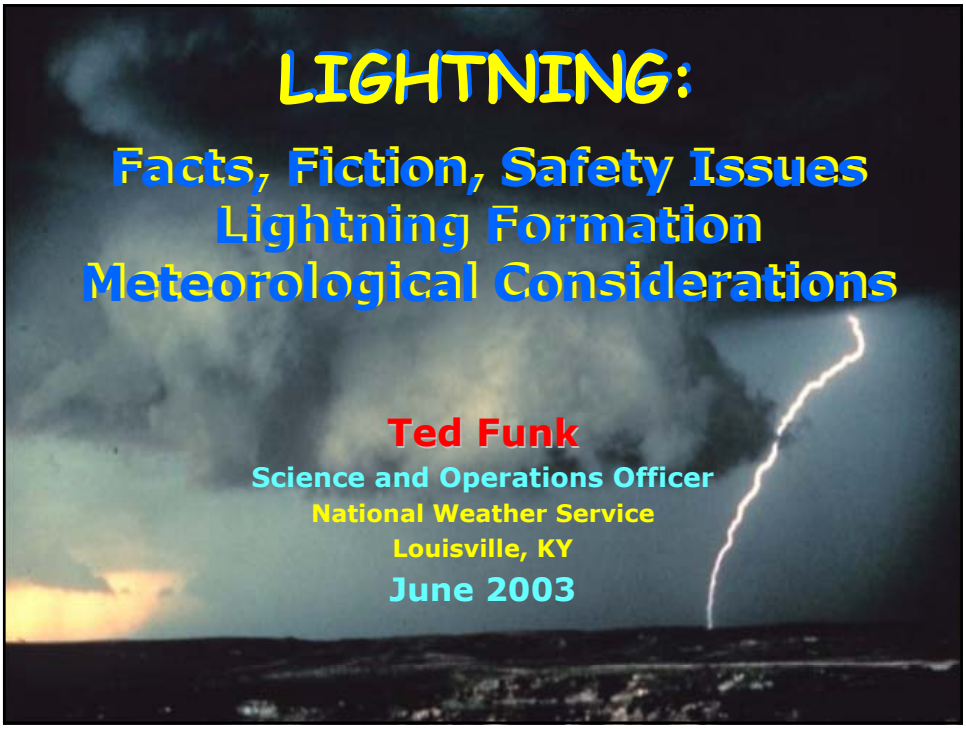
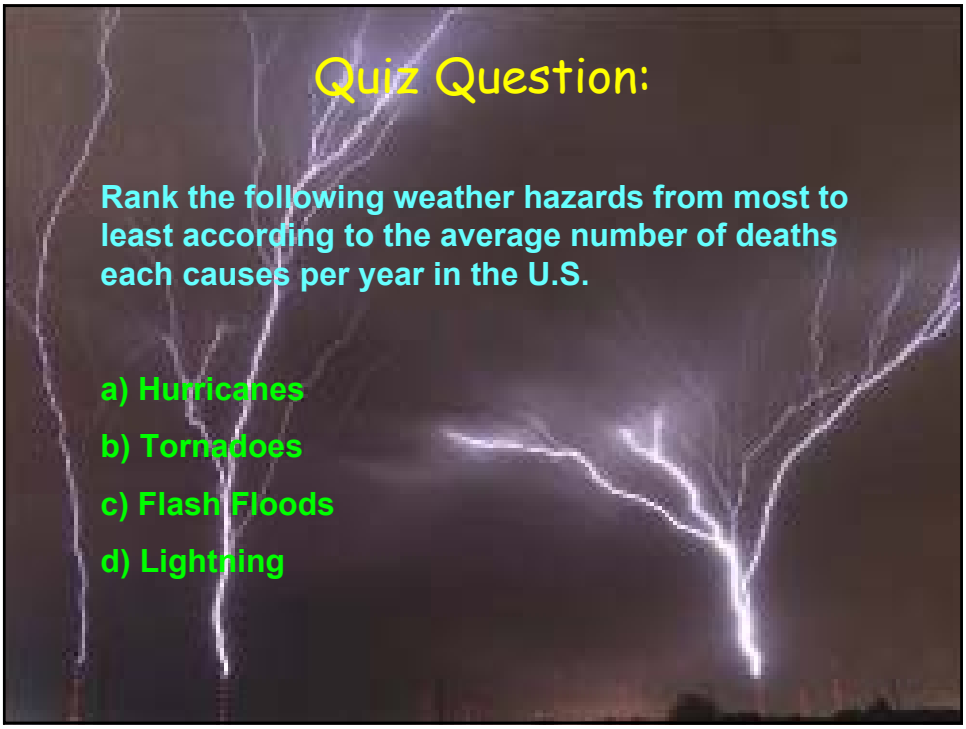
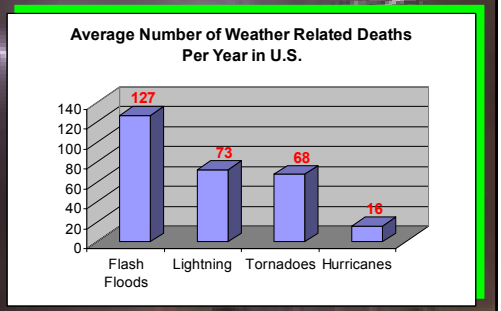

LIGHTNING:
Facts, Fiction, Safety Issues
Lightning Formation
Meteorological Considerations
Ted Funk
Science and Operations Officer
National Weather Service
Louisville, KY
June 2003


Quiz Question:
Rank the following weather hazards from most to least according to the average number of deaths each causes per year in the U.S.
a) Hurricanes
b) Tornadoes
c) Flash Floods
d) Lightning

Answer:

Rank the following weather hazards from most to least according to the average number of documented deaths each causes per year in the U.S.

1) Flash Floods: 127
2) Lightning: 73
3) Tornadoes: 68
4) Hurricanes: 16

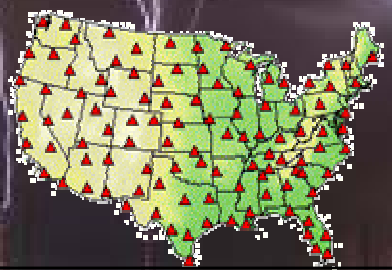


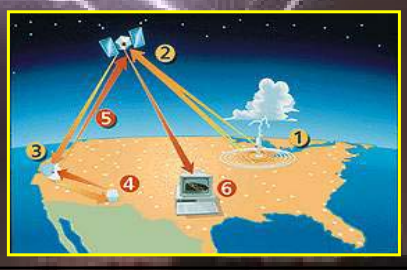
National Lightning Detection Network (NLDN)

The NLDN was started by University of Arizona scientists; it monitors millions of cloud-to-ground (CG) lightning strikes every year across the lower 48 states. The network operates 24 hours day, 365 days a year.

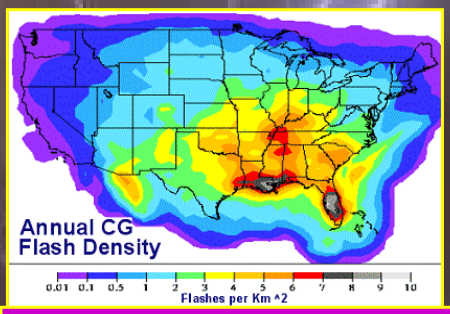
NLDN consists of over 100 remote, ground-based sensing stations located across the U.S. that instantaneously detect the electromagnetic signals given off when lightning strikes the earth's surface.

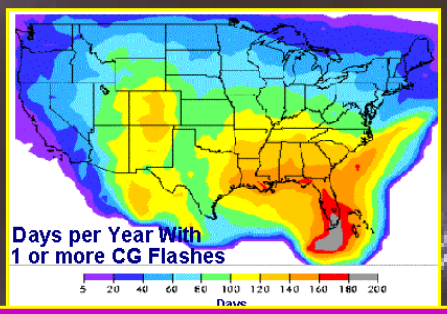
These sensors send data via satellite to the Network Control Center operated by Global Atmospherics, Inc. in Arizona. The data is processed to determine the location, time, polarity, and amplitude of each strike. This information then is communicated to users across the country.



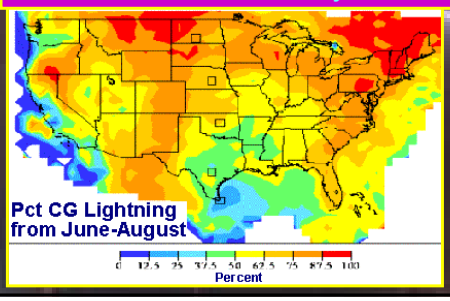


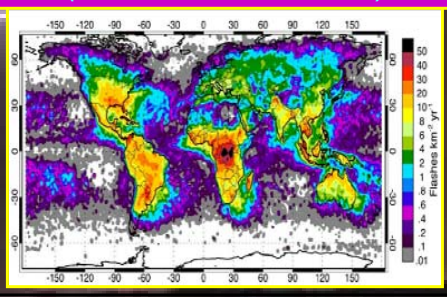
Lightning Climatology





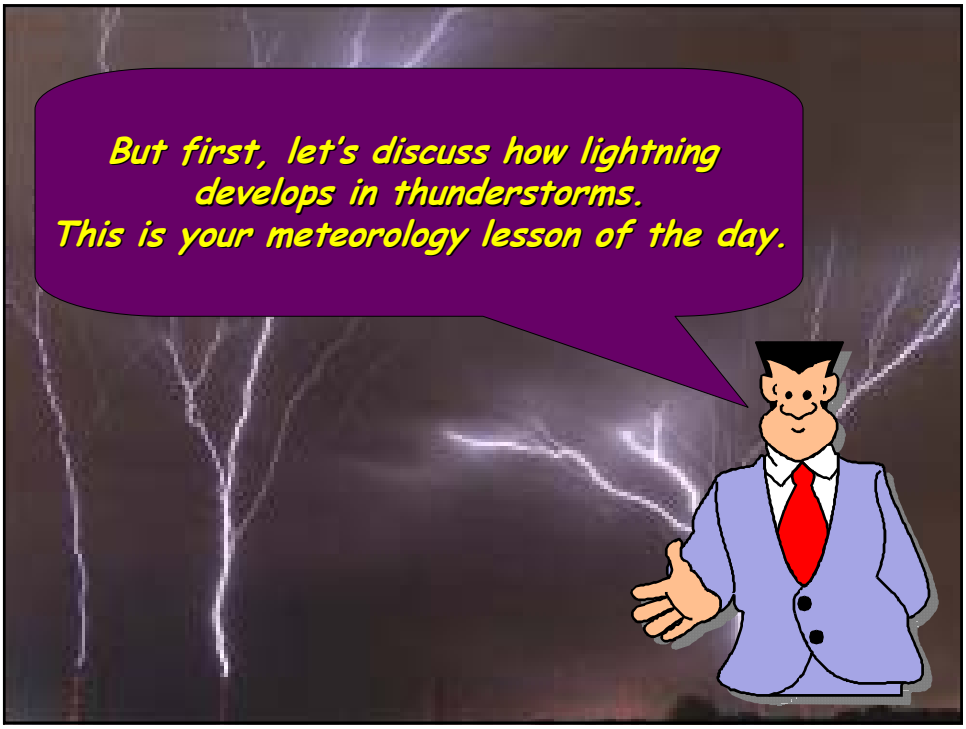
Every year there are an estimated 25 million cloud-to-ground (CG) lightning flashes in the United States and many more flashes aloft (cloud-to-cloud and intracloud)





Thoughts to Ponder

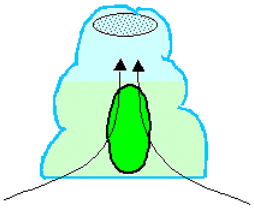
- Lighting kills on average 73 people per year in the U.S. and injures hundreds more. This is just documented cases; totals likely are higher given unreported or undocumented events
- Lighting deaths do not receive as much attention in the media as larger weather hazards such as tornadoes and hurricanes
- We have action plans for tornadoes and hurricanes (in areas affected), but likely don't for lightning, yet lightning kills more people per year on average than either of these other phenomenon
- Do we understand the dangers of lightning?
- Do we understand when lightning becomes a danger?



Isolated Storms: Charge Development and Distribution

Low CLWC
High CLWC
Low SC-CLWC
High SC-CLWC
Small ice only
Large & small ice

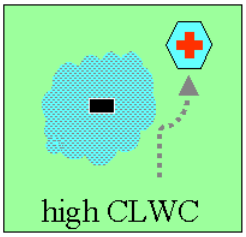
Developing Cu Stage



1. No graupel,
no electrification

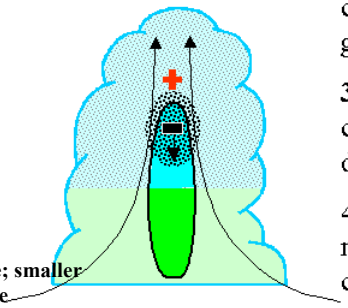
Isolated Storms: Charge Development and Distribution

Low CLWC
High CLWC
Low SC-CLWC
High SC-CLWC
Small ice only
Large & small ice



Tcu Stage

Graupel develops due to riming as supercooled water droplets contact and freeze on ice crystals between -10 and -20 C to form soft ice.



Larger graupel has (-) charge; smaller crystals above have (+) charge

1. Electrification begins at mid-levels with the development of graupel

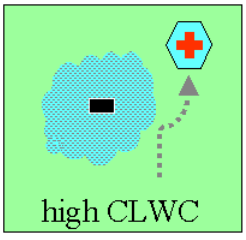
2. Electrification results from millions of collisions between graupel and ice crystals

3. A small amount of charge is transferred during each collision

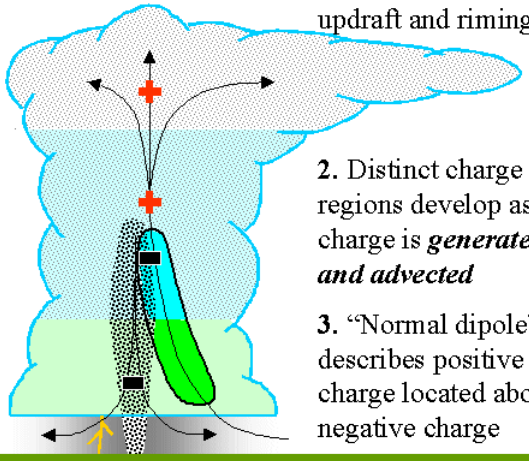
4. Graupel charges negative, ice crystals charge positive

Isolated Storms: Charge Development and Distribution

Low CLWC
High CLWC
Low SC-CLWC
High SC-CLWC
Small ice only
Large & small ice



Mature Stage

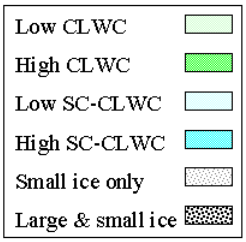


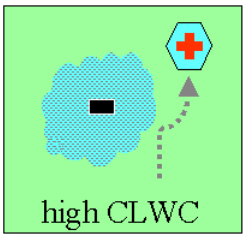
1. Electrification continues with the maintenance of strong updraft and riming

2. Distinct charge regions develop as charge is ***generated and advected***

3. "Normal dipole" describes positive charge located above negative charge

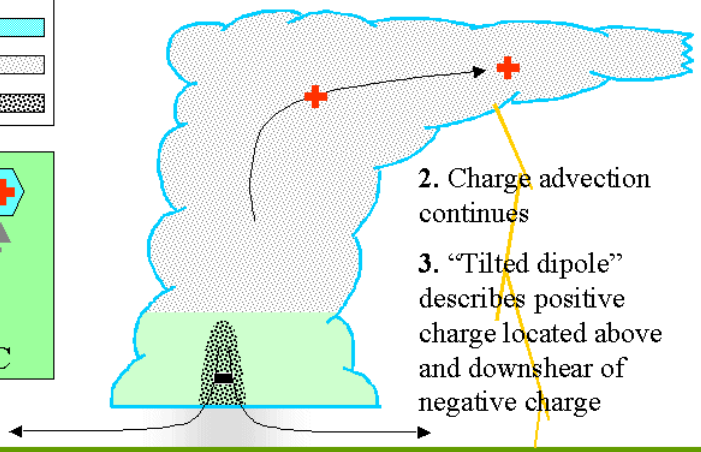
Isolated Storms: Charge Development and Distribution





Dissipation Stage

1. Charge generation ceases with weakening of updraft (no riming)



2. Charge advection continues

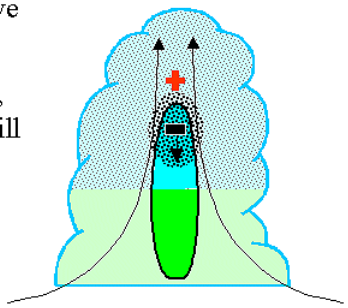
3. "Tilted dipole" describes positive charge located above and downshear of negative charge

Induction of Charge at the Earth's Surface

1. Positive charge is induced at the surface beneath the cloud as normal dipole develops

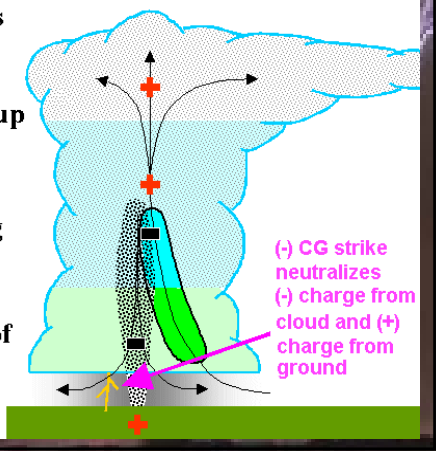
2. Upper positive charge is "shielded" from the surface by the negative charge below

3. If the cloud moves, the induced charge will follow like a shadow



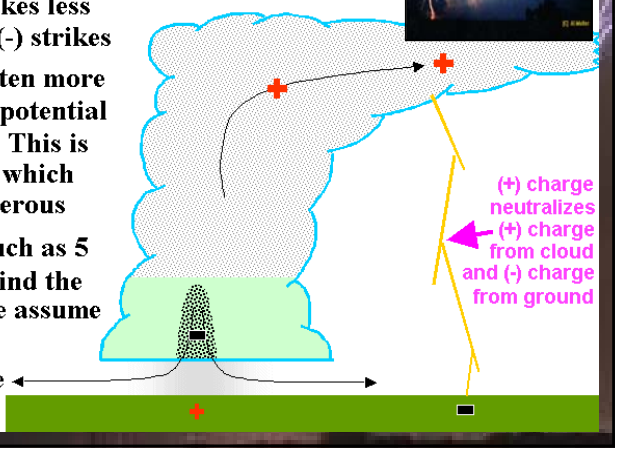
Induction of Charge at the Earth's Surface

1. As graupel descends, more positive charge is induced at surface
2. Electrical potential between cloud and surface builds as graupel descends
3. Channels of negatively-ionized air form in cloud and step toward surface (called stepped leaders)
4. This causes positively charged particles on surface to rise up tall objects (trees, houses, telephone poles) as channels of positively-ionized air begins to extend up toward cloud
5. When difference in electrical potential becomes too great, discharge (lightning strike) occurs; can be several ground return strokes (flickering lightning)
6. Frequency of (-) CGs depends on rate of charge generation, amount of riming, updraft strength, and distance between cloud and ground



Induction of Charge at the Earth's Surface

1. Positively charged particles are advected into anvil of storms
2. These particles are shielded less from ground than in storm core (which is dominated by negative charges) but a greater distance exists between anvil and ground
3. Greater distance requires increased potential differential which makes (+) CG strikes less common normally than (-) strikes
4. However, (+) CGs are often more powerful, due to greater potential needed to initiate strike. This is the "bolt from the blue" which can be particularly dangerous
5. (+) CGs can strike as much as 5 or 10 miles ahead or behind the main storm where people assume they are safe
6. (-) CGs rare at this stage in dissipating storm



Utility of Negative and Positive CGs

(-) CGs associated with fallout of graupel and provide *temporal and spatial* info about storm

Spatial:

storm location, motion, morphology, areal coverage

Temporal:

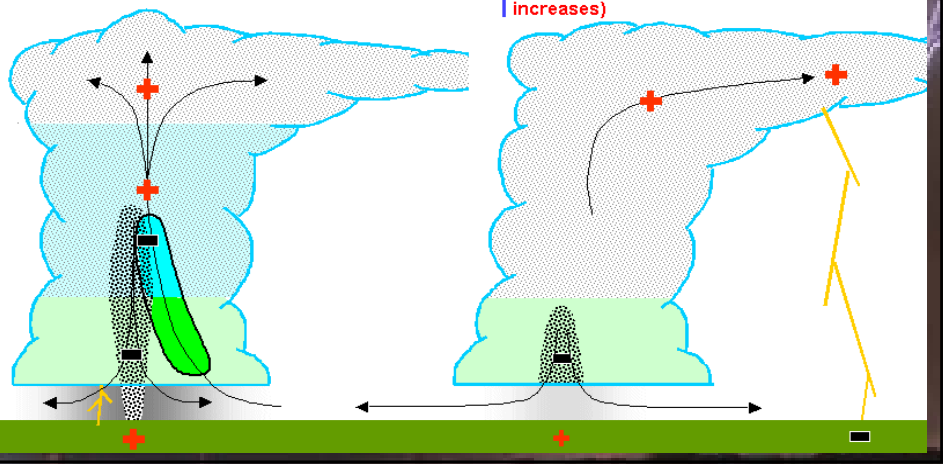
onset, intensification, dissipation, redevelopment

(+) CGs associated with formation of anvil and its exposure to surface

(+) CGs provide info about:

vertical wind shear (+CGs can indicate orientation of anvil)

storm dissipation (percentage of +CGs increases)



What is Thunder?

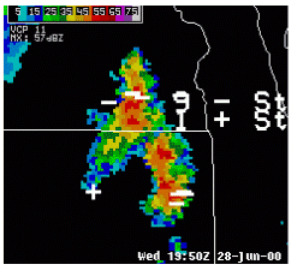
The lightning channel heats extremely rapidly to up to 50,000 degrees. The intense pressure and expansion of the heated air causes a shock wave heard as thunder. For every 5 seconds difference between seeing lightning and hearing thunder, the strike is about 1 mile away.

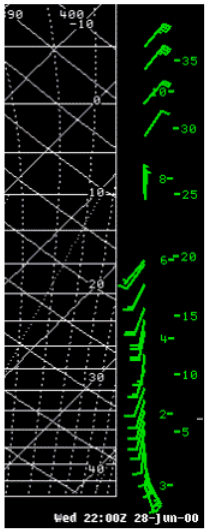
Florida Thunderstorm Case

- Positive CG occurring 10 miles away from storm core is consistent with
  - tilted dipole charge structure with positive charge on ice in anvil
  - vertical wind shear for the layer between steering- and anvil-level

Tilt
3.4°

Height/Temp
9,000' ASL
9° C





MCS Dynamics and Microphysics

- Formation of precipitation is different between convective & stratiform regions
- Convective regions are characterized by
  - -strong vertical motions (~10 m/sec) and high CLWC
  - -ice growth by ***deposition*** (water vapor condenses onto ice nuclei and freezes) ***and riming*** (supercooled droplets contacting and freezing on ice crystals)
- Stratiform regions are characterized by
  - -weak vertical motions (~0.1 m/sec) and low CLWC
  - -***advection of ice*** from convective regions
  - -ice growth by ***deposition and aggregation*** (coming together of ice particles due to different fall speeds, especially near 0 C, i.e., sticky particles)
  - -no graupel (riming occurs but is secondary)

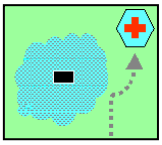
Charge Distributions and CG Lightning in MCSs

Overall charge distribution within MCSs takes into account:

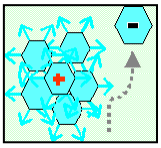
- **-cloud liquid water content**
- **-amount of charge transferred**
- **-particle fall speed**
- **-charge advection**
- **-charge induction at surface**

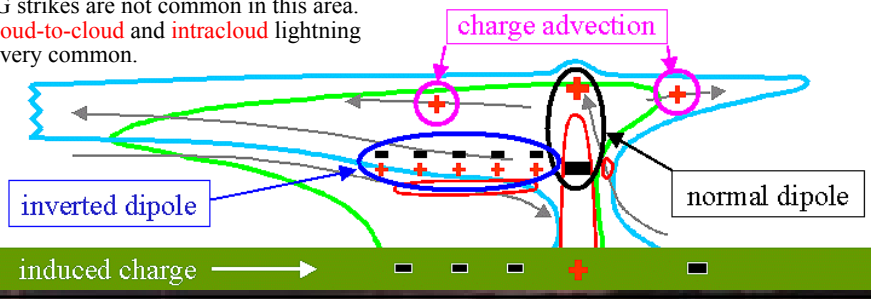
Broad layers of (+) and (-) charge in the stratiform area favor intracloud lightning with long, horizontal channels. This is called spider lightning, which can jump from cloud-to-ground as a (+) strike. But CG strikes are not common in this area. Cloud-to-cloud and intracloud lightning is very common.

In convective regions (high cloud liquid water content), graupel is (-) charged and crystals above are (+) charge (normal dipole)



In stratiform areas (lower cloud liquid water content), aggregates obtain (+) charge and crystals above (-) charge (inverted dipole); less charge is generated and advected





Charge Distributions and CG Lightning in MCSs

Convective region:

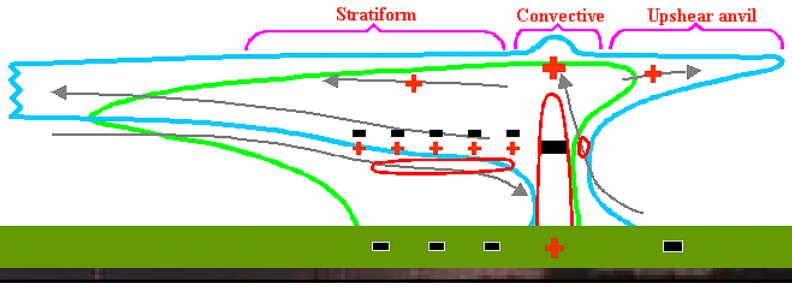
(-) CGs dominate with high flash rate (FR); low FR for (+) CGs; charge generation is high; (-) charge is dense and concentrated on graupel; (+) charge is less dense and dispersed on cloud ice at upper-levels and shielded from surface by (-) charge at mid levels

Stratiform region:

(+) CGs dominate with low FR; very low FR for (-) CGs; charge generation is small; advection of (+) charge is more than (-) charge; (+) charge located closer to surface (inverted dipole); FR is slightly higher in stratiform area than anvil region; spider lightning

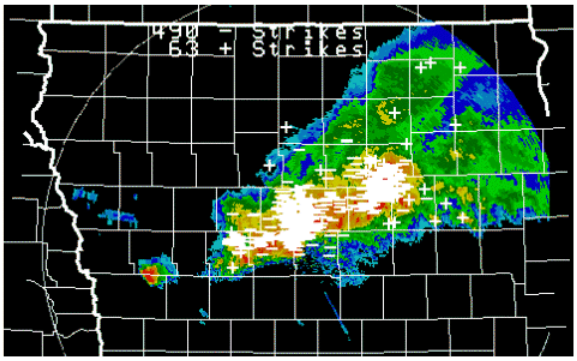
Upshear anvil region:

(+) CGs dominate with low FR; very low FR for (-) CGs; advection of (+) charge is more than (-) charge; charge located at upper-levels



Iowa Thunderstorm Case

- Radar-lightning overlay shows the correspondence between
  - negative CGs and convective precipitation (red-yellow colors)
  - positive CGs and stratiform precipitation (blue-green colors)



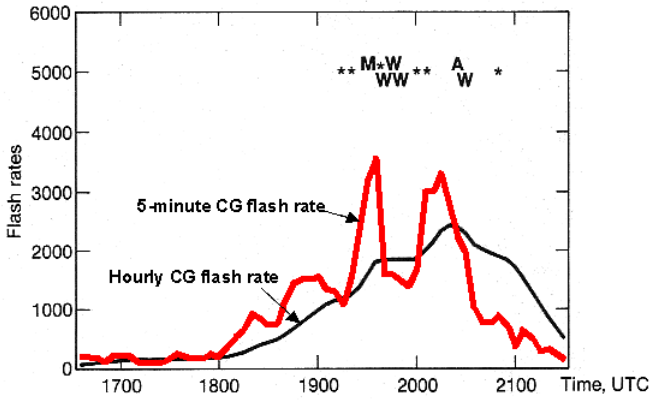
CG Flash Rate Vs. Storm Intensity

- As the updraft strengthens… **Enhanced Charging**
  - liquid water is condensed at a greater rate
  - graupel is produced at a greater rate
  - charge is generated and advected at a greater rate
  - the electrical potential from cloud-to-surface is ***increased***
  - CGs are produced at a ***greater*** rate
- But, as the updraft strengthens, **Elevated Dipole**
  - the normal dipole (graupel/ice level) is displaced higher
  - so cloud-to-ground electrical potential & CG rate are decreased

CG Flash Rate Vs. Severe Weather Reports

central MA on 2 June 1989

M = cell merger W = wind > 60 kt A = large hail > 0.75" * = weaker severe weather



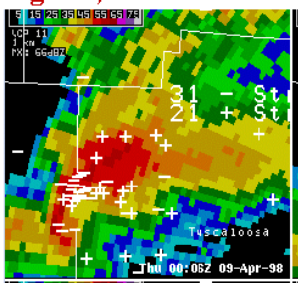
Summary: **Unusually high and variable flash rates associated with NSD storms often are a severe weather signature as enhanced versus elevated charging occurs within the storm. Severe weather is likely near the time of pulses in CG activity. Supercell storms, due to their tilted and intense updrafts, also can have variable flash rates and be PSD during their mature stages. This can be an indicator of large hail and tornadoes.**

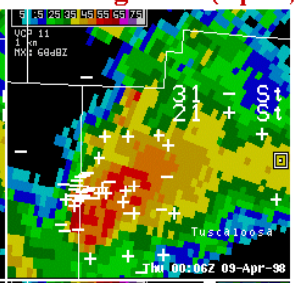
+CG Strikes in Tornadic Supercells

Birmingham, AL with F3 tornado on ground (Apr 9, 1998)

Tilt
0.5°

Height/Temp
4500' ASL
15° C



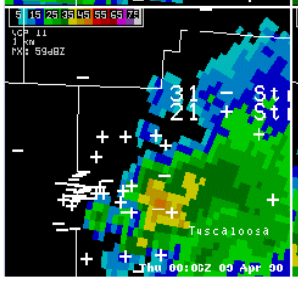


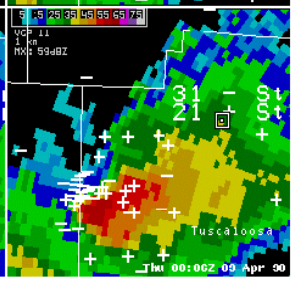
Tilt
2.4°

Height/Temp
13,900' ASL
–1° C

Tilt
7.5°

Height/Temp
39,000' ASL
–53° C



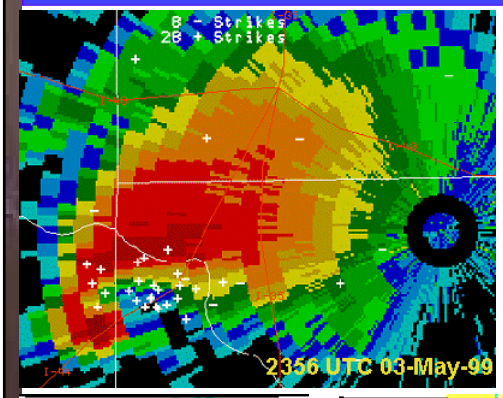


Tilt
4.3°

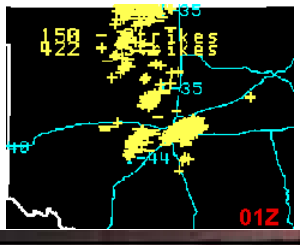
Height/Temp
23,200' ASL
–21° C

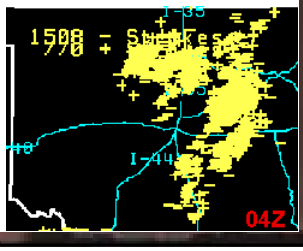
Note high percentage (40 pct) of +CG's (21) to total number (52); indicates a severe, tilted storm. Also note 3 +CG's at bottom of images; these are anvil strikes overtop of low-level weak echo region.

+CG Strikes in Tornadic Supercells

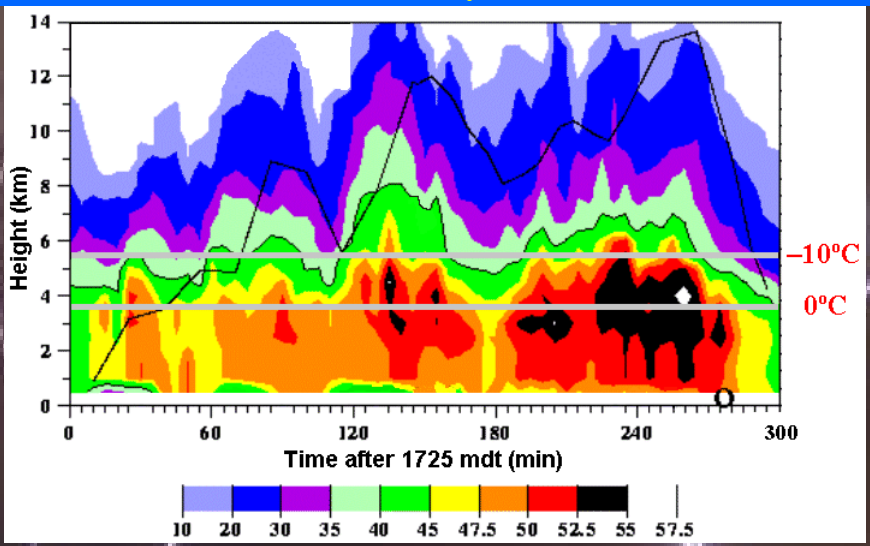


This supercell produced a violent tornado near Oklahoma City on May 3, 1999. Notice that it is PSD with a tornado on the ground. Note also the CG transition from NSD to PSD back to NSD as storms begin to form an MCS.





CG Strikes Vs. Heavy Rain Potential



This time-height cross-section shows a series of thunderstorms passing over same location for a few hours in Colorado. Note that highest reflectivity values are below -10 C. Thus, graupel and subsequent CG strike production would be reduced resulting in storms that are not severe (no elevated reflectivity cores) and producing relatively few CG strikes. However, efficient collision-coalescence in the low-level warm cloud (> 0 C) would result in very heavy rain and possible flooding in this cell training situation.

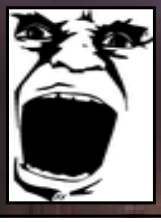
Electrification Quiz

- ***Initial electrification in a cloud begins at what temperature range?***
  - About -10 to -20 C
- ***What two particles are associated with electrification?***
  - Graupel and ice crystals
- ***What charge do these two particles acquire during collisions?***
  - Graupel acquires negative charge; ice crystals acquire positive charge
- ***Describe the normal, tilted, and inverted dipole charge distributions.***
  - Normal dipole: positive charge above negative charge
  - Tilted dipole: positive charge above and downwind from negative charge
  - Inverted dipole: negative charge just above positive charge in stratiform area of MCS leading to horizontal spider lightning
- ***True or False: Strong storms usually are NSD with variable flash rates; very high flash rates and pulses in flash rates can be indicative of severe weather occurrence.***
  - True
- ***CG flash rate depends on what main factors:***
  - Rate of charge separation and advection
  - Density of cloud (how much liquid water, graupel, and crystals are in cloud)
  - Distance between cloud and ground
  - Intensity of the updraft
  - Amount of shielding in cloud

Did You Pass the Quiz???

If so, your meteorology lesson is finally over!!!
Claps and cheers!

If not, you must repeat the meteorology section.
Boos and hisses!



Lightning Facts

-Lightning is up to 50,000° F in temperature, hotter than the surface of the sun
-Lightning is only about 1 inch in diameter
-An average lightning flash has the energy of a 1-kiloton explosion
-Lightning voltage is 300 million volts; lightning current averages 30,000 amps, but ranges from 10,000 to 200,000 amps (as a comparison, a house normally is wired for 200 amps and 120 volts)
-The U.S. has about 25 million cloud-to-ground lightning flashes each year, and up to 70 million lightning flashes aloft (cloud-to-cloud and intracloud)
-Florida is the lightning capital of the U.S.; central Florida is "lightning alley"
-Rwanda (central), Africa is the lightning capital of the world, receiving nearly 2.5 times the amount of lightning in Florida
-The central California coast has the least lightning activity in the U.S.
-Lightning is the #2 weather killer in the U.S., but the #1 weather killer in Florida
-Lightning kills up to 100 people and injures up to 1000 people per year in the U.S.
-Lightning also can have a huge economic impact in the U.S.

Lightning Myths

MYTH: Lightning never strikes the same place twice.
TRUTH: Lightning often strikes the same place, especially if it's a tall isolated object. For example, the Empire State Building is struck multiple times each year.

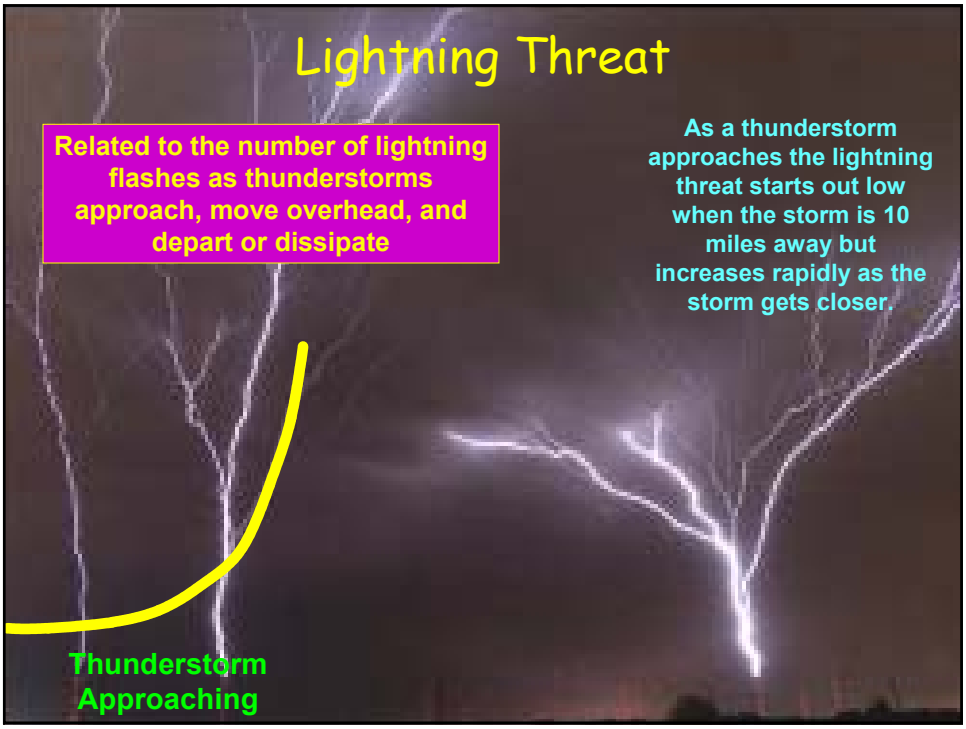
MYTH: If it's not raining (or clouds are not overhead), I'm safe from lightning.
TRUTH: Lightning can strike more than 3 miles from the parent storm, far outside the rain. In fact, anvil lightning and "bolts from the blue," although infrequent, can strike 5-15 miles or even farther from the main storm.

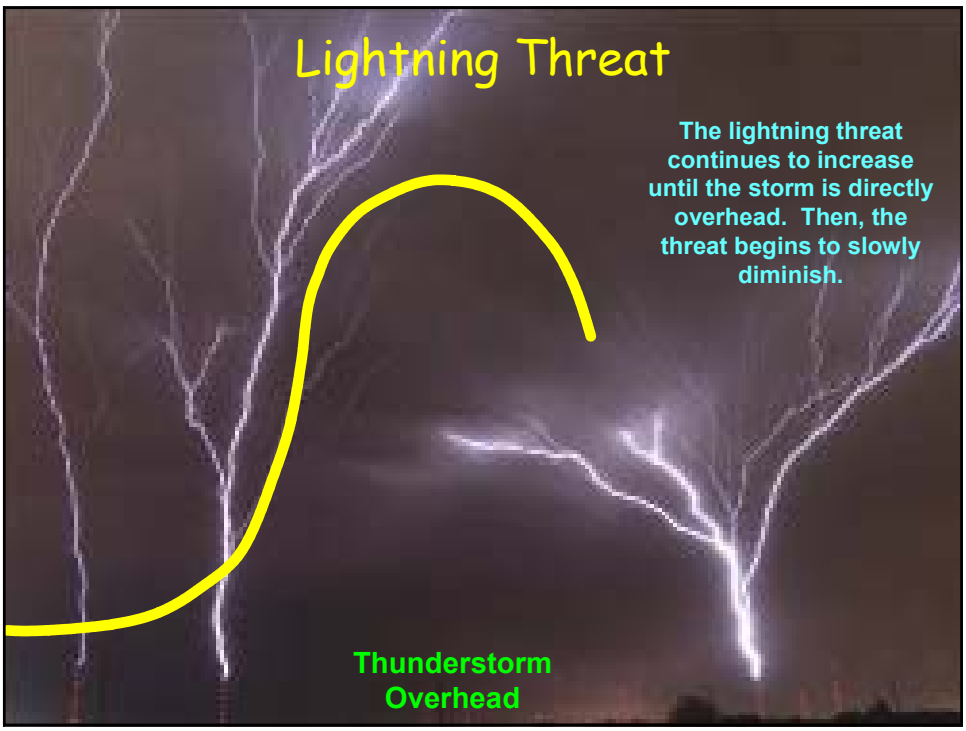
MYTH: Rubber tires protect you from lightning in a car by providing insulation.
TRUTH: Lightning cares not about a little rubber! Most cars are reasonably safe from lightning due to their metal roof and frame which allow the lightning to find a path to the ground around the car. Thus, convertibles, motorcycles, and bicycles offer no lightning protection.

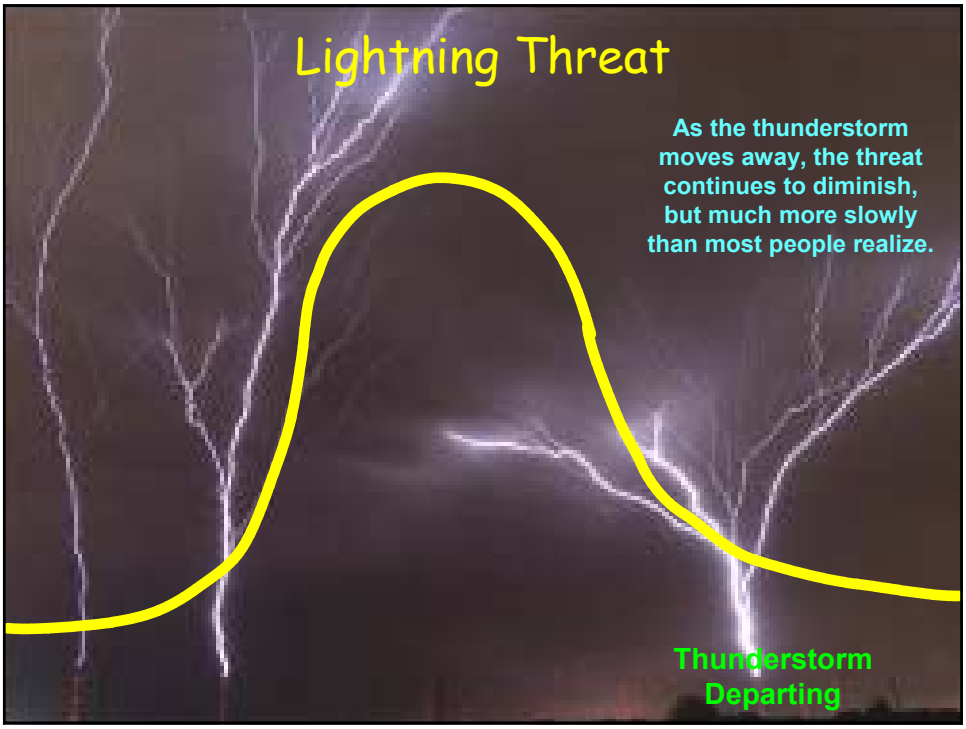
MYTH: A lightning victim is electrified; if you touch them, you might be electrocuted.
TRUTH: The human body does not store electricity. It is perfectly safe to touch a lightning victim to give them first aid and CPR, if necessary. Call 911.

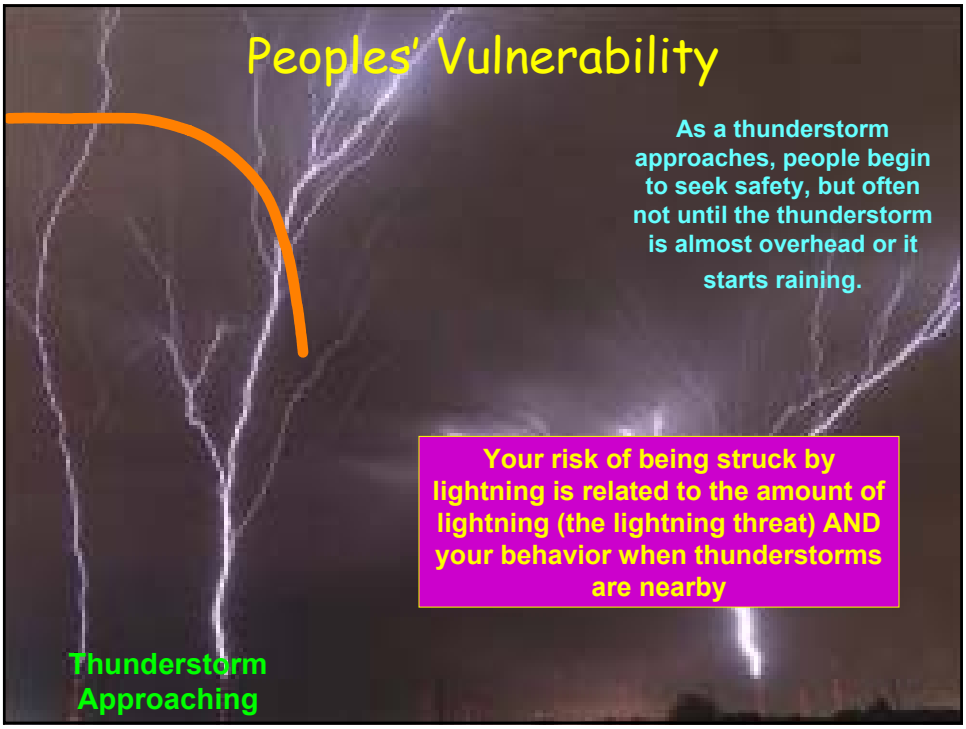
MYTH: If outside in a thunderstorm, go under a tree to stay dry.
TRUTH: Trees, especially tall ones, easily can be struck. Do you want to be under one?

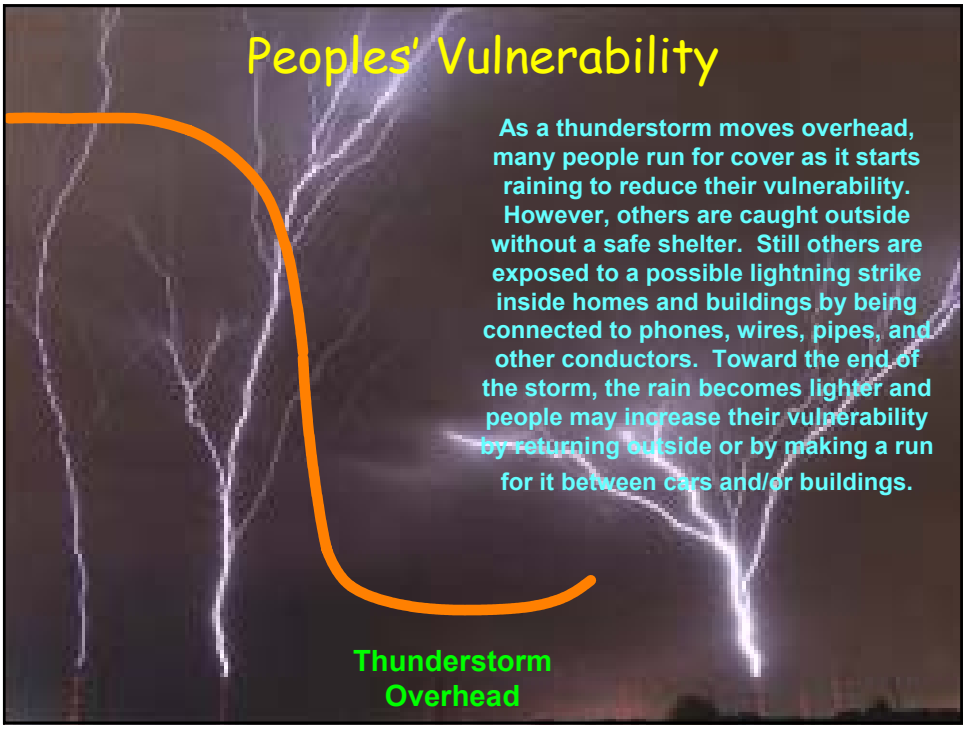
MYTH: Lightning burns people to death instantly, perhaps even charbroils them.
TRUTH: Lightning often leaves some surface burns to the skin, but normally burns do not kill people (cardiac or even respiratory arrest does). Most victims survive, but many of the survivors will experience life-long medical problems.

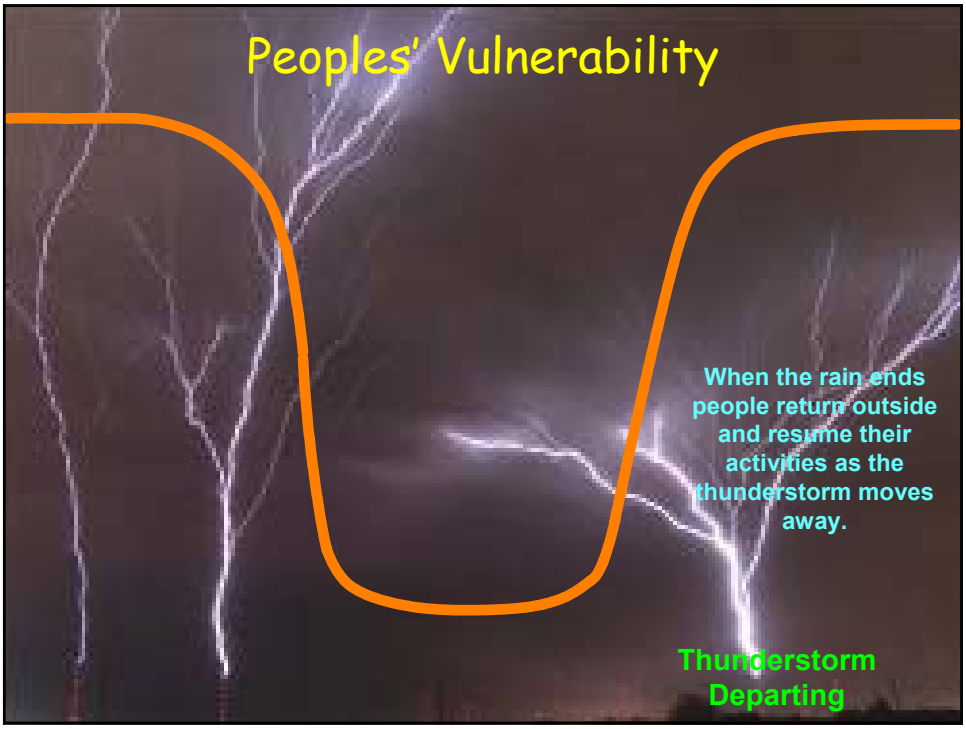

Lightning Threat
Related to the number of lightning flashes as thunderstorms approach, move overhead, and depart or dissipate
As a thunderstorm approaches the lightning threat starts out low when the storm is 10 miles away but increases rapidly as the storm gets closer.
Thunderstorm Approaching

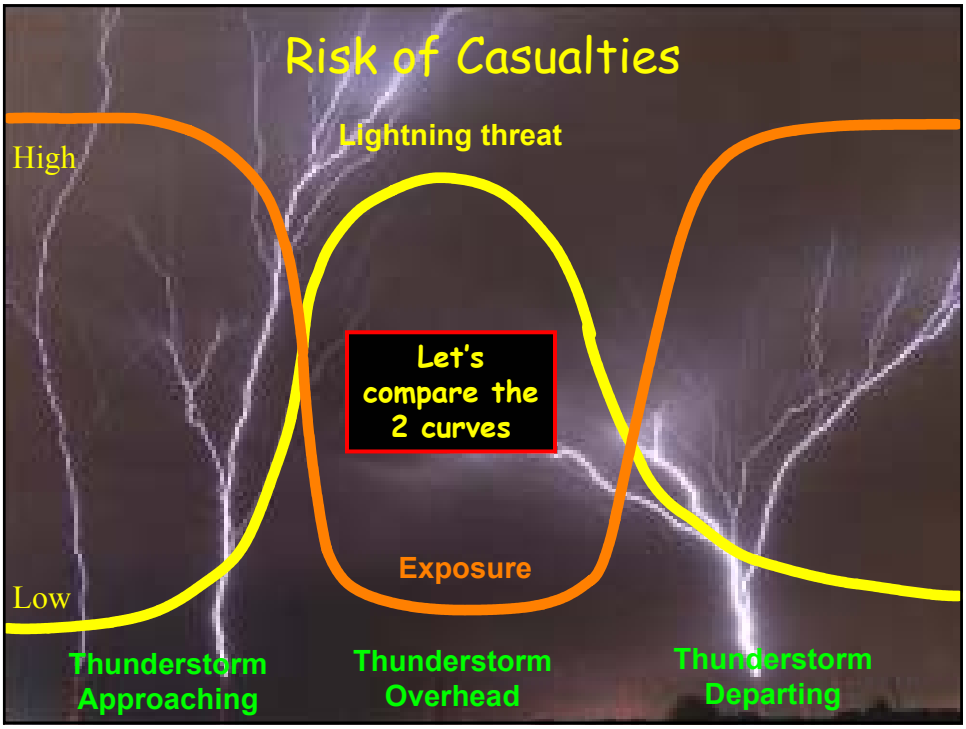

Lightning Threat
The lightning threat continues to increase until the storm is directly overhead. Then, the threat begins to slowly diminish.
Thunderstorm Overhead

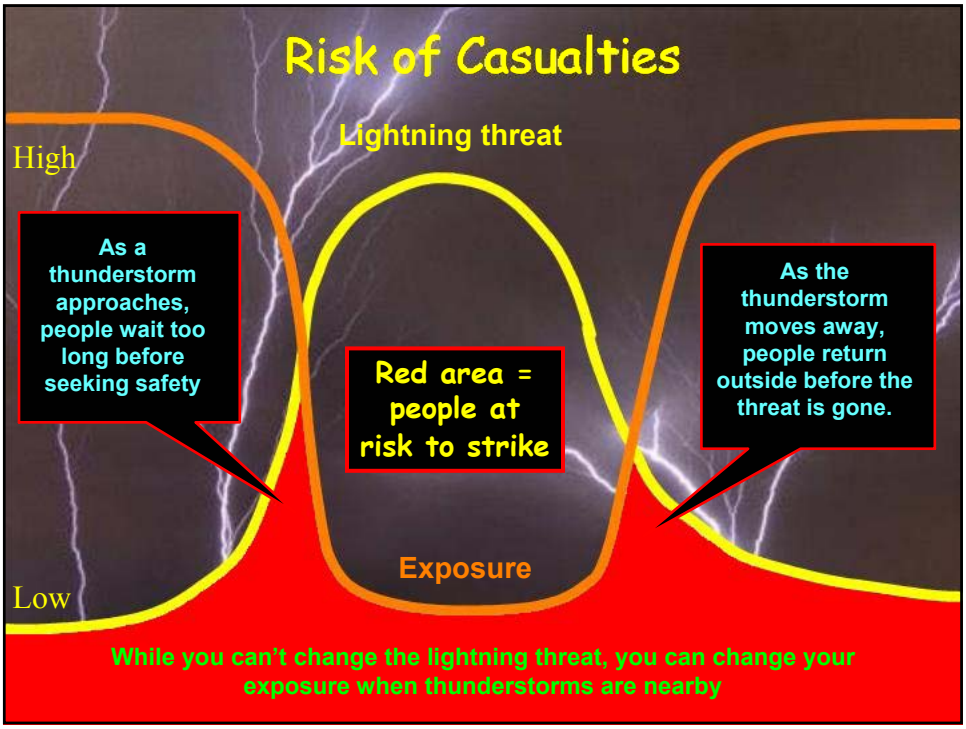

Lightning Threat
As the thunderstorm moves away, the threat continues to diminish, but much more slowly than most people realize.
Thunderstorm Departing


Peoples' Vulnerability
As a thunderstorm approaches, people begin to seek safety, but often not until the thunderstorm is almost overhead or it starts raining.
Your risk of being struck by lightning is related to the amount of lightning (the lightning threat) AND your behavior when thunderstorms are nearby
Thunderstorm Approaching

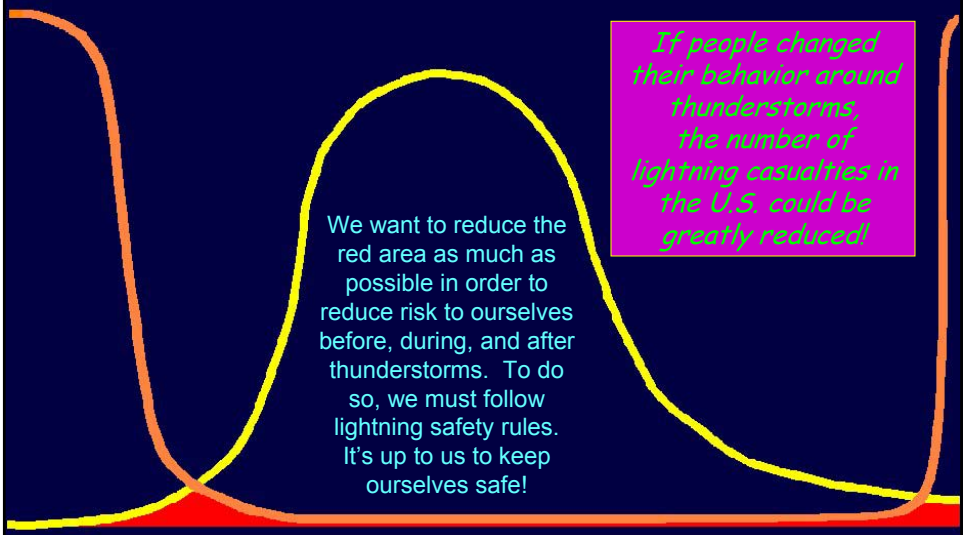

Peoples' Vulnerability
As a thunderstorm moves overhead, many people run for cover as it starts raining to reduce their vulnerability. However, others are caught outside without a safe shelter. Still others are exposed to a possible lightning strike inside homes and buildings by being connected to phones, wires, pipes, and other conductors. Toward the end of the storm, the rain becomes lighter and people may increase their vulnerability by returning outside or by making a run for it between cars and/or buildings.
Thunderstorm Overhead


Peoples' Vulnerability
When the rain ends people return outside and resume their activities as the thunderstorm moves away.
Thunderstorm Departing


Risk of Casualties
Lightning threat
High
Let's compare the 2 curves
Exposure
Low
Thunderstorm Approaching
Thunderstorm Overhead
Thunderstorm Departing


Risk of Casualties
Lightning threat
High
As a thunderstorm approaches, people wait too long before seeking safety
Red area = people at risk to strike
As the thunderstorm moves away, people return outside before the threat is gone.
Exposure
Low
While you can't change the lightning threat, you can change your exposure when thunderstorms are nearby

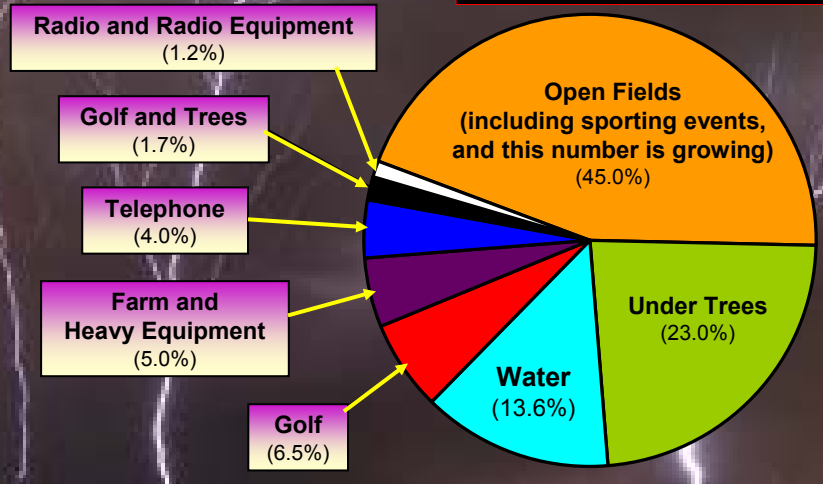
Reducing Casualties



Education and awareness are critical in reducing the number of lightning casualties. A lack of knowledge can lead to very tragic consequences.

Hazardous Activities and Locations During Lightning

The pie chart reveals that about 93% of casualties occur outside, and only 7% inside.



Lightning Casualties In U.S. (1959-1994)

Lightning Victims

Of the hundreds of people struck by lightning each year in the U.S., only about 10 percent are killed (roughly 73 *documented* but likely around 100), leaving around 90 percent with various injuries, degrees of disability, and life-long problems. Many of the deaths are caused by cardiac arrest (heart stoppage) due to the strike.

While many victims survive a lightning strike, their lives and the lives of those around them may be changed forever

U.S. 2000 Census population	280,000,000
Odds of being struck by lightning in a given year (reported deaths & injuries)	1/700,000
Odds of being struck by lightning in a given year (estimated total deaths & injuries)	1/240,000
Odds of being struck in a lifetime (~ 80 yrs)	1/3000
Odds you will be affected by someone being struck (10 people affected for each 1 struck)	1/300

Victims may experience:

Outward appearance:
-confusion, a few have serious burns

Mentally:
-difficulty with mental processes, easily distracted, memory loss, irritability, (i.e., neurological problems)

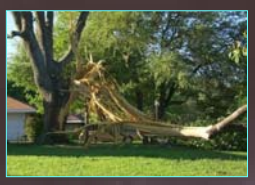
Energy level:
-easily fatigued, difficulty sleeping

Pain:
-headaches, joint pain (both can be very intense)

Lightning Safety

Stay away from power lines, telephone poles, and corded phones.

Get off of open baseball, football, and soccer fields.



Do not stand under or near trees, especially tall, isolated trees

Get out of swimming pools and away from open water.

Stay away from fences with metal poles and other metal objects

Put down golf clubs and take off metal spiked shoes.

Get out of boats and take safety on land.

Lightning Safety Indoors

A house or other substantial building offers the best protection from lightning.

Indoor Safety Tips:

►Avoid contact with corded phones. Phone use is the leading cause of indoor lightning injuries in the U.S. Lightning finds a way from the strike point to the ground. Thus, it can travel long distances in phone and electrical wires inside and outside the house.

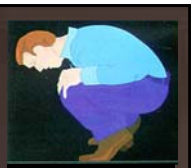
►Protect personal property from a direct or indirect strike. Unplug unnecessary electrical equipment, including computers, TVs, stereos, etc.

►Avoid contact with plumbing, as lightning can travel through it. Do not wash your hands, take a shower, wash dishes, or do the laundry. Water inside the house does not "draw" lightning, but is a good conductor if lightning strikes in or near the home.

►Stay away from windows and doors, and stay off porches to protect from potential direct hits closeby.

►Do not lie on concrete floors or lean against concrete walls, since these may contain wire meshes or metal reinforcing bars, which lightning can travel through.

Lightning Safety Outdoors



Last Resort!

Outdoors is the most dangerous place to be during a lightning storm.

Outdoor Safety Tips:

►Postpone activities promptly. Go quickly inside a completely enclosed building. Suspend sporting events (games/practices) immediately and have everyone go inside a building or car. Avoid sheds, picnic shelters, baseball dugouts, and bleachers.

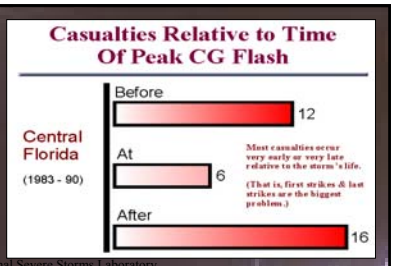
►If no such building is available, get inside a hard-topped all-metal vehicle with the windows up. The vehicle's steel frame provides some protection if you are not touching metal.

►If no shelter or vehicle is available, be the lowest point on the ground as lightning often hits the tallest object. Crouch down on the balls of your feet. Do not lie flat.

►Get out of the water, which is a great conductor of electricity. Stay off the beach and out of boats and canoes. If caught in a boat, crouch down in the center away from metal hardware. Lightning can strike the water and travel some distance beneath and away from its point of contact. Avoid puddles of water.

►Avoid metal! Don't lean against vehicles. Get off bicycles and motorcycles. Stay away from clothes lines, fences, exposed sheds, and electrically conductive objects. Don't hold metal items such as golf clubs or tools. Take off metal spiked shoes.

The 30-30 Rule of Lightning Safety



National Severe Storms Laboratory

Use the "**30-30 Rule**" to know when to seek shelter as a storm approaches and after it departs:

When you see lightning, count the time until you hear thunder. If this time is 30 seconds or less, go to a safe place. If you cannot see the lightning, just hearing the thunder is a good back up rule to use to take cover.

Wait 30 minutes or more after hearing the last thunder before leaving the safe location. This will help guard against any "bolts from the blue."

The "30-30 Rule" will not work well for "first-strike" lightning from locally developing thunderstorms. Thus, watch for developing convection and seek shelter before the first lightning is produced.

BE QUICK TO HALT OUTDOOR ACTIVITIES BUT SLOW TO RESUME THEM AFTER THE RAIN HAS ENDED

For More Information on Lightning…

www.lightningsafety.noaa.gov (NWS's lightning safety website)

www.lightningsafety.noaa.gov/teachers.htm (NWS lightning safety: tools for teachers)

www.nssl.noaa.gov/researchitems/lightning.html (lightning information from NOAA's National Severe Storms Laboratory)

www.lightningsafety.com/ (National Lightning Safety Institute)

www.patrick.af.mil/45og/45ws/LightningSafety/index.htm (45th Weather Squadron lightning safety website)

www.thomson.ece.ufl.edu/lightning (boating safety)

www.uic.edu/labs/lightninginjury (lightning safety research program)