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Reproducing Electric Field Observations during Magnetic Storms by means of Rigorous 3-D Modelling and Distortion Matrix Co-estimation

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Electric fields induced in the conducting Earth during magnetic storms drive currents in power transmission grids, telecommunication lines or buried pipelines. These geomagnetically induced currents (GIC) can cause severe service disruptions. The prediction of GIC is thus of great importance for public and industry.
A key step in the prediction of the hazard to technological systems during magnetic storms is the calculation of the geoelectric field. To address this issue for mid-latitude regions, we developed a method that involves 3-D modelling of induction processes in a heterogeneous Earth and the construction of a model of the magnetospheric source. The latter is described by low-degree spherical harmonics; its temporal evolution is derived from observatory magnetic data. Time series of the electric field can be computed for every location on Earth's surface.
The actual electric field however is known to be perturbed by galvanic effects, arising from very local near-surface heterogeneities or topography, which cannot be included in the conductivity model. Galvanic effects are commonly accounted for with a real-valued time-independent distortion matrix, which linearly relates measured and computed electric fields. Using data of various magnetic storms that occurred between 2000 and 2003, we estimated distortion matrices for observatory sites onshore and on the ocean bottom. Strong correlations between modellings and measurements validate our method. The distortion matrix estimates prove to be reliable, as they are accurately reproduced for different magnetic storms. We further show that 3-D modelling is crucial for a correct separation of galvanic and inductive effects and a precise prediction of electric field time series during magnetic storms.
Since the required computational resources are negligible, our approach is suitable for a real-time prediction of GIC. For this purpose, a reliable forecast of the source field, e.g. based on data from satellites analysing the solar wind, is necessary.