Thunderstorms, Tornadoes and Severe Weather

- Thunderstorms
- Supercells
- Tornadogenesis
- Forecasting and Hazards
(b) **Average number of days per year with thunderstorms.**
John Park Finley

"As an area of low barometer advances to the Lower Missouri Valley, warm and cold currents set in towards it from the north and south, respectively. Warm and moist regions emanate from the Gulf and the cold and comparatively dry air from regions of the British Possessions [Canada]. The marked contrasts of temperature and moisture, invariably foretell an atmospheric disturbance of unusual violence, for which this region is peculiarly fitted...."

published as a Signal Service Professional Paper in 1881

In 1882 Finley established a network of “storm reporters” to gather severe storm information for the daily weather map makers in Washington.

Source: Bain News Service, publisher
Cyclone: circulation around any low pressure center (not size dependent) mid-latitude (1000 mile), hurricane (375 mile), tornado (0.16 mile)

US: 100,000 thunderstorms annually, 10% severe, 1300 tornados
The Thunderstorm Project

The Weather Bureau during 1945 initiated a project for study of the development and structure of individual thunderstorm cells.

“Observations and measurements in thunderstorms will be obtained over an area of about sixty square miles in the Orlando locality by means of airplane and glider flights, three radiosonde and several radar stations, and approximately fifty surface recording stations.”

* Ferguson Hall (L) Lt. Col. Lewis Meng (C) Dr. Horace Byers (R)
Ingredients for thunderstorm development

• In 1987 Charles (Chuck) Doswell simplified the list of ingredients necessary for thunderstorm production
  • Instability
  • Moisture
  • Lift
  • Shear (added later, super cells (squall lines, convective complexes))
Ingredients for Thunderstorm Development

• Instability
  – Warm air trapped below cooler air aloft: density differentials

• Moisture
  – At the macroscopic scale it comes from the Gulf of Mexico
  – At smaller scales it comes from the grasses, corns and wheat! Evapotranspiration.

• Lift
  – Mechanical
    • Orographic (of considerable importance in eastern Colorado)
    • Convergence
    • Frontal Wedging
  – Buoyant
    • Latent heat!
Stages of Thunderstorm Development

(a) Cumulus stage
(b) Mature stage
(c) Dissipating stage

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Thunderstorm stages of development

- **Cumulus stage**
  - Differential Heating
  - Thermals produce fair-weather cumulus clouds
  - Weak updrafts that initially “topple”
    - Turkey towers
  - This mechanism humidifies the region just above the surface (vertical mixing)

Source: Landsat Photograph of rolling cumulus clouds.
• Mature Stage: Characterized by well defined updrafts and downdrafts
• Mature Stage
  – Characterized by well defined updrafts and downdrafts
  – **Downdraft is significantly enhanced through entrainment**
    • Cold dry air aloft is heavy; is pulled into the downdraft and evaporates some of the moisture which has a cooling effect, thus intensifying the downward motion

Microburst
Downdraft
• Mature Stage: Microburst downdraft
• Mature Stage: Gust fronts and bow echoes
  – Thunderstorm begins to become outflow dominant (the downdraft)
  – Entrainment causes the structure to evaporate
  – Heavy rain and hail cause the leading edge of the storm to bow outward
    • Gust front
    • Bow echo
Gust Front
Gust Front of an outflow dominant storm
Shelf Cloud: An outflow dominant storm
Thunderstorm stages of development (cont’d)

- **Dissipating Stage**
  - Updraft is choked with cold outflows
  - Anvil begins to “sag”: Mammatus clouds

Mammatus Clouds
Severe Thunderstorms

Winds > 58 miles/hr (50 knots) or
Hail stones > 1 inch
The Cap! Where is the top of the boundary layer?

Temperature Inversion Enhances Development of Severe Thunderstorms
Supercell Thunderstorms

- Extend 65,000 ft (20km) height, 12-30 miles (50km) in diameter, persist for several hours.
- It is believed supercells account for:
  - Nearly all significant tornadoes
  - Almost all significant hail (i.e. > 2.00”)
  - Much of the significant wind damage each year.
- These long-lived, persistent updrafts come in many shapes and sizes
  - Low Precipitation
  - High Precipitation
  - Classic
Severe storms are more likely to form when there is vertical wind shear. Wind shear (pt 1) is changing wind direction and/or wind speed with distance. In this case, the wind speed is increasing with increasing altitude, this is vertical wind shear.
Wind shear and storm movement result in tilted updrafts (pt 3). The updraft and downdraft coexist, can last longer and get larger and stronger than an air mass thunderstorm.
Wind shear will also rotate the tilted updrafts (mesocyclone). Low pressure in the core of the mesocyclone creates an inward pointing pressure gradient force needed to keep the updraft winds spinning in circular path (low pressure also keeps winds spinning in a tornado).
Low Precipitation Supercell

If the storm relative winds at mid-upper levels are excessive: precipitation is carried too far downwind, inhibiting rain-cooled outflow formation on the rear flank - LP supercell

Source: Jeff Evans, Storm Prediction Center
High Precipitation Supercell

IF THE STORM RELATIVE WINDS AT MID UPPER LEVELS ARE WEAK:

- A large amount of precipitation will form near/in the updraft and will wrap around the mesocyclone - HP supercell

- HP supercells tend to be outflow dominated. rain-cooled outflow undercuts the mesocyclone limiting the potential for long-lived tornadoes.

- very large hail and bow echo evolution common.

Source: Jeff Evans, Storm Prediction Center
Long-lived and/or multiple tornadoes are most likely when there is a balance between low-level inflow and outflow such that the mesocyclone does not occlude rapidly - classic supercell

Source: Jeff Evans, Storm Prediction Center
Linear mesoscale complex

SUPERCELLS

Thunderstorms and Tornadoes
Lightning streak/flash is made of several individual strokes that ionize the atmosphere (3-4, 50 millisecond spacing)

Rapid expansion of air (>33,000 °C) creates the sound wave Thunder
Lightning Formation – Charge Separation

- **We don’t exactly know why it happens**

- One theory:
  - Hail stones tend to have a warmer surface than ice crystals
  - When warm hail collides with colder ice, electrons transfer from ice to hail
  - Hail (-) is bigger and heavier and settles toward the bottom of the cloud
  - Smaller (+) ice crystals are lofted to the top.
Lightning

- May occur:
  - Between cells in the same storm
    - inter-cloud lightning
  - Within a cloud
    - intra-cloud lightning
  - Cloud to air
  - Cloud to ground (CG)

- Lightning forms when a charge separation occurs in a cloud
  - The earth is trying to equalize the electrical difference
  - Negative charges want to flow to the ground.
Tornados

Tilting and stretching of the mesocyclone draws the circulation closer to the axis of rotation, increasing the wind speeds.
Newtonia, MO., Aug., 1882, about 6pm from a rough pencil sketch made from memory.
The earliest known photograph of a tornado 1884

Wall cloud

Funnel cloud

Tornado
1925 Tri-State Tornado

Note:
Percentage refers to total number of buildings and homes destroyed in the community.
“Tornado” was banned from forecasting in 1885!

- The law was changed in 1939, but not implemented until the 1950s

The Wizard of Oz popularizes tornadoes, but never uses the word in the movie!

Source: The Wizard of Oz, 1939.
THE FIRST OPERATIONAL TORNADO FORECAST (!)
establishing the Severe Local Storms Unit

Airplanes thrown about like toys by the tornado that, on March 20, 1948, struck Tinker Air Force Base, Oklahoma

Source: http://www.nssl.noaa.gov/GoldenAnniversary/Historic.html
Ted Fujita and Photogrammetric Analysis

- Known for his Fujita scale
- Known to be the discover of microbursts and multivortices
- Was the first to use photographs and films of tornadoes to gather numerical data

<table>
<thead>
<tr>
<th>EF-Scale Number</th>
<th>3-Second Gust Speed (mph)</th>
<th>Damage Descriptions Based on the Typical Construction of One- and Two-Family Residences</th>
</tr>
</thead>
<tbody>
<tr>
<td>EF0</td>
<td>65-85</td>
<td>Beginning of visible damage; loss of roof covering material, gutters, and/or awning; loss of vinyl or metal siding.</td>
</tr>
<tr>
<td>EF1</td>
<td>86-110</td>
<td>Broken glass in doors and windows; uplift of roof deck and loss of significant roof covering material; collapse of chimney; garage doors collapse inward; failure of porch or carport.</td>
</tr>
<tr>
<td>EF2</td>
<td>111-135</td>
<td>Entire house shifts off foundation; large sections of roof structure removed; most walls remain standing, however top floor exterior walls collapse.</td>
</tr>
<tr>
<td>EF3</td>
<td>136-165</td>
<td>Most interior walls of top story collapsed; most walls collapsed in bottom floor, except small interior rooms.</td>
</tr>
<tr>
<td>EF4</td>
<td>166-200</td>
<td>Total destruction of entire building.</td>
</tr>
<tr>
<td>EF5</td>
<td>&gt;200</td>
<td></td>
</tr>
</tbody>
</table>

Source: http://www-news.uchicago.edu/releases/98/981120.fujita.shtml
http://www.spc.noaa.gov/faq/tornado/#Research
Annual Average Incidence of Tornadoes in the United States; Average Number of Tornadoes and Tornado Days each Month
Tornado Deaths over 50 Years

<table>
<thead>
<tr>
<th>Decade</th>
<th>Number of Tornado Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950s</td>
<td>1500</td>
</tr>
<tr>
<td>1960s</td>
<td>900</td>
</tr>
<tr>
<td>1970s</td>
<td>1000</td>
</tr>
<tr>
<td>1980s</td>
<td>500</td>
</tr>
<tr>
<td>1990s</td>
<td>400</td>
</tr>
</tbody>
</table>
Jon Schaefer, director of the NOAA/NWS Storm Prediction Center, Norman, Oklahoma, reported in an article for USA Today that the energetic output of a tornado is on the order of 10,000 kilowatt hours, “while a hurricane contains 10,000,000,000 kilowatt-hours. (For comparison, a Hydrogen Bomb also contains 10,000,000,000 kilo-watt hours.) However, because a tornado is so much smaller than a hurricane, the energy density (energy per unit volume) of a tornado is about 6 times greater for a tornado than for a hurricane. In terms of energy density, a tornado is the strongest of nature’s storms.”
(http://www.usatoday.com/weather/wtwistqa.htm)
Locations of National Weather Service Stations

http://www.weather.gov/