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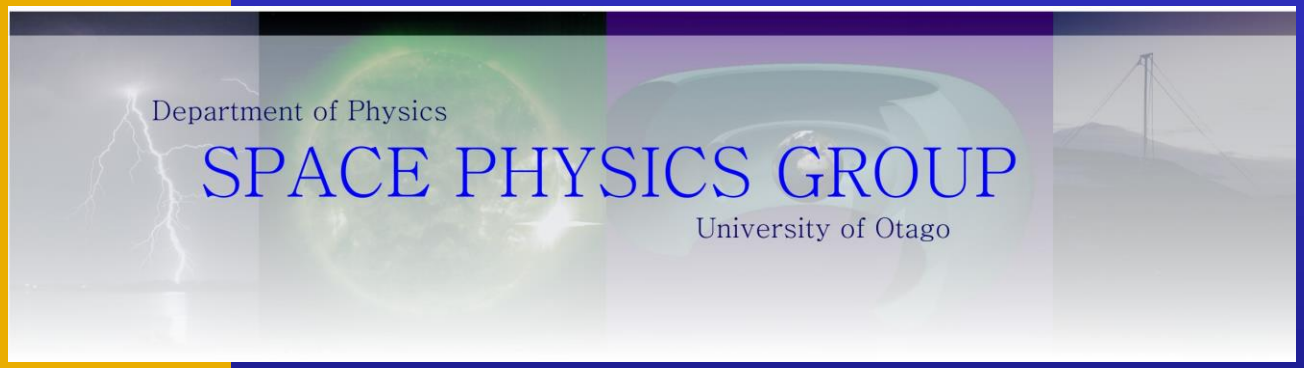
NEW ZEALAND

And then the Sun went "Bang"

An overview of Space Weather research



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NEW ZEALAND

Prof. Craig J. Rodger
Department of Physics
University of Otago
Dunedin
NEW ZEALAND

U3A Timaru
West End Hall, West End Park
130pm Monday 26 August 2019

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What is Space Weather?

"Space Weather" is a generic term for how the changing space environment impacts our technological systems. It is most commonly used to describe the links where processes which start on the Sun drive activity in and around the Earth which can pose a hazard to such systems.

There are multiple ways that different systems can be affected, through different physical processes.

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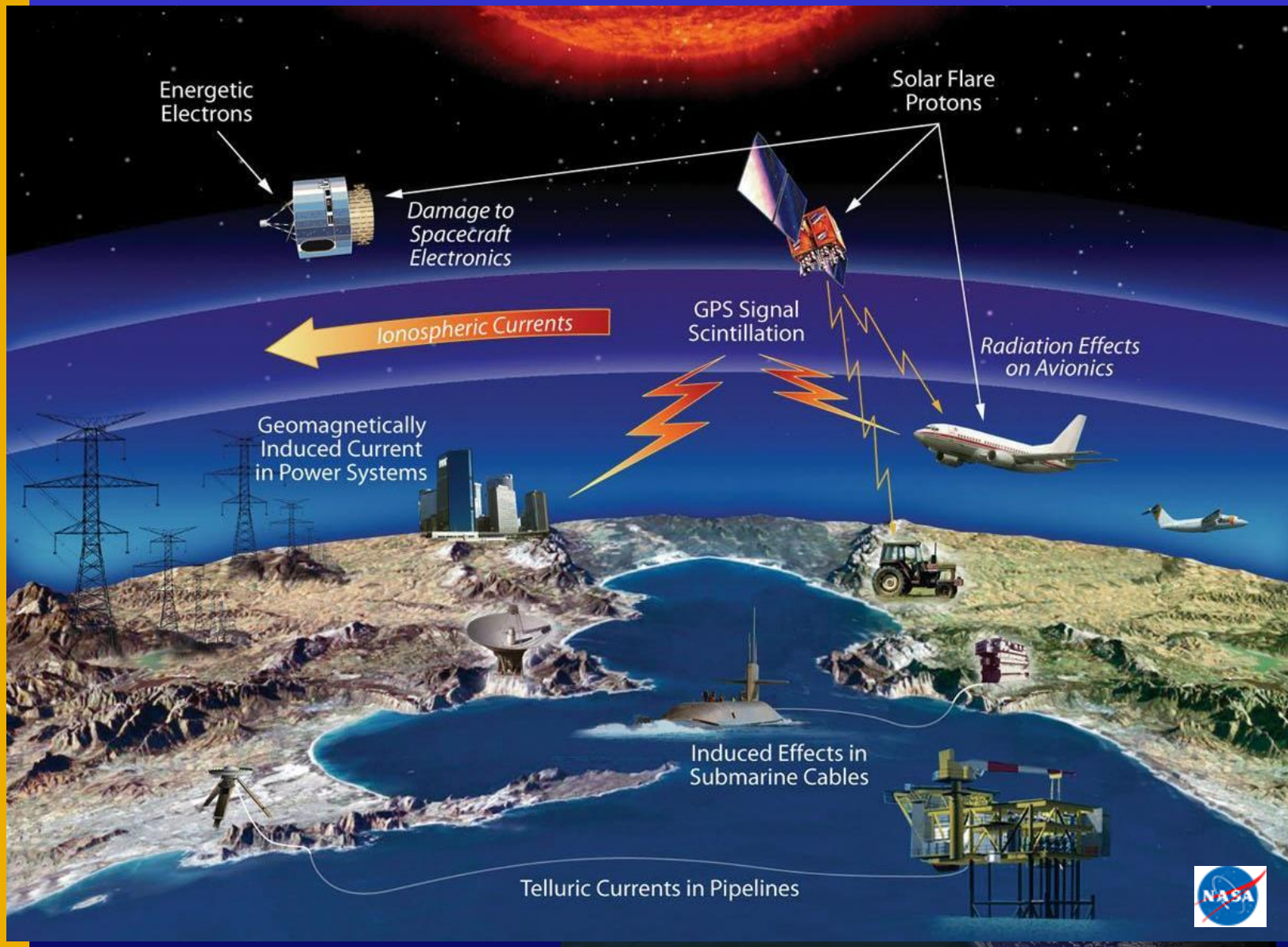
What is Space Weather?



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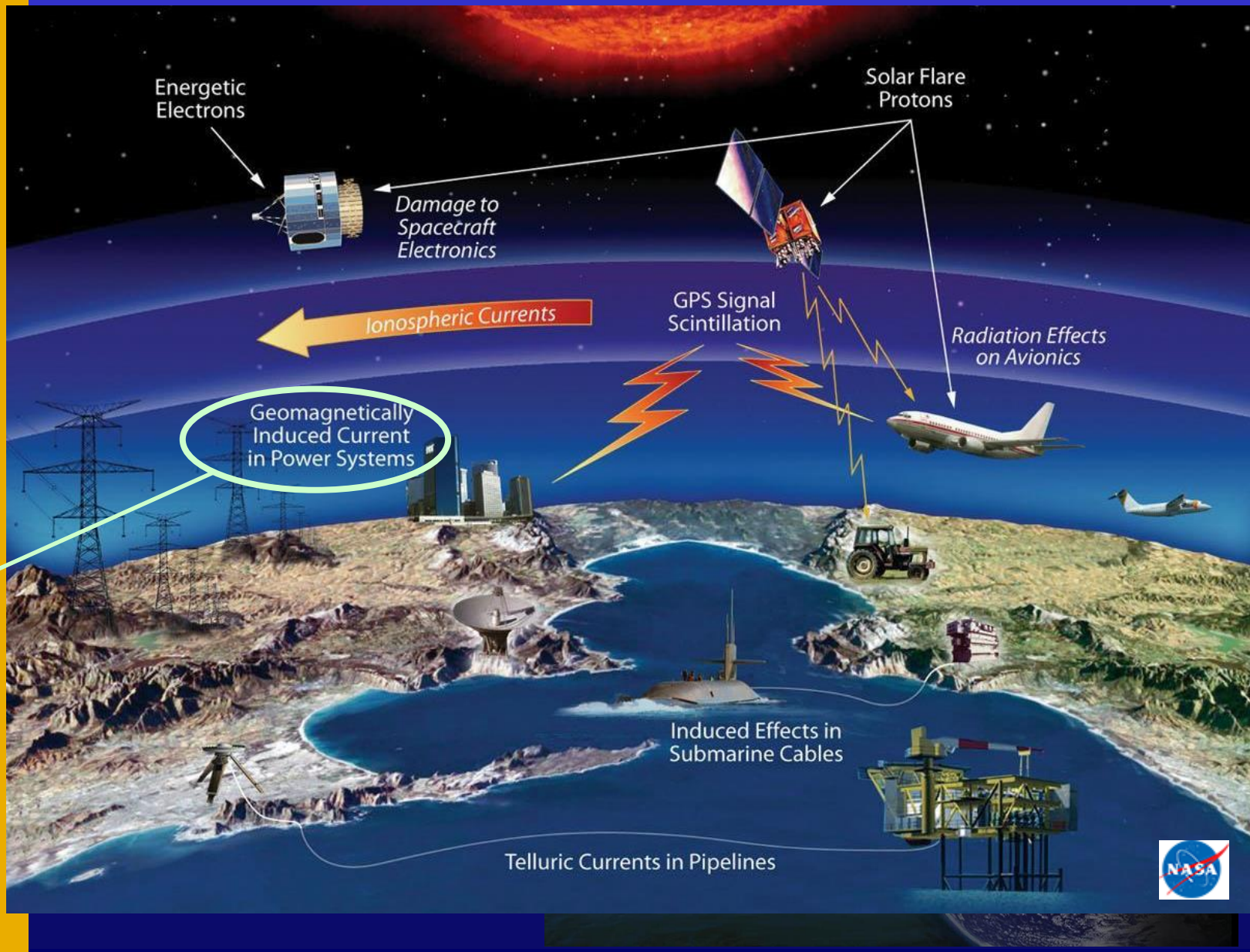

My group has recently started work in NZ on this issue (more later).

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The Source of Space Weather

We normally view the Sun as being unchanging with a constant output. And as far as Sun light, warming the surface of the Earth, this is very close to be accurate.

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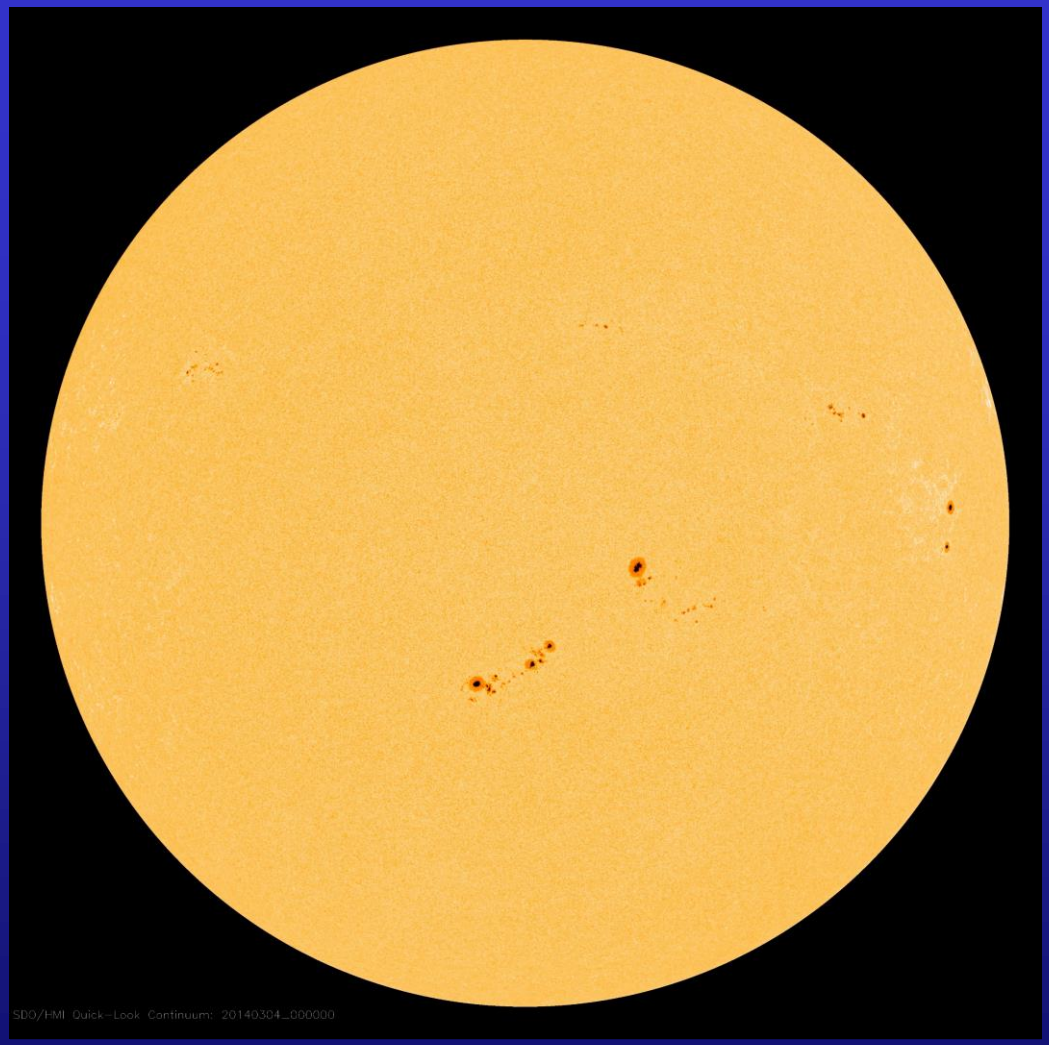
The Source of Space Weather



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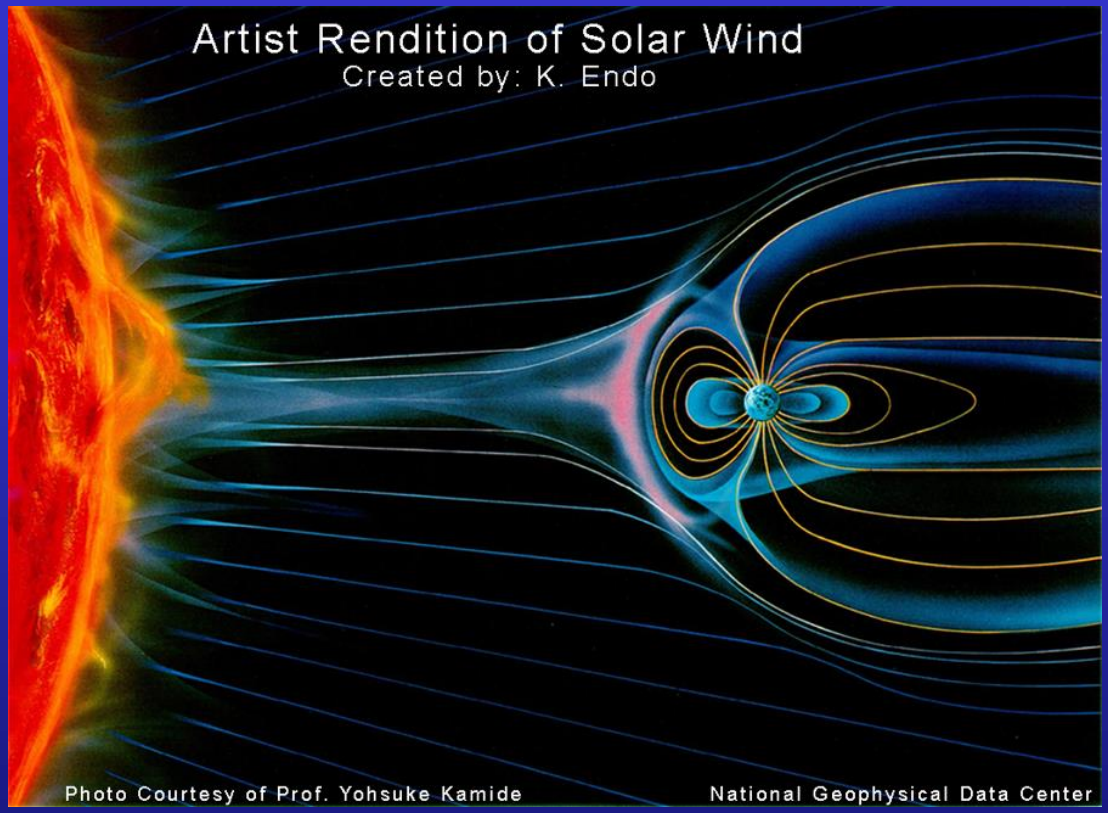
Sun-Earth connections

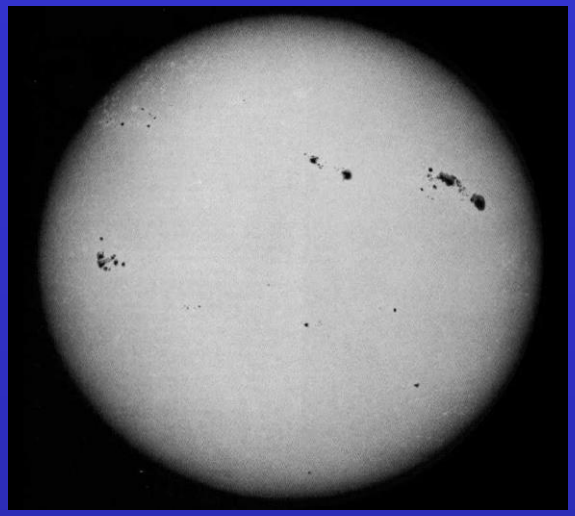


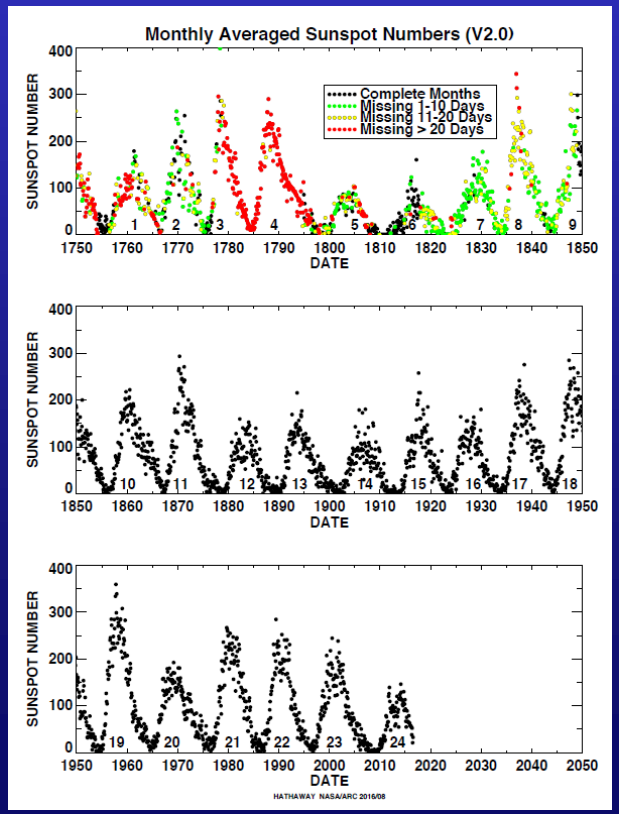
The Sun "forces" the Earth-system in multiple ways. Gravitationally (e.g., tides), electromagnetic radiation (e.g., heat) but also through a near constant stream of particles we call the "solar wind".

This is the normal situation, when the Sun is quiet.

The Sun and the Solar Cycle

Sunspots are dark spots on the *photosphere* where the temperatures are 2000 K cooler than the surrounds. A small "pore" is only 2500 km across and last for an hour, while the largest *sunspots* are 50,000km across and persist for many months.





- "Discovered" by Galileo Galilei in 1610.
- Records have been kept since the mid - 17th century (daily observations from Zurich since 1749).
- period is ≈ 11.4 years.

http://solarscience.msfc.nasa.gov/images/Zurich_Color.pdf

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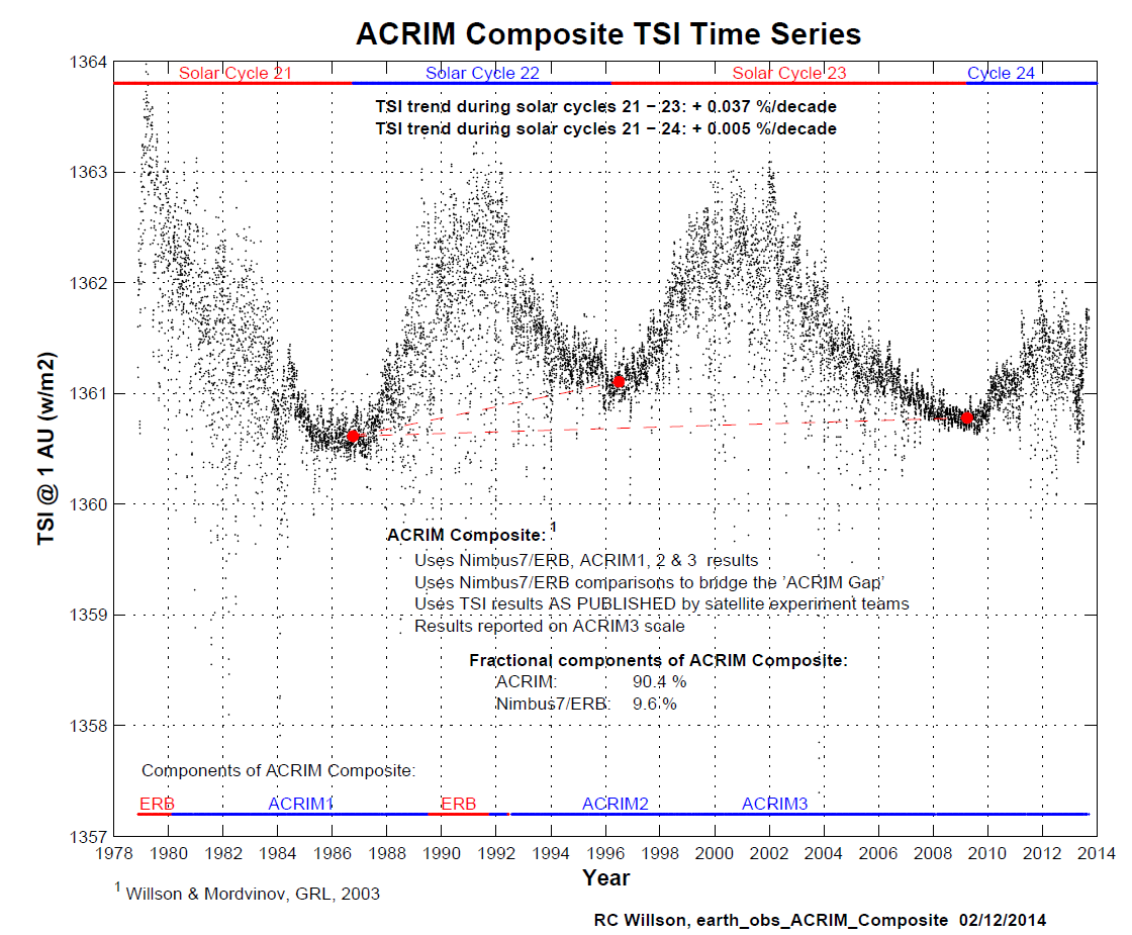
Total Solar Irradiance

Of course total solar irradiance (summed over all wavelengths) hardly changes. This used to be know as the solar constant, but satellite measurements show that it varies by ~0.08% over the 11-year sunspot cycle (less power during solar minimum).

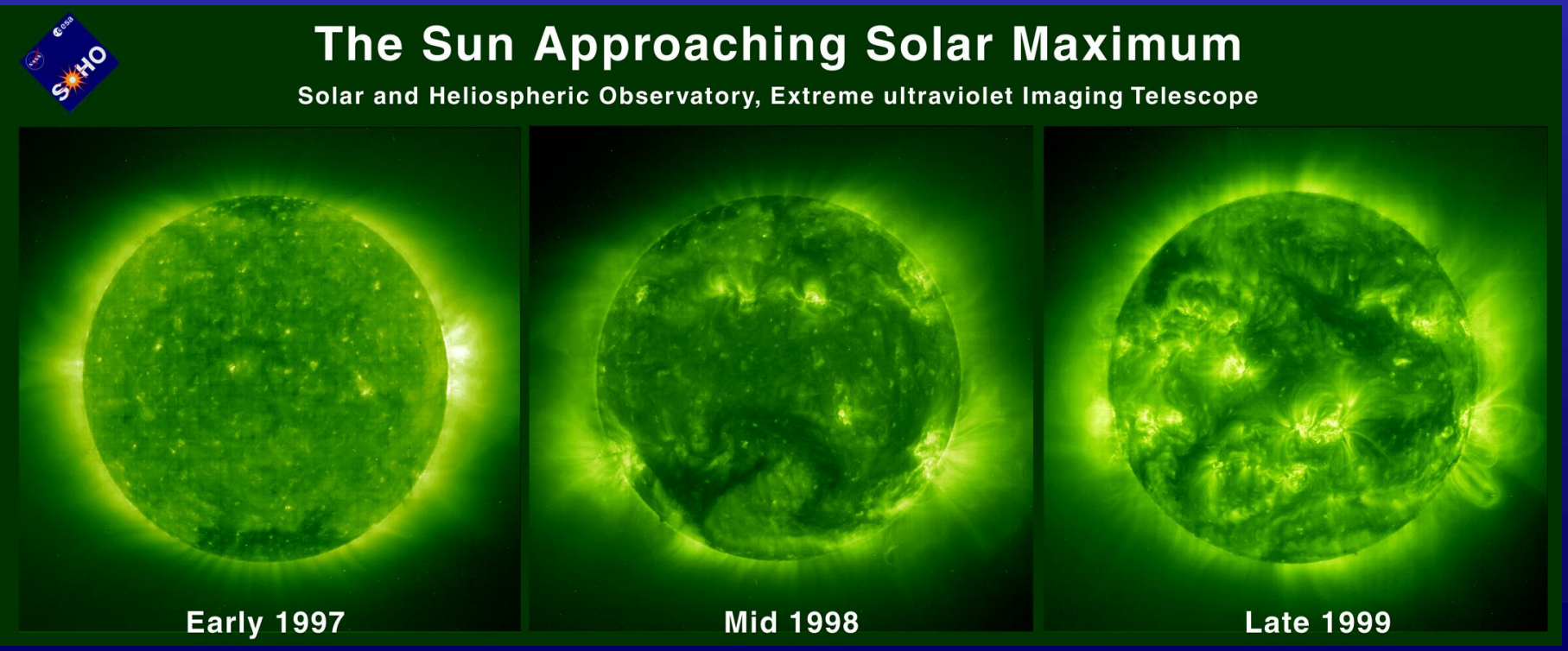


Solar Extreme UV

Note that the more energetic radiation (EUV and X-rays) changes significantly over the solar cycle, even if they are not very significant to the total energy present in the extraterrestrial beam.

EUV ~300 Å ~10 times more at solar max than min

(also more energetic, ~10 times more than the UV which does reach the ground)



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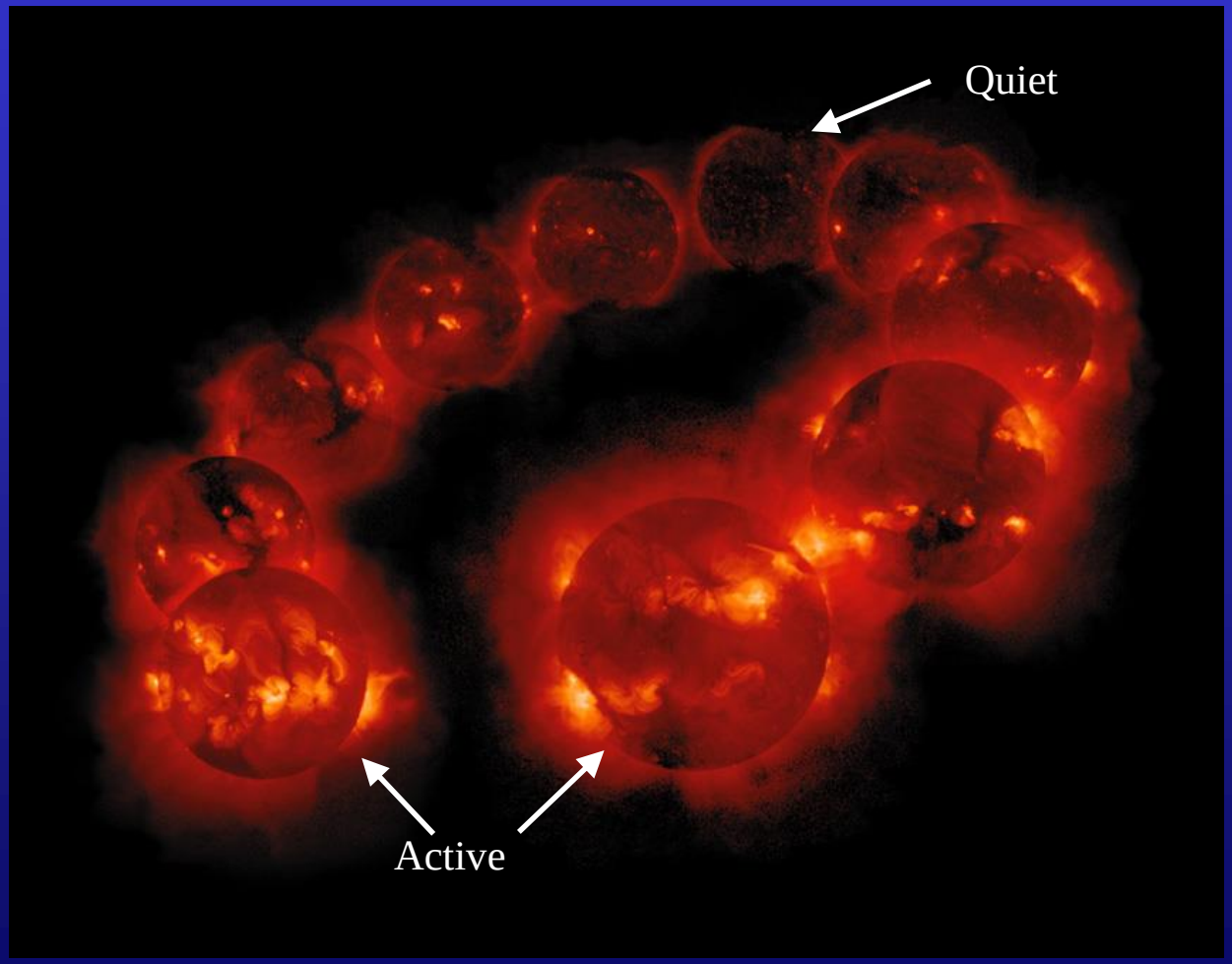
Solar X-Rays

The most dramatic changes are seen when one looks at X-ray wavelengths. At *solar maximum* (most *sunspots*) there is 100 times more X-ray energy at ~1-10 Å than at **solar minimum**.



"**Changing Sun**" mosaic were created by Greg Slater and Charlie Little (LMSAL) using the Yohkoh Soft X-Ray Telescope. **10 images spaced ~9 months apart over 7.5 years.**

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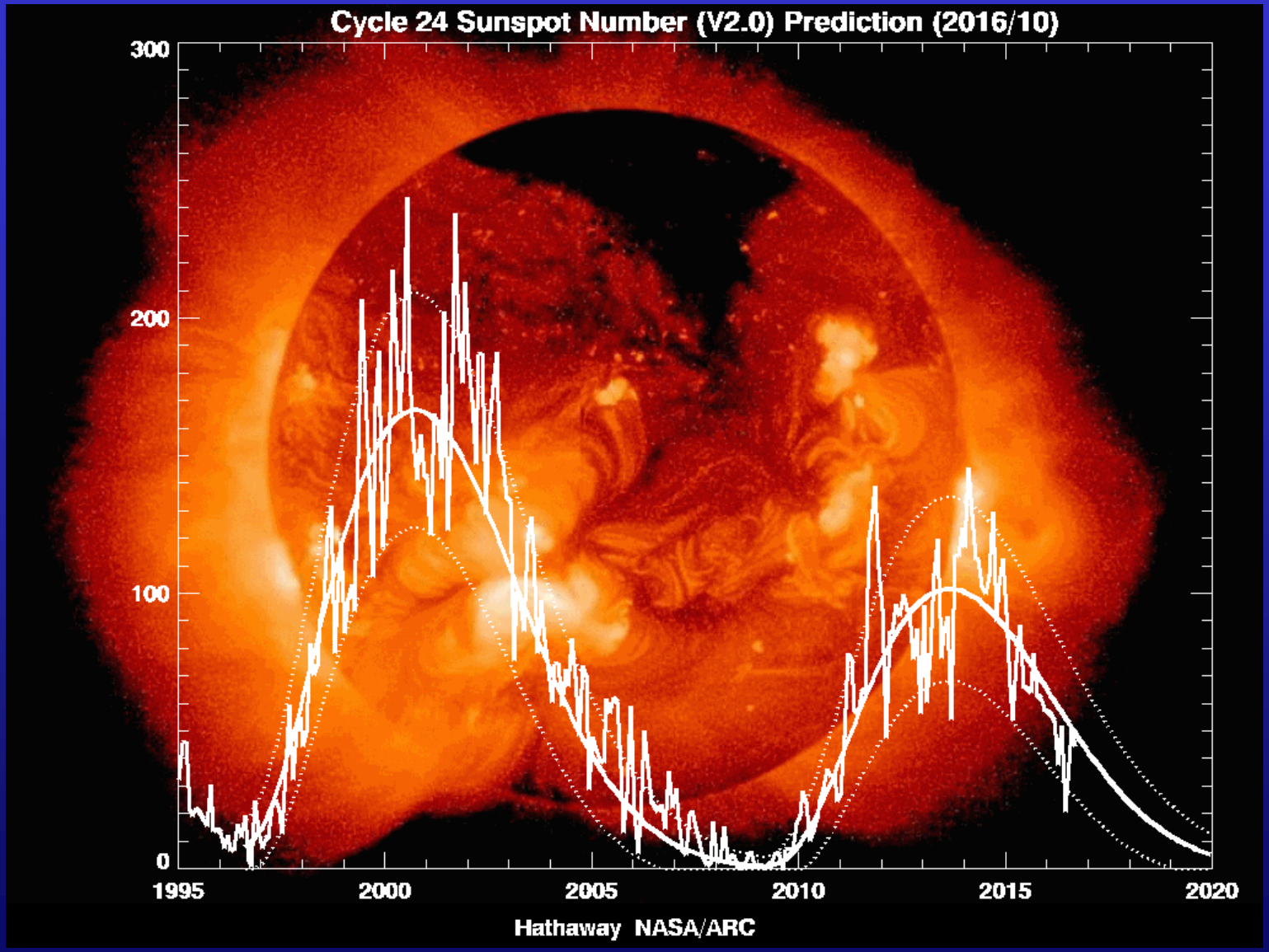
Where are we now in the cycle?



But in December 2016 David Hathaway (NASA) retired.

http://solarscience.msfc.nasa.gov/images/ssn_predict_l.gif

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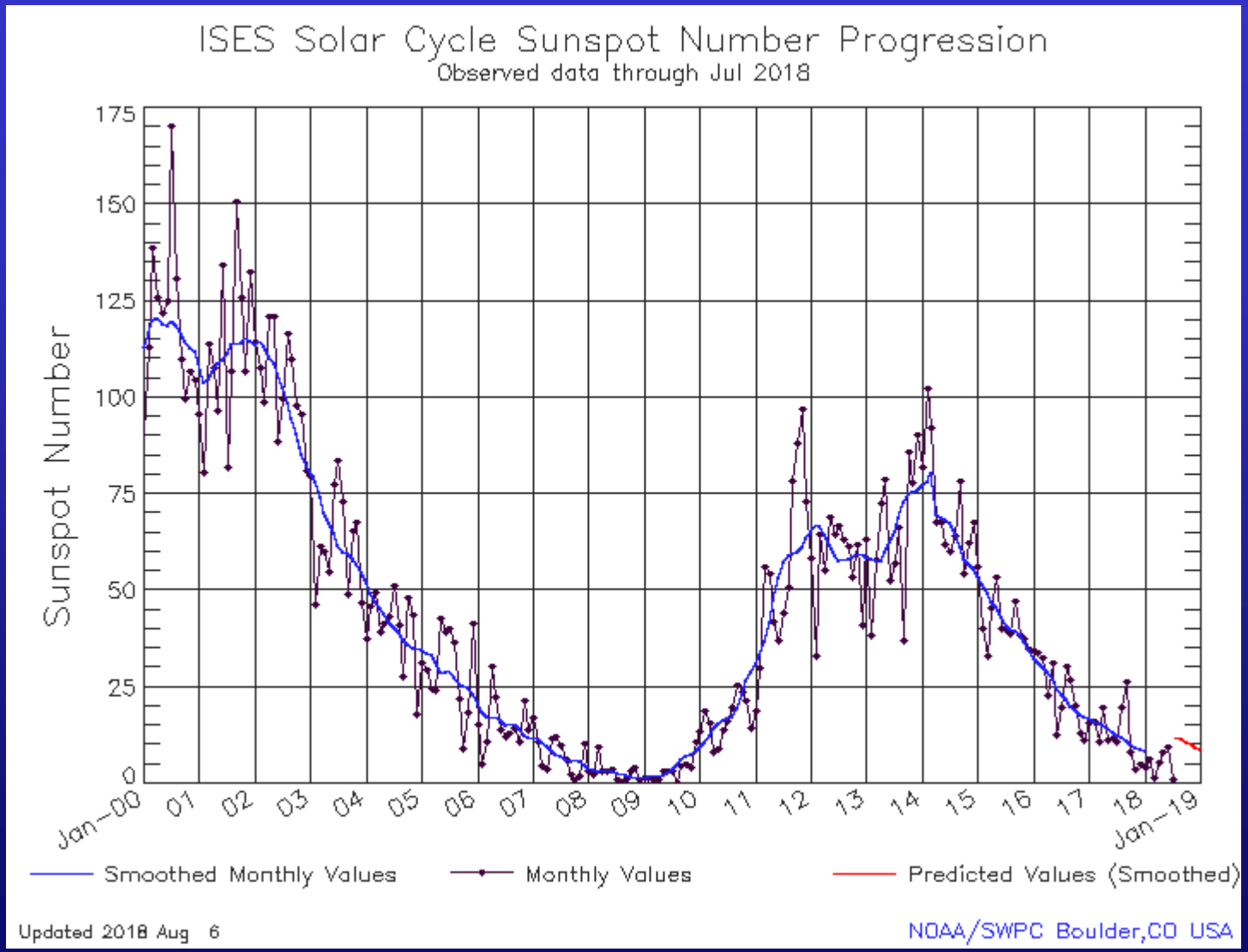
So, where are we now in the cycle?



https://www.swpc.noaa.gov/products/solar-cycle-progression

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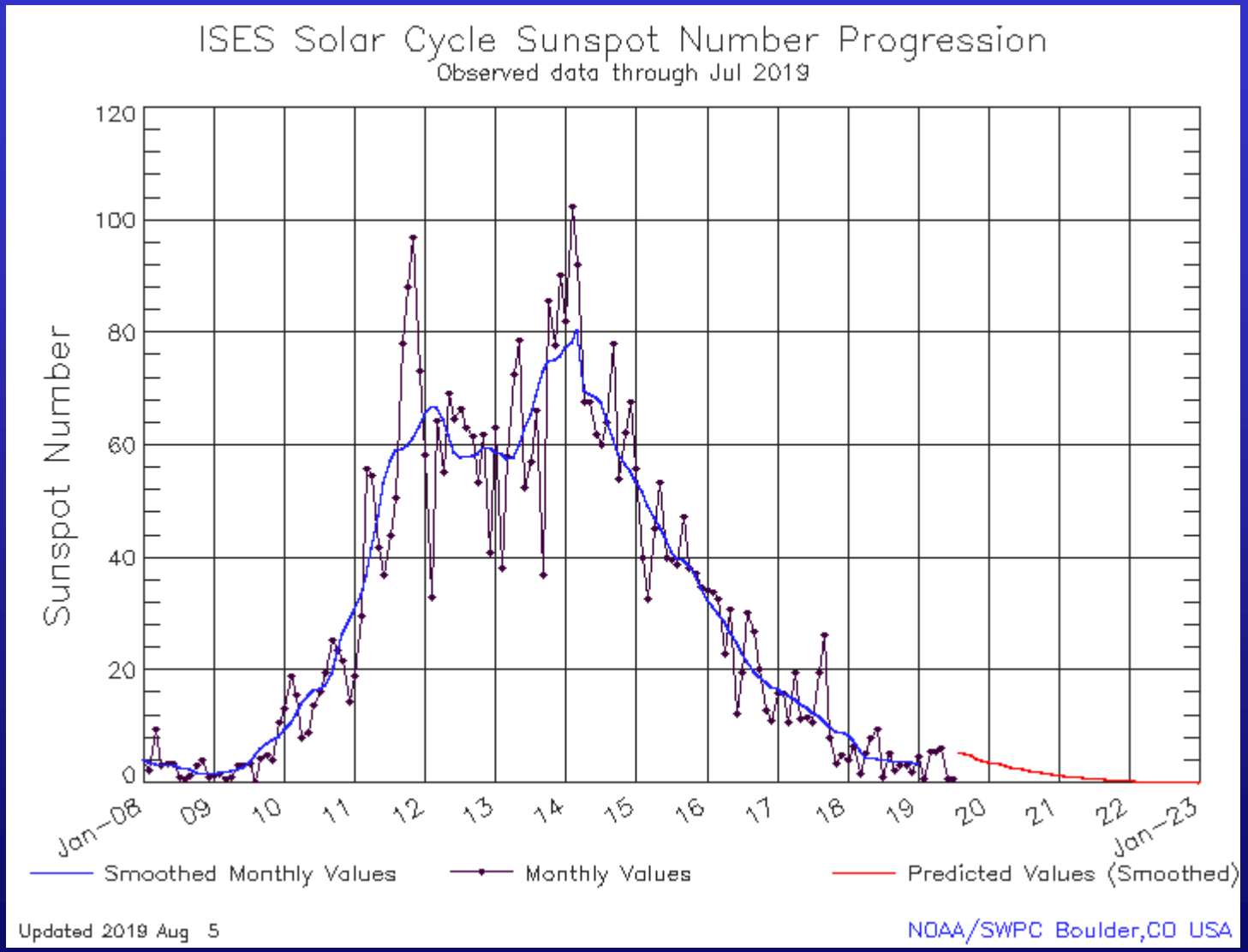

https://www.swpc.noaa.gov/products/solar-cycle-progression

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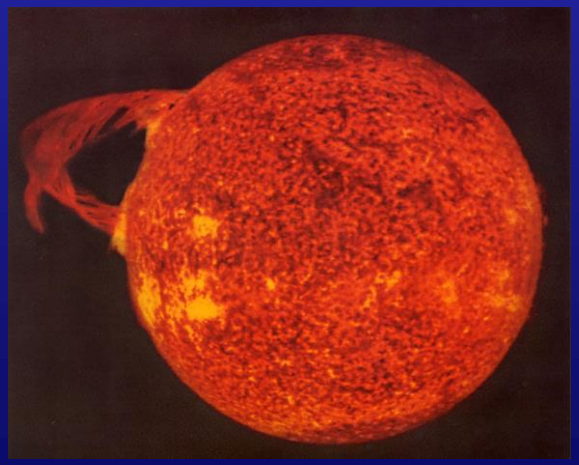
What happens when the Sun goes bang?

When the Sun is active, as well as the background total energy output of the Sun going up (a small amount), it is also more likely to "go bang" – that is, the biggest explosions in the solar system occur on the surface of the Sun. A number of processes can occur, all of which have effects on the Earth's environment – and can impact on human activity.

Lets look at each in turn:

- X-ray flare
- Solar Proton Event/
  Solar Energetic Particle Event
- Coronal Mass Ejection
- Geomagnetic Storms

Let us examine each one in turn.



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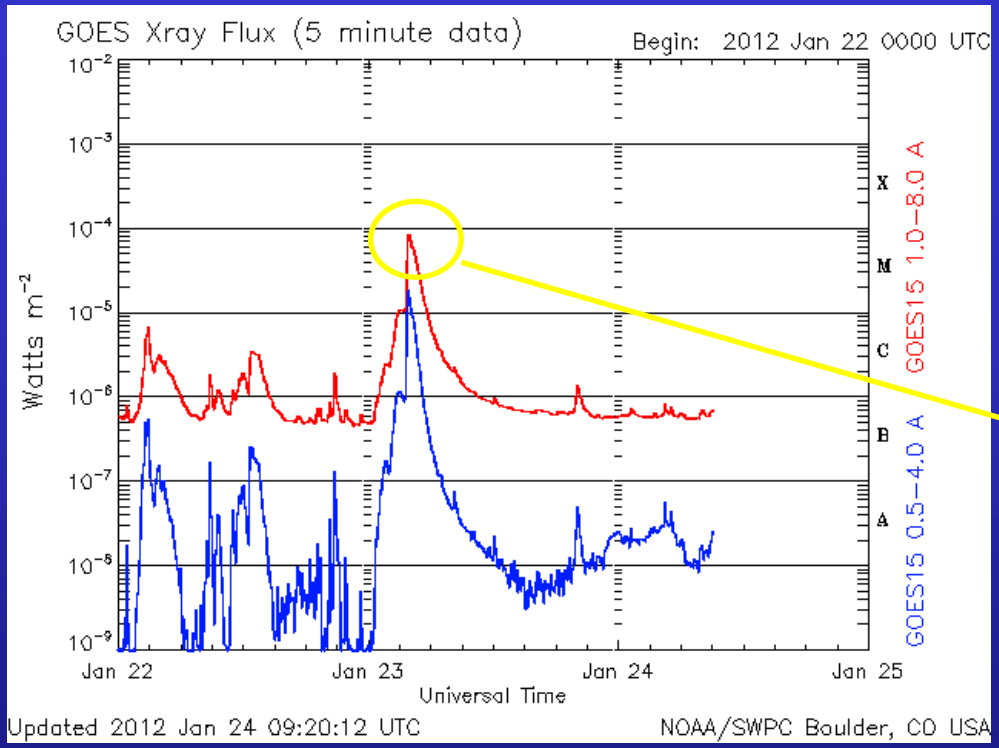
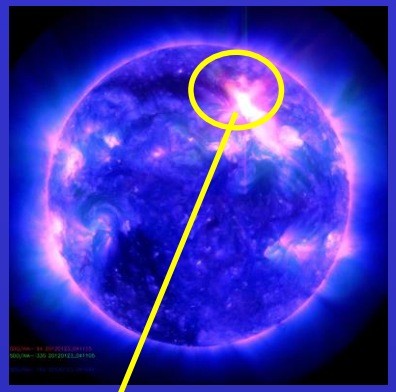
Solar X-ray Flares





X-ray flare from early January 2012 at ~4UT.

A solar flare is a violent explosion in the Sun's atmosphere releasing up to a total energy of 6×10^{25} Joules (this is equivalent to a 14 billion mega ton H-bomb).

Solar flares take place in the solar atmosphere, heating plasma to 10's of millions of degrees. Most flares occur in active regions around sunspots. Flares are powered by the sudden release of magnetic energy stored in the corona on the timescales of minutes to 10's of minutes.

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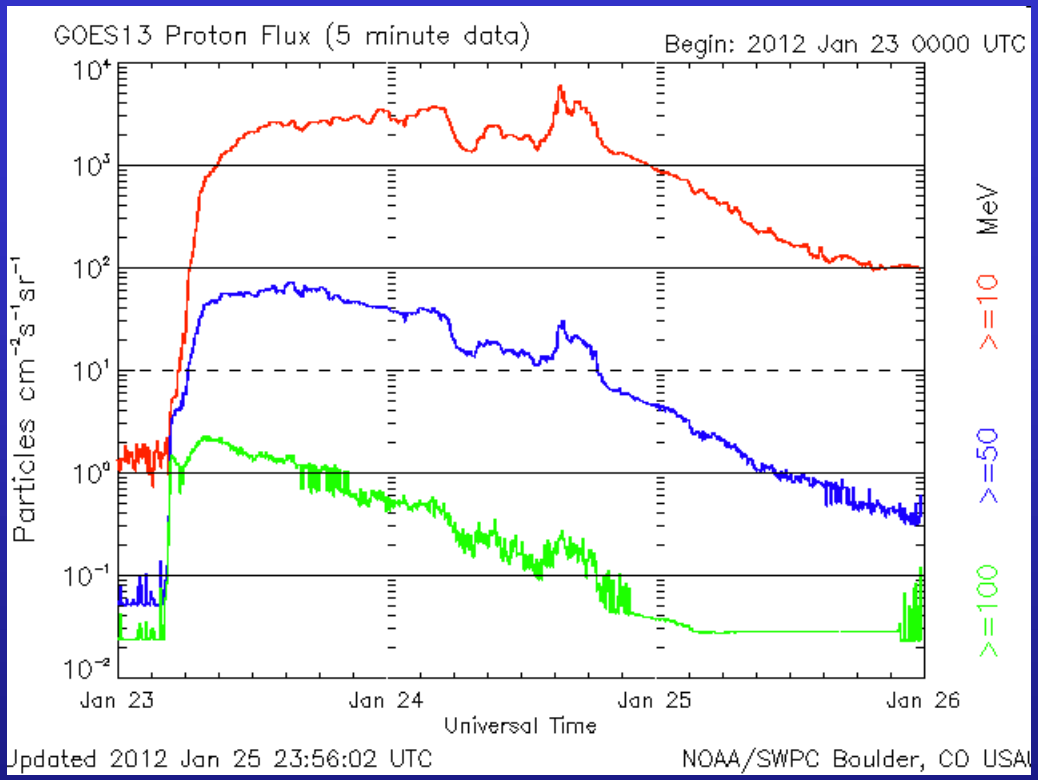
Solar Proton Events



The highest energy component of proton population which comes from the Sun is at relativistic levels. They have kinetic energies so high that they reach the Earth within minutes.

As these are charged particles, they are funneled into the polar atmosphere by the magnetic field of the Earth.

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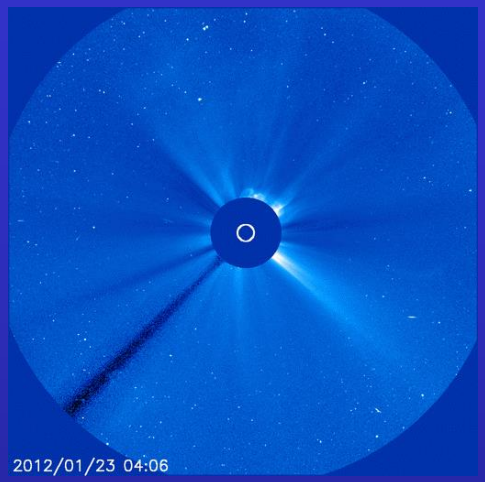
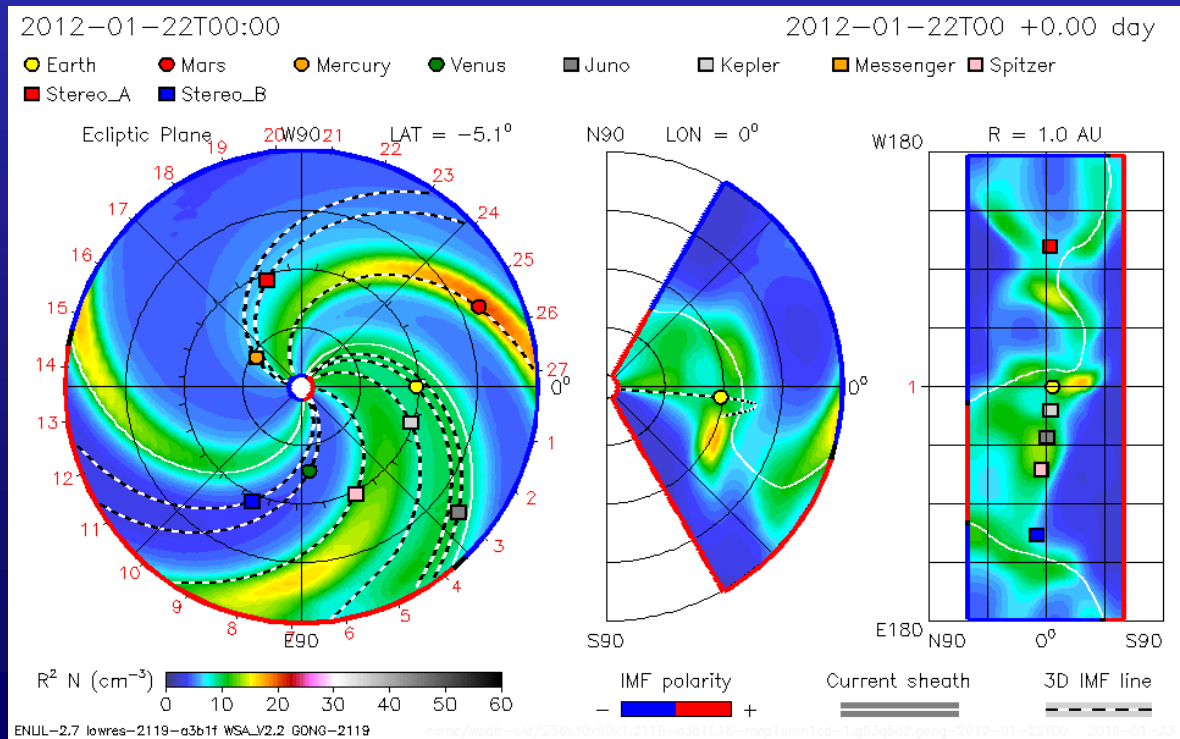
Coronal Mass Ejections



SOHO satellite view on 23 January 2012.

CME launched by the X-ray flare event.



NASA Goddard Space Flight Centre Modelling.

This work showed the CME was likely to strike the Earth late afternoon (~14:18UT) on 24 Jan 2012.

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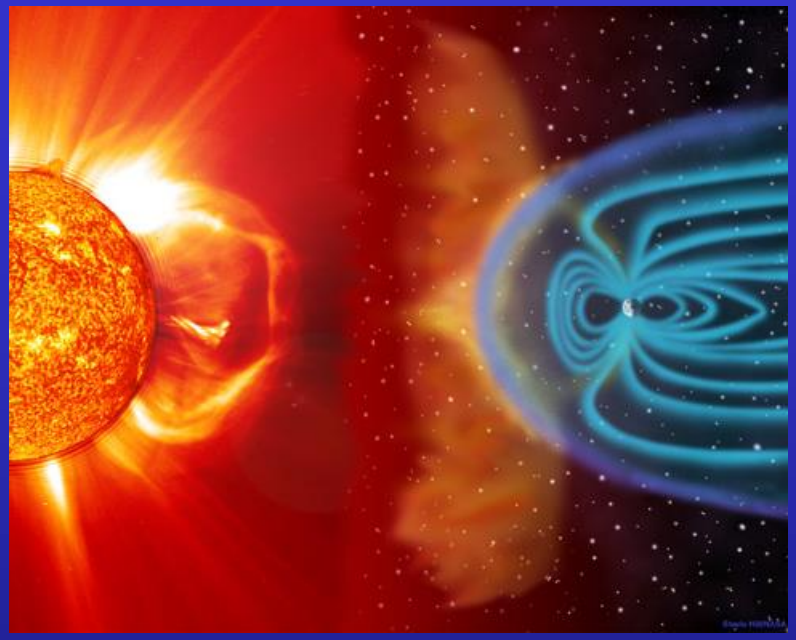
Geomagnetic Storms



The space around the Earth is dominated by the Earth's magnetic field, which protects our atmosphere from the solar wind. This forms the magnetosphere.

When a CME hits the magnetosphere, it is squashed, changing the field shape, setting up currents in space and on the ground, and triggering a geomagnetic storm.

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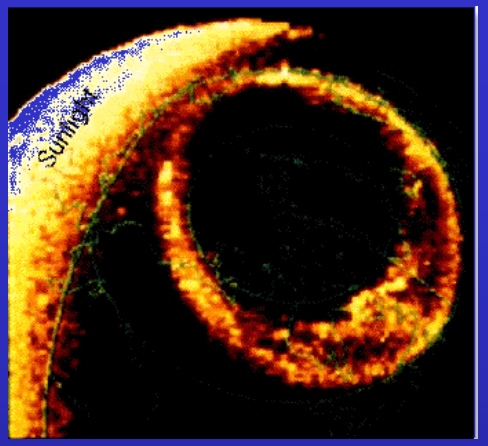
Geomagnetic Storms

One consequence of a geomagnetic storm is an enhancement in aurora seen in the atmosphere above the north and south poles.



Auroral Oval seen from space.

Example of aurora seen over Dunedin (New Zealand) in November 2004.

Example of Aurora Australis seen from the International Space Station (17 Sept 2011)

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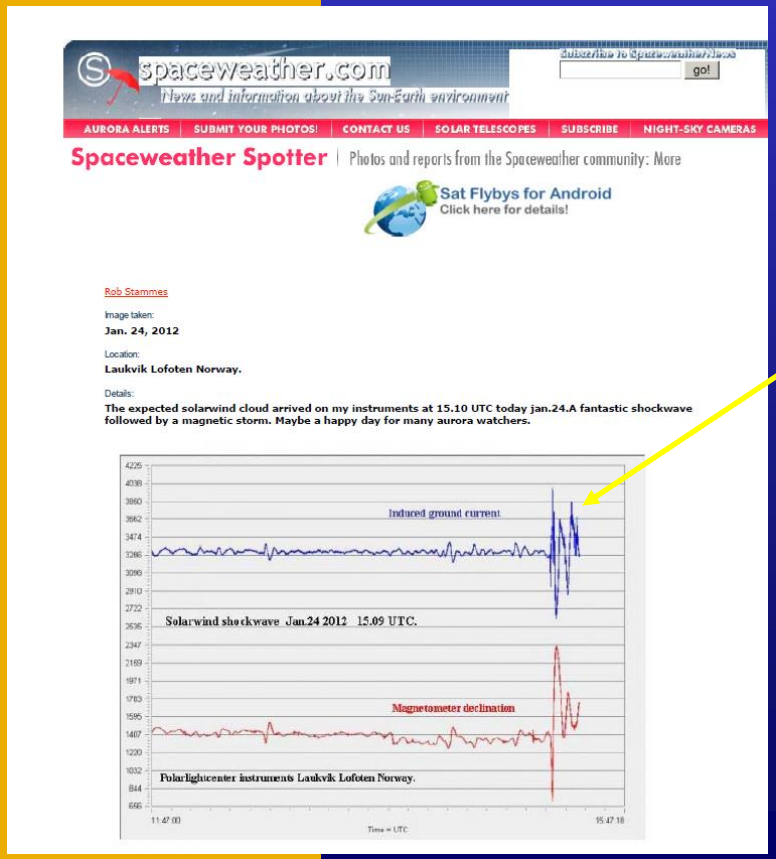
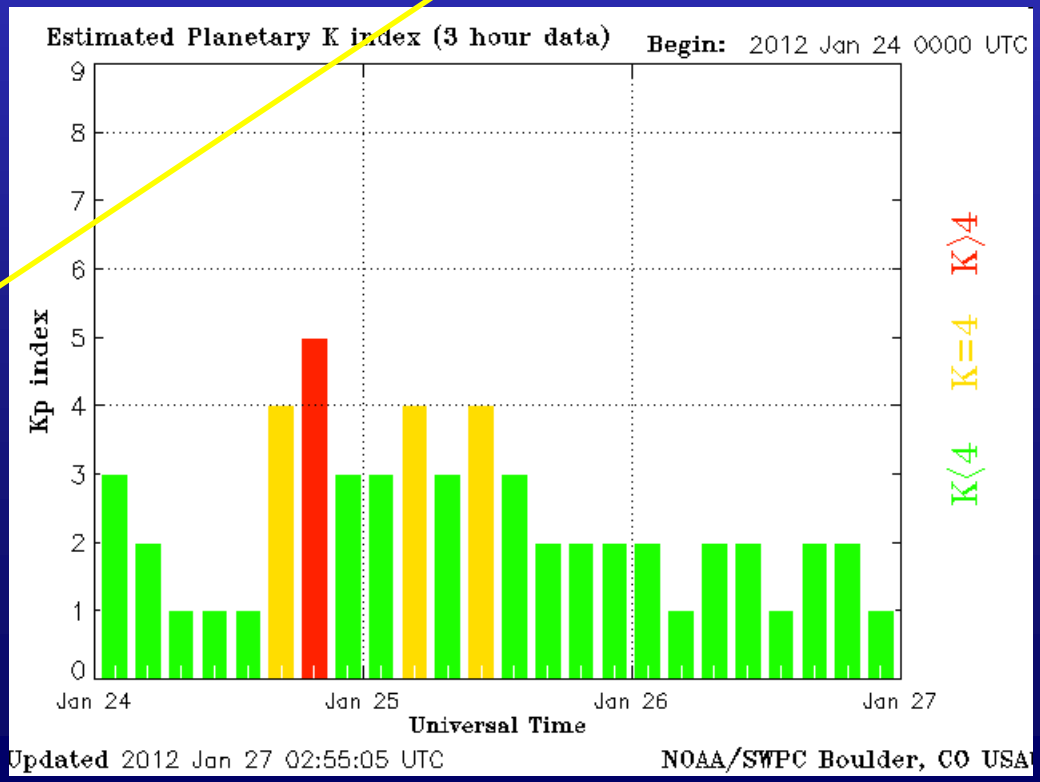
Geomagnetic Storms

The Goddard modelling suggested that the CME launched on 23 January 2012 would hit the Earth at 14:18 UT on 24 Jan 2012, with an uncertainty of ±7 hours. **It was actually seen to arrive at 15:09 UT!**

It also triggered a geomagnetic storm shortly afterwards.





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Abisko, Sweden (24 Jan 2012)

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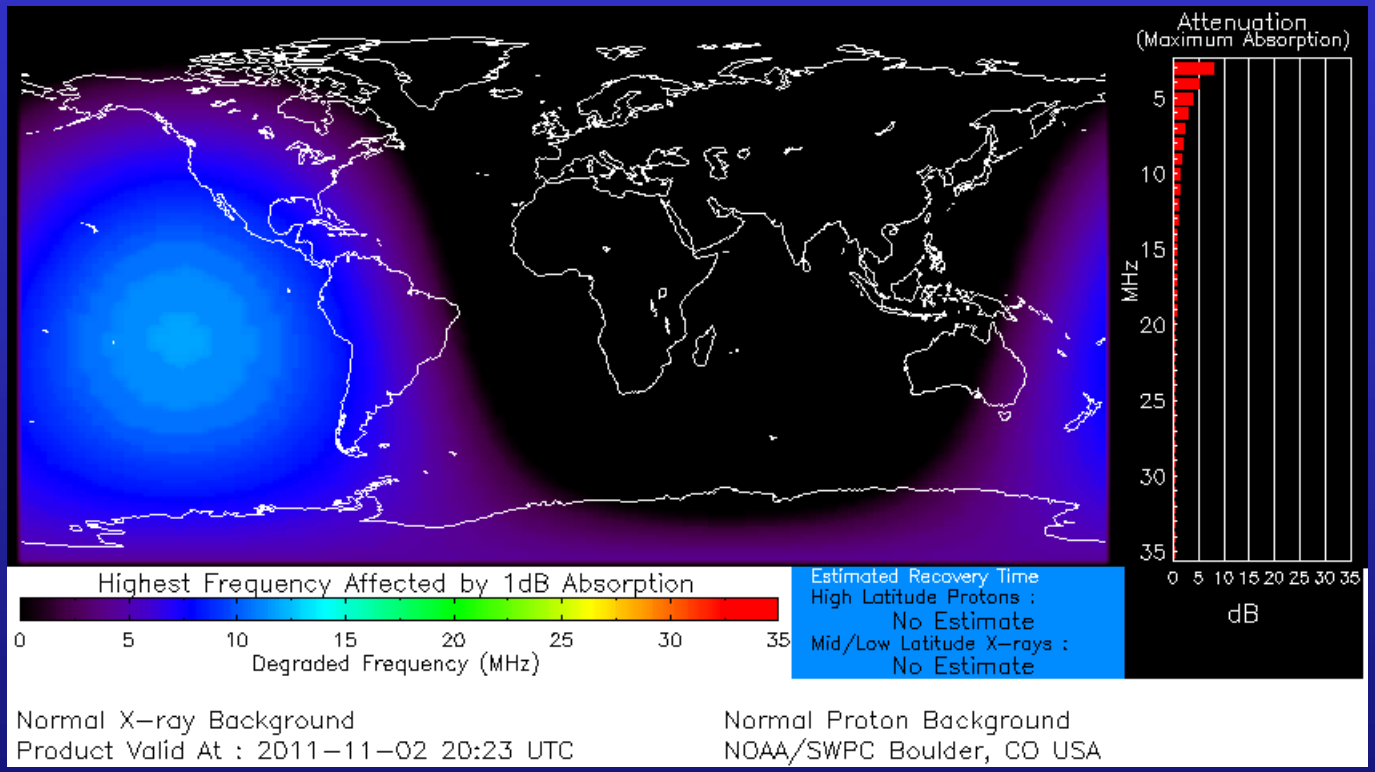
Why should you care? X-Rays



During the peak period of the X-ray flare (which lasts tens of minutes to an hour), the sunlit side of the Earth is being "zapped" by the waves. **This will degrade HF radio communications and low-frequency navigation signals.**

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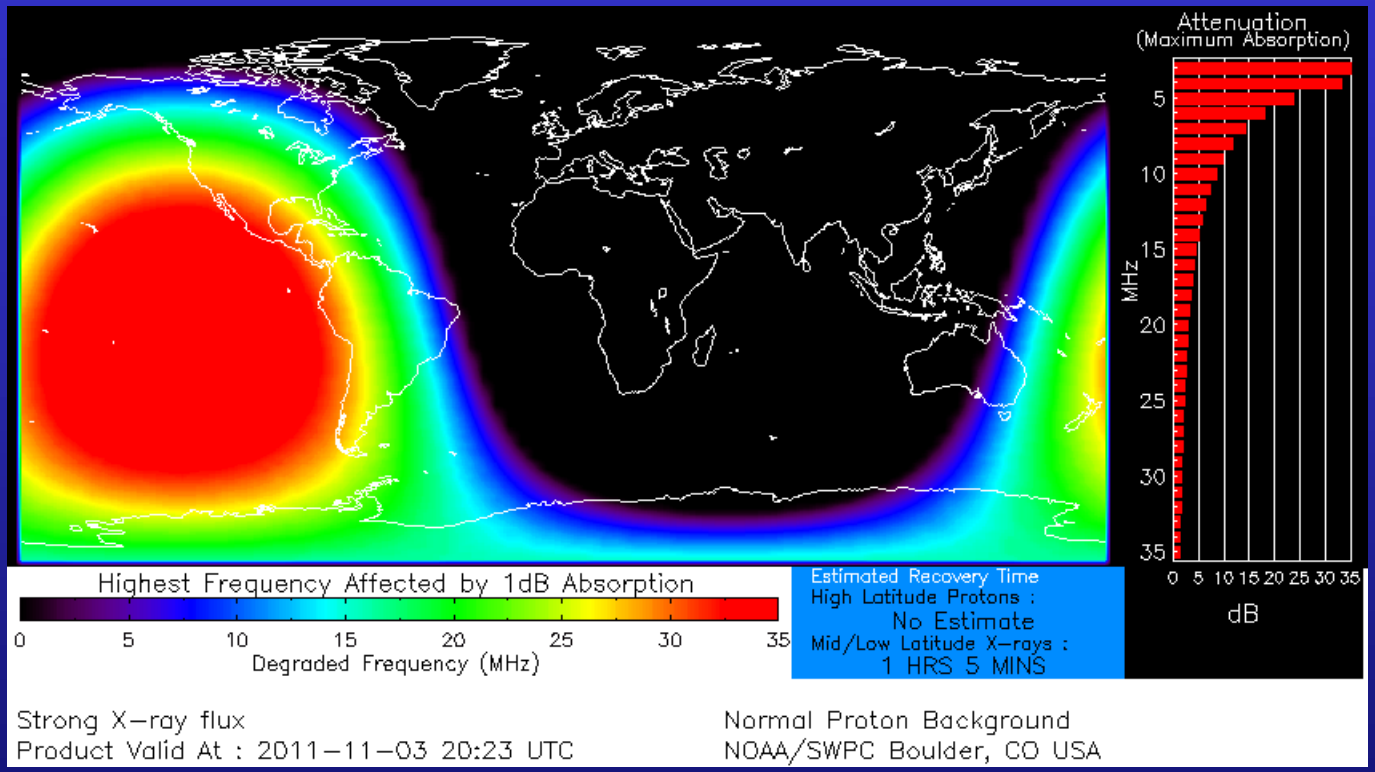

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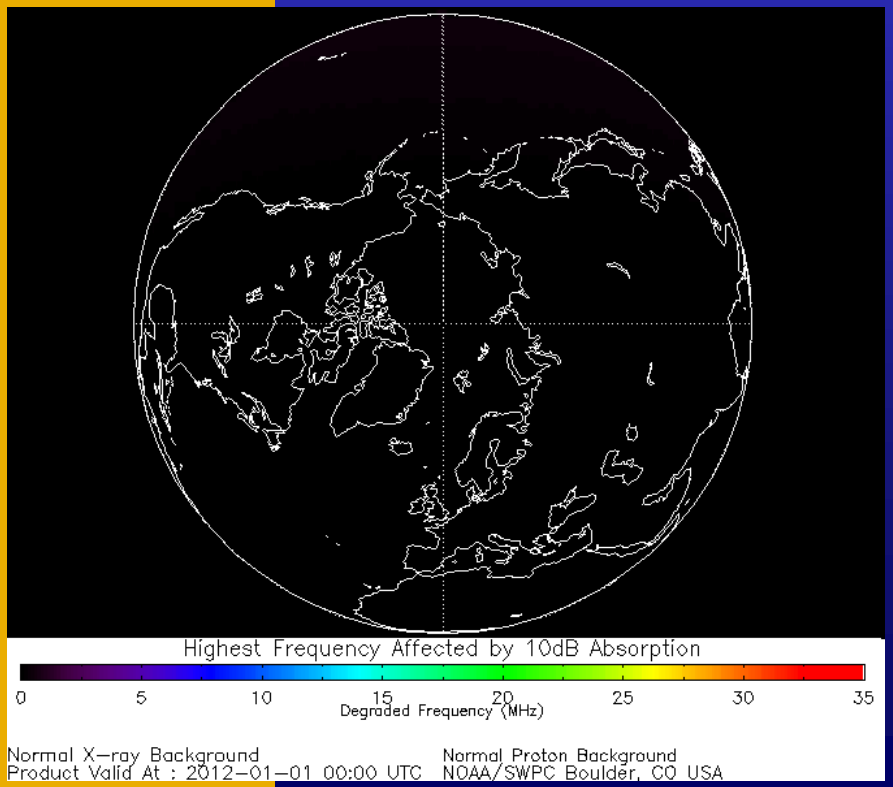
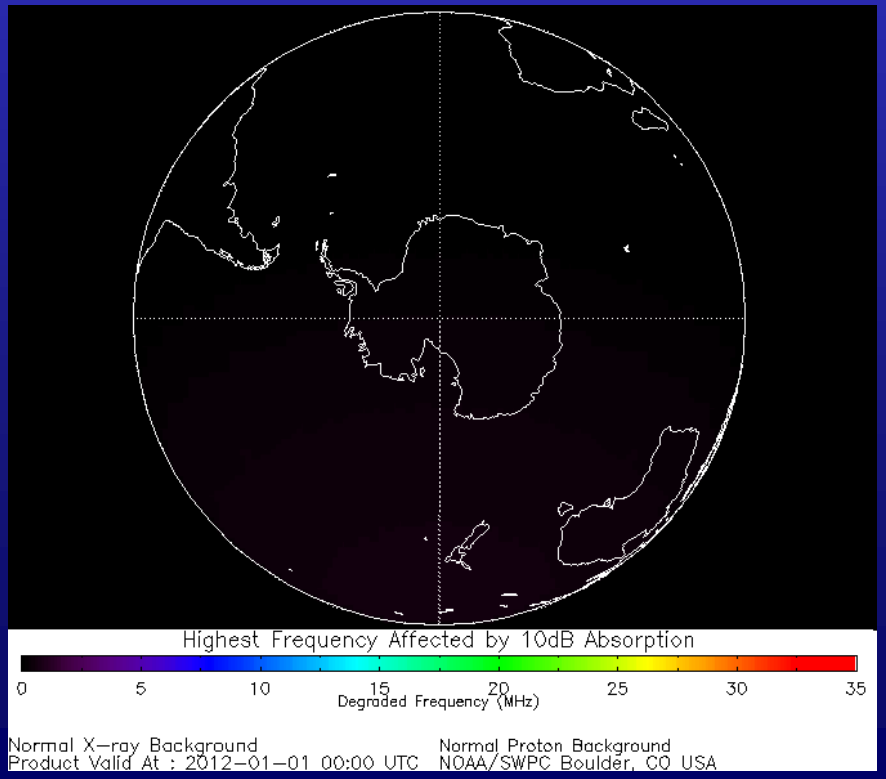
Why should you care? Solar Proton Events

As these are charged particles, they are funneled into the polar atmosphere by the magnetic field of the Earth. Here they will degrade HF radio communications for several days.

The example below is for 23-24 January 2012





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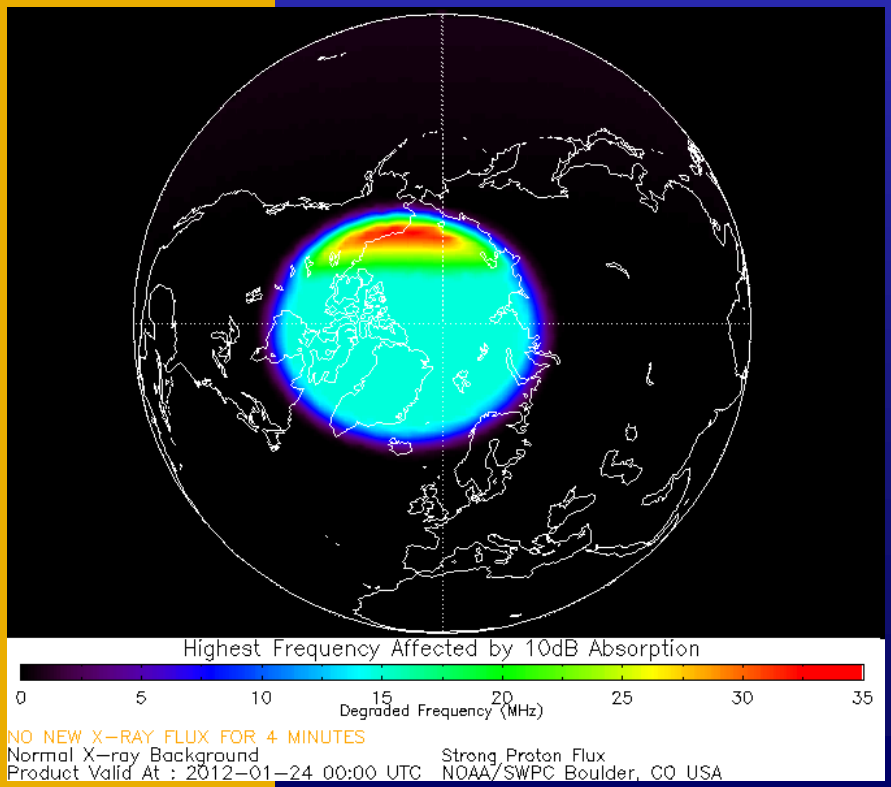

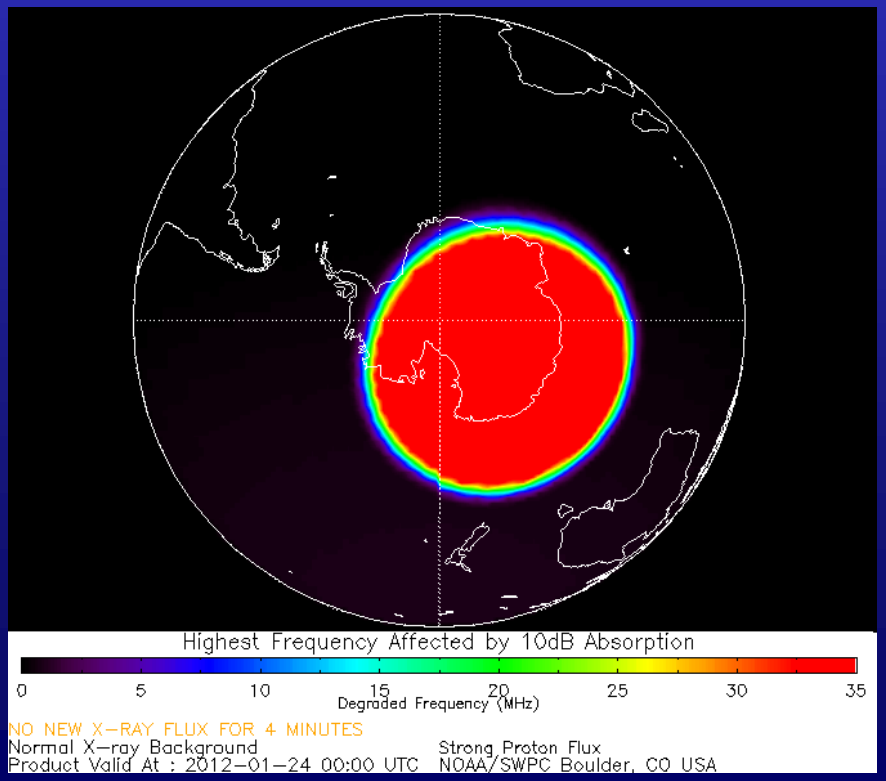

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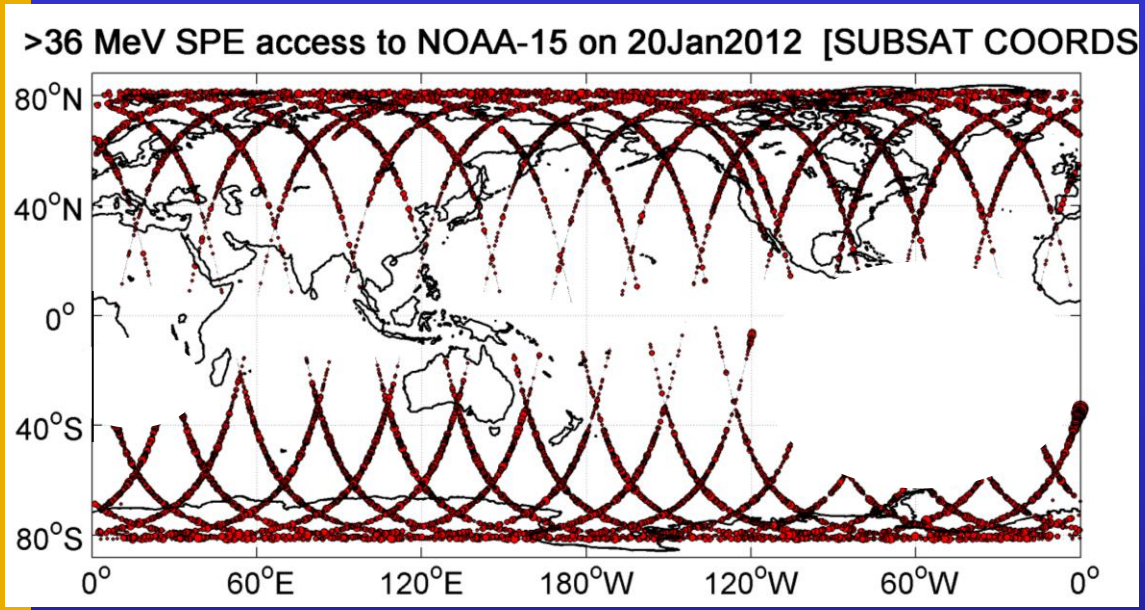
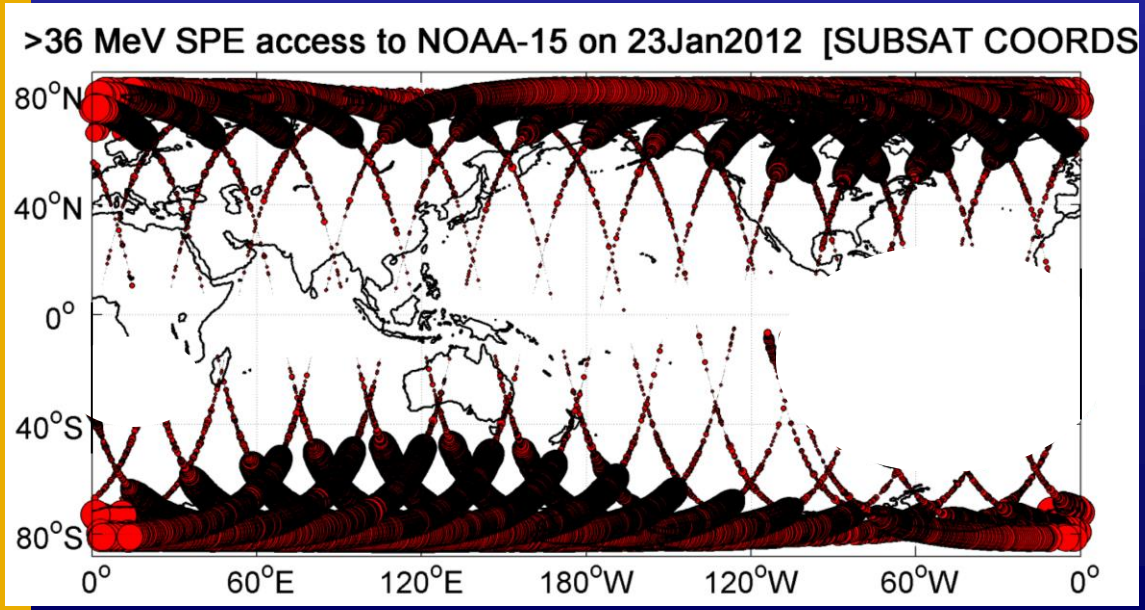
Solar Proton Events





Example of changed flux of high-energy protons observed by a satellite at ~850 km altitude before (20 Jan 2012) and during the Solar Proton event (23 Jan 2012).

The size of the marker is logarithmically dependent upon the intensity of the flux.

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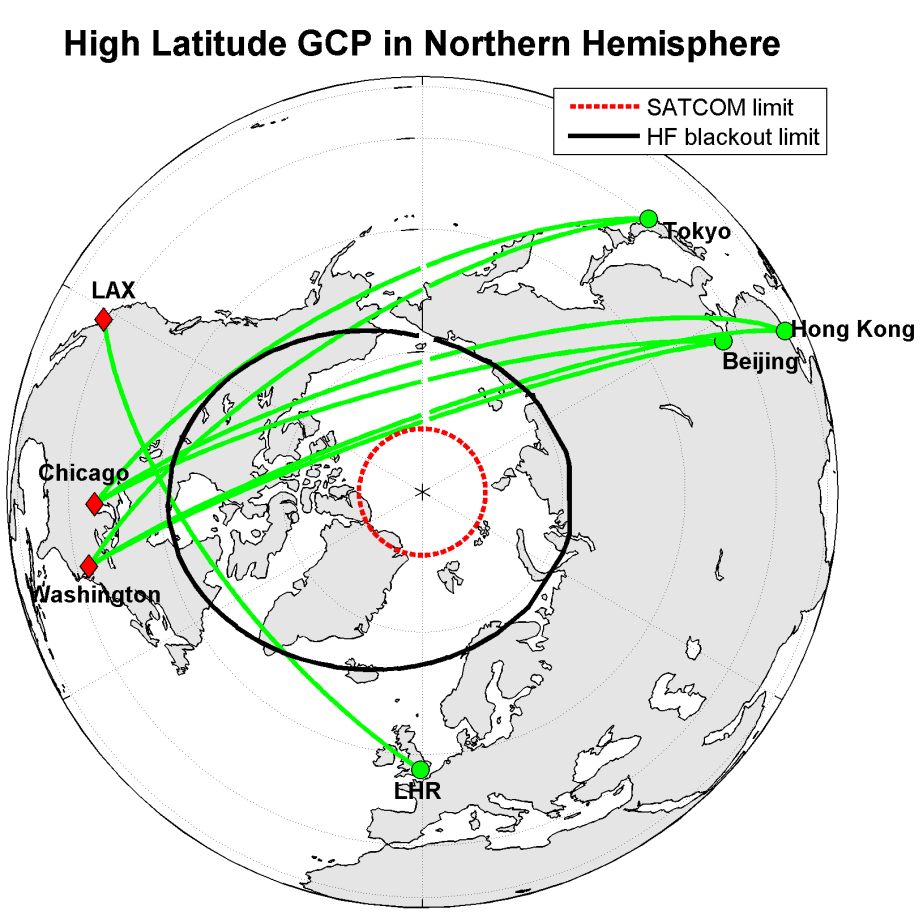

International rules require flights to maintain communications with Air Traffic Control and their company over the entire route of flight.

Many airlines rely upon SATCOM, which uses geosynchronous communication satellites. This is impossible above 82° latitude.

Beyond this HF radio links are needed.

For safety's sake, airlines sometimes need to move their flight paths away from the pole – making longer routes, burning more fuel, and hence costing more money!

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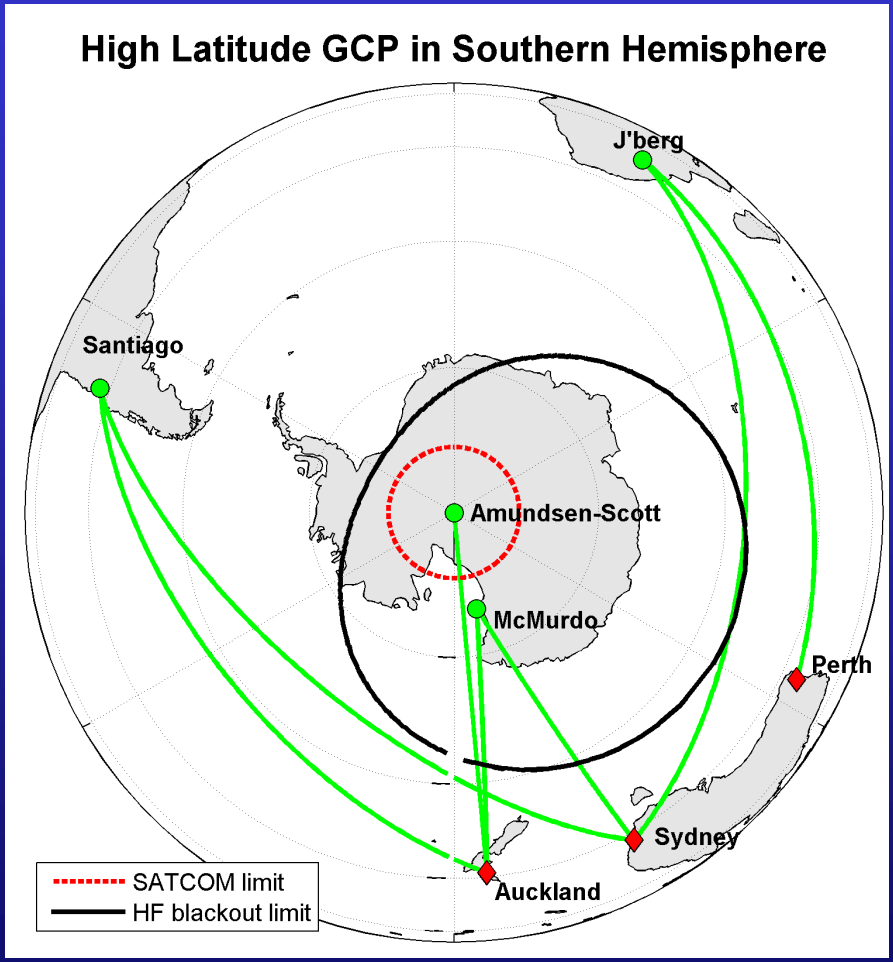

Many airlines rely upon SATCOM, which uses geosynchronous communication satellites. This is impossible above 82° latitude.

Beyond this High Frequency (HF) radio links are needed.

This is <u>probably</u> less of an issue in the Southern Hemisphere, except for flights to and from the Antarctic.

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Why should you care? Solar Proton Events

THE WALL STREET JOURNAL. BUSINESS

Delta Reroutes Flights As Solar Storm Hits Earth

By DOUG CAMERON

Delta Air Lines Inc. said Tuesday that it was rerouting some transpolar flights between Asia and the U.S. to avoid the impact of the largest solar storm in almost a decade.

The Atlanta-based carrier said some flights to Detroit from Hong Kong, Shanghai and Seoul took a more southerly routing on overnight flights, though a spokesman said planes flew faster to keep schedules intact. Tuesday departures from the U.S. were

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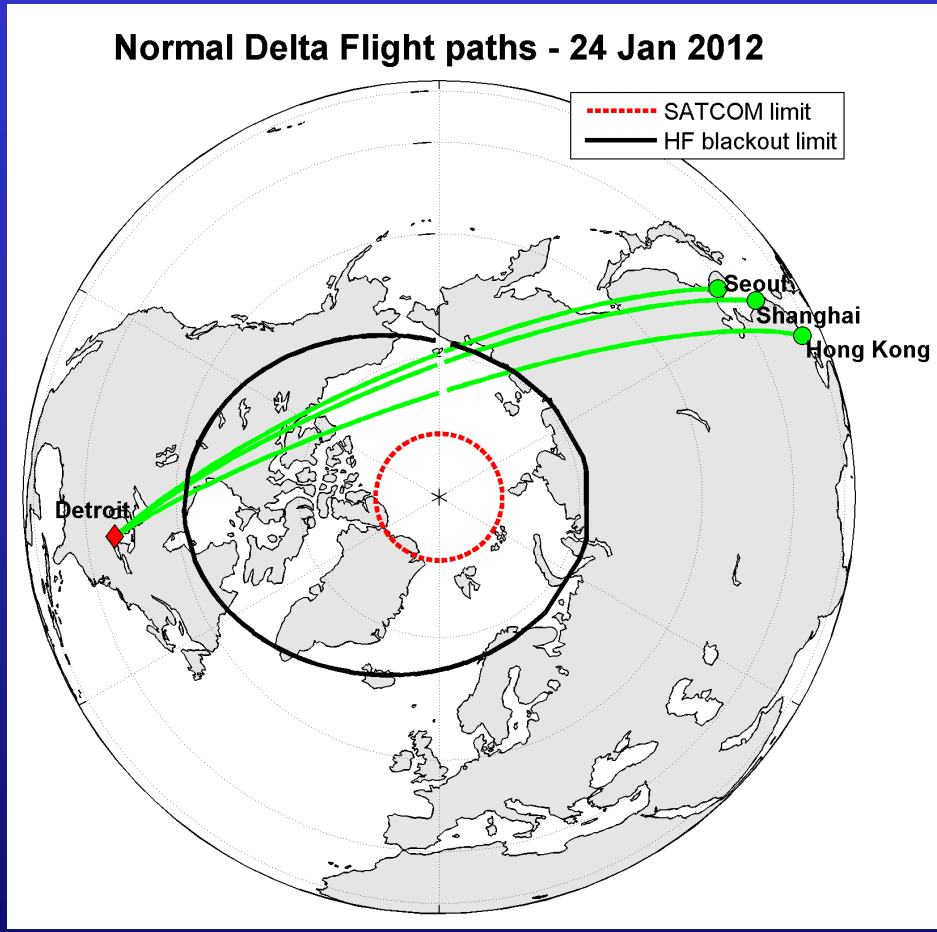
Money From MF Global Feared Gone

Citi Chairman Considers Departure

The Wall Street Journal 24 Jan 2012



And this happened in January 2012 too – the US carrier Delta Airlines re-routed flights from Detroit to Seoul, Shanghai and Hong Kong onto routes that took them away from the poles! **That costs money!**

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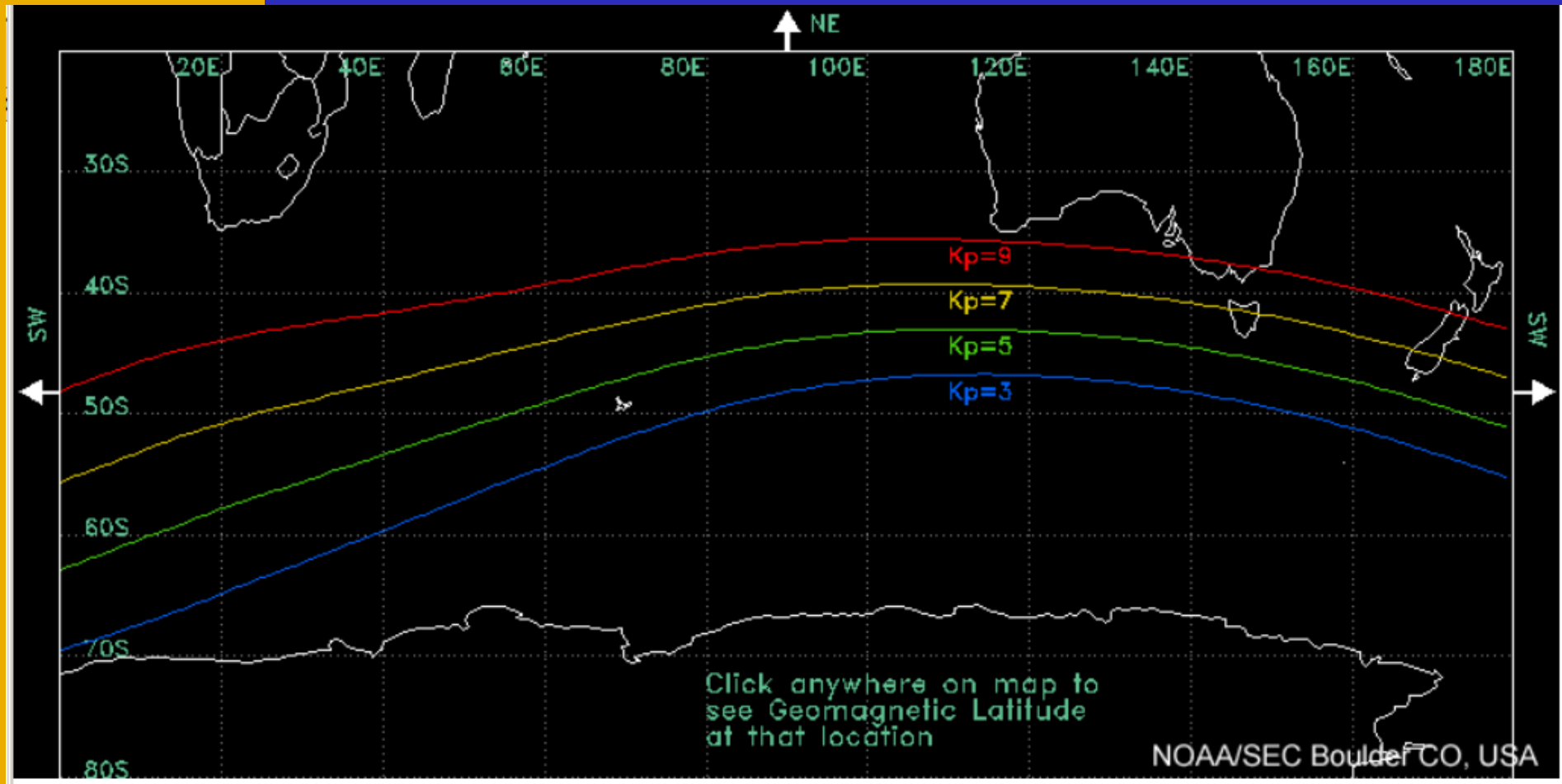
Why should you care? CME & Geomagnetic Storms

Alas, aurora over Dunedin is not very common, but it is possible.



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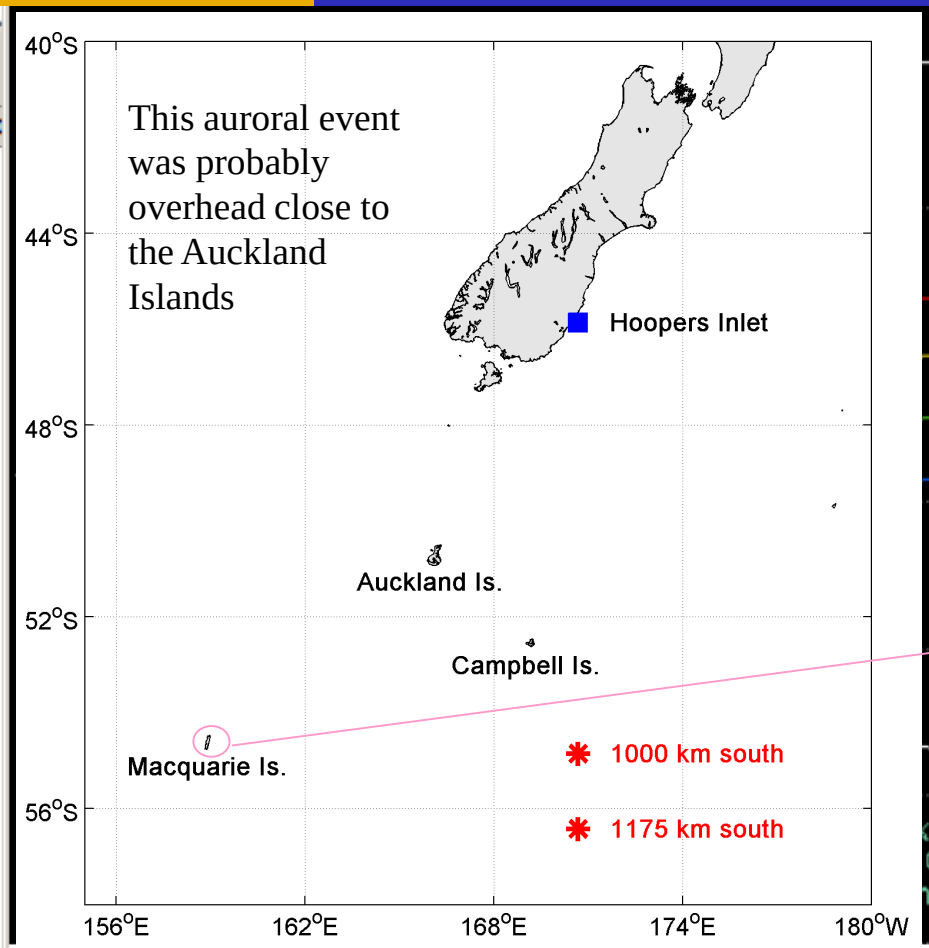

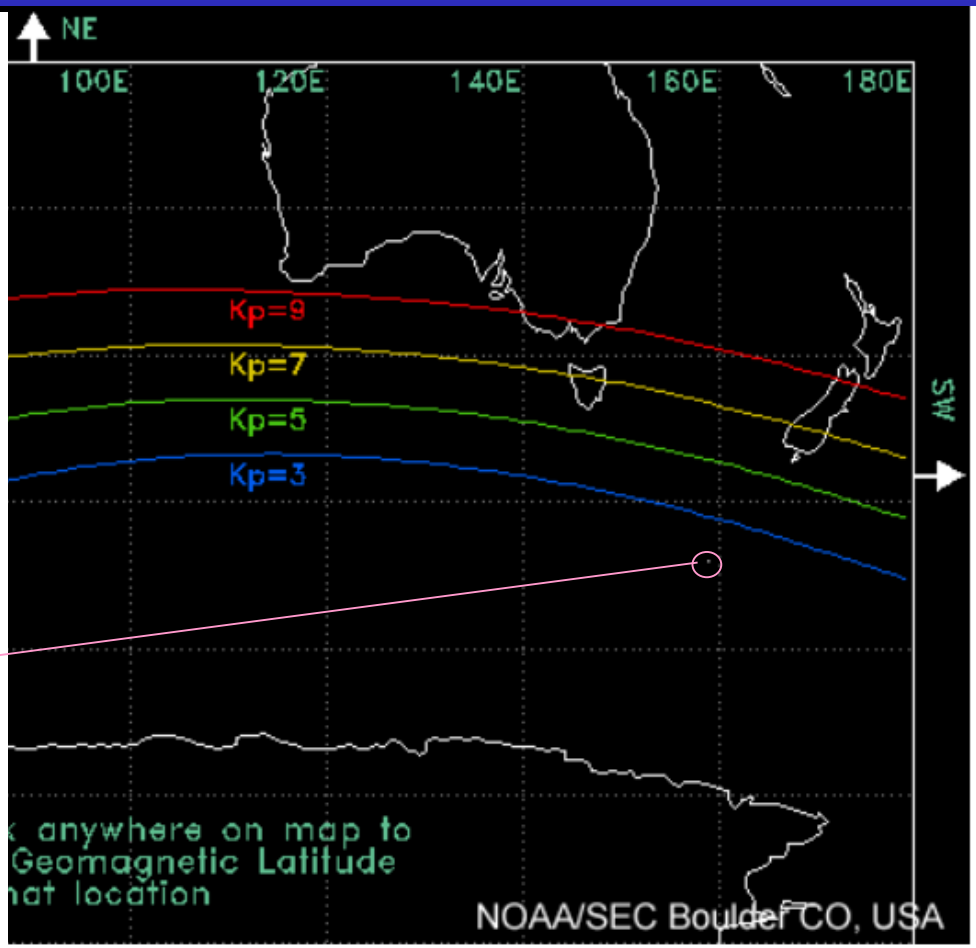

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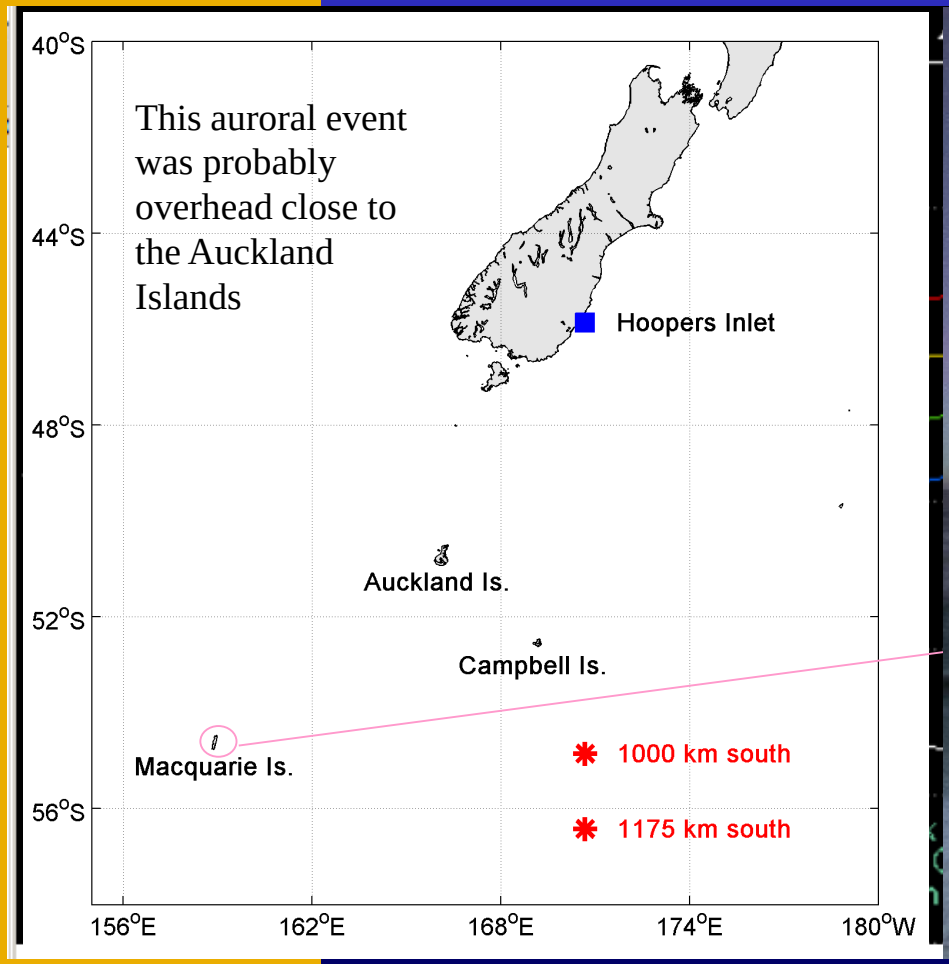
Why should you care? CME & Geomagnetic Storms

Alas, aurora over Dunedin is not very common, but it is possible. Aurora is much more common 1000km South of Dunedin.



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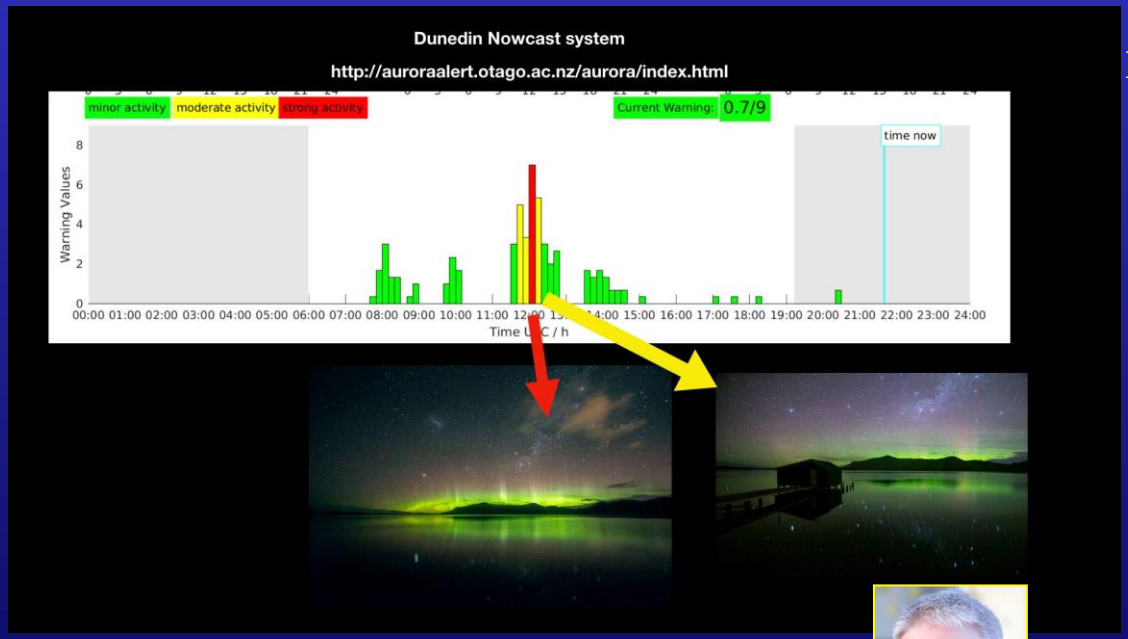
Aurora Alerting system -
now online thanks to the MBIE funding!

As of early 2017 we started running a aurora alert system, which provides "nowcasting" of auroral activity (particularly for the lower South Island). And it seems to work quite well!



17 August 2017

auroraalert.otago.ac.nz

OTAGOmuseum

Ian Griffin

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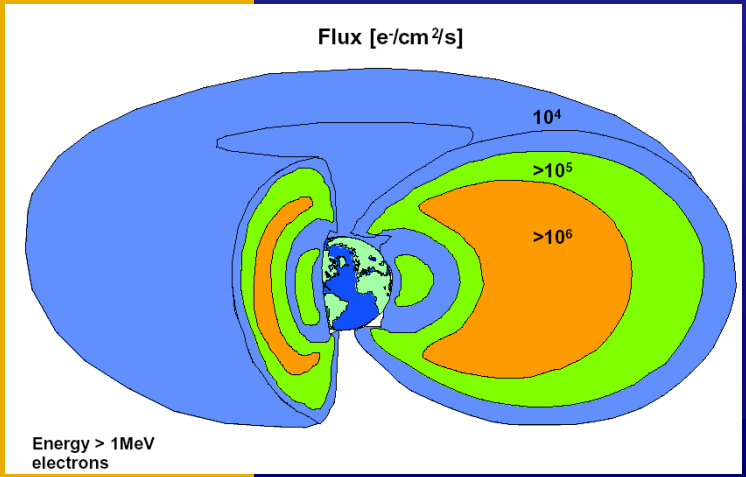
Why should you care? CME & Geomagnetic Storms

However, the geomagnetic storm kicked off by a CME can have two important "space weather" effects:

- Boosting the hot electron content in the belts which surround the Earth (which are a threat to satellites and also increases the radiation dose to astronauts).
- The changing magnetic field drives currents in the Earth which can damage the electrical power grid!!!

In my remaining time will concentrate on the second of these.



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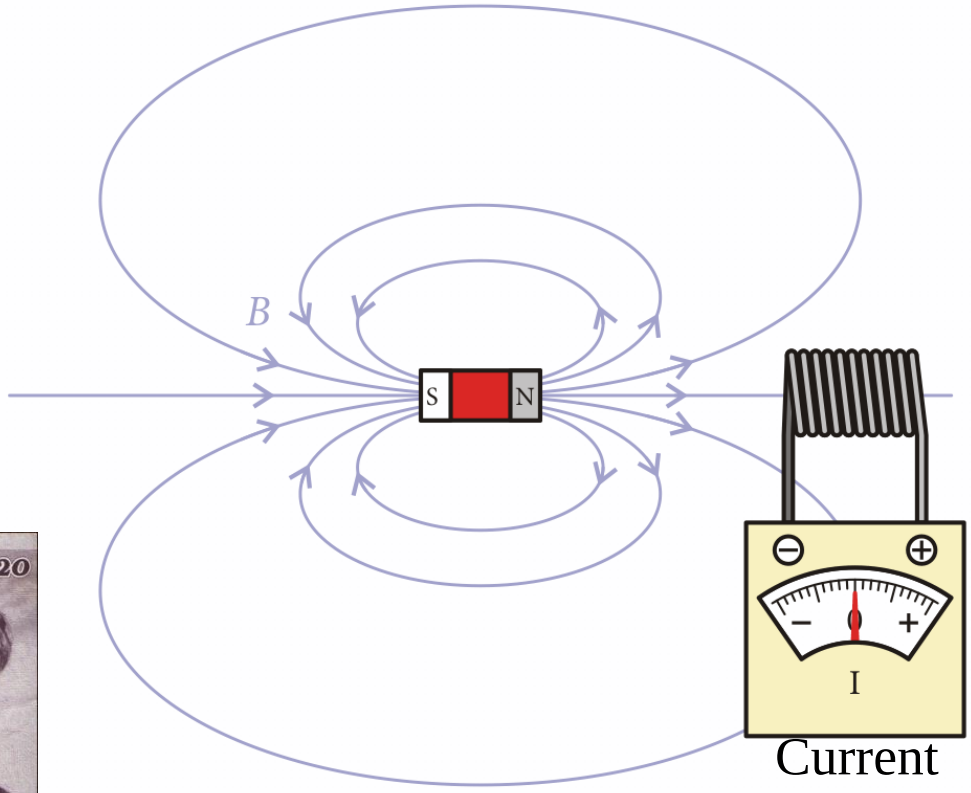
Faraday's Law of Induction

A moving magnet will produce a changing magnetic field.



Famous physicist Michael Faraday demonstrated the law of induction, where a **changing magnetic field induces a current** in a conductor (like a wire, or the ground).

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Effect on power systems - local scale

These can be local to a specific transformer in a given substation, potentially destroying a transformer.

New Jersey, March 1989.
USA

courtesy Metatech

South Africa, Oct 2003

GIC = Geomagnetically induced currents

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Effect on power systems - NZ

On 6 November 2001 at 2:53pm a large geomagnetic storm started. At this time a transformer in Dunedin failed!

Alarms occurred at multiple locations across the South Island and a transformer in Christchurch went offline.

GIC = Geo-magnetically Induced Currents

The transformer at Dunedin / Halfway Bush (HWB T4) suffered a major internal flashover - it was **subsequently written off**.

Halfwaybush Substation, Dunedin.

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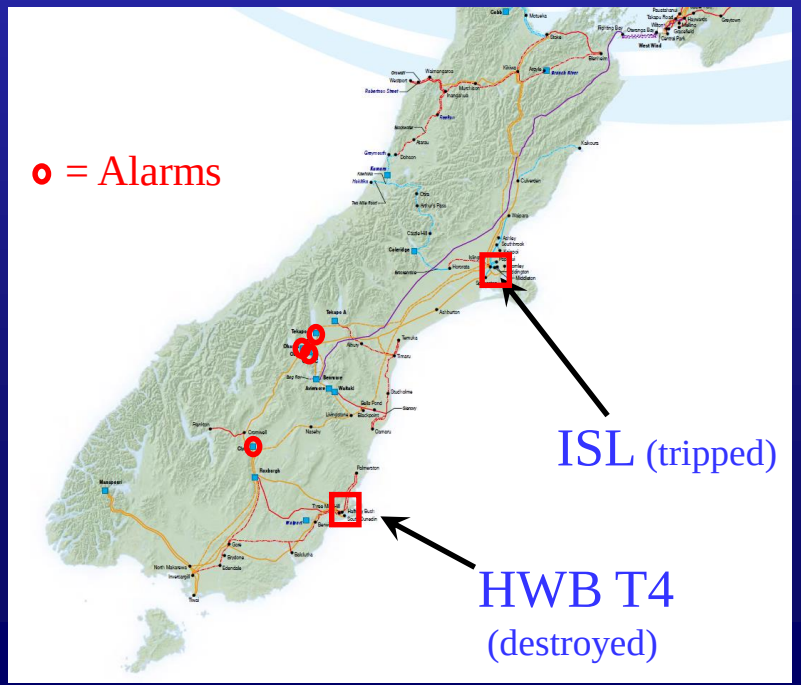

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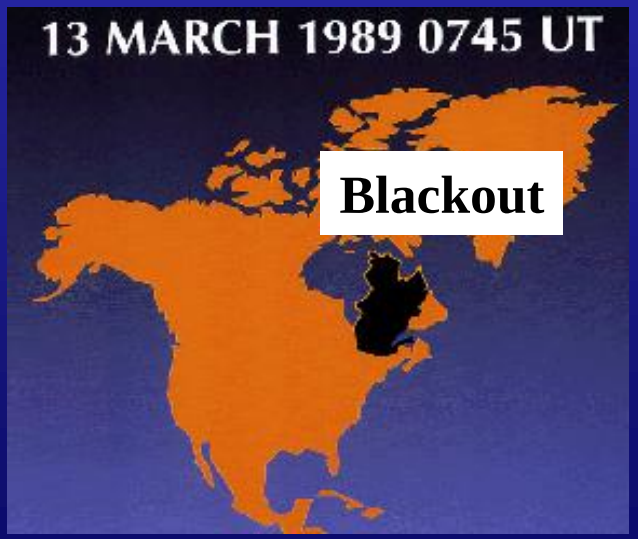
Effect on power systems - regional scale

Most dramatic to date "great magnetic storm" of March 1989.

Hydro-Québec's (TransÉnergie) electric transmission system collapsed in 92 seconds.

- ~ 9 million people were left without electricity
- blackout lasted around nine hours for most places
- some locations were in the dark for days

Over 200 significant power grid problems across the continent.



GIC = Geomagnetically induced currents

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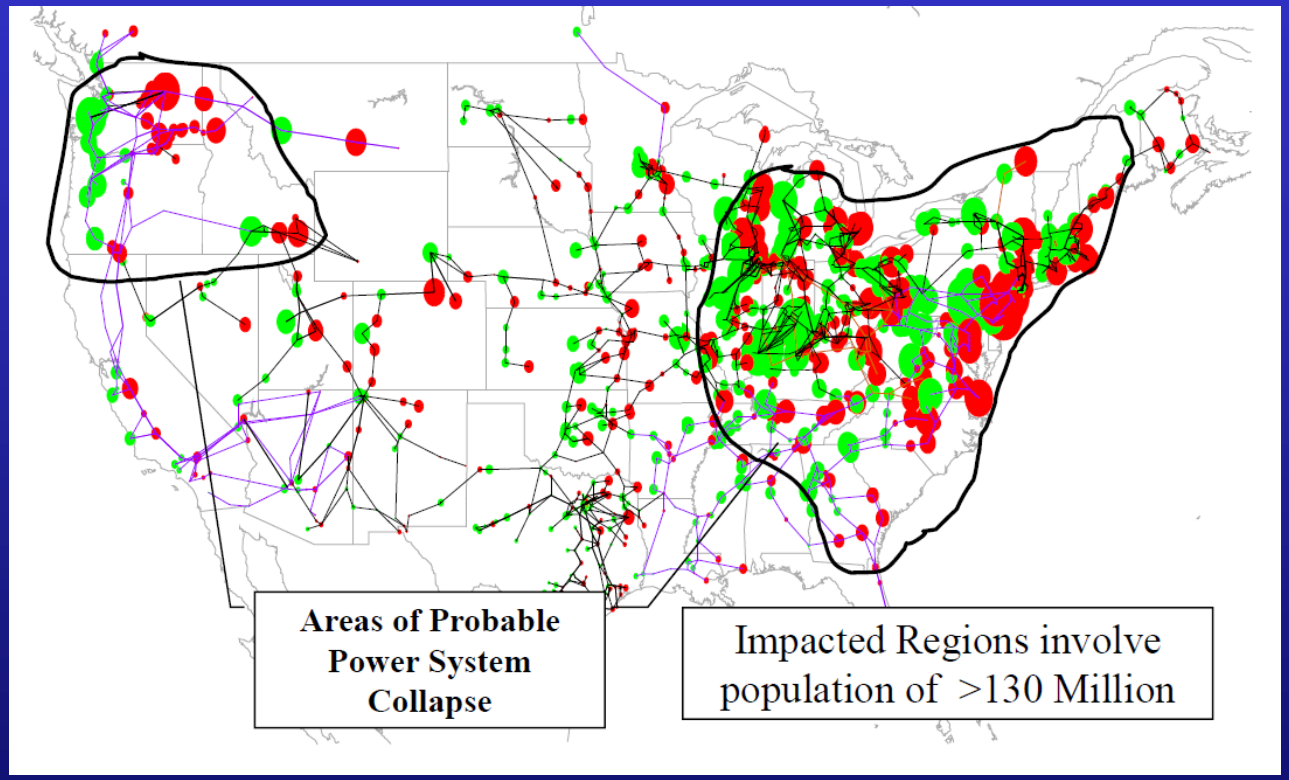
Should we worry for the biggest storms?

Modelling for the USA for a May 1921-like "severe" storm predicted destruction of >300 primary transformers (out of 2,100 total):

* Replacements might take a year or more
* Cost in the first year as high as US$2 trillion



Source: Baker, D. N., et al. (2008), Severe Space Weather Events: Understanding Societal and Economic Impacts, 144 pp., National Academies Press, Washington, D. C., USA.

Much action stimulated in the USA. In October 2015, the **National Space Weather Strategy** & **National Space Weather Action Plan** released.

GIC risk mitigation research in NZ

MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HIKINA WHAKATUTUKI

Solar Tsunamis: Mitigating Emerging Risks to New Zealand's Electrical Network

New Zealand Team

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VICTORIA UNIVERSITY OF WELLINGTON

United Kingdom Team

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Projected nominally started 1 October 2015 & finished on 30 September 2018

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Our project goals

1. Understand the occurrence of GIC in the New Zealand electrical transmission network.

- what is happening in space?
- could this be used to provide better forecasting?

GIC = Geomagnetically Induced Currents

2. Test Transpower's existing mitigation protocols

- how well will these work?
- would other approaches work better?

3. Predict the likely impact of severe/extreme geomagnetic storms in the New Zealand grid.

- identify likely hotspots, changes with solar conditions.

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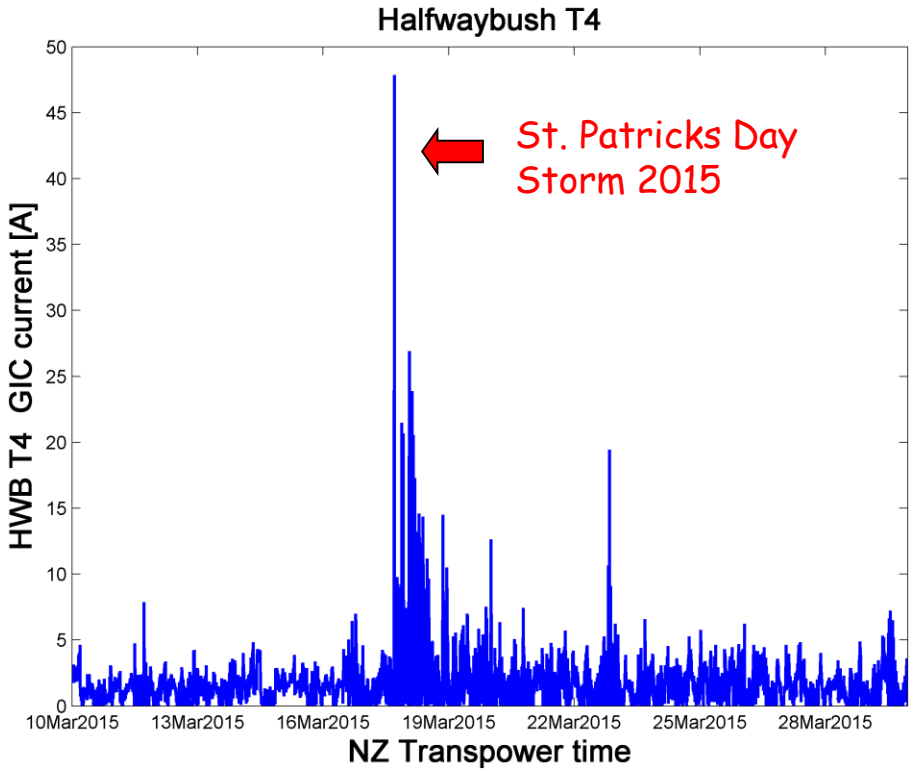
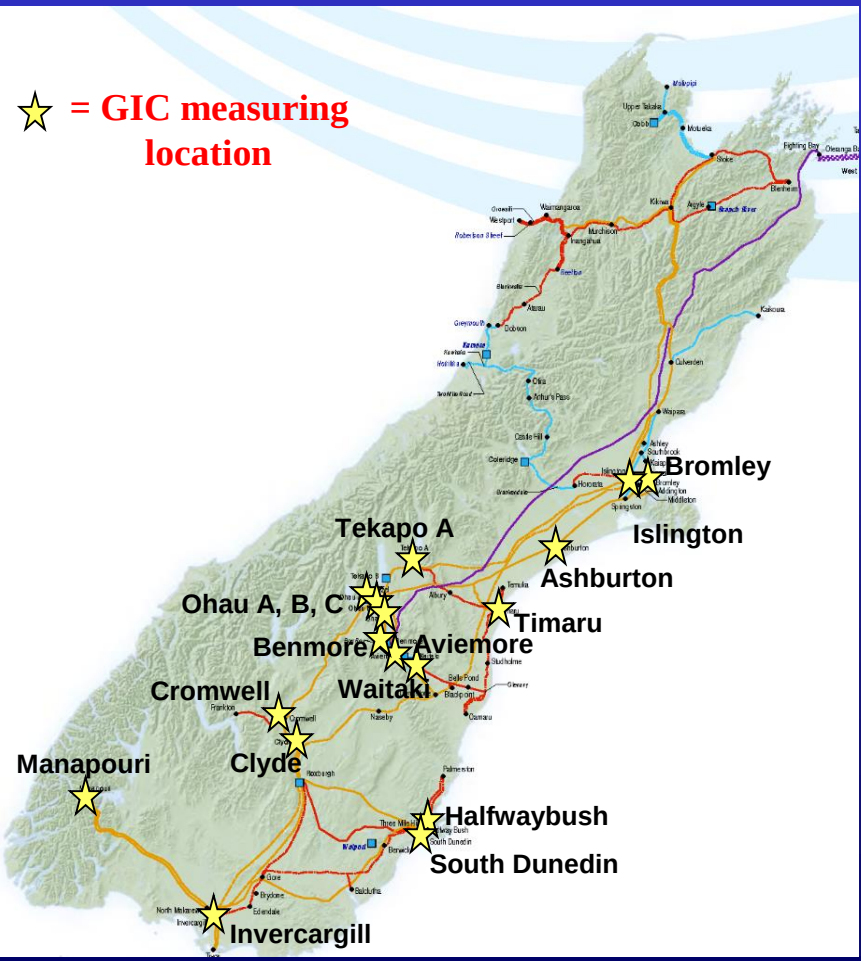
Possibly the best GIC data in the world!

Step One was to use the GIC measurements which have made by Transpower. These have been continuously archived from more than 14 years, from many different South Island locations!

This is an internationally important dataset.





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GIC = Geomagnetically induced currents

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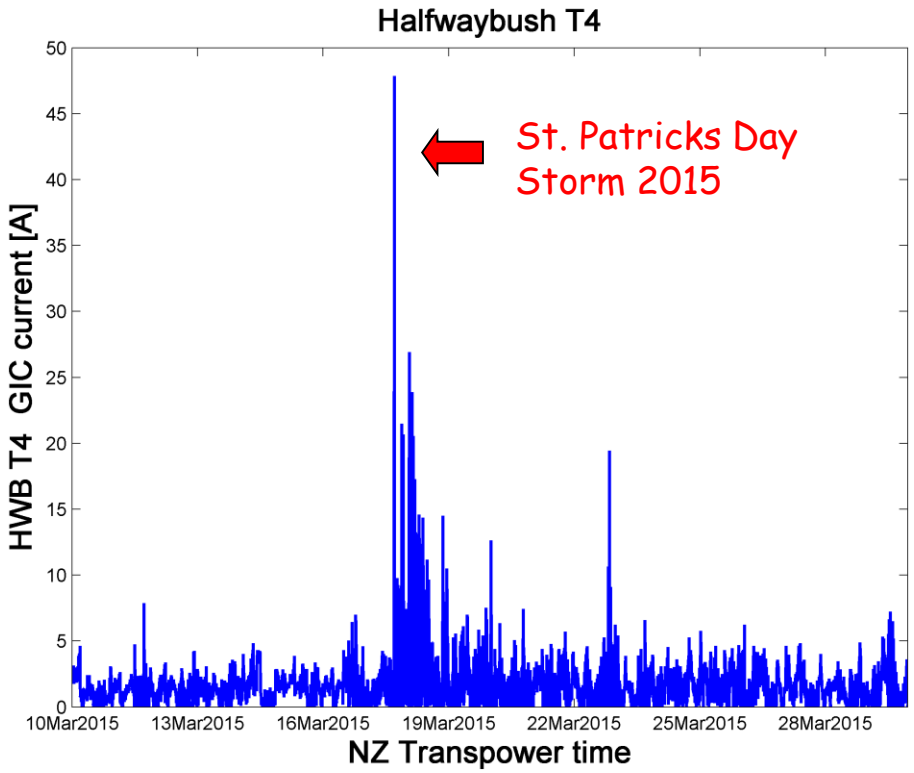
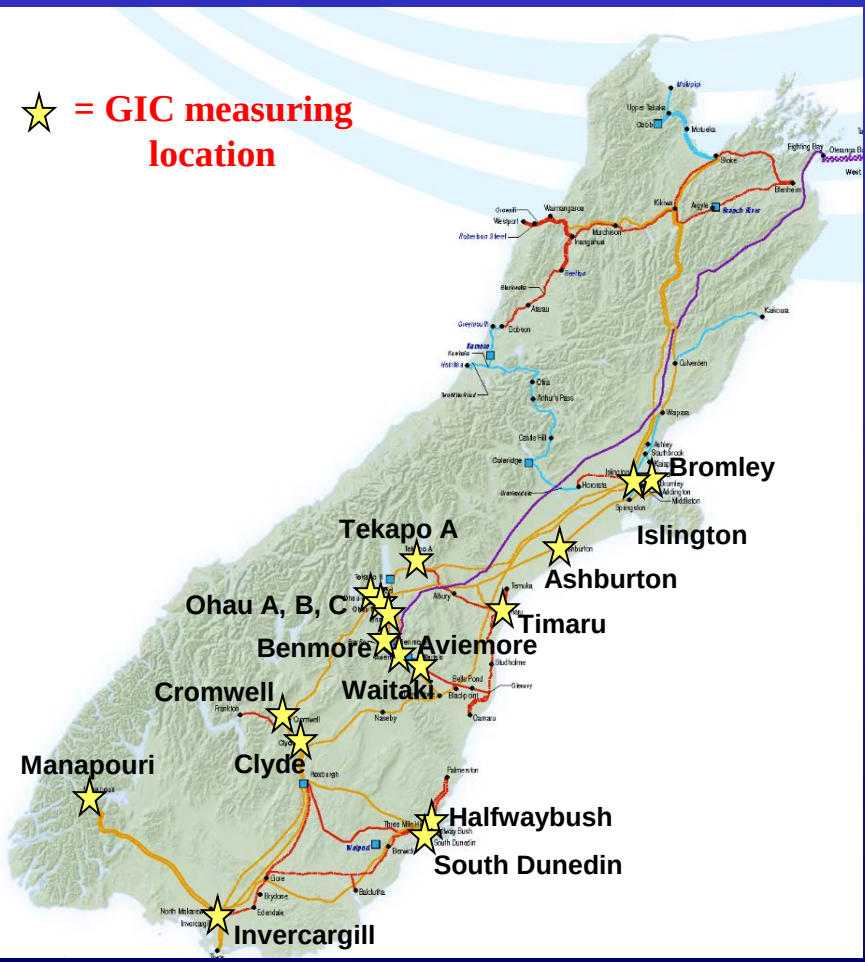
Possibly the best GIC data in the world!

Step Two has been to build a numerical model of the New Zealand electrical network, simulate GIC, and validate it with the Transpower GIC data.

Then we can examine protocols and severe storms.





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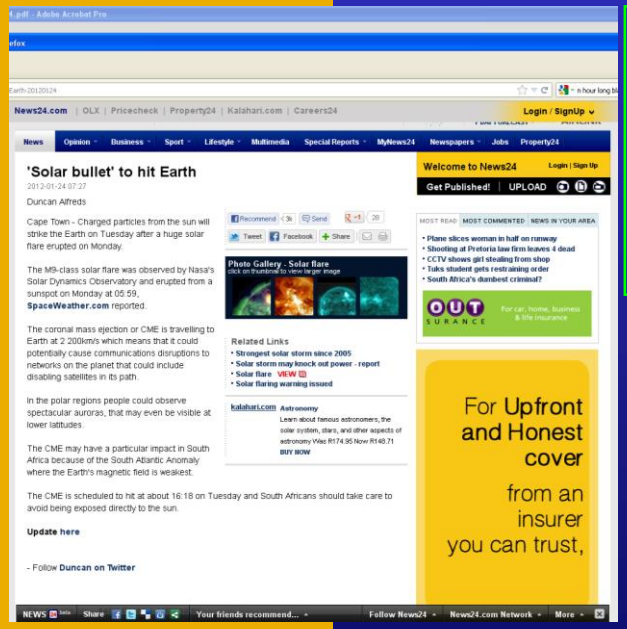
But don't worry too much!

I was visiting South Africa in late January 2012 when the solar-triggered activity occurredI have often been using as an example in this talk. A line on a local news webpage seems to have triggered a lot of panic:



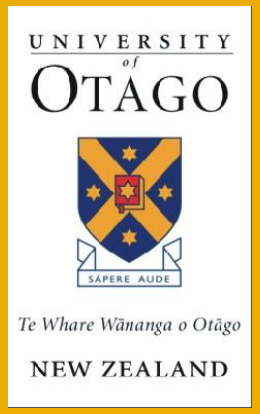
The CME is scheduled to hit at about 16:18 on Tuesday and South Africans should take care to avoid being exposed directly to the Sun.

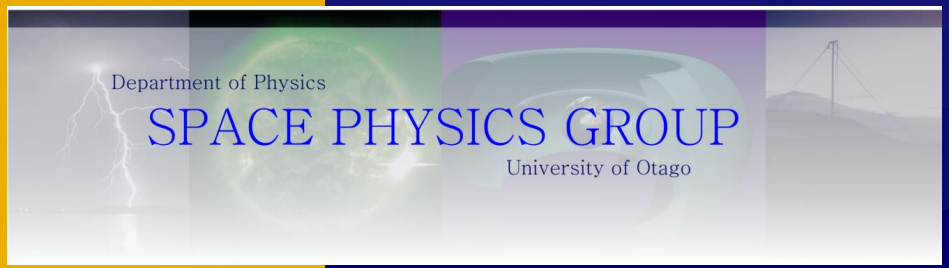
http://www.news24.com

At that time was at the ***SANSA Space Science*** in Hermanus for a small meeting. This place is the home of Africa's Space Weather HQ.

After the story South African social media (facebook, twitter, etc) & talk radio went crazy. SANSA were deluged with calls about whether it was safe to be outside, if the world would end, etc.

My groups primary support has come from:





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Craig Rodger above Tautuku Bay, about 2 hours drive south of Dunedin in the scenic Catlins area [28 December 2013].

Thankyou!

Are there any questions?