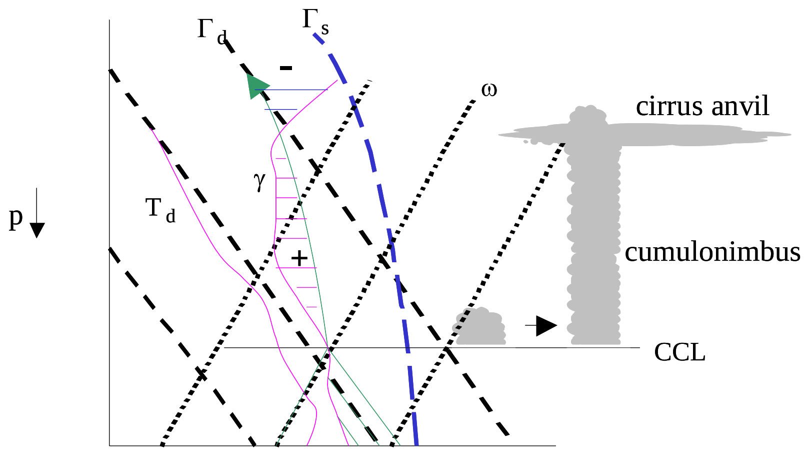
Thunderstorms

If the atmosphere is sufficiently unstable, convective development can result in the thunderstorm, a cumulonimbus cloud (C_b) with lighting discharge, possibly hail, and, in extreme cases, accompanied by a tornado.

The likelihood of thunderstorm activity and the amount of energy released in such a storm can be traced out on a thermodynamic diagram. In the example below, surface heating during the day has initiated the formation of cumulus clouds at the CCL but a deep conditionally unstable layer has resulted in great vertical development.

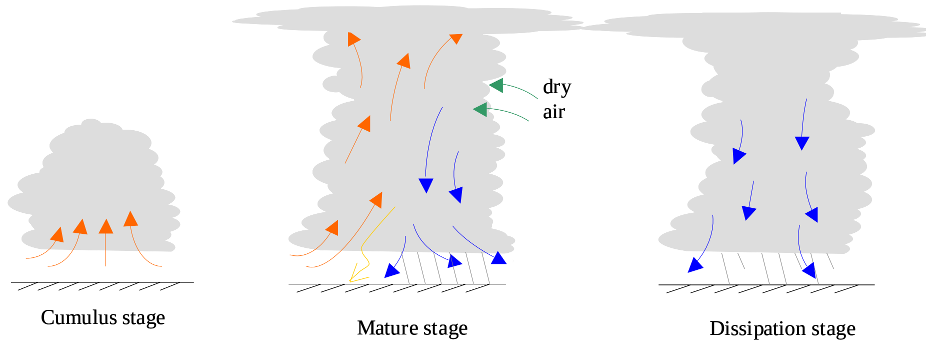


The positive area where the process curve (Γ_s) is to the right of the sounding represents (is proportional to) the amount of energy released in the cloud to produce strong upward motion (~ 10 m/s). At the top, the cloud meets a stable layer, the upward motion is suppressed and the cloud spreads out into an anvil of cirrus. In this negative area the stable (warm) environment consumes the energy of the cloud and limits the height of the cloud.

Annually, there are about 100,000 thunderstorms within the 48 contiguous states. They are ranked #1 in fatalities (manly deaths from lightning strikes), #2 in injuries, and #3 in property damage compared with other natural phenomena (hurricanes, floods, earthquakes etc.).

Air mass thunderstorms are thunderstorms not associated with weather fronts. They form mostly in the summer as the sun heats the surface and causes convection. They are usually not the most severe type of storm.

There are three basic stages in the lifespan of a thunderstorm:



In the formative cumulative stage, there are updrafts at all points at the base of the cloud. In the mature thunderstorm, there will also be a strong downdraft caused by both (a) the drag of rain and hail falling through the cloud and (b) evaporative cooling as dry air is entrained into the cloud. In the dissipating stage, there are weak downdrafts throughout the cloud.

The typical lifetime of an air mass thunderstorm is one hour or less.

Severe thunderstorms(NWS definition: ¾ inch hail and/or wind gusts of 0 knots) generally require strong vertical shear in the wind in addition to the conditions preciously specified, and are usually associated with conditions in which there is divergence aloft to enhance the updraft. The vertical shear of the wind causes a tilting of the updraft so that, when precipitation becomes too heavy to be supported by the updraft, it falls into the downdraft region rather than remaining to reduce the intensity of the updraft.

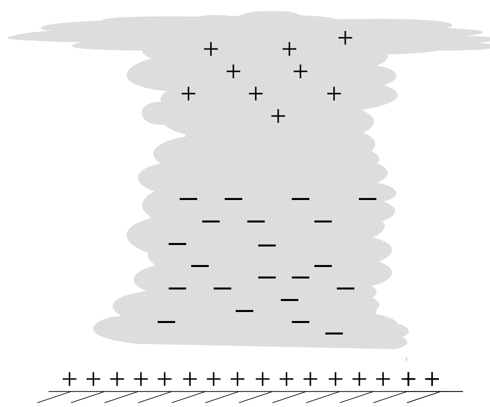
Violent updrafts keep hailstones suspended in the cloud long enough to grow to considerable size.

Downbursts are intense downdrafts from the base of a cumulonimbus which spread out horizontally on reaching the ground producing a gust front. Gust fronts are particularly dangerous to aircraft during take off or landing.

Electrification of clouds

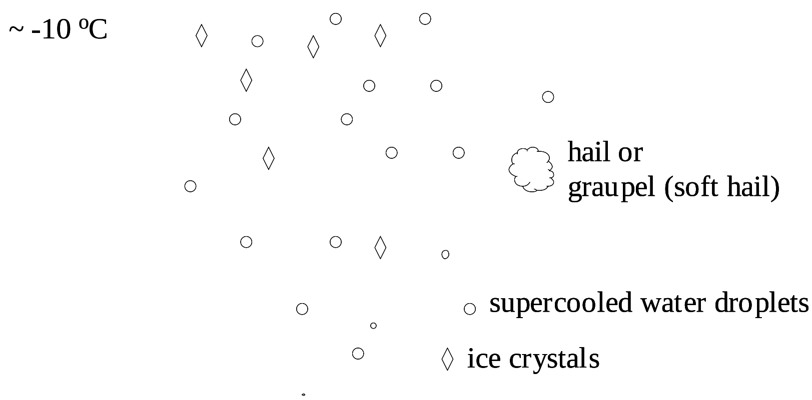
Charge separation: Some of the water molecules in ice are always dissociated into positive and negative ions and the number of these ions is greater at higher temperatures. Therefore, the warmer end of the ice rod will contain more positive and negative ions than the colder end. Since ions migrate from regions of high concentration to regions of low concentration, both the positive and negative ions will tend to migrate from the warmer toward the colder end of the ice rod. However, the mobility of the negative ions in ice is essentially zero, whereas that of the positive ions is quite high. Therefore, the positive ions migrate toward the cold end where they build up a positive space charge which eventually prevents any further migration of positive ions into the region along the rod, with the cold end positively charged and the warm end negatively charged.

The effect of electrification in a cloud is to create a charge distribution in which positive charges accumulated in the upper part of the cloud and negative charges accumulate in the middle and lower part of the cloud. This induces a positives charge on the surface.



Positive charge "shadow" as the cloud moves over the earth

There is uncertainty concerning the process of charge separation but there are several theories concerning how it might occur. One concerns the interaction between warmer hailstones and colder ice crystals. There are three steps in the process:



1. Collisions between hail or graupel and supercooled water droplets causes freezing of the previously liquid water and the release of latent heat maintains the hail or graupel at a high temperature than the ice particles.

1. Collision, but not accretion, between the colder ice particles and the warmer hail or graupel causes a charge separation and the transfer of a positive ion from the warmer object to the colder one.

2. Updrafts in the cloud carry the small, positively charged, ice particles to the upper part of the cloud while the heavier, negatively charged, hail and graupel migrate to lower levels.

The discharge

Lightning occurs most often (80%) within a cloud but also occurs from cloud to ground (20%). The air is generally a poor conductor but, when the electrical potential builds up sufficiently, there can be a breakdown and a lightning discharge.

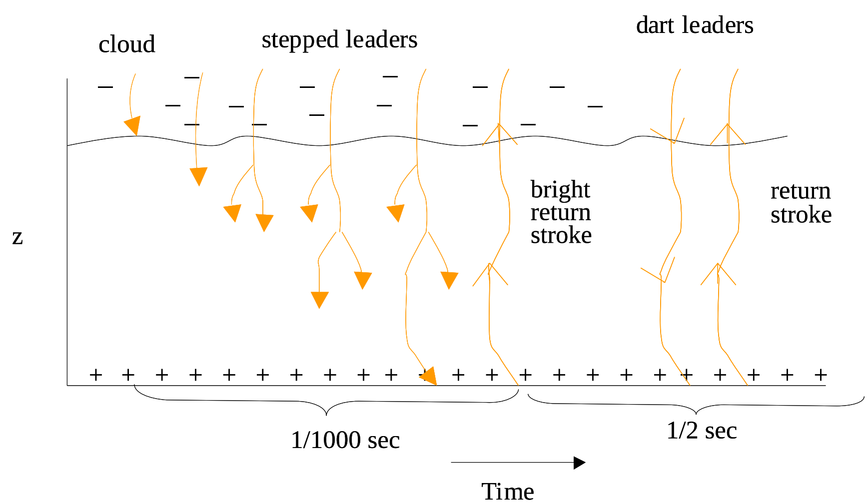
Cloud to ground lightning flashes originate near cloud bases in the form of an invisible (to the human eye) discharge, called the stepped leader, which moves downward toward the earth in discrete steps. Each step lasts for about 1 μs during which time the steeped leader advances about 50 m;

the time interval between steps is about 50 μm

The discharge occurs in the following manner. When the localized electric field exceeds 3 million volts/meter along a path several tens of meters long, a discharge of electrons rushes towards the cloud base and towards the ground. This usually proceeds in a series of discrete steps, each discharge covering 50 to 100 m, about 50-millionths of a second apart (1/20000 sec).

This stepped leader is very faint and barely perceptible. As the leader approaches the ground, a current of positive charge starts upward to meet it. When this occurs, a large, luminous return stroke surges upward to the cloud along the path of the stepped leader. The discharge takes only about 1/10000 sec and our eye cannot discern the direction of stroke but rather, just sees it as an instantaneous flash.

The initial stoke is usually followed by a series of dart leaders along the original path and consequent return strokes. This might take a total of about ½ second. One photographed case documented 26 such flashes.



The path of the electrical current is only a few cm wide but the stroke heats the air to almost

30,000 ^{o}C (five times the surface temperature of the sun). The resulting shock wave (from the rapid expansion) of the air) is what we know as thunder.

While light travel at 109 km/hr, sound travels such more slowly, about 340 m/s (1 km in 3 seconds or 1 miles in 5 seconds) so we can calculate how far away a lighting stoke is by timing the difference between the appearance of the flash and the sound of the thunder.