Supercells

Base lecture and Graphics created by
The COMET Program
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Objective

• “To be able to forecast and better recognize supercell storms in all their forms and have a better understanding of how they form and the severe weather elements that accompany these storms.”
Overview

• Introduction to Supercells
• Supercell Types and Features
• Supercell Environments and Evolution
• Supercell Processes
• Operational Supercell Issues
Introduction
Definition

• Supercell storms are those storms with long-lived cores and rotating updrafts.

• Supercells tend to have
  – one of several distinctive radar reflectivity patterns
  – they contain mesocyclones
  – and they generally have a different storm motion than other nearby ordinary cells.

• Supercells are frequent producers of large hail, strong winds, and tornadoes.
Supercell Terminology (Mesocyclone)

- A mesocyclone is a rotating vortex in conjunction with the updraft in a supercell storm.

- Supercells develop mesocyclones by tilting environmental and/or locally generated horizontal vorticity.
Mesocyclone Example

- When viewed with Doppler velocity imagery a typical mesocyclone appears as a cyclonic circulation ~2-10 km in diameter with values of the toward-and-away velocity couplet on the order of 25 to 75 m/s.
Supercell Terminology (WER)

• Because of the very strong updraft associated with supercell storms they are able to suspend a great many precipitation particles aloft. This overhang creates a weak echo region (WER) when observed on radar.

• The existence of a WER is a good indicator of a potentially severe storm.
Supercell Terminology (BWER)

- The still stronger updraft causes a change in the configuration of the WER. A cavity sometimes develops in the mid-level overhang, creating what is known as a “bounded weak echo region” or BWER.

- An updraft of this magnitude and longevity can produce very large hailstones (>2 inches) and the “steadier state” of the supercell can result in a long hail swath at the surface.
BW ER Example

- Here’s a BW ER in cross section

- On a PPI scan a BW ER looks like a reflectivity donut
Supercell Terminology
(Hook Echo)

- In the more intense supercells, the mid-level mesocyclone will eventually become strong enough to wrap precipitation around to the backside of the updraft, creating a characteristic pendant or hook echo.
Hook Echo Example

- The low-level mesocyclone is located within the notch of the hook echo
Supercell Terminology (V-Notch)

- In the stronger supercell cases, a slot of weaker radar reflectivity known as a V-notch may also appear on the downshear edge of the reflectivity field
Other Supercell Features
(FFD, RFD and Flanking Line)
Supercell Visual Features

Classic Supercell Visual Features

- Overshooting Top
- Flanking Line
- Mammatus
- Striations
- Anvil
- Virga
- Mammatus

Upshear

Tornado
Wall Cloud
Large Hail
Wall Cloud
Small Hail
Heavy Rain
Moderate to Light Rain

Downshear

East

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Supercell Types and Features
Supercell Classifications

There are four categories of supercell storms

1. Classic Supercells
2. Heavy Precipitation (HP) Supercells
3. Low Precipitation (LP) Supercells and
4. Shallow (a.k.a. Mini or Low-topped) Supercells

All of these may be either Right-moving, Left-moving, or both (Splitting storms)
Classic Supercells

- Wedge-shaped, generally isolated long-lived storms with rotating updrafts
- Often possess a WER or BWER and/or a hook echo
- Frequent producers of severe weather including large hail, strong winds, tornadoes, and heavy rain
HP Supercells

- More common east of the Plains states
- Produce heavier rain than classic supercells and tend to be less isolated than other supercell types
- Are capable of producing extreme hail falls, tornadoes, prolonged downburst winds and flash flooding
HP Supercell Evolution

• Have a “kidney bean” shape on radar
  – Stages 3, 4, and 5
HP Supercell Example
LP Supercells

- Most common along the dryline of west Texas and in the High Plains
- Are generally smaller in diameter than classic supercells
LP Supercells

- Still capable of producing severe weather especially large hail and to a lesser extent tornadoes, although funnel clouds are common.
Shallow Supercells

- Are much smaller both horizontally and vertically than the other supercell types. These mini storms may be as small as only 20,000 ft (~6 km) tall with much smaller horizontal dimensions than classic varieties being as small as 6 km in diameter!
Shallow Supercell Example
Supercell Environments and Evolution
Synoptic Patterns

- Favorable conditions conducive to supercells often occur with identifiable synoptic patterns.
- The favorable ingredients that support supercells in these environments are lots of instability and shear.

Johns, 1993
Environmental Factors

Because they are so long-lived and intense it is highly desirable to be able to determine in advance if supercells are likely

- Luckily the length and shape of a hodograph can be very helpful in making this determination!

- Strong and deep vertical wind shear values (> =25 m/s or ~50 kts over the lowest ~6 km AGL) tend to be associated with supercell formation
Supercell Shear: Splitting Storms

Hodograph for Splitting supercell

Orange Arrow = 0-6 km Shear Vector
Green Arrow = Supercell Motion
Red Arrow = 0-6 km Mean Wind

Ray, AMS 1986

Stephenville, TX (SEP) 03-08-92 20 UTC Observed

Height (km) AGL
0-6 km Length = 25 m/s (50 kts)
BRN = 28 SREH = 85 m^2/s^2
= Observed Storm Motion

0-6 km Mean Wind
Evolution with a Straight Hodograph

Supercell Evolution with a Straight Hodograph

- Mid-level Mesocyclone
- Mid-level Updraft

AMS/Ray 1986
Supercell Shear: Right-movers

Hodograph for
Right-moving supercell

- Orange Arrow = 0-6 km Shear Vector
- Green Arrow = Supercell Motion
- Red Arrow = 0-6 km Mean Wind

Ray, AMS 1986

Hodograph for Observed Right-moving Supercell

- Denver, CO (DEN) 07-16-94 21 UTC Modified

- Length ≈ 35 m/s (70 kts)
- X = 0-6 km Mean Wind
- ▼ = Observed Storm Motion

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Evolution with a Clockwise-Curved Hodograph
Supercell Shear: Left-movers
Evolution with a Counterclockwise-Curved Hodograph

Supercell Evolution with a Counterclockwise-Curved Hodograph

- Mid-level Mesocyclone
- Mid-level Updraft

AMS/Ray 1986
Impact of CAPE

- Supercells, like other severe thunderstorms, usually occur with significant instability (CAPE values 1000-2000 J/kg or more).

- Very severe storms with some supercell characteristics can also form when shear values are negligible, but CAPE values are extremely large (> 5,000 J/kg).

- In some highly dynamic environments supercells can form with a minimal amount of CAPE and with tremendous low-level shear*. 
However, supercells most commonly form when the environmental vertical wind shear and instability are balanced.

BRN values between 10-50 are generally associated with supercell storms.
Mini supercells occur when CAPE is shallow and values are small. They most typically arise in two very different environments:

1) with land-falling hurricanes and
2) in wintertime high shear low buoyancy winter situations.
Shallow Supercell Environments

- The thing that these two environments have in common is **extreme** low-level shear values (sometimes 60 kts over the lowest 2-3 km AGL!)
Supercells with Bow Echoes

St. Cloud, Minn (STC)
4 July 1977
12 UTC

CAPE = 4000 J/kg

Evolution of a bow echo into a comma echo during the 4th of July, 1977 downbursts. Downbursts “A” and “C” were associated with a bow echo while “B” was associated with a hook echo.

Modified from Fujita, 1978
Important Supercell Processes
Shear Creating Vorticity

- When the vertical wind profile is sheared, horizontal vorticity is present in the environment. We can visualize this vorticity if we imagine the rotation that would be imparted to paddle wheels placed in the environment.
Vertical wind shear and buoyancy gradients across the cloud act to tilt the convective tower in the downshear direction. For a given amount of shear, a stronger updraft will not tilt as much as a weaker updraft simply because its vertical momentum is stronger.
Storm Tilt (cont.)

- The precipitation in a storm tilted by shear will largely fall downshear of the updraft, producing a distinctive reflectivity pattern with a tight gradient near the updraft.
- Even though the precipitation is not falling back on the updraft as it does for non-sheared convection, this does not appreciably extend the life of the storm. The cold pool produced by the precipitation can still kill the storm.
Vorticity

Shear-induced Vorticity and the Right Hand Rule

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Rotation Creates Low-Pressure

- It is also important to understand that at this scale, wherever there is rotation, low pressure is induced regardless of the direction of the rotation.
Tilting Process
Stretching Process

- Vertical stretching (like by a strong updraft) also increases rotation
Splitting Process
Splitting Storm Motion

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Additional Effect
Comparing Pressure Patterns

Pressure Pattern in Supercell Developing with Unidirectional Shear

Pressure Pattern in Supercell Developing with Clockwise-curved Shear
Right-Moving Supercell Processes

Klemp, 1987/The COMET Program
Operational Issues with Supercell Storms
Supercell Locations in Squall Lines

- Supercells within lines tend to become bow echoes, but cells at the ends of squall lines can remain supercellular for long periods of time.
Detecting Shallow Supercells

- Shallow supercells present a particularly difficult forecasting challenge because they are accompanied by the same severe weather elements (including tornadoes) as their bigger counterparts, but are much more difficult to detect at any appreciable distance from the radar.

- Also, they often catch forecasters off guard because they can occur even in low buoyancy environments where typical severe weather indices would not indicate the potential for severe weather.
Tornadoes with Supercells

- Note that a mid-level mesocyclone, and sometimes a hook echo, may be present for a considerable length of time before tornadogenesis, IF a tornado even occurs.
- Recent research has shown that in the U.S. our best guess is that only 20-30% of supercell storms produce tornadoes. However, the same study found that such storms almost always produced severe weather in the form of hail or high winds.
Tornado Evolution with Supercells

Supercell Occlusion Process

Adapted from Burgess and Lemon, 1990
Supercell Longevity

- Recent research has shown that especially long-lived supercells (\( > 4 \) hrs) tend to develop and evolve in environments with deeper stronger shear than supercells that live for 2 hours or less.

- The same study has shown that thankfully from a forecast perspective, the longest lived supercells tend to be more isolated than the shorter lived supercells.
Supercell Demise

- All good things must come to an end, and eventually something kills even supercell storms.
- The two most common reasons for a supercell to decay include:
  1. its own cold pool eventually cutting off the supply of potentially unstable air or
  2. moving into an unfavorable environment
- Colliding with other convective storms can also disrupt supercells.
Summary

- Supercell storms are those storms with long-lived cores and rotating updrafts.
- Supercells tend to have:
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  - a different storm motion than other nearby ordinary cells.
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Summary (cont)
There are four categories of supercell storms

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- All of which may move to the right or left of the mean wind, or both (Splitting storms) depending on the hodograph shape
Summary (cont)

- Supercell structure and evolution depend on the characteristics of the environmental buoyancy and shear.
- Supercells are likely when the environmental wind shear is strong (> 50 kts over 0-6 km AGL).
References

- COMET CD-Module, Anticipating Convective Storm Structure and Evolution with online key points at http://www.comet.ucar.edu/modules/mod8/index.htm


References (cont)


References (cont)


