What are we trying to forecast? - *getting the right science into the impact of an L5 mission*

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A recognised risk

Strategic National Risk Assessment — December 2011

The Strategic National Risk Assessment in Support of PPD 8: A Comprehensive Risk-Based Approach toward a Secure and Resilient Nation

Overview

The Strategic National Risk Assessment (SNRA) was executed in support of Presidential Policy Directive 8 (PPD-8), which calls for creation of a National Preparedness Goal, a National Preparedness System, and a National Preparedness Report. Specifically, national preparedness is

Threat/ Hazard Group	Threat/Hazard Type	National-level Event Description
Natural	Animal Disease Outbreak	An unintentional introduction of the foot-and-mouth disease virus into the domestic livestock population in a U.S. state
	Earthquake	An earthquake occurs within the U.S. resulting in direct economic losses greater than $100 Million
	Flood	A flood occurs within the U.S. resulting in direct economic losses greater than $100 Million
	Human Pandemic Outbreak	A severe outbreak of pandemic influenza with a 25% gross clinical attack rate spreads across the U.S. populace
	Hurricane	A tropical storm or hurricane impacts the U.S. resulting in direct economic losses of greater than $100 Million
	Space Weather	The sun emits bursts of electromagnetic radiation and energetic particles causing utility outages and damage to infrastructure
	Tsunami	A tsunami with a wave of approximately 50 feet impacts the Pacific Coast of the U.S.
	Volcanic Eruption	A volcano in the Pacific Northwest erupts impacting the surrounding areas with lava flows and ash and areas east with smoke and ash
	Wildfire	A wildfire occurs within the U.S. resulting in direct economic losses greater than $100 Million

Strategic National Risk Assessment Scope

To inform homeland security preparedness and resilience activities, the SNRA evaluated the risk from known threats and hazards that have the potential to significantly impact the Nation's

A recognised risk

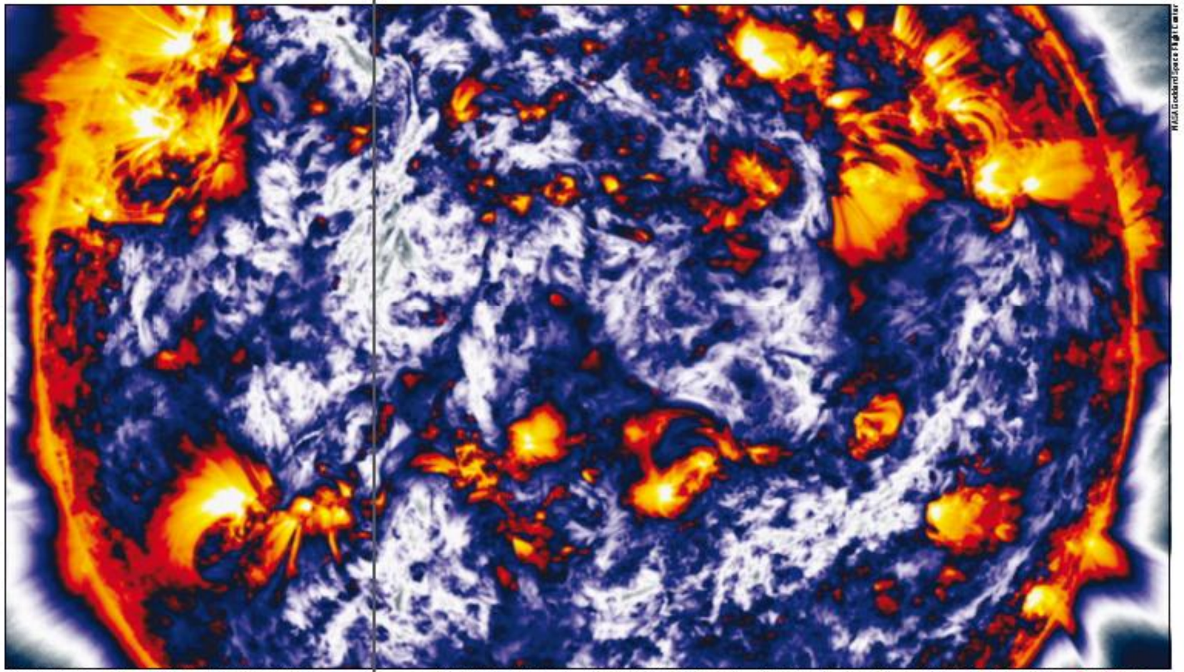
- Space weather now widely recognised as a risk that must be **considered** in national & international resilience planning:
  - UK, Sweden, Netherlands, US, …
  - EU, OECD, NATO-CEP, …
- The (political) challenge now is to consider the scale and detail of mitigation
  - ultimately an economic case, but for now
  - *what is the science that links L5 data to that case?*
  - *and how do we avoid hyperbole?*

Solar flares &

physicsworld.com Feature: Space weather

What if a solar super-storm hit?

Super-storms on the surface of the Sun are more than just an interesting oddity of astrophysics. As explains, they can occur at any time and – if sufficiently strong – could cripple our modern way of life here on Earth



One September day in 1859, over the course of a few minutes, an event occurred that was to have spectacular consequences here on Earth. A sudden flash of brightness, known as a solar flare, had just erupted on the Sun, releasing about 10^{22} kJ of energy – equivalent to 10 billion Hiroshima bombs exploding at the same time. A massive coronal mass ejection (CME) hurled out about a trillion (10^{12}) kilograms of charged particles at speeds of some 3000 km/s. As the material interacted with the Earth's magnetosphere – the magnetic shield that usually protects us from high-energy charged particles from space – it triggered the largest ever "solar super-storm" on record.

Known as the Carrington Event – after the English astronomer Richard Carrington who spotted the flare – this super-storm saw the magnetic field around the Earth being stretched and torn apart. Accompanied by numerous sunspots, it led to the northern lights being seen as far south as the equator and created surges of energy that crippled the world's electronics infrastructure.

Back in the mid-19th century, that infrastructure amounted to no more than about 200000 km of telegraph lines and so the impact on the human population was relatively benign. But today's world, which relies hugely on space technology and massively interconnected networks of power lines and fibre-optic cables, would be severely damaged if a Carrington-type event were to repeat itself. The consequences could be catastrophic and long-lasting.

In fact, it has now dawned on us – thanks to data from NASA's Kepler mission, numerical modelling and the study of historical records – that the mood of our nearest star is far more hostile than we used to think. According to Jim Green, director of NASA's planetary-science division, the Earth is, on average, in the path of Carrington-level events every 150 years – putting us five years overdue. Moreover, according to estimates made by Pete Riley, a heliophysicist at NASA and the US Department of Defense, the probability of another Carrington Event occurring within the next decade is as high as 12% (*Space Weather* 10 S02012).

In recent decades, we have already seen glimpses of the dangers that could lie in store. In March 1989, for example, a geomagnetic storm that was about a third of the strength of the Carrington Event caused an electricity grid operated by the Canadian firm Hydro-Québec to fail, triggering a nine-hour blackout for about six million people. Meanwhile, the "Halloween storm" of October 2003 – which was about half as intense as Carrington – disabled a number of satellites, destroyed a dozen transformers in South Africa and crippled a large section of its power systems. These events should have been a wake-up call, but little has been done about the potential threats. As the heliophysicist Pete Worden, director of NASA's Ames Research Center, candidly puts it: "Space weather destroys stuff."

So what can be done?

SolarMAX is on the case

To help find answers, I was last year invited by the UK and European space agencies to take part in a 40-strong international, multidisciplinary task force of experts, led by Worden and Green. Over a period of six weeks, our group – dubbed SolarMAX – gathered at the International Space University in Strasbourg, France, to work out the risks from a solar super-storm to our modern way of life and to identify the best ways of limiting the potential damage. The result was a 100-page document to be disseminated to governments, space agencies and industry. You can read the full report online (http://ow.ly/yDOXp), although the human impact of a storm might be more apparent in my fictionalized account of the dramatic aftermath of such an event (see box on p27).

It would be nice to pretend that everything will be fine in the event of a solar super-storm striking the Earth, but our findings were sobering. Severe disturbances to the Earth's magnetic field would induce electric currents in the ground and overhead transmission lines – in fact, if the cables are long enough, the currents would be large enough to melt high-voltage AC transformers, which are critical components in all power grids. New transformers typically take up to a year to manufacture and install – and utility companies rarely keep backups as these devices cost at least \$10m each. Any Carrington-level event would therefore generate widespread power outages that would last months, if not years, across most of the developed world, in particular North America and Europe. The lower latitudes of India and China, coupled to generally less conductive soil and more robust power infrastructures, means they would not be nearly as badly affected.

Without power, people would struggle to fuel their cars at petrol stations, get money from cash dispensers or pay online. Water and sewage systems would be affected too, meaning that health epidemics in urbanized areas would quickly take a grip, with diseases we thought we had left behind centuries ago soon returning. Worse still, most of the developed world works on a "just-in-time" philosophy, meaning that there is never more than two to three days' worth of supplies available in urban areas at any given moment, be it food, fuel or medicine.

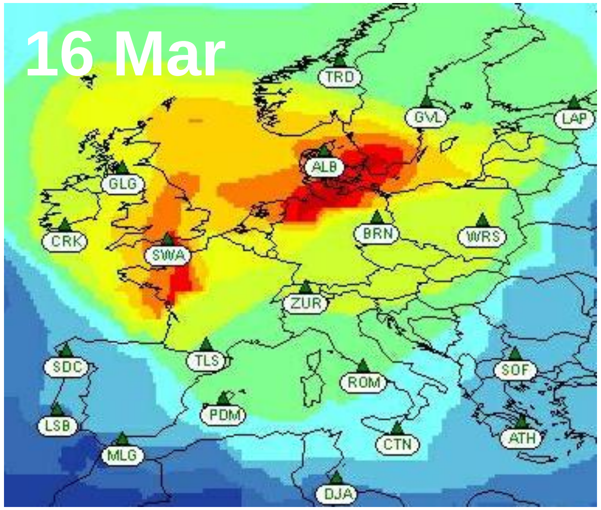
Nuclear power plants are another concern as they

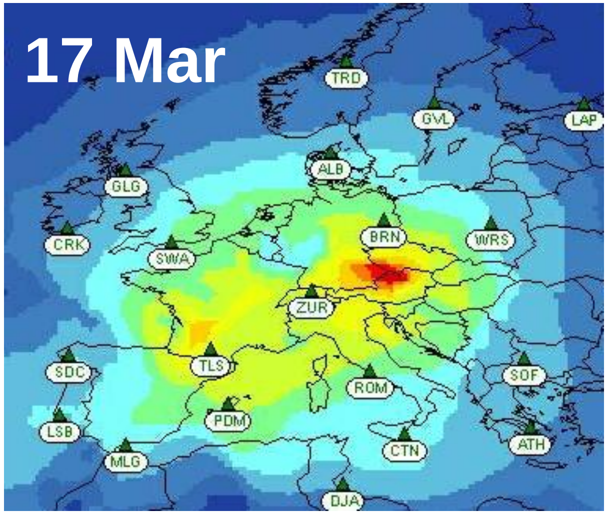
Powerful force Enhanced by gradient filters more commonly used in photography and graphic design, this image of the Sun taken by NASA's Solar Dynamics Observatory reveals fiery coronal loops (orange) amid cooler regions (blue).

Solar flares & the prophets of doom

- As with all big risks, space weather appeals to our love of scare stories (a current favourite of the media!)
  - So public discussion spans whole range of ideas from *end-of-civilisation-as-we-know-it* to *it-can't-happen-here*.
- So we have to work hard to provide balance
  - What is the real level of risk? And what can we do about it?
  - Show how science and engineering knowledge transcends personal and organisational experience (20-year horizon?)
  - Most economic impact arises from geomagnetic activity: *power is critical impact politically*, (but GNSS is also growing issue)
  - What are key drivers? Coronal mass ejections! Also stream interaction regions.

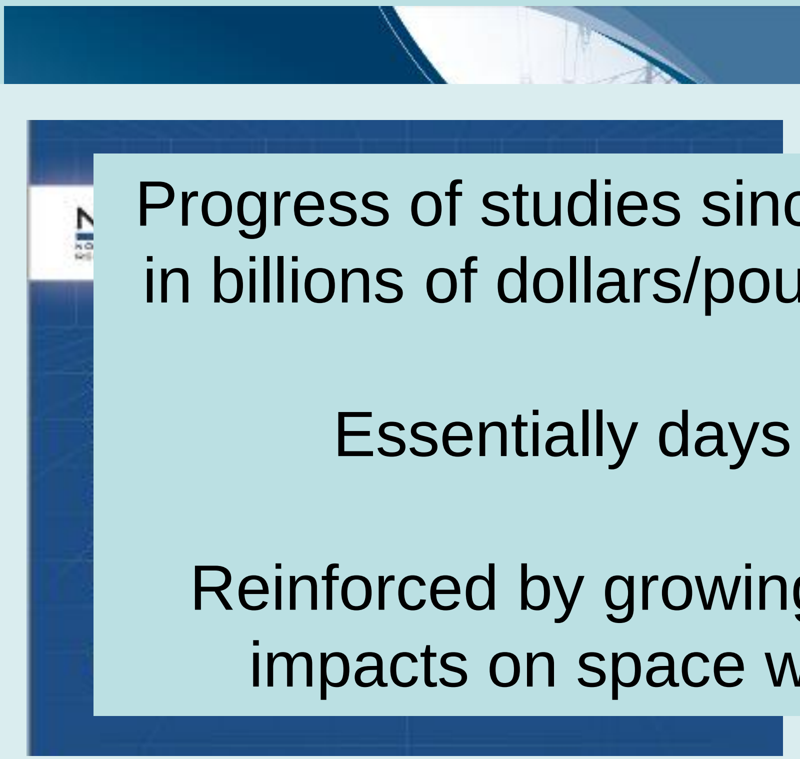
St Patrick's Day solar storm 2015

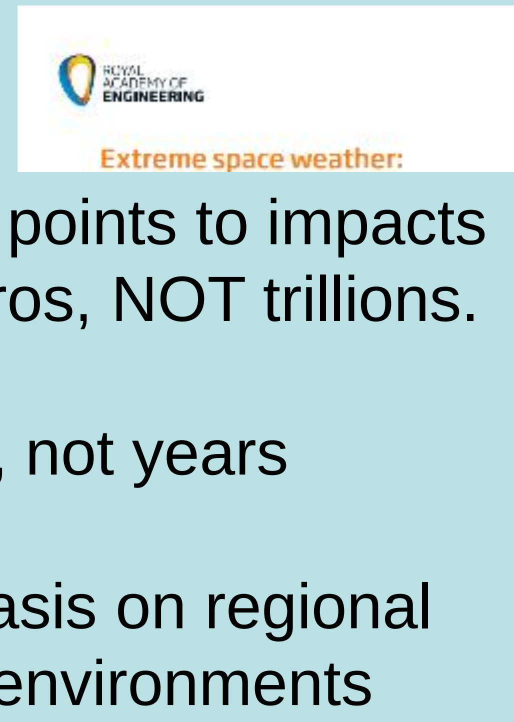




- Largest geomagnetic storm, so far, of this solar cycle
- Major disturbance of ionosphere:
  - Night-time ionosphere over S. England heavily depleted, compared to normal
  - EGNOS (GPS correction system) degraded, see left (red = best performance, blue = worst)
- Aurora seen in north of UK
- Cause may be interaction of CME & solar wind stream
  - Shows need for better solar wind monitoring @ L1 and L5

Growing range of impact studies





Progress of studies since 2010 points to impacts in billions of dollars/pounds/Euros, NOT trillions.

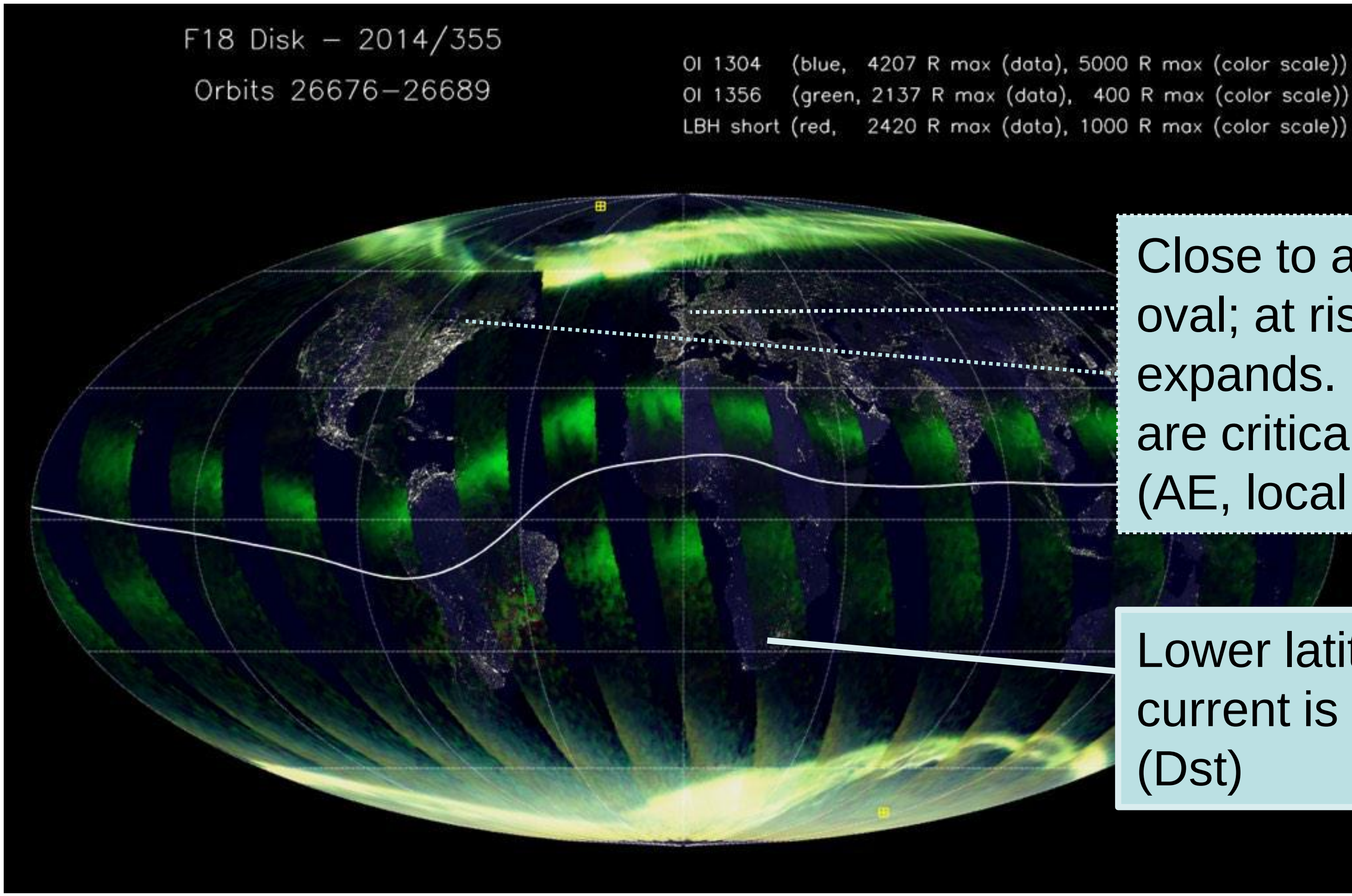
Essentially days of GDP, not years

Reinforced by growing emphasis on regional impacts on space weather environments

NERC GMD report (2012)

RAEng study (2013): *peer-reviewed*

Localising the risk:
the two faces of the aurora



Close to auroral oval; at risk when it expands. Substorms are critical driver (AE, local B, ~~Kp~~)

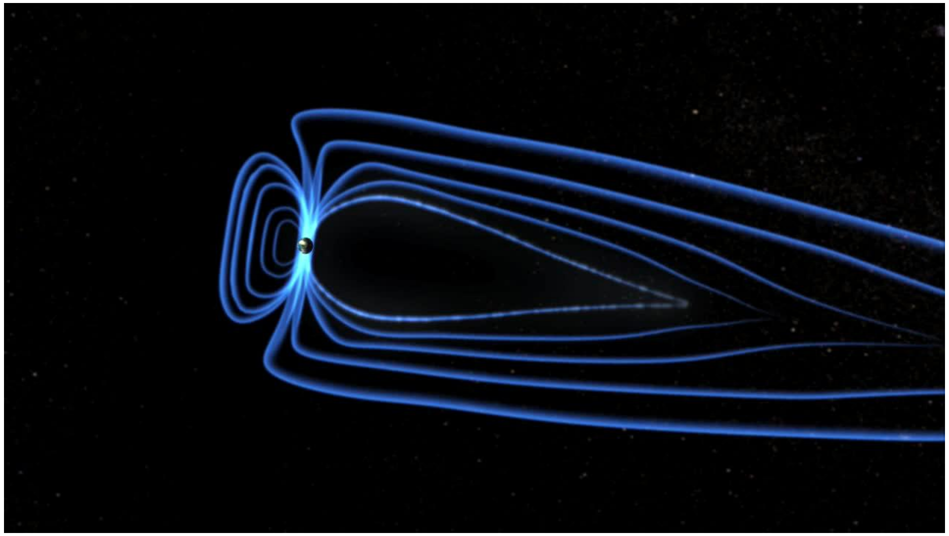
Lower latitudes; ring current is key driver (Dst)

The importance of sub-storms (Dungey cycle)

RAL Space

- Fundamental dynamic of externally-driven magnetospheres (Earth, Saturn, ….)
- Focuses energy from solar wind into bursts that are localised in space & time

Courtesy NASA



- Big storms comprise a series of sub-storms which structure the ground impacts (when, where, repetition, ...)
- Key challenge: how can solar wind monitoring and modelling (e.g. L5) can support better sub-storm forecasts:
  - E.g. via SWPC/CCMC geospace modelling work

Regional impact:
a key issue for understanding?

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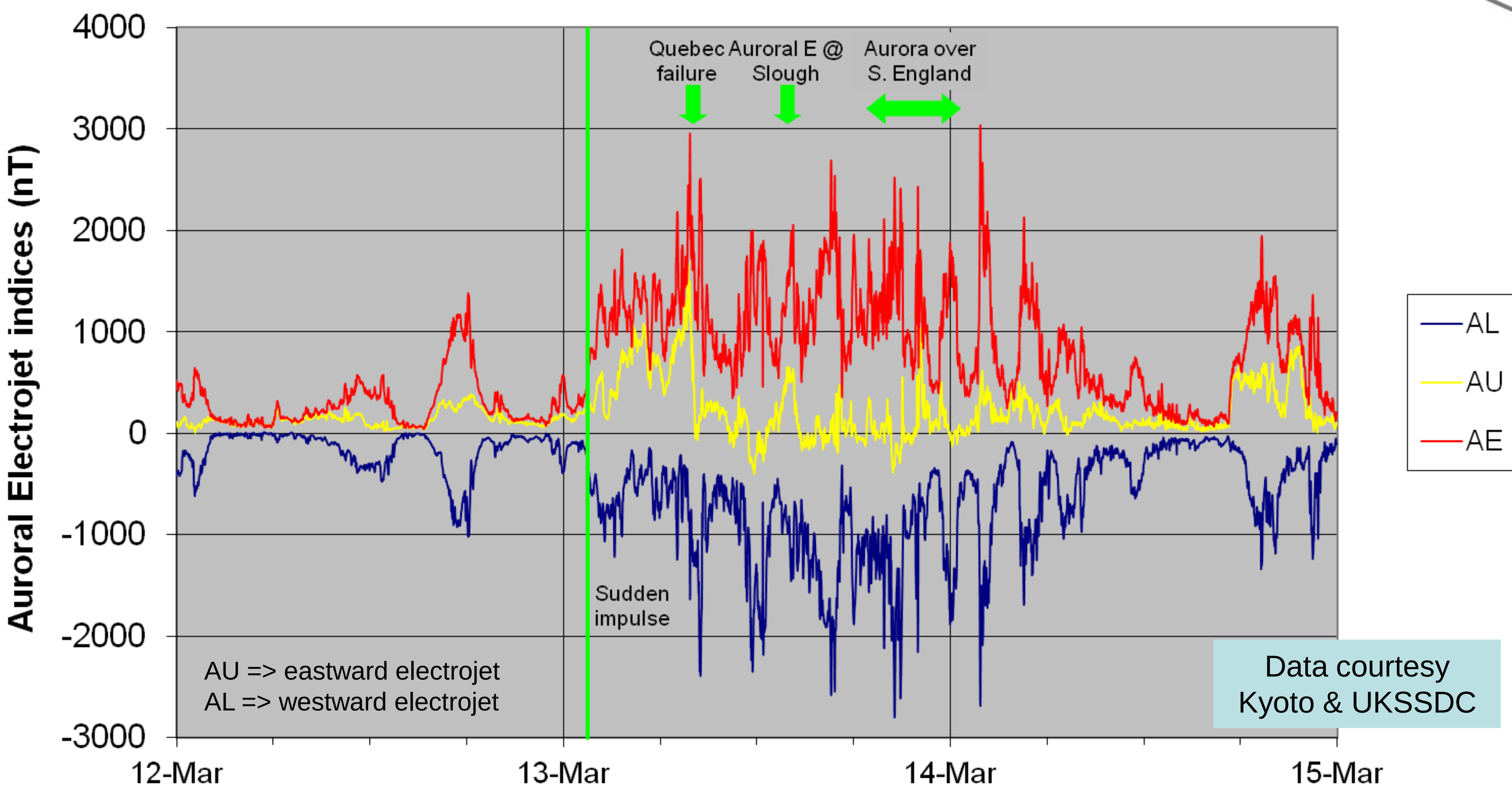
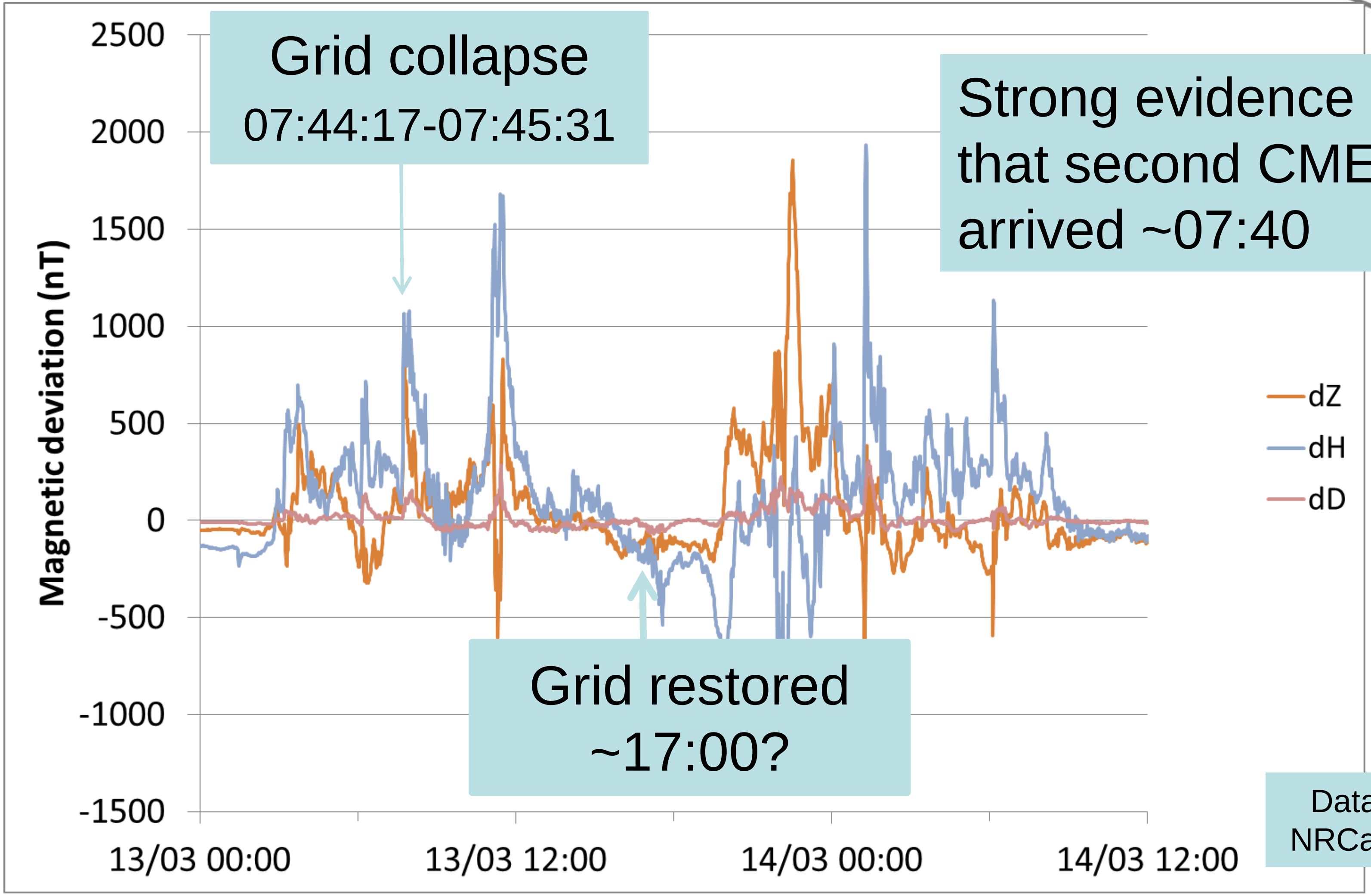
The March 1989 storm

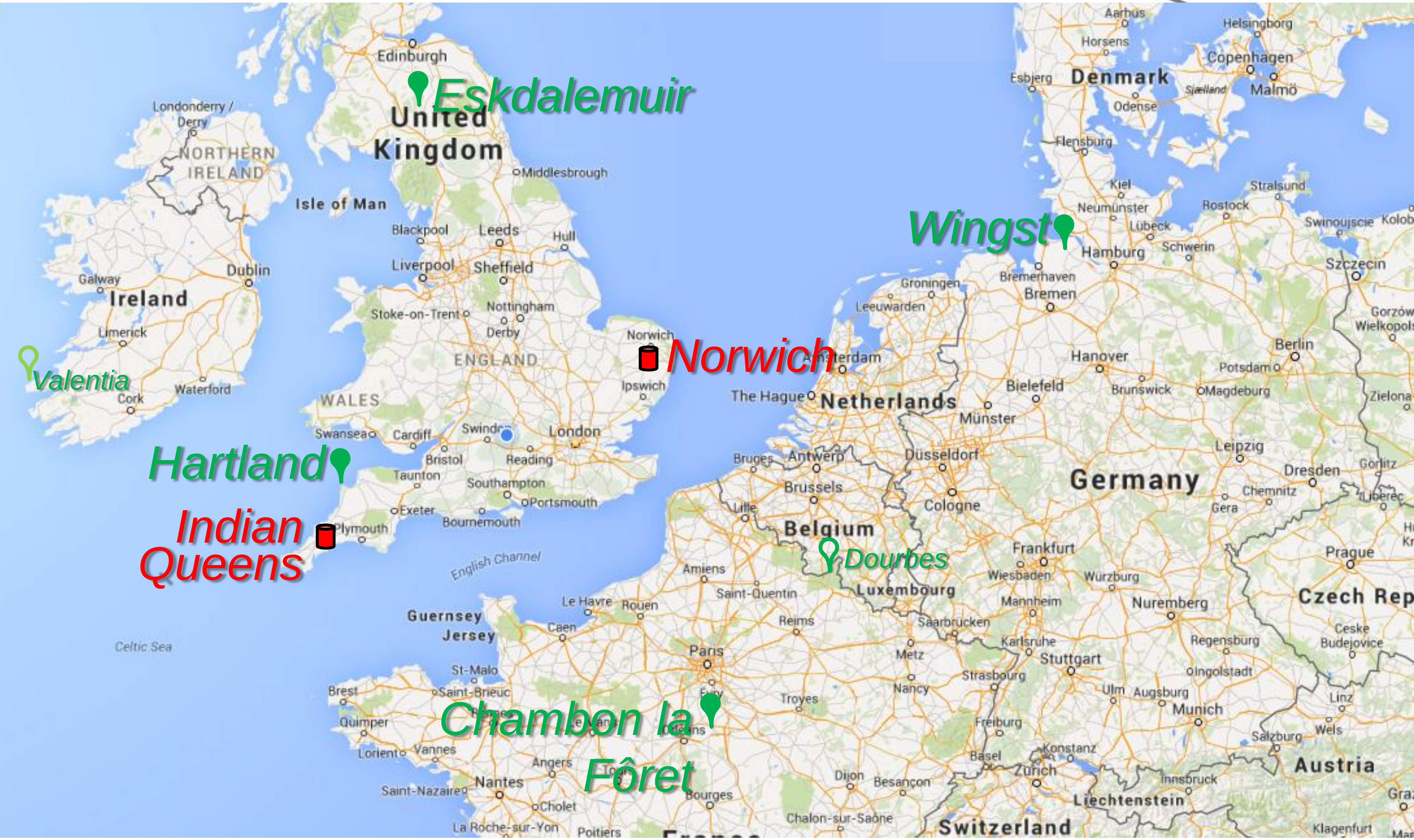


The storm in Canada:
Ottawa magnetometer



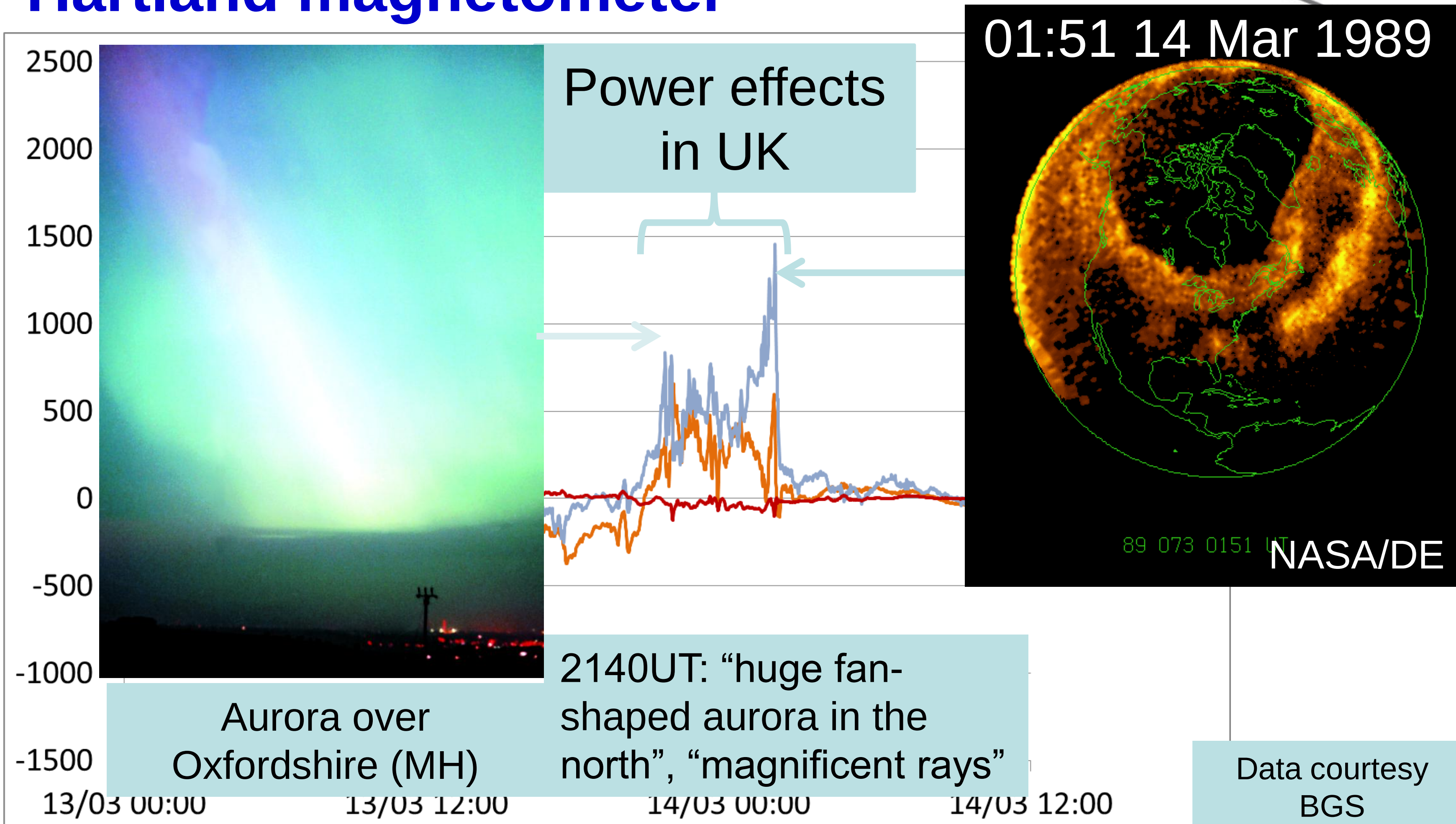
Data courtesy NRCan & NGDC

Now to Europe …



The Storm in S. England

Hartland magnetometer



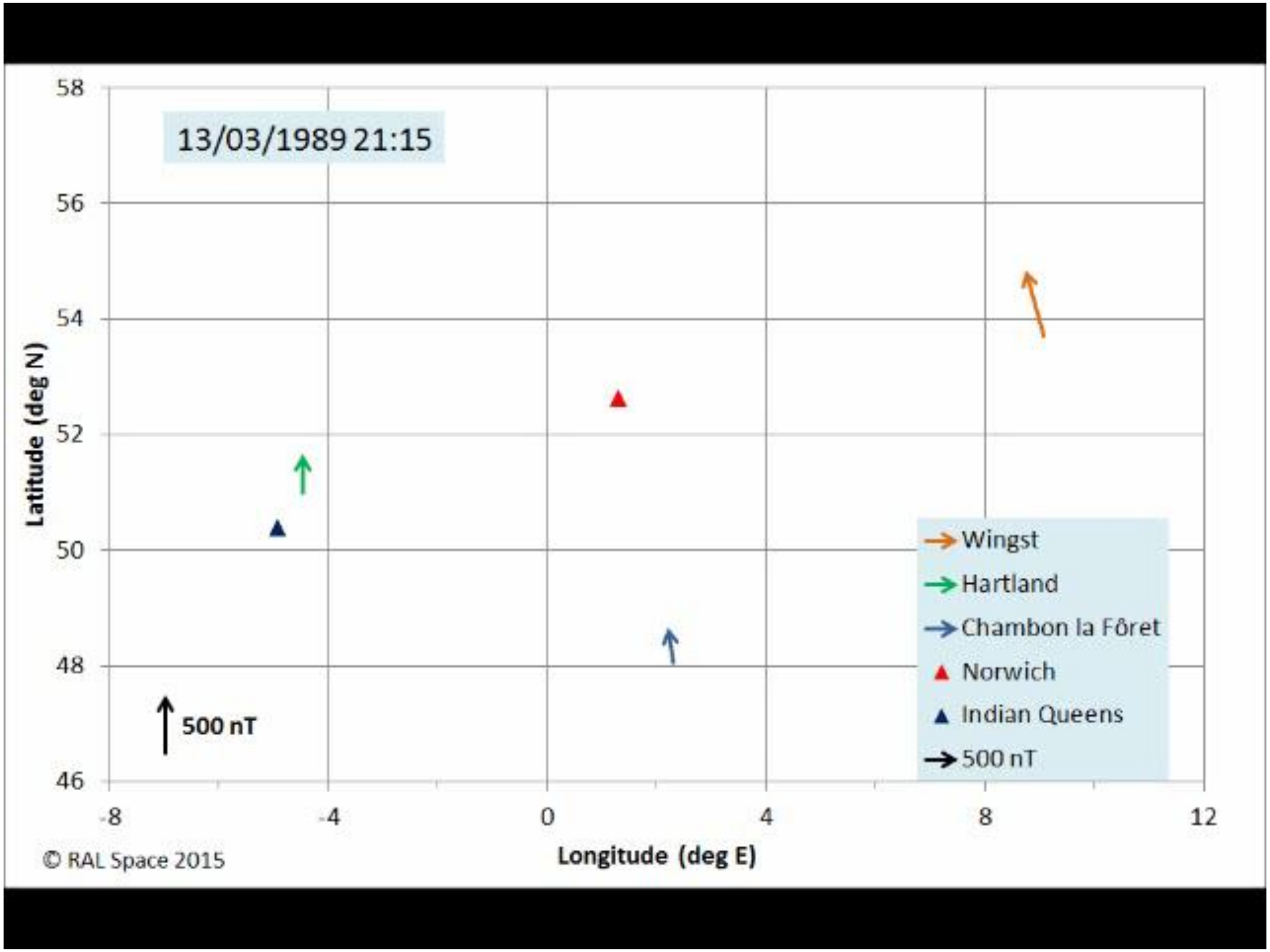
Aurora over Oxfordshire (MH)

Power effects in UK

2140UT: “huge fan-shaped aurora in the north”, “magnificent rays”

Data courtesy BGS

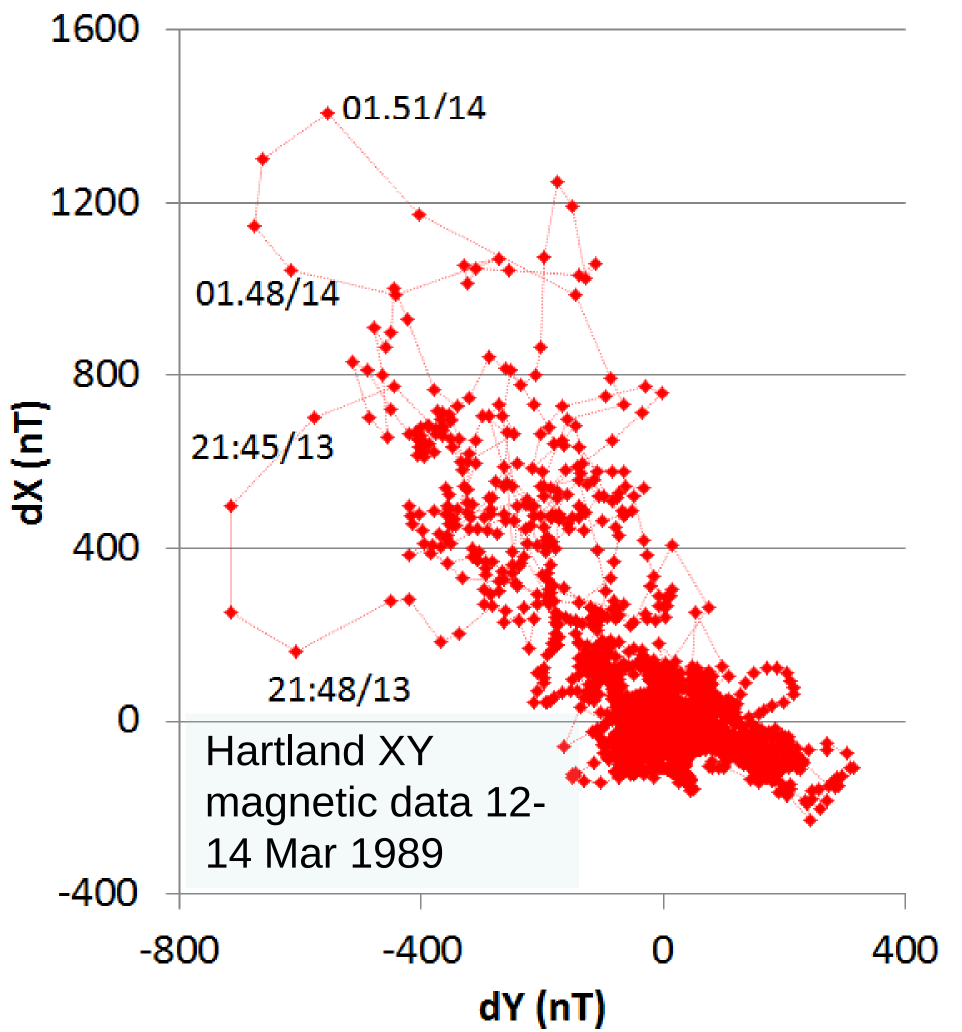
A wider picture



Vectors are XY deviation from mean XY

Data courtesy BGS (Hartland), GFZ/NGDC (Wingst), IPGP (Chambon le Fôret)

Rotating fields



- Hodogram confirms rotating fields in 1989 event over UK
  - Peak around 21:40/13 shows clear rotation
  - Also later peak at 01:50/14, but opposite sense of rotation

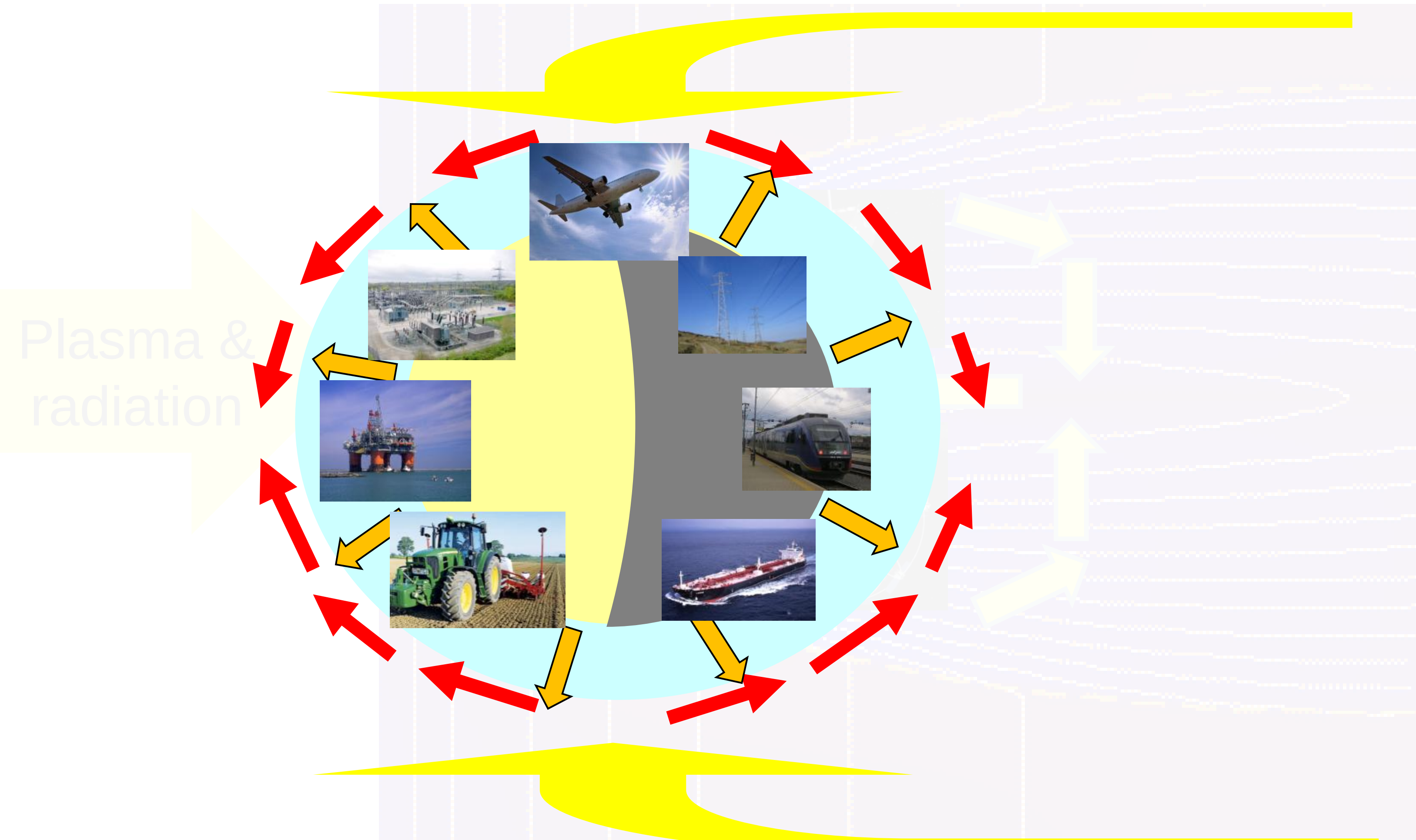
Data courtesy BGS

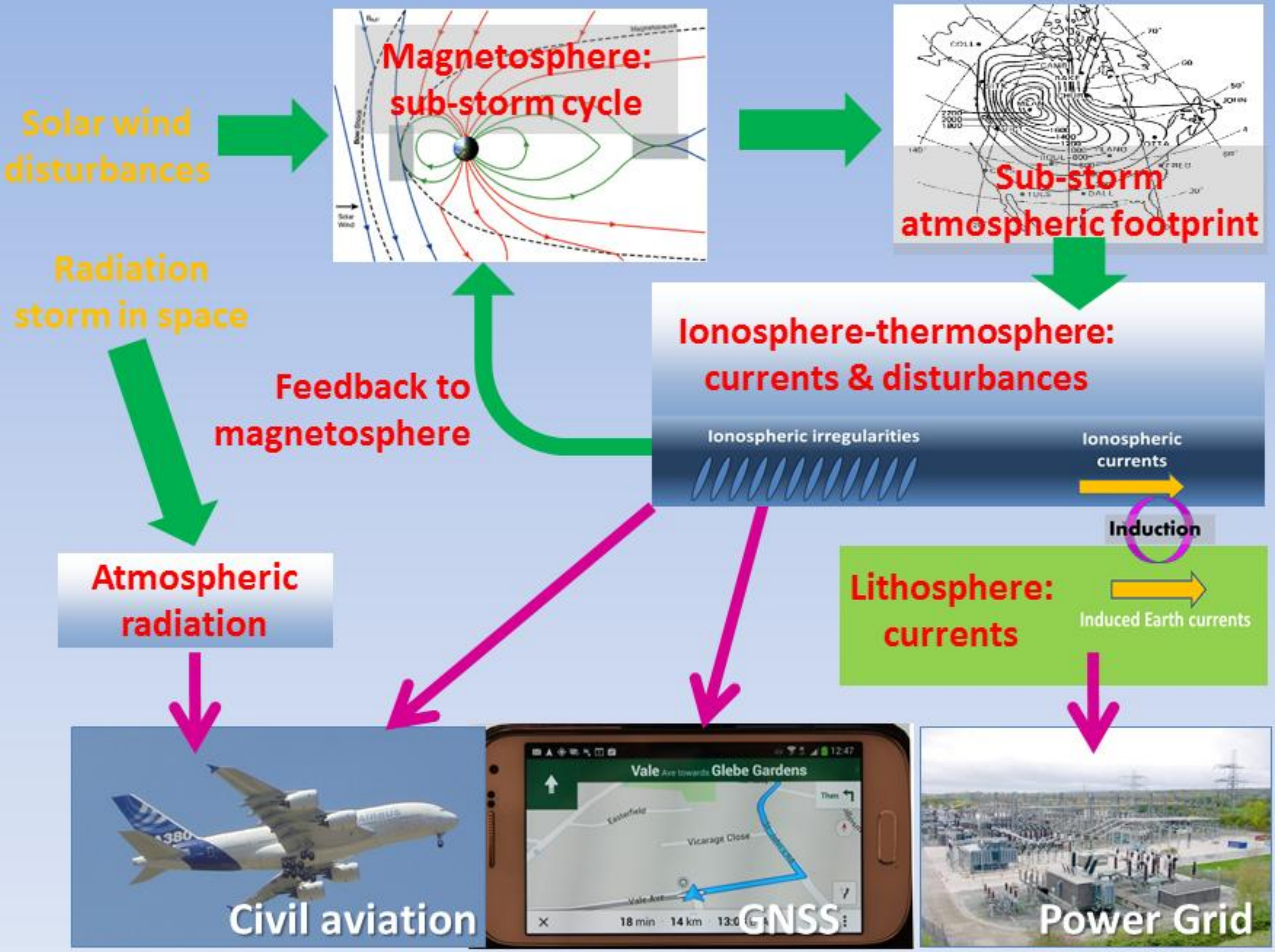
Summary

- Case for L5 space weather must be underpinned by realistic assessment of impact (esp. on power grids)
  - Engineering studies now suggest impacts of billions, not trillions.
  - Science of sub-storms reinforces this message; they drive intense localised features in auroral current systems
  - So individual sub-storms have regional impact (but series of sub-storms may impact multiple regions, eg Canada & UK as in 1989)
- Important to explore how L5 data can drive geospace models that include sub-storms
  - Not just older global response models (eg Kp forecasts)
- But also important to avoid hyperbole in our case
  - There is increasing awareness of space weather hyperbole in policy community; they stress the reasonable worst case

SPARES

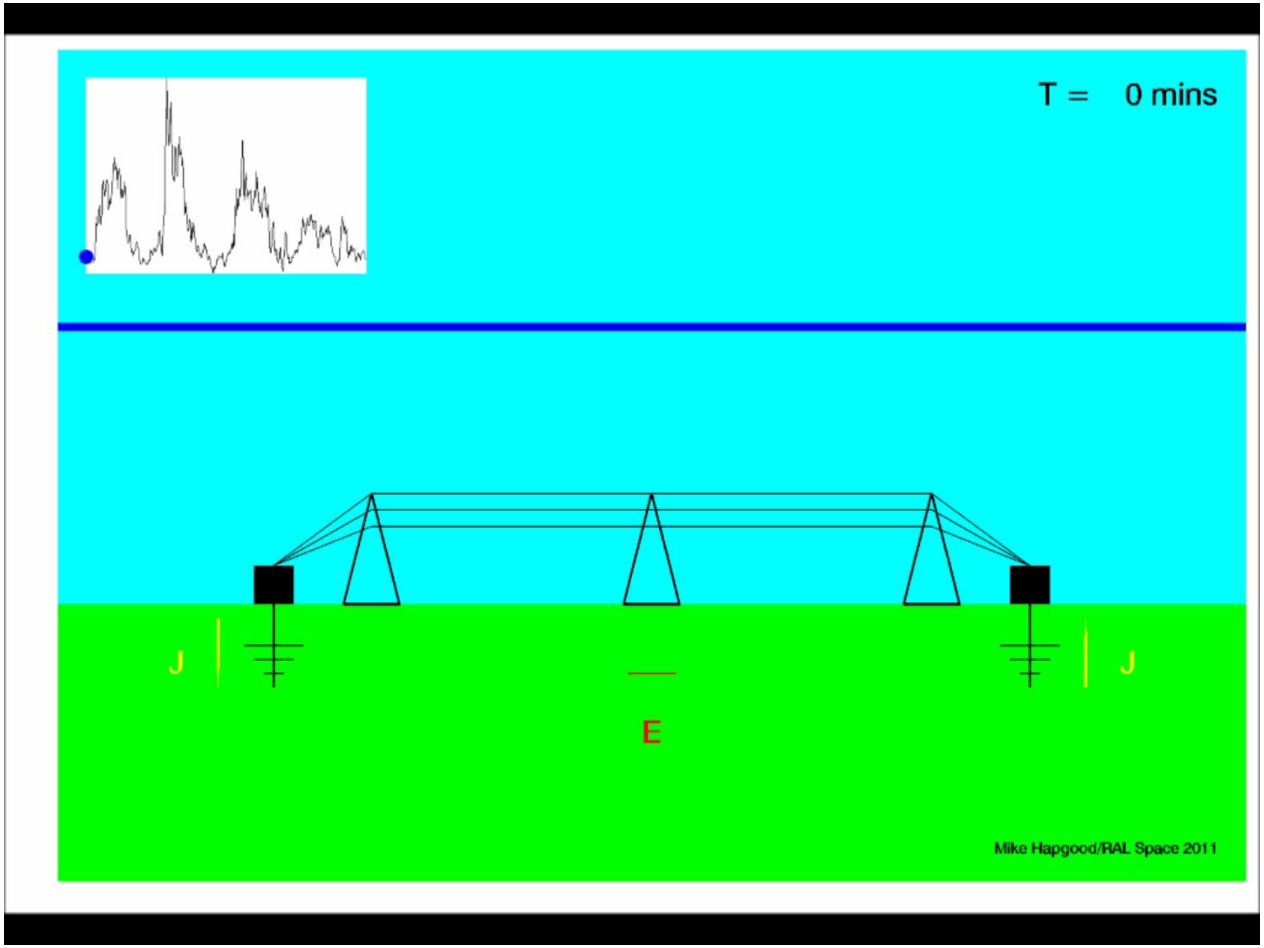
Geospace: focusing of space weather by Earth's magnetosphere





Solar wind disturbances
Magnetosphere: sub-storm cycle
Sub-storm atmospheric footprint
Radiation storm in space
Ionosphere-thermosphere: currents & disturbances
Feedback to magnetosphere
Ionospheric irregularities
Ionospheric currents
Induction
Atmospheric radiation
Lithosphere: currents
Induced Earth currents
Civil aviation
GNSS
Power Grid

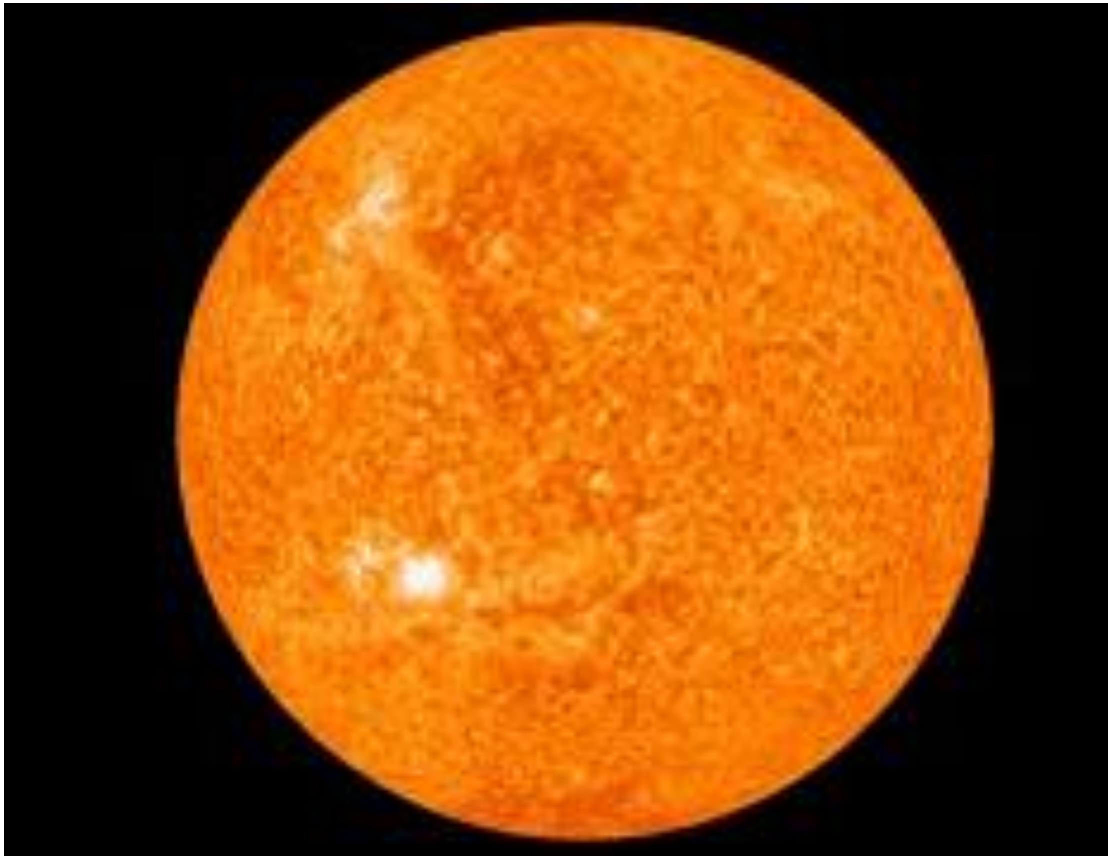
Electric currents in the Earth … and the grid



- Magstorms add quasi-DC electric currents to power grids
- Also other grounded infrastructure
  - Ocean cable power systems
  - Pipelines
  - Railway circuits

Predicting solar eruptions:
a long-term goal

RAL Space



- Nat Grid needs better multi-day forecasts of magstorms
  - Drive mitigation with higher skill score forecasts
  - Less false alarms
- Improve multi-day forecasts of eruptions
  - Track source 50 deg ahead of eruption!
  - COSPAR Roadmap

And finally …

https://www.youtube.com/watch?v=RNIqVONI_ZA

27 Feb 2014:

- major aurora seen across UK
  - great timing & superb skies
  - and tall aurora!
  - a wonderful natural phenomenon
- Key points
  - UK is close to auroral zone => high SpW risk
  - Major focus for public engagement