ESCI 340 - Cloud Physics and Precipitation Processes
Lesson 11 - Thunderstorms
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References:

A Short Course in Cloud Physics, 3rd ed., Rogers and Yau, Ch. 13
The Lightning Discharge, Uman
Fundamentals of Lightning, Rakov

General Characteristics

- A thunderstorm is a storm that produces thunder and lightning.
- In a thunderstorm, updrafts can easily exceed 50 mph, and have been observed at over 80 mph.
- Thunderstorms require some lifting mechanism to start the initial upward motion. This mechanism can be any one of the four lifting mechanisms that we discussed earlier:
  - Orographic lifting
  - Frontal wedging
  - Convergence
  - Convective lifting

Distribution

- On average there are about 45,000 thunderstorms around the world every day.
- Most thunderstorms occur over land, and in the Tropics.
- Each year the U.S. experiences around 100,000 thunderstorms.
- Florida and the Gulf Coast experience the most thunderstorms in the U.S., because mT air that moves over the hot land is very unstable.
- Eastern New Mexico and Colorado also experience numerous thunderstorms, due to mT air moving upslope toward the Continental Divide.
- The fewest thunderstorms occur on the West Coast, because cool, stable mP air.

Air Mass Thunderstorms

- Air mass thunderstorms are associated with mT air.
- Stages of development of air mass thunderstorms

  Cumulus stage: Strong updrafts.

  Mature stage: Precipitation begins and downdrafts form from both the frictional drag of the precipitation, and due to entrainment of dryer air and evaporation of precipitation.

  Dissipating stage: Downdrafts have shut off the updrafts that feed the storm. Clouds evaporate as the storm dissipates.
- Air mass thunderstorms are more likely to occur over mountains or hills, due to differential heating and orographic lifting.
- The sea-breeze is a common cause of air-mass thunderstorms along Floridas coast.

Gust Fronts and Downbursts

- Thunderstorm downdrafts are cool because of two factors:
- Entrainment of unsaturated, cooler air from outside of the thunderstorm.
- Evaporation of precipitation into the air.
- As the cool downdraft hits the ground it spreads out.
- The leading edge of the downdraft acts like a miniature cold front, and is called the gust front. As the gust front passes the wind become gusty, and the temperature drops.
- The lifting of warm, moist air along the gust front can trigger new thunderstorm development.
- If the downdraft is very strong it is called a downburst.
  - Downbursts can be quite damaging to trees, building, power lines, and airplanes.
  - They are often mistaken for tornadoes by people who experience them.
  - A very narrow downburst is sometimes called a microburst.

Severe Thunderstorms

- A thunderstorm is classified as severe if any one of the following conditions are met:
  - It produces winds in excess of 50 knots (58 mph).
  - It produces hail larger than one inch in diameter.
  - It produces a tornado.

Supercell Thunderstorms

- Thunderstorms are also classified according to the number and strength of the updrafts, or cells.

  Single-cell: In a single-cell thunderstorm there is only one main updraft and downdraft. Most air mass thunderstorms are of this variety.

  Multi-cell: Multi-cell thunderstorms have more than one updraft.

  Supercell: These have a single, rotating updraft.

- The type of thunderstorm produced is largely determined by the type of vertical wind shear present.

- Although the updraft in most supercell thunderstorms rotates cyclonically, they can also rotate anticyclonically.

  - The rotating updraft is called a ***mesocyclone*** if it is rotating counterclockwise, and a ***meso-anticyclone*** if it is rotating clockwise.

- Mesocyclones and anticyclones have large Rossby number,

$$R_o = \frac{\text{INER}}{\text{COR}} = \frac{V}{fR}, \tag{1}$$

  which is a measure of the importance of the ***intertial term***, INER, to the ***Coriolis term***, COR, in the horizontal momentum equation,

$$\frac{d\vec{V}}{dt} = -\nabla\Phi - \hat{k} \times f\vec{V}. \tag{2}$$

$$\text{INER} \qquad\qquad \text{COR} \tag{3}$$

  - For very large Rossby numbers ($R_o >> 1$) the inertial term is much, much larger than the Coriolis term, and the Coriolis term can be neglected without significant error. This type of circulation is in ***cyclostrophic*** balance.
  - For very small ($R_o << 1$) Rossby numbers the Coriolis term is much, much larger than the inertial term, and the inertial term can be neglected without significant error. This type of circulation is in ***geostrophic*** balance.
  - For Rossby numbers neither very large nor very small, no terms can be omitted. This type of circulation is in ***gradient*** balance.

- The rotating updrafts in supercell thunderstorms are therefore in cyclostrophic balance, and Coriolis is not a factor in their dynamics.

- Nonetheless, most supercells have cyclonic rotation. This is due to the dynamic pressure induced at the top of the storm due to the upper-level winds.

  - The horizontal vorticity (rotation) wind shear in the boundary layer, which is due to the wind shear, gets tilted into the vertical by the updraft.

  - This creates two vortices rotating around the vertical. The vortex to the right of the wind rotates cyclonically, while the one to the left rotates anticyclonically.
  - The wind tends to veer with height, so aloft the wind is coming at an oblique angle to the storm. This induces high pressure over the anticyclonic vortex, and low pressure over the cyclonic vortex.
  - The high pressure over the anticyclonic vortex impedes its development, while the low pressure over the cyclonic vortex enhances its development.
  - The anticyclonic vortex is usually short-lived, while the cyclonic vortex persists.

Thunderstorms and the Global Electrical Circuit

- The upper atmosphere is a good conductor of electricity because there are a lot of ions present.
- The troposphere is a poor conductor of electricity, because there are not many ions.
- The earth normally has a negative charge, and the upper atmosphere normally has a positive charge.
- There is a constant leakage current through the atmosphere that could neutralize the earth-atmosphere charge imbalance in about 10 minutes.
- Thunderstorms provide the mechanism for pumping positive charges into the upper atmosphere. They can therefore be thought of as the electromotive force for the global electrical circuit.

Observed Electrical Properties of a Thunderstorm

- The top of a thunderstorm (cumulonimbus) cloud becomes positively charged.
- The bottom of the cloud becomes predominantly negatively charged, although there are often smaller pockets of positive charge near the bottom as well.
- The precise mechanism for this charge separation is not completely understood, though some mechanisms will be discussed in the next lesson.
- The negative charge at the bottom of the cloud induces a positive charge at the ground.
- Lightning is a discharge of electricity between the oppositely charged centers, either from the cloud to the ground, or within the cloud.
- Globally there are on the order of 50 to 100 lightning flashes every second.