Warning Methodology

Screen, Rank, Analyze, Decide (SRAD)

1. **Screen** the storms that threaten life and property over your CWA.

    - Severe Hazards (tornado/wind/hail): Load a 4-panel display showing a 60-minute loop of MRMS': Reflectivity at Lowest Altitude, Maximum Estimated Size of Hail (MESH) and 60-min MESH Tracks, 60-min 0-2 km Rotation Tracks, and Vertically Integrated Ice *(Note: An alternative could be a single-site lowest-tilt, Base Reflectivity, 60 minute time lapse loop with algorithm overlays. Use this alternative display if the MRMS products are experiencing latency.)*

2. Identify the highest **Rank**ed storm. Factors to consider include:

    - Near-storm environment
    - Storm reports
    - Rapidly-intensifying storms
    - Deviant motion (i.e., right-mover, left-mover)
    - Convective mode (ordinary cell, multicell, supercell, derecho, etc.)
    - Maximum Expected Size of Hail (MESH) value
    - Azimuthal shear / Rotation Tracks values
    - Signatures: Inflow notch, three-body scatter spike (TBSS), hook echo, Tornado Debris Signature (TDS), rear inflow jet (RIJ) etc.
    - Societal / population considerations
    - Storms which are under-warned or have a warning that's due to expire soon (<10 min)

    Go to Step 4 to immediately issue a warning for your highest ranked storm if:

    - It exhibits a high confidence severe signature (e.g., TDS) and/or it has a high confidence report, and
    - It's unwarned, under warned, or has a warning set to expire in less than 5 minutes.

    Otherwise, go to step 3.

3. **Analyze** the highest ranked storm's structure and hazards.

    - Use the "All Hazards Decision Chart" as a quick reference.
    - Use the Warning Decision Cycle checklists as detailed reference.
        - Updraft Strength
        - Tornado
        - Severe Hail
        - Severe Wind

4. Make your **Decision**. Consider the following factors when determining motion, duration, polygon orientation, and wording:

    - Tornado
        - Choose WarnGen Track type: "One Storm" and track the low-level vortex, but regard the parent storm's motion.
        - Be sure to account for possible mesocyclone occlusion(s) and motion uncertainty in your polygon (don't try to be too precise).

  - Capture multiple threats in close proximity with a single polygon when necessary.
  - **Avoid:**
    - "Tornado Emergency" wording unless there is very high confidence of a significant (EF2+) tornado moving into an urban area.
  - Non-mesocyclonic: Track the updraft interaction with the low-level boundary(ies).

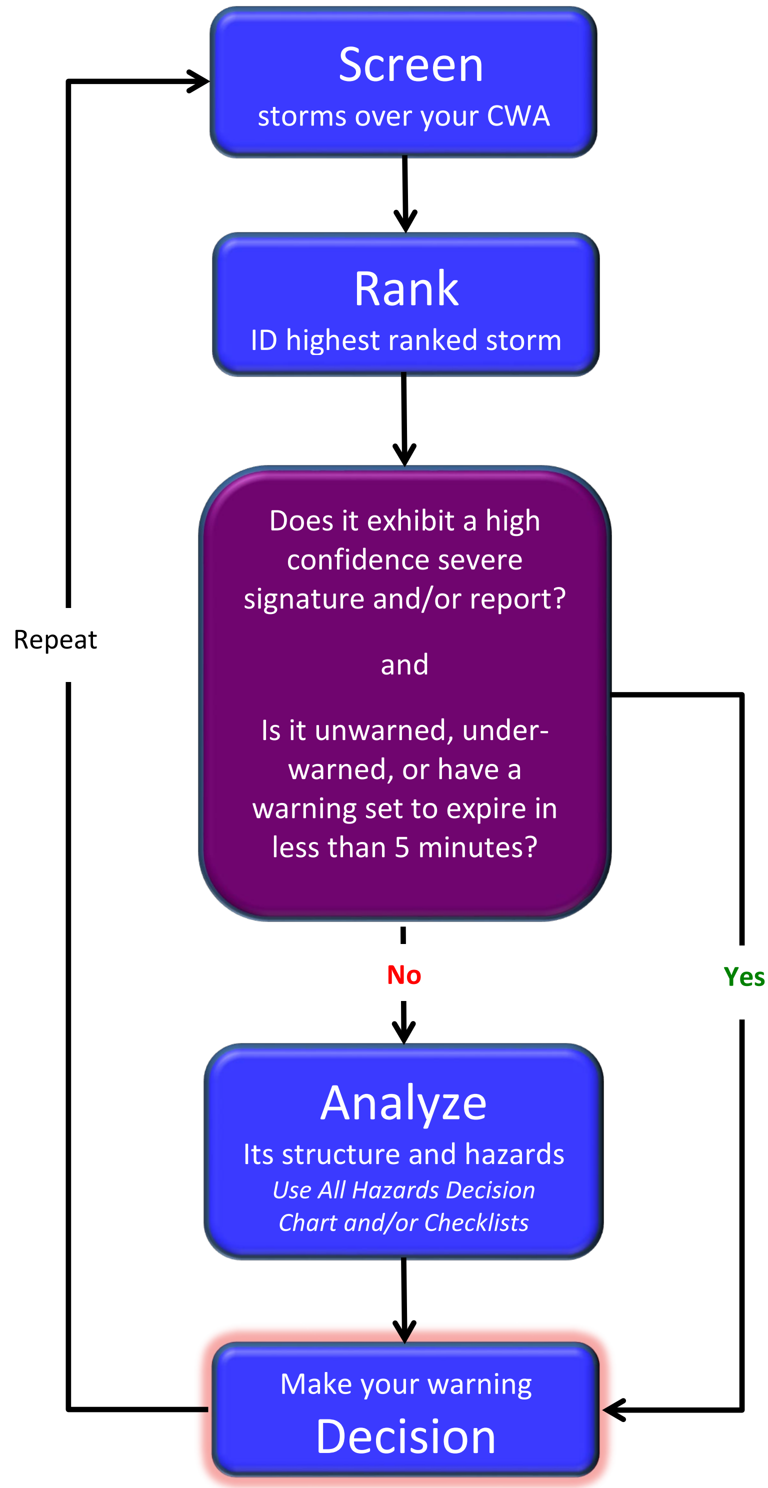
- Severe Hail/Wind
  - Individual cell: Choose WarnGen Track type: "One Storm" and track the updraft/downdraft interface region; be sure to include both the updraft and downdraft regions in your polygon.
    - Supercell: Anticipate deviant motion; include the Rear Flank Downdraft (RFD) in your polygon.
  - Multicell: Choose WarnGen Track type: "One Storm" and track the area where cells mature; ensure polygon includes existing severe threat as well as anticipates new cell development.
    - Bow Echo/QLCS: Choose WarnGen Track type: "Line of Storms" and track the gust front; include trailing severe winds and hail in your polygon.

NOTE: One SRAD cycle (steps 1-4) should take about 5 minutes (with experience).

5. Repeat the SRAD process until no new warnings are required.

WDTD Suggested Warning Methodology:

Screen, Rank, Analyze, Decision (SRAD)



Tornado

The Significant Tornado Parameter and Non-Supercell Tornado Parameter characterize mesocyclonic and non-mesocyclonic tornado potential, respectively. Use the following three tables to better understand those parameters and the three ingredients method to QLCS tornado events. NOTE: Exceeding "preferred values" indicates favorable conditions; Not meeting "necessary values" indicates unfavorable conditions.

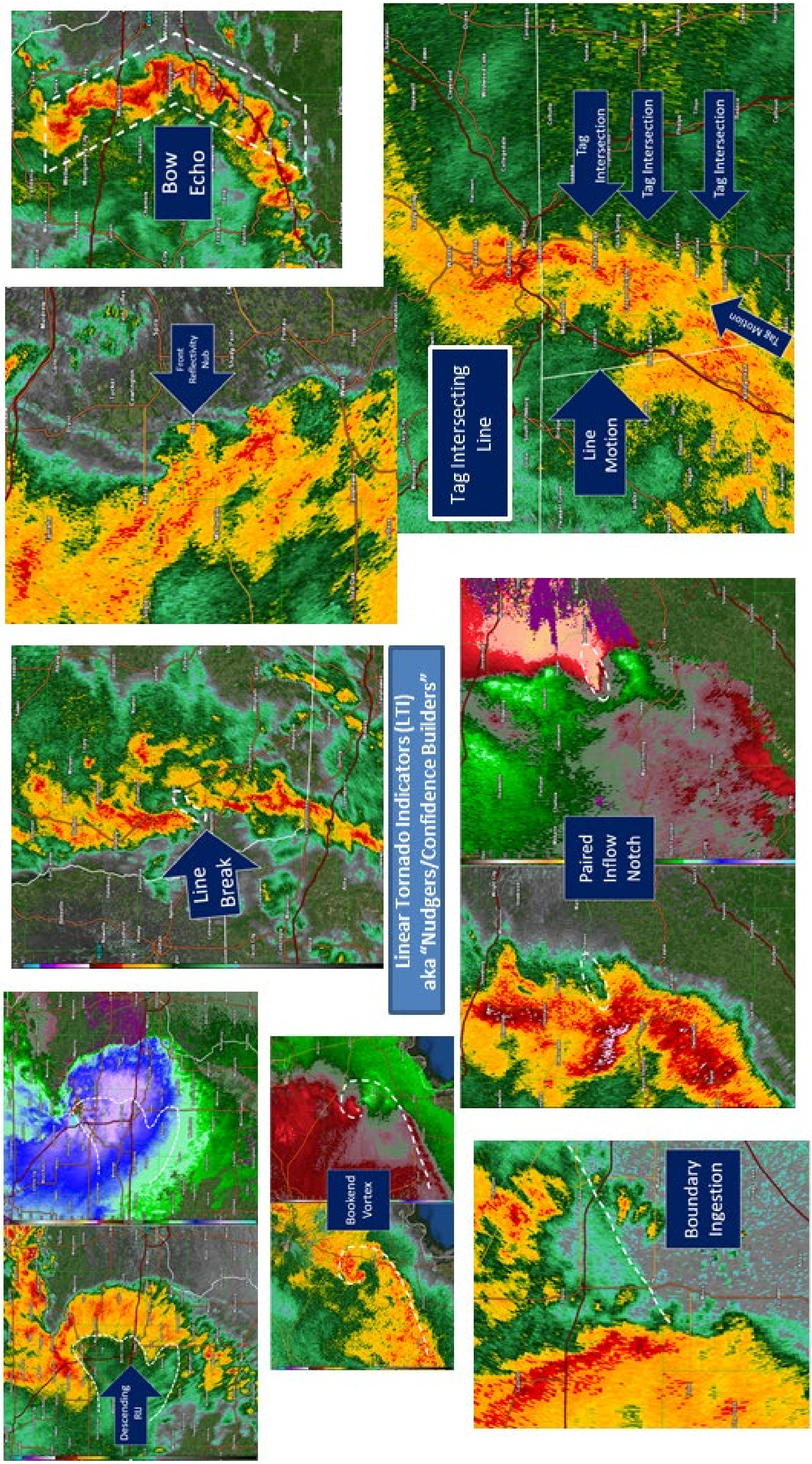
Mesocyclonic Parameters	Necessary Value	Preferred Value
0-1 km shear	≥15 kts	≥20 kts
Significant Tornado Parameter (Eff)	>0	>1
100 mb mean parcel mixed layer CAPE	>0 J/kg	>1500 J/kg
100 mb mean parcel mixed layer CIN	>-200 J/kg	>-50 J/kg
100 mb mean parcel LCL height	<2000 m	<1000 m
Effective storm relative helicity (effective inflow layer SRH)	>0 m2/s2	>150 m2/s2
Effective bulk wind difference (EBWD)	≥25 kts	≥40 kts

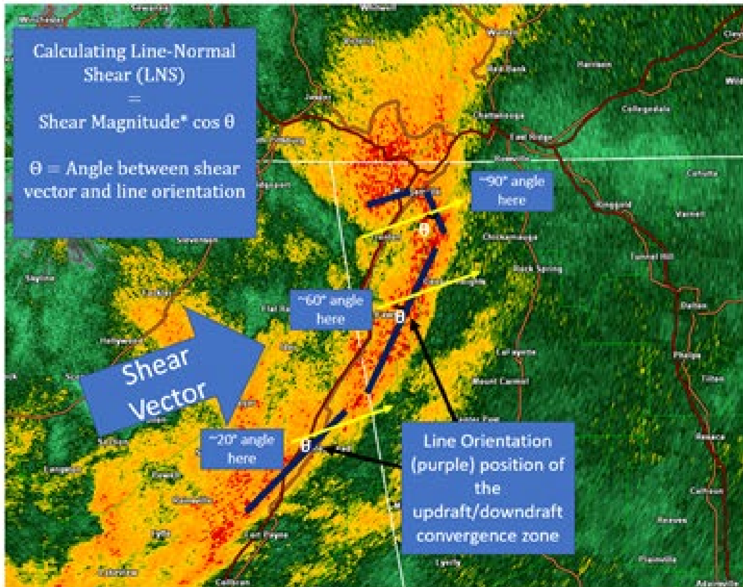
Non-Mesocyclonic Parameters	Necessary Value	Preferred Value
Non-Supercell Tornado Parameter		>1
0-3 km mixed layer CAPE	>0 J/kg	>100 J/kg
Mixed layer CIN	>-225 J/kg	>-25 J/kg
0-1 km lapse rate		>9° C/km
Surface relative vorticity		$>8x10^{-5} s^{-1}$
0-6 km bulk wind difference	≤35 kts	≤25 kts

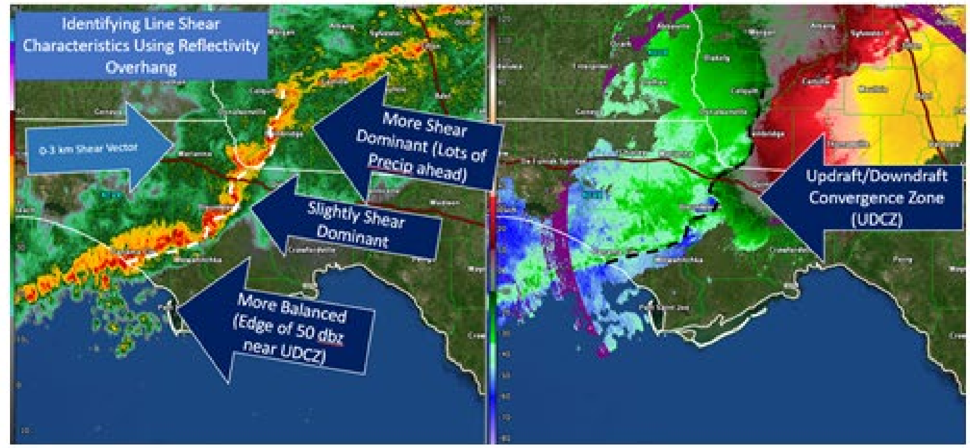
QLCS Parameters (Three Ingredients Method)	Necessary Value	Preferred Value
0-3 km line normal bulk shear		≥30 kt
Rear inflow jet or outflow caused surge in line		Yes
0-3 km mixed layer CAPE		≥40 J/kg

When favorable environments for tornadoes exist (Significant Tornado Parameter > 0 or Non-Supercell Tornado Parameter >1), use the following rotational velocities and qualitative radar signatures to aid in tornado decision making.

Radar Signatures	Mesocyclonic	Non-Mesocyclonic	QLCS
Storm Type			
Discrete, surface-based supercell	Yes		
Reflectivity (Z) core aloft (~0 °C) co-located w/misoscale vortex along the boundary		Yes	
Quasi-linear convective system (QLCS)			Yes
General Features			
Acceleration & convergence into a strong, low-level mesocyclone prior to tornadogenesis	Yes		
Formation of cold pool		No	
Descending rear inflow jet (RIJ)			Yes
Enhanced surge			Yes
Line break			Yes
Updraft deep convergence zone (UDCZ) entry/inflection point			Yes
Paired front/real inflow notch			Yes
Boundary ingestions			Yes
Front reflectivity nub			Yes
Mesocyclone/Tornado Features			
Tornado vortex signature (TVS)/ tornado signature (TS)	Yes	Yes	Yes
Contracting bookend vortex			Yes
Tight/strong mesovortex			Yes
Max V_{rot} at 0.5°	≥30 kts	≥20 kts	≥25 kts
Tornado debris signature	Yes	Yes	Yes


Linear Tornado Indicators (LTI)
aka "Nudgers/Confidence Builders"
Bow Echo
Tag Intersecting Line
Tag Intersection
Tag Intersection
Tag Intersection
Tag Motion
Line Motion
Front Reflectivity Nub
Line Break
Paired Inflow Notch
Descending RIJ
Bookend Vortex
Boundary Ingestion





Be quicker to warn in favorable environments/history of tornadoes

Overall more shear, more rotation = more threat

QLCS Tornado Warning Techniques

<u>Three-Ingredients Method</u>

1. 0-3 km LN Shear ≥ 30 kt
2. Established Rear Inflow Jet
3. Balanced/Near Balanced portion of line

Warning Threshold is all 3 ingredients + 5 Indicator/Nudgers

<u>Multiply Line Normal Shear by # of Indicators Method</u>

0-1 km LNS * number of LTIs = 150

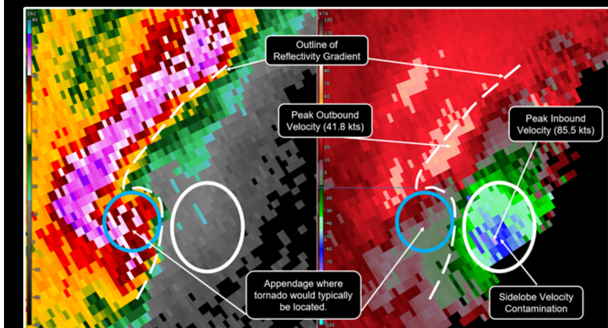
0-3 km LNS * number of LTIs = 300

Any 20 kt V_{rot} Meso in > 25 kt 0-1 km Shear

MCV and Supercell-like Structures = Much Higher Tornado Threat

Identifying A Sidelobe Imposter Circulation

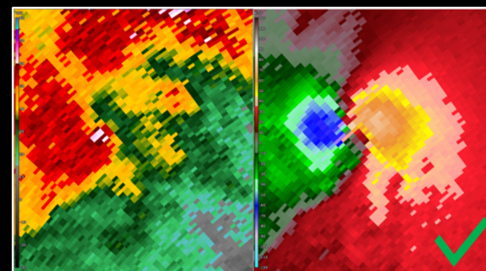
1. Location



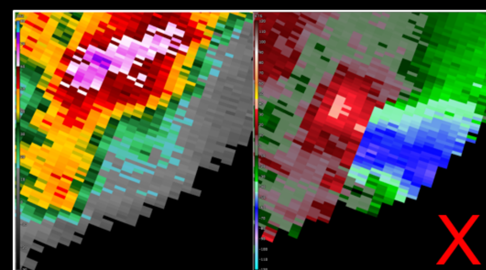
Valid: Located near the RFD with reflectivity >20 dBZ

Imposter: Often located near FFD/inflow with all or some portion reflectivity <20 dBZ

2. Texture

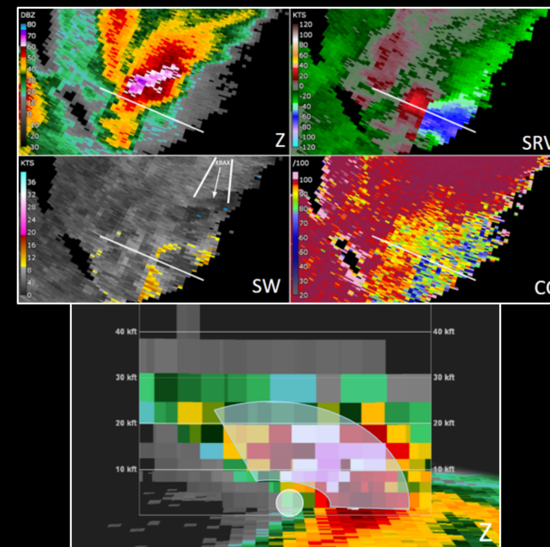


Valid: Smooth increase in velocities as they approach circulation center



Imposter: "Blocky," No clear gradient in velocities

3. Cross-Section/3D



Extent of highly reflective targets aloft for sidelobes to strike

Increase confidence in imposter

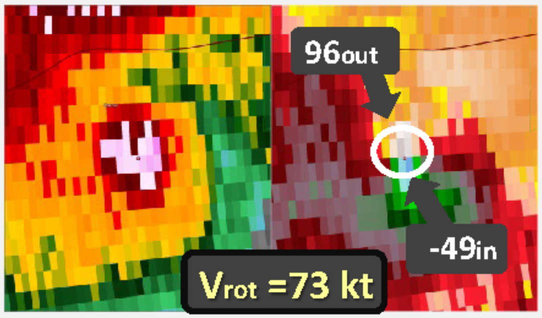
Impact-Based Tornado Warning Guidance

30 kt V_{rot}	40* kt V_{rot}	50* kt V_{rot}	70* kt V_{rot}
If STP >0 – Tornado Warning Likely Needed	Considerable Tag With TDS, STP >1	Considerable Tag Without TDS, STP >1	Catastrophic Tag With TDS, STP >6

Put this into context with other available information and your professional judgement/experience

Measuring V_{rot}

$$V_{rot} = \left| \frac{V_{r[max]} - V_{r[min]}}{2} \right|$$



Important To Remember…

- V_{rot} relationships weaken at ranges > 70 nmi
- Is the velocity in area of > 20 dBZ?

Nowcasting Significant Tornadoes

* Median EF-2 cases begin at this V_{rot} and STP >3. STP 1-3 cases have a slightly higher FAR but may still be sufficient for considerable tag. QLCS cases may require slightly lower thresholds and examination of shear variables rather than STP.

TDS Height Threshold

EF2+: 8,000-10,000 ft.

Upgrade to Catastrophic Tag

"Tornado Emergency" if:

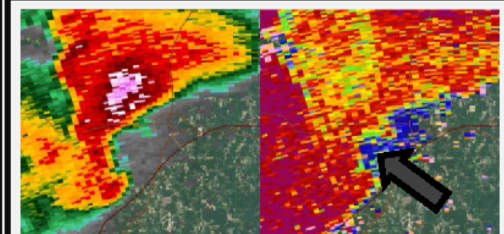
(Must meet BOTH)

1. Tornado 100% confirmed via TDS or credible source
2. Destructive tornado/catastrophic damage potential

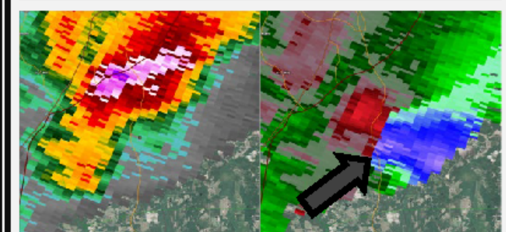
V_{rot} ≥ 70 kt, STP ≥ 6.0

Evaluate/update with SVS frequently!

Potential Pitfalls



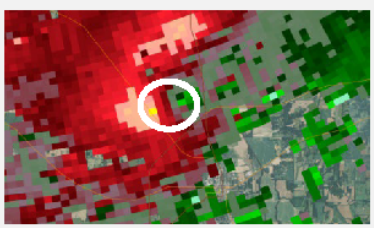
CAUTION: Low CC in inflow area can APPEAR to be TDS
Make sure the dBZ is ≥20



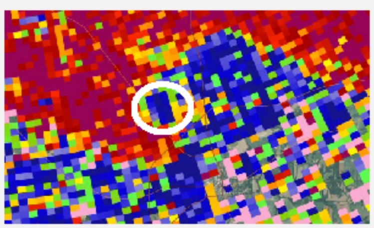
Vertical Side Lobe Contamination
Strong velocity in Weak Z below strong meso aloft, may not be valid signal

Tornado Debris Signature (TDS) Identification

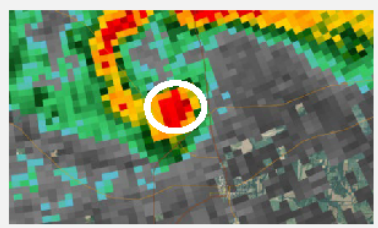
Criteria for a "Radar Confirmed Tornado"



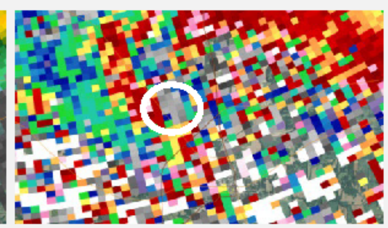
First, Identify a valid velocity circulation at the lowest elevation tilt



Is the CC below 0.90?



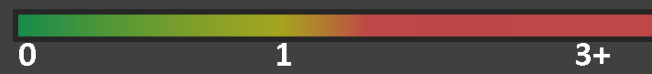
Collocated with Z above 30 dBZ?



ZDR near zero? – Not necessary but adds confidence

Time continuity
+
Height continuity
ADDS CONFIDENCE!!

Significant Tornado Parameter



Chances for significant tornadoes with higher V_{rot} increase as STP increases

But BE AWARE of how STP is put together and calculated

$$STP = \frac{MLCAPE}{1500} * \frac{2000 - ML\,LCL}{1000} * \frac{ESRH}{150} * \frac{EBWD}{20} * \frac{200 + MLCIN}{150}$$

The mlLCL term is set to 1.0 when mlLCL < 1000 m, and set to 0.0 when mlLCL > 2000 m;

the mlCIN term is set to 1.0 when mlCIN > -50 J kg-1, and set to 0.0 when mlCIN < -200;

the EBWD term is capped at a value of 1.5 for EBWD > 30 m s-1, and set to 0.0 when EBWD < 12.5 m s-1.

Lastly, the entire index is set to 0.0 when the effective inflow base is above the ground.

If the boundary layer is mis-analyzed (too stable) the STP can go to zero erroneously

SPC Mesoanalysis is a 40km resolution analysis - finer scale details can and will impact overall tornado potential

Tornado Warning Points of Emphasis*

* To be used in the full context and after completion of all NWS Warning Ops Training

Supercell Warning Confidence Thresholds

Significant Tornado Parameter (STP)

Includes these ingredients:
- Surface-based CAPE
- Surface-based LCL height
- SRH
- 0-6 km BWD

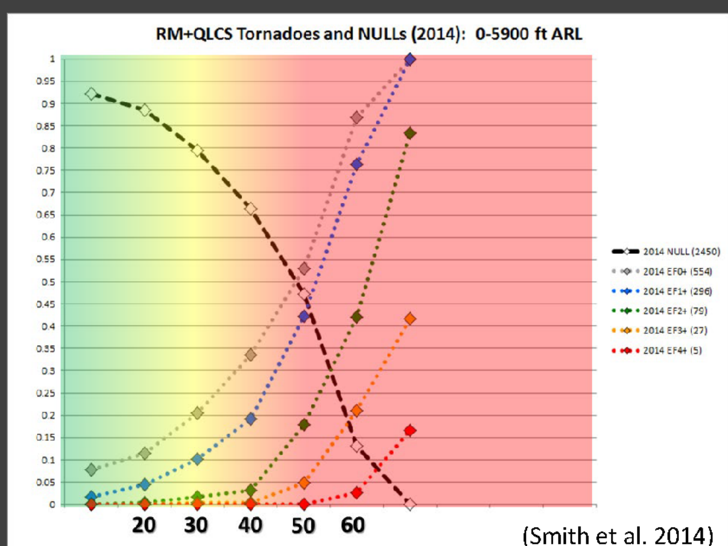
When using STP, be sure to also examine these ingredients individually during any severe weather mesoanalysis!

Is the Environment Favorable?

Given a 30 kt Vrot Signature:

Warning may be unnecessary	Environment favorable enough to be cautious	TOR WARN
0	1	3

STP Values



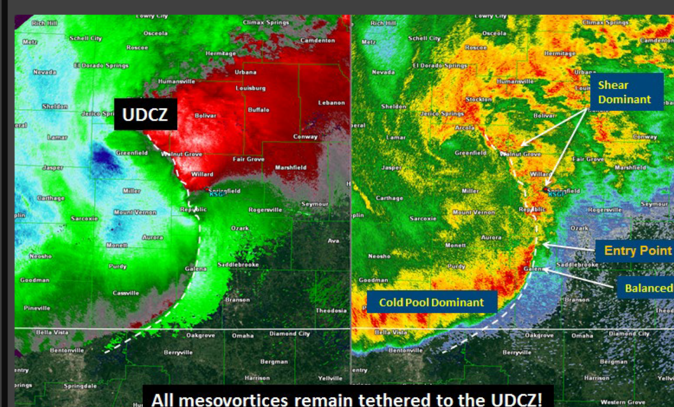
Keep in Mind...

- Presence of a hook indicates a supercell, not NECESSARILY a tornado, evaluate velocity data
- Evaluate the storm/velocity at all elevation angles!
- Warn downstream with sufficient lead time
- Vrot methods/Pitfalls/TDS Identification (see reverse side)
- Attempt to limit false alarm area
- Collaborate on the CWA borders as much as possible
- Avoid "blanket" warnings in QLCS when possible

QLCS Three Ingredients Method

Key features to look for when assessing QLCS tornado potential:

1. Slightly shear dominant portion of line
2. 0-3km shear >30 kts
3. Surges/Bows in line



Other features to watch for:
- UDCZ entry/inflection point
- Descending RIJ or reflectivity drop
- Line break
- Paired front/rear inflow notch
- Front reflectivity nub
- Contracting bookend vortex (Vr > 25 kts)
- Tightening mesovortex (Vr > 25 kts)

Remember: Rotational Velocity will assess CURRENT intensity, but likely not provide much lead time on QLCS tornadoes. Stronger environments may require more proactive warnings.

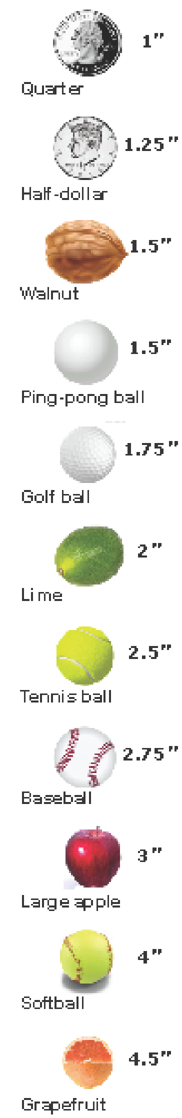
Significant Hail Parameter and Large Hail Parameter characterize hail size potential. Use this table to better understand some of the key ingredients relating to hail size.

Parameters	Base Severe (≥1")	Significant (≥2")	Giant (≥4")
Large Hail Parameter (LHP/LGHAIL)	≥4	≥5	≥8
Most unstable CAPE (MUCAPE)	≥1600 J/kg	≥1850 J/kg	≥3000 J/kg
Effective bulk wind difference (EBWD)	≥30 kt	≥40 kt	≥46 kt
700-500 mb lapse rate		≥6.5 °C/km	≥7.0 °C/km
Surface to equilibrium level bulk shear [Shear$_{EL}$/LCL-EL(Cloud Layer)]		≥46 kt	≥60 kt
Significant Hail Parameter (SHP)		>1	

If you think a thunderstorm contains hail, below are some general, radar base-data hail signatures. NOTE: These values are typical, but may not apply in all situations.

Hydrometeors	Z	ZDR	CC	KDP
Severe rain/hail Mix	>55 dBZ	>1 dB	0.90-0.96	1-3 °/km (rain/hail mix) 3-4 °/km (hail melt possible) >4 °/km (significant hail melt)
Severe, dry hail	>55 dBZ	<1 dB	0.95-0.97	<1 °/km
Significant (≥2") hail	>65 dBZ	~0 dB	<0.9	No Data

Common hail sizes:



In favorable environments for severe hail, use the following significant values to guide specifying hail sizes in warnings. Many times parameters conflict with each other, and the lack of one parameter does not necessarily preclude a hail size.

Radar Signatures	Base Severe (≥1")	Significant (≥2")	Giant (≥4")
Thunderstorm type	Discrete thunderstorm	Discrete supercell	Discrete supercell*
* Mini-supercells (~24-32 kft top) rarely produce hail in the giant category, so identifying one usually can often be exclusionary to giant hail detection			
Reflectivity Height			
50 dBZ thickness above melting level	≥16 kft		
60 dBZ height		Above -20 °C	
65 dBZ height			Above -30 °C
Storm-Top Divergence ΔV			
10.5-11.5 kft freezing level	74-115 kts	126-148 kts	233-267 kts**
11.5-12.5 kft freezing level	80-120 kts	135-155 kts	
12.5-13.5 kft freezing level	110-143 kts	152-170 kts	
13.5-14.5 kft freezing level	115-147 kts	160-180 kts	
14.5+ kft freezing level	135-178 kts	188-209 kts	
** Values based on freezing level not available for giant hail (Boustead, 2008; Blair et al., 2011)			
Other Features			
Three body scatter spike (TBSS)	Likely		
Max hail size from algorithm (HDA or MRMS)	≥1"	≥2"	
Bounded weak echo region (BWER)		Yes	
Updraft persists		≥30 min	
Highest V_{rot} at any elevation		≥28 kts	≥40 kts

Wind

Use the following significant values to better understand the key environment ingredients in wet microburst, dry microburst, and QLCS/derecho situations. NOTE: Exceeding "preferred values" indicates favorable conditions; Not meeting "necessary values" indicates unfavorable conditions.

Wet Microburst Parameters	Necessary Value	Preferred Value
0-3 km maximum theta-e difference (Theta E Diff)		>25 K
Microburst Composite (MBCP)	5-8	≥9
Surface-based CAPE (SBCAPE)	≥3100 J/kg	≥4000 J/kg
0-3 km lapse rate	>8.4 °C/km	
Downdraft CAPE (DCAPE)	≥900 J/kg	≥1100 J/kg
Precipitable water	≥1.5"	

Dry Microburst Parameters	Necessary Value	Preferred Value
Inverted-V sounding		Yes
Most unstable CAPE (MUCAPE)	1-500 J/kg	
100-mb mean parcel LCL height	>3 km AGL	Above Melting Layer
0-3 km lapse rate	≥Dry adiabatic	
Effective bulk wind difference (EBWD)		<30 kts

QLCS/Derecho Parameters	Necessary Value	Preferred Value
Derecho Composite Parameter (DCP)		>2
Downdraft CAPE (DCAPE)	>0 J/kg	>980 J/kg
0-6 km mean wind		>16 kts
Most unstable CAPE (MUCAPE)	>0 J/kg	>2000 J/kg
Effective bulk wind difference (EBWD)		>20 kts

In favorable environments for severe wind, use the following signatures in severe thunderstorm decision making for supercell, microburst, and QLCS situations.

Radar Signatures	Supercell	Microburst	QLCS/ Derecho
General Thunderstorm Signatures			
Rear-flank downdraft	Yes		
Rapid formation of strong reflectivity or VII core at -10 °C		Yes	
Descending core bottom		Yes	
Mid-altitude radial convergence (MARC) ΔV		>15 kts	>50 kts
Low-level velocity (<1500 ft AGL)	>50 kts	>30 kts	>50 kts
Fast storm motion	Maybe		Yes
Wet/Melting Hail Signature			
Three-body scatter spike (TBSS)		Yes	
Correlation coefficient (CC)		0.93-0.96	
Specific differential phase (KDP)		>3 °C/km	
QLCS/Derecho/Cold-Pool Driven Signatures			
Strong leading reflectivity gradient			Yes
Bow echo			Yes
Rear inflow jet (RIJ)			Yes
Deep convergence zone			>10 kft
Gust front hugs close to reflectivity gradient			Yes
Linear weak echo region (WER) along leading edge			Yes