The Influence of Conductivity Disturbances on the Global Electric Circuit

WACCM Meeting 2/28/2017

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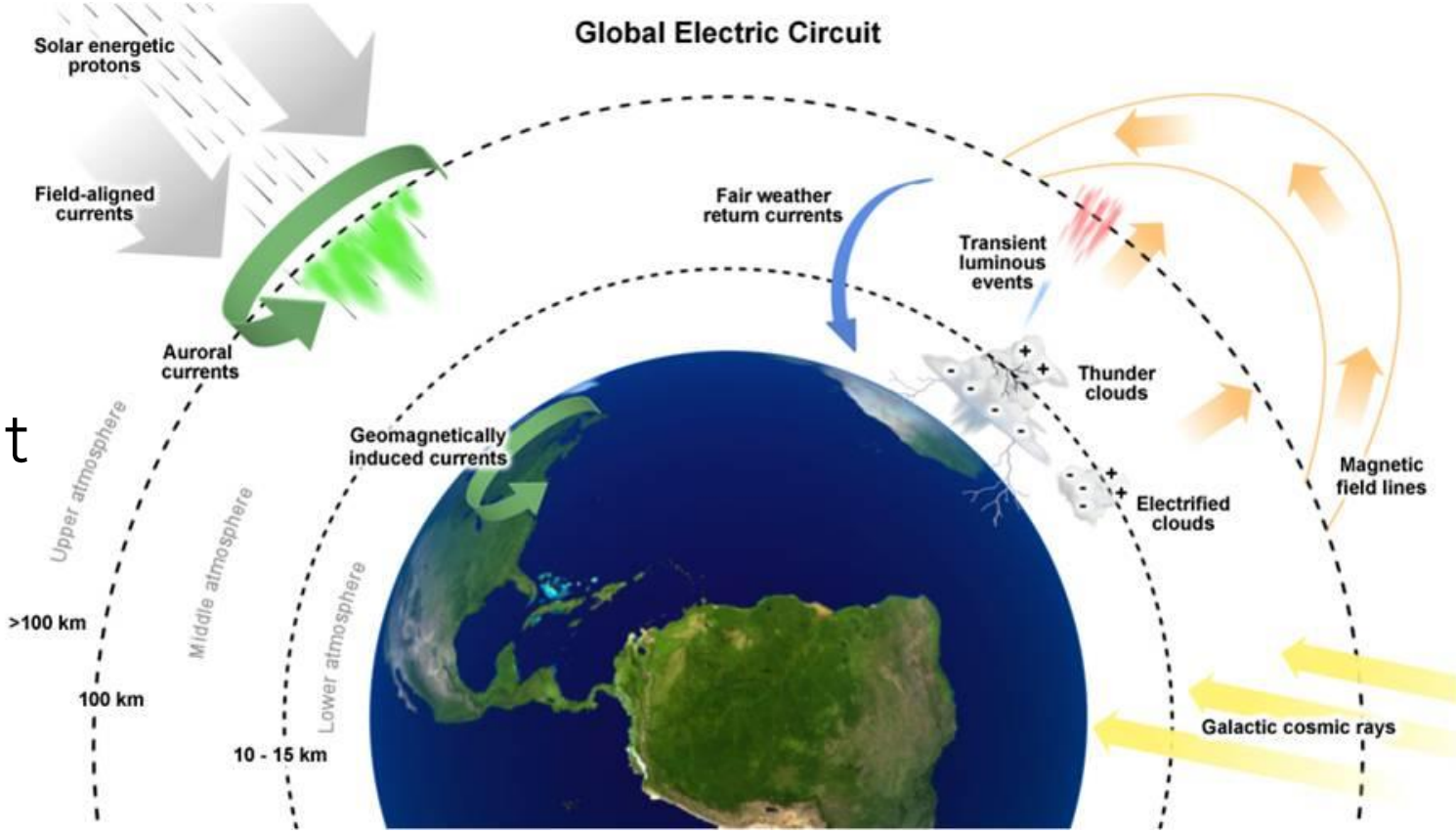
Outline

- Overview of the Global Electric Circuit
- Global Model: WACCM-GEC
  - Conductivity
  - Sources
  - Magnetosphere
- WACCM-GEC Experiments
  - Solar cycle
  - Volcanic eruptions
- Summary

GEC Background

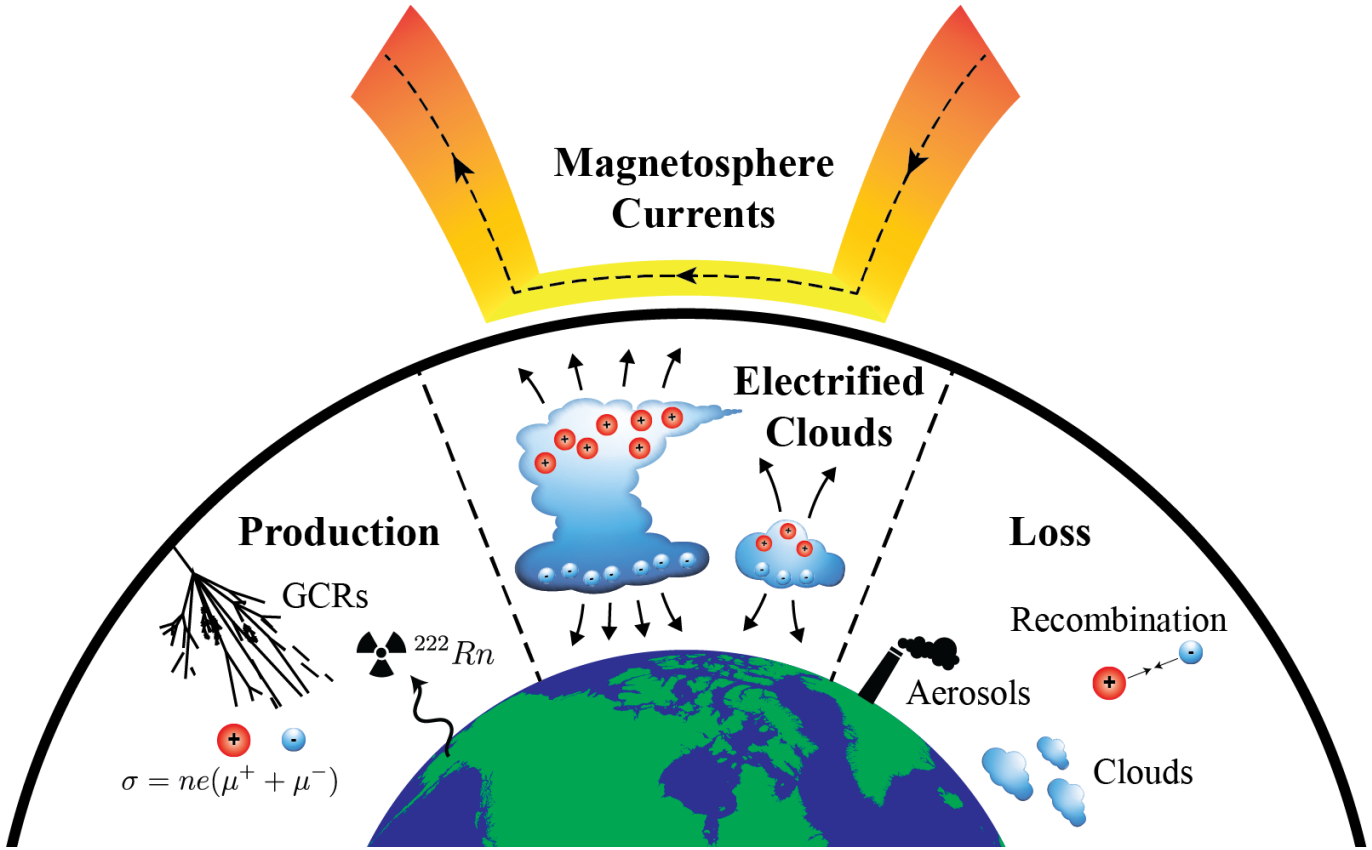
- Thunderstorms create a potential difference between the ground and ionosphere (capacitor)
- Current flow within the atmosphere is dependent upon the conductivity
- Previous models require limiting assumptions on conductivity and source distributions



WACCM-GEC Components

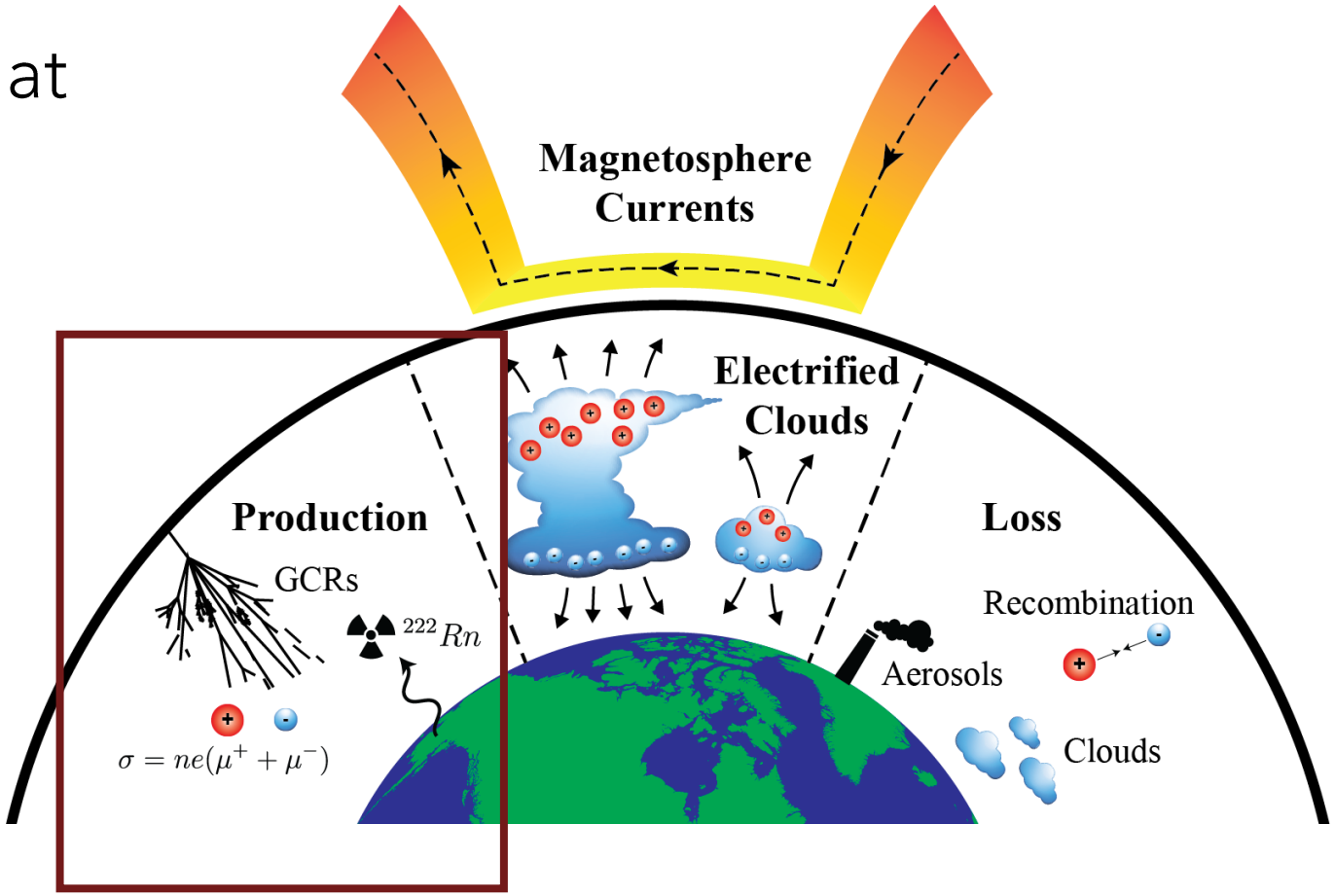
- Conductivity
- Sources
- Ionospheric Potential
- Current solver

$$\nabla \cdot \sigma \nabla \phi = S$$



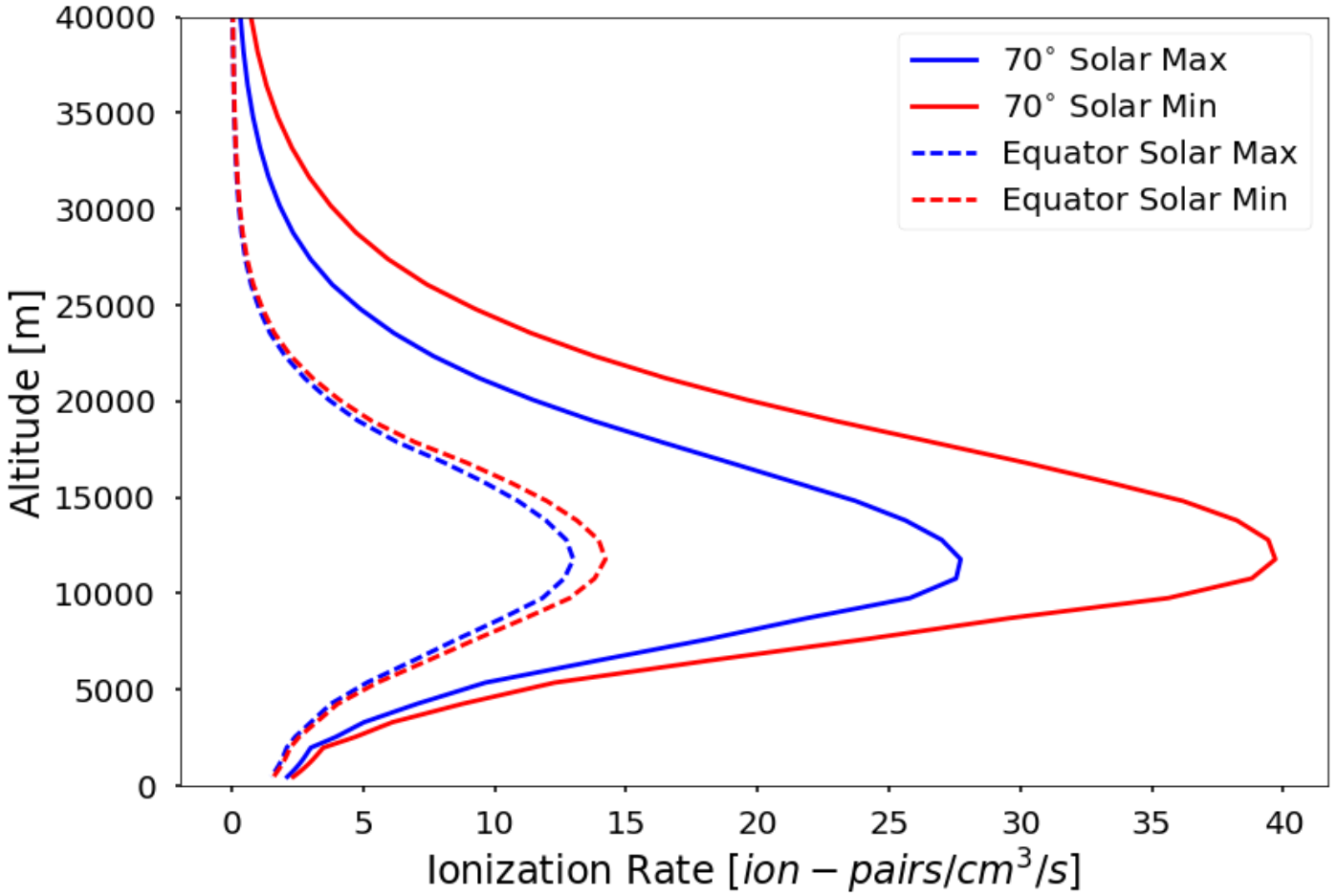
Making the atmosphere conductive

- Highly energetic particles that create ion pairs
- Galactic cosmic rays (GCRs)
- Solar Proton Events
- Radioactivity/Radon



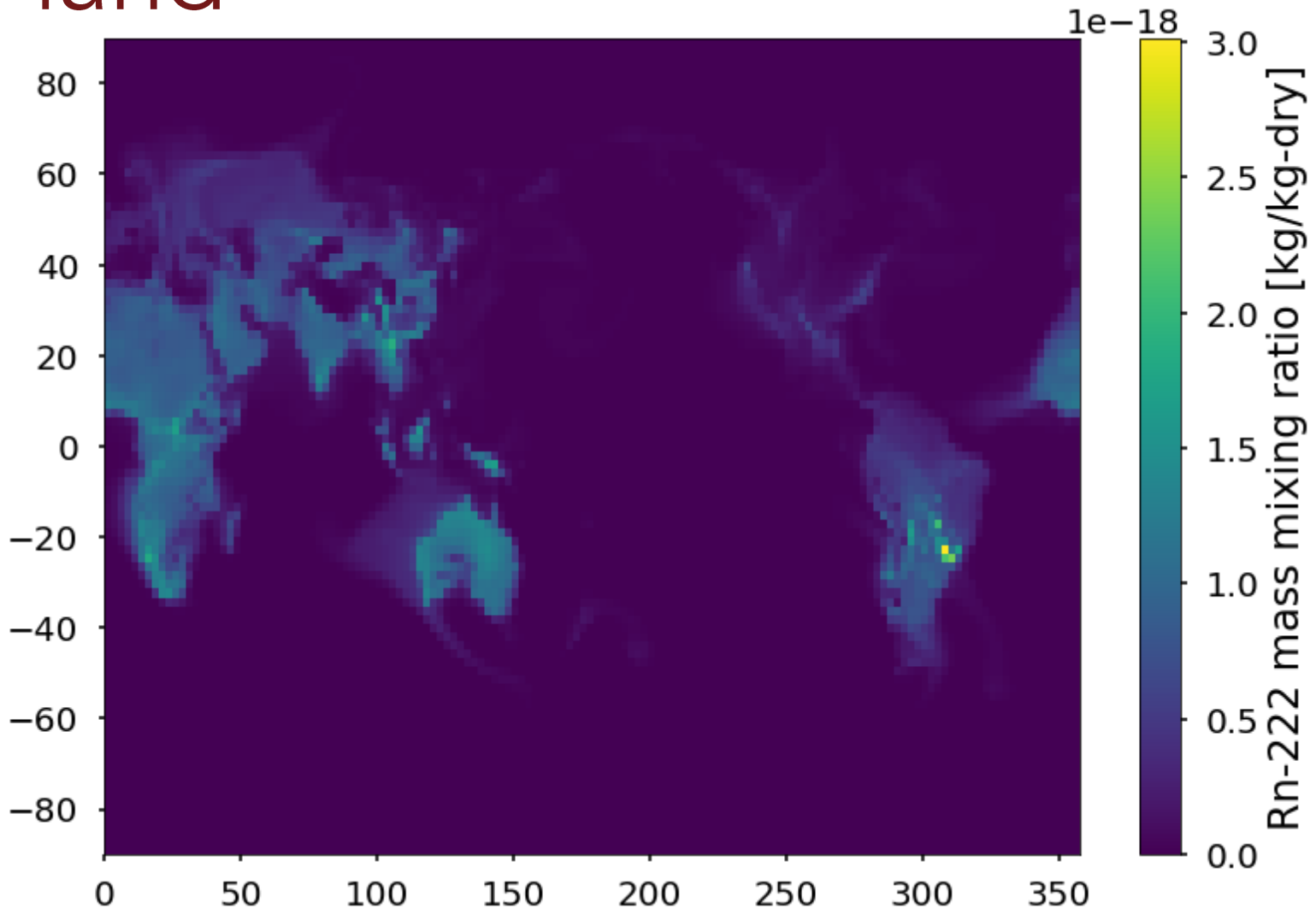
GCR flux in the lower atmosphere

- Anti-correlated with solar cycle (sun's magnetic field)
- Dependence on geomagnetic latitude (Earth's magnetic field)
- Use CMIP6 daily solar-forcing dataset to create ion-pair



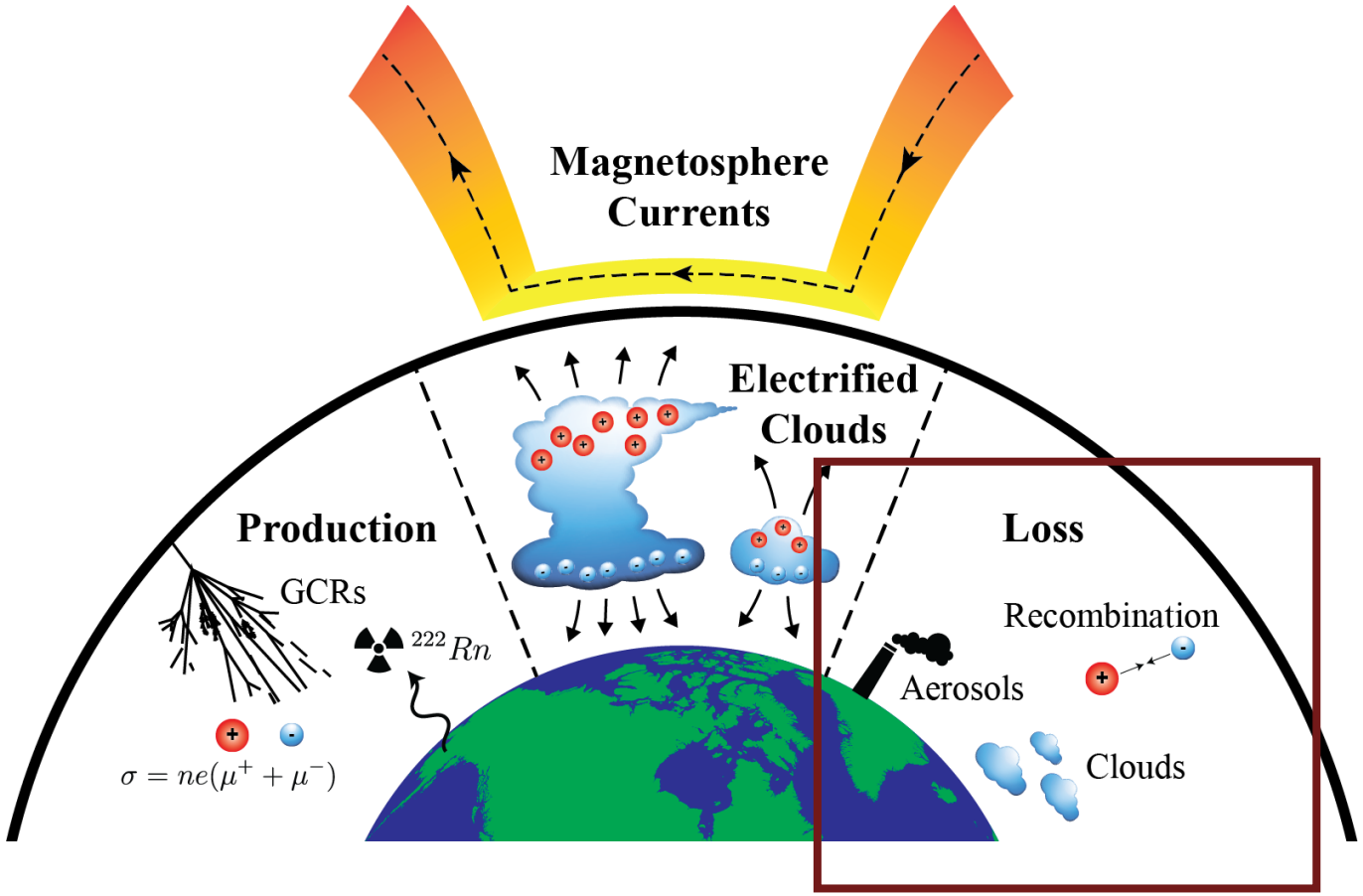
Radon flux from land

- New advected constituent within the model
- Dominant ionization source in the boundary layer
- Only emitted over land surfaces



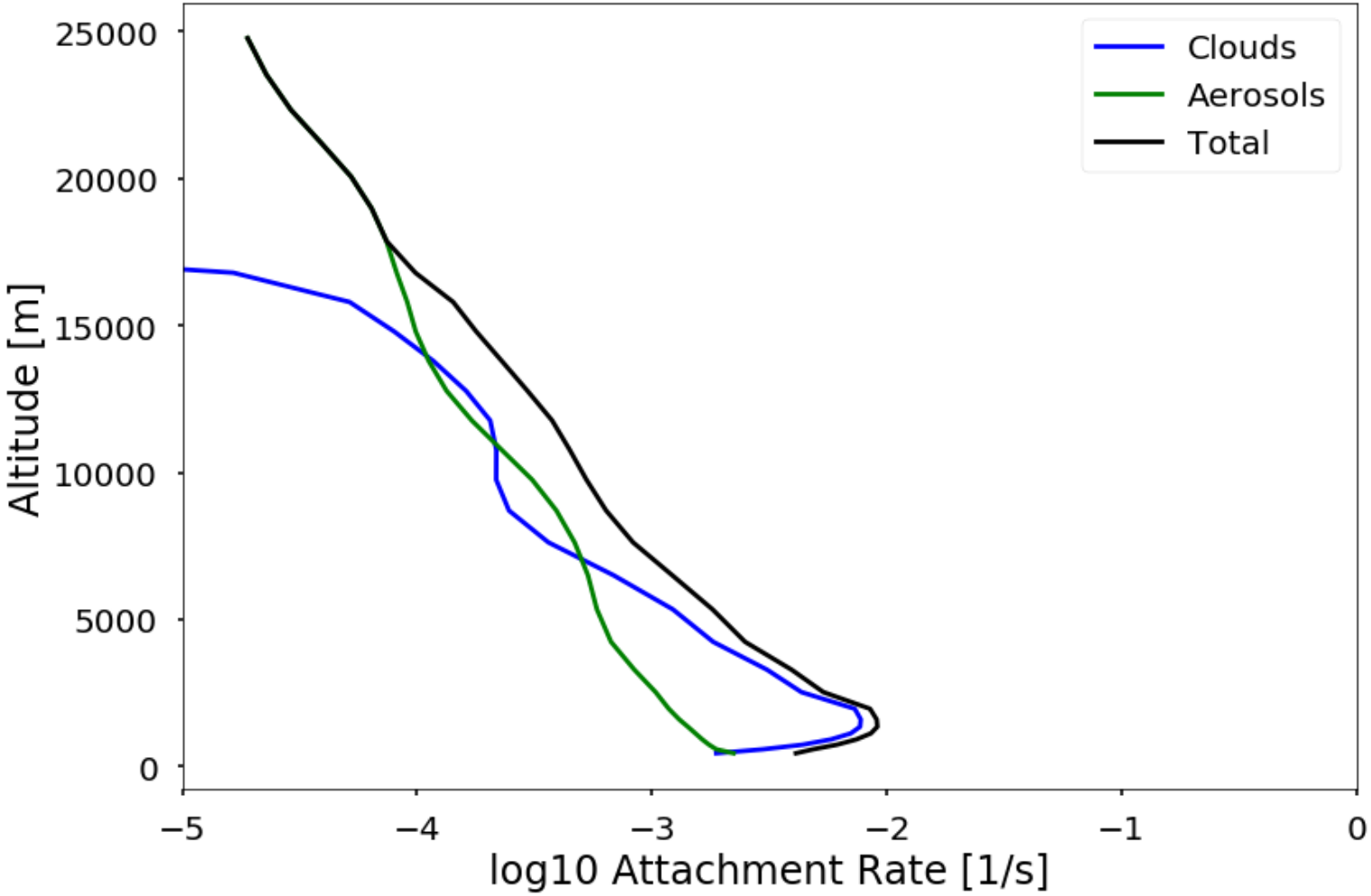
Making the atmosphere more resistive

- Ions can attach to larger, slower particles
- Recombination
- Aerosols
- Clouds



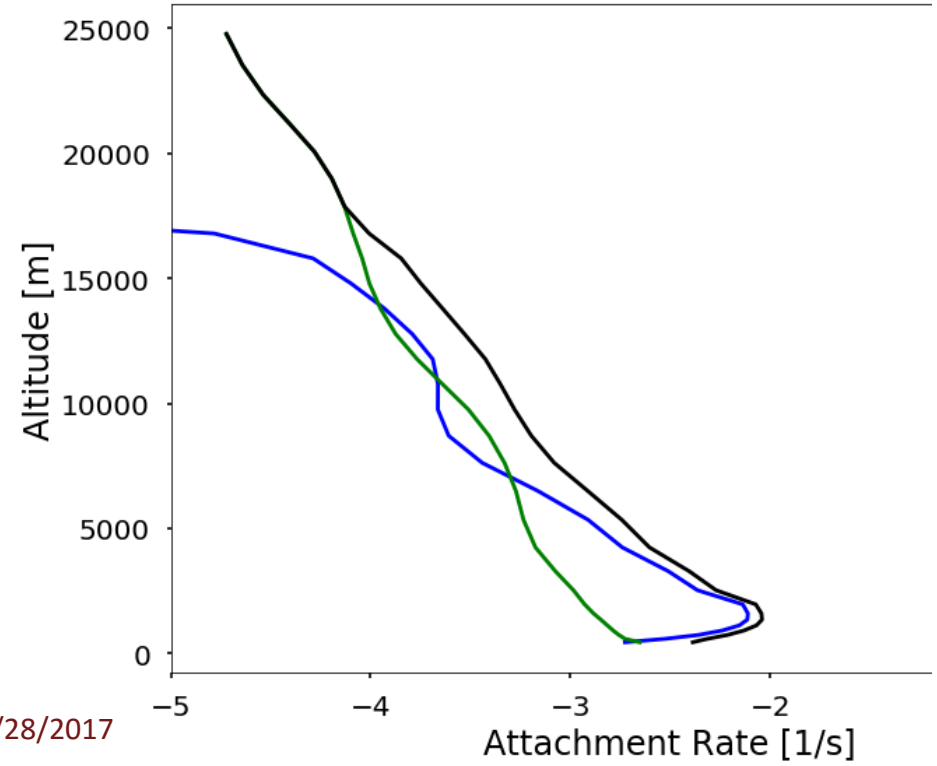
Aerosols are the dominant loss mechanism in the middle atmosphere

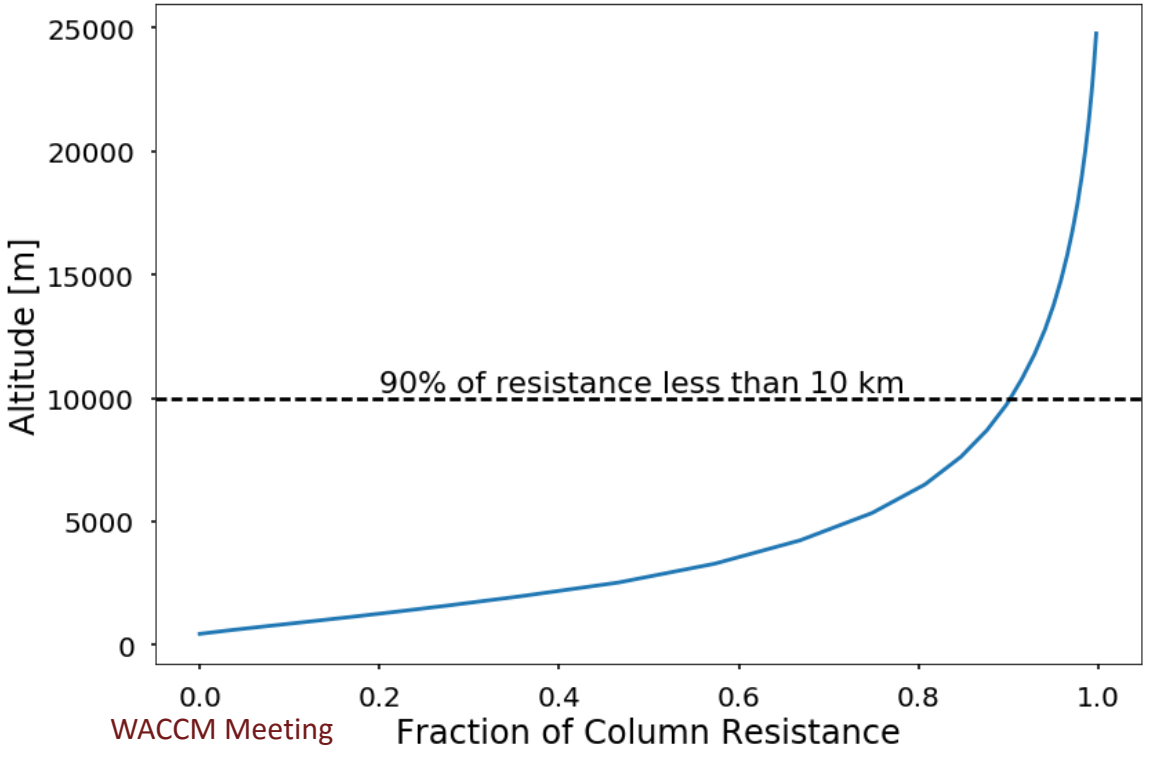
- Attachment rate for aerosols is based on the aerosol size and number concentration (Hoppel/Frick 1986)
- Obtain MAM4 aerosol concentrations within the code



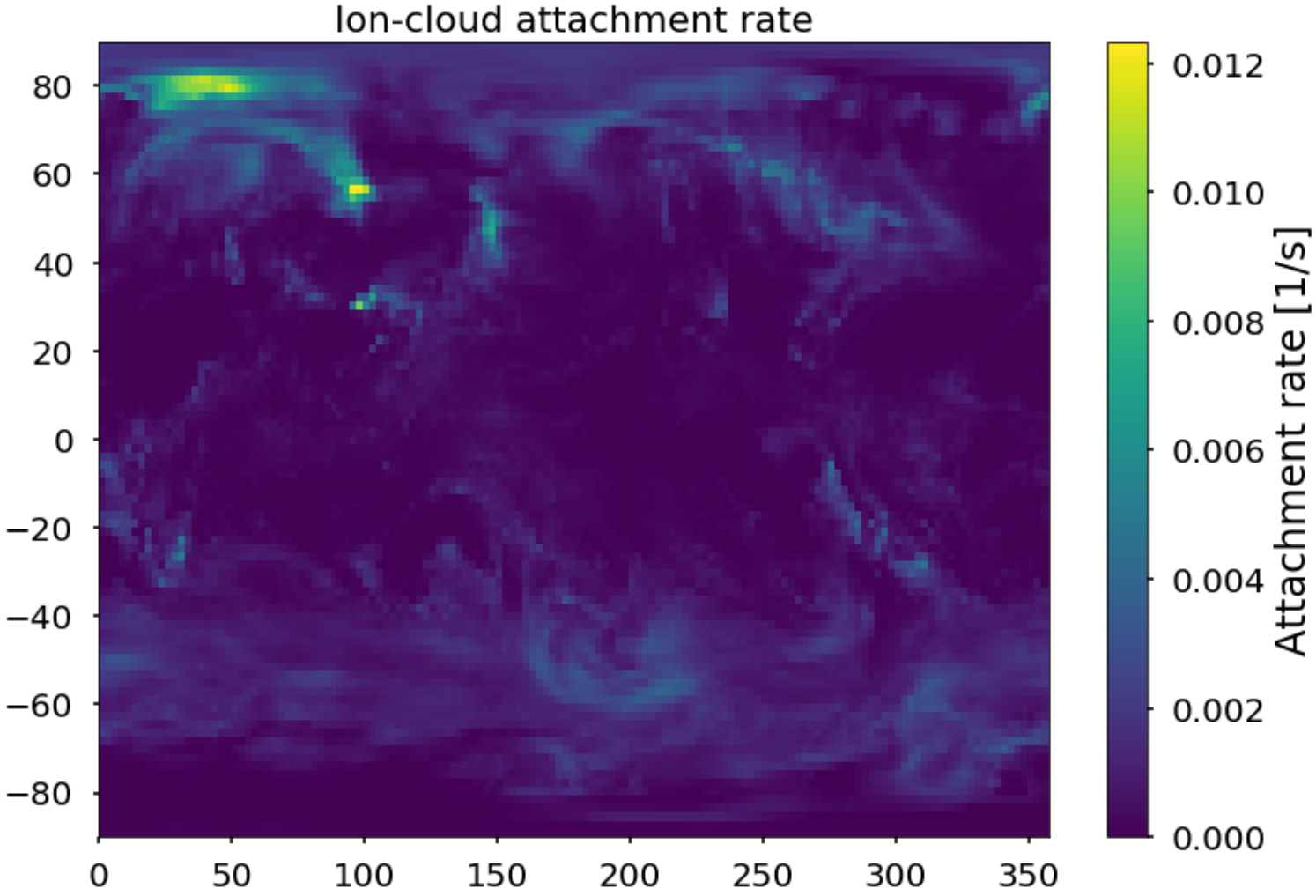
Clouds act as a significant resistor in the circuit at low altitudes

- Attachment to water droplets (Pruppacher/Klett 1998)
- Utilize the 2-moment microphysics to determine the droplet concentration and size distribution



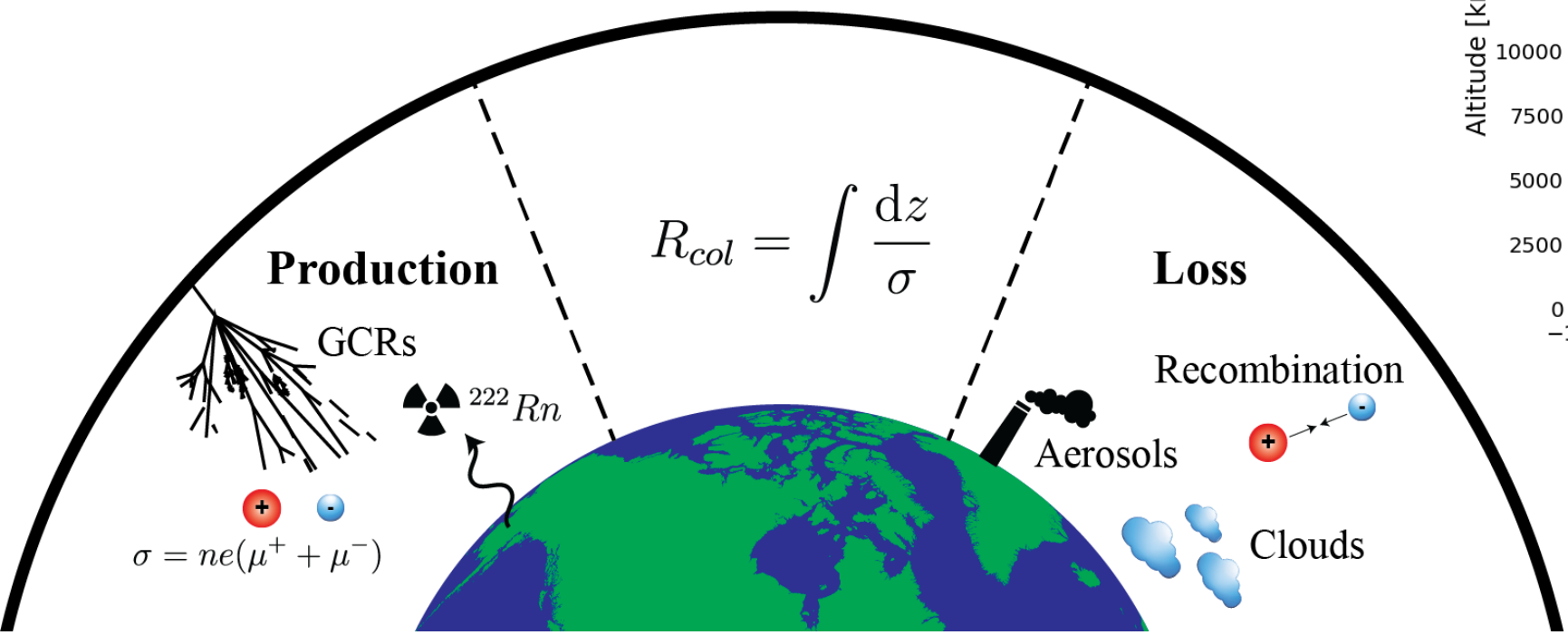


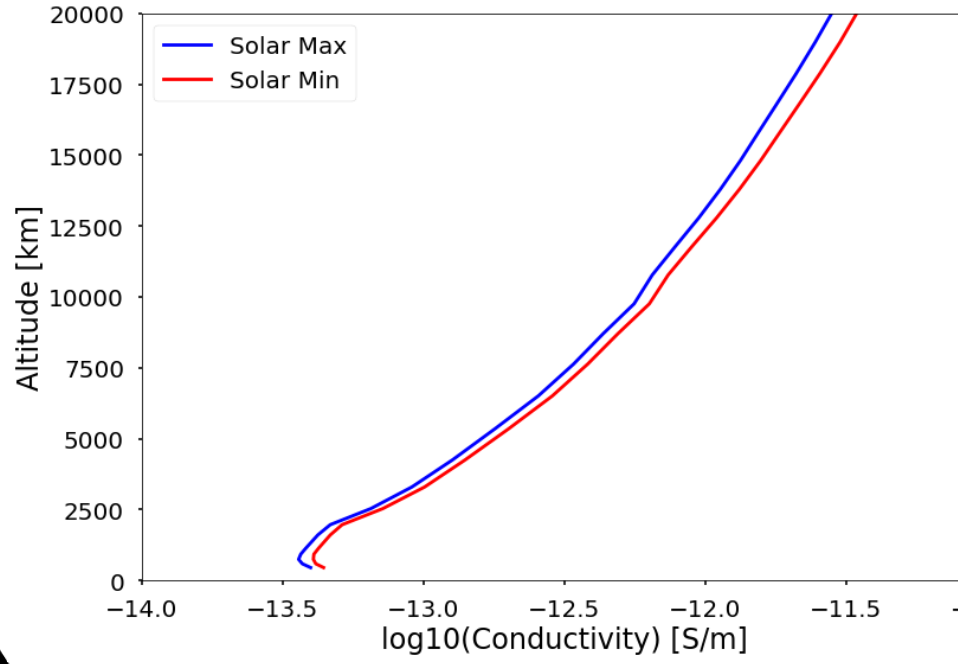
Clouds cover the earth causing significant increases in column resistance



Find the total resistance of the atmosphere through the conductivity

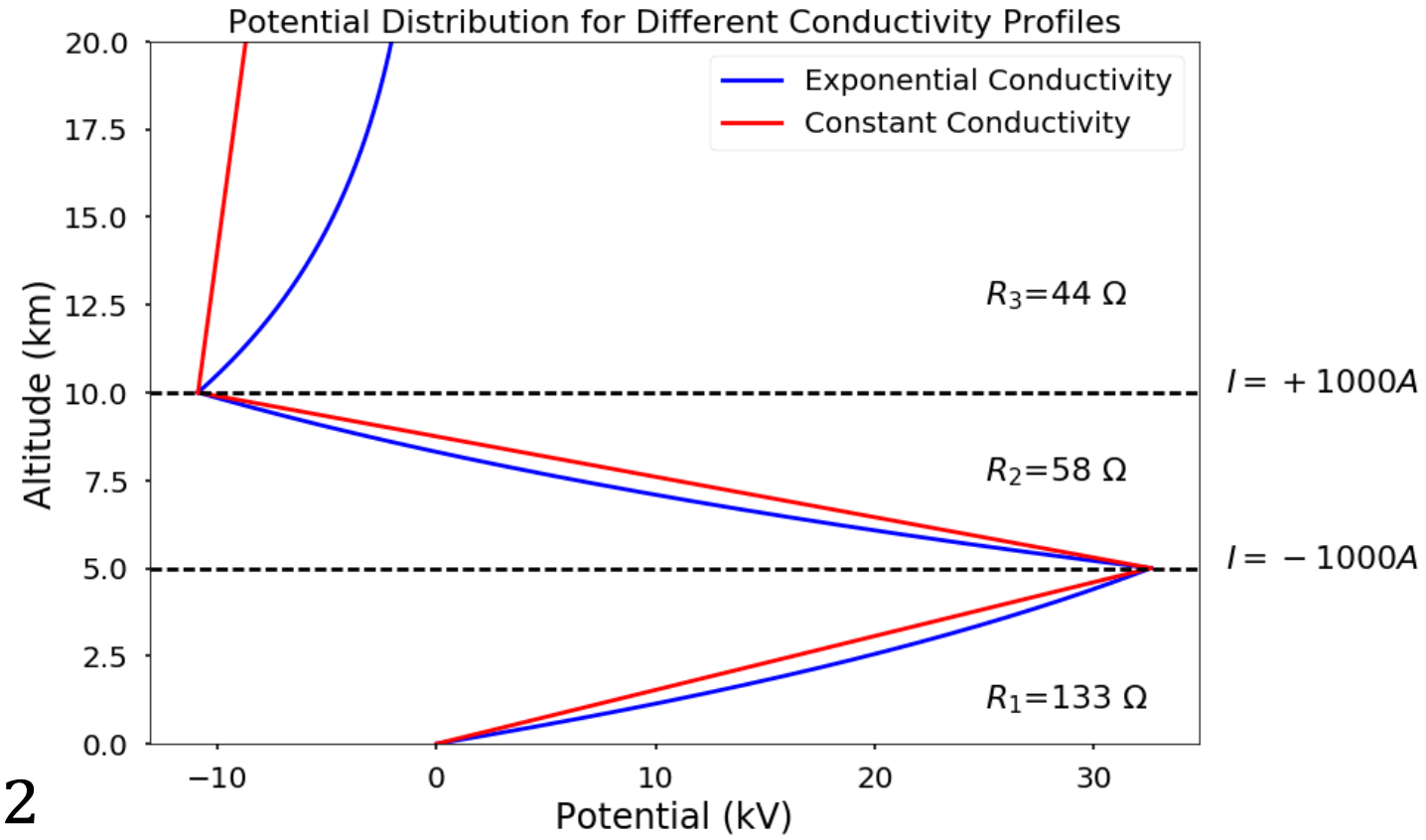
$$R_{tot} = \left(\sum_{col} \frac{A_{col}}{R_{col}} \right)^{-1}$$





Driving a current through the circuit

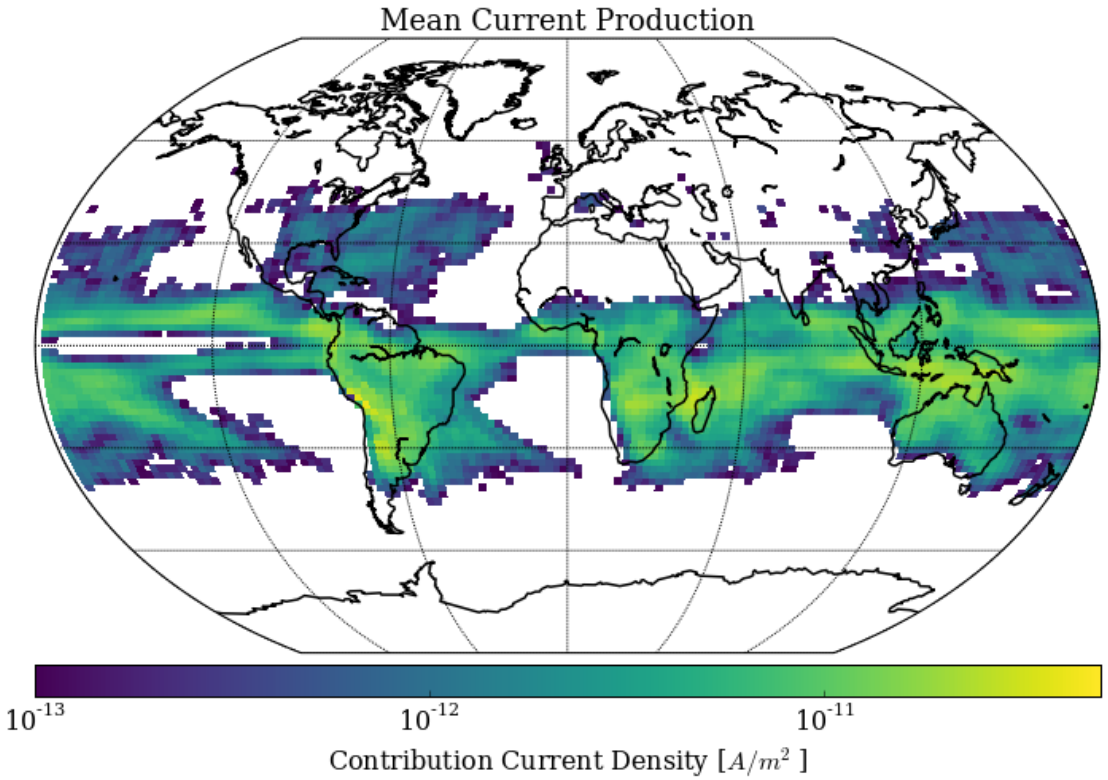
- Thunderstorms separate charge which act like a dipole current
- Charging mechanism is related to updrafts and ice in storms

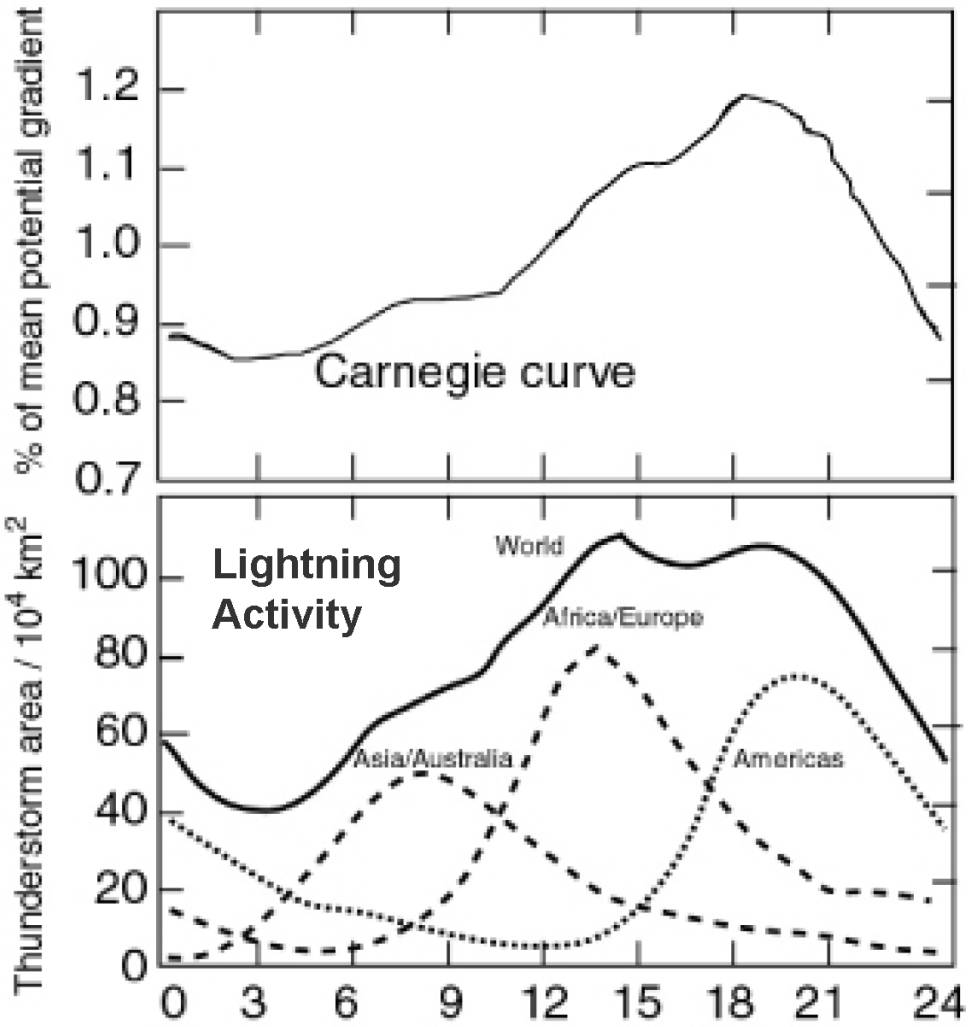


$$I_{GEC} = IR_{dipole} = \frac{R_2}{R_1 + R_2 + R_3}$$

WACCM-GEC Sources

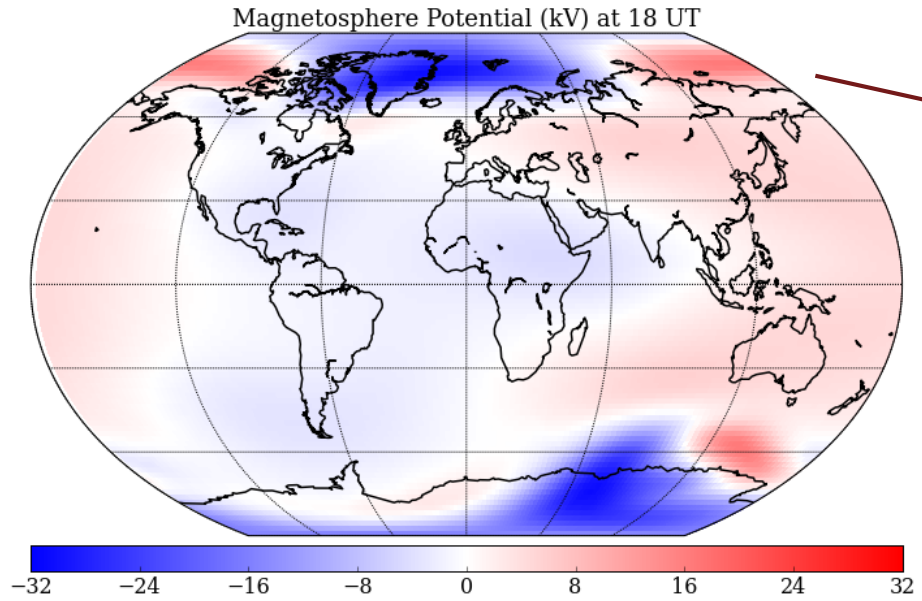
Diurnal variation due to preferential land-mass heating



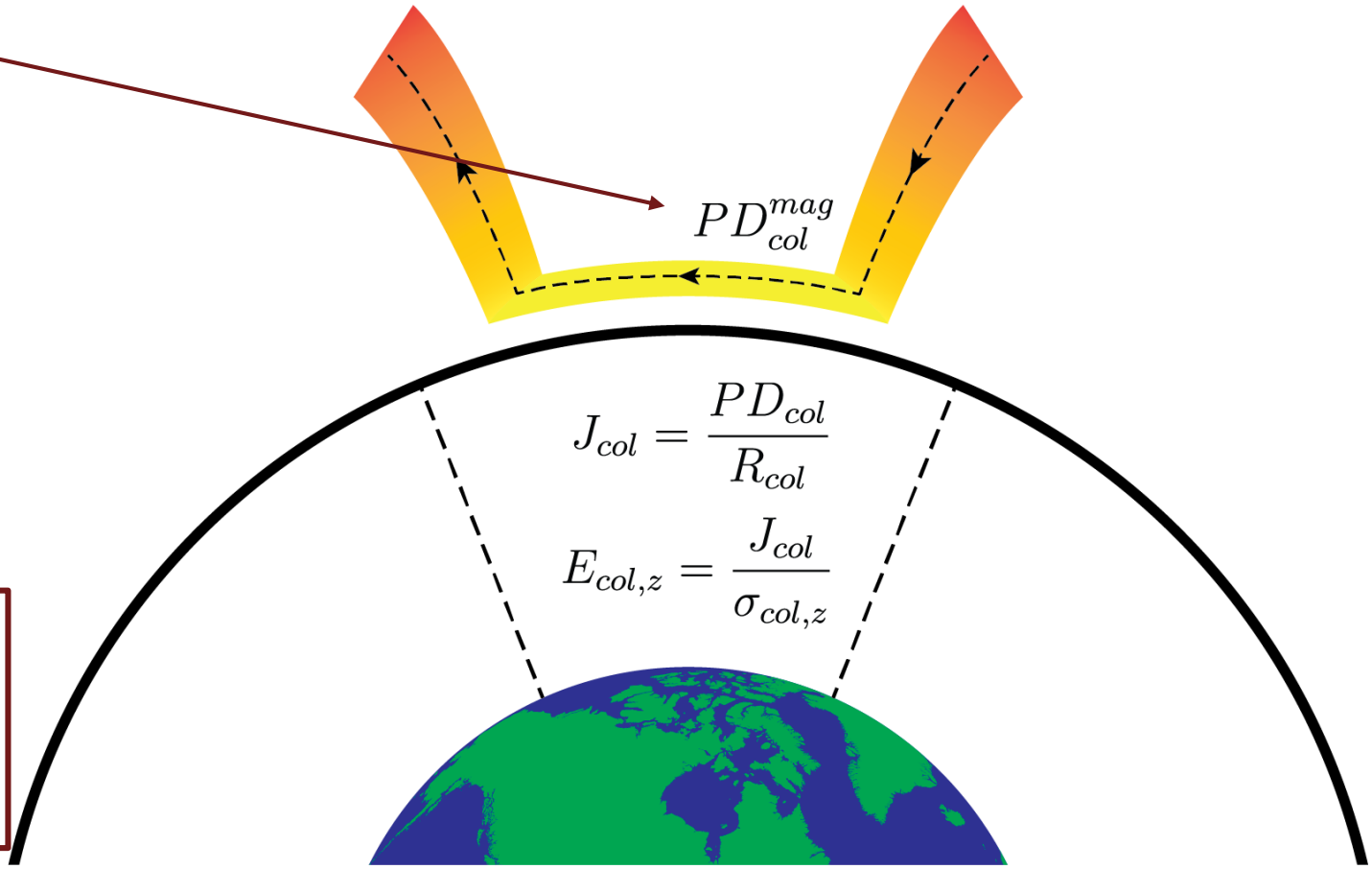


Whipple & Scrase 1936

Potential at high latitudes is not uniform



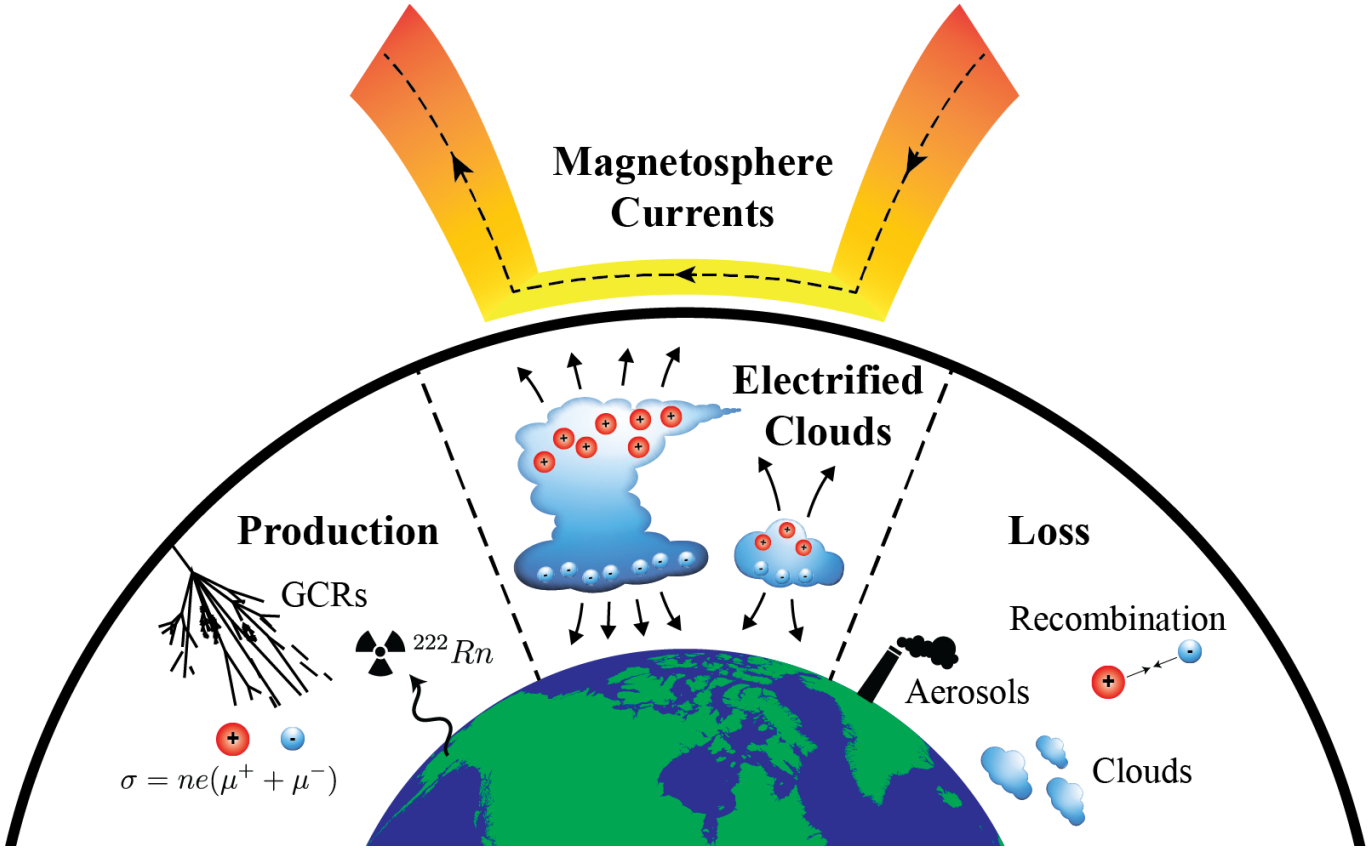
$$PD_{col} = PD_{GEC} + (PD_{col}^{mag} - PD_{float})$$



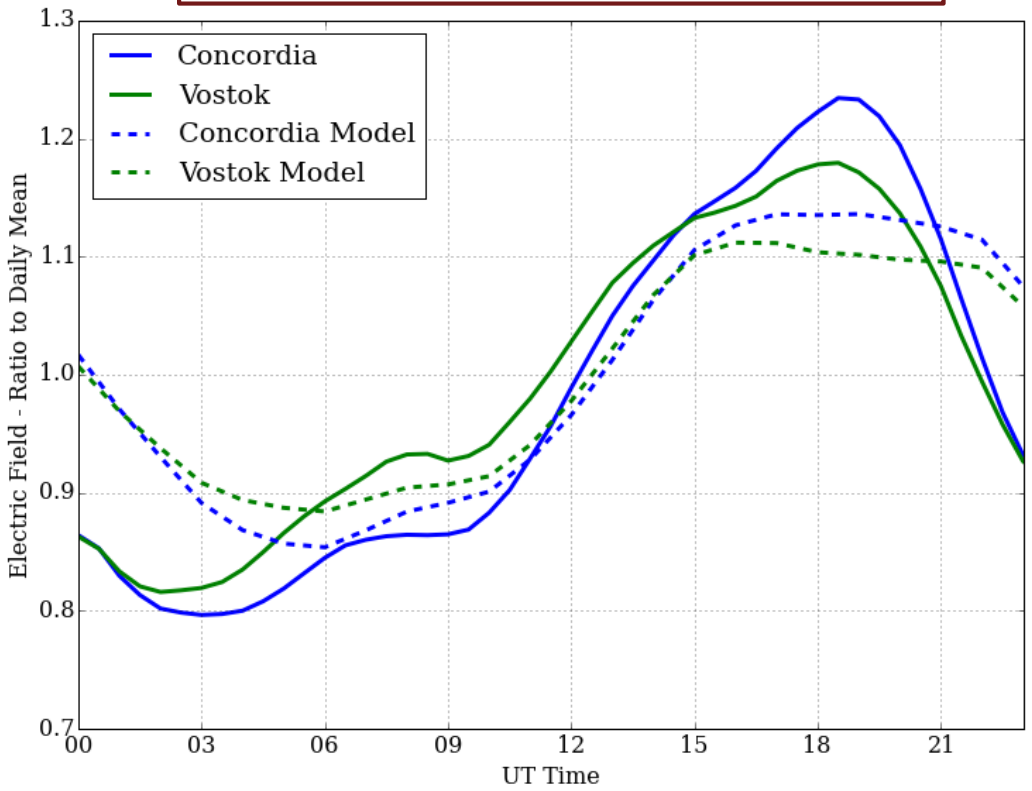
Integrate the leakage current through each column contributed by the magnetosphere

$$PD_{float} = \int_{4\pi} \frac{PD_{col}^{mag}}{R_{col}} \mathrm{d}S \ * R_{tot}$$

WACCM-GEC First Results

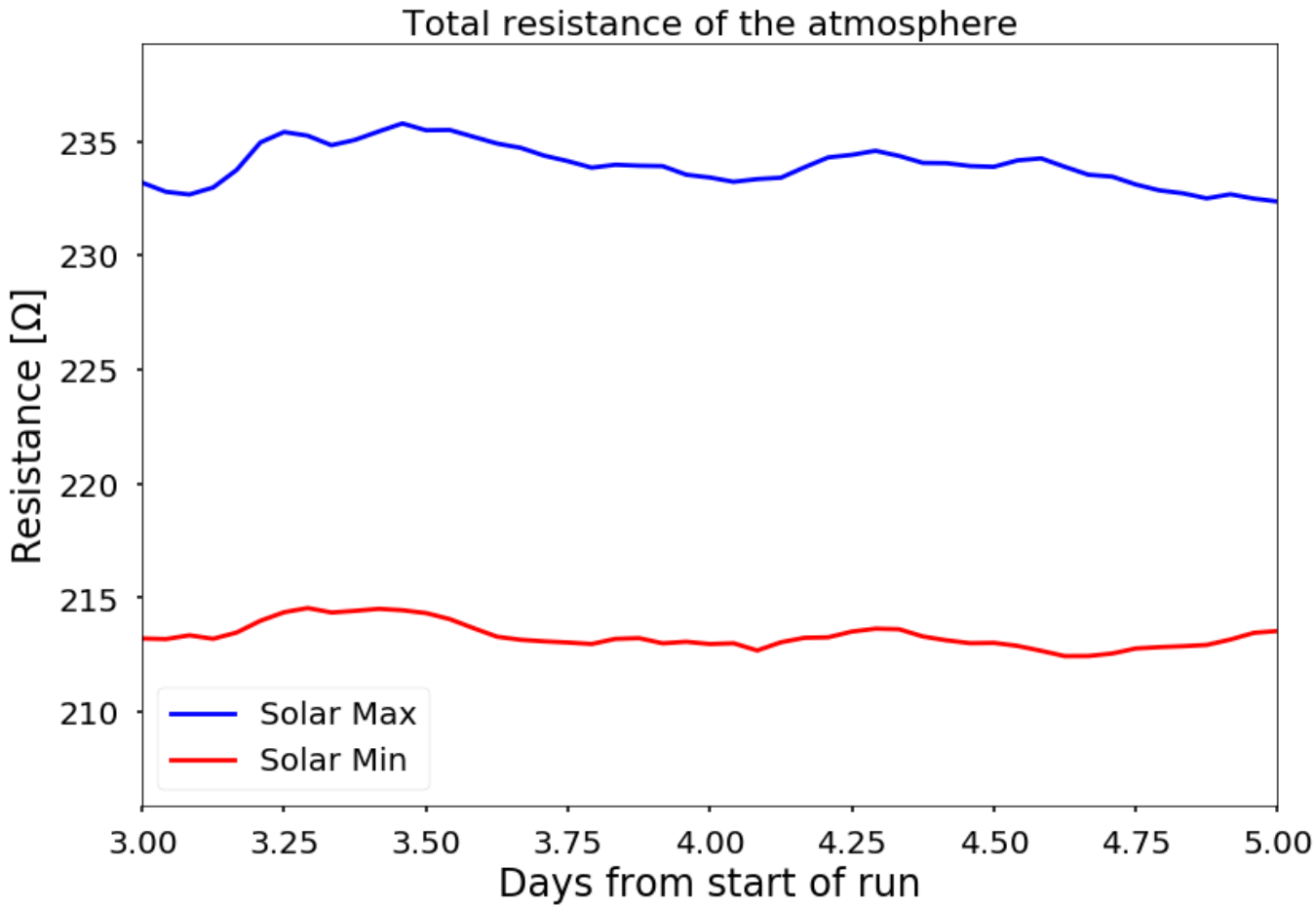


Model E-fields compared to observational E-fields



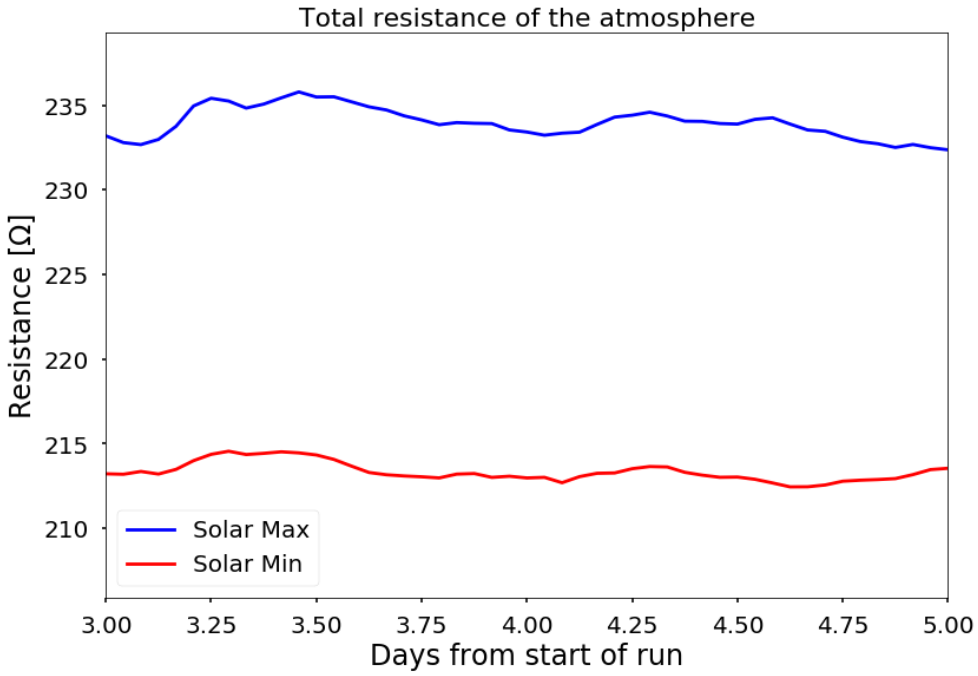
Solar Cycle Variations

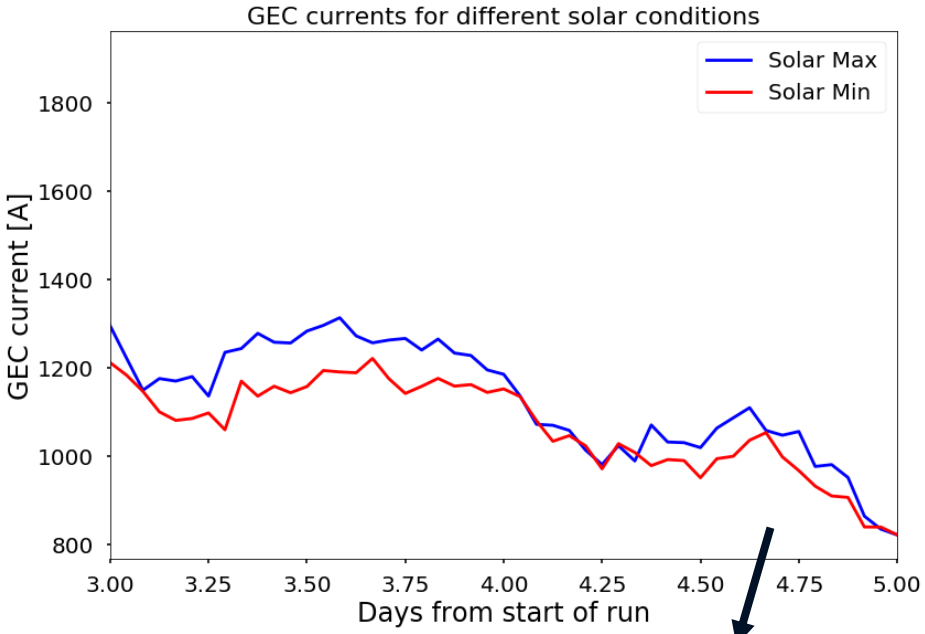
- Solar-min -> more ionization less resistance
- Solar-max -> less ionization more resistance

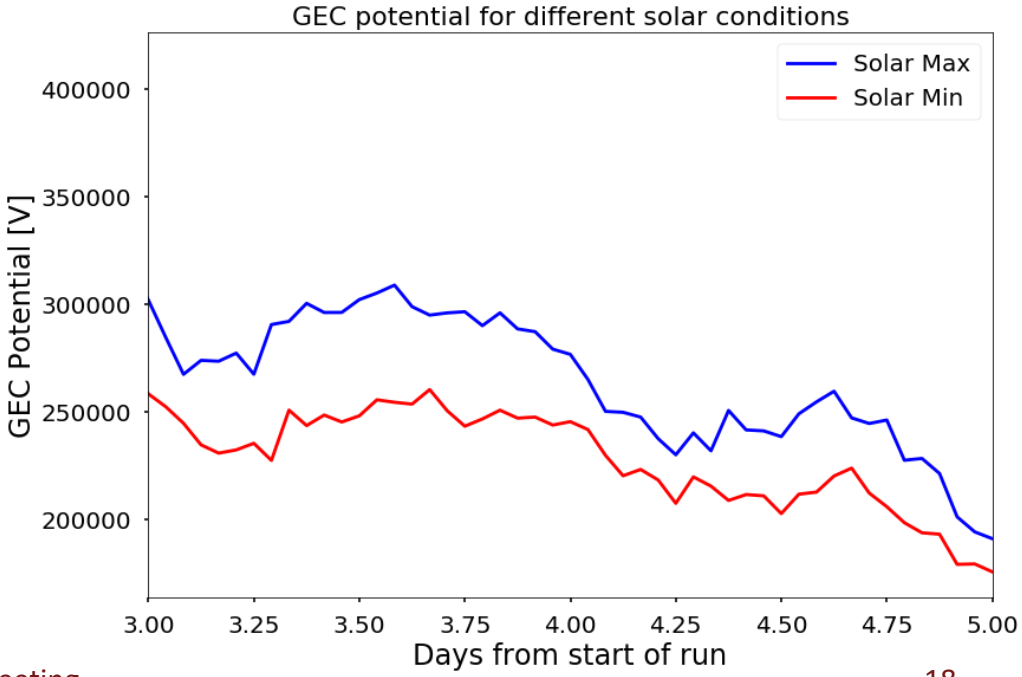


Solar Cycle Variations

- Similar currents
- Larger potential during solar max due to larger resistance

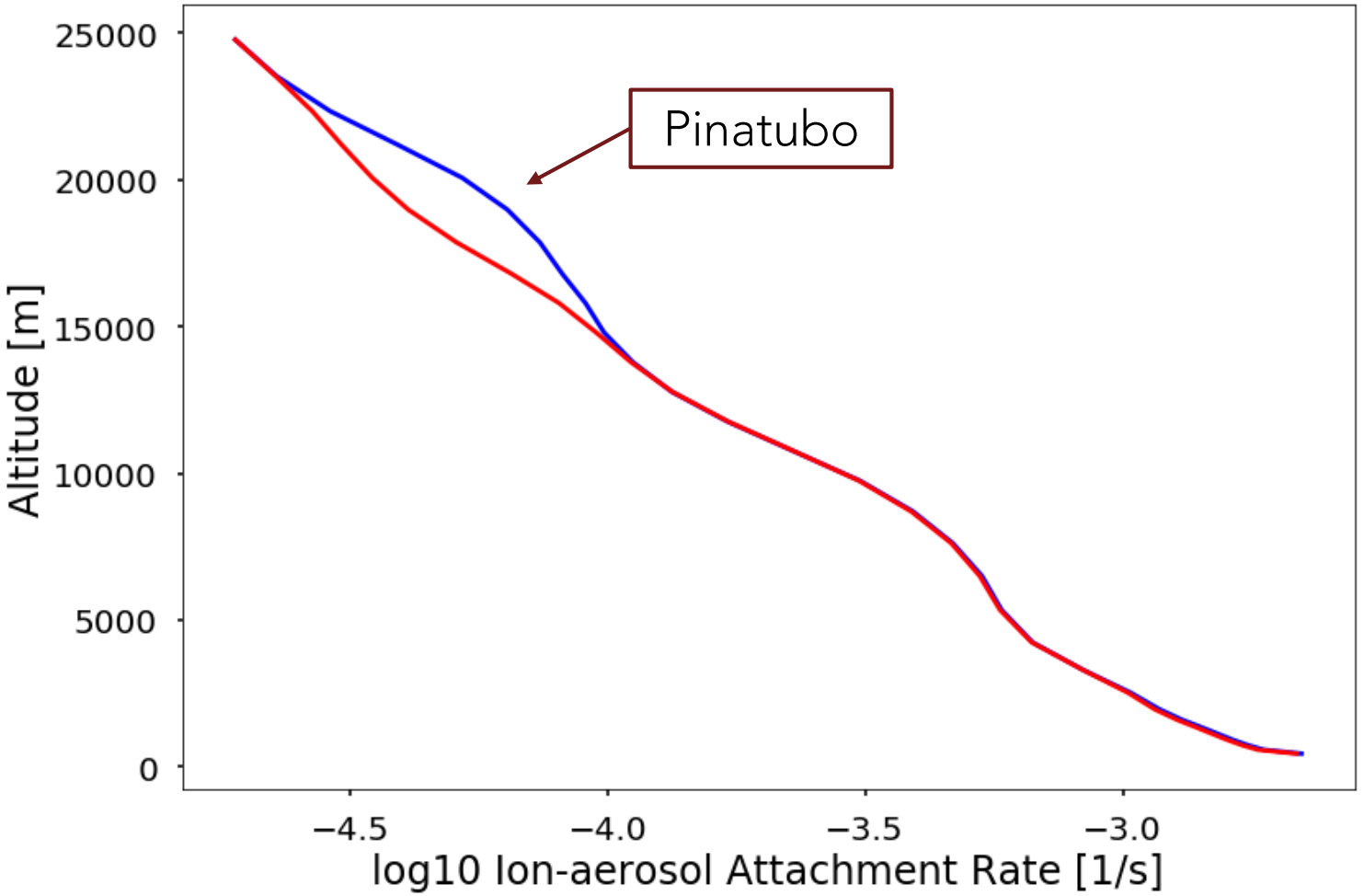






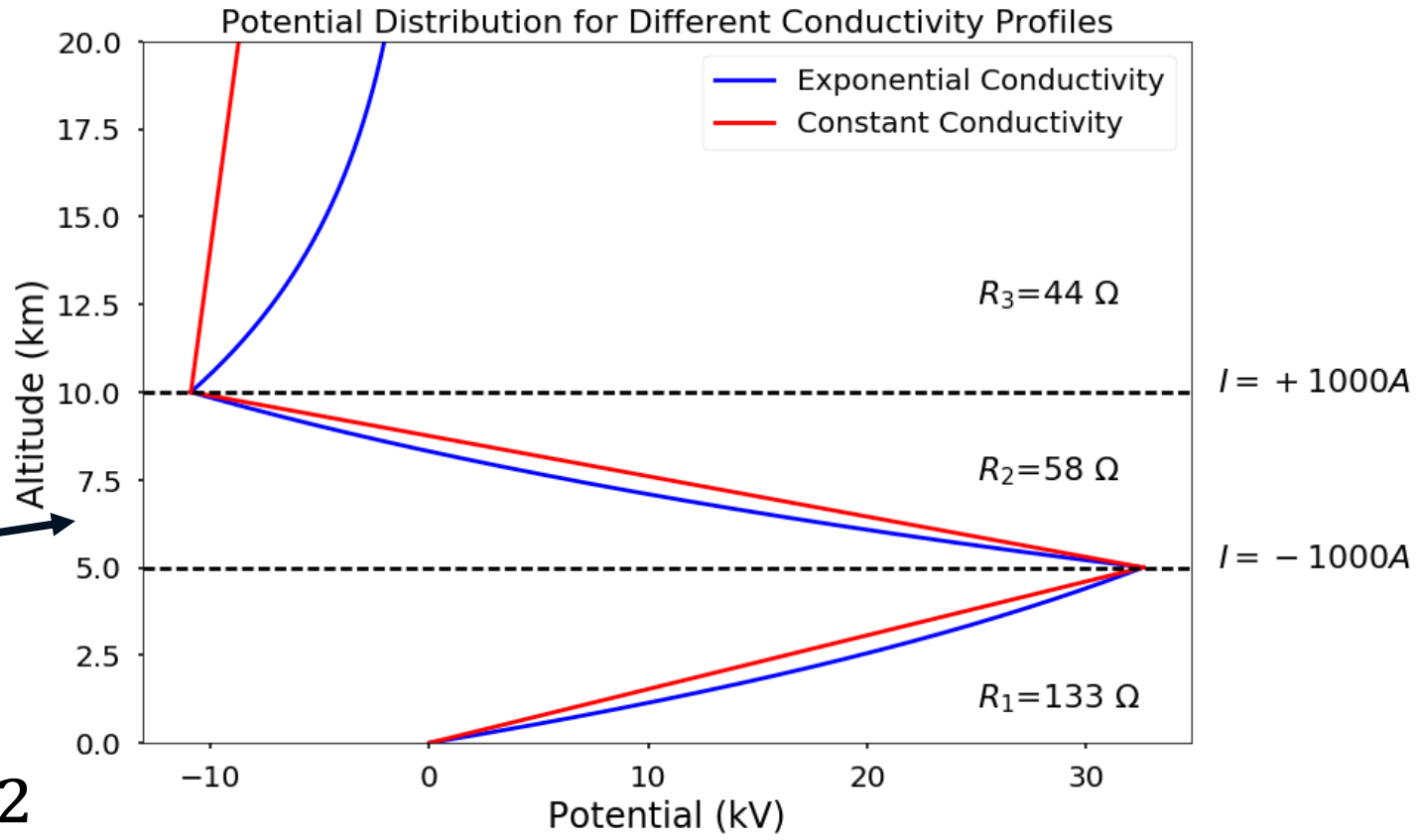
Volcano Variations

- Pinatubo run for 1991
- Stratospheric aerosols don't modify the GEC column resistance significantly
- 90% of column resistance is in the first 10 km altitude



Volcanos do influence the sources

- Local dipole resistance can be modified more than the total column resistance
- Aerosols between the source region amplify the GEC current

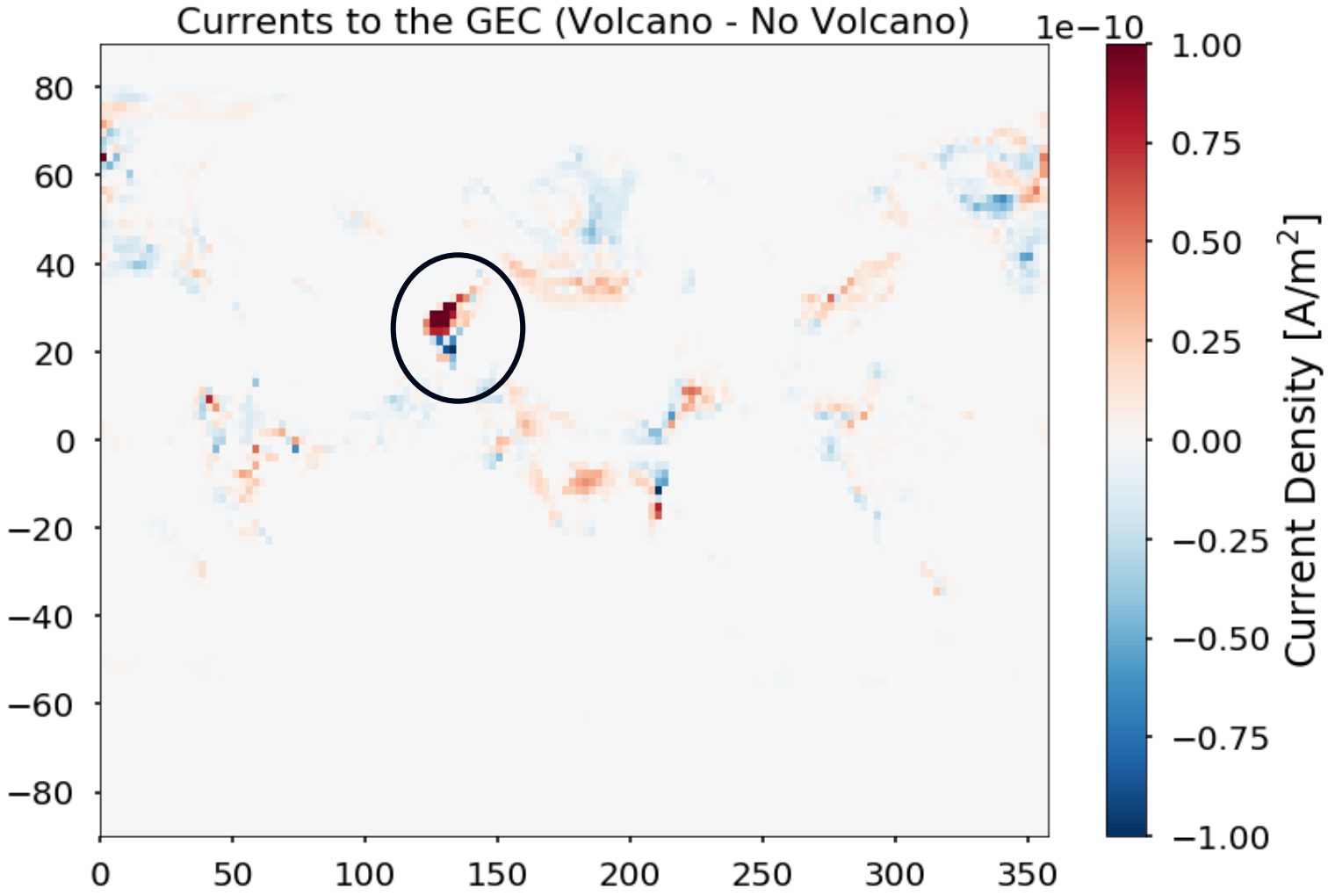


$$I_{GEC} = IR_{dipole} = \frac{R_2}{R_1 + R_2 + R_3}$$

Volcanos can amplify the source current

- Pinatubo run for 1991
- Depending on the altitude of the aerosol layer the dipole resistance can be increased, leading to more current in the GEC

$$I_{GEC} = IR_{dipole}$$



Summary

- Complicated interplay between resistance and sources
- Not a linear relationship for driving the GEC potential
- Solar min/max GCR variations modify the total resistance by more than 10%
- Volcanic aerosols can locally amplify the current due to an increased dipole resistance
  - They also slightly increase the total resistance of the circuit

WACCM-GEC

- Coming soon to CESM2!
- To run: Set namelist variable: do_global_circuit = .true.

- Future work:
  - Couple E-field with microphysics
  - Run more experimental configurations

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