Severe Weather and Tornadoes
What is severe weather?

- Large, damaging hail (20 mm, or \(\frac{3}{4}\) in)
- Damaging winds (60 mph, 50 kt, or 25 m s\(^{-1}\))
- Tornado
- Or all of the above
- Mesoscale with strong updrafts!
- **Thunderstorm**: Any storm that produces thunder
Frontal Squall
Mid-Latitude Squall Line Anatomy

Backshear anvil can be much more extensive
Mesoscale Convective Complexes

- Form in late afternoon or evening
- Several thunderstorms combine
- Many convective cells
- Outflow boundaries trigger new convection
- Characteristics:
  - $100,000 \text{ km}^2$ with cloud top temperature $<-32^\circ\text{C}$
  - Must stay that large for 6 h
  - Elliptical, $(\text{minor axis})/(\text{major axis}) > 0.7$
- Cause nighttime rainfall max in Great Plains
- Some severe weather, but mostly beneficial rain
A single entity with long-lasting, rotating updraft
Supercell storms account for most tornadoes and damaging hail
Characteristics
- Single vertically aligned cell
- **Hook-shaped radar echo** in plan view
- Middle level reflectivity overhangs updraft (Weak Echo Region)
- Matures in 90 minutes
- Updraft rises in “**Echo-free vault** or Bounded Weak Echo Region.
- Precipitation (Hail) carried across storm to other side.
- Thus it never loads the updraft
Supercell Evolution in Plan View

- Initially more or less round
- Moves with surrounding wind
- Becomes elongated parallel with shear.
- Hook-shaped radar echo
Mature Supercell Thunderstorm
Anatomy of a Supercell Thunderstorm

- Require shear and powerful instability
- Shear causes sloping updrafts
- Hydrometeors fall from updrafts
- So precipitation loading is less of a factor
- Crossing mid-level and surface inflows form front- and rear flank downdrafts (FFD & RFD)
- Which generate permanent merging outflow boundaries
- That maintain a long-lasting (hours) updraft
Supercells and Tornadoes

- Most F2-F5 tornadoes form in supercells
- Rotating updraft forms a mesocyclone
- Tips horizontal vorticity (low-level shear) into the vertical
- Causing cyclonic and anticyclonic rotation on the flanks of the updraft
Tornado Characteristics

- Must have a funnel cloud extending from cloud base to the surface
- Maximum winds can be as strong as 100 m/s, or 200 mph
- Size ranges a few meters to nearly a kilometer, 100m typical
- Typically about 1000 per year (20-50 of which a “violent”)

**Type I** Tornadoes
- Form within the *Mesocyclone* of a supercell thunderstorm
- Strongest tornadoes are Type I

**Type II** Tornadoes
- Form along stationary or slowly moving wind-shift lines
- Much weaker

**Operational Enhanced Fujita Scale**
(Feb 2007, uses 3 s gust))
- Weak \( F0, 65-85 \)
  \( F1, 85-110 \) mph
- Strong \( F2, 111-135 \) mph
  \( F3, 135-165 \) mph
- Violent \( F4, 166-200 \) mph
  \( F5, > 200 \) mph
Shelf cloud and precipitation shaft
Shelf cloud and rotating wall cloud
Mesovortex Wall Cloud
Significant Tornado Alley
(1 day/decade, 60% near peak)
When do Tornadoes Occur During the Day?
When Do Tornadoes Occur During the Year

![Graph of U.S. Tornadoes by Month 2003-2005]
Tornado Motion

- Form in warm sector or in warm air above the cold frontal surface
- Flow is from the SW so that Tornadoes generally move SW-NE
- Often with a looping or cycloidal motion
Tornado Forecasting

- Starts with forecasting instability based upon large scale flow.
  - Jet stream
  - Air masses
- Set up **Watch Boxes** within which Tornado formation is likely
- Based upon radar and visual observation the Watch becomes a **Warning**
- Meaning *tornado in the ground*.
- Radar cannot detect tornadoes, but it can tell where to look
Mesocyclone
SUMMARY

- Severe Weather: Hail > 20 mm, 25 m/s wind, or a tornado
- Mesoscale Convective Complex: Nearly circular mass of self-sustaining convection in heartland
- Supercell Thunderstorms
  - Shear causes tilting updraft that unloads condensate
  - Intertwining inflow-updrafts distribute rain to flanking downdrafts
  - Intersecting outflow boundaries sustain updraft
  - Spawn Type I Tornadoes
- Tornadoes
  - Funnel cloud reaches the ground
  - Form afternoon and evening
  - May & June are the “cruelest months” in the lee of the rockies
  - Move SW to NE
  - 10s of m to a km in diameter
  - Fujita Scale F0 to F5
- Forecasting
  - Watch Boxes set based upon synoptic situation
  - Warning when it touches down on the ground
  - Radar is a key tool
Lee Cyclogenesis
Where do Frontal Cyclones Form?

- **Lee of the Rocky Mountains**
  - Alberta
  - Colorado Wyoming, New Mexico

- **Gulf Coast**
  - TX-LA boarder
  - Off Georgia-Carolinas Coast
Jet Max (or Jetstreak) passes over the Mountains
What happens when the wind blows over a mountain range?

- We assume that the Rossby number is small.
- Troposphere is shallower over the mountain.
- Air moves faster.
- But how does it deflect meridionally?
- Would the flow be different if the wind came from the East?
East Wind in the Mountains

- Flow starts to deepen just a bit before the mountain.
- Initially turns cyclonically.
- Flow becomes shallower, compressing the vorticity tubes, as it passes over the mountain.
- The air both turns anticyclonically and bends to lower latitude where the Coriolis parameter is smaller.
- Straightens out on the lee side of the mountains.
West Wind in the Mountains

- Flow starts to deepen just a bit before the mountain
- Initially turns cyclonically
- Flow becomes shallower, compressing the vorticity tubes, as it passes over the mountain
- The flow turns anticyclonically and bends to higher latitude where the Coriolis parameter is greater---opposing effects.
- Overshoots on the lee side of the mountains forming a Lee Trough
- This is where Lee Cyclogenesis starts
- In the steady state (never reached) a train of vorticity (Rossby) waves extends downwind
Some New Features

- Cold dry air
- Cool moist air
- Descending air from upper troposphere
- Warm dry air
- Warm moist air at surface and aloft
- Dry Line
- Upper-level Front
The Upper Front and the Dry Line

A. Upper level front leads dry line and cold front

B. Upper level front and dry line aligned to form a single boundary

C. Cold front leads, storms along cold front
Upslope Snow (& Sometimes Rain)

- Cyclonic circulation passes S or SE of the end of N-S mountain range.
- As through the mountain gap in NM & AZ
- East wind around the northern flank flows up the slope, cools adiabatically and snows
Patterns of Weather
Figure 9.1

Courtesy of the Department of Atmospheric Sciences
University of Illinois at Urbana-Champaign
Relation to Upper Trough & Upper Front
Occlusion Stage

A: Intrusion of upper level front over warm front
- stratosphere
- tropopause
- dry air
- Band of warm moist air aloft
- upper level front
- warm front
- warm moist air

B: Cold Occlusion
- stratosphere
- tropopause
- band of warm moist air aloft
- warm front
- cold air
- colder air
- cold front

C: Warm Occlusion
- stratosphere
- tropopause
- band of warm moist air aloft
- warm front
- cold air
- colder air
- cold front

Precipitation:
- South
- North
Summary

- Over North America, extratropical cyclones form
  - Lee of the Rockies
  - Gulf Coast
  - Over the Gulf Stream

- Lee Cyclogenesis
  - Anticyclonic flow over mountain
  - Cyclonic trough form in the lee only under a west wind

- Jet MAX (streak) passes over the Rockies

- Deepening Low
  - Dry Line separates warm moist from warm dry air at the surface
  - Upper Front separates sinking warm dry air aloft from ascending warm moist air
  - Upper front can catch the warm front in the occlusion process
Nor’easters
Snowstorms in the Northeast
What Makes East-Coast Snowstorms So Intense?

- Strong thermal contrast between sea and land in winter and early spring
- Superposition of Jet Streaks from the Polar-Front and Subtropical Jets (More during El Niño)
- Ocean is a source of sensible and latent heat
East-Coast Storm Tracks
If the Cyclone Stays West of the Mountains

Only one Jet Streak
Precursor Front Sets Up Cold-Air Damming as Jet Streaks Approach
Jet Streaks in Phase as Cyclone Deepens Offshore
Merged Jets and a Strong, Occluded Coastal Storm
Setting the Stage for a Gulf-Coast Nor’easter

Precursor cyclone that pushes the front far south and two merging Jet Streams
Two Jet Streaks Approach as the Cyclone Forms
Open Wave With Merging Jet Streaks
Jet Streaks Merge SE of Occluded Low
New Years Blizzard of 2000

Carolina Snowstorm
GOES-8 Colorized IR
January 25, 2000 @ 0545 UTC
Summary

- Gulf coast and offshore sources
- Intense because of:
  - Contrast between land and sea
  - Merging Jet Streaks from Polar-Front and Subtropical Jets
  - Sea is a source of latent and sensible heat
- Cold air damming and onshore flow cause heavy snow