

Tornadogenesis in Supercells: The Three Main Ingredients

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Environmental Parameters

Supercells occur within environments exhibiting several well-known characteristics

- Ample low-level moisture
- Sufficient CAPE (instability)
- Deep-layered vertical wind shear
- Significant forcing mechanism

While these parameters are related to supercell tornadoes, they are not the primary ingredients needed for tornadogenesis.

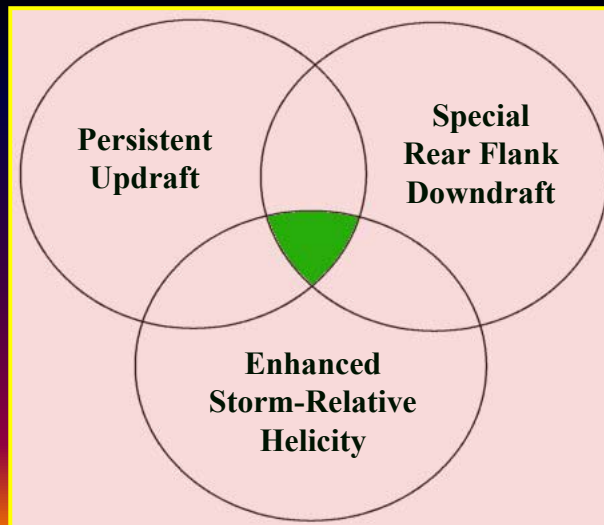
The Tornado Cyclone

- To predict severe weather, we usually need to look no farther than the detection of a supercell thunderstorm on Doppler radar, as most supercells produce wind damage and/or large hail.
- However, to forecast tornadoes, we need to understand the tornado genesis process itself. This process occurs in a small part of the storm, i.e., within the “**tornado cyclone**.”
- A tornado cyclone typically is a few kms (1–2 miles) across. Most supercells have a low level tornado cyclone that extends to near the ground, although in many cases the cyclone does not contract to form a tornado. Doppler radar usually observes the tornado cyclone, not usually the tornado itself.
- **So the key is determining under what conditions are tornado cyclones most likely to produce tornadoes.**

3 Ingredients for Tornado Formation

- Supercell tornado formation appears to follow a process of:
 - 1) Development of a persistent rotating updraft
 - 2) Development of a “special” rear flank downdraft that contains rotation to aid in the development of rotation to the ground
 - 3) Focusing of that low level rotation through convergence and upward spin up into the updraft
- **All 3 ingredients must occur in concert to form significant (F2 or higher) tornadoes; since these ingredients are uncommon in the atmosphere, the joint occurrence of all 3 make significant tornadoes also uncommon.**
- **Walker, short-lived tornadoes can occur within supercells or non supercells without all 3 ingredients.**

3 Ingredients for Tornado Formation



Persistent Updraft

- The first step in tornadogenesis is the development of a persistent, rotating updraft. This can occur on a variety of scales, from the radar observed mesocyclone on a scale of several kms, down to scales closer to that of the tornado itself that may not be as readily observed on radar at appreciable distances.
- The updraft must persist long enough to ingest air containing enhanced storm relative helicity (SRH) in order to develop rotation. If the environmental vertical wind shear is strong, then horizontal turning in the atmosphere creates enhanced SRH that is tilted into the updraft to produce vertical rotation.

Persistent Updraft

- The stronger the updraft and higher the ambient SRH, the more likely the updraft can organize into a significant mesocyclone. Thus, the presence of high values of ambient CAPE and SRH is important to the rapid development and persistence of a rotating updraft. This process can occur in as short as about 10 minutes or as long as about an hour.
- Recent research suggests that 0–3km CAPE may be as or more important than total CAPE in an attempt to assess the degree of low level vertical acceleration important in the tornadogenesis process.
- The updraft then must continue to persist as the RFD develops, focuses, and concentrates rotation below it. It must also persist through the tornado life cycle. Thus, the longer an updraft persists, the more likely tornado formation becomes.

Persistent Updraft

- A persistent, rotating updraft creates a dynamic pressure gradient force that allows low level air to be pulled upward into the updraft. This is important, i.e., the ability of the updraft to create boundary layer lift below the level where positive parcel buoyancy creates lift. This allows for the ingestion of low level SRH.
- A strong low level cold pool beneath the updraft is detrimental to tornado formation, as this causes a cold outflow that blocks the ingestion and steep lift of moist, unstable, sheared air.
- Large values of low level humidity, as evidenced by low lifting condensation levels (LCLs) are more conducive to tornado formation, as strong cold pools are inhibited.

Enhanced SRH

-Storm-relative helicity (SRH) estimates thunderstorm's potential to acquire a rotating updraft given an environmental vertical wind shear profile. It integrates the effects of S-R winds and the horizontal vorticity (generated by vertical shear of the horizontal wind) within the inflow layer of a storm.

-Directional (speed) shear favors “streamwise” (“crosswise”) horizontal vorticity that are conducive to right turning supercells and tornadoes (splitting supercells).

-Traditionally, 0-3 km SRH is used to evaluate storm type and rotation potential. Large-scale (measurable) values of 300-500 m^2/s^2 are considered strong. These values indicate the potential for storm rotation, which is related to tornadoes, but not potential for tornadoes themselves.

-More important is SRH in the 0-1 km layer in order to create low-level rotation. Look for measurable values around 100-300 m^2/s^2 .

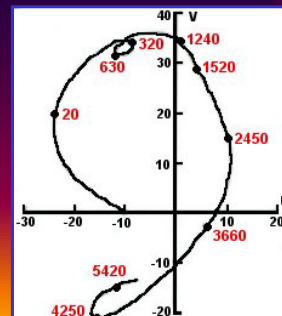
Enhanced SRH

-Given high amounts of ambient SRH, some supercells will and some will not produce tornadoes. Thus, large-scale environmental SRH is not enough. There must be local augmentation of SRH to generate tornadoes.

-SRH varies quite strongly on scales that are never sampled with normal sensor networks, i.e., soundings, profilers, VAD. These much higher, narrow zones of SRH result in the baroclinic generation of horizontal vorticity that is tilted and stretched vertically to generate strong low-level rotation.

-Tornadic supercell inflow values of SRH sometimes exceed 1000 m^2/s^2 !

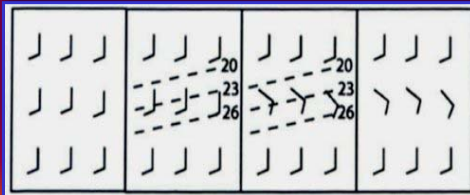
Hodograph constructed from mobile Doppler observations of the inflow region of the June 2, 1995 Dimmitt, TX violent tornadic supercell (from VORTEX).



Enhanced SRH

-Tornado formation in supercells is most common when the storm interacts with a boundary. The boundary focuses and provides the high levels of SRH.

-Boundaries include fronts, outflow boundaries, cloud-no cloud boundaries (including anvil shadows), horizontal convective rolls, old temperature gradient zones, etc. These boundaries may be undetectable in Metar surface data. They may or may not be evident in visible satellite imagery.



A temp contrast (baroclinicity) that develops on uniform low-level flow will generate horizontal vorticity that alters low-level wind flow. This can cause a large local increase in convergence and SRH. This condition persists even after the temp contrast weakens, making the boundary undetectable or diffuse, despite its potential importance to tornado development.

Enhanced SRH

Ideas to remember in the warning process:

-If environmental (synoptic) values of SRH are high, less local augmentation is needed for tornadogenesis (and vice versa).

-If environmental SRH is relatively low, tornadoes can still occur if a significant boundary intersects the storm resulting in a pronounced local increase in SRH.

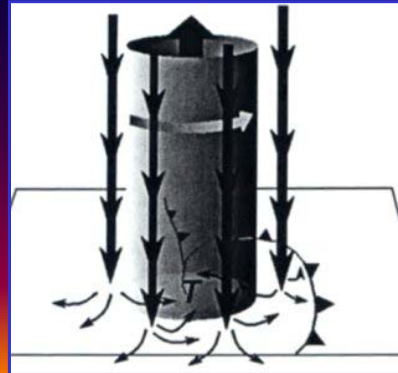
-Monitor radar, surface data, and satellite data for the presence and evolution of boundaries, both in the pre-storm and near-storm environments. Be especially cognizant of earlier boundaries that may have faded from detection in satellite or surface data, as they still may be important in generating localized SRH.

-If a supercell translates parallel to the boundary, then tornadogenesis is especially likely.

Special RFD

- Rear flank downdrafts in tornadic supercells seem to have an unusual character compared to non-tornadic supercells and thunderstorm downdrafts in general.

- The RFD helps translate rotation to the ground. Upon reaching the ground, some of the RFD air wraps around and flows into the low-level updraft vortex, while other air flows away from the vortex.



Special RFD

- In a study of 30 supercells, those tornado cyclones that produced tornadoes were associated with RFDs that reached the ground with more CAPE, less CIN, and larger values of wet bulb and equivalent potential temperature (i.e., a warm RFD).

- This allows more of the RFD air to flow into the rotating updraft zone and stretch vertically, thereby enhancing low-level rotation.

- What governs the thermodynamic character of the RFD?

- **low level humidity**, i.e., small surface/low level dewpoint depressions and low LCLs, in the near storm environment (not always common)

- **size and type of precipitation particles** in the hook echo (i.e., the rear side precipitation cascade)

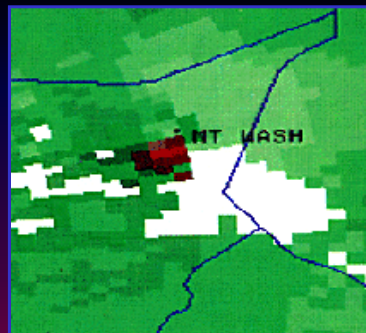
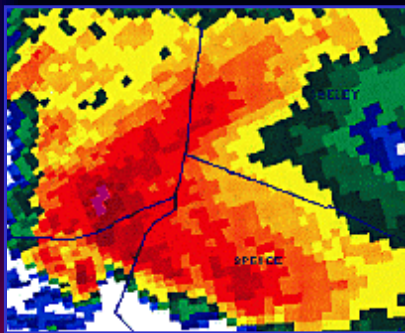
Special RFD

-Environments with relatively high dewpoint depressions (e.g., surface temps in 80s or 90s with dewpoints in 60s) favor a cold RFD (due to more evaporation) and hinder tornadogenesis, unless other processes or reports suggest otherwise. In such cases, the nature of precipitation in the hook echo becomes increasingly important.

-Relatively few, large drops or hailstones will cause little cooling, but will lead to an enhanced reflectivity area in the hook. In contrast, large amounts of small drops could result in evaporation and cooling that is a detriment to tornadogenesis.

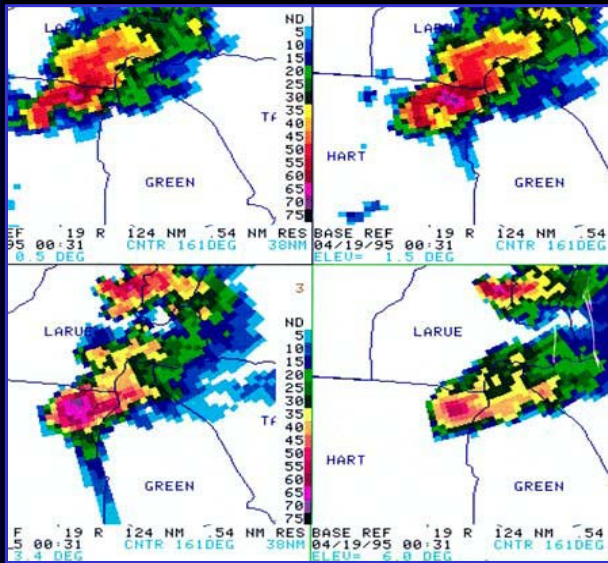
-This is consistent with our observation that some tornadic supercells in Kentucky have been associated with an area of high reflectivity in the hook, close to the tornado location. This reflectivity max likely is due to large drops and hail, thereby decreasing evaporation. Swirling debris within the tornado cyclone may also contribute to the max.

Tornadic Supercell in Kentucky



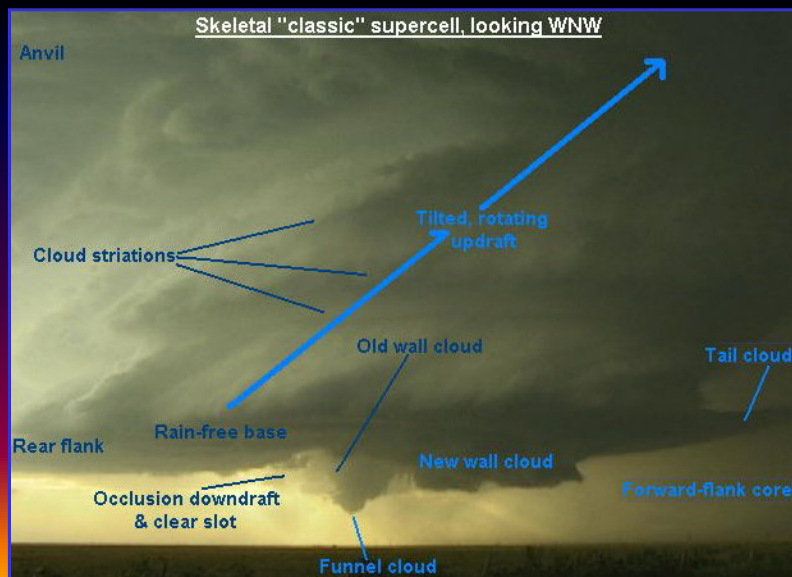
The May 28, 1996 tornadic supercell had a definitive reflectivity max at the time an F3 tornado was on the ground. The RFD is evident by the blue pixels just south of the max. The reflectivity configuration suggests that some RFD air was wrapping around and up into the tornado cyclone. Storm-relative velocity showed the tornado cyclone (probably not the tornado itself), with enhanced inflow and SRH just east of the cyclone. The cyclone intensified and contracted at 0.5 degree elevation prior to this time, suggesting tornadogenesis.

Non-Tornadic Supercell in Kentucky



This supercell on April 19, 1995 produced golfball to baseball size hail (note the high reflectivity core aloft and hail spike). The environment was characterized by dry air aloft and moderate low-level humidity, and strong vertical wind shear. The shear resulted in mesocyclone development and an apparent tornado cyclone at the lowest level (SRM data not shown). But the absence of at least 1 of the 3 parameters (warm RFD) precluded tornado development, despite the low-level hook.

Supercell Cloud



Summary

-Supercells normally produce severe weather. But, relatively few produce tornadoes. Thus, understanding and identifying (or at least inferring) those processes associated with significant tornadoes (F2 or more) is crucial.

-These processes include a persistent updraft, enhanced low-level SRH, and a warm, special RFD. However, even these processes are not the “answer” to the tornadogenesis problem at all times.

-Weaker tornadoes are possible in supercells despite the lack of an ingredient. The “apparent” lack of an ingredient, however, may be because of a potentially difficult to detect process (e.g., enhanced SRH along a boundary).

-Doppler radar may not resolve low-level small-scale circulations, but usually will resolve the mesocyclone and perhaps the tornado cyclone at close range.

-The best way to improve tornado warnings is through a joint effort to incorporate 1) knowledge of the storm environment (local SRH, low-level RH, boundaries, etc.), 2) acute radar signature analysis skills, and 3) accurate and timely spotter reports.