Ch 15: Thunderstorms and Tornadoes

Thunderstorms - Introduction

- There are many types
  - Ordinary thunderstorms—air-mass thunderstorms
  - Severe thunderstorms
- Usually form in an unstable environment - in the mT air mass
- Often triggered by:
  - strong surface heating
  - terrain
  - frontal boundaries - examples:
    - cold, warm fronts
    - sea-breeze fronts
    - dryline
- Act to transport warm, moist air aloft, and bring down cool air to the surface
  - hence, thunderstorms act to stabilize the atmosphere
Air mass thunderstorms - Life Cycle

- Tend to form:
  - Where with limited wind shear
  - When parcels of air lifted from surface by turbulent overturning
  - along shallow zones where surface wind converge
- There are three stages describing the life cycle of an air-mass thunderstorm
  - cumulus
  - mature
  - dissipating
- Total life span for an air mass thunderstorm is about 45-60 minutes

Cumulus Stage

- Observed as a growing cumulus cloud
- Dominated by updraft - transporting warm, moist air upward
- No precip is reaching the surface at this stage, though it begins to form in the cloud
- Air parcel temperatures in the cloud are warmer than the surrounding air.
- The mixing of environmental air and air in the cloud is called entrainment.
Mature Stage

- Storm is most intense
- Cloud tops can reach tropopause height - generating overshooting tops, can be seen in satellite imagery
- Ice and water may both be present in the cloud
- Lightning and thunder may be present
- Storm is characterized by warm updraft and cold, downdraft
- Precip is reaching the surface
- Downdraft can produce strong, gusty winds at surface

Dissipating Stage

- Storm is dominated by the downdraft
- Precip intensity at the ground weakens
- end up with a cold pool air at the ground, warm air is now aloft
- hence, the storm has stabilized the environment
Severe Thunderstorms

- Often thunderstorms are severe, producing hail, damaging surface winds, flash floods and tornadoes
- The NWS defines a severe thunderstorm as one that produces hail at least three-quarters of an inch in diameter and/or surface wind gust of 50 knots or greater and/or produce a tornado.
- Severe thunderstorms form in an environment characterized by:
  - large instability
  - large amounts of environmental vertical wind shear. Vertical wind shear is when the winds increase in strength with height
- Severe thunderstorms usually extend all the way to the tropopause and can be seen in satellite imagery as storms producing overshooting tops.
Types of severe storms

- The atmosphere generates a number of different types of severe storms. Some examples include:
  - Supercell thunderstorms
  - Squall lines
  - Mesoscale Convective Complexes
  - Bow Echoes
  - Derechoes

Supercell Thunderstorms

- Supercells are indeed impressive storms, generating hail, damaging winds, and tornadoes.
- Most all significant tornadoes are produced by supercells
- Can persist for 12 hours at a time and can travel hundreds of miles
- They form in an environment that has **large instability** and **large vertical wind shear**

- Supercells are unique in that the storms updraft rotates. This rotating updraft is called a **mesocyclone**
- How does the mesocyclone form within a supercell?
Ingredients for Severe Thunderstorms

- A triggering mechanism to initiate the convection, e.g.,
  - dryline
  - cold front
  - terrain
- Large convective instability (warm air at low levels, cold air aloft)
- Lots of low-level moisture
- Lots of vertical shear (suggests what needs to be overhead?)

Downbursts

- Are really nothing more than strong downdrafts
- If the diameter of the downdraft is **4 km or less**, the downburst is called a **microburst**
- If the diameter of the downdraft is **greater than 4 km**, the downburst is called a **macroburst**
- Downbursts can produce winds comparable to weak tornadoes
- Initially, people attributed microburst damage to tornadoes
Mesohigh and gust front

• The downdraft also can produce two other features associated with a storm.
• **Mesohigh** - an area of high pressure at the surface created by the cold heavy pool of air associated with the downdraft
• **Gust front** - the leading edge of the cold air associated with the downdraft
• Gust front passage is noted by:
  – calm winds
  – then gusty winds and a temp drop
  – then precip
• The gust front is a convergence region between the cool outflow and the warm, moist inflow → able to force the warm, moist air upward, generating a new cell
• If a storm continuously regenerates in this manner, it is called a **multi-cell** storm.

Shelf (arcus) and roll clouds are often associated with gust fronts.
Radar image of an outflow boundary. As cool air from inside the severe thunderstorms (red and orange colors) spreads outward, away from the storms, it comes in contact with the surrounding warm, humid air, forming a density boundary (blue line) called an *outflow boundary* between cool air and warm air. Along the outflow boundary, new thunderstorms often form.

Dust clouds rising in response to the outburst winds of a microburst north of Denver, Colorado.
• **Downbursts - An aviation hazard**
  - Downbursts are capable of producing strong wind shear - or large changes in wind speed and direction over a short distance.
  - Responsible for numerous airliner crashes over the years.

![Diagram showing downburst and microburst](https://example.com/downburst_diagram)

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**Squall Lines**

- A squall line may be thought of as any line of convective cells.
- It may be a few tens of kilometers long or 1000 km long.
- Squall lines are usually composed of a series of ordinary cells spread along and behind the leading edge of the system.

- However, a squall line may also be composed of a series of supercells.
- Behind the leading edge of the squall line is often an extensive region of stratiform precipitation.
Pre-frontal squall-line thunderstorms may form ahead of an advancing cold front as the upper-air flow develops waves downwind from the cold front.

A model describing air motions and precipitation associated with a squall line that has a trailing stratiform cloud layer.
Derechos (day-ray-sho)

- A squall line may be labeled a Derecho if it is followed by an extended area of damaging winds.
- The derecho shown to the right produced winds greater than 100 MPH over IA and IL.

![Derecho Image]

Bow Echoes

- One of the more significant and intriguing forms of severe weather is the bow echo.
- Bow echoes are relatively small (20-120 km long), bow-shaped systems of convective cells that are noted for producing long swaths of damaging surface winds.
- They are observed both as relatively isolated convective systems and as sub-structures within much larger convective systems such as a squall line.
The red and orange on this Doppler radar image show a line of intense thunderstorms (a squall line) that is moving south southeastward into Kentucky. The thunderstorms are producing strong straight-line winds called a *derecho*. Notice that the line of storms is in the shape of a bow.

**MCCs**

- Mesoscale convective complexes (MCCs) represent a larger form of MCS organization.
- A system is identified as an MCC based on its characteristics as depicted on IR satellite imagery.
- The physical characteristics include a general cloud shield with continuously low IR temperatures less than -32° C over an area 100,000 km², with an interior cold cloud region with temperatures less than -52° C having an area of 50,000 km².
- MCCs often last for 6-12 h, and are especially known for producing heavy amounts of rain, although severe winds, hail, and tornadoes can also occur during the early phases of MCC evolution.
The Great Flood of 1993

The heavy arrow represents the average position of the upper-level jet stream from mid-June through July, 1993.

Thunderstorm Distribution over the U.S.

- Plotted are the number of days each year when thunderstorms are observed.
  - note max's along gulf coast, especially Florida
  - also CO
- estimated that more than 40,000 thunderstorms form each day around the world
Distribution of Hail over the U.S.

- Plotted is the average number of days when hail is observed.
- Notice that it is not a max along the gulf coast/Florida.
- Is a max over the Great Plains region of the U.S.

Lightning and Thunder

- Lightning is a large discharge of electricity, an giant spark, which occurs in mature thunderstorms.
- Two types of discharges:
  - in cloud or between clouds
  - cloud to ground (less frequent)
- The lightning stroke heats the air instantaneously to 30,000°C → this heating generates a shock wave that propagates away from the flash—heard as thunder.
- We see the lightning flash instantaneously, but thunder is often heard shortly thereafter as sound travels at about 330 m/s. Hence, thunder travels about 1 km in 3 seconds (1 mile per 5 seconds).
- Sometimes you can see the lightning flash, but can’t hear the thunder....., why?
Refraction of sound waves

- Light and sound waves will travel at different speeds through mediums with different densities - this is called refraction.
- In the atmosphere, sound waves travel faster in warm air than in cold air.
- As the sound wave propagate into the warmer air at lower levels, they change direction, much like light passing through a prism.
- Hence, the sound wave is refracted upward, can't here the thunder beyond a critical distance, usually around 15 km.

Charge Distribution in Clouds

- Most all lightning is observed in cold clouds - those containing water, supercooled water, and ice.
  - Within a cold cloud, a region of positive charge is generated at the top of the storm.
  - A region of negative charge builds up in the lower part of the storm.
- How is this charge distribution created??
  - One theory suggests that the charge separation is created as hail and graupel fall through supercooled drops and ice crystals.
- The resulting collisions separate the charge:
  - The large hail and graupel particles acquire negative charge and fall the lower part of the storm.
  - The smaller supercooled water particles and ice crystals acquire positive charge - are carried to the top of the storm in the updraft.
Evolution of the lightning stroke

- As the area of negative charge builds up near the base of the cloud, it induces an area of positive charge at the ground - opposite signed charges attract each other.
- The negative charges in the base of the cloud and the positive charges at the ground create a potential difference, or a voltage, just like a battery.
- Once the voltage reaches a critical strength, the atmosphere tries to reduce it.

- First, a **stepped leader** is created at the base of the cloud
  - the stepped leader is a channel through which electrons in the cloud can travel to the ground
  - the stepped leader is invisible to the eye
  - it travels discretely to the ground, 50-100 meters at a time
  - it then stops for about 50 microseconds, then travels another 50-100 meters.
• As the stepped leader gets close to the ground, a positively charged **traveling spark** is initiated on some tall object on the ground.
• The traveling spark moves upward and eventually connects with the stepped leader.

![Image](image.png)

(b)

• Once the stepped leader and the return stroke have connected, then electrons from the cloud can flow to the ground, and positive charges can flow from the ground to the cloud.
• This flow of current from the cloud to the ground is visible at the **return stroke**.
  – the return stroke is several cm in diameter
• After the first discharge, it is possible for another leader to propagate down the channel created by the first stepped leader.
  – This new leader is called a **dart leader**.
• A subsequent return stroke propagates upward from the ground to the cloud.
• This can happen 3-4 times in quick succession.

![Image](image.png)

(c)
Time exposure of an evening thunderstorm with an intense lightning display near Denver, Colorado. The bright flashes are return strokes. The lighter forked flashes are probably stepped leaders that did not make it to the ground.

Lightning rods are placed on buildings to protect them from lightning damage!
Types of lightning

- Ribbon lightning
- Forked lightning
- Bead lightning
- Ball lightning
- Sheet lightning
- Heat lightning

A fulgurite that formed by lightning fusing sand particles.
The four marks on the road surface represent areas where lightning, after striking a car traveling along south Florida’s Sunshine State Parkway, entered the roadway through the tires. Lightning flattened three of the car’s tires and slightly damaged the radio antenna. The driver and a six-year-old passenger were taken to a nearby hospital, treated for shock, and released.

Cloud-to-ground lightning strikes in the vicinity of Chicago, Illinois, as detected by the National Lightning Detection Network.
A cloud-to-ground lightning flash hitting a 65-foot sycamore tree. It should be apparent why one should *not* seek shelter under a tree during a thunderstorm.

**Avoid dangerous places during lighting !!**

**Tornadoes**

- A *tornado* is a rapidly rotating column of air that blows around a small area of intense low pressure with a circulation that reaches the ground--made visible with the funnel cloud

- On average:
  - They last for about 10 minutes
  - Create a damage path about 4 miles long
  - The diameter of most tornadoes is between 100 and 600 m

- Some tornadoes touch down briefly

- A few tornadoes have been observed to last for hours, creating a damage path 100's of km long

- Most of the time, their occurrence is isolated, but sometimes, tornado outbreaks occur

- How strong can tornadic winds get?

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150 knots for this one
Tornado incidence by state. The upper figure shows the number of tornadoes reported by each state during a 25-year period. The lower figure is the average annual number of tornadoes per 10,000 square miles. The darker the shading, the greater the frequency of tornadoes. (NOAA)

**TABLE 14.1**

<table>
<thead>
<tr>
<th>DECADE</th>
<th>TORNADOES/YEAR</th>
<th>DEATHS/YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950–59</td>
<td>480</td>
<td>148</td>
</tr>
<tr>
<td>1960–69</td>
<td>681</td>
<td>94</td>
</tr>
<tr>
<td>1970–79</td>
<td>858</td>
<td>100</td>
</tr>
<tr>
<td>1980–89</td>
<td>819</td>
<td>52</td>
</tr>
<tr>
<td>1990–99</td>
<td>1,220*</td>
<td>56</td>
</tr>
</tbody>
</table>

*More tornadoes are being reported as populations increase and tornado-spotting technology improves.
Average number of tornadoes during each month in the United States.

**Tornadic Winds**

- The tornado is heading northeast at 50 knots
- Rotational speed is 100 knots
- The strongest winds are on its southeast side.
A powerful multi-vortex tornado with three suction vortices.

Tornadic Winds

• The Fujita Scale (F scale) is used to estimate tornadic wind speeds based on the damage produced:

<table>
<thead>
<tr>
<th>SCALE</th>
<th>CATEGORY</th>
<th>MPH/mts</th>
<th>KNOTS</th>
<th>EXPECTED DAMAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>F0</td>
<td>Weak</td>
<td>40–72</td>
<td>35–62</td>
<td>Light: tree branches broken, sign boards damaged</td>
</tr>
<tr>
<td>F1</td>
<td></td>
<td>73–112</td>
<td>63–97</td>
<td>Moderate: trees snapped, windows broken</td>
</tr>
<tr>
<td>F2</td>
<td>Strong</td>
<td>113–157</td>
<td>98–136</td>
<td>Considerable: large trees uprooted, weak structures destroyed</td>
</tr>
<tr>
<td>F3</td>
<td></td>
<td>158–206</td>
<td>137–179</td>
<td>Severe: trees leveled, cars overturned, walls removed from buildings</td>
</tr>
<tr>
<td>F4</td>
<td>Violent</td>
<td>207–260</td>
<td>180–226</td>
<td>Devastating: frame houses destroyed</td>
</tr>
<tr>
<td>F5*</td>
<td></td>
<td>261–318</td>
<td>227–276</td>
<td>Incredible: structures the size of autos moved over 100 meters, steel-reinforced structures highly damaged</td>
</tr>
</tbody>
</table>

*The scale continues up to a theoretical F12. Very few (if any) tornados have wind speeds in excess of 110 m/s.

Practice assessing F-scale values to tornadic damage.

http://www.pbs.org/wgbh/nova/tornado/damage.html
A devastating F5 tornado about 200 meters wide plows through Hesston, Kansas, on March 13, 1990, leaving almost 300 people homeless and 13 injured.

Total destruction caused by an F5 tornado that devastated parts of Oklahoma on May 3, 1999.
Supercell Tornado Formation
Associated with thunderstorm

Spinning vortex tubes created by wind shear.

The strong updraft in the thunderstorm carries the vortex tube into the thunderstorm, producing a rotating air column that is oriented in the vertical plane.

Some of the features associated with a tornado-breeding supercell thunderstorm as viewed from the southeast. The storm is moving to the northeast.
A tornado-spawning supercell thunderstorm over Oklahoma City on May 3, 1999, shows a hook echo in its rainfall pattern on a Doppler radar screen. The colors red and orange represent the heaviest precipitation.

Wall Clouds

- Wall clouds are a lowering of cloud base at low levels in the storm
- Wall clouds are a visible manifestation of the mesocyclone at low levels, in other words, the wall cloud contains significant rotation
- The tornado often forms from within the wall cloud, with the funnel cloud descending to the ground
- How the tornado forms is still a mystery....,
A classic tornadic supercell thunderstorm showing updrafts and downdrafts, along with surface air flowing counterclockwise and in toward the tornado. The flanking line is a line of cumulus clouds that form as surface air is lifted into the storm.

A funnel cloud extends downward from the base of a nonsupercell thunderstorm over central California.
(a) Along the boundary of converging winds, the air rises and condenses into a cumulus congestus cloud. At the surface the converging winds along the boundary create a region of counterclockwise spin. (b) As the cloud moves over the area of rotation, the updraft draws the spinning air up into the cloud, producing a nonsupercell tornado, or landspout.

Tornado Observations

- When there is a good chance of tornadic formation within the next few hours, a **tornado watch** is issued by the Storm Prediction Center in Norman, Oklahoma (http://www.spc.noaa.gov/)
- When a tornado has been spotted by:
  - trained spotter
  - on radar
- Then a tornado warning is issued
- **Observation with a radar:**
  - We now have a national network of radars called the Weather Surveillance Radar (WSR-88D) that can observe tornadic storms
  - Recall that the tornado forms from the mesocyclone at low levels.
  - The mesocyclone can be observed with a radar and is called a "hook echo"
  - Important!: the radar can not see the tornado itself since the scale of the tornadic circulation is very small (on average 100 m wide).
  - The radar can see the mesocyclone which is 2-4 km wide.
Interpretation of Doppler Velocities

- In addition to the radar reflectivity field, radars collect information about the wind
- Doppler radars measure the radial velocity
- The radial velocity is defined as the component of the wind in the direction parallel to the radar beam orientation

Doppler radar display of winds associated with the supercell storm that moved through parts of Oklahoma City during the afternoon of May 3, 1999. The close packing of the winds blowing toward the radar (green and blue shades), and those blowing away from the radar (yellow and red shades), indicate strong cyclonic rotation and the presence of a tornado.
Graduate students from the University of Oklahoma use a portable Doppler radar to probe a tornado near Hodges, Oklahoma.

A powerful waterspout moves across Lake Tahoe, California.