long-lived, very widespread and particularly intense





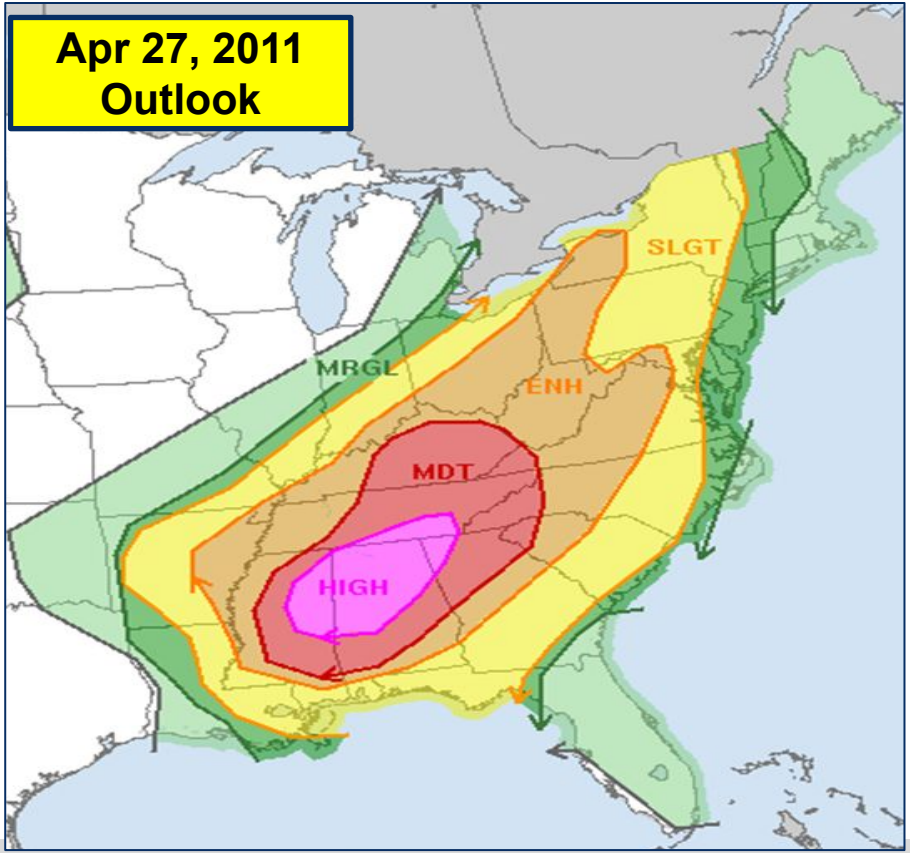



* NWS defines a severe thunderstorm as measured wind gusts to at least 58 mph, and/or hail to at least one inch in diameter, and/or a tornado. All thunderstorm categories imply lightning and the potential for flooding. Categories are also tied to the probability of a severe weather event within 25 miles of your location.

National Weather Service

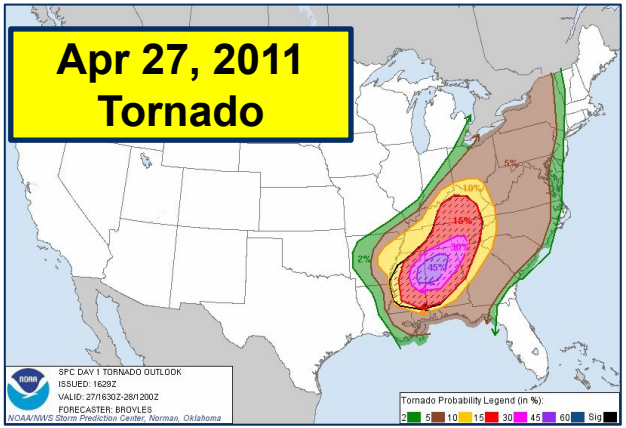
www.spc.noaa.gov

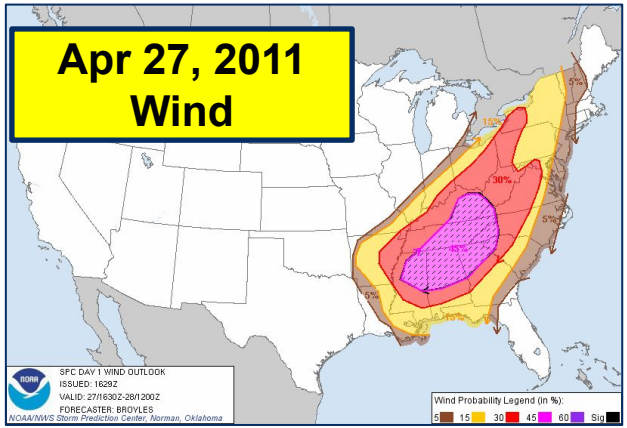
Storm Prediction Center Outlooks

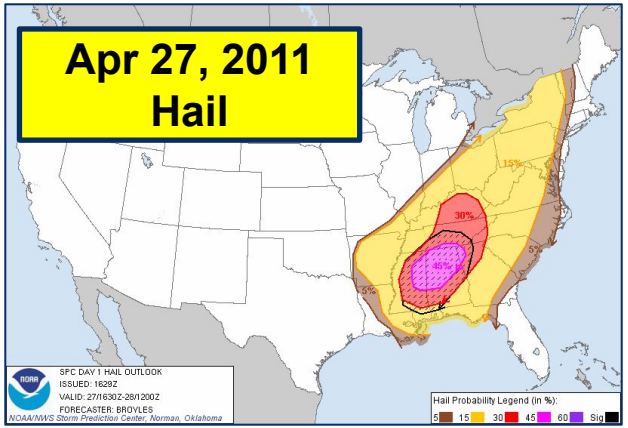


Storm Prediction Center Outlooks

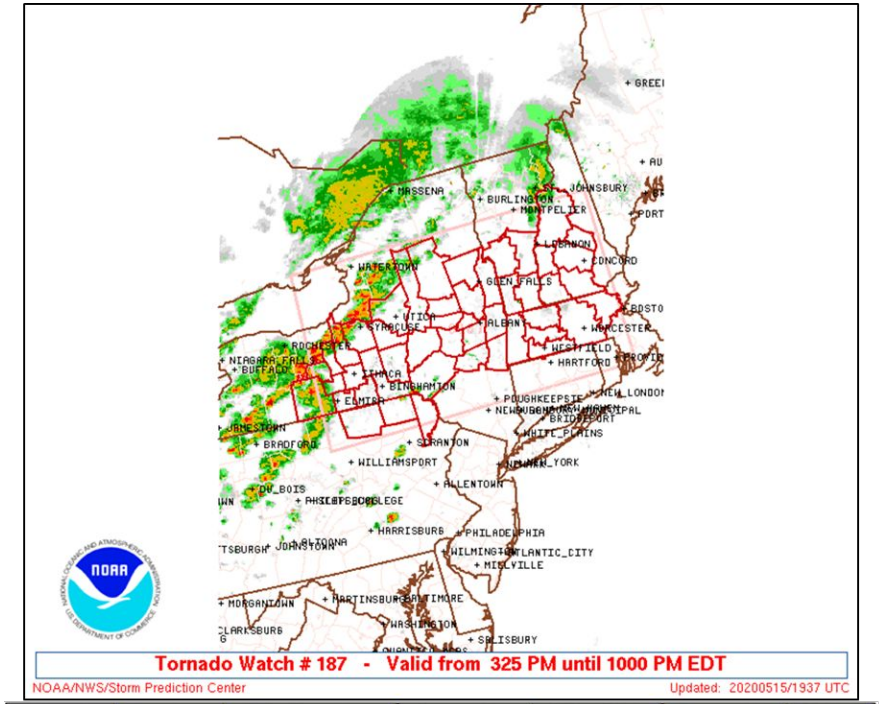
Each outlook is subdivided into different threat categories for tornadoes, wind, and hail. As of Spring 2020, this now includes Day 2 Severe Weather Outlooks as well!



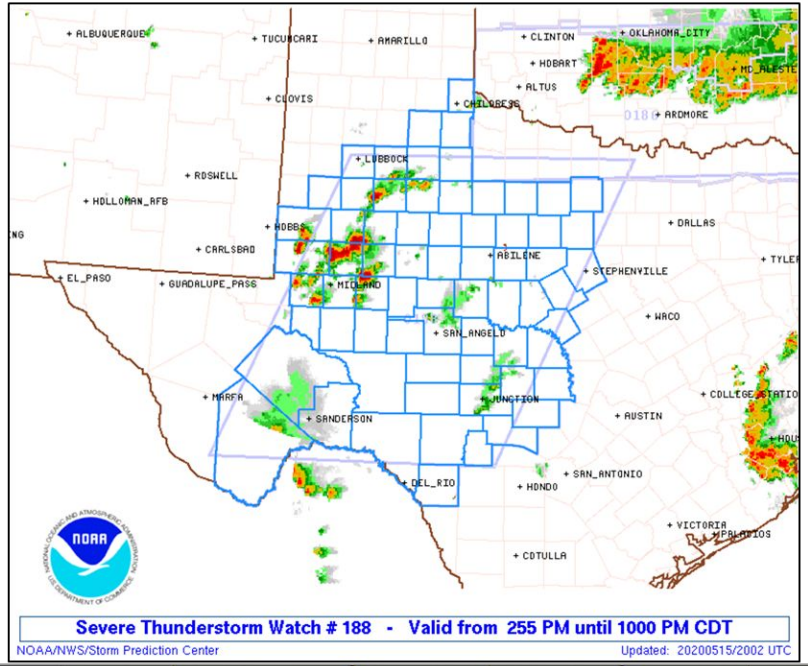




Tornado Watch vs Severe Thunderstorm Watch



Hazard	Tornadoes	EF2+ Tornadoes	Severe Wind	65 kt+ Wind	Severe Hail	2"+ Hail
Likelihood	Moderate	Low	High	Low	Moderate	Low

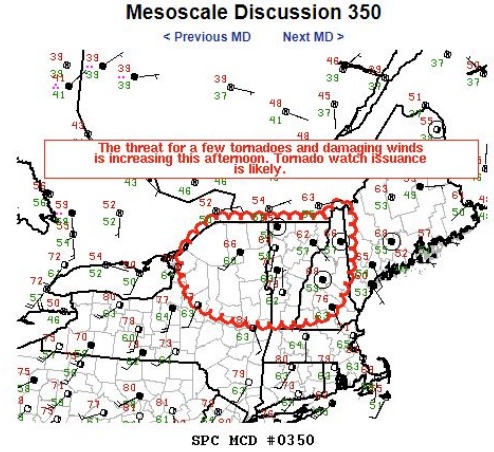


Hazard	Tornadoes	EF2+ Tornadoes	Severe Wind	65 kt+ Wind	Severe Hail	2"+ Hail
Likelihood	Low	Very Low	High	Moderate	Moderate	Moderate

The main difference is whether tornado threat is moderate or low. Other hazards may be more important!

SPC's Mesoscale Discussions

Outlines their thoughts on the need for Convective Watches and some of their notations during watches



Mesoscale Discussion 0350
NWS Storm Prediction Center Norman OK
0118 PM CDT Fri May 04 2018

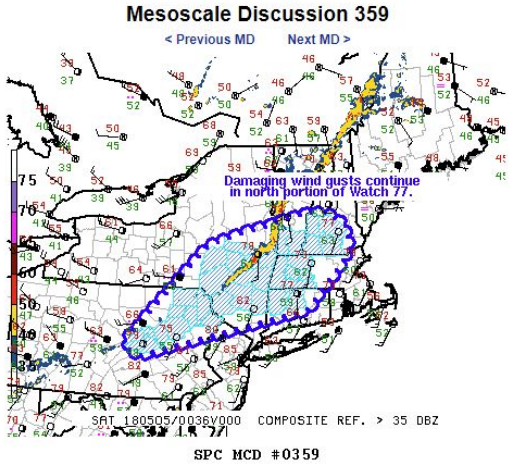
Areas affected...Portions of northern NY...VT...NH...and far western ME

Concerning...Severe potential...Tornado Watch likely

Valid 041818Z - 041945Z

Probability of Watch Issuance...80 percent

SUMMARY...The threat for a few tornadoes is increasing this afternoon, and damaging winds will become likely with a line of thunderstorms moving in from the west. Tornado watch issuance is likely.



Mesoscale Discussion 0359
NWS Storm Prediction Center Norman OK
0750 PM CDT Fri May 04 2018

Areas affected...Eastern NY and PA into portions of New England

Concerning...Severe Thunderstorm Watch 77...

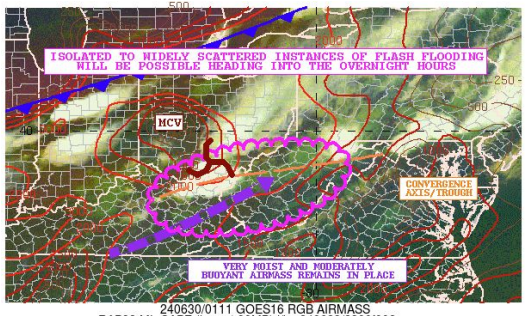
Valid 050050Z - 050215Z

The severe weather threat for Severe Thunderstorm Watch 77 continues.

SUMMARY...Damaging wind gusts expected to continue for the next hour or two along the squall line. Greatest risk will be in northern portions of the watch area.

You don't have to understand all the meteorological jargon, but it can tell you where forecasters are leaning and gives focused messaging based on trends.

WPC does these for heavy rain and snow too!



240630/0111 GOES16 RGB AIRMASS
RAP32 ML CAPE (lowest 90MB) J/kg 240629/2300f002
WPC MPD #0516

Mesoscale Precipitation Discussion 0516
NWS Weather Prediction Center College Park MD
920 PM EDT Sat Jun 29 2024

Areas affected...Far Southern OH...Northeast KY...Much of WV

Concerning...Heavy rainfall...Flash flooding possible

Convective Warning Criteria

Severe Thunderstorm Warning

- Thunderstorm wind gusts ≥ 58 mph & or:
- Hail ≥ 1 inch in diameter

Tornado Warning

- Doppler Radar indicated rotation
- Confirmed reports of a tornado

Flash Flood Warning

- 6 inches or more of flowing water over roadways
- A rapid rise in water that is a threat to life & property

Tiered Impact Based System

Wording gets stronger the greater the threat to life.

Also includes:

- Tornadoes
- Flash Floods
- Snow Squalls

Thunderstorm
Damage Threat Categories

Considerable / Destructive Tags

Thunderstorm Damage Threat (tag category)	Wind	Hail diameter	WEA?
Base (no tag; default)	58 mph (60 mph will appear in the warning)	1.00 inch (U.S. quarter)	NO
Considerable	70 mph	1.75 inch (golfball)	NO
Destructive	80 mph	2.75 inch (baseball)	YES

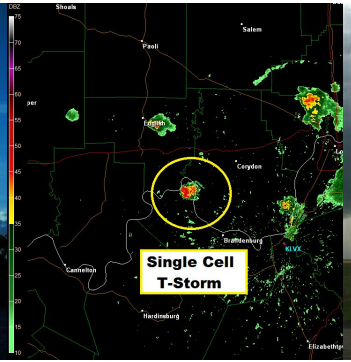
Impact Based Severe Thunderstorm Warning Example

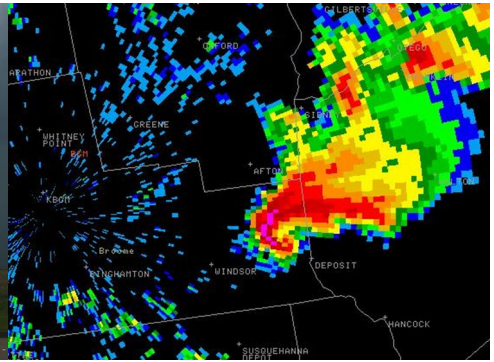
Tag Information at the end of the warning

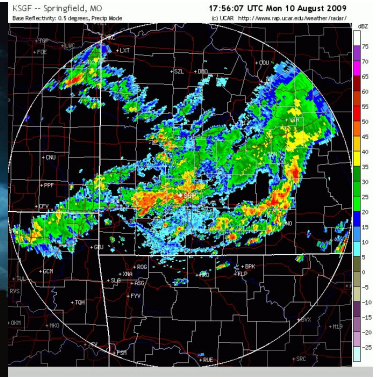
```
TORNADO...POSSIBLE
THUNDERSTORM DAMAGE THREAT...CONSIDERABLE
HAIL THREAT...RADAR INDICATED
MAX HAIL SIZE...1.00 IN
WIND THREAT...OBSERVED
MAX WIND GUST...70 MPH
```

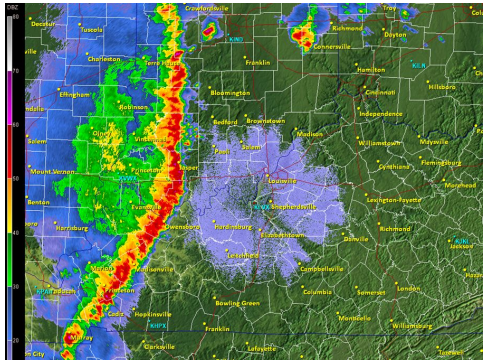
WIRELESS EMERGENCY ALERTS CAPABLE

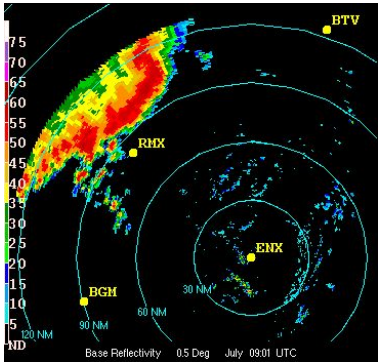
Environment Gives Storm Many Shapes and Sizes





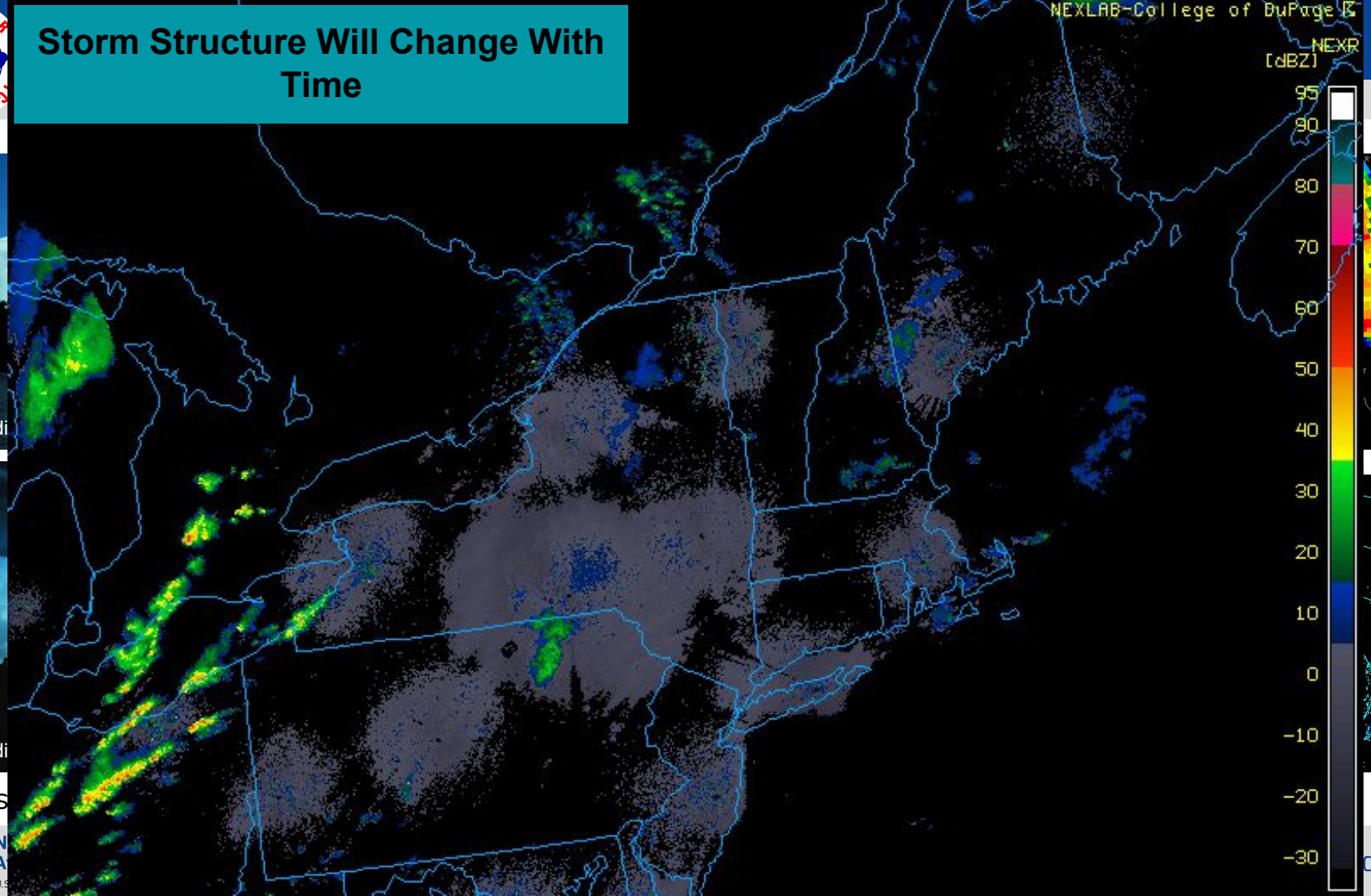


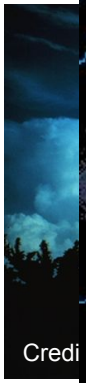


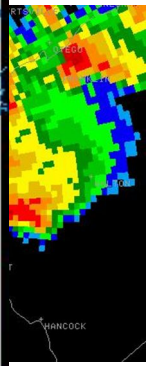


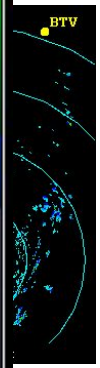
A storm's structure on radar gives us a general clue of what it's capable of.

Storm Structure Will Change With Time

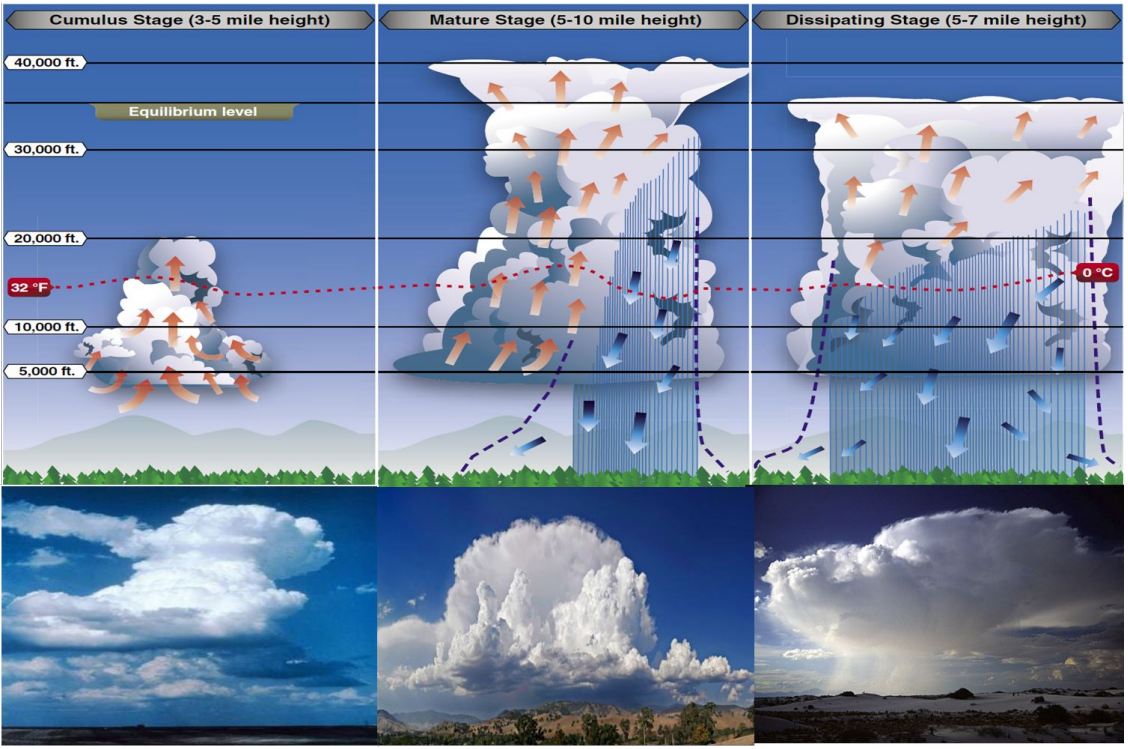








The Single Cell

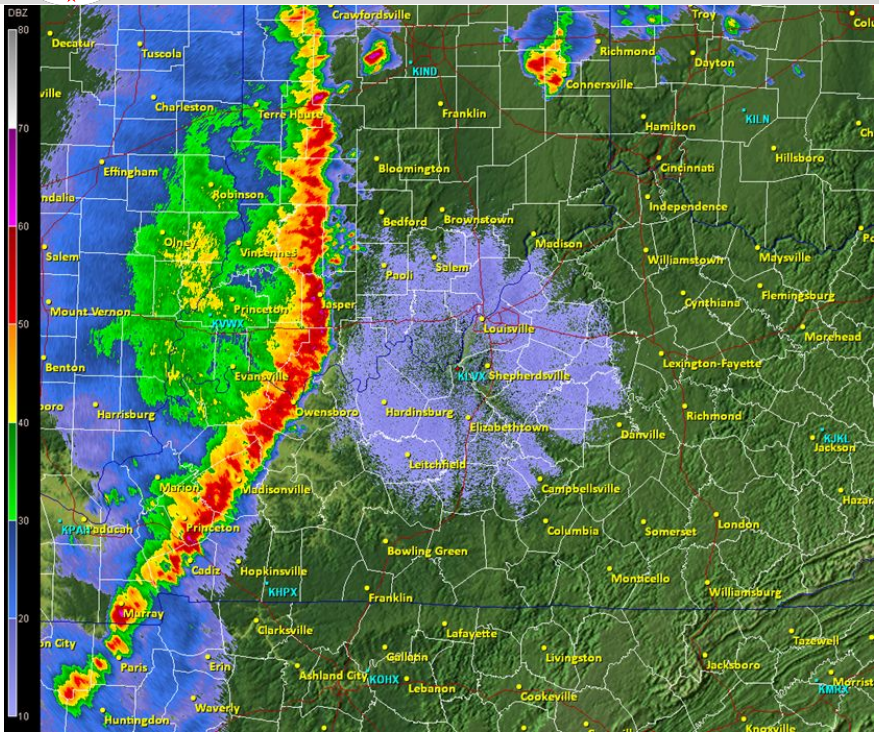


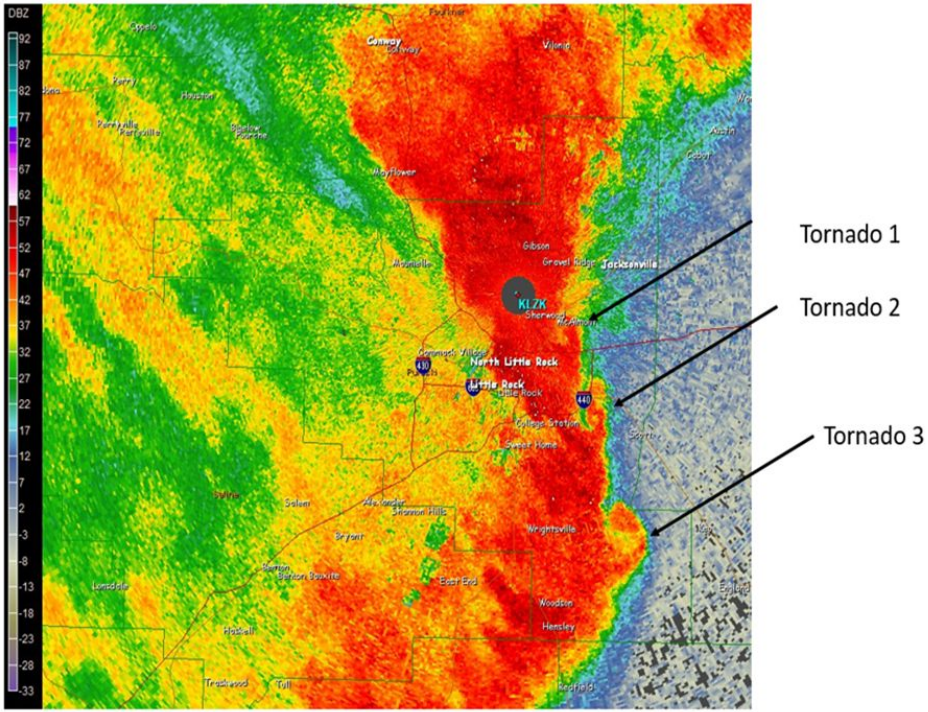
- Downdraft overtakes the convective updraft.
- Causes the storm to dissipate, usually within an hour.
- Sometimes, the downdraft wind is strong enough to do minor damage.
- Look for an overshooting top above the anvil – indicates more vigorous updraft and likelihood for damaging winds.

The Multi-Cell

- Very common over the summer months which is formed by the merger of multiple single cell thunderstorms.
- New storms form along the leading edge of rain cooled air (aka gust front).
- These types of storms can be severe and produce wind, hail and a low chance of a tornado.
- Flooding is possible for slow moving multi-cell storms if rainfall continuously moves over the same areas.

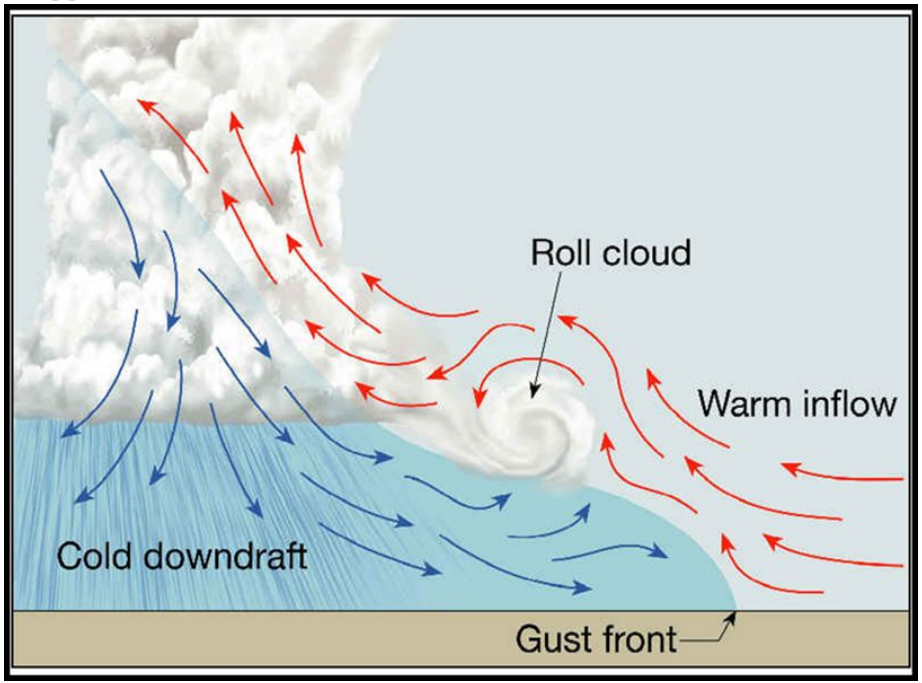
Squall Lines (Quasi-Linear Convective System)





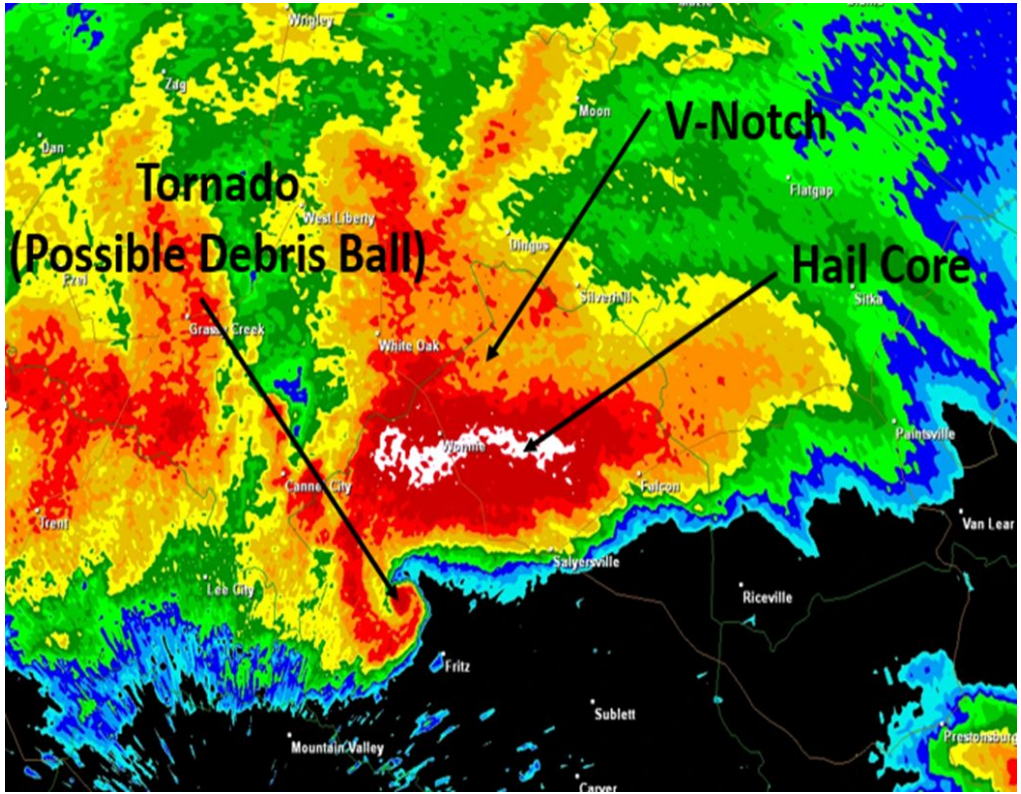
QLCS - Lines of intense winds and short-lived tornadoes can occur, especially if there's any kind of folding in front of or behind the line of storms..

Shelf/Roll Cloud



This is the defining quality of an organized area of straight line winds. It may not always approach severe limits, but it is a pretty good sign.

Supercells



- Named “Supercell” when they display strong mid-level rotation.
- Has a longer life-cycle (separation of updraft + downdraft from wind shear)
- Also capable of dropping very large hail up to 2-4 inches in diameter (Look for blues/green colors within clouds).
- Can last 20-60 minutes but can also persist longer in a favorable environment.
- About 1 out of 5 produce tornadoes.

Supercells

May 2022 - Spotter Jon O'Connor in Williston

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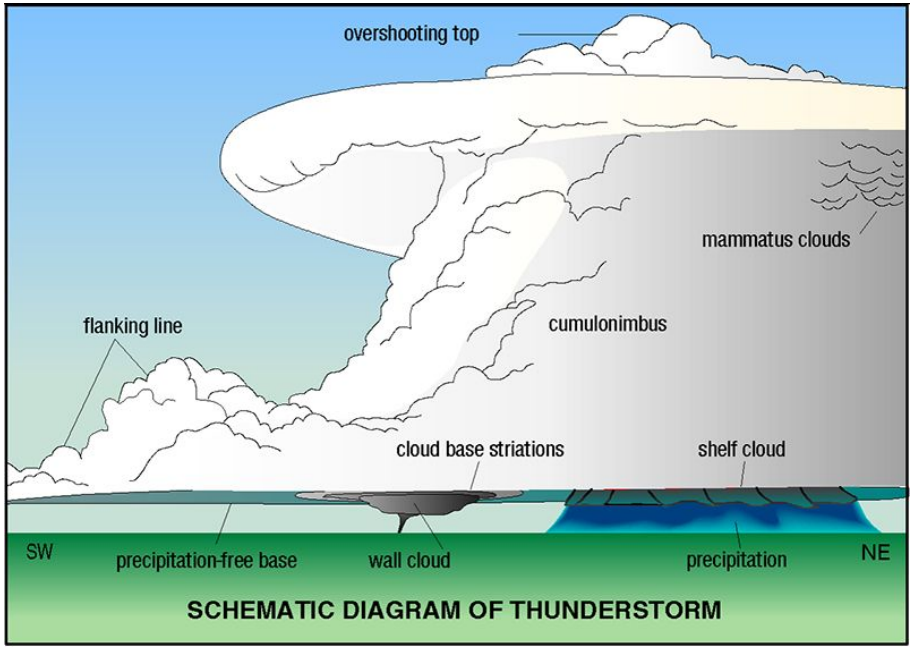
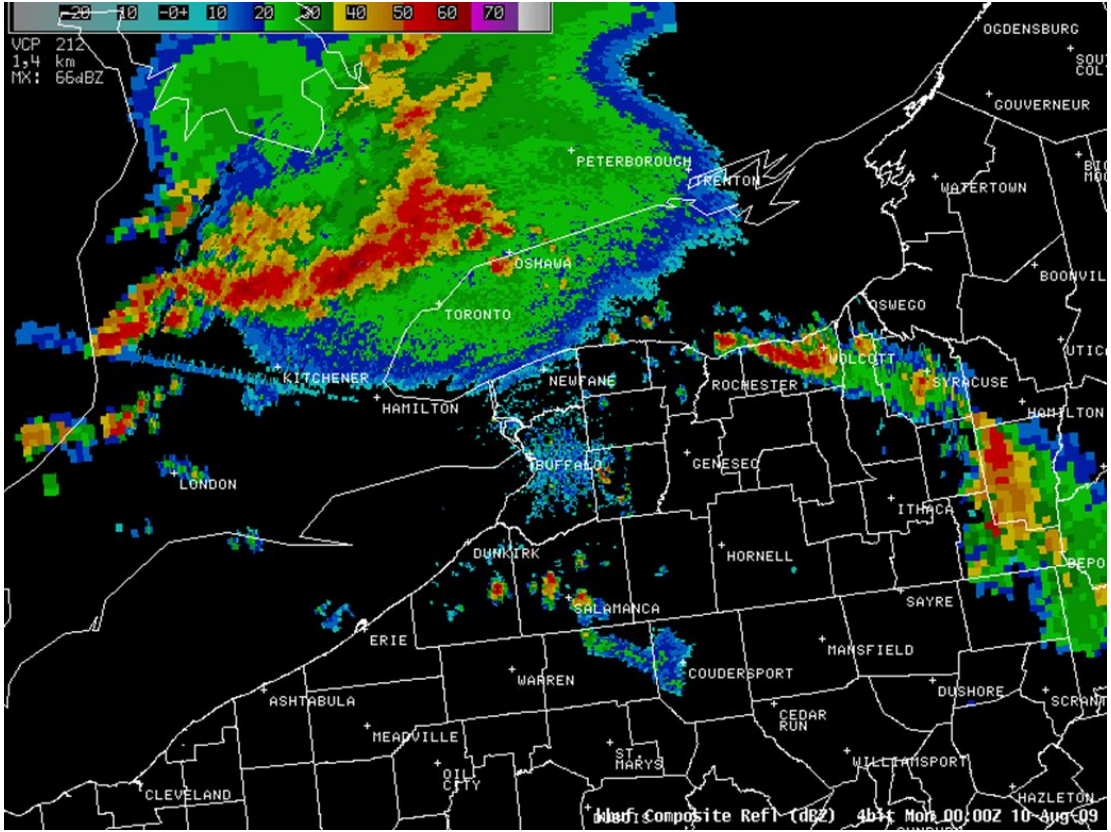
Supercell's Basic Appearance



Wall Cloud is a defining characteristic. Up here, it can be hard to see with our variable terrain, forestation, and higher likelihood its rain-wrapped.

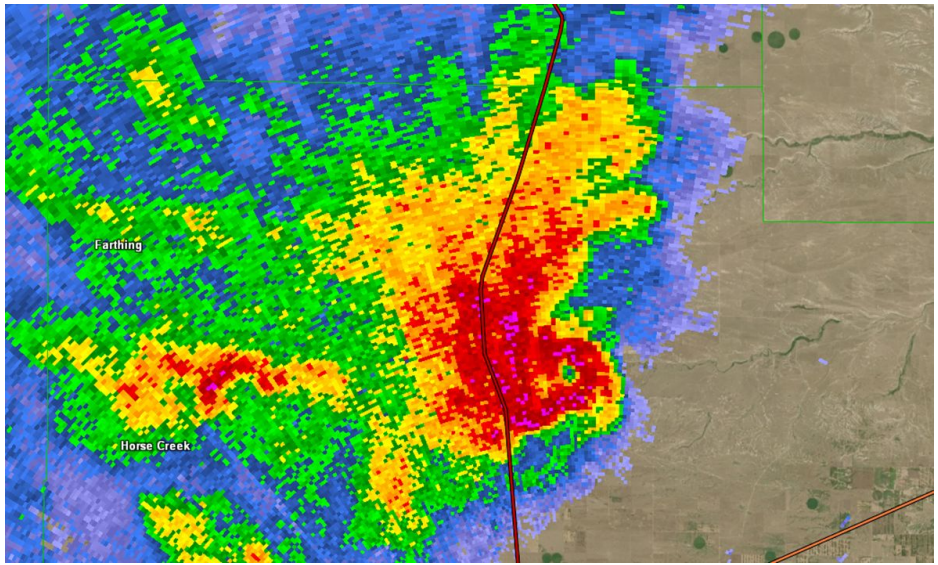
Radar Basics



- **Displays energy reflected back to the radar**
- **Shows location and movement of rain, snow, hail, etc.**
- **Radar energy can also reflect back off birds, insects, and ground targets**

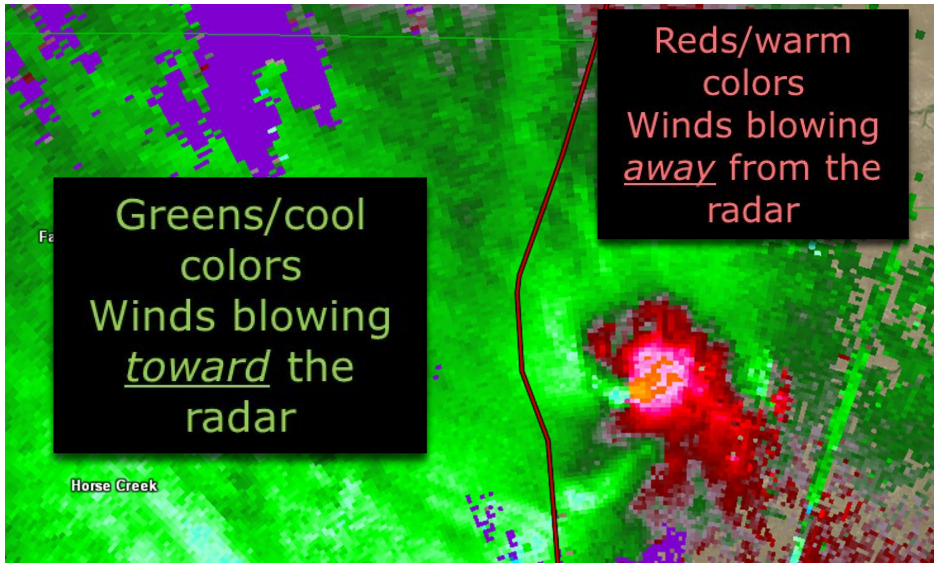
Reflectivity and Velocity

Reflectivity: Main function is storm intensity and structure.



Big changes over small distances are usually an indication of severe weather.

Velocity: Main function is learning wind speed and flow in the storm.



Look for rotation across the whole storm and whether winds are moving opposite ways.

Reflectivity and Velocity

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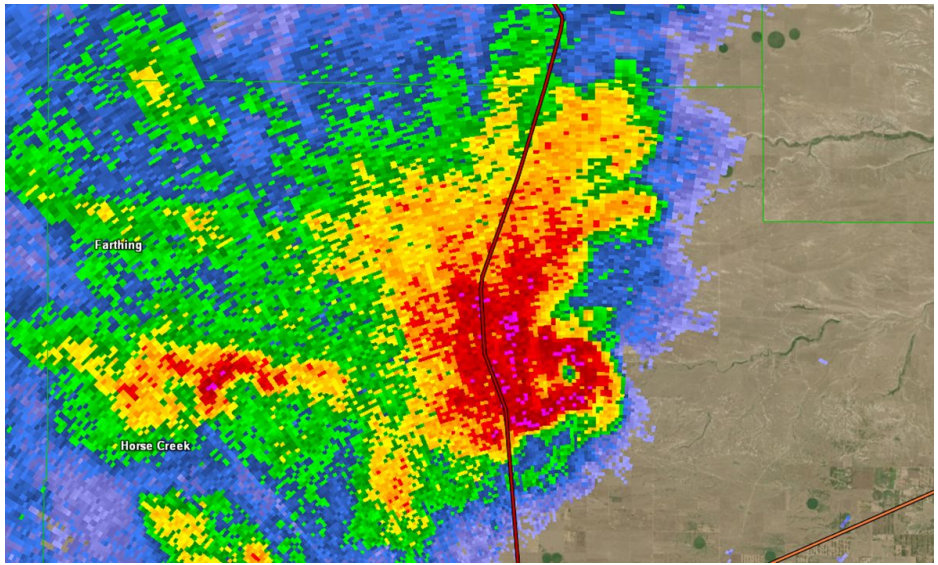

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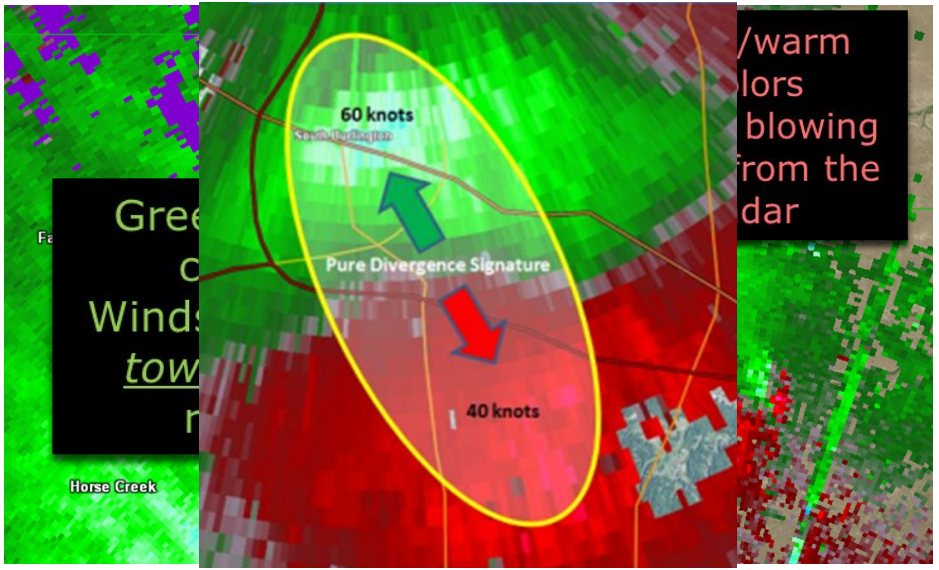
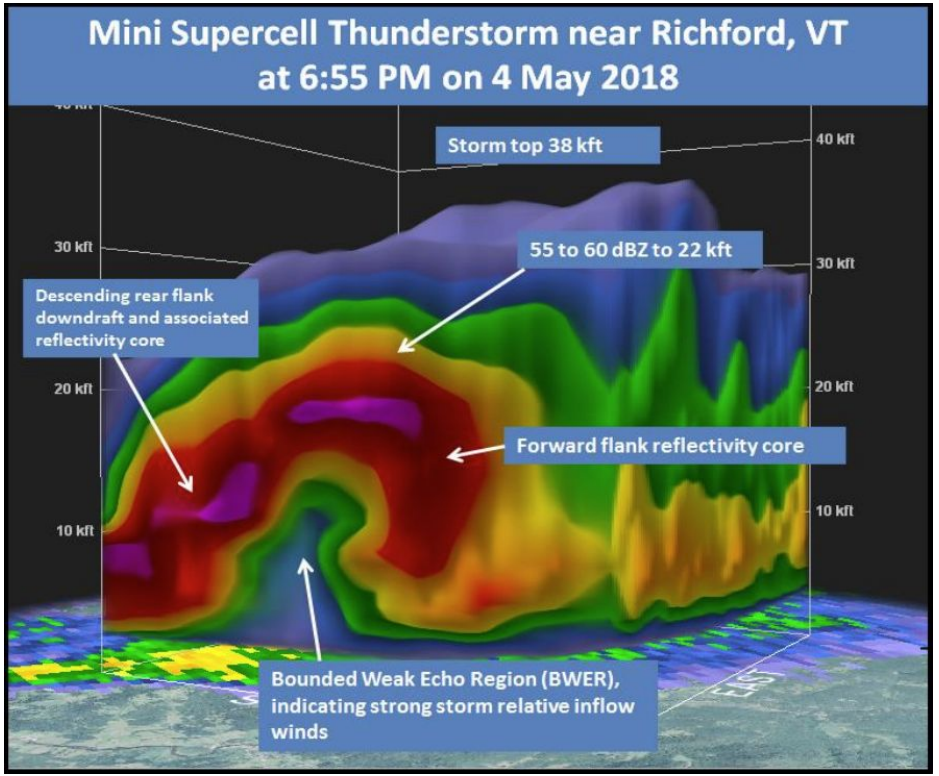


Look for rotation across the whole storm and whether winds are moving opposite ways.

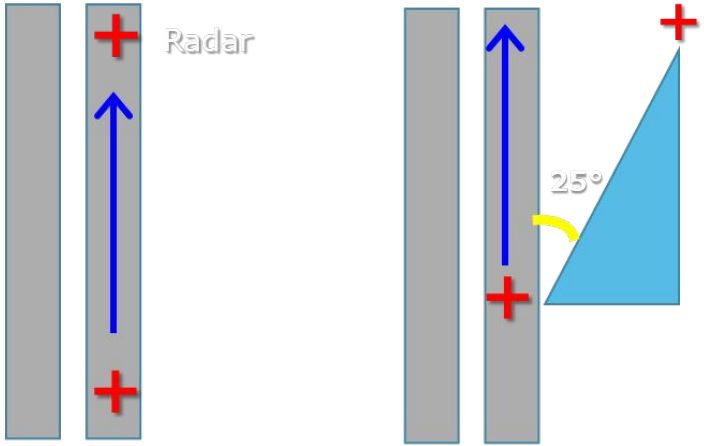
Reflectivity Note: Bounded Weak Echo Region

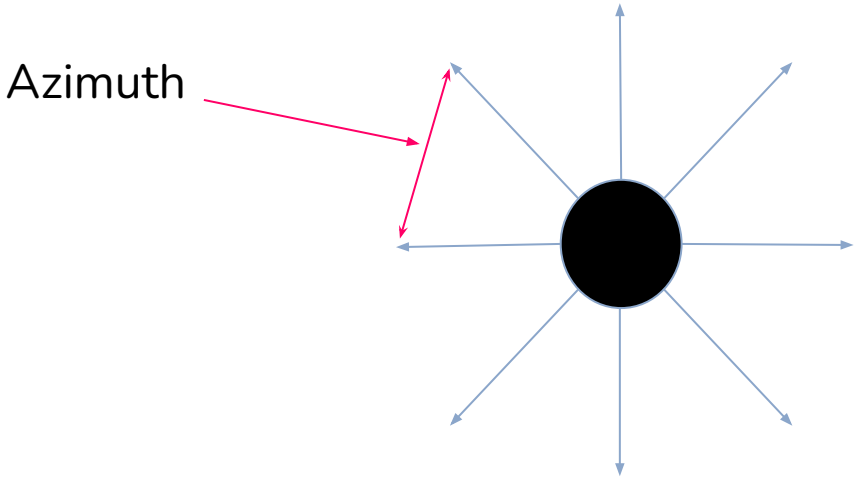
- An important feature of a supercell.
- Depending on the radar slice, it appears as a donut hole. It can show up in reflectivity or differential reflectivity.
- Requires looking up and down radar tilts to assess. Sometimes storms create similar shapes, but the max reflectivity must be aloft.



Important Notes About Radar Velocity

Some mental math has to be done when a target is not moving directly towards radar. Speeds will be underestimated if storm is moving at an angle. If a storm is moving tangential to the radar beam, radar doesn't see velocity.



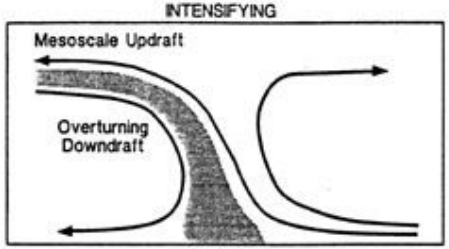


Look for rotation comparing winds on different azimuths.

Look for convergence or divergence by comparing winds on the same azimuth.

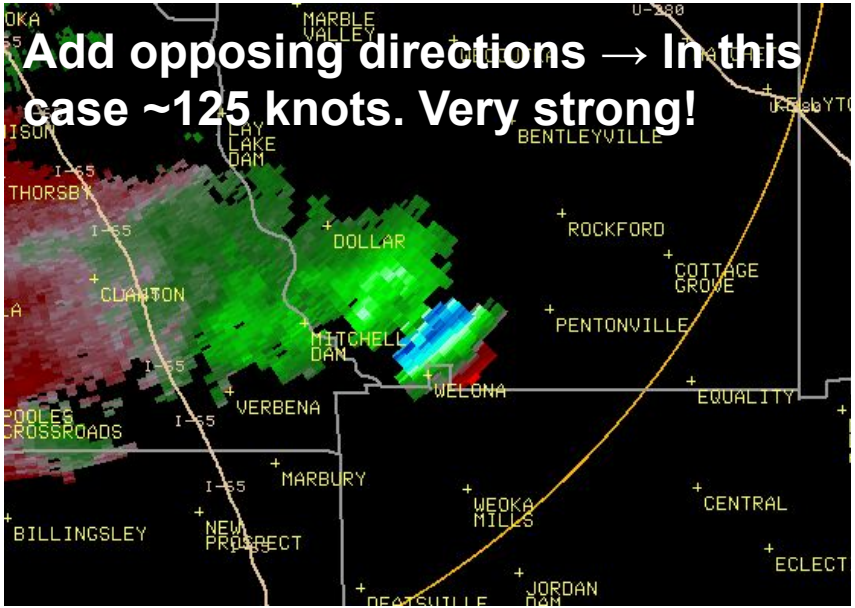
Important Notes About Radar Velocity

Middle Altitude Radial Convergence (MARC): Downburst possible with a 25 knot difference around 10-15 km above ground.

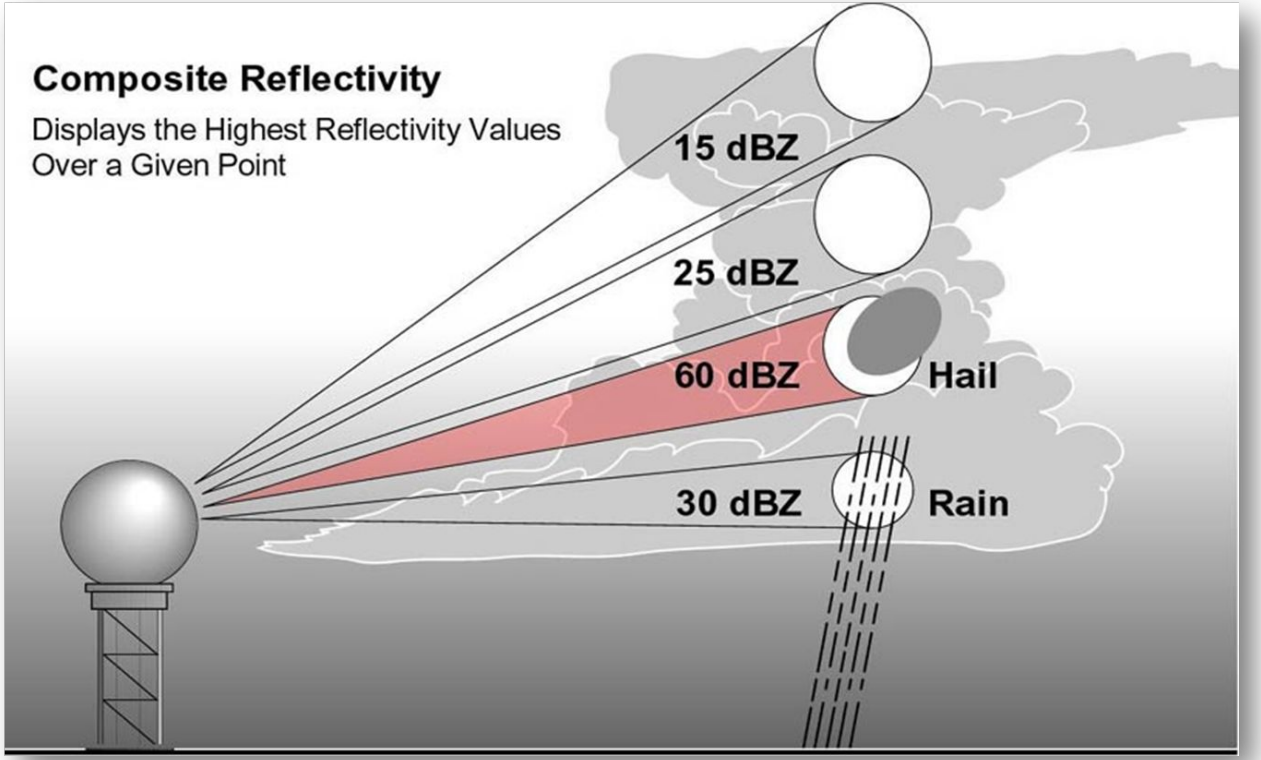


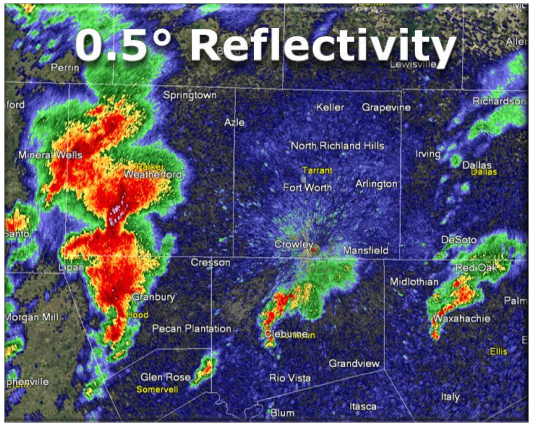
Schematic diagram of Squall Line from Rasmussen and Rutledge 1993. Shaded region signifies vorticity zone.

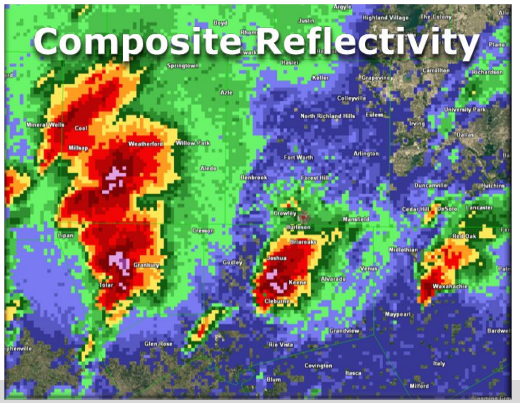
Storm Top Divergence: Find strongest updrafts at anvil level. Look for winds greater than 80 knots.



What is Composite Reflectivity



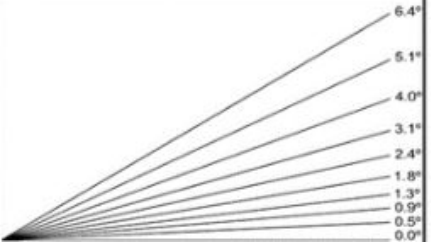




Scanning Strategy

- What elevations radar scans and how frequently can be tweaked to measure certain weather phenomena better.

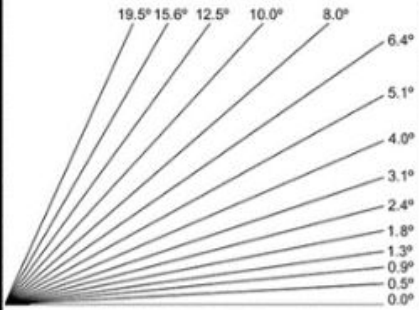
No weather on the scope

Slices	Tilts	VCP	Time*	Algs.	Usage	Limitations
	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 VCPs 31/32.	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.

Scanning Strategy

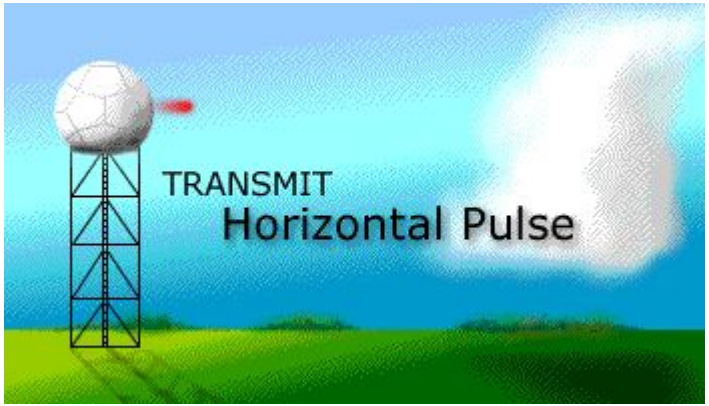
- What elevations radar scans and how frequently can be tweaked to measure certain weather phenomena better.

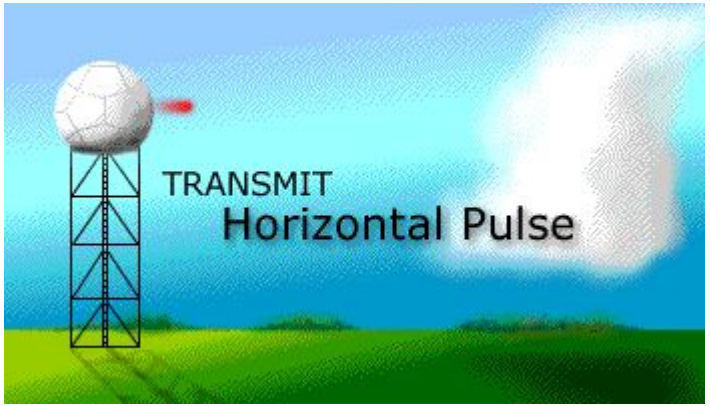
Severe Weather Scanning

Slices	Tilts	VCP	Time*	Algs.	Usage	Limitations
	14	12	4.3 mins	AVSET SAILS	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	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 SZ-2 (Split Cut) tilts. RF only mitigated for split cuts. Limited to a single SAILS scan.

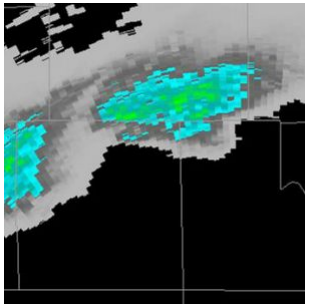
What is Dual Pol

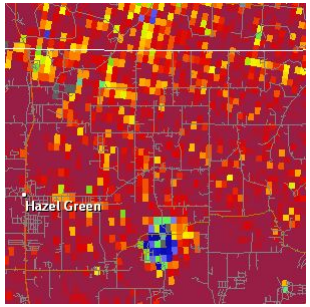
Radar stands for Radio Detection and Ranging. So it's a radio wave. The polarization refers to the orientation of the beam.

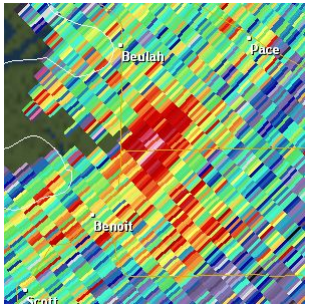


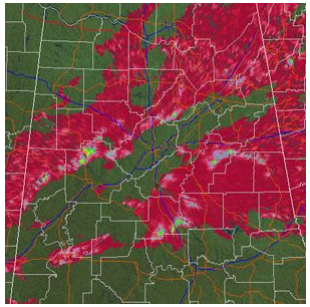


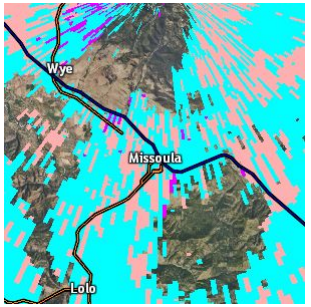
What is Dual Pol?

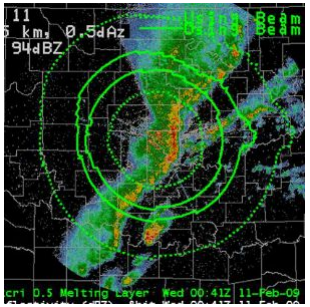




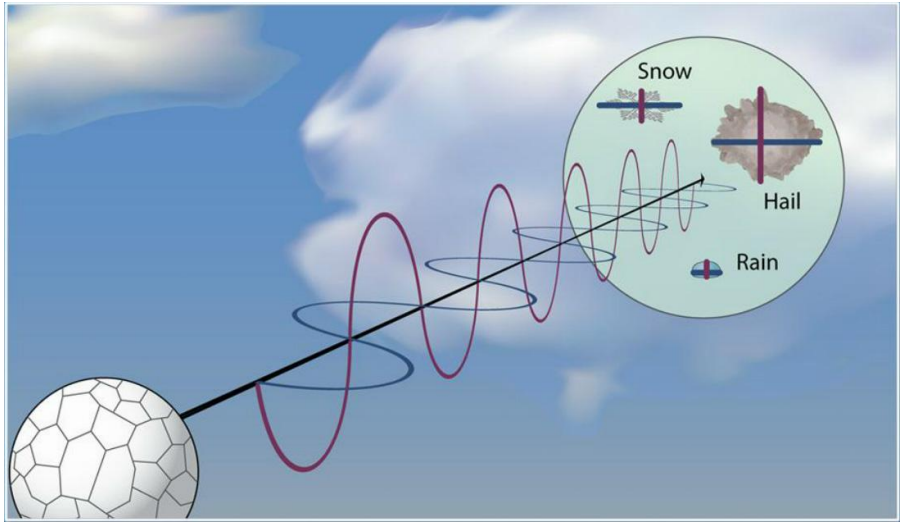








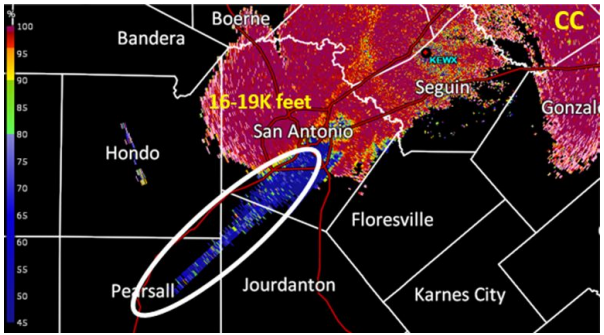
Back when NEXRAD WSR-88D was implemented, dual-pol was installed, but broader applications weren't known until 2003!

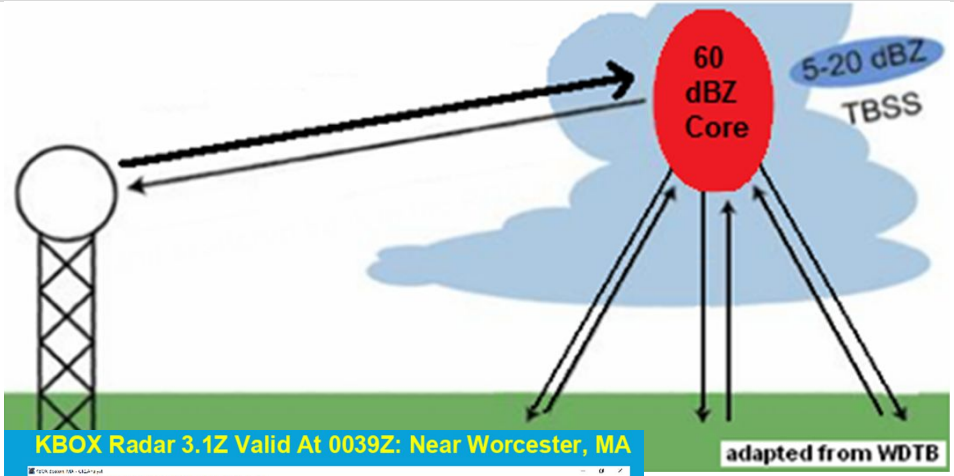


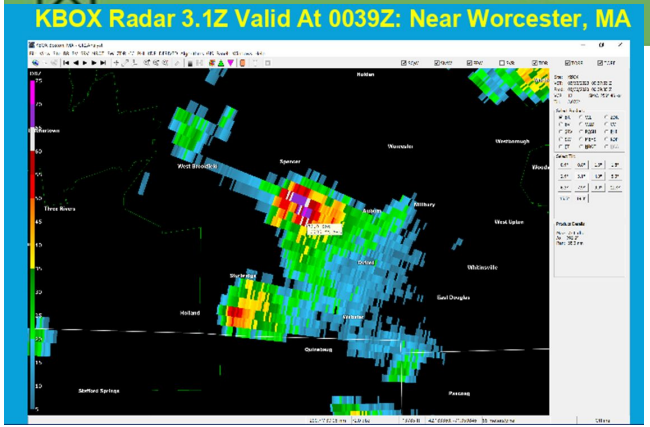
But sending a vertical and horizontal pulse open up a world of possibility.

Reflectivity Note: Hail Spike

- Hail scatters the beam differently from liquid water droplets.
- It creates all kinds of radar artifacts.
- While this makes hail detection fairly easy, the question is often severity.
- You can spot it in CC, velocity, and differential reflectivity (ZDR).

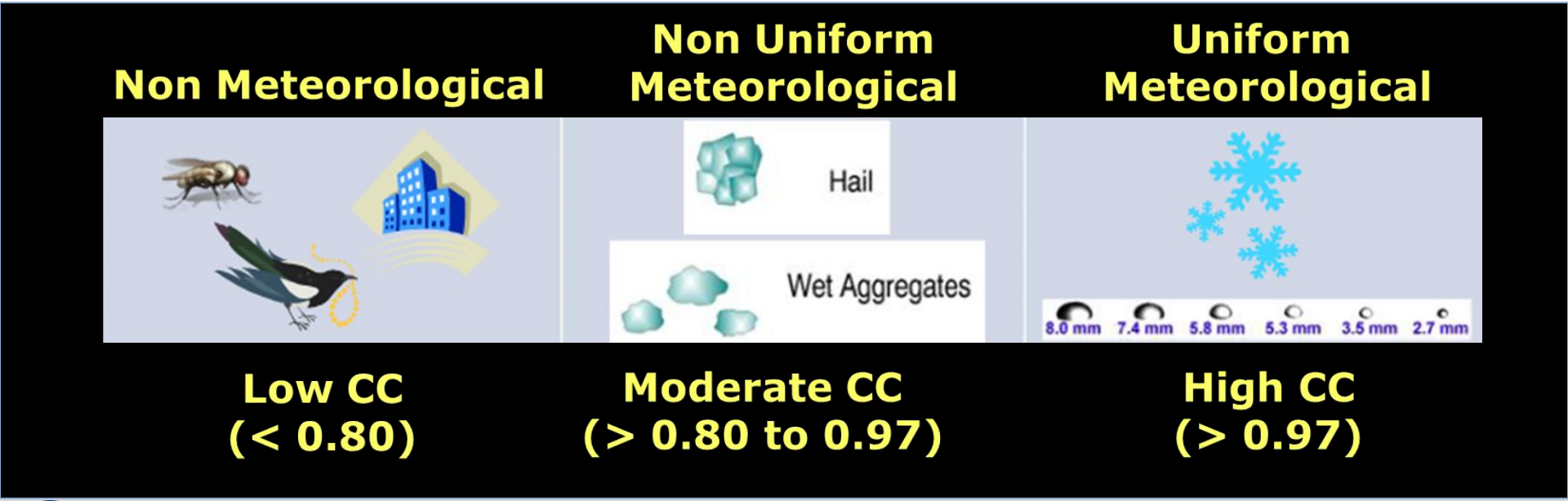






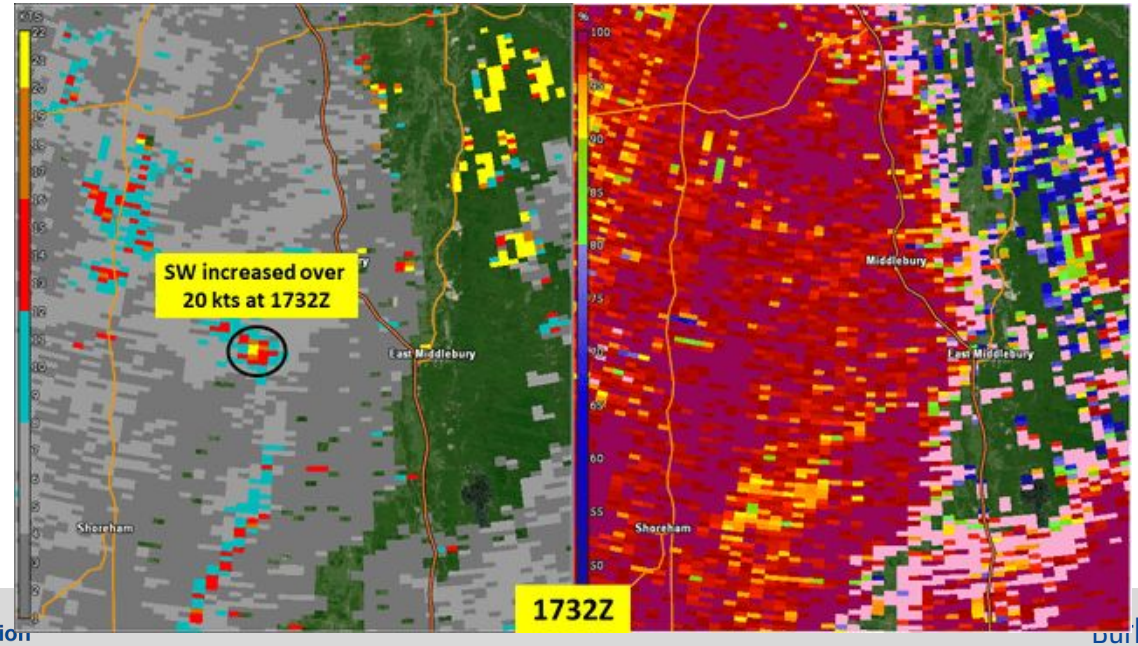
Dual Pol: Correlation Coefficient

Measures uniformity between the horizontal and vertical pulses. Correlation Coefficient answers if targets have different sizes and shapes and is best for finding melting snow, hail, and tornado debris balls (made of non-meteorological targets)



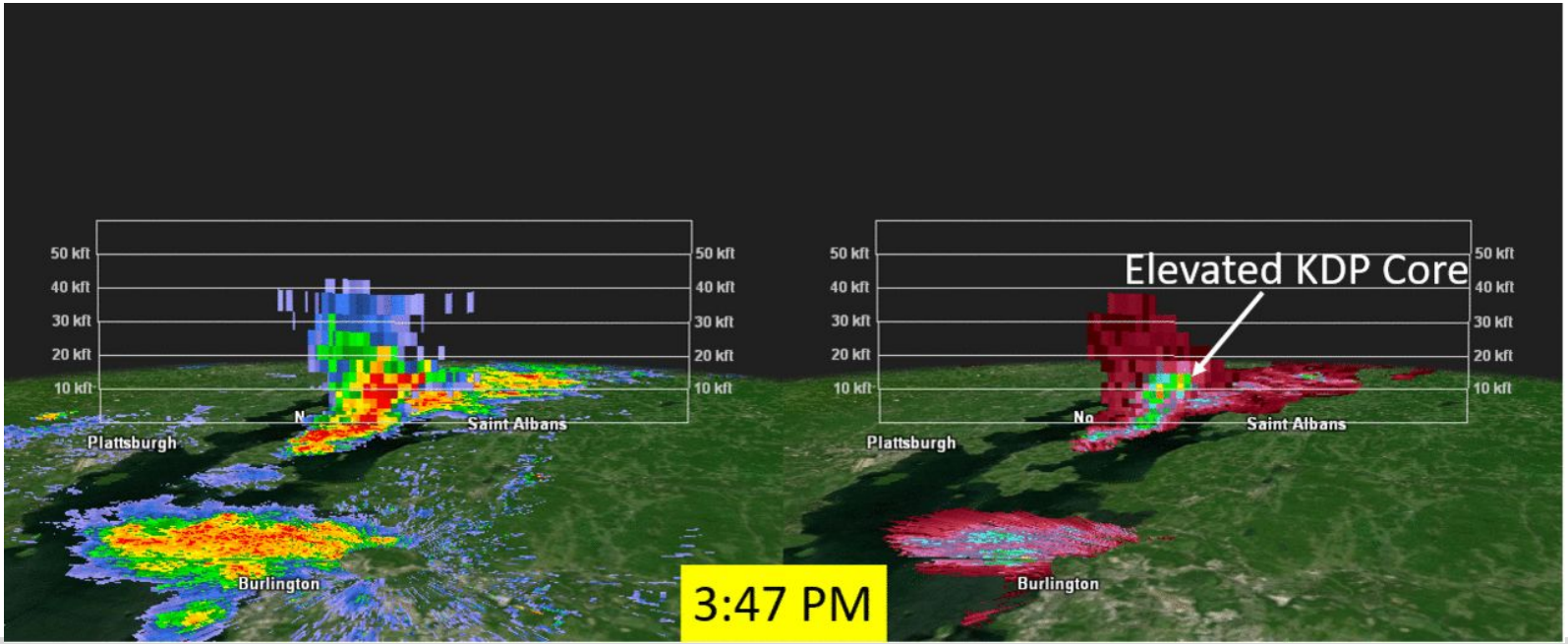
Dual Pol: Spectrum Width and Correlation Coefficient

Spectrum width measures **how variable wind speeds are and shows turbulence and shear**. With correlation coefficient, it can locate tornadoes on radar with a close eye or the leading edge of gust fronts. Here's tracking both for the rare Middlebury tornado in March 2021.



Dual Pol: KDP - Specific Differential Phase

This function of dual polarization is primarily about finding the heaviest rain. **High KDP means big drops**! One can detect wet microbursts as well if high KDP descends from the mid-levels towards the ground, like this case July 30th, 2019.



Dual Pol: Differential Reflectivity (ZDR)

This depicts the shape of the target. Positive values indicate its wider than it is tall. Near zero indicates the target is relatively equal. Negative values indicate its taller than it is wide. So hypothetically…

What is the Z_{DR} of this cow?

A. $Z_{DR} > 0$

B. $Z_{DR} = 0$

C. $Z_{DR} < 0$

Dual Pol: Differential Reflectivity (ZDR)

This depicts the shape of the target. Positive values indicate its wider than it is tall. Near zero indicates the target is relatively equal. Negative values indicate its taller than it is wide. So hypothetically…

What is the Z_{DR} of this corn cob?

A. $Z_{DR} > 0$

B. $Z_{DR} = 0$

C. $Z_{DR} < 0$

Dual Pol: Differential Reflectivity (ZDR)

This depicts the shape of the target. Positive values indicate its wider than it is tall. Near zero indicates the target is relatively equal. Negative values indicate its taller than it is wide. So hypothetically…

What is the Z_{DR} of this basketball?

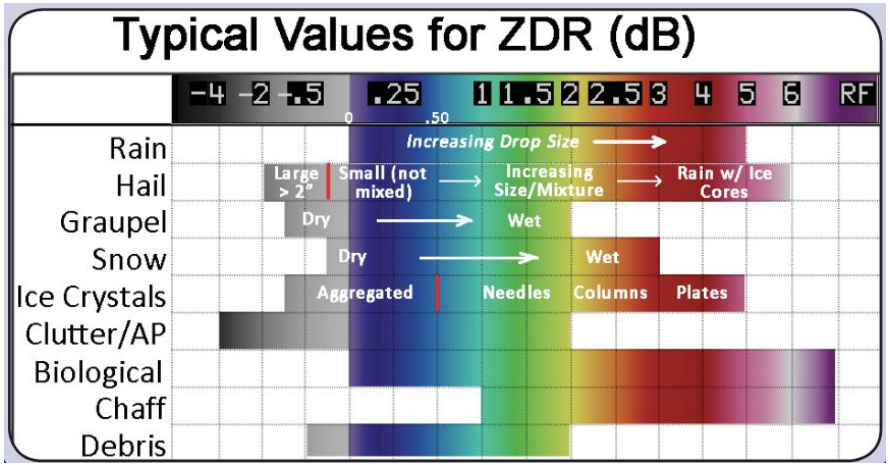
A. $Z_{DR} > 0$

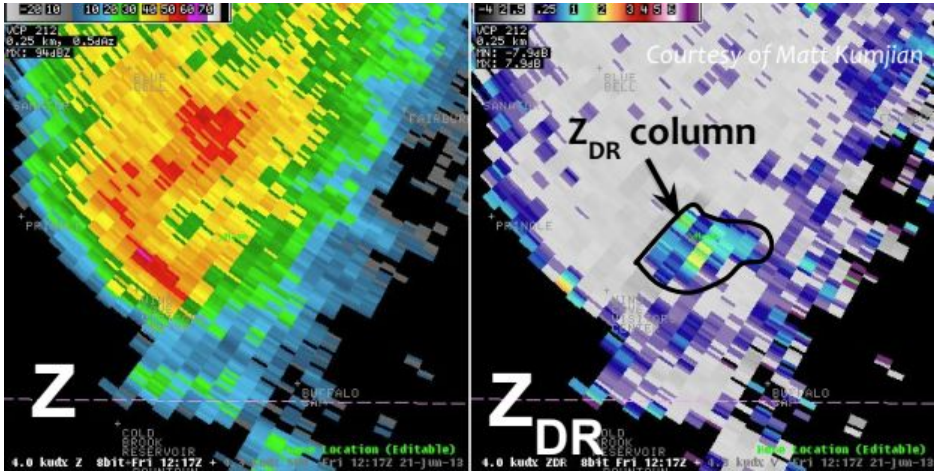
B. $Z_{DR} = 0$

C. $Z_{DR} < 0$

Dual Pol: Differential Reflectivity (ZDR)

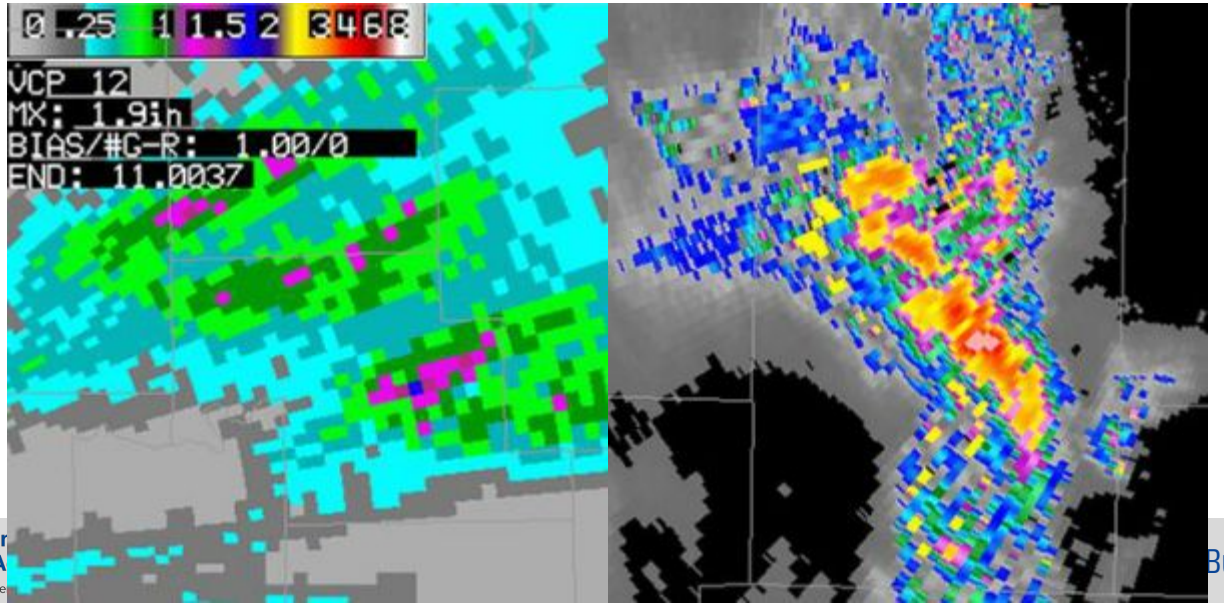
Remember that raindrops are shaped more like a hamburger. So wetter objects tend to be positive. Objects that are dry, like giant hail or dry snow are negative. Clutter also is. So if there's an area of clutter aloft in the middle of a storm, you can locate bounded weak echo regions in identifying updrafts with ZDR too. Lots of functions!





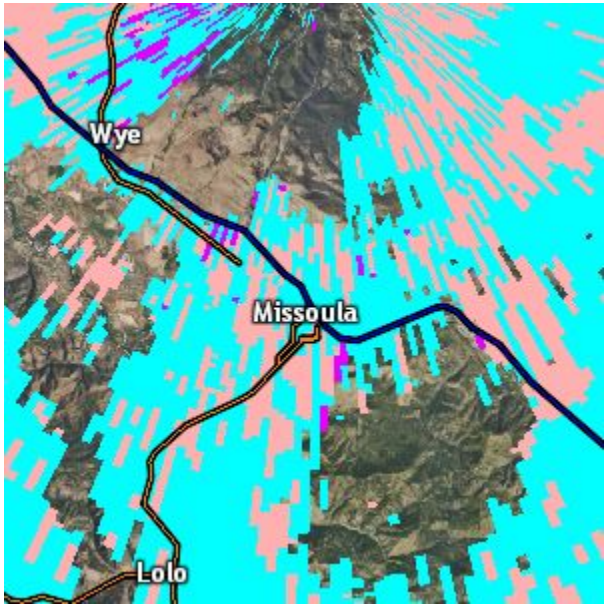
Dual Pol: Precipitation Accumulation and Rain Rates

The added depth of seeing storms in two different kinds of pulses can help precipitation estimates. It's not bias corrected at all, and we tend to notice a high bias in estimating rain in our region. It is prone to hail contamination as well. It's a tool in the belt to find the heaviest rain, but we're not often making decisions solely based on these.



Dual Pol: Hydrometeor Classification

Based on polarity, dual pol can estimate precipitation type. We usually don't rely on this too much, but it can be handy in pointing out non-meteorological targets if there's anything that may cause confusion.



Multi-Radar, Multi-Sensor (MRMS)

Using More Than One Radar at Once

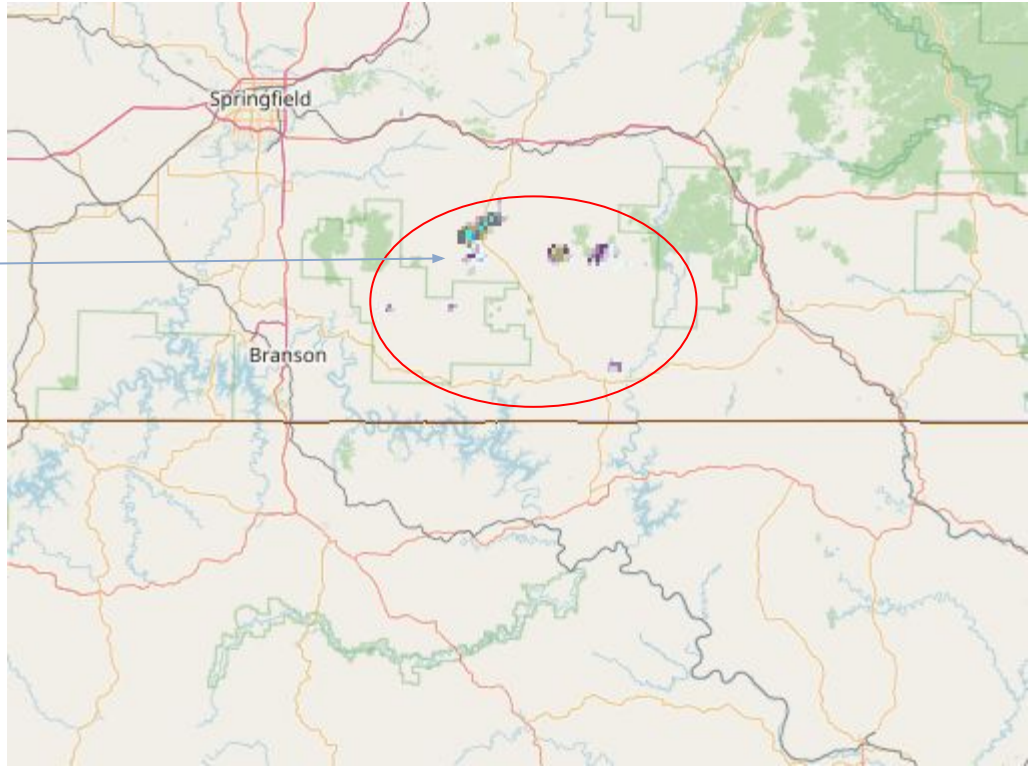
You can make some more refined measures by applying multiple radars to a storm. Here's some of the applications.

- *Composite Reflectivity Based on several radars (overcomes cone of silence)*
- *Estimated Streamflow (Important for Flash Flood detection)*
- *Maximum Estimated Hail Size & Vertically Integrated Ice*
- *Maximum Azimuthal Shear (Finding Supercells and Gust Fronts)*
- *More Radar Precipitation Estimates!*
- *Even algorithms to estimate severe thunderstorm potential*

MRMS: Finding Reflectivity at Specific Thresholds

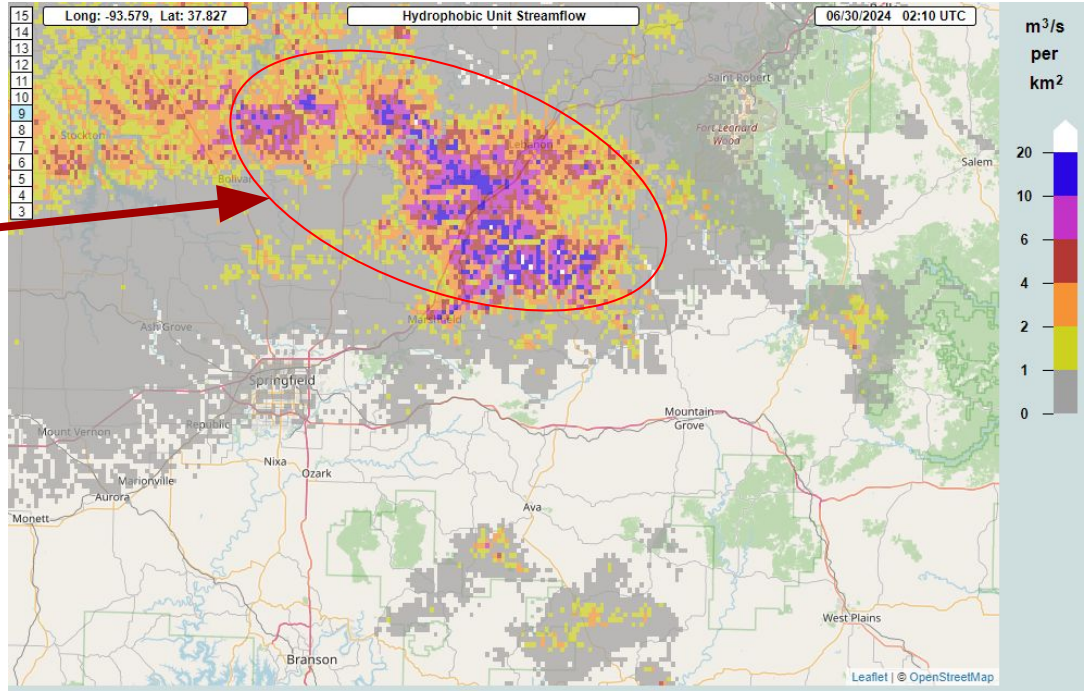
- You can look at slices like what if you have 50 dBZ above the freezing layer. You're likely to have lightning if you start observing these numbers. So if none is occurring, you can get some lead time on lightning development. But not airtight.

- You can also look at -20 C for these values to forecast hail potential.



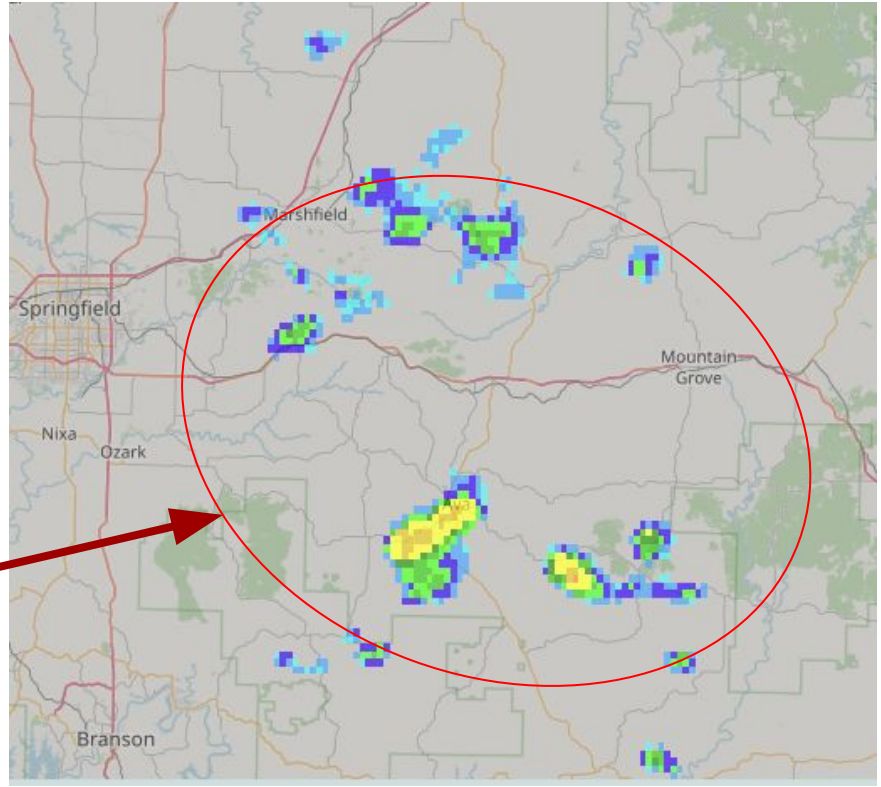
MRMS: Streamflow

- Uses the MRMS rainfall estimates and basin geography in its model to forecast where excess water is.
- Extremely useful for flash flood detection.
- There are 3 primary models for different situations:
  - CREST - Normal
  - SAC-SMA - Complex Basins
  - Hydrophobic - Burn Scars or Saturated Soil



MRMS: MESH

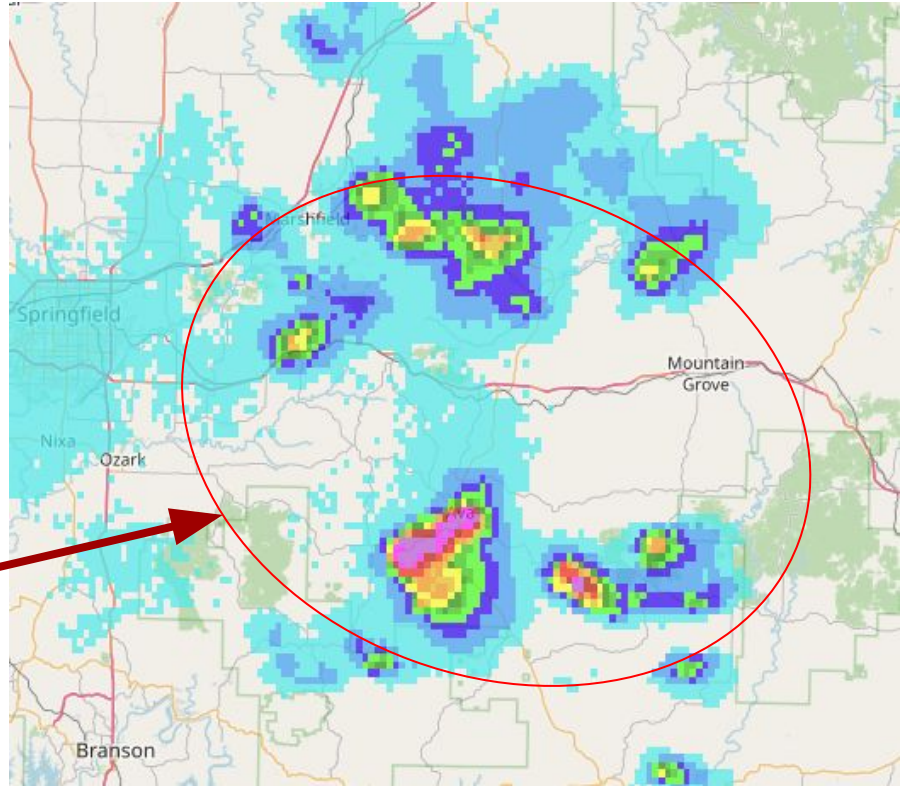
- You can use these to estimate how large hail is and the size of the hail core.
- Tends to overestimate hail size. We usually knock off a quarter inch off its estimated value.
- Struggles on days we have graupel or tiny hail in early spring.
- These values are around 0.33-0.67” (pea to dime size hail)



MRMS: Vertically Integrated Ice

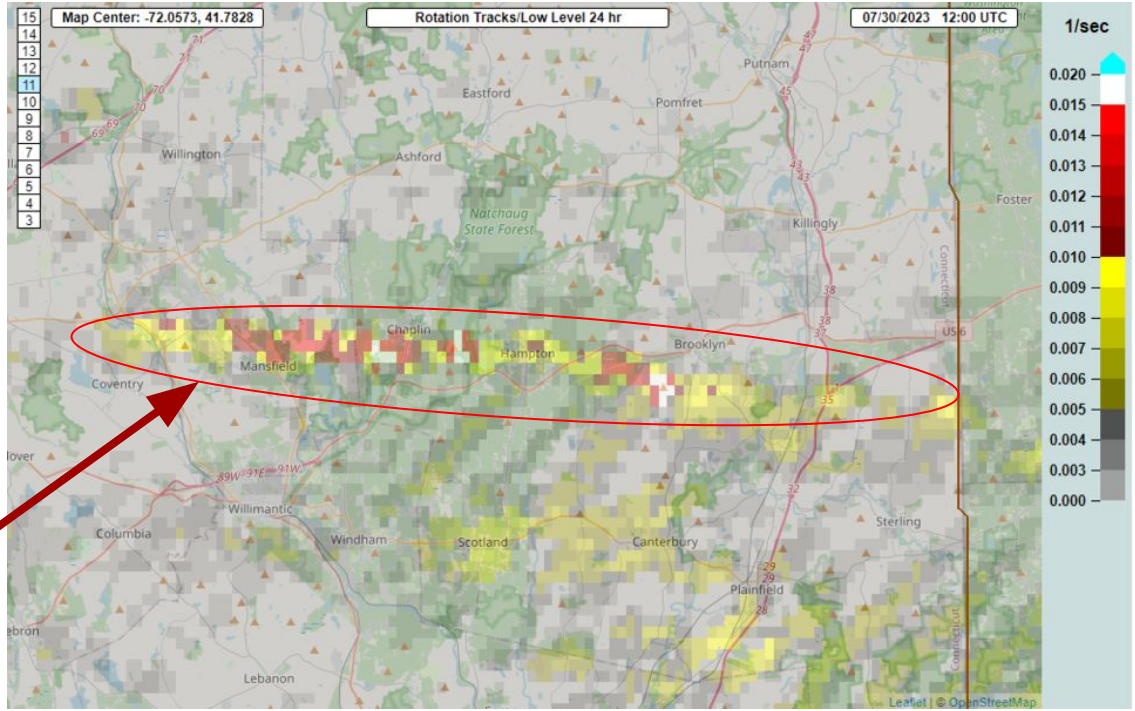
Vertically Integrated Ice

- You can use these to estimate how large hail is and the size of the hail core.
- Find storms with most water and ice loading. More likely to produce hail and downburst winds.



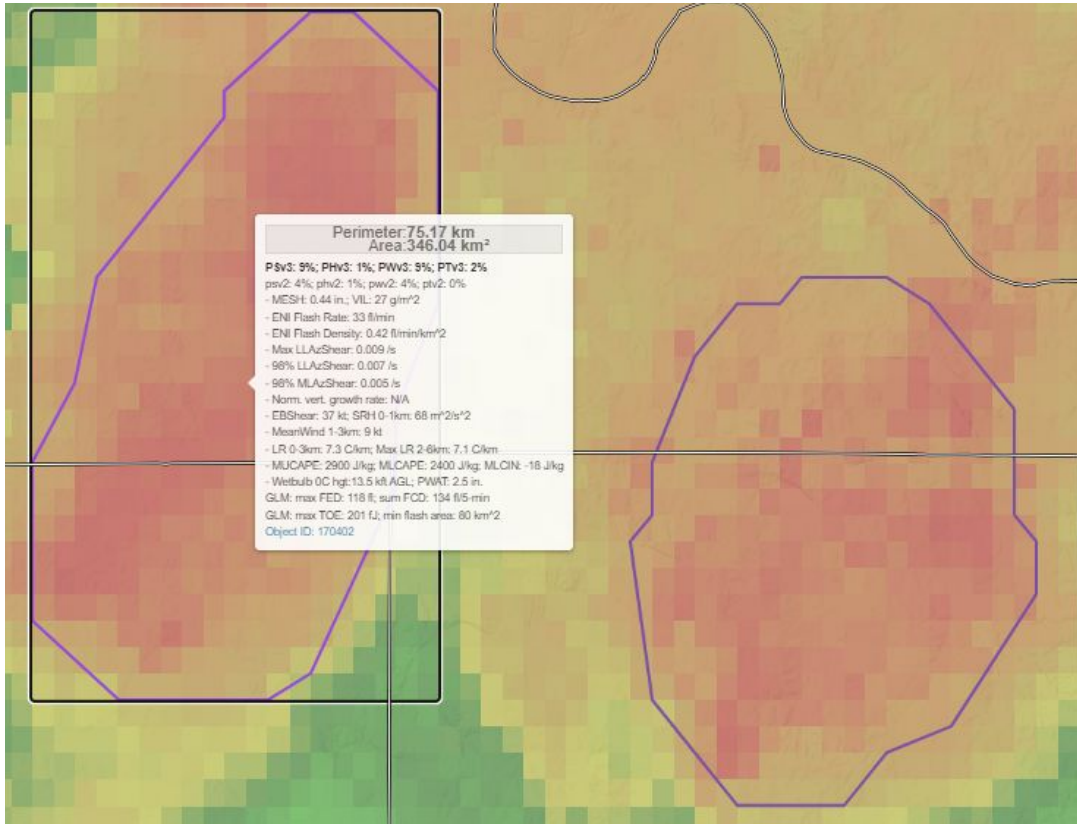
MRMS: Azimuthal Shear Tool

- Let's say you walk in to a lot of supercells and must make snap judgments which will make a tornado first.
- This can help you quickly locate the one with the greatest amount of spin.
- You can stitch these together to make rotation tracks. Helpful for hunting down tornado paths if reports are spotty.
- Can also appear along squall lines.



MRMS: ProbSevere

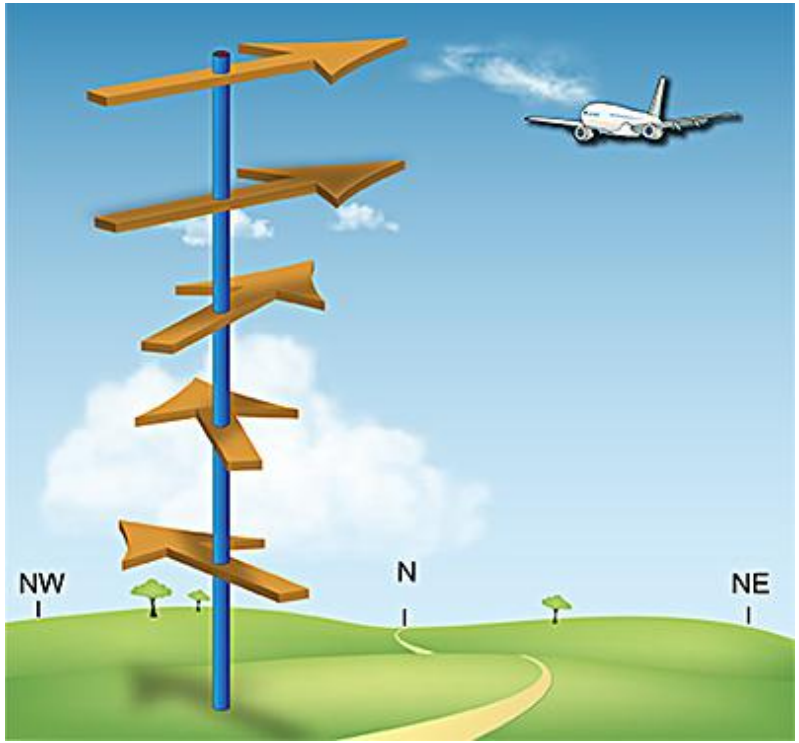
- Sucks in all the different MRMS parameters to forecast the probability a storm is producing severe winds, severe hail, or a tornado.
- Another helpful way to rank which storms are the most likely to be severe or causing tornadoes.
- It's not perfect, but a great tool to have.

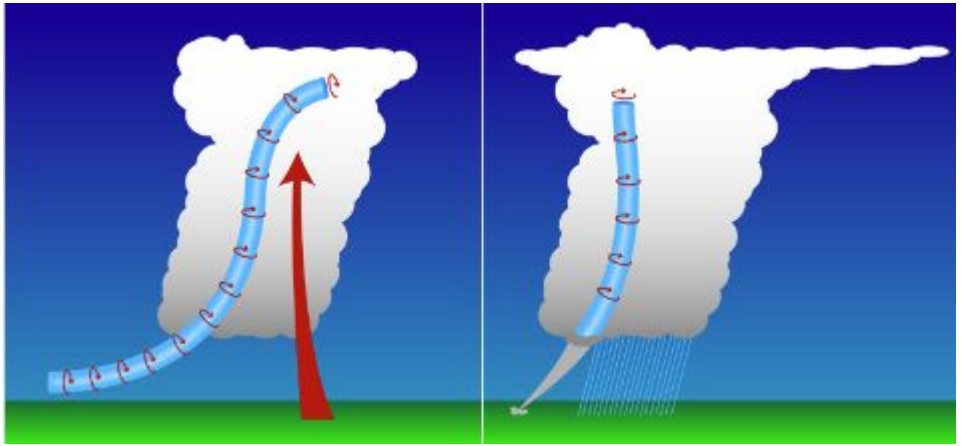


How Do We Forecast What Storms Might Do?

- We closely look at what is changing as storms track in different places at different time.
  - Radar and satellite trends
- We get a sense for the environment and how that will affect how storms could behave.
  - Soundings and mesoanalysis (boundary hunting)
- Models are never perfect, but they give us ideas of how things evolve.

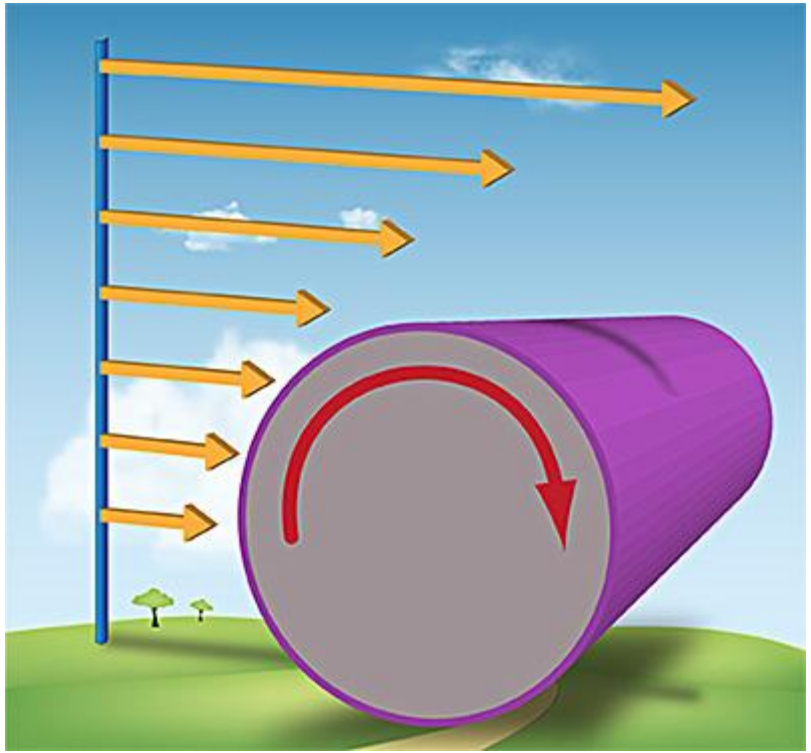
Directional Shear

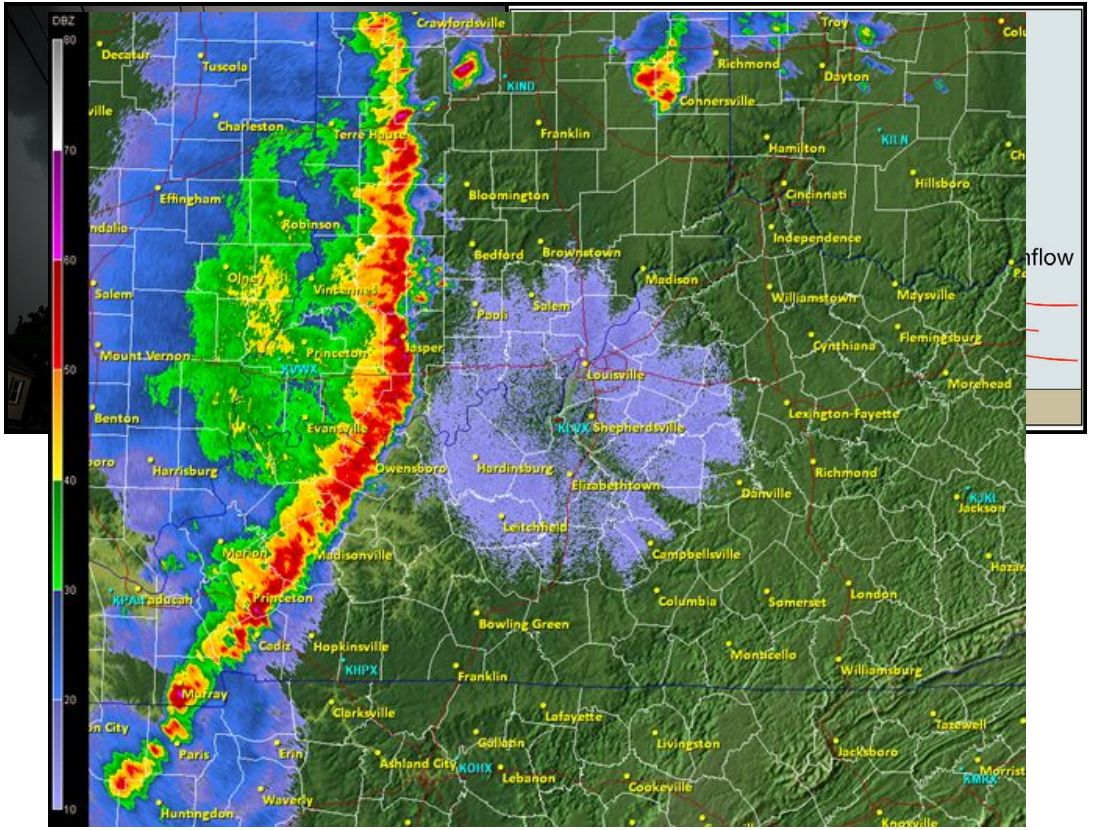




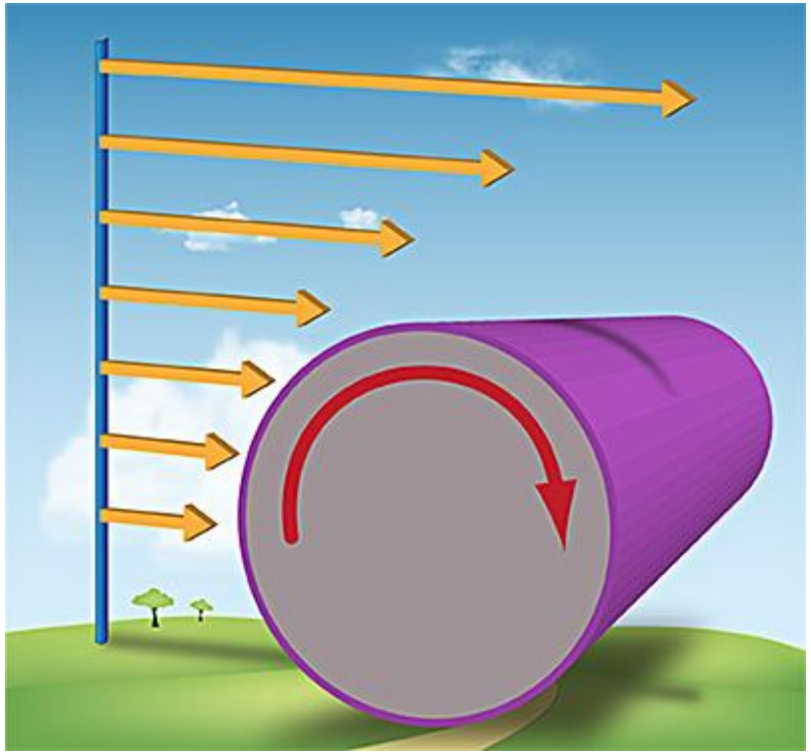
- Turning winds ideal for supercells
- Bowing segments in lines
- Can be supportive of derechos in extreme instability

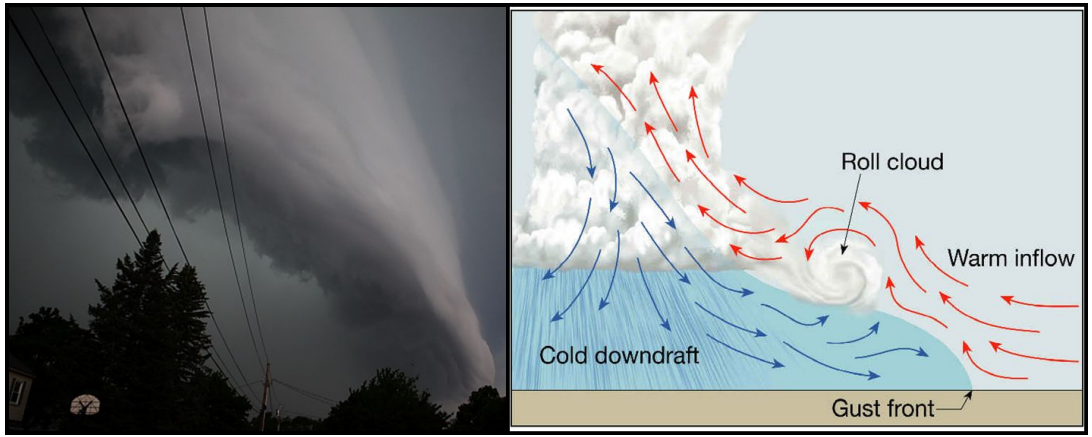
Unidirectional (Speed) Shear





Unidirectional (Speed) Shear



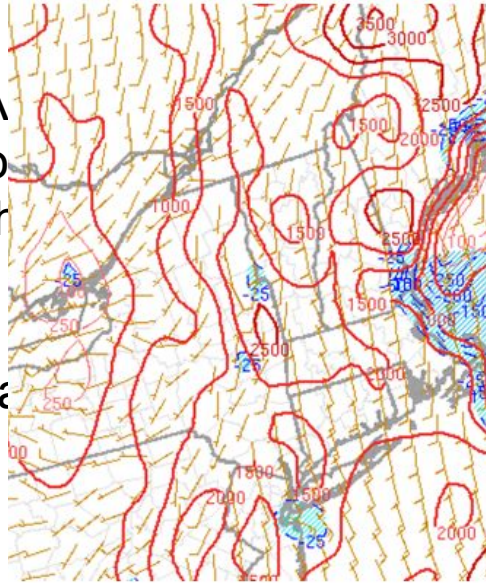


- **High speed over top gust fronts create rolls.**
- **If shear and instability are well balanced, this produces those really long line of thunderstorms.**

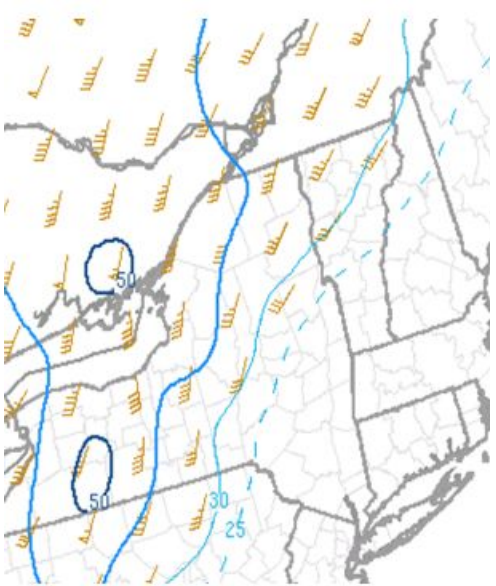
Using Mesoanalysis Tools

- If you've ever read our storm write ups, you will almost always find a RA mesoanalysis map. Like our review o the significant microburst over Moriah NY in August 2022.

- We closely watch the balance of shea and instability to determine whether storms will strengthen and what severe hazards to anticipate.



CAPE and CIN

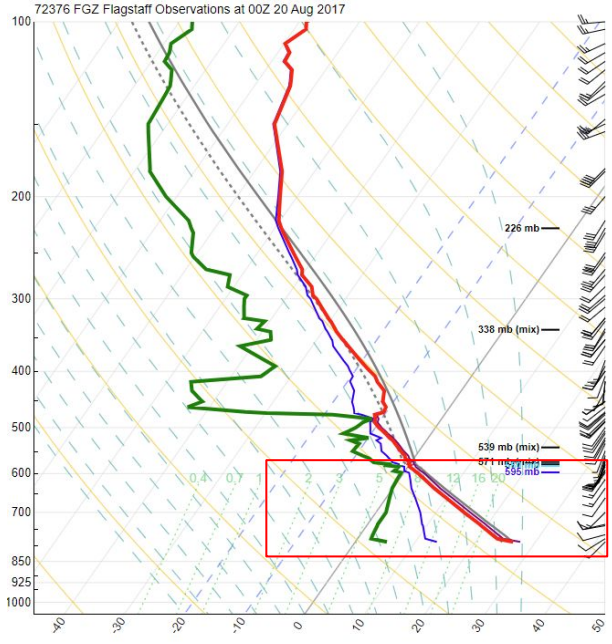


0-6km Shear

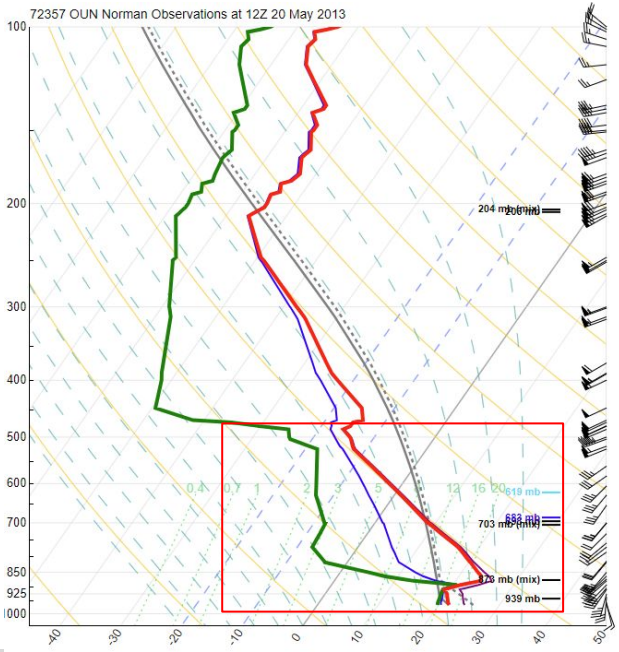
Mesoanalysis: Skew-Ts

- Certain kinds of sounding profiles are associated with severe weather. Look out for steep red curves, dry air, wind profiles, if it could be unstable, etc.

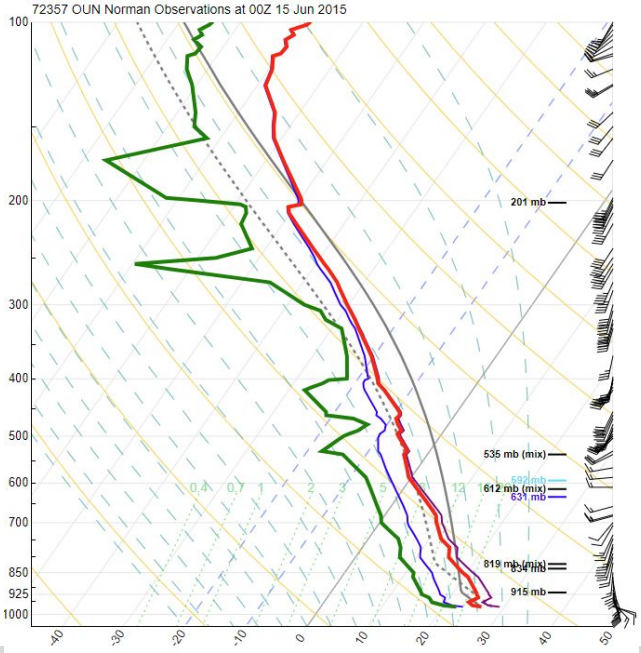
Inverted V



Loaded Gun

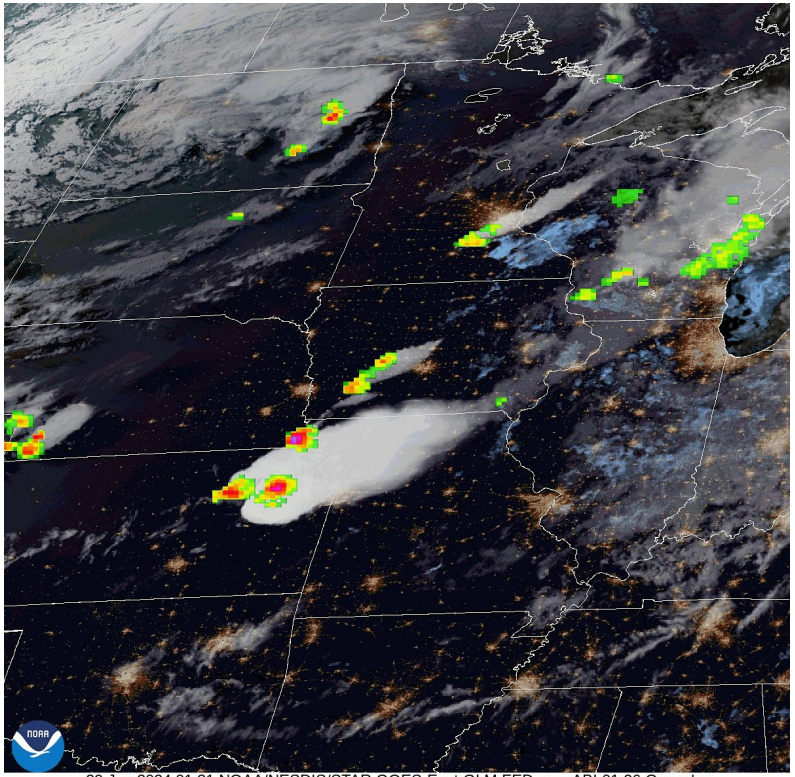


Wet Microburst



Satellite Functions

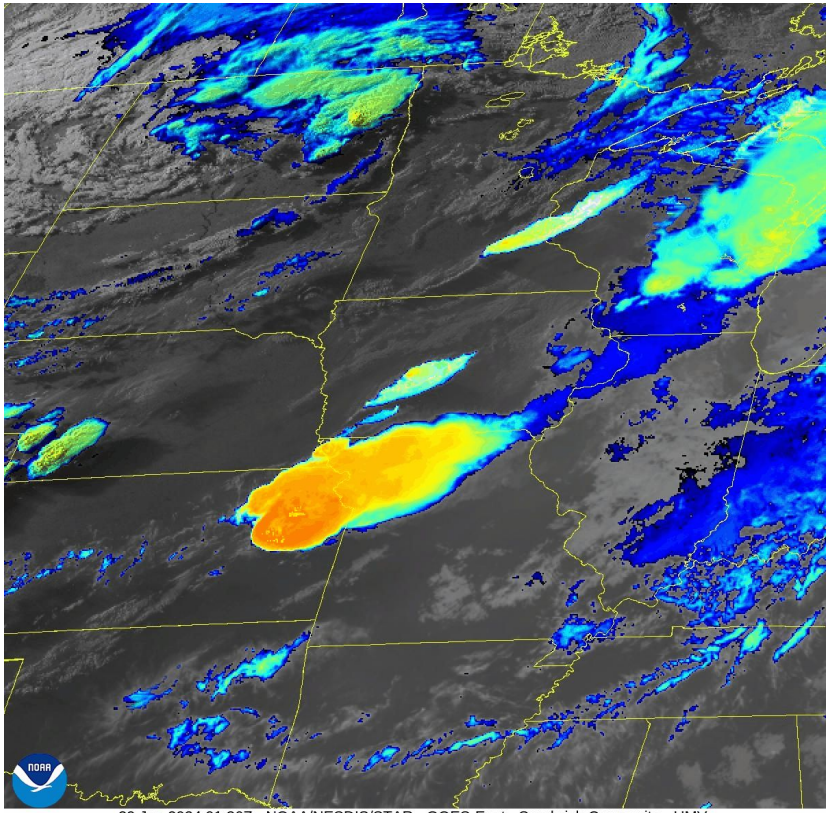
- Global Lightning Mapper creates a background brightness map and uses changes in it to detect whether lightning is occurring from space!
- Increases in lightning can help locate the strengthening storms.
- We also use ground networks, but if they fail, we also have satellite capabilities!



29 Jun 2024 01:31 NOAA/NESDIS/STAR GOES-East GLM FED over ABI 01:26 Geocolor

Satellite Functions

- Thunderstorm evolution can be observed by changes in the representation of clouds on satellite. We look for changes in structure to forecast intensification or weakening.
- You can pick out features like overshooting tops in strong convection. Conversely if cloud tops are lowering, you can assume your thunderstorm's updraft is failing.

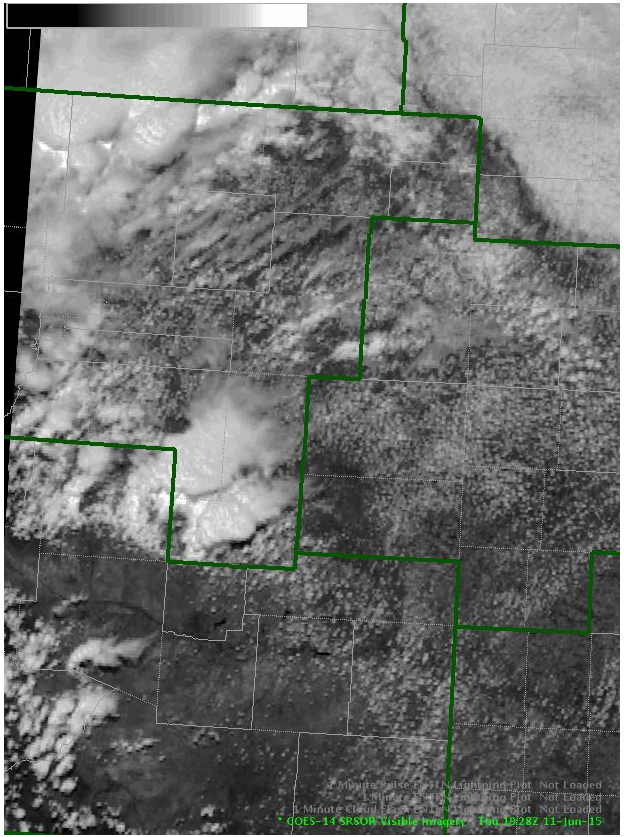


29 Jun 2024 01:36Z - NOAA/NESDIS/STAR - GOES-East - Sandwich Composite - UMV

Satellite Functions

- Visible satellite imagery has the highest resolution. You can find boundaries like this gust front at the foothills of the Rockies.

- With one minute data, we can track the speed of outflow boundaries even, and have even issued warnings based on cloud motions in visible satellite imagery.



The Importance of Reference Sheets and Local Study

Wind

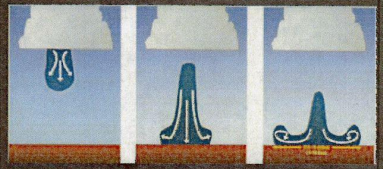
Near Storm Environment

Storm Characteristics

Individual Cell Downburst/Microburst

Wet Microburst:
- Wet microburst severity index (WMSI) > 80
- Microburst composite (MBCP) ≥ 5-8
- 0-3 km max theta-e difference ($\Delta\theta_e$) > 25°C
- Surface-based CAPE (SBCAPE) ≥ 3100 J/kg
- Downdraft CAPE (DCAPE) ≥ 900 J/kg
- Precipitable water (PW) ≥ 1.5"

Dry Microburst:
- Inverted-V sounding (apex based in mid-levels)
- Most unstable CAPE (MUCAPE) > 0 J/kg
- 100-mb mean parcel LCL height > melting level
- Weak effective bulk wind difference (EBWD)
- Weak boundary layer winds
- 0-3 km lapse rate (LR_{0-3}) ≥ dry adiabatic

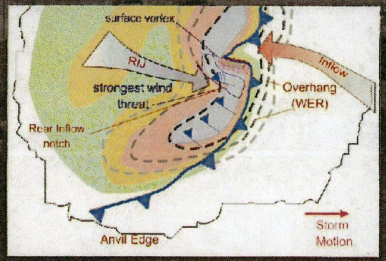


- Rapid formation of strong core aloft
- Descending core bottom
- Mid-altitude radial convergence (MARC) (0°C to lifted condensation level (LCL)) ΔV > 15 kt
- Wet hail signature (Three-Body Scatter Spike (TBSS), CC ~ 0.93-0.96, KDP > 3°C/km)
- Low-level (< 1500 ft AGL) velocity (V) > 30 kt

Note: Beware of low reflectivity (Z) cells w/high lifted condensation levels (LCLs) at 0°C and/or strong wind in mixing layer

Quasi-Linear Convective System (QLCS)/Derecho/Cold-Pool Driven

- Derecho composite parameter (DCP) > 2
- Downdraft CAPE (DCAPE) > 980 J/kg
- 0-6 km mean wind > 16 kt
- Most unstable CAPE (MUCAPE) > 2000 J/kg
- Effective bulk wind difference (EBWD) > 20 kt



- Strong leading reflectivity (Z) gradient
- Bow echo
- Rear inflow jet (RIJ)
- Mid-altitude radial convergence (MARC) ΔV > 50 kts at 3-5 km AGL
- Deep convergence zone (DCZ) > 10 kft
  - > 15-20 kft is optimal
- Gust front hugs close to reflectivity (Z) gradient
- Linear weak echo region (WER) along leading edge
- Fast storm motion

Note: A mesovortex w/RIJ produces strongest wind

The Importance of Reference Sheets and Local Study

Hail

Near Storm Environment

Storm Characteristics

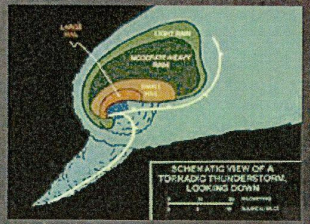
Severe (≥ 1-inch)

- Large hail parameter (LHP) > 4
- Most unstable CAPE (MUCAPE) ≥ 1600 J/kg
- Effective bulk wind difference (EBWD) ≥ 29 kt

- Discrete thunderstorm
- Weak echo region (WER)
- 50 dBZ thickness above the melting level ≥ 16 kft
- Reflectivity (Z) ≥ 60 dBZ
- Correlation coefficient (CC) = 0.93-0.97
- Three body scatter spike (TBSS)
- Storm-top divergence (STD) ΔV > 70-102 kt
- Hail detection algorithm (HDA) ≥ 1"
- Max estimated size of hail (MESH) ≥ 1"

Significant (≥ 2-inch)

- Significant hail parameter (SHIP) > 1
- Large hail parameter (LHP) ≥ 5
- Most unstable CAPE (MUCAPE) ≥ 1850 J/kg
- Effective bulk wind difference (EBWD) ≥ 39 kt
- 700-500 mb lapse rate (LR_{7-5}) ≥ 6.5°C/km
- Surface to equilibrium level bulk shear ($Shear_{EL}$) ≥ 46 kt



- Discrete supercell
- Bounded weak echo region (BWER)
- Updraft persists ≥ 30 min
- 60 dBZ above -20°C
- Correlation coefficient (CC) ≈ 0.7-0.9
- Differential reflectivity (ZDR) ≈ 0 dB
- Storm-top divergence (STD) ΔV > 130-162kt
- Peak rotational velocity (Vr) > 27-41 kt
- Hail detection algorithm (HDA) ≥ 2"
- Max estimated size of hail (MESH) ≥ 2"

Giant (≥ 4-inch)

- Large hail parameter (LHP) ≥ 8
- Most unstable CAPE (MUCAPE) ≥ 3000 J/kg
- Effective bulk wind difference (EBWD) ≥ 46 kt
- 700-500 mb lapse rate (LR_{7-5}) ≥ 7.0°C/km
- Surface to equilibrium level bulk shear ($Shear_{EL}$) ≥ 60 kt

- Storm-top divergence (STD) ΔV > 233-267 kt
- Peak rotational velocity (Vr) > 39-56 kt

The Importance of Reference Sheets and Local Study

Radar Estimated Hail Type/Size

Storm-Top Divergence

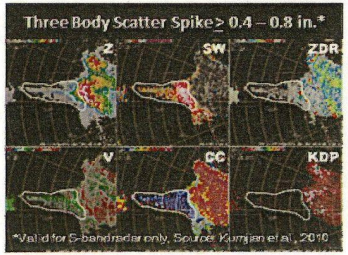
Peak V (kts)	Max Hail Size (in.)
70-102	Quarter (1")
115-147	Golf ball (1.75")
174-207	Baseball (2.75")
233-267	Softball (4")

Adopted from Witt and Nelson, 1991

Mesocyclone

Hail Size (in.)	Peak Rotational Velocity (kt)
1.75" to 2.00"	27-41
≥4"	39-56

Source: Blair et al., 2011



DUAL-POL RADAR HAIL SIGNATURES

Z:
45-59 dBZ = Hail poss
≥60 dBZ = Hail likely

ZDR:
-0.3 to 1 dB ≈ Dry or large hail
> 1 dB ≈ More liquid

CC:
0.93 - 0.97 ≈ 1-2" hail
0.70 - 0.90 ≈ ≥2" hail

KDP:
<1°/km ≈ Mostly dry hail
>3°/km ≈ Rain/hail combo or melting hail

Hail Event Type	Signature	
Severe Hail (with little rain)	Z > 55 dBZ	ZDR < 1 dB
	CC ≈ 0.95-0.97	KDP < 1°/km
Severe Hail Mixed w/Rain	Z > 55 dBZ	ZDR ≈ 1-2 dB
	CC ~0.93-0.96	KDP > 0.5°/km
Sub-Severe Dry Hail	Z ≈ 45-55 dBZ	ZDR ≈ 0 dB
	CC > 0.98	KDP ≈ 0°/km
Sub-Severe Melting Hail	Z > 55 dBZ	ZDR > 2 dB
	CC ≈ 0.92-0.96	KDP > 4-5°/km
Significant (≥2") Hail	Z > 55 dBZ (>45 dBZ)	ZDR ≈ 0 dB or lower
	CC < 0.9 (possibly 0.7)	KDP not displayed

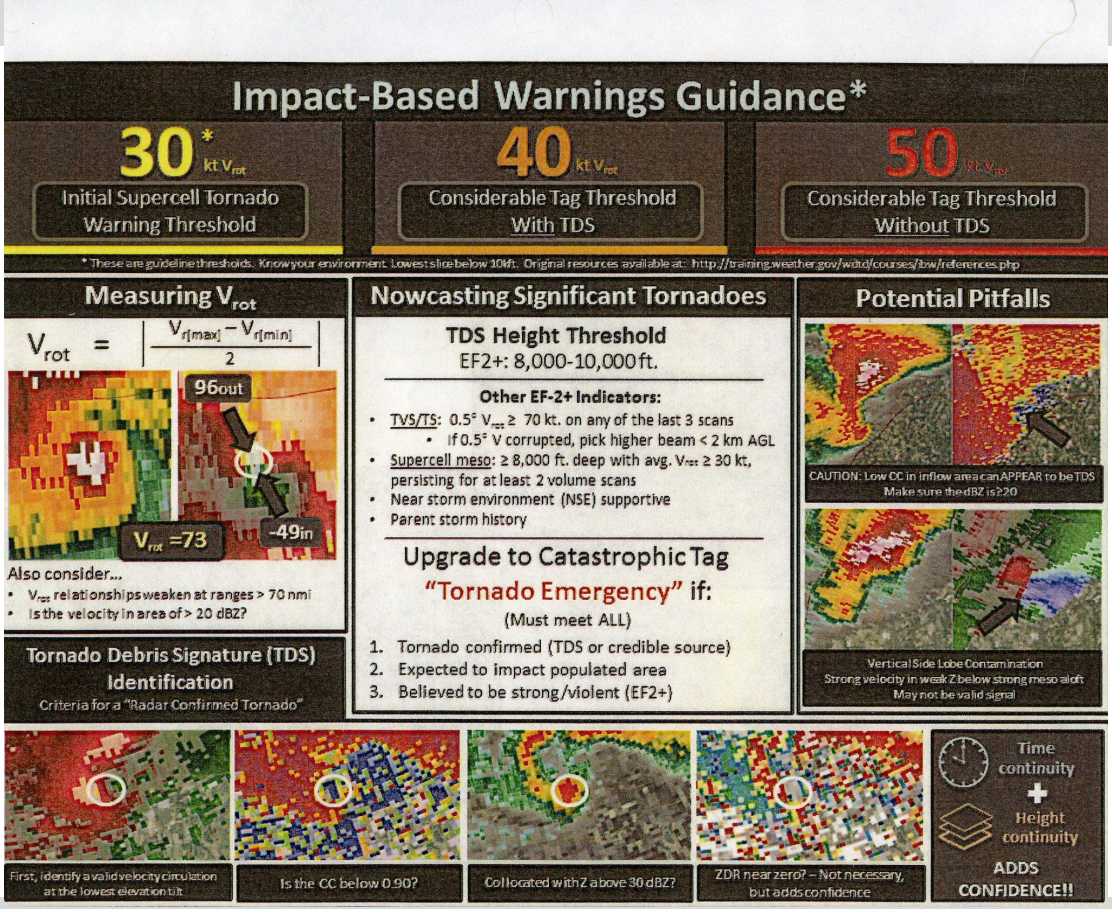
Severe (1") Hail Warning Criteria:

50-dBZ Echo Height Above the Melting Level

Melting Level	50 dBZ height 25th Percentile
6500	22000
7000	23000
7500	24000
8000	24900
8500	25900
9000	26900
9500	27900
10000	28800
10500	29800
11000	31900
11500	32900
12000	33900
12500	34900
13000	35800
13500	36800
14000	37800
14500	38800

Source: Cavanaugh and Schultz, 2012

The Importance of Reference Sheets and Local Study



The Importance of Reference Sheets and Local Study

From our own region - Taber, Duell, and LaRocca study for BTV

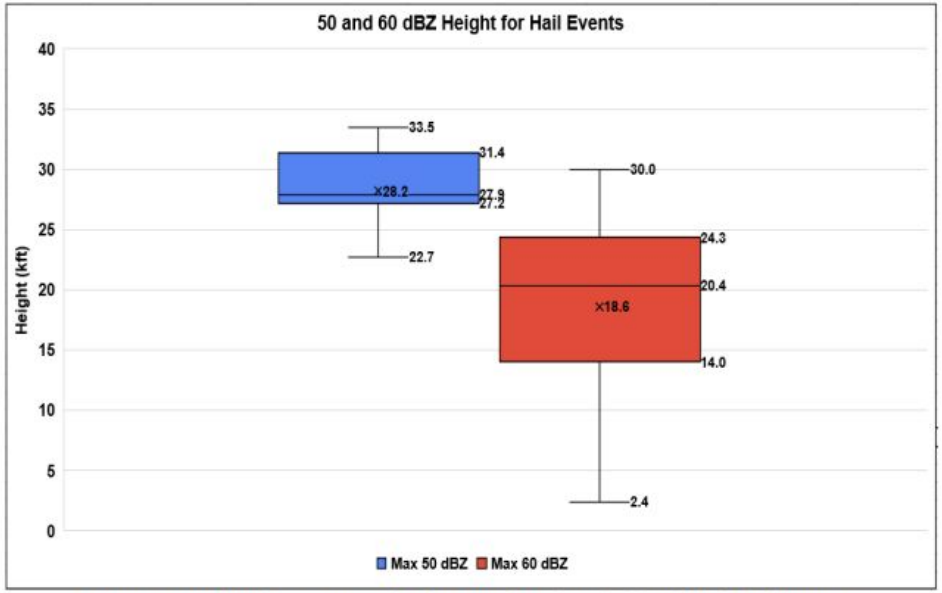


Figure 12: As in Fig. 6, except for the 50 and 60 dBZ height (kft) for hail events.

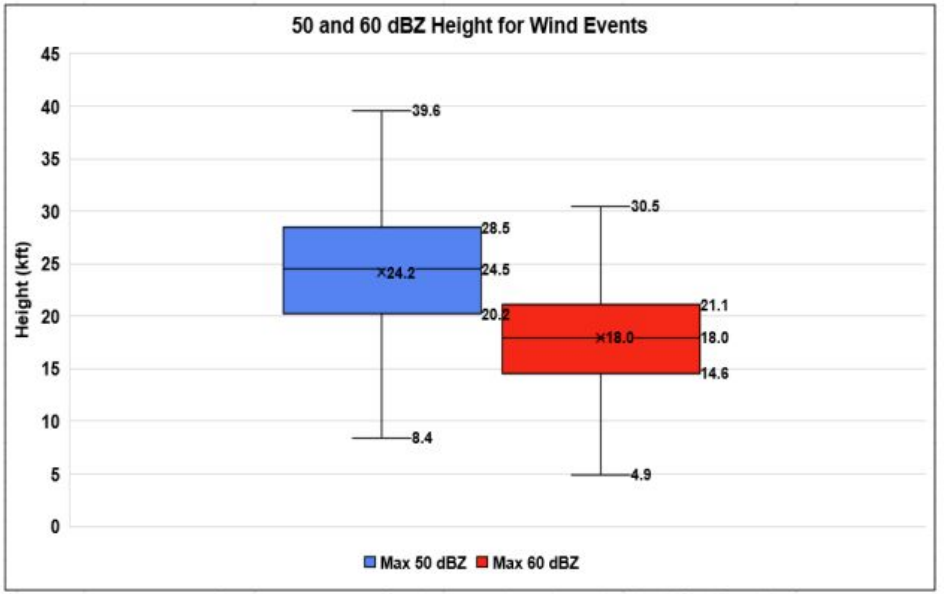


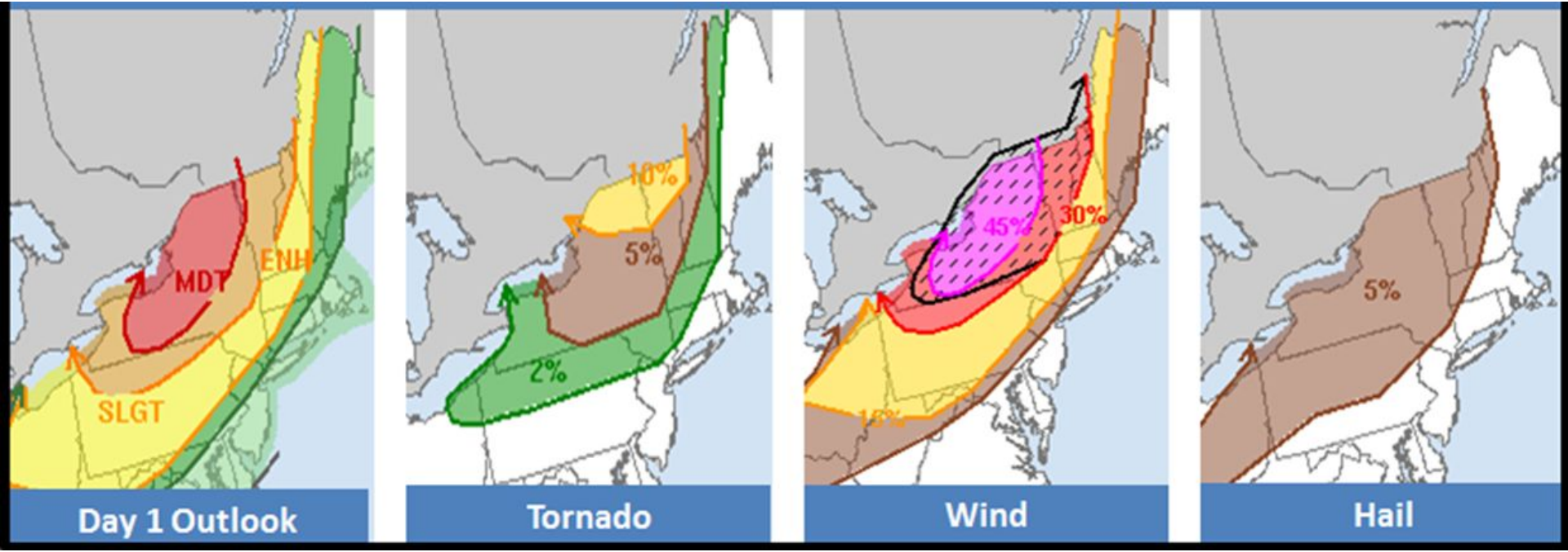
Figure 13: As in Fig. 6, except for the 50 and 60 dBZ height (kft) for wind events.

These are powerful tools to establish a baseline when we consider warnings.

Let's Analyze a Couple Severe Events in our Area

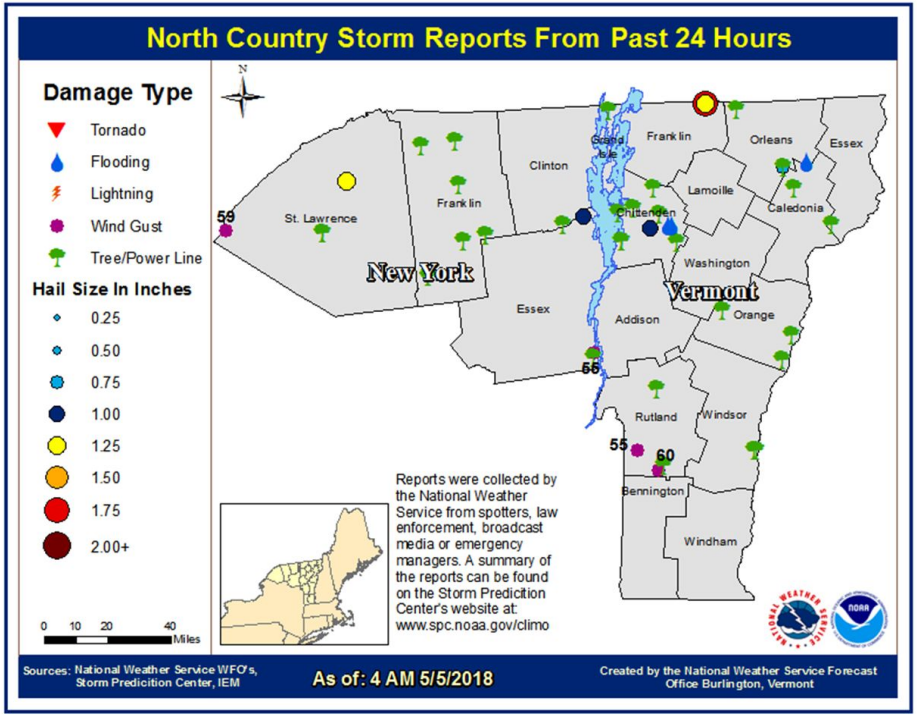
May 4th, 2018 Severe Weather

- Moderate Outlook from SPC was the first time since 2012.



May 4th, 2018 Severe Weather

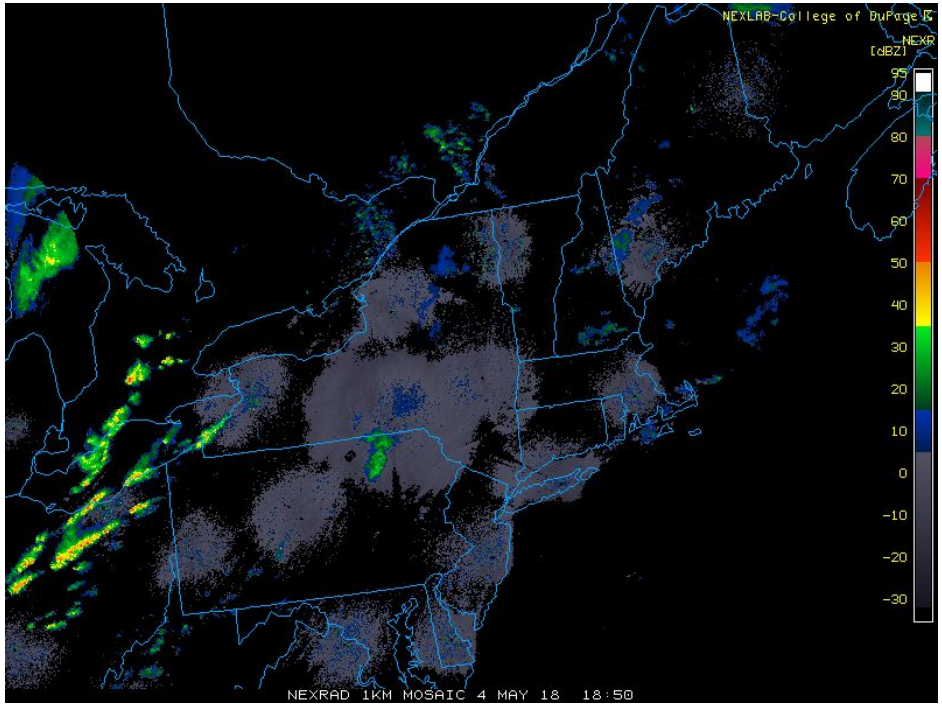
- Widespread damage and some hail across the region.




Uprooted trees in Shelburne, VT

May 4th, 2018 Severe Weather

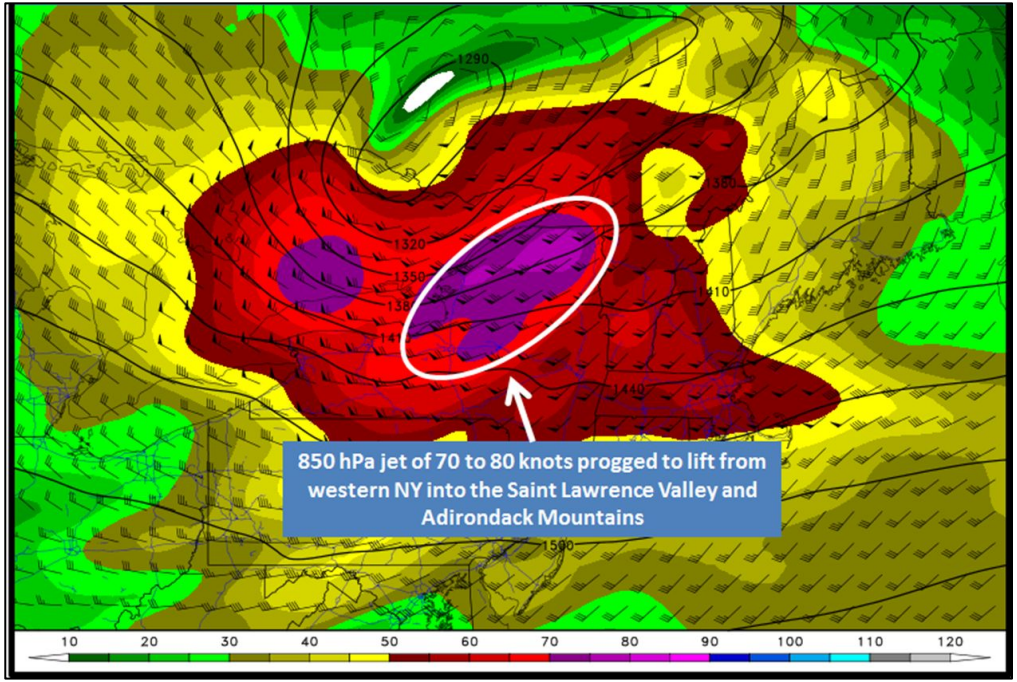
- Widespread damage and some hail across the region.

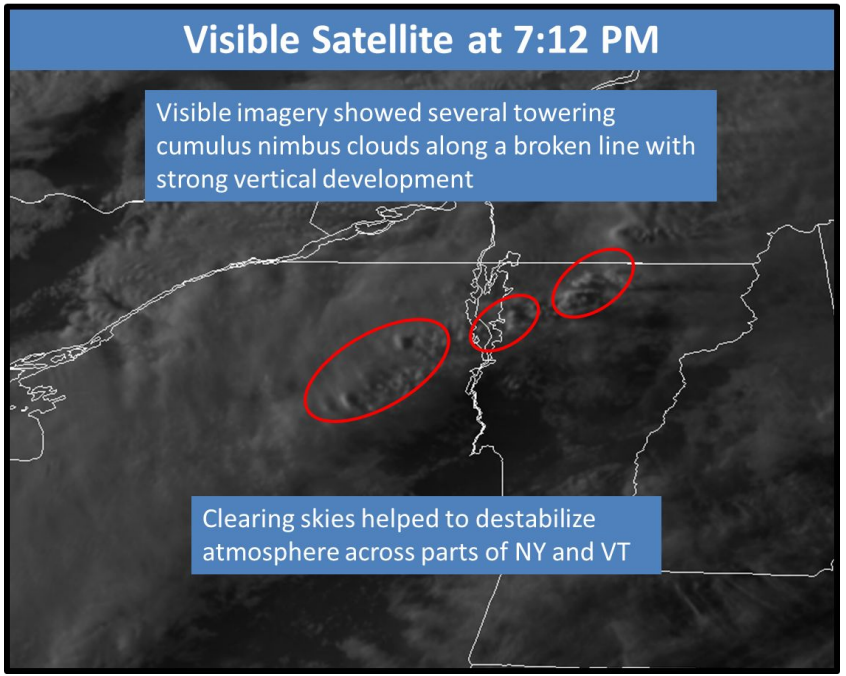



Uprooted trees in Shelburne, VT

May 4th, 2018 Severe Weather

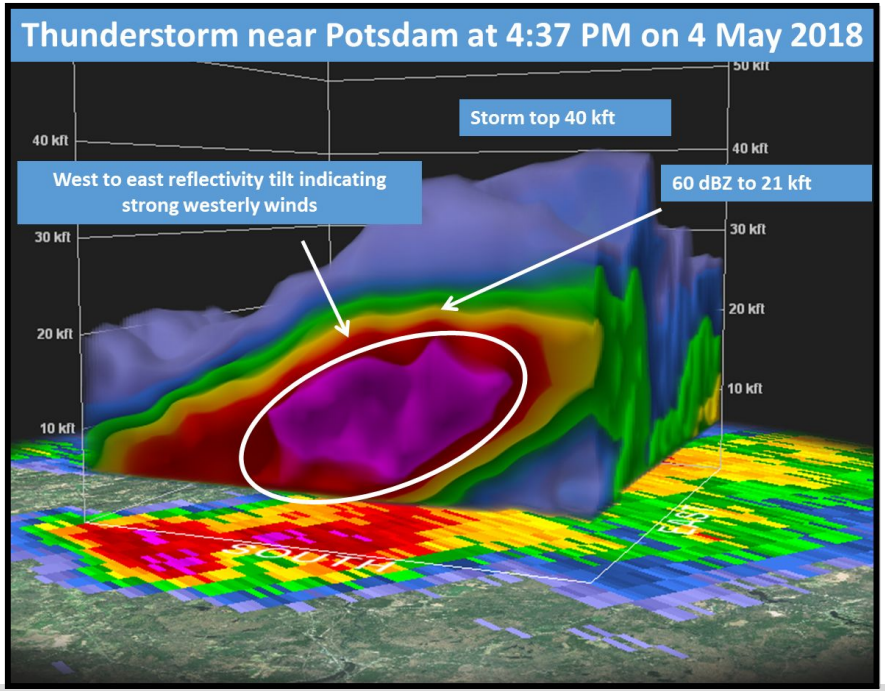
- Very potent low, little cloud contamination ahead of the event.

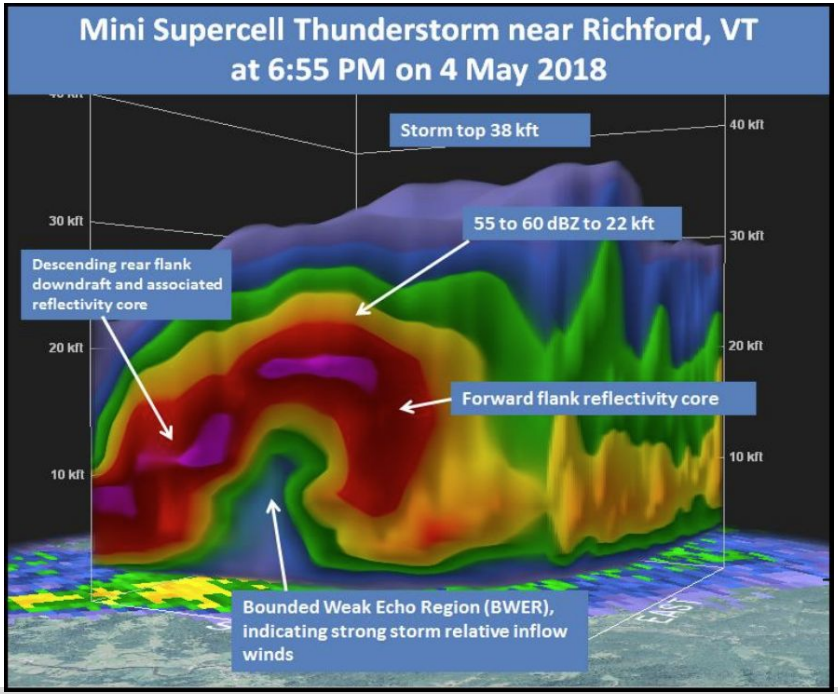




May 4th, 2018 Severe Weather

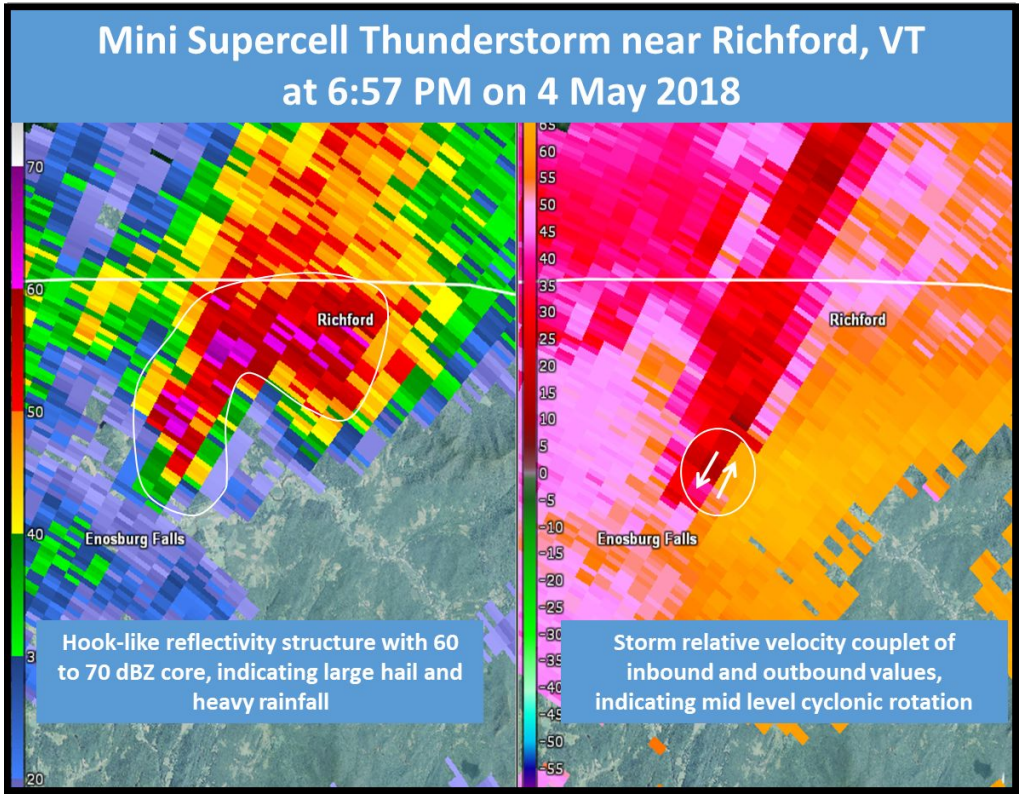
- Strong shear and very strong forcing produced supercells and damaging downbursts. Better instability in VT caused more developed storms.





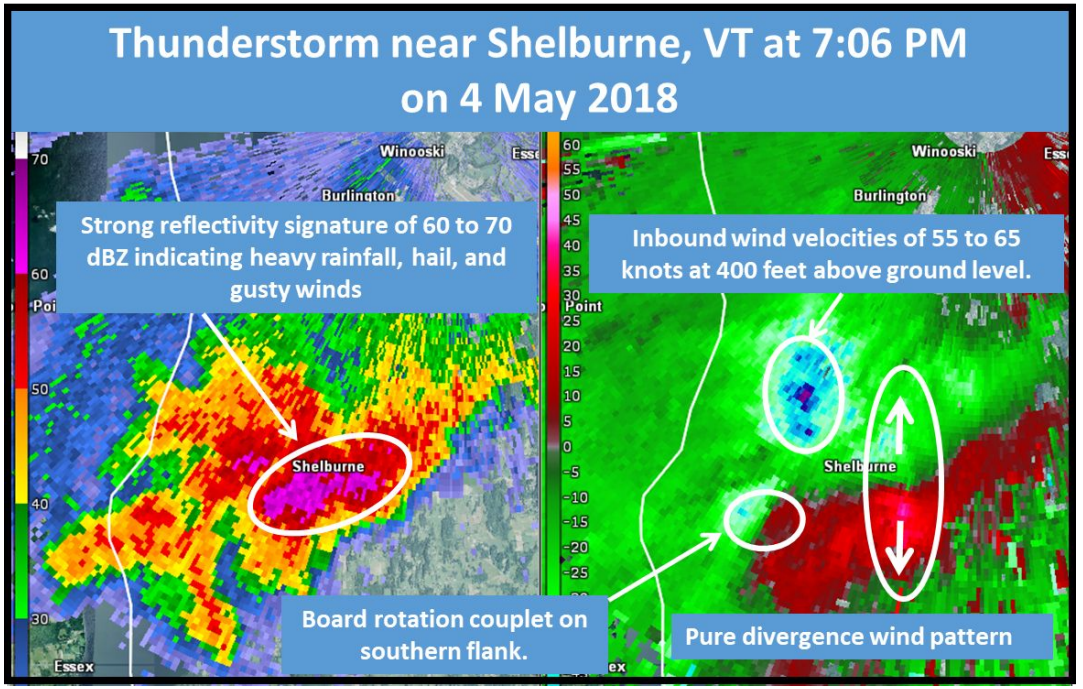
May 4th, 2018 Severe Weather

- We had a clear supercell near Richford. The couplet helps enhance inflow and separates the updraft and downdraft, making efficient hail production.
- Even though it never produced a tornado, supercells typically create more hazardous weather, like the 1.75” hail (golf-ball).



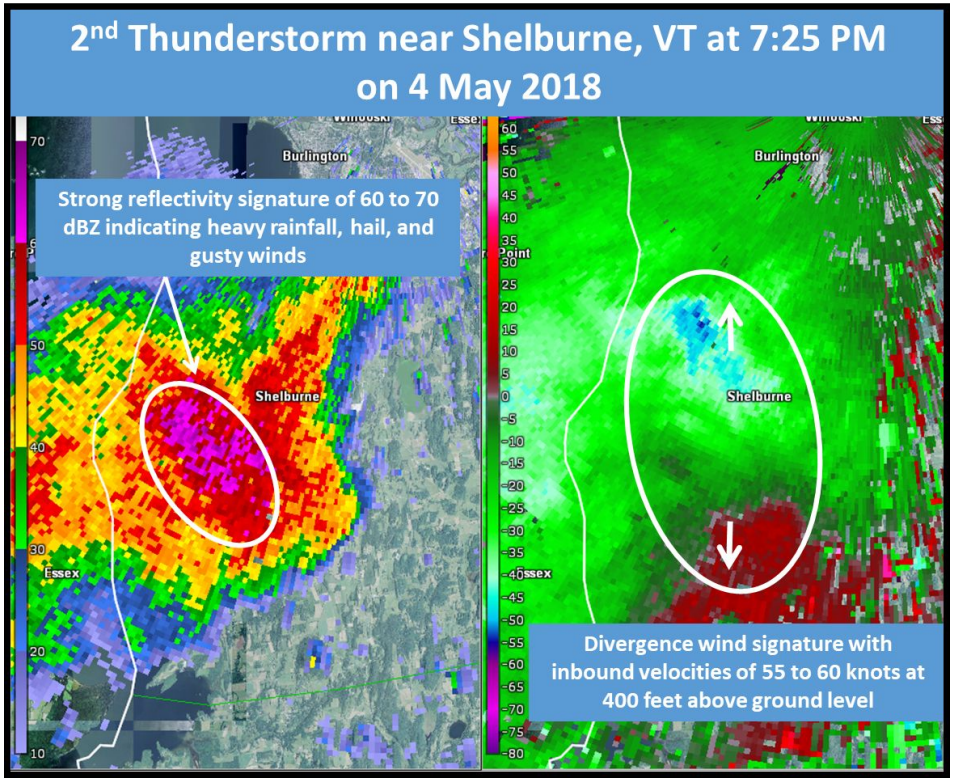
May 4th, 2018 Severe Weather

- 60-70 dBZ can indicate melting hail. The environment loses heat melting that hail, and it can strengthen the intensity of the downburst.
- This downburst may have aided in producing a small area of rotation to the southwest of the core, but it would also cut off the inflow into that storm.



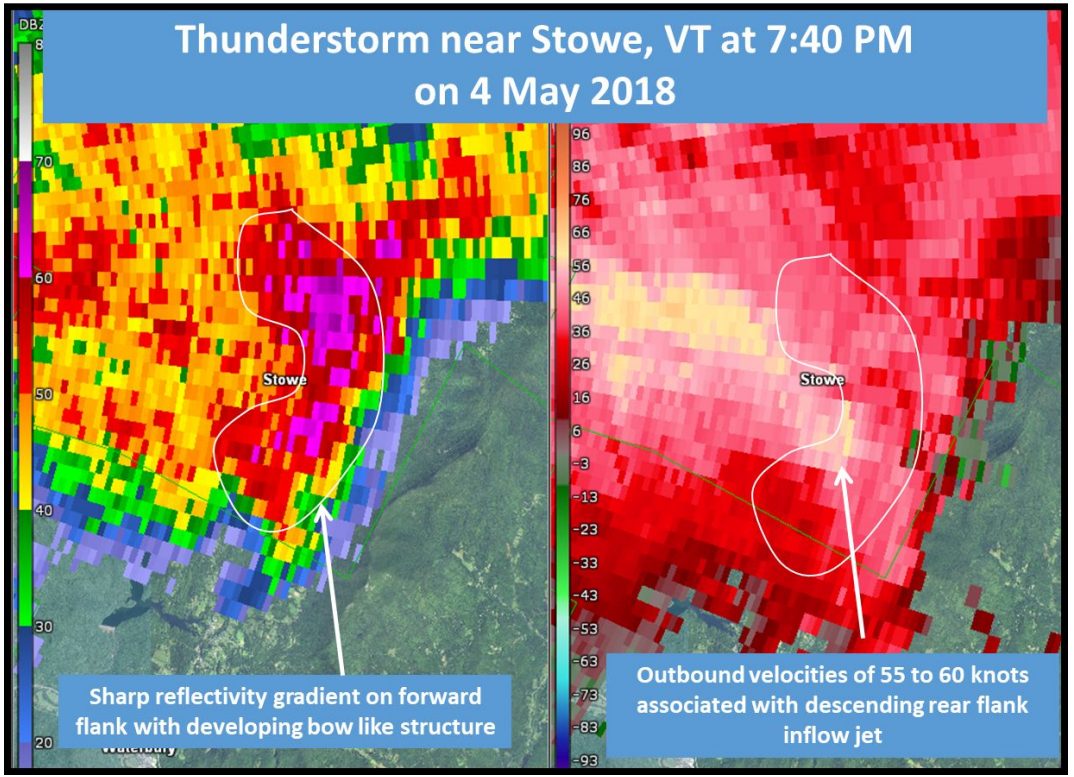
May 4th, 2018 Severe Weather

- Shelburne got hit twice, and is part of why they had the most concentrated damage of this event. Another classic downburst situation unfolded just 20 minutes later.



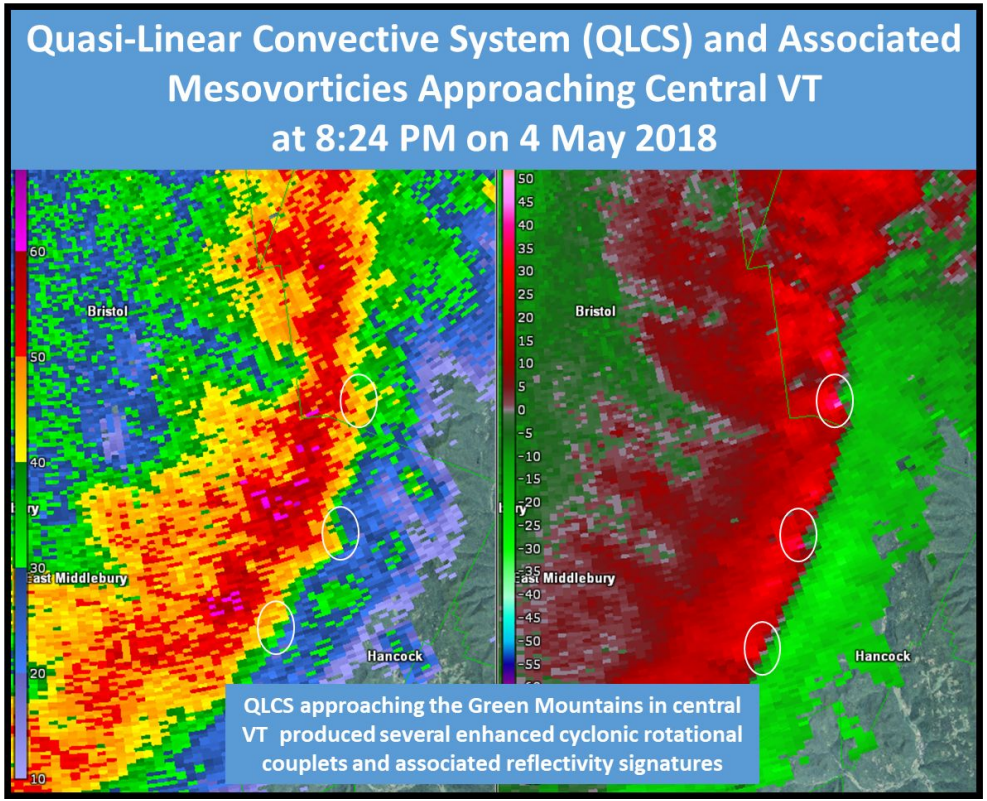
May 4th, 2018 Severe Weather

- This tiny bow produced several downed trees in Stowe.
- Reflectivity gradients are indicative of strong winds pushing droplets in more concentrated areas. A sign of the downburst to come.



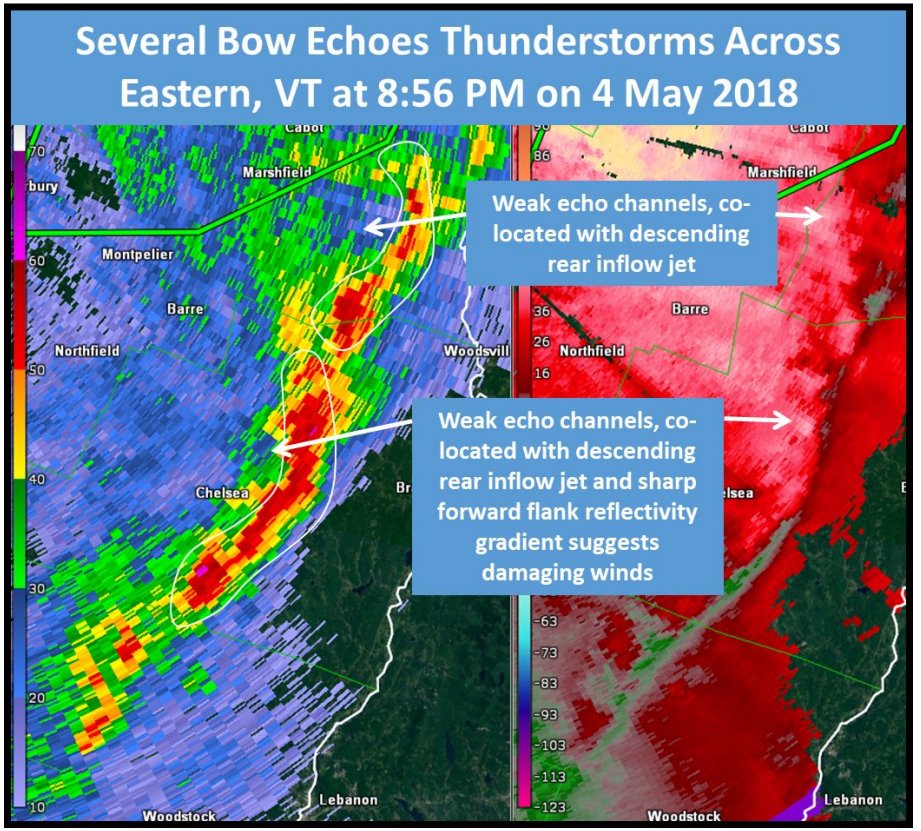
May 4th, 2018 Severe Weather

- We had several of these vortices running out ahead of these.
- None of these produced any tornadoes, but in such a strongly sheared, dynamic environment, we have to closely watch for any funny business in larger lines.



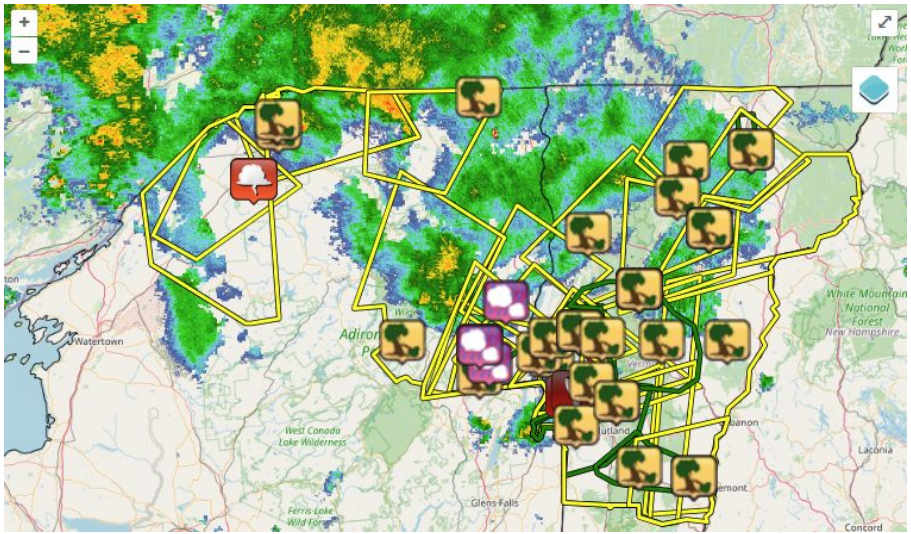
May 4th, 2018 Severe Weather

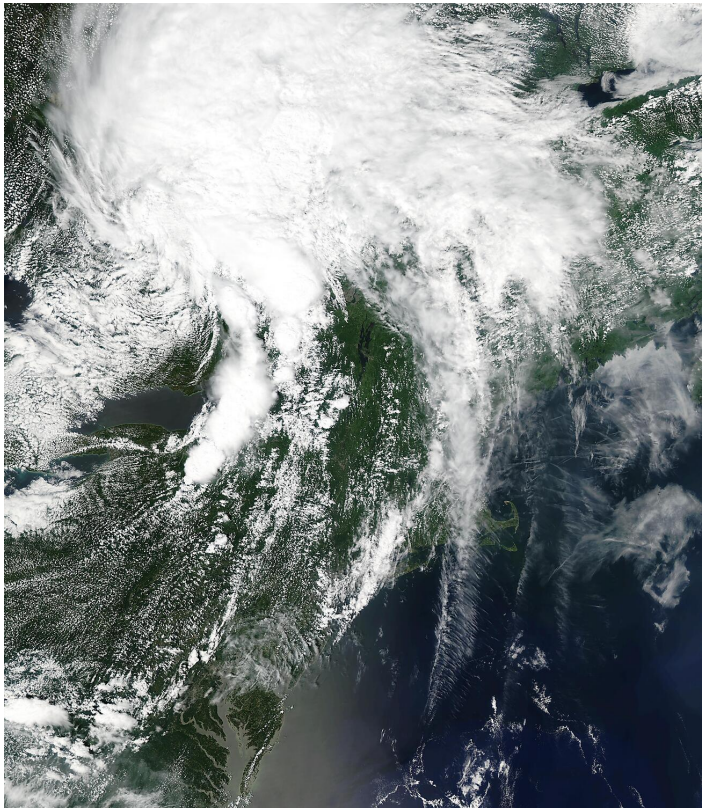
- Whenever we observe drops in reflectivity behind bowing shapes, that's indicative of air quickly descending to the ground.
- Classic situation for straight-line winds. At the bookend, you can get vortices as well.



July 13th, 2023

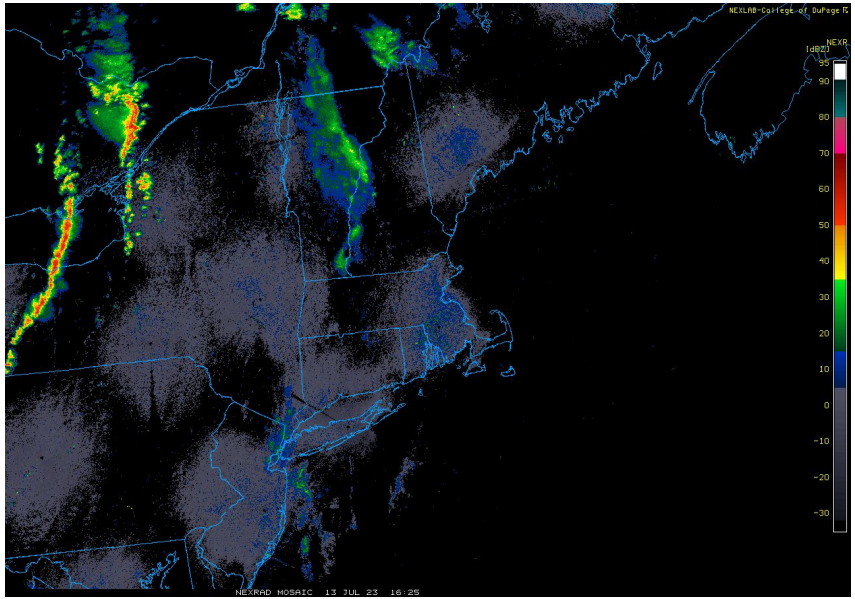
- While Vermont was dealing with impacts from flooding July 9th-11th, one of our higher end severe outbreaks quietly took place July 13th, and included a tornado.

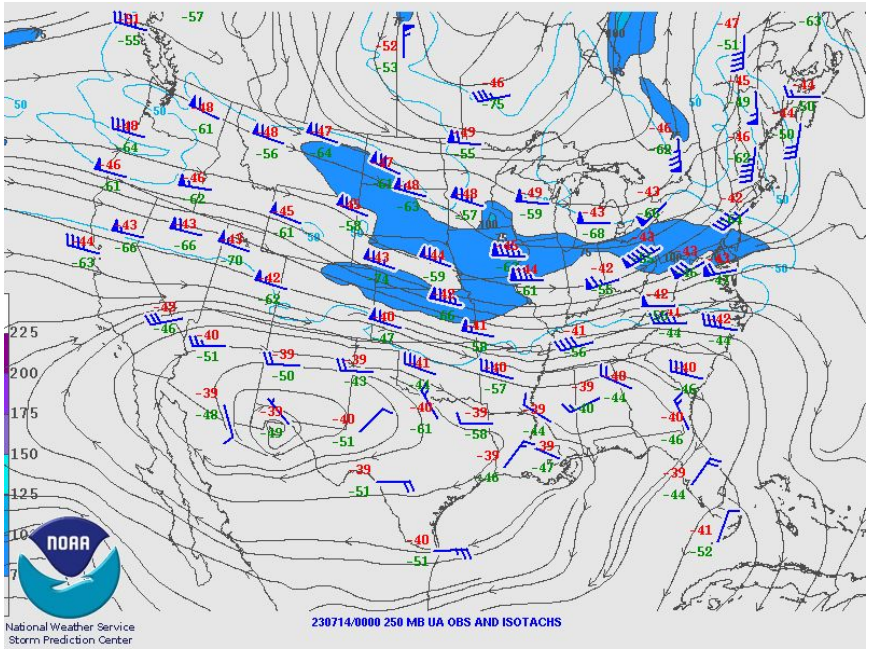




July 13th, 2023

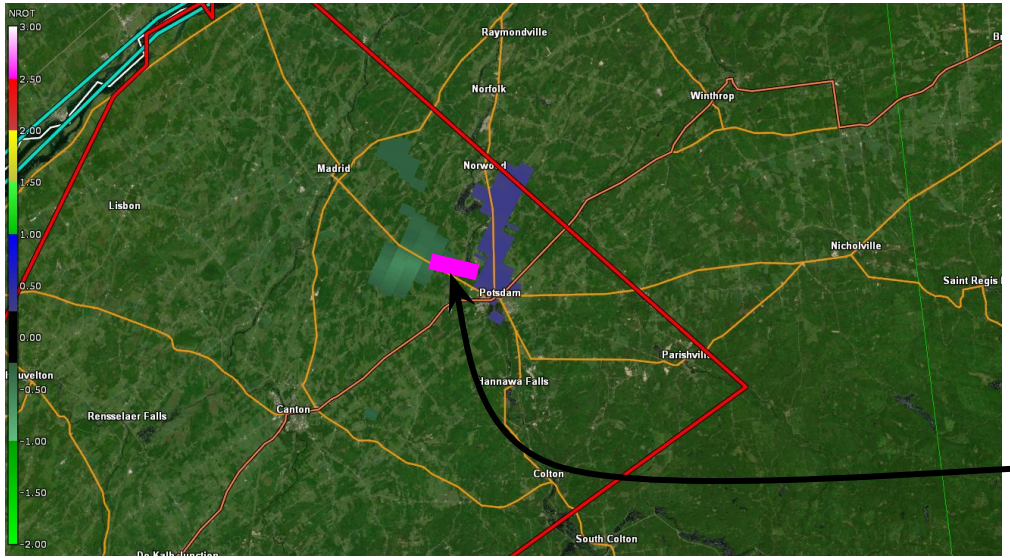
- Negative tilt troughs can be trouble - a coupled jet streak in summer helps thunderstorms ventilate and usually results in thermal packing that help fronts strengthen.





July 13th, 2023

- Storm near Potsdam, New York produced a funnel cloud about 2 PM, but broad rotation likely prevented further development.

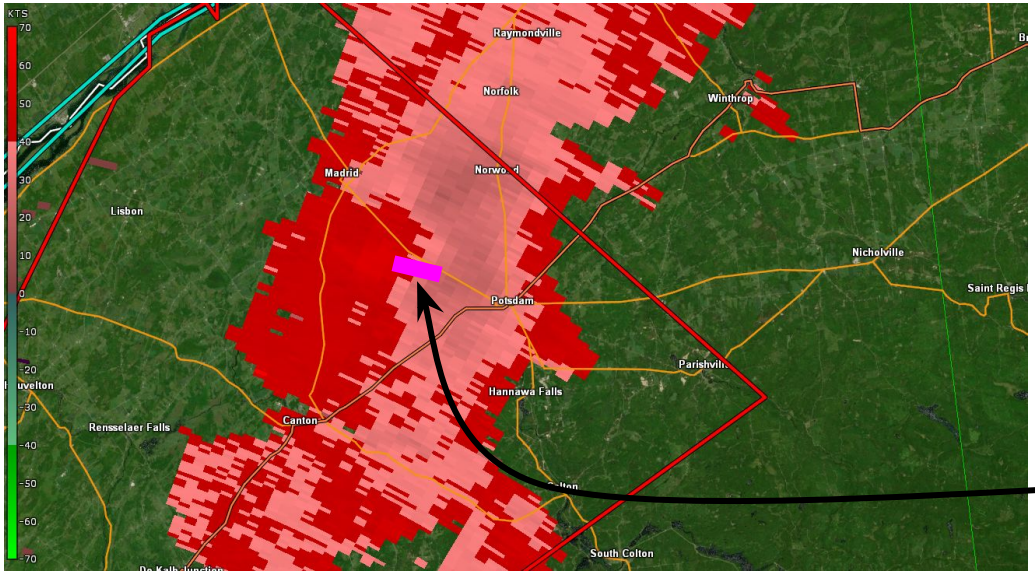


KTYX - 2:06 PM 0.5 degree NROT

Radar rotational calculations detected the spin, but not gate-to-gate. Pink line shows gap.

July 13th, 2023

- Storm near Potsdam, New York produces a funnel cloud about 2 PM, but broad rotation likely prevented further development.

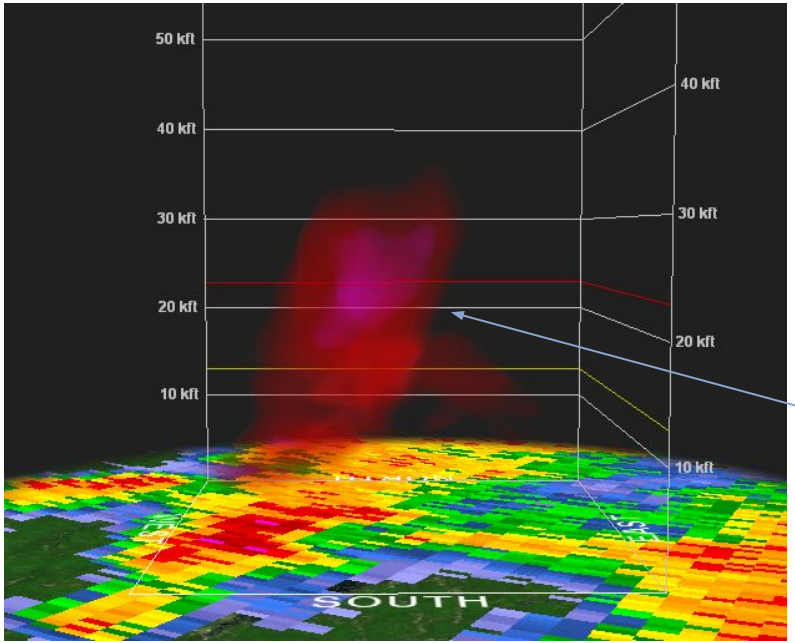


KTYX - 2:06 PM 0.5 degree storm relative velocity

From review, the azimuthal shear was about 20-25 knots. At this distance from the radar, better tornado chances occur with speeds > 35 knots.

July 13th, 2023

- A long-lived storm produced damaging winds up to 85 mph and multiple reports of 1” hail.

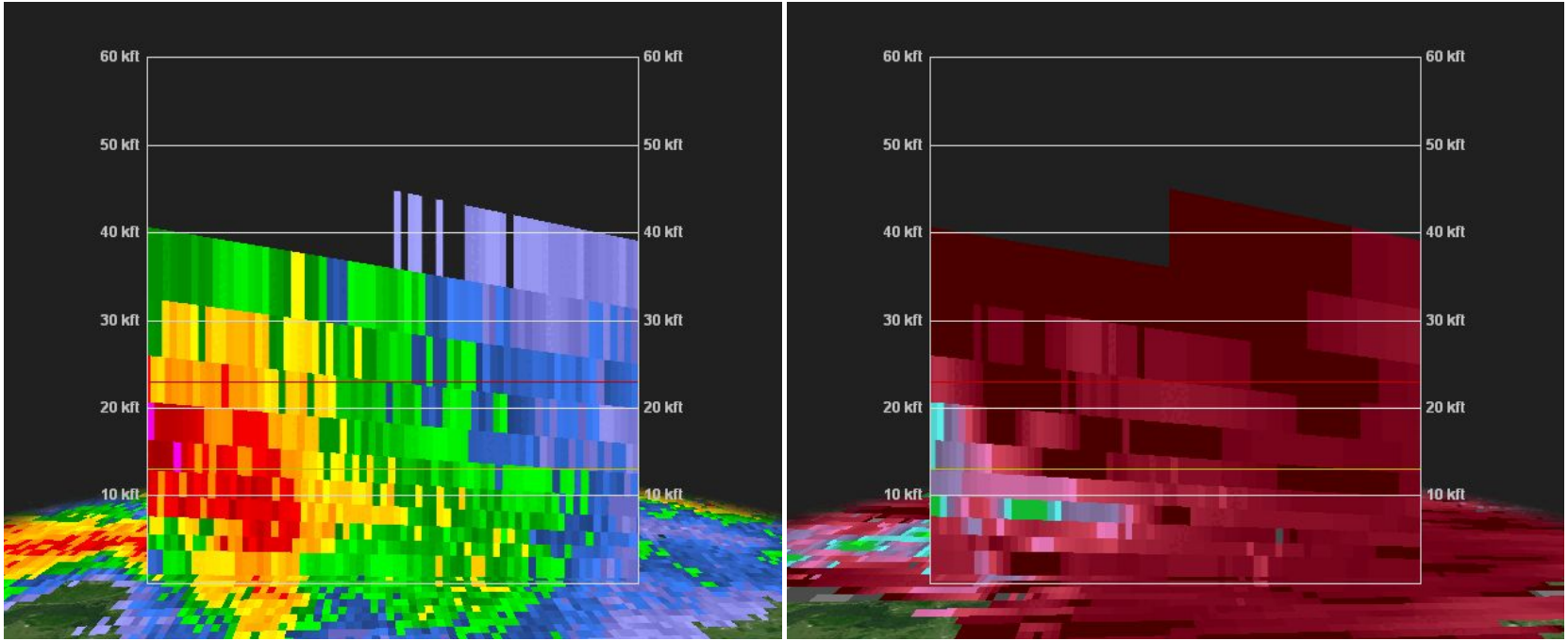


KCXX - Volumetric scan of hail producing storm near Schroon Lake 5 PM.

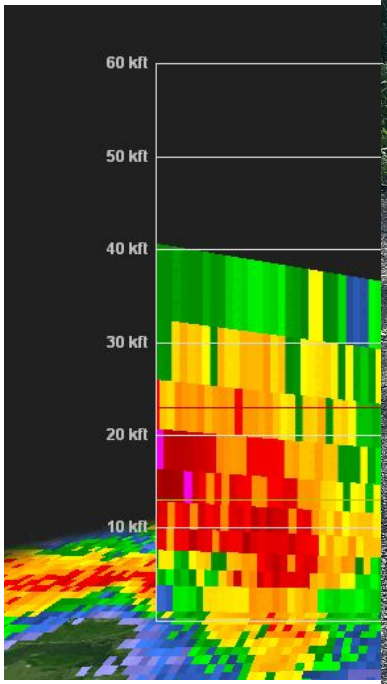
50 dbz core above 30000 feet, and 60 dbz not far below it about 28000 ft!

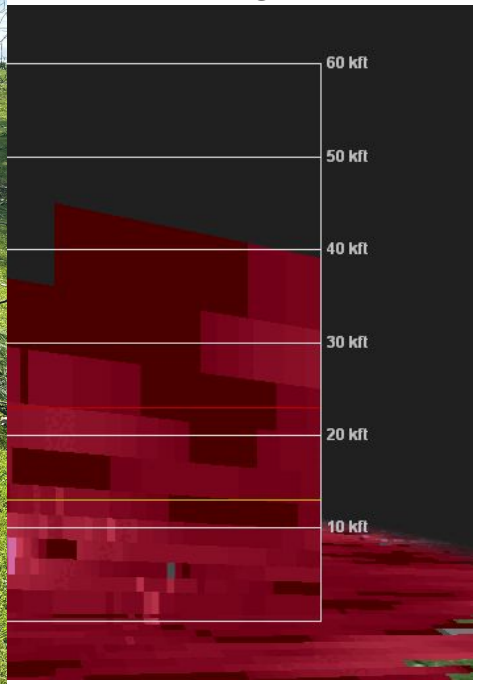
July 13th, 2023

- Reflectivity (left) and KDP (right) shows thunderstorm dropping its core near Crown Point, where estimated winds up to 85 mph due to the damage.



- Reflectivity (left) a opping its core near Crown Point, whe o the damage.



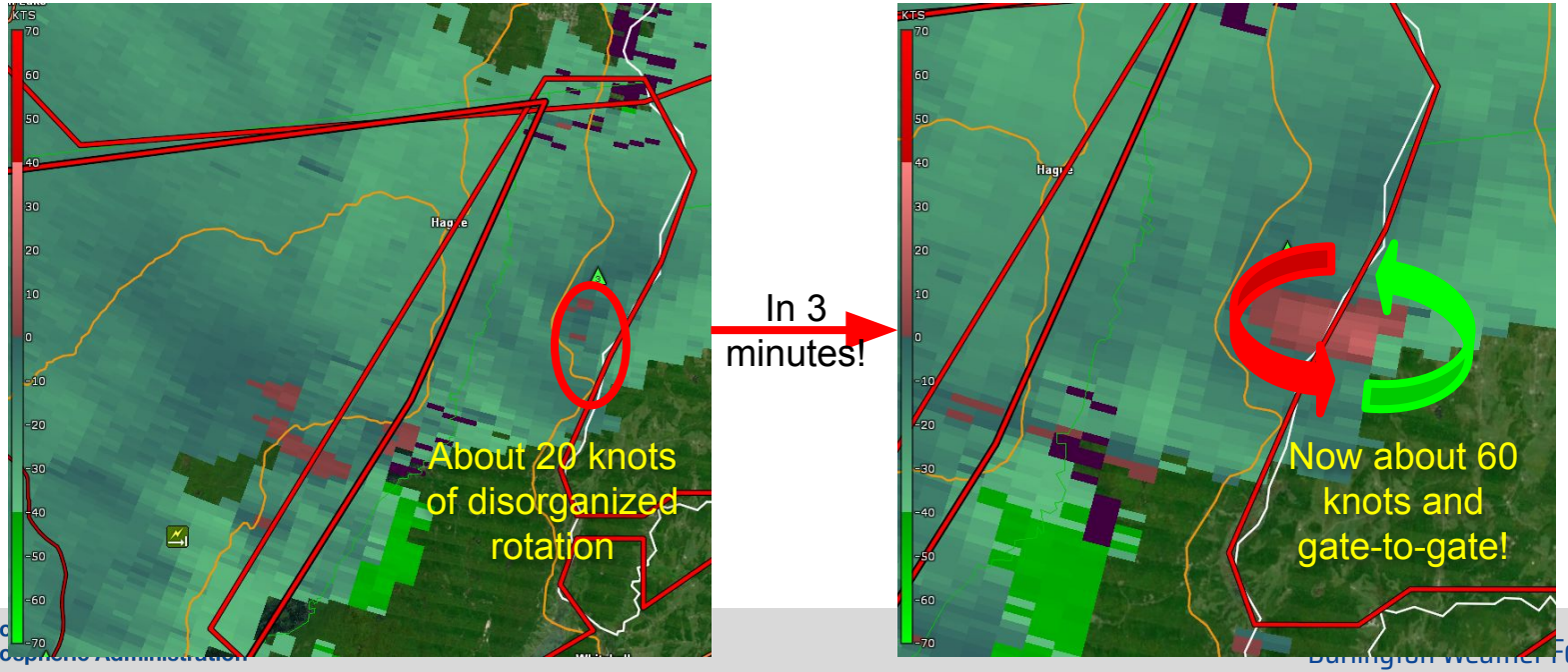


July 13th, 2023

- An EF-0 with 85 mph winds tracked from Benson to Hortonia crossing the Warrior Lakes. The tornado wasn't photographed, but we surveyed the damage.

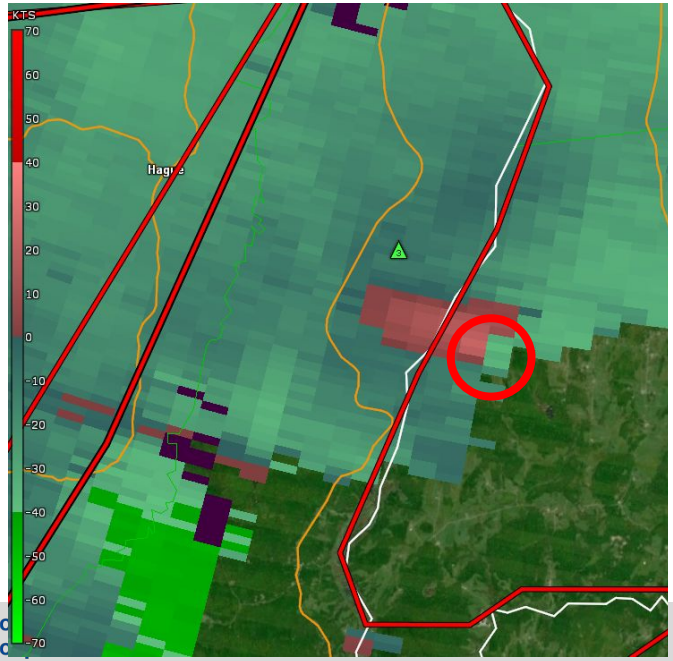
July 13th, 2023

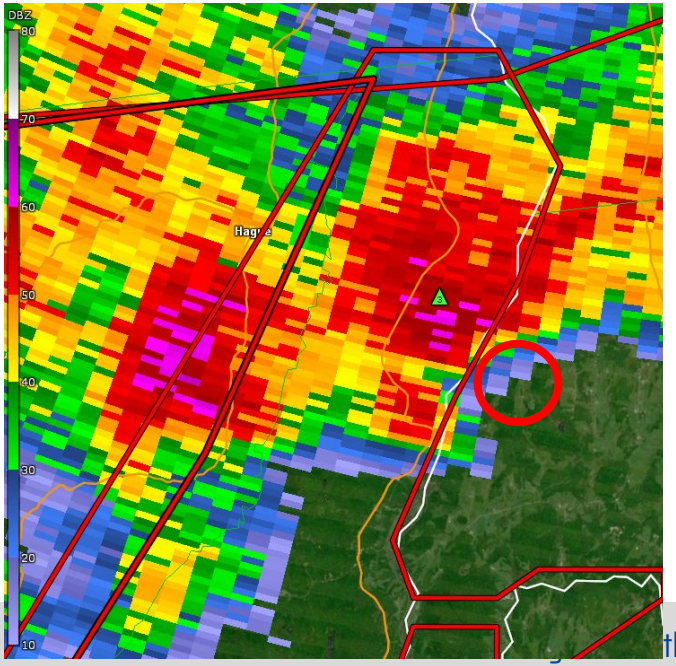
- The tornado developed a bit to the south of the mesocyclone. Rotation developed very quickly, forcing forecasters to make very quick assessments.



July 13th, 2023

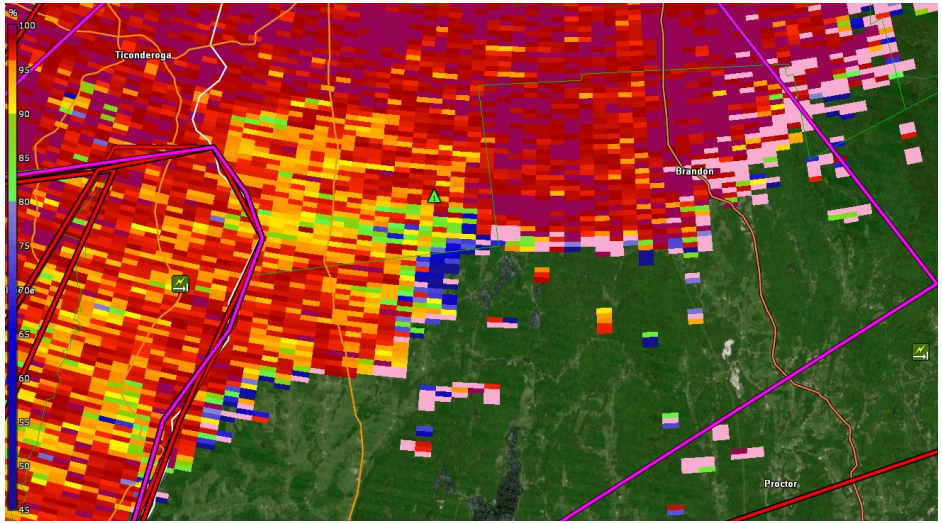
- You need more than rotation to confirm a tornado. Look for signs of debris and other confidence boosters. There was little reflectivity in the region of strongest rotation. This radar scan would not boost confidence.

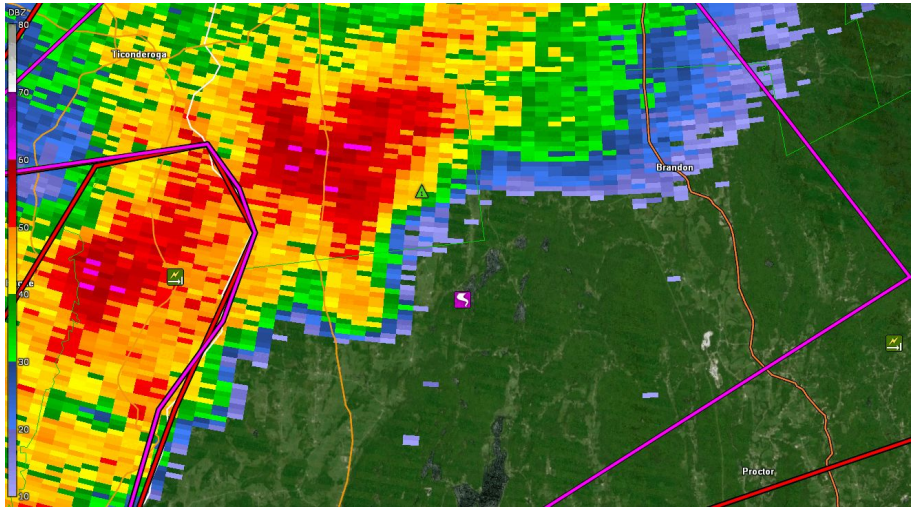




July 13th, 2023

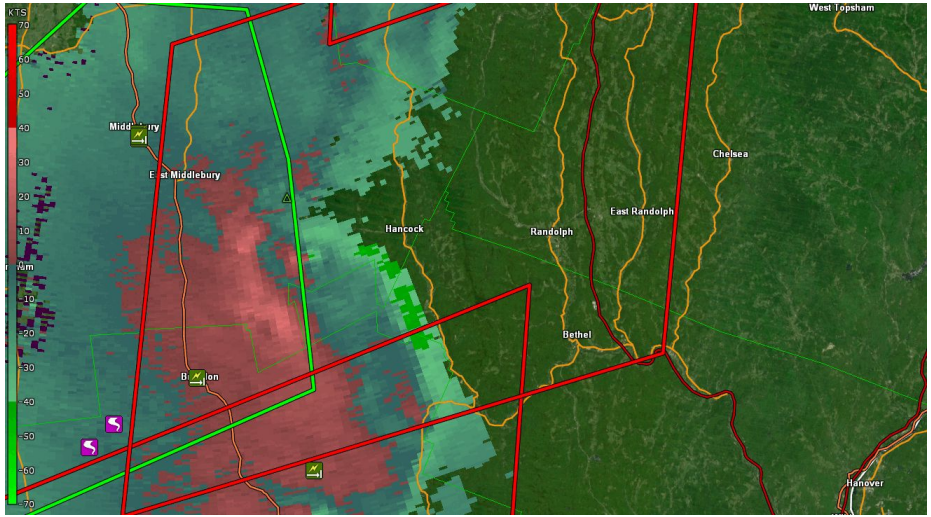
- Tornado debris is highly reflective, but not homogenous. Confidence in a tornado increases if high reflectivity is coupled with very low correlation coefficient (Tornado debris signature). That was not present here. Hook-like feature had high CCs.

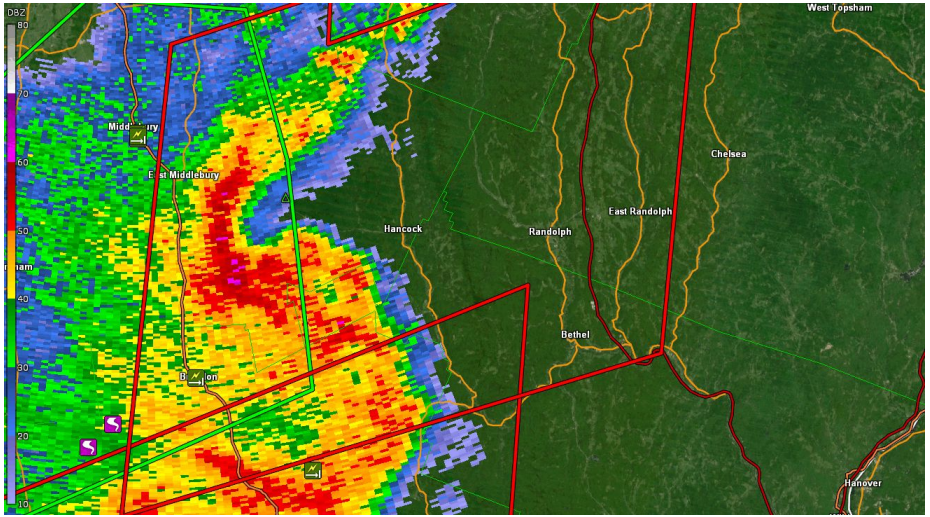




July 13th, 2023

- A large bow formed in central Vermont and knocked trees down in West Braintree about 7:15 PM (1.3 degree scan due to beam blockage). Outbound velocity maxed out about 40 knots, but moving at an angle to radar.





Severe Weather Operational Summary

- Severe weather in the North Country is rarely clear cut.
- So we have to use every tool in our kit to keep a watchful eye.
- We build off pattern recognition, climatology, and model forecasts to help drive our expectations. We watch radar, satellite, and the latest information from mesoanalysis to adjust forecast storm evolution as it occurs.
- Beam blockage poses serious challenges. Especially outside the Champlain Valley, we rely on reports.

Ways to Relay Information

National Weather Service
Burlington

Serving Vermont and northern New York

weather.gov/btv/skywarn

802.862.2475 (Hit *)

1.800.863.4279 (Line for Spotter Reports)

nws.er.btv.operations@noaa.gov

US National Weather Service Burlington, VT

@NWSBurlington

@NWSBurlington

https://www.weather.gov/btv/stormreport

A good spotter report includes:

1. Who you are
2. Where you are
3. What weather you saw
4. What time it took place
5. How long did it last

What to report:

1. Tornado/Funnel/Waterspout
2. Wind Damage
3. Hail (measure tip-to-tip)
4. Very heavy rain & Flooding
5. Heavy snow amounts
6. Freezing Rain/Sleet
7. Lightning Damage
8. Wx. Related Injury/Fatalities

Review Questions!

1. When a storm is moving at an angle to the radar beam, the velocity is what?

   a. Overestimated

   b. Underestimated

   c. Unreadable

   d. Unaffected

Review Questions!

2. Which of the following is a sign of hail in a storm?

   a. **Reflectivity values above 60 dBZ (especially when 20000 ft above ground)**

   b. **Correlation Coefficient values below 0.9**

   c. A Tornado Vortex Signature

   d. **ZDR values close to zero**

   e. High values of Convective Available Potential Energy (CAPE)

   f. **Storm Top Divergence above 100 knots**

Review Questions!

3. Which of these radar signatures indicate damaging wind potential

   a. Mid-altitude azimuthal divergence

   b. Rear-inflow jet

   c. Bounded weak echo region

   d. 40 dBZ at 15,000 feet above the ground

Review Questions!

4. What type of ***shear*** is conducive to tornadoes

   a. Directional Shear

   b. Speed Shear

   c. Sheer Willpower

Review Questions!

5. What are ***three*** radar signatures that confirm a tornado is on the ground?

   a. Correlation Coefficients of 0.99 away from reflectivity signatures

   b. Rotational Velocity over 70 knots on the lowest scan

   c. Correlation Coefficients of 0.9 or less with reflectivity above 30 dBZ

   d. Vertical continuity of Correlation Coefficient

   e. KDP values > 5

   f. ZDR values near 0 at the hook echo.

Thanks for your attendance!

Robert Haynes – robert.d.haynes@noaa.gov

You're welcome to send questions and feedback to me anytime.