Monitoring and Analysis of Geomagnetically Induced Currents in the British Isles

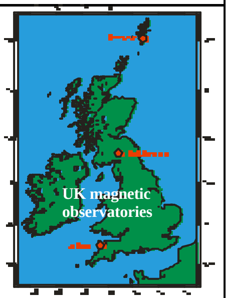
Alan Thomson (awpt@bgs.ac.uk), Allan McKay and Ellen Clarke

Geomagnetism, British Geological Survey, West Mains Road, Edinburgh EH9 3LA, UK

A Review of Previous Work – *in association with Scottish Power since 1999, and comprising GIC monitoring and geomagnetic activity data and forecasts*

Current Activities – *electric field modelling in the UK and continental shelf and preliminary GIC modelling in the UK power grid*

Future Developments – *improving services to the power industry through ESA space weather pilot project*



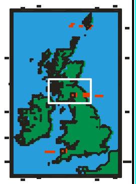
Previous Work

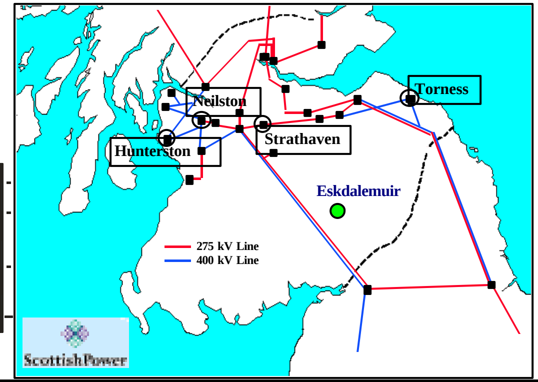
- **Monitoring Geomagnetically Induced Currents (GIC)**
  - On transformers in the Scottish Power grid
  - Monitoring equipment (GIC and gas) installed at 3 sites in January 2000, now at 4 sites
- **Monitoring and Predicting Geomagnetic Activity**
  - Hourly geomagnetic data and daily forecast service provided by BGS
  - Used by Scottish Power in its daily operations since October 1999.
- **GIC Study**
  - Analysis of GIC during significant magnetic storms (2000-2002) in relation to measurements at UK and northern European geomagnetic observatories.
  - Time Domain, Frequency Domain, Linear Transfer Function Models

Previous Work: Monitoring GIC in Real Time

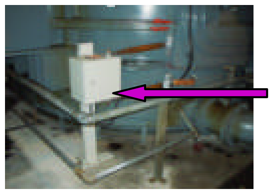
Scottish Power Grid

Circa 2000



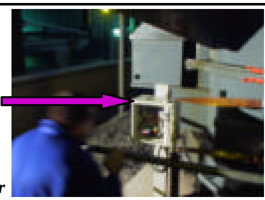


Previous Work: Monitoring GIC in Real Time



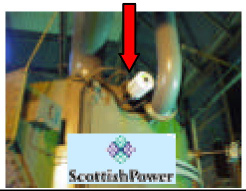
Hall Effect Probe

Hydran Gas Analyser



Data are available at the grid control centre

Operator alarm set at 5 Amps

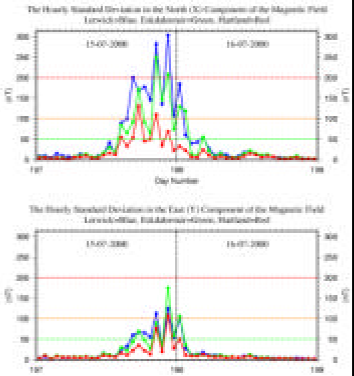


BGS supply of magnetic data is used for confirmation of current as GIC

Previous Work: Geomagnetic Activity Monitoring

Hourly Standard Deviation (HSD)

- Gives an indication of the total magnetic spectral power during the hour
  - related to the surface electric field through the magnetotelluric relation, $E(w)=Z(w)H(w)$
- Simple index to compute
  - real-time on-line provision made possible
- Magnetic substorms typically last 10 minutes to a few hours
- Single data spikes unlikely to have an effect
  - important when operating automatically in real time.



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Previous Work: Geomagnetic Forecasts

Geomagnetic Activity Forecasts

- gives broad view of likely activity for non-specialist
- attempts to relate to conditions observed in UK

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BRITISH GEOLOGICAL SURVEY: GLOBAL SEISMOLOGY AND GEOMAGNETISM GROUP
        GEOMAGNETIC ACTIVITY FORECAST FOR SCOTTISH POWER
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      Forecast Interval (GMT)     Forecast Global Activity Level

Noon 15-JUL-2000 to Noon 16-JUL-2000         MAJOR-STORM
Noon 16-JUL-2000 to Noon 17-JUL-2000         MINOR-STORM
Noon 17-JUL-2000 to Noon 18-JUL-2000            ACTIVE

                     ADDITIONAL COMMENTS
Yesterday the magnetic field was at MINOR-STORM levels both globally
and in the UK.

A major solar event has been observed from a region near the centre
of the solar disk and a full halo CME was observed. These observations
mean that the event is very likely to be geoeffective. The shock is
expected to impact the earth's magnetosphere sometime during the latter
half of the 15th July, but the exact timing is difficult to predict.
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            TODAYS FORECASTER: Ellen Clarke
            BGS CONTACT PHONE: 0131 667 1000 (switchboard)
            BGS CONTACT FAX  : 0131 668 4368
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Global Activity Level	Typical Maxima of UK Observatory Hourly Standard Deviations (nT)		
	LERWICK	ESKDALEMUIR	HARTLAND
QUIET-UNSETTLED	<20	<20	<15
ACTIVE	20-50	20-30	15-20
MINOR-STORM	50-150	30-60	20-40
MAJOR-STORM	>150	>60	>40

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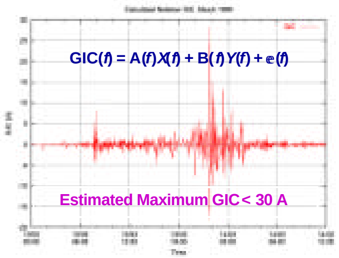
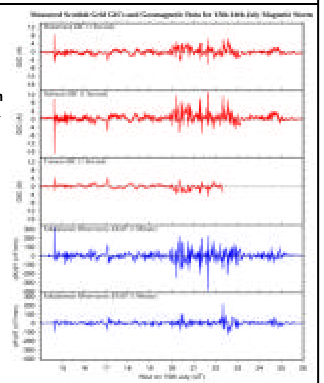
Previous Work: GIC Analysis

Simple time and frequency domain phase correlations, using B and dB/dt

Right: dB/dT and GIC data for July 2000

Below: Transfer function derived from July 2000 storm and applied to March 1989 superstorm, using Esk data





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Current Activities: Conductivity and Electric Field Models of UK Continental Shelf

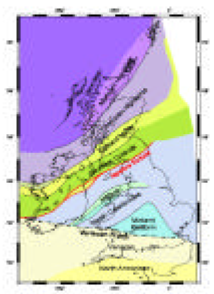
Thin Sheet Model

- appropriate to 'low frequency' GIC range of 100-1000s

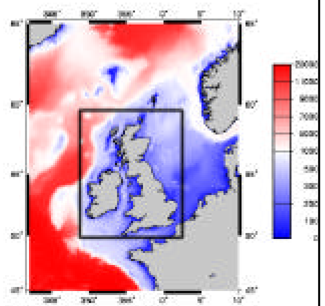
-Horizontal field only required

-Non-uniform source fields can be used

-Includes shelf seas and bathymetry



Tectonic terrane map (from BGS tectonicterrane model). Main crustal resistivity contrasts of UK: Highlands/ Hebridean resistive. Midland Valley/ Southern Uplands conductive.



Conductance (conductivity x depth product) of ocean assuming sea-water resistivity of 0.25 Ohm.m. Model area outlined. NOAA/ETOPO5 bathymetry used to calculate conductance.

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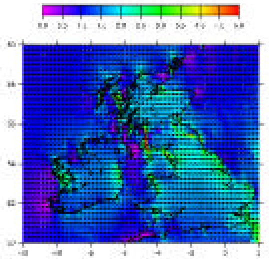
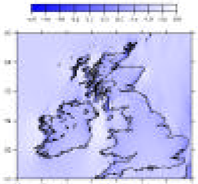
Current Activities: Electric Field

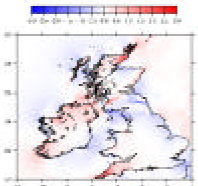
Example: North - South plane wave magnetic variation (East – West ionospheric electrojet) at 750s period



E-field magnitude and direction (mV/km.nT)



'Regional' East-West *E*-field from thin sheet model



'Anomalous' North-South *E*-field resulting from lateral changes in conductivity

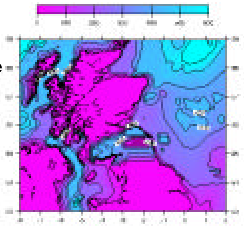
- significantly more complicated in central Scotland

Current Activities: Comparison with Data

Under assumption of induction in the Earth via quasi-uniform sources, a vertical field indicates presence of lateral changes in conductivity.

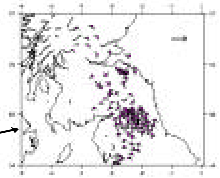
Induction arrows (right) are determined from the transfer functions that relate the vertical field to horizontal driving fields. They point to concentrations of electrical current (e.g. conductivity contrasts).

Conductance map compatible with measured induction arrows



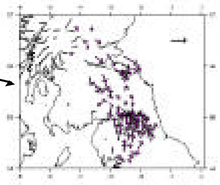
Model

(scale =0.5 per nT; period = 750 s)



Measured Data

(20 years of field campaigns by Univ. Edinburgh)



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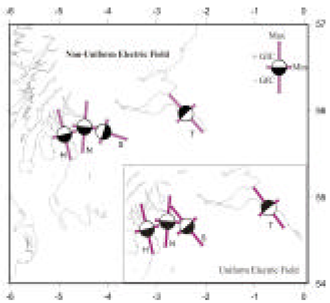
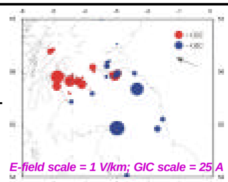
Current Activities: GIC Modelling in Association with FMI

Below: Dependence of GIC on source field polarisation.



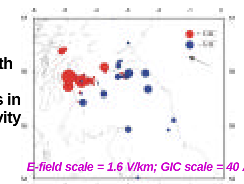
Right:

Simple model of constant *E*-field.



Right:

E-field with lateral variations in conductivity and sea water.



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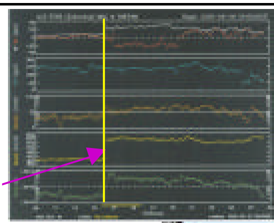
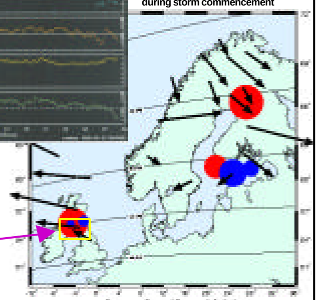
Future Opportunities: Grid Operator Issues

Key Issues for Improved Service to Industry – *based on discussions with Scottish Power*



ACE Data for July 2000 Storm



Excerpt from BGS/FMI animation of July 2000 Storm, during storm commencement

Increased warning time of CME arrival, based on L1 monitor – *automated shock monitoring*

Estimates of peak GIC magnitude in the grid – *where are the biggest currents flowing in response to geomagnetic drivers?*

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Future Opportunities: ESA Pilot Project (1)

The Partnership.

BGS as service developer and Scottish Power as the service user.

Aiming for simple, yet reliable system within financial constraints set by pilot project.

The Proposed Solution.

(1) Interplanetary shock detection: pattern recognition and event detection techniques, e.g. neural networks, wavelet and spectral analysis. More than one algorithm for robustness.

(2) Grid GIC model: merging a model to compute the flow of GIC in the Scottish power network with a model that computes the induced surface electric field which drives the GIC. The induction model will take as input the magnetic variations recorded at the UK observatories operated by BGS, or simplified electrojet structures.

The current reliable BGS-SP communication system will be augmented to transmit relevant warnings and data to the Scottish Power grid control room.

Future Opportunities: ESA Pilot Project (2)

Prior Experience.

(1) Progressive development of GIC expertise and in service provision

(2) Near real time data acquisition, processing and delivery, e.g. magnetograms for geophysical exploration

Data Requirements.

UK geomagnetic data and public domain L1 data

Development Risks.

(1) Spiky/noisy/missing data – *real time data management issues*

(2) Variability of ionospheric driving currents – *'blue sky research'*

(3) Accuracy of shock monitor & GIC estimates – *'fit for user purpose'*

Benefits.

(1) Economic benefit to user – *addresses user's concerns*

(2) Potential application beyond UK grid – *dependent on scale size of variations*

(3) Public awareness – *adding to real time monitoring on BGS web pages*

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Monitoring and Analysis of Geomagnetically Induced Currents in the British Isles: Summary

Reviewed Previous Activities on GIC

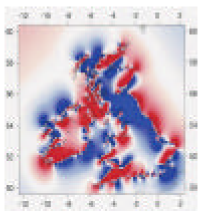
– in association with Scottish Power plc, FMI

Summarised Current Activities

– electric field modelling in the UK and nearby continental shelf

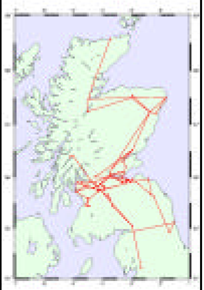
Identified Opportunities for Future Developments

– improving service to industry through space weather pilot project



Electric Field Modelling

GIC in Power Grid



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