Analysis of the diurnal variation of the global electric circuit (GEC) from different numerical models


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GEC models using current dipoles

- We use two 3-D GEC models:
  - RBF model based on radial basis function (GEC-RBFmodels-v0.2) [Bayona et al., 2015]. Code available at https://bitbucket.org/vbayona/gec-RBFmodels
  - FVS model based on finite volume method with structured mesh [Jánšky and Pasko, 2014]
- Variables of mean U
- Earth surface is used either flat or with topography.
- Source dipole currents are input based on data obtained from global circulation model INMCM4.0.

GEC model equations

- Steady state continuity equation:
  \[ \vec{\nabla} \cdot \vec{j} = S_{\text{atm}} \]
  (1)
  where current density \( \vec{j} \) is the product of electric field \( \vec{E} \) and conductivity \( \sigma \), and \( S_{\text{atm}} \) is the current source term.
- Steady state continuity equation is solved in two steps:
  - Five of source continuity equation to obtain resistance of atmosphere \( R_0 \):
    \[ \vec{\nabla} \cdot \vec{\nabla} \vec{j} = 0, \quad \text{U}_{\text{th}} = 1 \]  \( R_0 = \frac{\text{U}_{\text{th}}}{\sigma_{\text{atm}}} \) \( J_{\text{atm}} = \int \vec{j} \, d\vec{S} \) \( J_{\text{atm}} = 0 \)
  - Continuity equation with dipole sources to obtain upward current
    \[ \vec{j} = \vec{j}_0 + \frac{\vec{R}_0}{\vec{R}} \vec{J}_{\text{atm}} \]  \[ \vec{R} = \int \vec{\nabla} \times \vec{\nabla} \vec{j} \, d\vec{S} \]
  - Provides solution with balanced areal total current at THI \( \vec{J}_{\text{th}} \):
    \[ \vec{j} = \vec{j}_0 + \frac{\sigma_{\text{atm}}}{\text{U}_{\text{th}}} J_{\text{atm}} \]  \[ \vec{J}_{\text{th}} = \int \vec{j} \, d\vec{S} = 0 \]  (6)

Methods using current above storms

- The alternative method of obtaining current flowing upwards to the THI \( \vec{J}_{\text{th}} \) uses the knowledge of global distribution of current at 20 km produced from thunderstorms and electrified cloud.
- Peterson et al. [2012,2016] use ice scattering signals from 85Ghz passive microwave observations to characterize the electric field above clouds overhead by aircraft. Ice scattering signal is globally measured by TRMM satellite—these data are labeled TRMM-P15.
- Kalb et al. [2016] use mean currents above electrified clouds obtained from overflights combined with total storm count from precipitation and cloud feature database based on TRMM satellite observations [Lin et al., JAS, 87, 309, 2018]—these data are labeled TRMM-K14.
- Kalb et al. [2016] also develop method to obtain current density at 20 km from climate model CESM—these data are labeled CESM-K16.

Conclusions

- The two GEC three dimensional models (RBF and FVS) are validated by applying them to fundamental GEC problems of calculating GEC resistance and fair weather electric field.
- It was found that model results obtained using topography and yearly averaged conductivity from climate model WACCM differ very weakly from diurnal variation obtained using exponential conductivity.
- Diurnal variation of GEC obtained using different methods were compared.
- In general results based on climate models show smaller amplitudes while methods using overflights combined with satellite data agrees better with fair weather field measurements at Vostok.
- Full description of results will be published in [Jánšky et al., JCR, 2016; to be submitted].

Resistance of the atmosphere

- First to validate the 3-D GEC models we evaluate only equations (2) and (3) and compare them with analytical result for exponential conductivity obtained from integral:
  \[ R = \left[ \int 0 \leq \phi \leq 2\pi \int 0 \leq \theta \leq \pi \frac{1}{\sin \theta} \frac{\partial R}{\partial \phi} d\phi d\theta \right]^{-1} \]  (7)
- Resistances in Ohm, calculated by FVS and RBF models are compared with integral approach. The three cases of conductivity are compared. The first is using exponential conductivity, the second is exponential conductivity including topography and the third one corresponds to the yearly average of conductivity obtained from WACCM for conditions including 22Rm ionization, aerosol and clouds.

Comparison of diurnal variations

- Experimental measurements of fair weather electric field from Vostok are used as reference [Burns et al., JAS, 69, 2061, 2012].
- FVS model based on yearly averaged conductivity profile from WACCM and current sources from Mareev and Volodin [2014] shows small amplitude.
- Results obtained using parametrization developed by Kalb et al. [2016] combined with climate model CESM provides higher amplitude but it is still smaller than experimental data.
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