

The Earth System - Atmosphere III



Thunderstorms

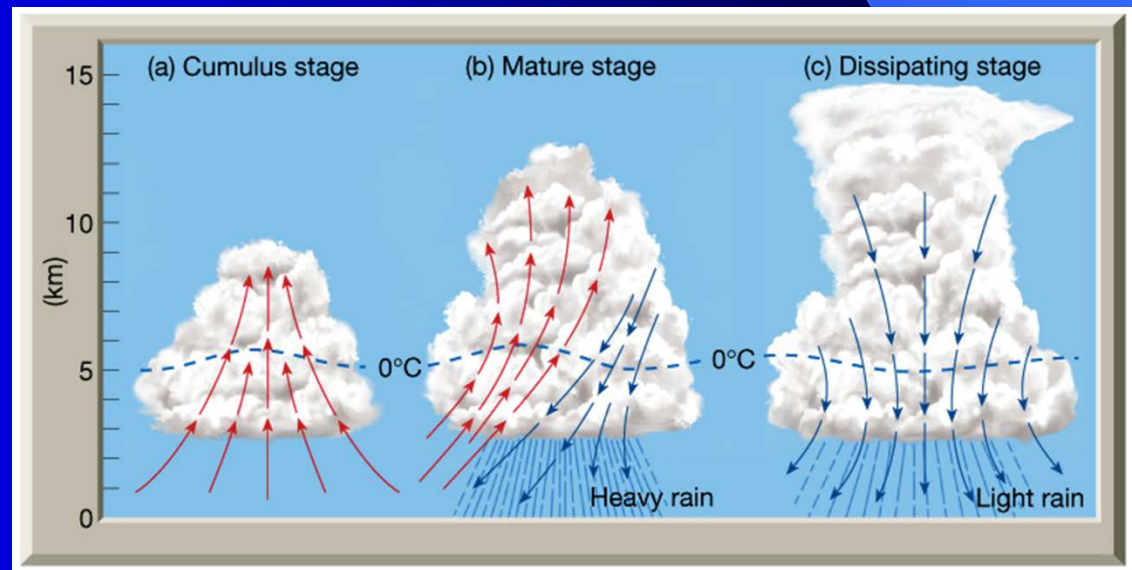
1. A thunderstorm is a storm that produces lightning (and therefore thunder)
2. Thunderstorms frequently produce gusty winds, heavy rain, and hail.
3. Thunderstorms form when warm, humid air rises in an unstable environment.
4. **Air-mass thunderstorms** are triggered by the unequal heating of the Earth's surface. Produced within mT air masses. Strong-lived, but not gusty or hail-producing.
5. **Severe thunderstorms** are also triggered by the unequal heating of the Earth's surface, but also involve lifting of the warm air by a front or mountain slope. Diverging winds aloft that draw air upwards from lower levels also contribute.
6. Highest occurrence rate for thunderstorms is found in Florida, followed by the plains east of the Rockies in Colorado and New Mexico.

Air-Mass Thunderstorms

1. Frequently occur in mT air moving north from the Gulf of Mexico.
2. The warm humid air mass is heated from below by the ground, and thus rendered unstable.
3. Strong preference for Spring and Summer, and for mid-afternoon.
4. Generally occur as scattered isolated cells, because of the uneven heating of the ground.

Stages of development on air-mass thunderstorms

1. Cumulus Stage
2. Mature Stage
3. Dissipating Stage

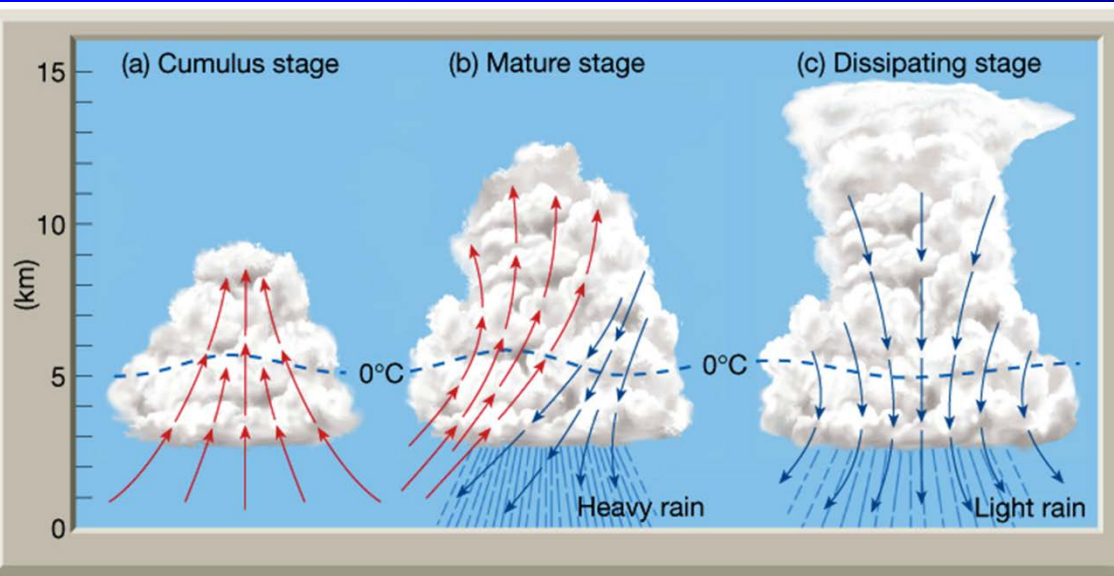


Cumulus Stage

- Thermals over hot parts of the ground produce fair weather cumulus clouds that evaporate after a few minutes.
- The rising air increases the humidity, and eventually the clouds do not evaporate, but grow vertically.
- Growth continues because of the release of latent heat (as the moisture condenses), which heats the air further.
- This stage is dominated by **updrafts**.
- Once the cloud rises through the freezing level, the Bergeron process begins producing precipitation.
- Eventually, the precipitation is too great for the updrafts to support.
- The falling precipitation causes drag on the air, and initiates a **downdraft**.

Cumulus Stage

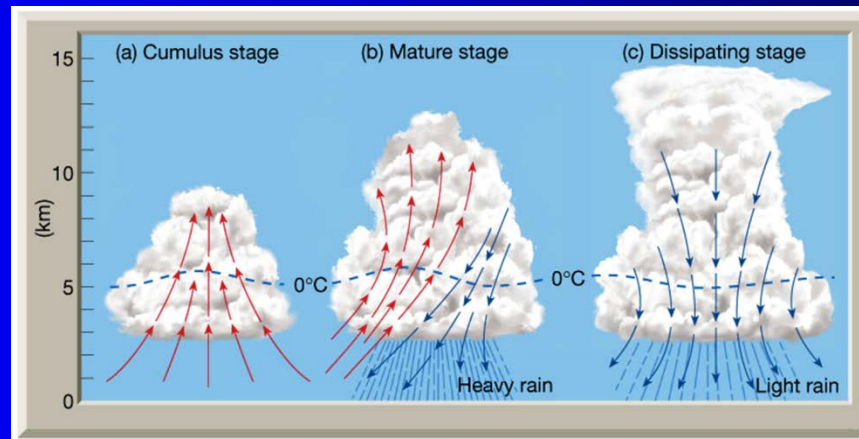
- The creation of the downdraft is further aided by the influx of cool, (dense), dry air surrounding the cloud, in a process called **entrainment**.
- Entrainment intensifies the downdraft because it brings in cool and therefore dense air.
- Because this air is also dry, it allows some of the falling precipitation to evaporate, thus cooling the air in the downdraft.



(b)

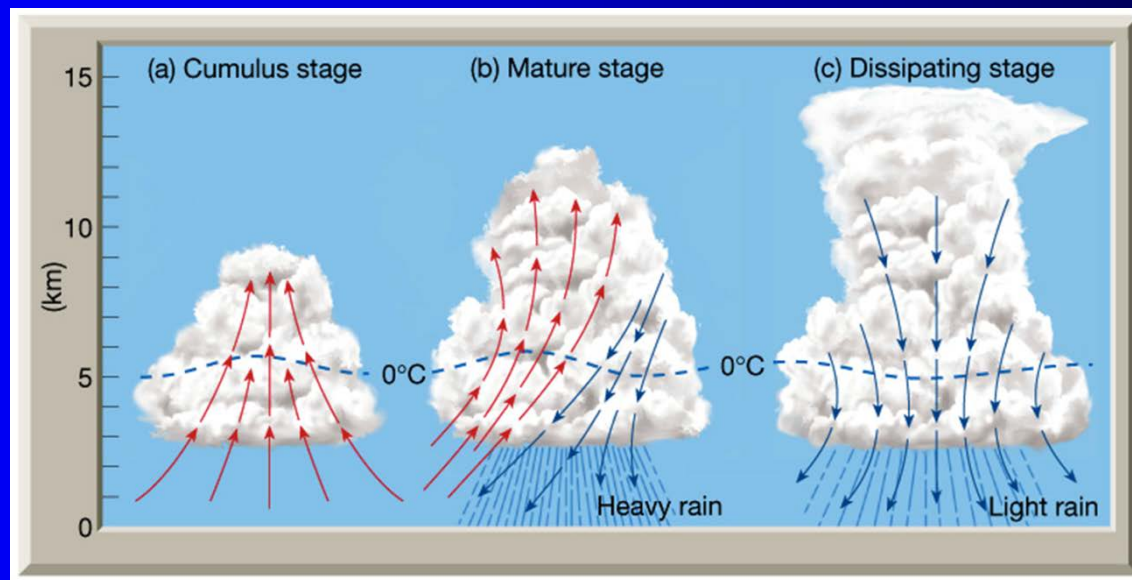
Mature Stage

- As the downdraft leaves the base of the cloud, precipitation starts. This is the beginning of the mature stage.
- The cool downdrafts spread laterally over the surface.
- Updrafts exist side by side with downdrafts, continuing to enlarge the cloud.
- When the cloud grows to the top of the unstable region, often located at the base of the stratosphere, the updrafts spread laterally, producing the anvil cloud tops.
- The top of the cloud is usually made up of ice-laden cirrus clouds, which are spread downwind by strong winds.
- The mature stage is the most active stage of a thunderstorm, producing gusty winds, lightning, heavy precipitation and some hail.



Dissipating Stage

- Once the downdrafts start, they entrain the cool dry air surrounding the cell.
- The cooling effect of falling precipitation and the influx of colder air marks the end of thunderstorm activity.
- Since the updrafts no longer occur, the cloud is starved of moisture, and will eventually evaporate.
- Only about 20% of the moisture is precipitated. The rest evaporates.
- Air mass thunderstorms can contain more than one cell.

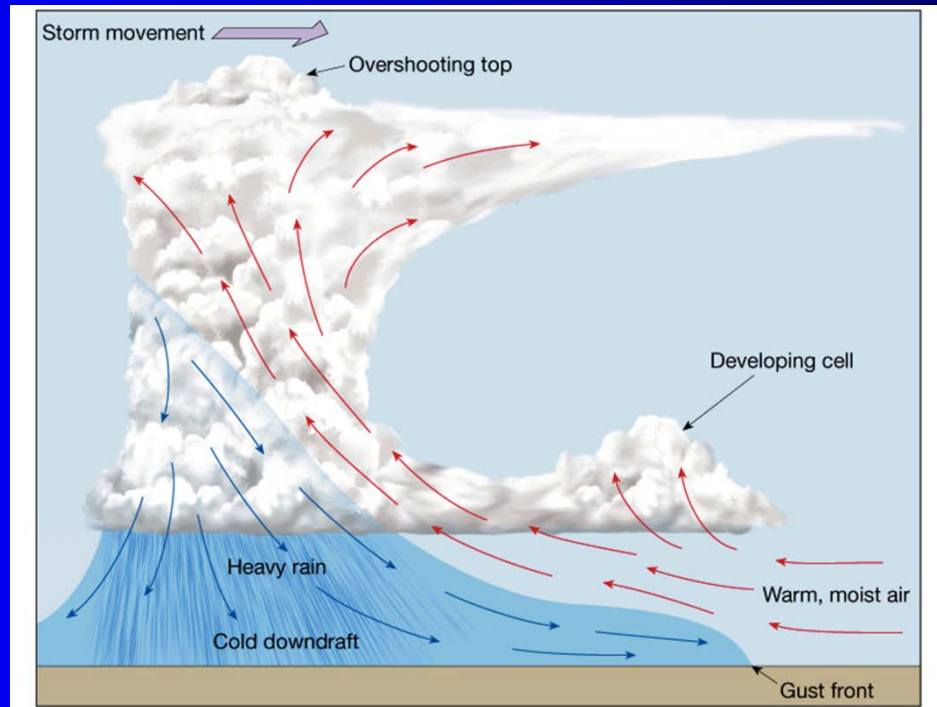


Severe Thunderstorms

1. A severe thunderstorm is one
 - with winds >93 km/h, or
 - produces hailstones with diameters >1.9 cm, or
 - gives a tornado.
2. Severe thunderstorms can produce heavy downpours and flash flooding, as well as strong gusty straight-line winds, large hail, frequent lightning, and perhaps tornadoes.
3. Severe thunder storms can be long-lived, lasting many hours.
4. A **key factor in their long lives** is the existence of strong vertical wind shears, i.e, changes with height of wind speed or direction.
5. The updrafts become tilted, so that the precipitation that falls high in the cloud falls into the downdraft, not the updraft.
6. The updrafts can thus continue to develop and build upwards.
7. If the updrafts are sufficiently strong, the cloud top reaches the stable lower stratosphere - this is called **overshooting**.

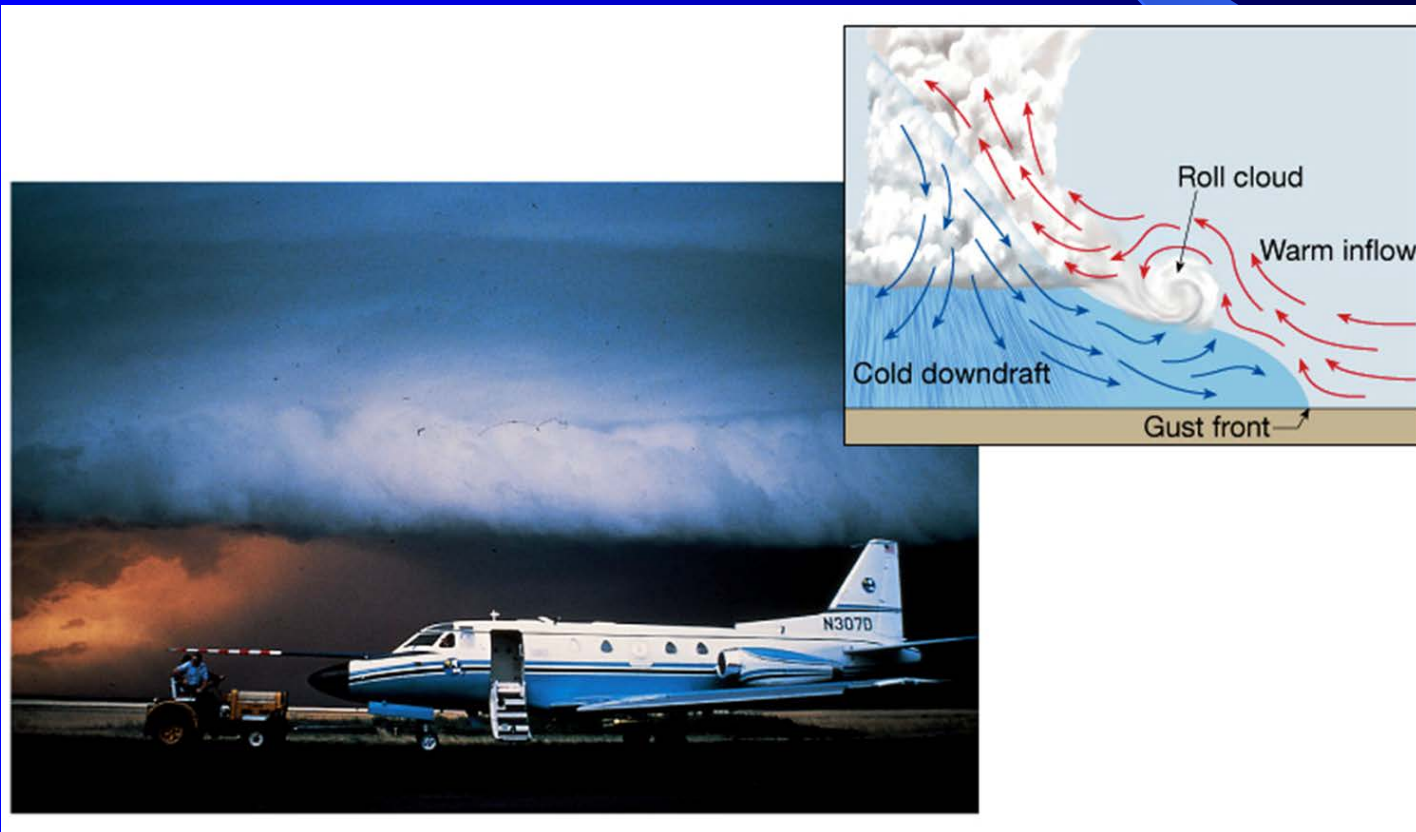
Severe Thunderstorms

1. When the downdrafts reach the surface, the denser cool air spreads out over the ground. Acting like a wedge, the cool air forces warm moist surface air up into the cloud.
2. Thus the downdrafts help to maintain the updrafts, sustaining the storm.
3. The flow of cool air from the downdraft into the warm air at the surface produces a **gust front**.



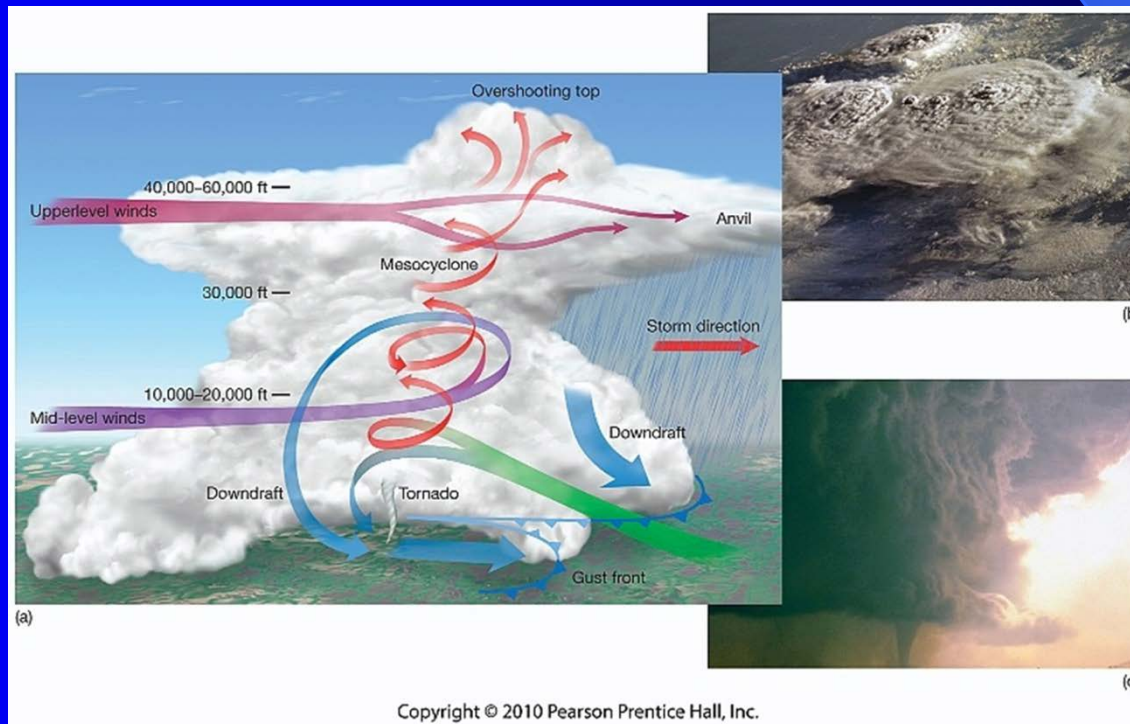
Severe Thunderstorms

1. Gust fronts sometimes cause visible dust clouds, or a **roll cloud** between the cold and warm air. A roll cloud rotates.
2. A gust front can also cause the lifting needed for the formation of new thunderstorms many km away from the initial storm.



Supercell Thunderstorms

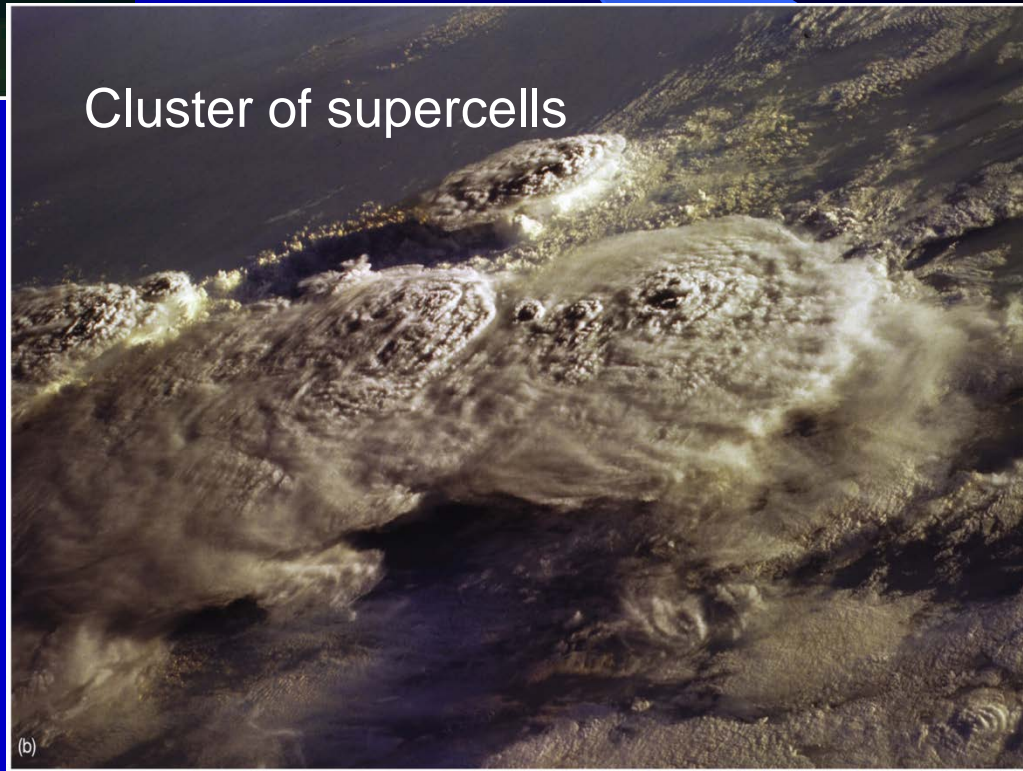
1. A **supercell** consists of a single, very powerful, thunderstorm cell that can extend up to heights of 20 km, and last for several hours. Have diameters between 20 and 50 km.
2. Virtually all of the most severe tornadoes are spawned by supercells, although less than half of the supercells produce tornadoes.
3. **Vertical wind gradients** can cause the updraft to rotate (provide a torque).



Supercell thunderstorm

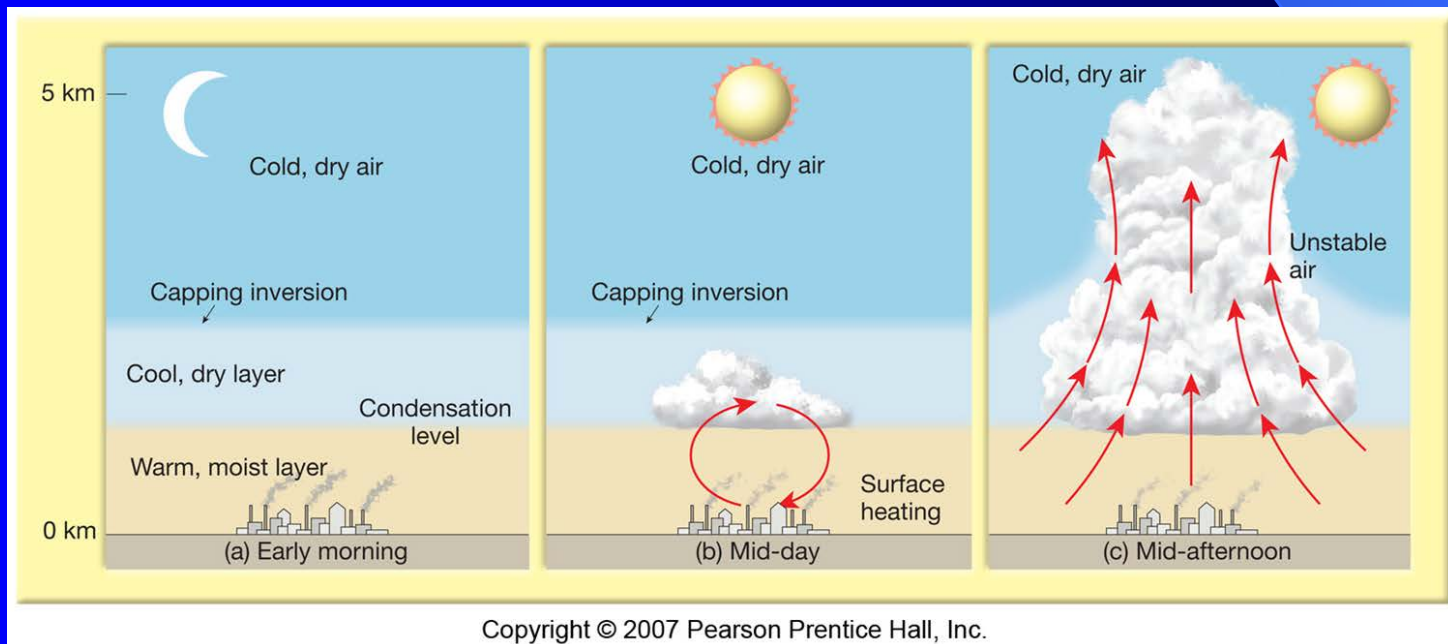


Cluster of supercells



Supercell Thunderstorms

1. Supercell requires a large amount of latent heat to make the lower troposphere warm and moist.
2. A temperature inversion a few km above the surface seems to do this. Warm humid air below the inversion cannot mix with cold dry air above.
3. Surface heating continues to heat the trapped air below the inversion.
4. Eventually the inversion is locally eroded by strong mixing.



Supercell Thunderstorms

1. The trapped air below erupts explosively, producing unusually strong cumulonimbus clouds, with concentrated and persistent updrafts. Thus a supercell is formed. (Rayleigh-Taylor instability)
2. The temperature inversion also seems to encourage the development of a few very large storms, rather than a lot of smaller ones.

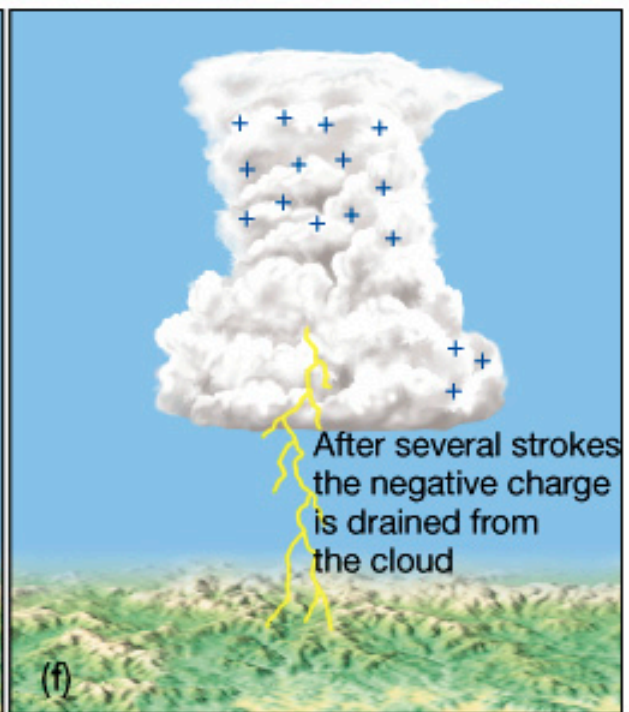
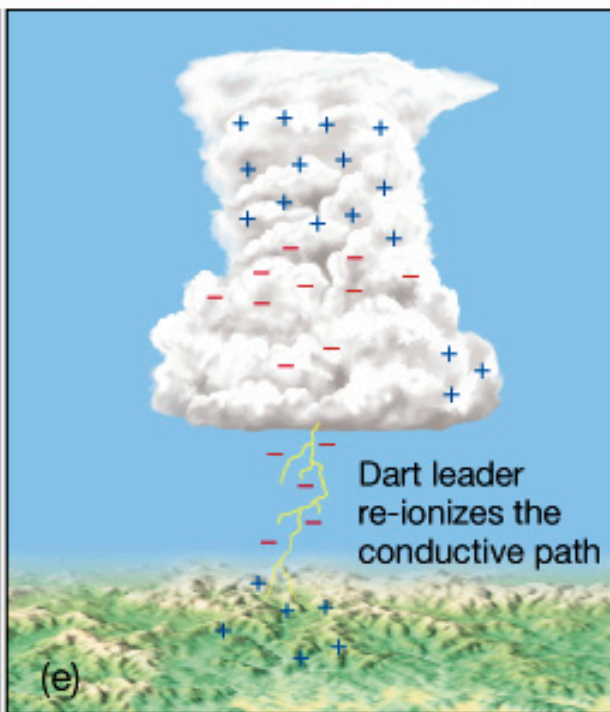
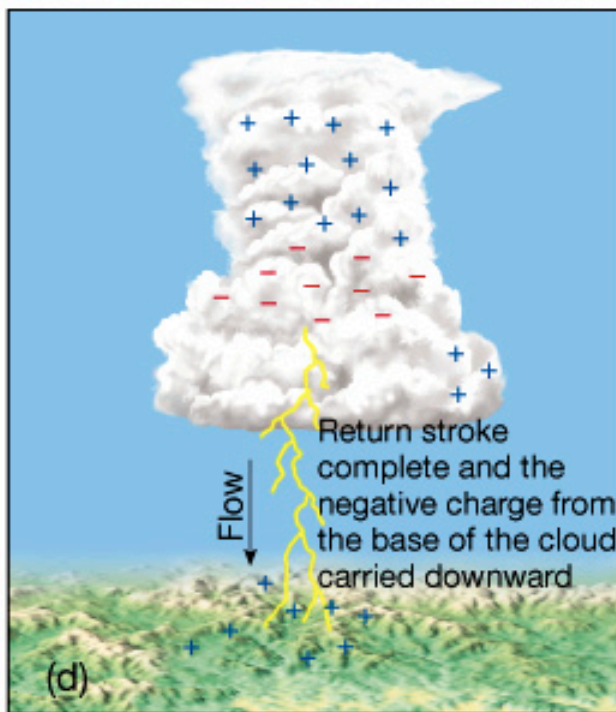
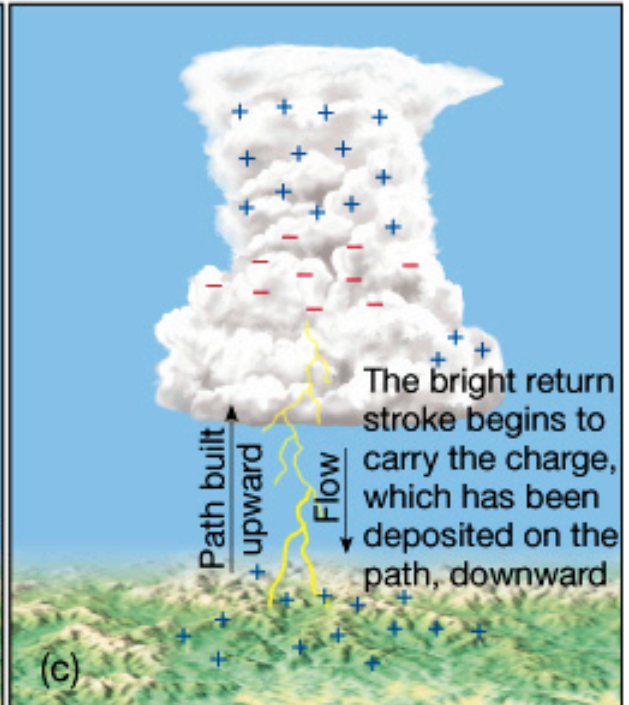
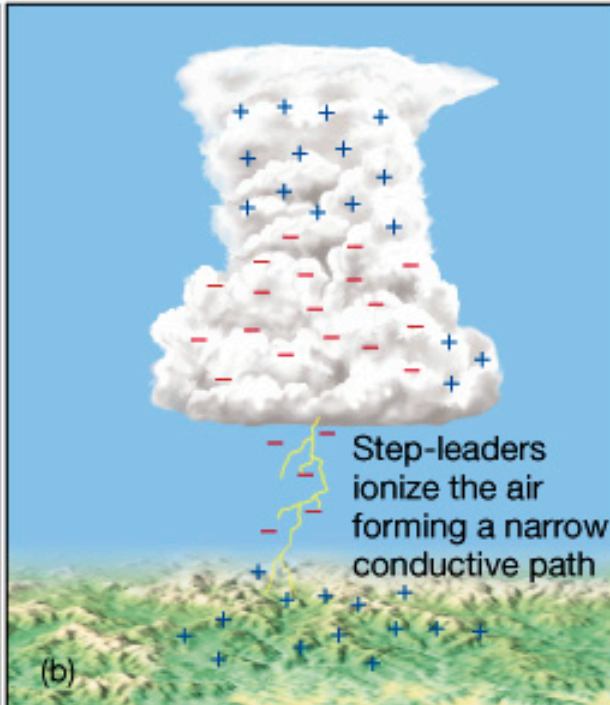
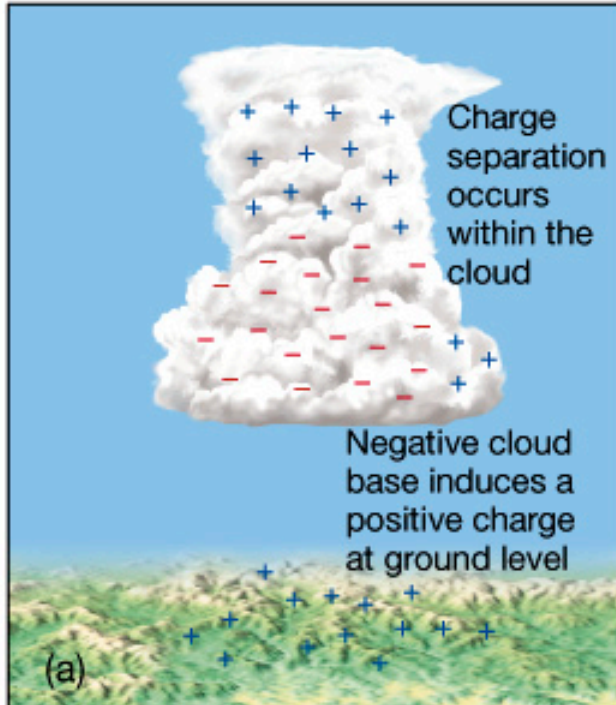
Lightning & Thunder

1. **Lightning** is an electrical discharge through the air, and **thunder** is the result of the explosive heating of air by the discharge.
2. Lightning occurs primarily in the violent mature stage of development of a cumulonimbus cloud. (These clouds are chiefly a summertime phenomenon at midlatitudes, which is why we don't get thunderstorms in winter.)
3. Cloud to cloud most common, cloud to ground most important for us.



Lightning & Thunder

- **Basically:**
- Charge separation occurs in the cloud, with excess electrons at the base
- These electrons repel electrons on the Earth, inducing a positive charge on the Earth's surface.
- If the charges involved are large enough, the potential difference between the cloud and the Earth reaches high enough values that the cloud will discharge, i.e. send some of its excess electrons to the ground.



Lightning & Thunder

1. Discharge emits visible light.
2. Air breaks down (ionizes) when the electric field exceeds 30,000 volts per cm
3. **Thunder** is the sound caused by explosive heating of the air by the lightning. Sudden expansion initiates sound waves that we hear as thunder. A **thunderstorm** is a storm that produces thunder.
4. Thunder always accompanies a lightning discharge. If the lightning is too far away, we don't hear the thunder. Then called **Heat Lightning**. Just ordinary lightning.
5. Light travels almost instantaneously from the lightning to an observer on the ground. The sound of the thunder travels at 330 m/s. Thus you can estimate " **how far away the storm is** " by counting steam engines. Dividing this number by 3 gives the distance to the storm in km. (or divide by 5 to get miles)

Lightning Safety

TABLE 10–A Lightning Casualties in the U.S. by Location or Activity

Rank	Location/Activity	Relative Frequency
1	Open Areas (including sports fields)	45%
2	Going Under Trees to Keep Dry	23%
3	Water Related Activities (swimming, boating, and fishing)	14%
4	Golfing (while in the open)	6%
5	Farm and Construction Vehicles (with open exposed cockpits)	5%
6	Corded Telephone (#1 indoor source of lightning casualties)	4%
7	Golfing (while mistakenly seeking “shelter” under trees)	2%
8	Using Radios and Radio Equipment	1%

Source: National Weather Service

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Do not be the highest thing around!

Tornadoes



Tornadoes

1. **Tornadoes are** violent windstorms that take the form of a rotating column of air (vortex) that extends downwards from a cumulonimbus cloud.
2. They form in association with strong thunderstorms that often produce hail.
3. Strong tornadoes often form near the hail boundary.
4. Fewer than 1% of thunderstorms produce tornadoes.



(a)

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(b)

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Tornadoes

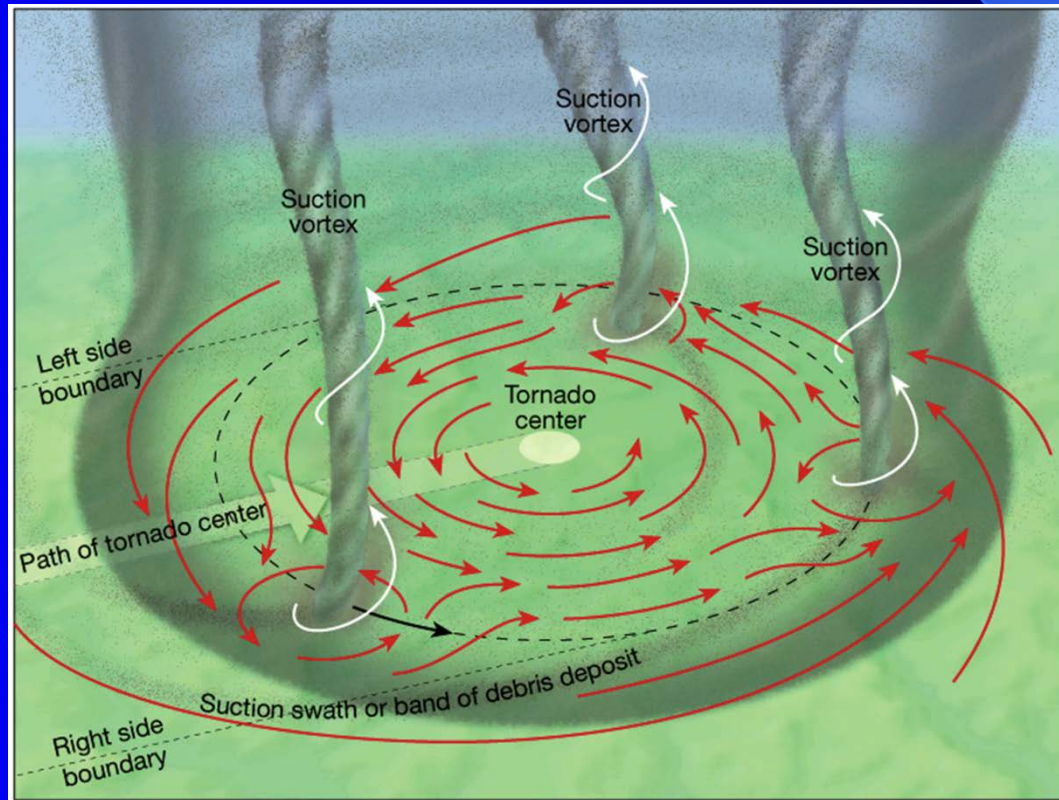
1. Air pressure within a tornado can be up to 10% lower than outside.
2. Surrounding air rushes into the vortex.
3. As the air streams inwards, it spirals upward around the core until it merges with the airflow of the parent thunderstorm.
4. The air is cooled adiabatically. If it cools below the dewpoint, the resulting condensation is visible. If the air is too dry, the vortex may be marked only by the dust and debris that it carries.



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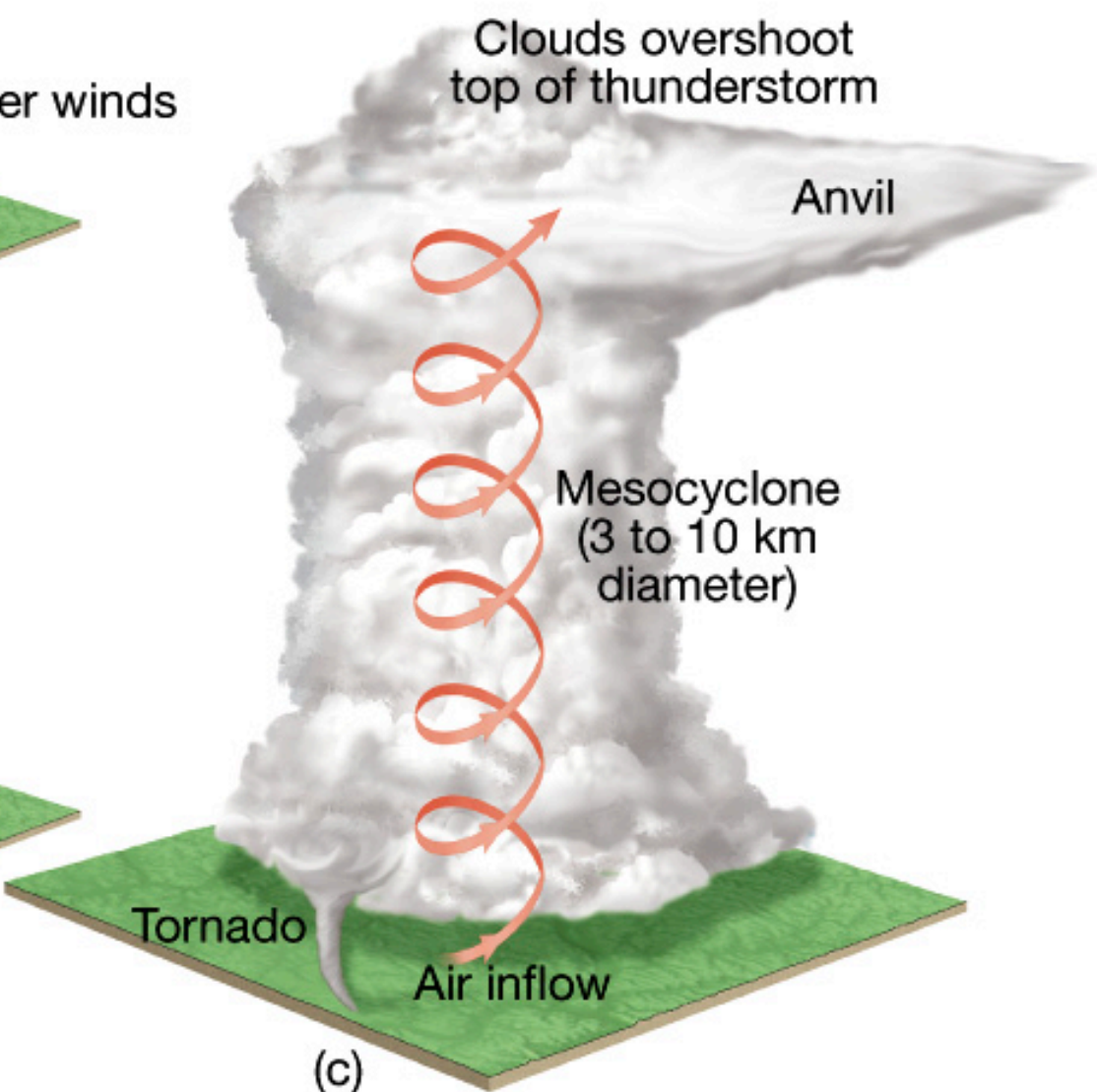
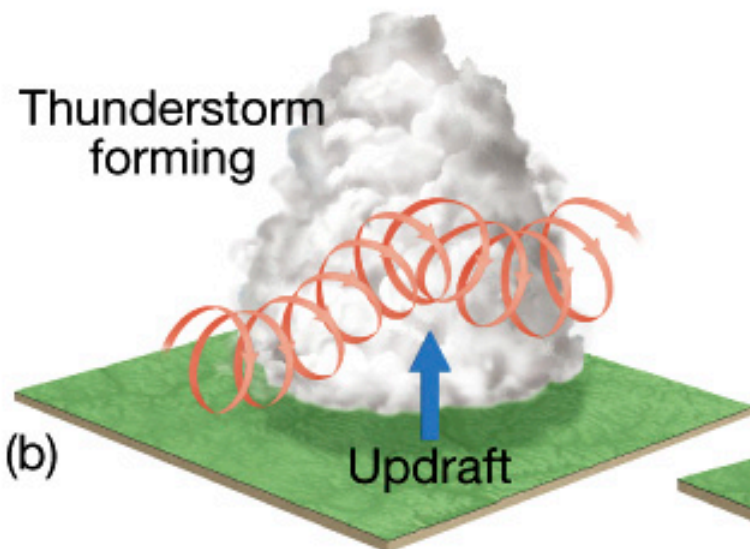
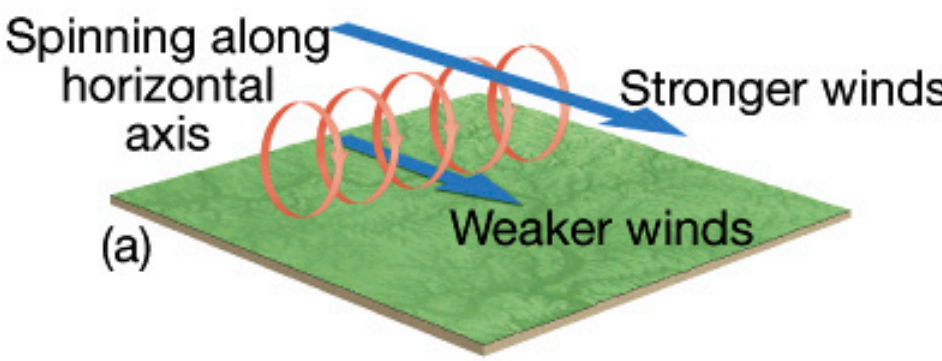
Tornadoes

1. Some tornadoes have multiple small **suction vortices** that are about 10 m across and have winds speed of up to 480 km/hour. These are what cause major but isolated damage.
2. The main tornado and the suction vortices all rotate counter clockwise, and the suction vortices move counter clockwise with the main air flow.
3. Difficult to gather *in situ* data from tornadoes.



Tornado Development

1. Tornadoes can form in any situation that produce severe weather - cold front, squall lines, tropical cyclones (hurricanes).
2. Formation of a tornado requires the existence of a **mesocyclone**, which is a vertical cylinder of rotating air about 3 to 10 km across that occurs in the updraft of a severe thunderstorm
3. **Mesocyclone formation** depends on the presence of a vertical wind shear, with strong winds aloft and weak winds near the surface.
4. Wind shear produces rotation of air about a horizontal axis.
5. Strong updrafts can sometimes tilt the horizontally rotating air to the vertical direction.
6. As the mesocyclone develops, it becomes taller and narrower. Because of the latter, strong winds develop (conservation of angular momentum).



Tornado Development

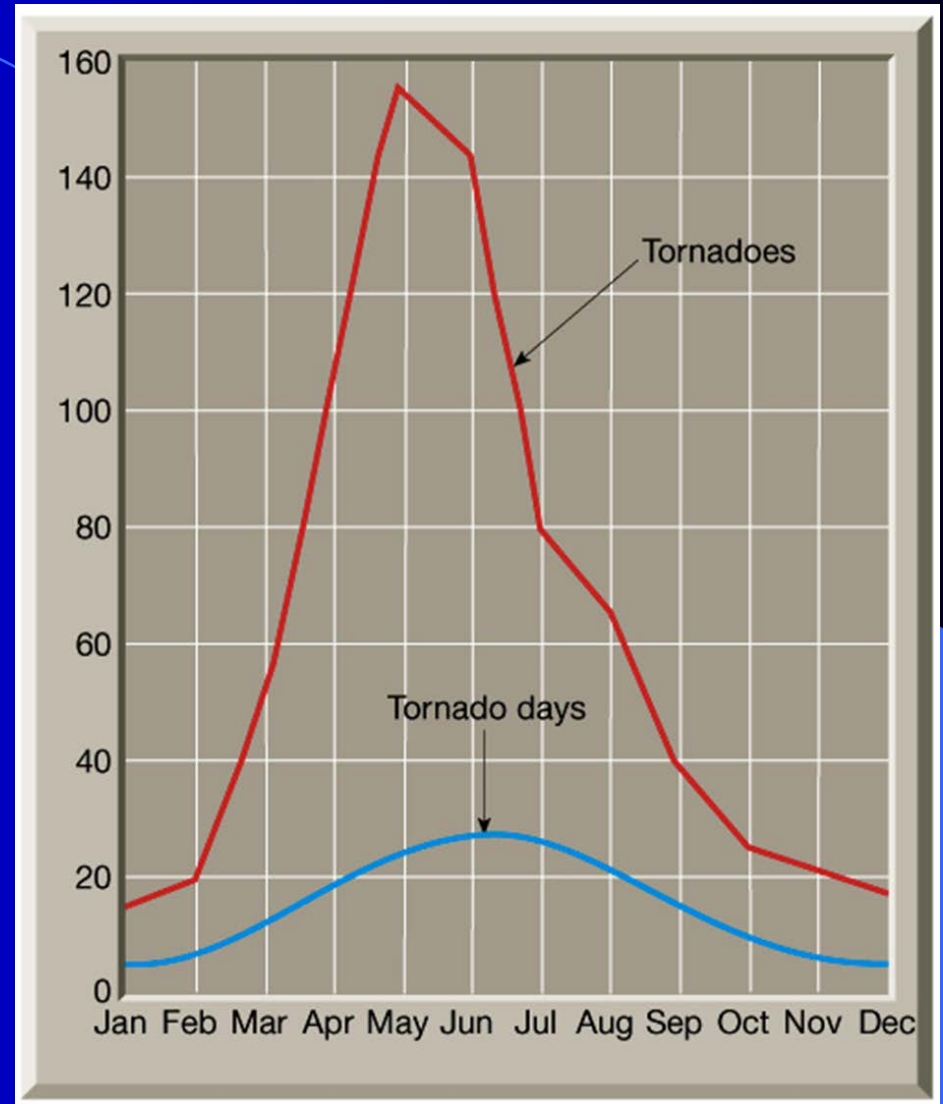
1. Narrowing column of rotating air stretches downwards, until a dark slowly rotating portion protrudes below the cloud base. Called a **wall cloud**.
2. Then a slender and rapidly spinning vortex emerges from the base of the wall cloud, to form the **funnel cloud**.
3. If the funnel cloud makes contact with the ground, it is classified as a tornado.



(d)

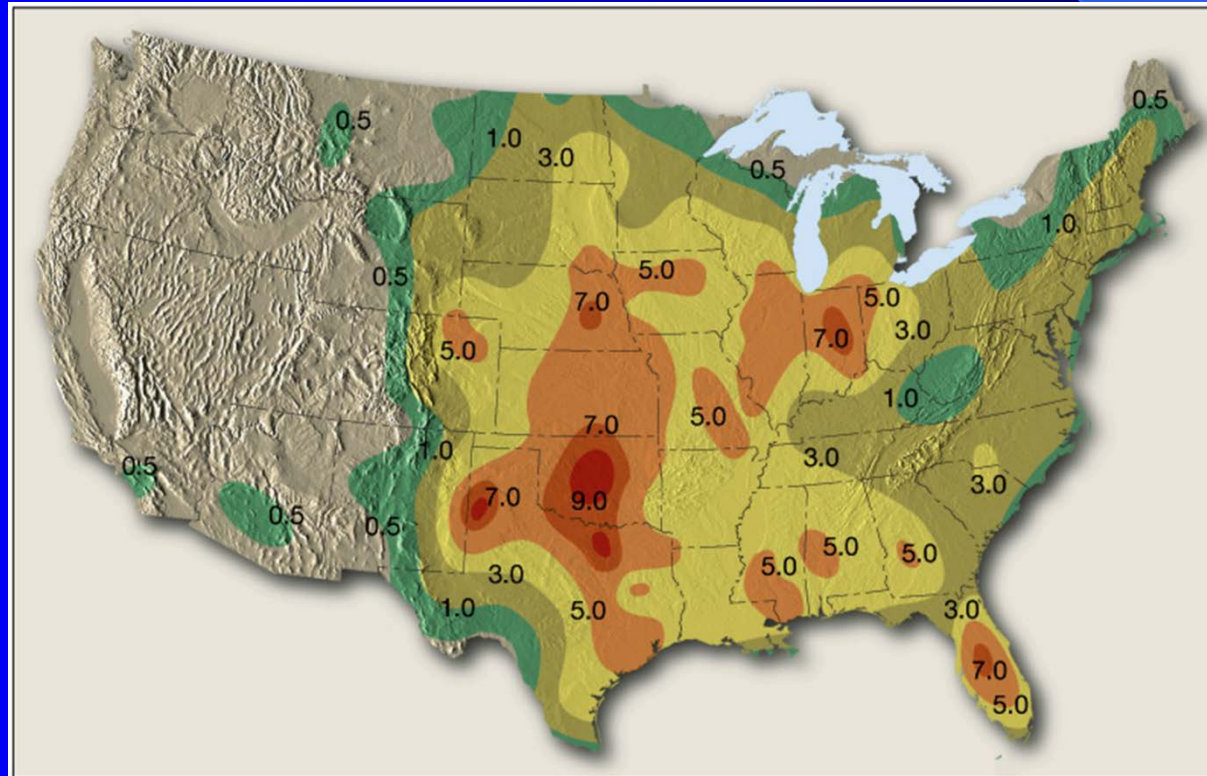
Tornado Climatology

1. Severe thunderstorms, and thus tornadoes, are often spawned along the cold front or squall line of a midlatitude cyclone, or in association with supercell thunderstorms.
2. Need contrasting air masses (cP or cA from the north meeting mT from the Gulf of Mexico). These are most likely to meet in the central US, where there are no mountains.
3. Highest occurrence rate is April - June.



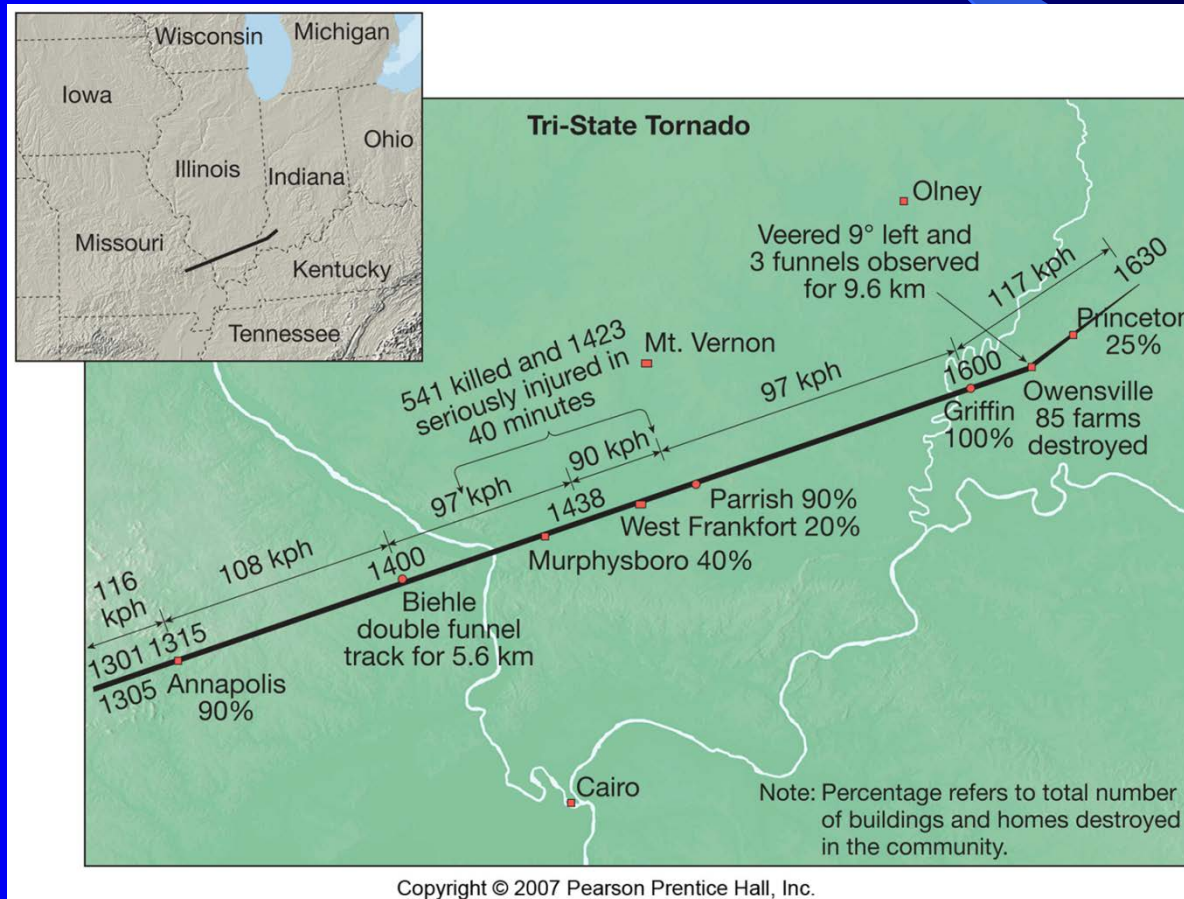
Tornado Climatology

1. The center of maximum occurrence moves across the country through the year. April, S.E. Atlantic; May-June, southern great plains, then to northern plains and Great Lakes region.
2. Drift is caused by increasing northward penetration of warm Gulf air.
3. Maximum annual occurrence rate is for Oklahoma.



Tornado Climatology

1. Average tornado has a diameter between 150 and 600 m, ground speed of 45 km/hr., and cuts a path about 26 km long.
2. Large tornadoes last longer than small ones, and have higher wind speeds.



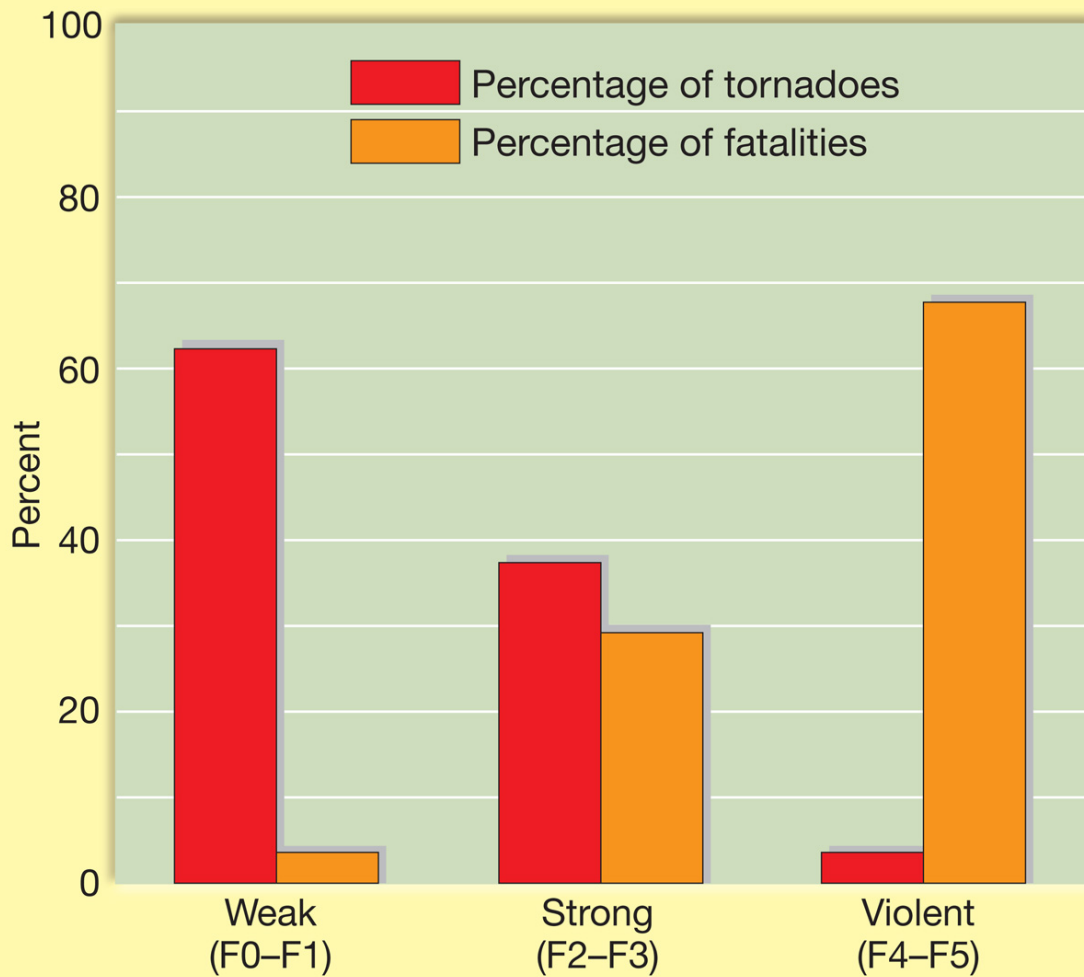
Fujita Intensity Scale

1. Most tornado damage is caused by high winds. These cannot be measured, so the damage caused is taken as a proxy. (People are injured or killed by flying debris.)
2. Fujita scale starts at F0 and goes to F5. F5 causes "incredible" damage.
3. Violent tornadoes (Fujita 4 and 5) include only about 2% of total.
4. Drop in air pressure not important - most buildings are not airtight.

TABLE 10-2 Enhanced Fujita Intensity Scale*

Scale	Wind Speed		Damage
	Km/Hr	Mi/Hr	
EF-0	105–137	65–85	<i>Light.</i> Some damage to siding and shingles
EF-1	138–177	86–110	<i>Moderate.</i> Considerable roof damage. Winds can uproot trees and overturn single-wide mobile homes. Flagpoles bend.
EF-2	178–217	111–135	<i>Considerable.</i> Most single-wide homes destroyed. Permanent homes can shift off foundations. Flagpoles collapse. Softwood trees debarked.
EF-3	218–265	136–165	<i>Severe.</i> Hardwood trees debarked. All but small portions of houses destroyed.
EF-4	266–322	166–200	<i>Devastating.</i> Complete destruction of well-built residences, large sections of school buildings.
EF-5	>322	>200	<i>Incredible.</i> Significant structural deformation of mid- and high-rise buildings.

*The original Fujita scale was developed by T. Theodore Fujita in 1971 and put into use in 1973. The Enhanced Fujita Scale is a revision that was put into use in February 2007. Winds speeds are estimates (not measurements) based on damage, and represent 3-second gusts at the point of damage. More information about the criteria used to evaluate tornado intensity can be found at <http://www.spc.noaa.gov/efscale/> and at <http://www.spc.noaa.gov/faq/tornado/ef-scale.html>.



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