The Science of Lightning

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Except where noted, most images are from Steven A. Ackerman and John A. Knox's *Meteorology: Understanding the Atmosphere* (2nd edition, 2007)

What is lightning?

- **Electrical discharge in sky**
  - Often (but not always) reaches the ground—then it's a safety issue!
  - Generally associated with ***thunder***storms
- Back up, start with **thunderstorms!**
  - Useful primer for both lightning and tornadoes (more later)

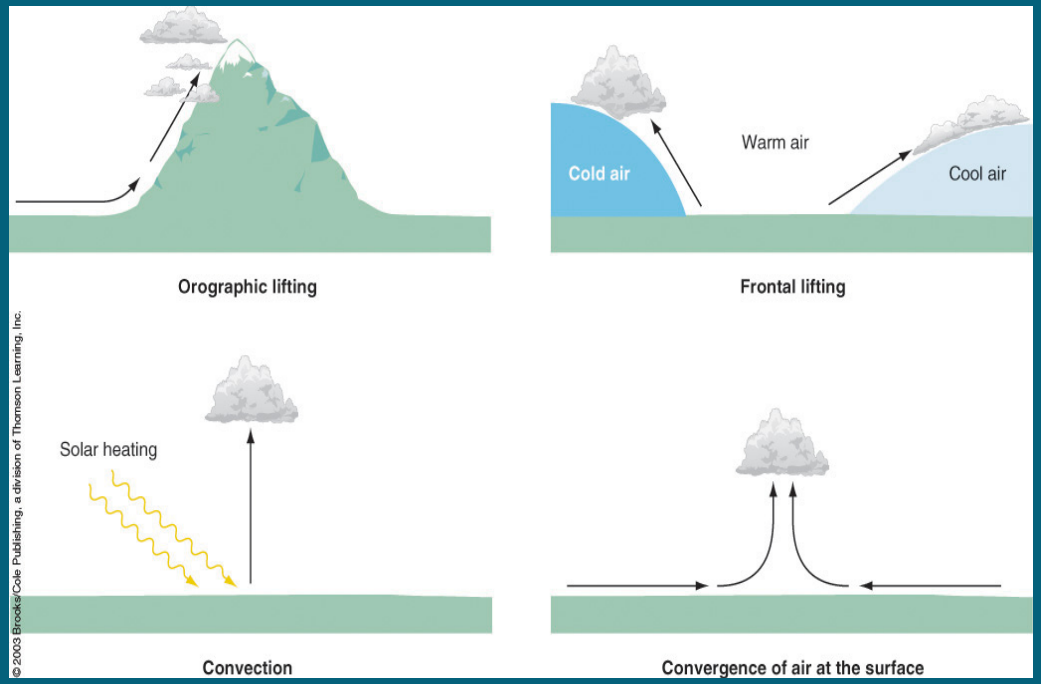
What is a thunderstorm?

- **Cloud/cluster of clouds that causes:**
  - Lightning/thunder
    and also:
  - Heavy precipitation
  - Hail
  - High winds
  - Tornadoes

- Type of cloud:
  Cumulonimbus (note spreading "anvil" top)

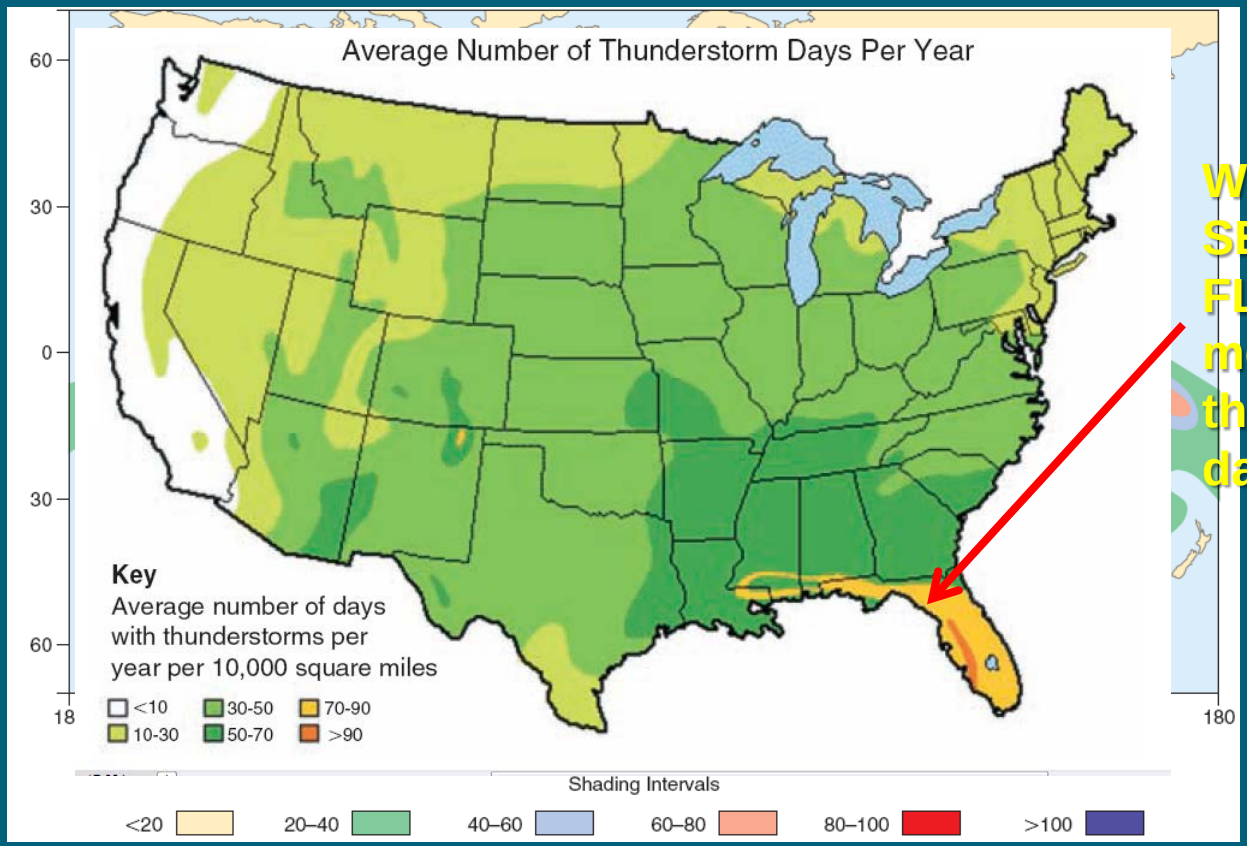
Thunderstorm triggers

- **Lifting mechanism**
  - Mountains
  - Fronts
  - Pure convection
  - Surface convergence
  - "**Boundaries**" of all types
- **Buoyancy**
  - Warm, moist air at surface; cooler, drier air aloft
  - Usually air becomes buoyant only after reaching saturation
  - Lifting mechanisms cool air to saturation
  - Result: **rising air (updraft) up to tropopause** (anvil forms)
  - http://profhorn.aos.wisc.edu/wxwise/AckermanKnox/chap11/growTW.html



Thunderstorm climatologies

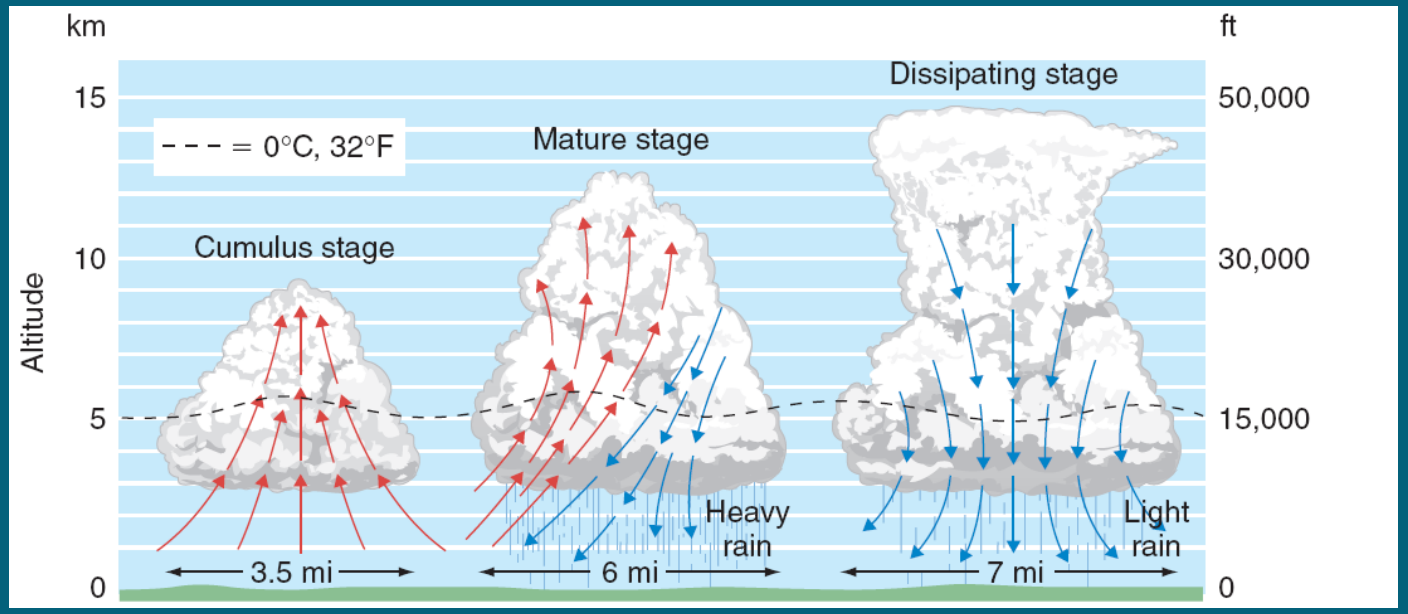
- **Simple rule:** where it's warm and moist and where lifting mechanisms are present, you get thunderstorms!



Why does the SE, especially FL have the most thunderstorm days?

*So far we're ignoring "vertical wind shear,"
which makes thunderstorms and their life cycles very different!

"Air mass" thunderstorm* life cycle



- **Updraft** condenses moisture out of air
- Precipitation forms via special processes
- Falling precipitation leads to **downdraft**
- Downdraft kills updraft, thunderstorm dies

Precipitation types in a thunderstorm

- Rain
- Freezing rain
- Sleet
- Snow
- Hail (right)
- Graupel (snow crystal covered with frozen rain)

http://www.noaa.gov/features/02_monitoring/hailstone.html

Electrical charge generation in a thunderstorm

- Normally, clouds don't have enough charge separation to "light a spark"
- **Thunderstorms "self-electrify"**
- **How?** (Details still debated)
  - Graupel/hail forms, falls through cloud
  - Graupel collides with smaller ice particles
    - Graupel gains – charge via collisions
    - Smaller ice particles become + charged
  - Smaller ice particles rise in updraft

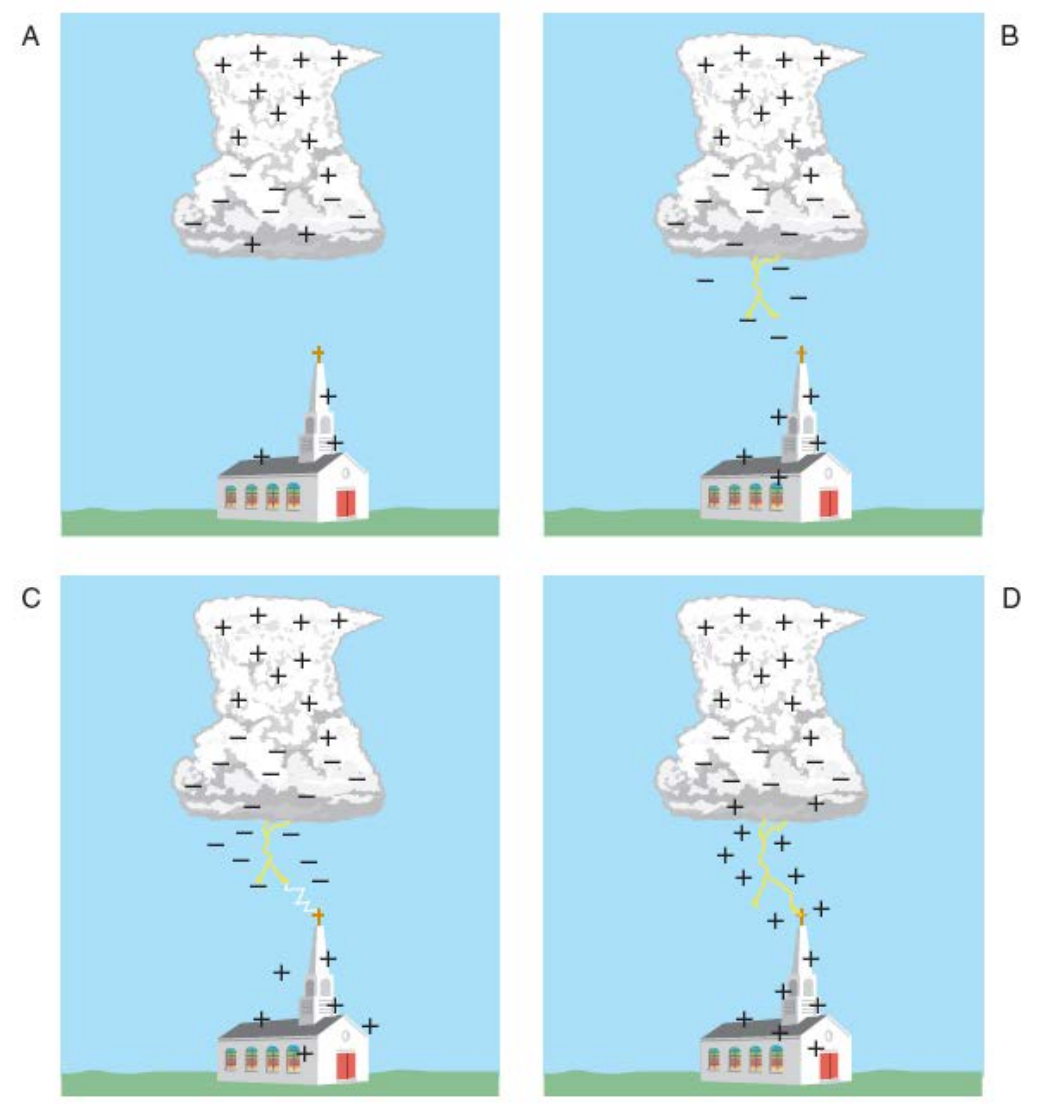
http://www.srh.noaa.gov/srh/jetstream/lightning/images/electricfield.gif

Life cycle of a lightning bolt

Negative charge in cloud induces positive charge at ground, esp. on tall objects

Flow of charge creates **stepped leaders**. More positive charge on protruding objects; charge moves up from ground to **"attach"** to the stepped leader

(2 milliseconds)



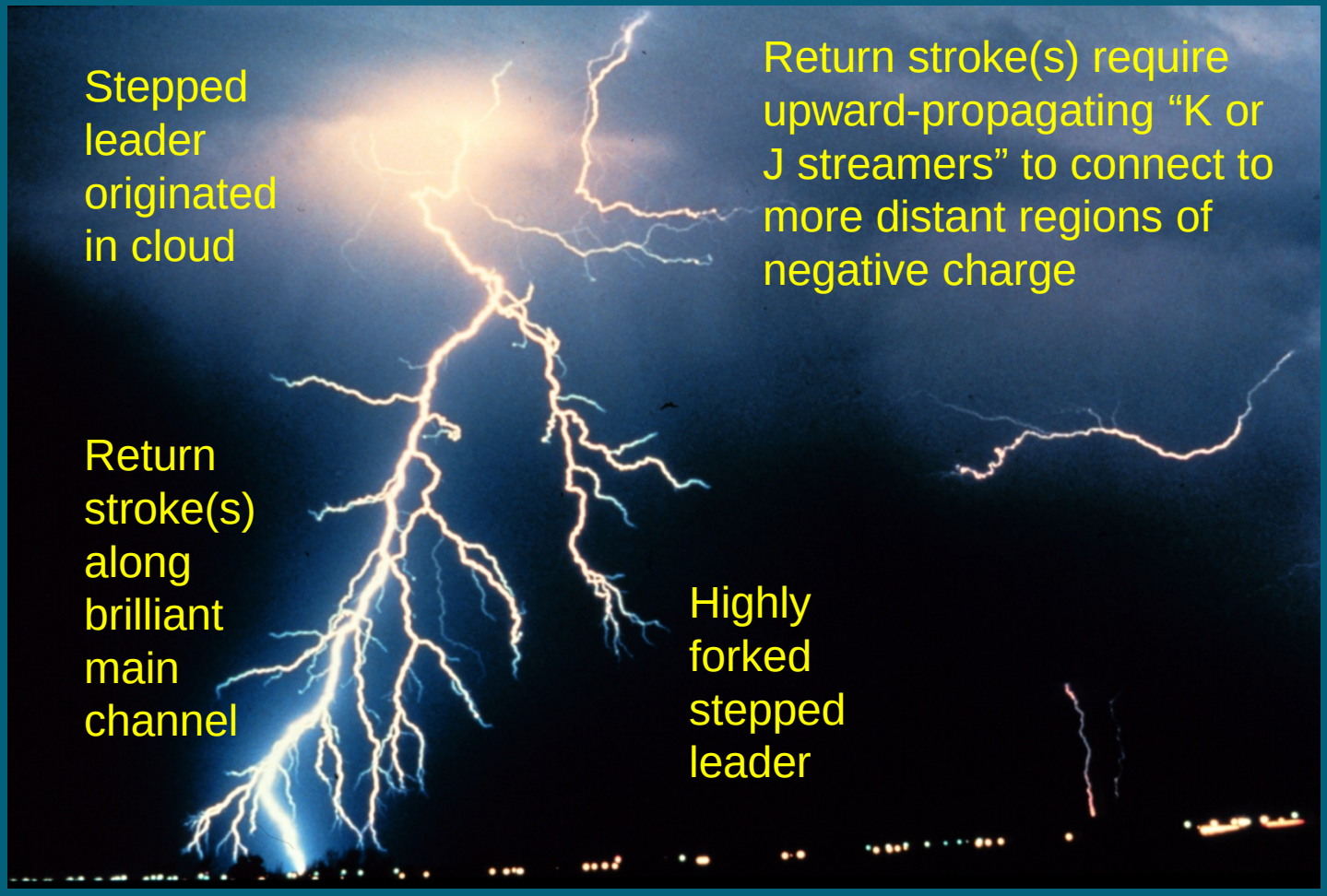
Pilot leader originates from negative charge in cloud and extends downward

(20 milliseconds)

Brilliant **return stroke** propagates upward from object to cloud (100 microseconds)

Dart leader moves down main channel, more return strokes

Time-lapse image of a lightning bolt



http://www.photolib.noaa.gov/bigs/nssl0010.jpg

Theory explains…

- **Charge separation theory explains why:**
  - **Lightning doesn't happen with non-thunderstorm clouds** ***(Why?)***
  - **Lightning doesn't happen at the very beginning stage of a thunderstorm** ***(Why?)***
  - **Lightning *does* happen most often with a tall, anvil-topped cumulonimbus cloud** ***(Why?)***
  - **"Bolts from the blue" usually aren't** ***(Why? Where do you think they come from?)***

DEMO!

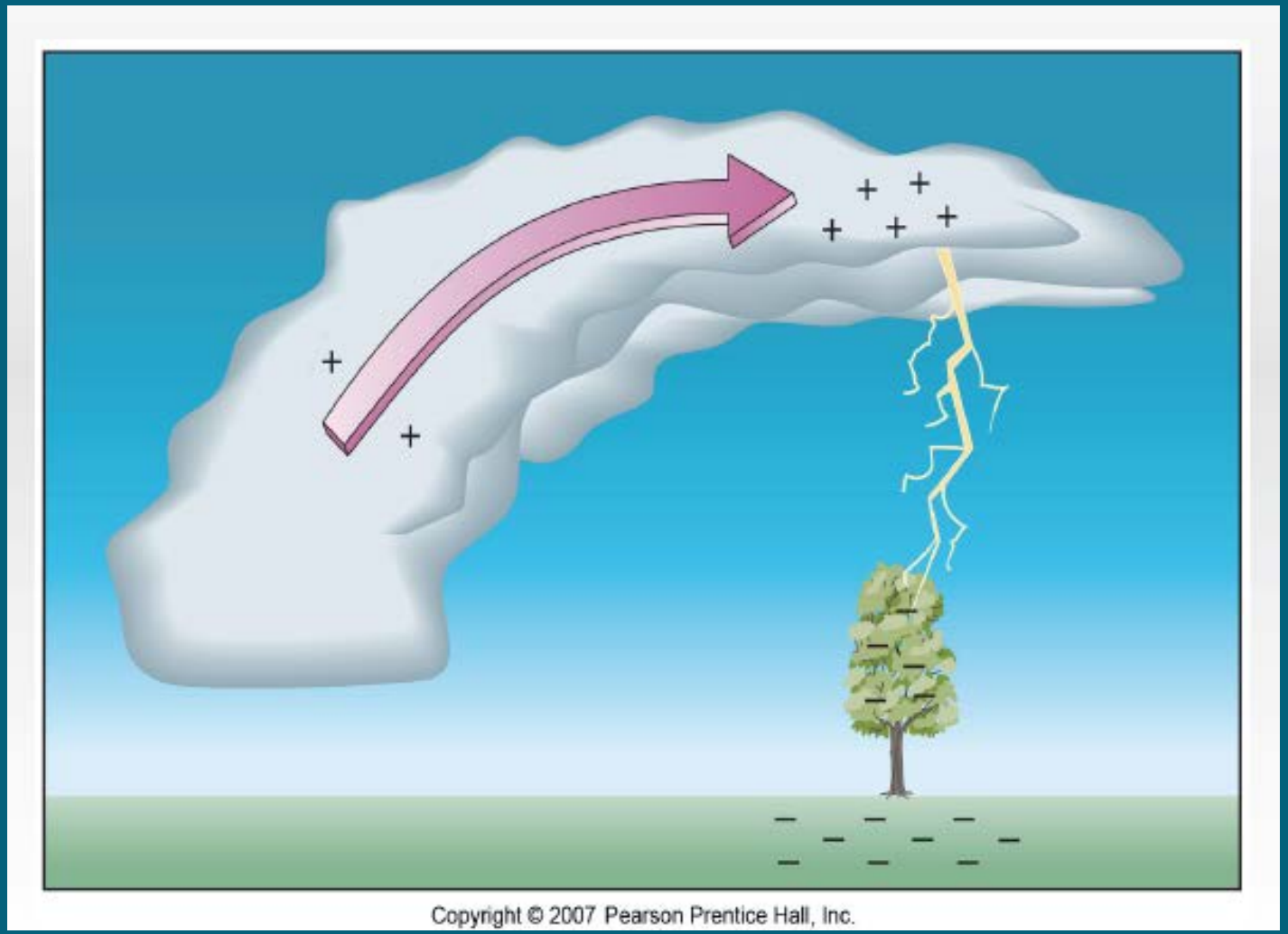
What's going on here?

How are the sparks formed by the Van de Graaff generator similar to lightning?

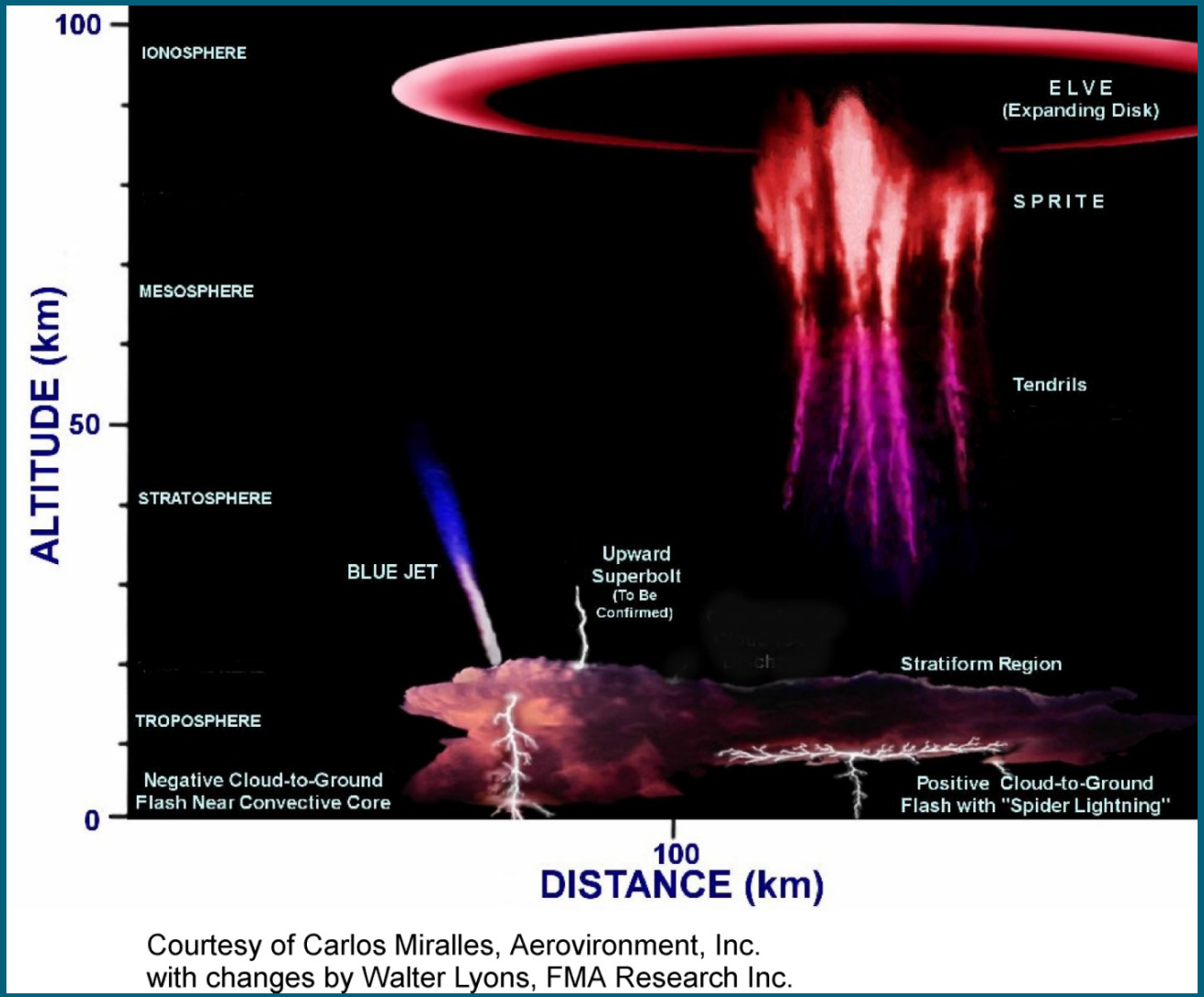
Types of lightning

- **CG, CC, IC:** cloud-to-ground, cloud-to-cloud, in-cloud
  - Tropics: 10 cloud discharges for every ground discharge
  - Mid-latitudes: equal ratios (except in Great Plains, Pacific NW)
- **Negative:** the usual charge of lightning
- **Positive:** rare (5%), very long and powerful, come out of anvil ("bolt from blue"); also in winter storms
- **Sheet:** bolt is blurred/diffused by precipitation
- **Ball:** rare, bizarre, safer form (Plasma? Silicon chemistry?)
- **Elves/sprites/jets:** bolts out the tops of thunderstorms

“Bolt from the blue”

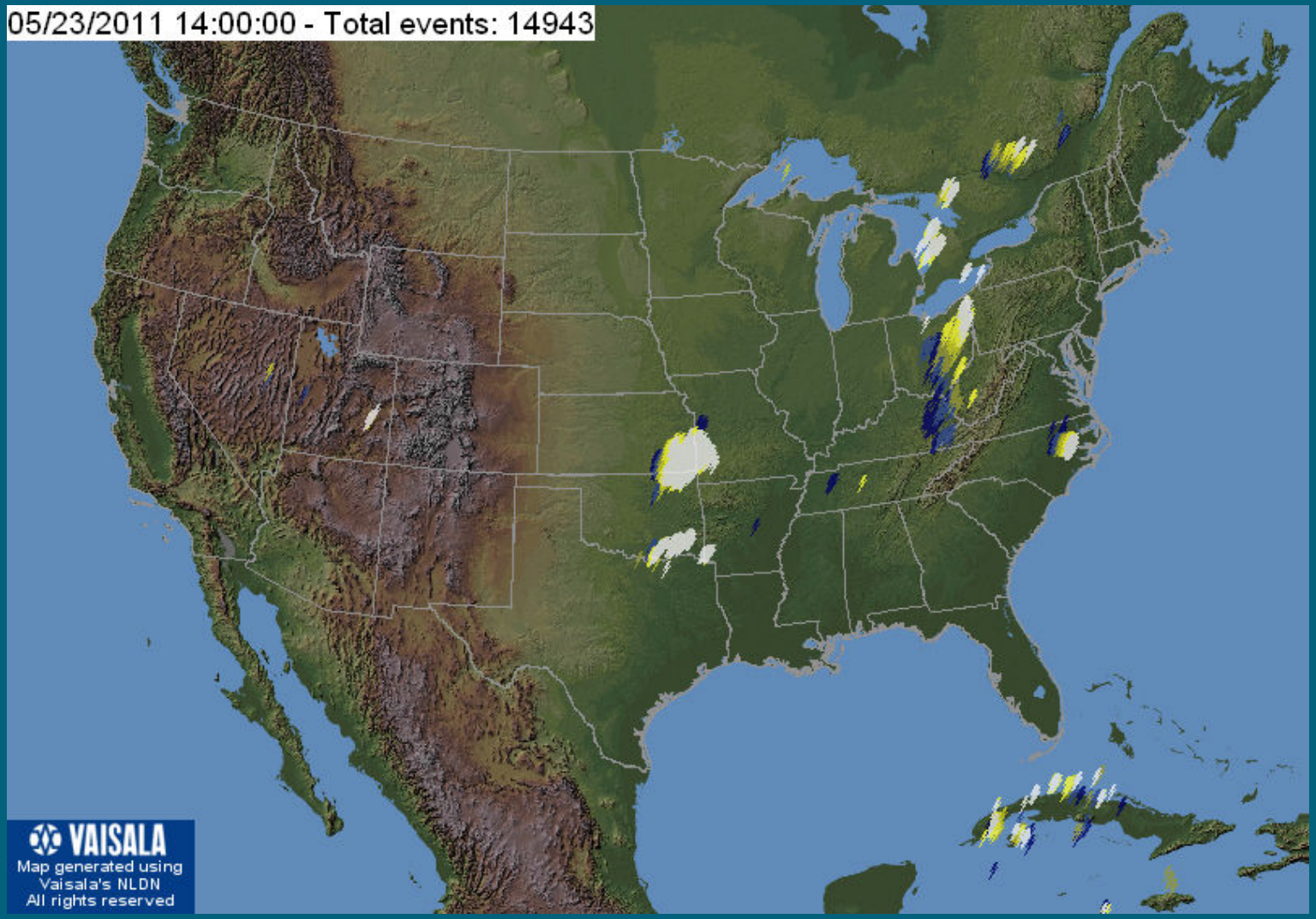


Elves, etc.



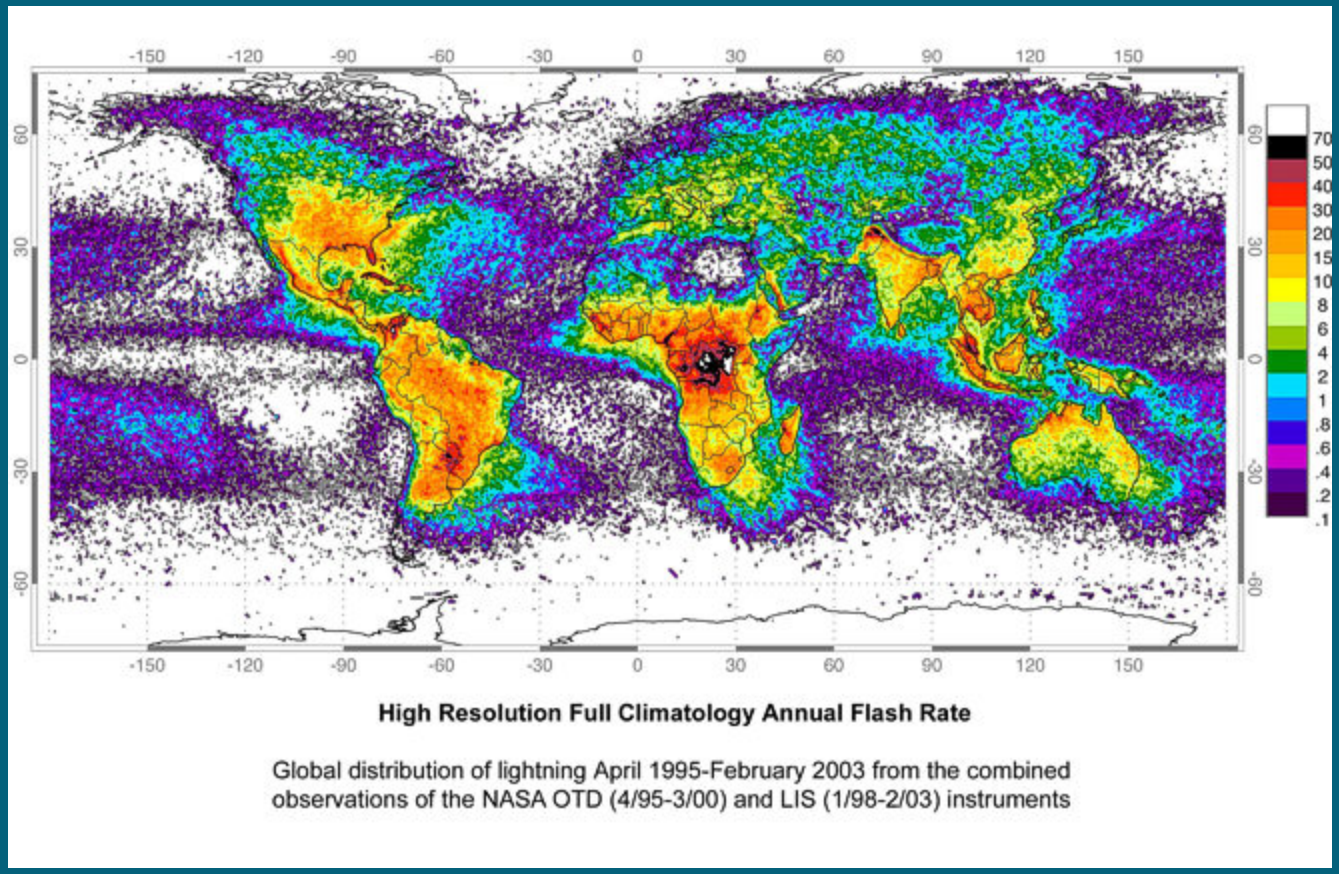
Courtesy of Carlos Miralles, Aerovironment, Inc.
with changes by Walter Lyons, FMA Research Inc.

Current Lightning Strikes



http://thunderstorm.vaisala.com/explorer.html

Total lightning climatology (global, from satellites)



Statistics:

Global CG rate:
12-16 flashes/sec

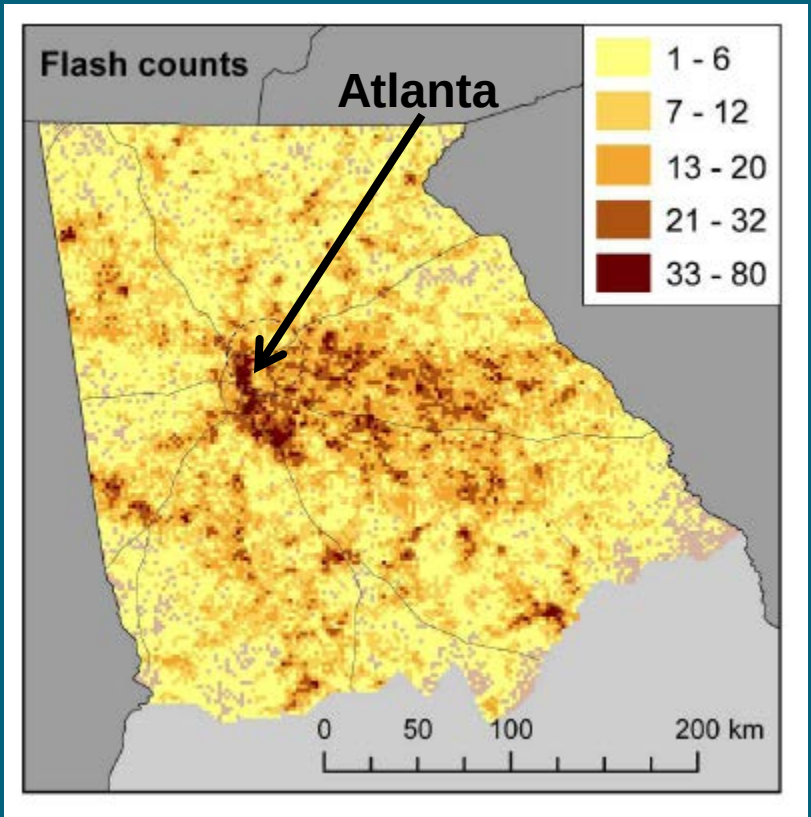
Global total rate:
40-50 flashes/sec

70% of lightning between 30˚N-30˚S; in U.S., **Florida** tops

http://www.srh.noaa.gov/jetstream/lightning/images/hirez_annualflashrate_72dpi.jpg

Urban Enhancement of Lightning?

- Recent studies have found evidence of enhanced CG lightning over and downwind of cities
- Theories:
  - Buildings enhance convergence
  - Thermal circulation from urban heat island
  - Aerosols



From Stallins and Rose, 2008
http://journals.ametsoc.org/doi/pdf/10.1175/2008EI265.1

What is thunder?

- Acoustic waves due to lightning flash-frying the air
- Return stroke channel temperature: **30,000˚C (~50,000˚F)**
- Atmospheric pressure in channel explodes to **up to 100 times normal pressure** (think Ideal Gas Law)
- **Rapid adjustment** of this pressure imbalance causes supersonic shock wave and then acoustic waves, which we hear and call “thunder”

http://www.shorstmeyer.com/wxfaqs/thunder/thunder.html

The “flash-to-bang time” rule

- **Speed of light:** about 186,000 miles/sec
- **Speed of sound:** about 770 mph
- Lightning reaches your eyes instantaneously
- Sound moves 770 mph x 1 hour/3600 sec
  - = **0.21 miles per second**
- So, **“flash-to-bang time” of 5 seconds** means that the origin of the sound wave is 0.21 x 5 = **1.05 miles away**
- This rule is based on very “sound” science!
- Thunder can be heard up to about 10 miles away (50 sec between flash and boom)

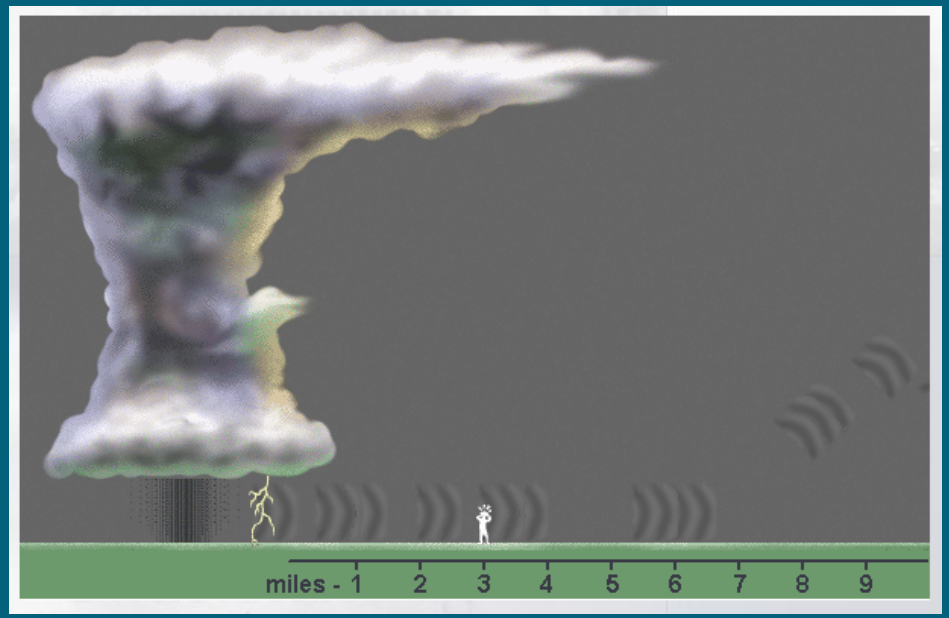
Heat lightning

- When does lightning not cause thunder? Never! (Unless it occurs in the vacuum of space.)
- But, **there are times we can't hear the thunder**
- **Heat lightning: Lightning seen, thunder *not* heard**
- **Cause of heat lightning: refraction of sound waves** away from the listener's ears
- What causes the refraction? Cold air aloft bends the waves upward (or warm air aloft bends the waves downward)

Lightning applet

http://profhorn.meteor.wisc.edu/wxwise/AckermanKnox/chap11/thunder_and_lightning.html

- **User-programmable** (you can put the person at different locations)
- Thunder occurs 5 seconds/mile after bolt
- **Heat lightning:** Crude simulation of refraction at far right of image
- **Lightning safety:** beware anvil's "bolts from blue"



Targets of lightning

- **Prime targets for lightning:**
  - Objects taller than surroundings
  - Objects that are good conductors
  - Fast-moving objects
    - Planes
    - Rockets

http://www.srh.noaa.gov/ffc/html/ltg703.shtml

- **Classic examples:**
  - Buildings, trees (Braselton, GA at right)
  - People on water, on golf courses, on corded phones
- **Franklin's lightning rods:** channel lightning through the rod to the ground, instead of through the building
  - Houses with tile/slate roof 7 times safer because of rods

Human victims of lightning

- **In 2010, 29 Americans in 19 states were killed by lightning** (long-term average is 57; 34 in 2009; 0 so far in 2011). Of these 29 deaths:
  - 100% were outside
  - 76% were male
  - 42% were between the ages of 10-29
  - 48% occurred out in an open space
  - 28% were standing under a tree
  - 21% were in GA and AL

Human victims of lightning

- **Estimate: only 10% of lightning victims are killed!**
- The other 90% can experience one or more of:
  - Short-term memory loss
  - Headaches, ringing in the ears
  - Personality changes
  - Fatigue
  - Brain damage (due to heart stoppage)
- **1-in-625 chance** you will be affected by someone being struck!

Lightning safety

- **"Thunder rule":** go in if you hear thunder, period…
  - **"When thunder roars, go indoors!"**

- **"If you can see it, flee it; if you can hear it, clear it."**

- **Safe shelter:** Building with electricity/plumbing, hard topped vehicle with closed windows
  - What's it like to be in a car struck by lightning? http://www.youtube.com/watch?v=ve6XGKZxYxA

Lightning safety

- **Outside:** stop activities immediately; get down, get away from trees and tall objects
  - Closed car is safe for lightning (but not for tornadoes)
- **If lightning near:** crouch down low, stand on balls of feet (don't lie down)
  - Make yourself smallest target possible; minimize contact with ground

- Don't be this guy… http://www.youtube.com/watch?v=8qy9Hi6a_v8

Lightning safety

- **Inside:** stay off corded phones, turn off/unplug electrical appliances, stay out of tub/shower, avoid concrete floors and walls
  - Lightning channeled through phone lines, electrical wiring, plumbing, metal rods in concrete
- Online safety tutorial for kids: http://www.lightningsafety.noaa.gov/multimedia/Lightning_Game.swf

- **Demo – why a tree is not a safe shelter from lightning**

Main sources of information

- Ackerman, S.A., and J.A. Knox, *Meteorology: Understanding the Atmosphere* (2nd edition), Brooks/Cole, 2007.
- Wallace, J.M., and P.V. Hobbs, *Atmospheric Science: An Introductory Survey* (2nd edition), Academic Press, 2006.
- http://www.lightningsafety.noaa.gov/
  - Good resources for teachers, plus activities and games (mainly for younger students)

Questions?

CG lightning climatology

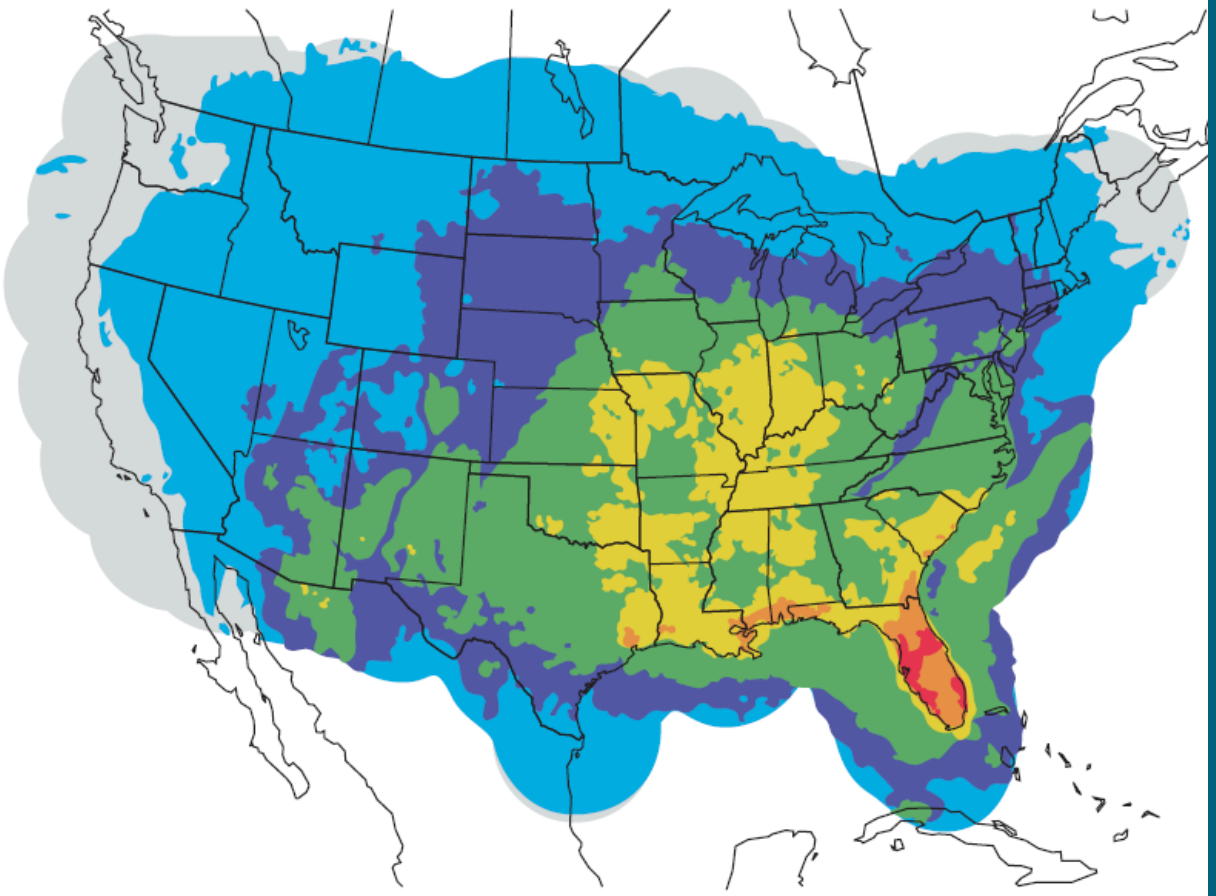


Figure 11.35
The average number of cloud-to-ground lightning flashes per kilometer across the lower 48 United States, as measured electronically by the National Lightning Detection Network for the years 1989 through 1998. More than 216 million flashes were recorded during this period.
(Source: Orville, R. and Huffines, G. Cloud-to-Ground Lightning in the United States: NLDN Results in the First Decade, 1989–1999, Monthly Weather Review, May 2001, Figure 3.)

- http://svs.gsfc.nasa.gov/vis/a0000000/a0000100/a0000186/a0000186.mpg