A UK Perspective on Understanding Geo-magnetic Hazard to National Power Grids

Alan W P Thomson
Head of Geomagnetism Research
awpt@bgs.ac.uk

- What we know and don’t know about GIC
  - Report from a UK – South Africa Workshop
  - Has helped define recent research goals
- UK & European Developments
  - 10+ years working with UK utilities and government
  - EU commission consortium project EURISGIC, 2011-2014
  - ESA space situational awareness program

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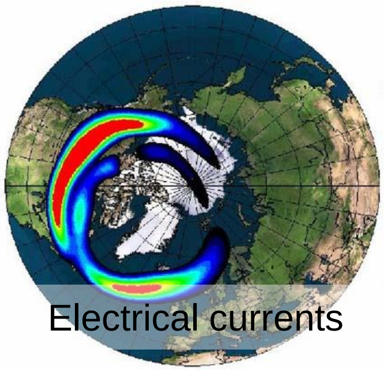
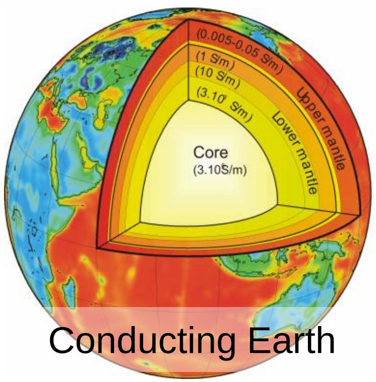
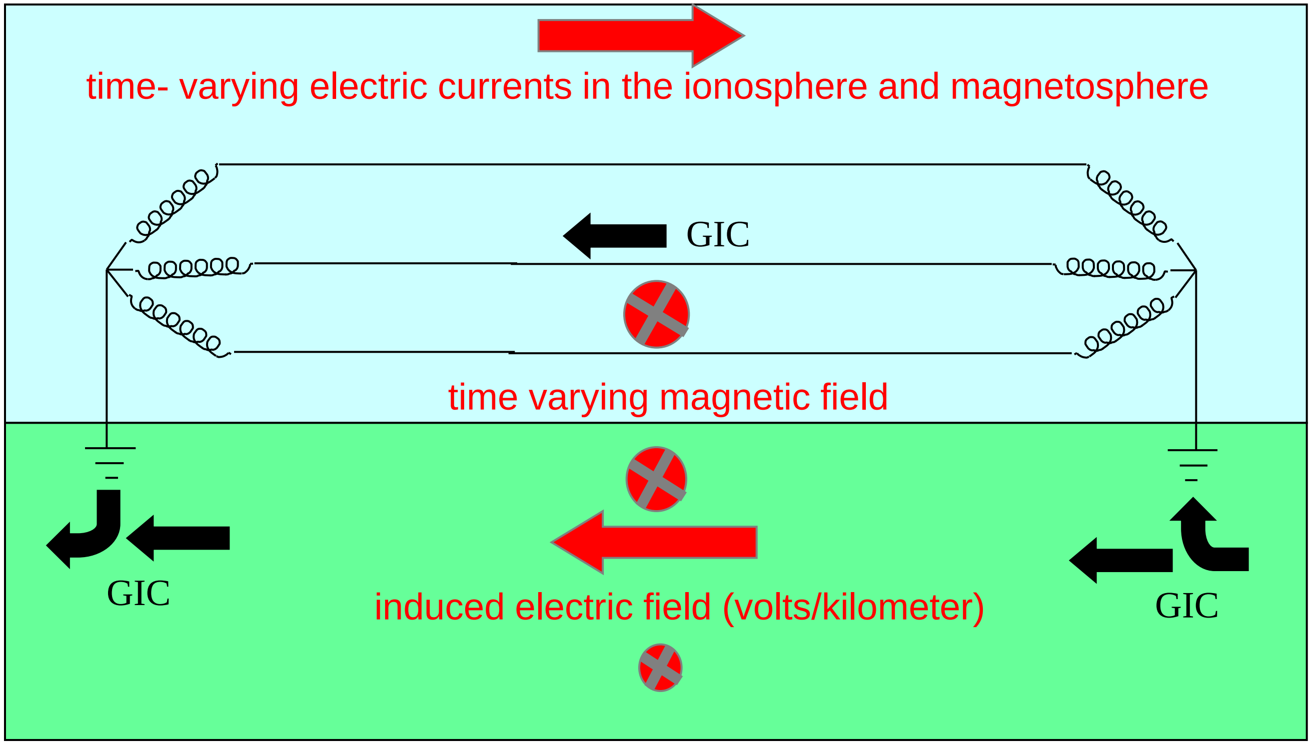
Why Does Space Weather Cause Grid Problems?







Geomagnetically induced currents (GIC) are near-DC producing

- Half-cycle saturation of transformers, voltage harmonics, overheating, increased reactive power demand, and/or drop in system voltage
- Leading to transformer burn-out (big storm) or shortened lifetime (many smaller storms)

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Applied geoscience for our changing Earth

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UK – South Africa Workshop December 2008

- Background
  - Knowledge exchange grant through UK's Royal Society
  - Short duration, promoting African science, and promoting free exchange of ideas and experience
- Participants
  - UK: Jim Wild (Lancaster), Alan Thomson (BGS)
  - SA: Pierre Cilliers (Hermanus), Trevor Gaunt (Cape Town), Ben Opperman (Hermanus), Lee-Anne McKinnell (Rhodes Univ), Pieter Kotze (Hermanus), Chigo Ngwira (Rhodes), Stefan Lotz (Rhodes)
  - Expertise in space physics, geophysics and electrical power engineering
- Outcomes
  - Similarities and differences in UK and SA transformers and grid set-ups
  - Translation of terms between scientists and engineers
  - Education on space and geophysics for engineers
  - Summary of 'what we think we know' and 'what we think we don't yet know' in Thomson *et al*, Advances in Space Research, 45 (2010),1182–1190.

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What Experience Has Taught Us:
Major Knowns in GIC Research

- **Science**
  - Solar storms that cause high GICs are statistically more likely during periods close to solar maximum and in the descending phase of the solar cycle, but they do also occur at all other times in the solar activity cycle
  - GICs are larger in countries and regions where the geology is generally more resistive and a multi-layered and laterally varying ground conductivity model gives better prediction of GICs, than the simpler assumption of an homogeneous Earth
  - The magnetospheric and ionospheric currents that drive GICs are different at different latitudes and the dominant cause of GICs in power grids is the time rate of change of the Earth's magnetic field

- **Industry**
  - GICs have been shown to affect power systems at all latitudes and can affect many power transformers simultaneously at multiple points across regional and continental scale networks.
  - Series capacitors in transmission lines may interrupt GIC flow, but are expensive. However some strategies involving capacitors may increase GIC and reactive power demands.
  - Transformer dissolved gas analysis identifies GIC-initiated damage before complete transformer failure occurs. This is especially true if the rate of gassing simultaneously increases in widely separated transformers across a network

Summarised from Thomson *et al*, Advances in Space Research, 45 (2010),1182–1190

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What Experience Has Taught Us:
Major Unknowns driving Research Requirements

- **Science**
  - What are the solar and interplanetary events and signatures that are most 'geo-effective'?
    - Event magnitude, duration, location, onset time
  - What are the characteristics of extreme geomagnetic storms that pose the highest risk to power systems?
    - Better geophysical modeling and prediction of ground and ionosphere currents & fields
    - Spatial and temporal scales
  - What is an adequate distribution of magnetometers for GIC modeling in any country?

- **Industry**
  - Which information (e.g. monitoring & forecasts), given on what timescale, is most useful in managing GIC risk?
  - What are the characteristics of power transformers that determine susceptibility to GICs and therefore determine the damage sustained under different levels of GICs?
  - What are the transformer failure mechanisms initiated by GICs?

Summarised from Thomson *et al*, Advances in Space Research, 45 (2010),1182–1190

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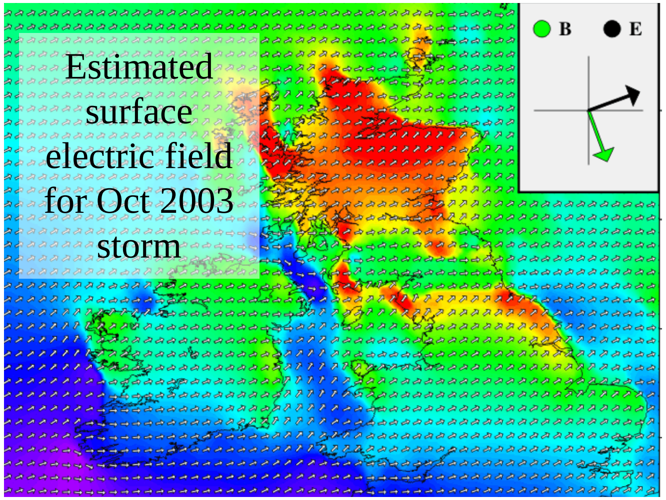
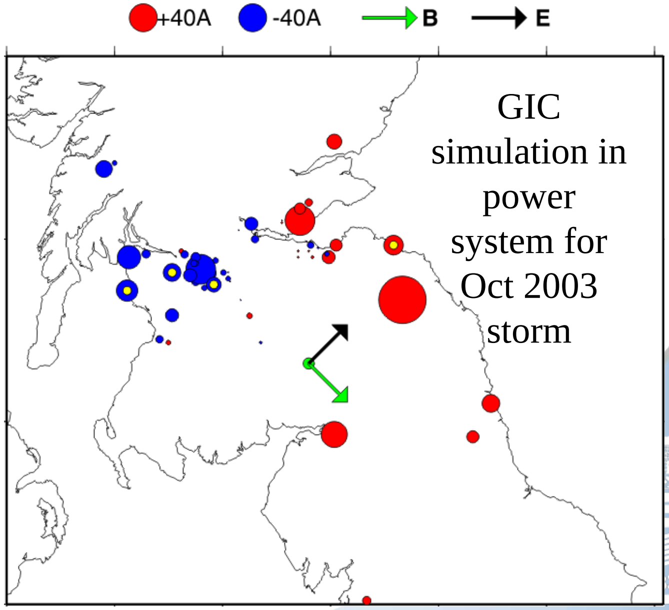
Partnerships 2001-2007:

BGS, Government, Scottish Power & European Space Agency

- GIC and electric field modelling (2001-2004)
  - BGS with Edinburgh University
  - Used extensive electric field database of Southern Scotland and Northern England compiled by university researchers over 40 years, to <u>improve model *E*-field </u>accuracy
- ESA space weather pilot projects in GIC (2003-2007)
  - ESA asked: is there a market for space weather services in Europe?
  - Economic report was generated
    - “Substantial value” in providing space weather services for ‘ground’ technologies
  - 15 pilot projects (including BGS) were co-funded to help test market potential by delivering ‘<u>state of art’ services</u>





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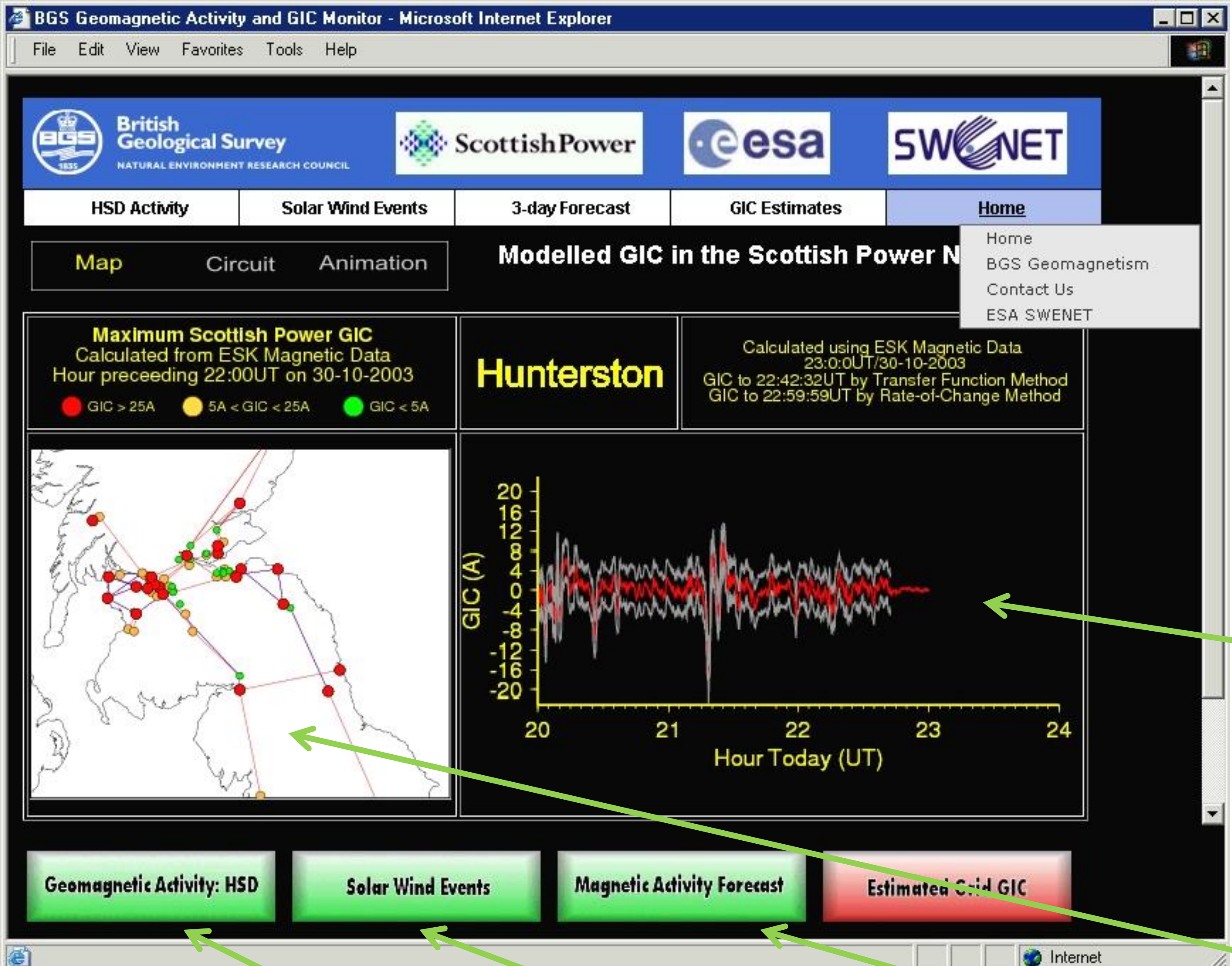
GIC Analysis Tool



http://www.geomag.bgs.ac.uk/spower2/

'State of the art' demonstrator package, operational during 2005-2008

Updated every 10 minutes

Time series displays for the 4 GIC logging sites

Animation of complete grid response to GIC

Near real-time geomagnetic, solar wind monitors & geomagnetic forecasts

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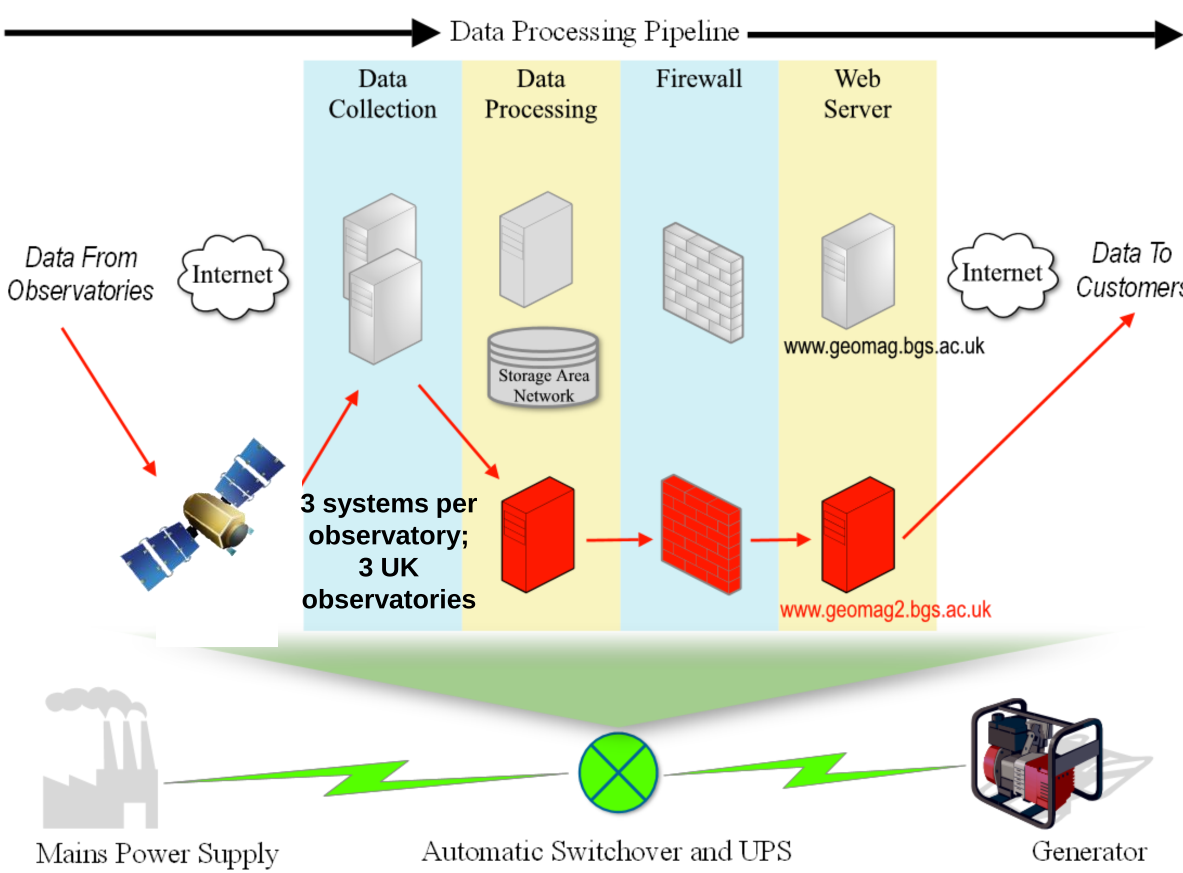
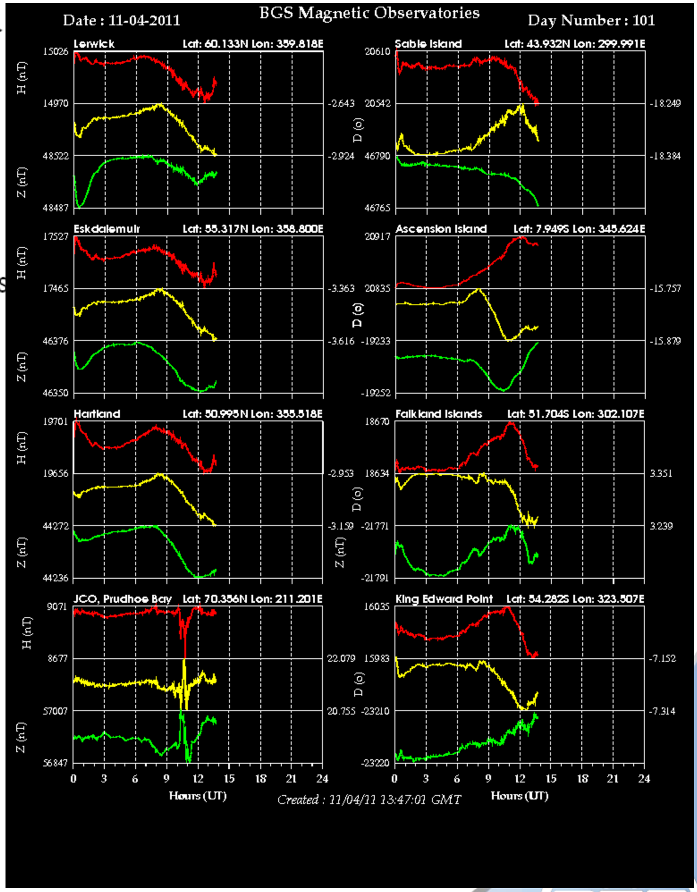
Supporting Real-Time Modelling:

How to Achieve a High Reliability in Magnetic Data Supply for Monitoring and Prediction





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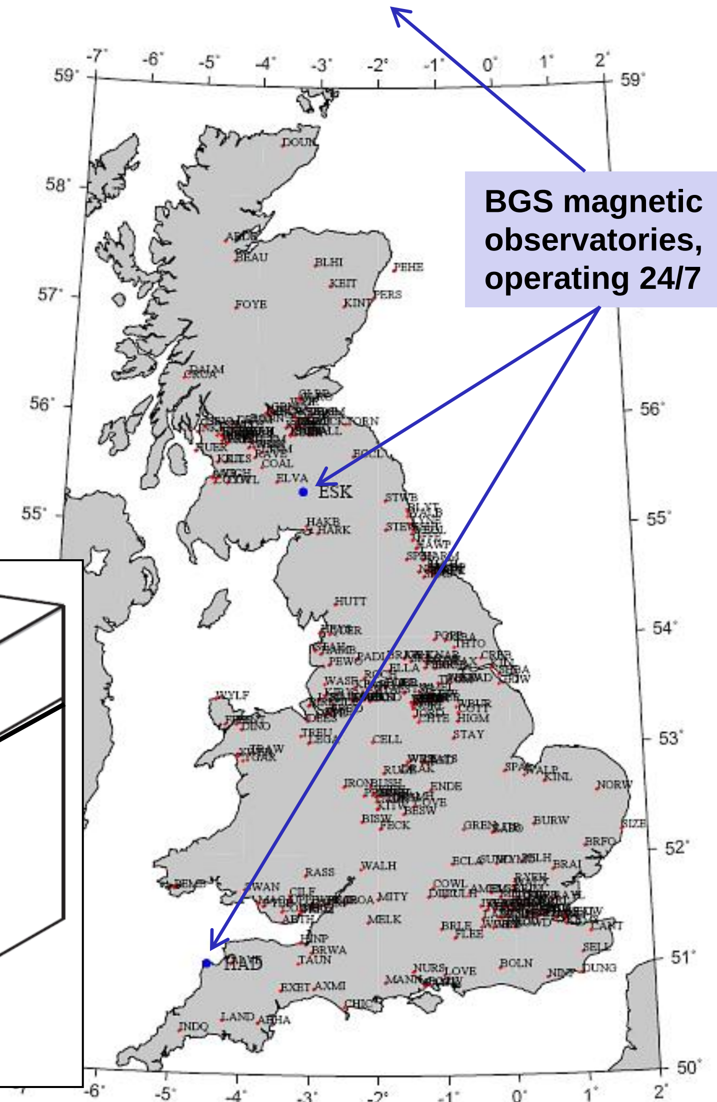
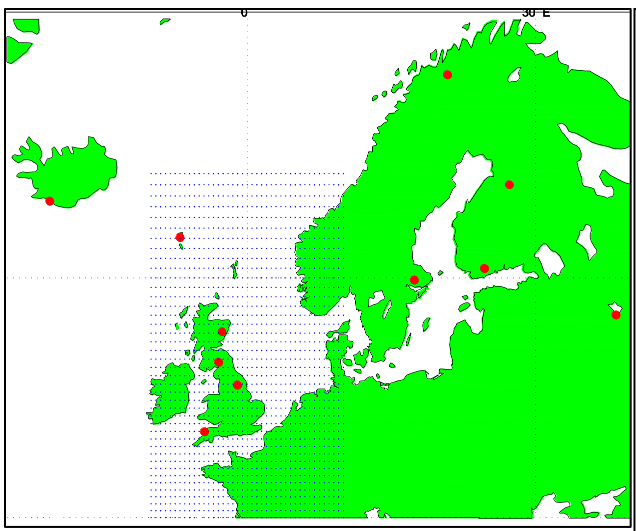
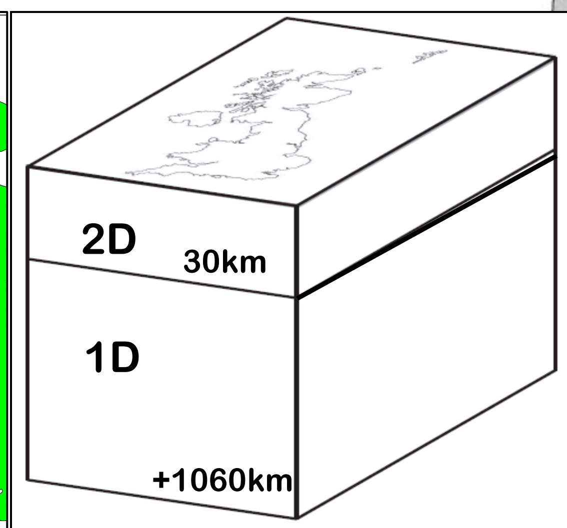
Partnerships 2008-2011:
BGS, University of Lancaster

- Improve source field modelling (interpolated across UK– below left)
- Check Earth conductivity model (below right)
- Extend and modernise power grid model and accuracy (right)





Red dots = magnetometer data; blue dots = interpolated magnetic field variations



2D model of upper crust conductivity; Radial 1D model of deep crust and mantle

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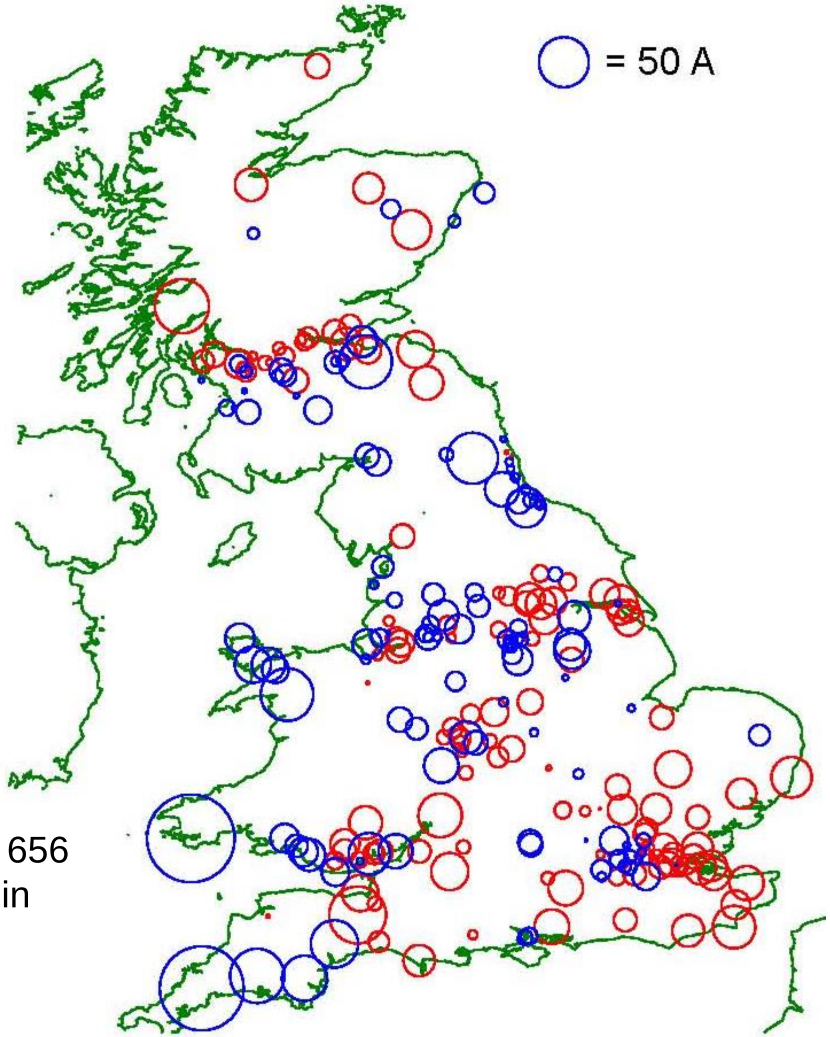
Where are we in 2011?



dB/dt = 656 nT/min

Estimated GIC flow at major UK transformers at 21:24, 30th October 2003

A New UK GIC Model for 2010

- **252 nodes**
- **379 connections**
- One transformer per node (v. simplified)
- One connection between linked nodes (v. simplified)
- Electrical characteristics of transformers assumed identical (v. simplified)
- **Interpolated magnetic field to provide fine scale detail**
- **3D Earth model, includes sea water conductivity, to provide fine scale ground response**

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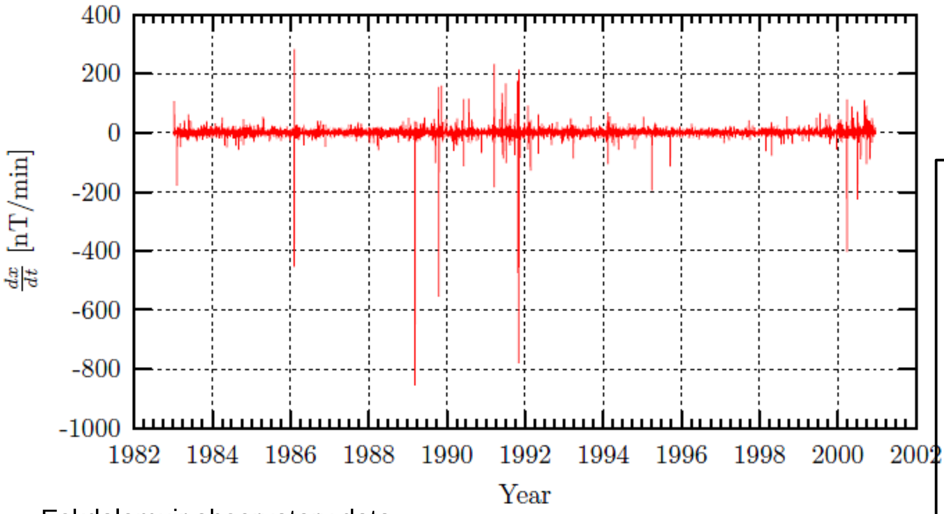
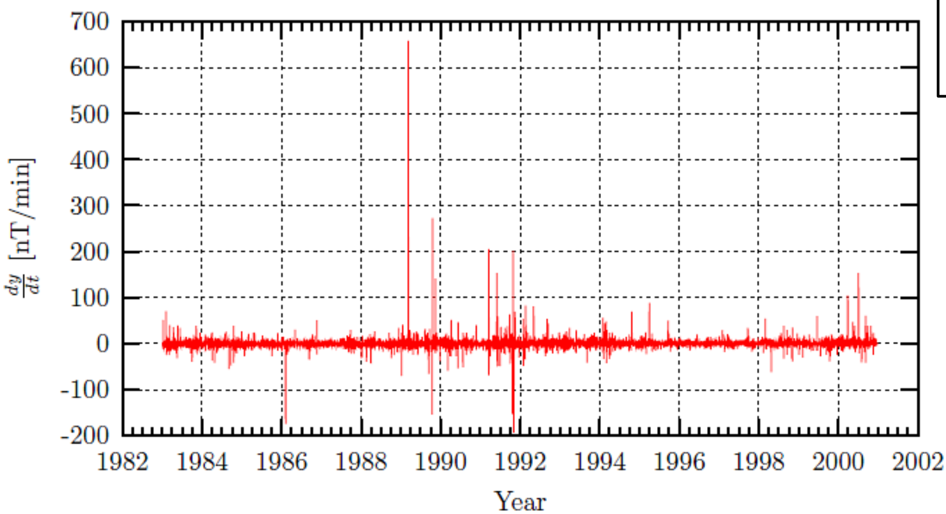
UK Worst Cases?

Maximum dB/dt in Digital Age: 1983-2011



Eskdalemuir observatory data



Top 6 Events Since 1983

d*H*/dt	Date+Time	Date	GIC
1262 nT/min :	**1991.8545890 :**	**8 Nov 1991 :**	?
934 nT/min :	1989.1970015 :	13 Mar 1989 :	?
729 nT/min :	1989.8048440 :	21 Oct 1989 :	?
628 nT/min :	**2003.8298326 :**	**30 Oct 2003 :**	**42A**
500 nT/min :	1991.8351846 :	1 Nov 1991 :	?
464 nT/min :	1986.1033143 :	7 Feb 1986 :	?

Events 1-3 are mentioned in Erinmez *et al* paper (2002) as 'causing problems'

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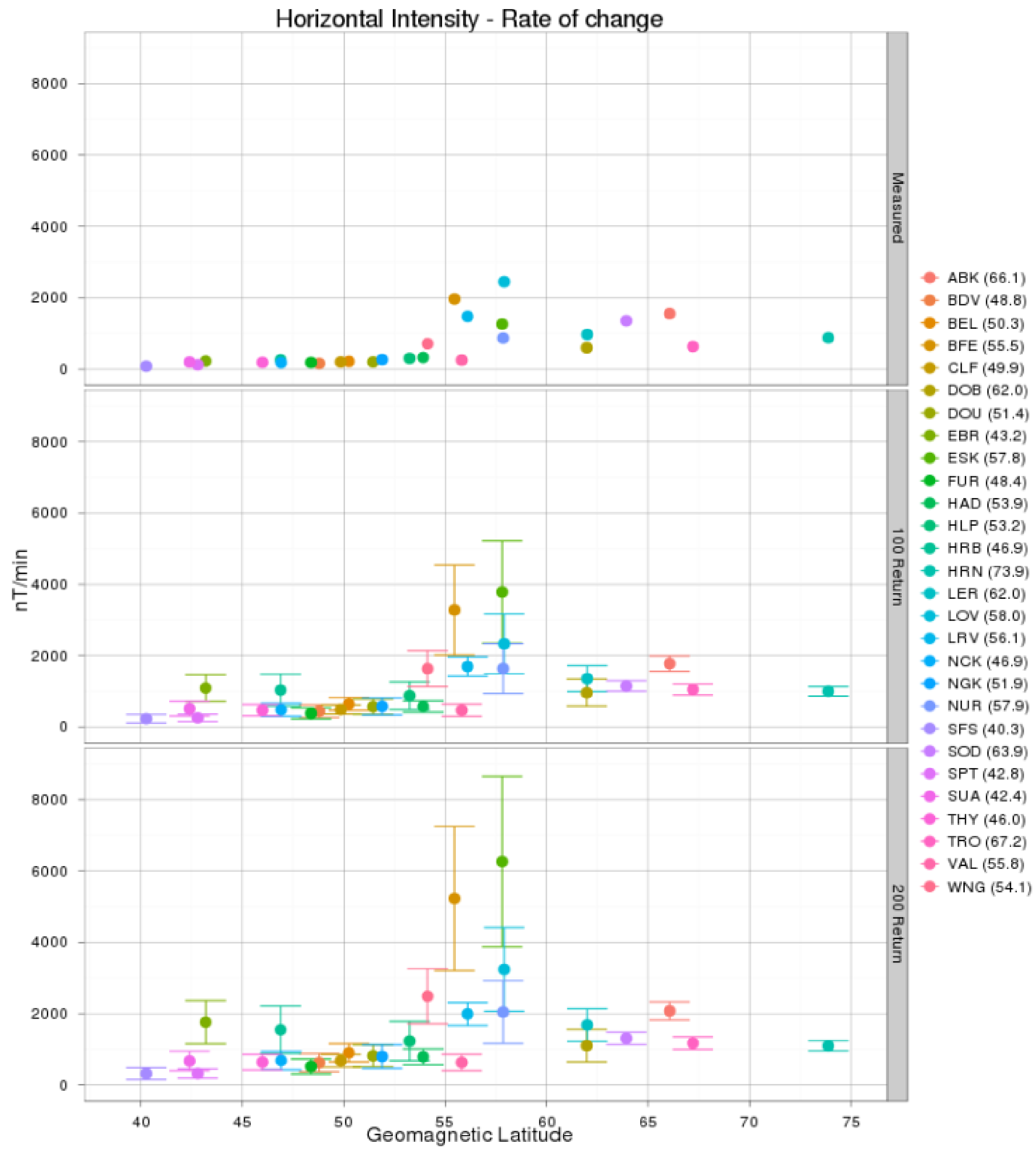
Worst Case Scenarios:
European Digital Records

- Technique of Extreme Value Statistics
- Bulge in activity level between ~53-62 degrees
- Superimposed on a weak trend with latitude
- Magnitudes:
  - 100 Year: 2000-3000 nT/min
  - 200 Year: 3000-5000 nT/min
- Caveats:
  - Outliers have largest uncertainties
  - Different observatories have different record length



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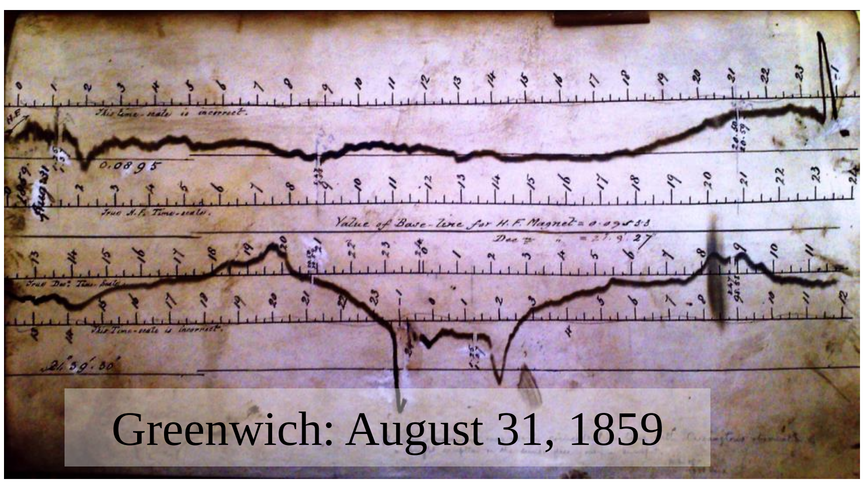
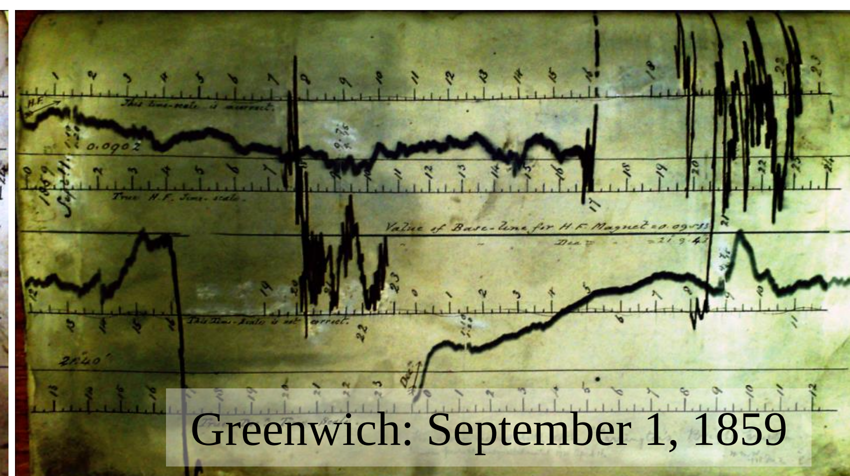
UK Archive Data

- Magnetic indices do not capture the instantaneous d*B*/dt
- BGS holds > 250,000 daily paper records of geomagnetic activity in the UK (1850-)
- Archive digitisation project may help uncover just ‘how big is big’, including study of the Carrington event (below)
- http://www.bgs.ac.uk/data/magnetograms/home.html?src=sfb



Greenwich: August 31, 1859



Greenwich: September 1, 1859

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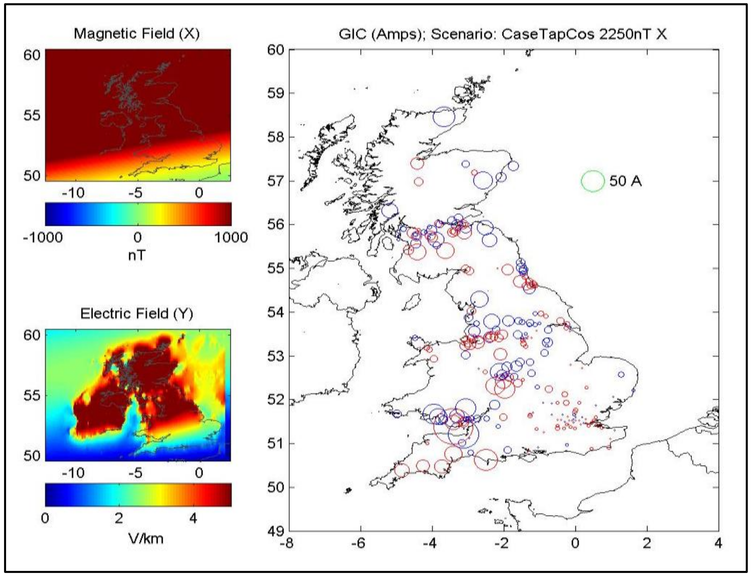
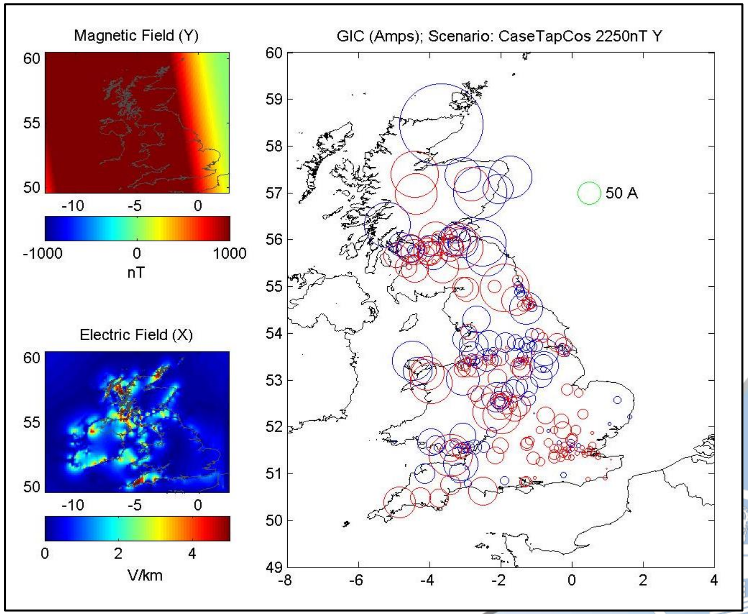
UK Landscape 2011

- ‘National Risk Assessment’
  - Any natural hazard with >0.1% chance of occurring once per annum
- Worst case scenario planning
  - Together with National Grid company
- Natural Hazards Partnership
  - Geomagnetic Storms: BGS and UK Met Office
  - Other hazards: earthquakes, flooding, ..., involving other UK science research institutes
- Space Environment Impacts Expert Group
  - Informing government
  - All UK space weather research groups represented
- Electrical Infrastructure Security summits and US-UK science partnerships
- UK Workshop on GIC, March 2011



Worst Case?
Tapered cosine electrojet: *H*-field 5000nT/min at 120 second period; E-W (above); N-S (below)



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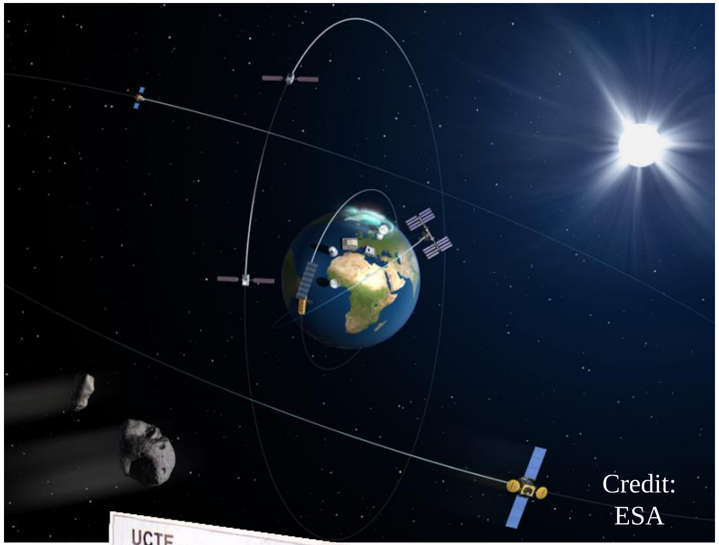
The Current European Dimension

- COST Action 724, 2004-2008
  - Explore the science issues underpinning space weather research
  - Bringing European researchers together
- COST Action ES0803, 2008-2012
  - Transitioning research to applications
  - Metrics
  - What research needs to be done?
- ESA Space Situational Awareness, 2012-2019
  - Space debris (natural objects and man-made), collision avoidance
  - Space weather monitoring, supporting infrastructure building, including effects on the ground
  - Linkages into NASA, NOAA, DoD
- Project 'EURISGIC', 2011-2014



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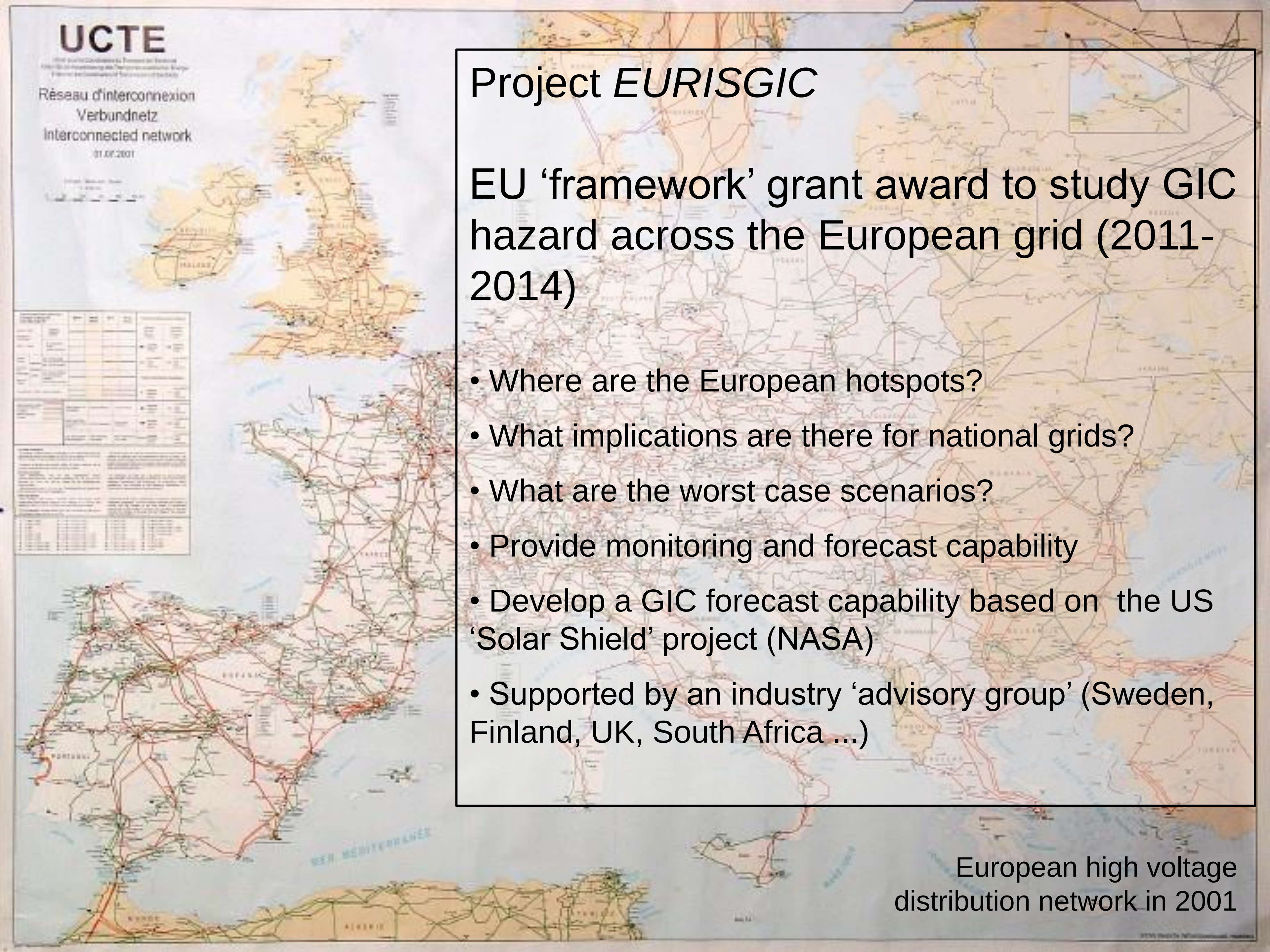
Project *EURISGIC*

EU ‘framework’ grant award to study GIC hazard across the European grid (2011-2014)

- Where are the European hotspots?
- What implications are there for national grids?
- What are the worst case scenarios?
- Provide monitoring and forecast capability
- Develop a GIC forecast capability based on the US ‘Solar Shield’ project (NASA)
- Supported by an industry ‘advisory group’ (Sweden, Finland, UK, South Africa ...)



European high voltage distribution network in 2001

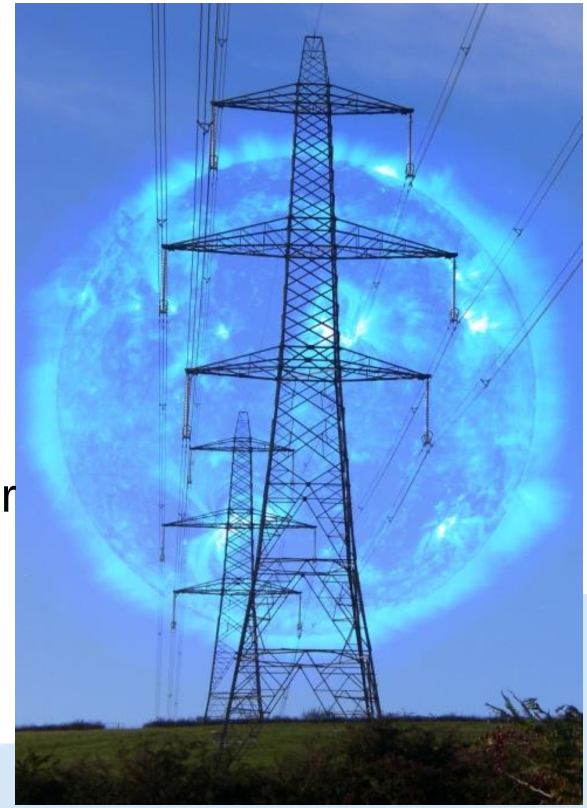
Closing Comments

Science Research Futures?

- Complexity of grid and 3D earth conductivity
  - Islands, seas and continental landmasses
- Ionospheric specification and forecasting
  - Data assimilation
- Sun-Earth model 'daisy-chaining'

- *Stakeholder Involvement?*
  - Industry: How do the science scenarios impact your transformers and hazard mitigation strategies
  - Governments: Where do you step in?

- *5-10 Years From Now?*
  - Cross-disciplinary research commonplace
  - Leading to fewer of our unknowns!



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