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).

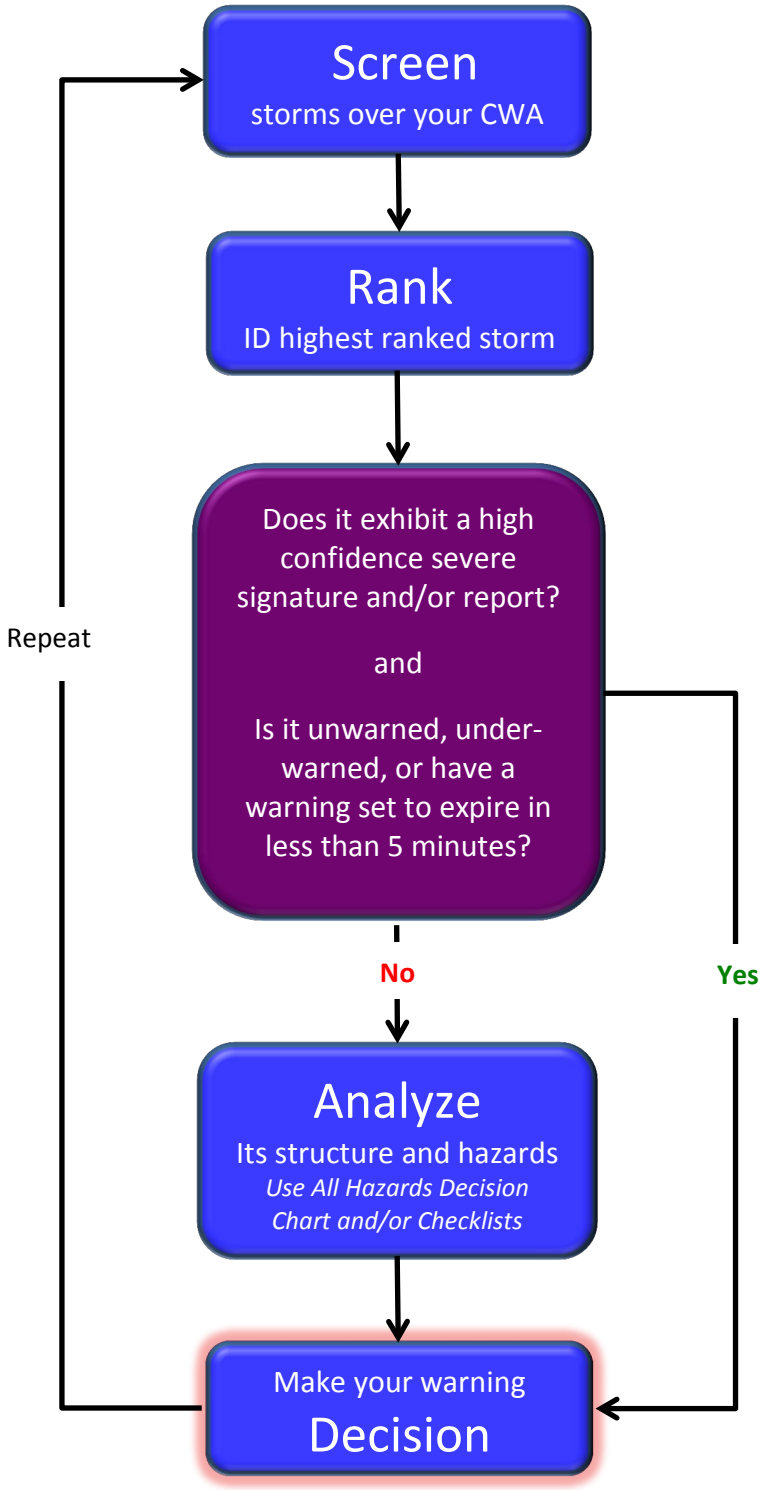
- Severe Hail/Wind
  - Individual cell: Choose WarnGen Track type: "One Storm" and track the updraft/downdraft interface region; be sure to include both the updraft and downdraft regions in your polygon.
    - Supercell: Anticipate deviant motion; include the Rear Flank Downdraft (RFD) in your polygon.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

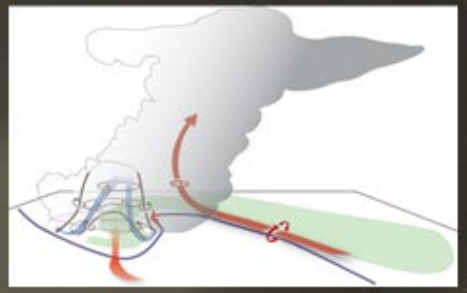


Tornado

Near Storm Environment	Storm Characteristics

Mesocyclonic

- Significant tornado parameter (Effective Layer) (STP_{eff}) > 1
- Effective bulk wind difference (EBWD) $\geq$ 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)

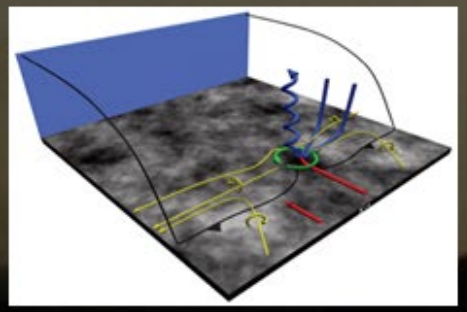
Non-Mesocyclonic (Landspout/Waterspout)

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



- Balanced or slightly shear dominant

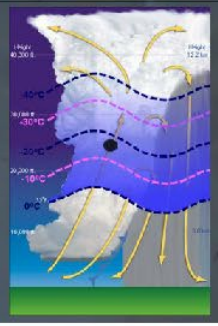
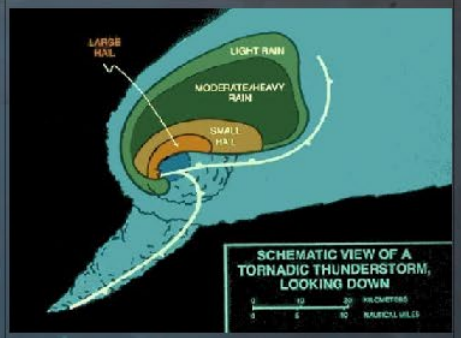
Confidence Builders (3 Ingredients Method):

- 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 $V_r \geq$ 25 kt
- Tight/strong mesovortex with $V_r \geq$ 25 kt
- Confirmed tornado/Tornado Debris Signature (TDS)

Nudgers:

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

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

Wind

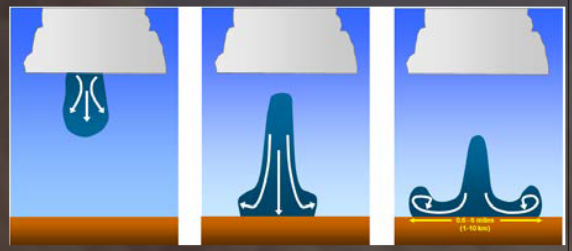
Near Storm Environment

Storm Characteristics

Individual Cell Downburst/Microburst

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

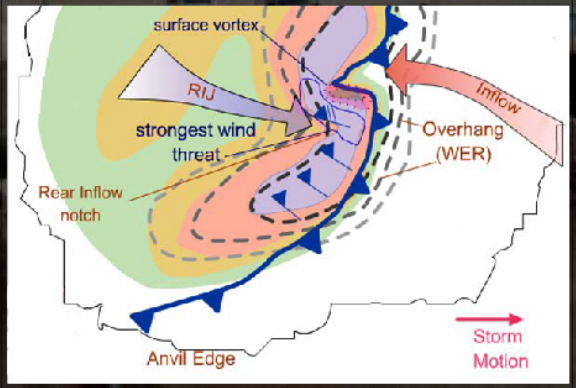


- Rapid formation of strong core aloft
- Descending core bottom
- Mid-altitude radial convergence (MARC) (0°C to lifted condensation level (LCL)) ΔV > 15 kt
- Wet hail signature (Three-Body Scatter Spike (TBSS), CC ~ 0.93-0.96, KDP > 3°C/km)
- Low-level (< 1500 ft AGL) velocity (V) > 30 kt

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



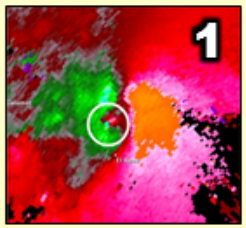
- Strong leading reflectivity (Z) gradient
- Bow echo
- Rear inflow jet (RIJ)
- Mid-altitude radial convergence (MARC) ΔV > 50 kts at 3-5 km AGL
- Deep convergence zone (DCZ) > 10 kft
  - > 15-20 kft is optimal
- Gust front hugs close to reflectivity (Z) gradient
- Linear weak echo region (WER) along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

Note: A mesovortex w/RIJ produces strongest wind

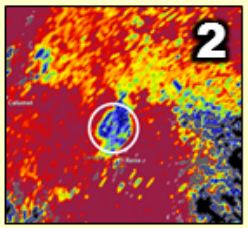
Radar Tornado Intensity Estimation Guidance

Identifying a Tornadic Debris Signature (TDS)

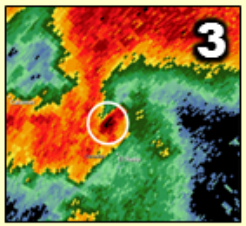
Provides radar confirmation of a damaging tornado in progress.



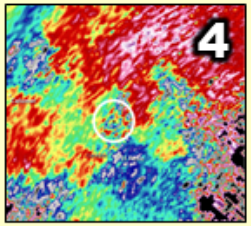
First, identify a valid velocity circulation.



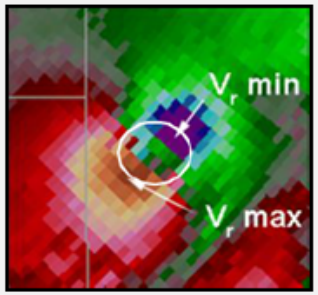
Next, ensure correlation coefficient (CC) is below 0.90



Next, ensure reflectivity is over 35 dBZ and co-located with #1/2



Not necessary but adds confidence: ZDR reduced to ~0 or below zero in spots.



$$V_{rot} = (|V_{in[max]}| + |V_{out[max]}|) / 2$$

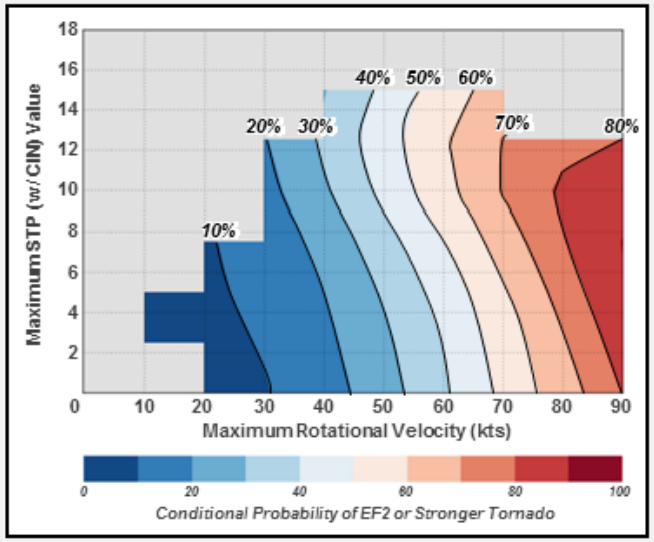
To determine rotational velocity, add the absolute value of the highest inbound and outbound velocity values in the couplet, and then divide by 2.

Considerations and Tips

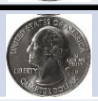
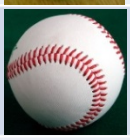
- EF2+ tornadoes are likely if TDS has debris ball (reflectivity > 50-55 dBZ)
- With split cut mode VCPs, TDS can have a slight offset from velocity sig.
- **Discriminating between supercellular weak and strong tornadoes**: Heidke Skill Scores maximized with LLRV in the 45-55 knot range.
- **In borderline intensity cases, push up a category if**: tornado is moving fast, conditions very favorable for EF2+, or signature is poorly sampled.

Tornado Intensity	Supercells Only: Rotational Velocity (kts)	QLCS Only: Rotational Velocity (kts)	MOST RELIABLE: Maximum TDS Height
	Only valid within 70nm of the radar site		
WEAK EF0/EF1	40 knots or less	30 knots or less	Under 8,000 ft
	Overlap 40-55 knots	Overlap 30-45 knots	Overlap 8-10 kft
STRONG EF2/EF3	55 to 75 knots	45 knots or more	10,000 to 15,000 ft
	Overlap 75-85 knots		Overlap 15-18 kft
VIOLENT EF4/EF5	85 knots or more	Insufficient cases	Over 18,000 ft

Conditional EF2+ Tor Probability



NWS Hail Size Chart

Description	Diameter	Updraft Speed
BB	< ¼”	< 24 mph
Pea	¼”	24 mph
Marble / Plain M&M	½”	35 mph
Dime	$^{7}/_{10}$”	38 mph
Penny	¾”	40 mph
Nickel	$^{7}/_{8}$”	46 mph
Quarter 	*(Severe)* 1”	49 mph
Half Dollar	1 ¼”	54 mph
Walnut / Ping-Pong Ball	1 ½”	60 mph
Golf Ball	1 ¾”	64 mph
Hen Egg / Lime	*(Significant)* 2”	69 mph
Tennis Ball	2 ½”	77 mph
Baseball 	2 ¾”	81 mph
Teacup / Large Apple	3”	84 mph
Grapefruit	4”	98 mph
Softball	4 ½”	103 mph
CD / DVD	4 ¾”	105 mph

Radar Estimated Hail Type/Size

Storm-Top Divergence

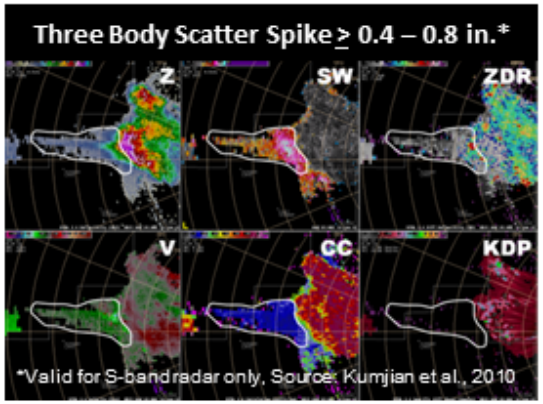
Peak ΔV (kts)	Max Hail Size (in.)
70-102	Quarter (1”)
115-147	Golf ball (1 ¾”)
174-207	Baseball (2 ¾”)
233-267	Grapefruit (4”)

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



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