



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

# Space weather and its impact on grounded technological infrastructure



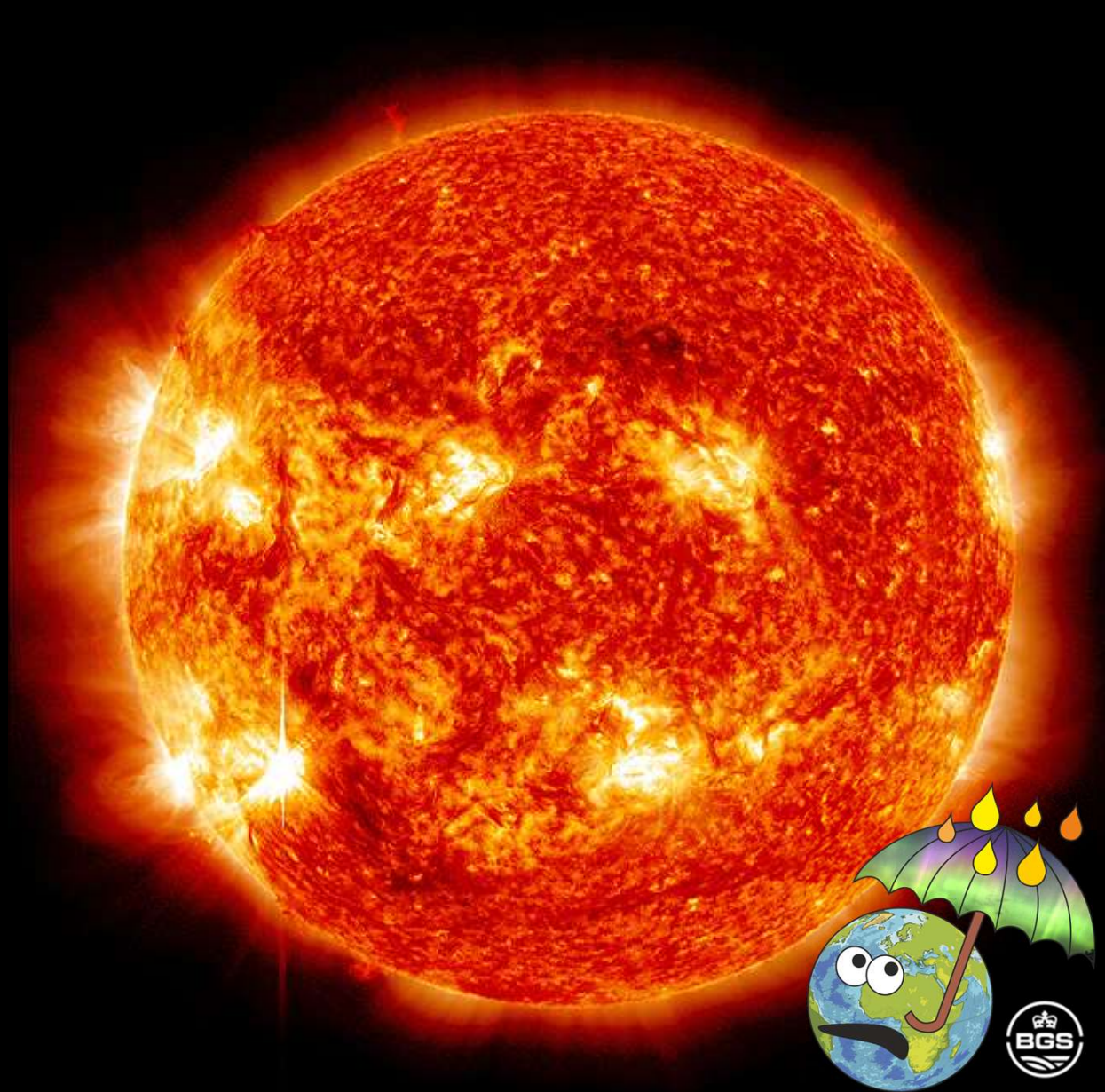
# Talk overview

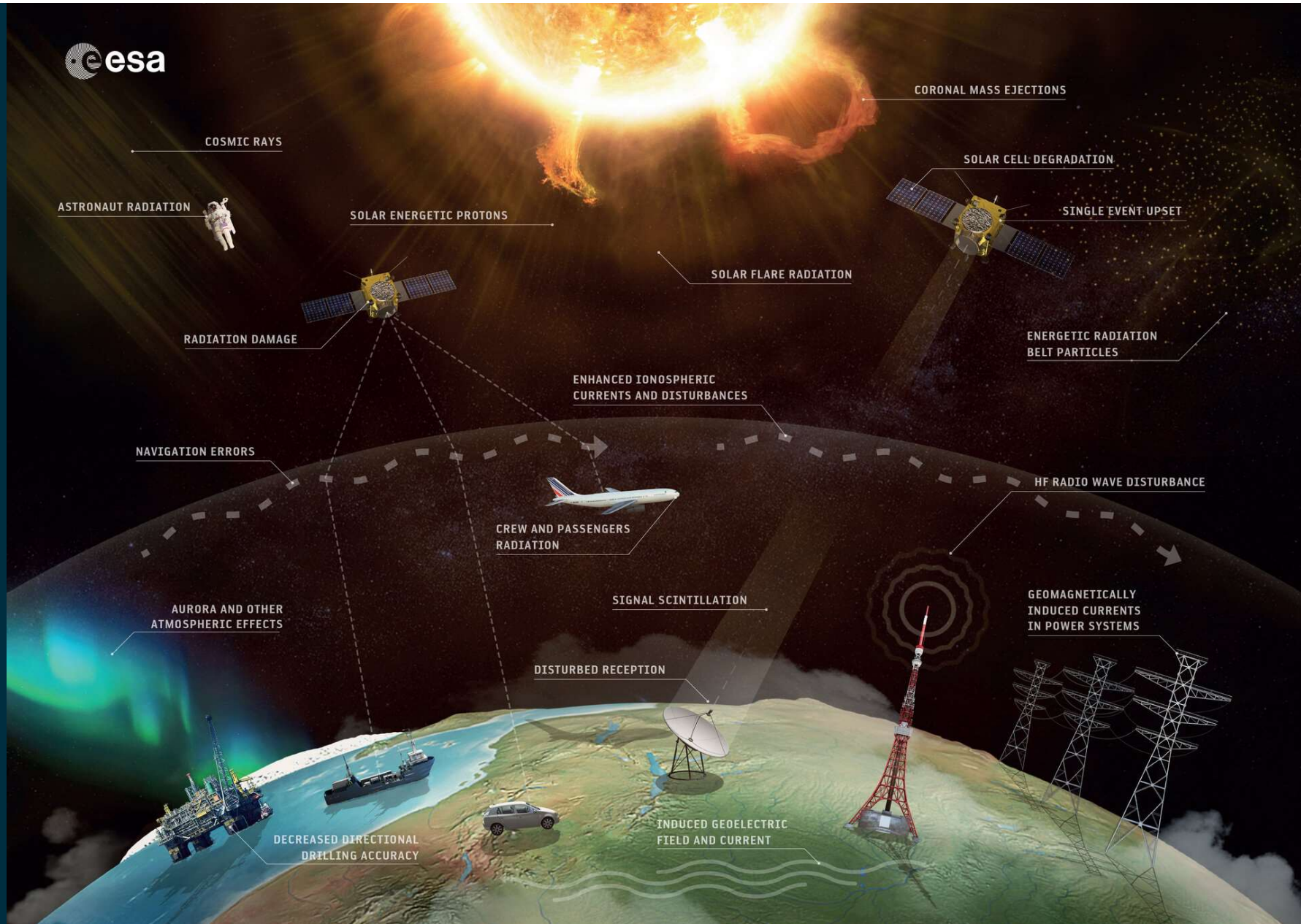
- Intro to space weather
  - What is it?
  - Why is it a hazard?
- Research into effects on grounded infrastructure
- Forecasting and space weather services at BGS
- Summary



# What is Space weather?

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





# 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

Impact <small>(of the reasonable worst case scenario using the impact indicators below)</small>	Level E		7 25†			
	Level D	34*	12 13 29			
	Level C	18 28 33* 36*	14 19 21 26† 27* 38	2 3 6* 15 16 17 20		
	Level B	30	24	35*	4 5 9* 10* 11* 23 32* 37	1
	Level A		8* 22	31		
		< 1 in 500	1 to 5 in 500	5 to 25 in 500	25 to 125 in 500	> 125 in 500
	<b>Likelihood</b> <small>(of the reasonable worst case scenario of the risk occurring in the next year)</small>					

\*Risk not plotted in the 2017 NRR | †COVID-19 is not included in the risk matrix and is therefore not included in these risks

### Malicious Attacks

- Attacks on publicly accessible locations
- Attacks on infrastructure
- Attacks on transport
- Cyber attacks
- Smaller scale CBRN attacks
- Medium scale CBRN attacks
- Larger scale CBRN attacks
- Undermining the democratic process\*

### Serious and Organised Crime

- Serious and organised crime – vulnerabilities\*
- Serious and organised crime – prosperity\*
- Serious and organised crime – commodities\*

### Environmental Hazards

- Coastal flooding
- River flooding
- Surface water flooding
- Storms
- Low temperatures
- Heatwaves
- Droughts
- Severe space weather
- Volcanic eruptions
- Poor air quality
- Earthquakes
- Environmental disasters overseas
- Wildfires

### Human and Animal Health

- Pandemics†
- High consequence infectious disease outbreaks†
- Antimicrobial resistance\*
- Animal diseases

### Major Accidents

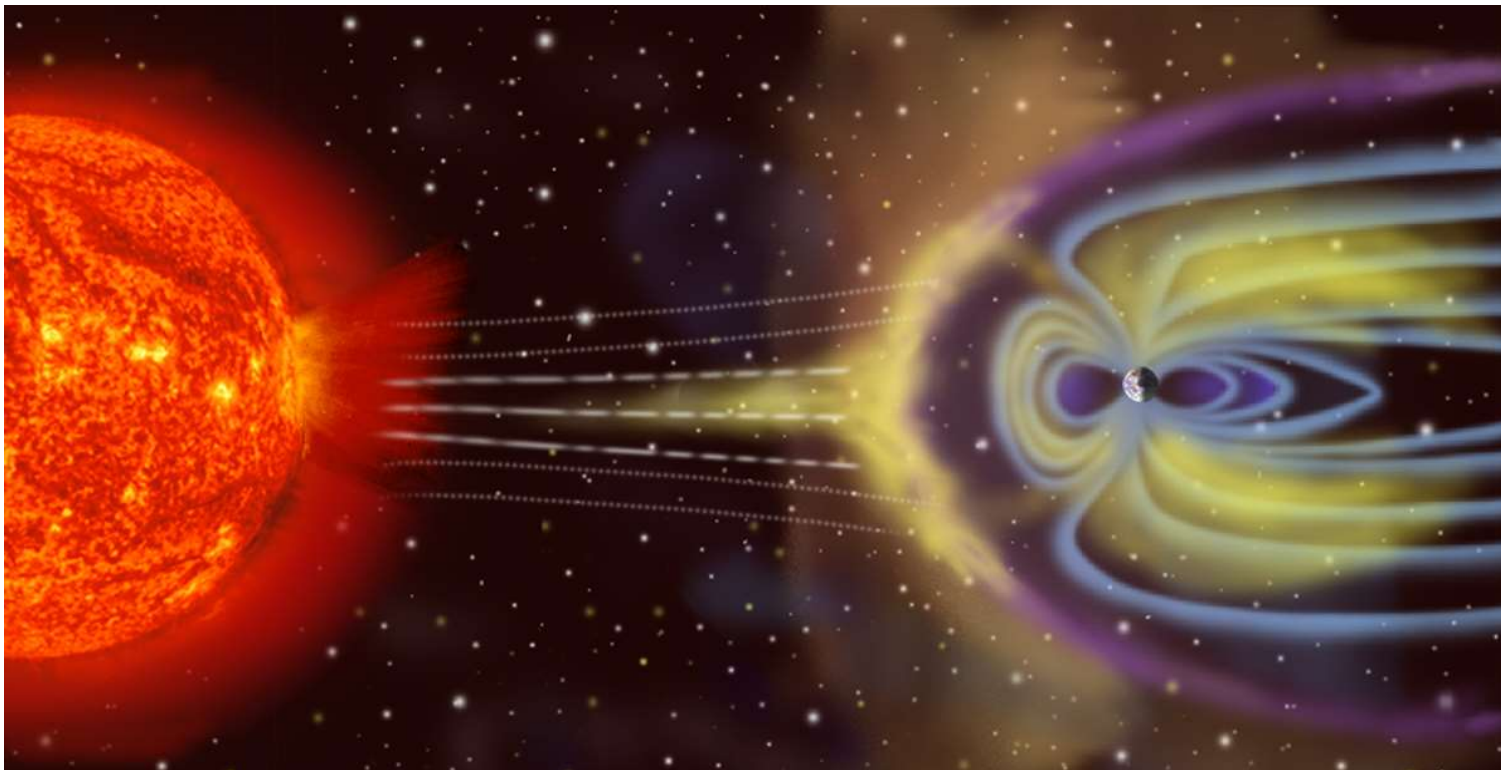
- Widespread electricity failures
- Major transport accidents
- System failures
- Commercial failures\*
- Systematic financial crisis\*
- Industrial accidents – nuclear\*
- Industrial accidents - non nuclear\*
- Major fires\*

### Societal Risks

- Industrial action
- Widespread public disorder

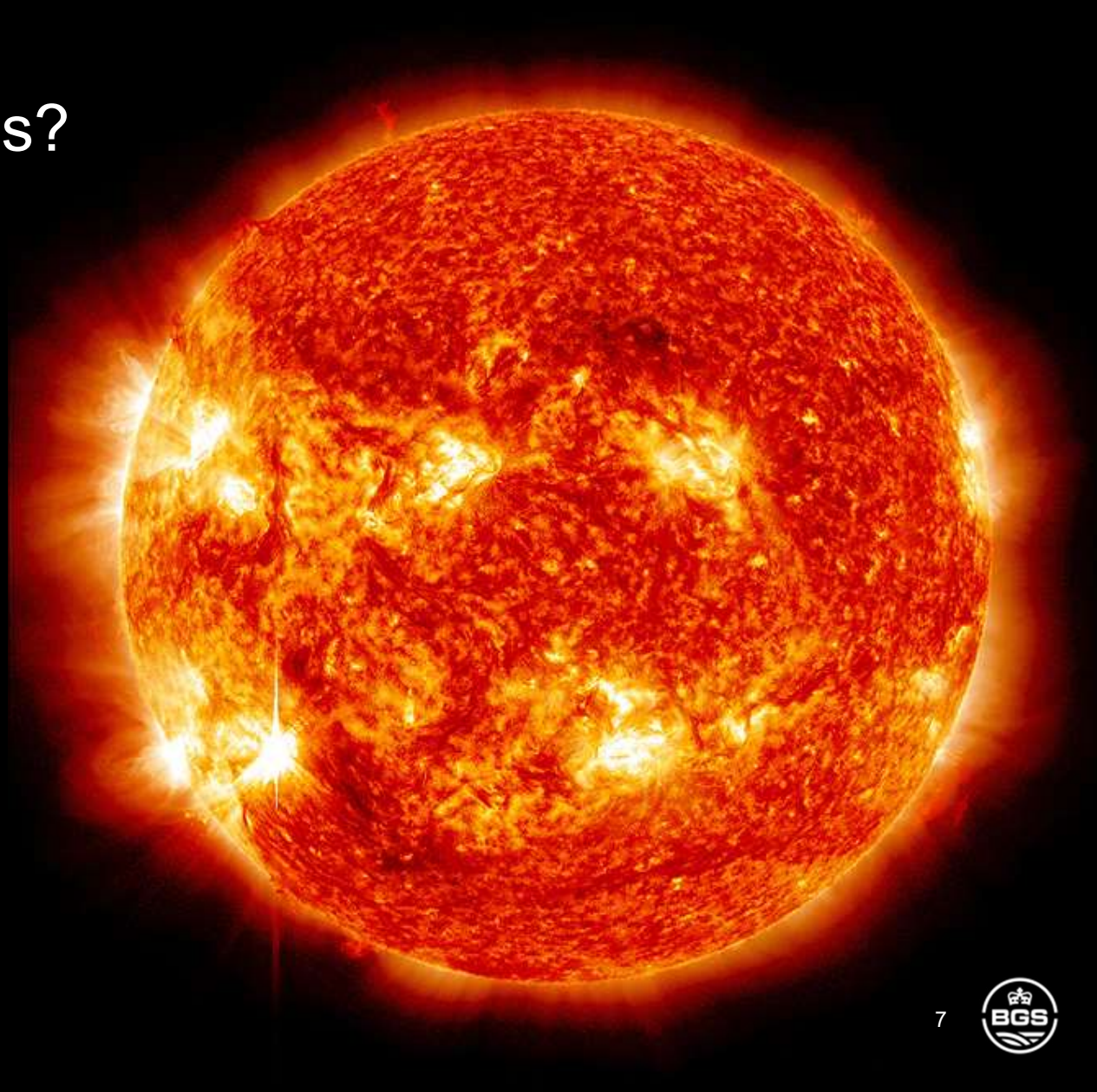
# Solar wind

- 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



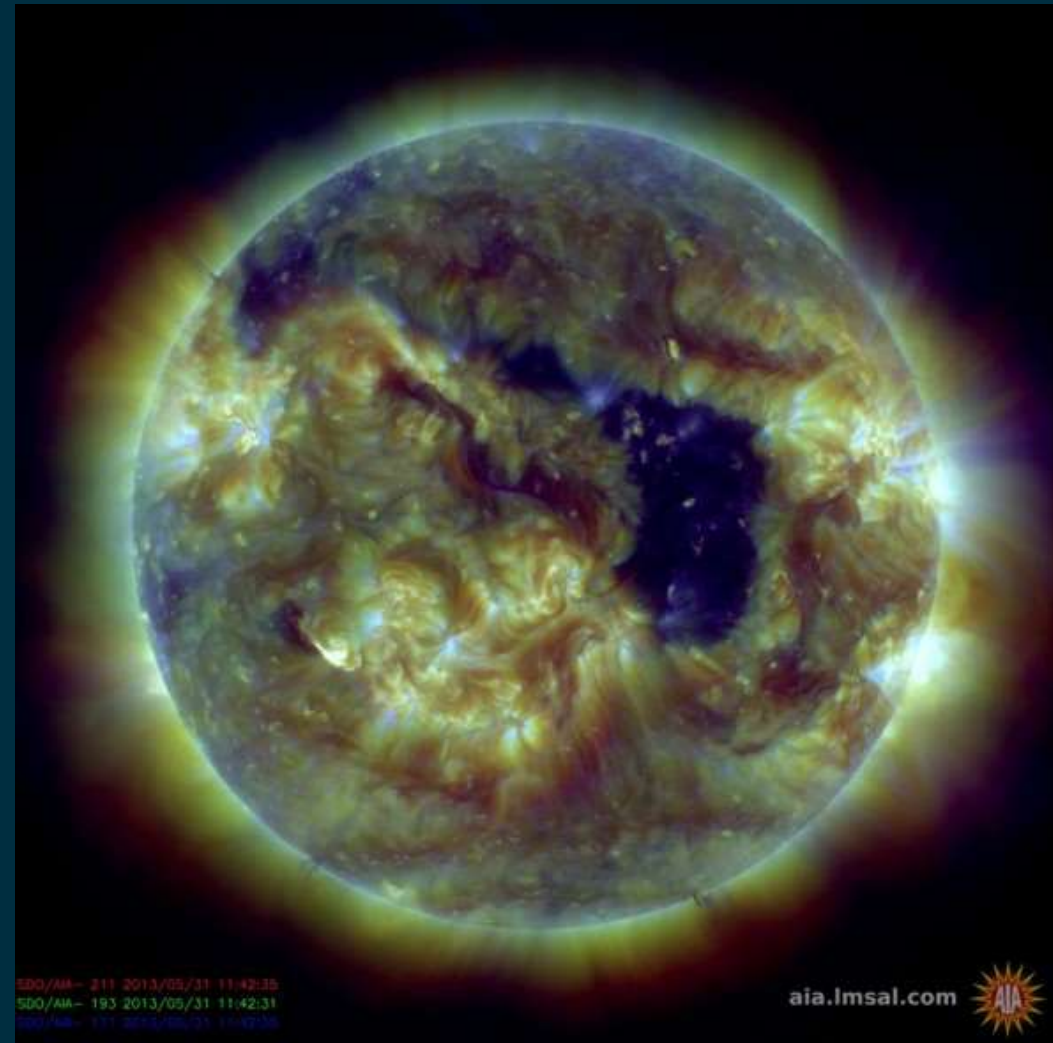
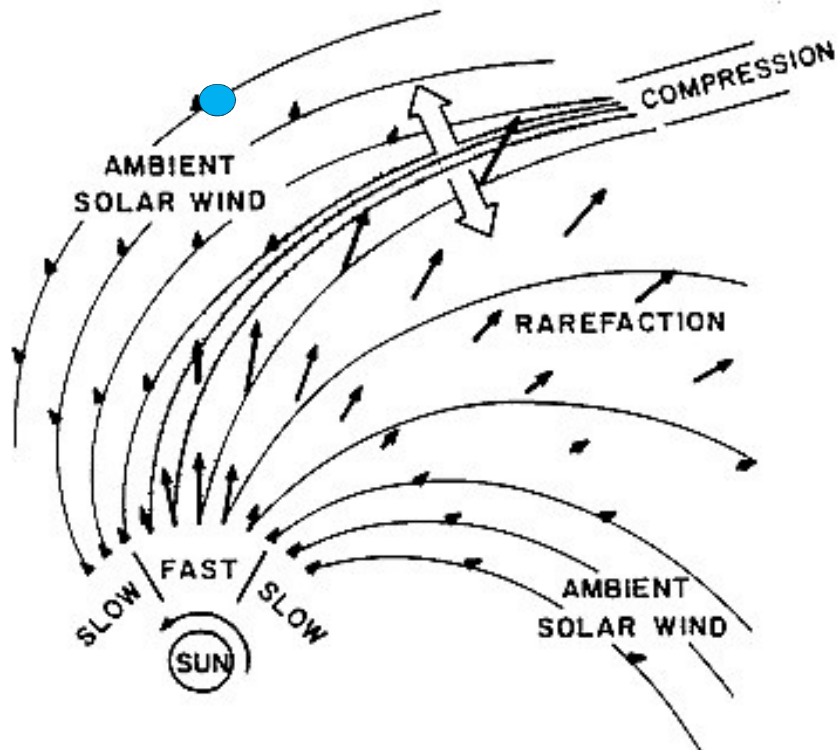
# What causes disturbances?

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



# Coronal holes

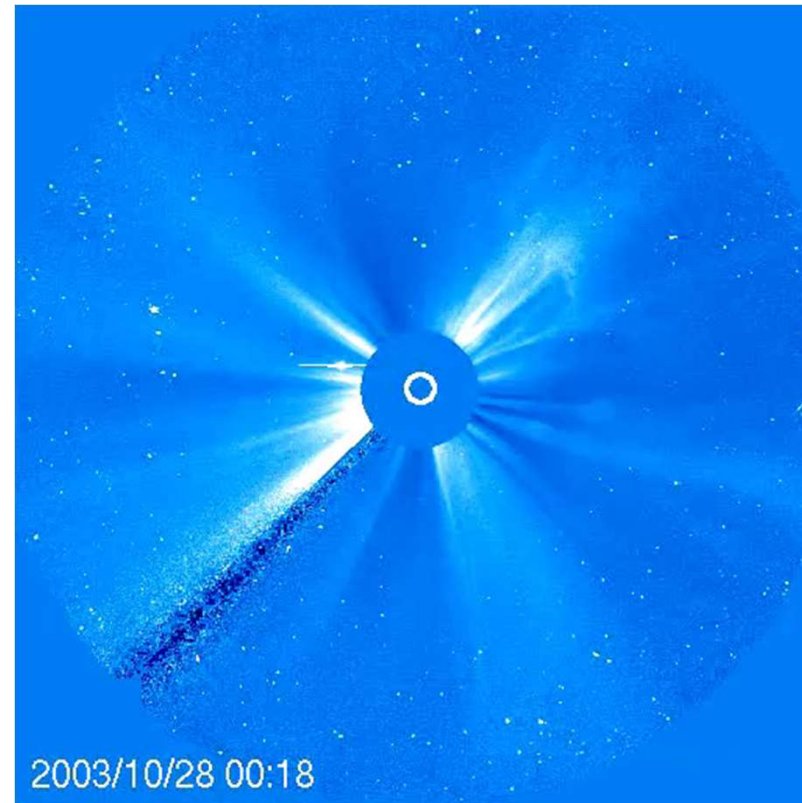
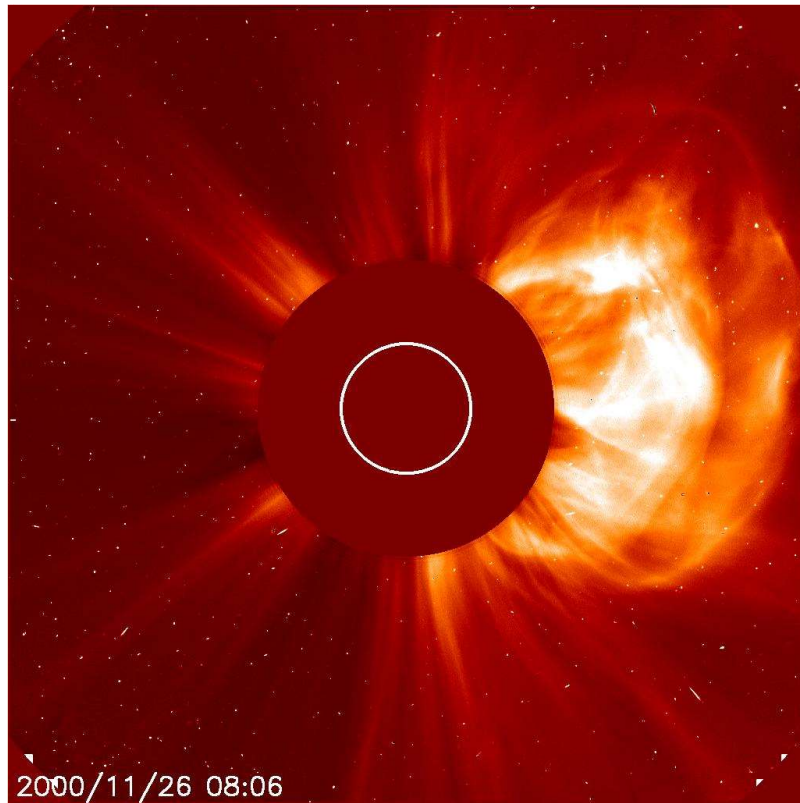
- High speed solar wind stream
- Typical velocity  $\sim 750$  km/s (compared to  $\sim 400$  km/s normally)





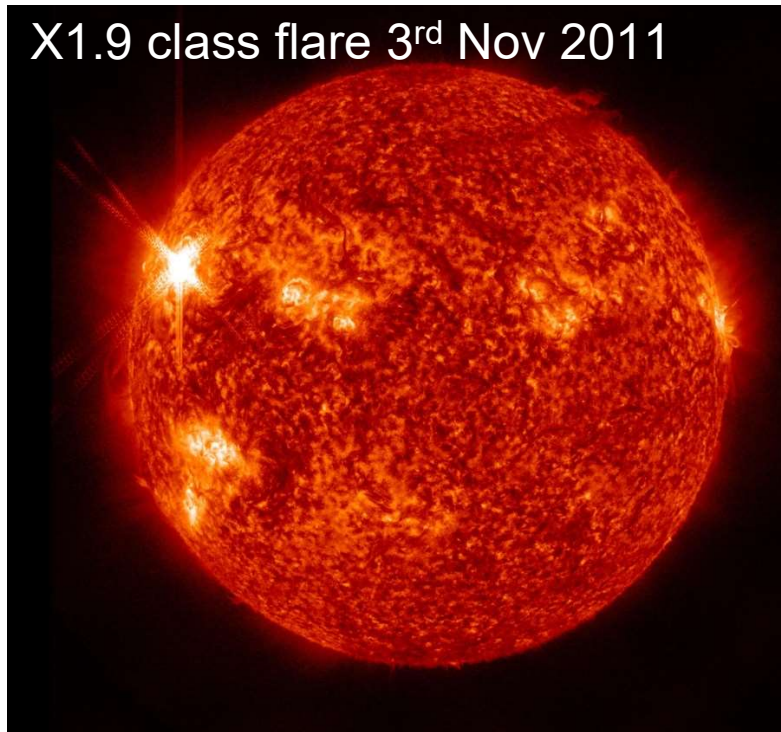
# Coronal mass ejections

- Release large quantities of plasma and magnetic field into space

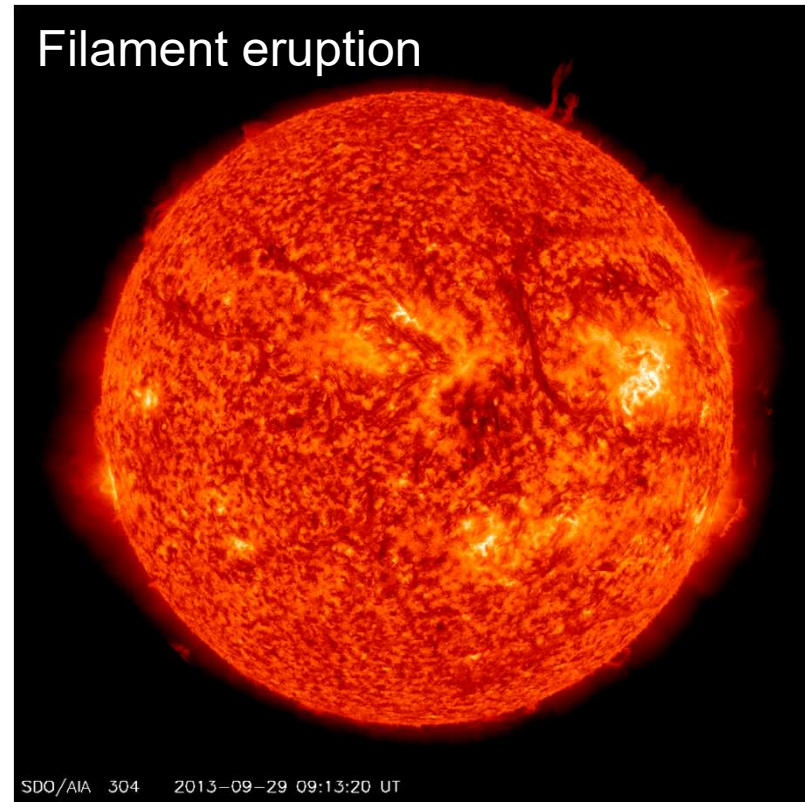


# Coronal mass ejections (CMEs)

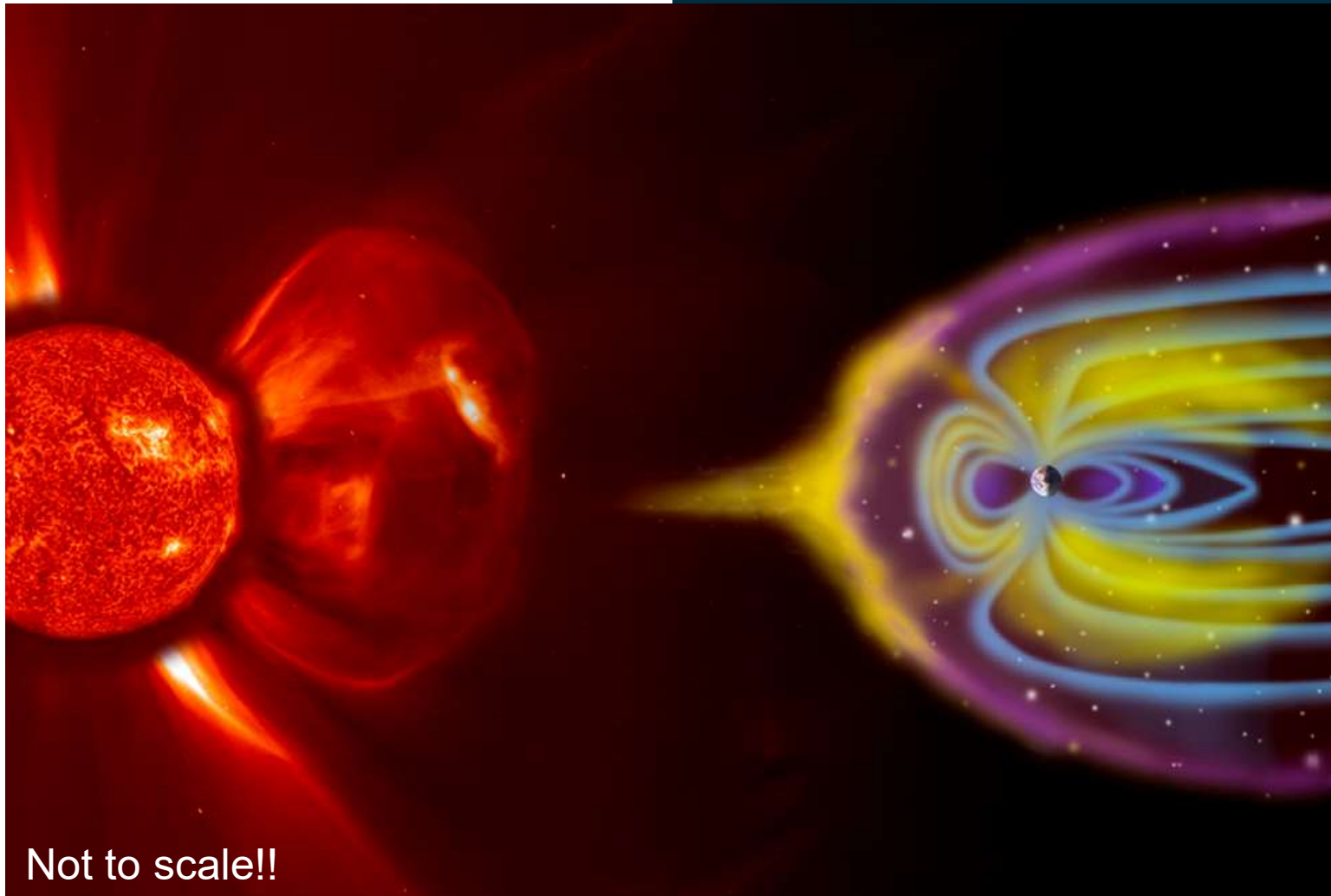
- Usually associated with solar flares or filament eruptions



Both images from SDO/NASA



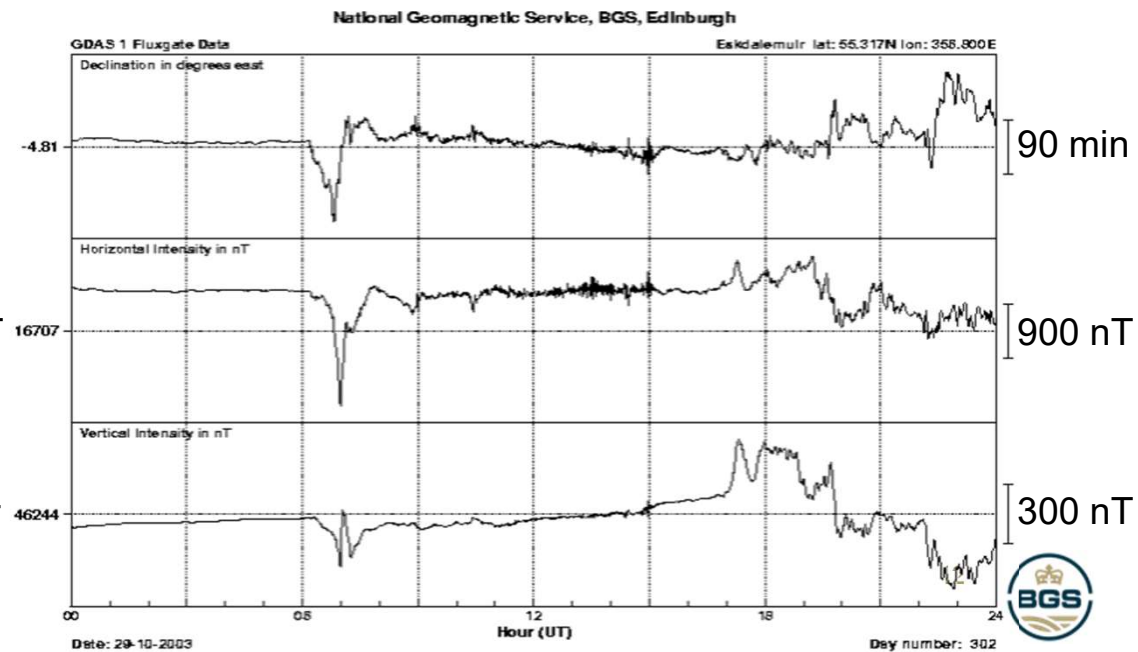
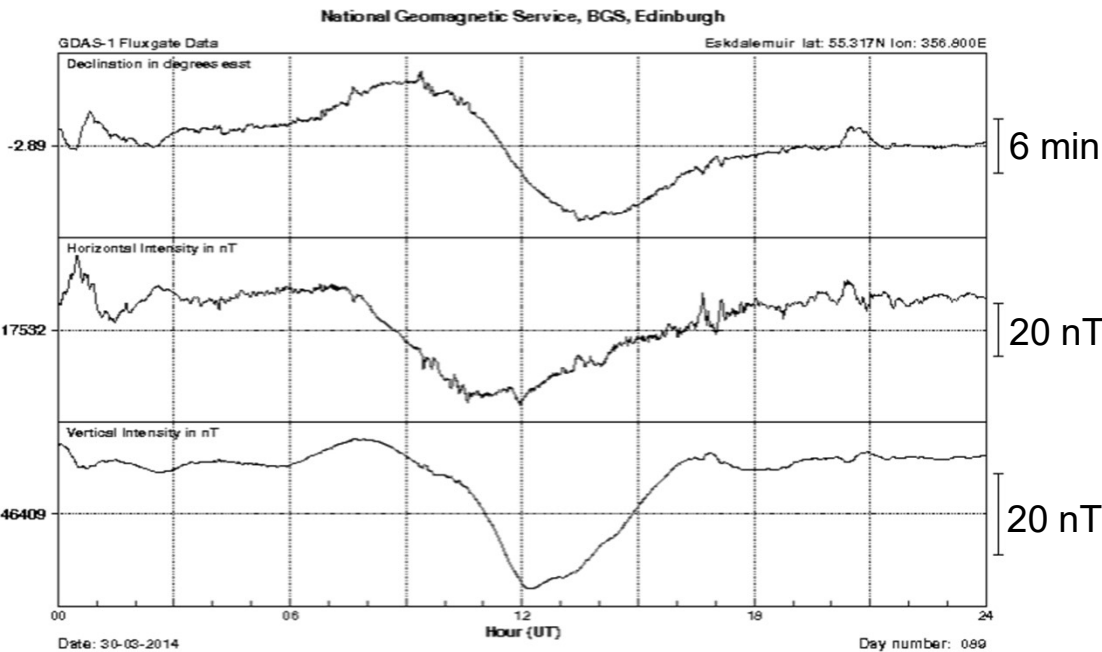
# Geomagnetic storm!



Not to scale!!

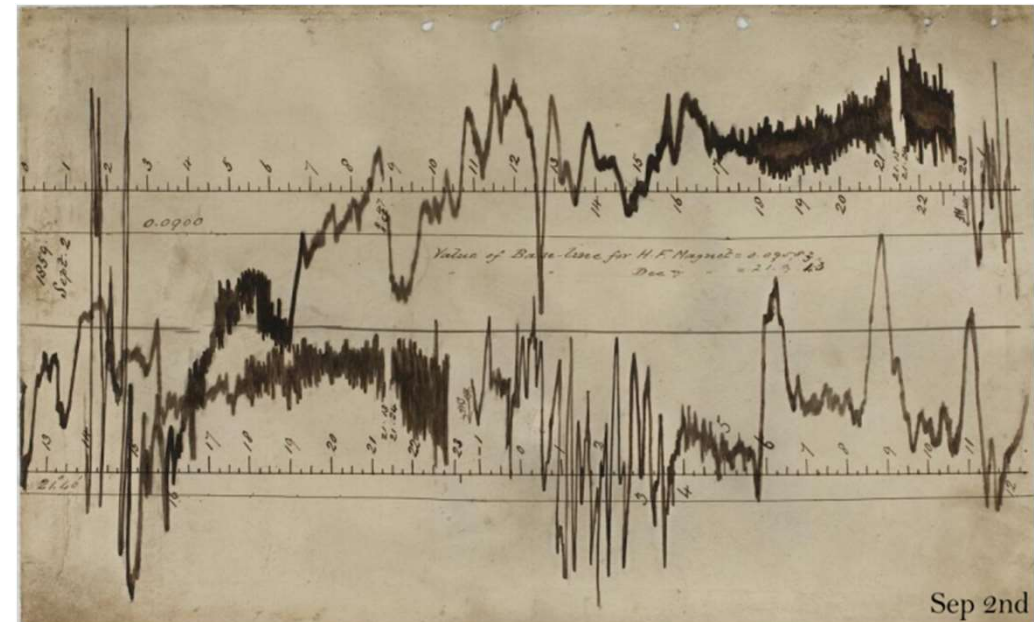
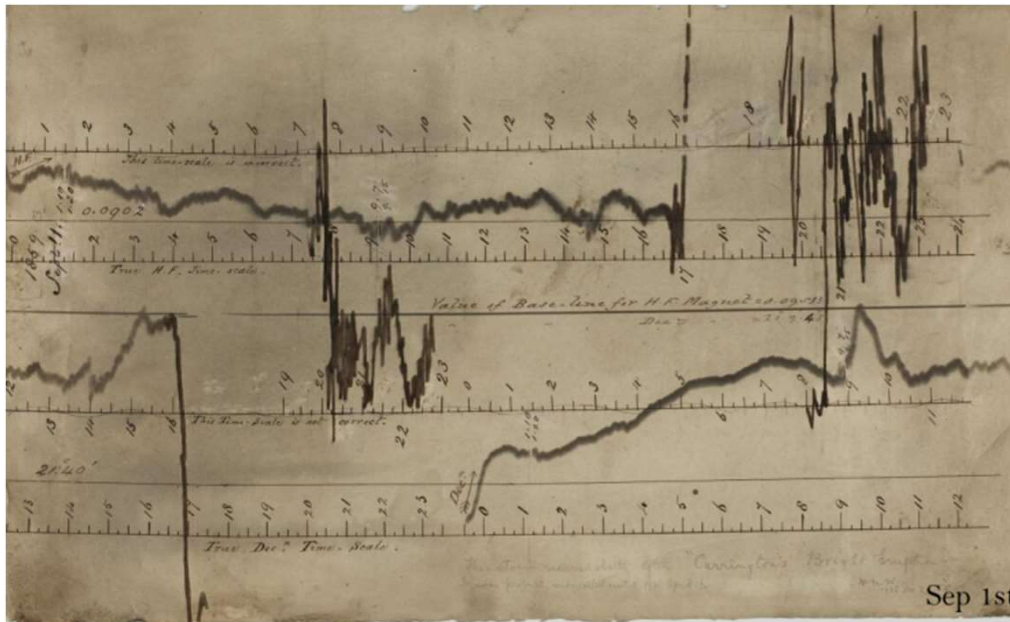
# Geomagnetic signature

- 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

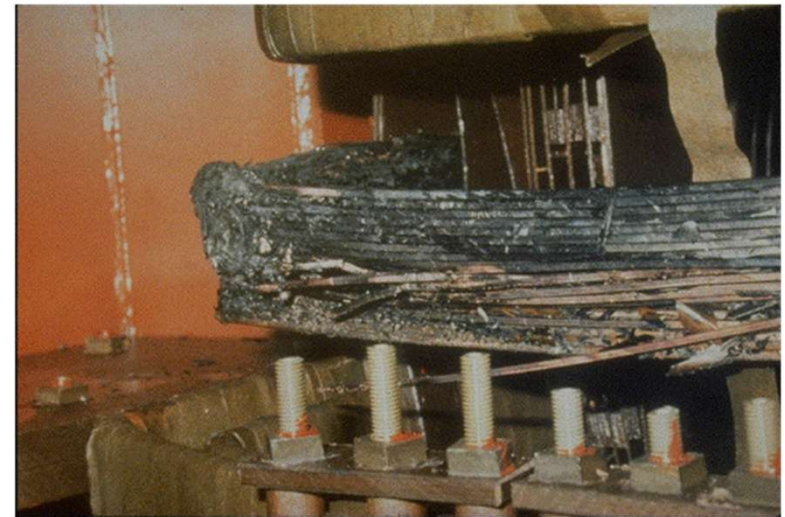
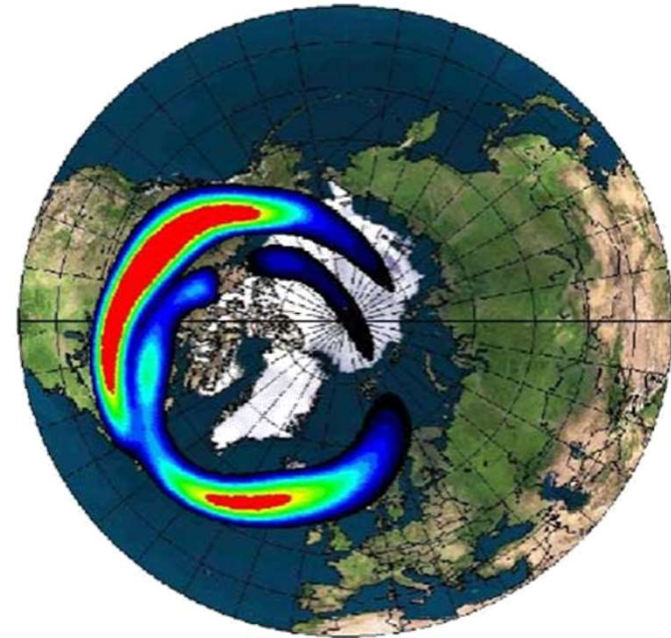
- Largest recorded event is the 'Carrington storm' in September 1859



- 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?

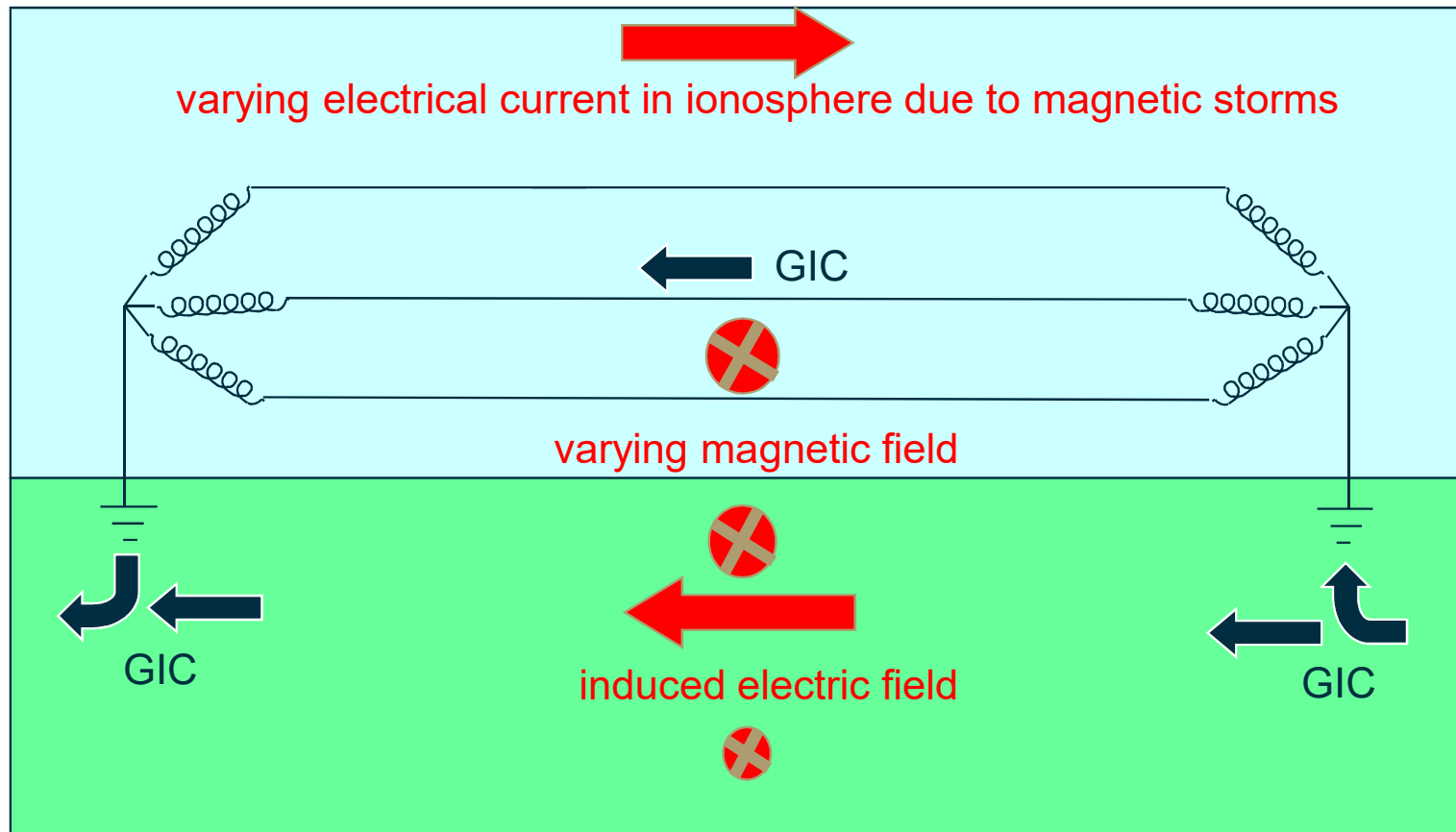
- Not a hazard to humans directly
- During a geomagnetic storm an electric field can be induced in the ground
- This causes currents to flow in ground-based infrastructure, including:
  - Power networks
  - Pipelines
  - Railways
  - Communication cables



# Research



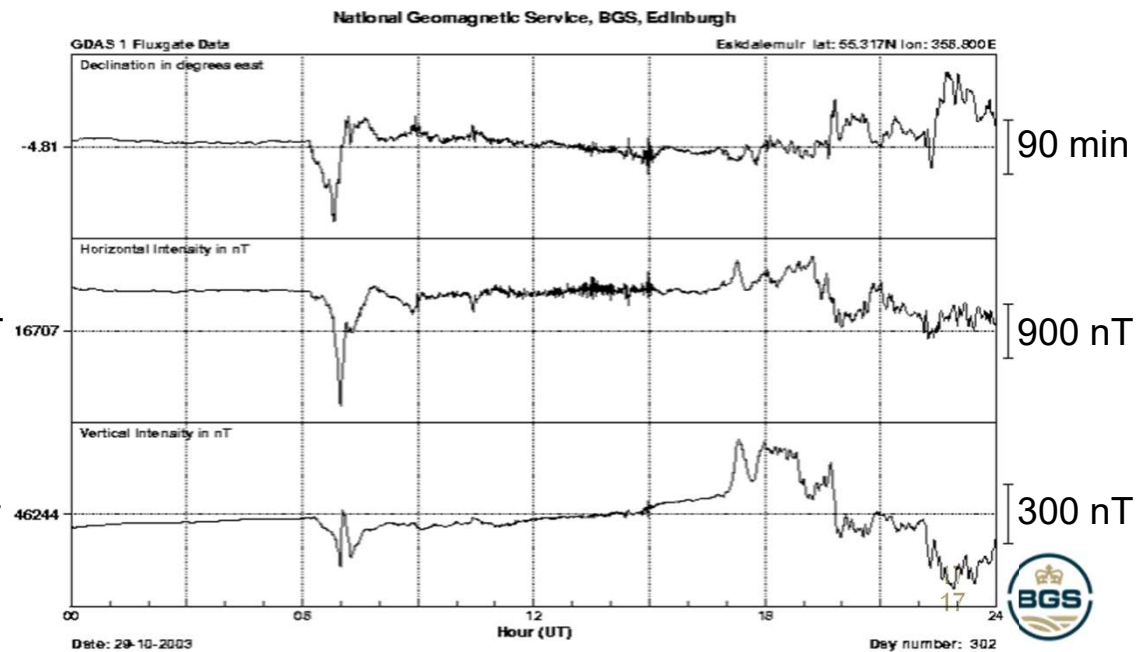
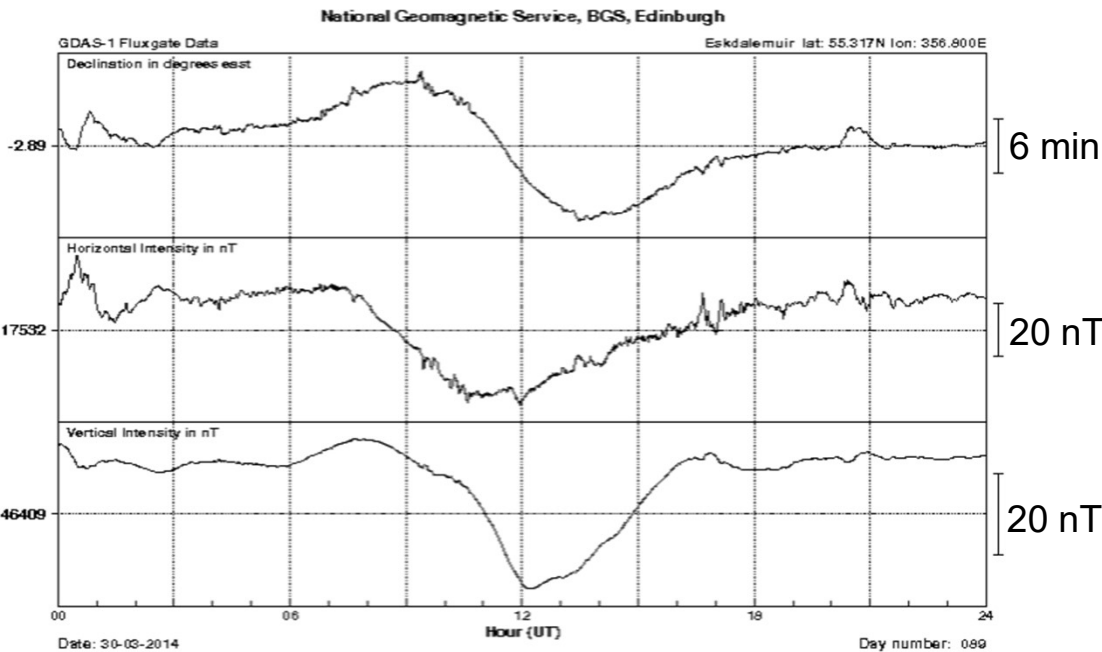
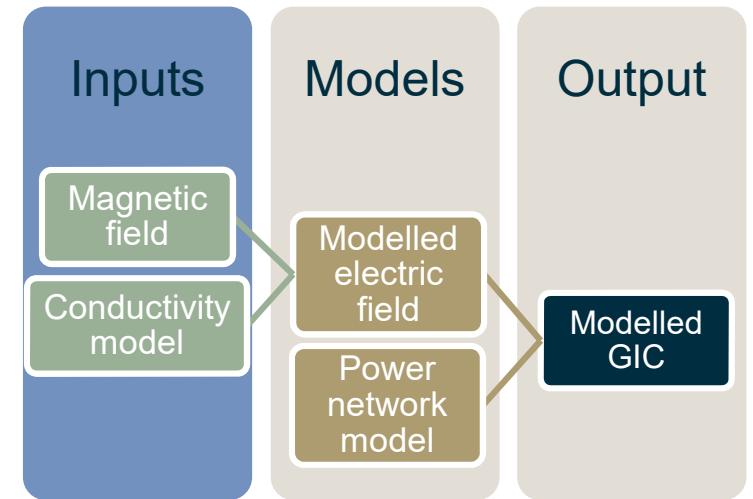
# Geomagnetically induced currents (GIC) in power networks





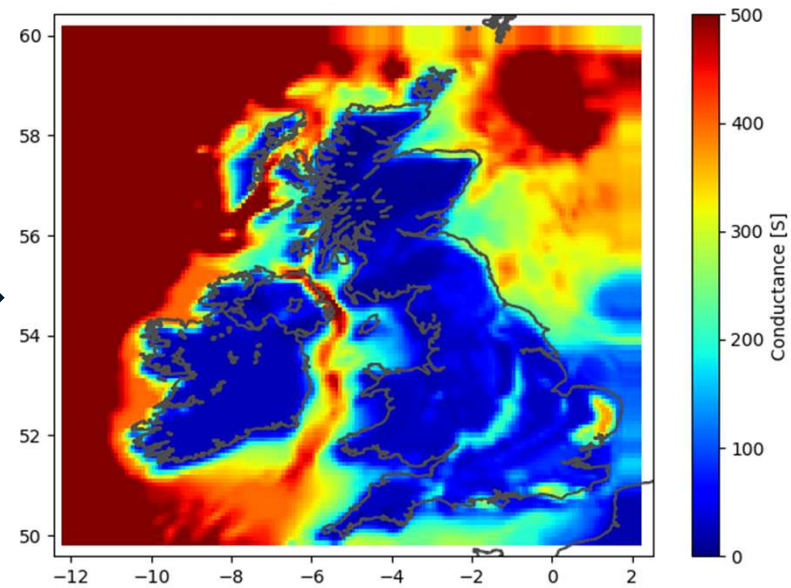
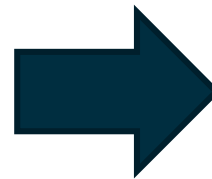
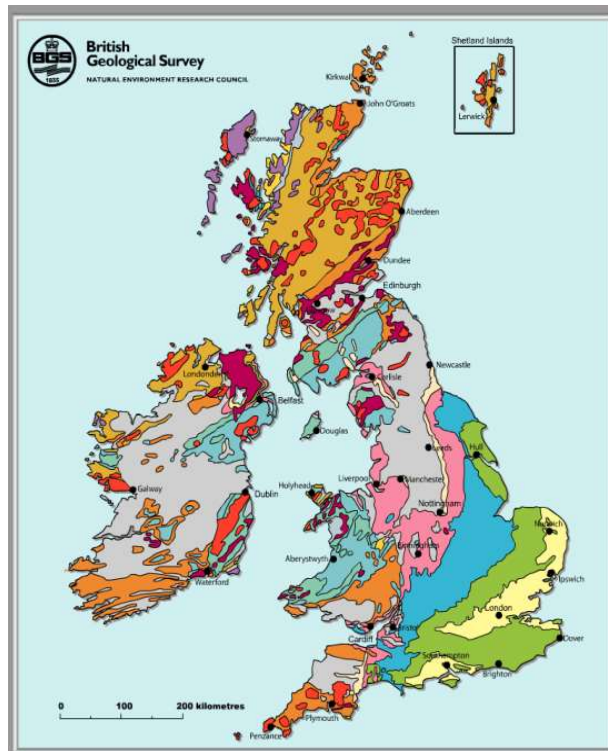
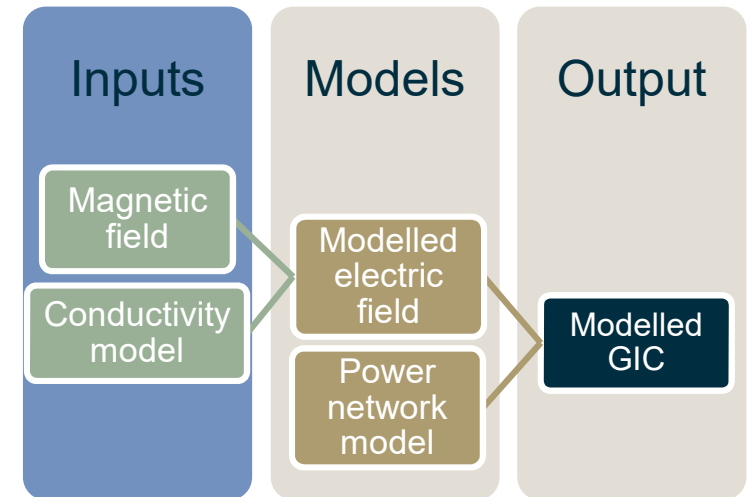
# Modelling GIC

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



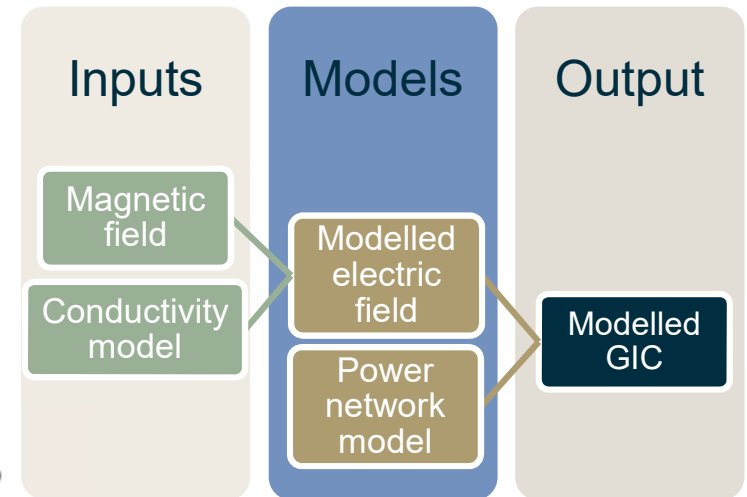
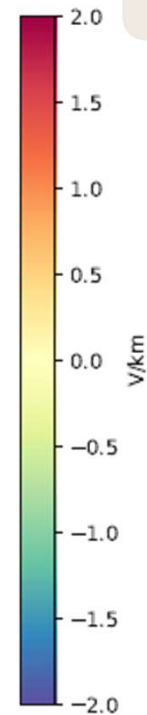
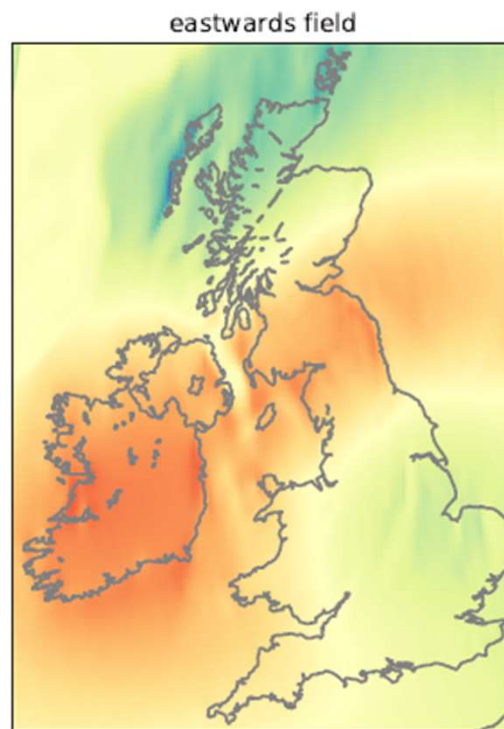
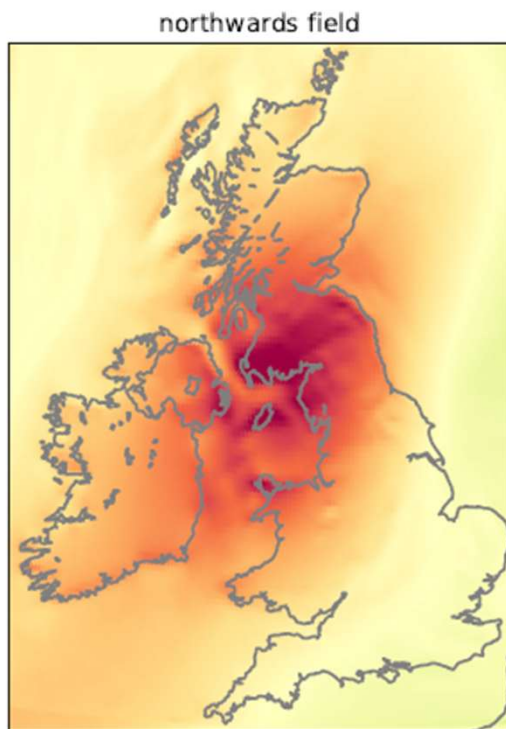
# Modelling GIC

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

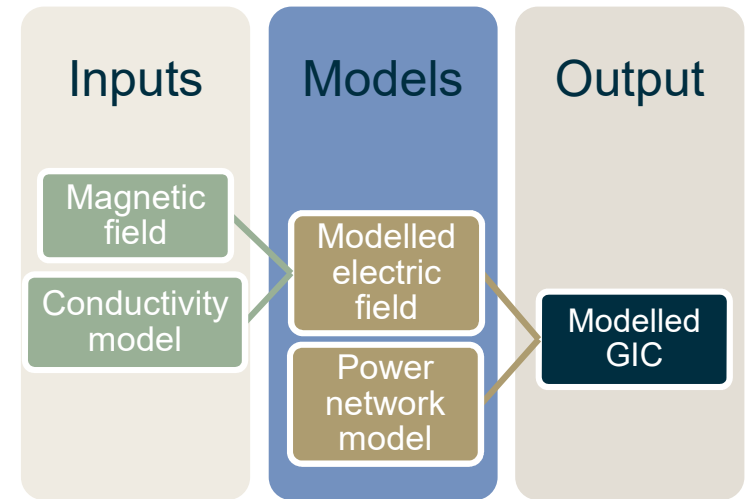
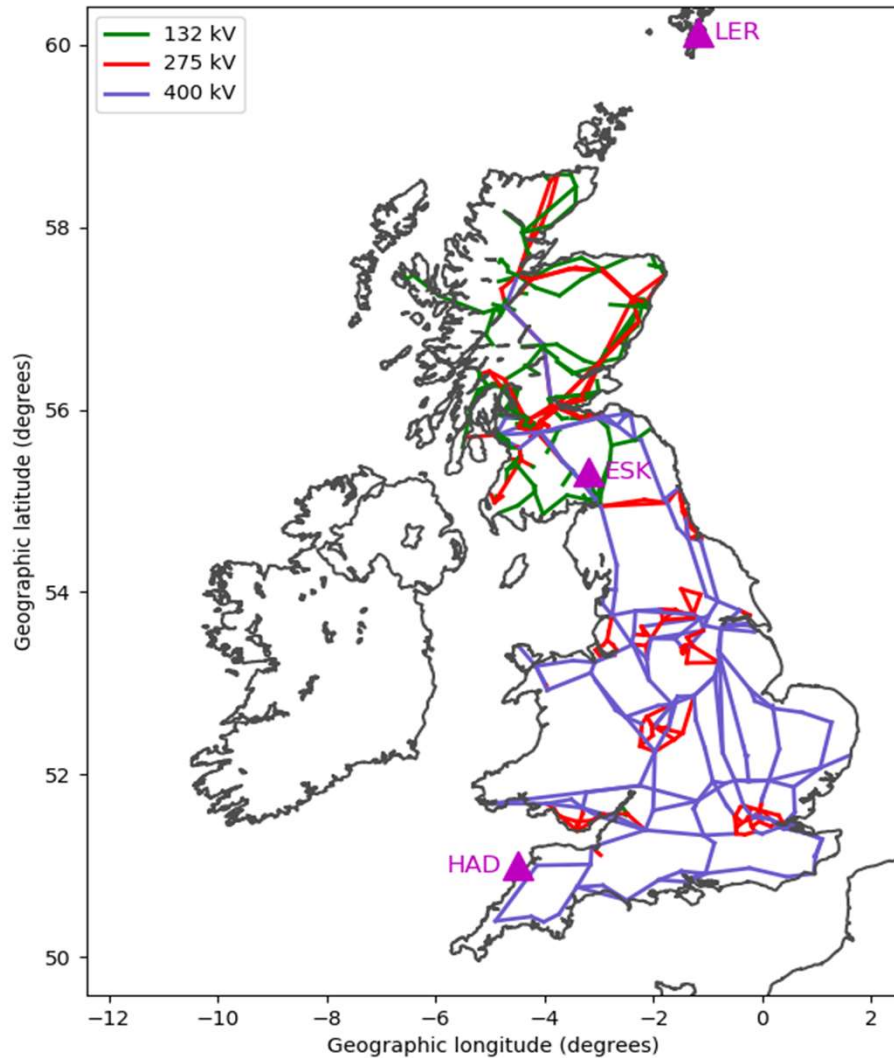


# Modelling GIC

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

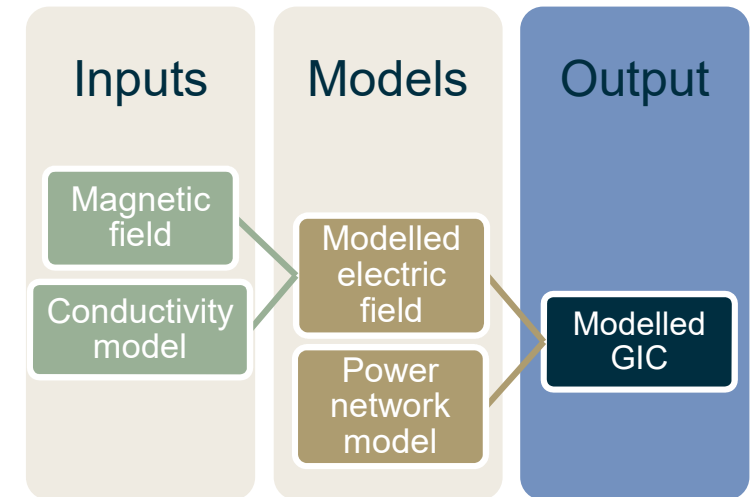
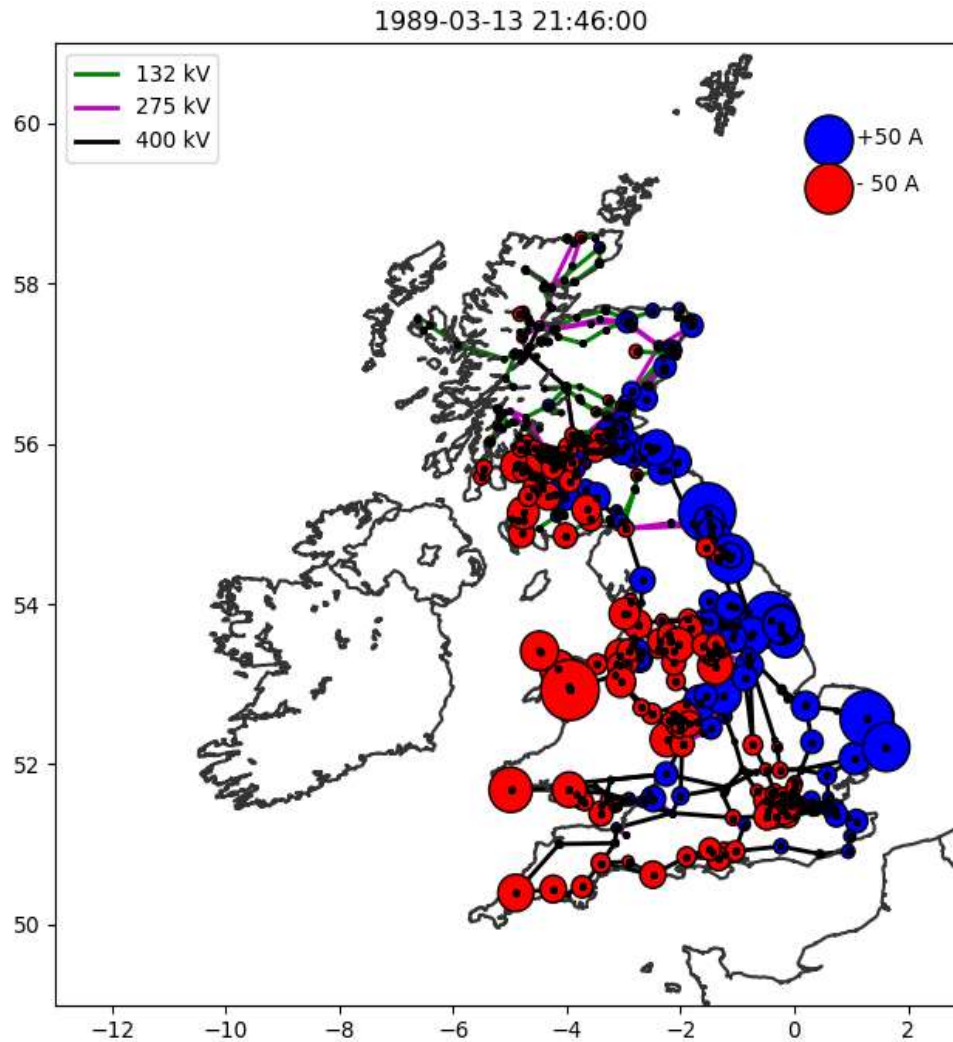


# Modelling GIC



- 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

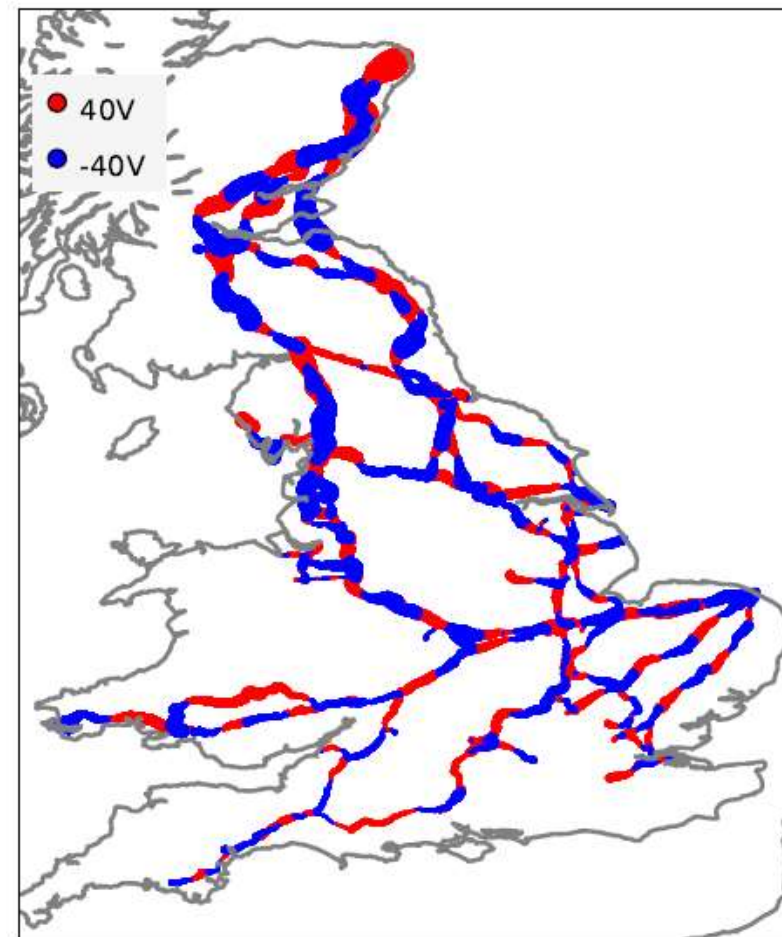
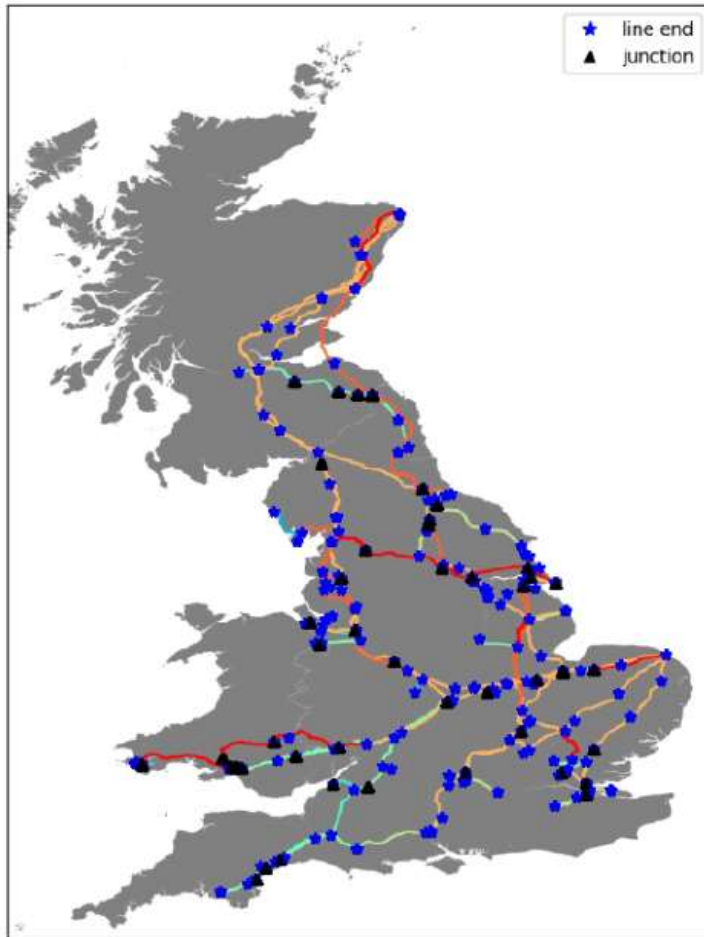
# Pipelines

- 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



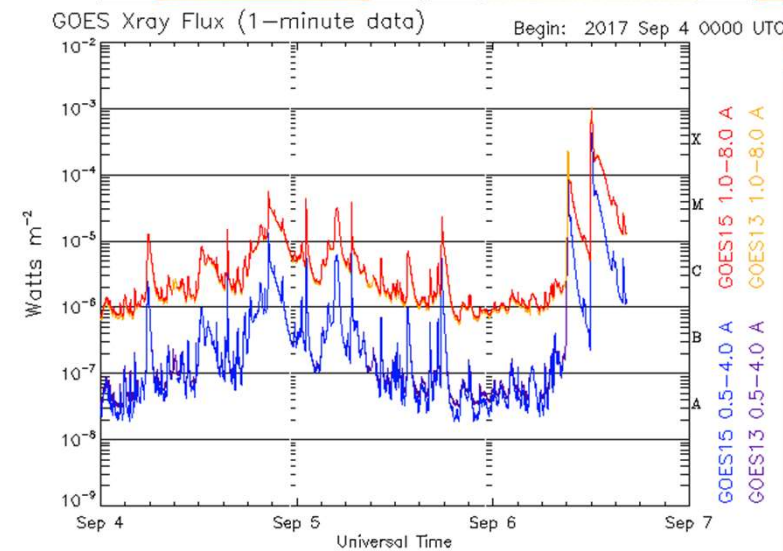
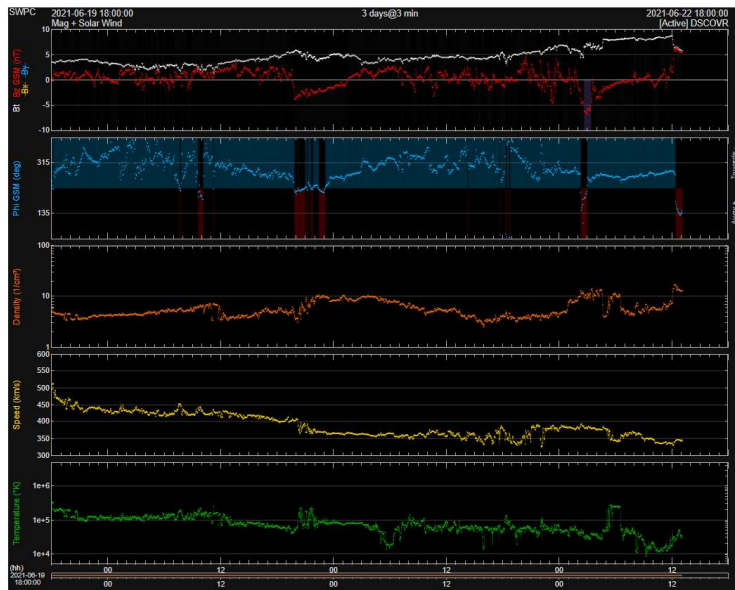
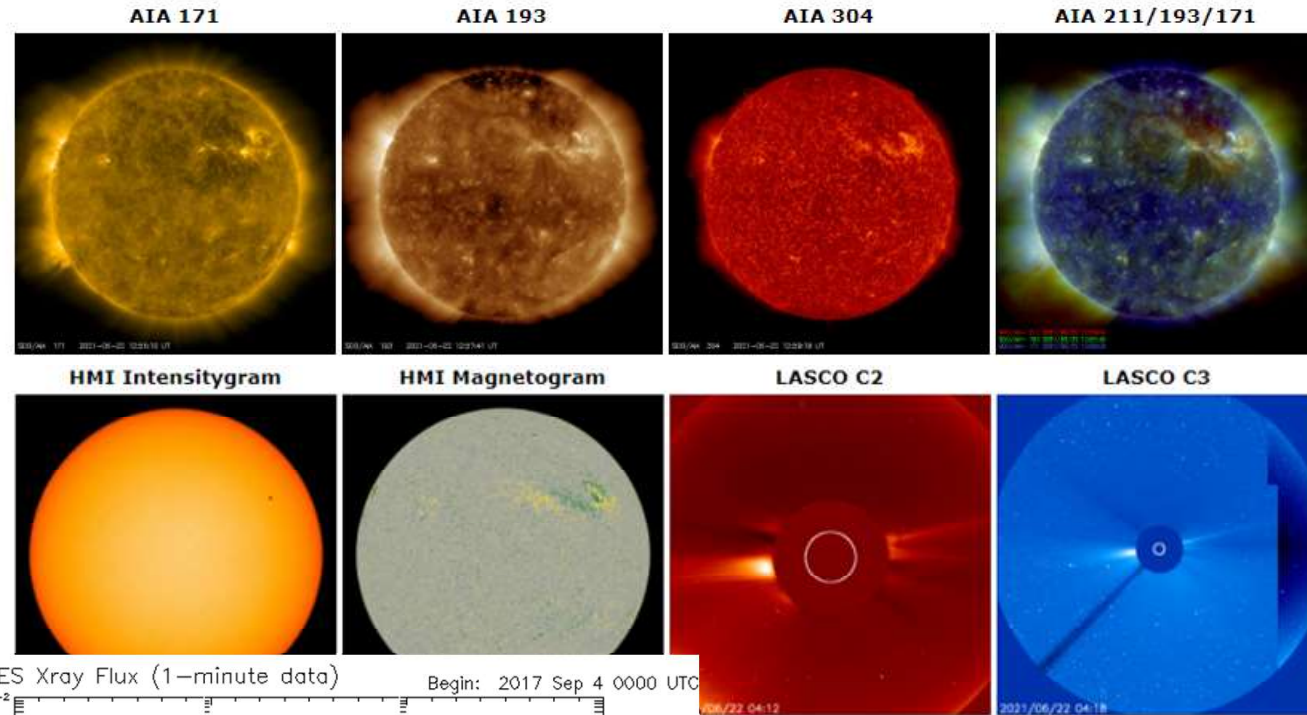
# Space weather forecasting & services



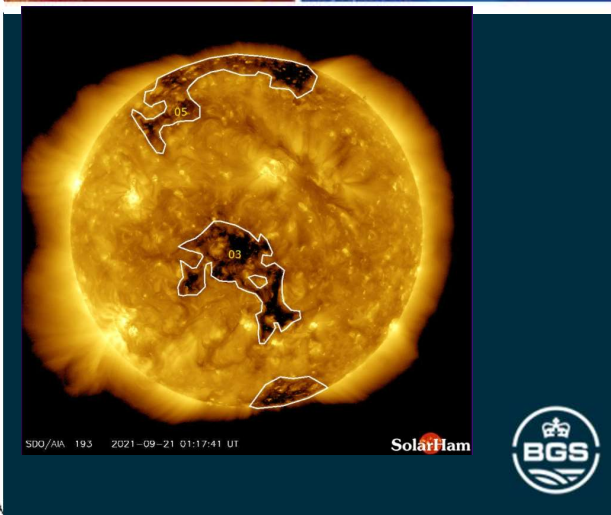


# Monitoring the Sun

- 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)



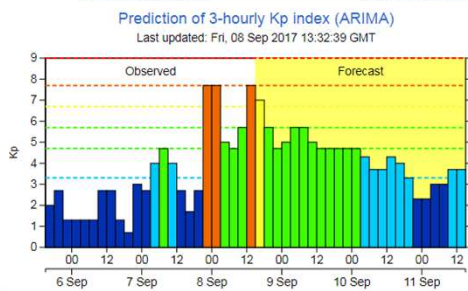
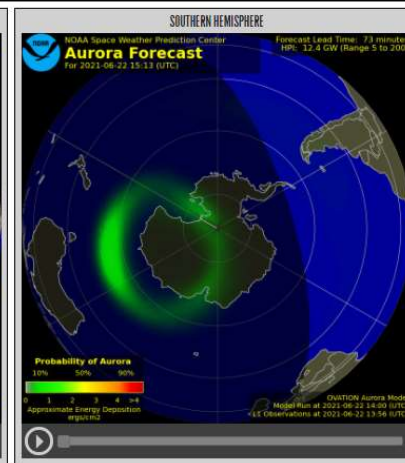
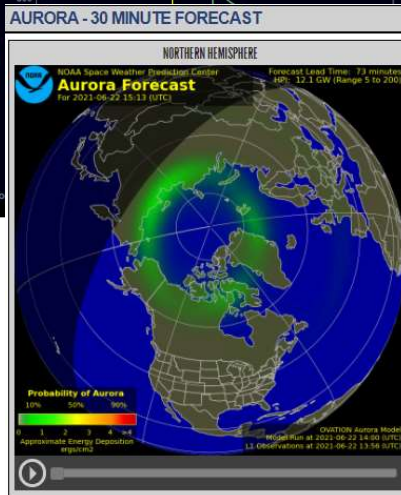
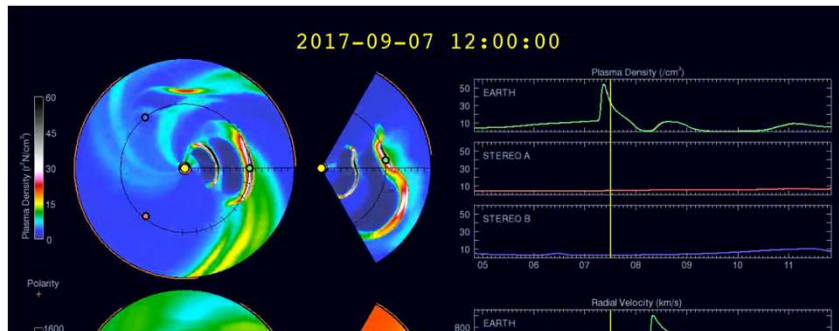
Updated 2017 Sep 6 16:23:11 UTC NOAA/SWPC Boulder, CO USA



# FORECASTING SPACE WEATHER

## Monitoring the Sun

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



THE EUROPEAN SPACE AGENCY

Welcome to the SSA Space Weather Service Network

Please note that all SSA-SWE Services are under review/construction

CURRENT SPACE WEATHER

SPACE WEATHER AT ESA

SERVICE DOMAINS

EXPERT SERVICE CENTRES

OTHER RESOURCES

CONTACT

REQUEST FOR REGISTRATION

Welcome to the SSA Space Weather Service Network

This dashboard provides a snapshot of the current space weather conditions based on the latest products from the SWE Network.

For a detailed overview of the current conditions, as well as access to forecasts, archives, alerts and interactive tools, we encourage you to register as a user and explore the full range of products and data available in our different Service Domains:

- Spacecraft Design
- Spacecraft Operation
- Human Spaceflight
- Launch Operation
- Transionospheric Radio Link
- Space Surveillance and Tracking
- Power Systems Operation
- Aviation
- Resource Exploitation System Operation
- Pipeline Operation
- Tourism
- General Data Service

Interplanetary medium

Near-Earth solar wind forecasts (EUHFORIA)

EUHFORIA (Earth) - 2021-06-24T10:13:23

Full product

Earth's Ionosphere and Thermosphere

Current ionospheric conditions at each ionosonde location

Full product

Earth's Magnetosphere and Radiation Belt

Nowcast Kp index

Full product

SWAP Active region annotated

AVIDOS

SEIBERSDORF LABORATORIES

Effective dose rate in  $\mu\text{Sv/h}$

Altitude: 10.00 km

Date: 22.08.2021

Full product

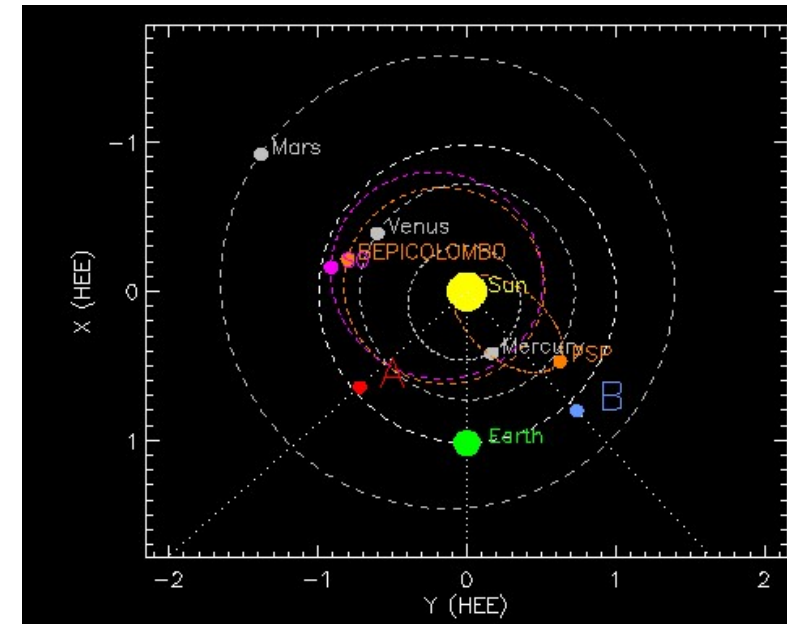
Latest News and Updates

Twitter

Tweets by @esaspaceweather

# 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](http://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](http://www.geomag.bgs.ac.uk/education/activitylevels.html)

### Activity during last 24 hours

Date	Global			Local (UK)		
	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](https://tinyurl.com/BGSforc)
  - @BGSSpaceWeather
  - Alert service @BGSAuroraAlert

**BGS Global Geomagnetic Activity Forecast**

Forecast period      Forecast Global Activity level



**Geomagnetic Disturbance Alert**  
**28th September 2020**  
**British Geological Survey**

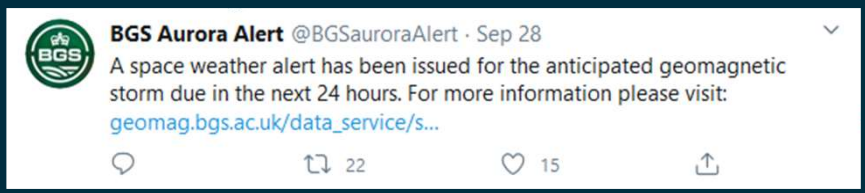
The Earth is currently under the influence of high-speed solar wind from a large coronal hole in an Earth-facing position. The solar wind speed began rising yesterday (Sunday 27<sup>th</sup>) with some aurora sightings reported in the north of Scotland overnight.

Geomagnetic activity is likely to reach STORM levels within the next 24 hours. As the coronal hole is large in size, the high speed stream is likely to remain elevated for the next couple of days, with further chances of STORM periods possible.

Assuming clear, dark skies, there is a greater chance of seeing the aurora this evening and possibly tomorrow evening. Those in Scotland, northern England and Northern Ireland may have the better chance.

For more information please visit:  
[http://geomag.bgs.ac.uk/data\\_service/space\\_weather/alerts/alert\\_2020-09-28.html](http://geomag.bgs.ac.uk/data_service/space_weather/alerts/alert_2020-09-28.html)

For current geomagnetic activity levels please see:  
[http://geomag.bgs.ac.uk/data\\_service/space\\_weather/Global\\_activity\\_now.html](http://geomag.bgs.ac.uk/data_service/space_weather/Global_activity_now.html)

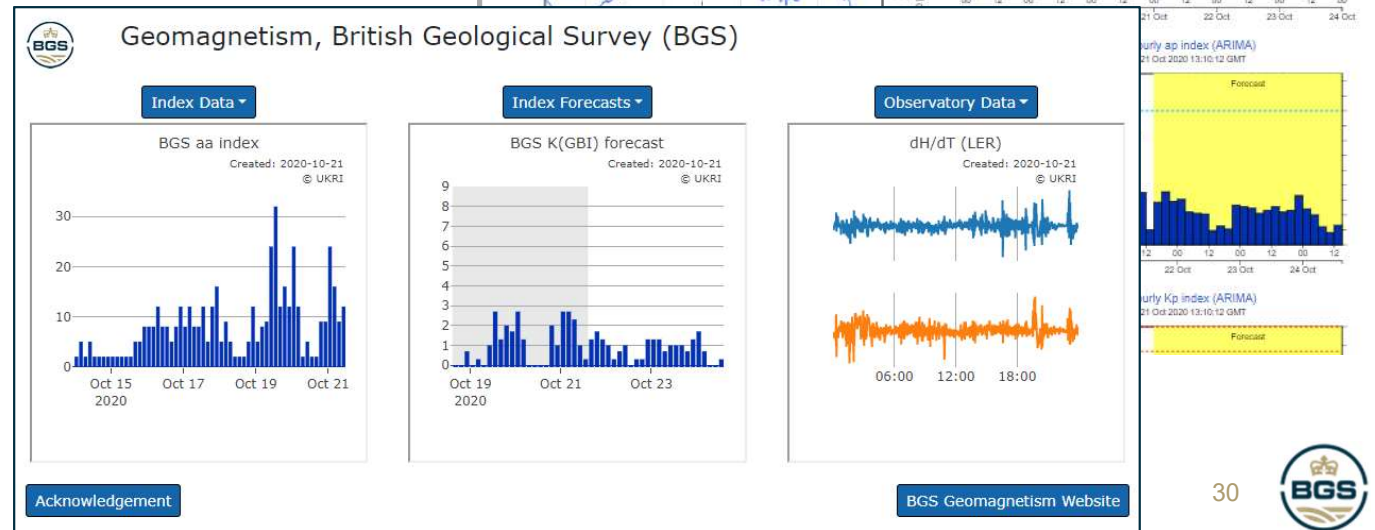
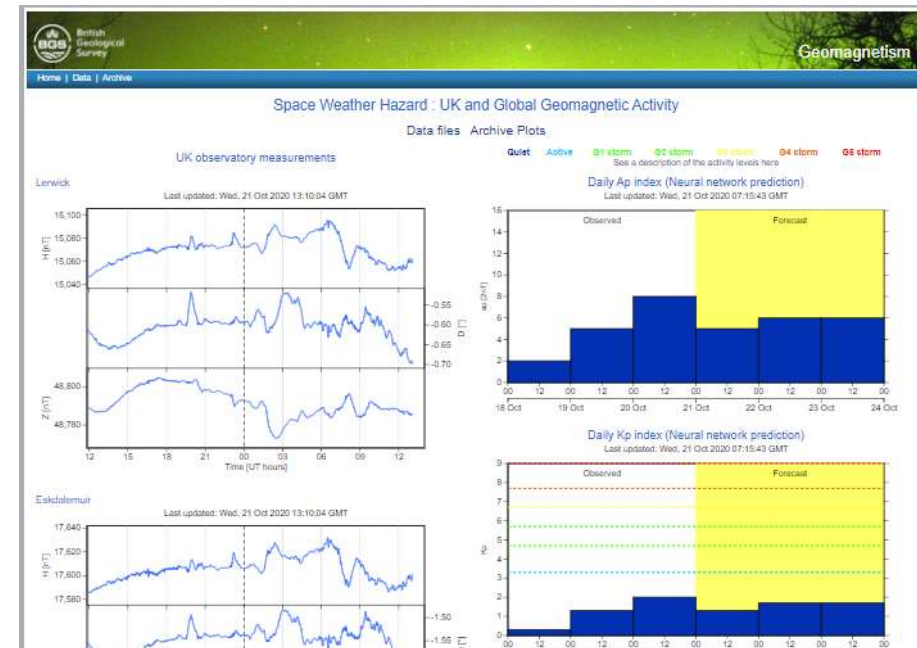


**BGS Aurora Alert** @BGSauroraAlert · Sep 28  
A space weather alert has been issued for the anticipated geomagnetic storm due in the next 24 hours. For more information please visit: [geomag.bgs.ac.uk/data\\_service/s...](http://geomag.bgs.ac.uk/data_service/s...)

22      15

# 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



### Data and Services



Data

Models & Compass Variation

Space Weather

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.

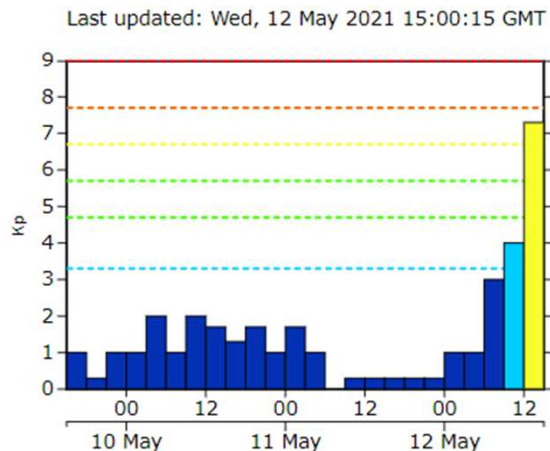
Description of the categories

More plots of current activity

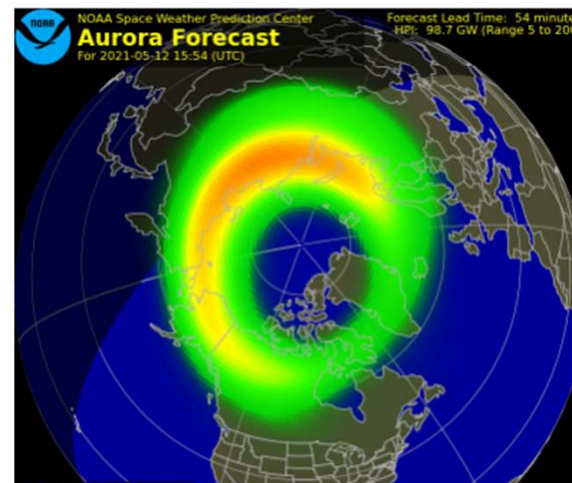
3-day forecast of geomagnetic activity

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



### Model of the current position of the aurora oval



[tinyurl.com/BGSSWx](https://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?

