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A Quasi-Static Global Electric Circuit (GEC) Model in WACCM

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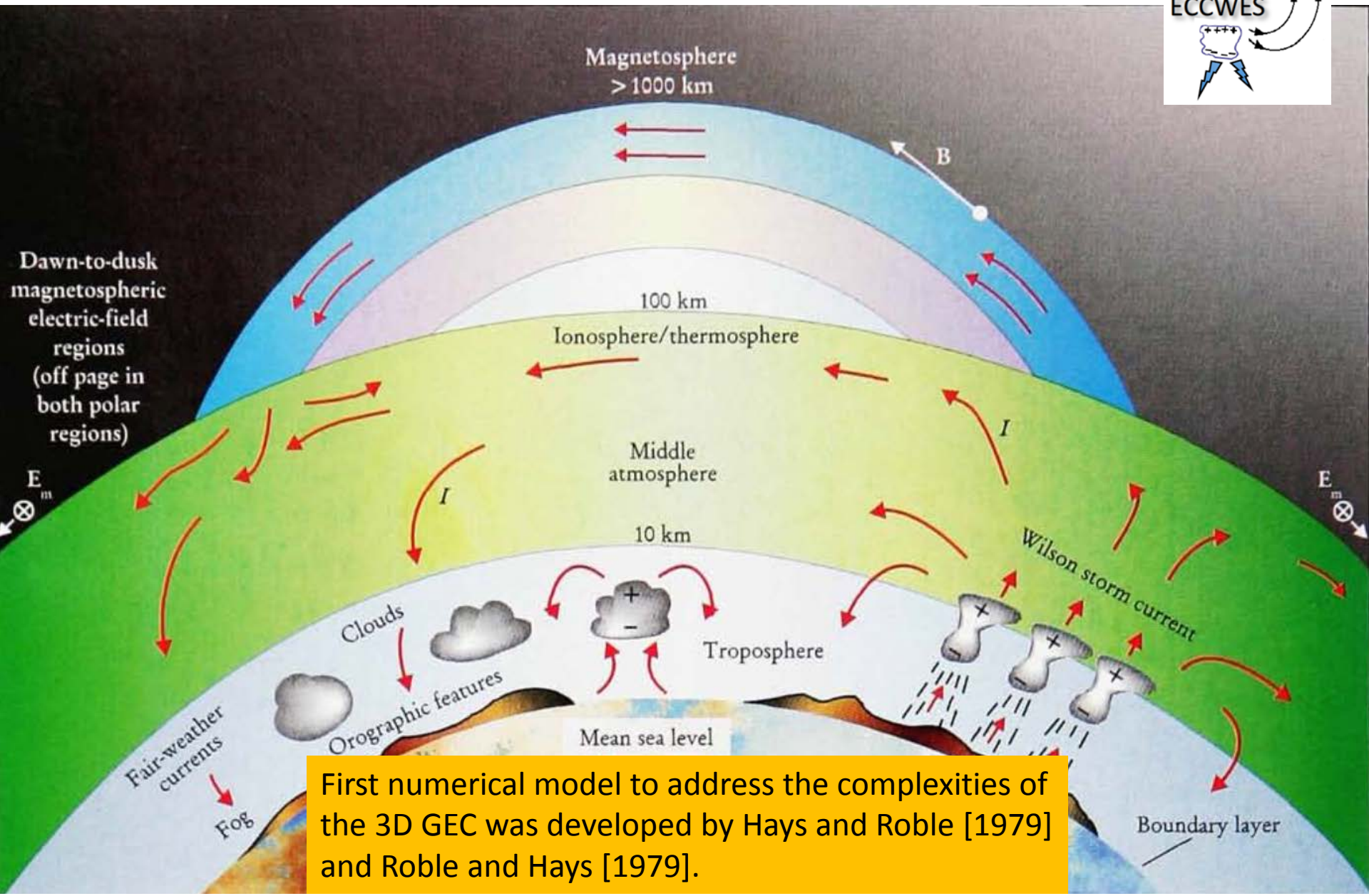
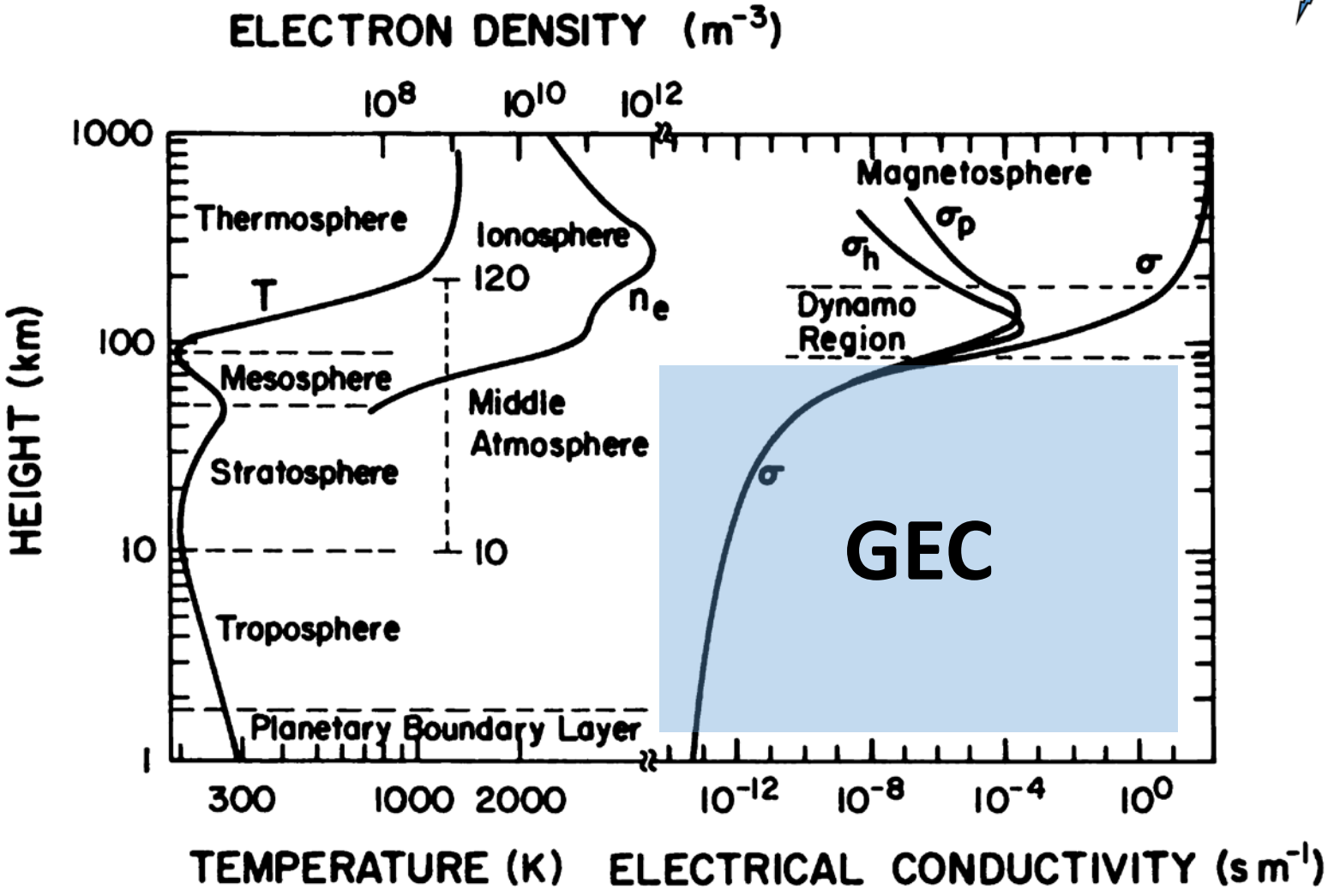
The DC Global Electric Circuit (GEC)



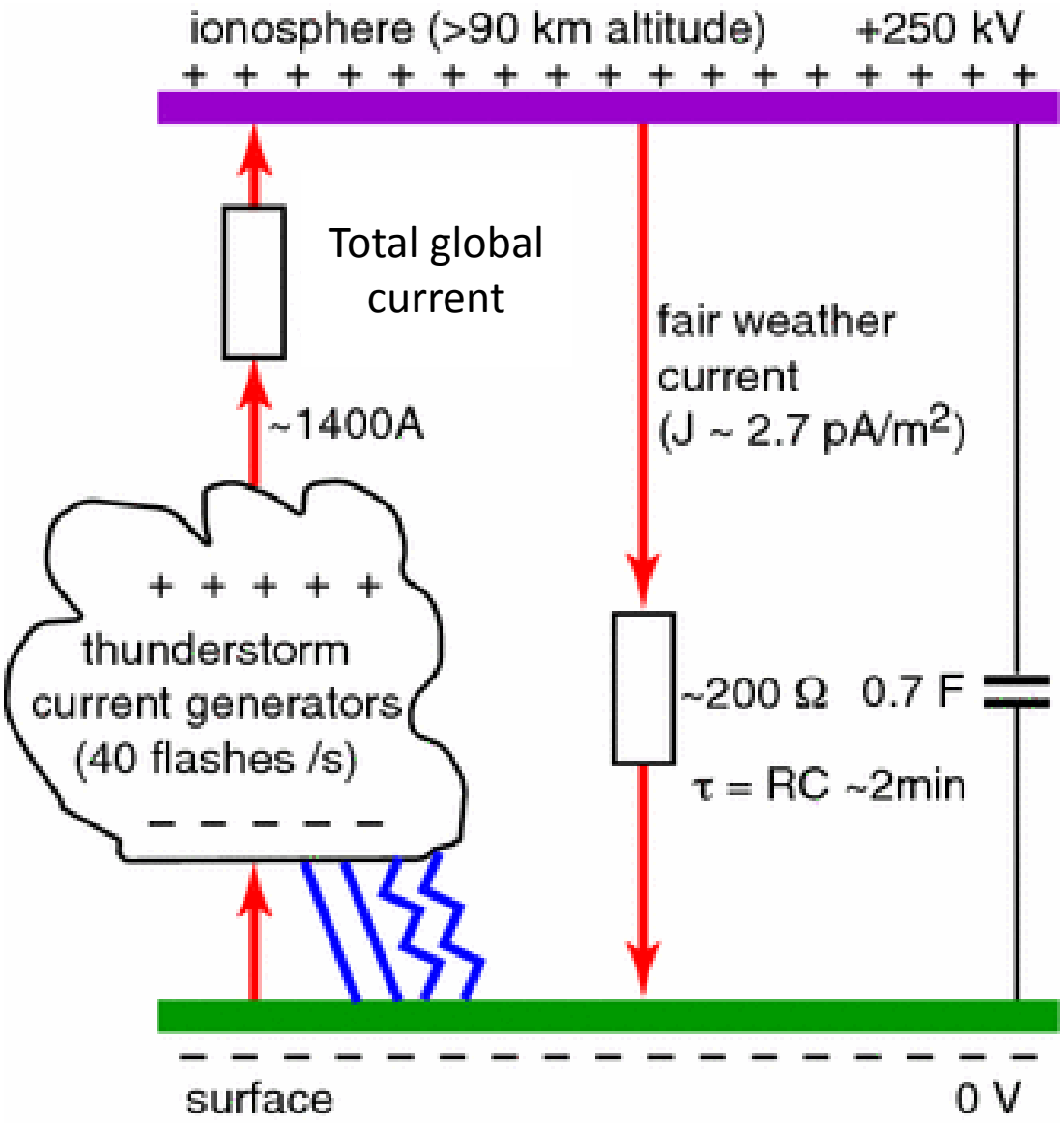
First numerical model to address the complexities of the 3D GEC was developed by Hays and Roble [1979] and Roble and Hays [1979].

Bering et al., Physics Today, 1998

Some properties of the GEC



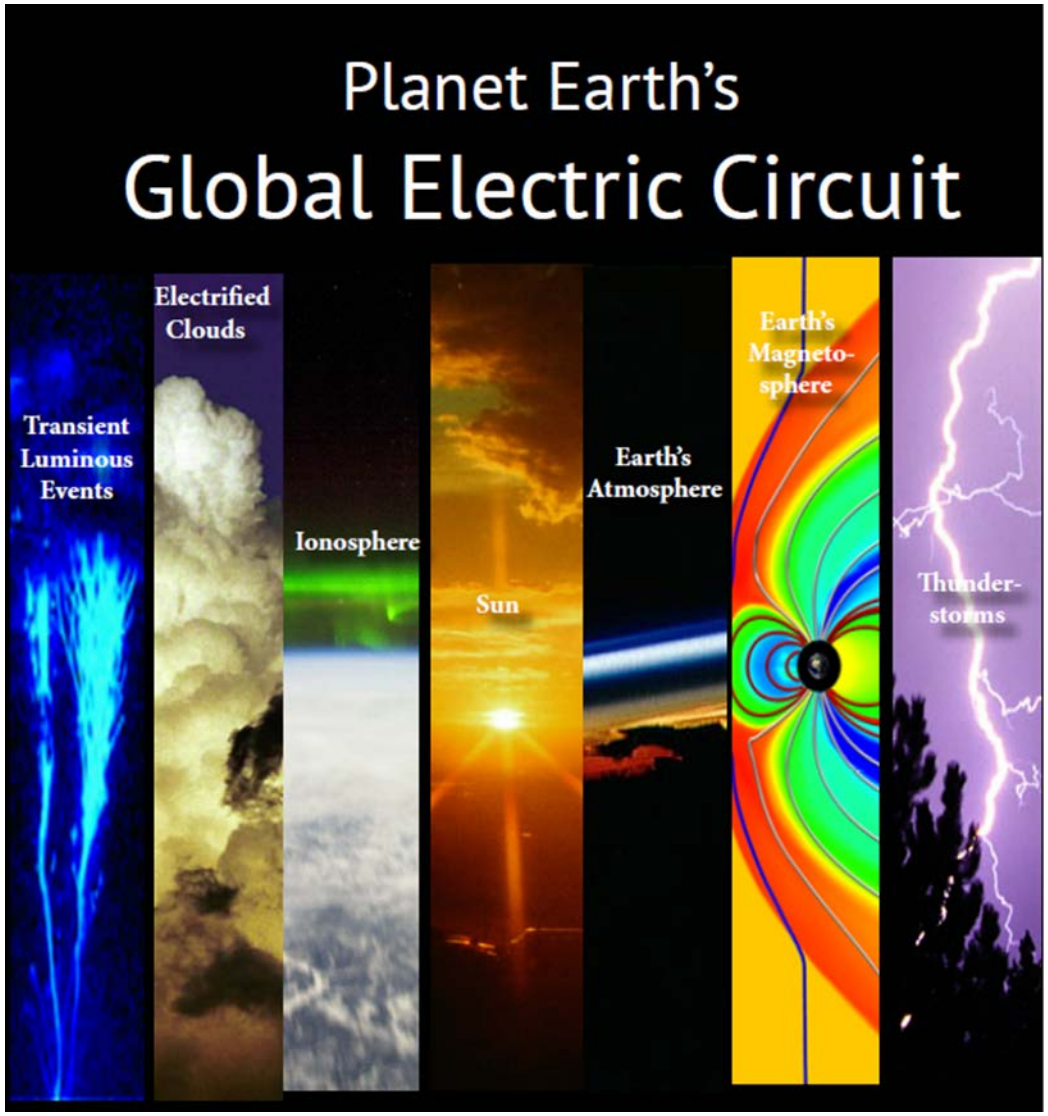
Some properties of the GEC



Kirkby, Surv Geophys 2007

Vertical electric field at the surface: 100-300 V/m

Why Study Currents of ~2pA/m^2



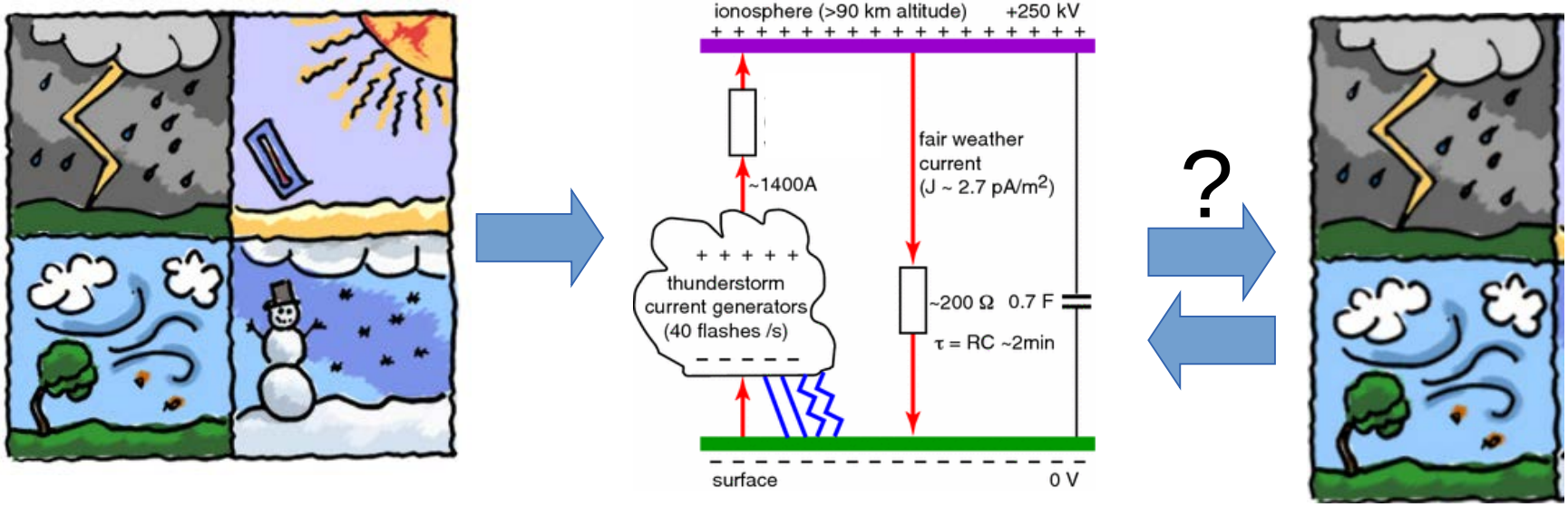
The GEC involves many aspects of solar-terrestrial physics:

- Galactic cosmic rays
- Solar wind IMF
- Magnetospheric potentials and particles
- Ionosphere processes
- Radon emissions from solid earth
- Cloud formation and electrification
- Atmospheric aerosols
- Charge generation from oceans
- Atmospheric dynamics…

Why Study Currents of ~2pA/m^2

The GEC has been invoked, through correlations, as a means by which climate changes may be linked to galactic and solar influences and raises the issue of how the electrical pathways are related to the climate system

SPARK/NCAR



WACCM-GEC Model

CESM1(WACCM) Framework

- Integrate a GEC capability into the Community Earth System Model, Whole Atmosphere Community Climate Model or CESM1 (WACCM) framework - see Marsh et al. (2013, J. Climate)
- Solve the steady-state current continuity equation at each time step, pressure level, and grid point within CESM1 (WACCM) to determine the GEC potential difference

WACCM-GEC Output

- GEC Potential, 3D current density, and 3D electric fields calculated at each model…
  - time-step (30 minutes)
  - grid point(2.5° longitude x 1.9° latitude)
  - pressure surface (66 pressure levels with a top boundary of 5.1×10^{-6} hPa or about 140 km altitude)

WACCM-GEC Model

Lucas et. al 2015, JGR

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

Baumgaertner et. al 2013 & 2014

Kalb et. al (2016 JGR submission)

Solve the steady-state current continuity equation globally within WACCM

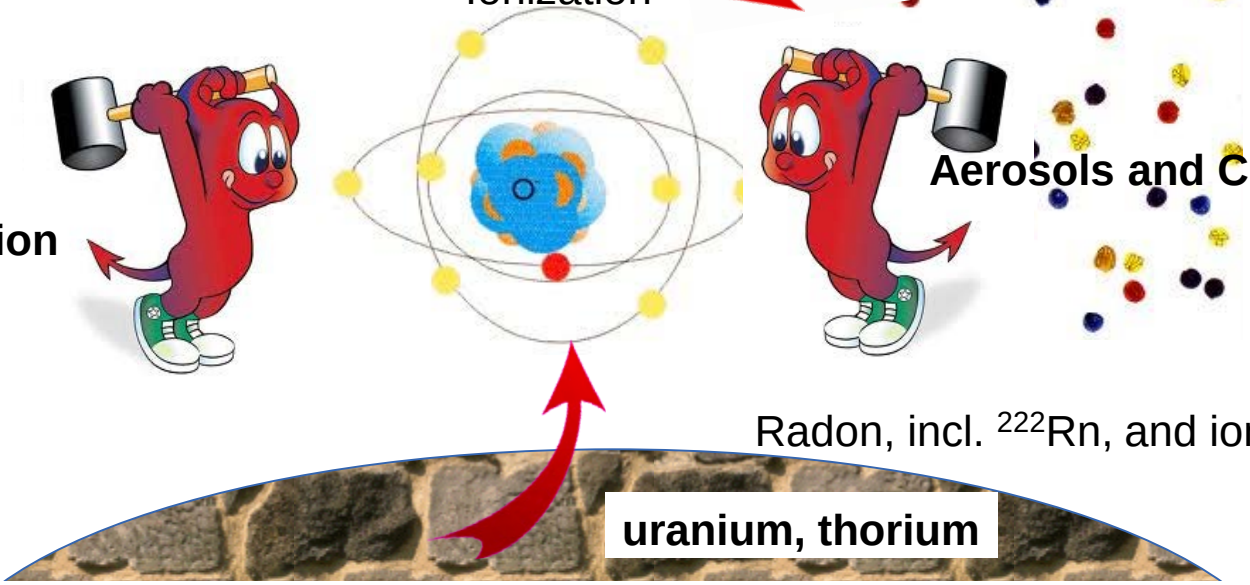
- Requires global distribution of conductivity and current sources
- Imposed Dirichlet boundary conditions at surface and ionosphere

Atmospheric Conductivity

Galactic cosmic rays

Solar energetic particles

Ionization



Ion-ion recombination

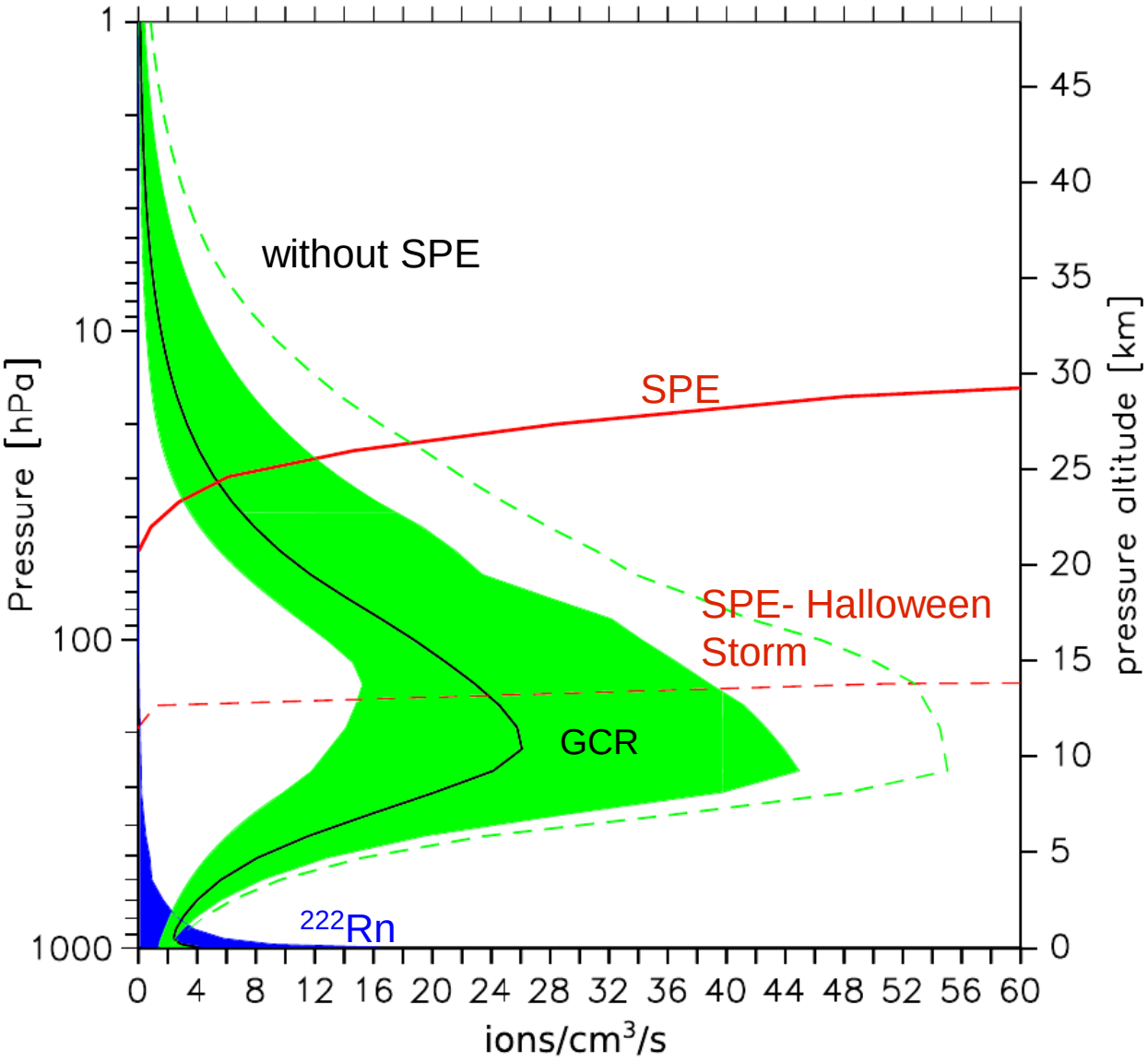
Aerosols and Clouds

Radon, incl. ^{222}Rn, and ionizing radiation

uranium, thorium

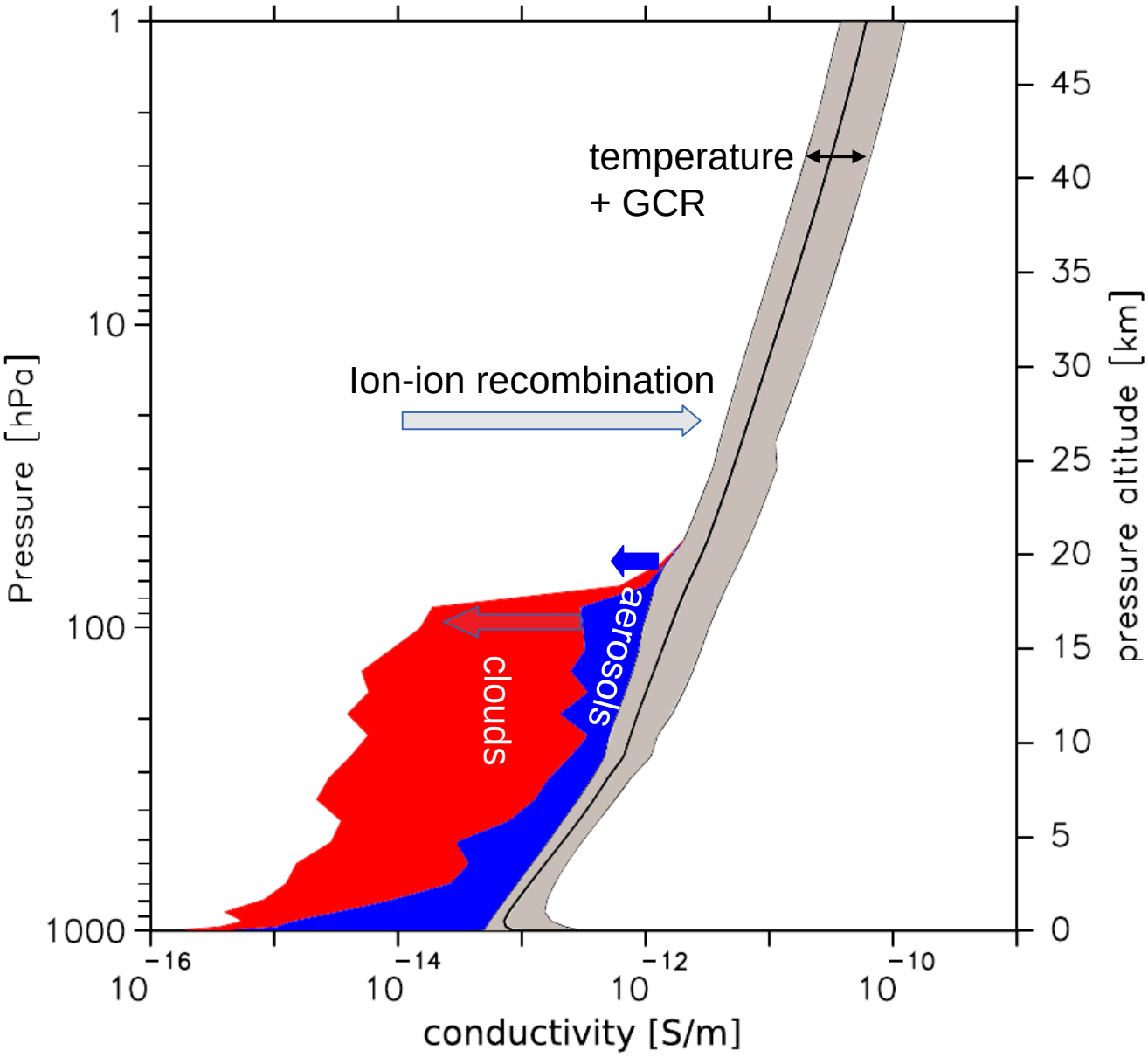
Conductivity = ion concentration · ion mobilities · charge

Ionization Production Rate



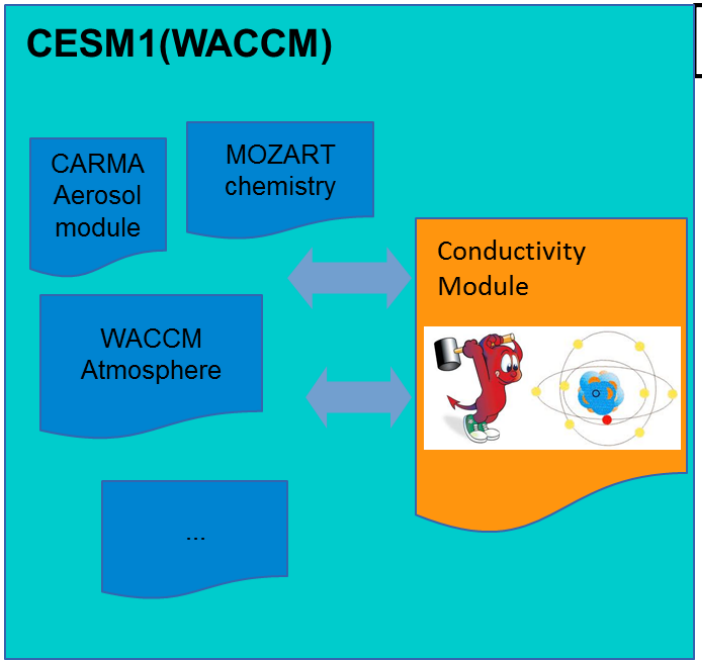
- Ionization rates have large variability
- Very distinct ionization source regimes

Atmosphere Conductivity



Locally, aerosols and fair-weather clouds can very effectively reduce conductivity

WACCM-GEC: Resistance

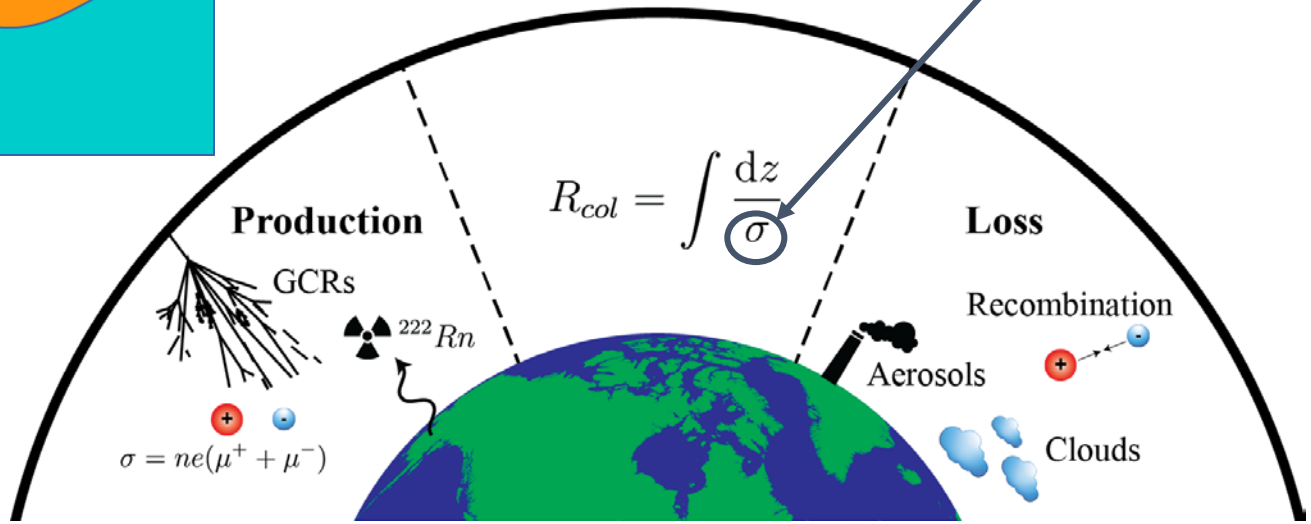


Baumgaertner et. al 2013 & 2014

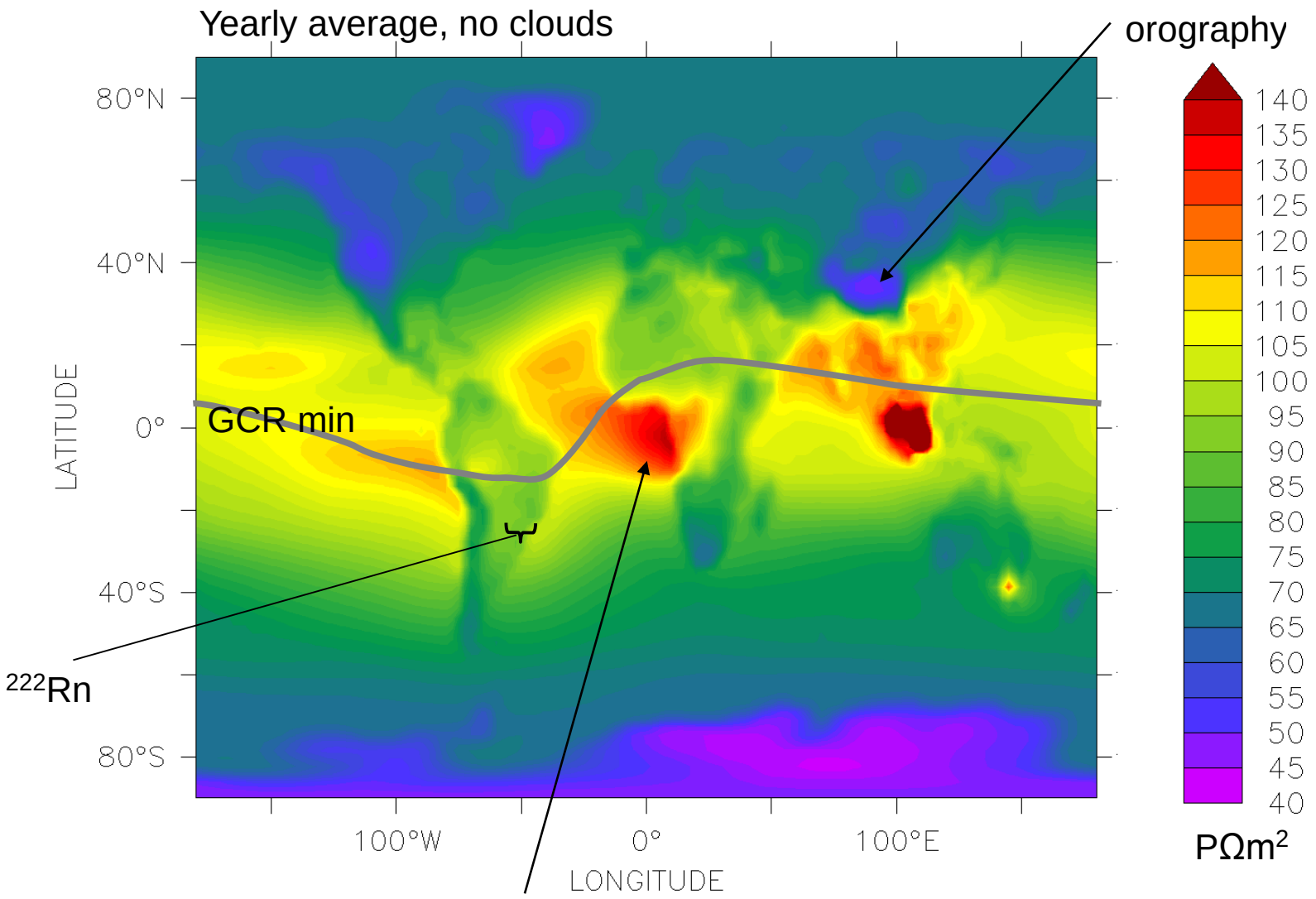
$$R_{tot} = \left(\sum_{col} \frac{A_{col}}{R_{col}} \right)^{-1}$$

Global conductivity distribution leads to column resistances and the total resistance of the atmosphere

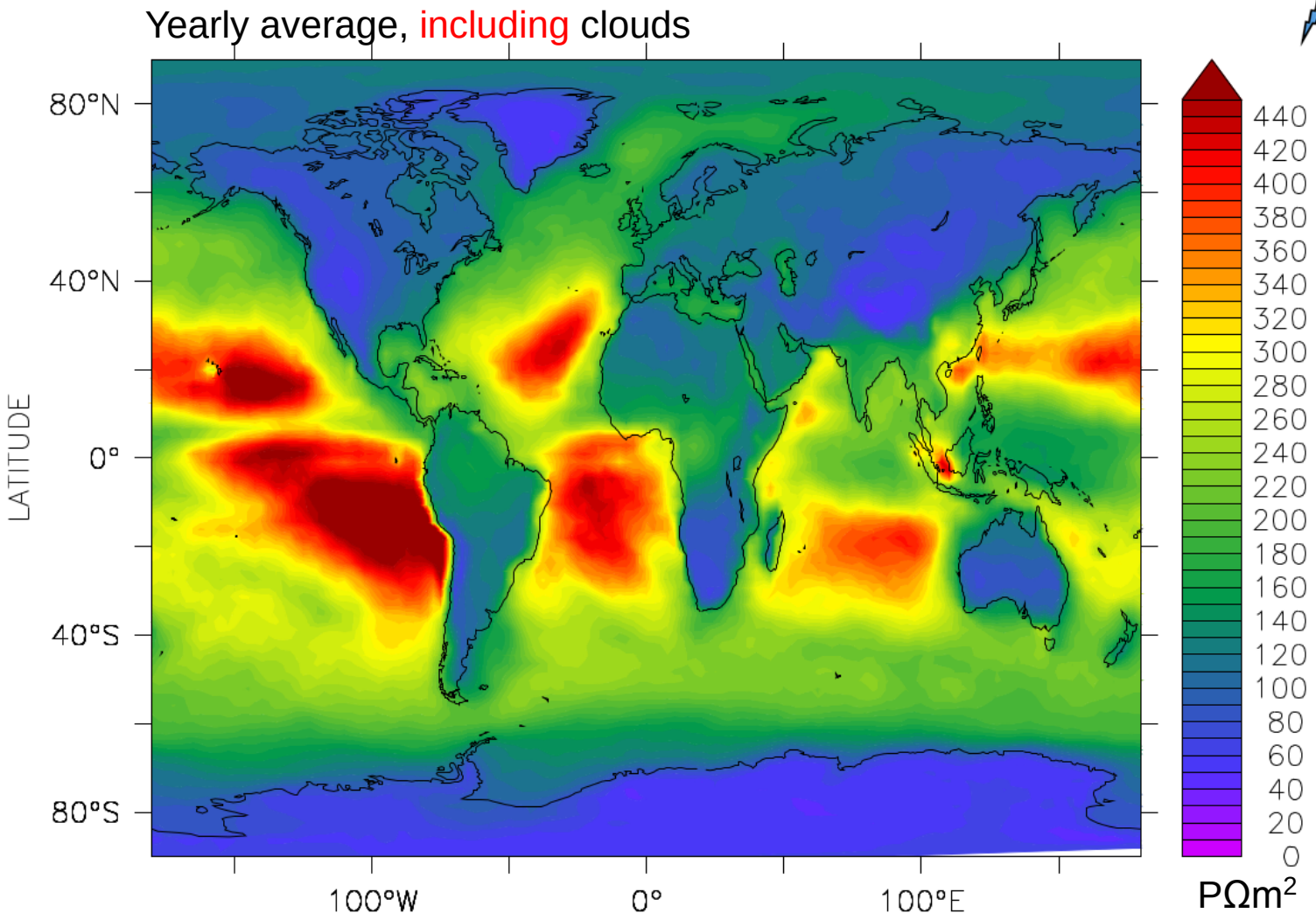
$$R_{col} = \int \frac{\mathrm{d}z}{\sigma}$$



WACCM-GEC: Column Resistance



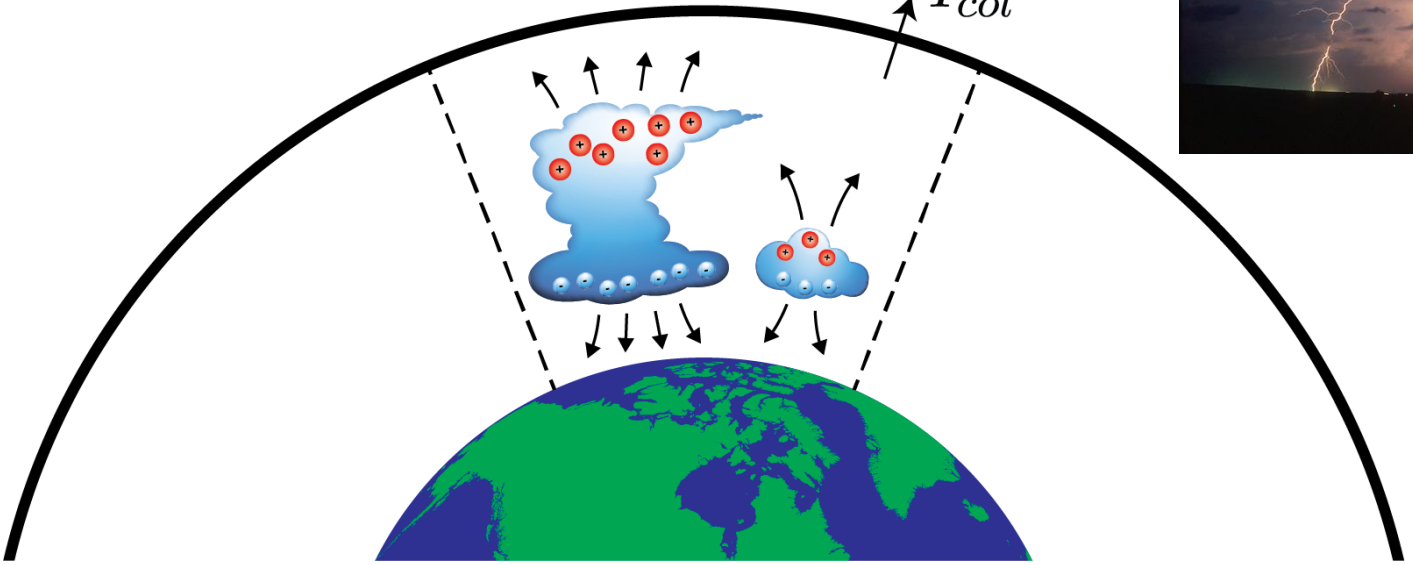
WACCM-GEC: Column Resistance



Fair weather clouds can double the column resistance

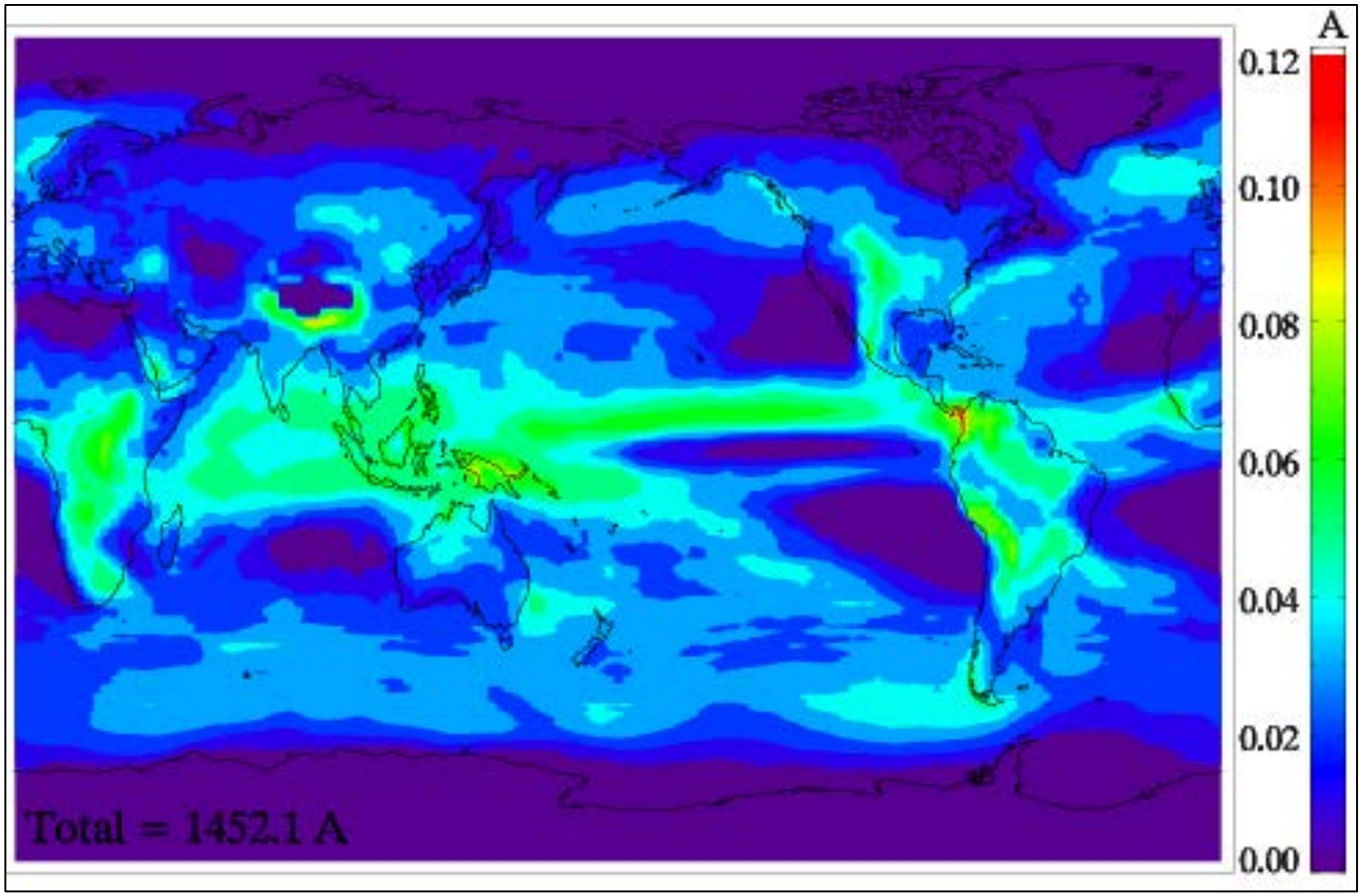
WACCM-GEC: Sources

$$I_{GEC} = \sum_{col} I_{col}$$



WACCM-GEC: Sources

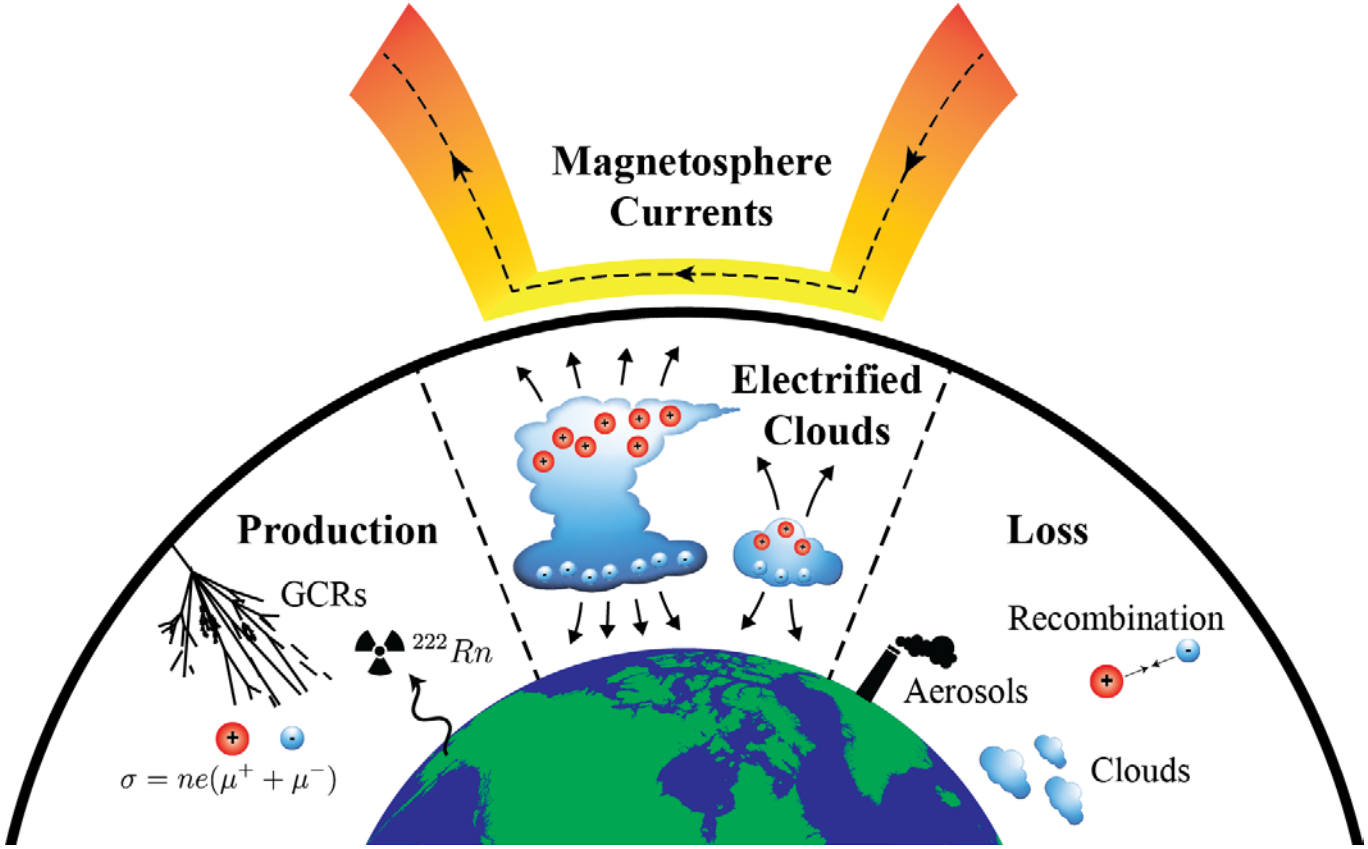
Mean Annual Global Current Distribution



- Mean global total current modeled with WACCM: 1452 A
- Model parameterization based on TRMM satellite observations and aircraft measurements
- Model yields reasonable spatial current distribution and global total current

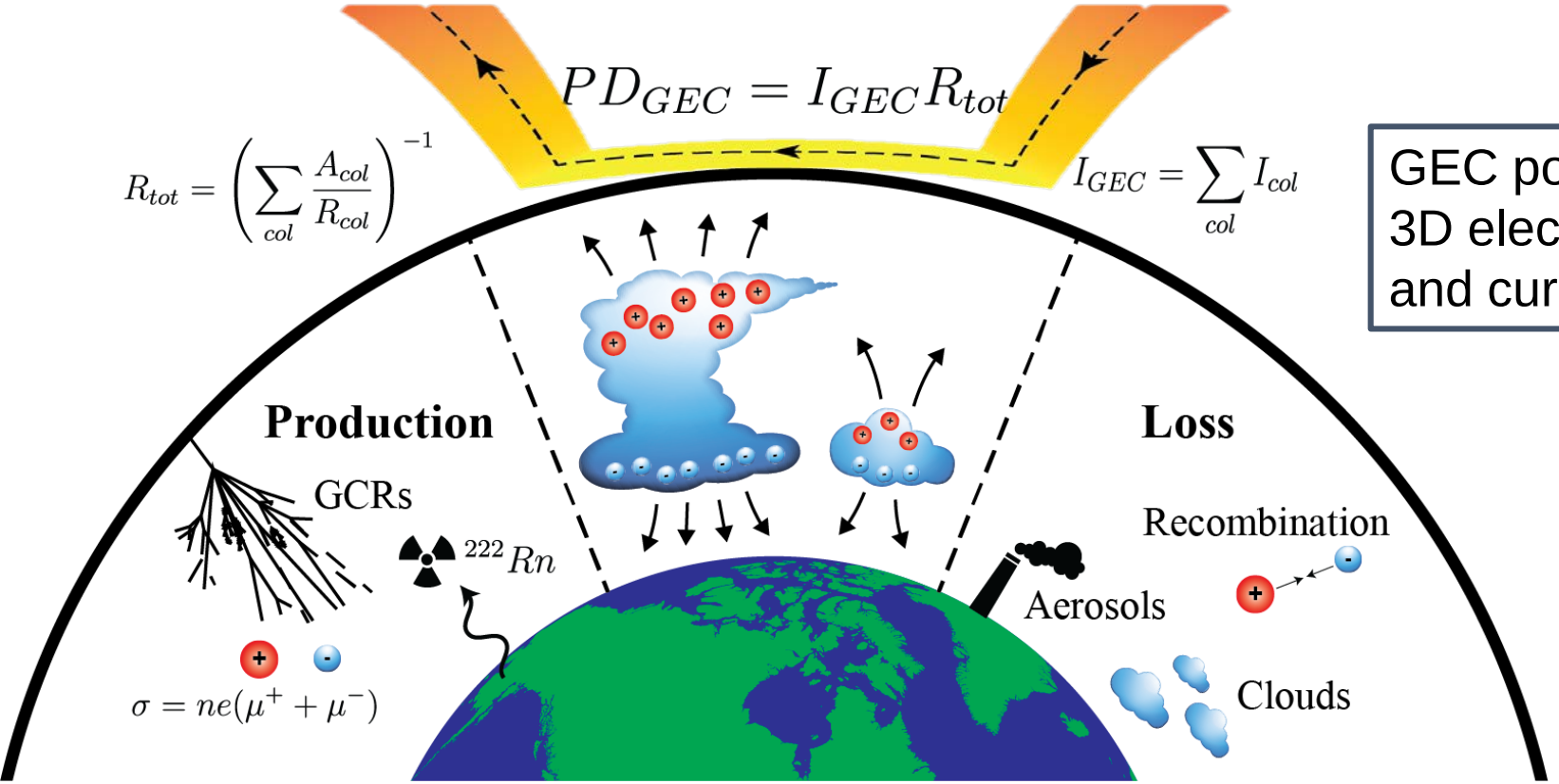
Kalb et. al (2016 JGR submission)

WACCM-GEC: Ionosphere Potential



WACCM-GEC: Output

Lucas et. al 2015, JGR

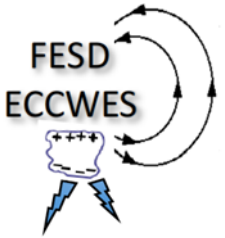


GEC potential, 3D electric fields and currents

WACCM-GEC: Summary

- GEC: very diverse field involving wide range of solar-terrestrial physics.
- WACCM-GEC: most comprehensive description of atmospheric conductivity available today.
- WACCM-GEC: New 3-D global electric circuit model of potential, currents, and electric fields self-consistently computed and evolved.
- WACCM-GEC: Enabling investigations of the electrical connections from the Sun to Earth’s surface

WACCM-GEC: Related Posters



CEDAR - MLT Poster Session – Wednesday, June 22, 2016

- COUP-14, Greg Lucas (student), Solar impacts on atmospheric electric fields
- MLTS-03, Jaroslav Jansky (Non-student), Analysis of the diurnal variation of the global electric circuit using different numerical models

WACCM-GEC: Cause and Effect

- GCR Flux
  - Forbush Variations -> Conductivity changes
  - Cloud condensation nuclei formation (direct or indirect)
  - Enhance onset of Lightning due to ionization

- Solar Wind
  - Magnetosphere-Ionosphere potential alters surface electric fields
  - Wilcox Effect – Crossings of the heliospheric current sheet (HCS) are correlated with weakenings in winter cyclones [Wilcox et al., 1973]
  - Mansurov Effect – IMF By changes are correlated with surface pressure variations at high latitudes [Mansurov et al., 1974]
  - Enhance onset of Lightning due to high speed streams [Scott et al., 2014]

- Aerosols
  - Ion attachment processes related to GEC resistance
  - Volcanic eruptions altering GEC downward currents and potential

- Cloud processes
  - Electrification remains an active research area
  - Resistivity is poorly described
  - GEC-related influence, feedback, and long-term trends