Modelling the Effects of Space Weather at the Earth's Surface: A UK Geoelectric Field Model

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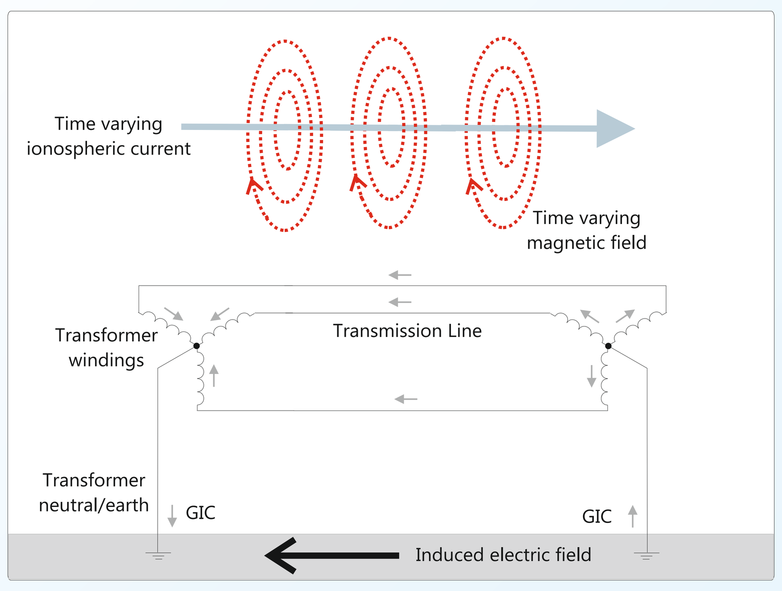
Geomagnetically Induced Currents (GIC), which can flow in technological systems such as power transmission grids, are a consequence of the geoelectric field induced at the surface of the Earth during geomagnetic storms. This poster describes the development of a new 3D 'Thin-Sheet' geoelectric field model which covers the whole of the UK and includes the influence of the surrounding shelf seas. The model can be used to compute the response of the geoelectric field to geomagnetic storms. In conjunction with a power grid model this enables us to estimate GIC flow in power networks. As an example, we consider the major geomagnetic storm of October 2003. It is envisaged that the model will form one component of a near real time GIC warning package which is currently being developed by the British Geological Survey (BGS) in conjunction with Scottish Power Plc. The magnetic field associated with the induced geoelectric field is easily calculated. Thus, the electric field model may also be of interest to those studying the effect of internal (induced) geomagnetic field signals on the total measured geomagnetic field.

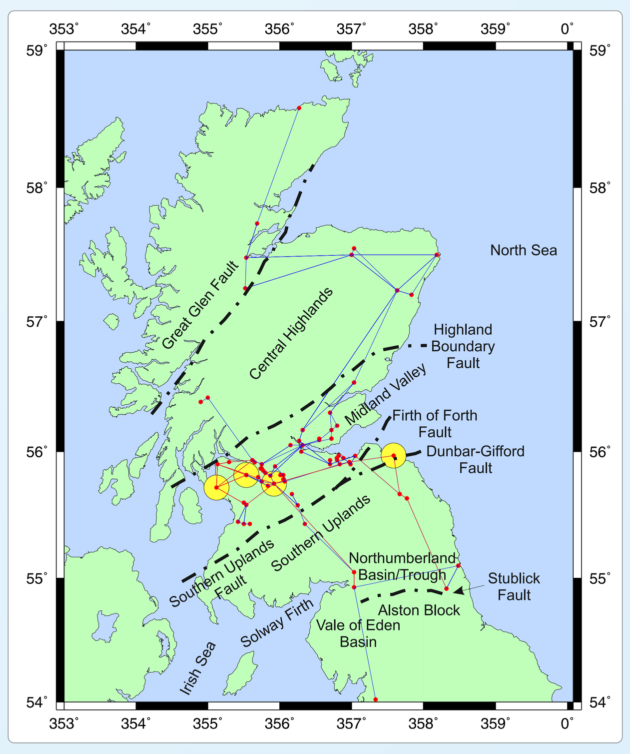
Background



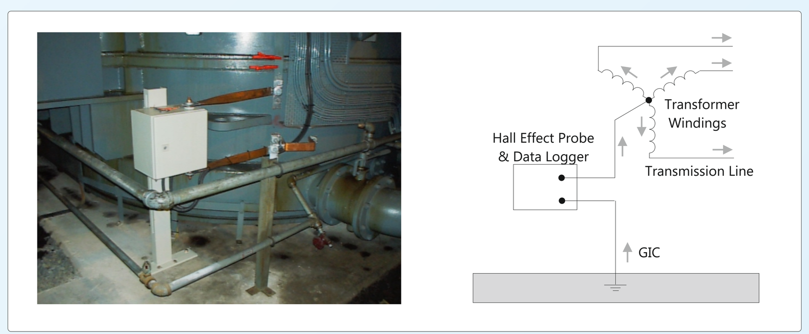
To be able to predict how GIC will flow in a power grid we need to understand how the geoelectric field responds to a geomagnetic storm.

***Left:** During a geomagnetic storm, an electric field is induced at the Earth's surface. A power grid provides a discretely grounded network which can short-circuit the induced electric field. GIC enter the power grid via the transformer neutral, and can damage equipment and cause protective equipment to malfunction.*

The induced geoelectric field depends on frequency, resistivity structure of the Earth, and spatial morphology of the magnetic field. Of these three, the electric field is probably most sensitive to the resistivity structure [3]. However, the geology of the UK is complex, and in addition, the UK is surrounded by shelf seas and the Atlantic Ocean to the West which are known to affect the observed electromagnetic fields [2].



Right: The Scottish part of the UK power grid covers an area of complex geology. Scottish Power Plc monitor GIC at four points (yellow circles) in the grid.

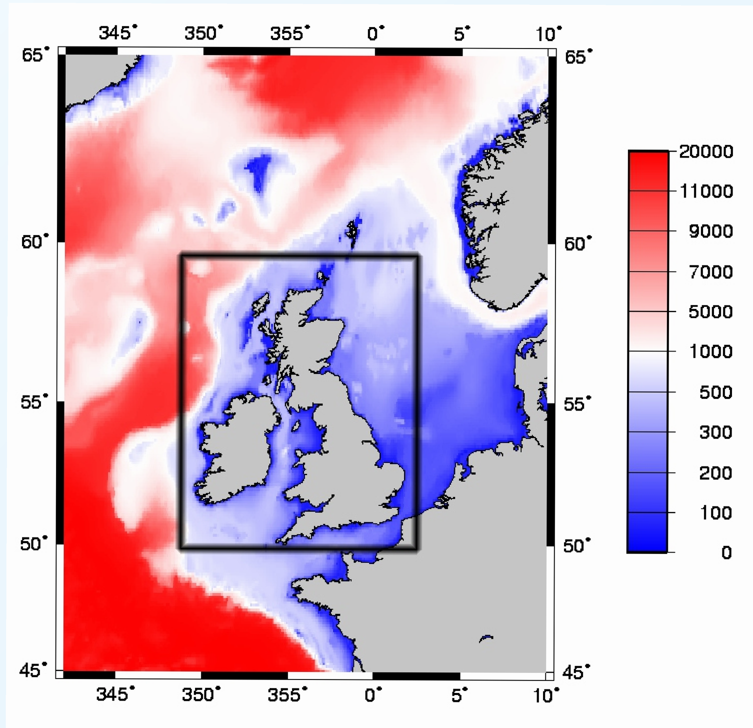


***Left:** a typical installation of a GIC monitor.*

Model Construction

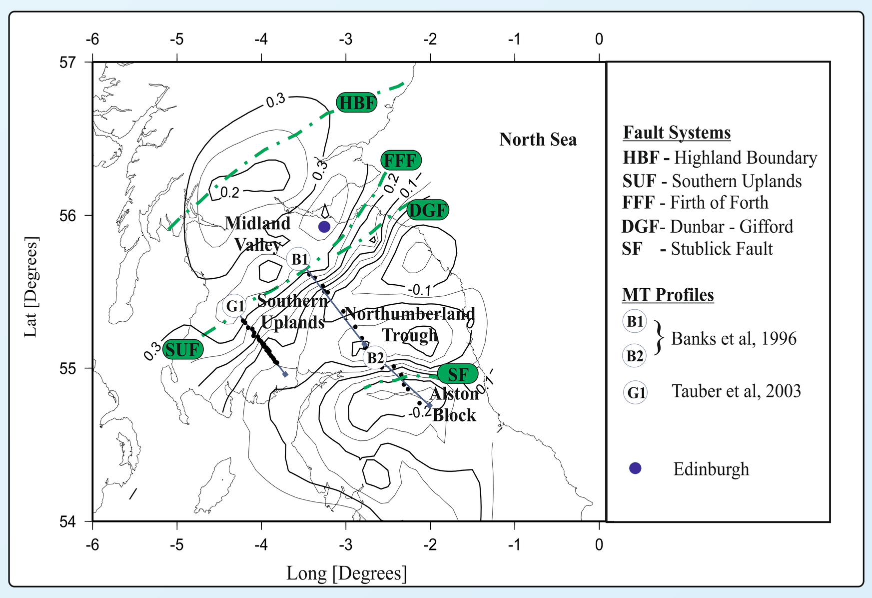
The typical variation period of GIC is from 10-1000s. Thus, the depth of penetration of electromagnetic fields in the Earth can be greater than 100km. Therefore, it is the gross geological structure underlying the UK which controls the overall response of the geoelectric field. However, the near surface (crustal scale) structure distorts the underlying response. We therefore employ a thin sheet modelling approach [8].

The model comprises a non-uniform thin sheet of laterally variable conductance (depth integrated conductivity) at the surface of a layered half-space. We use ETOPO5 bathymetry data, the spatial variation of observed magnetic fields and previous electromagnetic modelling [1,4] to control the distribution of conductance in the surface sheet.



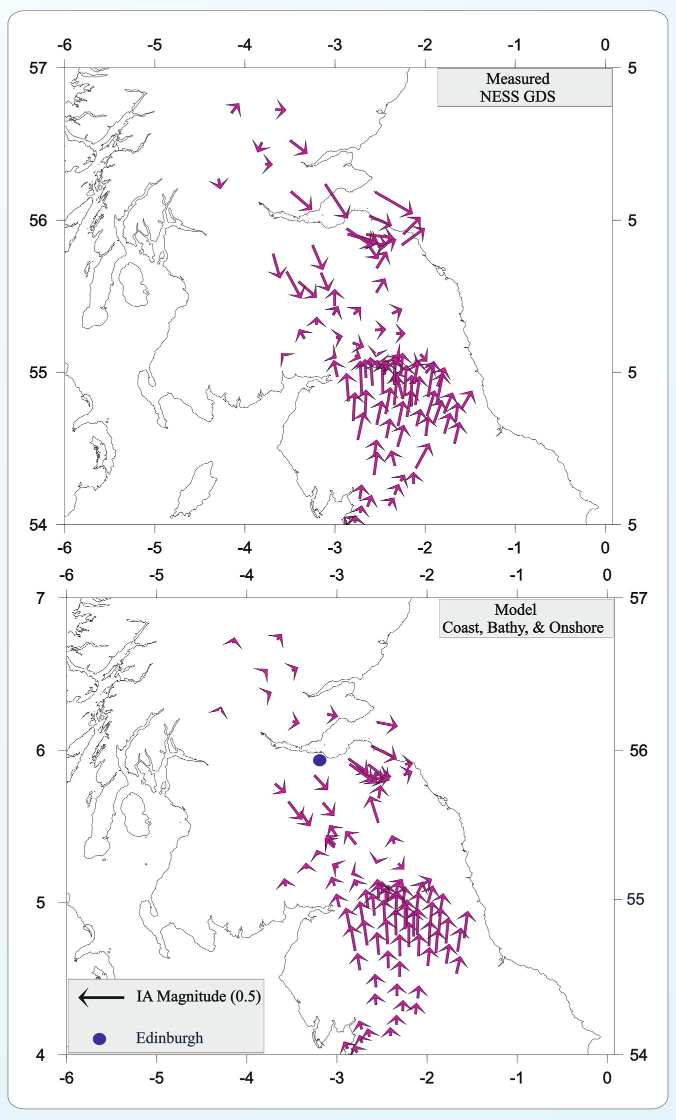
***Above:** Calculated conductance (S) of the surrounding shelf seas using ETOPO5 Bathymetry data.*

***Below:** Hypothetical event map [e.g. 5] of the observed anomalous vertical magnetic fields (nT) in Southern Scotland and Northern England when the reference magnetic field is 1nT and polarised north. Large spatial gradients of the vertical field indicates the presence of a conductivity boundary. This highlights the two main geological anomalies of the area which are likely to influence GIC in the Scottish Power grid: the Southern Uplands Fault and Northumberland Basin.*



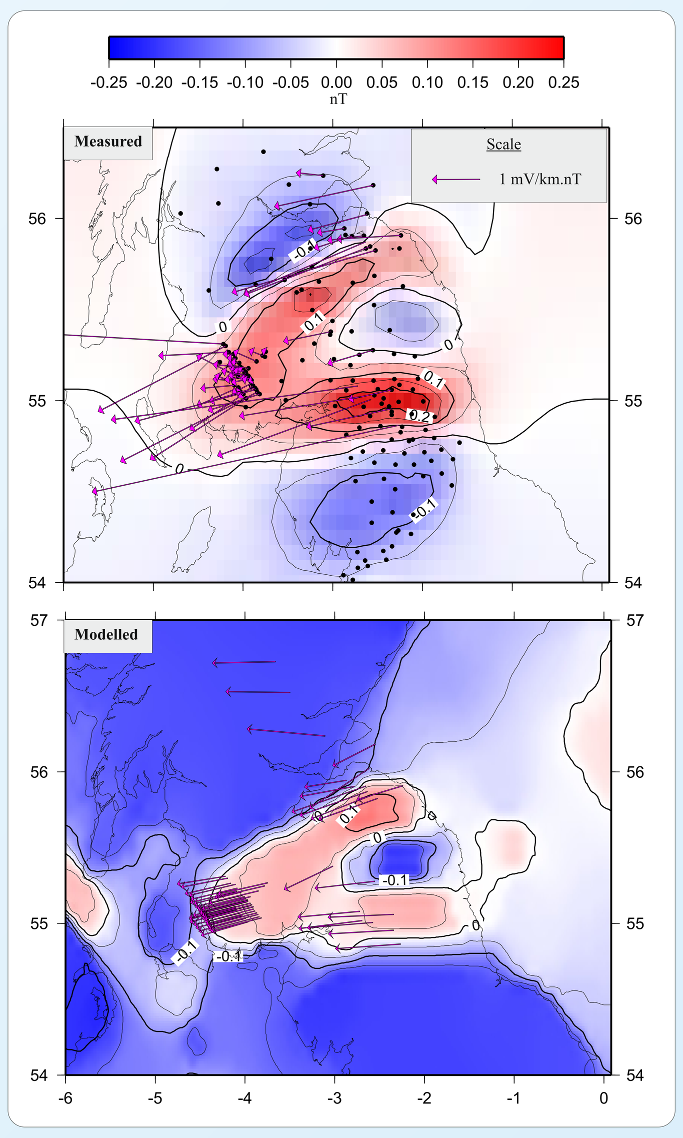
Comparison with Measured Data

We have compared the model to Southern Scotland and Northern England electromagnetic induction data collected from numerous field campaigns [7, and references therein]. These data are estimates of vertical magnetic field and telluric response functions. Tensor decomposition was used to correct the telluric response functions for the effect of static shift on the azimuth of the electric field [6].



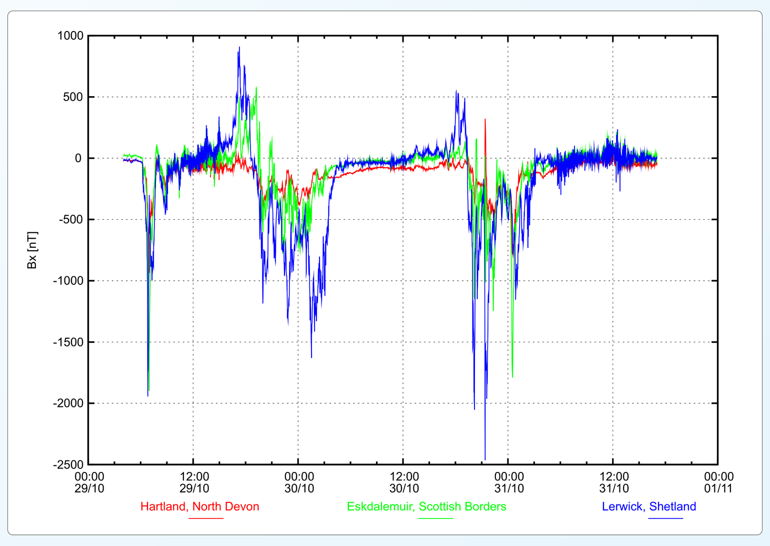
Above: Measured and modelled induction arrows in the Central Scotland and Northern England Region. The Parkinson convention is employed. Thus, the arrows point towards regions of higher conductance.

***Below:** Measured and modelled electric field vectors and the anomalous horizontal X (North) component of the magnetic field when the reference magnetic field is 1nT and polarised 0°N. The black dots are magnetic field measurement sites [see 6].*

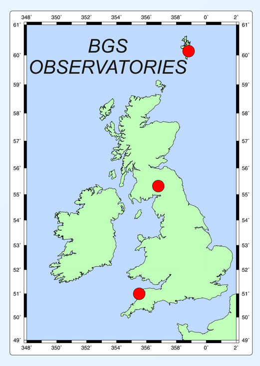


Applications and Future Work

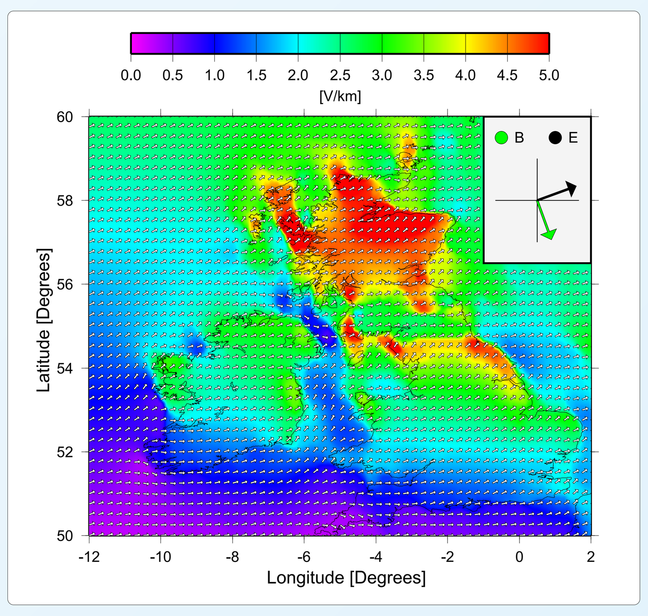
Models of the electric field, and BGS measurements of the magnetic field, enable us to calculate GIC throughout the Scottish Power grid. As part of an European Space Agency pilot project we have developed a preliminary model of the Scottish Power grid. This provides an estimate of GIC throughout the power grid in near real time, but is based on a 1D model of the surface electric field. Comparison with measured data highlights that more work is required. Future work will update the model of the power grid and include a non-uniform geoelectric field model.



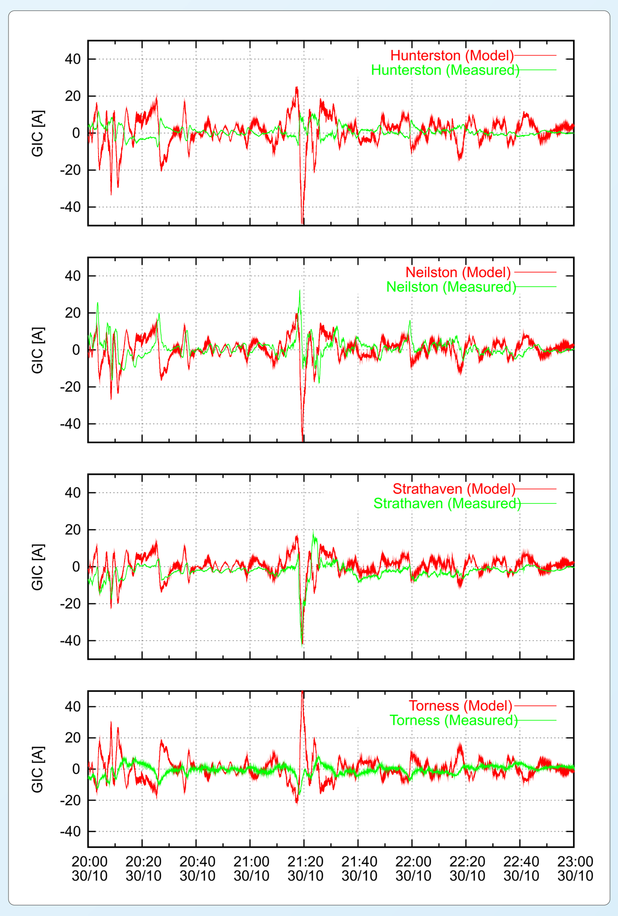
***Above:** X (North) component of the geomagnetic field at each of the BGS observatories during the 30th October geomagnetic storm. **Right:** The three UK BGS Observatories.*



***Below:** Modelled and measured GIC at each of the four Scottish Power monitoring sites during the 30th October 2003 magnetic storm. A 1D model of the Earth was employed to calculate the geoelectric field from BGS magnetic observatory. At one site (Strathaven) the model and measured GIC compare favorably, while at other sites the fit is less good. Work is in progress to include the 3D thin-sheet modelling, and update the grid model.*



***Left:** An estimate of the geoelectric field at the peak of the 30th October 2003 storm (approx. 21:20UT). The inset shows the direction of the surface electric field for a one-dimensional electrical model of the crust. The main map shows local variations due to the three-dimensional model employed.*



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References:
[1] D. Beamish et al, J. Atmos. Sol. Terr. Phys., 64:1779-1792, 2002
[2] D. Beamish, J. Geophys., 57:207-216, 1985
[3] G. Jiracek, Surv. Geophys., 11:163-203, 1990
[4] W. Jozwiak and D. Beamish, Geophys. J. R. astr. Soc., 85:629-643, 1986
[5] P. Ritter and R.J Banks, Geophys. J. Int., 135:923-942, 1998
[6] J.T. Smith, Geophys. J. Int., 130:65-72, 1995
[7] S. Tauber et al, Geophys. J. Int., 153:548-569, 2003
[8] G. Vasseur and P. Weidelt, Geophys. J. R. astr. Soc., 51:669-690, 1977
[9] A. Viljanen, Geophys. Res. Lett., 24:631-634, 1997