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).

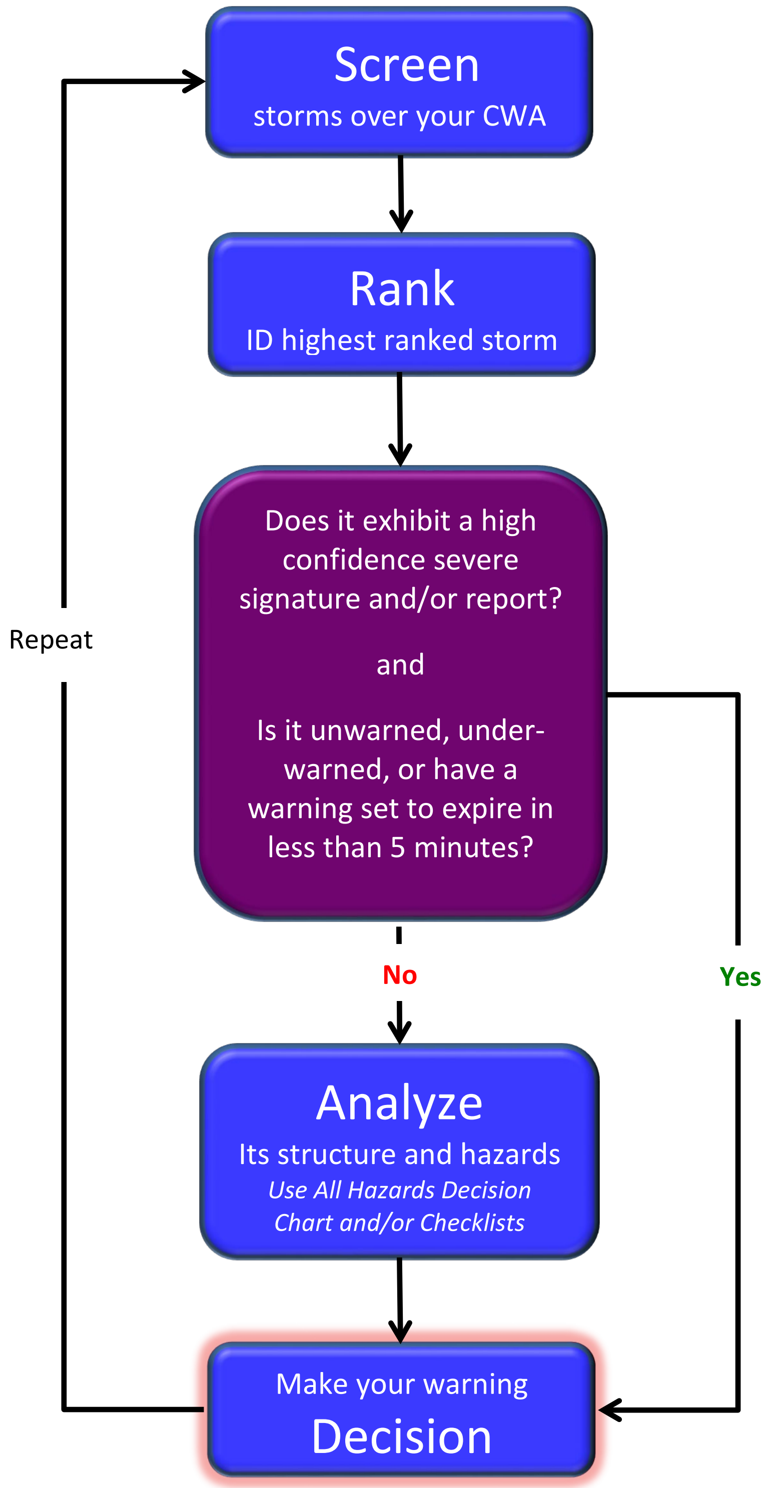
- Severe Hail/Wind
    - <u>Individual cell</u>: Choose WarnGen Track type: "One Storm" and track the updraft/downdraft interface region; be sure to include both the updraft and downdraft regions in your polygon.
        - <u>Supercell</u>: Anticipate deviant motion; include the Rear Flank Downdraft (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

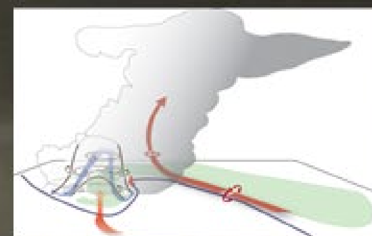
Near Storm Environment		Storm Characteristics

Mesocyclonic

Given a discrete supercell:

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

Note: STP_{500} improves skill by replacing ESRH with 0–500 m AGL SRH

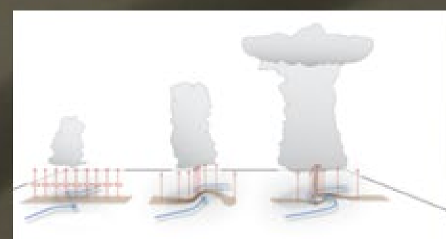


- Discrete, surface-based, classic supercell
- Acceleration and convergence into a strong, low-level mesocylone *(during pre-tornadic stage)*
- Tornado Vortex Signature (TVS) / Tornado Signature (TS)
- Tornado Debris Signature (TDS)

Non-Mesocyclonic (Landspout/Waterspout)

Given an updraft forming along a slow moving or stationary surface boundary possessing strong horizontal shears w/ misoscale vorticies:

- Non-supercell tornado parameter (NST) > 1
  - Surface relative vorticity (ζ_r) > 8 x 10^{-5} s^{-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
  - 0-6 km bulk shear ≤ 26 kt

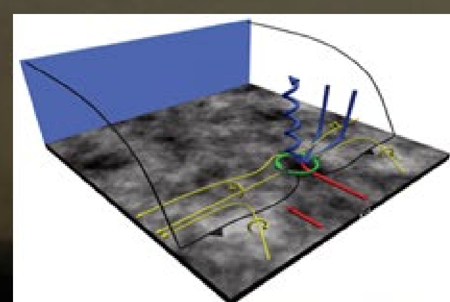


- Reflectivity (Z) core aloft (≈ 0°C) co-located with misoscale vortex along the boundary
- Tornado Vortex Signature (TVS) / Tornado Signature (TS)
- Tornado Debris Signature (TDS)
- Formation of precipitation core (cold pool) at the surface typically signals tornado dissipation

Quasi-Linear Convective System (QLCS)

Given a 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 tornado

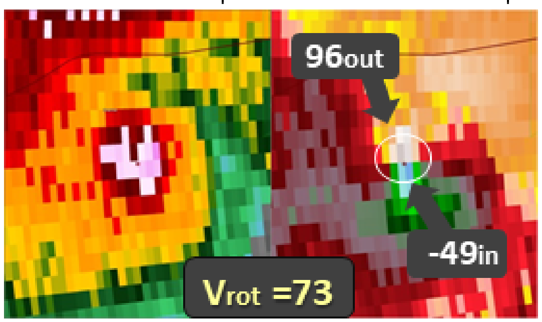
Impact Based Warnings Guidance

30 KT V_{rot}	40* KT V_{rot}	50* KT V_{rot}
If STP Non-Zero – Tornado Warning Likely Needed	Considerable Tag Threshold With TDS, STP >1	Considerable Tag Threshold Without TDS, STP >1

Put this into context with other available information and your professional judgement/experience. Scholarly sources available at https://training.weather.gov/wdtd/courses/ibw/references.php

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 Vrot 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.

At 30 kt V_{rot} 1.0 nm diameter or less preferred, at larger values (e.g. 60+ kt) much larger values can still be a serious threat. All must be inside of 90 nm.

TDS Height Threshold

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

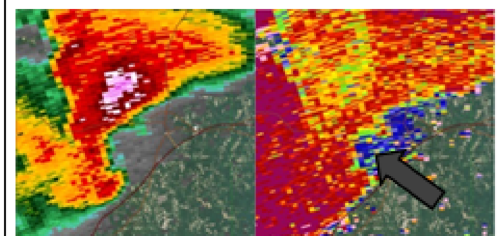
- Supercell meso: ≥ 8,000 ft. deep with avg. V_{rot} ≥ 30 kt., persisting for at least 2 volume scans increases probability
- Violent Tornado: Median cases Vrot ≥ 70 kt, STP ≥ 6.0

Upgrade to Catastrophic Tag "Tornado Emergency" if:

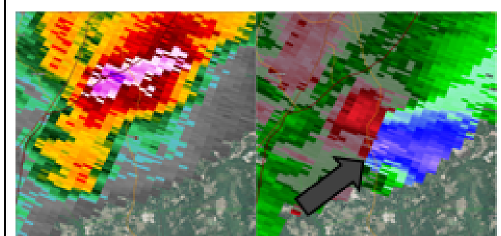
(Must meet ALL)

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

Potential Pitfalls



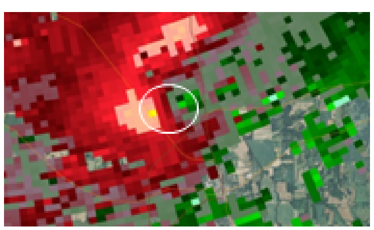
CAUTION: Low CC in inflow area can APPEAR to be TDS
Make sure the dBZ is ≥20



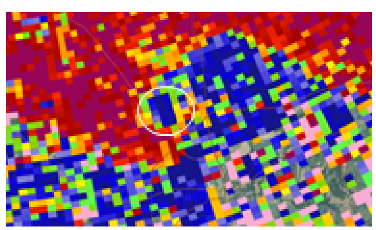
Vertical Side Lobe Contamination
Strong velocity in Weak Z below strong meso aloft, may not be valid signal

Tornado Debris Signature (TDS) Identification

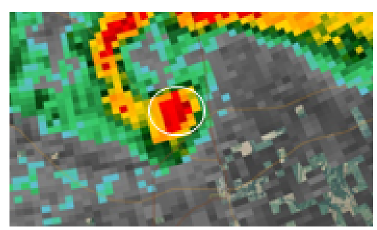
Criteria for a "Radar Confirmed Tornado"



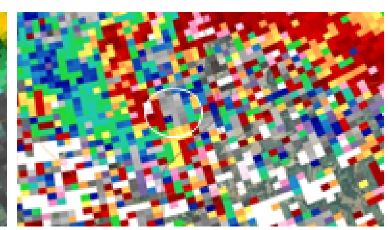
First, Identify a valid velocity circulation at the lowest elevation tilt



Is the CC below 0.90?



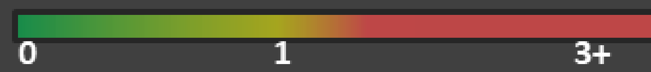
Collocated with Z above 30 dBZ?



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, studies based on 0-1 km, but 0-500 m is emerging.

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!

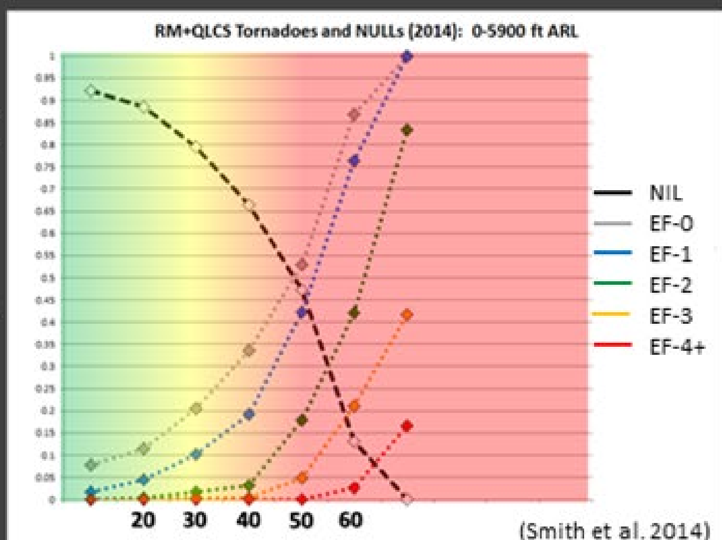
Is the Environment Favorable?

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.

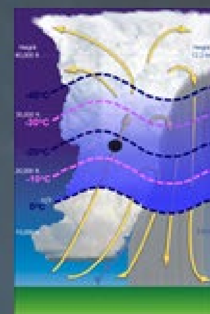
Hail

Near Storm Environment	Storm Characteristics

Severe (≥ 1-inch)

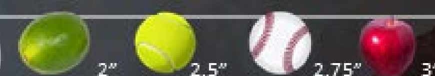
Given a discrete thunderstorm:

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



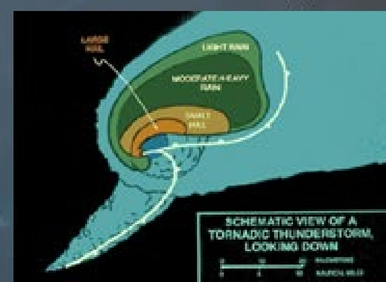
- Discrete thunderstorm
- Weak echo region (WER)
- 50 dBZ thickness above the melting level ≥ 16 kft
- Reflectivity (Z) ≥ 60 dBZ
- w/little rain: Z > 55 dBZ, CC = 0.95-0.97, ZDR < 1 dB, KDP < 1°/km
- w/rain: Z > 55 dBZ, CC = 0.93-0.96, ZDR = 1-2 dB, KDP > 0.5°/km
- Three body scatter spike (TBSS)
- Storm-top divergence (STD) ΔV > 74-135 kt
- Hail detection algorithm (HDA) ≥ 1"
- Max estimated size of hail (MESH) ≥ 1"

Significant (≥ 2-inch)



Given a discrete supercell:

- 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_{75}) ≥ 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
- Z > 65 dBZ (≈ 40 dBZ for LP), CC < 0.9, ZDR ≈ 0 dB
- Storm-top divergence (STD) ΔV > 126-188kt
- Peak mesocyclone rotational velocity (Vr) >27-41 kt
- Hail detection algorithm (HDA) ≥ 2"
- Max estimated size of hail (MESH) ≥ 2"

Giant (≥ 4-inch)

Given a discrete supercell:

- 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_{75}) ≥ 7.0°C/km
  - Surface to equilibrium level bulk shear ($Shear_{EL}$) ≥ 60 kt

Add to Significant (≥ 2-inch):

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

Radar Estimated Hail Size and Type

Storm-Top Divergence		Storm-Top Divergence		Storm-Top Divergence		Storm-Top Divergence		Storm-Top Divergence	
10,500–11,500 ft Freezing Level		11,500–12,500 ft Freezing Level		12,500–13,500 ft Freezing Level		13,500–14,500 ft Freezing Level		14,500+ ft Freezing Level	
ΔV (kts)	Hail Size (in.)	ΔV (kts)	Hail Size (in.)	ΔV (kts)	Hail Size (in.)	ΔV (kts)	Hail Size (in.)	ΔV (kts)	Hail Size (in.)
74-115	1.00" - 1.75"	80-120	1.00" - 1.75"	110-143	1.00" - 1.75"	115-147	1.00" - 1.75"	135-178	1.00" - 1.75"
115-126	1.75" - 2.00"	120-135	1.75" - 2.00"	143-152	1.75" - 2.00"	147-160	1.75" - 2.00"	178-188	1.75" - 2.00"
126-148	2.00" - 2.50"	135-155	2.00" - 2.50"	152-170	2.00" - 2.50"	160-180	2.00" - 2.50"	188-209	2.00" - 2.50"
148-172	2.50" - 3.00"	155-184	2.50" - 3.00"	170-188	2.50" - 3.00"	180-208	2.50" - 3.00"	209-230	2.50" - 3.00"
175	> 3.00"	185	> 3.00"	195	> 3.00"	215	> 3.00"	231	> 3.00"

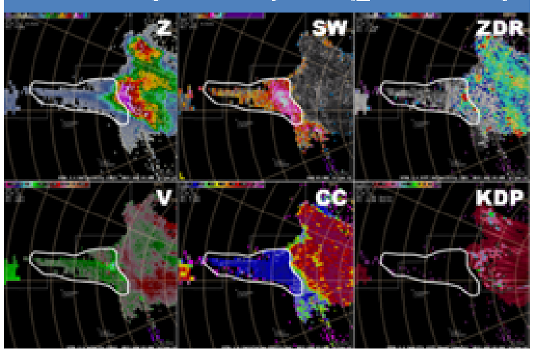
Boustead, J. M., 2008

Mesocyclone

Peak Rotational Velocity (Vr)	Hail Size
27-41 kt	1.75" to 2"
39-56 kt	≥ 4"

Source: Blair et al., 2011

Three-Body Scatter Spike ≈ (≥ 0.4 " - 0.8")



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

Dual-Pol Radar Hail Signatures

	Z 45-59 dBZ = Hail psbl >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 ≈ Dry hail 1-3°/km ≈ Rain/hail >3°/km ≈ Melting hail
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
Severe Hail (w/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 bB	CC ≈ 0.93–0.96	KDP > 0.5°/km
Significant (≥2") Hail	Z > 65 dBZ (≈40 dBZ for LP)	ZDR ≈ 0 dB	CC < 0.7 - 0.9	KDP "no data"

Wind

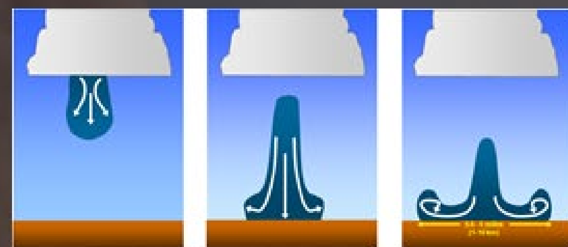
Near Storm Environment | Storm Characteristics

Individual Cell Downburst/Microburst

Given a discrete thunderstorm:

Wet Microburst:
- 0-3 km max theta-e difference ($\Delta\theta_e$) > 25°C
- Microburst composite (MBCP) ≥ 5-8
  - Surface-based CAPE (SBCAPE) ≥ 3100 J/kg
  - 0-3 km lapse rate (LR_{0-3}) > 8.4°C/km
  - 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



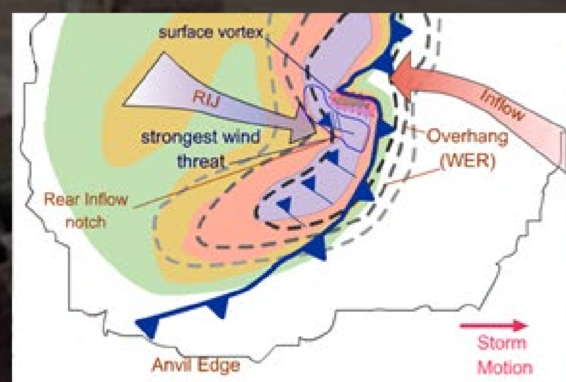
- Rapid formation of strong core aloft (best seen via time lapse loops of MRMS VII product or Z at -10°C)
- Descending core bottom
- Mid-altitude radial convergence (MARC) (0°C to lifted condensation level (LCL)) ΔV > 15 kt
- Melting hail signature (Three-Body Scatter Spike (TBSS), CC ~ 0.93-0.96, KDP > 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

Given a QLCS/derecho/cold-pool driven thunderstorm:

- 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