SWIGS
SPACE WEATHER IMPACT ON GROUND-BASED SYSTEMS

Validation of GIC in the GB High Voltage Network

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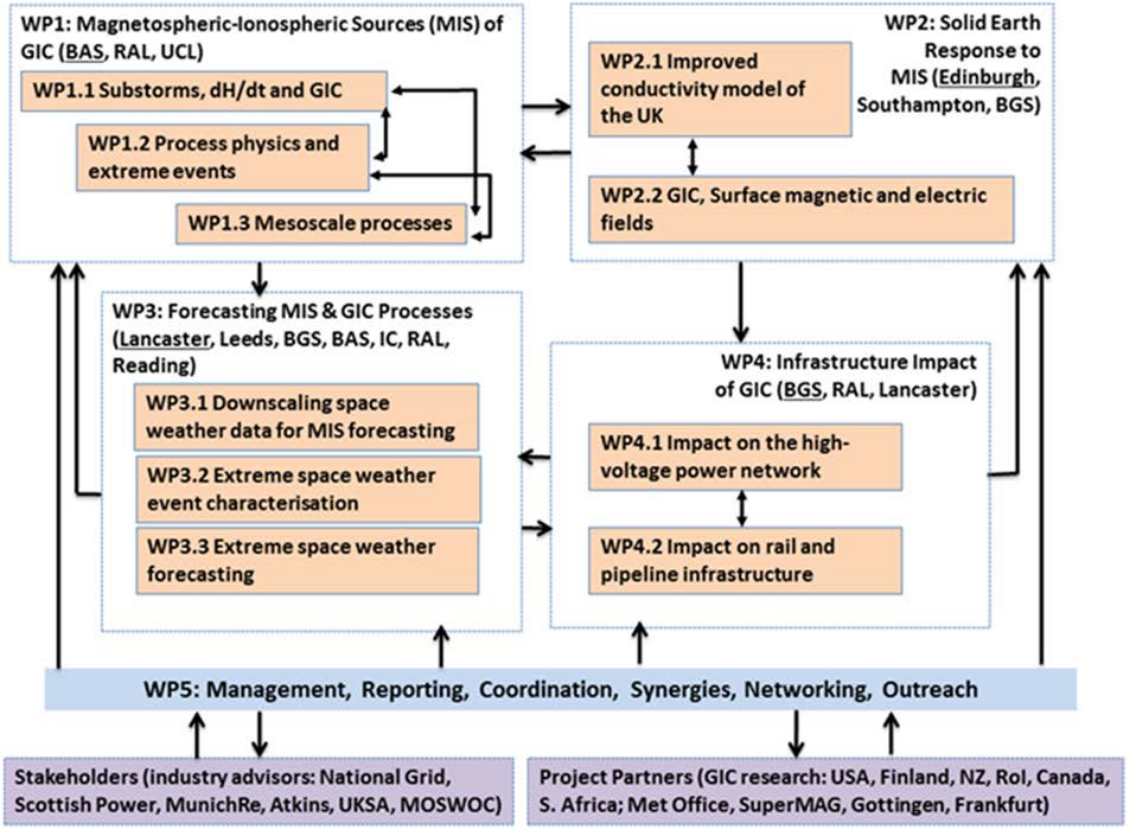
13th April 2018, EGU, Vienna

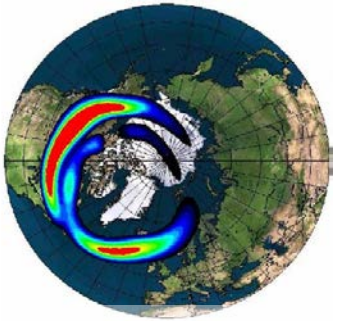
Space weather impacts on grounded structures (SWIGS)

- NERC Highlight Topic Award
- Understand/forecast the M-I changes with solar wind parameters
- Understand solid Earth response (MT, conductivity)
- Forecast GIC in grounded structures (rail, electricity, pipelines)

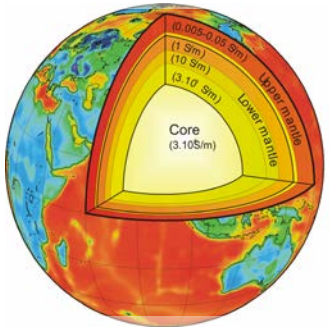


What are the risks from Geomagnetically Induced Currents?

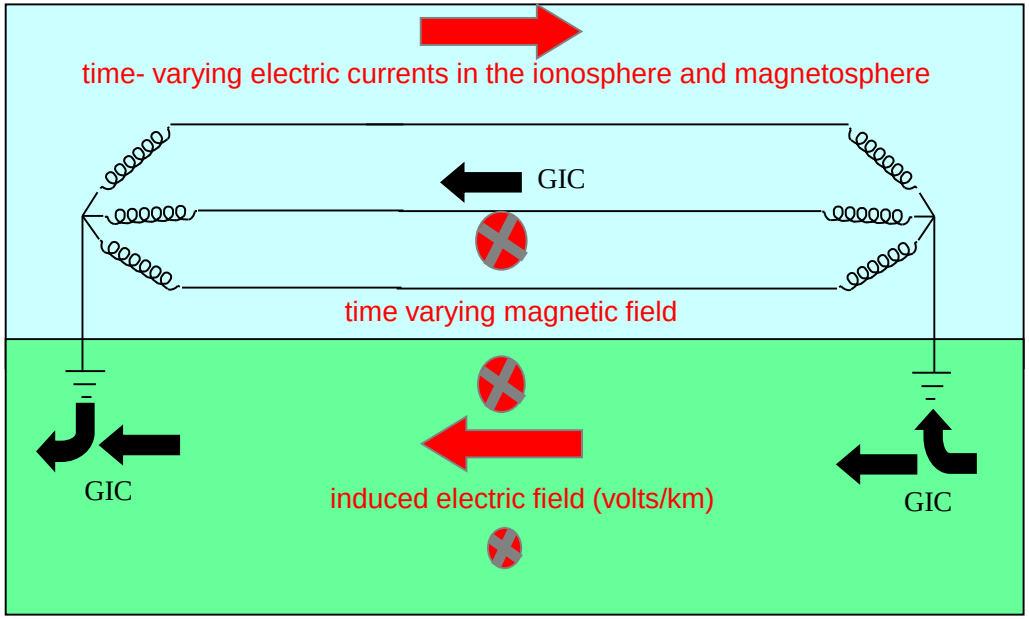
Secondary induced currents flow into grounded infrastructure



Electrical currents



Conducting Earth

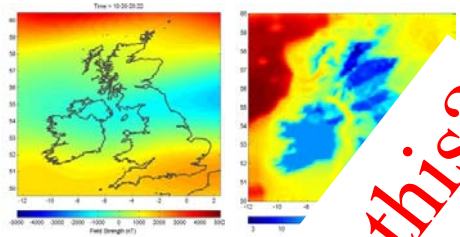


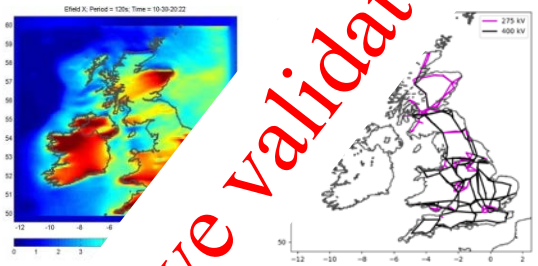
DC offset in transformer causes: voltage harmonics; loss of reactive power; flux escape from core; overheating; destruction of insulation

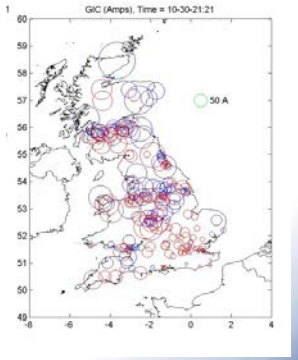
GIC modelling steps

- BGS use thin-sheet modelling:
  - Convert B-field → E-field
  - Use 2D conductance (coastline, geology)
  - Use 1D resistivity model (3-1000 km)
  - Use fixed period of variation (600 seconds)
- Compute geo-electric field

- Use HV model of network:
  - Derived from publically available data
  - 2016 UK model has:
    - >450 nodes
    - > 800 connection
  - Compute GIC using LP method







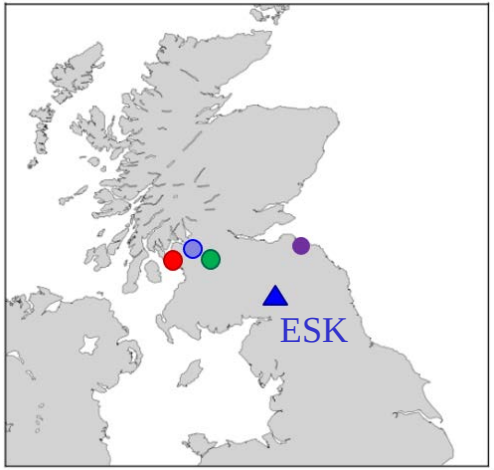
How do we validate this?

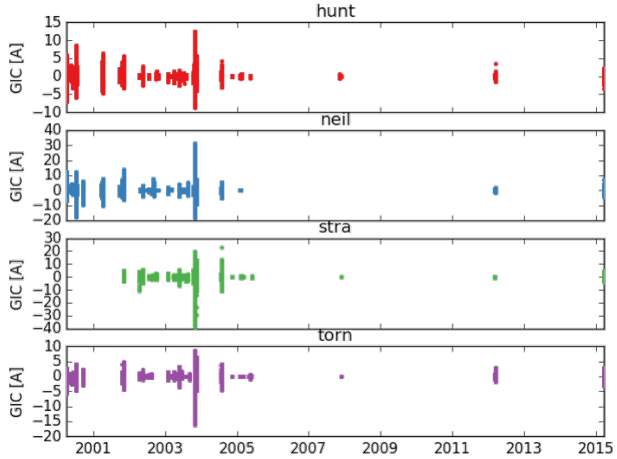
GIC measurements in UK

- Made at 4 sites since 2000; collected sporadically by BGS

- All in Scotland (nuclear power)
  - Torness (torn)
  - Hunterston (hunt)
  - Strathaven (stra)
  - Neilston (neil)

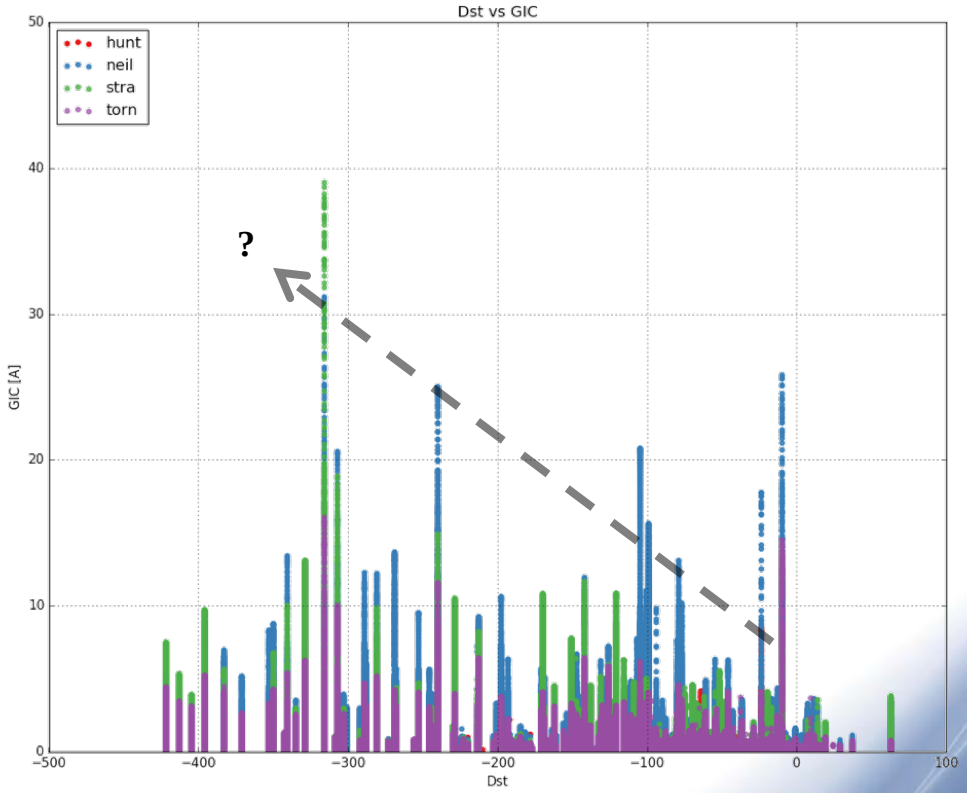
- Are these sites representative of the whole grid?





An aside: GIC vs Dst?

- Large GIC at mid/high latitude do not correlate well with Dst index
- Also do not correlate correlate with Kp or K (e.g. highest GIC at Kp8)

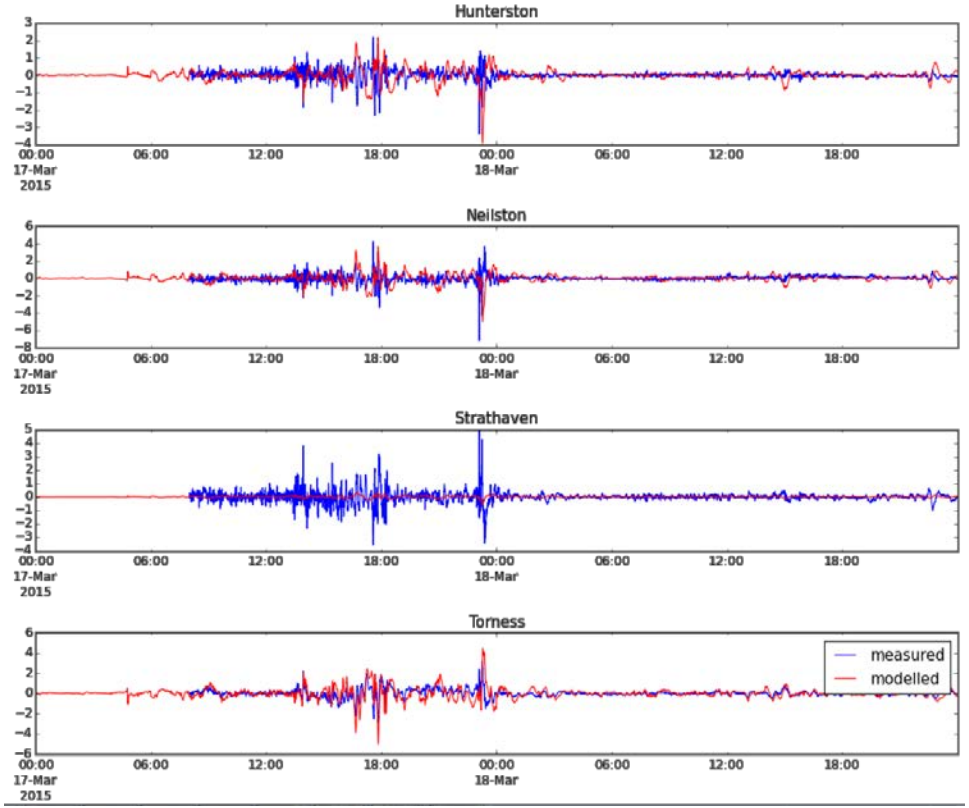


GIC models vs measurements

- 17-Mar-2015
  - 600 s period
  - Thin-sheet method used to estimate E-field
  - Lethinen-Pirjola to compute GIC

- Reasonable approximation between model and measure
  - Small GIC < 5A
  - Simpler grid model
  - Strathaven is wrong ☹

How can we do better?

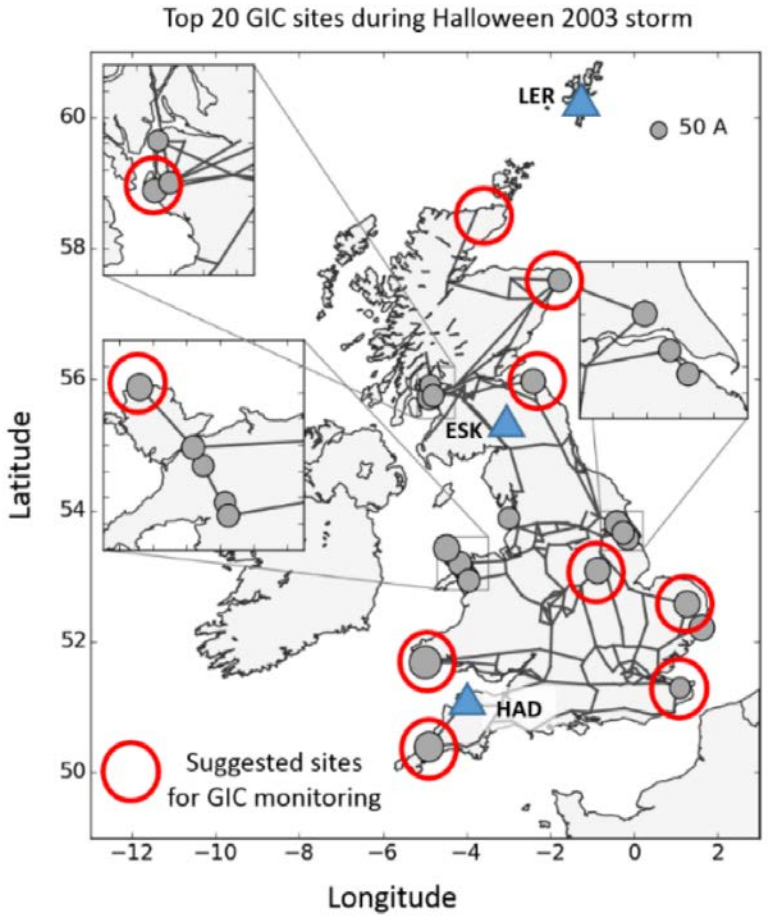


SWIGS DMM project

- Largest modelled GIC during October 2003 storm
  - ‘Edge’ nodes
  - Isolated nodes
  - Long lines

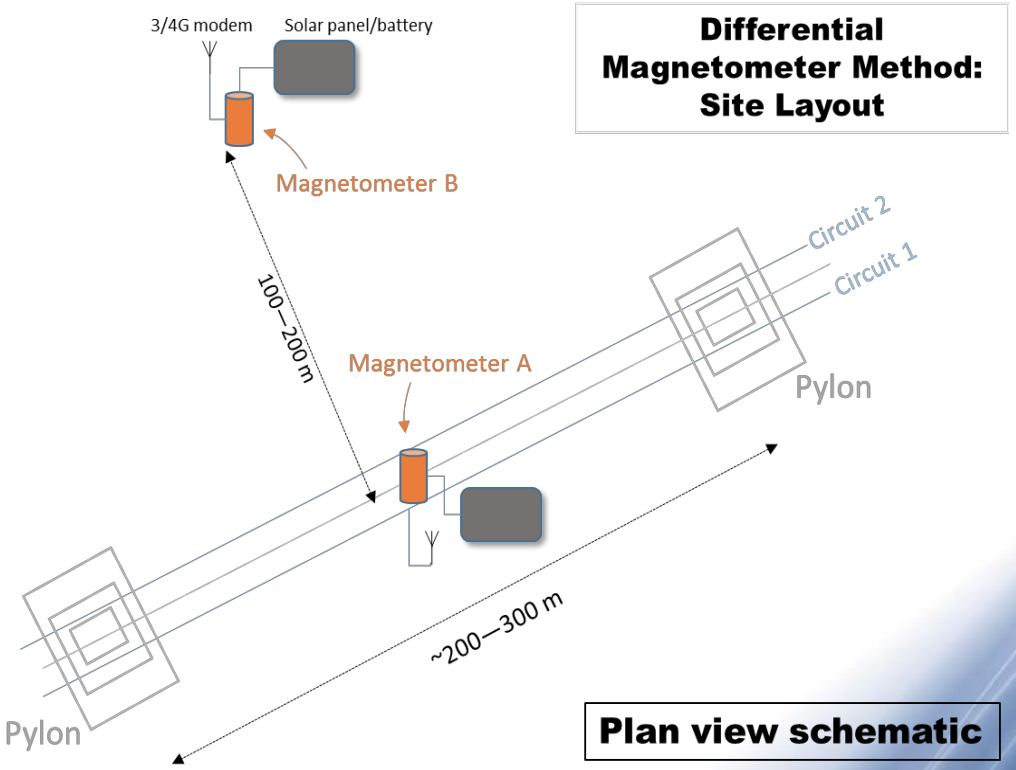
- There are no Hall probes so measure GIC through the differential magnetometer method

- Six sets of bespoke instrumentation
  - Visit 12 sites across the UK over ~3 years.
  - 3-6 month deployments



GIC measurements with DMM

- Use Differential Magnetometer Method (DMM) in GB
- Requires two variometers measure difference in B-fields
  - One under HV line
  - One > 100 m away
- Successfully used in Finland and Namibia (e.g. Matandirotya *et al.*, 2016)



DMM Hardware

- Sensys 3-axis fluxgate magnetometer
- EarthScope Digitiser/Logger
- Solar panel/battery
- 3/4G mobile network modem

- 1-second sampling
- Real-time data return
- Two magnetometers per site
- <1 nT accuracy over 30 minutes
- Buried for temperature stability

Various issues

UK grid is complicated!

- Well-connected topology
- Double-circuit lines
- Multiple transformers per substation
- What about pylon geometry?

Simple example:

- GIC of 10 A within a 7 m line height
  = 158 nT (max) underline
  = 2 nT at 100 m away

- Different heights, GIC, conductivity etc
- System be sensitive to ~0.1 A

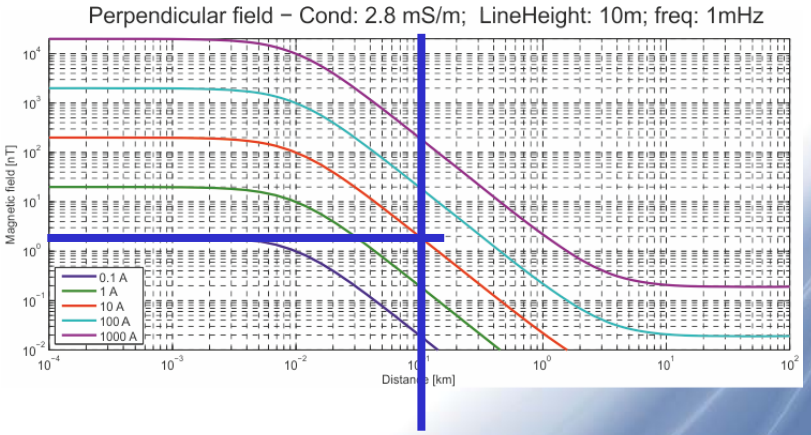
Current in an infinite
B: magnetic field (T)
R: distance (m)

$$B = \frac{\mu_0 I}{2\pi R}$$

GIC:
- Assume quasi-static
- Assume 1/3 current

$$B_{meas} = \sum_{j=1}^{2} \frac{B_j}{2}$$

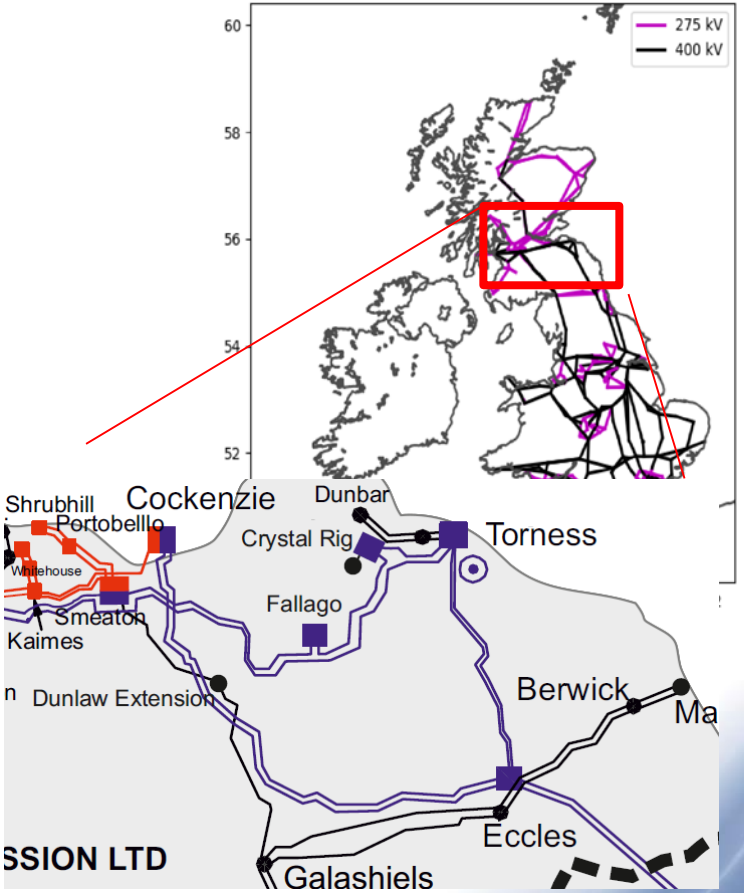
$$B_j = \frac{\mu_0 I}{3 \cdot 2\pi R_{1j}} + \frac{}{3 \cdot 2}$$



Various other issues

- Practical:
  - Siting of instrumentation (away from roads, people etc)
  - Land owner permission
  - Sunshine (or lack of!)
  - Mobile phone connection

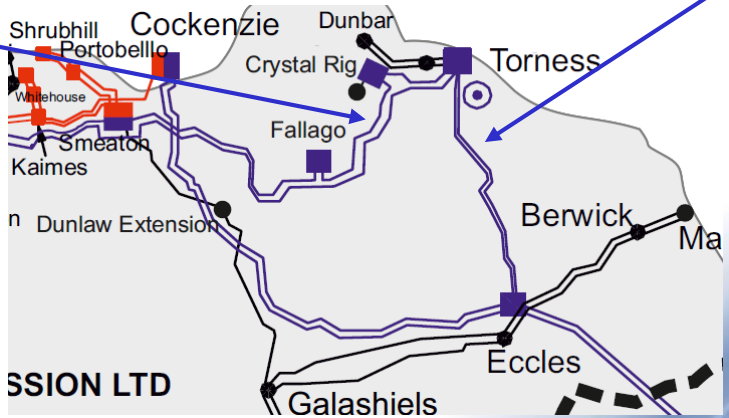
- Modelling more complex scenarios:
  - Non-contiguous lines
  - Errors in grid model
    - Network based on Ten Year Statement from National Grid UK
  - We measure **line currents** rather than Hall probe summation of GIC



Potential sites

Torness - Edinburgh

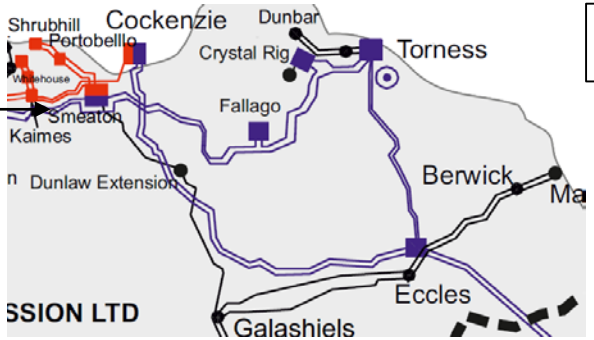
Torness – Edinburgh via windfarms



Example of an ambiguity

Map

Grid representation

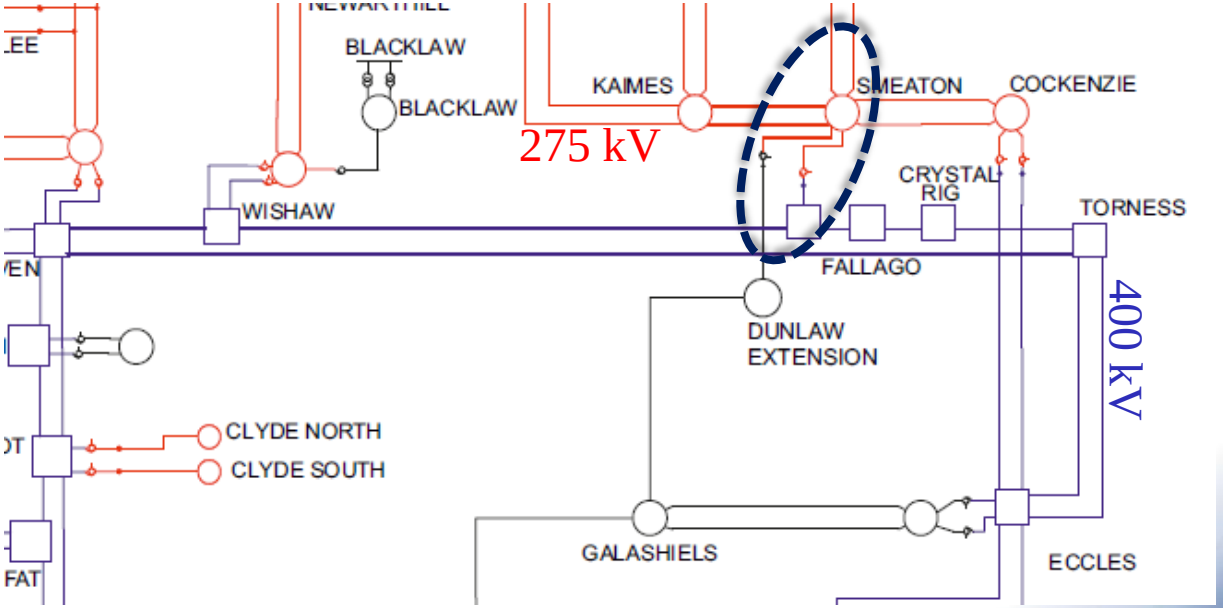


Line Voltages

400 kV

275 kV

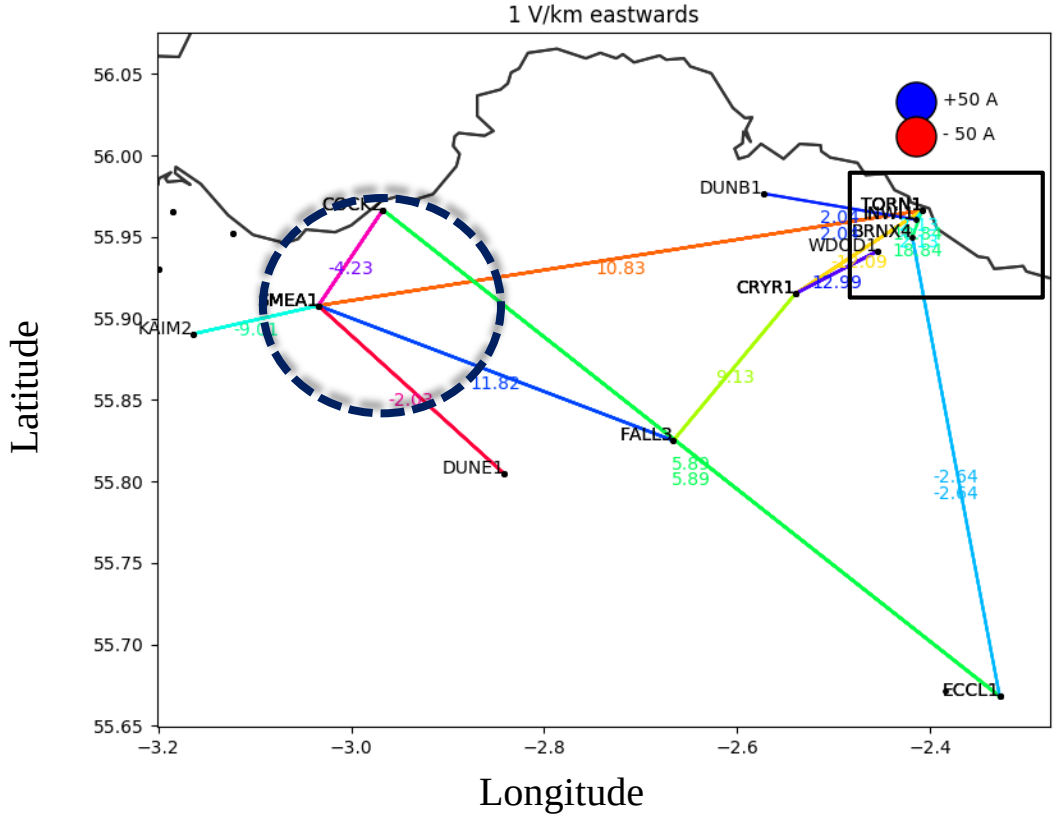
132 kV

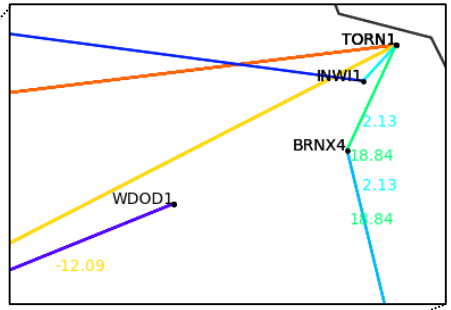


Which information do we believe?

Spreadsheet representation of GB network

- GIC for 1 V/km (eastwards)





Summary

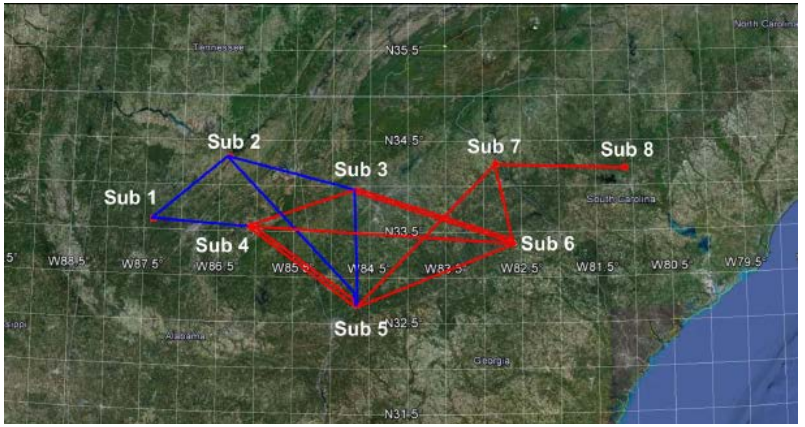
- Modelling of GIC is subject to many uncertainties:
  - gross grid model errors
  - Conductivity
  - Electric field etc
- GIC measurements are sparse and presently concentrated in Scotland
- Extend GIC measurements across UK using DMM method over next 3 years

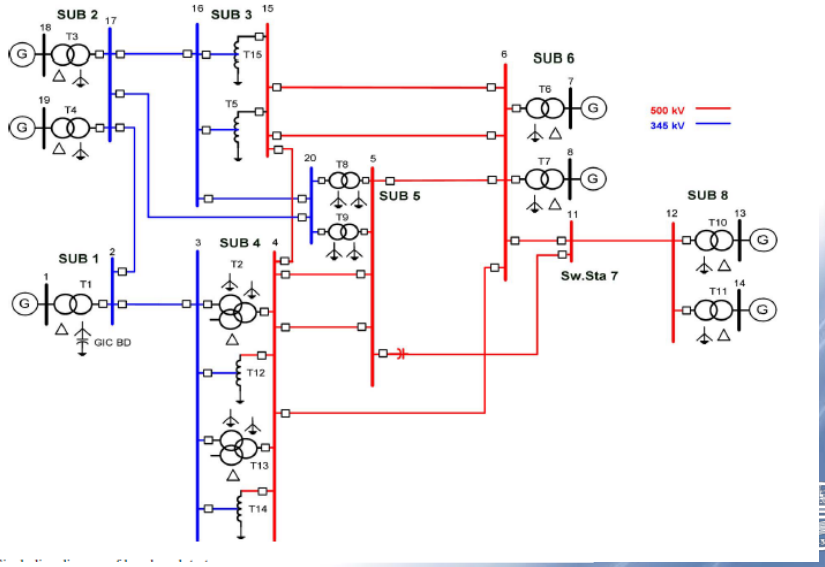
Time-lapse aurora
Shetland Islands
18-Mar-2018

Thank you for listening

GIC Modelling technique

- Comparison to Horton et al. (2012) benchmark
- Development of methodology to handle HV and LV buses inc virtual nodes
- Implementation in MATLAB and Python
- Application to UK 2016 HV model





Modelling technique / code

- Comparison to Horton et al. (2012) benchmark
- Reasonable match with voltages and GIC modelled (all 3 phases summed)
- Differences in computed *line length* cause variation (great circle vs lat/lon diff)

Substation #	Horton (A)	BGS code (A)	Diff (A)
2	115.6	114.2	1.4
3	139.8	137.8	2
4	20.0	19.2	0.8
5	-279.1	-280.5	1.4
6	-57.3	-53.2	4.1
8	60.9	62.5	1.6

What about the other parts of the modelling chain?