APPENDIX: Suggested Warning Methodology

Screen, Rank, Analyze, Decision (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. **<u>Rank</u>** the storms by order of threat. Identify the highest ranked 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. Generate your **<u>Decision</u>** using WarnGen. Collaborate with your warning team members. 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.

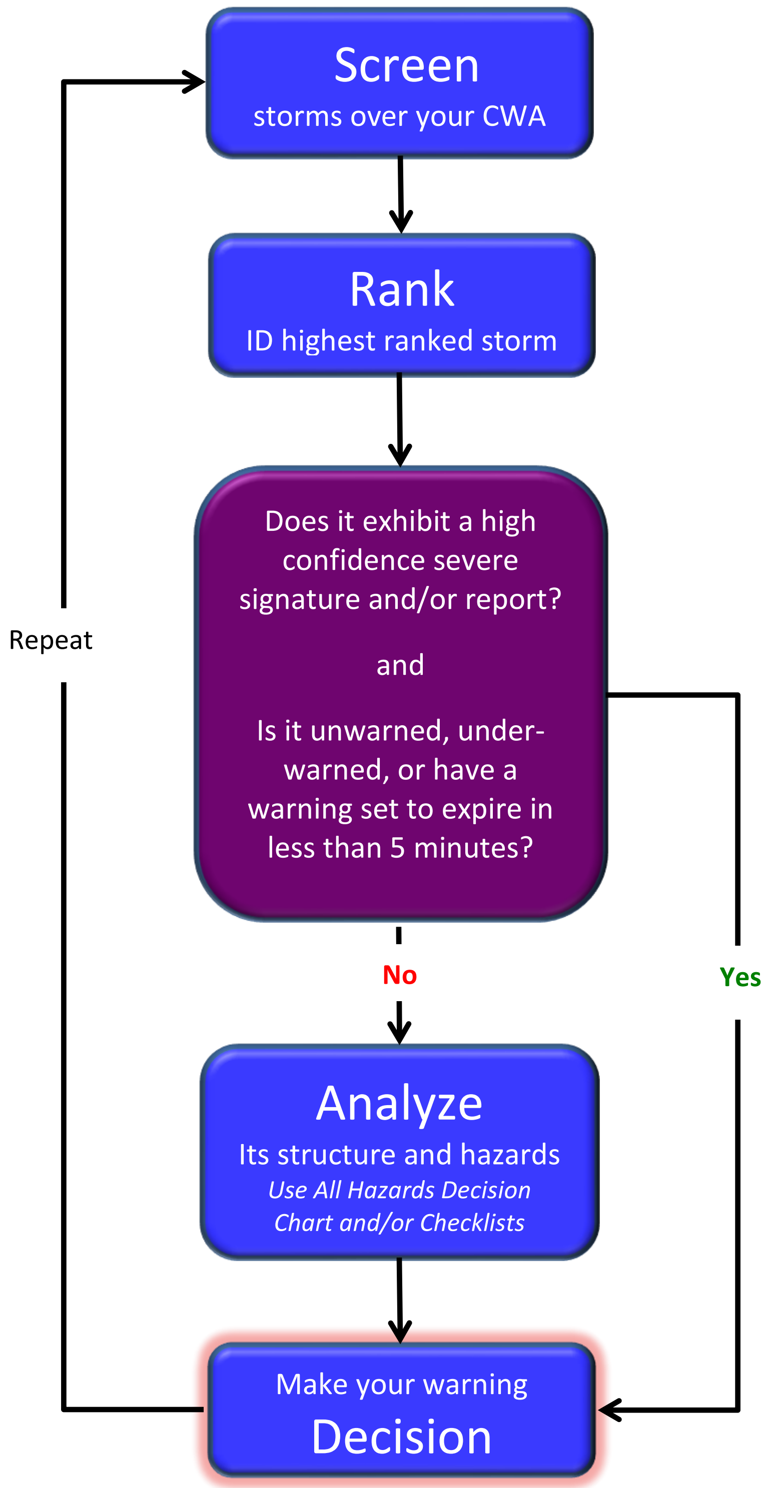
NOTE: One SRAD cycle (steps 1-4) should take about 5 minutes (with experience).

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

- Then, use the SRAD process to create Severe Weather and/or Flash Flood Statements.

WDTD Suggested Warning Methodology:

Screen, Rank, Analyze, Decision (SRAD)



Warning Decision Cycle Checklists

Temperature Levels

	0° C	-10°	-20° C	EL
Height (ft ARL)				

Updraft Strength Checklist

Feature	**Comments** (Do not take thresholds as inflexible values)
Reflectivity Height	Do high reflectivities extend to high altitudes? • 50 dBZ above -20°C suggests a strong updraft • MRMS 50 dBZ thickness above the melting level of 16 kft suggests a powerful updraft • 60 dBZ above -20°C suggests a powerful updraft • 50 dBZ above the equilibrium level suggests an extreme updraft
Low-level Inflow Notch	Does the storm possess a low-level inflow notch? *Note: Rarely seen beyond 70 nm from single site radar.*
Weak Echo Region (WER)/Bounded Weak Echo Region (BWER)	Is there a WER/BWER? Does WER persist > 5-10 min? • Use Reflectivity from surface to -10°C to identify a WER • BWERs are best seen at -10°C *Note: BWERs rarely exceed 3 nm wide and extend colder than -20°C. BWERs are more difficult to see in MRMS than single radar.*
ZDR Column Height	How high has the ZDR column extended during the past ~15 min? • ZDR column $\leq$ -10° C suggests a strong updraft *Note: ZDR columns rarely extend colder (higher) than -20°C*

Mesocyclone Strength	Is there a meso? How strong?
	• *Calculate rotational velocity (Vr) using the max and min velocities with the midlevel (~4-20 kft AGL) meso*
	  ○ Vr = 20-29 kts indicates a weak meso
	  ○ Vr = 30-39 kts indicates a moderate meso
	  ○ Vr = 40+ kts indicates a strong meso
	  Note: Known as the "20, 30, 40 rule." Relax these criteria beyond ~80 nm
	• Determine the mesocyclone's peak value on the MRMS 3-6 km Azimuthal Shear product
	  ○ Values > 0.01 s^{-1} indicate a moderate mesocyclone

Low-level Convergence	Calculate the magnitude and depth of the low-level convergence. • Magnitude (ΔV) > 50 kts suggests a strong updraft • Depth > 10 kft is impressive, > 15 kft is rare
Storm top Divergence	Does the storm exhibit strong storm top divergence? *Note: Calculate ΔV using the max and min velocities around the updraft summit.* • ΔV > 75-100 kts suggests severe updraft • ΔV > 130-160 kts suggests significant severe updraft *Note: Beware, true max velocity difference may be located between radar elevation slices.*
Trends	Evaluate the overall trend of the updraft strength signatures (above).

Tornado Checklist

Feature	Comments *(Do not take thresholds as inflexible values)*
Mesocyclonic Tornado only	
Near Storm Environment	Is the supercell in a favorable environment? • Significant Tornado Parameter (STP) (effective layer) > 1 • Effective Bulk Wind Difference (EBWD) > 40 kt • Effective Storm Relative Helicity (ESRH) > 150 m^2s^{-2} • 100-mb Mixed Layer Lifted Condensation Level (MLLCL) < 1000 m AGL • 100-mb Mixed Layer Convective Available Potential Energy (MLCAPE) >1500 J/kg • 100-mb Mixed Layer Convective Inhibition (MLCIN) < 50 J/kg within last hour *Note: Be careful to evaluate the environment in the storm's inflow, not within the storm itself.*
Mesocyclone LLRV	Given favorable mesocyclonic tornado environment, Low-Level Rotational Velocity (LLRV): • LLRV > 30 kts ~15% chance of tornado • LLRV > 60 kts ~ 50% chance of tornado
MRMS Azimuthal Shear Rotation Tracks	Is there strong low- and mid-level azimuthal shear (AzShear)? A tornado is likely if: • 0-2 km Rotation Track > $15x10^{-3}$ s^{-1} • 3-6 km Rotation Track > $10x10^{-3}$ s^{-1} *Note: More research relating tornado probabilities and MRMS AzShear needed. Use cautiously.*
Mesocyclone Base Altitude (ARL)	Given Mesocyclone Detection Algorithm (MDA) rank ≥ 5 (moderate intensity): • Meso base > 1000 m means ~13% chance of tornado • Meso base < 1000 m means ~40% chance of tornado *Note: Not applicable if lowest elevation scan is >~ 1000 m*
Low-level Storm-Relative Inflow	Is the storm's low level inflow accelerating and > the near storm background surface flow? *Note: This indicates that roots of updraft are surface-based. Look in lowest 3 kft AGL (range limited). Accelerating either from front or rear flank. Best view requires large radial storm motion component.*
Low-level Convergence	Is there significant low-level convergence beneath the mid-level meso? *Note: Not applicable if lowest scan is > ~1000m AGL.*
Non-Mesocyclonic Tornado only	
Near Storm Environment	Is the storm in a favorable environment? • 0-1 km Lapse Rate > 9°C/km • 0-3 km MLCAPE > 100 J/kg • MLCIN < 25 J/kg • Significant surface vertical vorticity with a slow moving wind shear boundary *Note: Don't wait for WER/BWER/meso. Boundary is not associated with a density current.*
Both Types	
Updraft Strength	*See Updraft Strength checklist*
Reports	Is there a tornado report? How confident are you of the report? • Public = Lowest confidence • Spotter/Chaser = Medium confidence • Multiple reports w/damage = High confidence
TVS/TS Strength	Is there a Tornadic Vortex Signature (TVS) or Tornado Signature (TS)? How strong? • TVS/TS ΔV = 50-70 kts means low chance of tornado • TVS/TS ΔV = 70-90 kts means moderate chance of tornado • TVS/TS ΔV = > 90 kts means significant chance of tornado

Tornado Debris Signature (TDS)	Is there a TDS?
	• Valid velocity circulation collocated with
	  ○ Reflectivity > 30 dBZ ○ CC < 0.9
	• Is there height continuity?
	  ○ Less than 8,000 ft (EF0/EF1) ○ 10,000 ft to 15,000 ft (EF2/EF3)
	  ○ Greater than 18,000 ft (EF4/EF5)
	Note: Not required, but adds confidence. Don't wait for a TDS to issue a Tornado Warning.

Severe Hail Checklist

Feature	**Comments** *(Do not take thresholds as inflexible values)*
Near Storm Environment	Is this storm in a favorable environment? Severe (≥ 1”) hail: • MUCAPE ≥ 400 J/kg • Effective Bulk Wind Difference (EBWD) ≥ 29 kt Significant (≥ 2”) hail: • Significant Hail Parameter (SHIP) > 1 • Large Hail Parameter (LHP) ≈ 4 ≈ Golf ball; ≈ 8 ≈ Baseball”; ≈ 14 ≈ Softball hail • Most Unstable CAPE (MUCAPE) ≥ 1300 J/kg • 700-500 mb lapse rates ($LR_{7\text{-}5}$) ≥ 6.5°C/km • Effective Bulk Wind Difference (EBWD) ≥ 39 kt • Surface to Equilibrium Level Bulk Shear ($Shear_{EL}$) ≥ 47 kt for ≥ 3.5” hail
Reports	Is there a severe hail report? How confident are you of it? • Public = Lowest confidence • Spotter = Higher confidence • Multiple reports, measured, w/damage = Highest confidence
Individual Storm Type	Is the storm an ordinary cell or a supercell? Ordinary Cell: • ≤ Golf ball (< 1.75”) hail is possible if the updraft persists for > 15-20 minutes Supercell with a deep, persistent (≥ 30 min) mesocyclone: • MRMS 3-6 km current Rotation Track ≥ $10 \times 10^{-3}\ s^{-1}$ ≈ severe hail • Vr > 27-41 kt ≈ significant (≥ 2”) hail; Vr > 39-56 kt ≈ giant (≥ 4”) hail possible
Convective Mode	Is the storm discrete or non-discrete (“messy”)? • Discrete storms experience less interference and updraft longevity is maximized
Reflectivity Height	Do high reflectivities (Z) extent upward to hail growth zone? • 50 dBZ thickness above the melting level ≥ 16 kft ≈ severe hail • 60 dBZ above -20°C ≈ significant (> 2”) hail • 50 dBZ above the equilibrium level (EL) ≈ significant (> 2”) hail
Three-Body Scatter Spike (TBSS)	Does the core produce a pronounced TBSS? *Note: Denoted by extremely high ZDR and very low CC located radially behind the high Z hail core.* • Suggests severe (≥1”) hail *Note: Absence of a TBSS does not indicate the absence of severe hail.*
Dual-Polarization-based Signatures	Does the core possess favorable dual-pol signatures? • Z: 45-59 dBZ ≈ Hail possible, ≥ 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, 0.7-0.9 ≈ ≥ 2” hail • KDP: < 1°/km ≈ Mostly dry hail, > 3°/km ≈ Rain/hail combo or melting hail
Storm Top Divergence	Does the storm exhibit strong storm top divergence? *Note…Calculate ΔV using the max and min velocities around the updraft summit.* • ΔV > 70-102 kt ≈ 1” hail • ΔV > 115-147 kt ≈ golf ball (≥ 1.75) hail • ΔV > 174-207 kt ≈ baseball (≥ 2.75) hail • ΔV > 233-267 kt ≈ giant (≥ 4”) hail *Note…Beware, true max velocity difference may be located between radar elevation slices.*
Hail Detection Algorithm (HDA)	What does the Hail Detection Algorithm (HDA) suggest? • ≥ 1” Hail Detection Algorithm (HDA) ≈ Severe (≥1”) hail
MRMS Maximum Estimated Size of Hail (MESH)	What does the MRMS Maximum Estimated Size of Hail (MESH) product suggest? • ≥ 1” MESH ≈ Severe (≥1”) hail *Note: MESH underestimates hail size in: Fast moving, highly-tilted storms, supercells which possess a giant Bounded Weak Echo Region (BWER); and storms with low-density, dry hailstones.*

Severe Wind Checklist

Feature	**Comments** *(Do not take thresholds as inflexible values)*
	Individual Cell Downburst only
Near Storm Environment	Is the storm in a favorable environment? • Wet Microburst (MB): ○ 0-3 km max Theta-e diff ($\Delta\theta_e$) > 25°C ○ DCAPE > 1250 J/kg ○ SBCAPE > 1000 J/kg ○ 0-3 km lapse rate > 7°C/km ○ MLLCL Height > 1000 m • Dry Microburst: ○ Inverted-V sounding (mid-level based) ○ Weak Effective Bulk Shear ○ MUCAPE > 0 J/kg ○ MLLCL Height > melting level ○ Weak boundary layer winds ○ 0-3 km LR ~ dry or superadiabatic
Characteristics	Does the individual cell exhibit favorable characteristics? • Strong elevated precip core rapidly forms Descending core bottom • MARC velocity signature (0°C to LCL) ΔV > 15 kts • Wet microburst: Wet hail signs (TBSS, CC ~ 0.93-0.96, KDP > 3°/km, ZDR decrease) *Note: Beware low Z cells with super high LCLs at 0°C and/or strong wind in mixing layer.*
	Supercell Rear Flank Downdraft (RFD) only
Near Storm Environment	Is the supercell in a favorable environment? • Eff Bulk Shear > 30 kt • Low LCL • Large CAPE • Steep sub-cloud adiabatic lapse rate
Characteristics	Does the supercell rear-flank downdraft (RFD) exhibit favorable characteristics? • Same as Individual Cell Downburst characteristics plus: Mesocyclone with MDA rank 5+ (Vr > 30 kt), developing large hook echo (>50 dBZ), DCZ > 10 kft (>15-20kt is optimal)
	MCS/Horizontally-Driven Wind only
Near Storm Environment	Is the MCS/horizontally driven wind in a favorable environment? • Widespread lift for storms • DCAPE > 980 J/kg • 0-6 km Mean Wind > 16 kt • MUCAPE > 2000 J/kg • Effective Bulk Wind Difference (EBWD) > 20 kt
Characteristics	Does the MCS/horizontally-driven wind exhibit favorable characteristics? • Strong leading reflectivity gradient • Bow Echo • Rear-inflow jet (RIJ) • MARC ΔV > 50 kt at 3-5 km AGL • DCZ > 10 kft (>15-20 kft is optimal) • Gust front speed matches system speed • Linear WER along leading edge *Note: A mesovortex coupled with a RIJ produces strongest wind.*
	All Types
Reports	Is there a severe wind report? How confident are you of the report? • Tree down=Low confidence, Multiple trees/powerlines down=Higher confidence, Structural damage=High confidence, Official measured gust=Highest confidence
Reflectivity Aloft	Does the storm exhibit a rapidly growing, high reflectivity core at the melting level? • Precip size distrib: 40 dBZ = poor, 50 dBZ = weak, 60 dBZ = significant, 70 dBZ = high *Note: Downdraft by evap. cooling. Lower dBZ threshold dry MB w/ high MLLLCL & strong ML wind.* • Melting hailstones: 50 dBZ = marginal, 60 dBZ = significant, 70 dBZ = High
Low-level Radial Velocity	Is there strong, low-level, radial velocity? • Downburst: > 30 kt within 20 nm of the radar, RIJ: > 50 kts within 20 nm of the radar *Note: For downbursts, radial V < actual V. For RIJs, radial V > actual V.* *Note: Threshold decreases w/ increasing range. RIJ wind is about 20-30% stronger aloft than at the surface. Sfc winds are stronger than winds aloft near downbursts & low-level mesos/mesovortices.*
Storm Motion	Is the storm fast-moving? • Downburst-generated sfc wind vector + storm motion vector ≈ Actual sfc wind vector • Max wind ≈ Gust front motion X (1.4-1.7) *Note: Not a significant factor for elevated storms and LP supercells.*

All Hazards Decision Chart

Tornado

Mesocyclonic

Near Storm Environment: Significant Tornado Parameter (STP) (effective layer) > 1, Effective Bulk Wind Difference (EBWD) ≥ 39 kt, effective SRH >150 m^2s^{-2}, MLLCL < 1000 m, MLCAPE > 1500 J/kg, MLCIN < 50 J/kg within last hour

Storm Characteristics: Discrete supercell, strengthening updraft, acceleration & convergence into a strong low-level meso, TVS. TDS means tornado is likely occurring

Non-mesocyclonic

Near Storm Environment: 0-1 km lapse rate > 9°C/km, 0-3 km MLCAPE > 100 J/kg, MLCIN < 25 J/kg, significant surface vertical vorticity associated with a slow moving wind shear boundary.

Storm Characteristics: Strong, rapidly growing updrafts via development of reflectivity core at -10° C, TVS. TDS means tornado is likely occurring

Severe Hail

Near Storm Environment:

≥1": MUCAPE ≥ 400 J/kg, Effective Bulk Wind Difference (EBWD) ≥ 29 kt

≥2": SHIP > 1, LHP ≈ 4 ≈ Quarter; ≈ 8 ≈ Baseball; ≈ 14 ≈ Softball hail, MUCAPE ≥ 1300 J/kg, EBWD ≥ 39 kt, 700-500 mb lapse rates ($LR_{7\text{-}5}$) ≥ 6.5 C/km, Surface to EL Bulk Shear ≥ 47 kt for ≥ 3.5" hail

Storm Characteristics:

≥1": Discrete storm, WER, 50 dBZ thickness above the melting level ≥ 16 kft, Z ≥ 60 dBZ, CC = 0.93-0.97, Storm-Top Divergence (STD) ΔV > 70-102 kt, Three Body Scatter Spike (TBSS), HDA ≥ 1", MESH ≥ 1"

≥2": Discrete supercell, BWER, updraft persists ≥ 30 min, 60 dBZ above -20°C, 50 dBZ above the EL, CC ≈ 0.7-0.9, ZDR ≈ 0 dB, STD ΔV > 130-162 kt, Peak Rotational Velocity (Vr) >27-41 kt, MESH ≥ 2"

≥4": STD ΔV > 233-267 kt, Peak Vr > 39-56 kt

Severe Wind

Individual Cell Downbursts

Near Storm Environment: Wet Microburst: 0-3 km max $\Delta\theta_e$ > 25°C, DCAPE > 1250 J/kg, SBCAPE > 1000 J/kg, 0-3 km lapse rate > 7°C/km, MLLCL > 1000 Dry Microburst: Inverted-V sounding (midlevel based), MUCAPE > 0 J/kg, MLLCL height > melting level, weak Effective Bulk Wind Difference (EBWD), weak boundary layer winds, 0-3 km lapse rates ~ dry or superadiabatic

Storm Characteristics: Strong, elevated precip core rapidly forms, descending core bottom, MARC (0°C to LCL) ΔV > 15 kt, wet hail signature (TBSS, CC ~ 0.93-0.96, KDP > 3°C/km), low-level V > 30 kt within 20 nm of radar, fast storm motion *Note: Beware of low Z cells w/high LCLs at 0°C and/or strong wind in mixing layer.*

Rear Flank Downdraft (RFD)

Near Storm Environment: Effective Bulk Wind Difference (EBWD) ≥ 39 kt, low LCL, large CAPE, steep sub-cloud adiabatic lapse rate

Storm Characteristics: Meso w/MDA rank 5+ (Vr > 30 kt), developing large hook echo (>50 dBZ), DCZ > 10 kft (> 15-20 kft optimal), fast motion

MCSs/Horizontally-Driven Wind

Near Storm Environment: Widespread lift, DCAPE > 980 J/kg, 0-6 km mean wind > 16 kt, MUCAPE > 2000 J/kg, Effective Bulk Wind Difference (EBWD) > 20 kt

Storm Characteristics: Strong leading Z gradient, bow echo, Rear Inflow Jet (RIJ), MARC ΔV > 50 kts at 3-5 km AGL, Deep Convergence Zone (DCZ) > 10 kft (> 15-20 kft is optimal), gust front speed matches system speed, linear WER along leading edge, fast storm motion

Note: A mesovortex w/RIJ produces strongest wind.

Flash Flood

Individual Cell

Near Storm Environment: High PW & RH (>70%) in convective layer, warm cloud layer > 10 kft, weak convective-layer wind < 10 kt

Storm Characteristics: Slow motion < 10 kt, Z > 50-60 dBZ (45-55 dBZ trop. env.), low echo centroid, CC > 0.96, ZDR = 2-5 dB (0.5-3.0 dB trop. env.), KDP > 1°/km

Multicell

Near Storm Environment: High PW & RH (>70%) in convective layer, LLJ transporting high moisture, slow MBE motion, slow (< 15 kt) motion of forcing mechanism, upwind instability

Storm Characteristics: Intra-storm seeding; collisions; slow motion; training / backward propagation < 15 kt; leading, parallel, or adjoining stratiform MCS

Antecedent Ground Conditions

Poor permeability (urban land use, clay soil, rock, ice, desert pavement, burn scars, etc.), poor drainage, saturated soil (recent rain, snowmelt, etc.), sloping terrain (mtns, canyons, hills, etc.)

Precipitation Accumulation

Does rainfall meet flash flood thresholds?

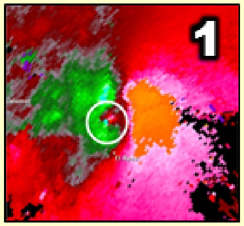
1. Pick your optimal precip source: Dual-Pol, legacy DHR, HPE, Bias HPE, MRMS
   a. Assess radar QPE biases
   b. Compare QPE with observations
2. Use FFMP for decision making
   a. Ratio > 100%, diff > 0"
   b. Look at 1-, 3-, and 6-hour durations
3. Is additional rainfall occurring or imminent?

Version FY18

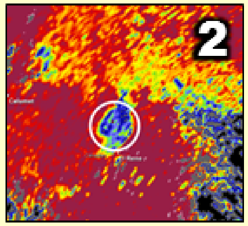
Radar Tornado Intensity Estimation Guidance

Identifying a Tornadic Debris Signature (TDS)

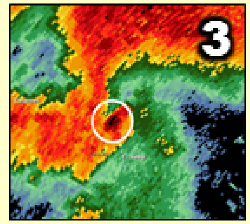
Provides radar confirmation of a damaging tornado in progress.



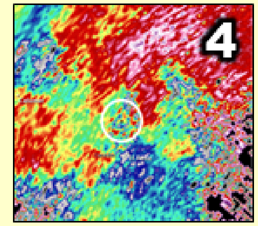
First, identify a valid velocity circulation.



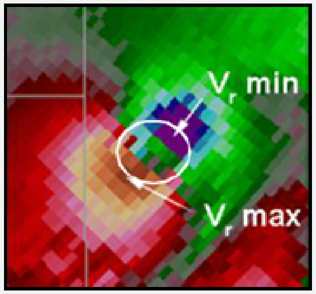
Next, ensure correlation coefficient (CC) is below 0.90



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.

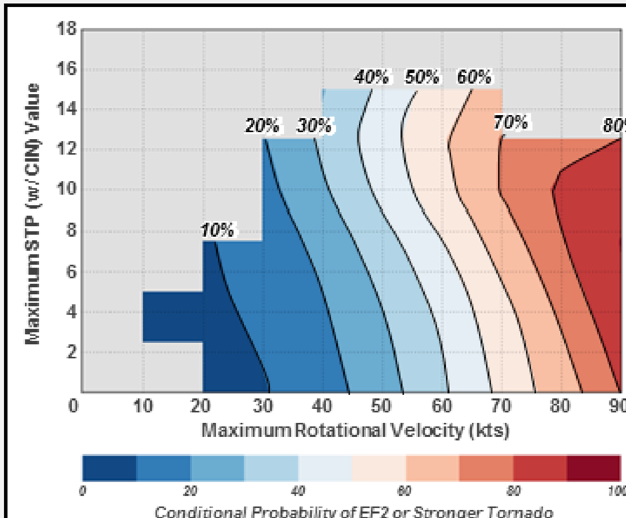
Considerations and Tips

- 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.

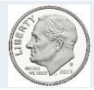
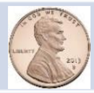
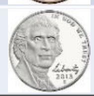
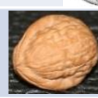
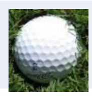
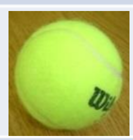
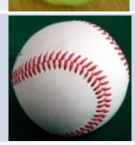
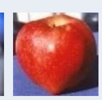
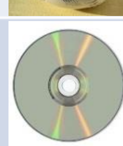
Tornado Intensity	Rotational Velocity (kts) — Supercells Only	Rotational Velocity (kts) — QLCS Only	Maximum TDS Height (MOST RELIABLE)
WEAK *EF0/EF1*	*40 knots or less*	*30 knots or less*	*Under 8,000 ft*
	Overlap 40-55 knots	Overlap 30-45 knots	Overlap 8-10 kft
STRONG *EF2/EF3*	*55 to 75 knots*	*45 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*

Only valid within 70nm of the radar site

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")

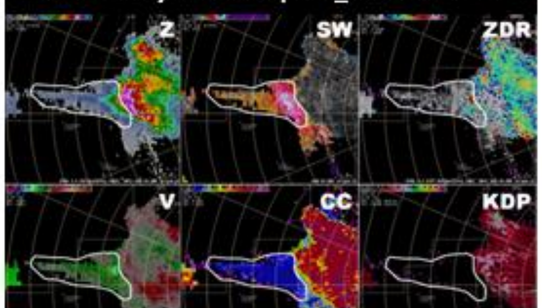
Adapted from Witt and Nelson, 1991

Mesocyclone

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

Source: Blair et al., 2011

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