Warning Methodology

Screen, Rank, Analyze, Decide (SRAD)

1. **<u>Screen</u>** the storms that threaten life and property over your CWA.

    - <u>Severe Hazards (tornado/wind/hail)</u>: 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 **<u>Rank</u>**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. **<u>Analyze</u>** 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 **<u>Decision</u>**. 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).

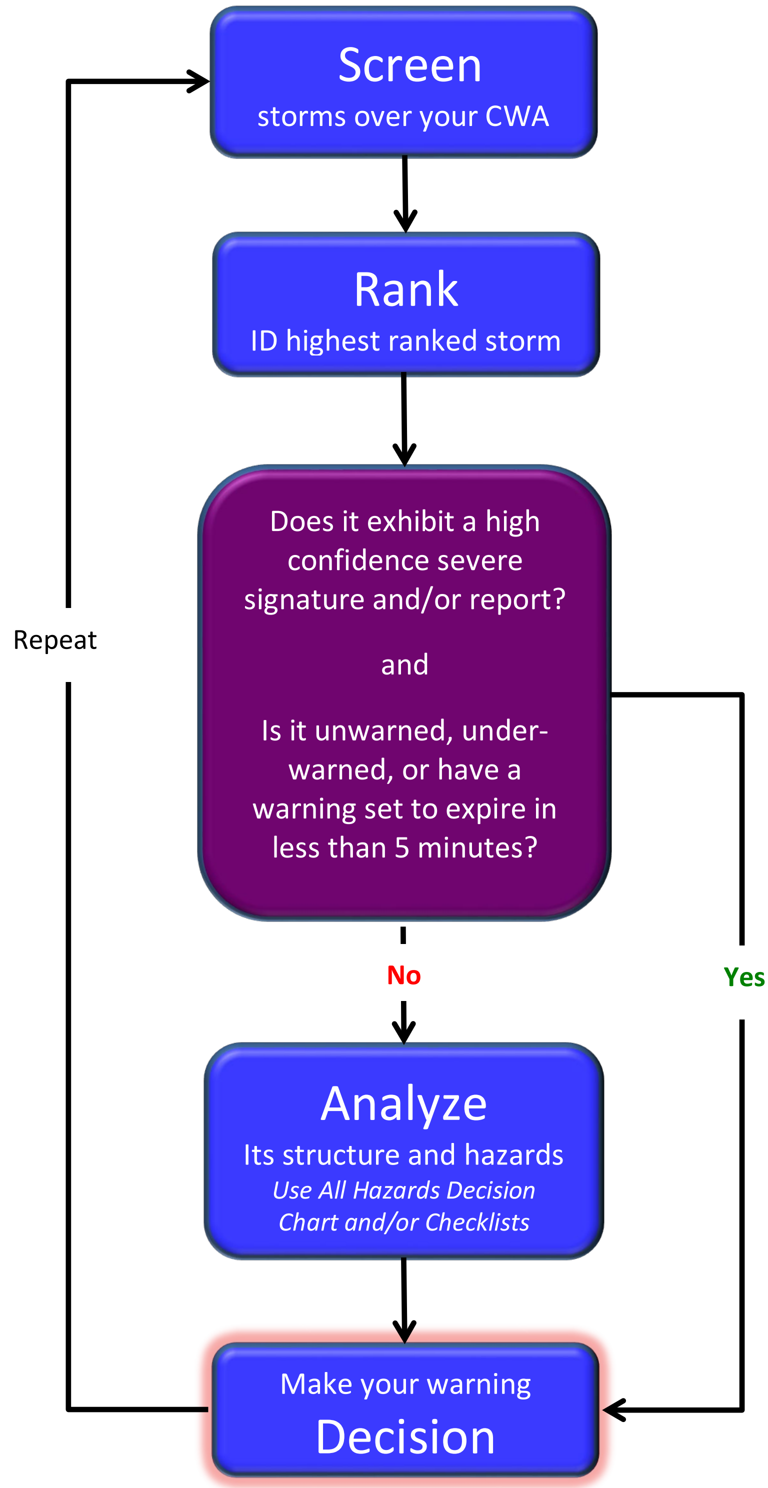
- Capture multiple threats in close proximity with a single polygon when necessary.
- **Avoid:**
  - "Tornado Emergency" wording unless there is very high confidence of a significant (EF2+) tornado moving into an urban area.
- Non-mesocyclonic: Track the updraft interaction with the low-level boundary(ies).

- Severe Hail/Wind
  - <u>Individual cell</u>: 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.
    - <u>Supercell</u>: Anticipate deviant motion; include the Rear Flank Downdraft (RFD) in your polygon.
  - <u>Multicell</u>: 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.
    - <u>Bow Echo/QLCS</u>: 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)

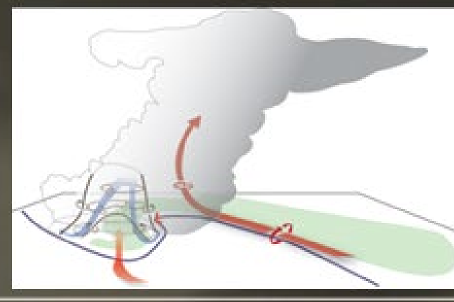


Tornado

Near Storm Environment	Storm Characteristics

Mesocyclonic

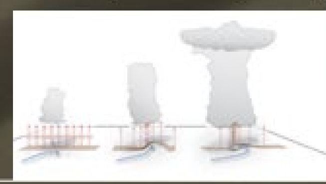
- Significant tornado parameter (Effective Layer) (STP_{eff}) > 1
- Effective bulk wind difference (EBWD) ≥ 39 kt
- Effective storm-relative helicity (ESRH) >150 m^2s^{-2}
- 100-mb mean parcel LCL (MLLCL) < 1000 m
- 100-mb mean parcel CAPE (MLCAPE) > 1500 J/kg
- 100-mb mean parcel CIN (MLCIN) < 50 J/kg within last hour



- Discrete classic or High Precipitation (HP) supercell
- Strengthening updraft
- Acceleration & convergence into a strong low-level mesocylone
- Tornado vortex signature (TVS)
- Tornado debris signature (TDS)

Non-Mesocyclonic (Landspout/Waterspout)

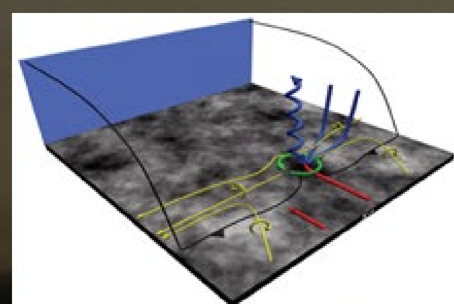
- Non-supercell tornado parameter (NST) > 1
- 0-1 km lapse rate (LR_{0-1}) > 9°C/km
- 0-3 km MLCAPE ($MLCAPE_3$) > 100 J/kg
- 100-mb mean parcel CIN (MLCIN) < 25 J/kg
- Stationary boundary with sfc relative vorticity (ζ_r) > 8 x $10^{-5}s^{-1}$



- Strong, rapidly growing updraft (best seen via Z at -10°C)
- Tornado vortex signature (TVS)
- Tornado debris signature (TDS)

Quasi-Linear Convective System (QLCS)

- 0-3 km line normal bulk shear ≥ 30 kt
- Rear Inflow Jet (RIJ) or enhanced outflow causing surge or bow in line
- 0-3 km MLCAPE ($MLCAPE_3$) ≥ 40 J/kg



- Balanced or slightly shear dominant

<u>Confidence Builders (3 Ingredients Method)</u>:

- Descending rear inflow jet (RIJ)/reflectivity drop
- Enhanced surge • Line break
- Updraft deep cnvg zone (UDCZ) entry/inflection point
- Paired front/real inflow notch • Boundary ingestions
- Front reflectivity nub
- Contracting bookend vortex with V_r ≥ 25 kt
- Tight/strong mesovortex with V_r ≥ 25 kt
- Confirmed tornado/Tornado Debris Signature (TDS)

<u>Nudgers</u>:

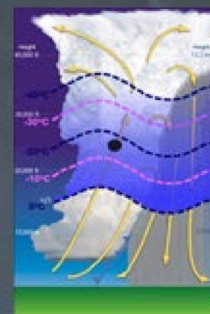
- Reflectivity tag intersecting a surge
- Cell merger/reflectivity spike near surge
- History of tornadoes

Hail

Near Storm Environment		Storm Characteristics

Severe (≥ 1-inch)

1″ 1.25″ 1.5″ 1.5″ 1.75″



Near Storm Environment

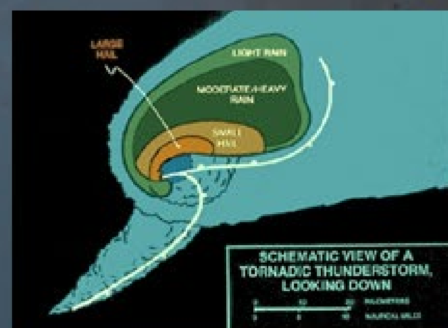
- Large hail parameter (LHP) > 4
- Most unstable CAPE (MUCAPE) ≥ 1600 J/kg
- Effective bulk wind difference (EBWD) ≥ 29 kt

Storm Characteristics

- 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)

2″ 2.5″ 2.75″ 3″



Near Storm Environment

- 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

Storm Characteristics

- 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)

4″ 4.5″ 4.75 - 5″

Near Storm Environment

- 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 Characteristics

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

Wind

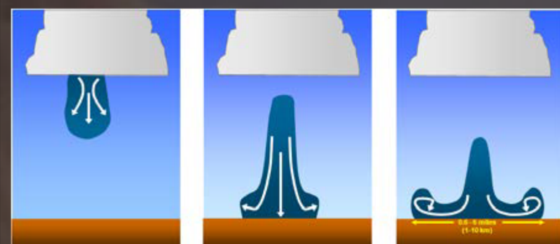
Near Storm Environment | Storm Characteristics

Individual Cell Downburst/Microburst

Near Storm Environment

<u>Wet Microburst</u>:
- 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"

<u>Dry Microburst</u>:
- 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



Storm Characteristics

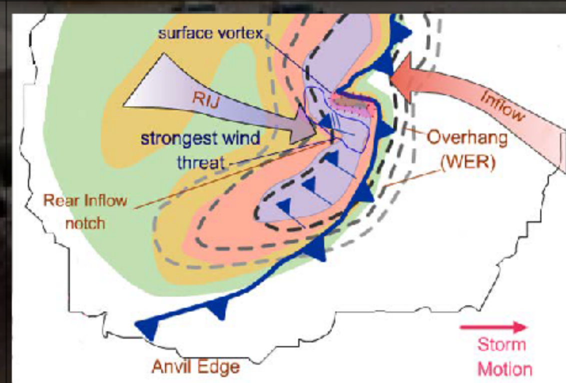
- Rapid formation of strong core aloft
- Descending core bottom
- Mid-altitude radial convergence (MARC) (0°C to lifted condensation level (LCL)) ΔV > 15 kt
- Wet hail signature (Three-Body Scatter Spike (TBSS), CC ~ 0.93-0.96, KDP > 3°C/km)
- Low-level (< 1500 ft AGL) velocity (V) > 30 kt

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

Near Storm Environment

- 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



Storm Characteristics

- 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

Impact-Based Warnings Guidance*

30* kt V_{rot}
Initial Supercell Tornado Warning Threshold

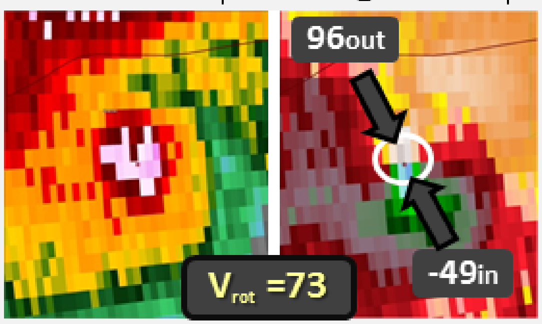
40 kt V_{rot}
Considerable Tag Threshold With TDS

50 kt V_{rot}
Considerable Tag Threshold Without TDS

* These are guideline thresholds. Know your environment. Lowest slice below 10kft. Original resources available at: http://training.weather.gov/wdtd/courses/ibw/references.php

Measuring V_{rot}

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

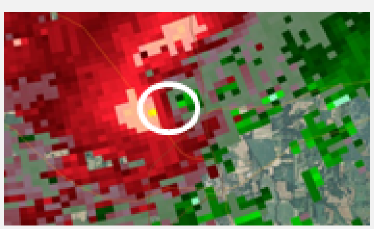


Also consider…

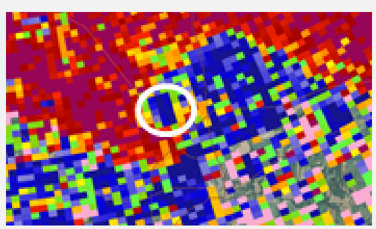
- V_{rot} relationships weaken at ranges > 70 nmi
- Is the velocity in area of > 20 dBZ?

Tornado Debris Signature (TDS) Identification

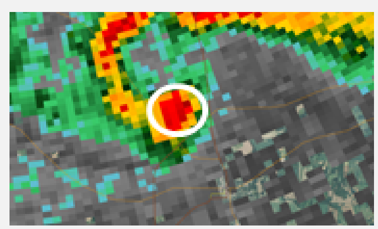
Criteria for a "Radar Confirmed Tornado"



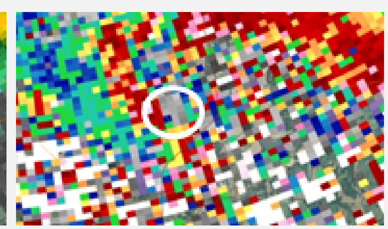
First, identify a valid velocity circulation at the lowest elevation tilt



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!!

Nowcasting Significant Tornadoes

TDS Height Threshold
EF2+: 8,000-10,000 ft.

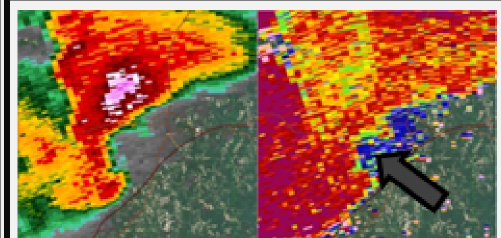
Other EF-2+ Indicators:

- TVS/TS: 0.5° $V_{rot} \geq$ 70 kt. on any of the last 3 scans
    - If 0.5° V corrupted, pick higher beam < 2 km AGL
- Supercell meso: ≥ 8,000 ft. deep with avg. $V_{rot} \geq$ 30 kt, persisting for at least 2 volume scans
- Near storm environment (NSE) supportive
- Parent storm history

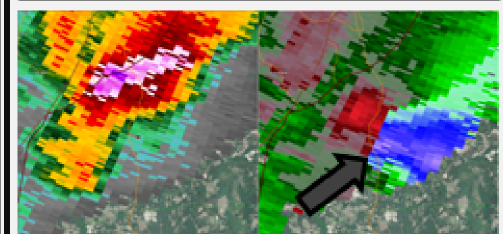
Upgrade to Catastrophic Tag "Tornado Emergency" if:
(Must meet ALL)

1. Tornado confirmed (TDS or credible source)
2. Expected to impact populated area
3. Believed to be strong/violent (EF2+)

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 Warning Points of Emphasis*

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

Supercell Warning Confidence Thresholds

Eff. Layer Significant Tornado Parameter (STP)

Includes these ingredients:

- MLCAPE [100 mb]
- MLCIN [100 mb]
- MLLCL [100 mb]
- Effective SRH
- Effective BWD

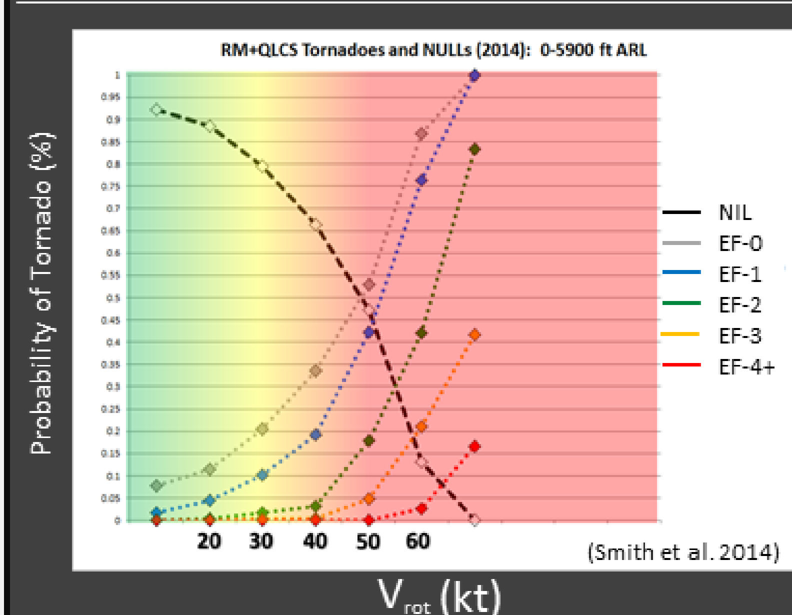
When using STP, be sure to also examine these ingredients individually during any severe weather mesoanalysis!

Is the Environment Favorable?

Given a 30-kt V_{rot} Signature:

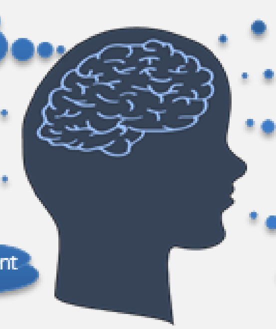
Warning may be unnecessary	Best Practice Warning Threshold	Above Warning Threshold
0	1	3

STP (Effective Layer) Values



Keep in Mind...

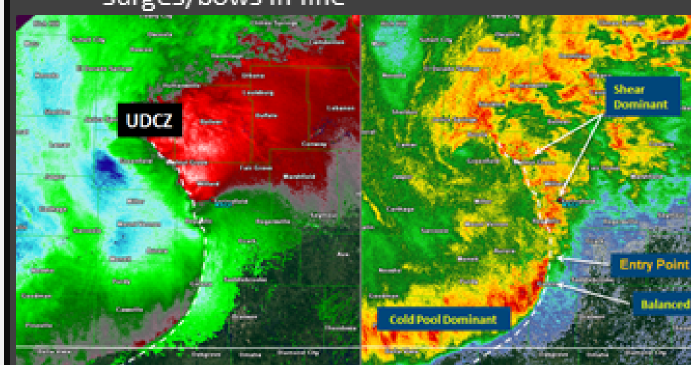
- Use velocity data – presence of a hook indicates a supercell, not NECESSARILY a tornado
- Evaluate the storm/velocity at all elevation angles!
- Warn downstream with sufficient lead time
- Remember V_{rot} methods/pitfalls/TDS identification (see reverse)
- Attempt to limit false alarm area
- Collaborate 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. Balanced or slightly shear-dominant portion of line
2. 0-3-km line-normal bulk shear >30 kts
3. RIJ or enhanced outflow causing surges/bows in line



Other features to watch for:

- Updraft/downdraft convergence zone (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)
- Cell merger/boundary ingestion

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

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")

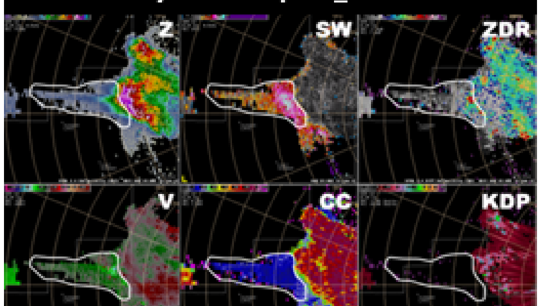
Adapted from Witt and Nelson, 1991

Mesocyclone

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

Source: Blair et al., 2011

Three Body Scatter Spike ≥ 0.4 – 0.8 in.*



*Valid for S-band radar only, Source: Kumjian et al., 2010

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