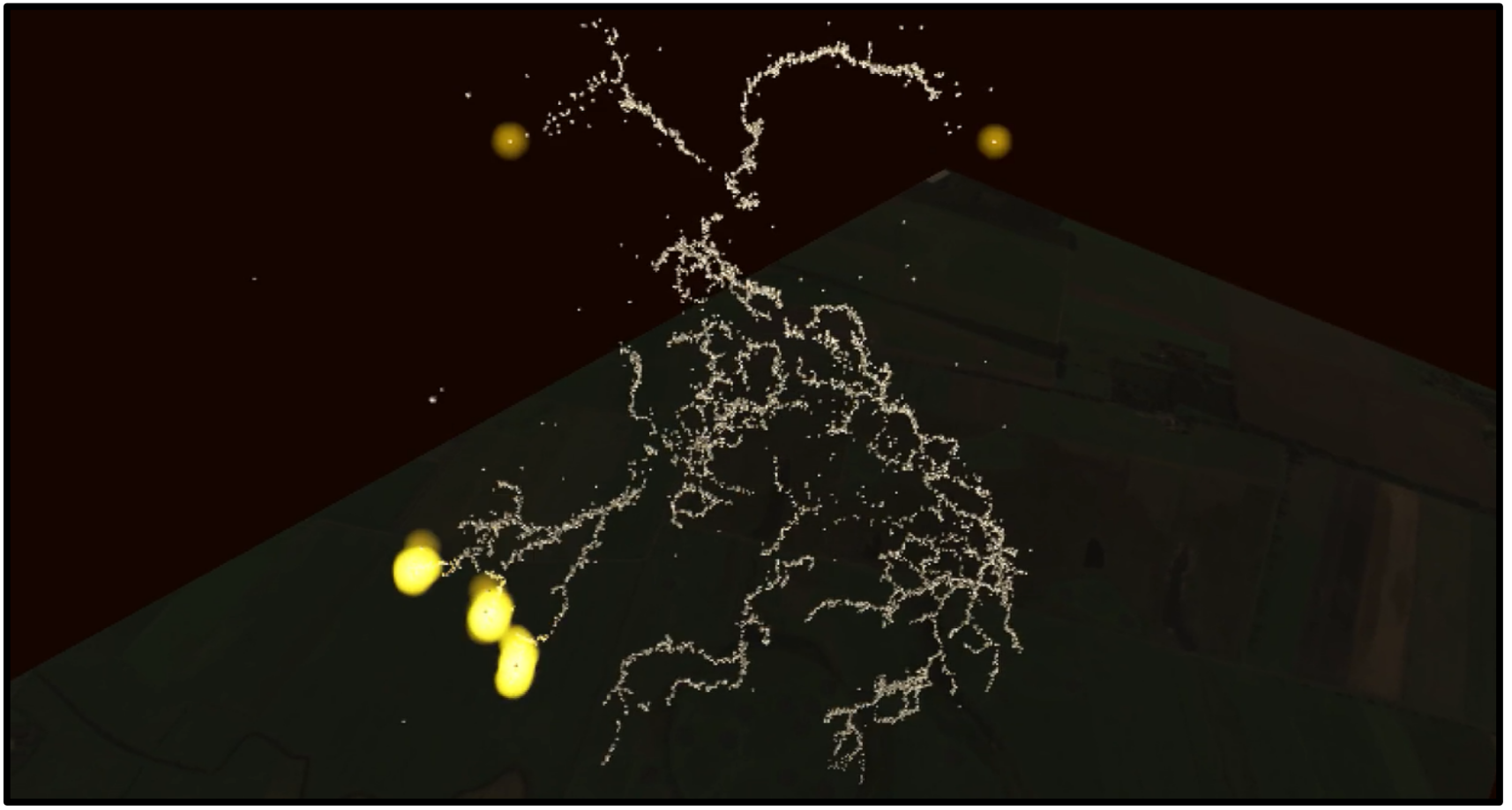
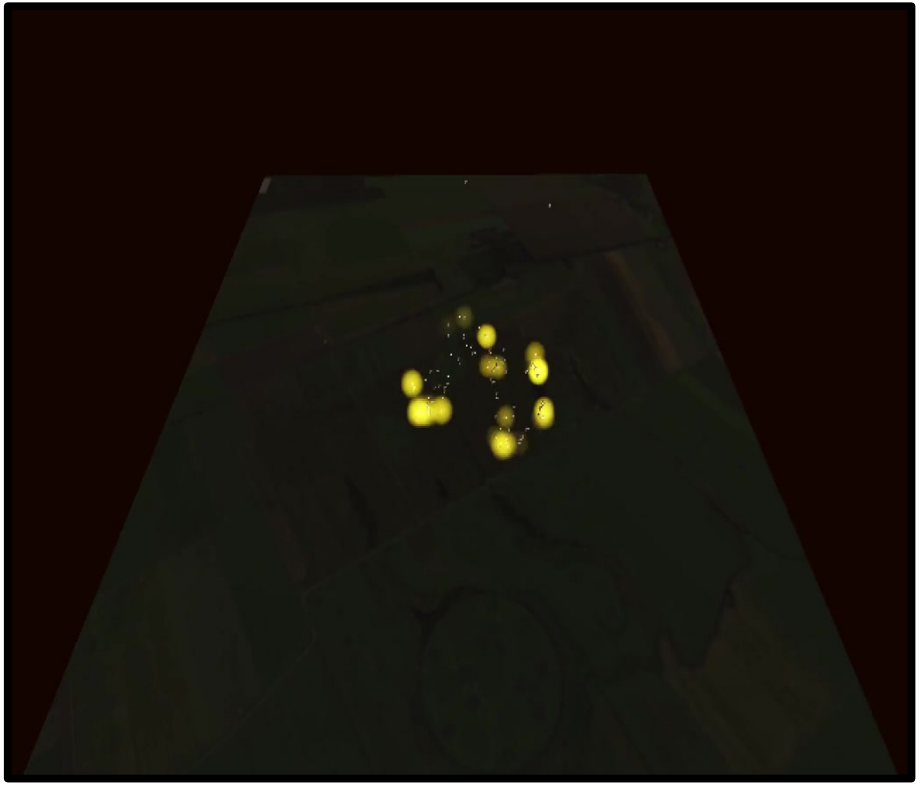
Lightning Suppression Methodology



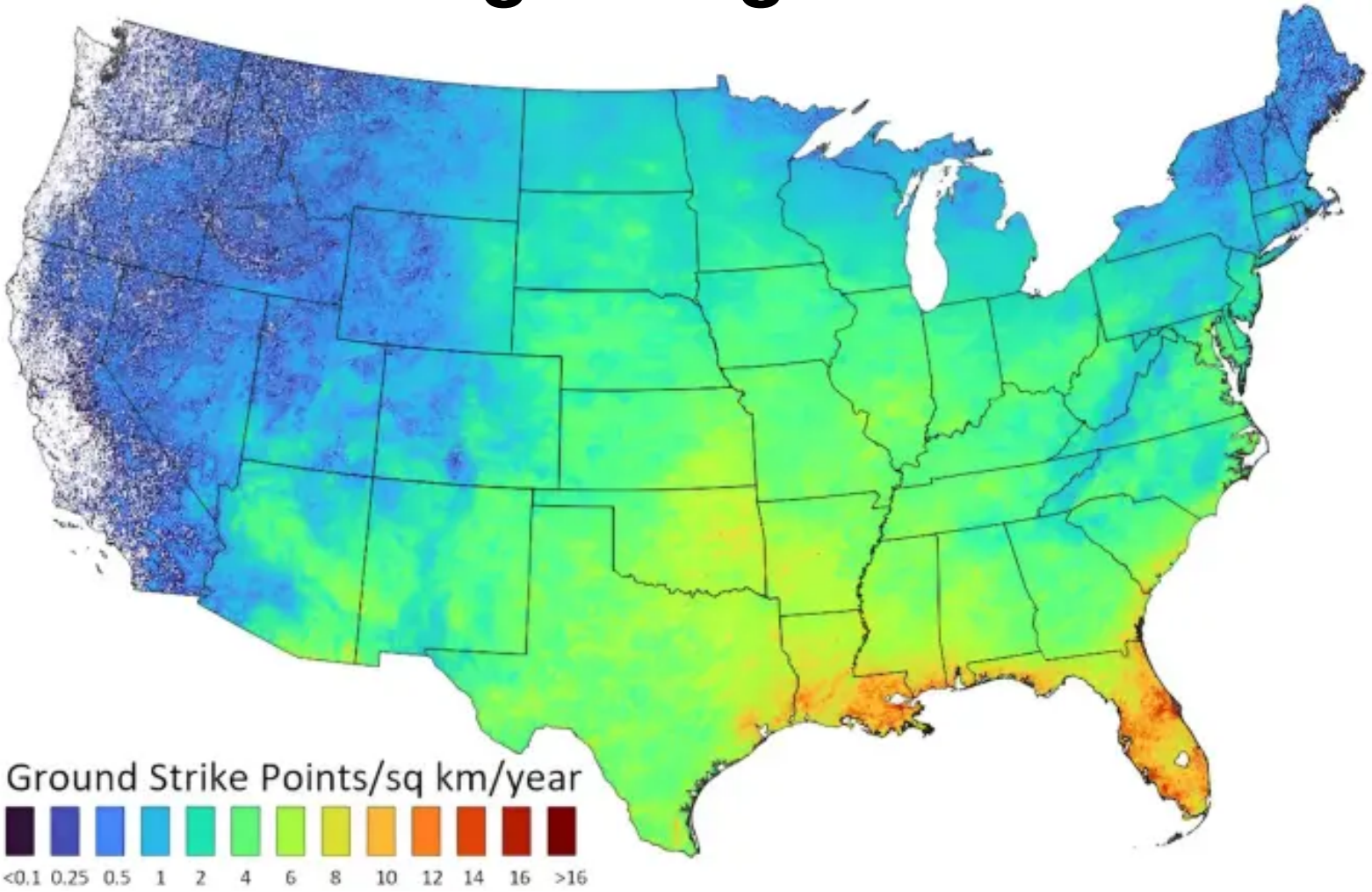
This animation shows a 5 km wide lightning flash recorded by the LOFAR radio telescope network that grew from a small (10 m) cloud region. Each dot is a radio source location.

What is Lightning?

- Lightning is flow of electricity in the air.
- Normally, the air is not a conductor of electricity.
- However, if the electric field is large enough, the electrons (negative charge) can be pulled away from the nuclei of the molecules (positive charge) and the air becomes a conducting medium.

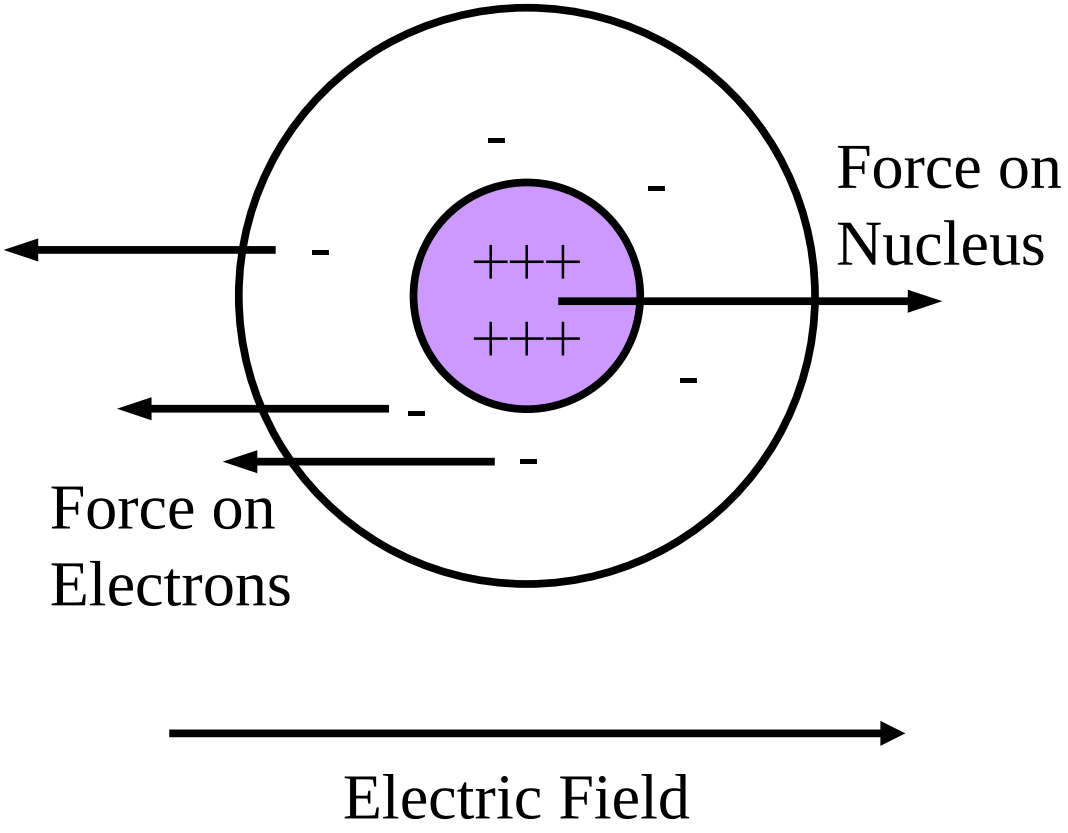


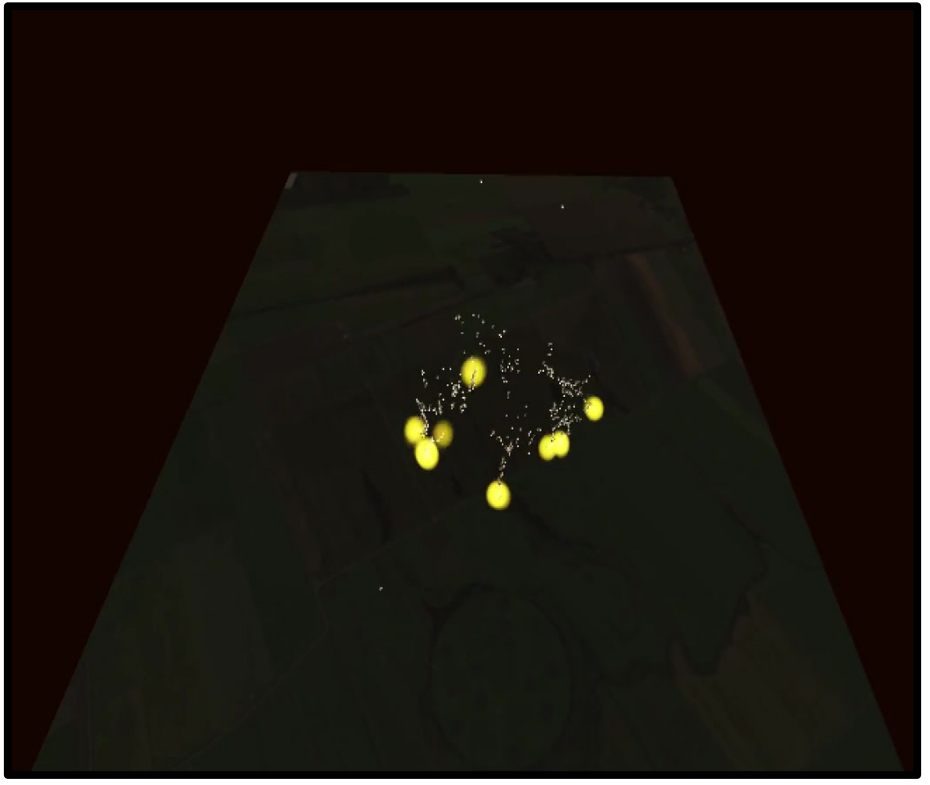
Where does Lightning Hit the Ground?



Credit: Vagasky et al, Bulletin of the American Meteorological Society/10.1175/BAMS-D-22-0241.1

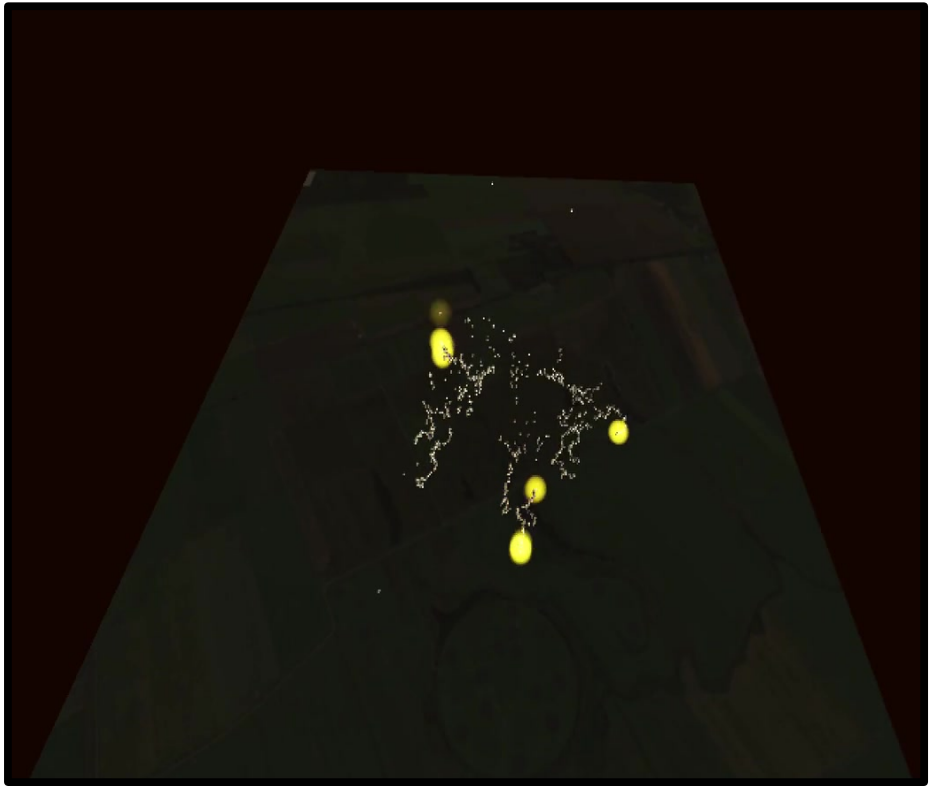
Large Electric Field Effect on Nucleus



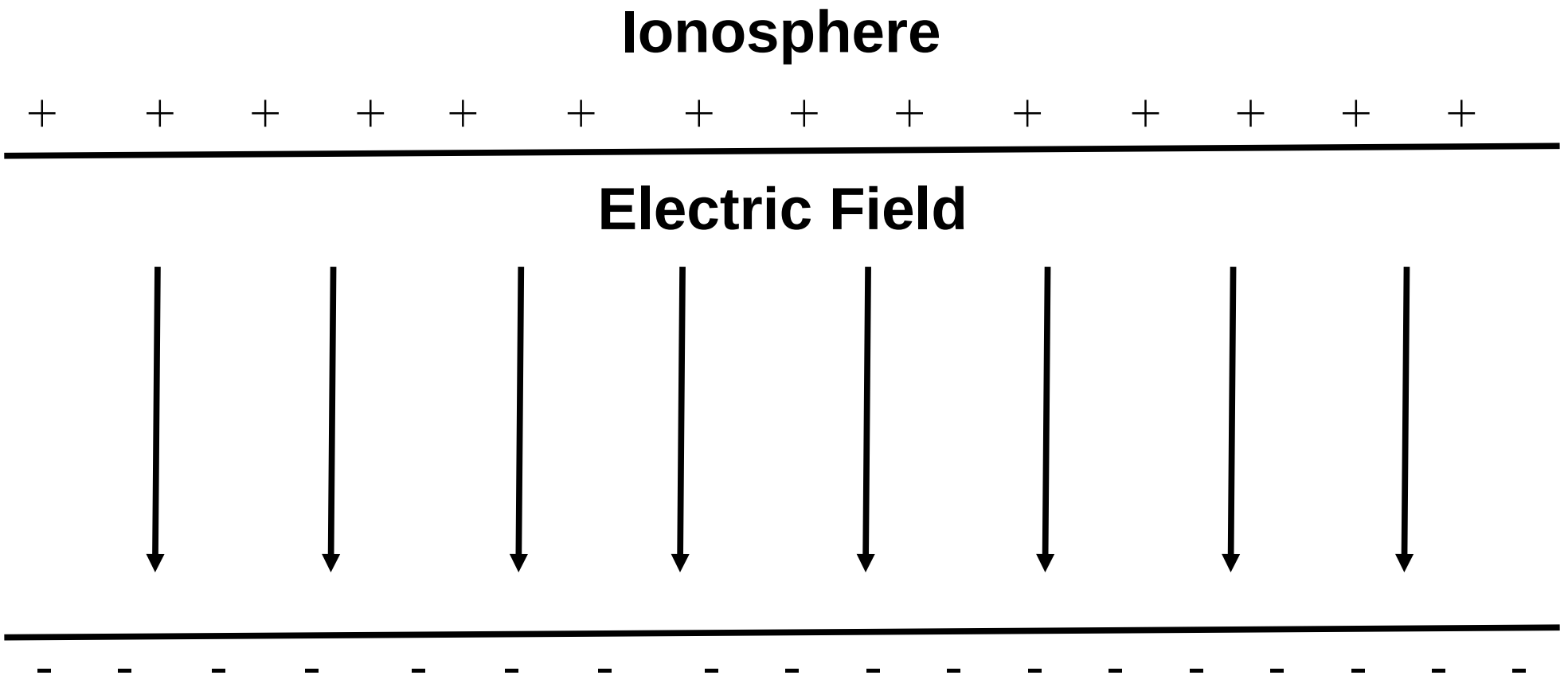


Electrical Breakdown of the Air

- In order to cause electrical breakdown of dry air (changing the air from a non-conductor to a conductor), the field strength needs to be about 3×10^6 volts/meter.
- If the air contains water drops, breakdown can occur with smaller fields (~1×10^6 volts/meter).



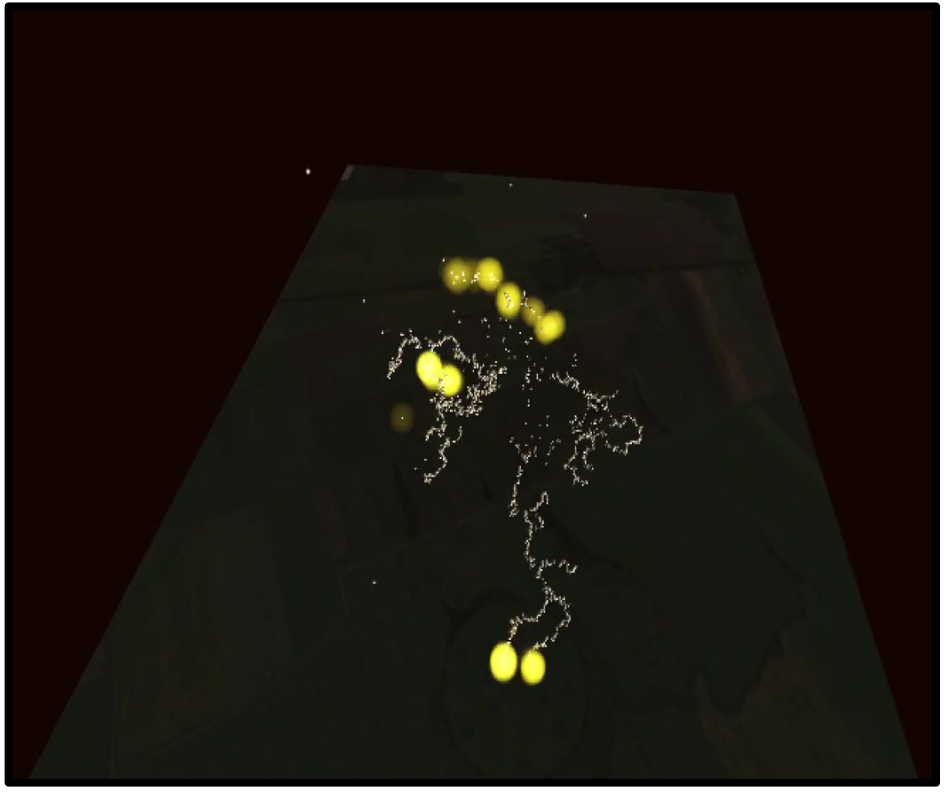
Fair Weather Electric Field of the Atmosphere



What is the cause?

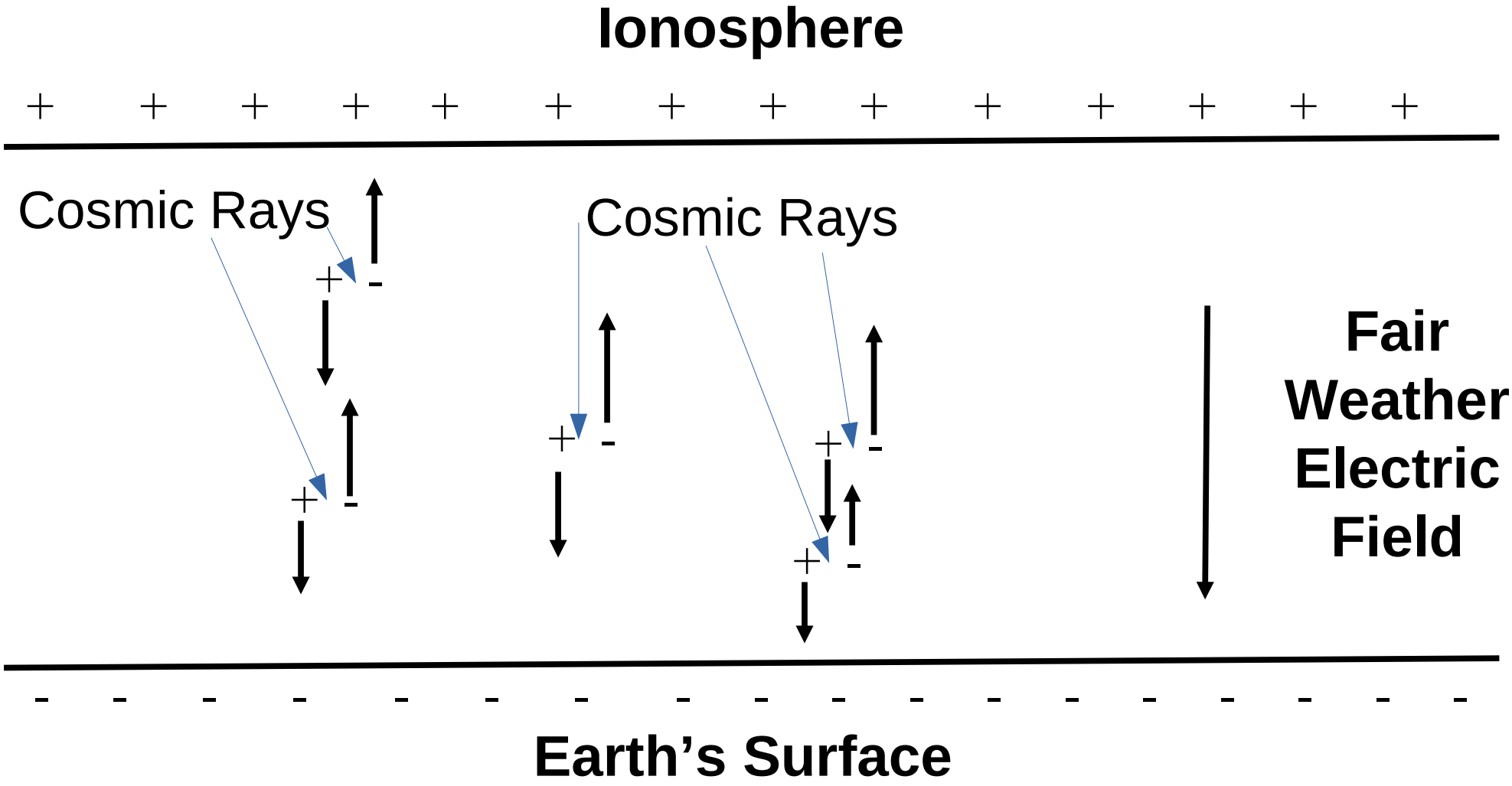
The “Electrode Effect”

- There are a number of free ions in the air at any one time.
- Ions are largely the result of cosmic rays coming through the atmosphere.
- Cosmic rays strike molecules and impart enough energy to break electron loose from atom, forming a positive and a negative ion.

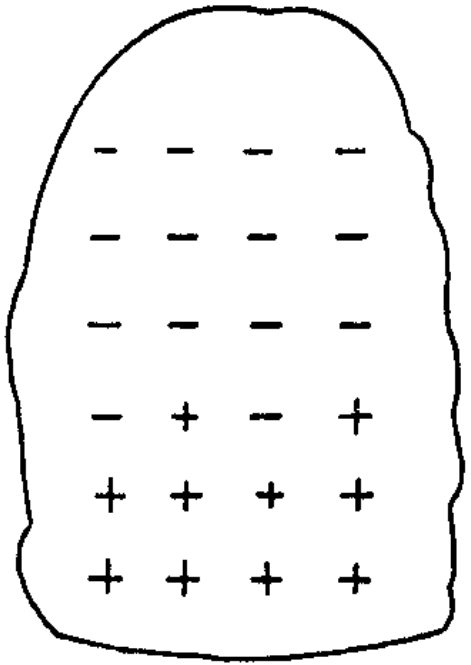


What are cosmic rays?

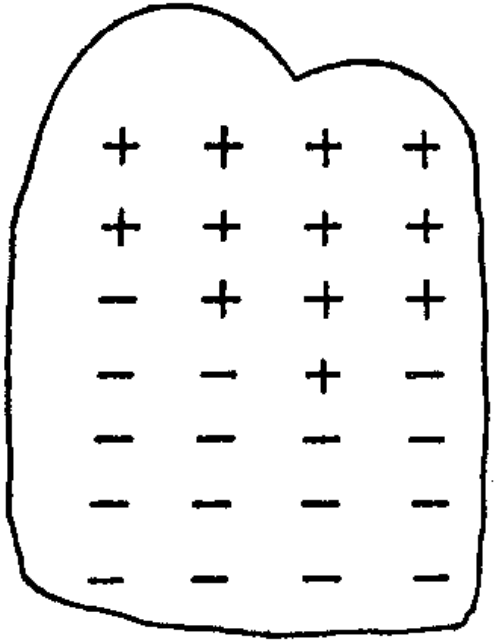
Electrode Effect → Fair Weather Electric Field



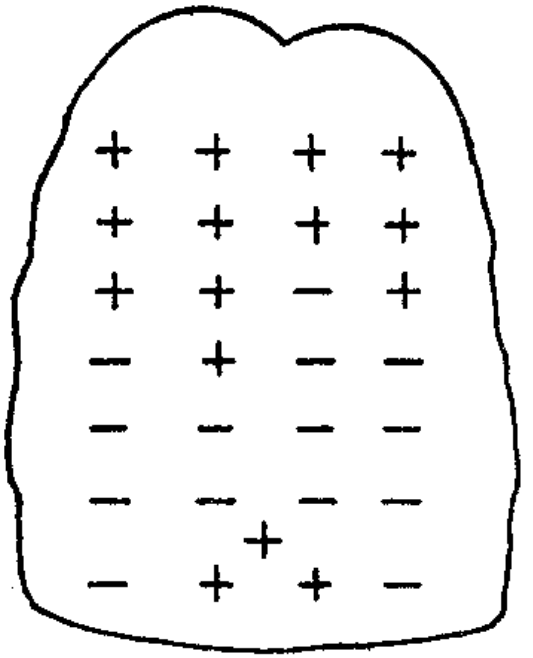
Types of Observed Charge Separation in Clouds



Cloud of Negative Polarity

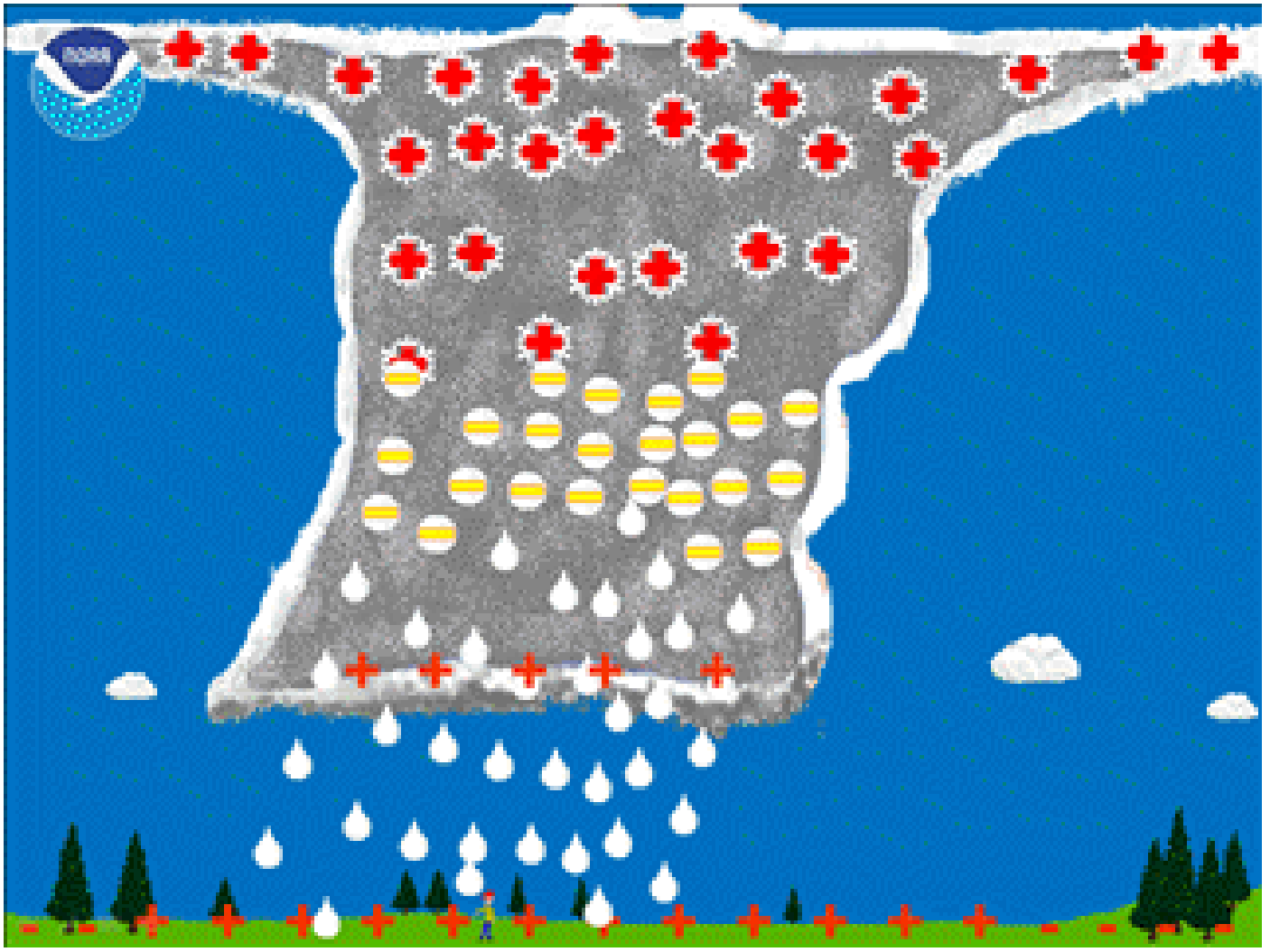


Cloud of Positive Polarity



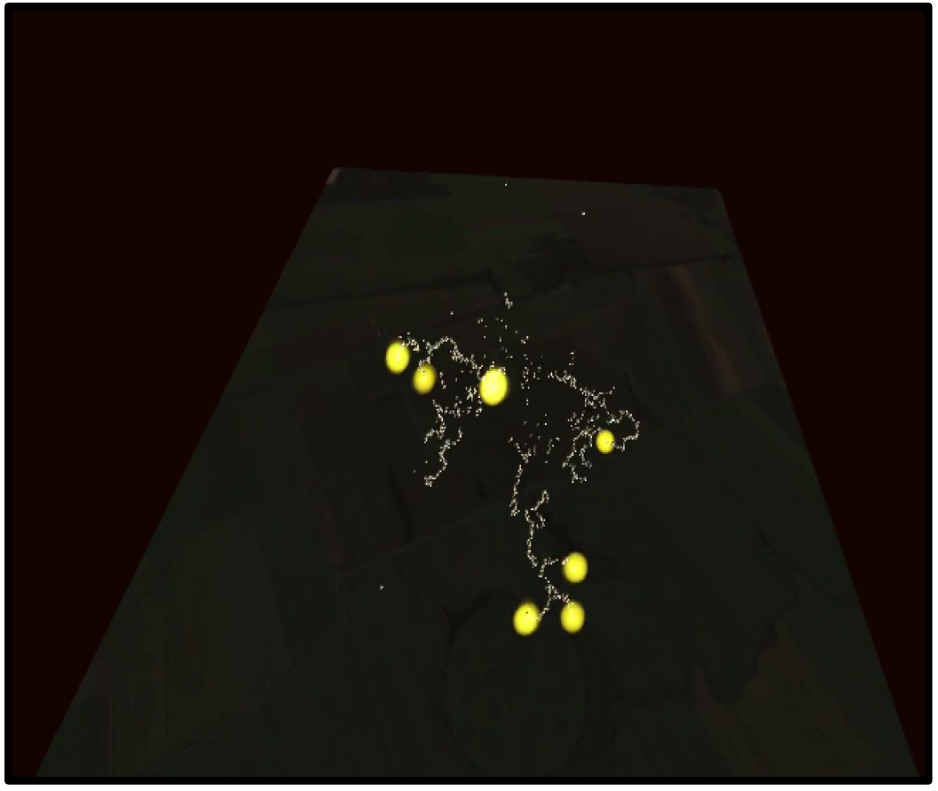
Cloud of Positive Polarity With Positive Charge in base

Typical Thunderstorm Charge Distribution



What is the Causes of Charge Separation?

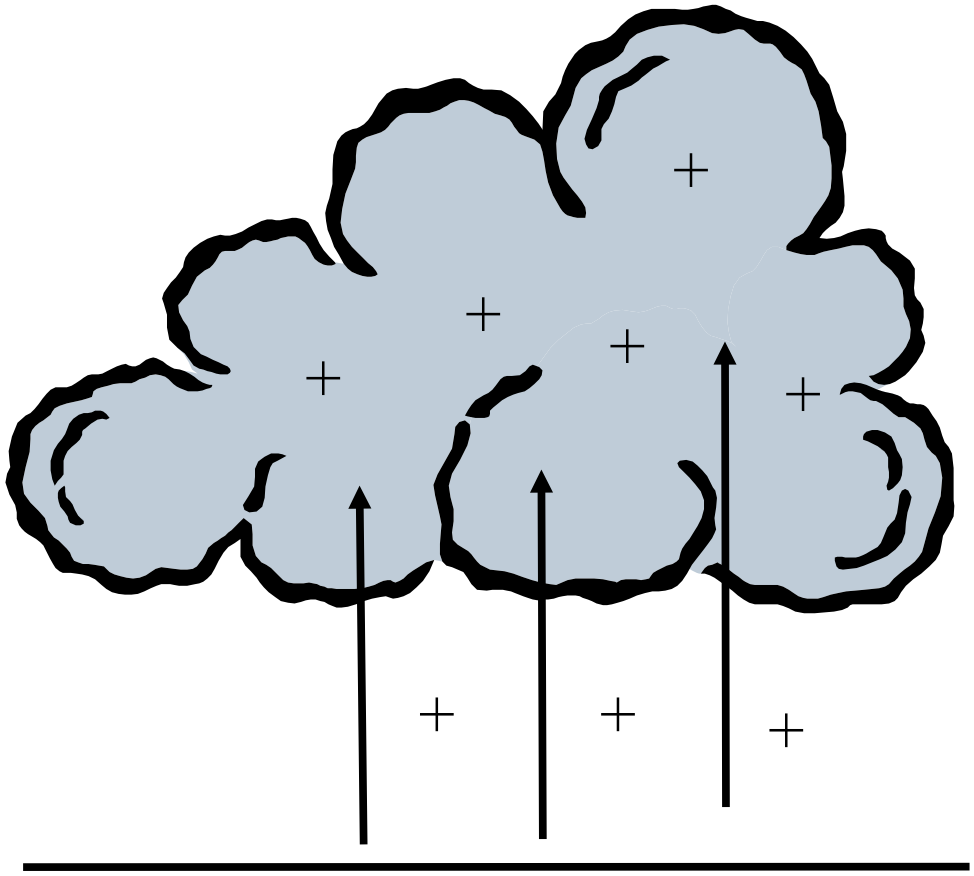
- A number of different theories.
- Actual effect is probably a combination of different mechanisms.
- We will talk about a couple:
  - **Convection**
  - **Thermoelectric Effects**



What does a theory mean in this context?

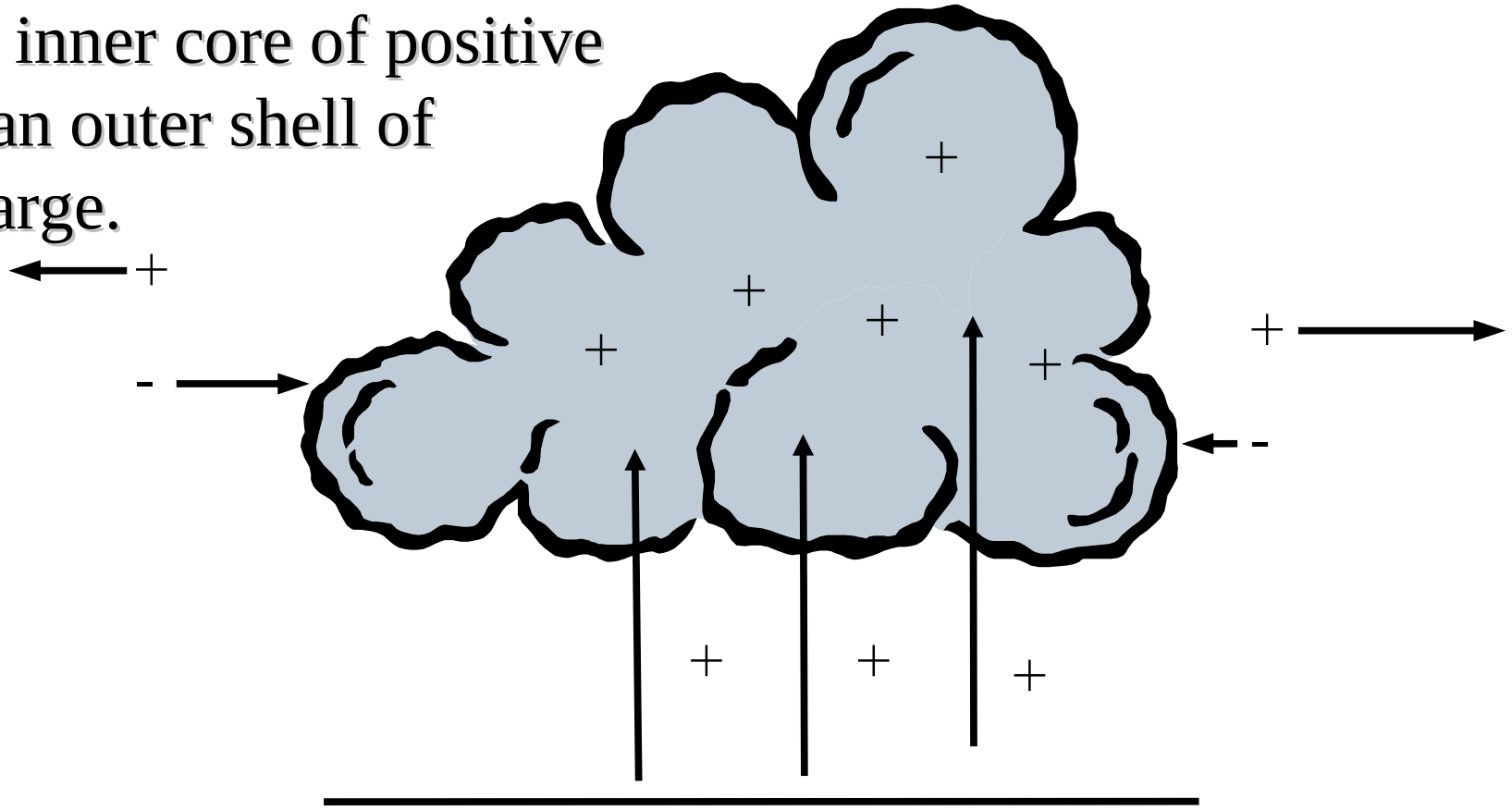
Convective Theory: Initial Cloud Formatin

- Under the fair weather electric field, it would be expect to find a net positive space charge near the surface of the earth.
- This air close to the earth's surface containing a positive space charge rises during convection to form a cloud.



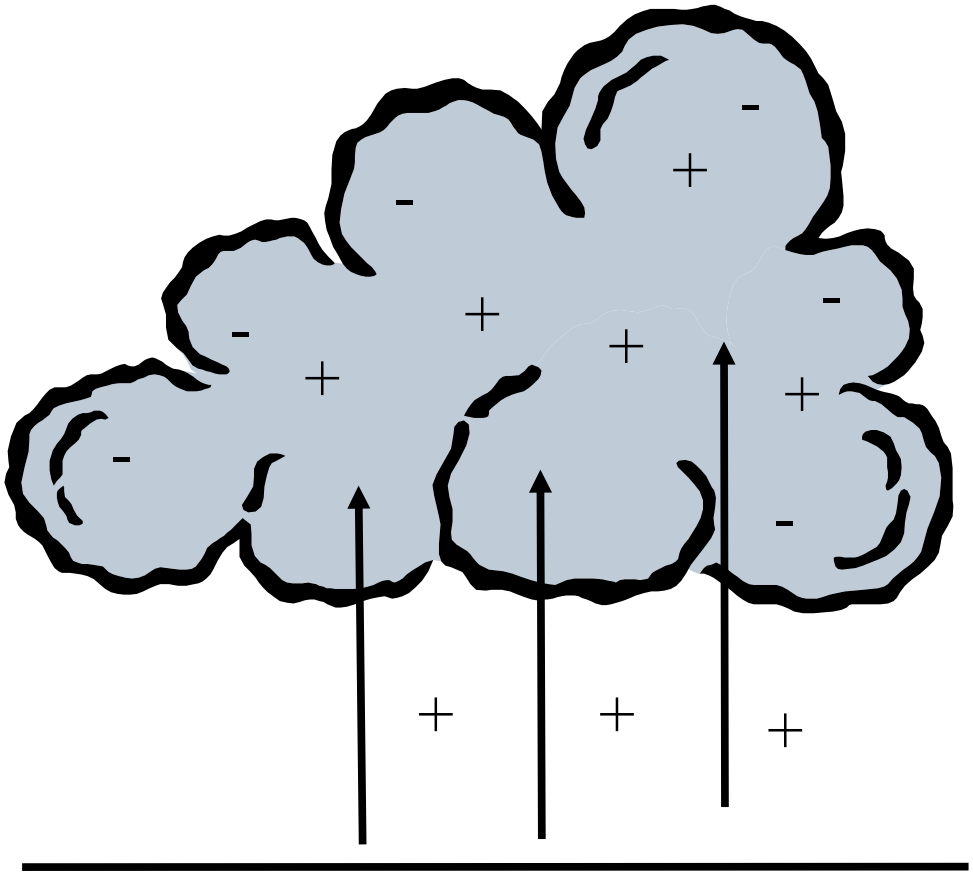
Convective Theory: Continued Growth

- As the cloud continues to grow, it develops an inner core of positive charge and an outer shell of negative charge.



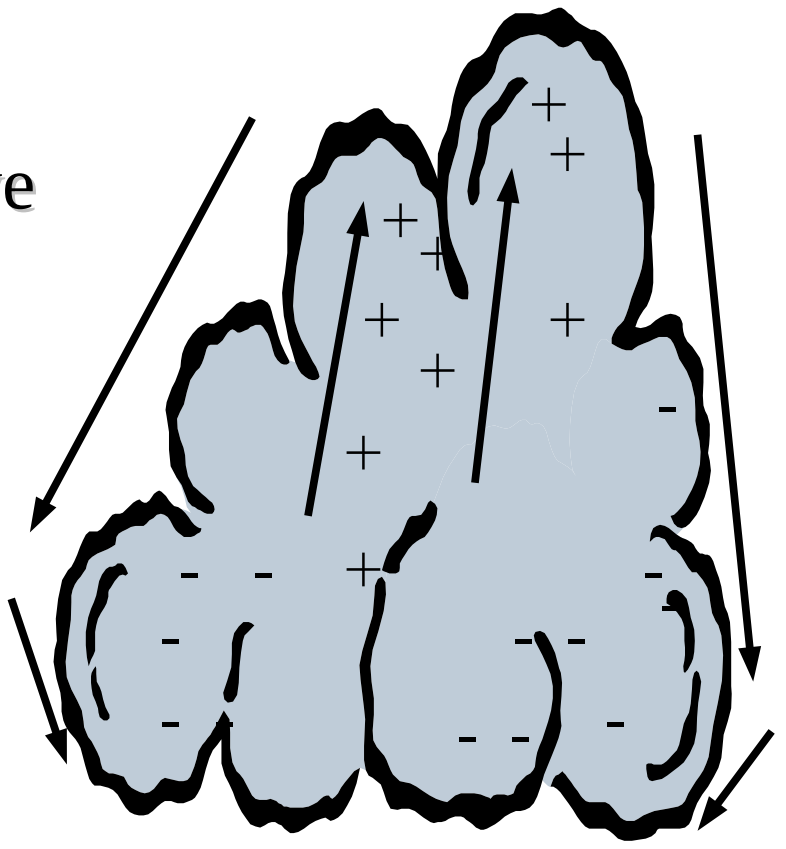
Convective Theory: Cloud Inside/Outside

- The inner portion of the cloud (the positive part) continues to rise, while the outer shell (the negative part) tends to move downward.



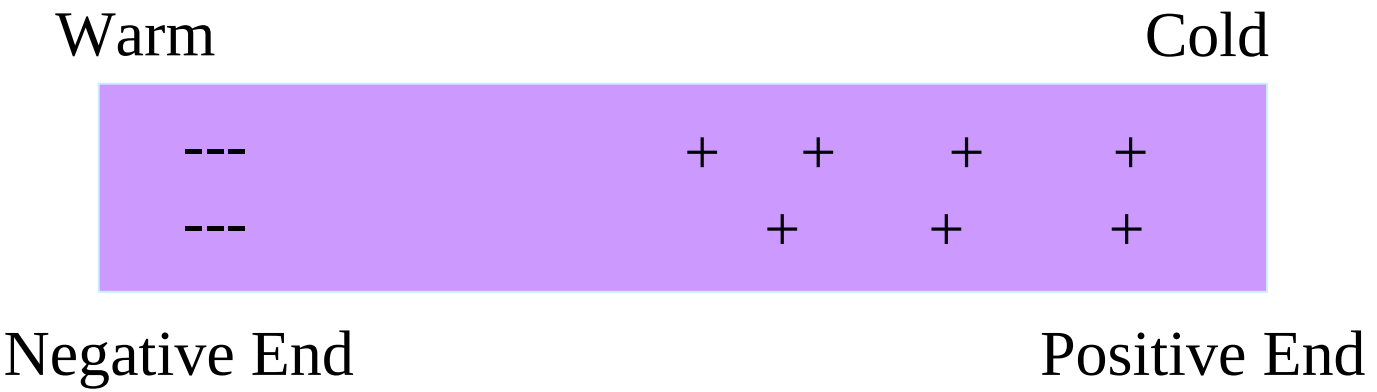
Convective Theory: End Result

- The end result is an accumulation of negative charge near the base of the cloud and an accumulation of positive charge in the upper portions of the cloud.



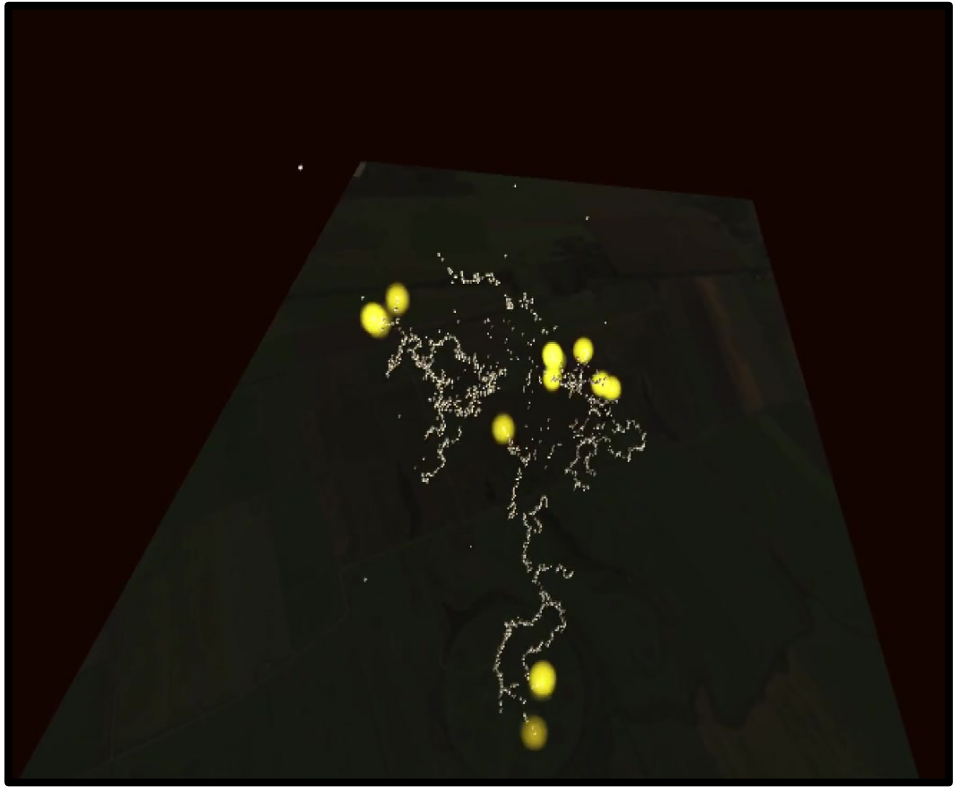
Thermoelectric Effects: Ice

- The water molecules in ice tend to dissociate into positive and negative ions, usually H+ and OH-.
- The positive ions have a greater mobility than the negative ions, by about a factor of 10.
- The higher the temperature, the greater the dissociation.



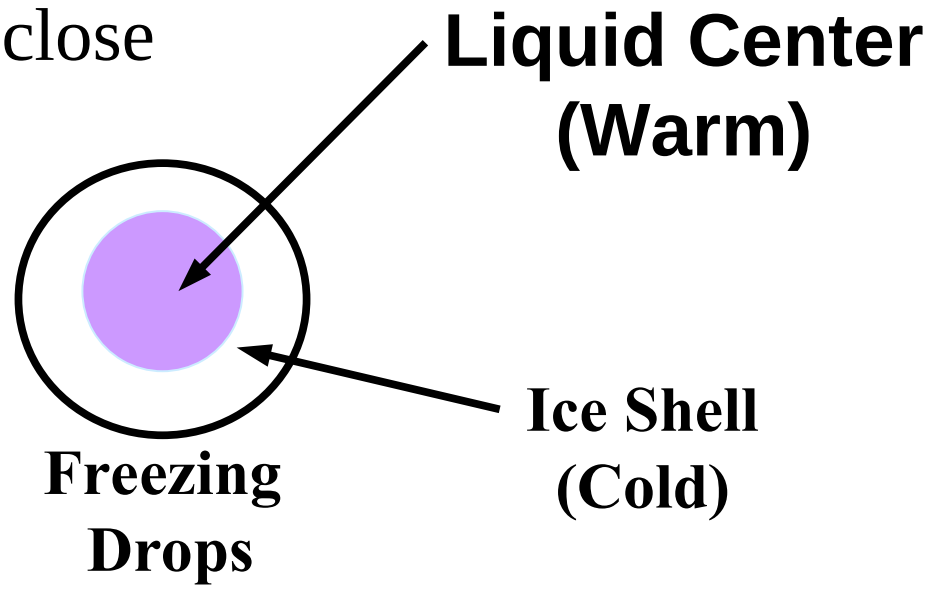
Net Result of Thermoelectric Effects

- The net result is that if there is a temperature gradient in the ice, the warm side will be negative and the cold side will be positive.
- Where will we find ice with a strong temperature gradient?
  - Freezing drops.



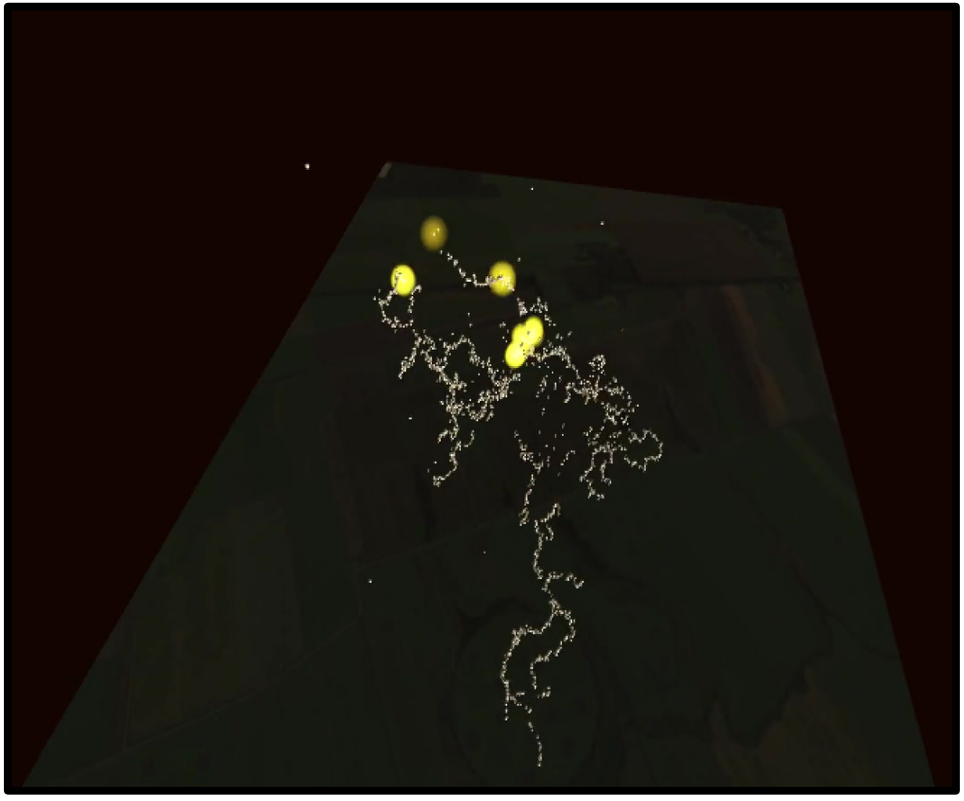
Freezing Drop: Temperature Distribution

- When the water drop freezes, the ice tends to form around the outside first, since it has to get rid of the latent heat of fusion to the air.
- The inside stays warm, which is close to 0 °C.



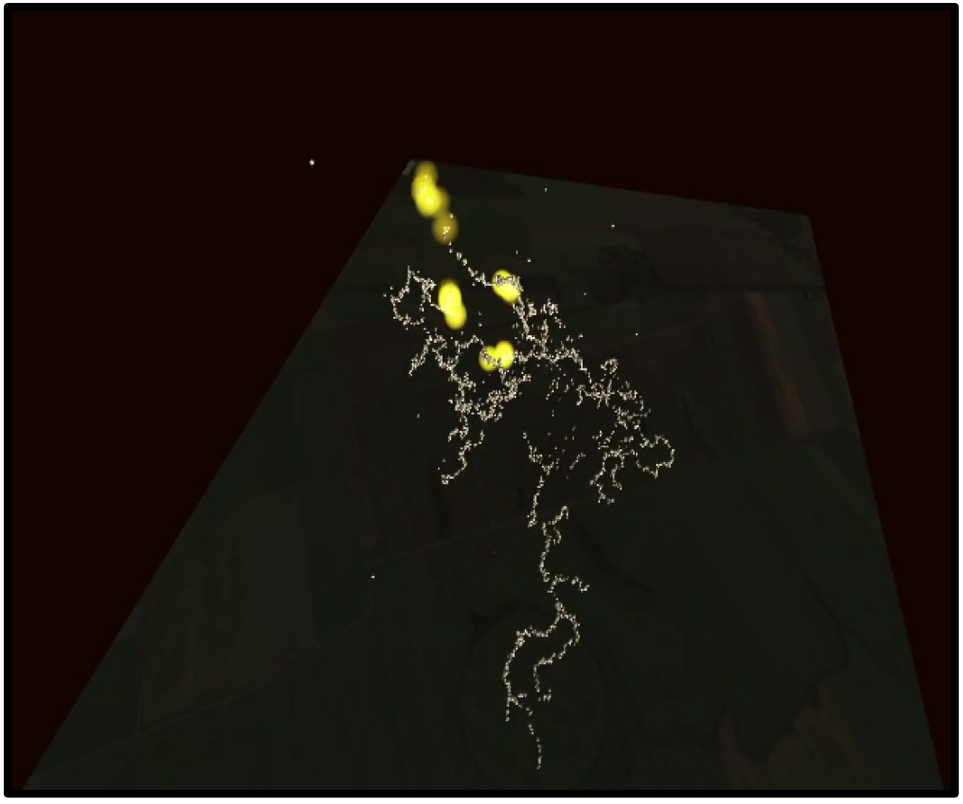
Thermoelectric Effects: End Result

- As the water freezes, it expands, which causes the ice shell to break and splinter.
- The small fragments of ice from the outside (having a positive charge) are carried upward in the updrafts while the bulk of the drop (having a negative charge) continues to fall or rises much more slowly in the updraft.



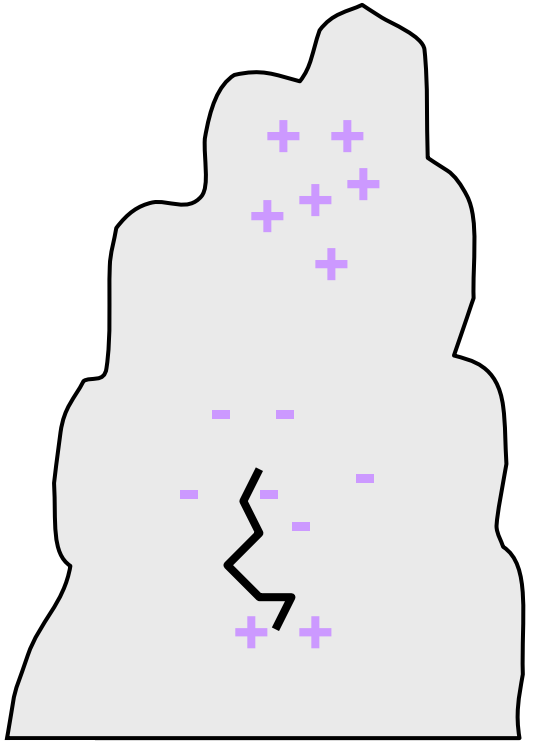
Other Theories of Electrification

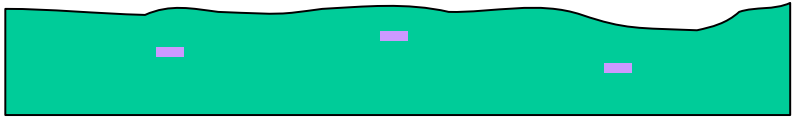
- There are a plethora of other electrification theories, some involving the thermoelectric properties of ice and other effects.
- Cloud ice is required.
- This is still an active area of research.



Components: Stepped Leader of Lightning

- Ionized Channel of Air
- Invisible or Faintly Luminous
- Branches
- Low Current (100 amps)





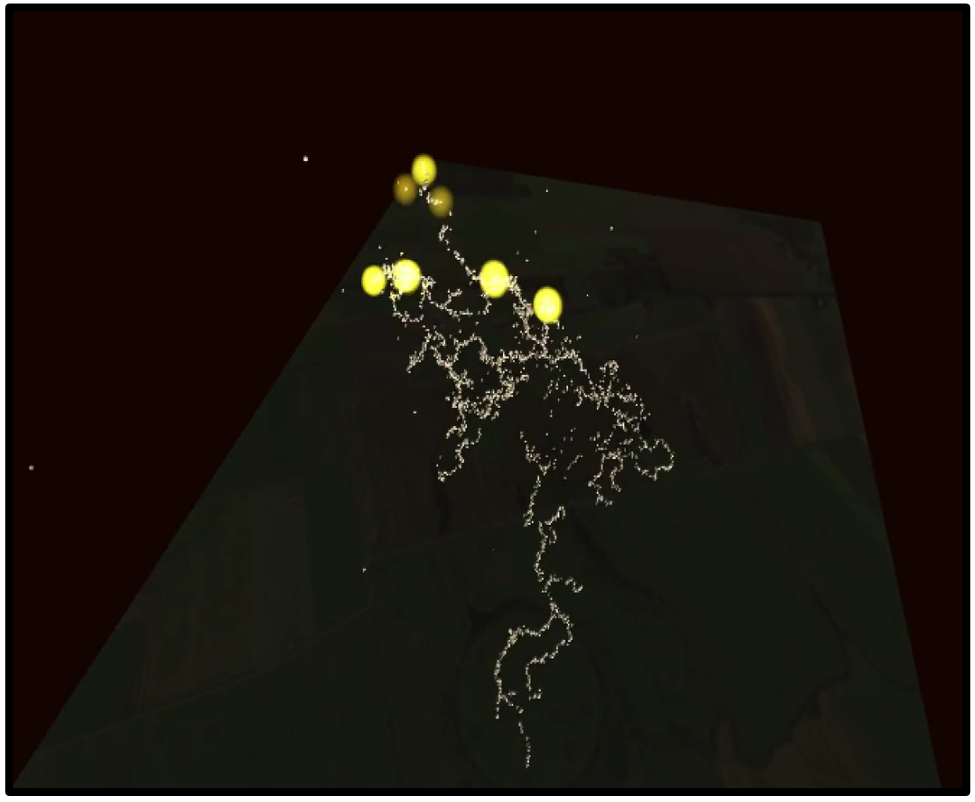
Components: Return Stroke of Lightning

- Connects Regions of Opposite Charge
- Visible
- High Current
  - Cloud to Ground
    - 20,000 amps
  - In Cloud
    - 2,000 amps
- Temperature 50,000 ^{o}F
- Pressure 10,000 mb

https://www.weathervideohd.tv/wvhd.php

Possible Lightning Modification Methods

- Decrease efficiency of charging mechanism.
- Increase conductivity of storm.
- Block the triggering mechanism.
- Discharge cloud at a controlled rate.



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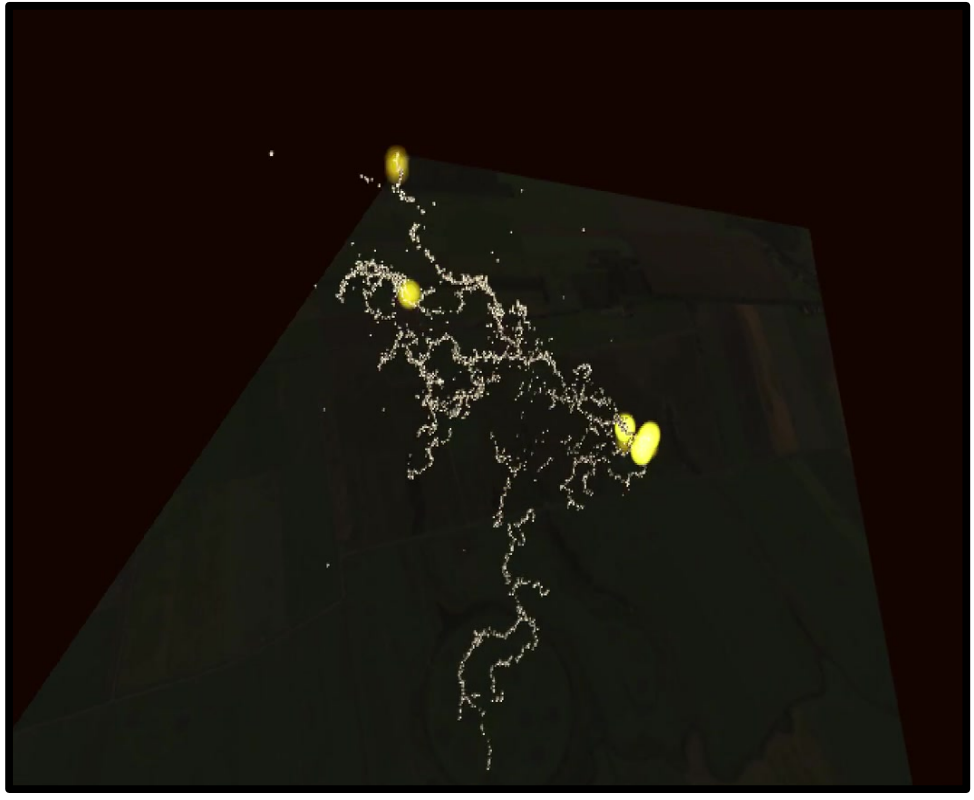
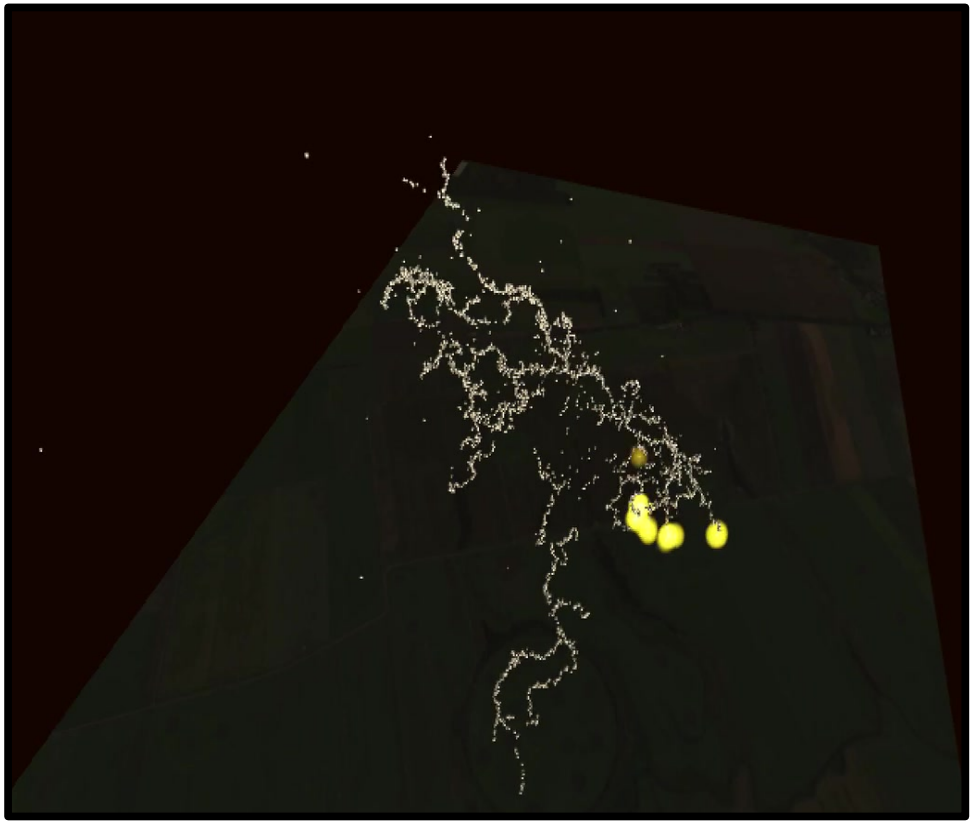


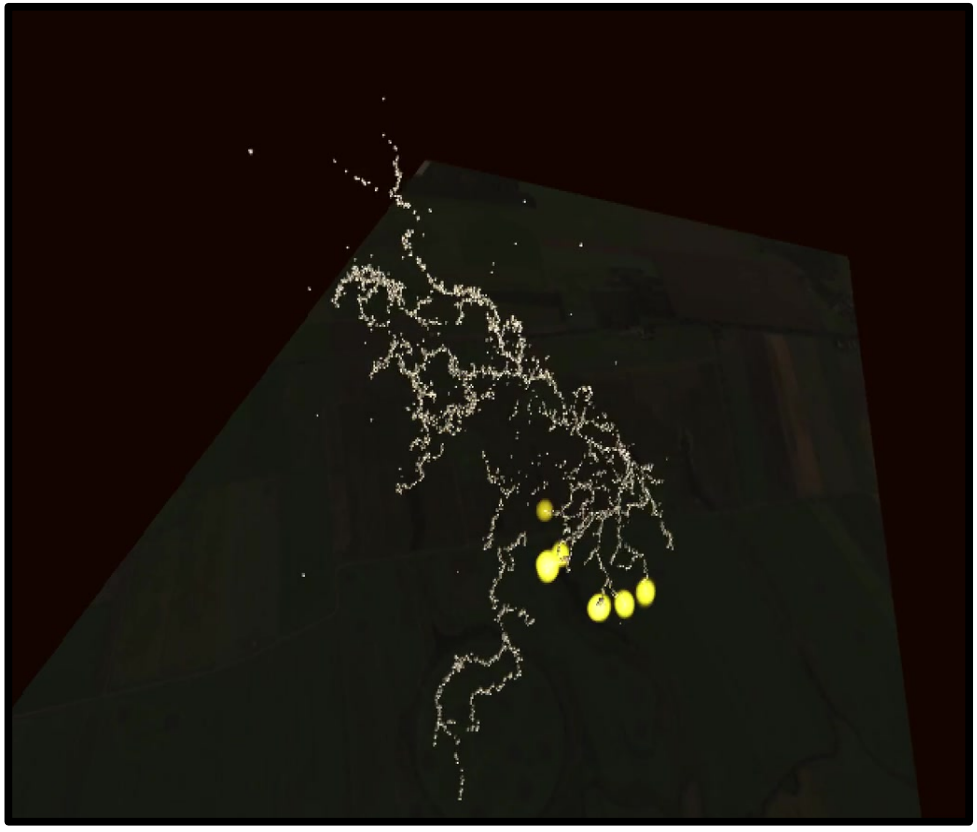
Modification of Lightning Experiment

- The only know weather modification experiment in which the object was to suppress lightning was Project Skyfire.
- Sponsored by the Forest Service and conducted in Missoula, Montana, in the late 60s and early 70s.



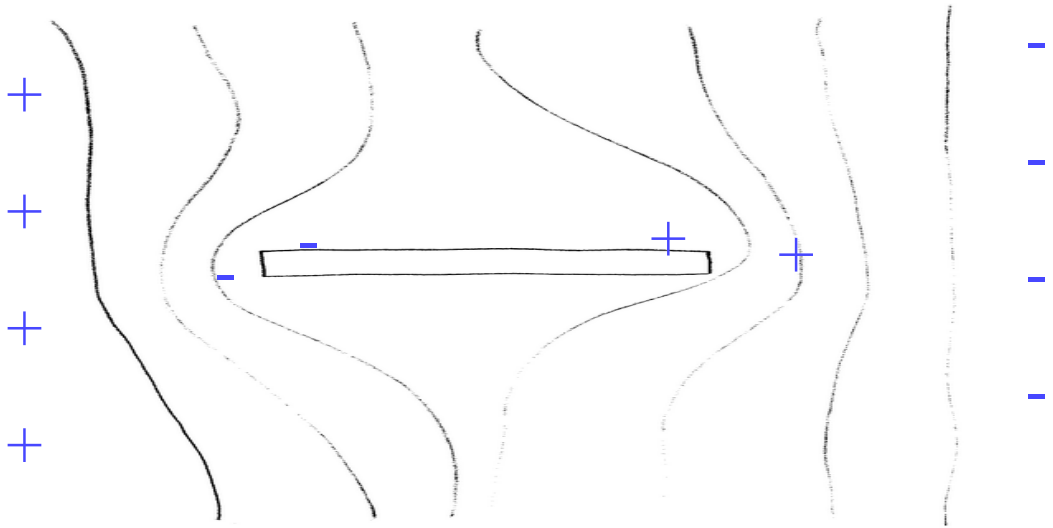
Why do charges Remain Separated in Cloud

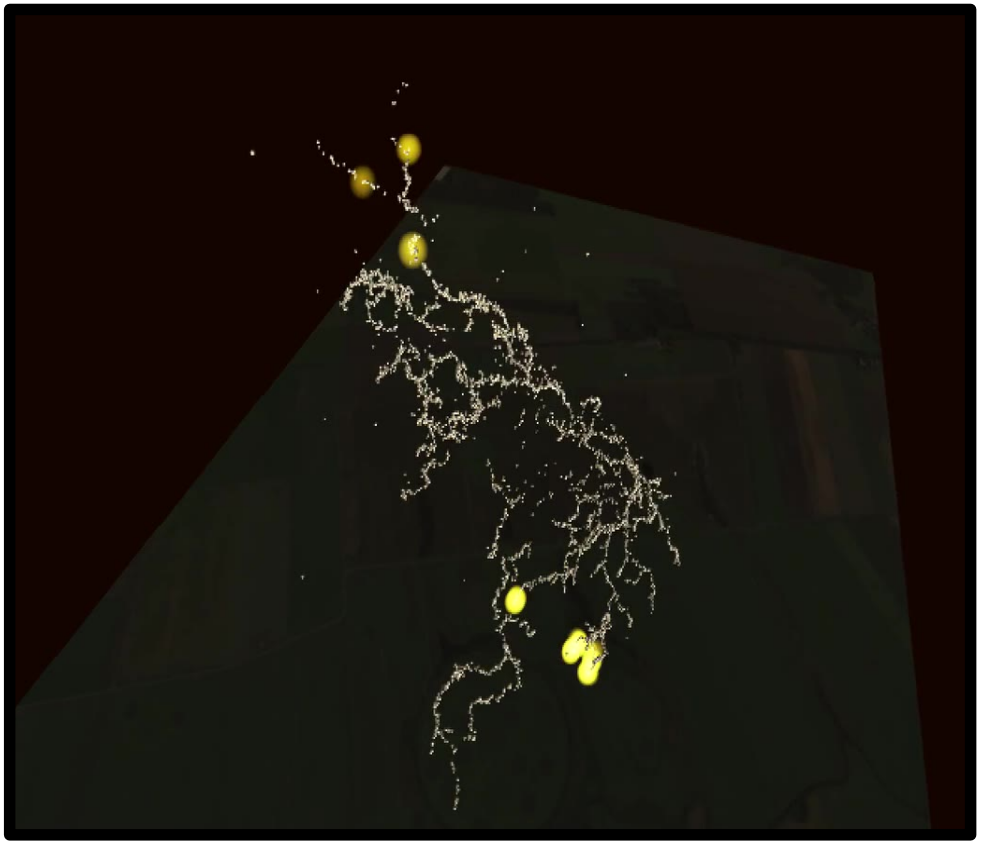
- Charges attach to the hydrometeors in the cloud and they move relatively slowly.
- Changes attached to larger particles move more slower.
- If the charges were not attached (free ions in the air), the current would flow much more rapidly and the charges (positive and negative centers) would neutralize one another.



How to get Free Ions in the Cloud?

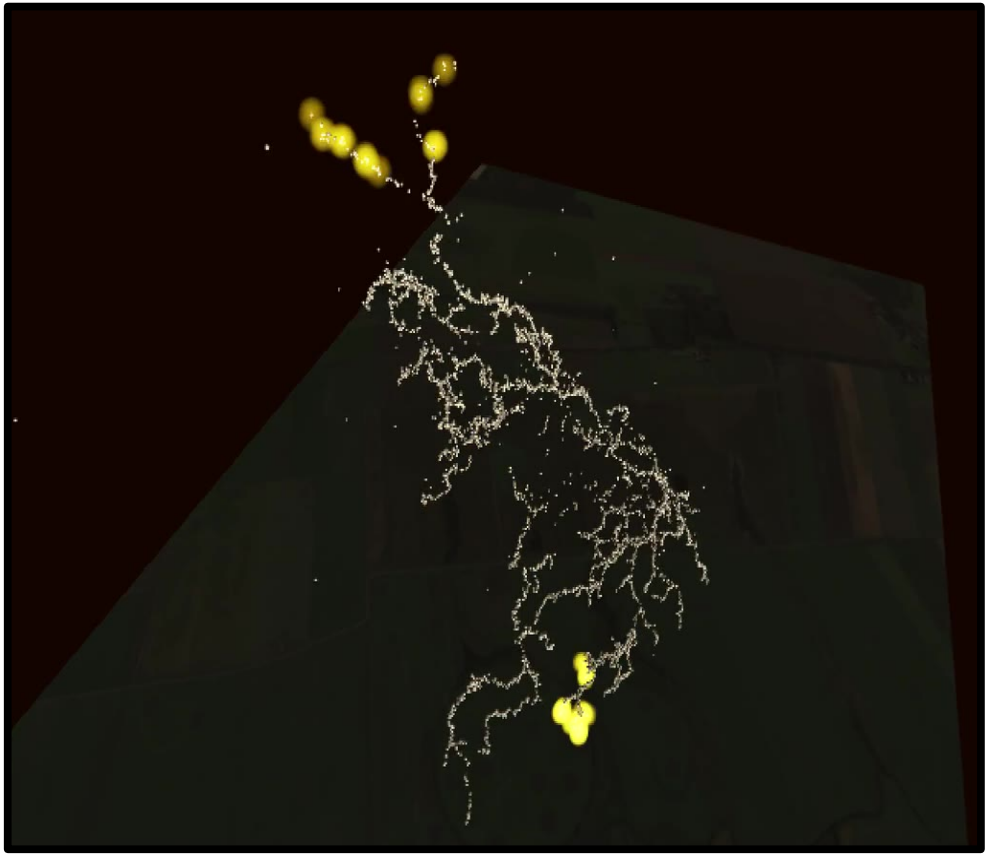
- If the fields are high enough, we will get corona discharge to occur.





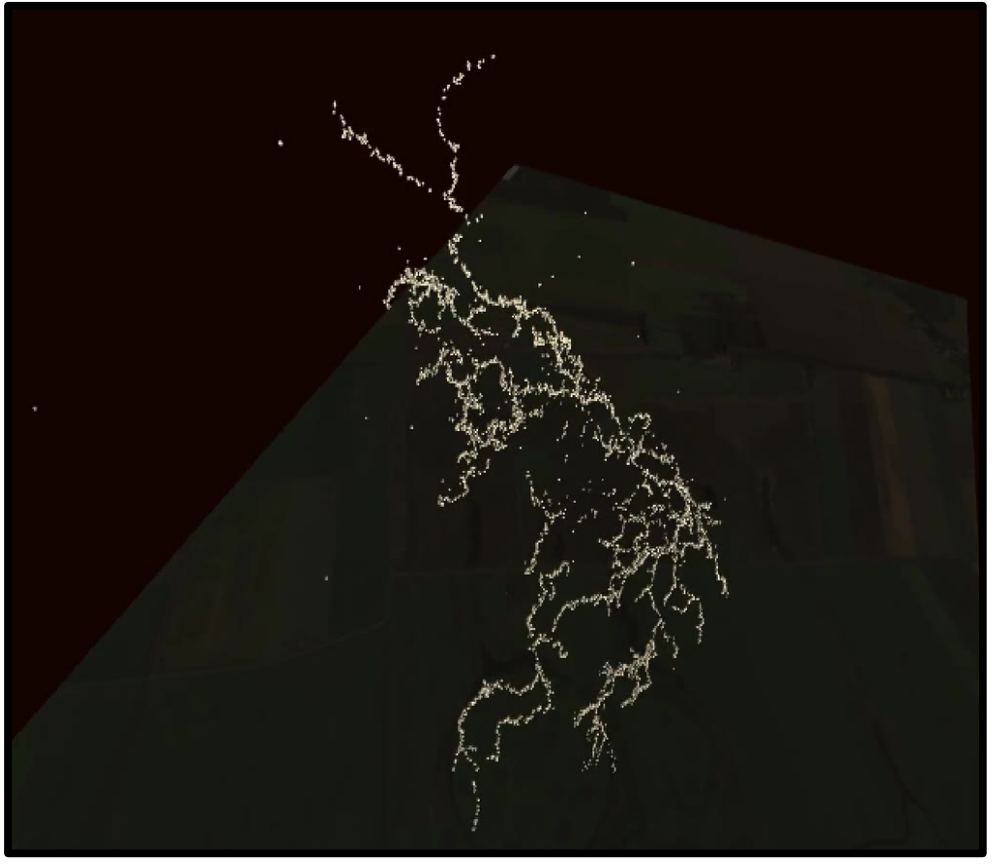
Generation of Free Ions in the Cloud

- Adding pointed objects into the cloud should produce free ions and should reduce the amount of charge separation in the cloud
  - Radar chaff?
  - Ice crystals?
    - Settled on ice crystals.
    - Seeded with AgI.



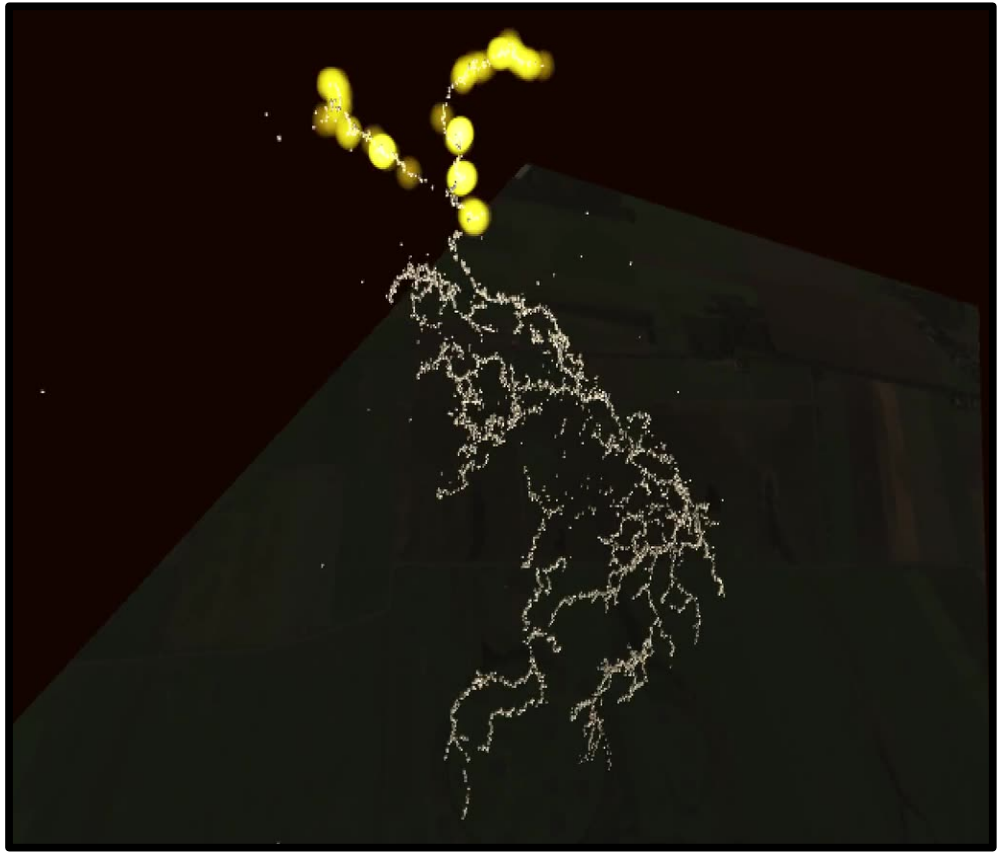
Generation of Free Ions in the Cloud

- Used a variety of seeding techniques and quantities of AgI.
- Concluded that the largest amounts of AgI was the most effective.
- As the methods employed varied, it was open to criticism from the statisticians.



Generation of Free Ions in the Cloud

- Reduction in cloud to ground lightning of 66%.
- Reduction in cloud to cloud lightning of 50%.
- Overall reduction in lightning discharges of 54%.



Triggered Lightning Video