British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

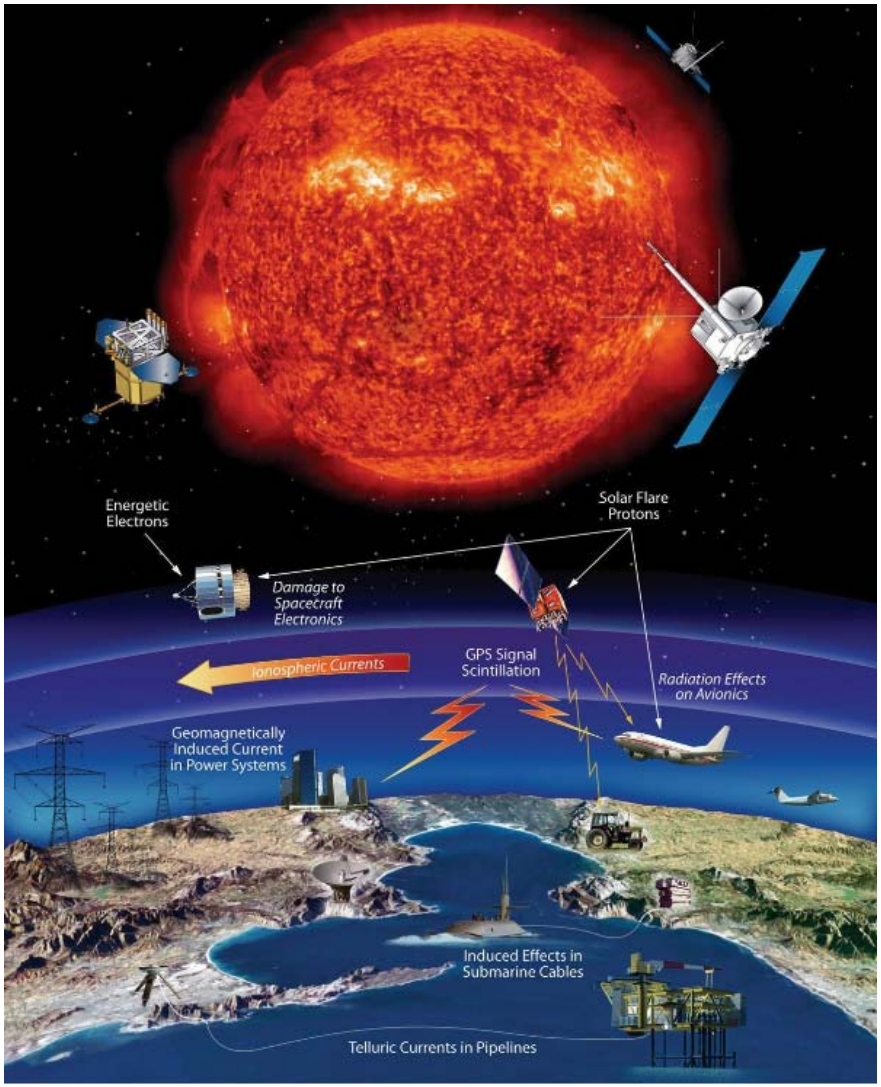
Applied geoscience for our changing Earth

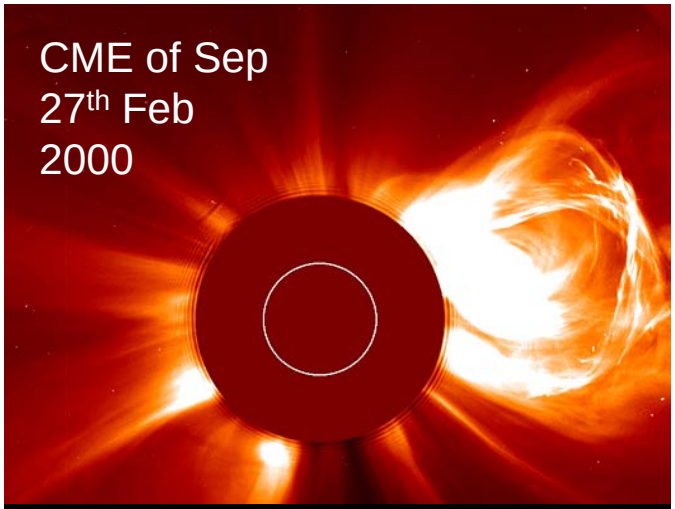
Ground-Based Magnetometer Arrays and Geomagnetically Induced Current in Power Grids: Science and Operations

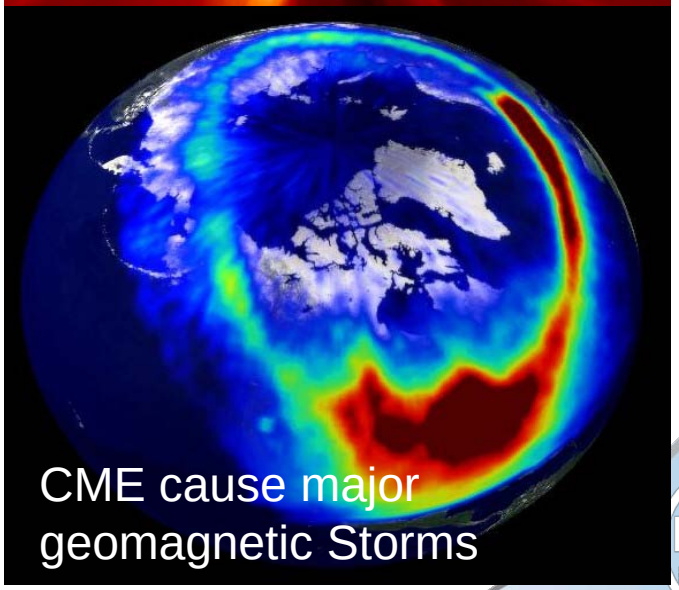
Alan W P Thomson (awpt@bgs.ac.uk),
Ciarán Beggan and Gemma Kelly

- Introduction
  - What is this hazard and how does it affect power grids?
- Scientific Research and Data Sources
  - Measuring and modelling geomagnetic & GIC data
  - Current research directions
  - Industry perceptions and needs
- Role for Geomagnetic Observatories
  - Real-time data, products & forecasts, e.g. indices
  - Supporting grid operations
- Conclusions

The Space Weather Hazard

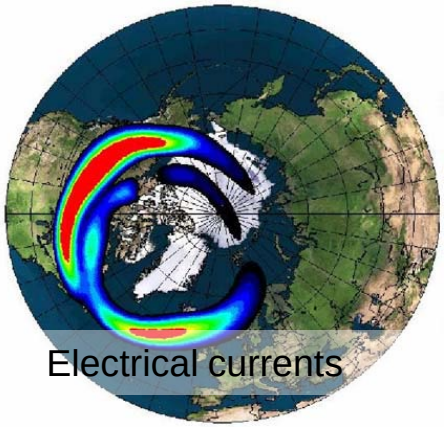


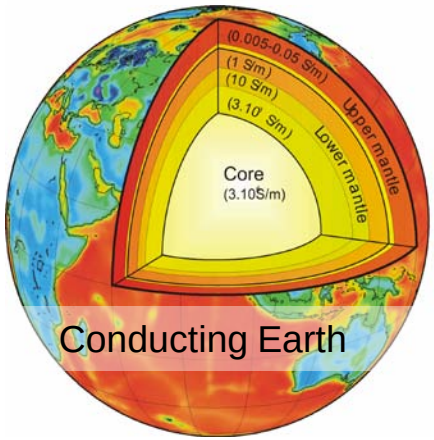


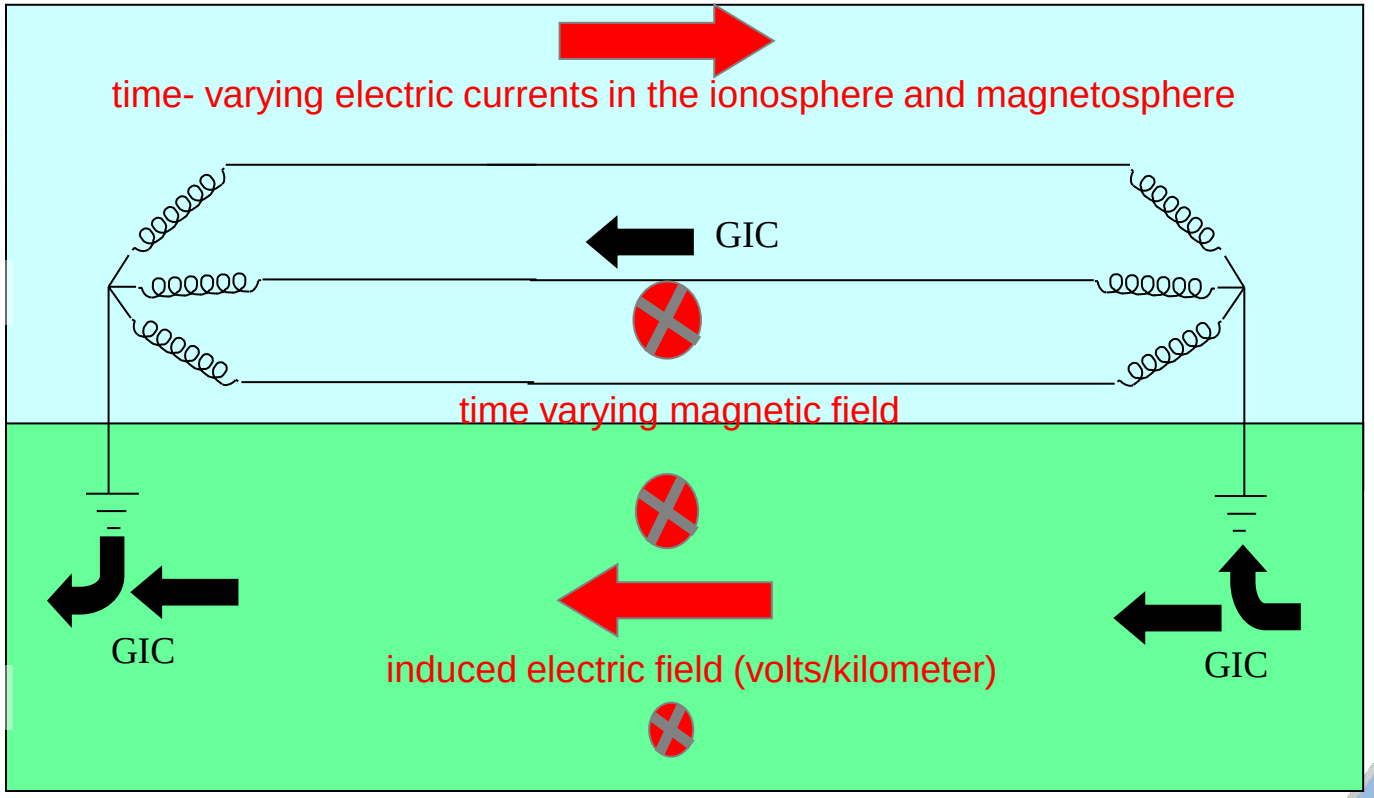


Credits: NASA and NASA/ESA

Why Does Space Weather Cause Grid Problems?

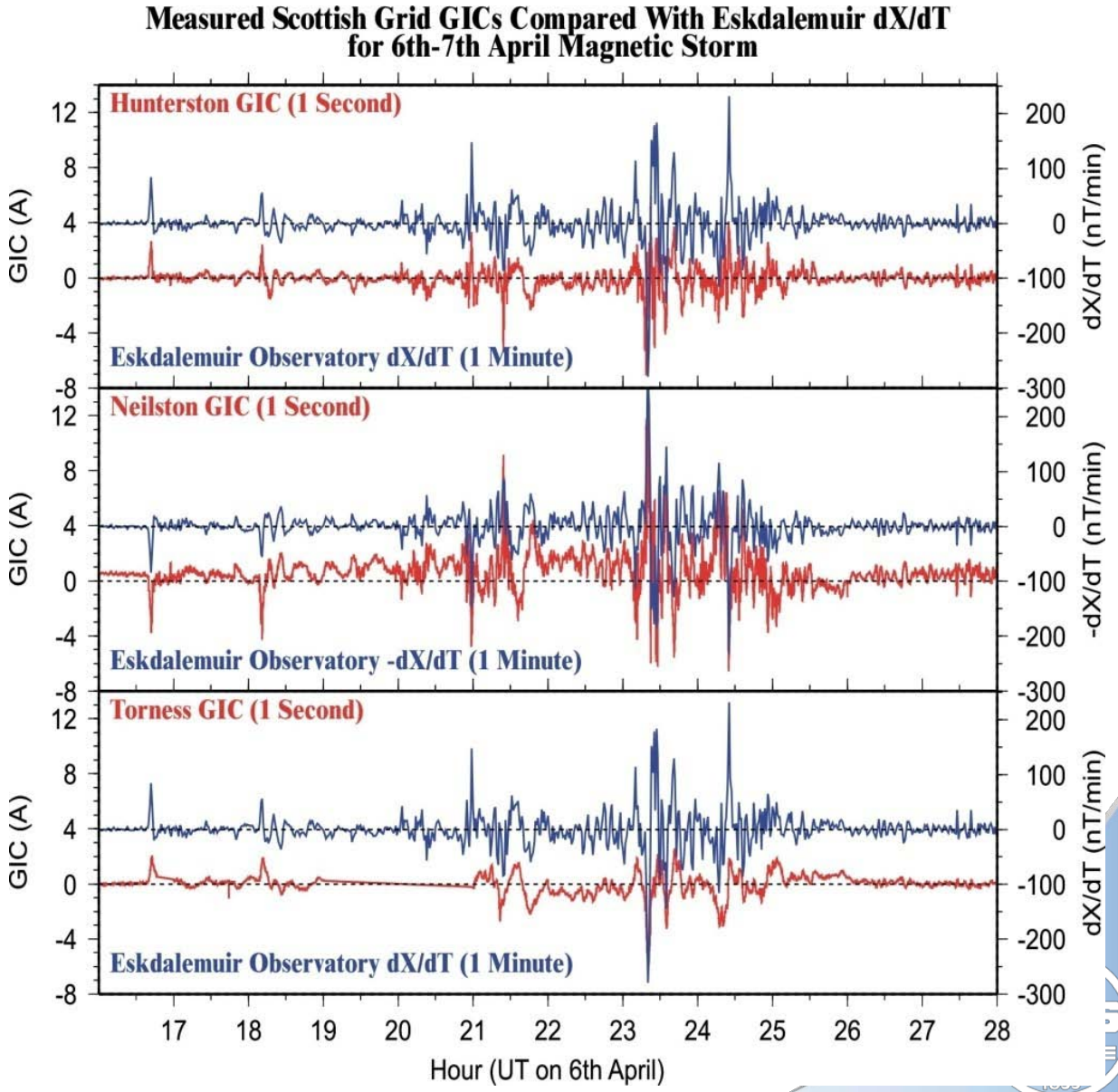






- Consequences
  - Transformer overheating
  - Voltage instability and sag
  - Protective device malfunction or tripping

Impact – Power Grids



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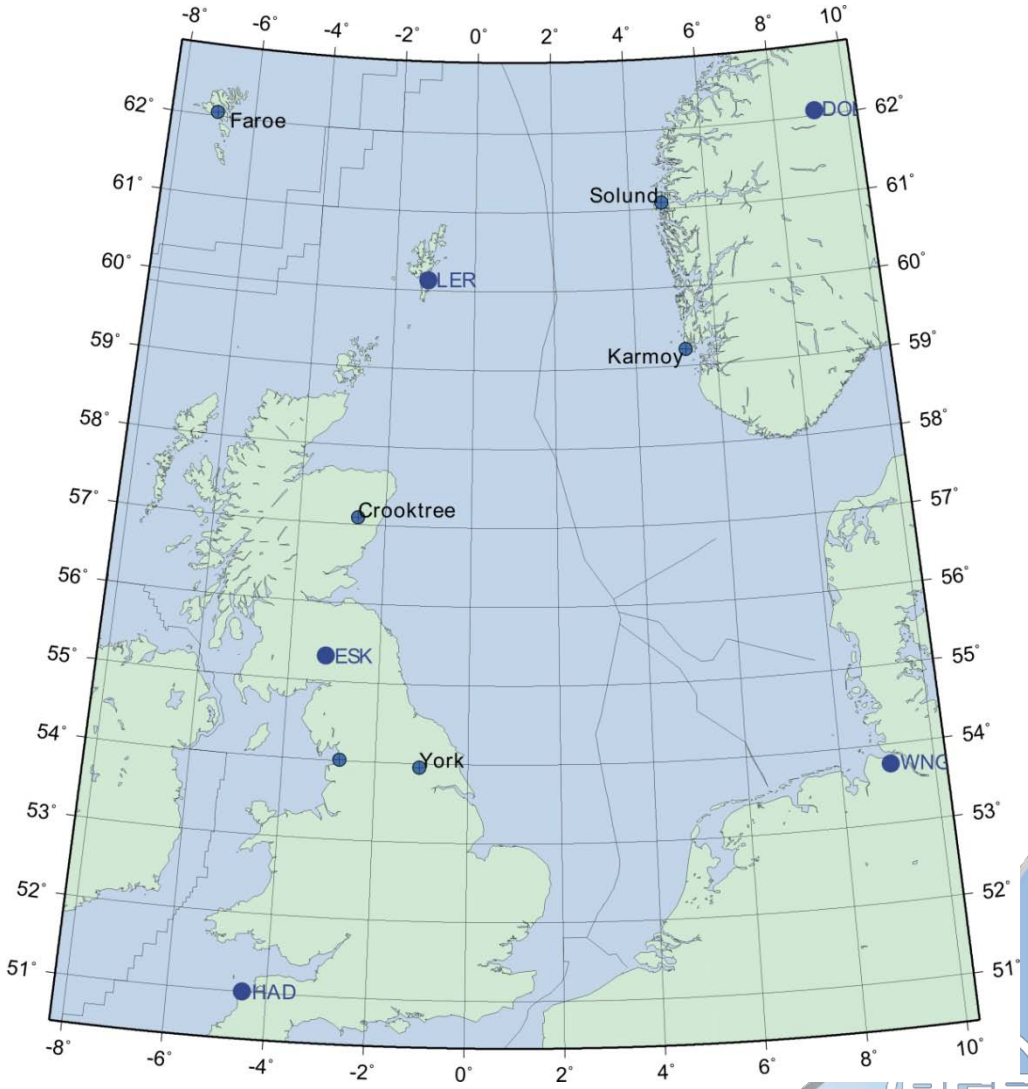
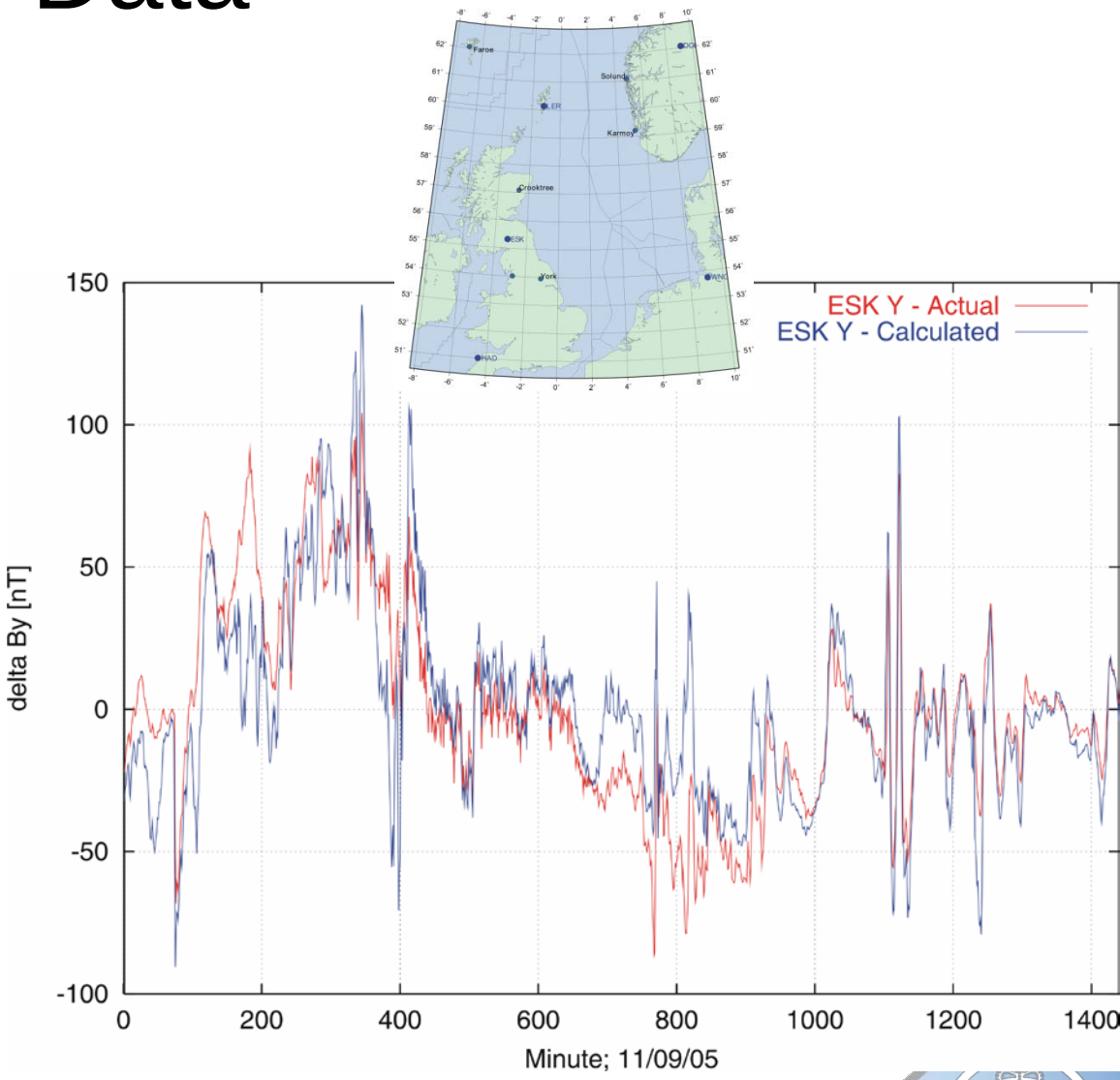
Geomagnetic Data

- Arrays of variometers & observatories
- Contributing real-time data for services
  - Or post-event data for analysis



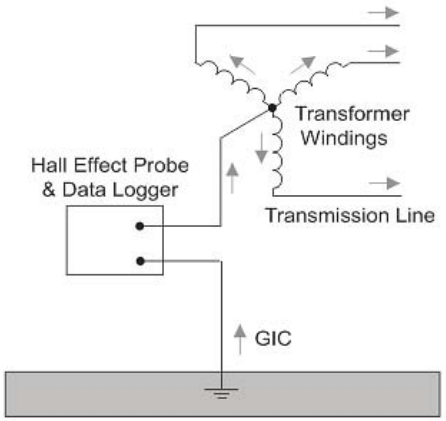
Geomagnetic Data

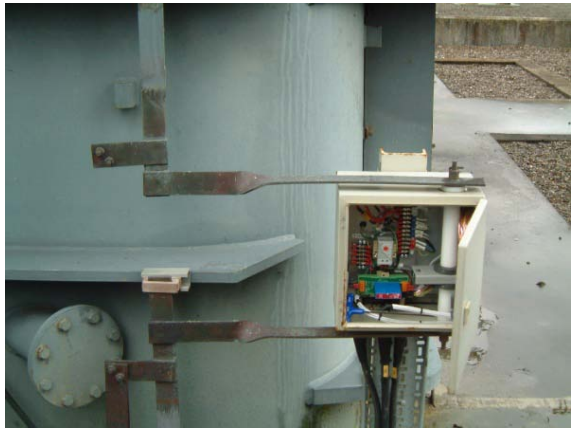
- Arrays of variometers & observatories
- Contributing real-time data for services
  - Or post-event data for analysis
- Interpolation of source fields via ‘spherical elementary current systems’ technique
  - Local basis functions to determine equivalent ionospheric currents from the magnetic field
  - Olaf Amm, 1997

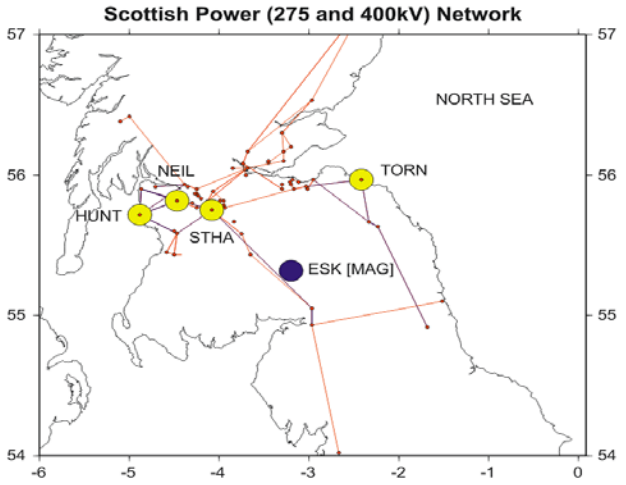


Power Industry GIC Data

- Sources of GIC data
  - UK (NG and SP)
  - US (Sunburst)
  - Finland (Gas pipeline monitored with magnetometers)
  - Canada (?)
- Industry GIC data sharing
  - Ad hoc basis
  - Trust
  - Personal contacts

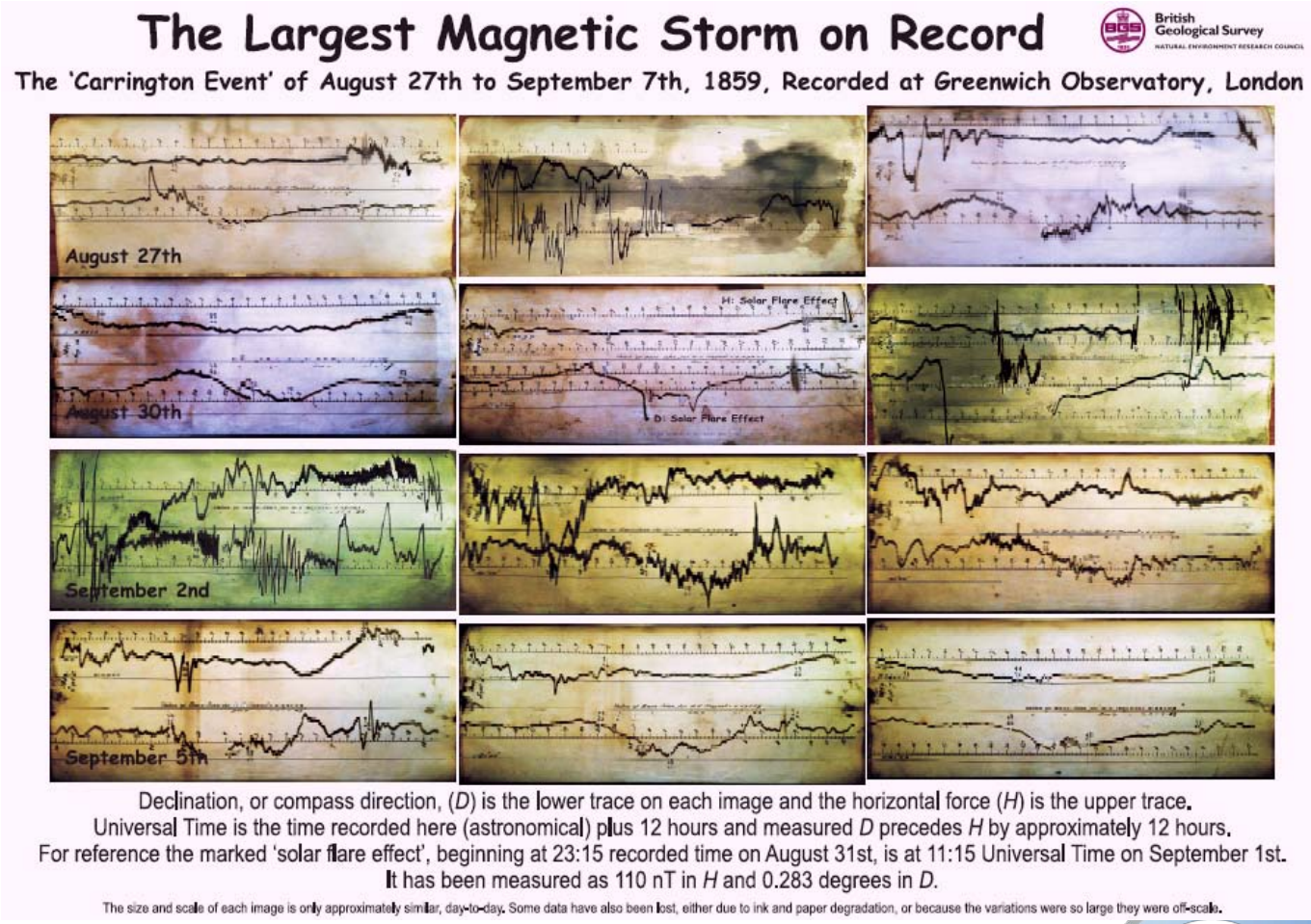






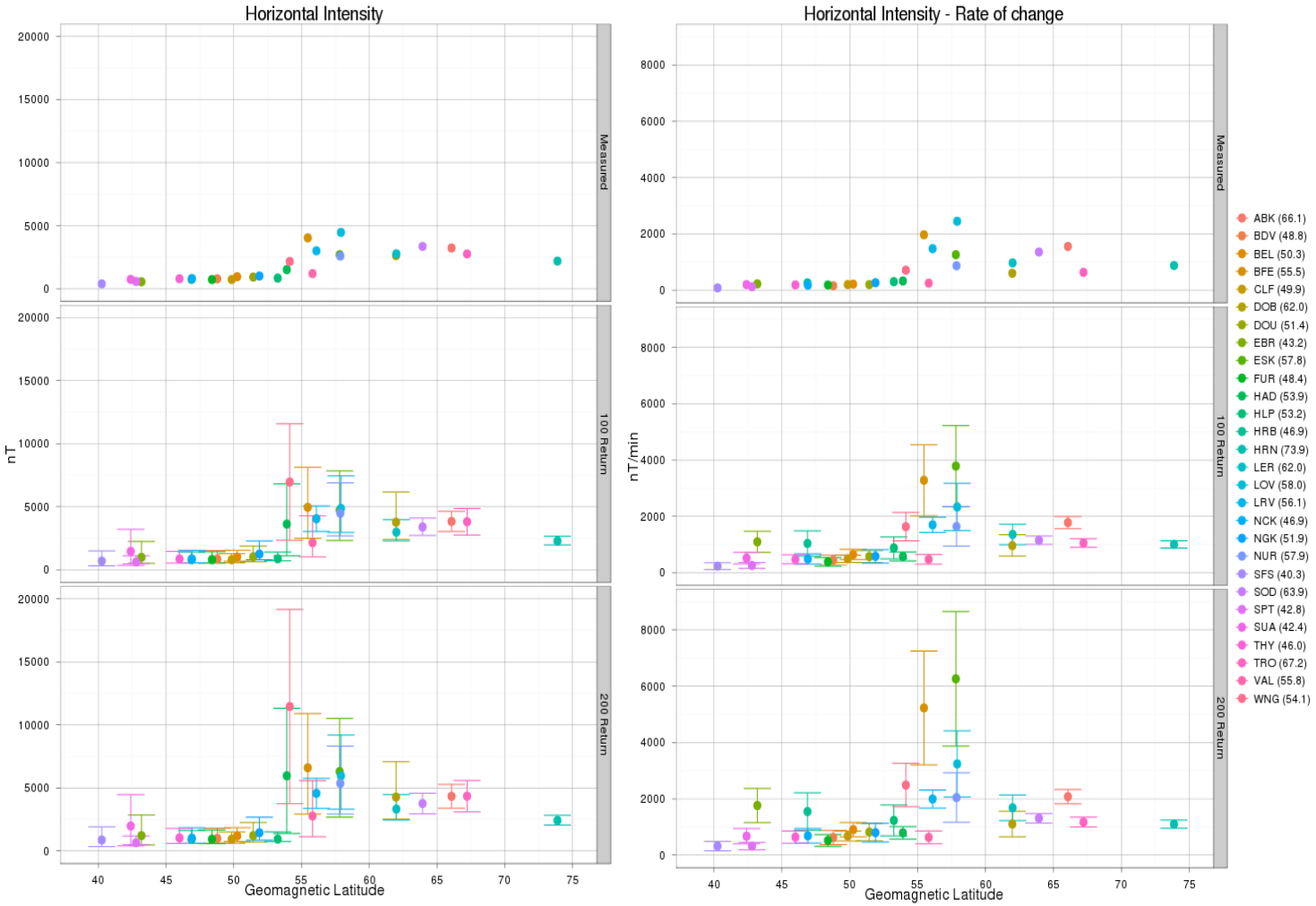
Power Industry Viewpoints

- Industry concerns
  - Voltage swings and possible transformer damage
  - Want maximised warning time and accuracy
  - Extreme events rather than ‘normal’ space weather



www.bgs.ac.uk/data/Magnetograms/home.html

Extremes in Geomagnetic Data

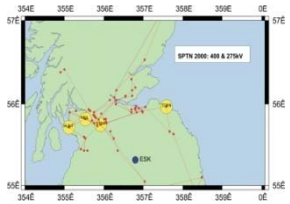


Will your magnetometers have sufficient dynamic range?

Scientific Research & Services

GIC Modelling

Grid Network Model (GNM)

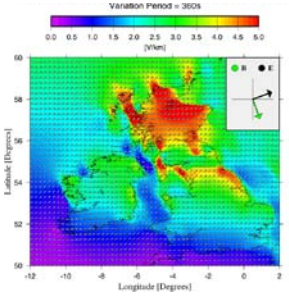


Network Admittance Earthing Impedance

GIC $\longrightarrow \mathbf{I} = (\mathbf{1} + \mathbf{YZ})^{-1}\mathbf{J}$

Source

Electric Field Model (EFM)



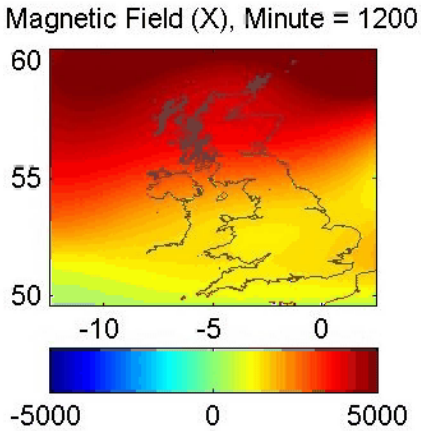
- Assume GIC are slowly changing w.r.t. 50/60 Hz
- Use Kirchoff Laws to formulate network matrix model
- Earthing/transmission line resistance from industry data

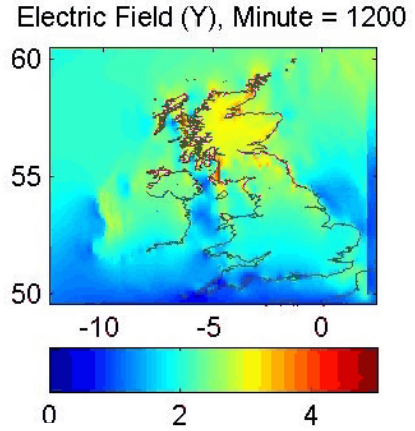
- Use the ‘thin sheet’ model of electric field
- Needs a 1D or 3D Earth conductivity model on a grid

$$E_y(t) = \frac{-1}{\sqrt{\pi\mu_0\sigma}} \int_{-\infty}^{t} \frac{\dot{B}_x(u)}{\sqrt{t-u}} du$$

(Some) Current UK Activities

- Updating ground conductivity model with geological data
- Increasing spatial resolution of model (10km → 1km grid)
- Improved grid network model (132 kV and above)
- Extreme event simulation
  - Example shown = 8 times scaled October 2003 storm





EURISGIC

http://www.eurisgic.eu/

Geo-Electric Field Monitoring

Project Summary

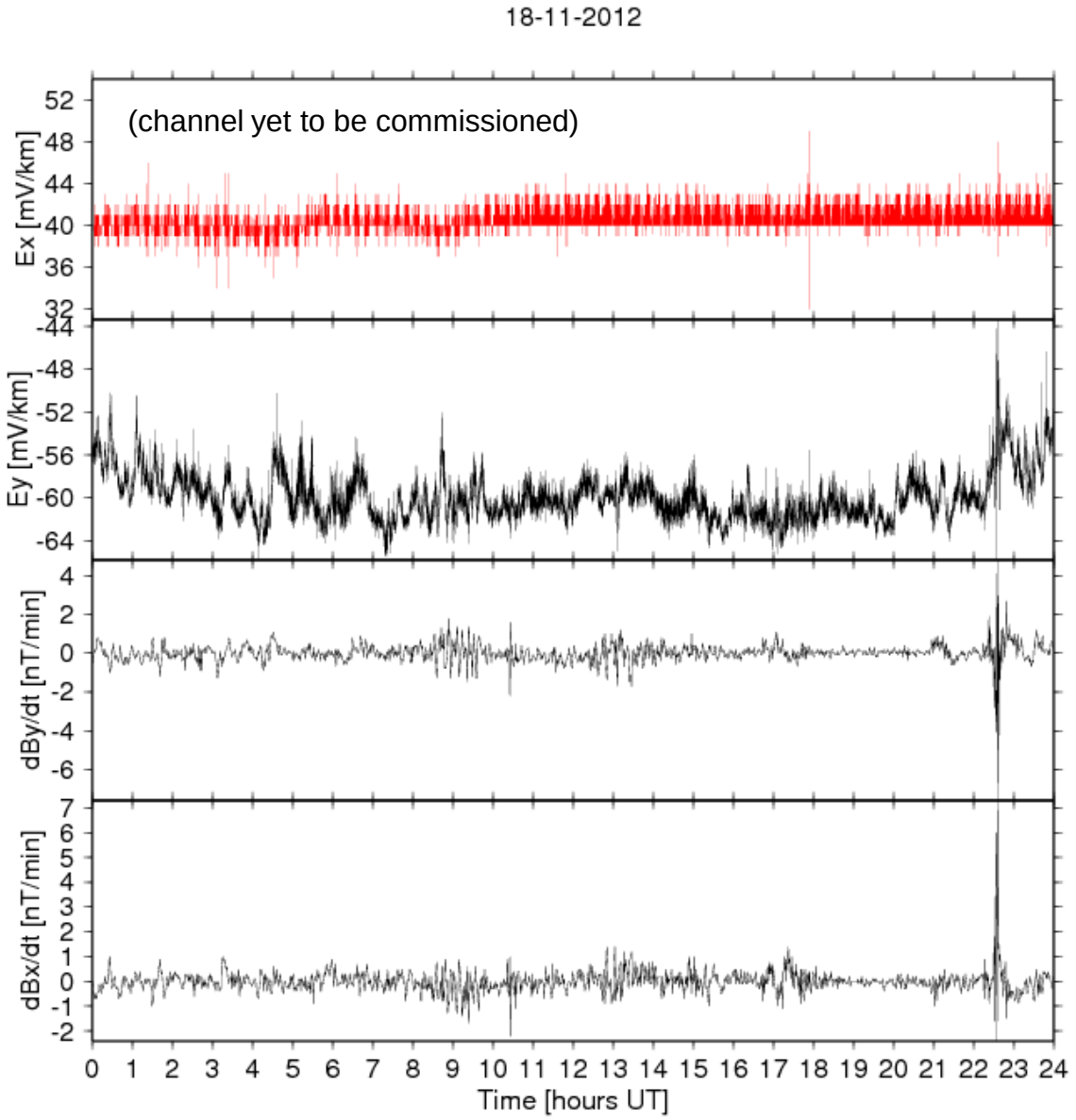
- Long-term measurements at: Eskdalemuir, Lerwick & Hartland
- NS & EW electrode lines
- Electrode line length: 50 – 100 m
- Electrodes installed depth: 0.5–1.0 m
- Monitoring period: 2 -5 years

Objectives

- Comparison of measured and modelled data to aid numerical model developments
- Longer term, project will provide magneto-telluric data for study of deep Earth conductivity

Installation Status

- First electrode pair (EW) installed at Eskdalemuir (12 September 2012)
- Second electrode pair planned for Eskdalemuir in October 2012
- Installations at Lerwick & Hartland planned for March 2013



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Geomagnetic Data for Space Weather Monitoring

- Local Data and Indices
  - dB/dt, 'D_{30}', observatory K index
  - Forecasts (ARMA, neural net, ...)
- Pseudo GIC data
  - From GIC:B-field transfer functions
  - Geo-electric and network model simulation
- Industry GIC data
  - Develop measurement hardware in partnership
  - Measure near DC current with magnetometers
- Regional magnetometer arrays
  - Finer scale structure in source fields
  - Interpolate with 'spherical elementary current system' method
  - Regional geophysical observatories?
    - add VLF, ULF, GPS, Riometers

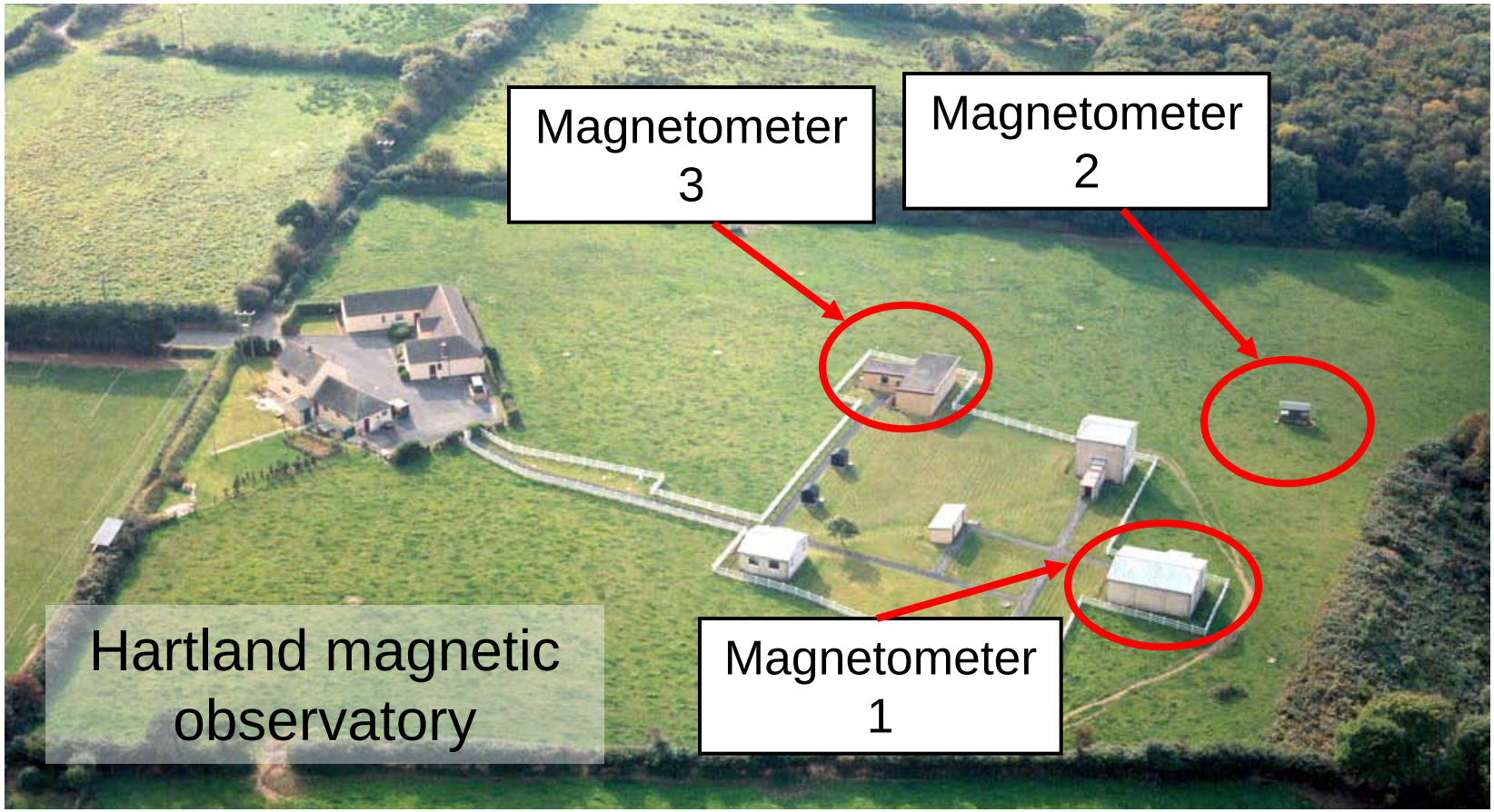
d30	nT/min
1	1
2	4
3	9
4	21
5	48
6	105
7	230
8	503
9	1096
10	2386

$D_{30}=9/7 * \ln(M_{30} + 1)$ where $M_{30} = |\max(dX/dt(30))|$

D_{30} Index: Courtesy of Peter Wintoft, Swedish Institute of Space Physics.

Real-time 24/7 geomagnetic data delivery

Key Role for Magnetic Observatories



- Reliable (data sampling & communication)
- Robust (fault tolerant)
- Redundancy (many systems)
- Providing 24/7 Operation

Conclusions

- Real time data are central to space weather applications
  - Raw data, indices and forecasts
- Measured and modelled GIC and geomagnetic variations are used by industry to aid operational decision making
  - Regional arrays provide appropriate spatial scales
  - Timeliness of data is crucial
- Data providers need to link up to provide regional scale coverage
  - In an ideal world funders would recognise this
- GIC modellers need measured geo-magnetic, geo-electric and GIC data to prove their models