Numerical Modeling of the Global Electric Circuit

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The theory behind the global electric circuit and atmospheric electricity has been around for nearly a century. Previous studies over this period have modeled the influence of individual physical perturbations to the global electric circuit by modeling equivalent circuits or making other simplifying assumptions on the distributions. These individual parametrizations have included galactic cosmic rays, clouds and aerosols, as well as thunderstorm distributions. With recent computing and modeling advancements the global electric circuit is able to be modeled with higher spatial and temporal resolution than ever before. Recently published results of global conductivity distributions and a new parametrizaton of source currents will be utilized within a new 3D numeric solver for the current continuity equation to determine the global distribution of currents.

1. Introduction

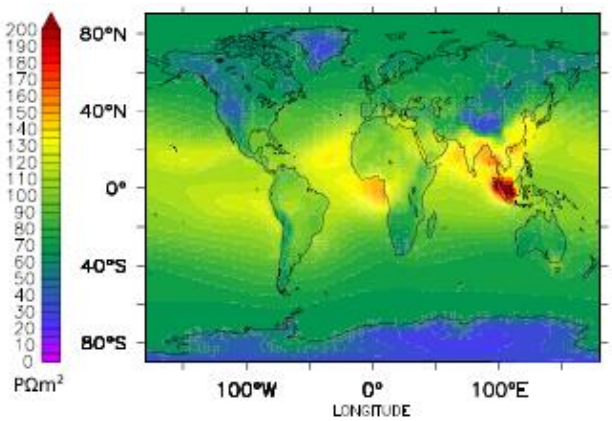
Aspects of the Global Electric Circuit (GEC) connections with the physical world have been investigated for the past century, since the Carnegie's famous voyage relating fair weather electric field measurements to storm activity across the globe. The original work of Hays and Roble [1] on modeling the GEC yielded new insights into how thunderstorm current sources affect global current distributions depending on their strength and location. Since this work, further models have been created to understand specific aspects of the circuit, such as conductivity [2], or creating an equivalent circuit model to incorporate specific parametrizations into a global simulation [3, 4].

The work discussed here will present a new GEC model that solves Poisson's equation throughout the atmosphere to get a global understanding of electrical coupling, with new high-fidelity conductivity and source models incorporated. The newly published conductivity data incorporates many related phenomena, such as realistic radon transport, cloud and aerosol distributions, and galactic cosmic ray fluxes, into an Earth System Model to obtain a global representation of currents, potentials and electric fields. The current source distribution is derived from TRMM satellite observations. Temporal and spatial variability of currents and electric fields due to these new source and conductivity distributions will be presented and discussed.

2. Model Inputs

2.1 Conductivity

Using a global circulation model to represent ionization and attachment processes in the atmosphere has allowed for a high fidelity representation of conductivity across the globe [2]. The incorporation of these processes allows one to see the temporal and spatial evolution of conductivity. Conductivity is one of the major parameters of the global electric circuit to identify where the currents will flow. Figure 1 shows the importance of using a high-fidelity model to obtain a conductivity distribution throughout the globe, due to localized features that can't be represented in more simplistic models.



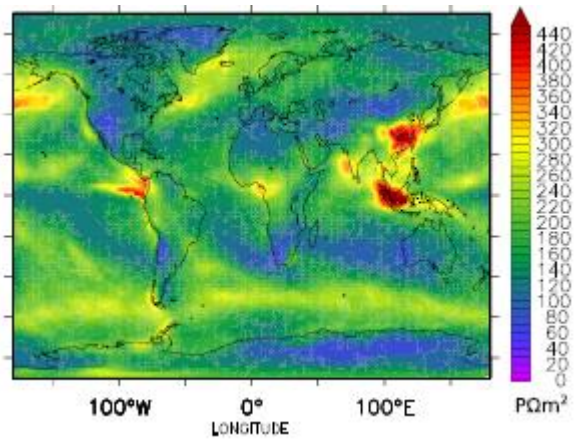


Figure 1: Mean model column resistance (PΩm^2) from the new conductivity module within CESM1(WACCM). The top image is without clouds, while the bottom image includes clouds [2].

2.2 Source Distribution

Utilizing the TRMM satellite with optical and radar measurements, a quantification of electrical currents above thunderstorms can be obtained. The strength of the storm current is correlated to aircraft overflight measurements that were done. The combination of these two measurement techniques allows for a global distribution of current sources to be incorporated into the global numeric model, as well as a temporal variability due to the repetitious satellite coverage. Figure 2 shows a one month average of the current generators in thunderstorms.

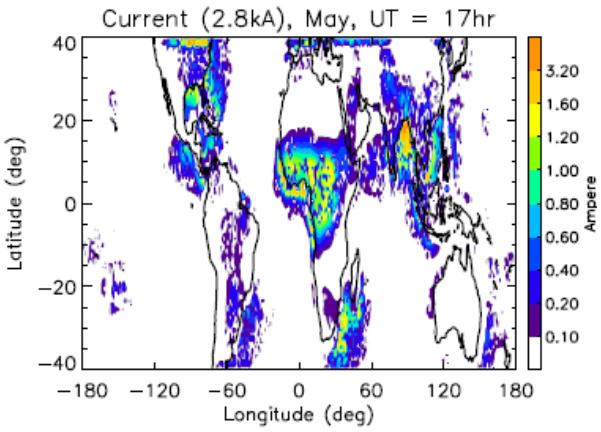


Figure 2: Mean current distribution derived from TRMM in May at Universal Time 17 hours.

3. Numerical Model

A new numeric model was developed to solve the quasi-static continuity equation with high resolution across the globe. The previously discussed conductivity, and source distribution, are the input parameters for the solver. The newly developed model utilizes radial basis functions to solve for potentials and currents throughout the atmosphere. The method was verified with test cases to known analytic solutions and a simplified finite element scheme.

4. Conclusions

Utilizing the newly developed conductivity and source distributions, and solving for the potential and currents throughout the atmosphere with the numeric model allows for the analysis of current distributions throughout the atmosphere with higher fidelity than before. This allows one to analyze how the GEC is changing temporally, as well as determine how different physical mechanisms affect the current distributions. The coupling between the physical and electrical connections within the atmosphere with higher temporal and spatial resolutions than any previous studies will be presented.

5. References

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