DR GEMMA RICHARDSON (gemk@bgs.ac.uk) AND COLLEAGUES IN THE GEOMAGNETISM TEAM

Space weather and its impact on grounded technological infrastructure

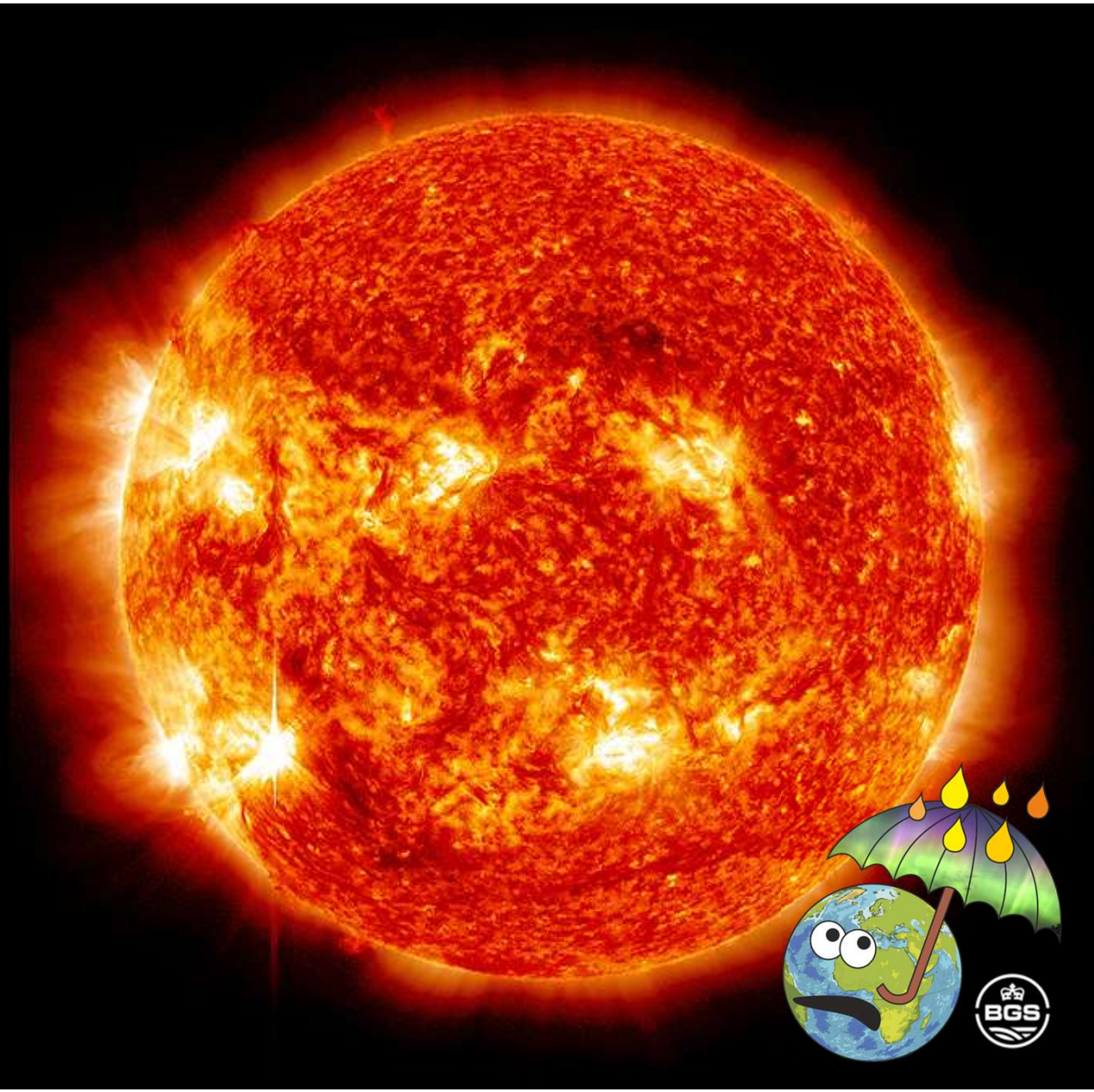
British Geological Survey

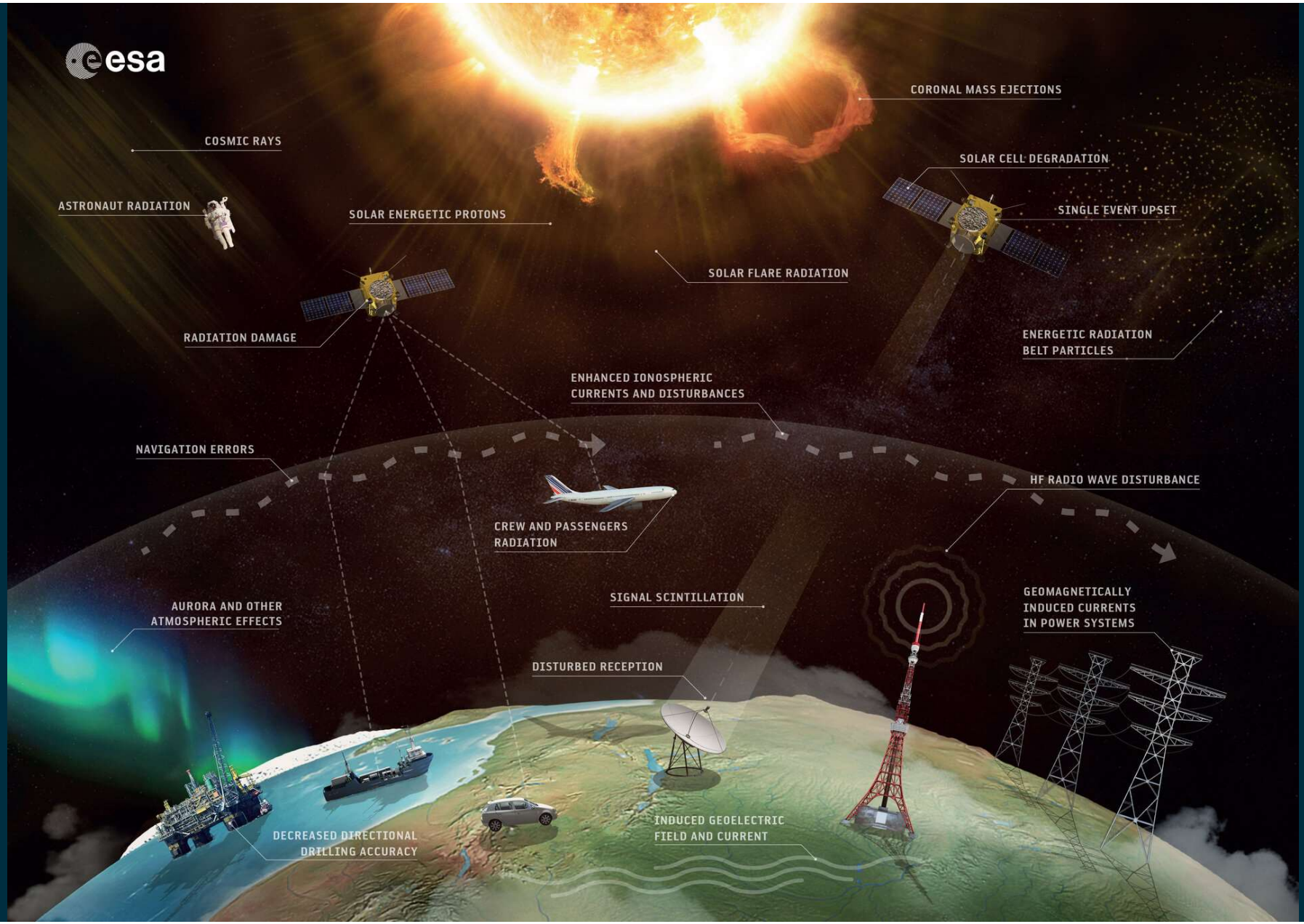
Talk overview

- Intro to space weather
  - What is it?
  - Why is it a hazard?
- Research into effects on grounded infrastructure
- Forecasting and space weather services at BGS
- Summary

What is Space weather?

"Space Weather" is a term to describe the variability in conditions in the near-Earth space environment.



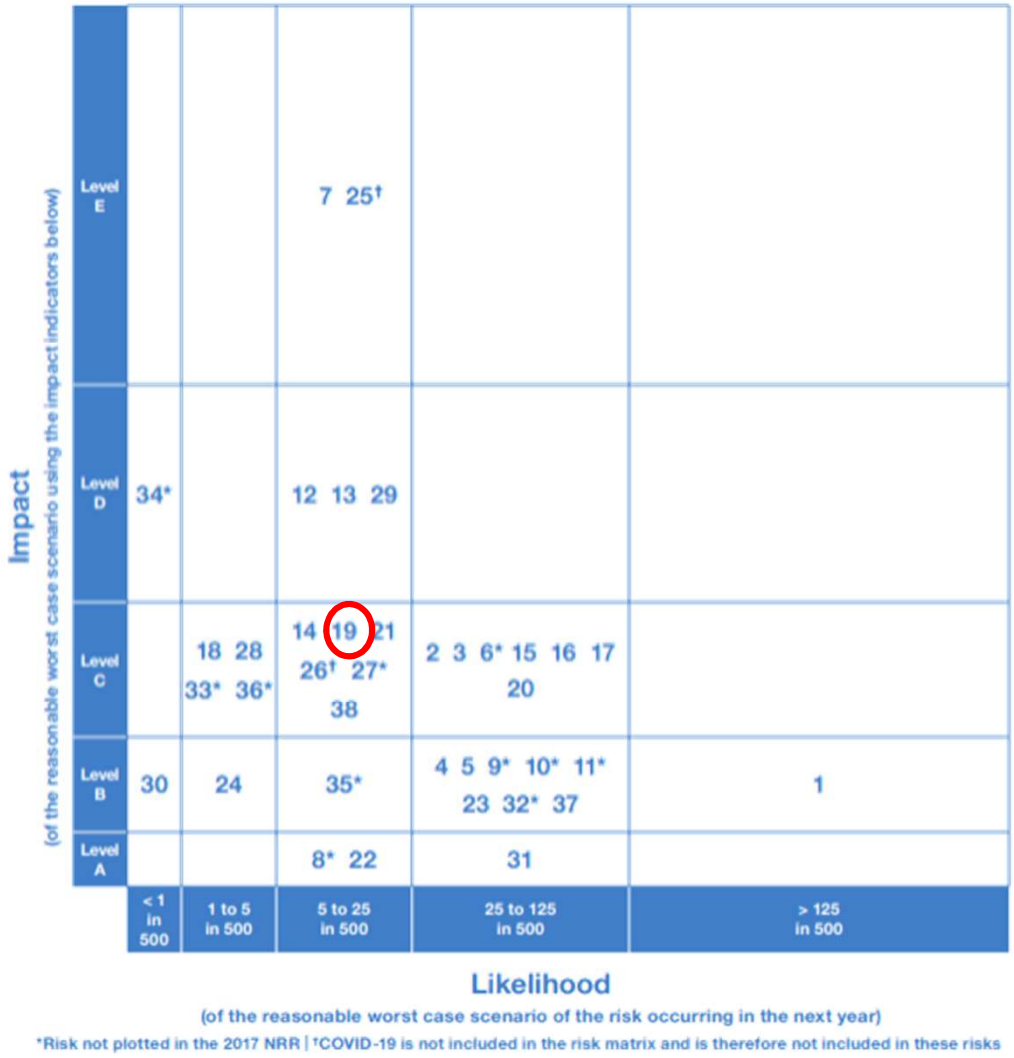

esa
CORONAL MASS EJECTIONS
COSMIC RAYS
SOLAR CELL DEGRADATION
ASTRONAUT RADIATION
SOLAR ENERGETIC PROTONS
SINGLE EVENT UPSET
SOLAR FLARE RADIATION
RADIATION DAMAGE
ENERGETIC RADIATION BELT PARTICLES
ENHANCED IONOSPHERIC CURRENTS AND DISTURBANCES
NAVIGATION ERRORS
HF RADIO WAVE DISTURBANCE
CREW AND PASSENGERS RADIATION
SIGNAL SCINTILLATION
GEOMAGNETICALLY INDUCED CURRENTS IN POWER SYSTEMS
AURORA AND OTHER ATMOSPHERIC EFFECTS
DISTURBED RECEPTION
DECREASED DIRECTIONAL DRILLING ACCURACY
INDUCED GEOELECTRIC FIELD AND CURRENT

Recognising the Risk

- Formally recognised on the National Risk Register in Jan 2012

Challenges:

- Global
- Interdependence of potential impacts
- Very little warning
- Uncertainty about reasonable worst case scenario



Malicious Attacks
1. Attacks on publicly accessible locations
2. Attacks on infrastructure
3. Attacks on transport
4. Cyber attacks
5. Smaller scale CBRN attacks
6. Medium scale CBRN attacks
7. Larger scale CBRN attacks
8. Undermining the democratic process*

Serious and Organised Crime
9. Serious and organised crime – vulnerabilities*
10. Serious and organised crime – prosperity*
11. Serious and organised crime – commodities*

Environmental Hazards
12. Coastal flooding
13. River flooding
14. Surface water flooding
15. Storms
16. Low temperatures
17. Heatwaves
18. Droughts
19. Severe space weather
20. Volcanic eruptions
21. Poor air quality
22. Earthquakes
23. Environmental disasters overseas
24. Wildfires

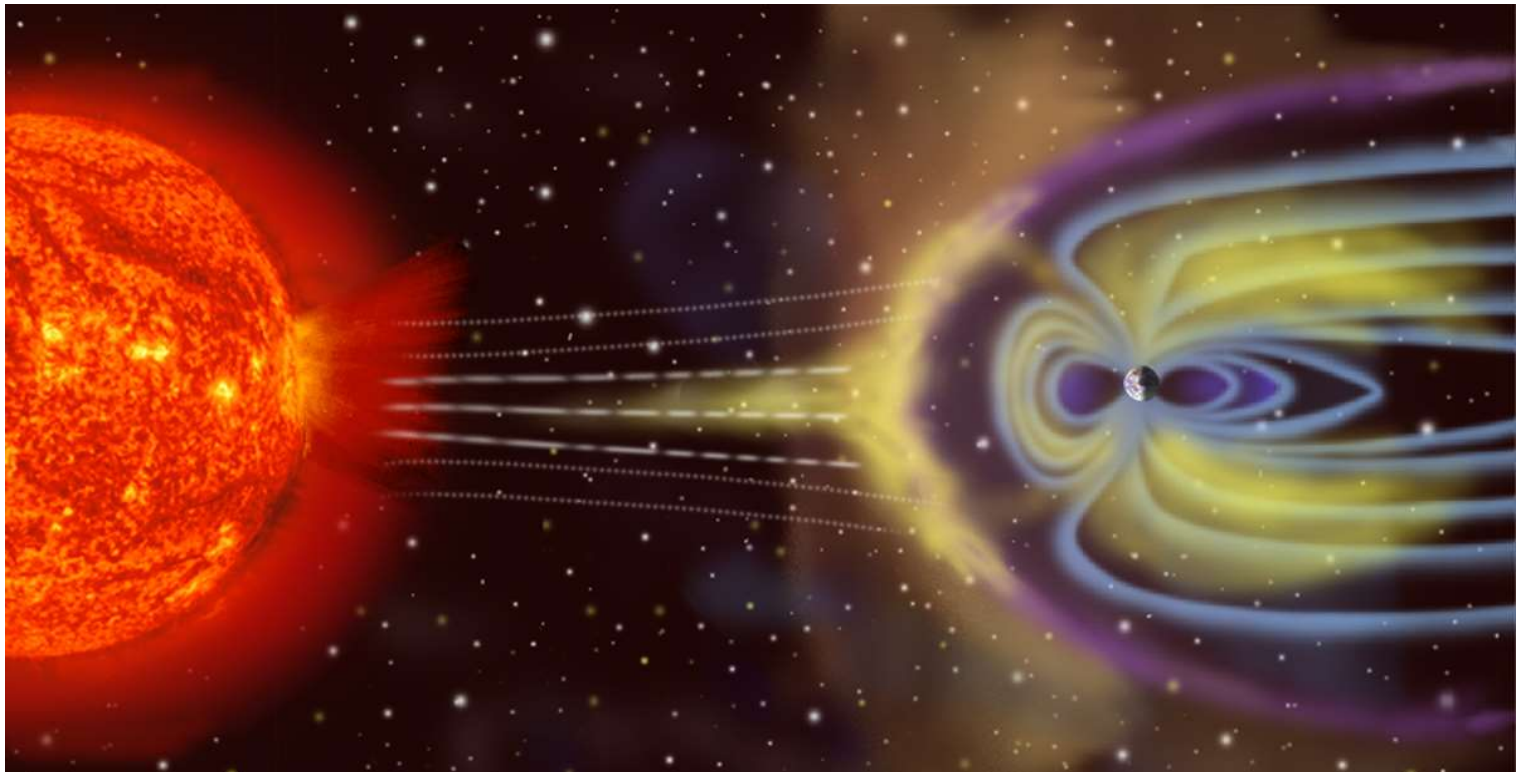
Human and Animal Health
25. Pandemics†
26. High consequence infectious disease outbreaks†
27. Antimicrobial resistance*
28. Animal diseases

Major Accidents
29. Widespread electricity failures
30. Major transport accidents
31. System failures
32. Commercial failures*
33. Systematic financial crisis*
34. Industrial accidents – nuclear*
35. Industrial accidents - non nuclear*
36. Major fires*

Societal Risks
37. Industrial action
38. Widespread public disorder

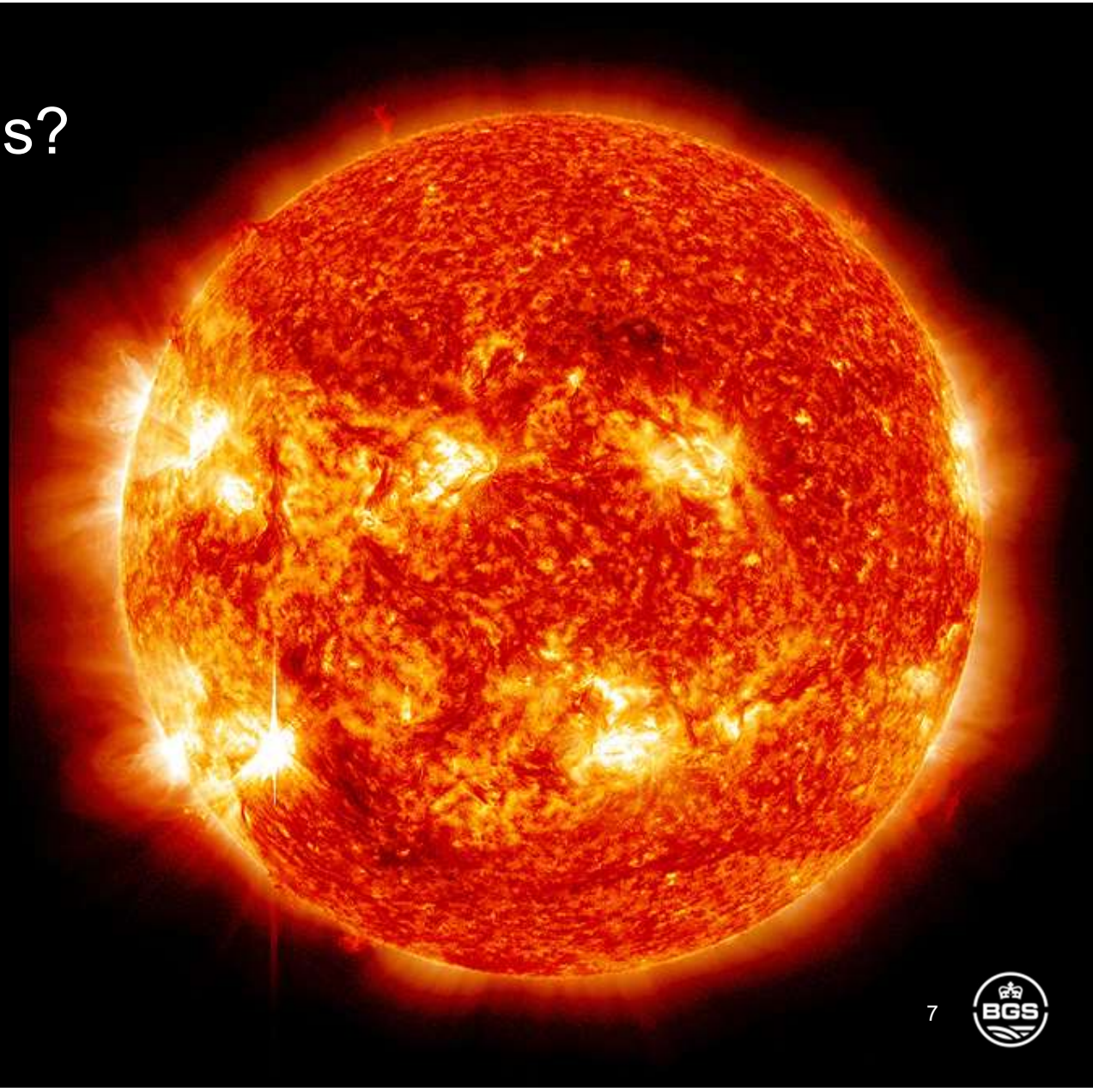
Solar wind

- Continuous stream of charged particles from the Sun
- Varies in density, speed and temperature and contains entrained solar magnetic field
- This Solar wind hits the Earth's magnetic field and interacts with it



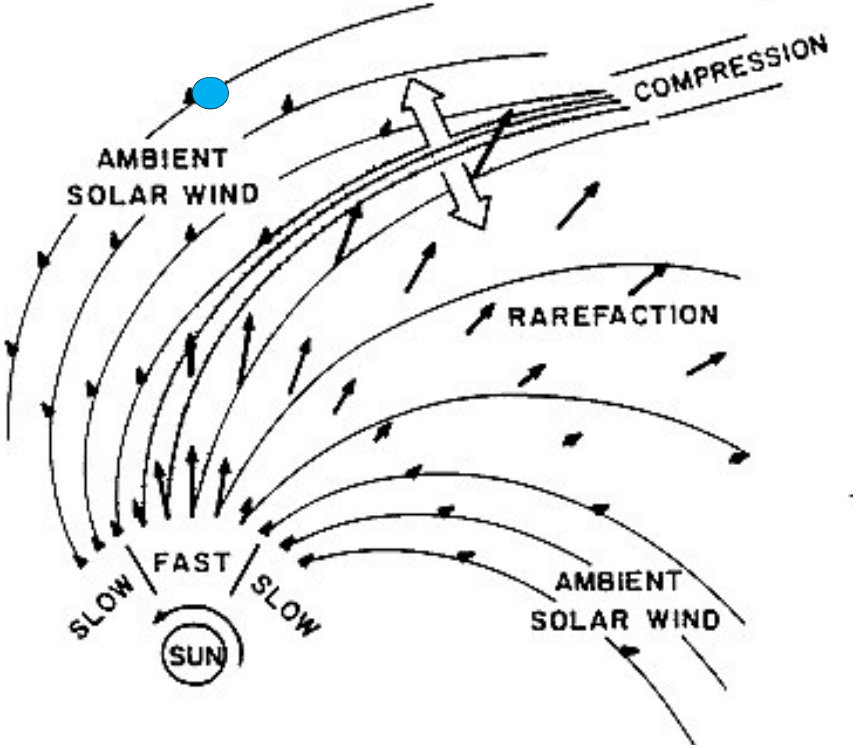
What causes disturbances?

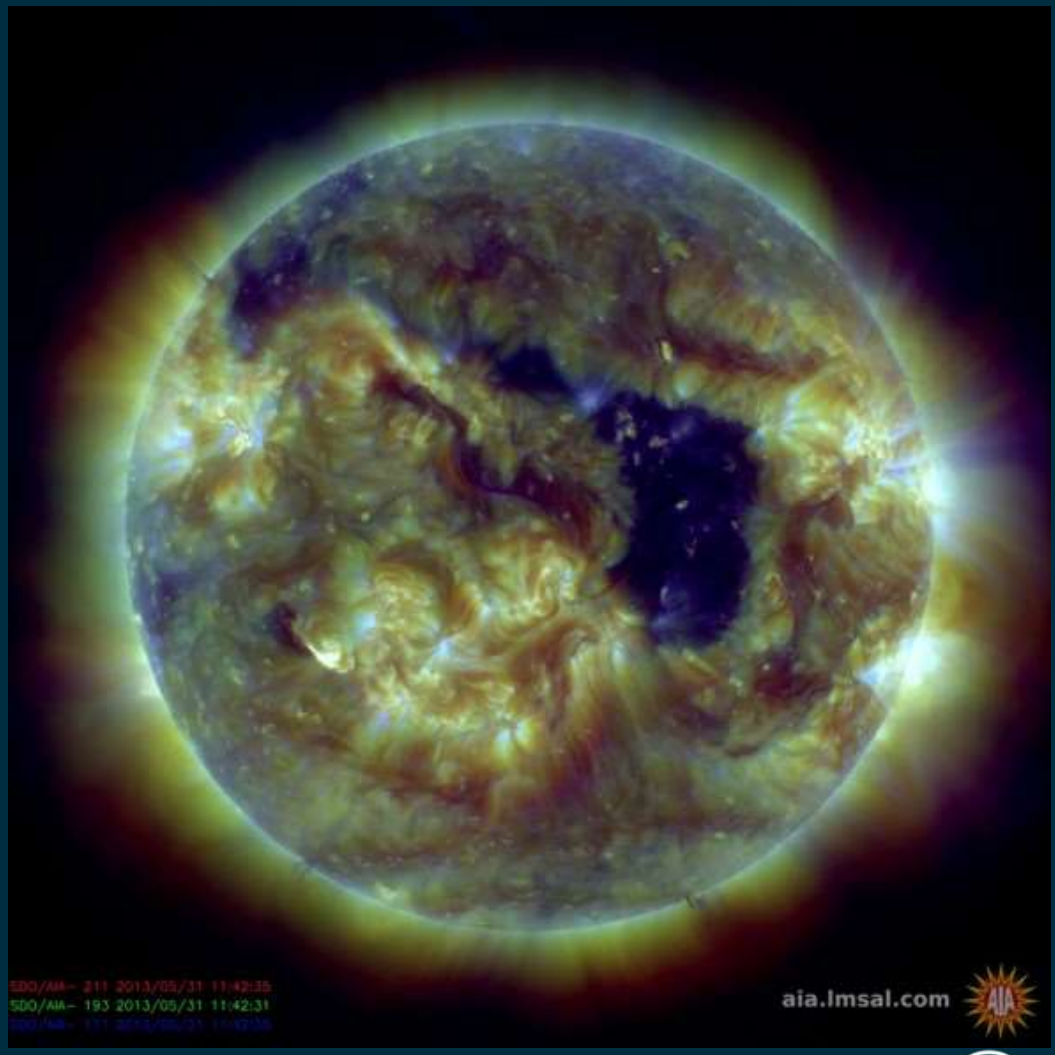
- Two main sources:
  - Coronal holes
  - Coronal mass ejections



Coronal holes

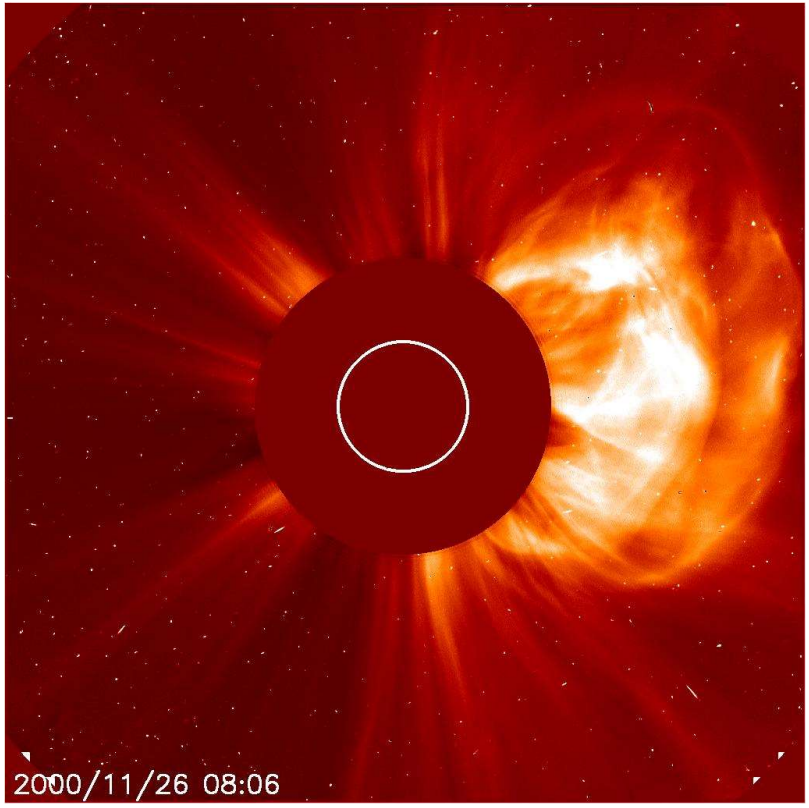
- High speed solar wind stream
- Typical velocity ~750 km/s (compared to ~400km/s normally)

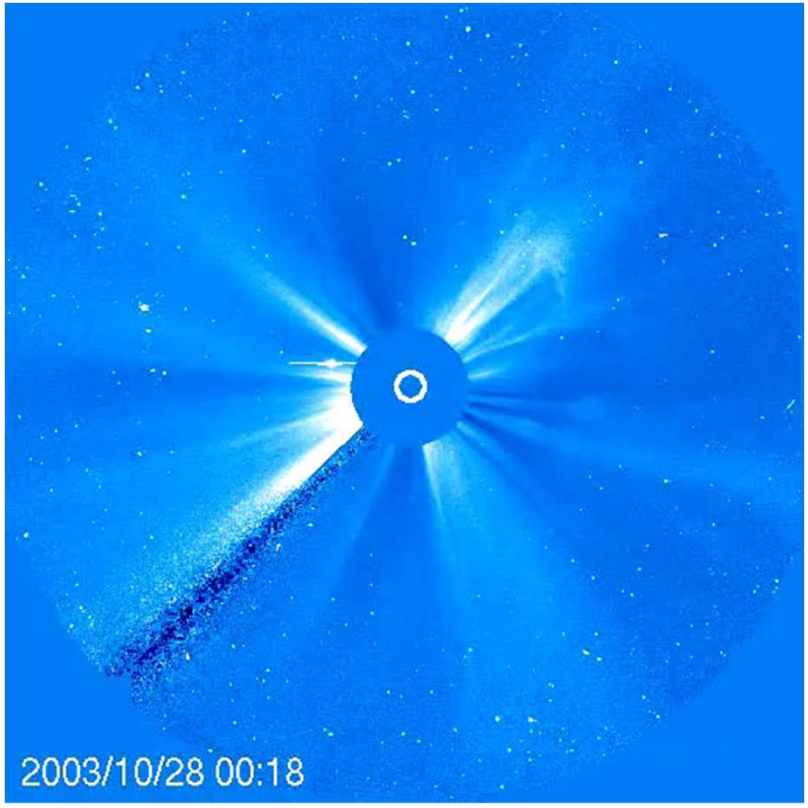




Coronal mass ejections

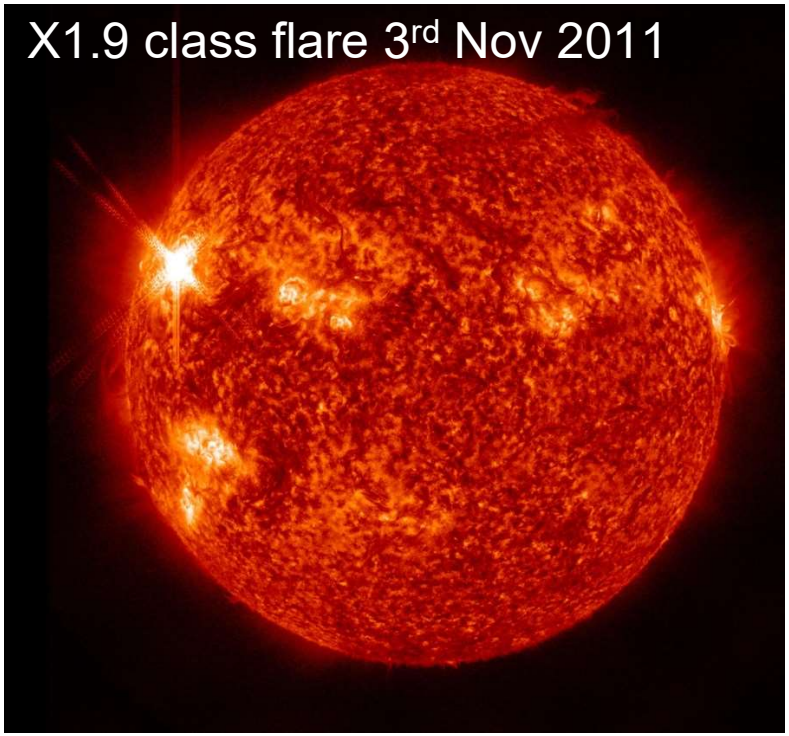
- Release large quantities of plasma and magnetic field into space

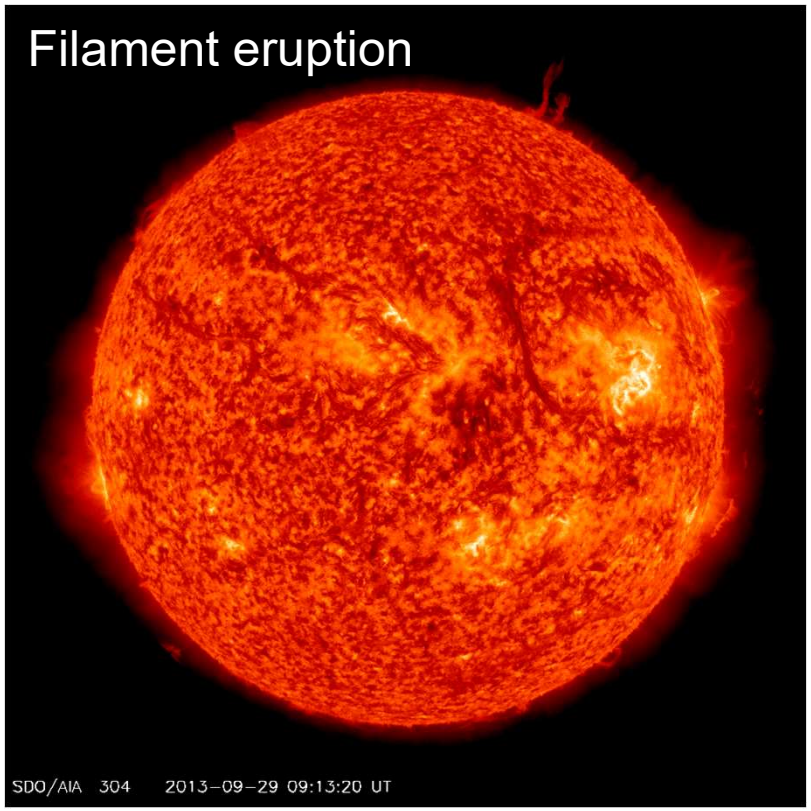




Coronal mass ejections (CMEs)

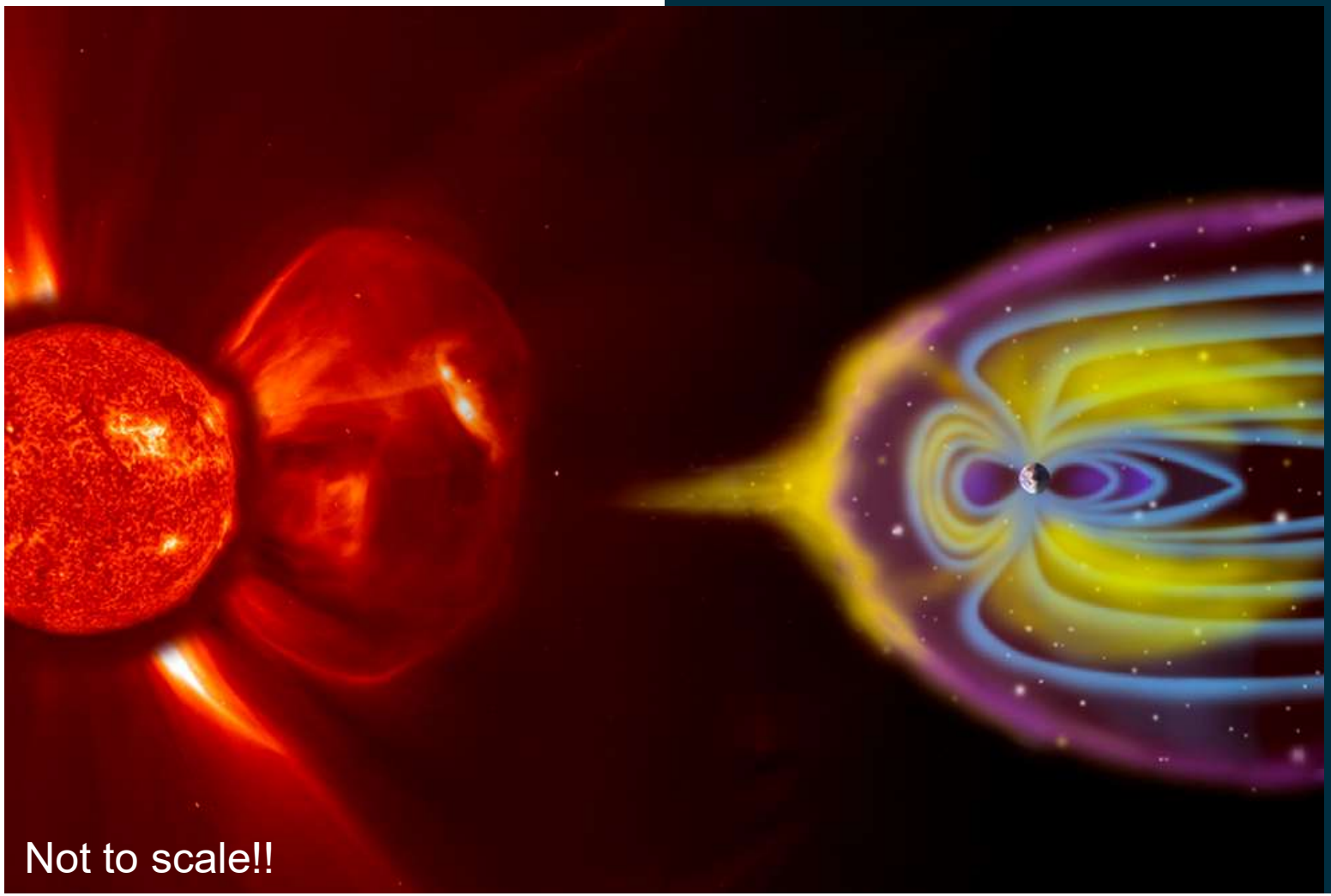
- Usually associated with solar flares or filament eruptions





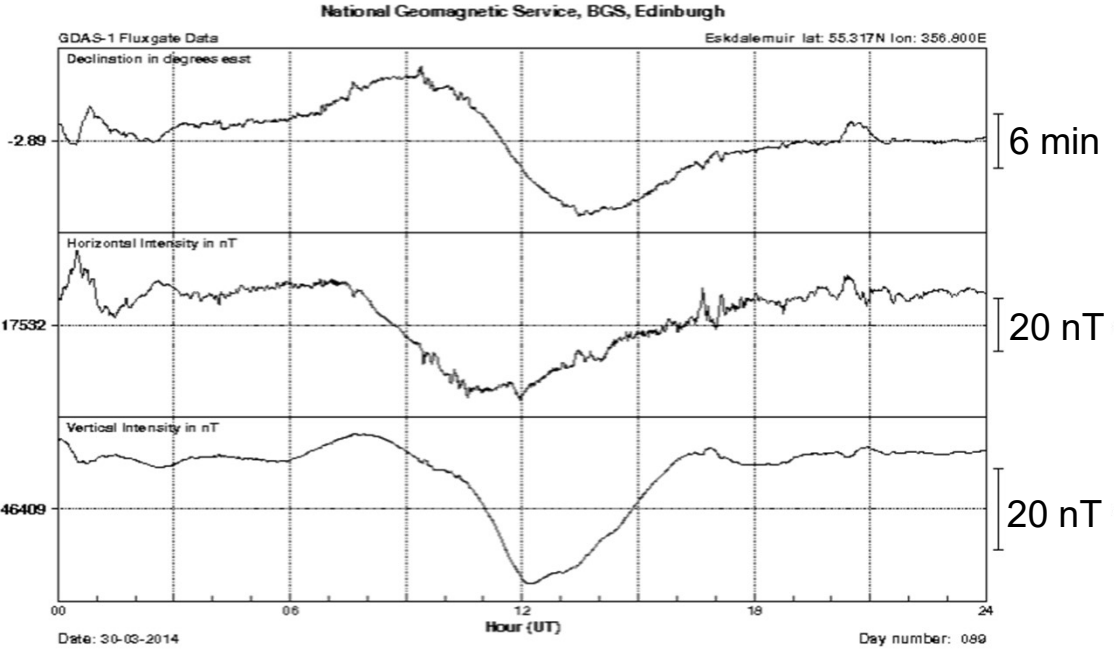
Both images from SDO/NASA

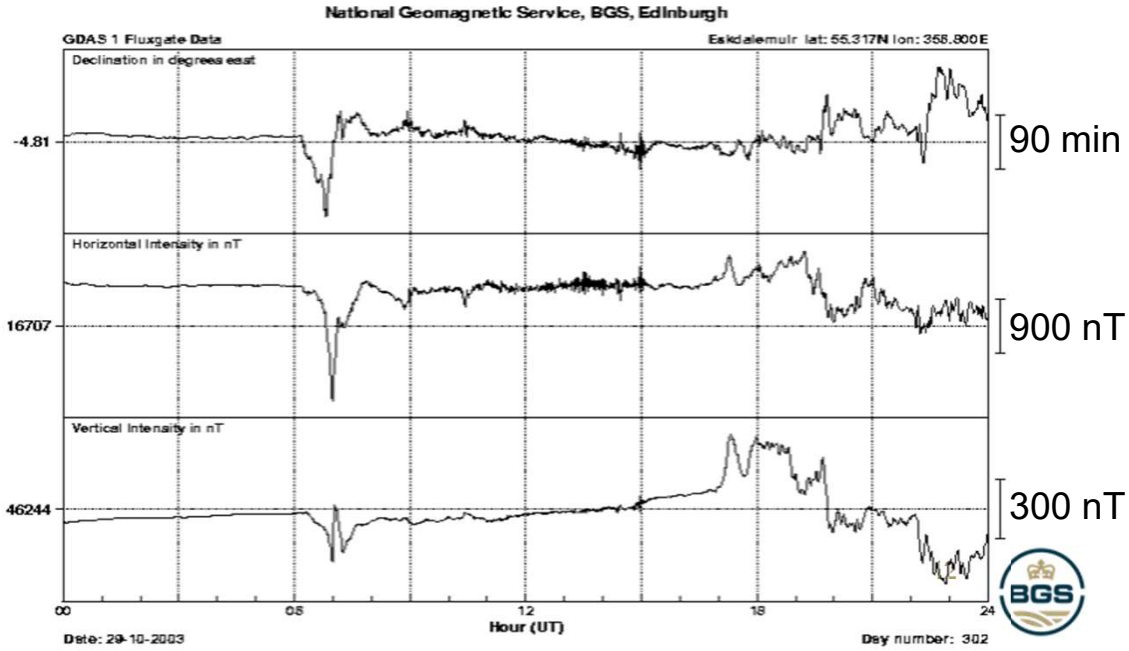
Geomagnetic storm!



Geomagnetic signature

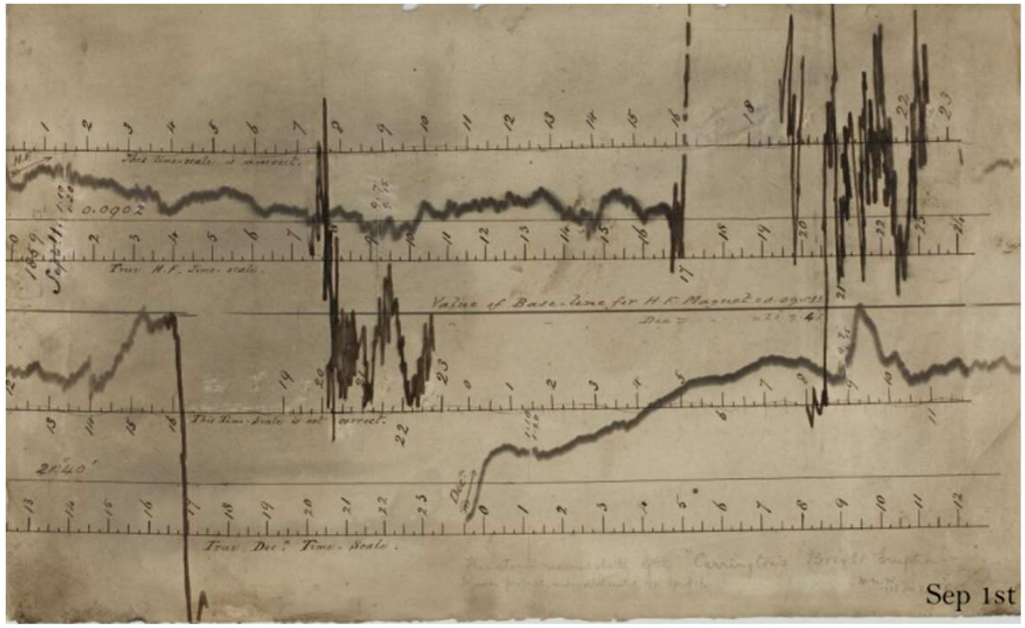
- Magnetic field we measure is from a combination of sources
- “External field” is relatively small, but high frequency
- On disturbed days the variations due to space weather become larger and much more variable

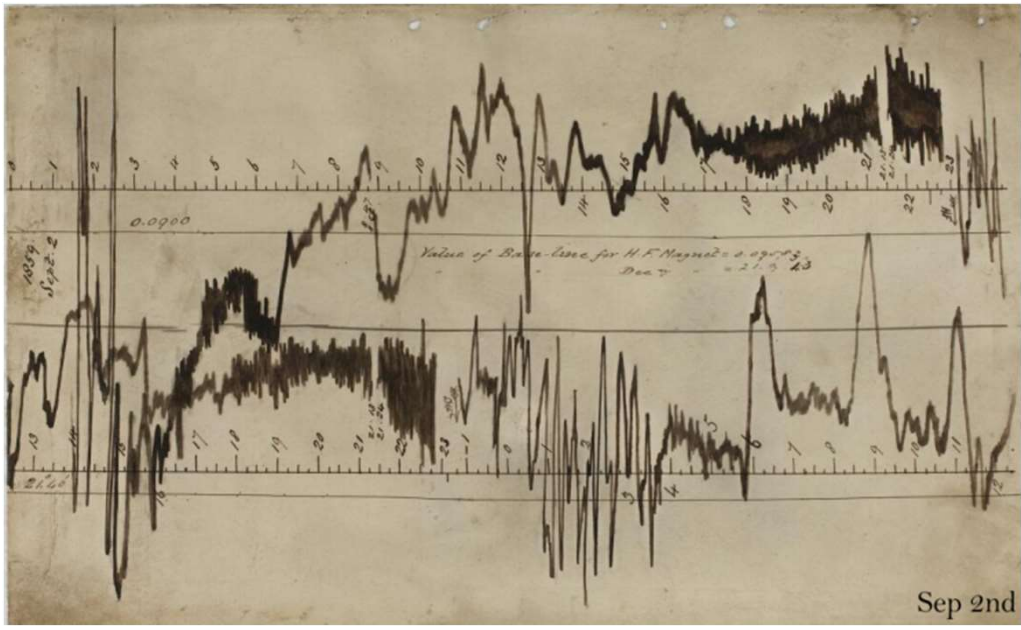




Big magnetic storms

- Largest recorded event is the ‘Carrington storm’ in September 1859



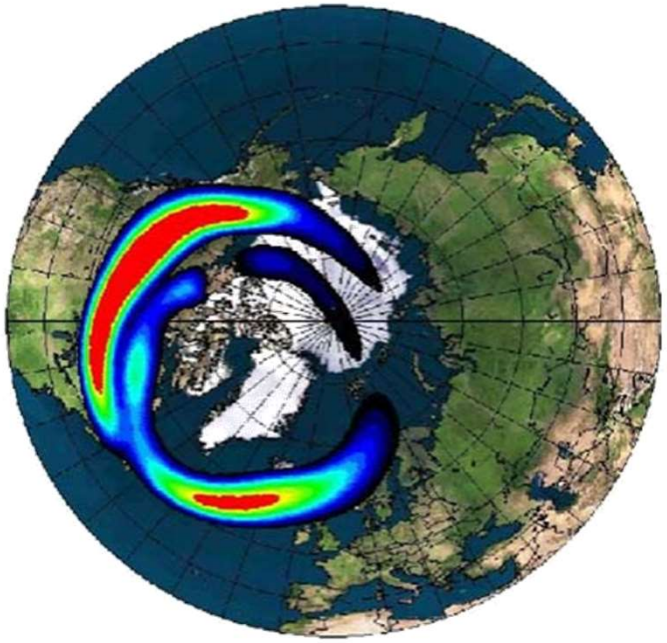


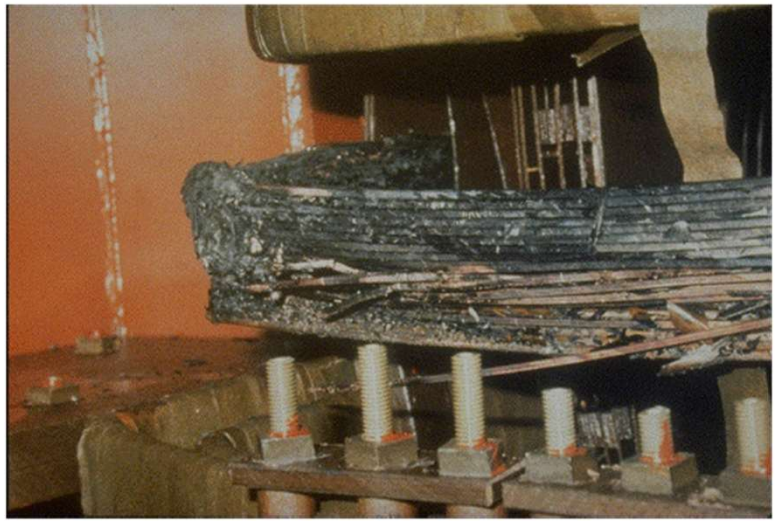
- There were reports of aurora sightings as far south as Cuba and Hawaii
- Telegraph systems sparked and failed and even started fires

What hazard does that pose?

- Not a hazard to humans directly

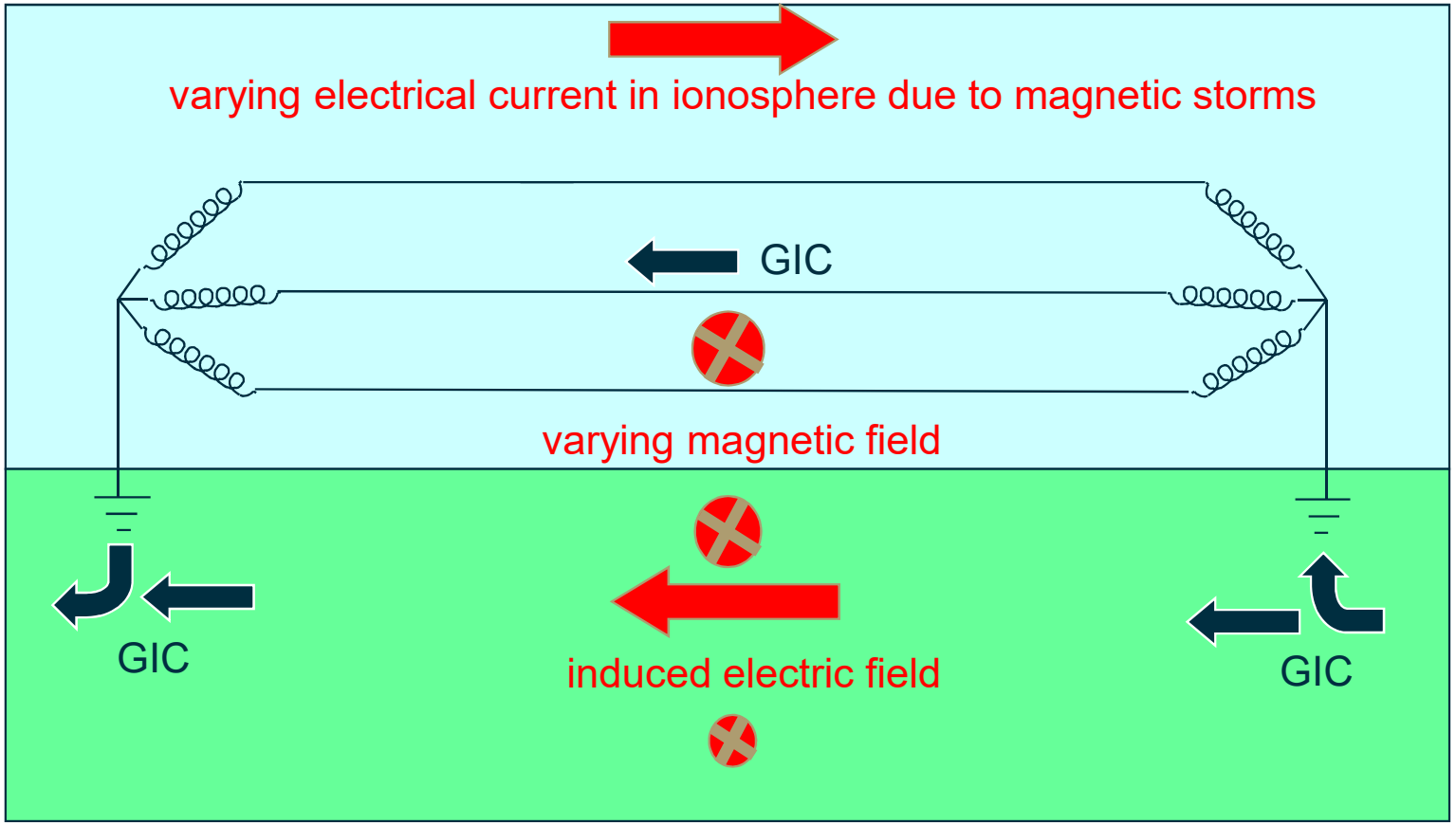
- During a geomagnetic storm an electric field can be induced in the ground
- This causes currents to flow in ground-based infrastructure, including:
  - Power networks
  - Pipelines
  - Railways
  - Communication cables





Research

Geomagnetically induced currents (GIC) in power networks



Modelling GIC

- Continuous measurements of magnetic fields at 3 UK (and 6 overseas) observatories
- Several variometers (School's magnetometer project and SWIGS)
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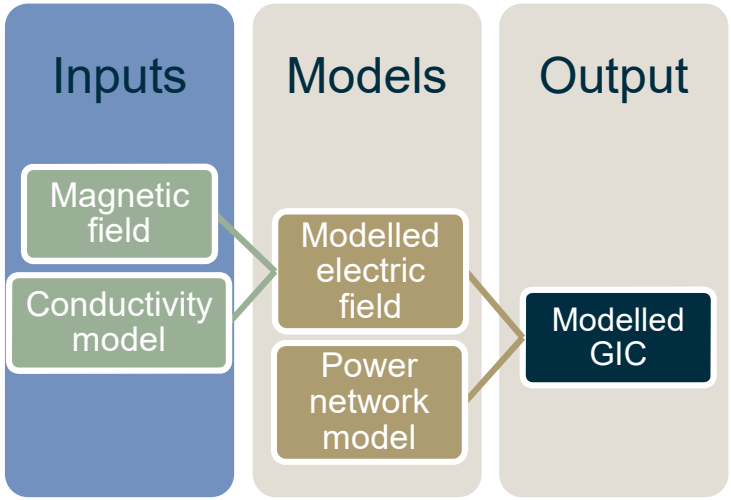
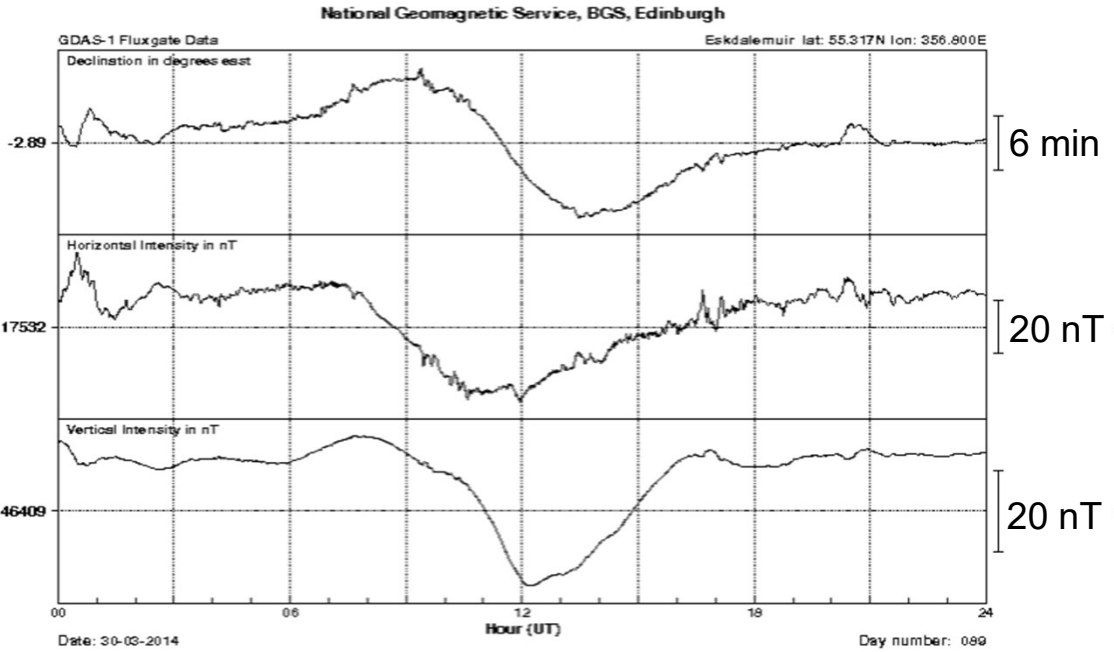
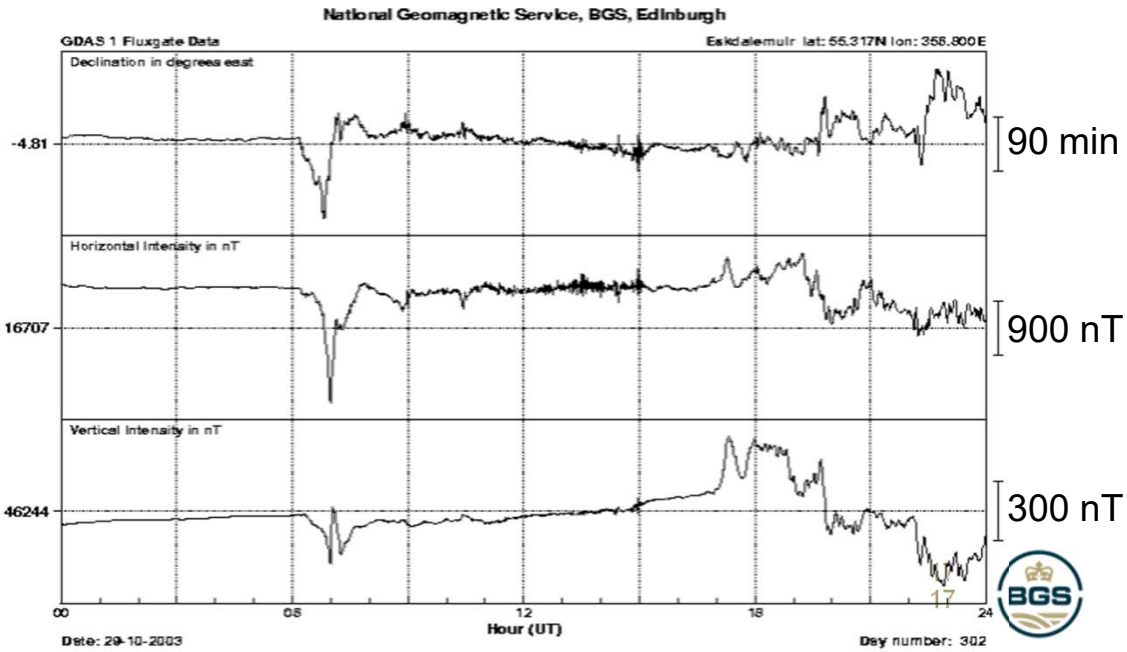
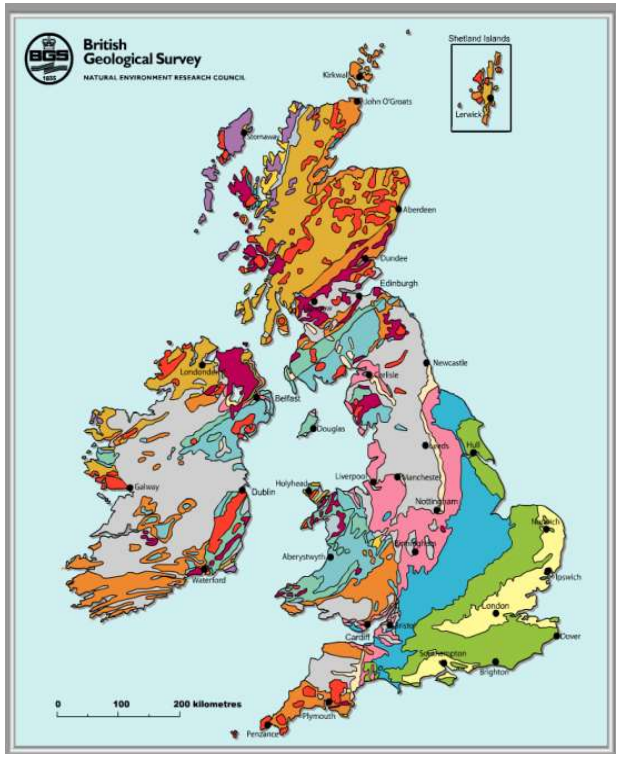


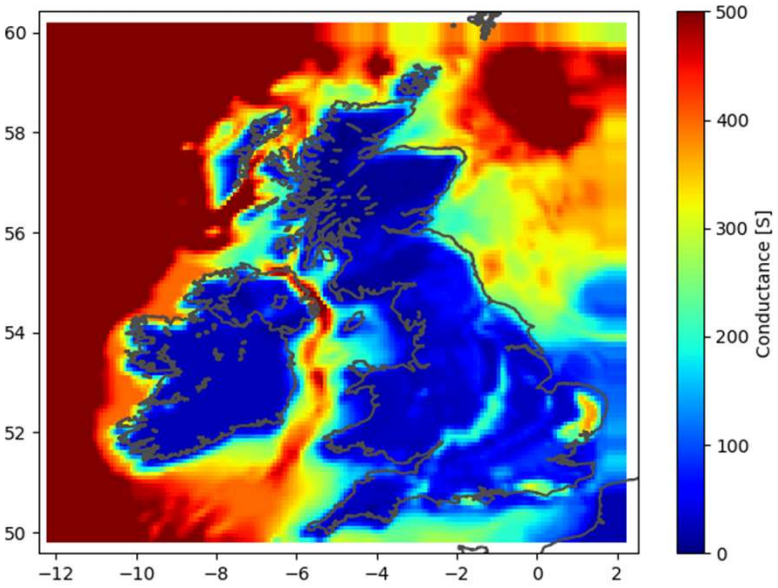


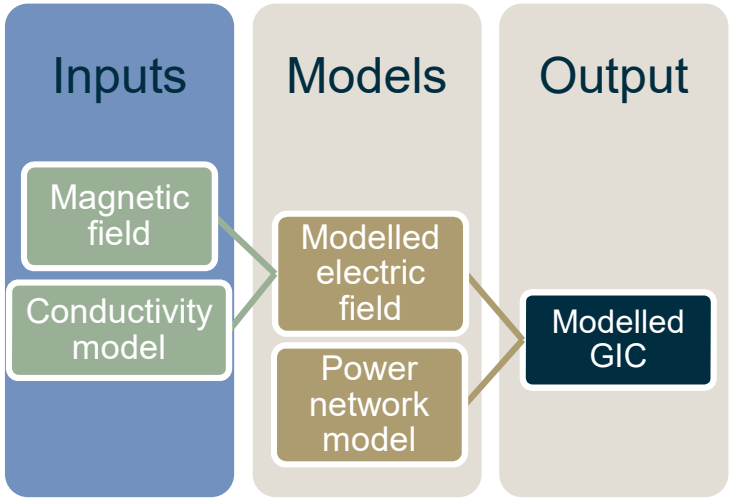


Modelling GIC

- Model the conductivity structure of the UK based on 1:625000 map of bedrock geology

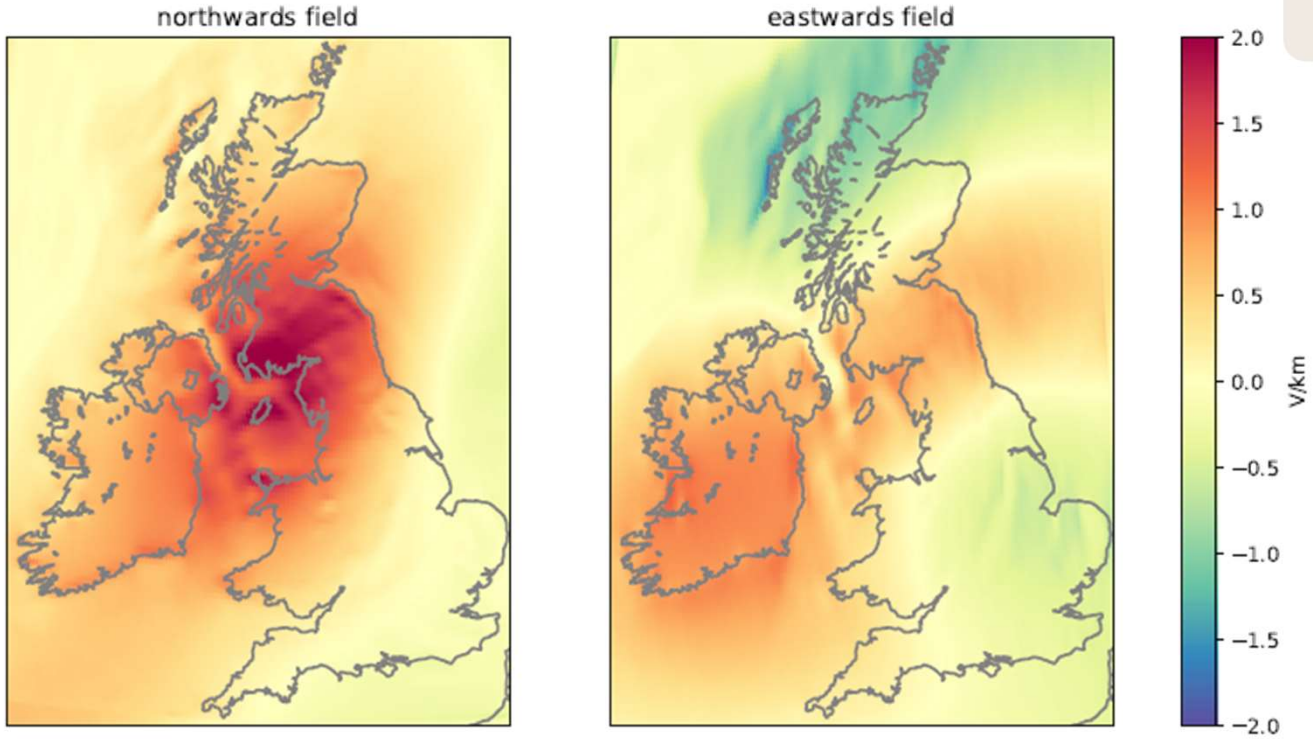


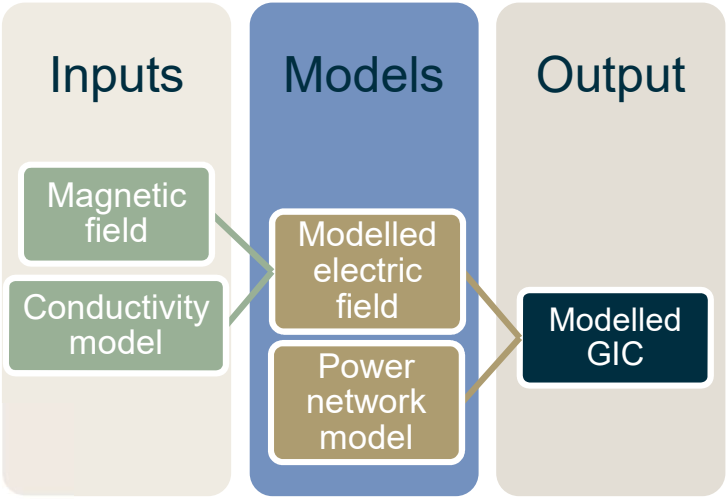




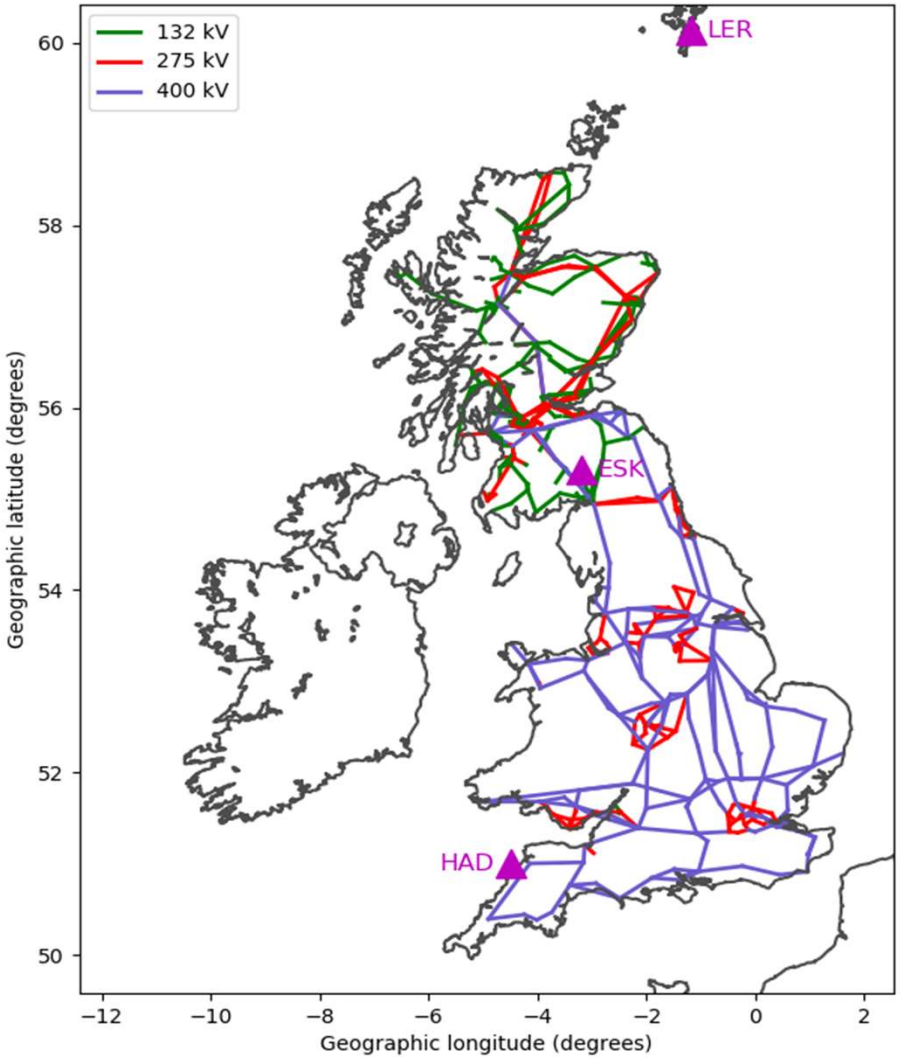
Modelling GIC

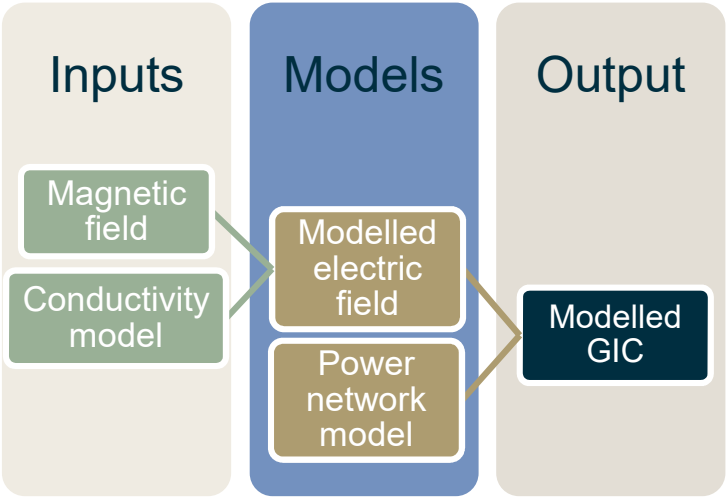
- ‘Thin Sheet’ modelling used to convert magnetic field changes to electric field induced in the ground





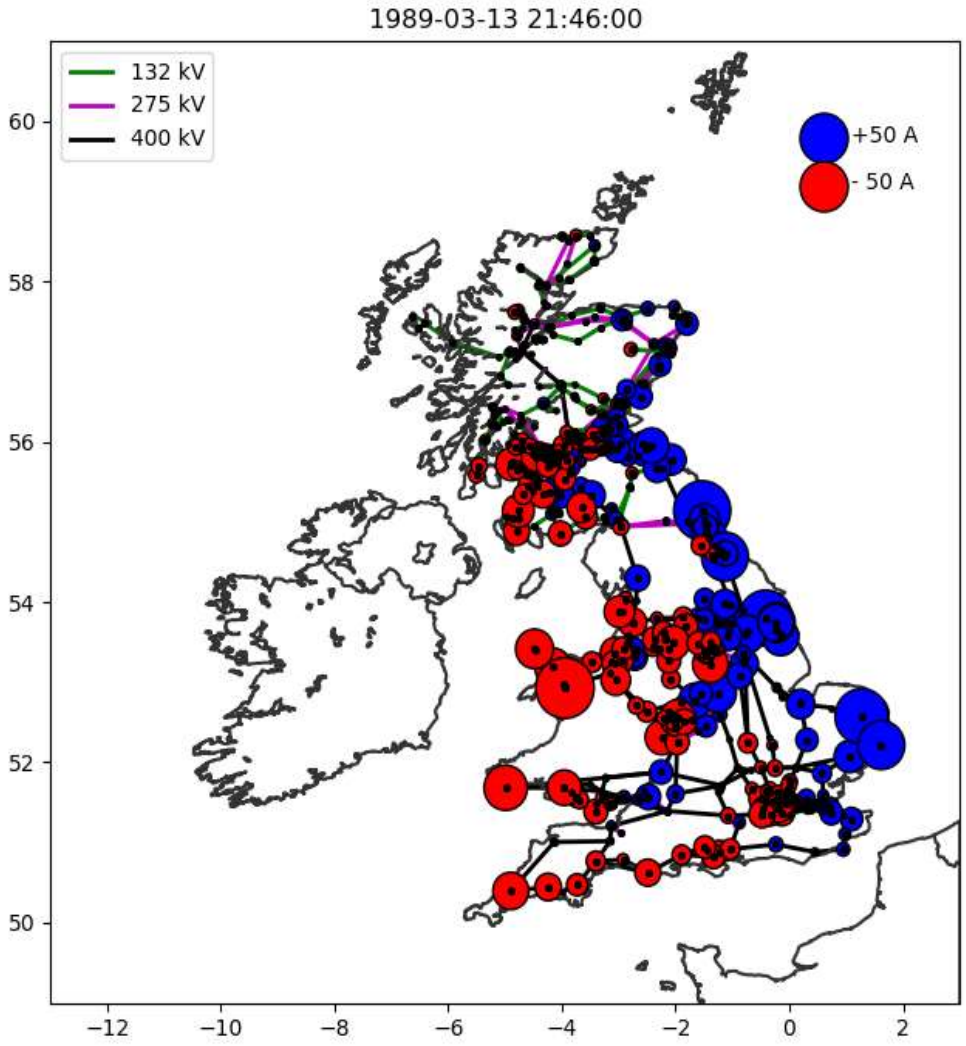
Modelling GIC

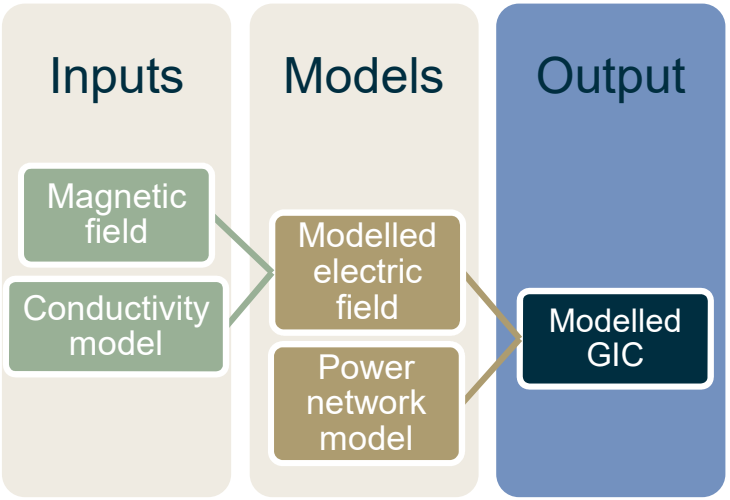




- Model of the UK power transmission network

Modelling GIC





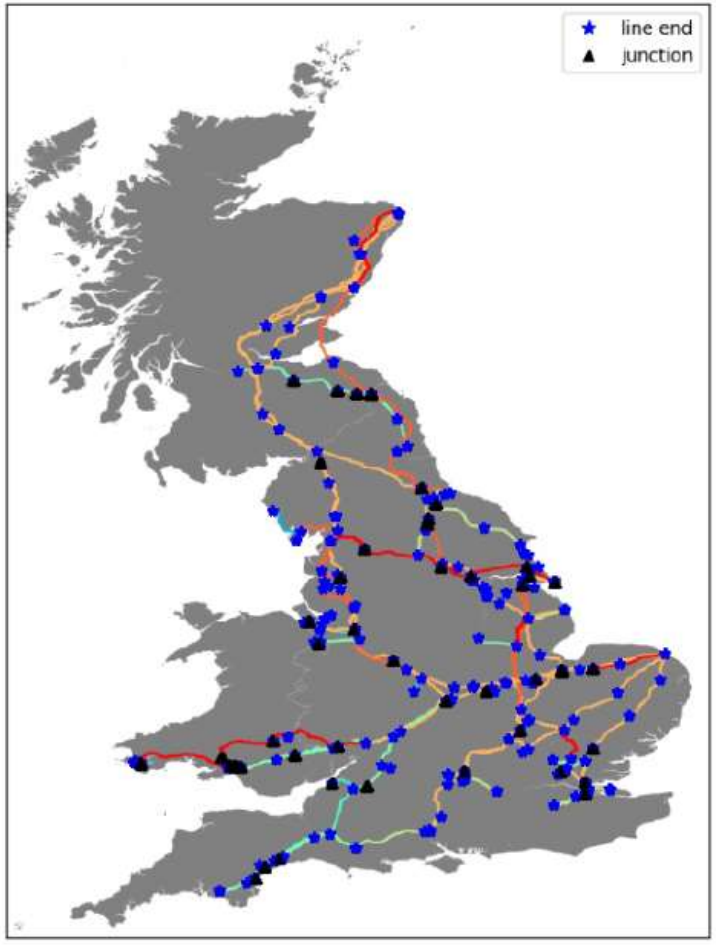
- Modelled electric field combined with the network model to calculate GIC at each substation and in the power lines

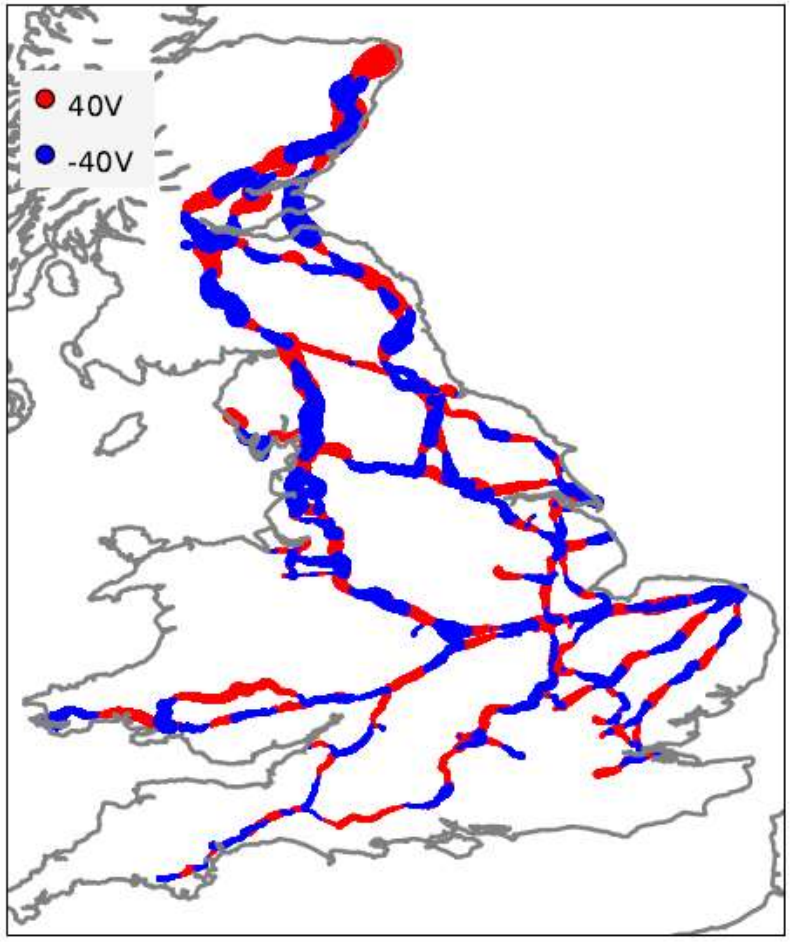
Pipelines

- Induced electric fields due to space weather also affect gas transmission pipeline networks
  - Pipelines are buried and prone to corrosion
  - Difference in potential between ground and pipe needs to be maintained at a specific level to prevent corrosion
- Modelling process very similar to GIC

Rosemary Oakeshott - *Gas pipeline internment*
CC BY-SA 2.0

Modelling Pipe-to-soil Potentials

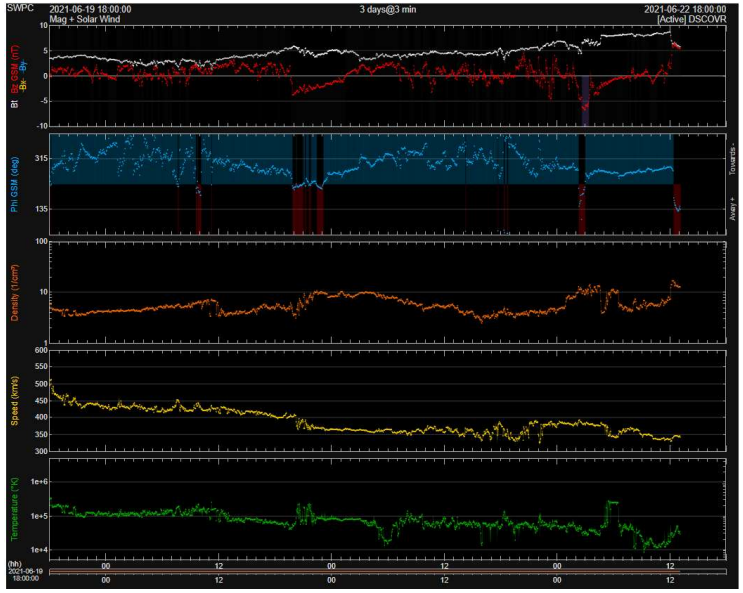


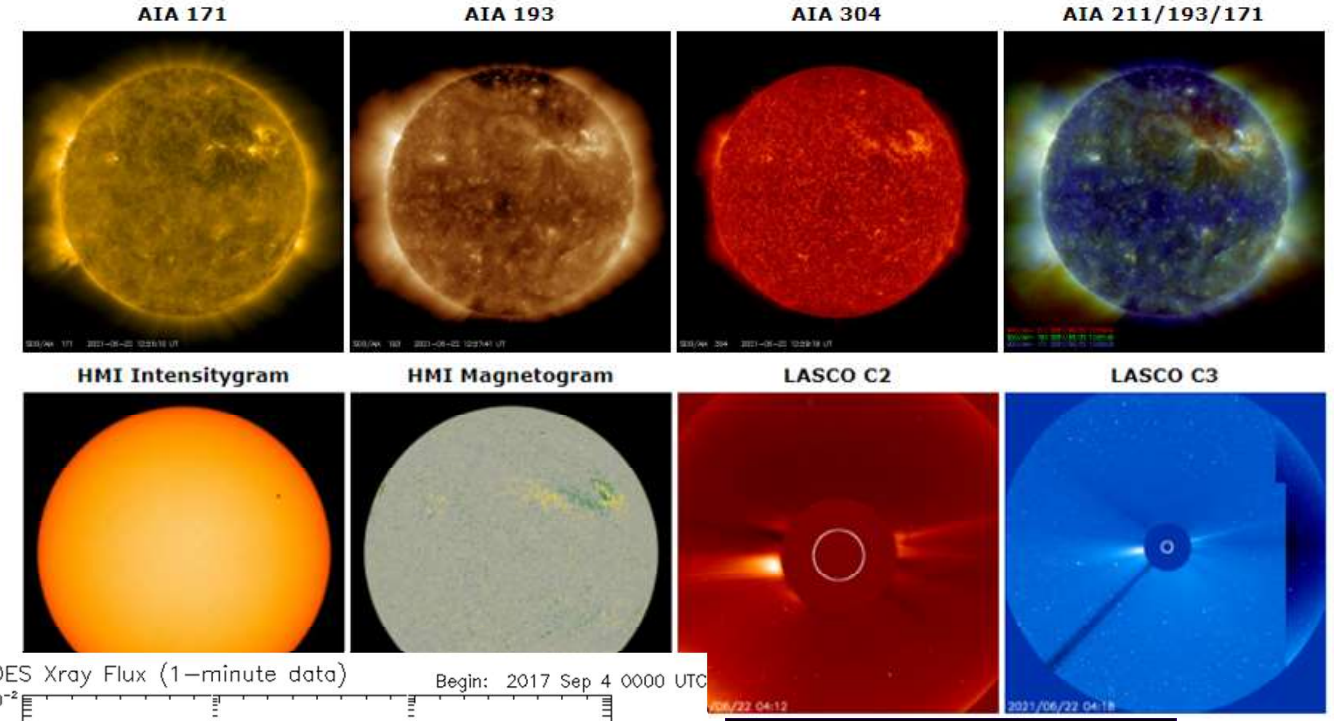


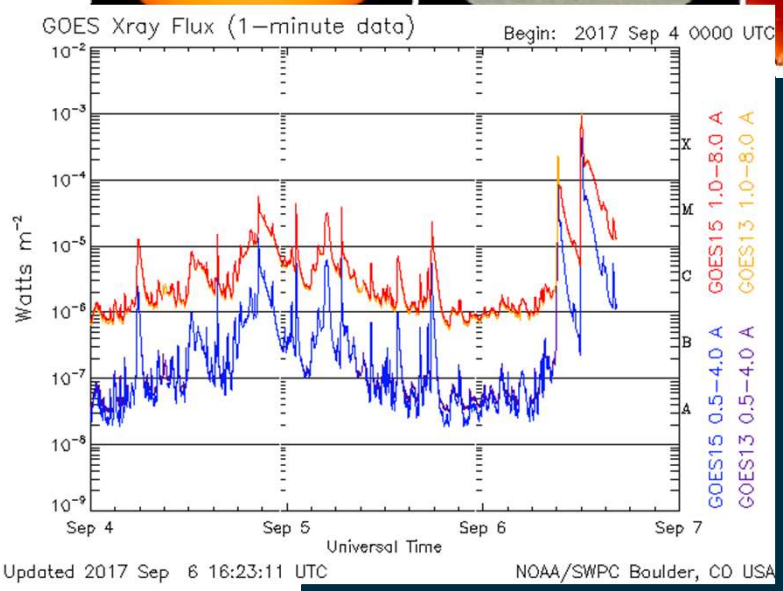
Space weather forecasting & services

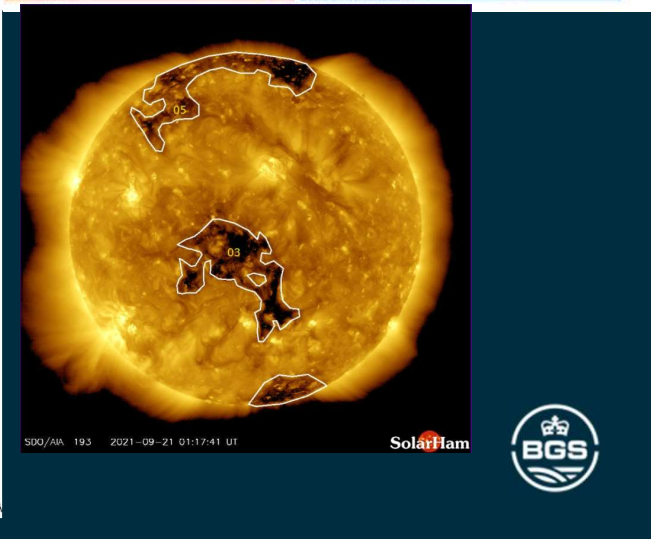
Monitoring the Sun

- Now have several satellites continuously monitoring the Sun (e.g. SOHO, SDO, DSCOVR, GOES)
- And several 24/7 operational space weather centres (e.g. Met Office in the UK)





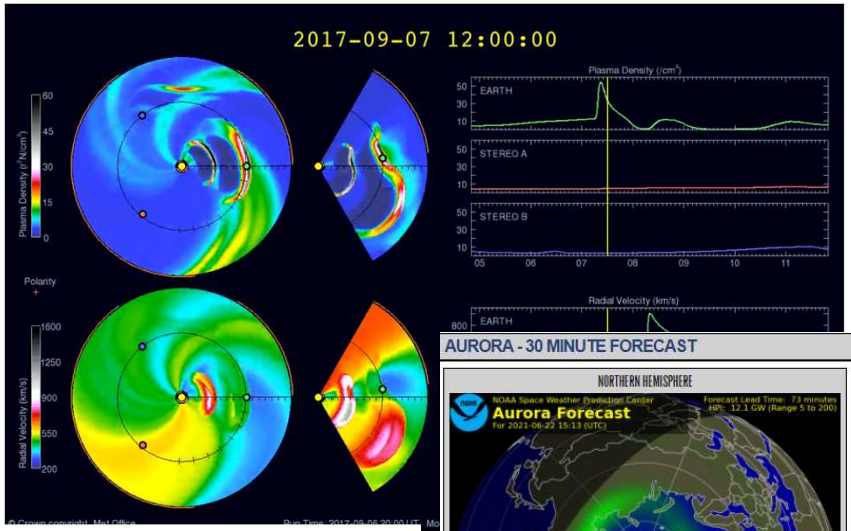


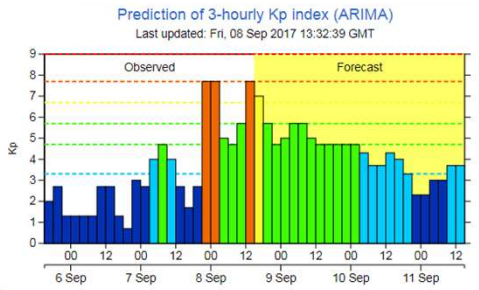


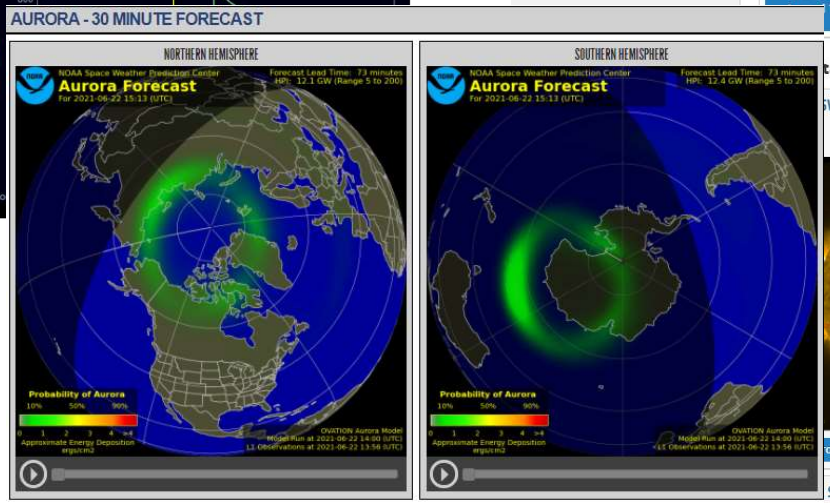
FORECASTING SPACE WEATHER

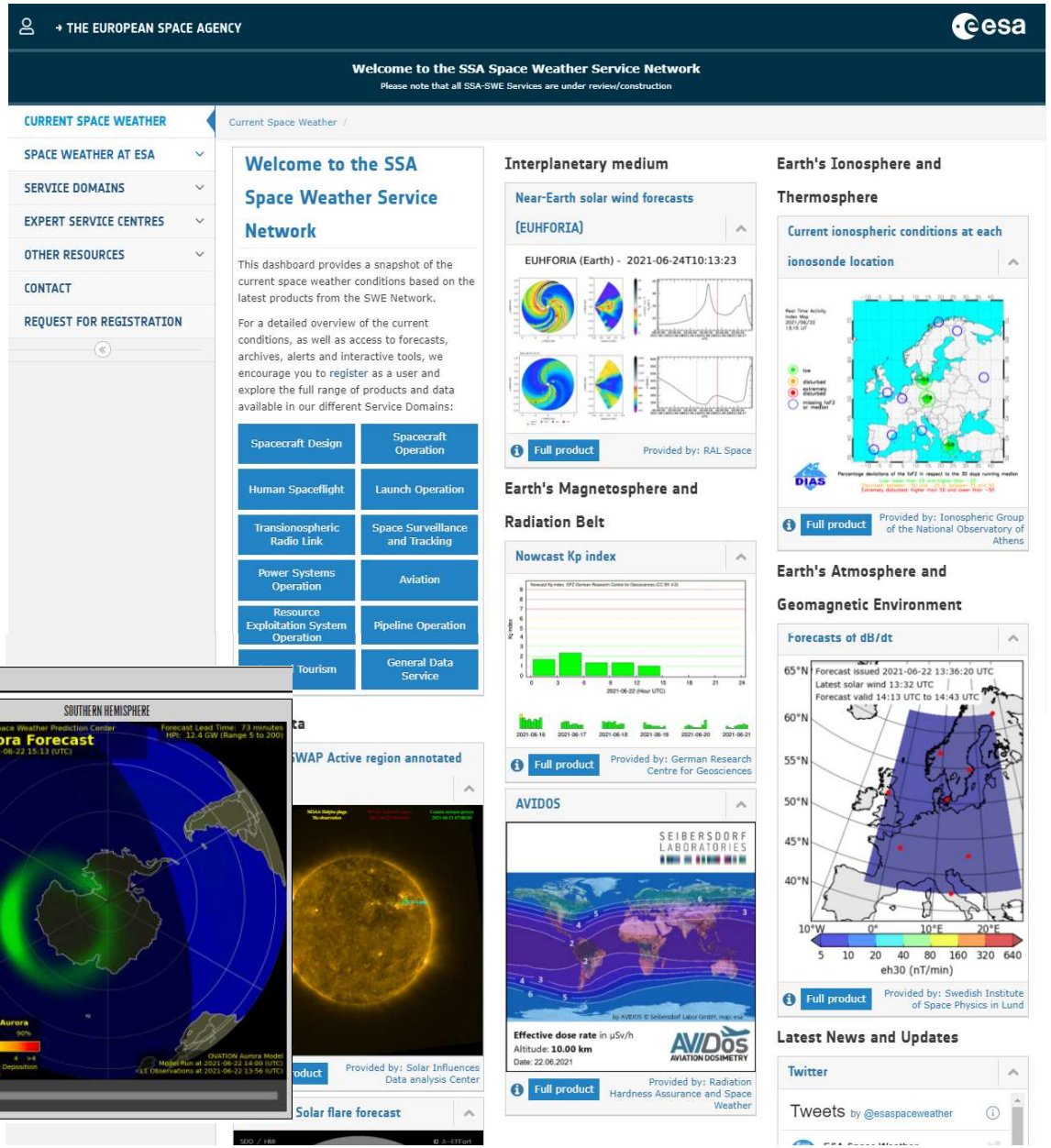
Monitoring the Sun

- Ever growing suite of data and models available in near-real-time



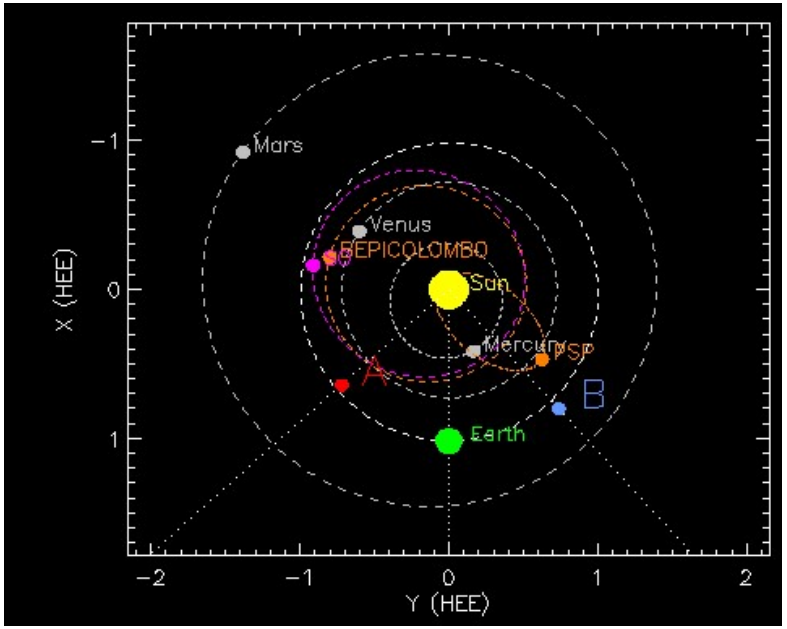






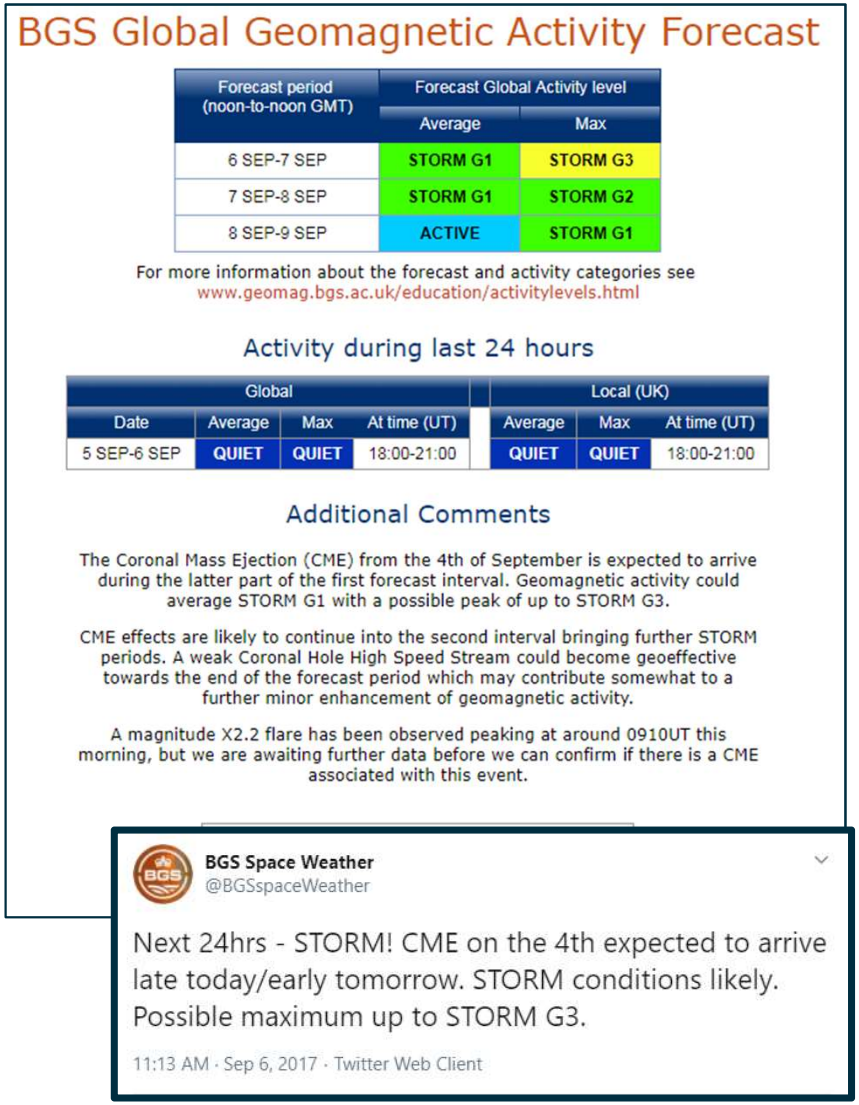
Problems in forecasting

- Limited data:
  - Almost all data sources are either at Earth or on the Sun-Earth line
- Fast CMEs:
  - Generally the most damaging CMEs are also the fastest, so provide the least warning
- Forecasts:
  - Currently most data forecasts are only accurate up to around an hour ahead



Space weather forecasts

- 3-day ahead space weather forecast
  - tinyurl.com/BGSforc
  - @BGSSpaceWeather



BGS Global Geomagnetic Activity Forecast

Forecast period (noon-to-noon GMT)	Forecast Global Activity level	
	Average	Max
6 SEP-7 SEP	STORM G1	STORM G3
7 SEP-8 SEP	STORM G1	STORM G2
8 SEP-9 SEP	ACTIVE	STORM G1

For more information about the forecast and activity categories see
www.geomag.bgs.ac.uk/education/activitylevels.html

Activity during last 24 hours

Global				Local (UK)		
Date	Average	Max	At time (UT)	Average	Max	At time (UT)
5 SEP-6 SEP	QUIET	QUIET	18:00-21:00	QUIET	QUIET	18:00-21:00

Additional Comments

The Coronal Mass Ejection (CME) from the 4th of September is expected to arrive during the latter part of the first forecast interval. Geomagnetic activity could average STORM G1 with a possible peak of up to STORM G3.

CME effects are likely to continue into the second interval bringing further STORM periods. A weak Coronal Hole High Speed Stream could become geoeffective towards the end of the forecast period which may contribute somewhat to a further minor enhancement of geomagnetic activity.

A magnitude X2.2 flare has been observed peaking at around 0910UT this morning, but we are awaiting further data before we can confirm if there is a CME associated with this event.

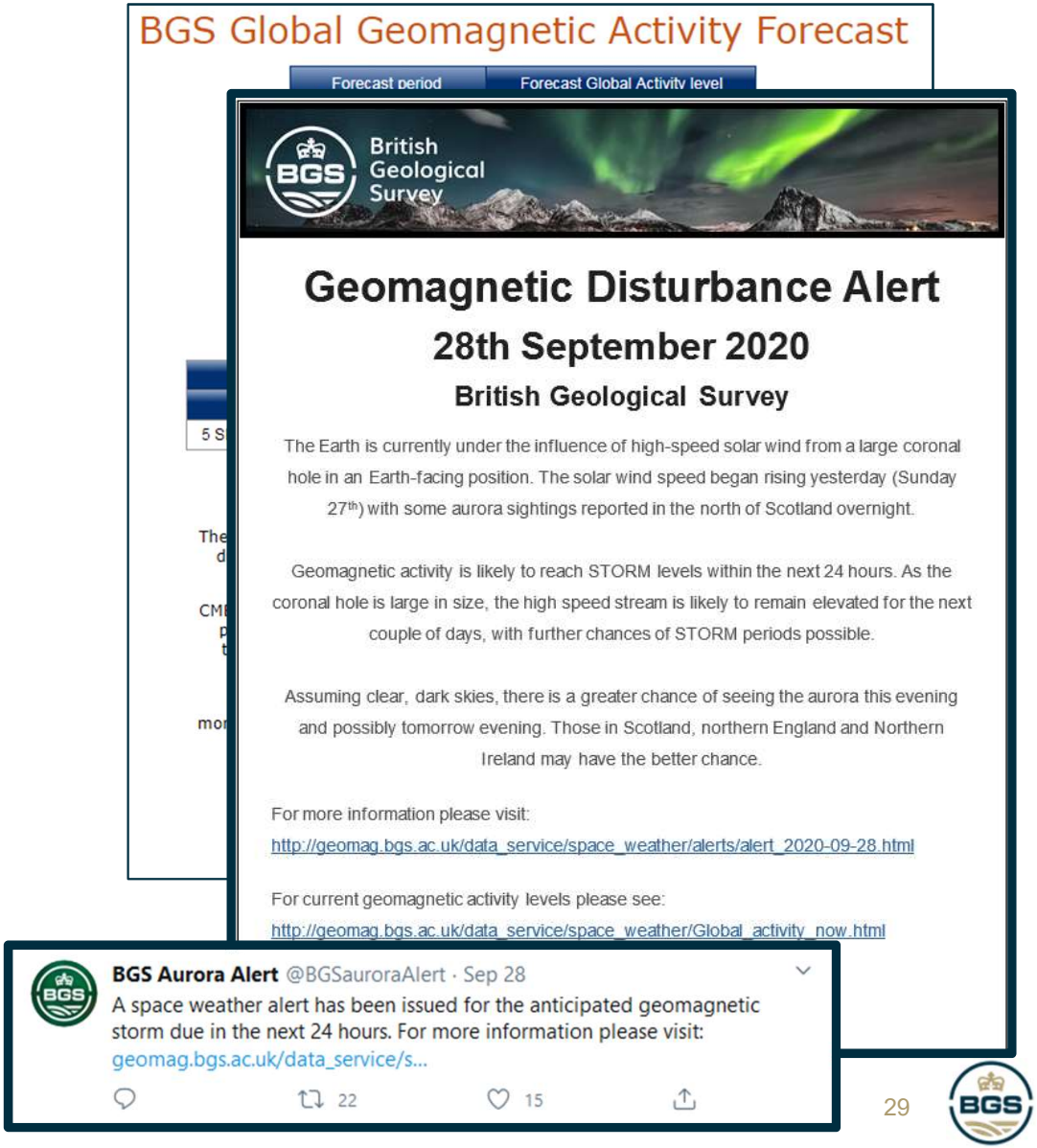
BGS Space Weather
@BGSspaceWeather

Next 24hrs - STORM! CME on the 4th expected to arrive late today/early tomorrow. STORM conditions likely. Possible maximum up to STORM G3.

11:13 AM · Sep 6, 2017 · Twitter Web Client

Space weather forecasts

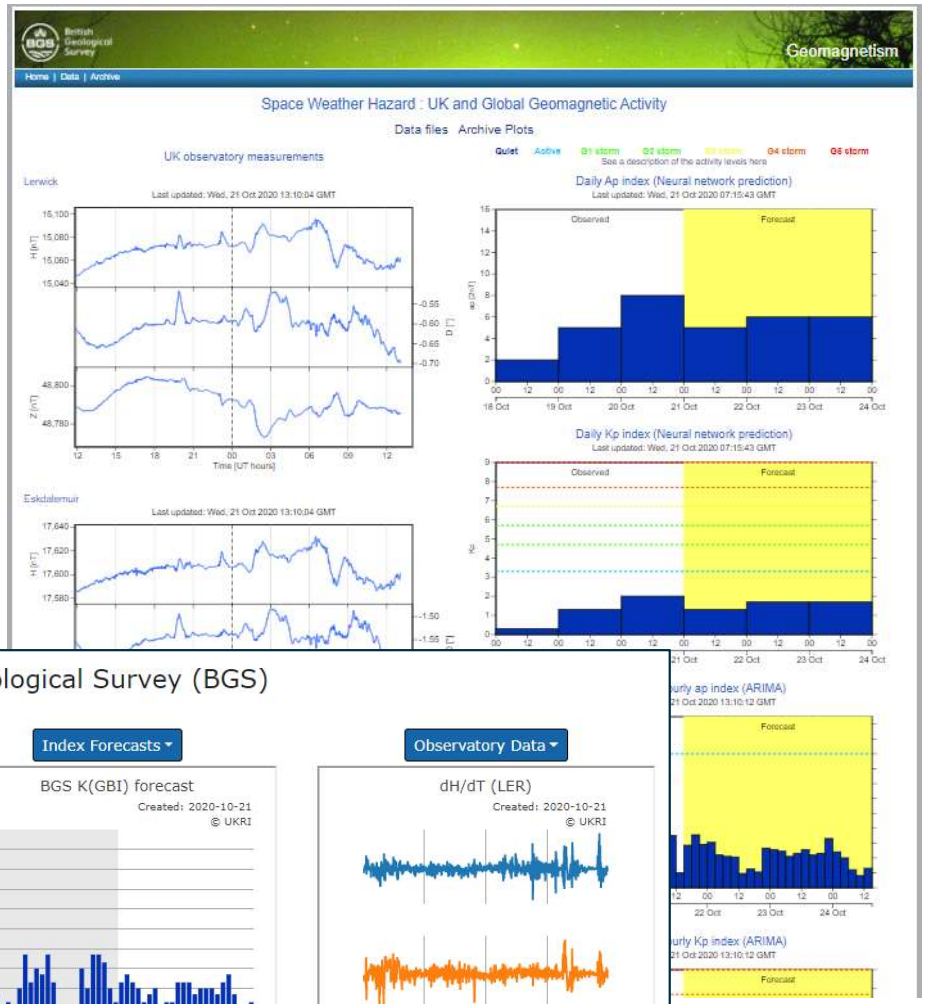
- 3-day ahead space weather forecast
  - tinyurl.com/BGSforc
  - @BGSSpaceWeather
  - Alert service @BGSAuroraAlert

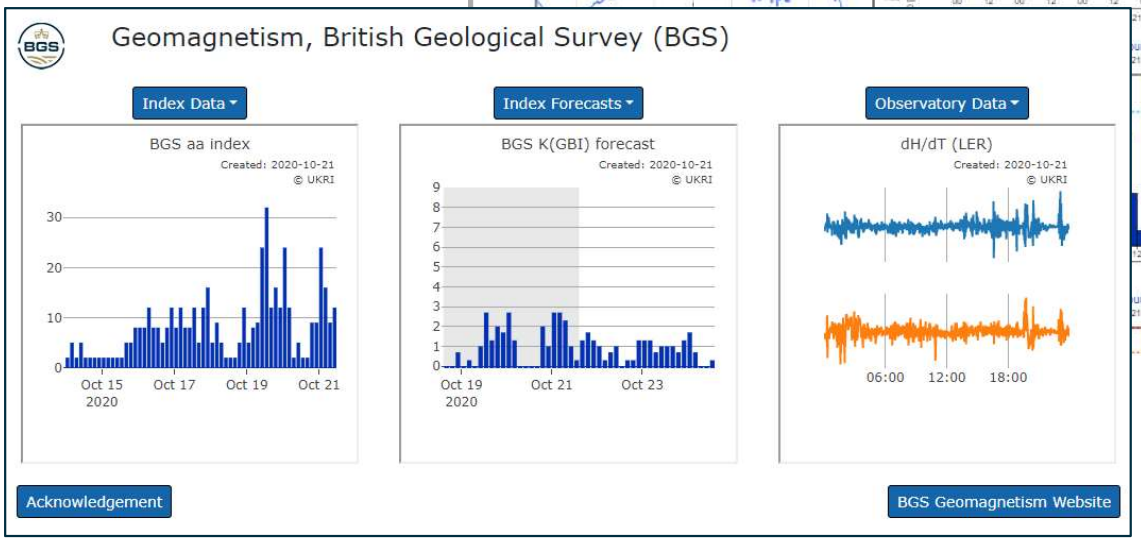


Space weather operations

- Real-time monitoring of GIC for National Grid
- Met Office partnership
- ESA SWE portal

- We provide:
  - Observatory data
  - Geomagnetic indices
  - Index forecasts





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Data and Services

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- Models & Compass Variation
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  - Solar & Geomagnetic Data
  - Solar & Geomagnetic Forecasts
  - Geomagnetic Pulsations
  - Geoelectric Field
  - Space Weather Alerts
  - *Current conditions*
  - Geomagnetically Induced Currents
  - Geomagnetic Coordinate Calculator
- Directional Drilling
- INTERMAGNET software

Current **Global** Geomagnetic Activity

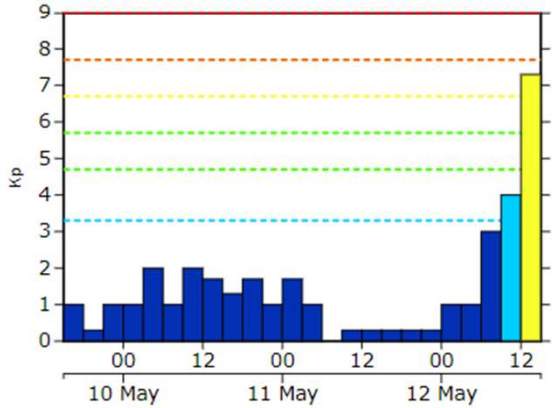
The dark red box indicates the current level of activity, with storm periods best for being able to see the aurora. The storm ratings range from G1 to G5 and the higher the number the better that chance for aurora viewing.

Description of the categories | More plots of current activity | 3-day forecast of geomagnetic activity

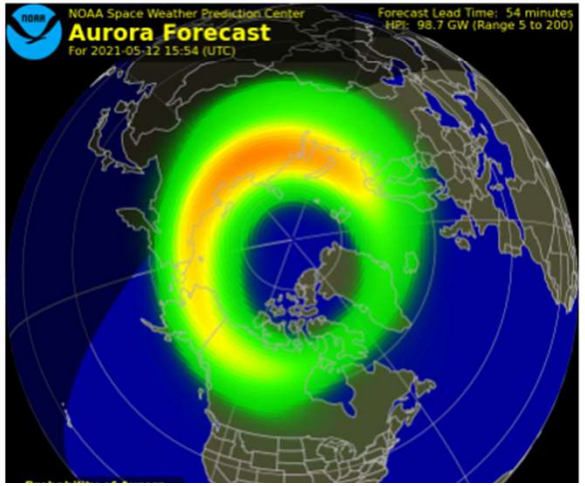
Click here to see a twitter map showing recent sightings, cloud cover and activity at the UK observatories

Global Geomagnetic activity in the last 72 hours

Last updated: Wed, 12 May 2021 15:00:15 GMT



Model of the current position of the aurora oval



tinyurl.com/BGSSWx

Summary

- Space weather can have wide-ranging impacts on technology
- Affects are global and affect many technologies at once
- Models of the geoelectric field, Induced Currents and Pipe-to-soil potentials are helping us understand and mitigate the risk
- Forecasting space weather is key to reducing the impacts
  - Improving all the time
  - But there are still challenges

THANK YOU FOR LISTENING

Any questions?