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The GB Electricity Transmission Network: Modelling, Monitoring and Mitigation

23 October 2012

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National Grid
Severe Risk Analyst

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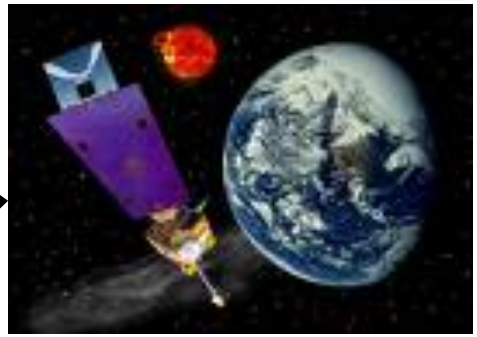
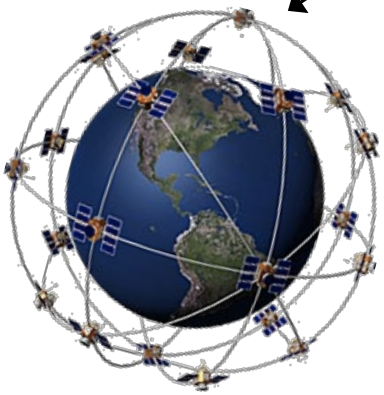
Effects of Geomagnetic Storms

Impacts from geomagnetic storms are wide-ranging with potentially significant consequences.



Satellite Operations

Manned Spaceflight



GPS

Power Grid Operations

Aircraft Operations

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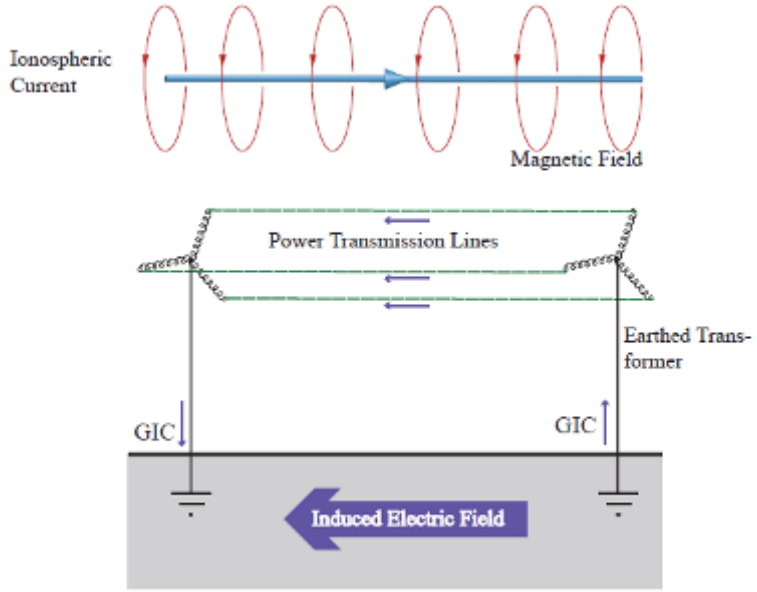
Geomagnetically Induced Current

- Electric currents in Ionosphere
- Induce fields in Earth's crust
- If resitivity of ground is high
- GICs flow out of earth, along transmission lines
- Earth themselves again through transformer neutrals
- Slowly varying, quasi-DC currents



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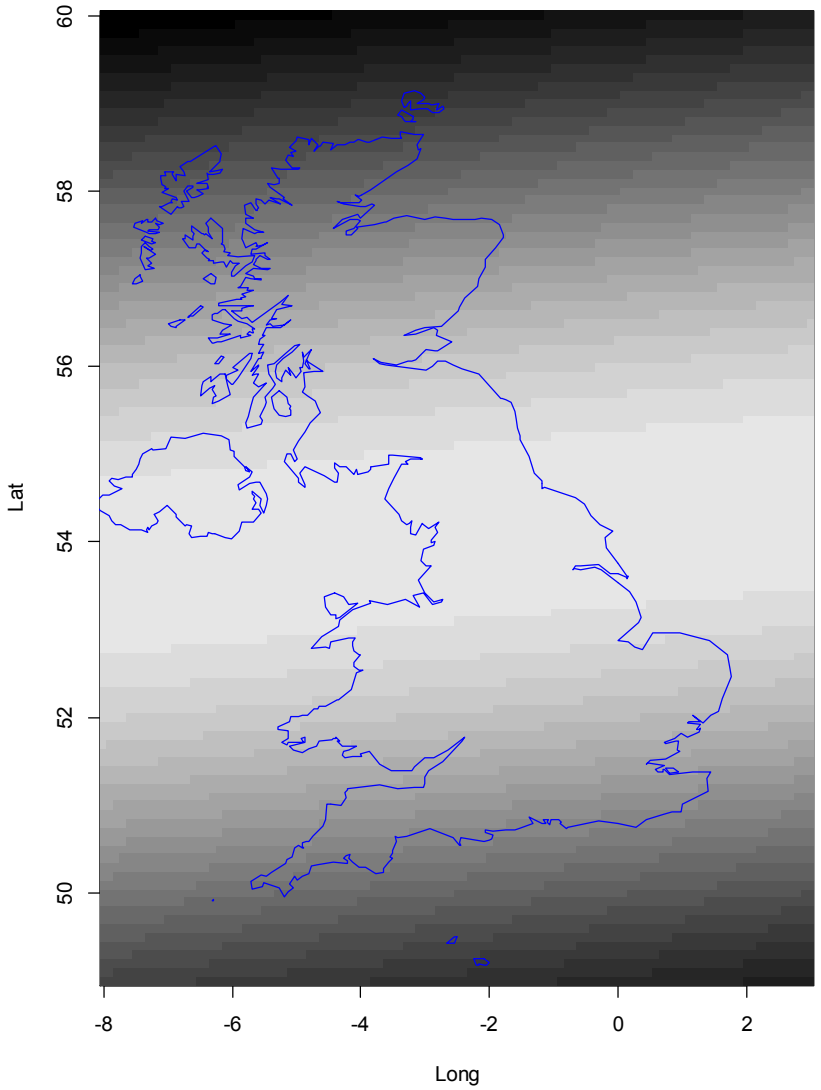
Effects on the system

- Magnetic flux leakage from core
  - Overheating, gassing, shutdown
    - Potentially catastrophic failure
- Distorted output waveform
  - Higher harmonics present
  - Protective relays triggered
  - Control assets switched out
- Increased reactive power consumption
  - Voltage instability

Jetstream Modelling

- Decide on severity of event:
  - 1 in 100 year storm
- Place jetstream in unfavourable position over UK



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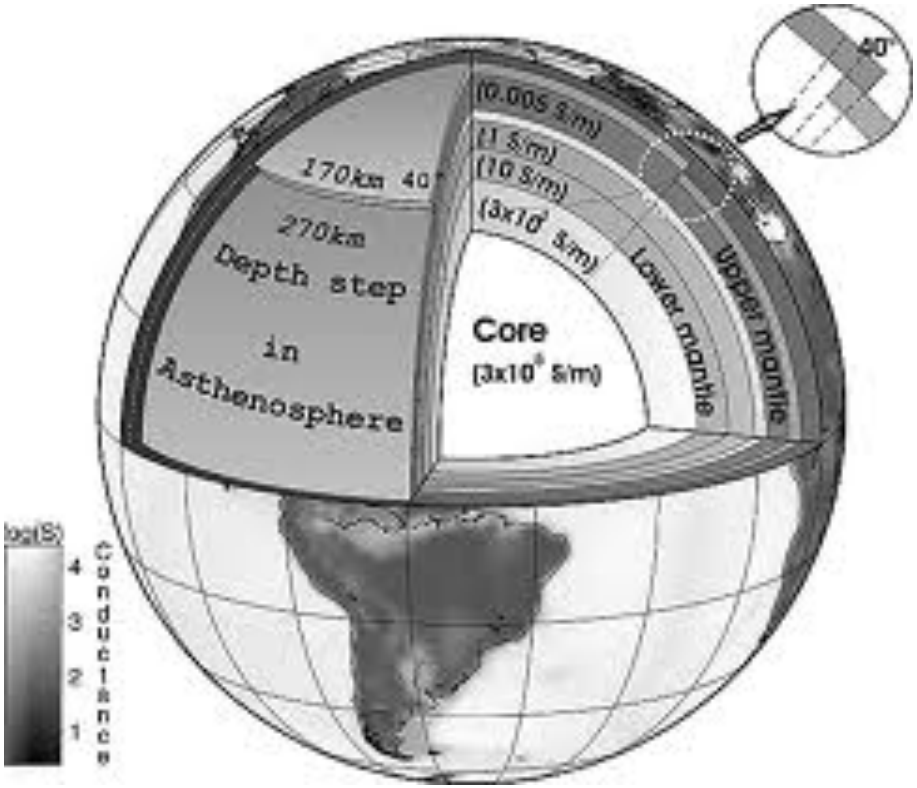
Geological Modelling

- Variations in geomagnetic field primarily produced by ionospheric currents
- Disturbances propagate down into earth – longer duration, greater the depth
- Layered conductivity model
- Down to depths of >500km



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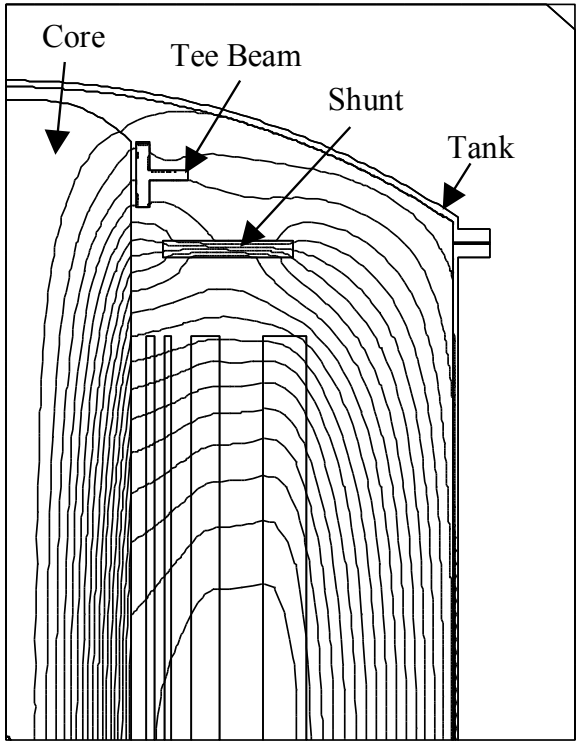
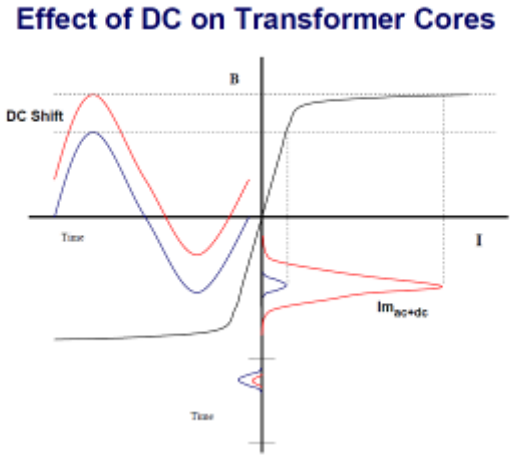
Transformer Modelling

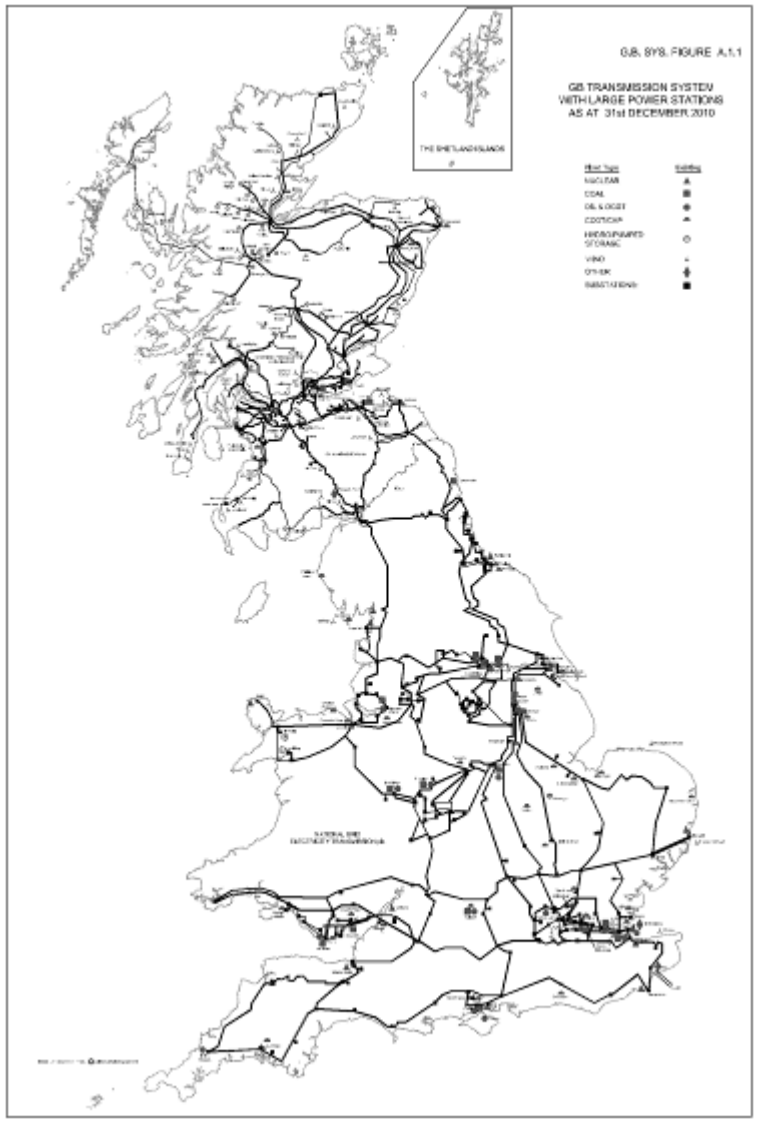




- Transformer specific
- Calculate magnetic flux paths
- Calculate hot spots
- Reactive Power consumption
- Production of harmonics

Network Modelling

- Represent transmission network in the model
  - England & Wales: 400 & 275 kV
  - Scotland: 275 & 132 kV
- Include Generator step-up transformers



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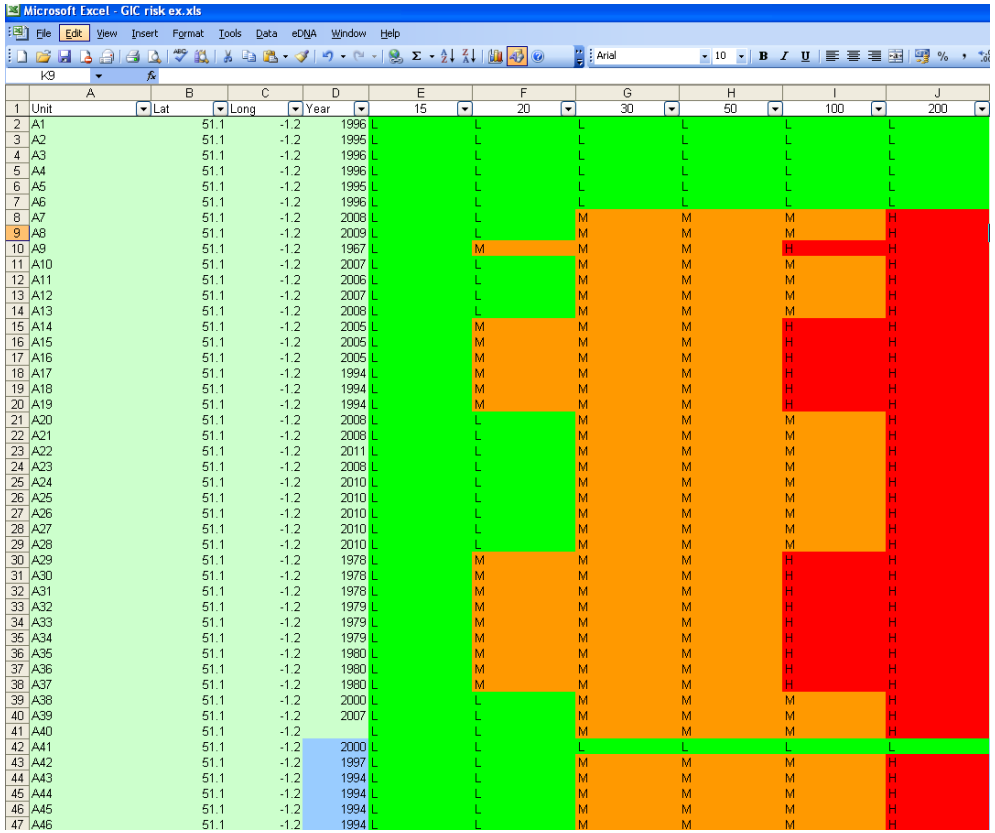
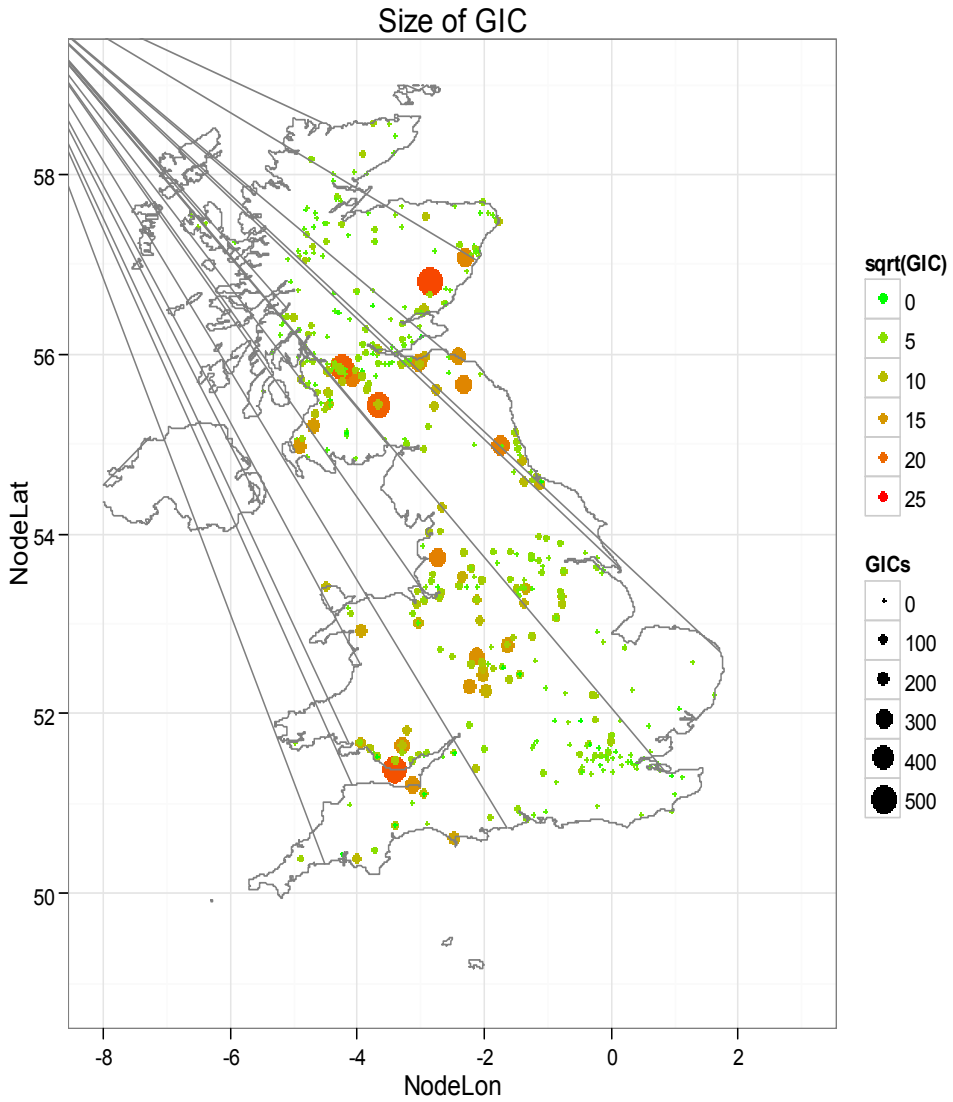
Transformer Modelling



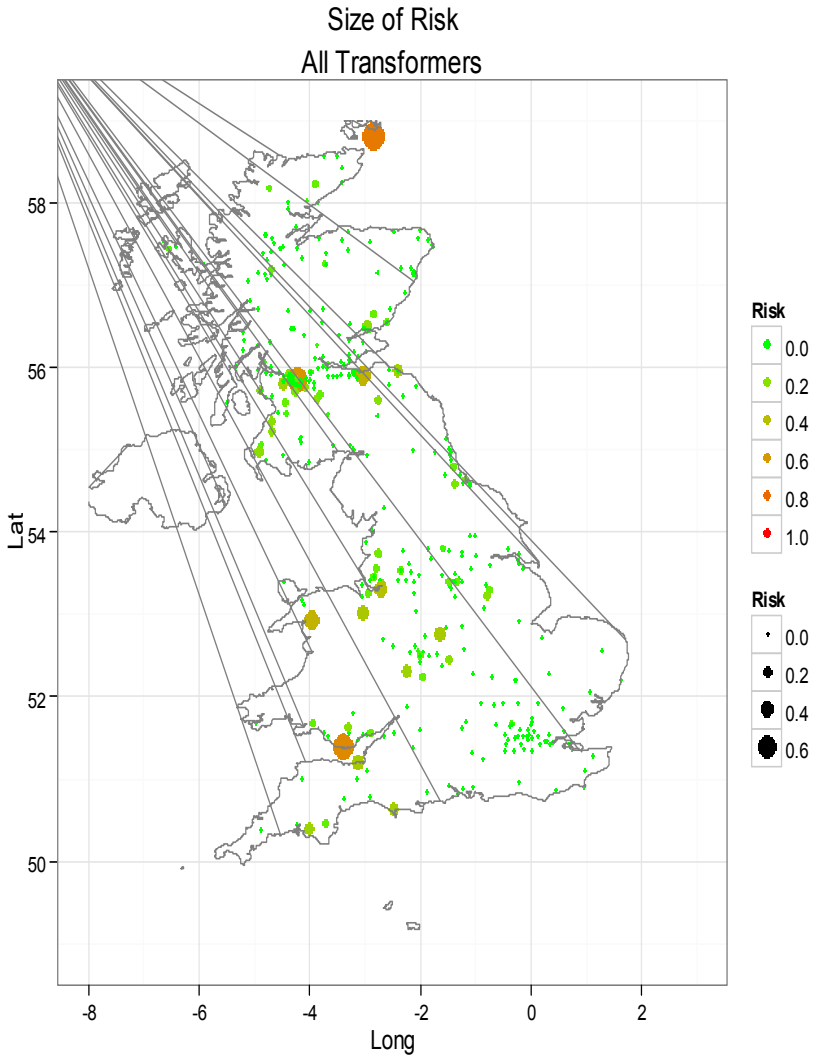
	A	B	C	D	E	F	G	H	I	J
1	Unit	Lat	Long	Year	15	20	30	50	100	200
2	A1	51.1	-1.2	1996	L	L	L	L	L	L
3	A2	51.1	-1.2	1995	L	L	L	L	L	L
4	A3	51.1	-1.2	1996	L	L	L	L	L	L
5	A4	51.1	-1.2	1996	L	L	L	L	L	L
6	A5	51.1	-1.2	1995	L	L	L	L	L	L
7	A6	51.1	-1.2	1996	L	L	L	L	L	L
8	A7	51.1	-1.2	2008	L	L	M	M	M	H
9	A8	51.1	-1.2	2009	L	L	M	M	M	H
10	A9	51.1	-1.2	1967	L	M	M	M	H	H
11	A10	51.1	-1.2	2007	L	L	M	M	M	H
12	A11	51.1	-1.2	2006	L	L	M	M	M	H
13	A12	51.1	-1.2	2007	L	L	M	M	M	H
14	A13	51.1	-1.2	2008	L	L	M	M	M	H
15	A14	51.1	-1.2	2005	L	M	M	M	H	H
16	A15	51.1	-1.2	2005	L	M	M	M	H	H
17	A16	51.1	-1.2	2005	L	M	M	M	H	H
18	A17	51.1	-1.2	1994	L	M	M	M	H	H
19	A18	51.1	-1.2	1994	L	M	M	M	H	H
20	A19	51.1	-1.2	1994	L	M	M	M	H	H
21	A20	51.1	-1.2	2008	L	L	M	M	M	H
22	A21	51.1	-1.2	2008	L	L	M	M	M	H
23	A22	51.1	-1.2	2011	L	L	M	M	M	H
24	A23	51.1	-1.2	2008	L	L	M	M	M	H
25	A24	51.1	-1.2	2010	L	L	M	M	M	H
26	A25	51.1	-1.2	2010	L	L	M	M	M	H
27	A26	51.1	-1.2	2010	L	L	M	M	M	H
28	A27	51.1	-1.2	2010	L	L	M	M	M	H
29	A28	51.1	-1.2	2010	L	L	M	M	M	H
30	A29	51.1	-1.2	1978	L	M	M	M	H	H
31	A30	51.1	-1.2	1978	L	M	M	M	H	H
32	A31	51.1	-1.2	1978	L	M	M	M	H	H
33	A32	51.1	-1.2	1979	L	M	M	M	H	H
34	A33	51.1	-1.2	1979	L	M	M	M	H	H
35	A34	51.1	-1.2	1979	L	M	M	M	H	H
36	A35	51.1	-1.2	1980	L	M	M	M	H	H
37	A36	51.1	-1.2	1980	L	M	M	M	H	H
38	A37	51.1	-1.2	1980	L	M	M	M	H	H
39	A38	51.1	-1.2	2000	L	L	M	M	M	H
40	A39	51.1	-1.2	2007	L	L	M	M	M	H
41	A40	51.1	-1.2		L	L	M	M	M	H
42	A41	51.1	-1.2	2000	L	L	L	L	L	L
43	A42	51.1	-1.2	1997	L	L	M	M	M	H
44	A43	51.1	-1.2	1994	L	L	M	M	M	H
45	A44	51.1	-1.2	1994	L	L	M	M	M	H
46	A45	51.1	-1.2	1994	L	L	M	M	M	H
47	A46	51.1	-1.2	1994	L	L	M	M	M	H

- Analyse over 1400 transformers on the high voltage network
- Classify risk by different design and year
- At different GIC levels
- Derive transformer-specific GIC to Risk function

GIC output

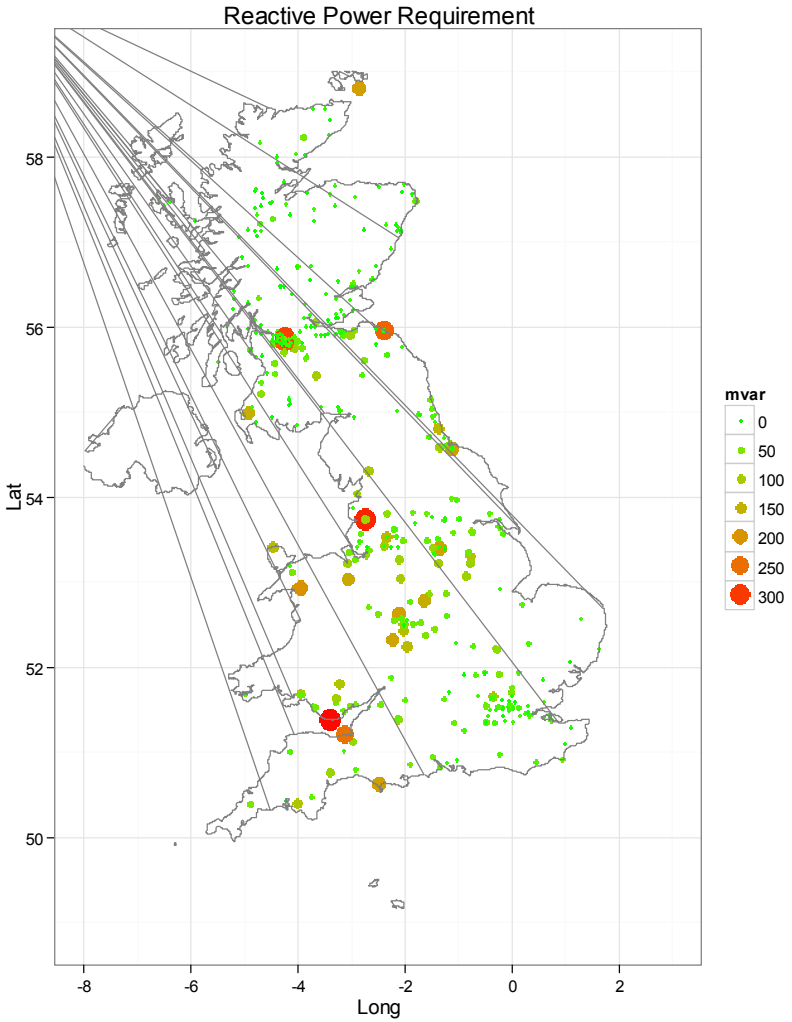

Size of GIC
NodeLat
58
56
54
52
50
-8
-6
-4
-2
0
2
NodeLon
sqrt(GIC)
0
5
10
15
20
25
GICs
0
100
200
300
400
500

Risk output



- Based on GIC flow and design of transformers at each node
- For one extreme scenario
- Different scenarios produce different risk profiles

Reactive Power Requirement



- Simple model
- Calculates on basis of GIC flow and voltage
- Assumes all types behave in same way
- Only for one scenario
- Order of magnitude results only

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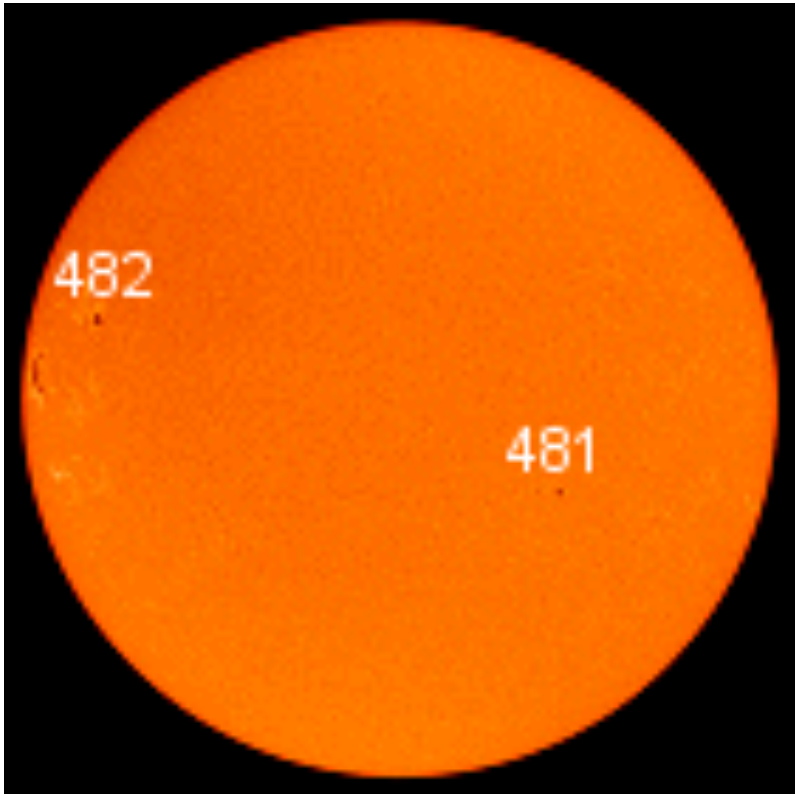
Monitoring

- 18 October 2003



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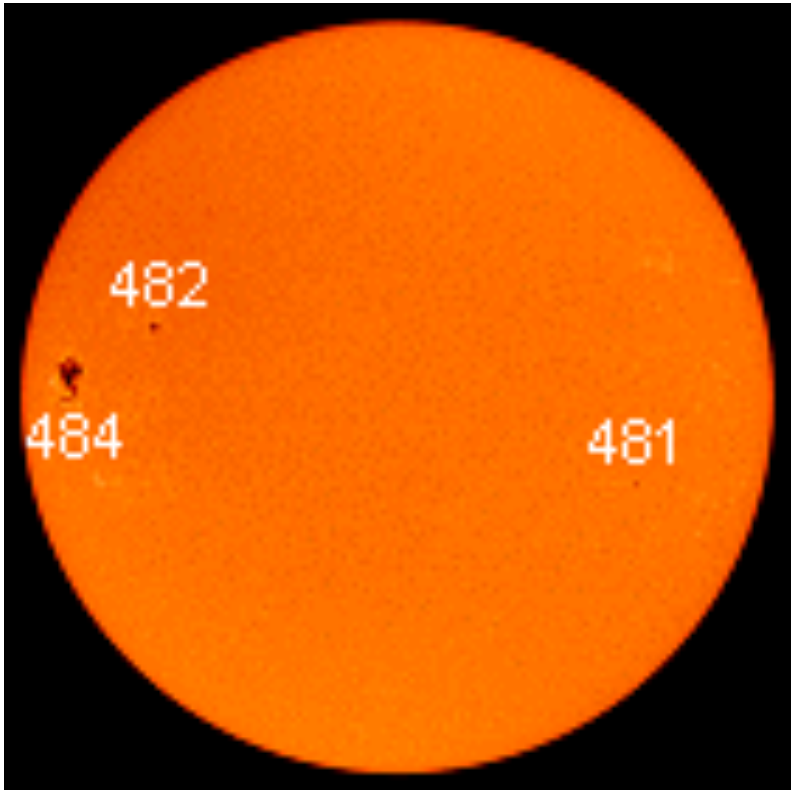
Sunspots for Halloween Storm

- 19 October 2003



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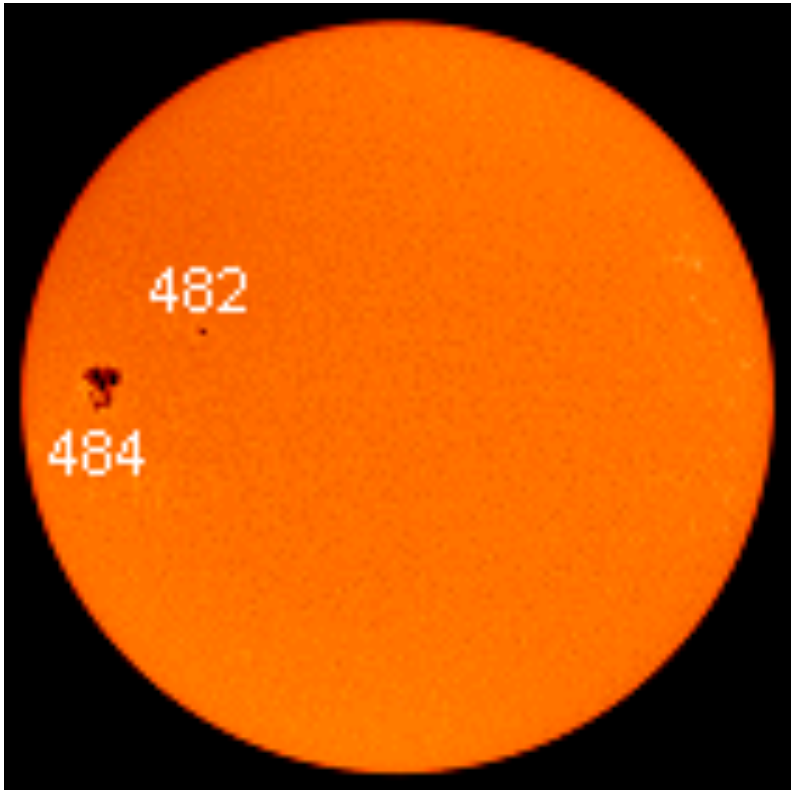
Sunspots for Halloween Storm

- 20 October 2003



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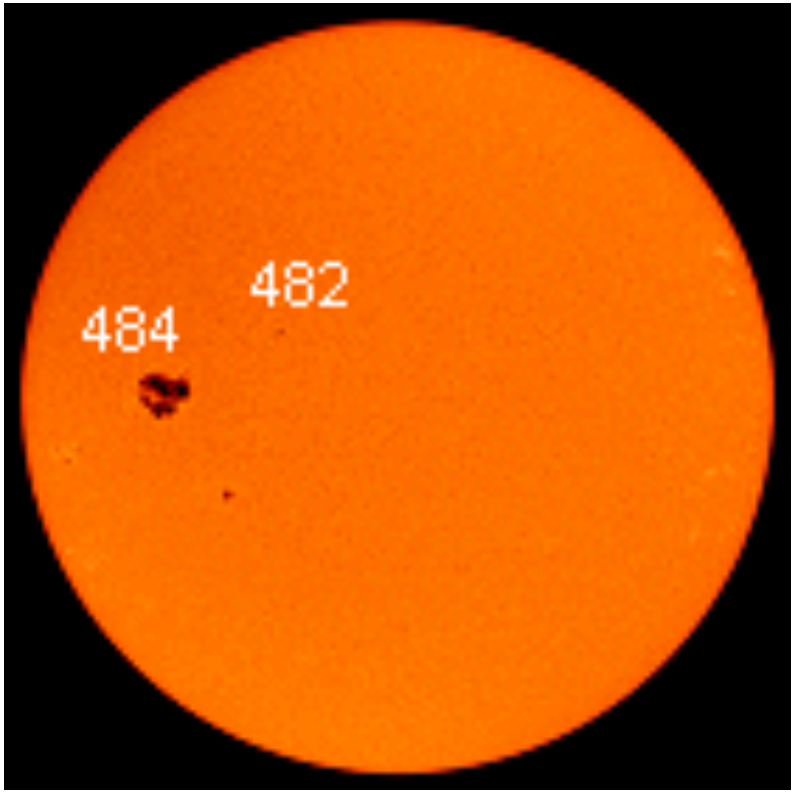
Sunspots for Halloween Storm

- 21 October 2003



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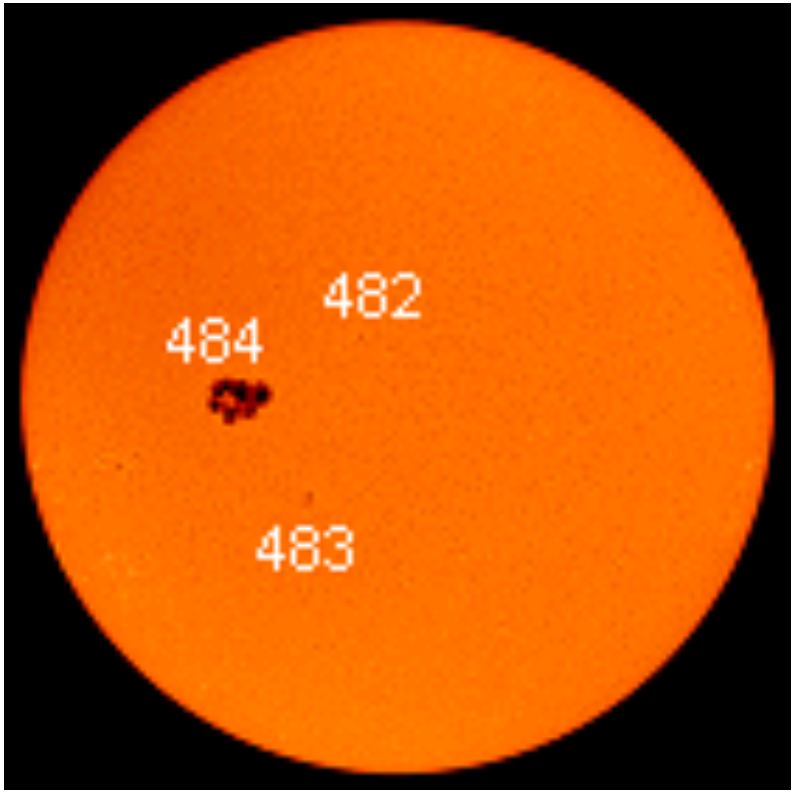
Sunspots for Halloween Storm

- 22 October 2003



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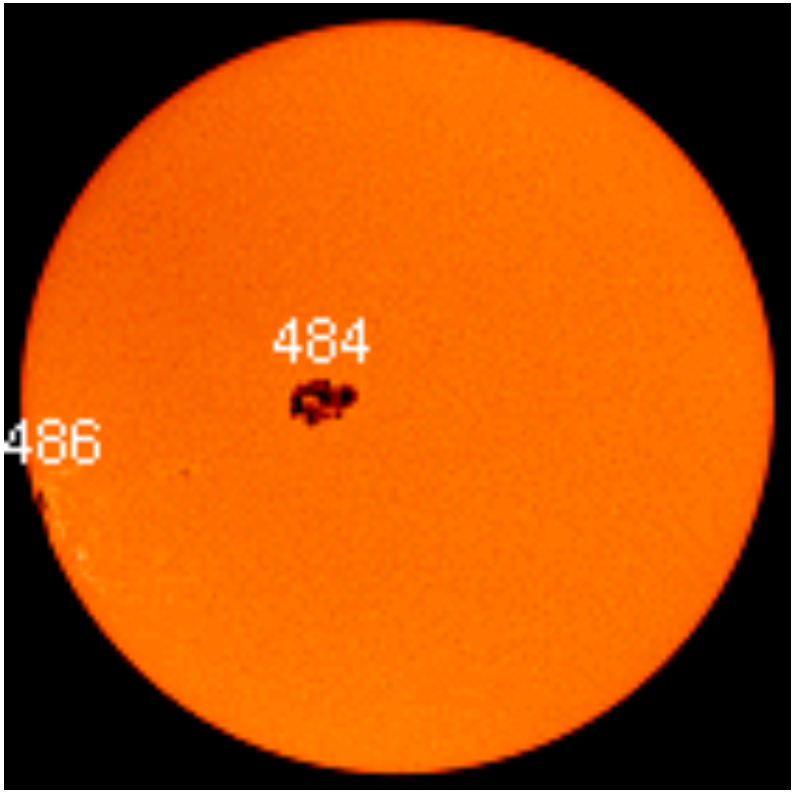
Sunspots for Halloween Storm

- 23 October 2003



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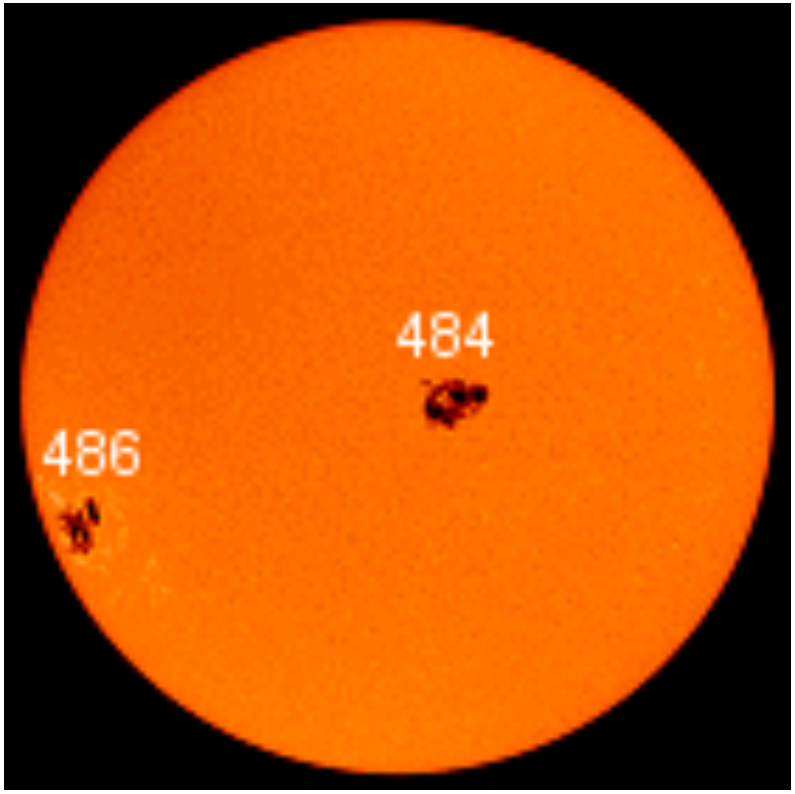
Sunspots for Halloween Storm

- 24 October 2003



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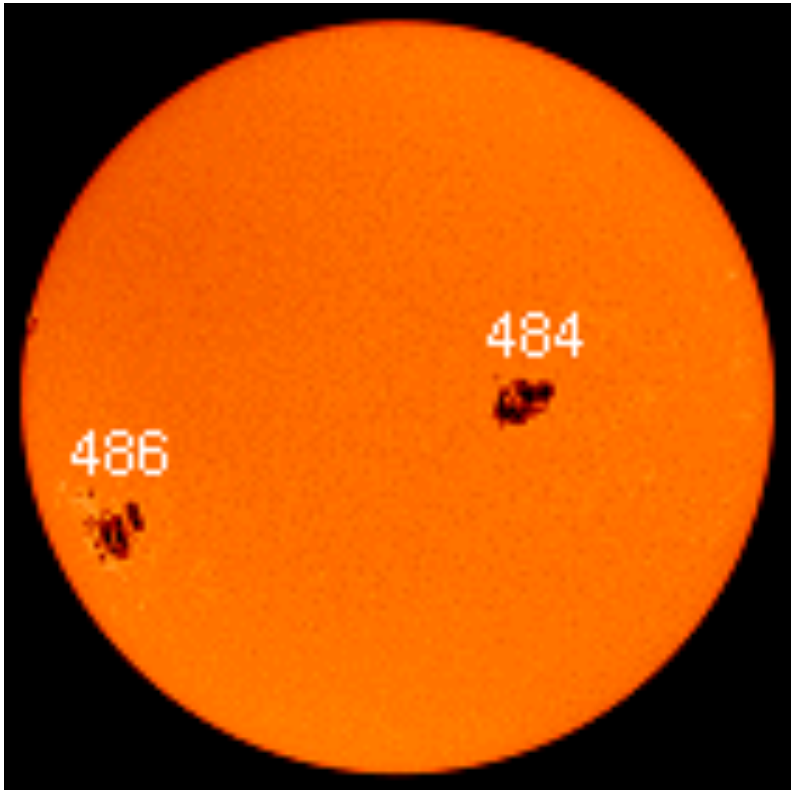
Sunspots for Halloween Storm

- 25 October 2003



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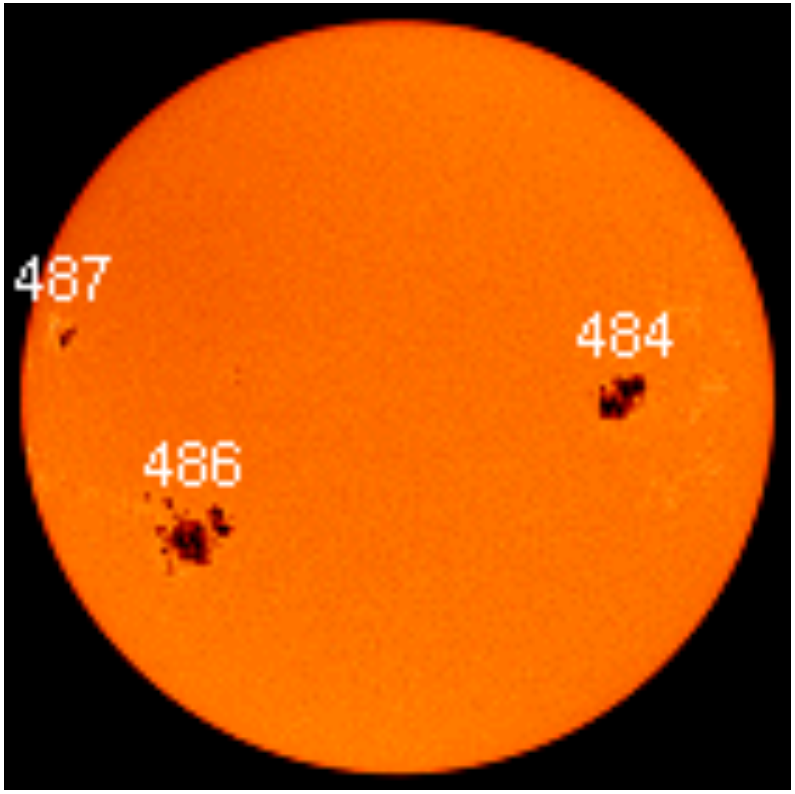
Sunspots for Halloween Storm

- 26 October 2003



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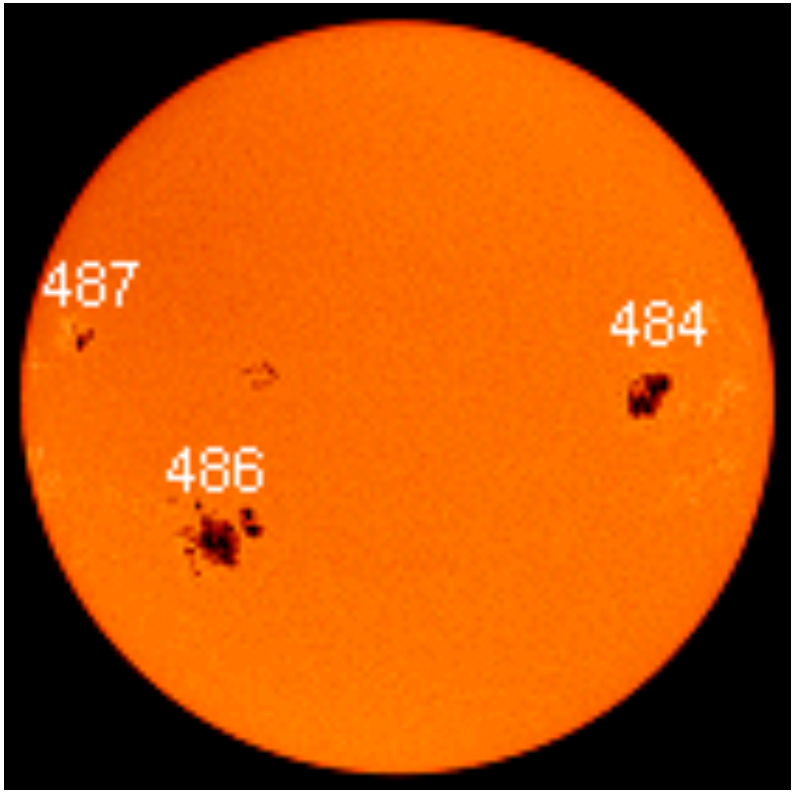
Sunspots for Halloween Storm

- 27 October 2003



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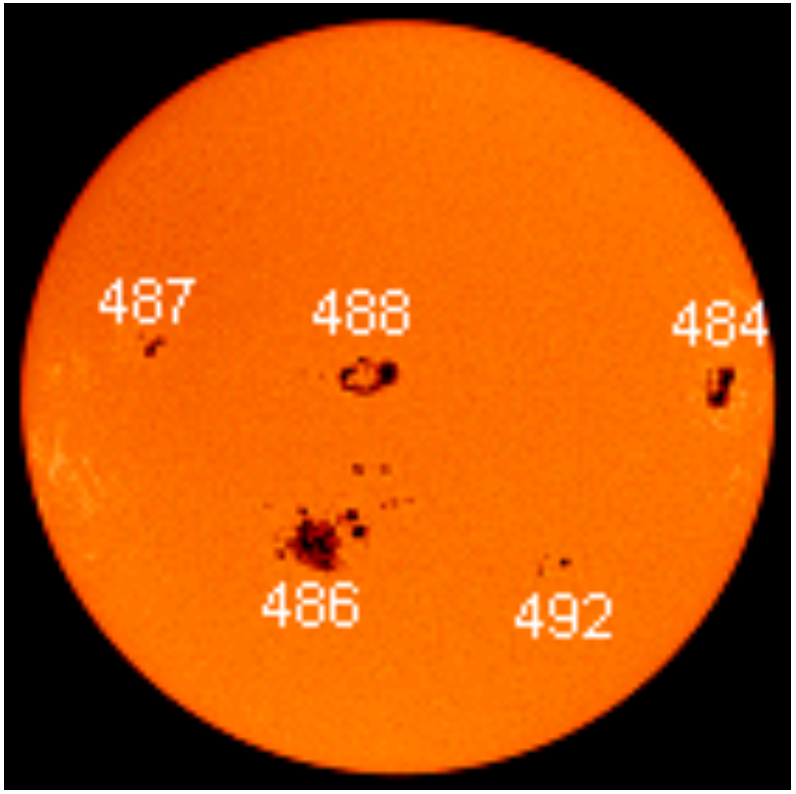
Sunspots for Halloween Storm

- 28 October 2003



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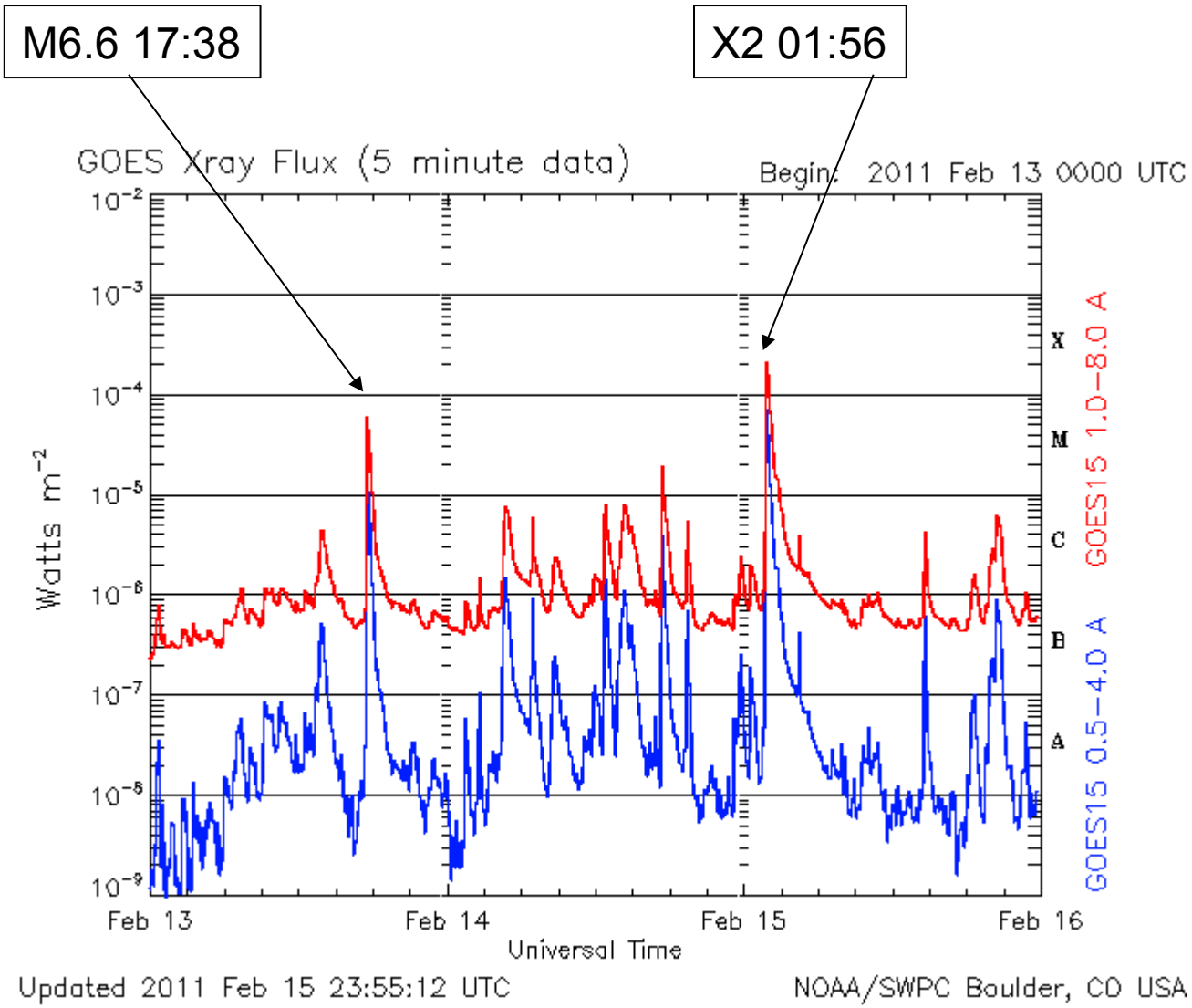
X-Ray burst from solar flare



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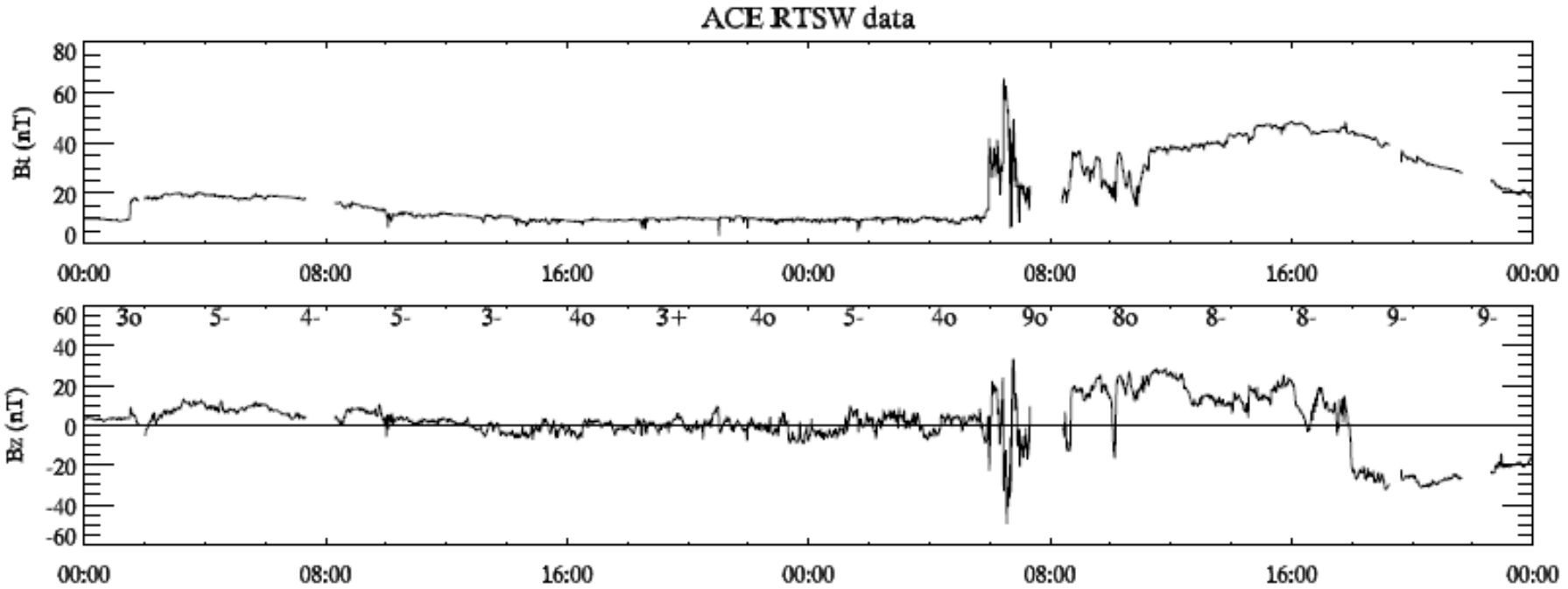
CME arrival at ACE



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Warning actions

- Day -4 onward
  - Monitor all available space weather sources carefully
- Day -1 Observe CME
  - Issue warning of possible system disturbance
- At T -30 minutes
  - Observe direction of Bz at ACE
  - Reissue warning of system disturbance

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Operational Mitigation Options:

- **ALL IN**:
  - All circuits returned to service and switched in
  - All Supergrid Transformers connected
  - Substations run solid
  - Extra generation instructed to synchronise
  - Extra reactive support made available
  - All monitoring and warning systems utilised

National Grid / BGS MAGIC Webtool Magnetometer records

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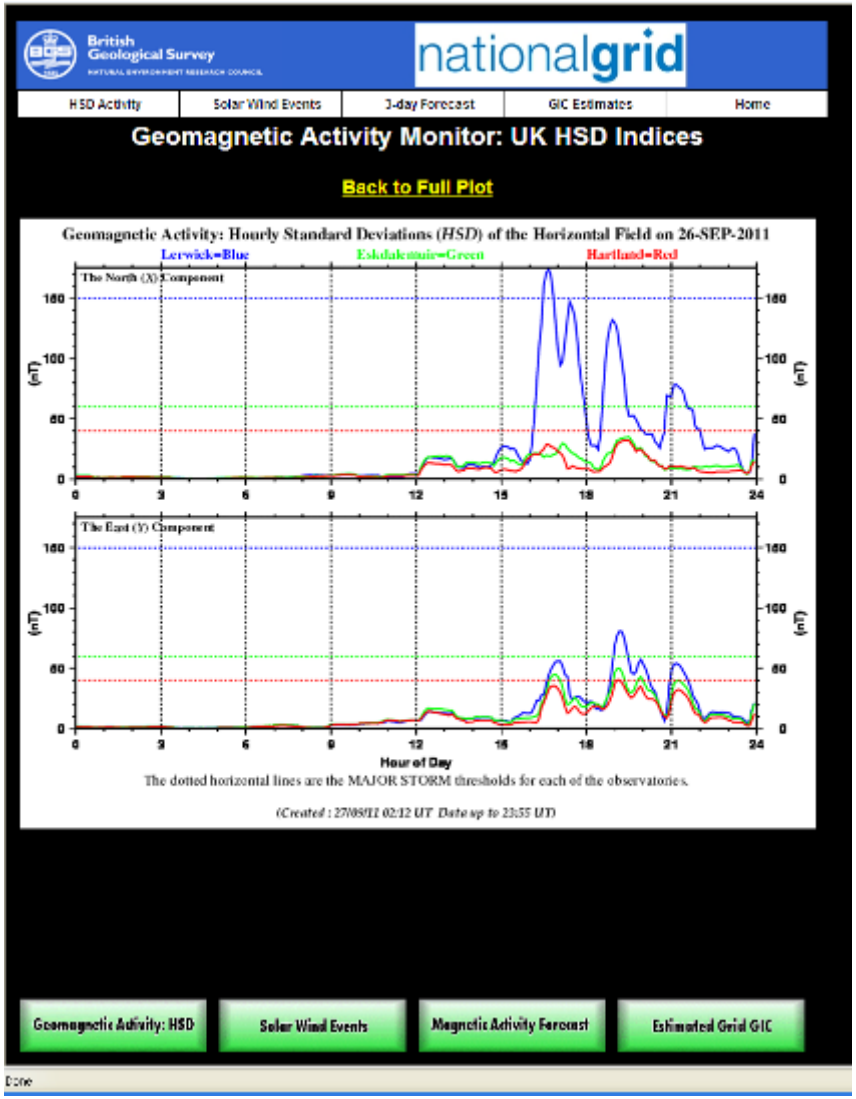
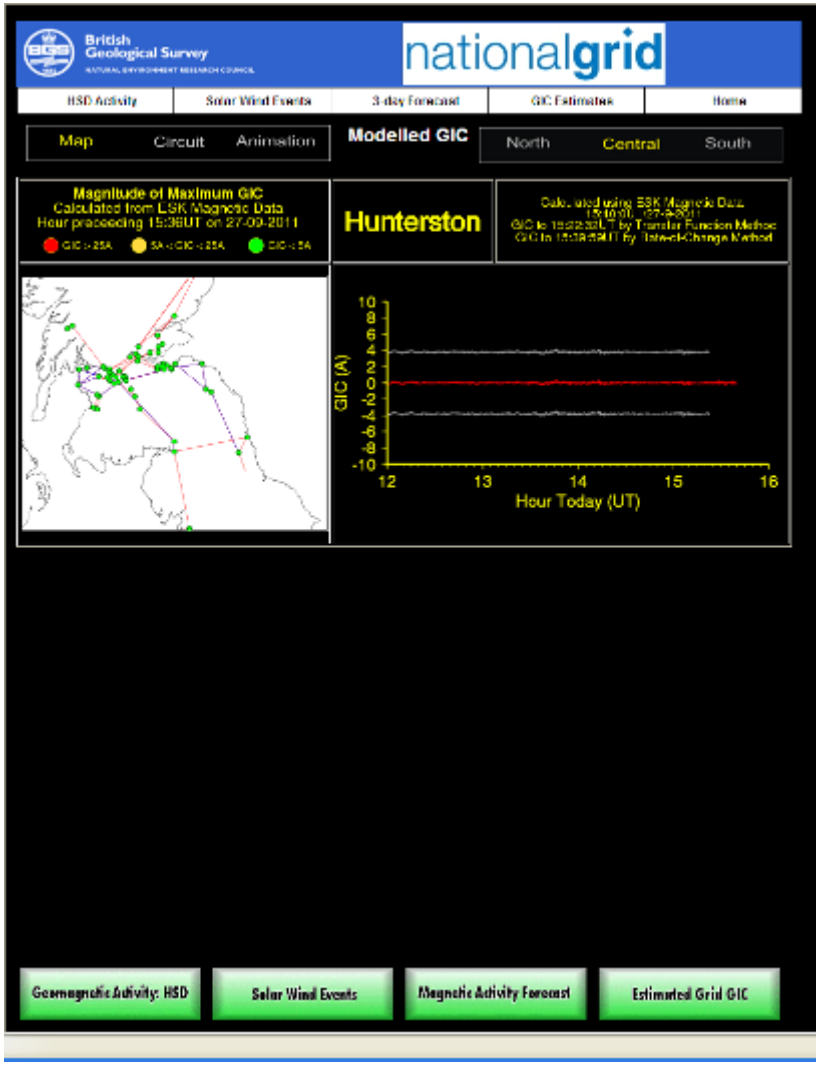


National Grid / BGS MAGIC Webtool Network Model display



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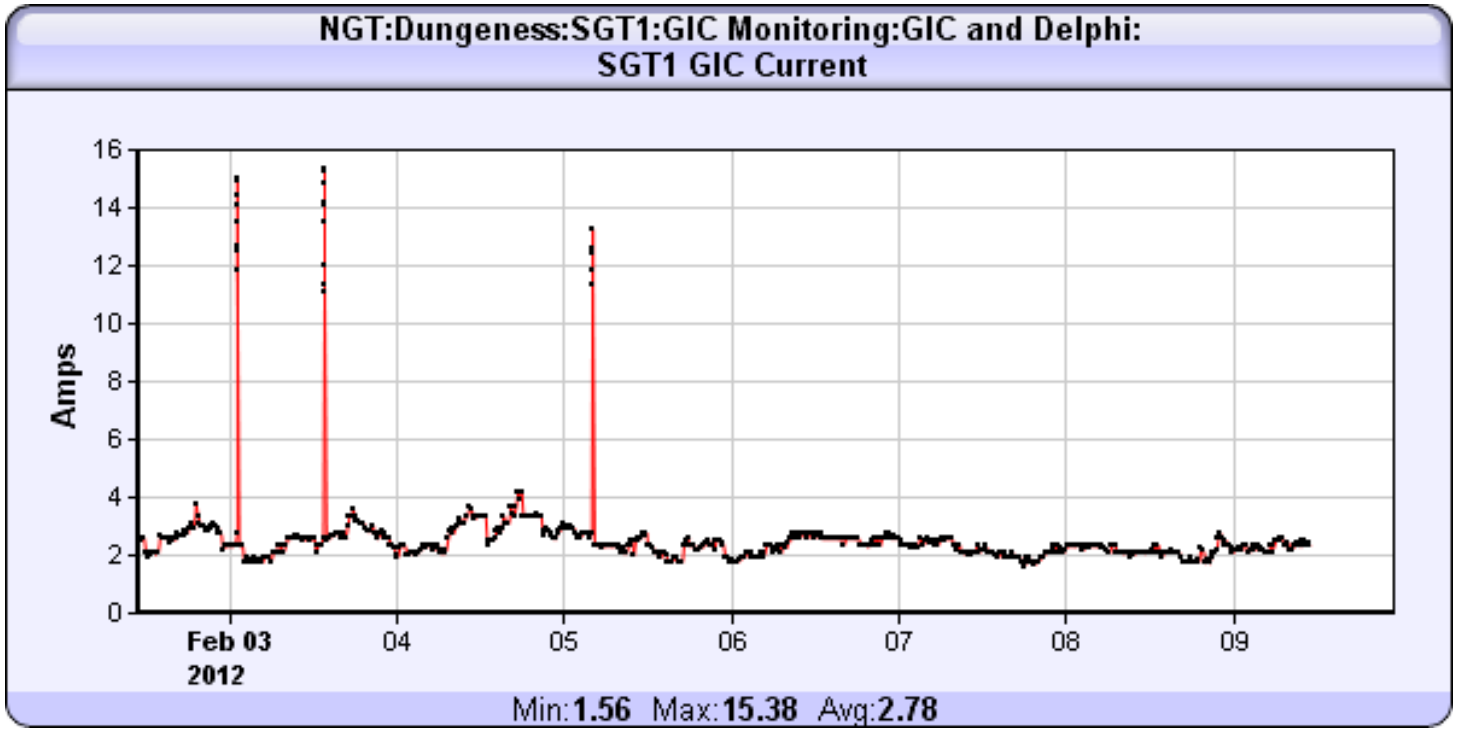
GIC Monitoring



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Cooperation for Cycle 24

RAL Space

SOLAR SHIELD

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Lancaster University
Manchester University
Cardiff University

EPRI ELECTRIC POWER RESEARCH INSTITUTE

The Royal Academy of Engineering

NOAA
NASA
NERC (UK)
NERC (US)

National Grid UK
(4 SUNBURST sensors)
National Grid US
(2 SUNBURST sensors)

Met Office

Scottish Power
DECC
Cabinet Office