Chapter 21
Lightning

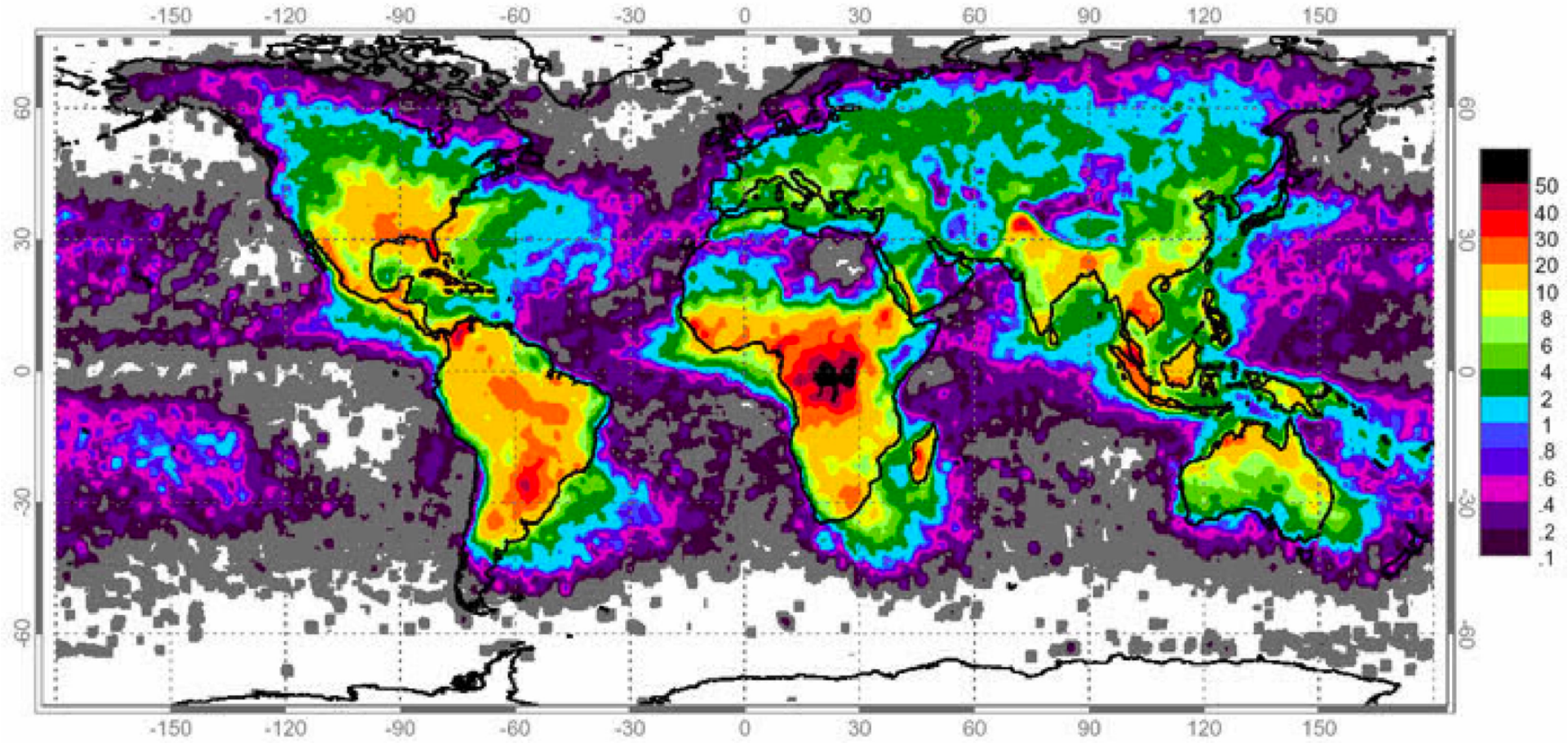
Lightning

- **Lightning** – an electrical discharge in the atmosphere
- Facts:
  - On average a lightning stroke is 5 km (3 miles) long and 2 to 3 cm (~1 inch) in diameter
  - Approximately 100 lightning strokes occur on the Earth every second
  - The temperature of a lightning stroke is 30,000 deg C (this is 5 times hotter than the surface of the Sun)
  - 20 million cloud-to-ground lightning flashes occur in the US each year
  - Approximately 50 people are killed and 300 people are injured by lightning each year in the United States

Types of lightning

- Types:
  - **In-cloud lightning**: within clouds
  - **Cloud-to-cloud lightning**: between clouds
  - **Cloud-to-ground (CG) lightning**: between the cloud and the ground
- Total lightning
  - Combination of in-cloud, cloud-to-cloud, and cloud-to-ground flashes
- What percent of lightning strokes are either in-cloud or cloud-to-cloud strokes?
  - > 80%

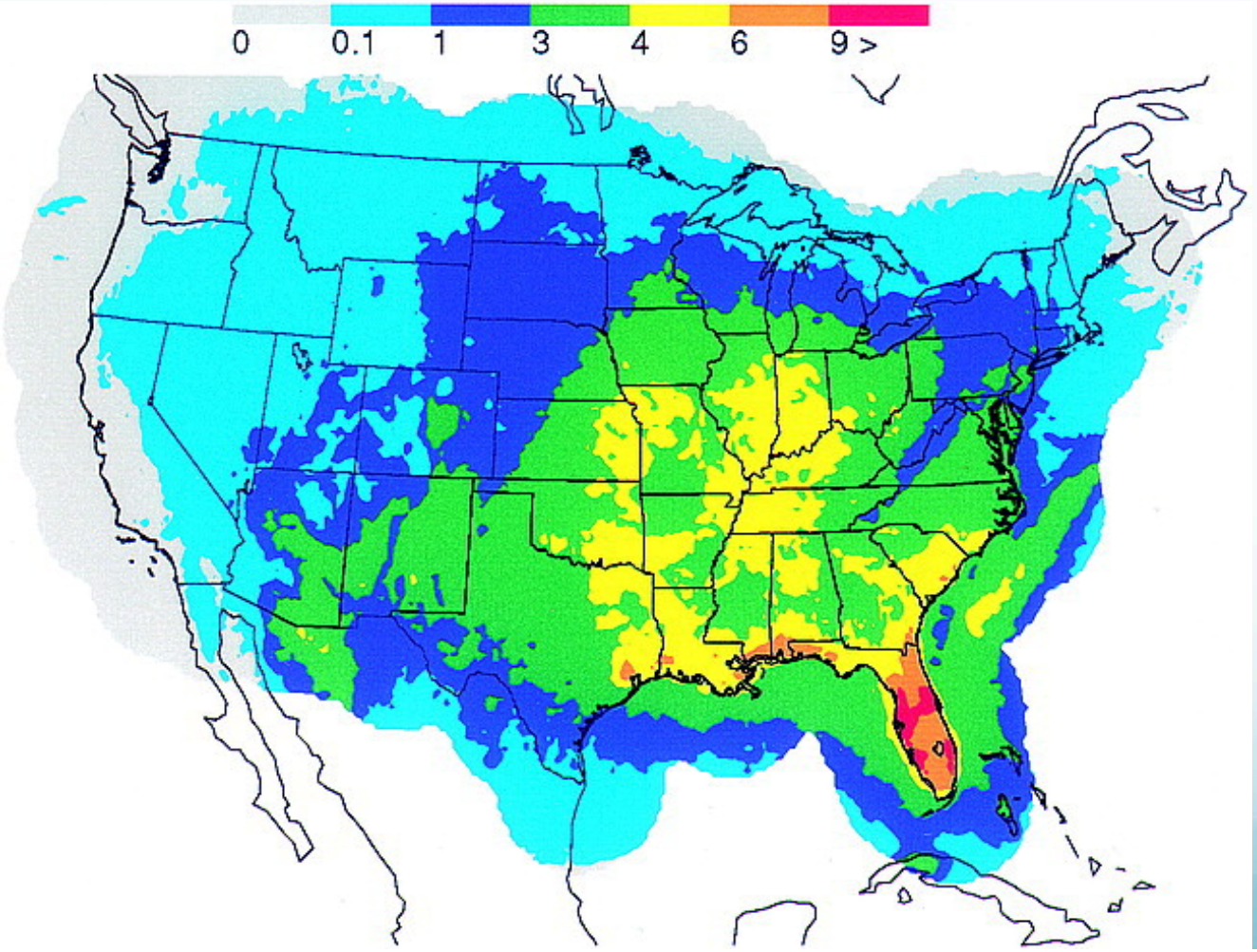
Where does lightning occur?



Courtesy of NASA

Average annual number of (total) lightning flashes per square km worldwide

Where do CGs occur in the U.S.?



- Number of cloud-to-ground lightning strikes per square km per year in the 10-yr period 1989-1998 in the U.S.

Electricity and charge

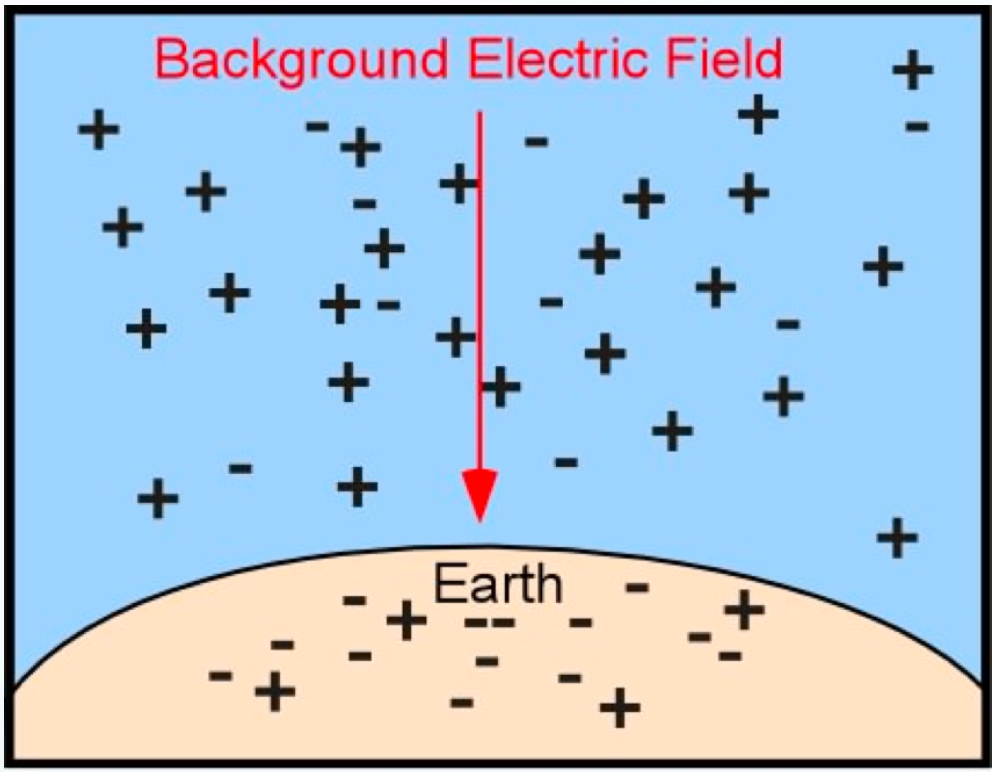
- **Proton** – positively charged particle
- **Electron** – negatively charged particle
- **Ion** – an atom with an unequal number of protons and electrons
- **Electrical current** – movement of an electrical charge (typically due to the movement of electrons)
- An electric field is present in any region where positive and negative charges exist.

Charges in an electric field

- A charge will experience attractive and repulsive forces in the presence of an electric field.
  - Like charges repel and opposite charges attract.
  - The magnitude of this force is measured in volts (V).
- The strength of the electric field is measured in volts / meter (V/m).

Fair weather electric field

- This is the background electric field that exists in the lower atmosphere
- In general the atmosphere is positively charged and the surface of the earth is negatively charged.
- The strength of this fair weather electric field is 100 V/m



Current will move easily through conductors (such as metal or water) and will move poorly (or not at all) through insulators (such as air or plastic).

Clicker Question

- True or false: Most lightning occurs over land than compared to oceans.
  A. True
  B. False

Clicker Question

- _____ is a negatively charged particle.
  A. A proton
  B. An electron
  C. An ion
  D. all of the above
  E. none of the above

Clicker Question

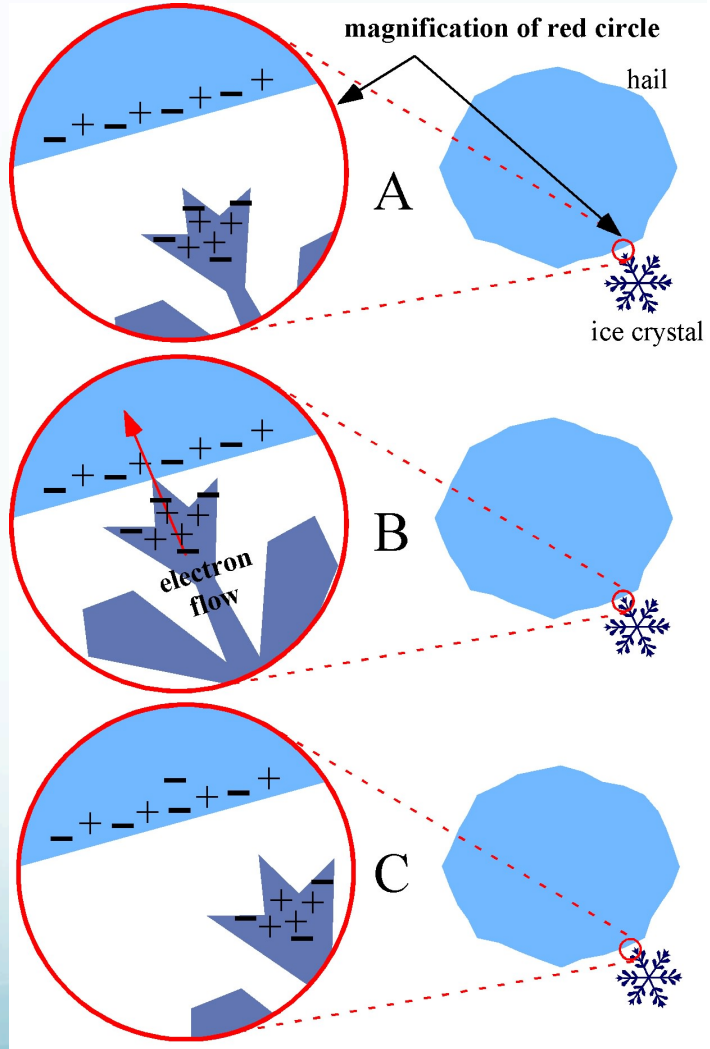
- For the fair weather electric field the atmosphere has a _____ charge and the earth's surface has a _____ charge.
  A. positive, positive
  B. negative, negative
  C. positive, negative
  D. negative, positive

Charging in thunderstorms

- The electric field right before a lightning stroke is typically 3,000,000 V/m
  - Much stronger than the fair weather electric field!
- How does a thunderstorm become charged so that lightning can occur?
  - Interface charging (also called non-inductive charging)
  - Induction charging
  - Other methods may also be important for creating the electric field in a thunderstorm
- Both interface and induction charging typically cause ice crystals in a thunderstorm to become positively charged and hail to become negatively charged.
  - How do they acquire charge?

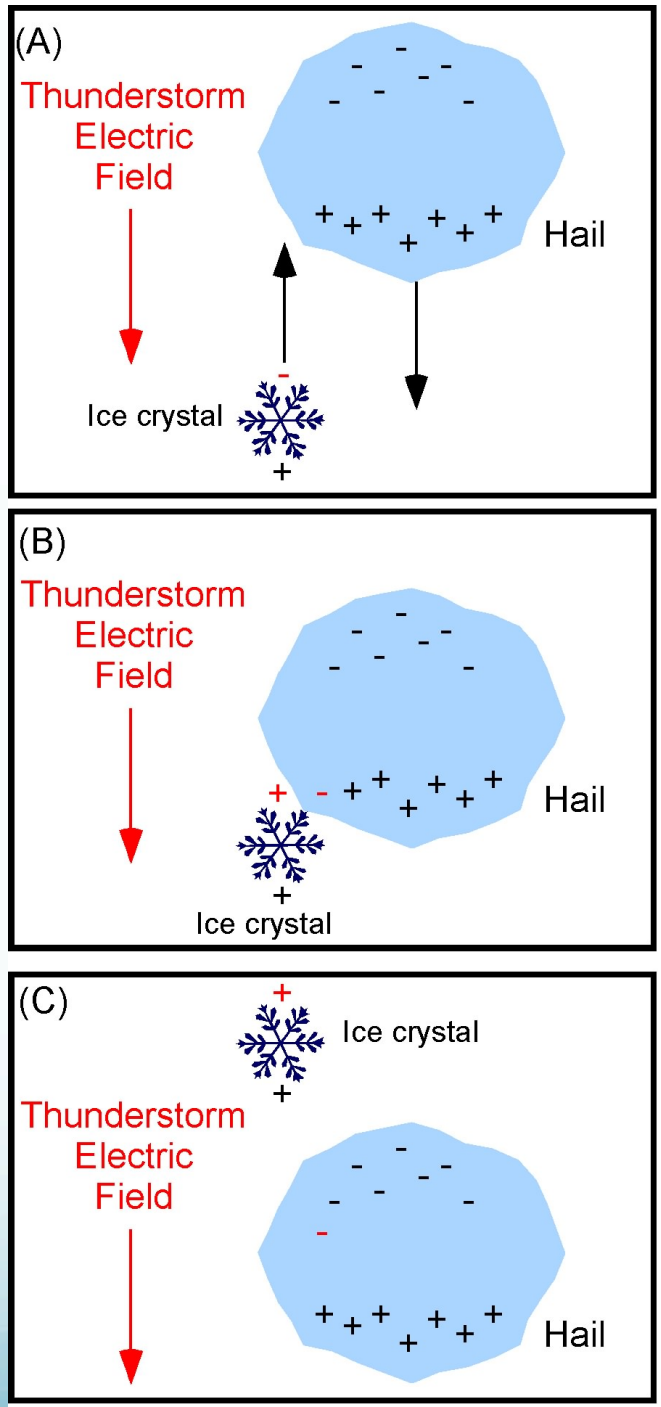
Interface (non-inductive) charging

- This process is based on charge transfer taking place between collisions of ice crystals and hail
  - Graupel (like small hail) and hail stones grow by supercooled liquid water freezing on them
    - A process called **riming**
  - Ice crystals grow by water vapor deposition (direct transfer of water vapor to ice)
  - Due to the different formation, the electrons on the surface of each particle are distributed differently
- When an ice crystal collides with a rimed ice particle, charge can be transferred between the two particles
  - Positive on ice crystals and negative to rimed particles like hail



Induction charging

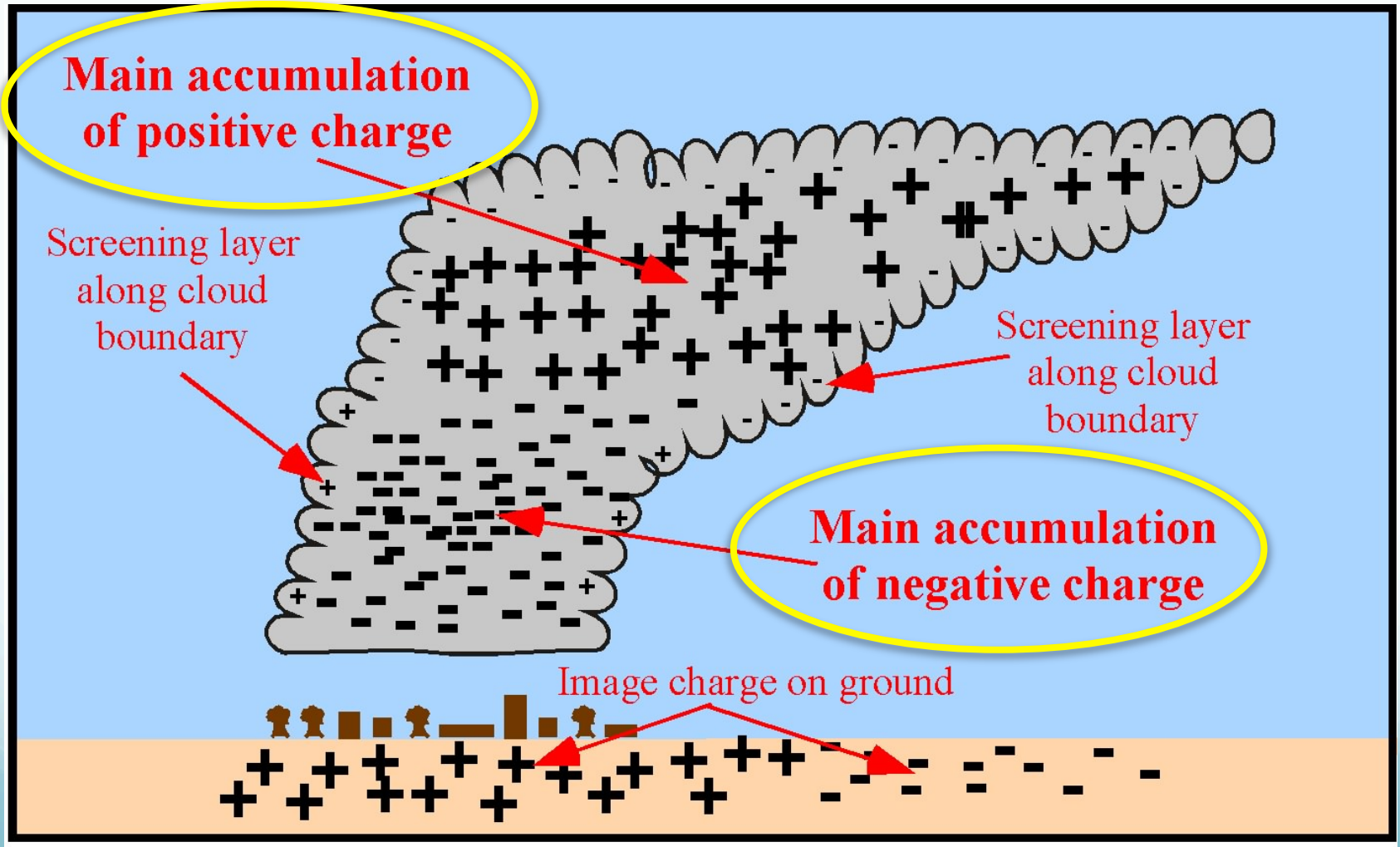
- This process is based on collisions again, but now the distribution of charge in each particle is determined by the local electric field
- The charge will align itself in each particle based on the ambient electric field
  - In other words, the charge distribution within the particle will be induced by the ambient electric field
- Since larger particles (like hail) have faster fall speeds than lighter particles (like ice crystals), the transfer will result in ice crystals getting positive charge and hail getting negative



Result of collisional charging

- Whether by interface (non-inductive) or induction charging, collisions transfer charge so that:
  - the larger particles (graupel, hail) acquire a net negative charge
  - the smaller particles (ice crystals) acquire a net positive charge
- Due to the different sizes (and thus fall speeds), the ice crystals are carried aloft and the hail is supported by the updraft or falls out of the cloud
- Thus, positive charge goes to the top of the cloud, and negative charge to the bottom

Typical storm charge structure



Clicker Question

- Through the process of interface (non-inductive) charging hail will acquire a _____ charge and ice crystals will acquire a _____ charge in a thunderstorm.
  A. positive, positive
  B. positive, negative
  C. negative, negative
  D. negative, positive

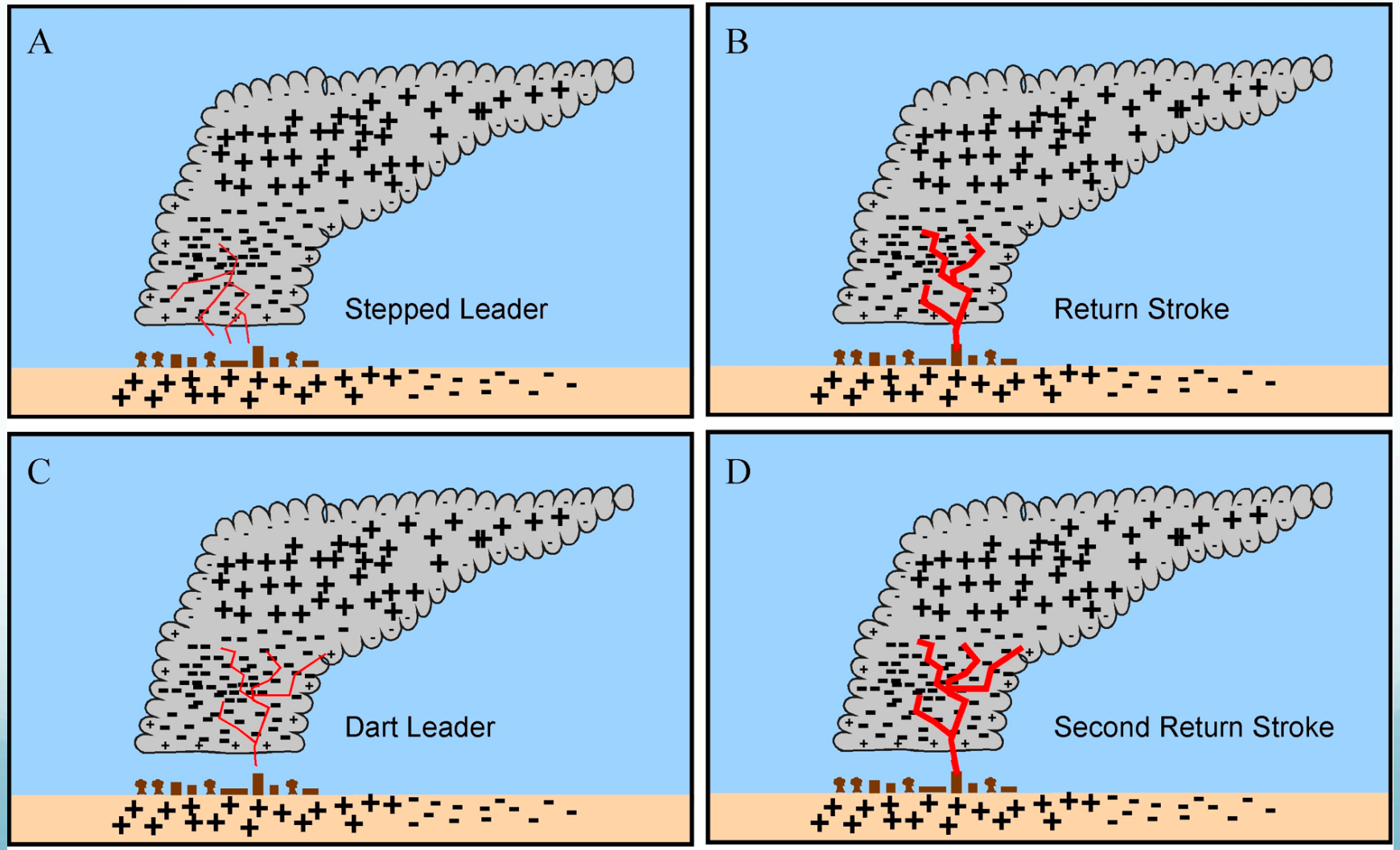
Clicker Question

- The top of a thunderstorm would have a _____ charge due to the presence of _____.
  A. positive, hail
  B. positive, ice crystals
  C. negative, hail
  D. negative, ice crystals

Clicker Question

- Which of the following statements about induction charging in a thunderstorm is true?
  A. Induction charging occurs due to differences in the arrangement of electrons on the surface of hail and ice crystals.
  B. Induction charging occurs due to sublimation of ice crystals.
  C. Induction charging can only occur in the presence of an electric field.
  D. All of the above.

Stages of a CG lightning stroke



Recap of a CG stroke

- What magnitude electric field is required before lightning can occur? **3,000,000 V/m!!!**
- **Stepped leader** – electrons moving towards the ground in a series of steps
- **Return stroke** – occurs when downward moving electrons meet upward moving positively charged atoms
  - This process can be repeated multiple times over the same path.
  - **Dart leader** – leader that occurs after the initial lightning flash

High speed video of a CG

- http://www.youtube.com/watch?v=JVXy-ZqqZ-g

Thunder

- What causes thunder?
  - A shock wave caused by the rapid expansion of air as it is heated rapidly by lightning
- How long does it take for the sound of thunder to travel 1 mile?
  - Sound travels 333 m/s (1100 ft/sec)
  - Takes 5 seconds to travel one mile
- How fast does light travel?
  - The speed of light is ~299 million m/s
  - Thus it travels so fast it nearly instantly arrives at our eyes
- How can you estimate the distance to a lightning stroke?
  - Count the seconds between when you see lightning and hear thunder
  - 5 seconds per 1 mile distance away

Related phenomena

- **Heat lightning** – Lightning seen on a clear night that originates from a thunderstorm so far off in the distance it cannot be seen or heard (the night sky will just flash)
- **Sheet lightning** – When lightning occur within or behind a cloud, illuminating the exterior of the cloud uniformly. Appears like a sheet of light.
- **St. Elmo's fire** – When charge is accumulated on tips of objects extending above the earth's surface (antennas, ship masts). Produces small sparks and sometimes a bluish green halo. Often a sign of an impending lightning strike.
- **Sprites** – One type of optical phenomena that occurs between the tops of thunderstorms and the mesosphere.

Lightning safety

- What should you do if a thunderstorm is approaching?
  - Go inside if possible
  - Stay away from electrical appliances and corded telephones
  - Avoid taking a shower or coming in contact with indoor water supplies
- What should you do if you can't go inside?
  - Crouch as close to the ground as possible and minimize the amount of your body that is in contact with the ground by staying on your toes or heels.
  - Do not go under trees (unless you are in a forest)
  - Do not lie on the ground
  - Remove metal objects if possible
  - Get in a car—A car with a metal frame is a very safe place in a thunderstorm.

When your hair stands up…

- What do you think is happening?
- If you were in this situation, would you stop to pose for a photo?
- This is common on mountaintops when a thunderstorm approaches or is overhead.

NOAA Photo Library

Clicker Question

- A visible flash of lightning occurs in the _____ stage of a lightning stroke.
  A. stepped leader
  B. return stroke
  C. dart leader
  D. second return stroke
  E. both b and d

Clicker Question

- Thunder is caused when air in the path of a lightning stroke is rapidly _____ causing the air to _____.
  - A. cooled, expand explosively
  - B. heated, expand explosively
  - C. cooled, contract violently
  - D. heated, contract violently

St. Elmo's fire and sprites

- Red sprites:
  - http://www.youtube.com/watch?v=1xVThAFfP0E
- St. Elmo's fire from an airplane cock pit
  - http://www.youtube.com/watch?v=RpJqkIU6c0Q