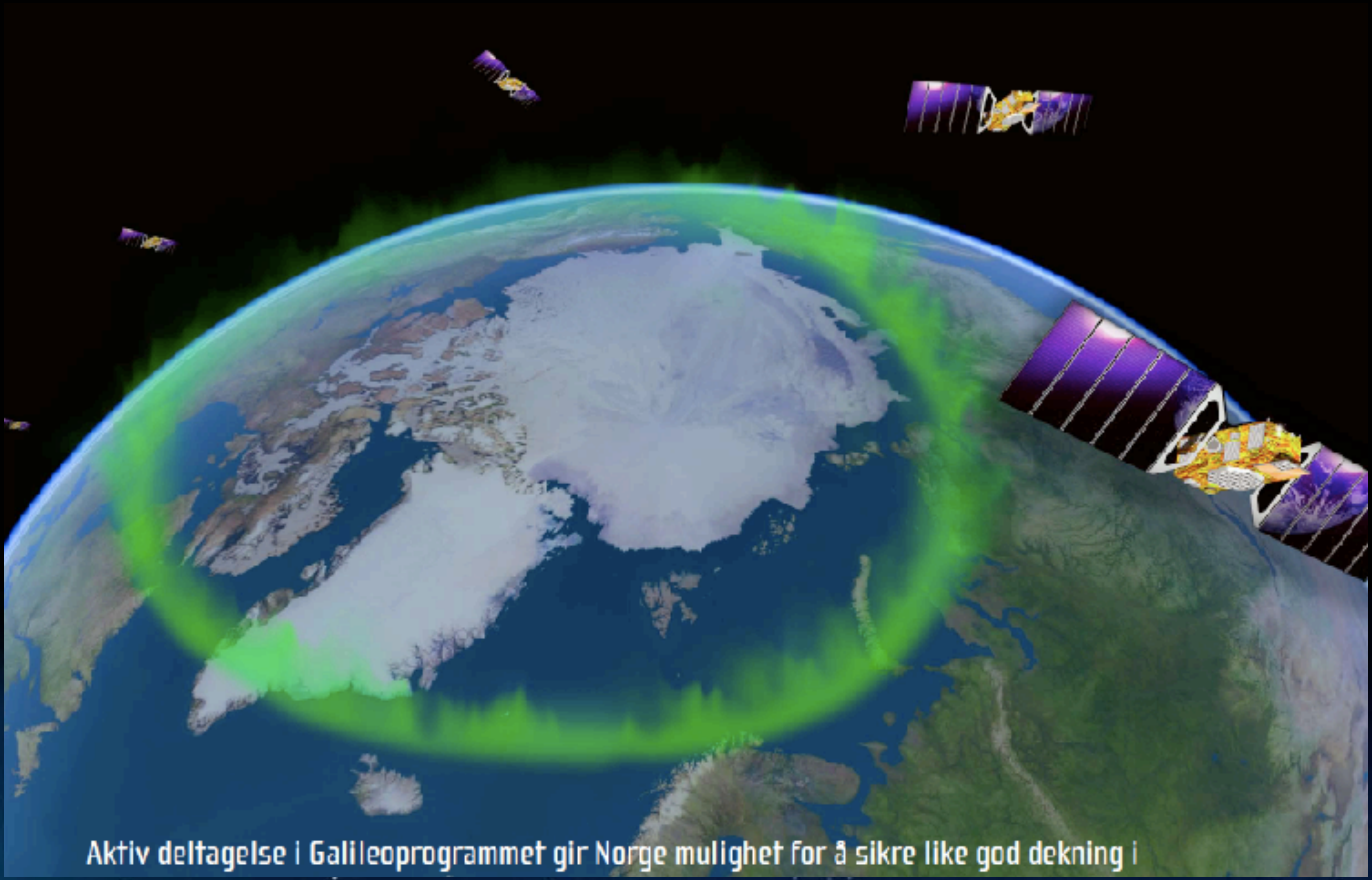
Space Weather Effects on Critical Operations and Activity in the High North



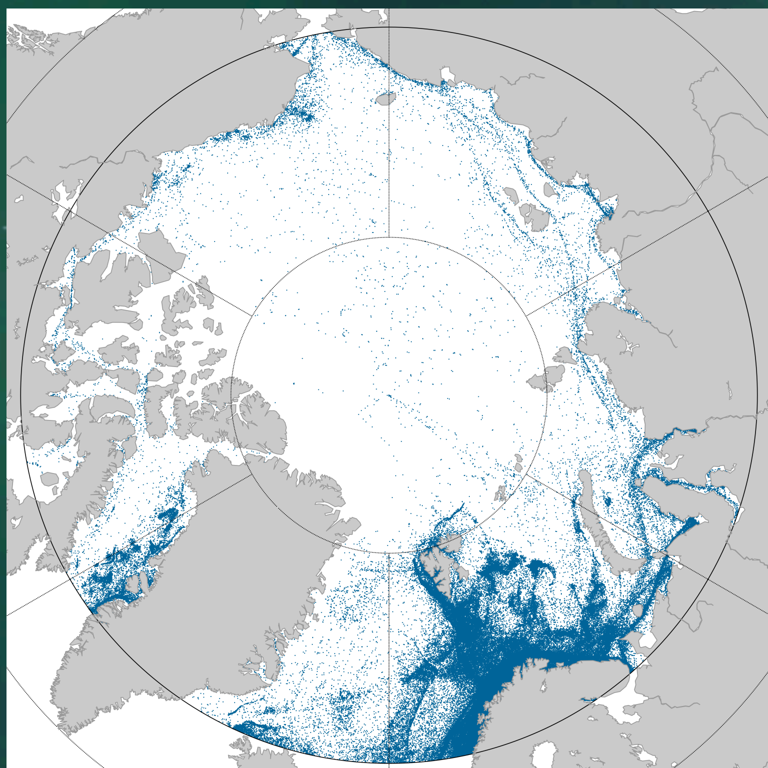
Pål Brekke
Senior Advisor
Paal@spacecentre.no

Norsk Romsenter
NORWEGIAN SPACE CENTRE

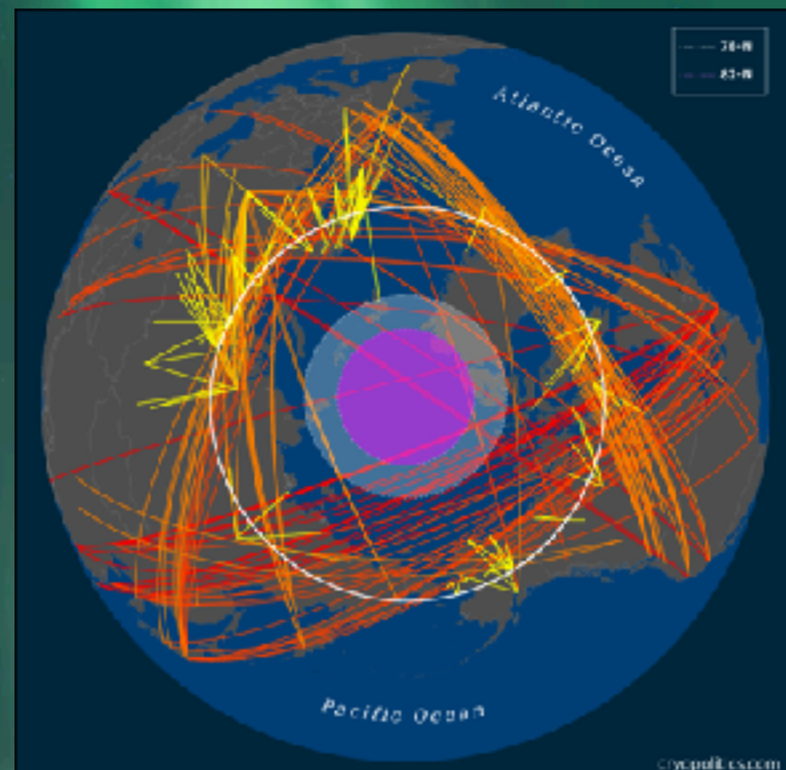
ISWI Workshop, Boston College, 31 July - 4 August 2017

Space Weather in the Arctic

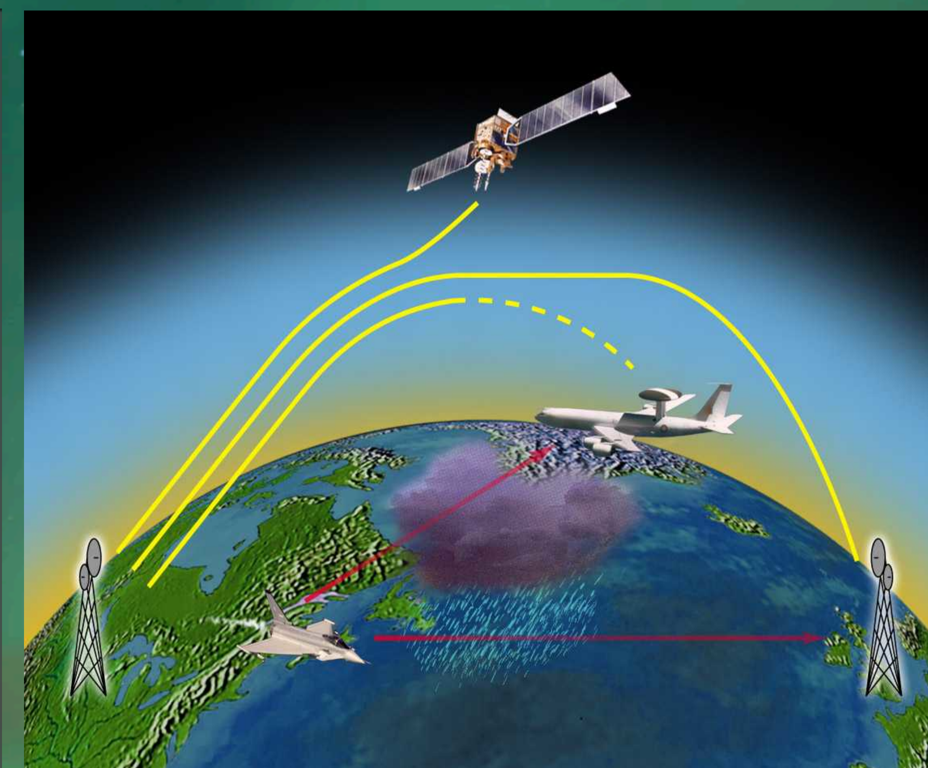
Space weather see no national boundaries - but in the Arctic there are some different challenges



Ship traffic from AisSat-1



Polar flights

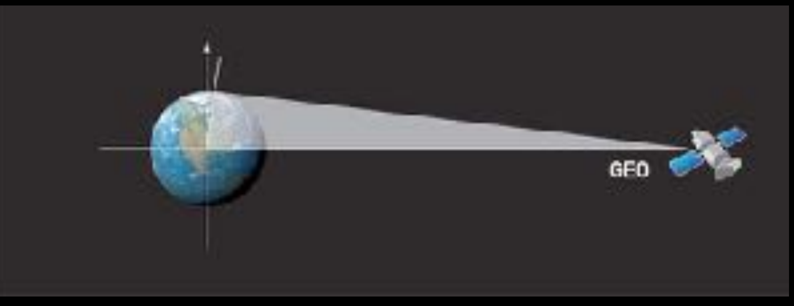


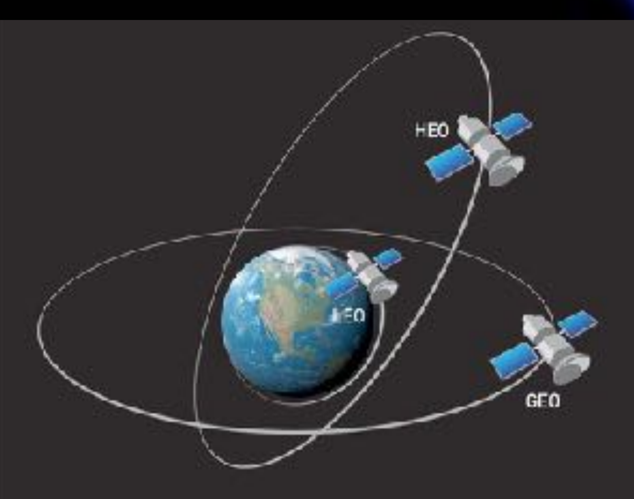
Radiocommunication

With increases activity in the Arctic region space weather will be an important part of Norway's role to ensure both safe navigation and good communication in these areas.

The need for reliable space weather forecast of high quality is necessary and highly wanted among Norwegian users.

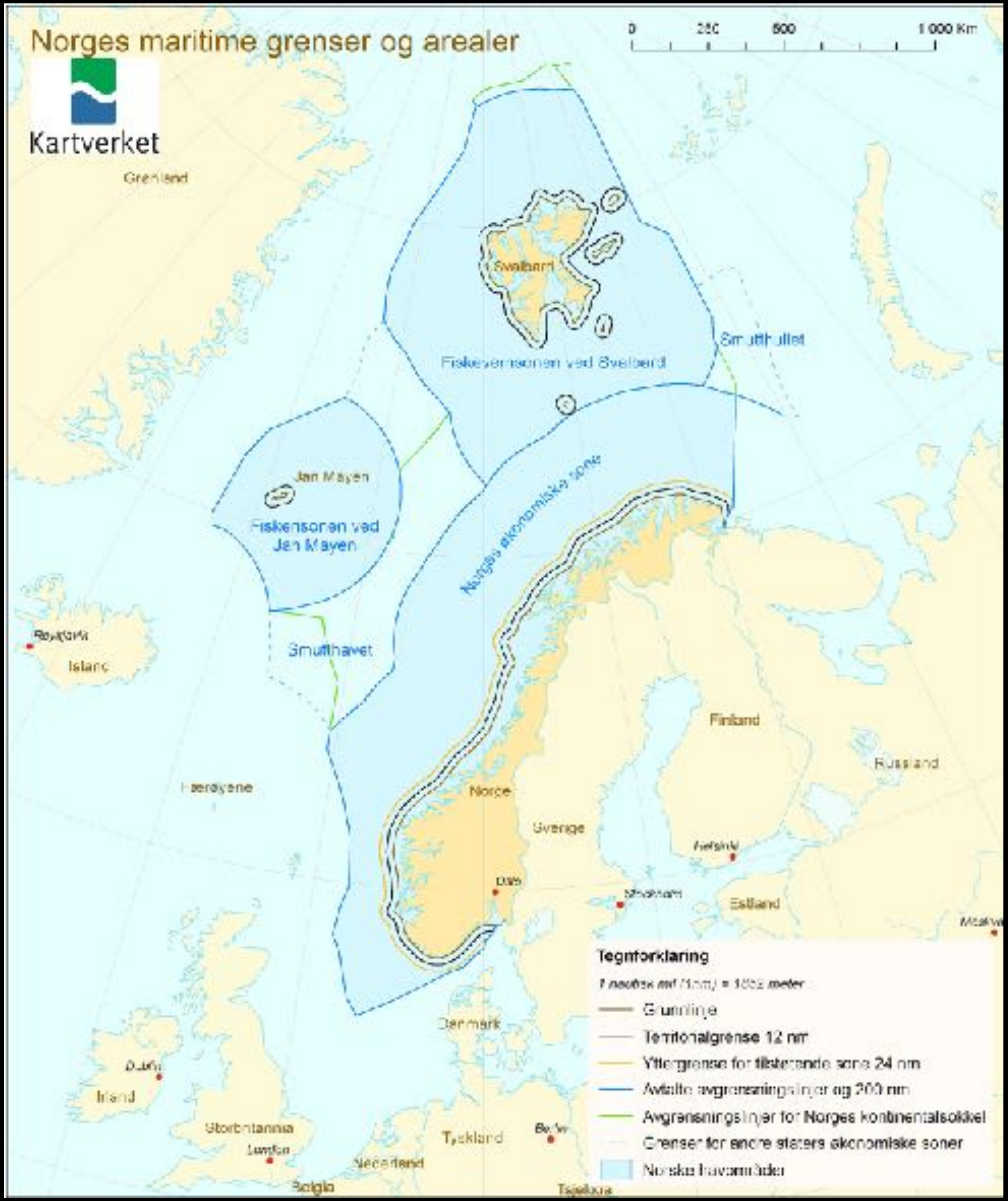
Norway - small space nation on top of the world




HEO
GEO

Why is space important to Norway?

- Norway has apart from Russia, Europe's largest area to manage, mostly in the Arctic or the High Arctic
- Norway and Russia manages one of the worlds largest well managed fish stocks in the Barents Sea
- Exploitation of oil- and gas resources
- More traffic through the Northern Sea Route increases traffic in Norwegian waters
- Opening of new sailing routes across the Arctic basin creates issues concerning safety and rescue



Search & Rescue in the Arctic

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Space Weather in the Arctic

Norway has

- operative demands
- interesting space weather infrastructure.
- several research groups on space weather (UiO, UiB, UiT, UNIS etc.)

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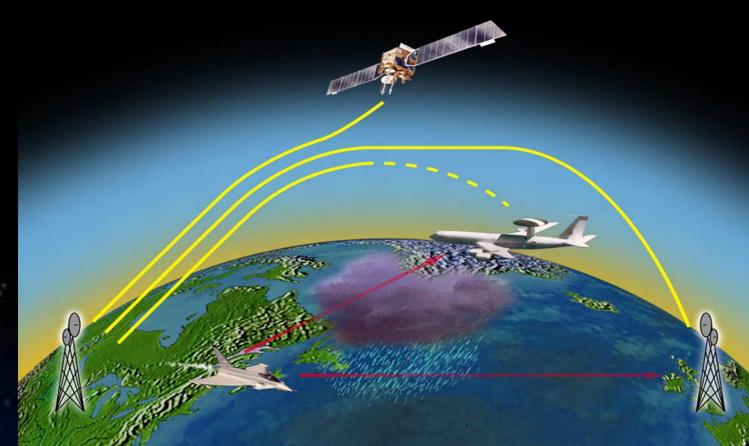
Long Traditions

Long traditions in space research - due to its northern location

- Observations of the Aurora before 1900
- Birkelands innovating aurora experiment (1886)
- National solar observatory in 1950.
- First launch of an aurora research rocket (1962)
- Early concerns about effects on military radio communication



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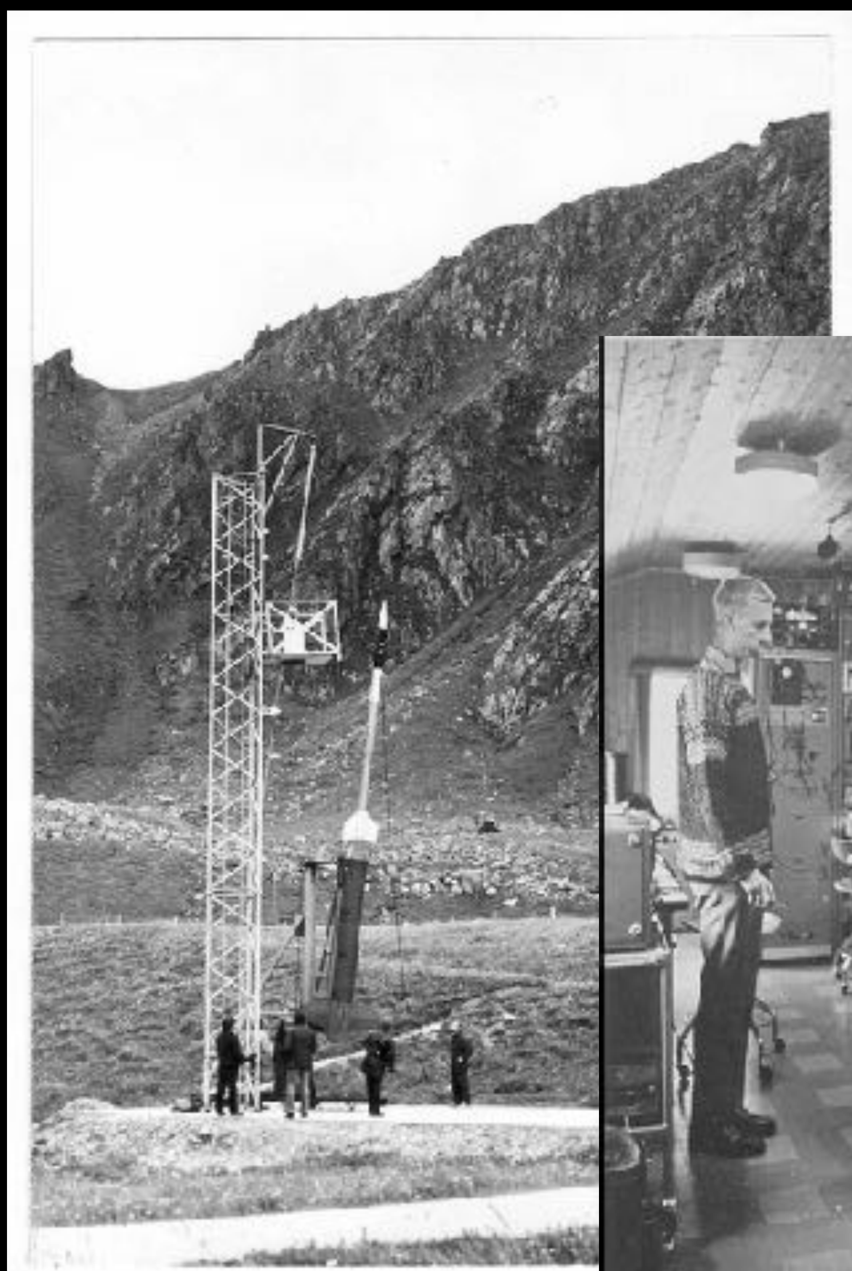
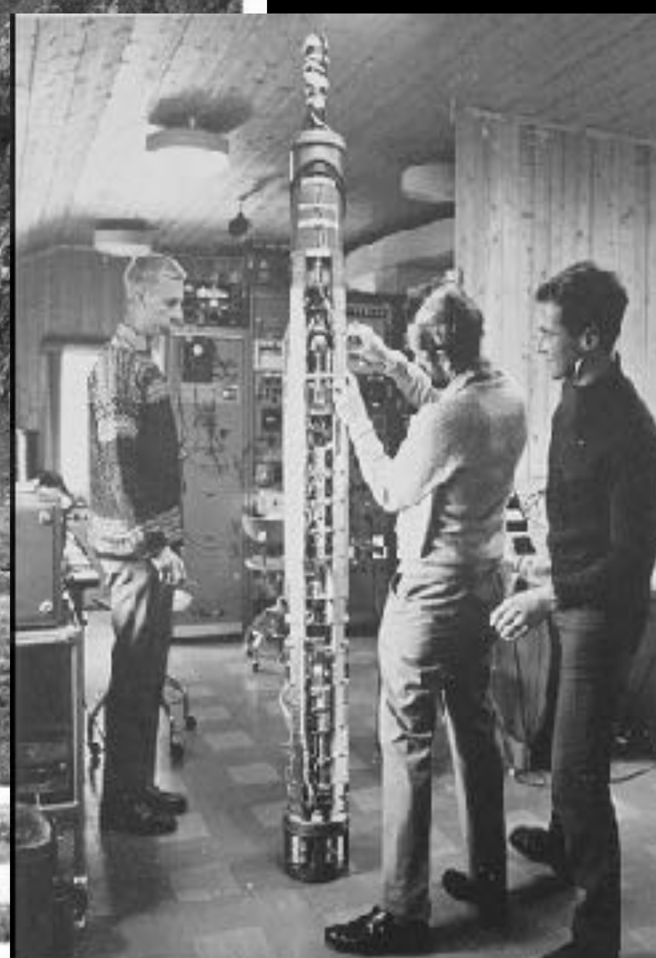
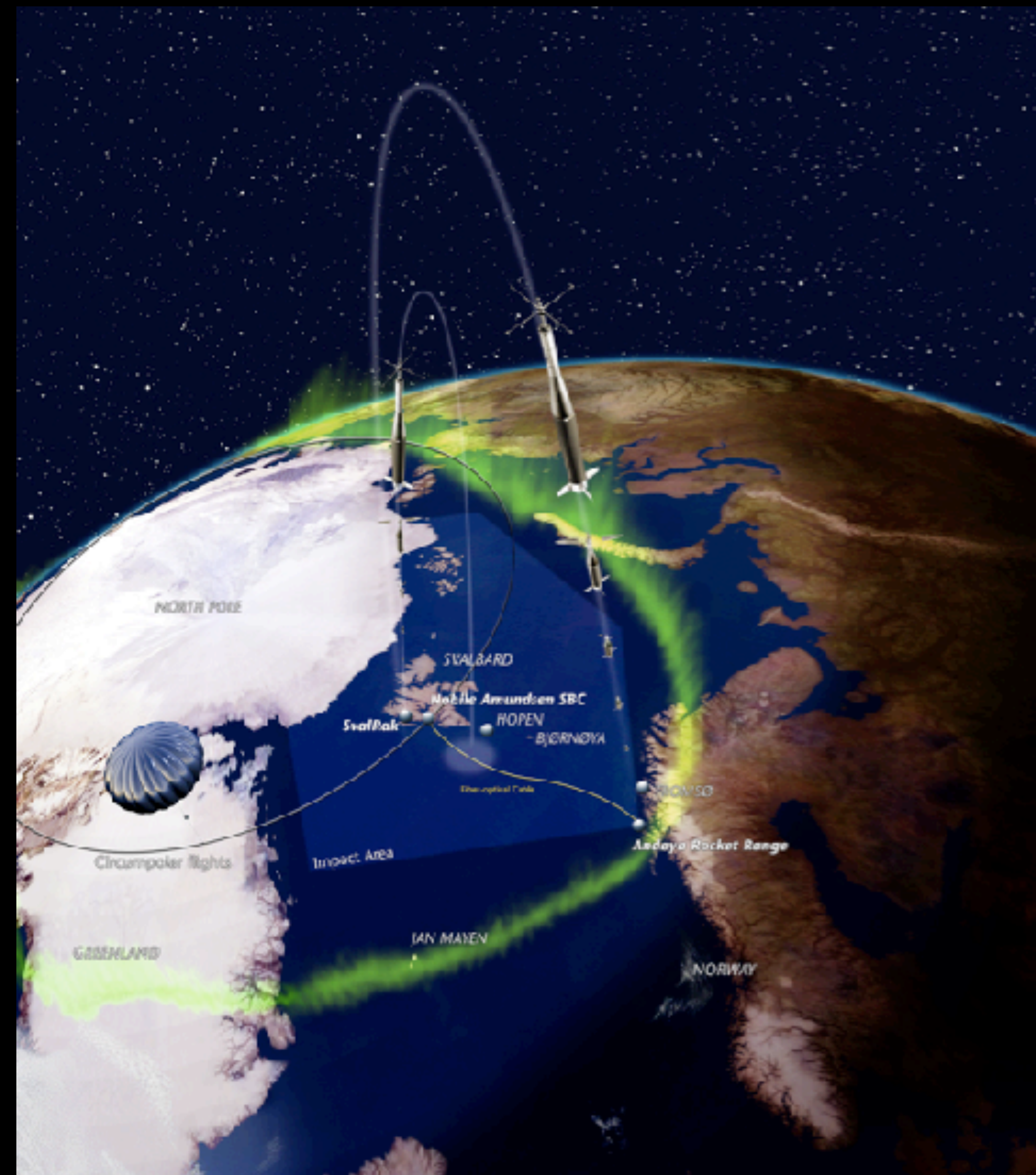
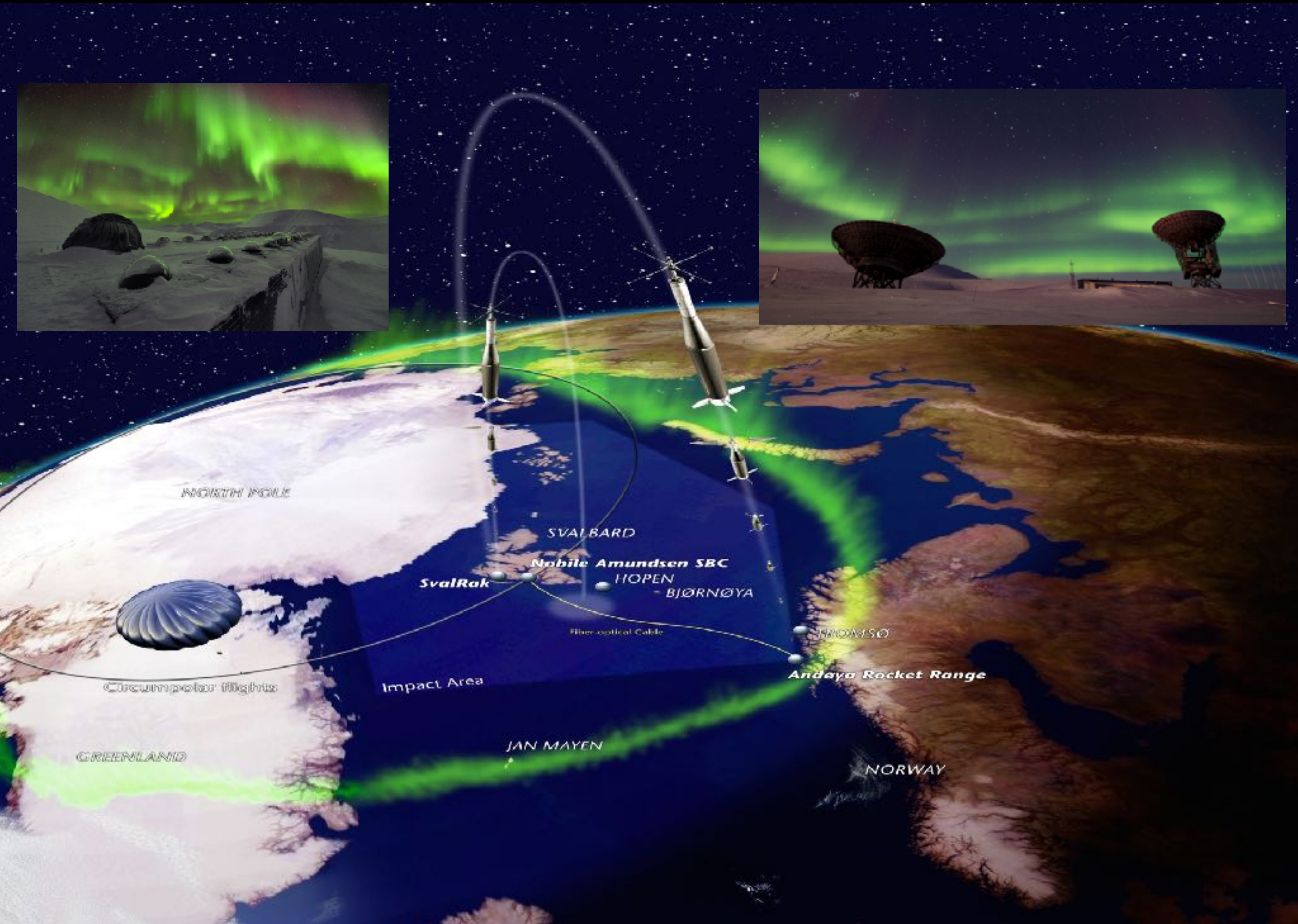
The very start of space research.
Andøya Rocket Range

Ferdinand from Oksebåsen, Andøya 18 august 1962








NORTH POLE
SVALBARD
Nobile Amundsen SBC
SvalRak
HOPEN
BJØRNØYA
Fiber-optical Cable
TROMSØ
Andøya Rocket Range
Impact Area
Circumpolar flights
GREENLAND
JAN MAYEN
NORWAY

ANDØYA SPACE CENTER

The Cost Effective Entrance to Space

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Launches


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Thursday, January 21, 1999 Published at 18:12 GMT

Sci/Tech

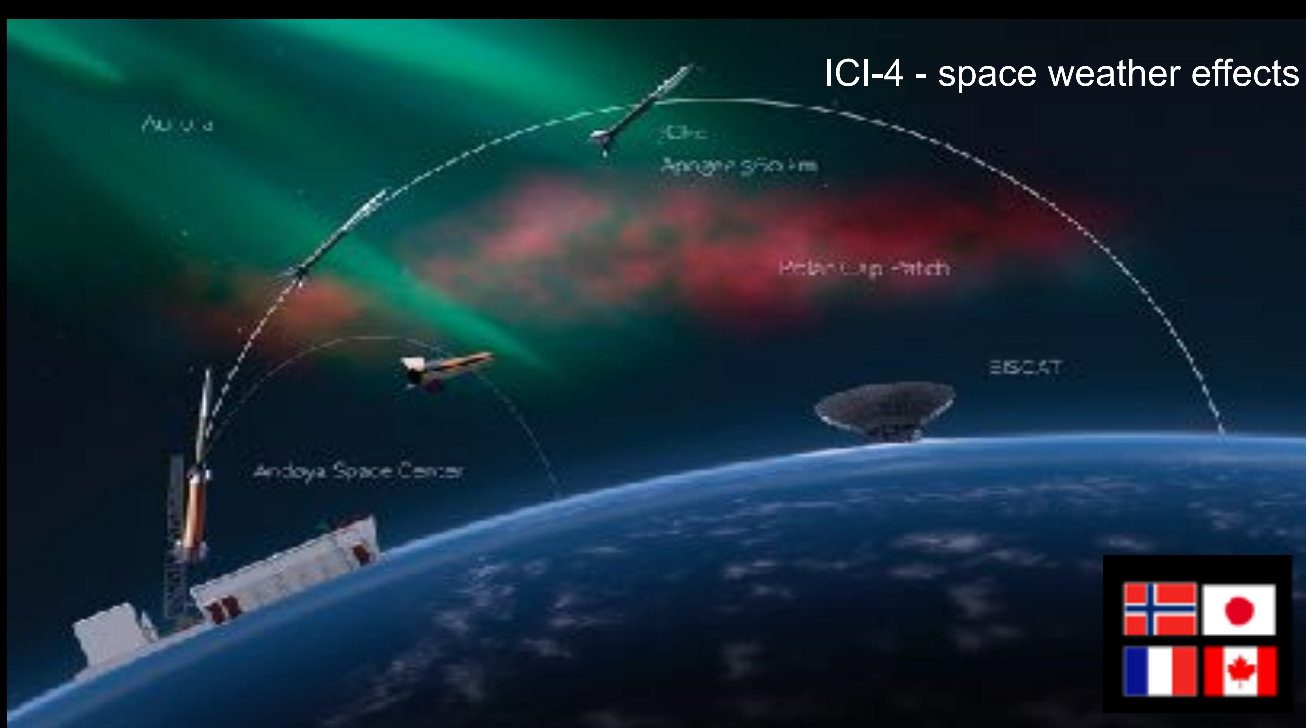
Successful Caper in Norway

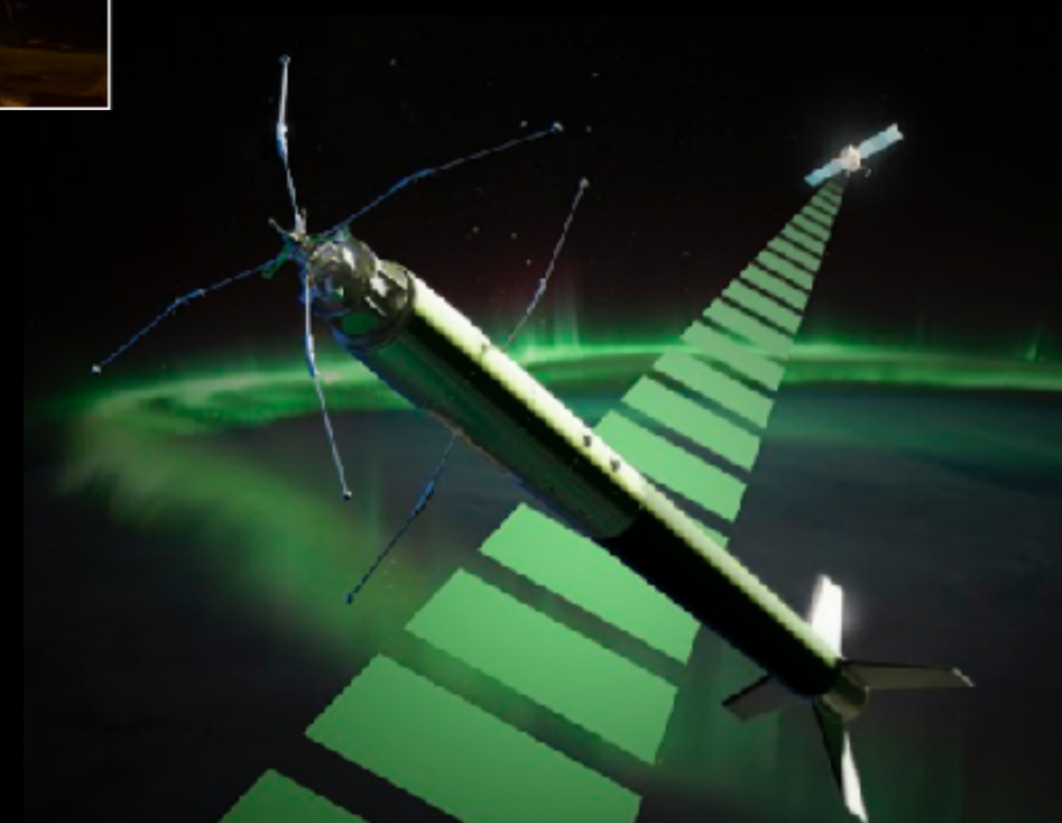
Poor conditions had delayed the launch

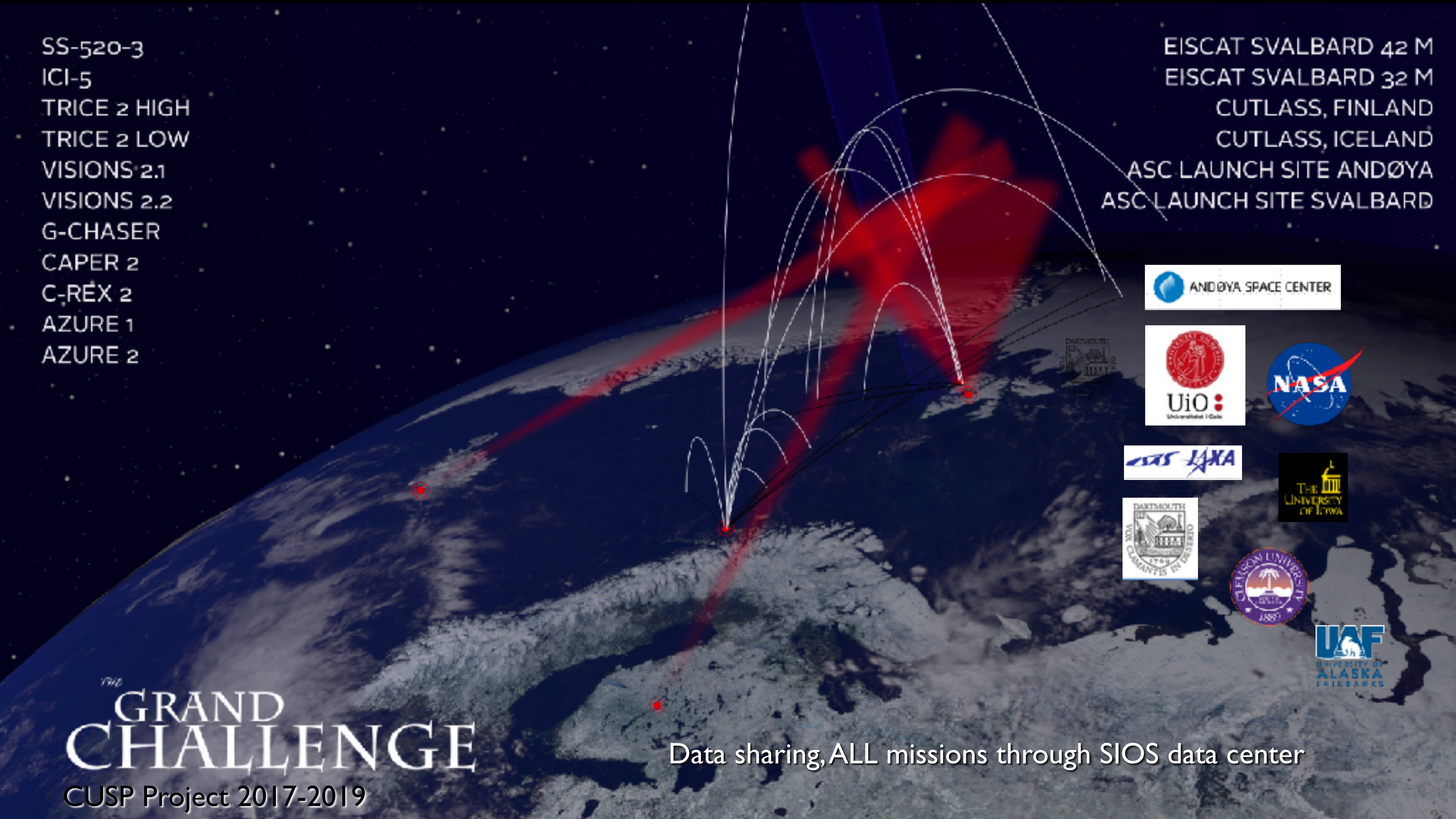
A rocket designed to investigate the "space weather" responsible for the Northern Lights blasted off from a rocket range in Norway on Thursday.

The Caper (Cleft Accelerated Plasma Experimental Rocket) was part of a joint US-Norwegian research project.

Launch of the NASA Charged Aerosol Release Experiment (CARE II) from Andoya Space Center in Norway, Sept. 16, at 19:06 GMT. -







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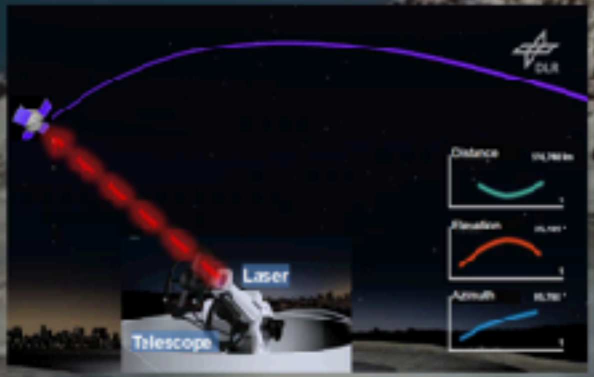
ALOMAR Observatory

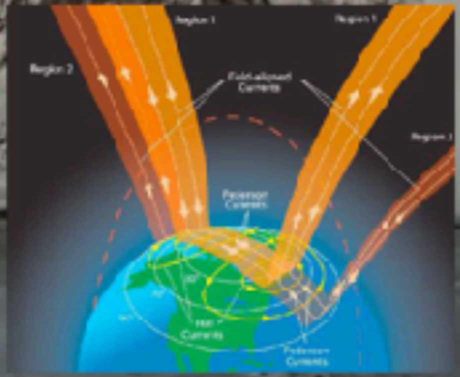
Arctic Lidar Observatory for Middle Atmosphere Research

International atmospheric observatory;

Norway, Germany, USA, Bulgaria, UK, Canada, Spain, France, Switzerland

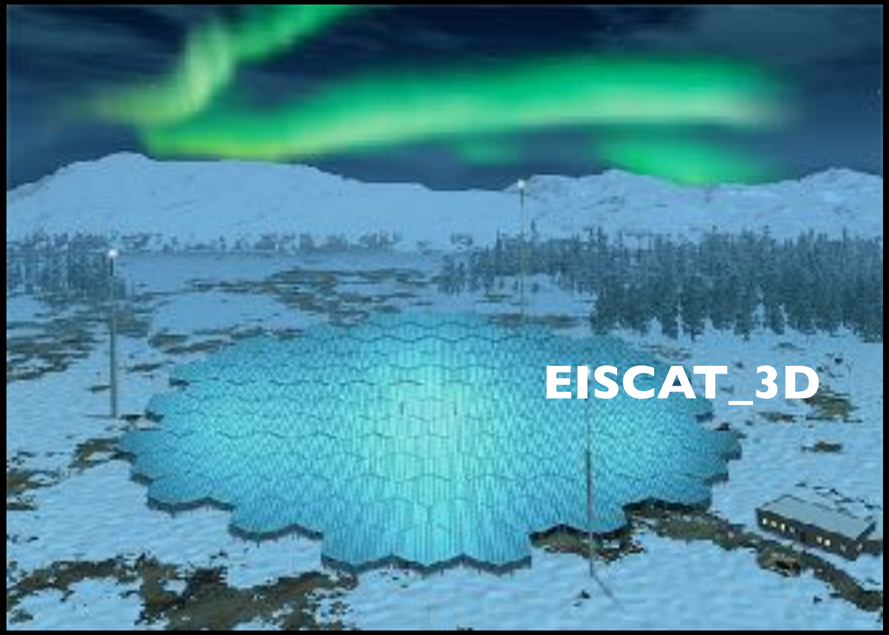
- Operating since 1994
- 4 day/night lidars: RMR, Fe, Ozone, Troposphere (covering 0 - 120km)
- 3 radars: MAARSY (MST), Saura MF, SKiYMET
- All systems operated by the ALOMAR staff
- 500 + publications in the 20 years of operation
- ALOMAR tropo-lidar: ADM-AEOLUS validation 2017 =>
  - Accepted by ESA
  - Operations funded by Norwegian Space Centre
- Ongoing work:
  - DLR Stuttgart to do optical tracking of space debris from Sept. 2018
  - Optically pumped magnetometer for investigations of Birkeland currents (MOM) by Tromsø Geophysical Inst. ~late 2018
-

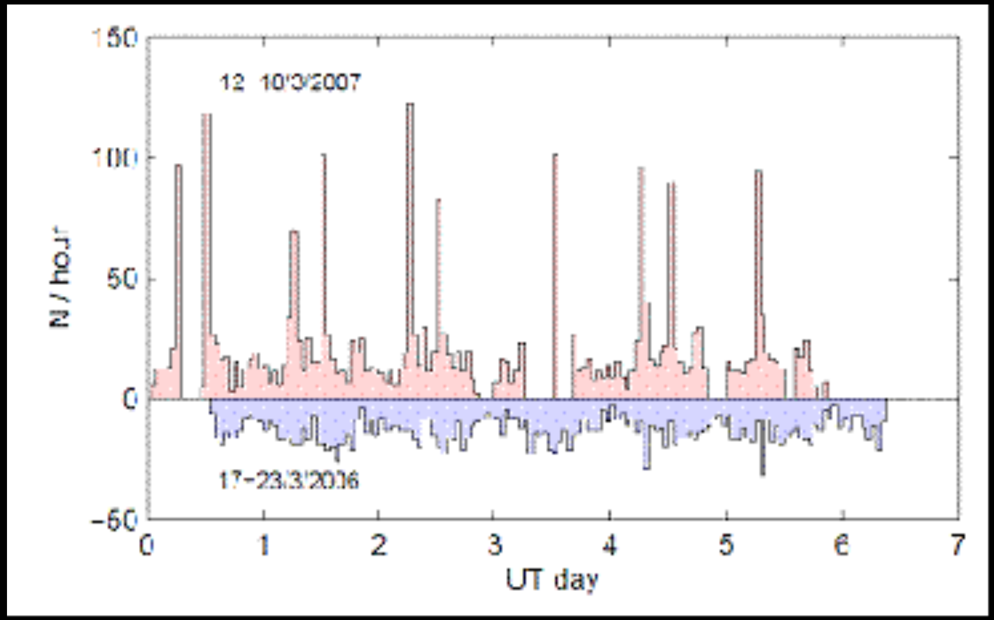




The EISCAT radars

EISCAT (European Incoherent Scatter) antennas in Norway, Sweden and Finland. Studies the interaction between the Sun and the Earth (ionosphere, plasma clouds etc.) Also useful for tracking space debris





Aurora Observatory at Svalbard
Kjell Henriksen Observatory

Rent a rom with a "view"

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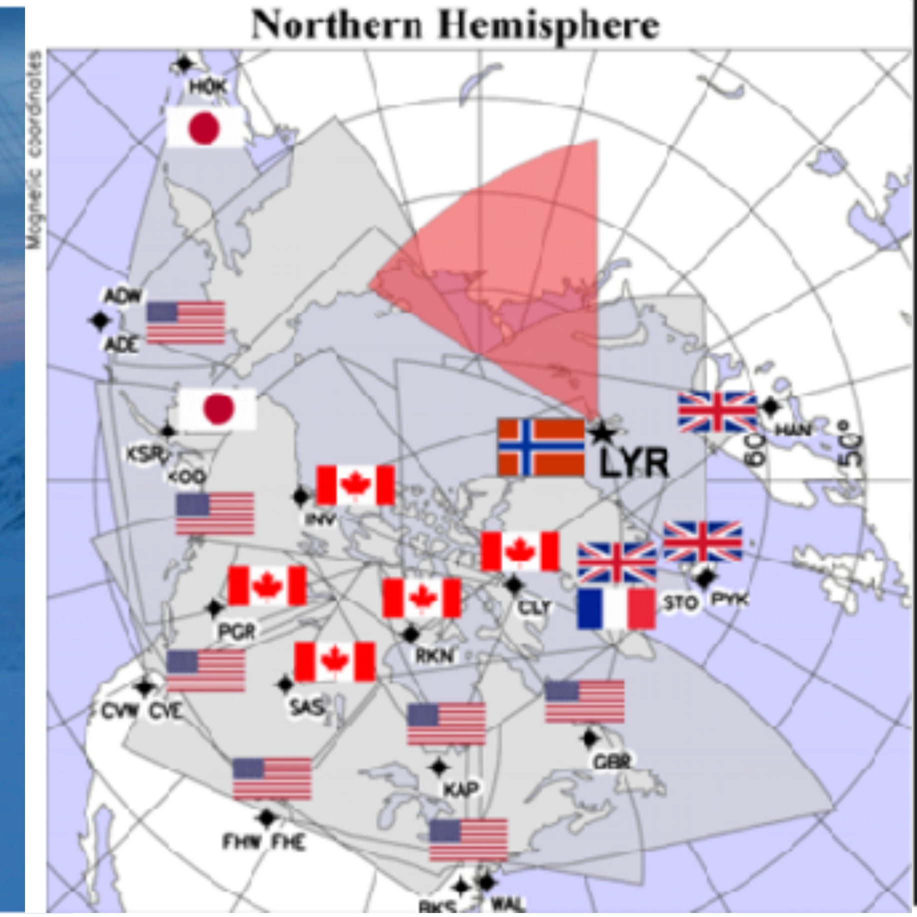
UNIS

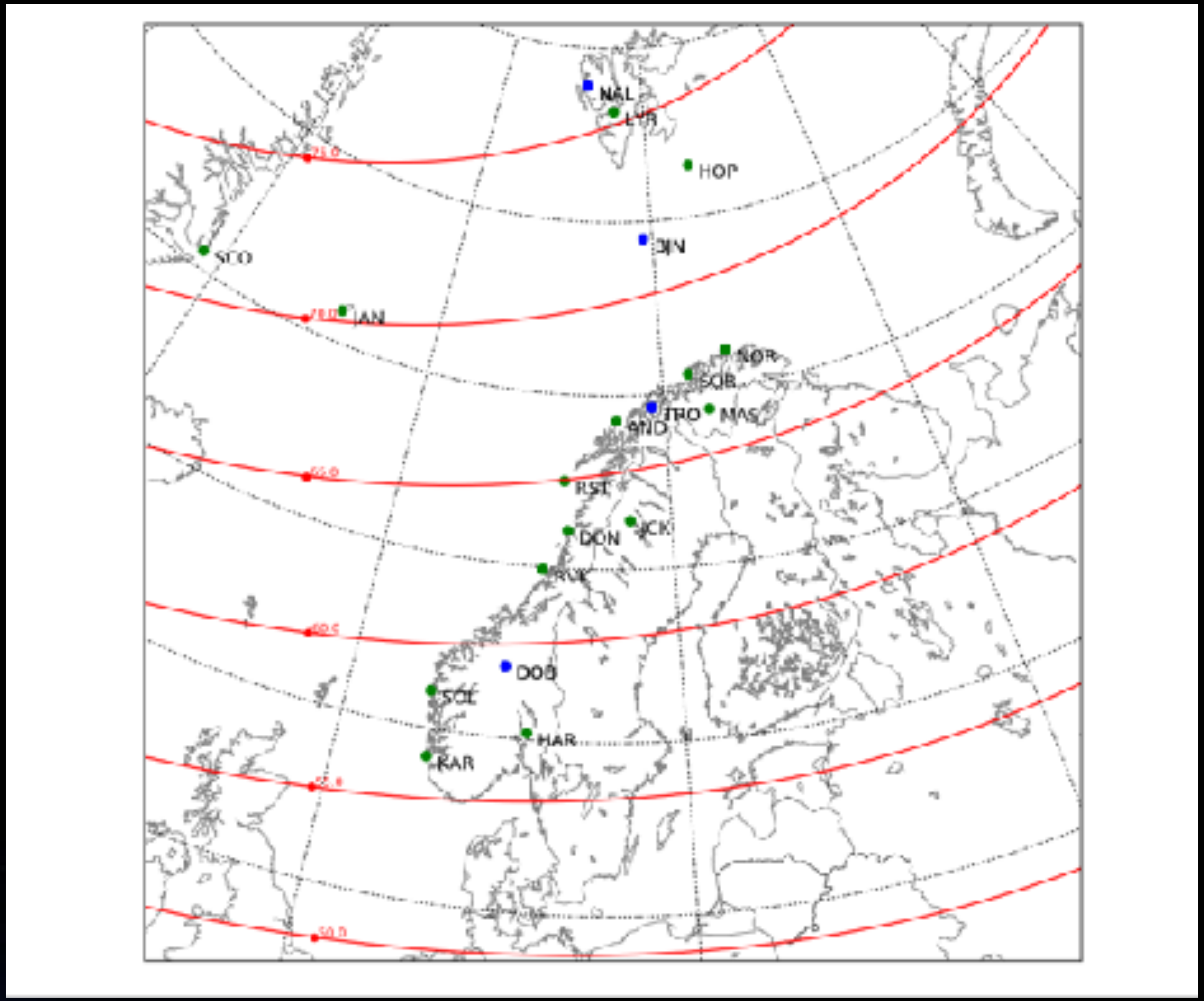


The Svalbard SuperDARN radar

- **Principal Investigator:** Prof. Dag A. Lorentzen, UNIS and The Birkeland Centre for Space Science (BCSS).
- **Co-Investigator:** Assoc. Prof. Lisa Baddeley, UNIS and BCSS,
- **Project Scientists:** Prof. Kjellmar Oksavik, Univ. of Bergen and BCSS
  Dr. Pål Brekke, Norwegian Space Centre and UNIS
  Prof. Jøran Moen, Univ. of Oslo and UNIS
  Prof. Fred Sigernes, UNIS and BCSS
- **Project engineer:** Dr. Mikko Syrjäsuo, UNIS and BCSS

Tromsø Geophysical Observatory (TGO)

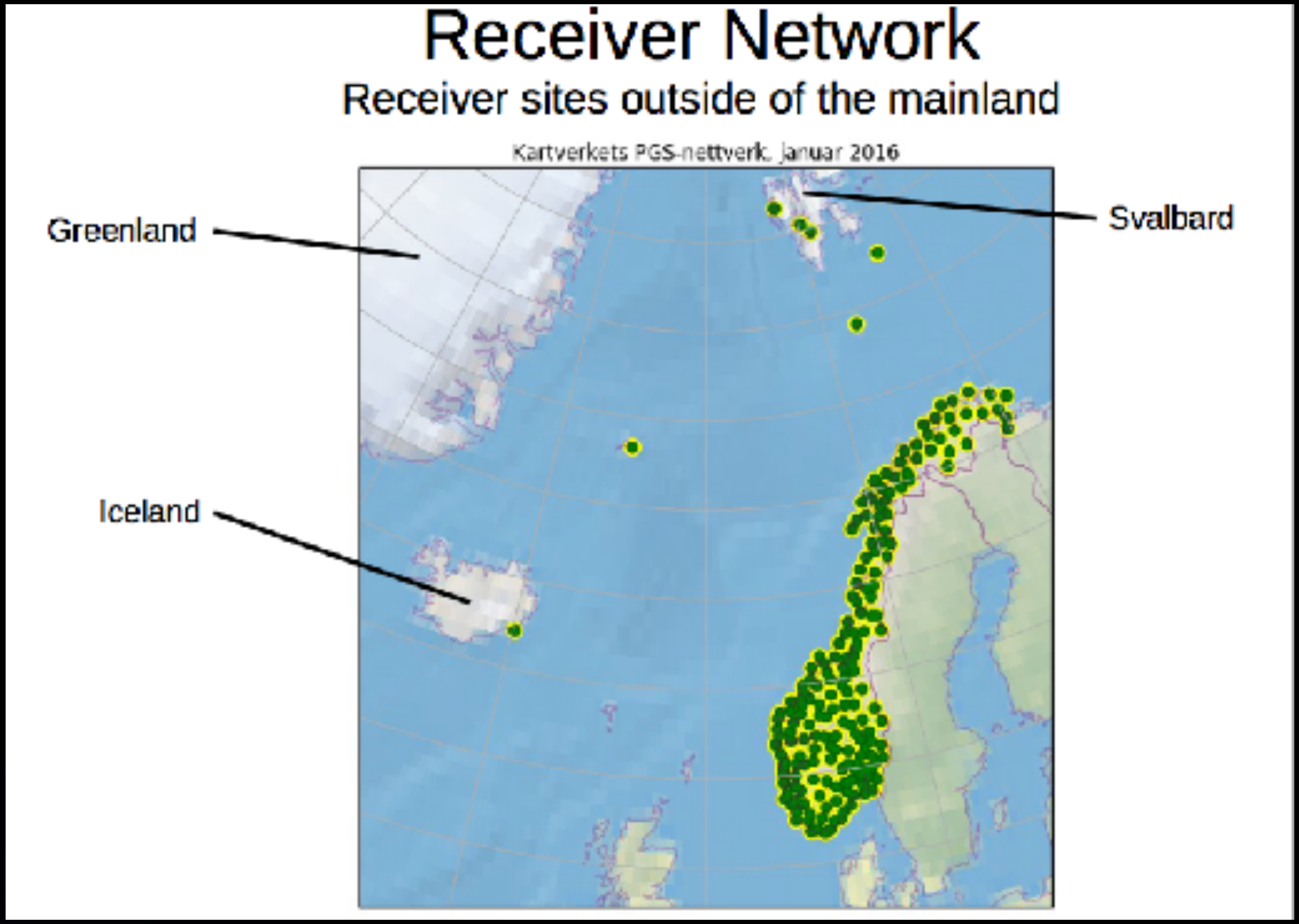
- Unit directly under the Faculty of Science and Technology at UiT
- Main Responsibility: Maintain observational time series (1928/32 – future) of the geomagnetic field in Norway (magnetometers) and electron density profile above Tromsø (ionosonde).
- Network off 14 magnetometers + other relevant systems.
- At present 8 employees (3 engineers, 5 scientists)



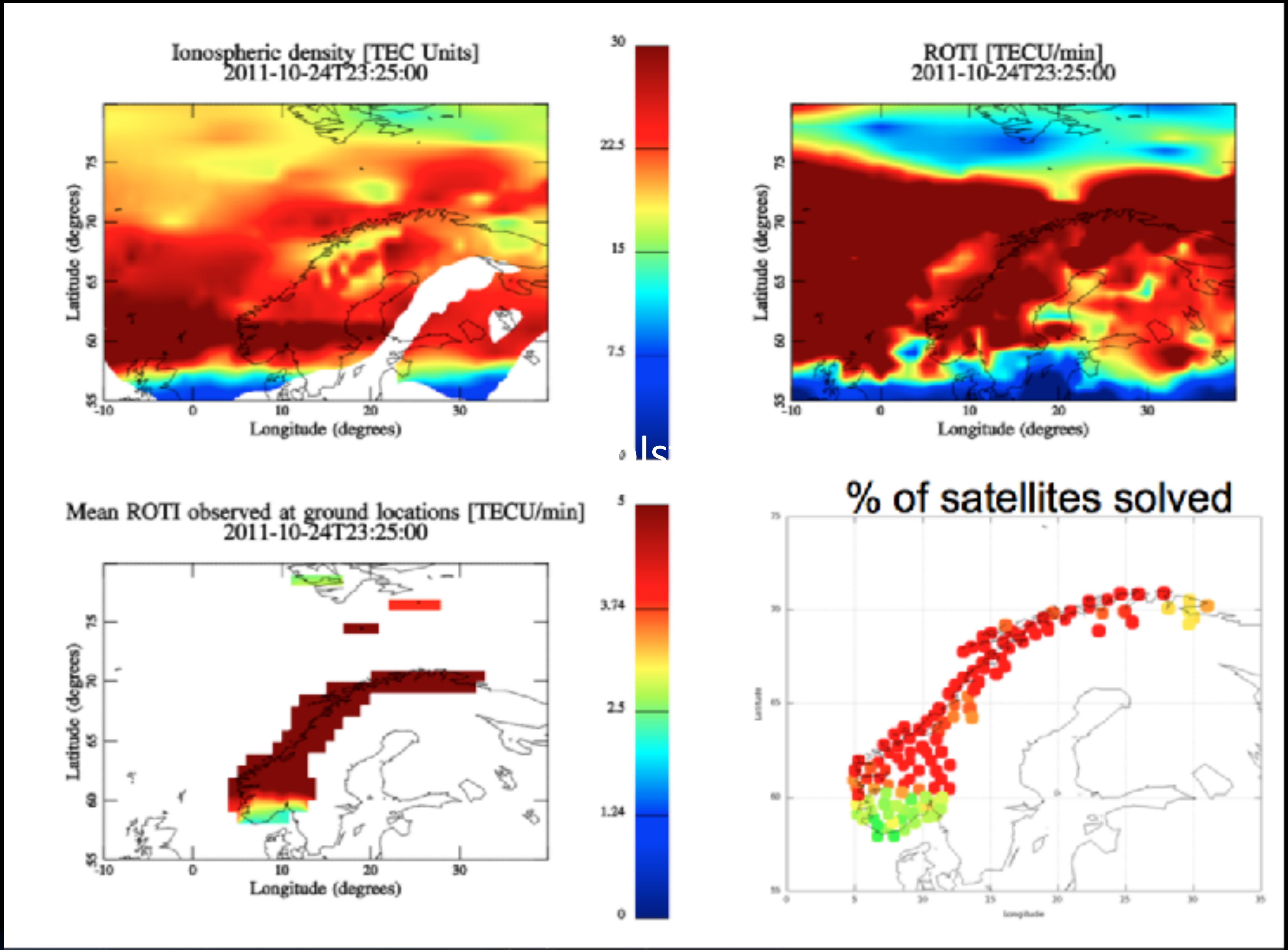
The Norwegian Mapping Authority

- Permanent Geodetic Stations on Norwegian Mainland and Svalbard
- The Norwegian Mapping Authority (NMA) has developed an ionospheric model based on the GNSS network.
- A network of 135 GNSS-receivers across Norway
- High ionospheric activity causes problems for calculating GPS-corrections in SATREF®

- SATREF® is a correction service they provide to the users



Solar storm effects on GPS

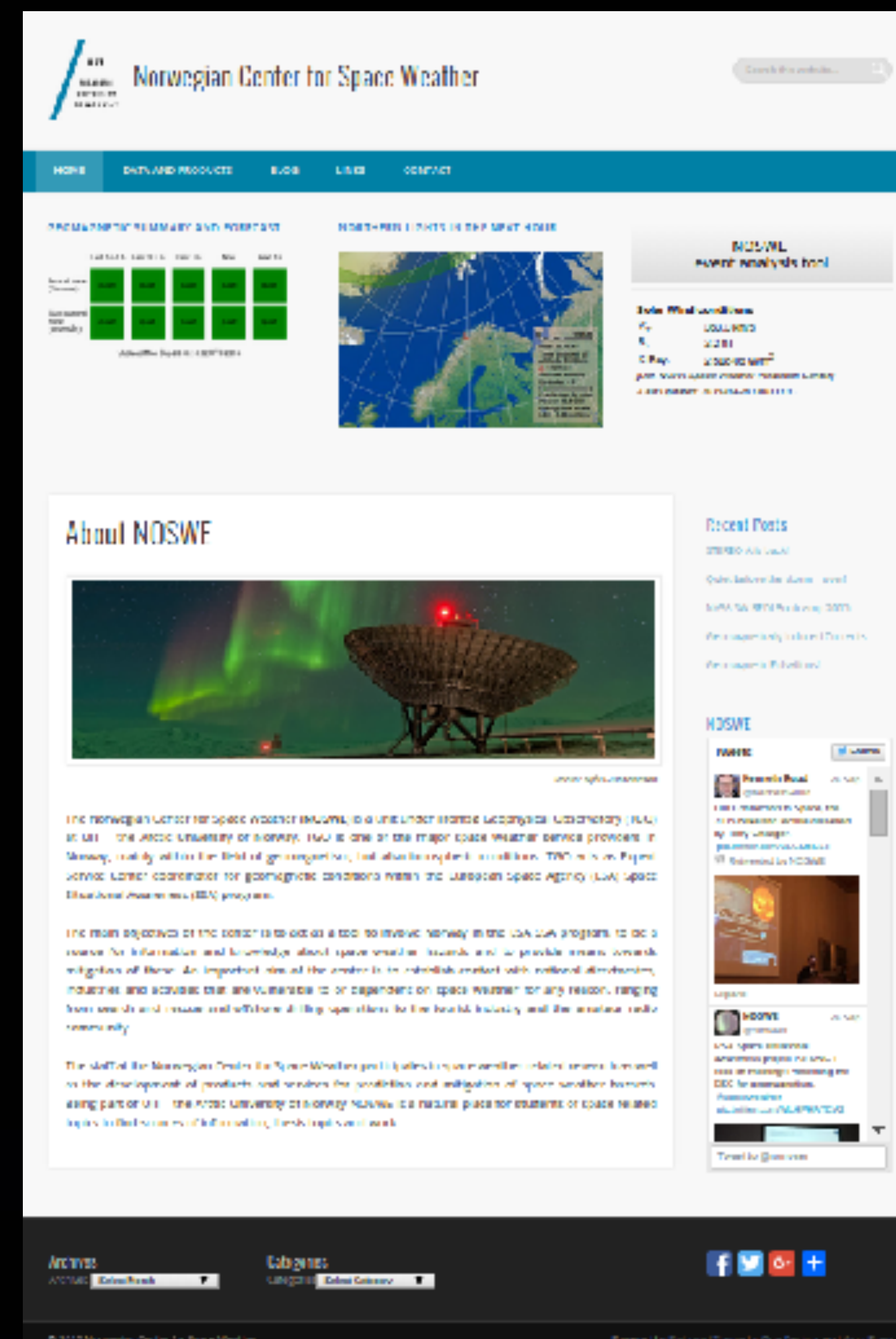


http://sesolstorm.kartverket.no

Norwegian Space Weather Center

Aim to get national responsibility for operational space weather acitivities.

Already planned emergency readiness with Norwegian Power Grid company (Statnett)
Will be built around a Space Weather monitoring center



We have initiated a collaboration with our national weather services (met.no) to distribute future space weather alerts/ warnings.

http://site.uit.no/spaceweather/

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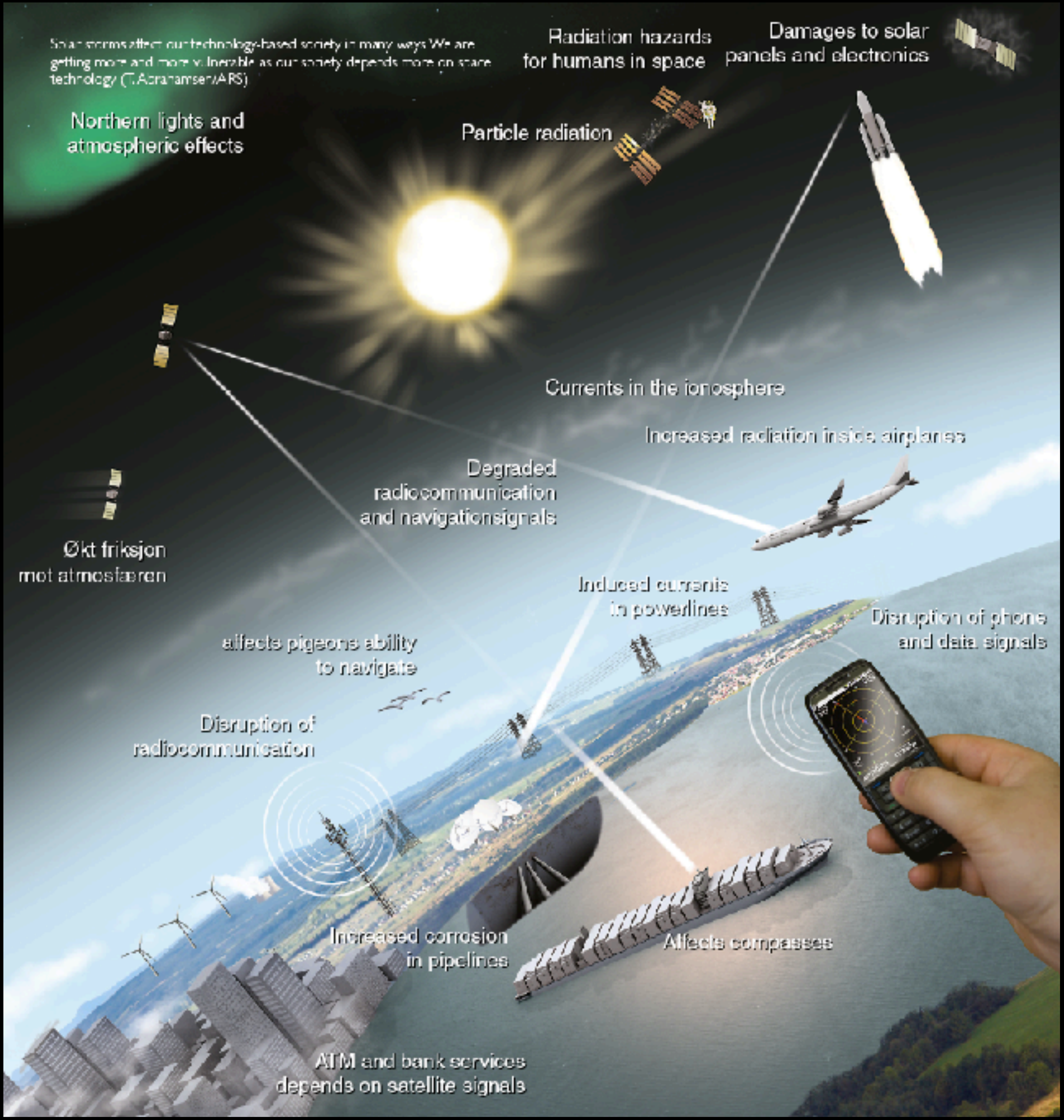
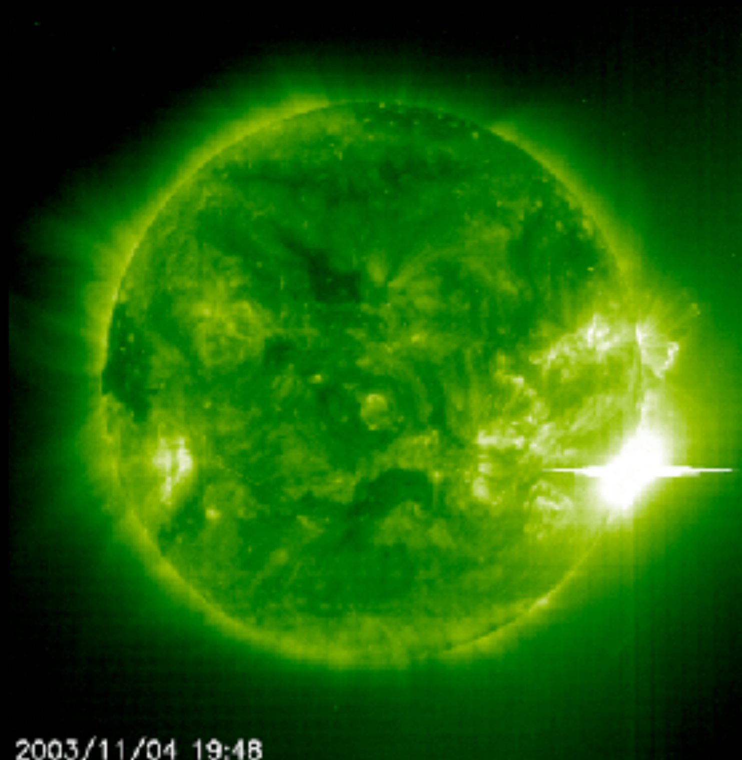
Space Weather

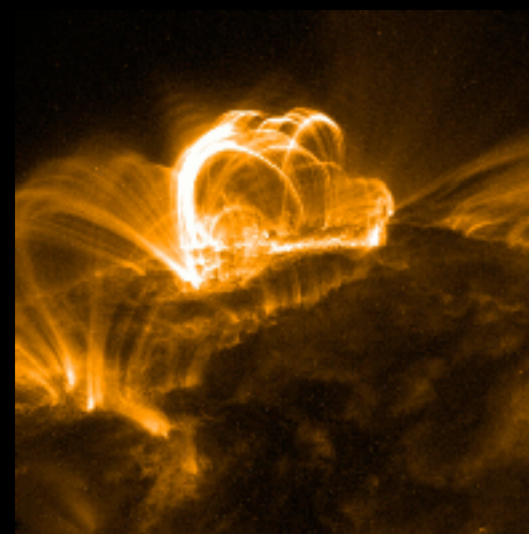


From the book «Our Explosive Sun» (P. Brekke)

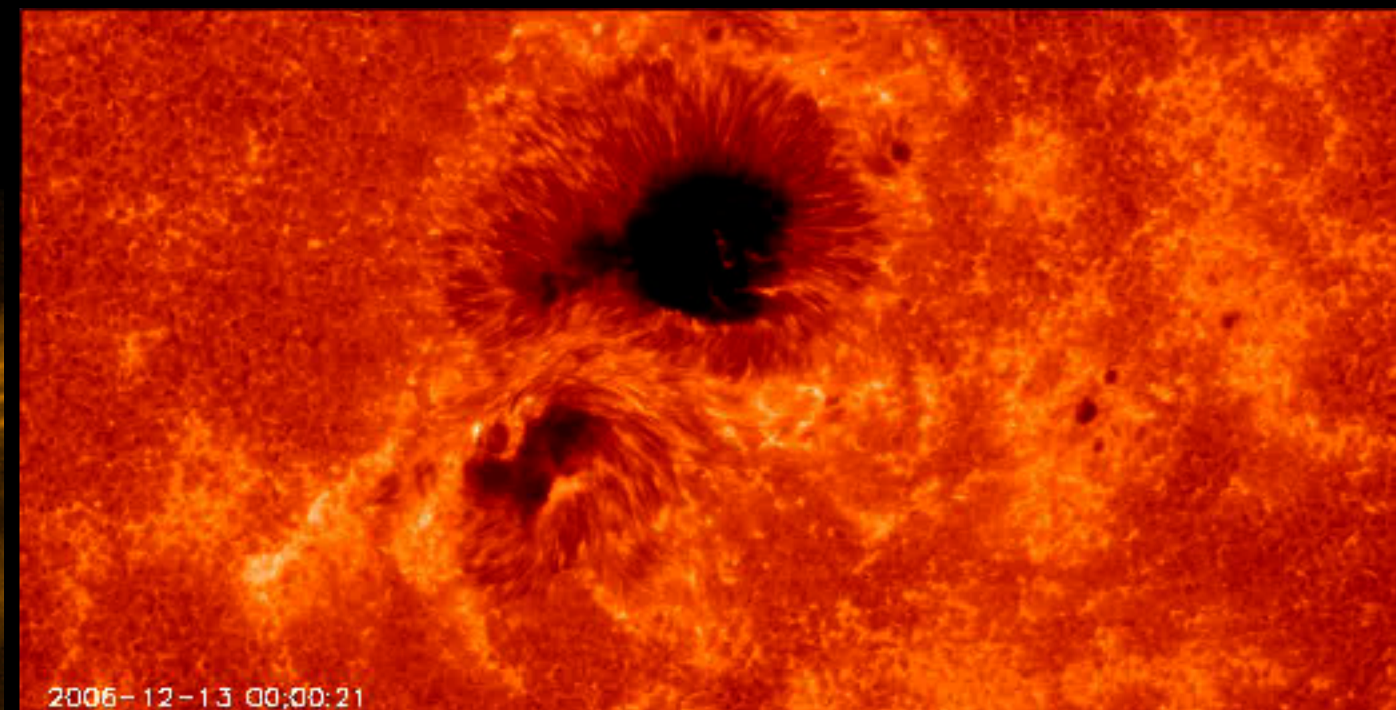
EXPLOSIONS ON THE SUN - FLARES



SOHO(NASA/ESA)

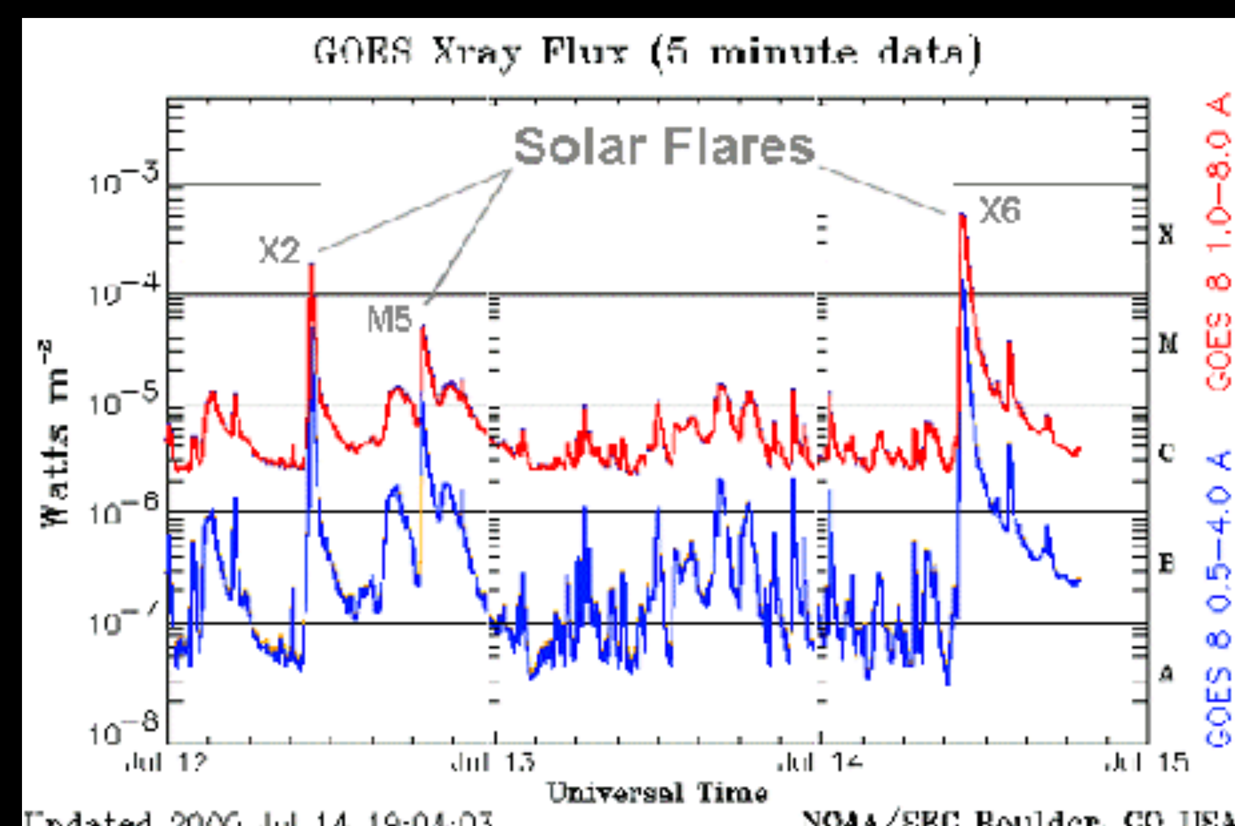


TRACE/NASA

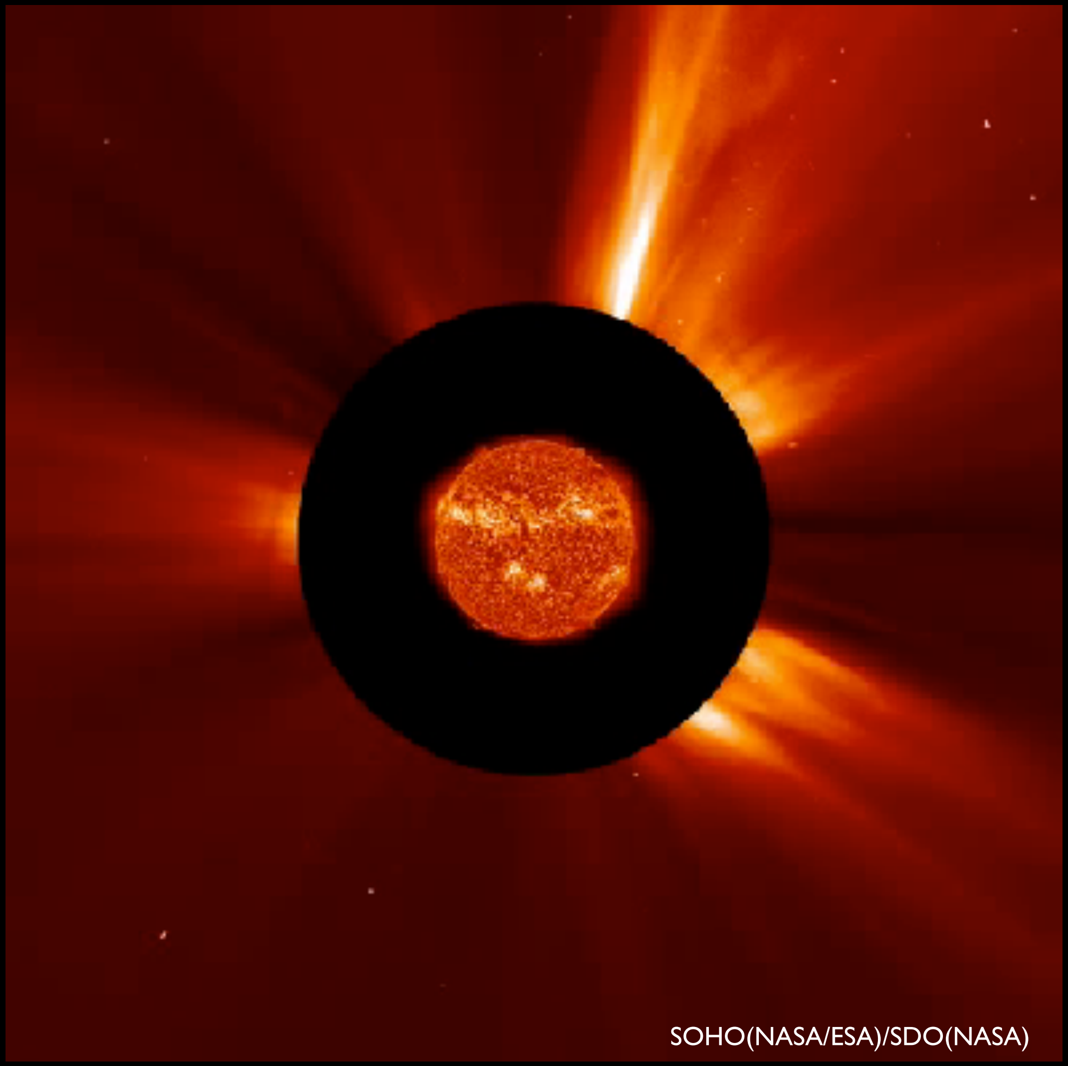


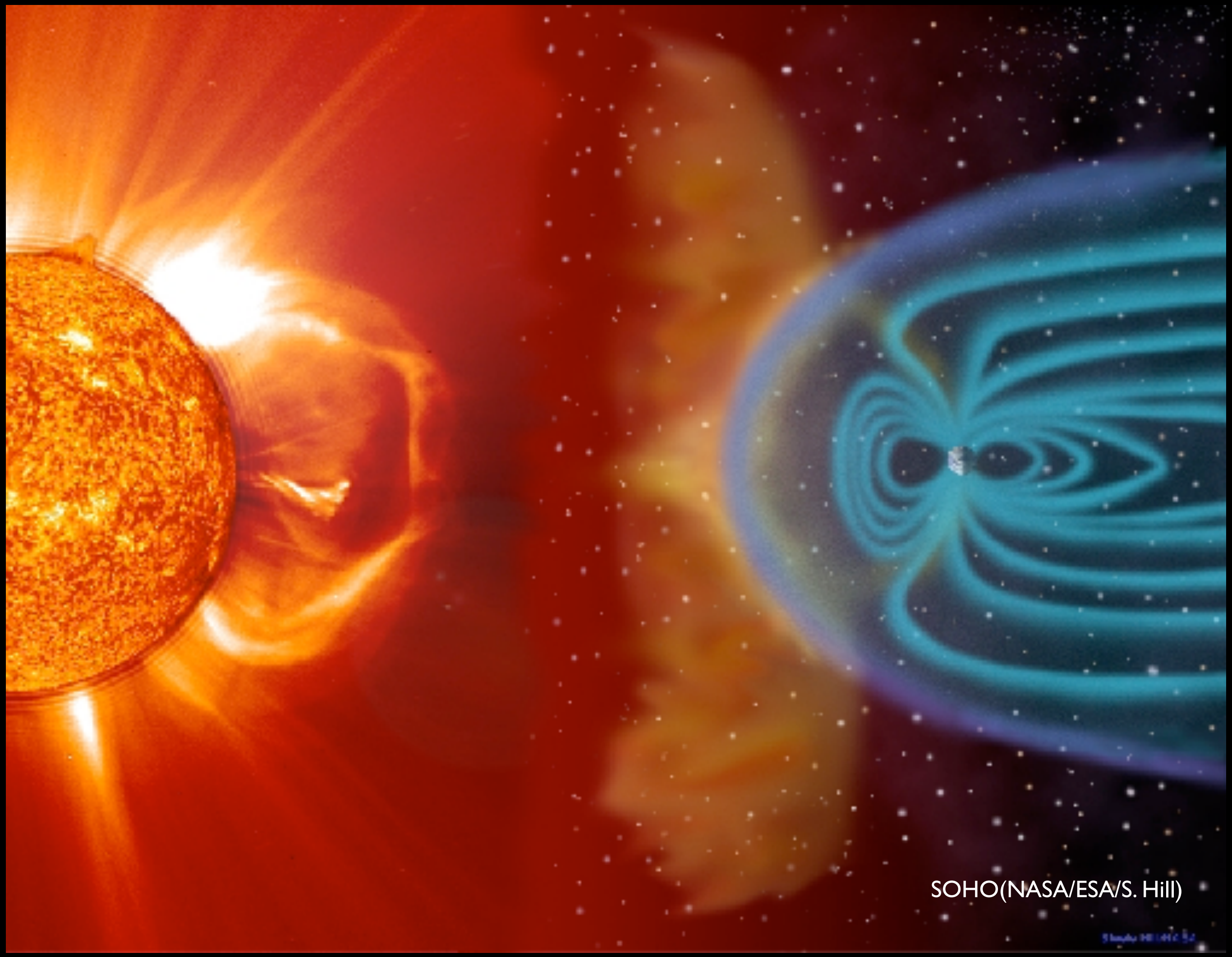
Hinode/JAXA

The magnetic field in large active regions on the Sun often gets unstable and result in violent explosions in the solar atmosphere – called “flares”. Flares emits large amounts of UV- and X-ray radiation.



GAS ERUPTIONS - CORONAL MASS EJECTIONS (CME)

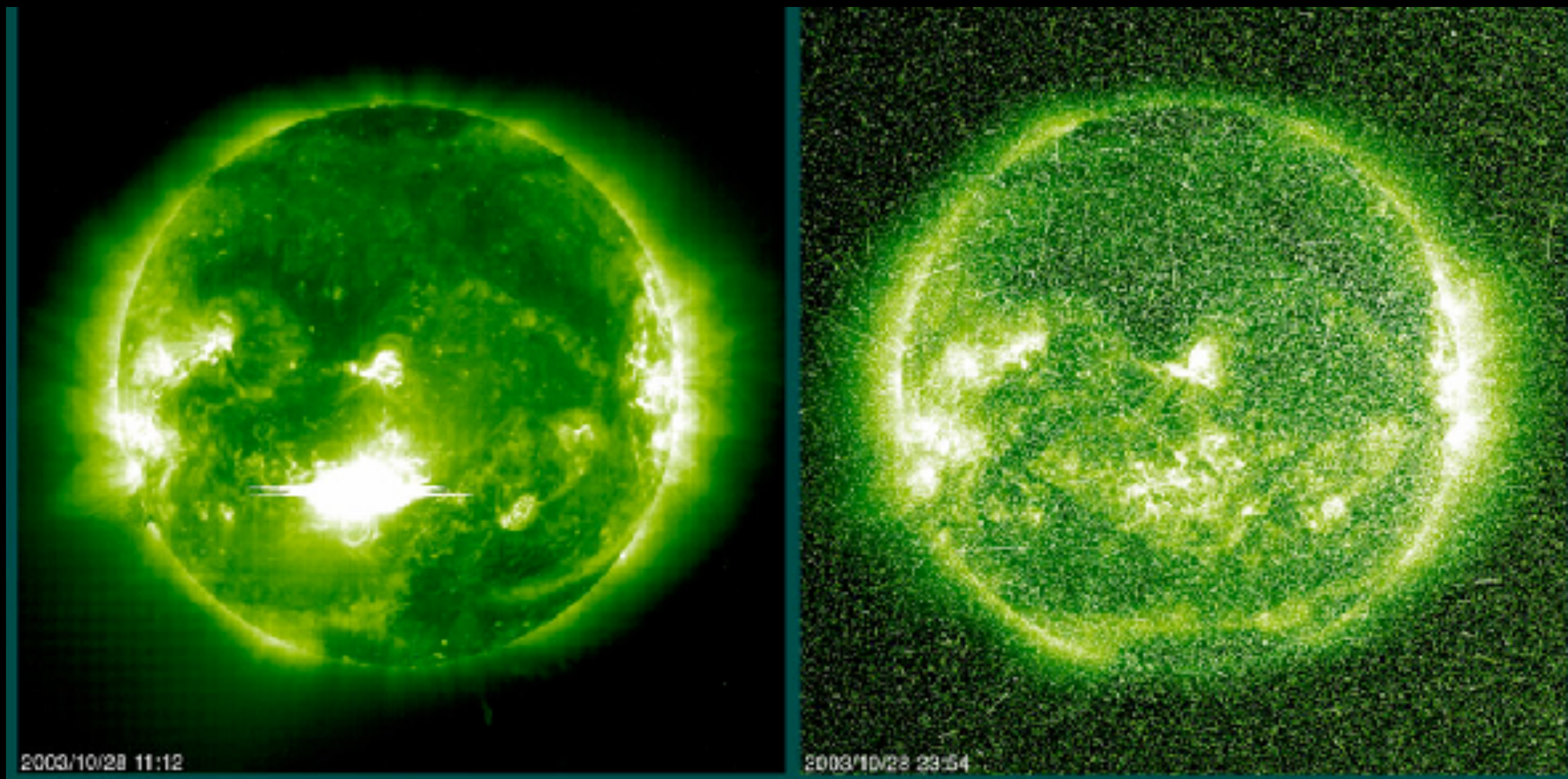


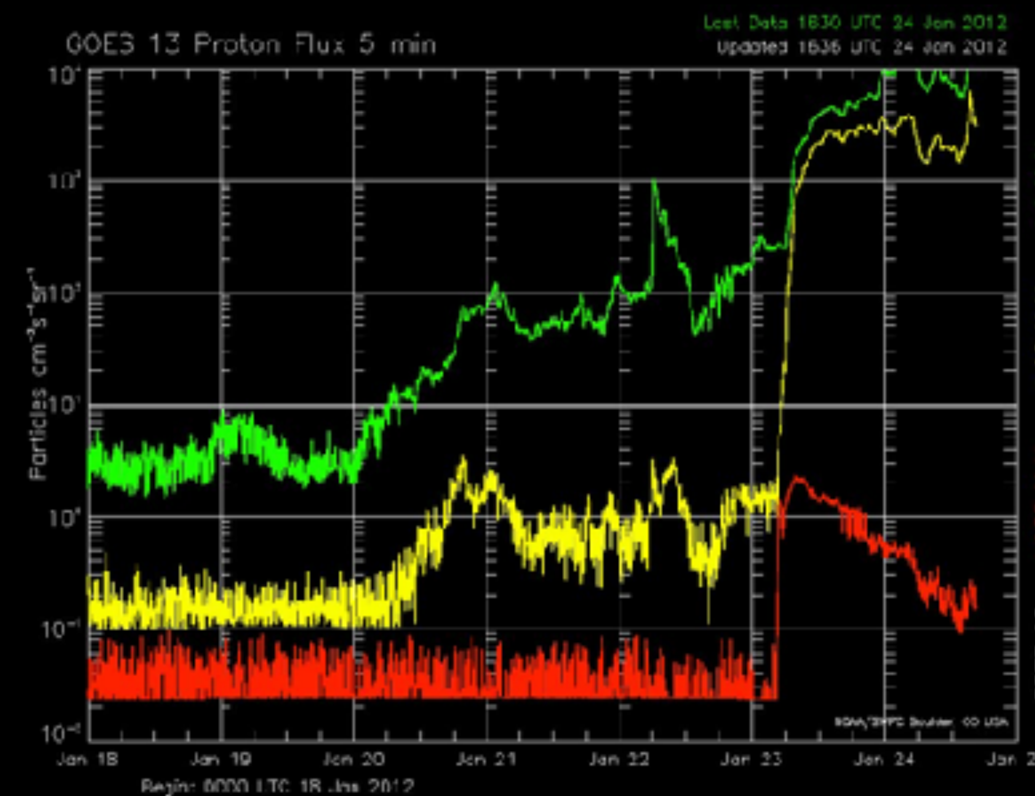


Sometimes large prominences can erupt and large amount of gas and magnetic fields are ejected out in space. The largest eruptions eject several billion tons of particles corresponding to 100,000 large battleships. Such eruptions are called Coronal Mass Ejections or CMEs for short. The bubble of gas will expand out in space and can reach velocities up to 8 million km/h. Still it would take almost 20 hours before it reach the Earth. Usually the solar wind spends three days on this journey.

If such an eruption is directed towards the Earth the particles will be deflected by our magnetosphere. The cloud of gas will push and shake the Earths magnetic field and generate a kind of “storm” which we call geomagnetic storms.

PARTICLE SHOWERS FROM THE SUN



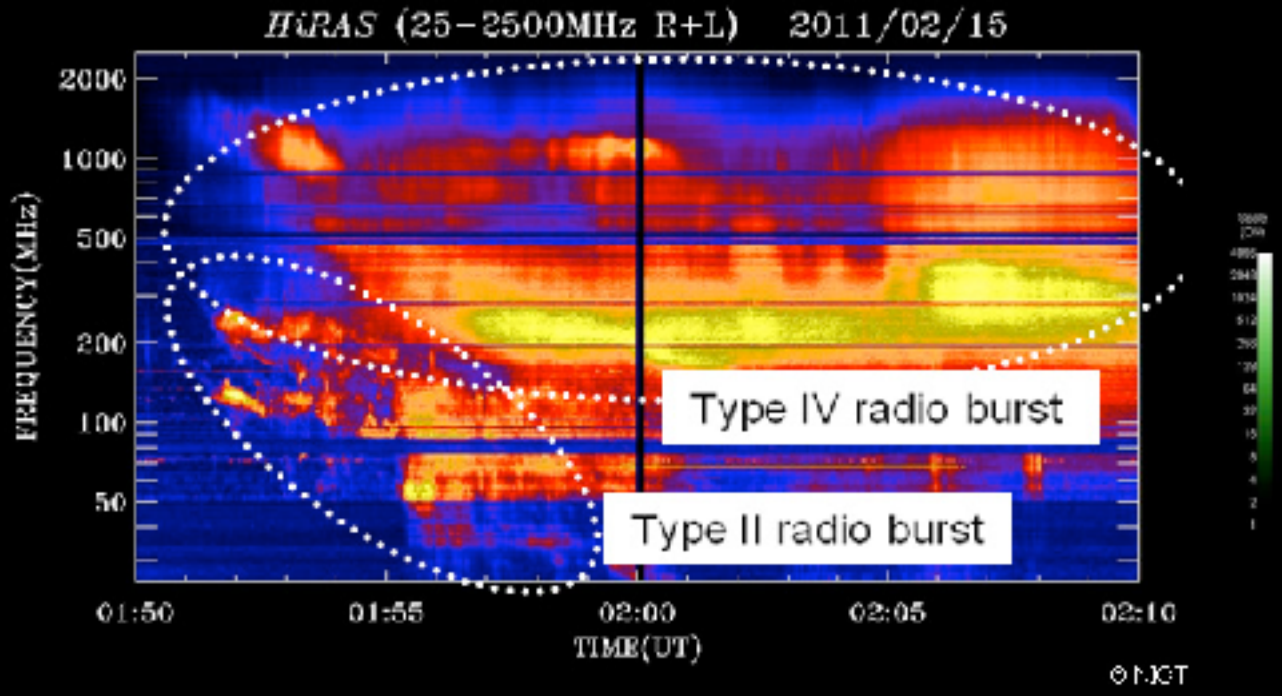


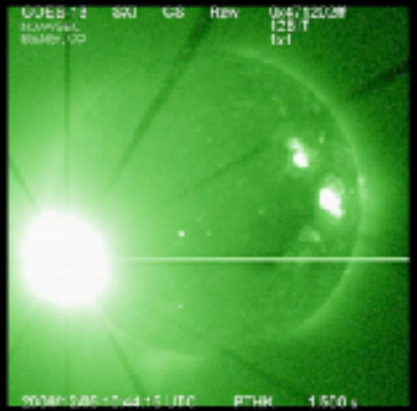
SOHO(NASA/ESA)

A few times explosions or eruptions will accelerate large amount of particles that travel at almost the speed of light. Such showers of particles consist mostly of protons and it takes less then an hour to reach Earth.

The protons have such high speed and energy that they can penetrate satellites and space ships. Thus, they can damage vital electronic equipment. They can also destroy the quality of images and scientific data from those satellites that are surveying the Sun as shown in the picture above. The particles “blind” the digital cameras and we see a large amount of noise in the images.

RADIO-BURST



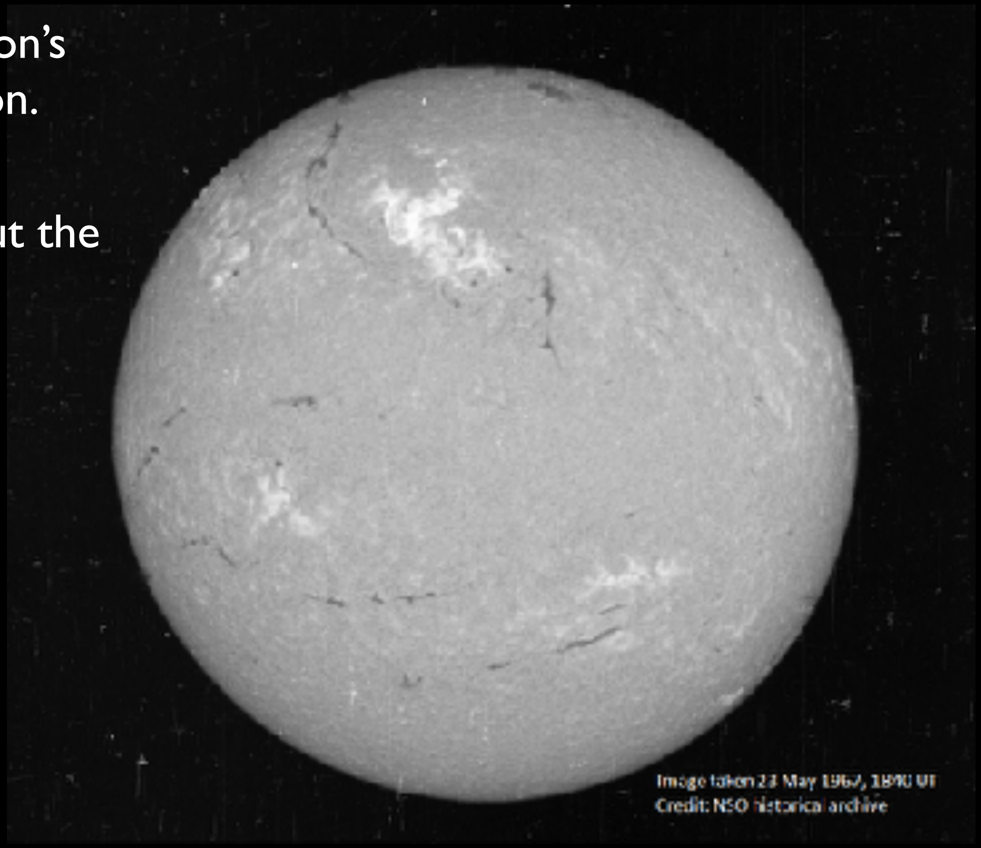


A few times eruptions on the Sun will generate strong burst of radio waves - often with the same frequencies as communications systems we use on Earth as well as the GPS frequency.

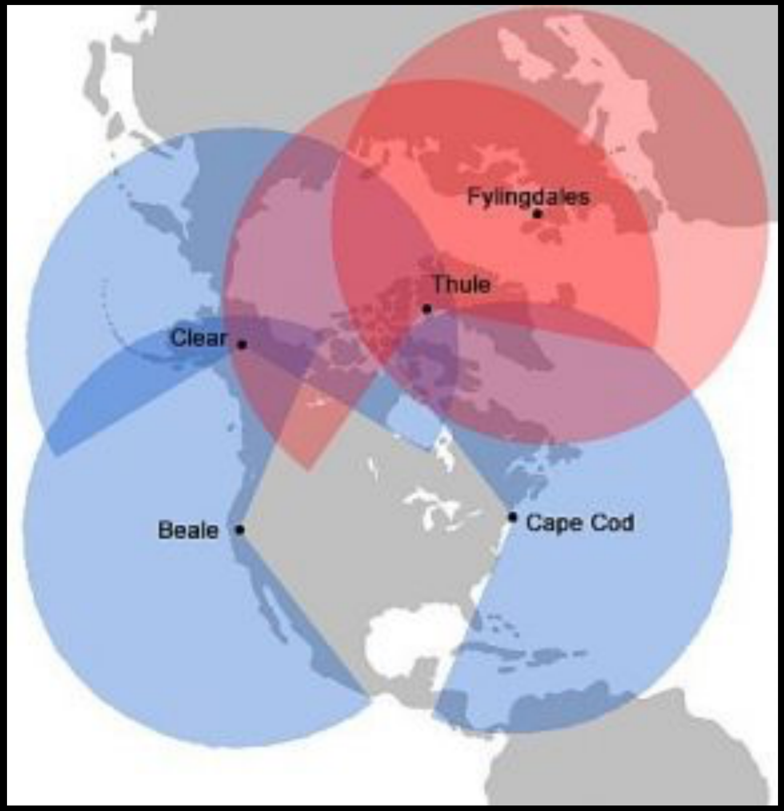
The 1967 solar storm - almost started a nuclear war

- On May 23, 1967, the Air Force prepared aircraft for war, thinking the nation's surveillance radars in polar regions were being jammed by the Soviet Union.

- Just in time, military space weather forecasters conveyed information about the solar storm's potential to disrupt radar and radio communications.



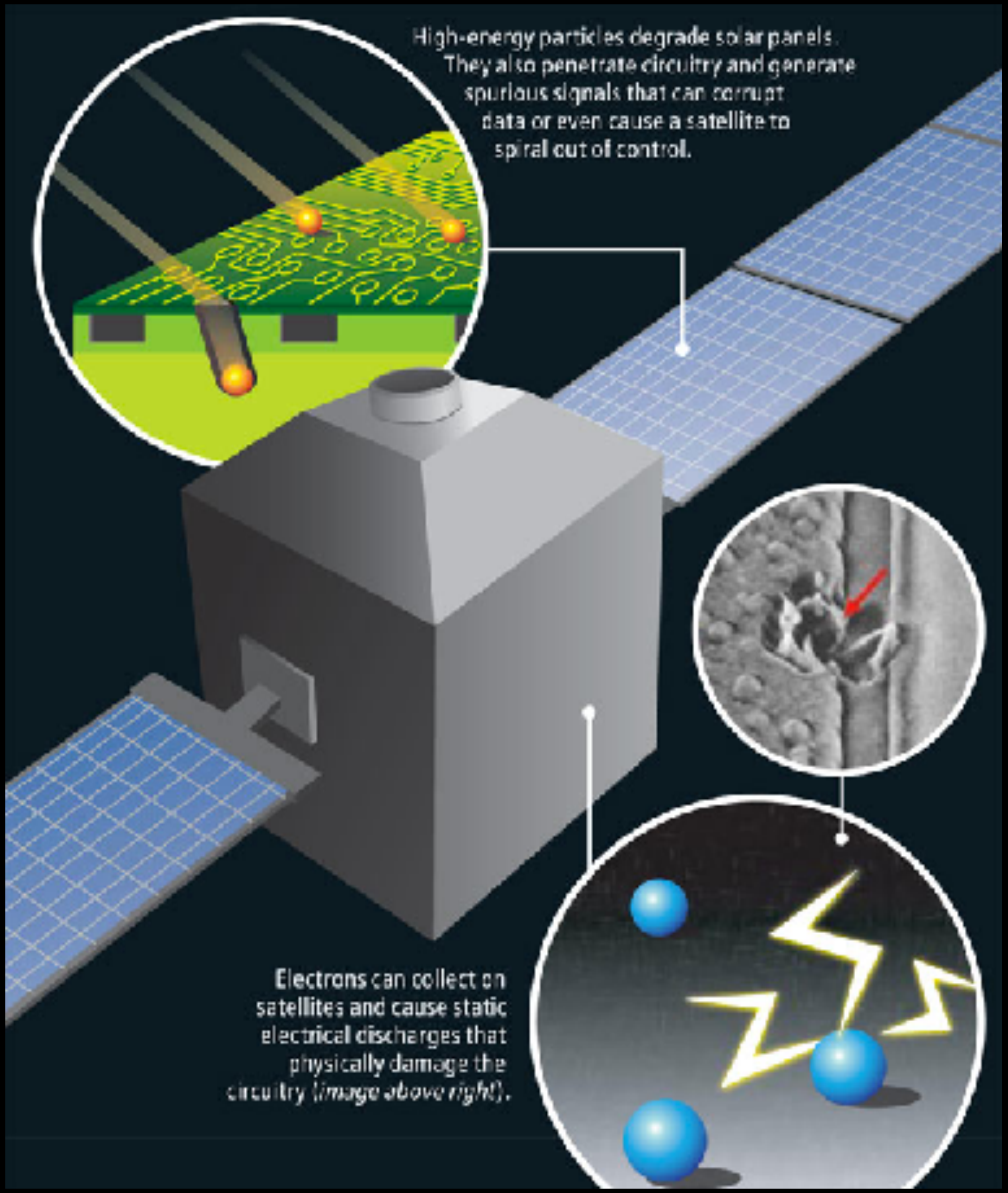
As the solar flare and radio burst event unfolded on May 23, radars at all three Ballistic Missile Early Warning System (BMEWS) sites in the far Northern Hemisphere were disrupted. These radars, designed to detect incoming Soviet missiles, appeared to be jammed. Any attack on these stations – including jamming their radar capabilities – was considered an act of war.

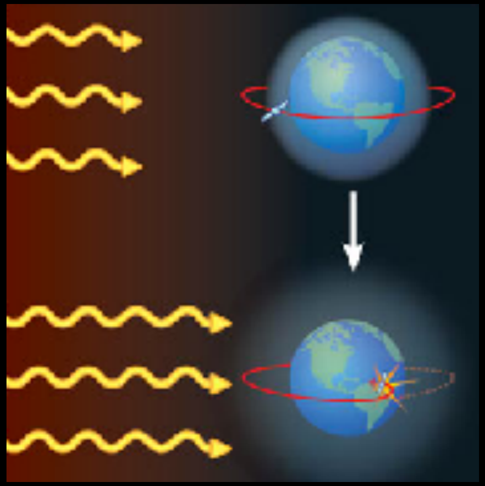


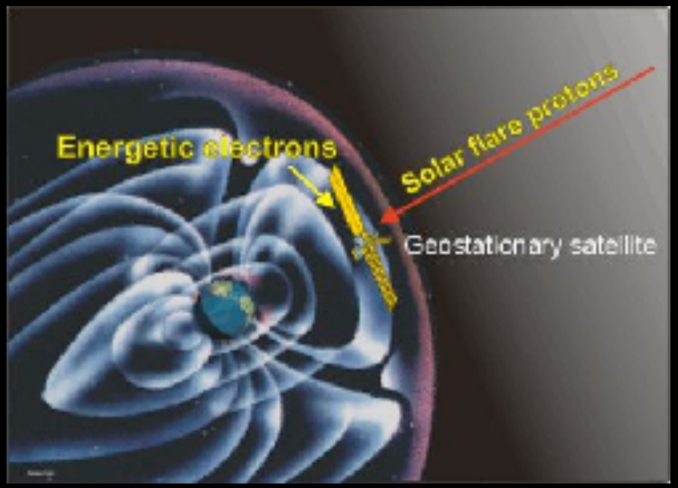
Effects on Satellites

Examples:

- Surface charging
- Single Event Upset (from high energy particles)
- Increased drag
- Interference and scintillation of the signal
- Space debris
- Orientation problems
- Nosie on the star trackers/navigation systems.
- Degradation of material/solar cells
- Hits by micro meteorites



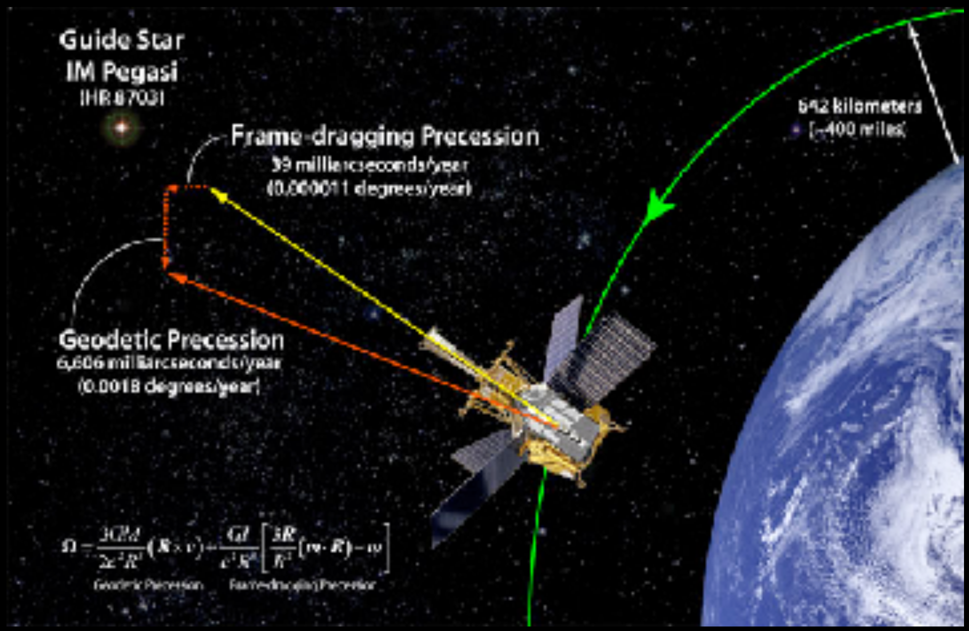


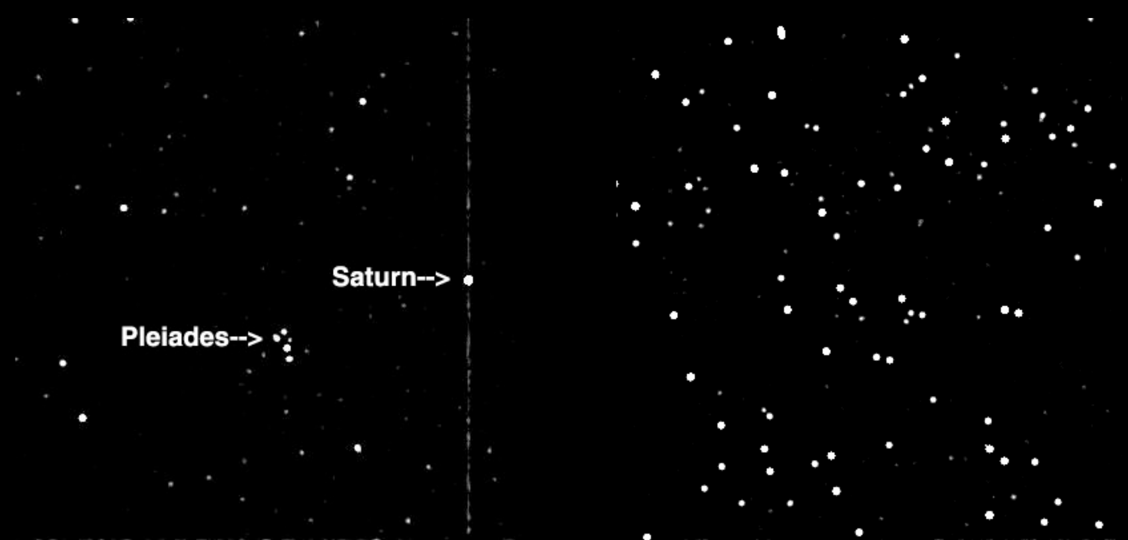


Orientation problems

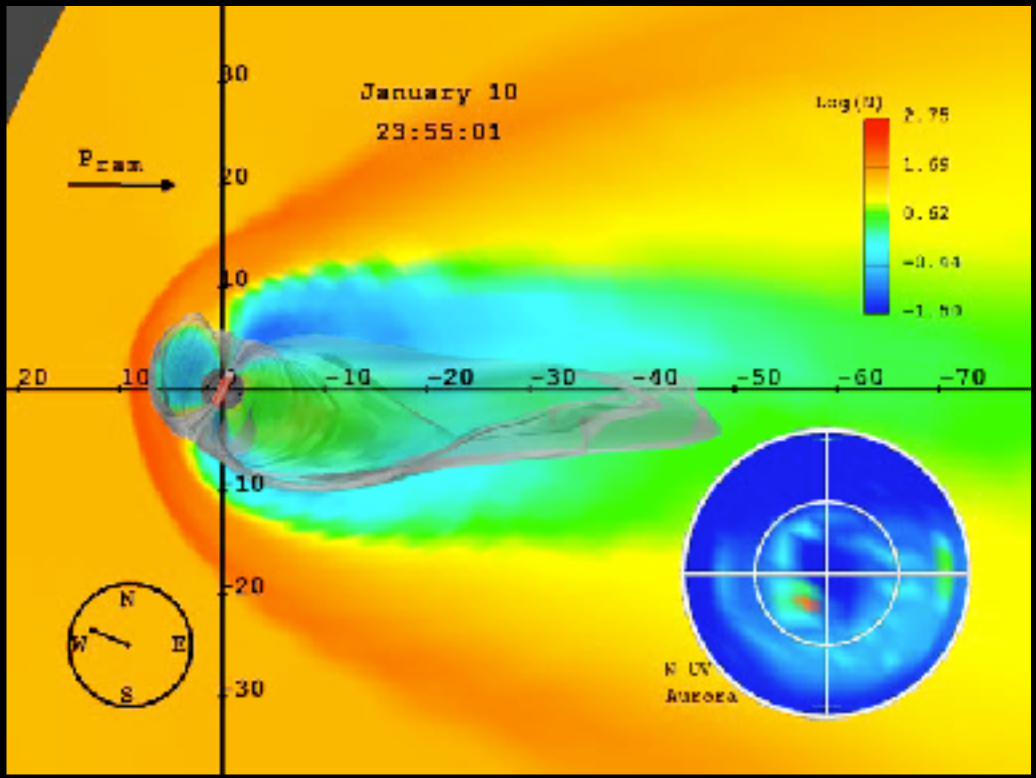
Some satellites use star trackers to «lock» into stars for navigation, others use the Earths magnetic field.

Star trackers can easily be «tricked» by false stars created by high energy protons hitting the CCD camera.





Før protonskur Etter protonskur

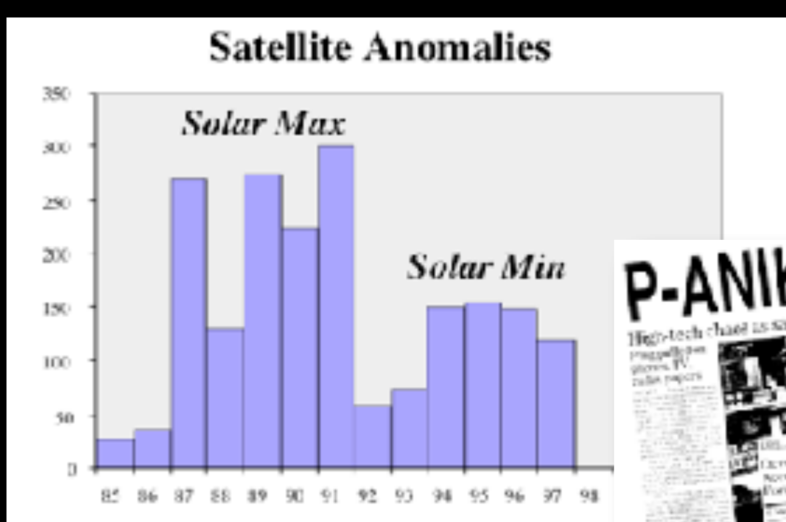


Magnetic navigation can be affected by dynamics in the Earths magnetic field.

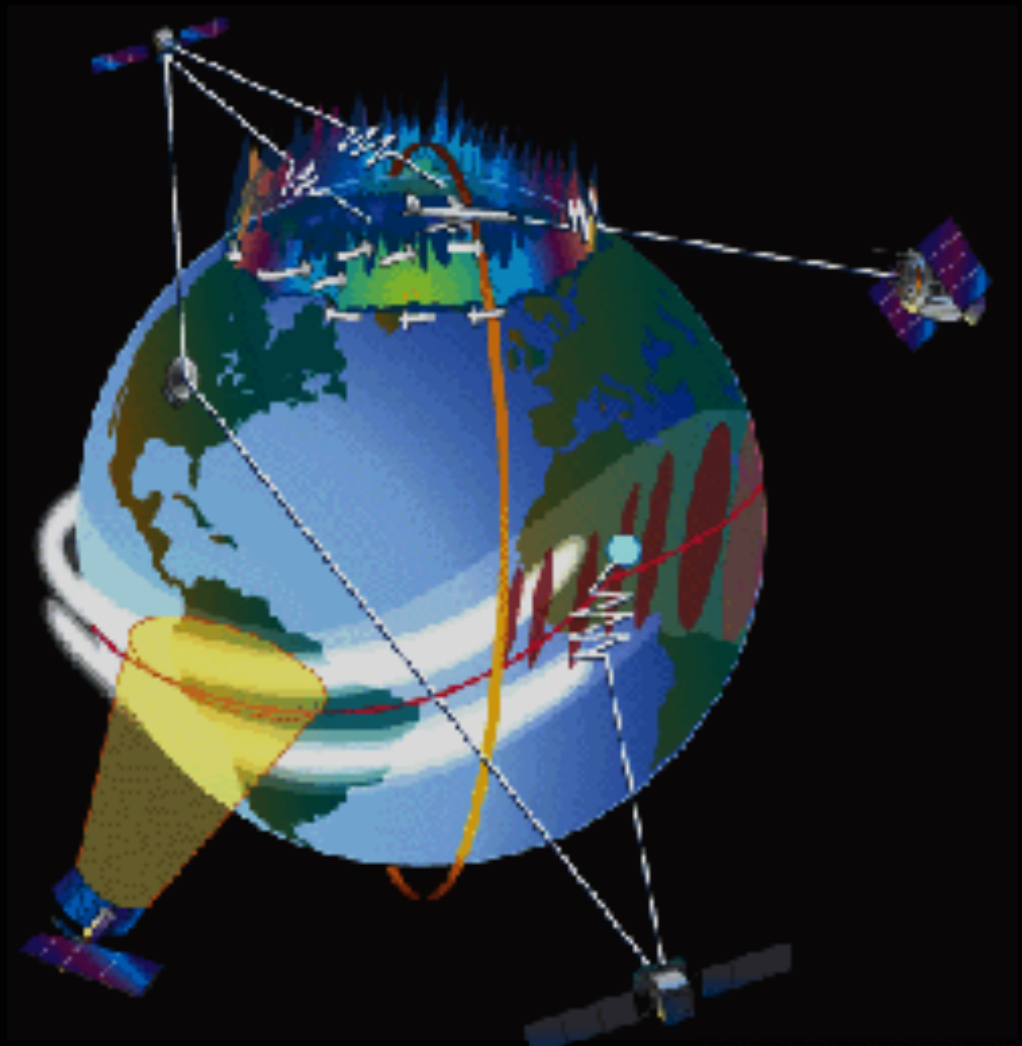
Damage to satellites

Some examples

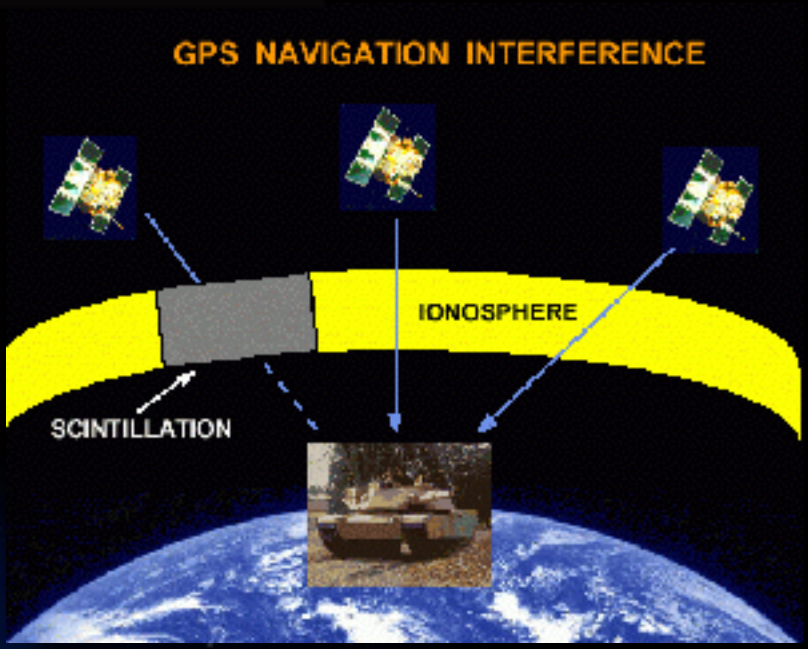
- Telestar 401 (Jan 11 1997)
- Galaxy IV (1998) – cost 250 mill USD
  - 80% of all pagers in USA failed
  - PC-Direct (internet)
  - CBS's radio and TV feeds
  - CNN's Airport Network
- A number of satellites are damaged
- Annual loss can reach $500 millions

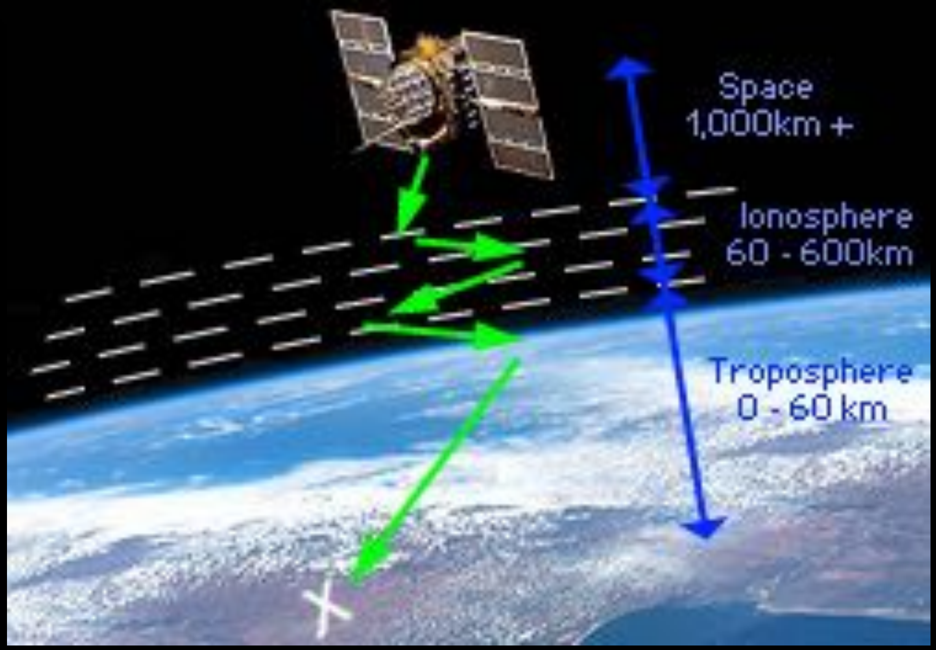


Navigation systems (GPS)



- Turbulence in the ionosphere causes scintillation in the satellite signal and can disrupt the reception.
- Total amount of electrons (TEC) along the path of the signal can introduce errors up to 100 meters.
- Radio bursts can «jam» the signals.





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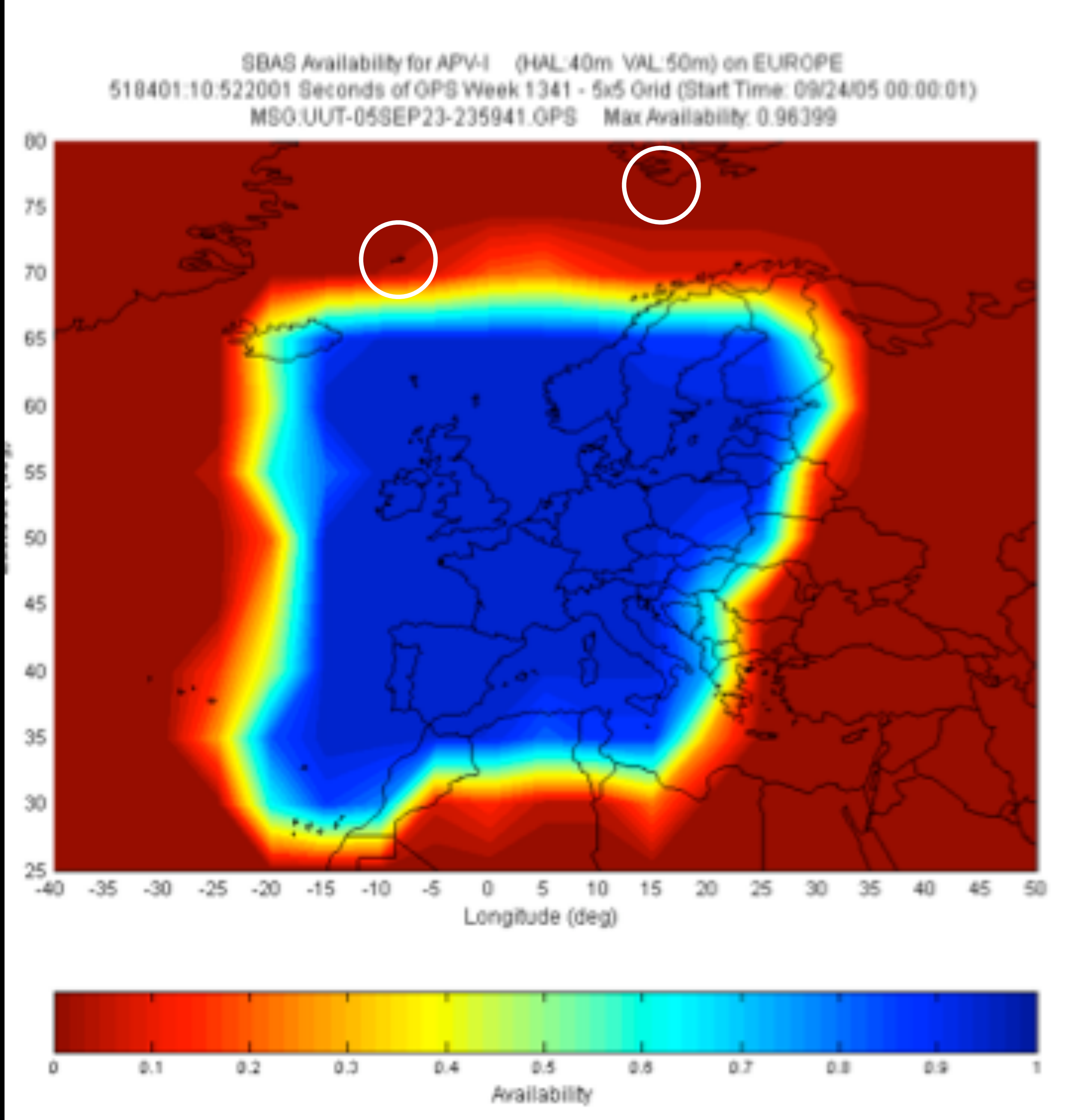
Limited EGNOS correction at high latitudes



- EGNOS provides corrections, but limited coverage far north.
- Two new EGNOS stations installed at Svalbard and Jan Mayen

- Another challenge: How will tracking of EGNOS signals via geostationary satellites work in the high north?

- These satellites are extremely low in the horizon and it is a challenge to decode data from them

Some do not care about GPS accuracy

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For others it is critical

- Errors in GPS based systems can be a serious problem.

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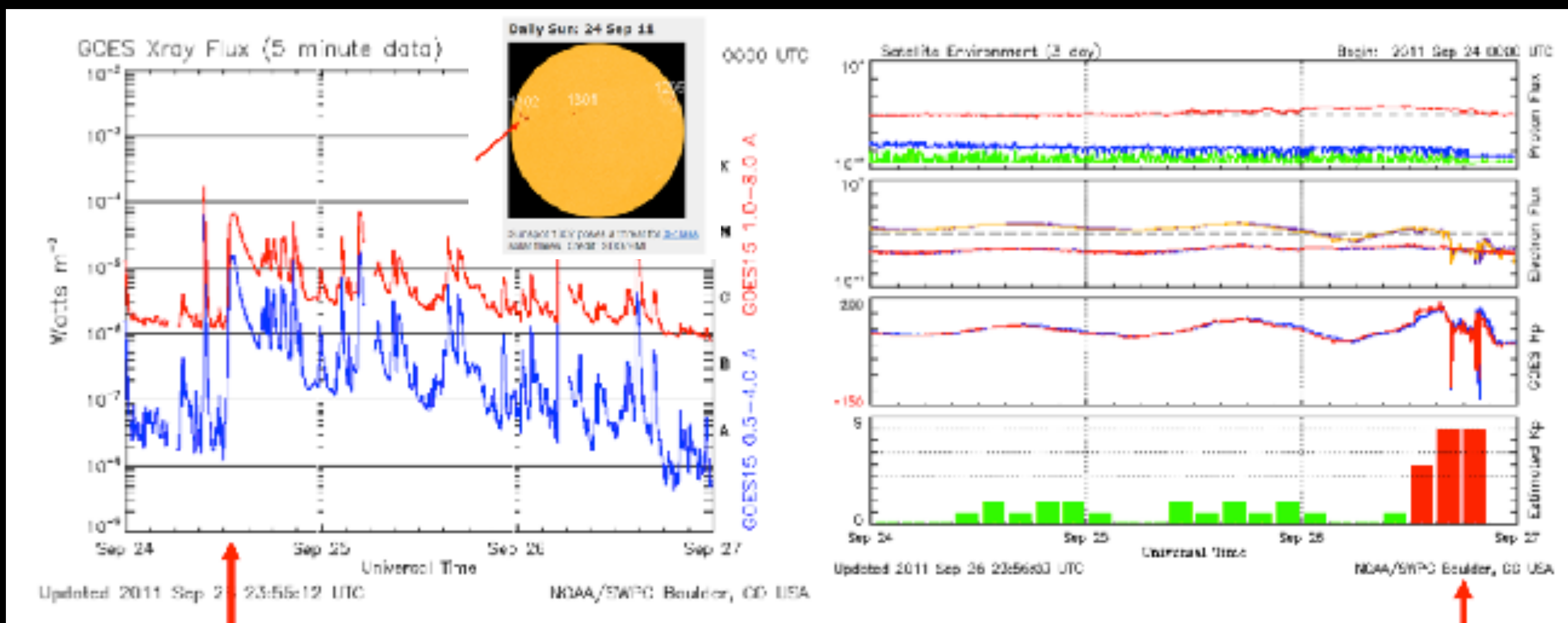
High precision positioning problematic

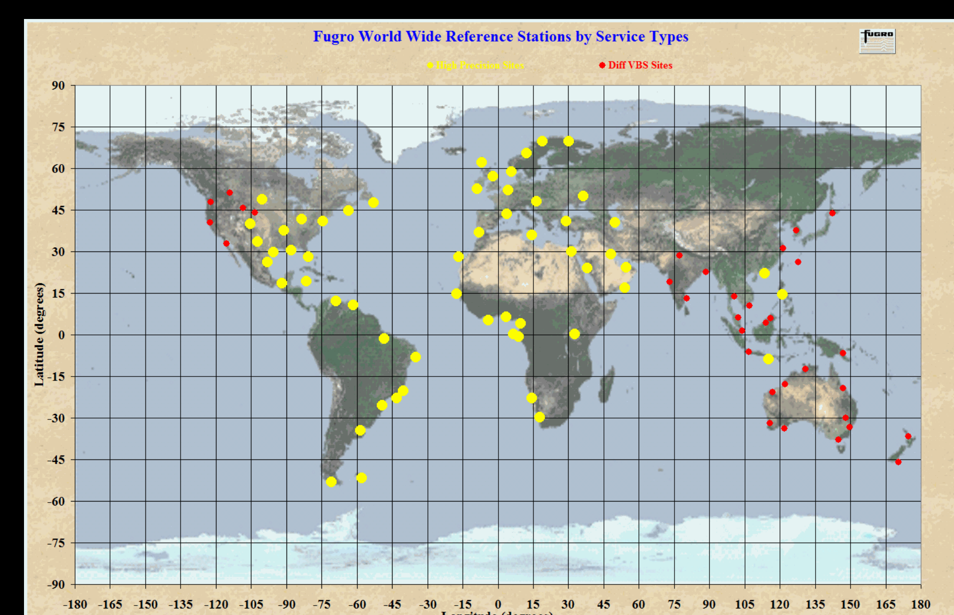
- Kongsberg Seatex - world leading within dynamical positioning. They experiences often disruption outside the coast of Brasil. This causes interruption of the operation.

Radio burst «jammed» the GPS system

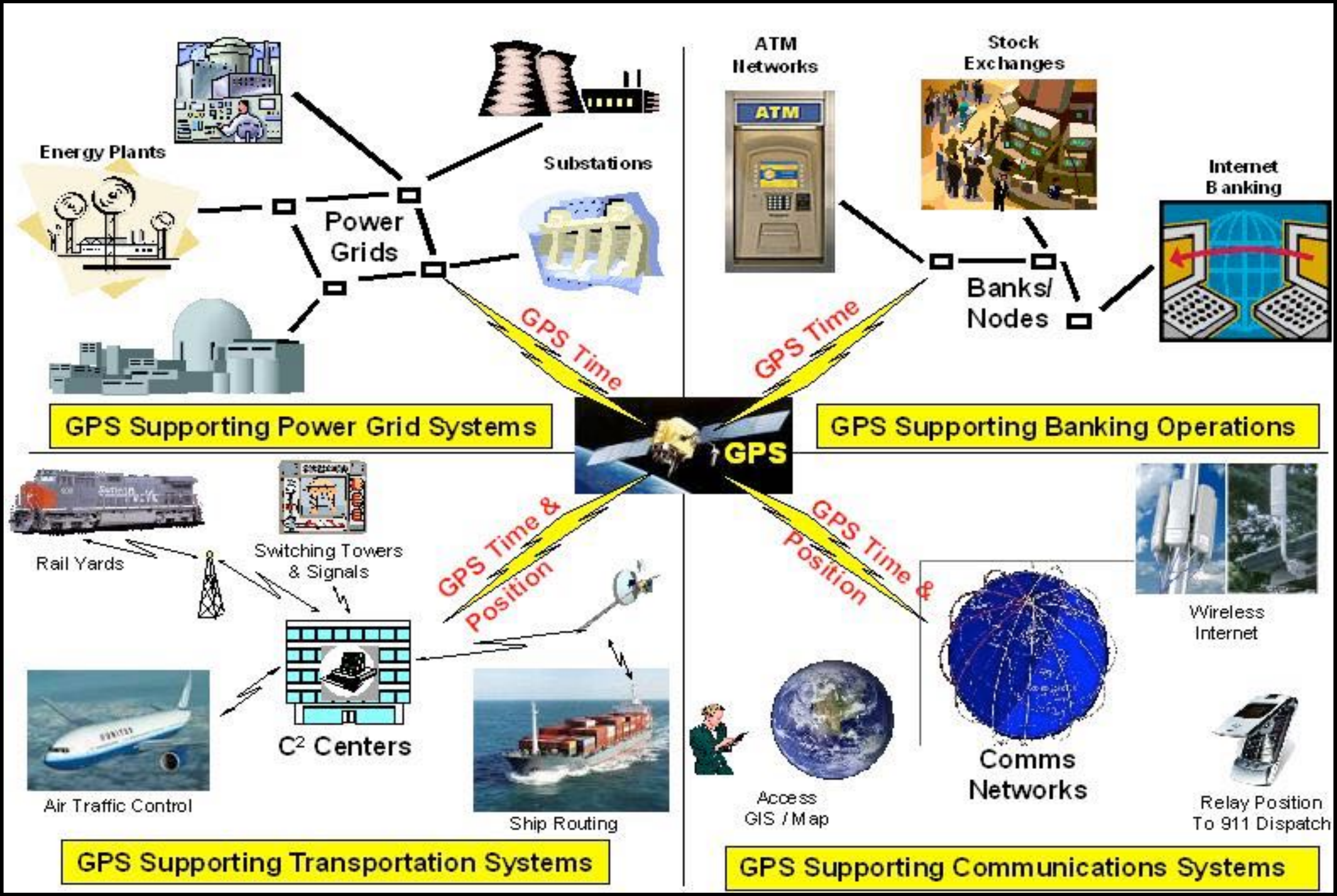
- 24 September 2011 - a radioburst affected the GPS network on the day-side of Earth.



#Event	Begin	Max	End	Obs	Q	Type	Loc/Frq	Particulars		Reg#
3590	1231	1313	1409	SAG	G	RBR	245	4800	CastelliU	1302
3590	1231	1253	1406	SVI	G	RBR	8800	1300	CastelliU	1302
3590	1231	1307	1410	SAG	G	RBR	610	80000	CastelliU	1302
3590 +	1232	1302	1411	SVI	G	RBR	2695	12000	CastelliU	1302
3590	1232	1253	1358	SVT	G	RBR	4995	1400	CastelliU	1302
3590 +	1232	1313	1410	SAG	G	RBR	410	68000	CastelliU	1302
3590 +	***1233***	***1320***	***1410***	***G15***	***5***	***XRA***	***1-8A***	***M7.1***	***2.9E-01***	***1302***
	3600	1233	1233		1233	SVT	G RBR	15400	51	
3590 +	*1234*	*1304*	*1405*	*SAG*	*G*	*RBR*	*1415*	*110000*	*CastelliU*	*1302*
3590	1234	1251	1415	SAG	G	RBR	15400	840	CastelliU	1302

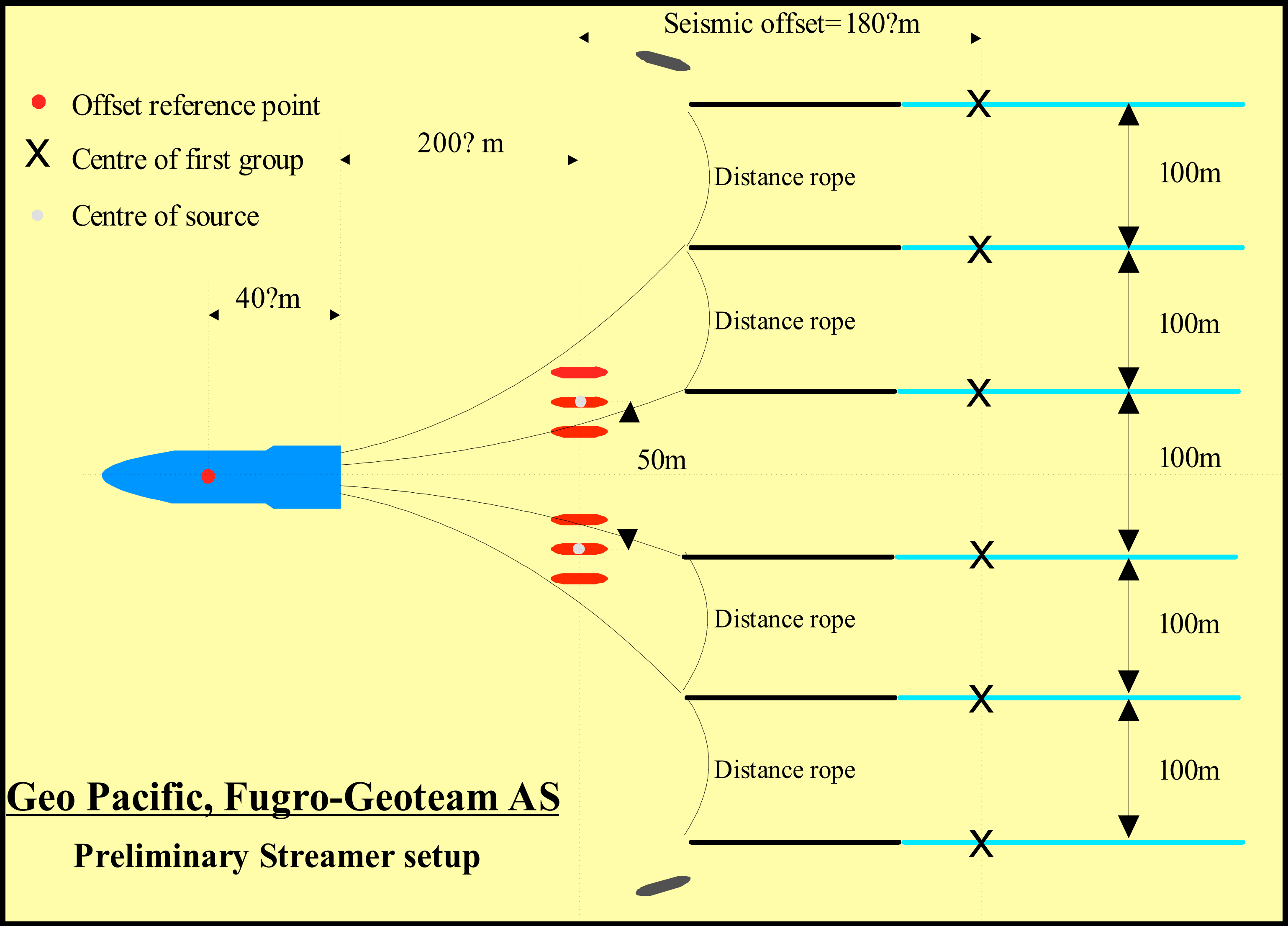


Extent of GPS Dependencies



K. VanDyke, DOT

Geomagnetic surveys - search for oil and gas

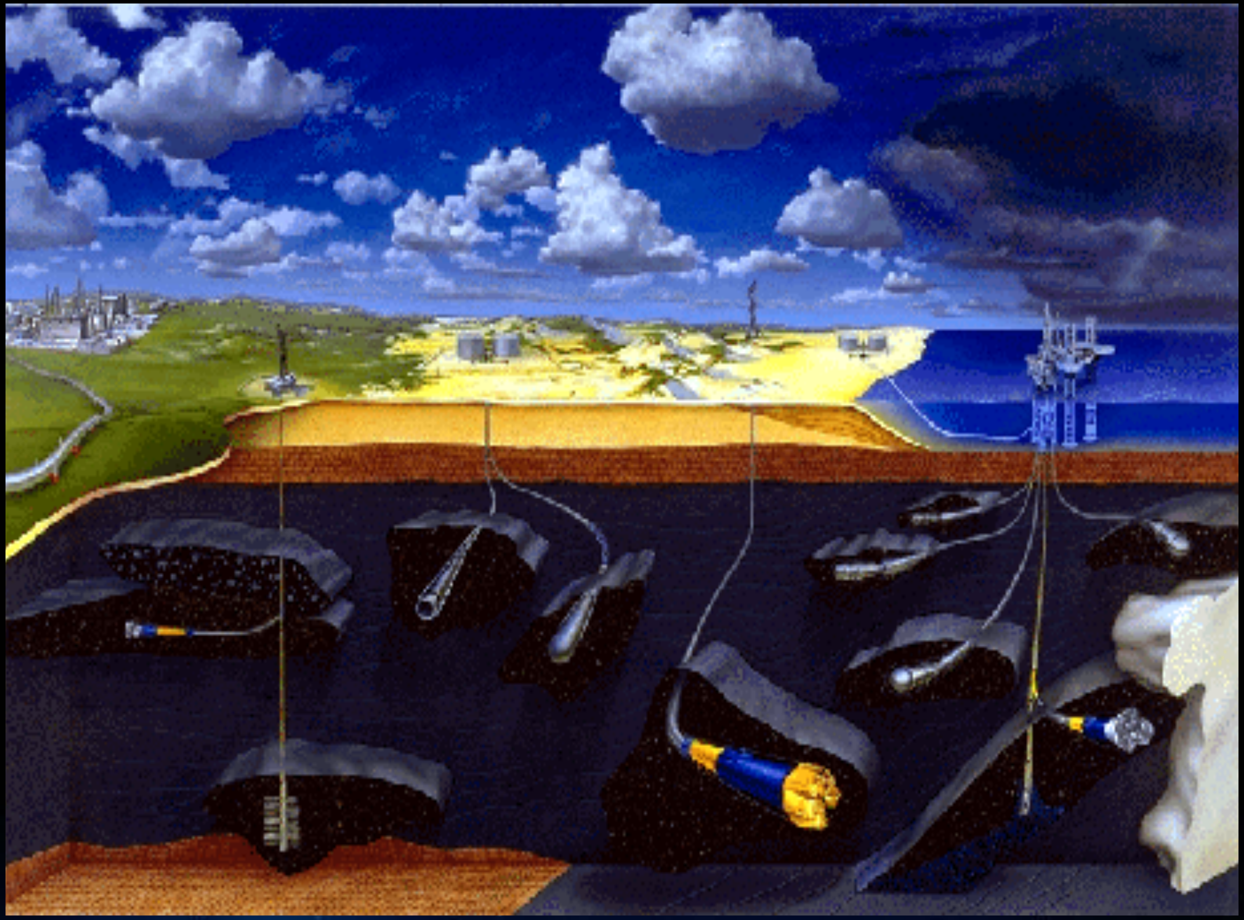


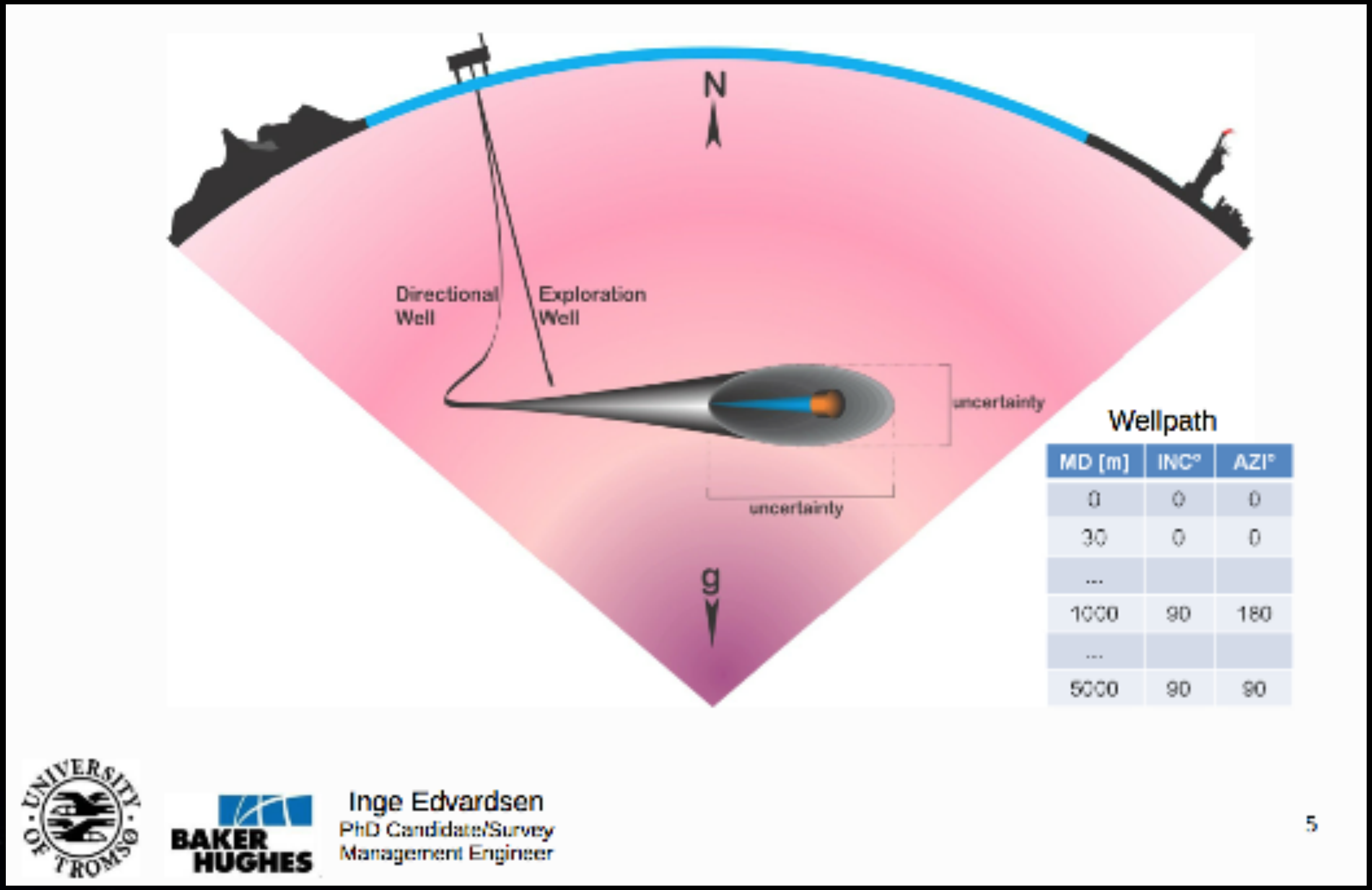
Fugro-Geoteam use ships with sensitive magnetometers on long cables.

Directional drilling

Directional drilling

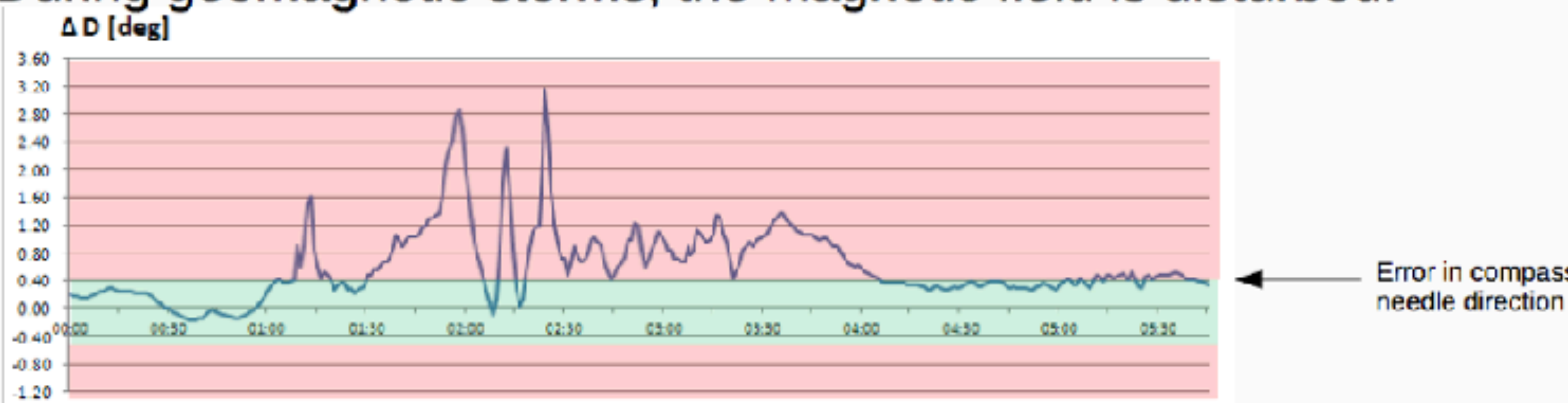
- Oil industry relies on geomagnetic maps to guide the drill and monitor the well direction.





Directional drilling

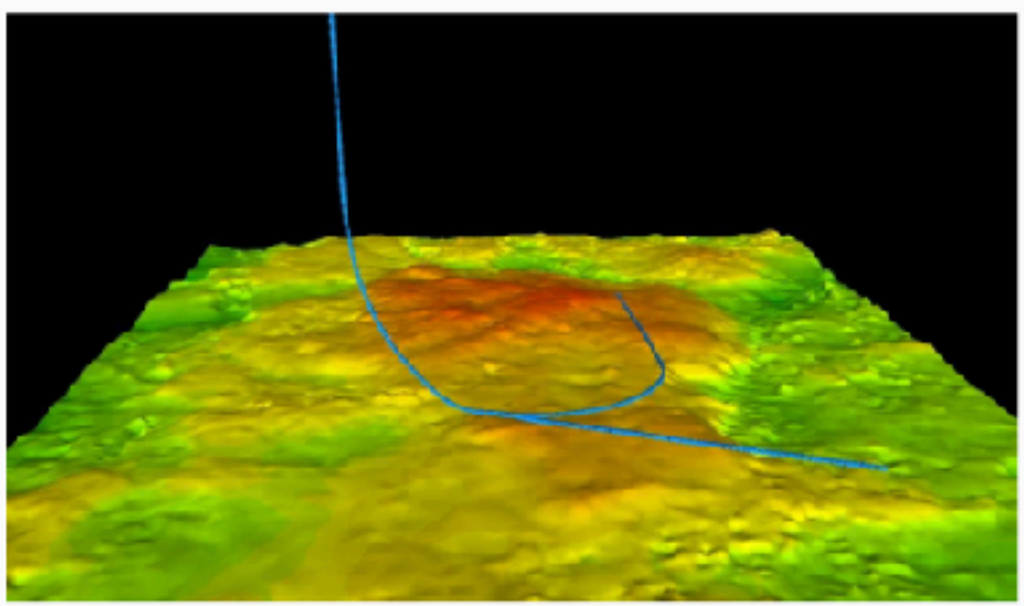
During geomagnetic storms, the magnetic field is disturbed:

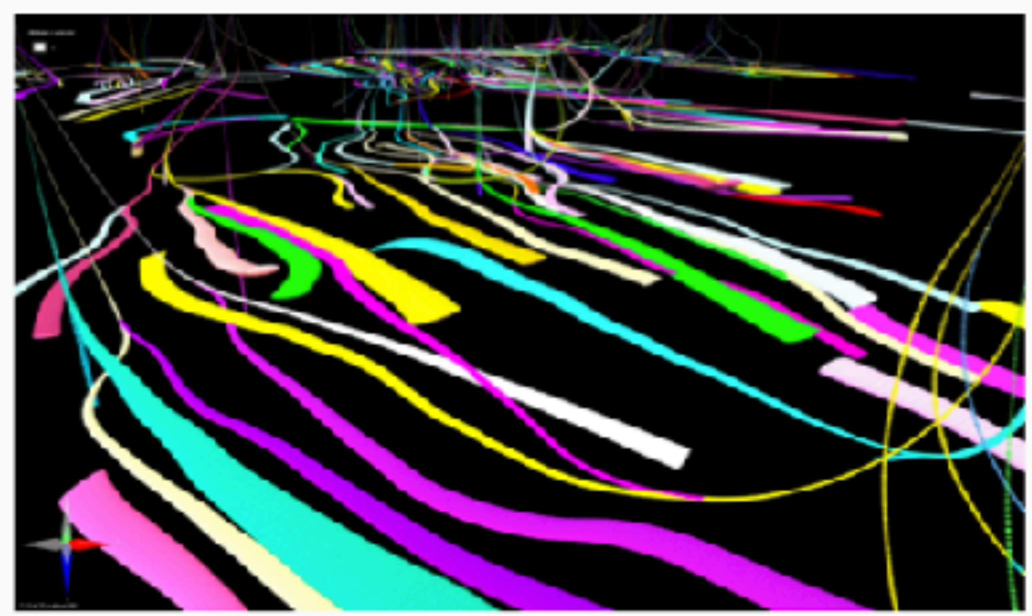


This has to be monitored and corrected for in order to:

Hit the Geological Target
(& maximize recovery)

Avoid Other Wells

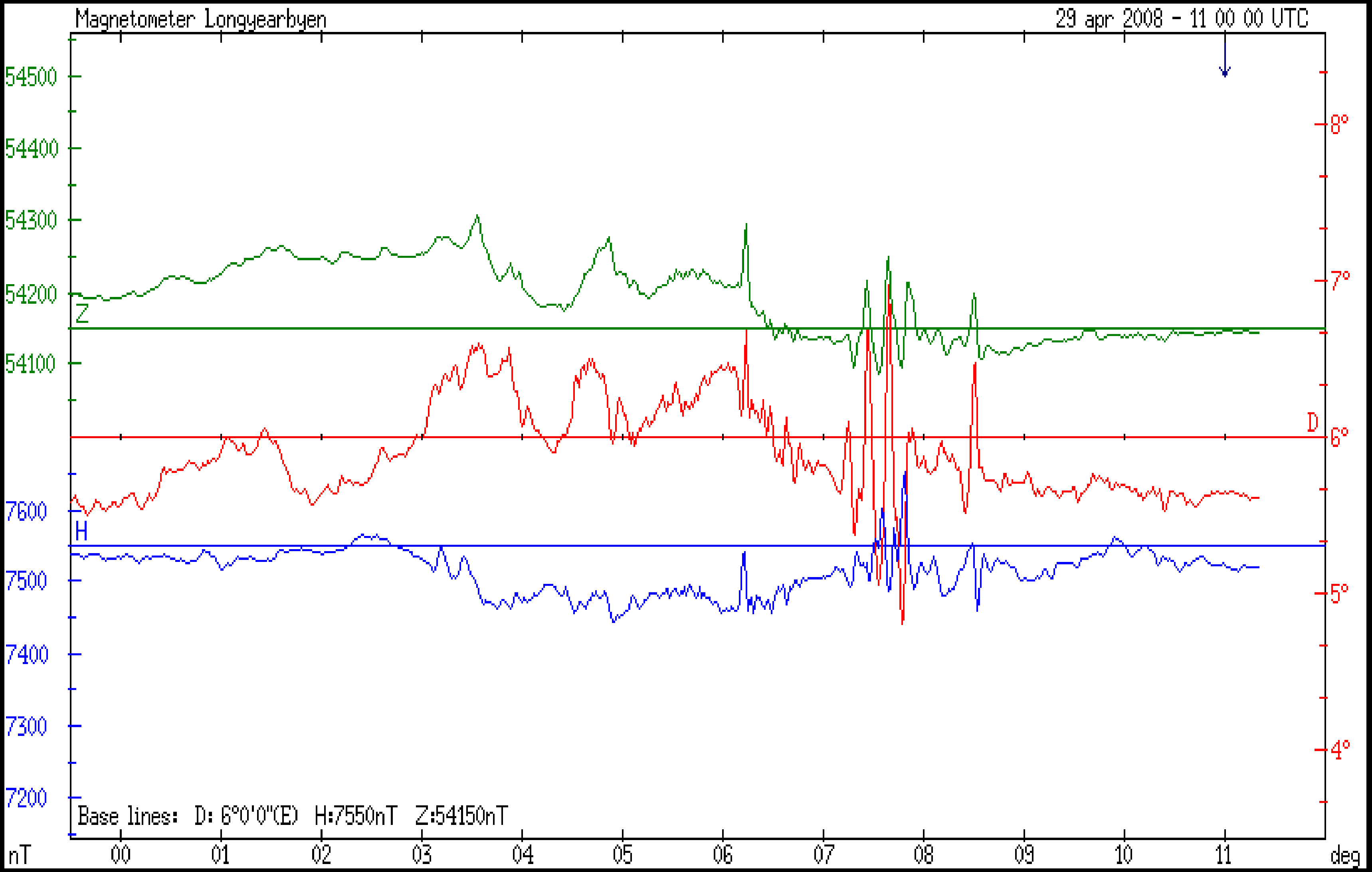


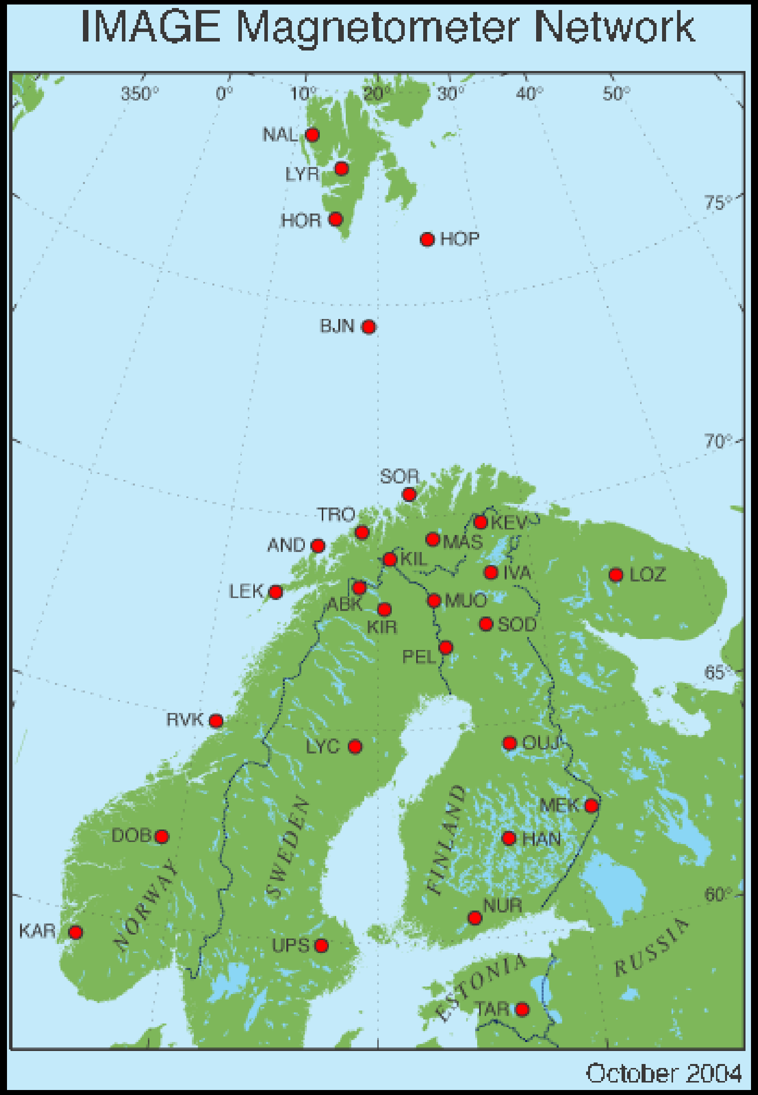


Inge Edvardsen
PhD Candidate/Survey Management Engineer

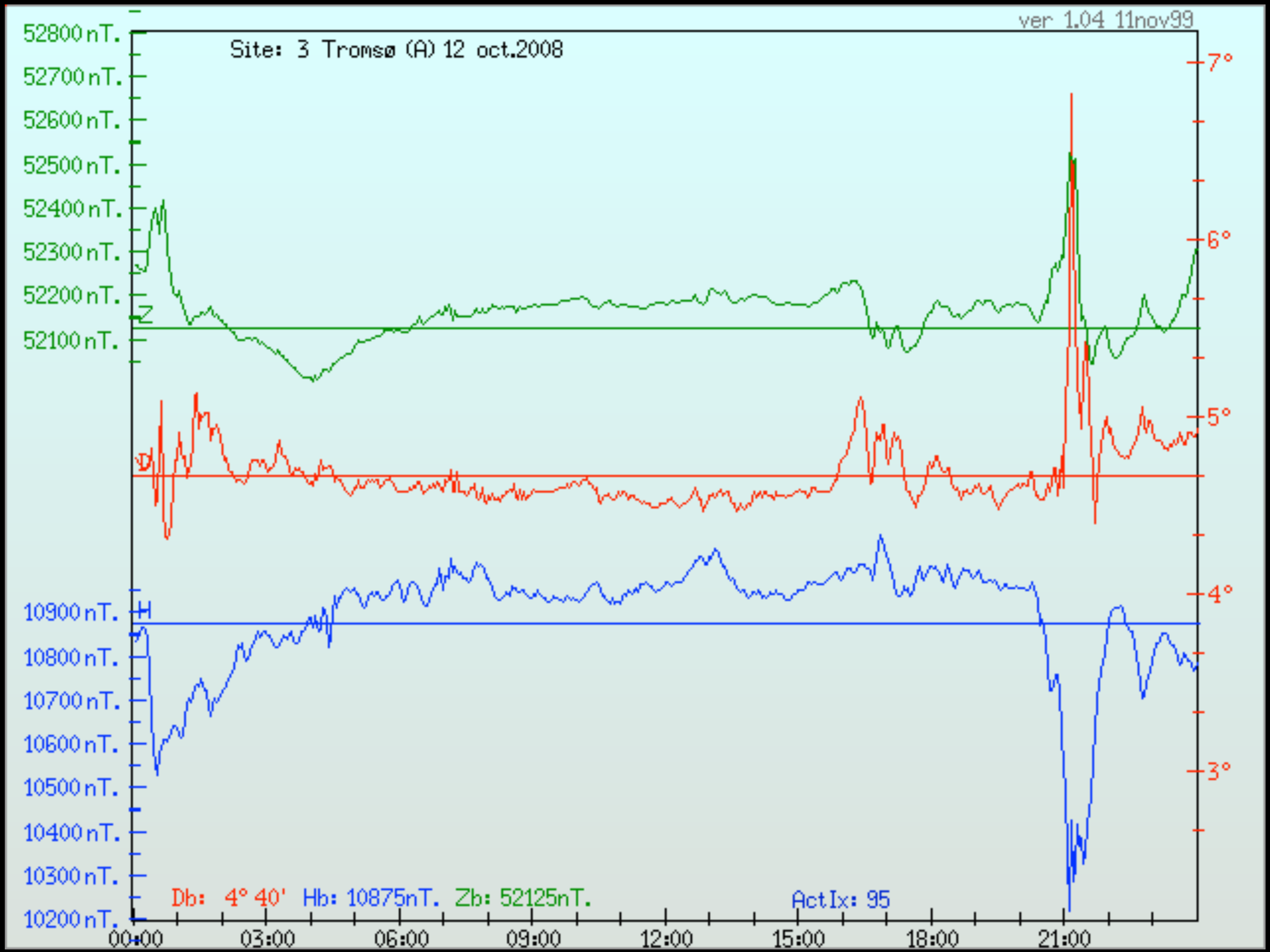
Drilling companies are buying spaceweather data

- UiT delivers "real-time" magnetometer data to the drilling companies to eitehr correct or extend the time they cam operate.



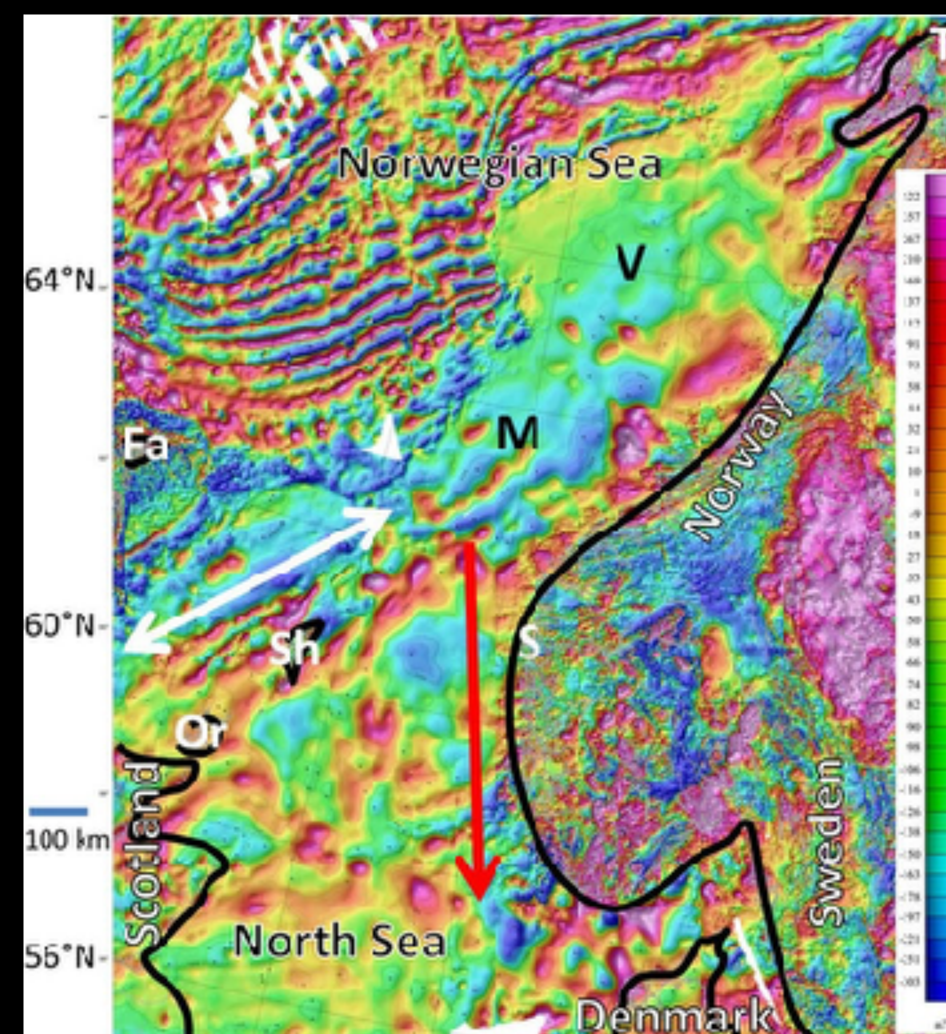


Effects on compasses



Impacts on animals

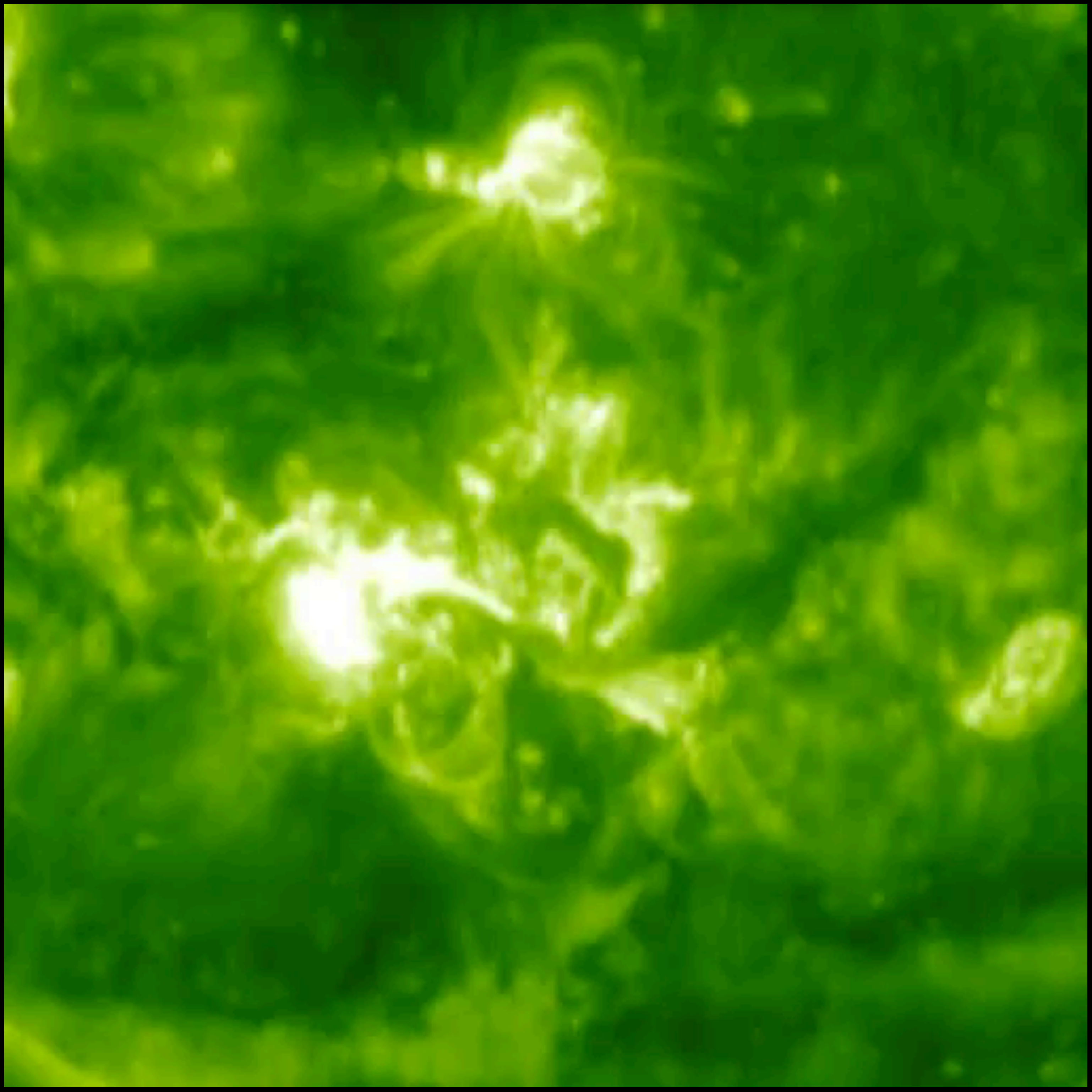
- The navigational abilities of homing pigeons are affected by geomagnetic storms
- Pigeons and other migratory animals, such as dolphins and whales, have internal biological compasses composed of the mineral magnetite wrapped in bundles of nerve cells.



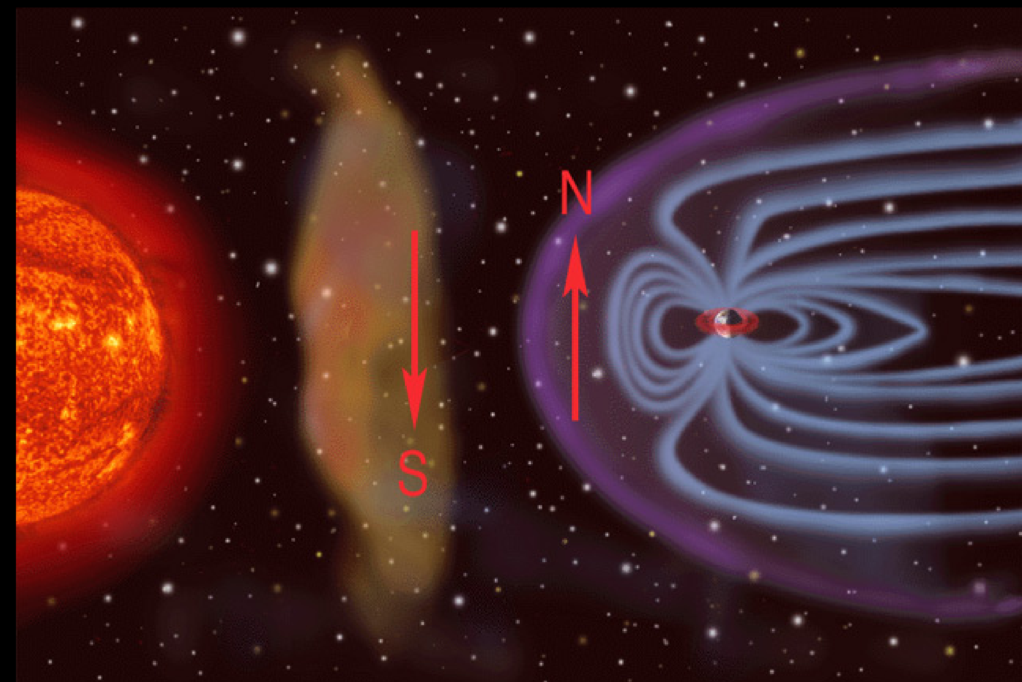
The Halloween-storms

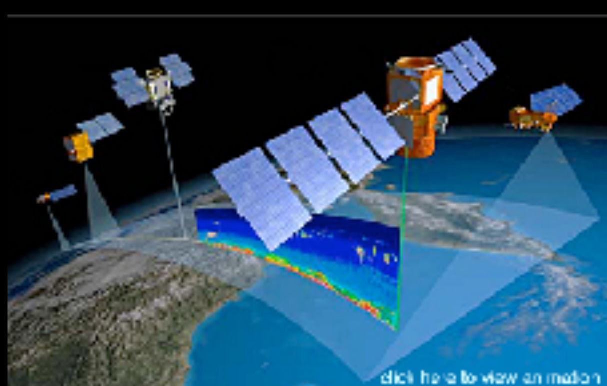
Giant sunspots developed

Solar storm 28th October 2003



Effects from the Halloween storms

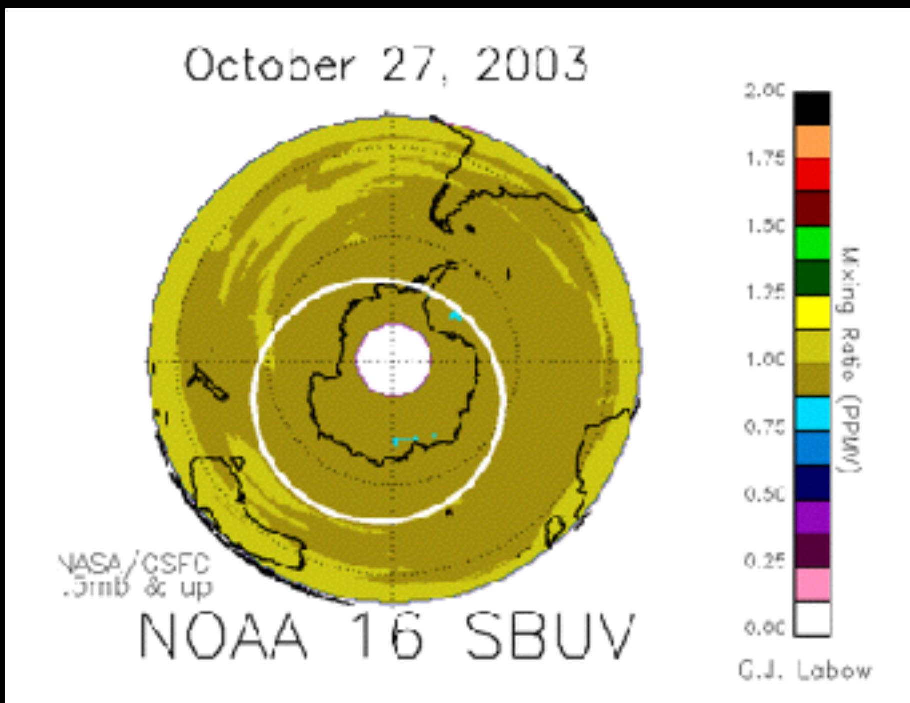


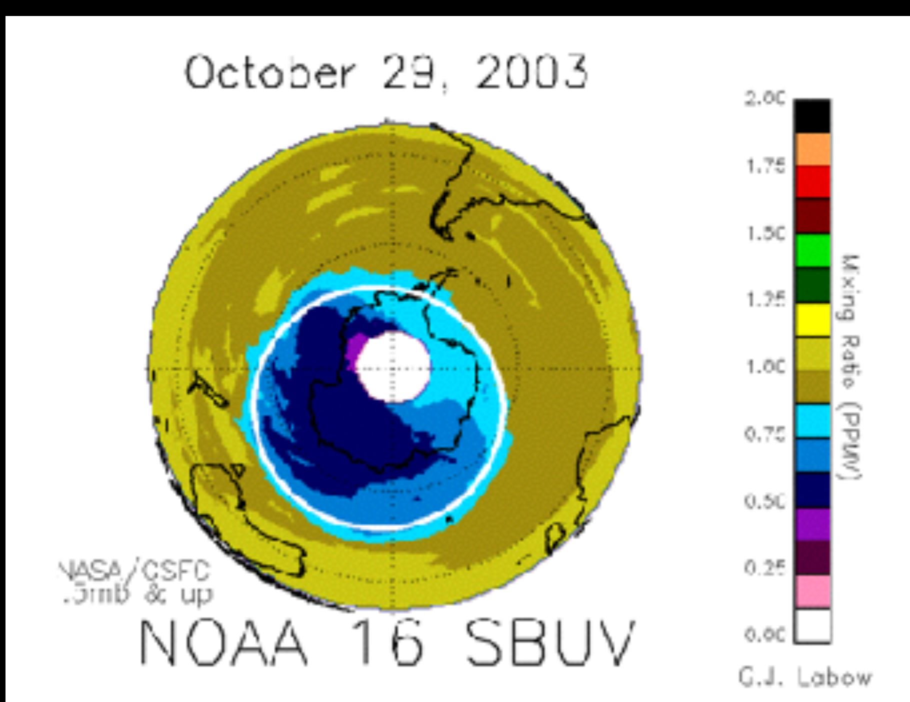


- More than 20 satellites and spacecrafts were affected (not including classified military instruments), Half of NASA satellites affected. One Japanese satellite lost
- Severe HF Radio blackout – affected commercial airlines
- FAA issued a first-ever alert of excessive radiation exposure for air travellers
- Power failure in Sweden
- Climbers in Himalaya experienced problems with satellite phones.
- US Coast Guard to temporarily shut down LORAN navigation system.
- Radiation monitor device on Mars Odyssey knocked out Parts of the Martian atmosphere escaped into space

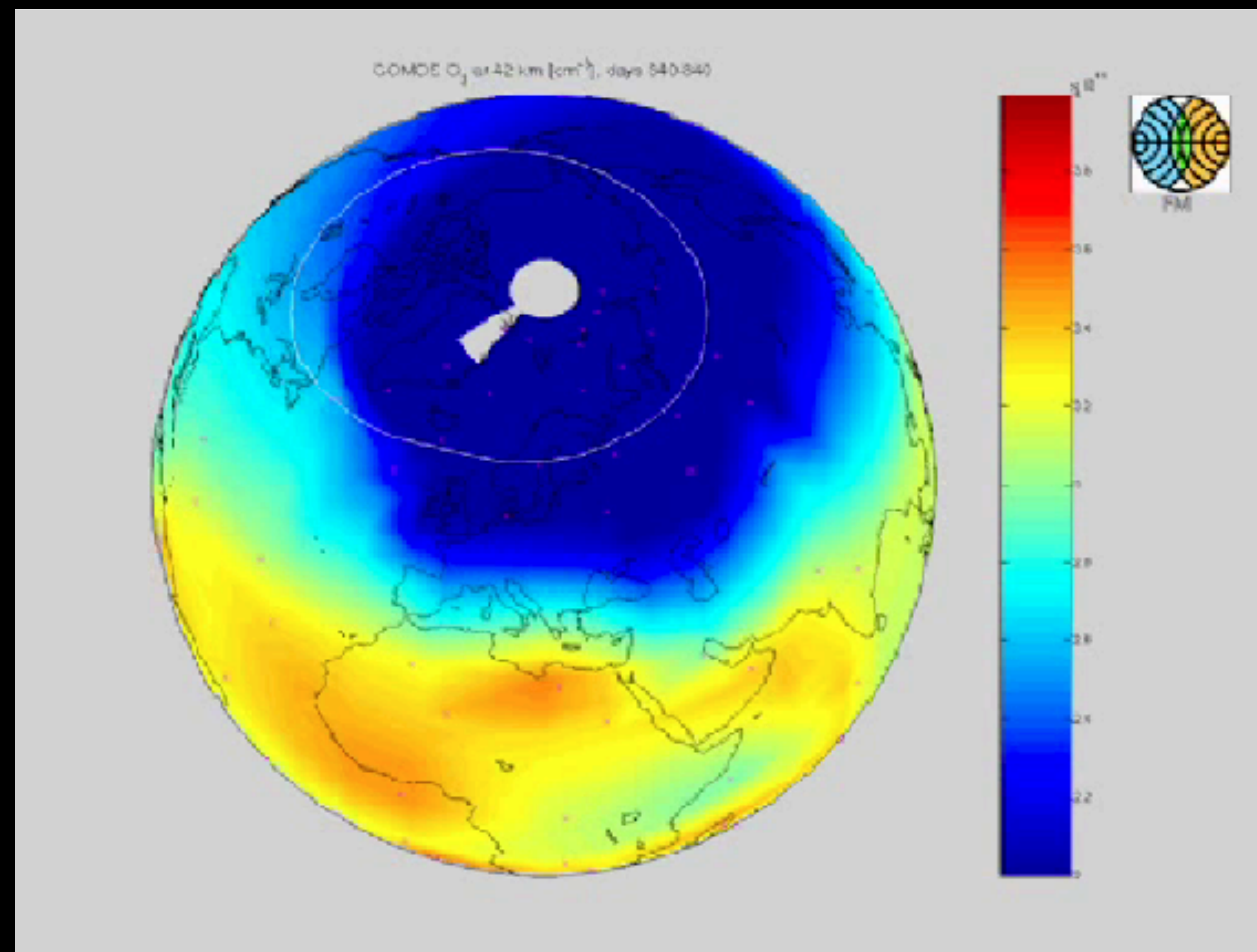
Protonevents affects the ozone-content

(ved 0.5 hPa eller ~55 km)





This event reduced the ozone content for 8 months (~42 km)



Source: Charles Jackman & Gordon Labow (NASA) og FMI

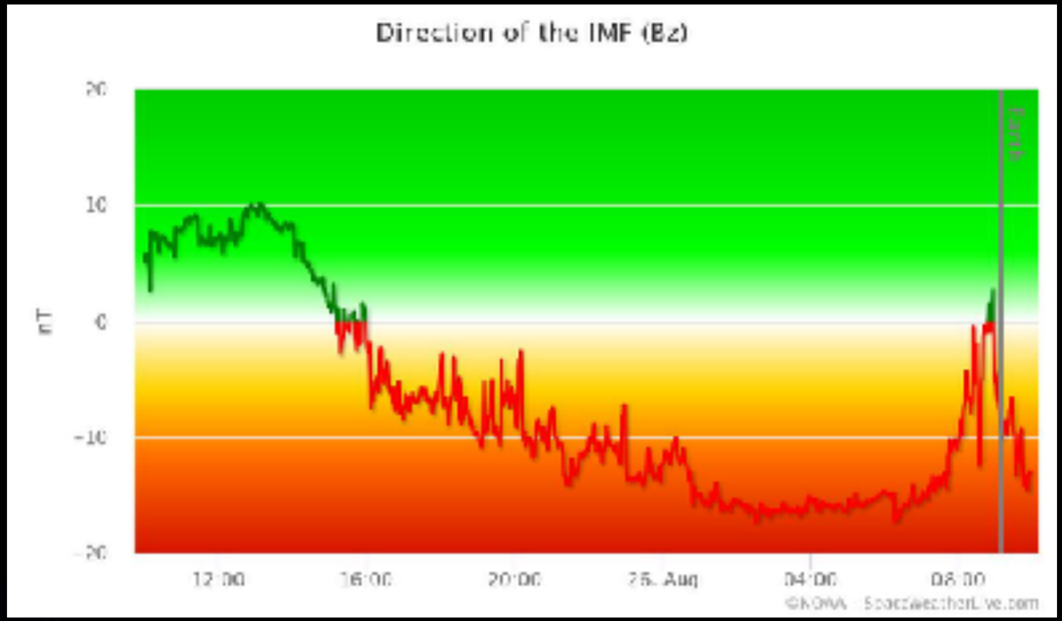
The Scandinavian Power Grid

Statnett, the Norwegian Power Grid Company, supervises and co-ordinates the operation of the entire Norwegian power system.

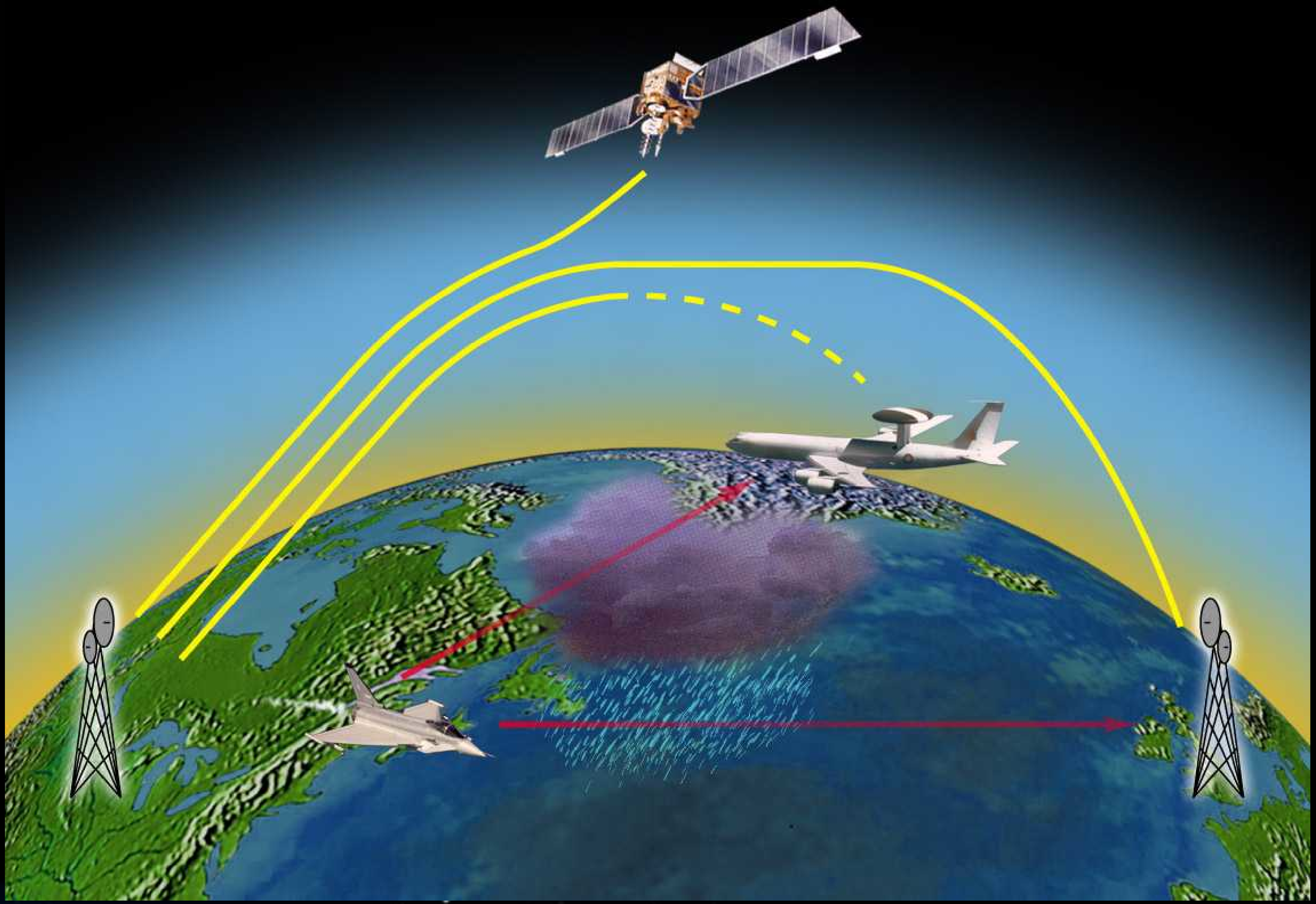
The have monitored GIC for about 15 years.

Their conclusion: The Norwegian grid is fairly robust - even for a super storm.

Transformer in Namsos went down on 26 August 2918
Same transformer went down in September 2017



Radio communication i polar regions difficult



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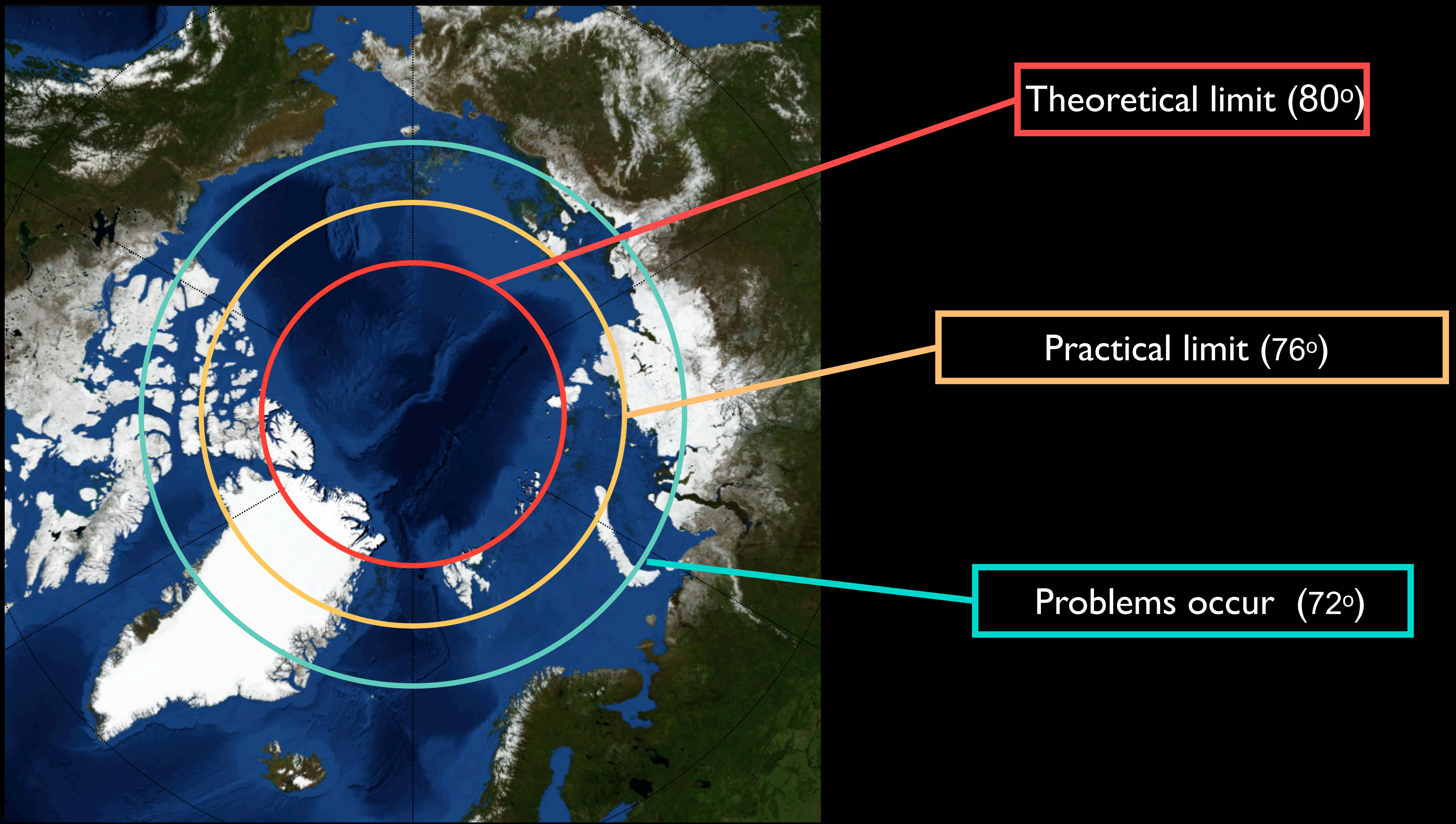
NORWEGIAN SPACE CENTRE

Limited Broadband and radio communication in the North



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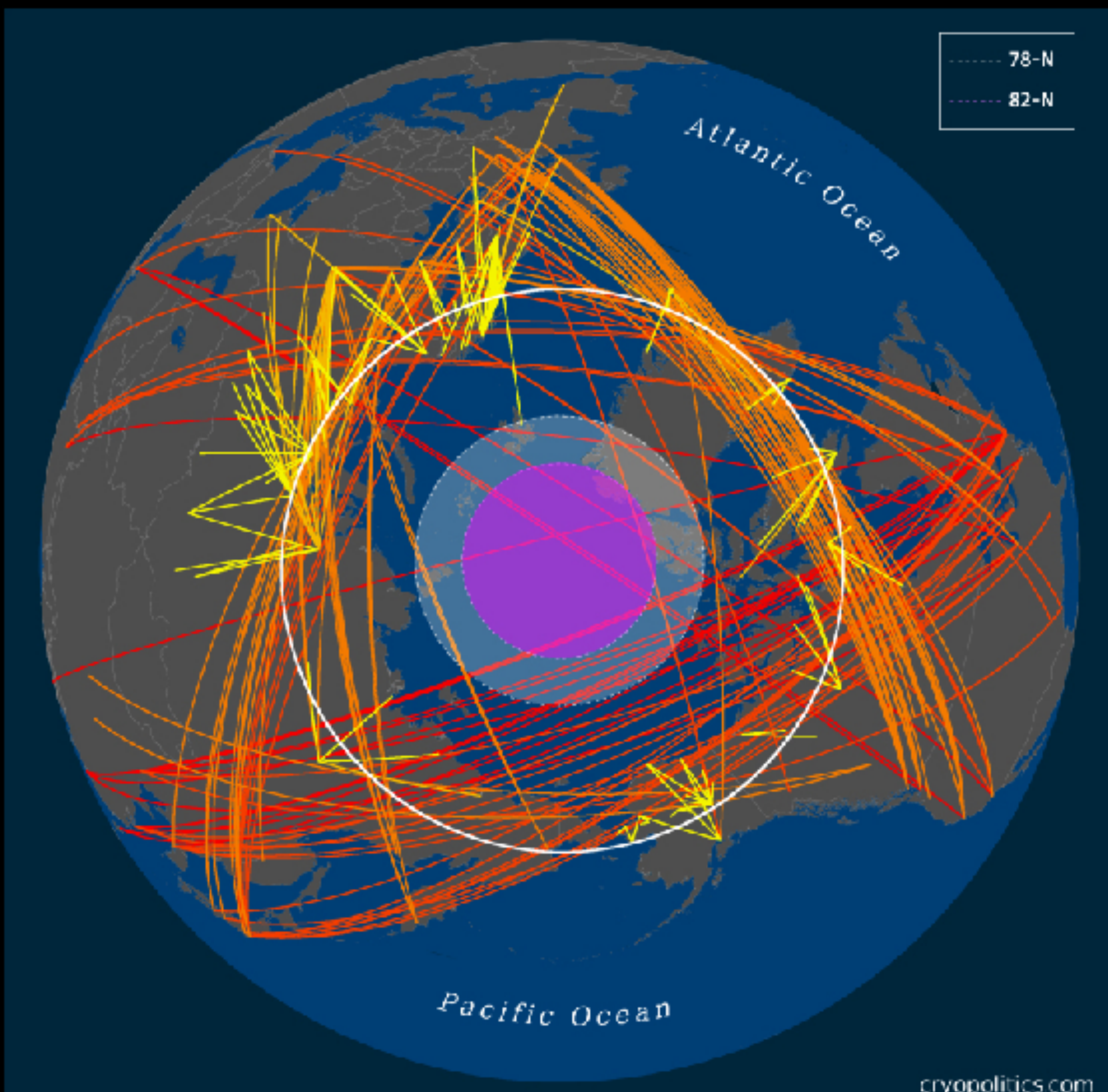
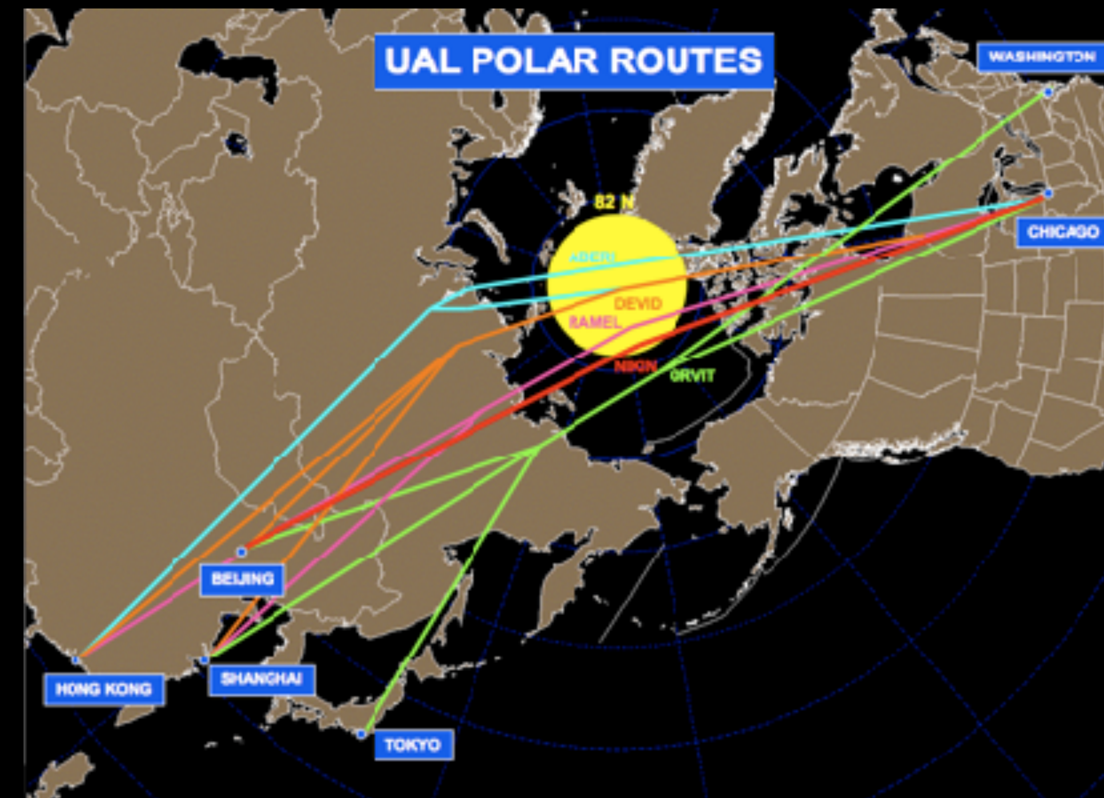
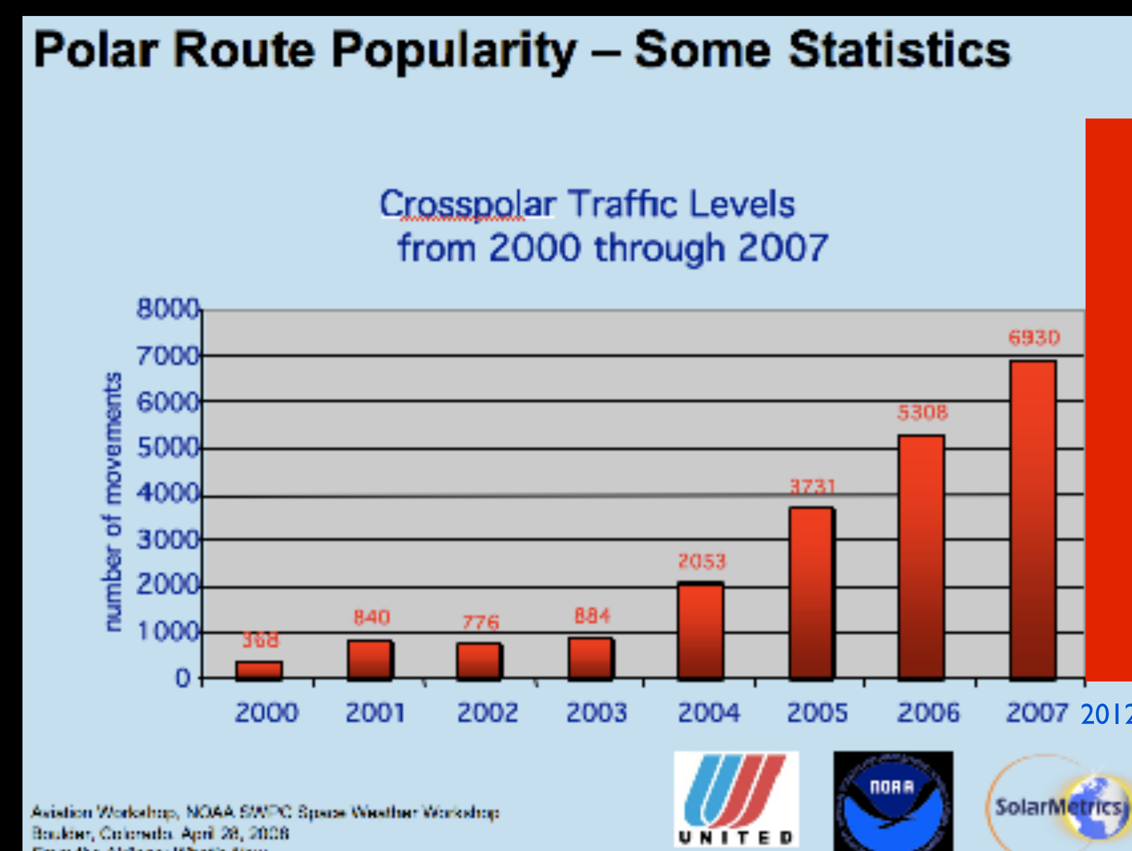
Polar routes

- Polar routes : 11.214 flights in 2012 (3,365,000 passengers)
- No satellite communication north of 82 degree

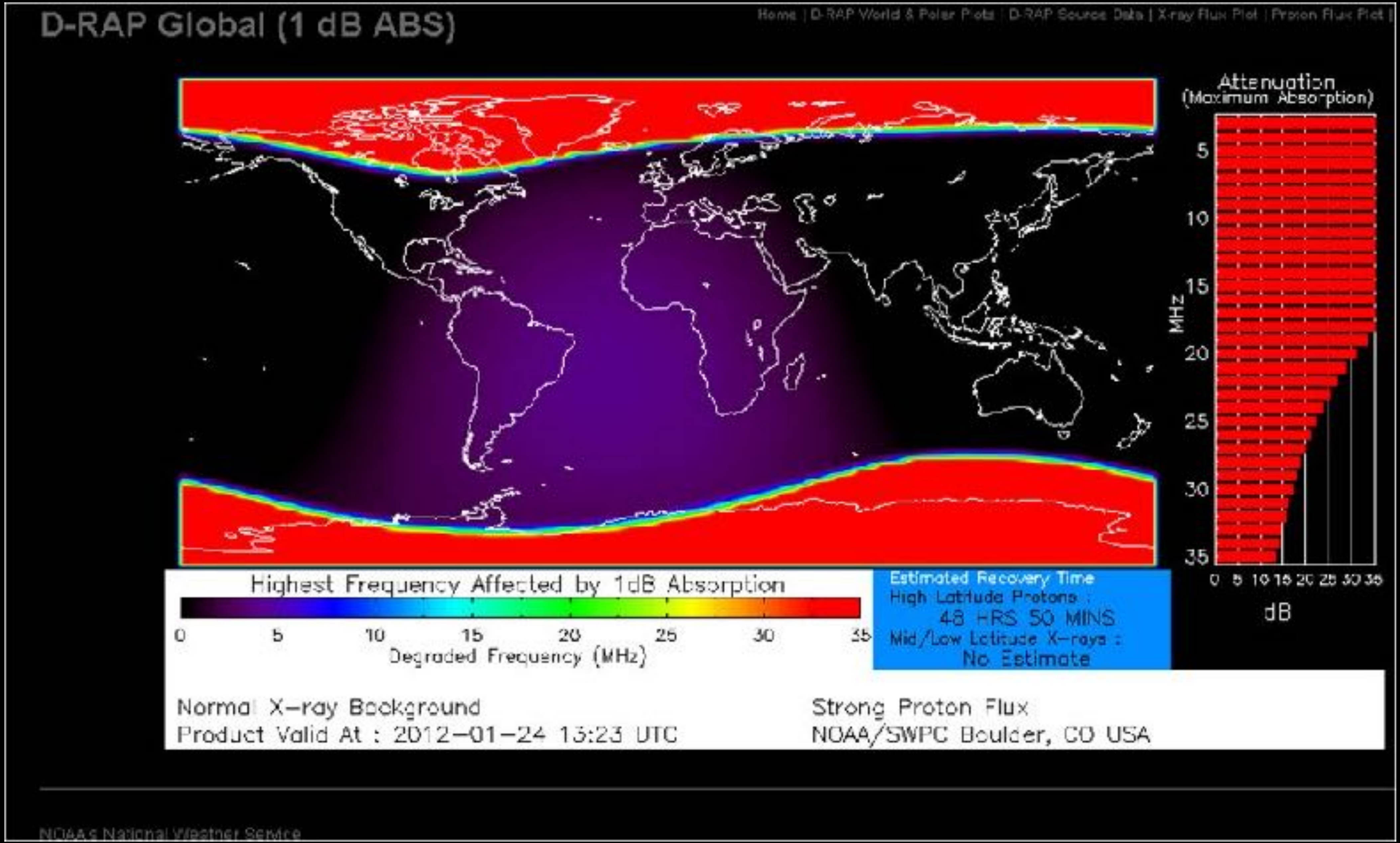






Flights were diverted

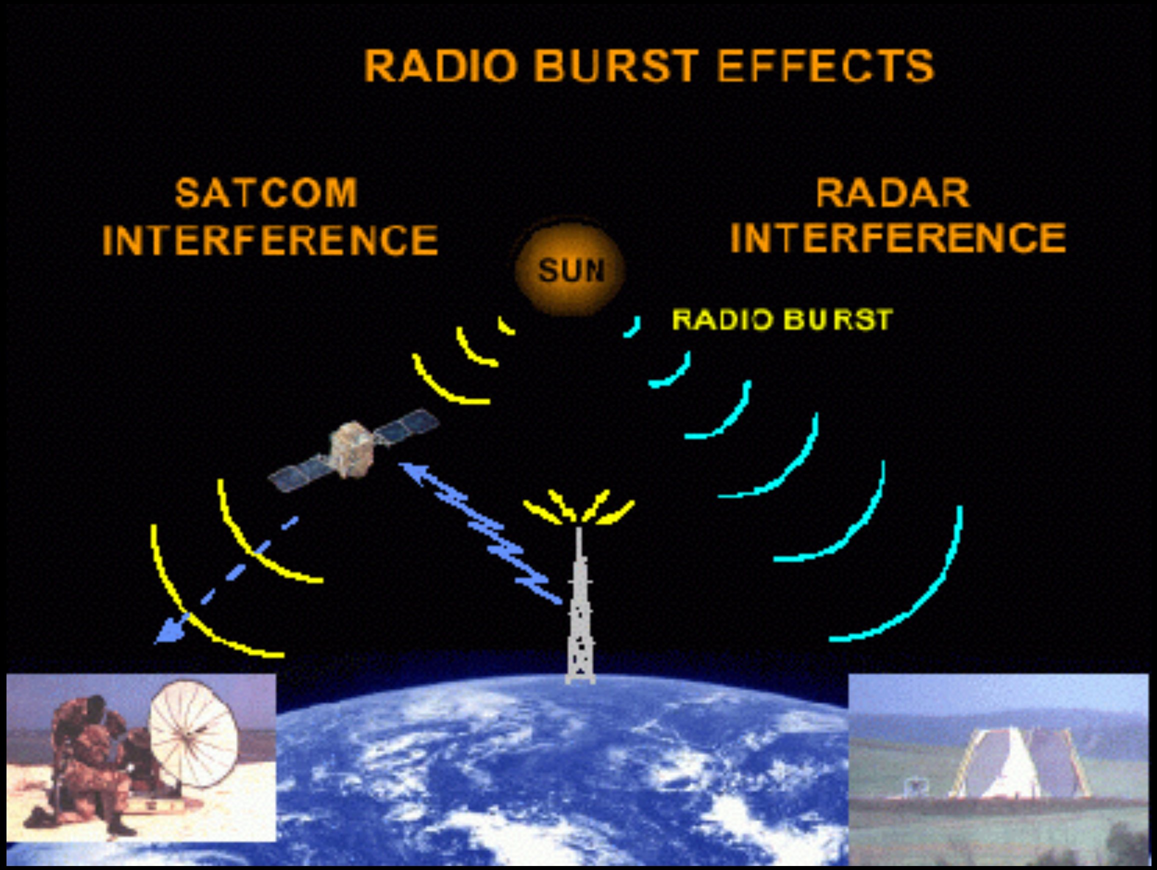
- Delte Airlines and United diverted some of their polar flights to avoid radio communication problems and increased radiation doses for the crew.
- The South pole was without radiocommunication for two days (where satellite communication is unavailable).



This graphic shows the energetic particles entering the D-region of the ionosphere. SWPC forecasters use this product to show where the energetic particles are entering and to give a visual to what is currently happening here at Earth. The red that can be seen at the poles is where the energetic particles enter and where airliners and spacecraft, should try to avoid.

Effects on military systems

- HF satelite communication (SATCOM) can be disrupted for several hours during strong flares.
- Some weapon systems use GPS for navigation.
- Military satellite systems
- Early warning systems
- Search and rescue



Arctic - Highway in the Sky

65 000 transits over Norwegian airspace

Increasing by >15% annually

Bodø Oceanic Control – main controll

Need high quality navigation and communication

Figure 3.1. Arctic Flight Information Regions as designated by the International Civil Aviation Organization. Source: based on information from the ICAO website.

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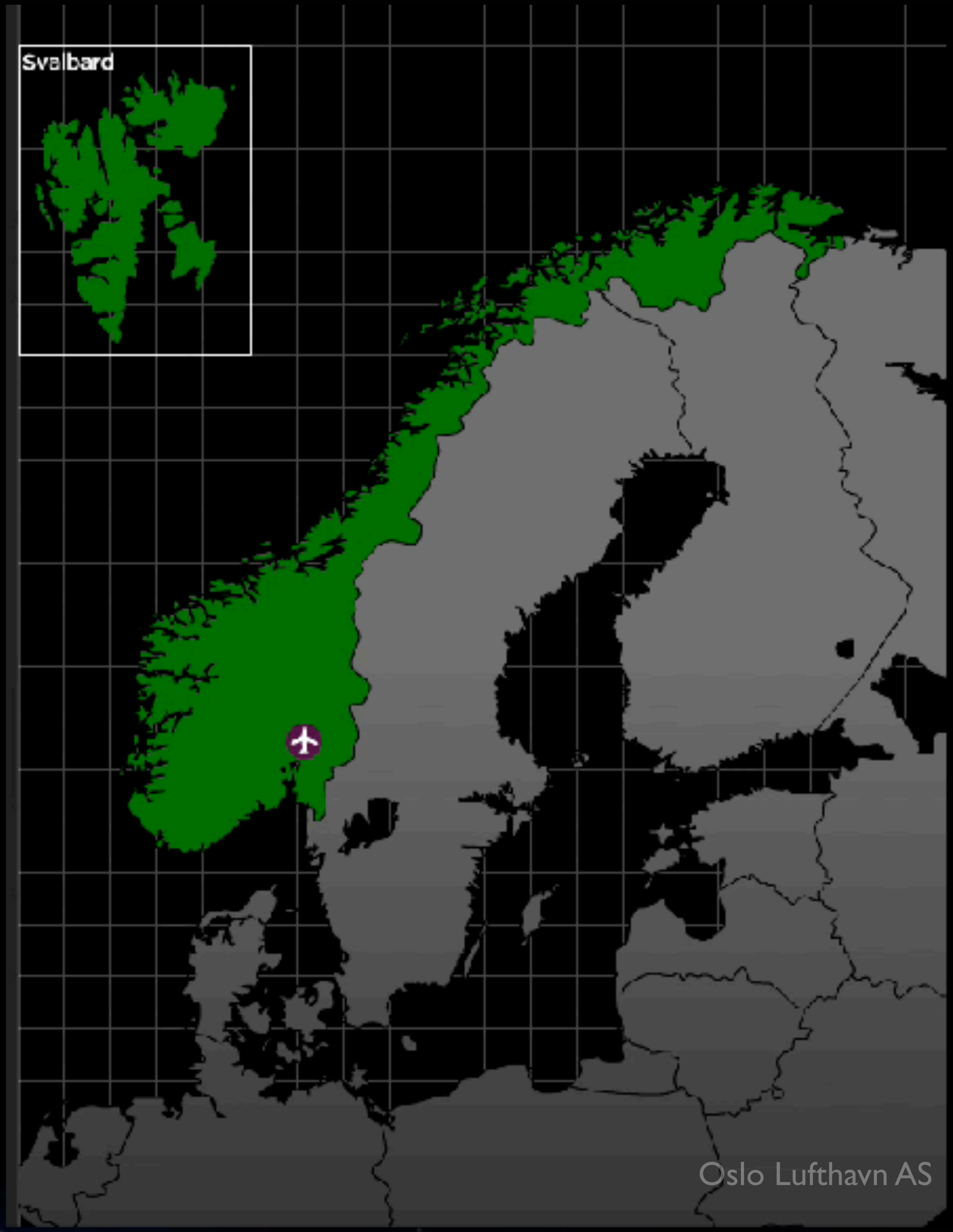
Aviation in the Arctic



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Flights to, from and at Svalbard

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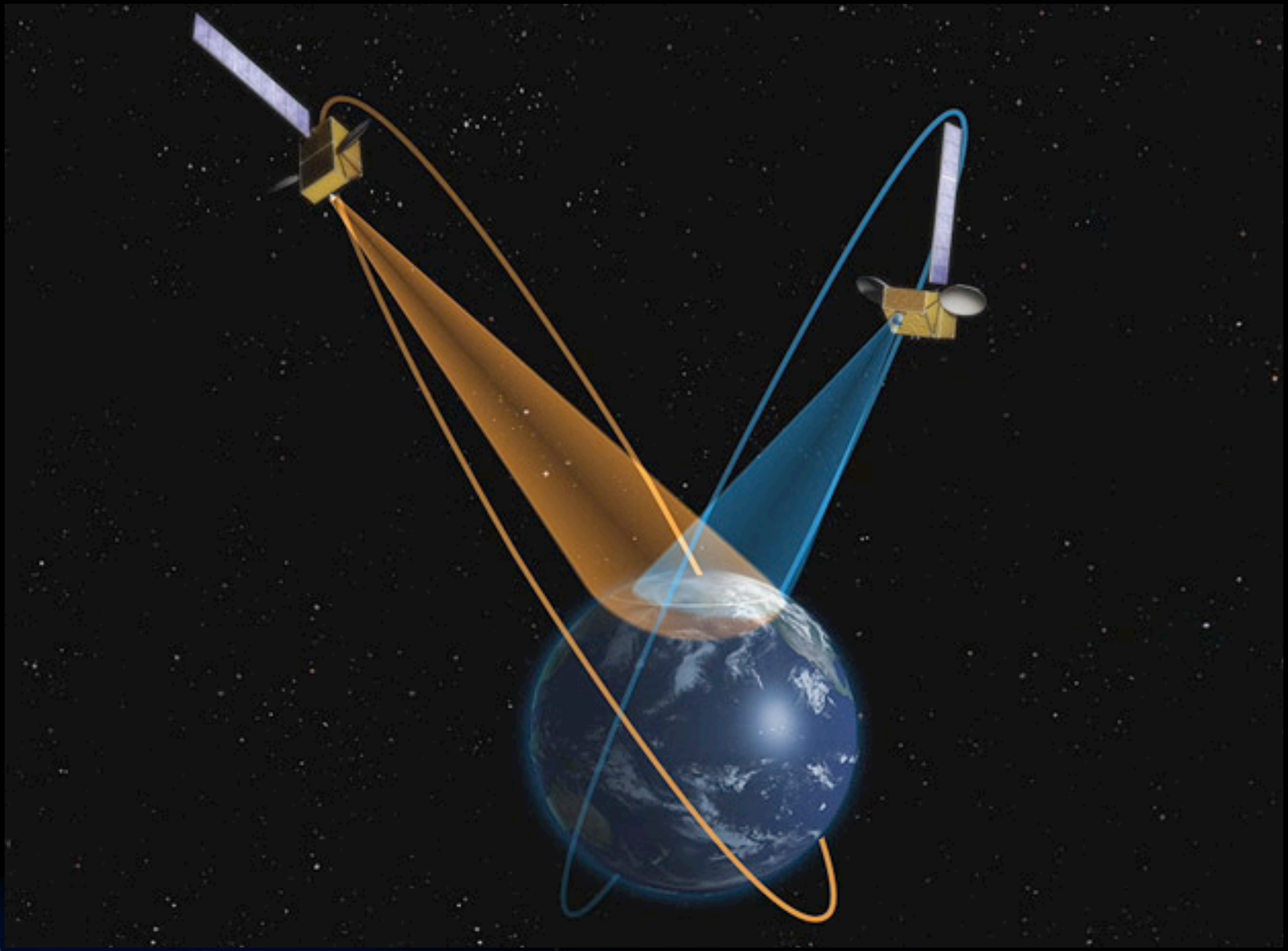
Polar Communication satellites

- The Norwegian Government is exploring the possibility of new communication satellites for the Arctic - possibly in collaboration with other arctic countries.



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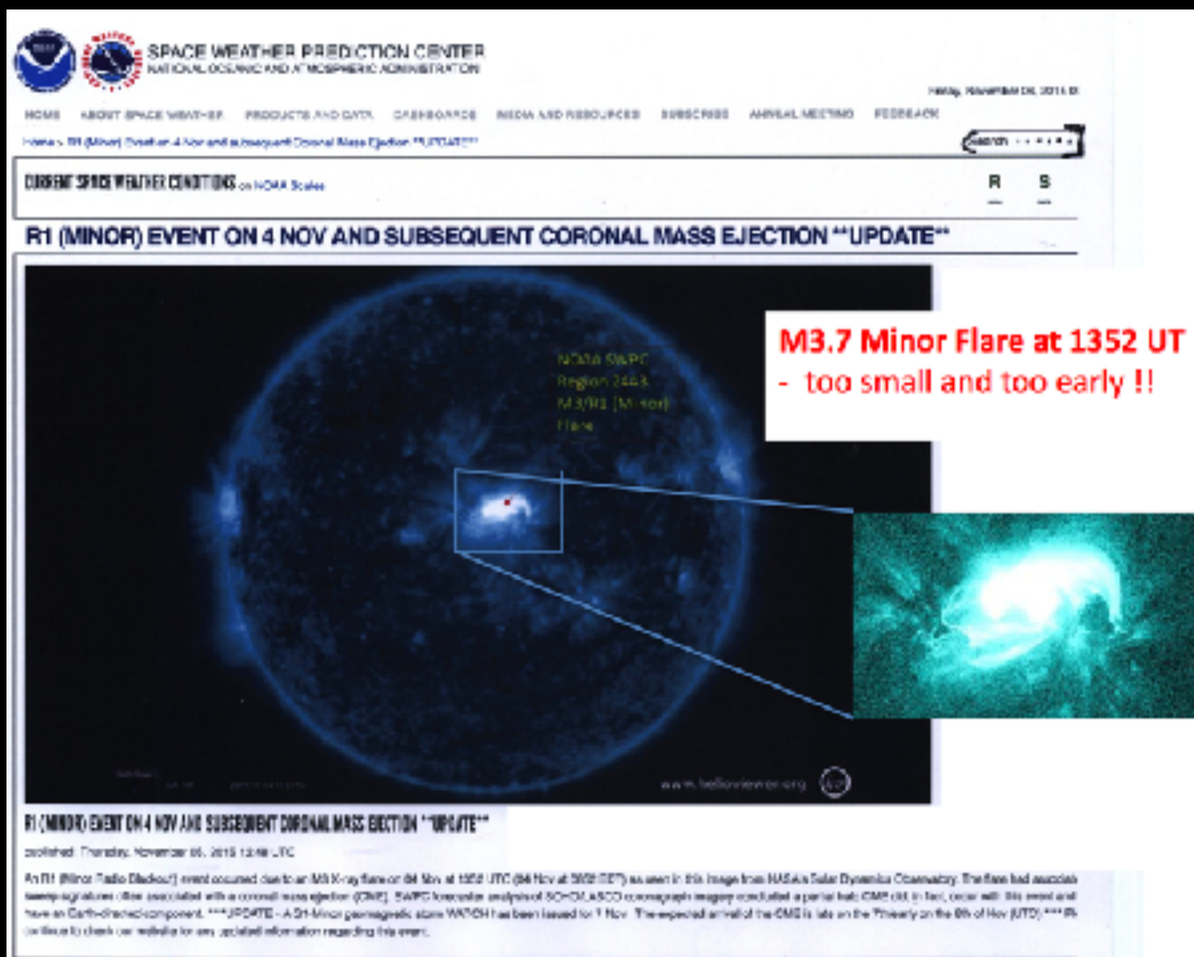
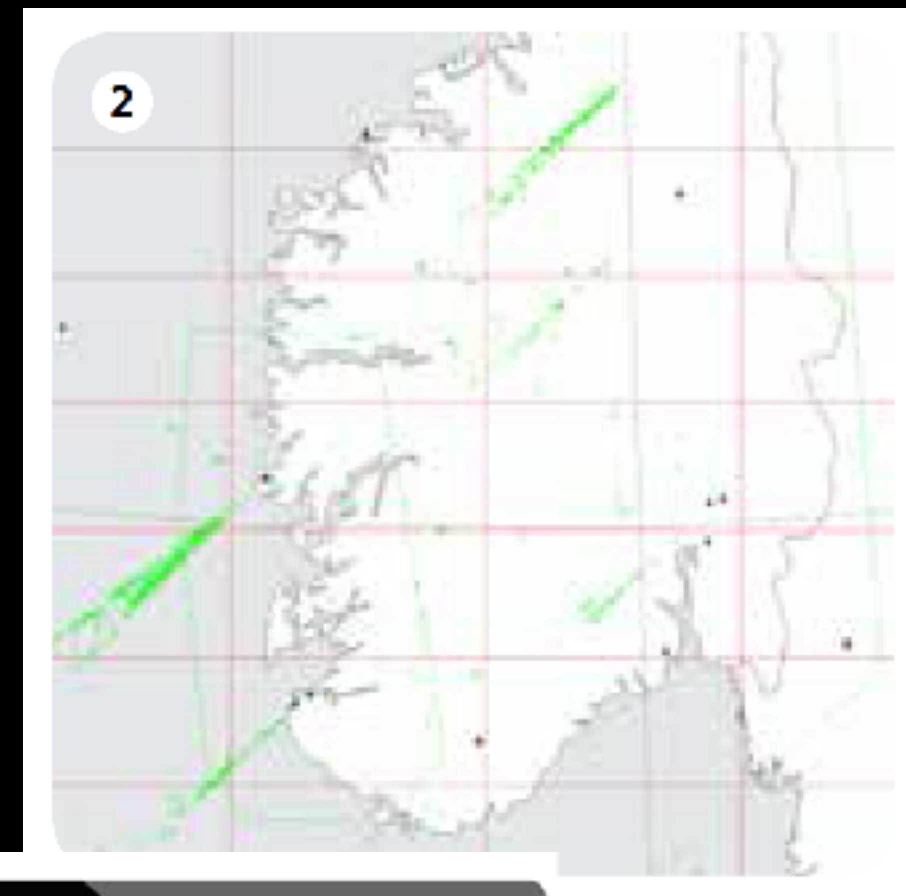
Radio burst affected flight radars

4 November 2015

The event led to 5776 delay-minutes for SAS





Avinor

Radio burst detection system

Kartverket

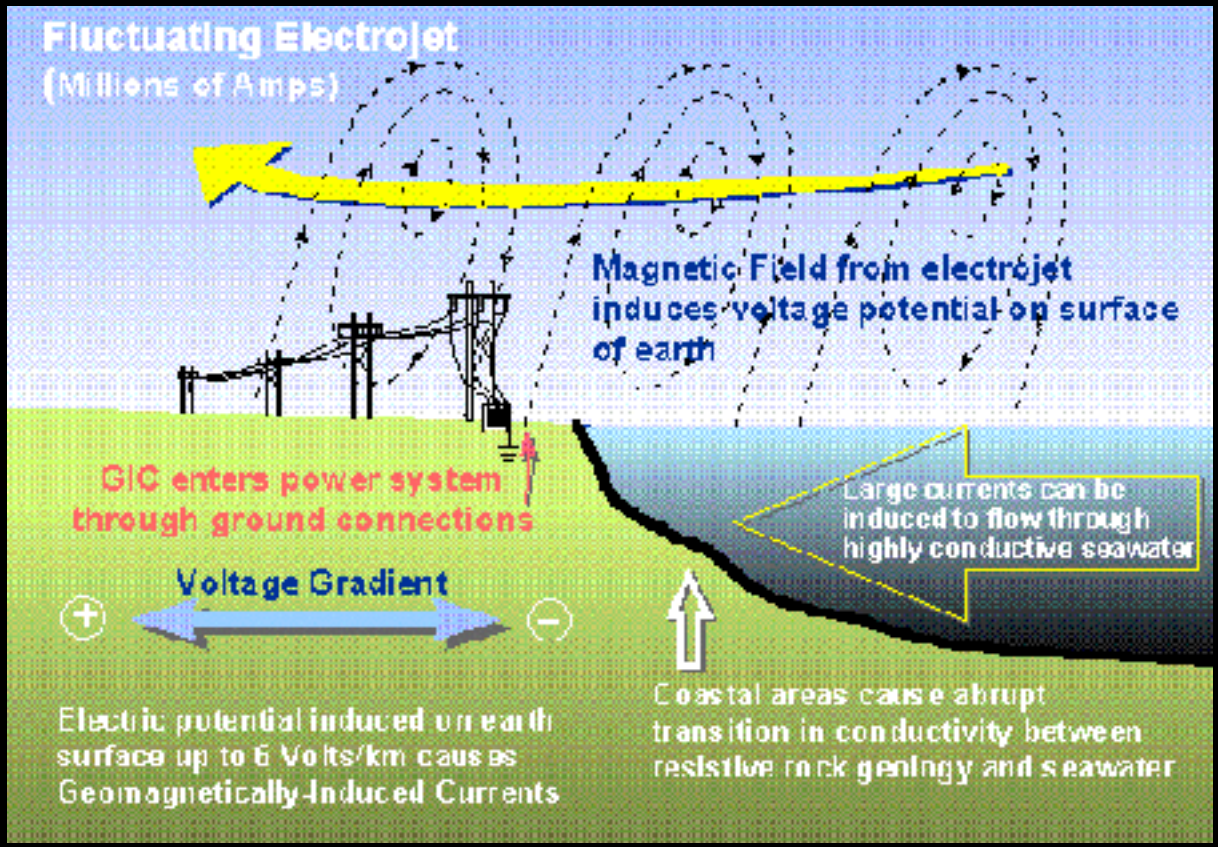
Radio Burst Radar

System Setup and Documentation

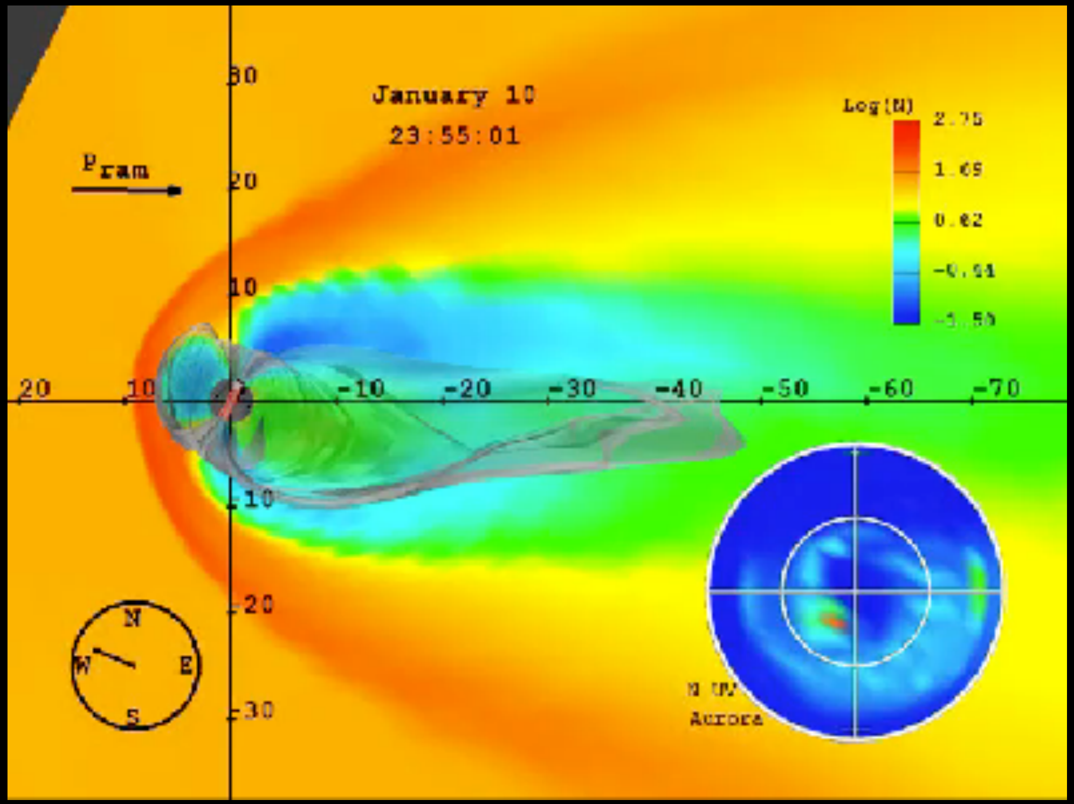
version 0.9

e-CALLISTO

Disruption of power grids

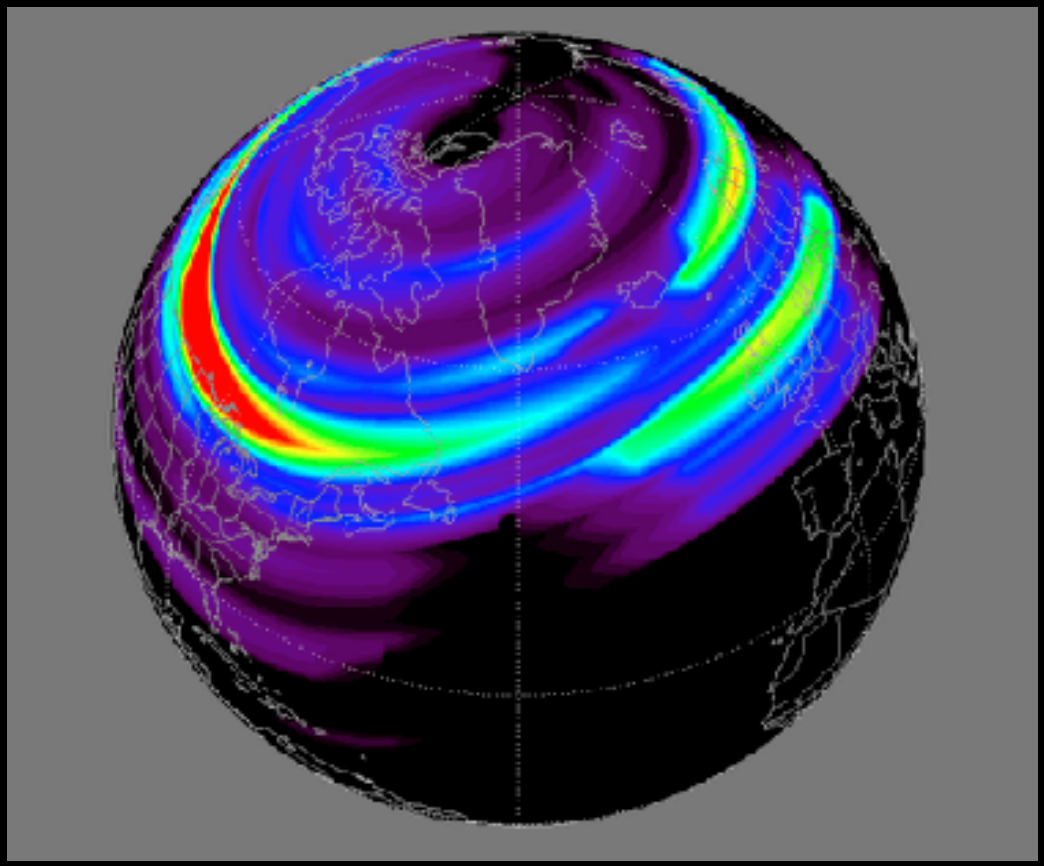


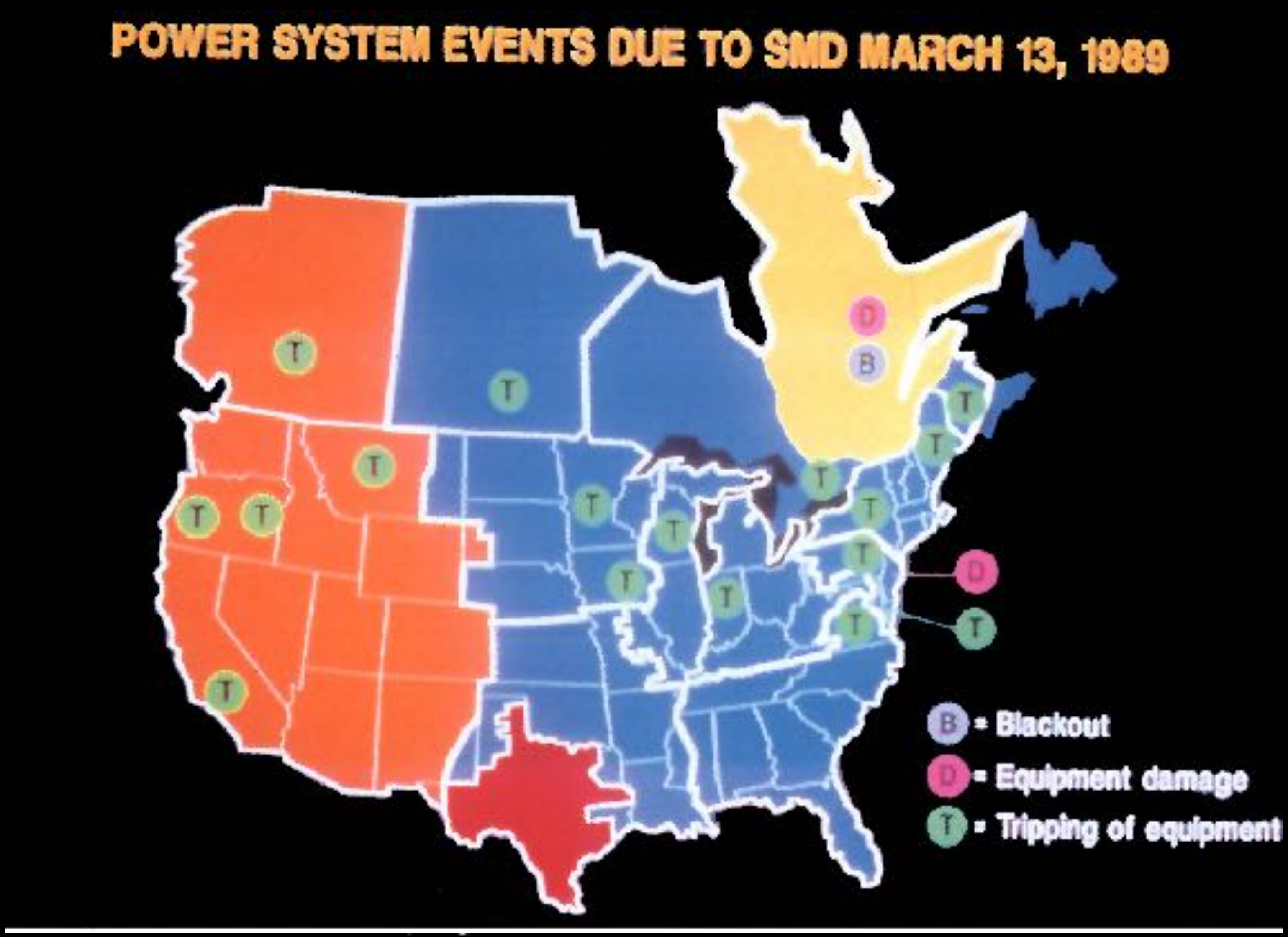
- These currents leaks into all lang conductors:
  - Power grids
  - Oil- and gas pipelines

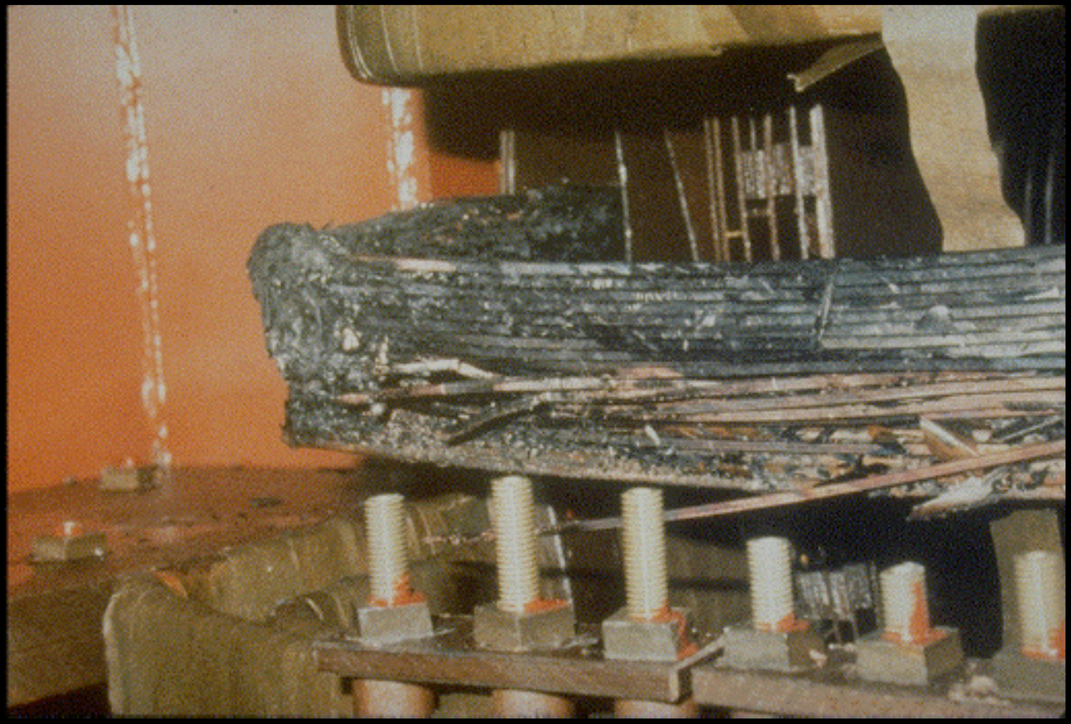


Power failure March 1989

- The entire power grid in Quebec collapsed
- The collapse almoste spread into the NE USA
- Such a collapse would have had en estimated $3-6 billion impact on the US economy.

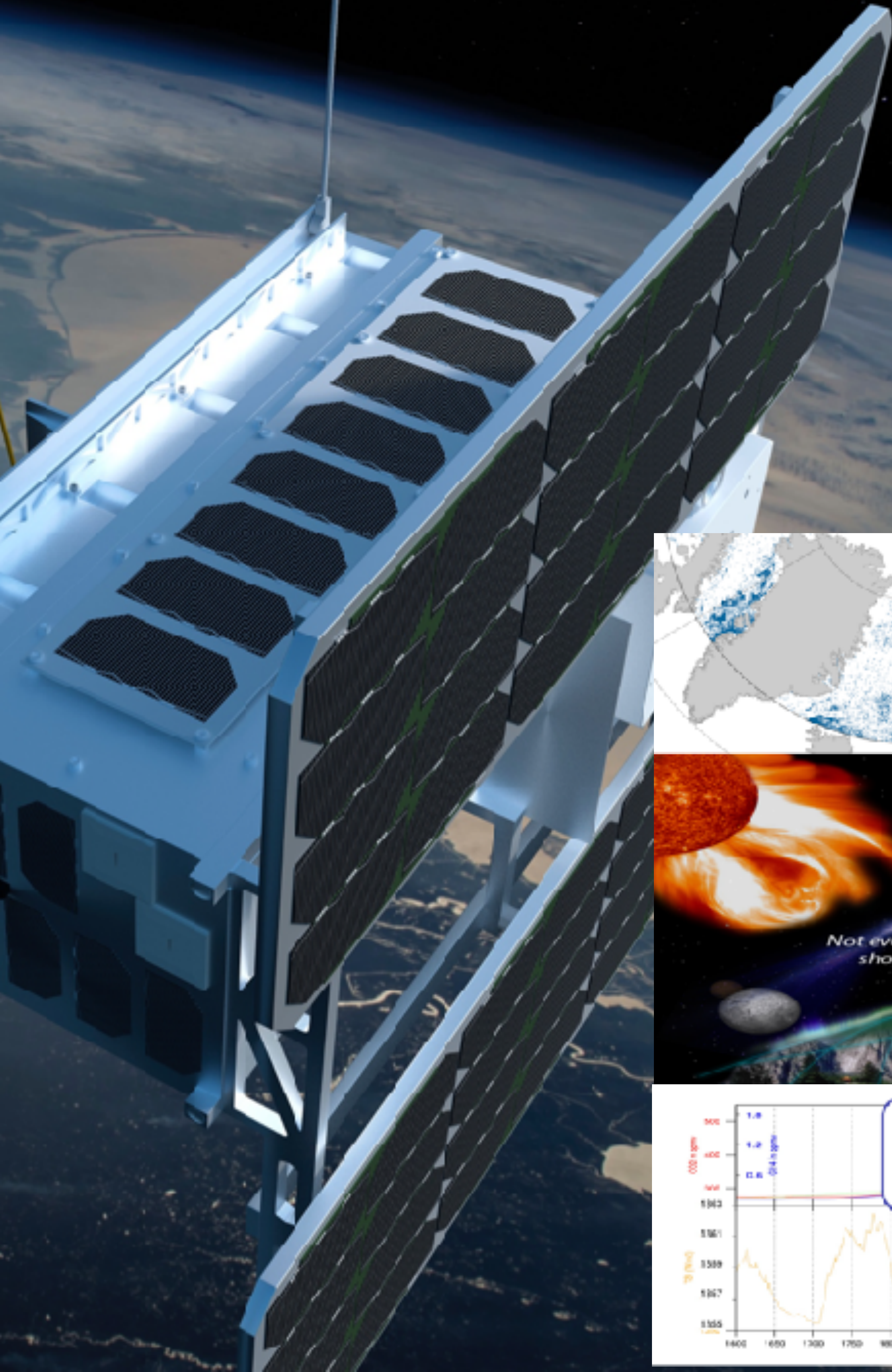


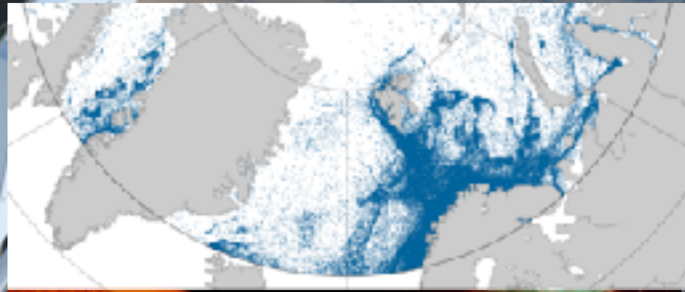


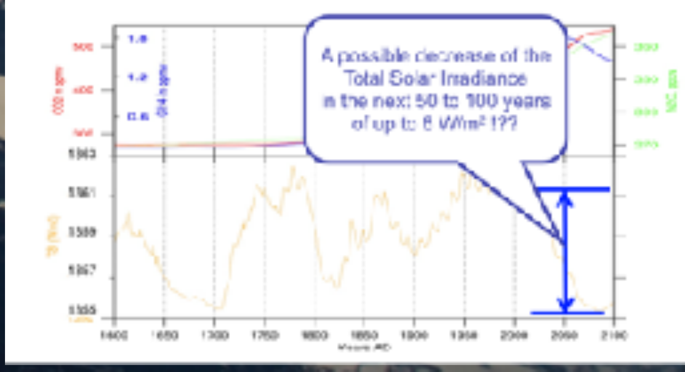


NORSAT-1

- **Primary payload :**
  - Next generation An Automatic Identification System (AIS) receiver from **Kongsberg Seatex** to acquire messages from maritime vessels;
- **Secondary payload** :
  - A Langmuir Probe instrument, intended to measure ambient space plasma characteristics
  - **University of Oslo**
- **Secondary payload :**
  - A Compact Lightweight Absolute Radiometer (CLARA), intended to observe total solar irradiation and variations over time.
  - **Physikalisch-Meteorologisches Observatorium Davos**







DSB - National Risk Analysis

The Directorate for Civil Protection and Emergency Planning (DSB)

5.6 SOLSTORM

BAKGRUNN

Solens overflate består av plasma som kan betraktes som en meget varm elektrisk ledende gass. Gassen strømmer kontinuerlig ut fra solen, og sammen med elektromagnetisk stråling påvirker dette Jorda og vårt nære verdensrom ved en rekke prosesser som med en fellesbetegnelse kalles romvær. Til tider oppstår voldsomme eksplosjoner i solas atmosfære, såkalte solstormer, hvor store mengder partikler, stråling og gass med magnetfelt slynges ut i verdensrommet. Jordas magnetfelt beskytter mot solstormer, men ved polområdene er denne beskyttelsen svakere. Romvær og solstorm er derfor et særlig aktuelt tema for Norge siden vi ligger langt nord.

Den såkalte *Carrington-stormen* i 1859 refereres ofte til som den kraftigste solstormen man har hatt erfaring med. Telegrafsystemet ble kraftig rammet, operatørene fikk elektriske sjokk, og branner oppsto i telegrafbygninger som følge av solstormen. Også i 1921 opplevde man en stor solstorm. Denne solstormen var ikke så kraftig som den i 1859, men medførte samme type konsekvenser og utfordringer for datidens samfunn.

Flere kraftige solstormer har de siste 20 til 30 årene medført forstyrrelser og avbrudd i tele- og strømforsyning med ujevne mellomrom og ulik varighet. I 2003 var det mange kraftige elektromagnetiske stormer på sola. I forbindelse med de såkalte *Halloween-stormene* ble det meldt om tekniske problemer med satellitter og satellittelefoner fra flere deler av verden. På grunn av problemer med radiokommunikasjon ble internasjonal luftfart på trans-atlantiske og polare ruter midlertidig redusert og trafikken omdirigert, og det ble sendt ut advarsel om økt strålefare for flypassasjerer. I USA ble også enkelte store krafttransformatorer skadet og ødelagt, og store områder ble mørklagt i noen timer. Kostnader som følge av solstormen ble anslått til å være minst fire milliarder dollar.

Også i Sverige mistet mange tusen mennesker strømmen i en kort periode som følge av denne solstormen.

National Research Council of the National Academies (2008). *Severe Space Weather Events–Understanding Societal and Economic Impacts.* Workshop Report; U.S. Department of Homeland Security, Federal Emergency Management Agency (FEMA), National oceanic and atmospheric administration (NOAA), US Department of Commerce, Swedish Civil Contingencies Agency (MSB) (2010): *Managing Critical Disasters in the Transatlantic Domain – The Case of a Geomagnetic Storm.* Workshop Summary February 23–24 2010.

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Users of Space Weather in Norway

Who:

- Oil&Gas companies
- Aviation
- Maritime Sector
- Power grid operators
- Satellite operators
- Survey, Construction, etc.
- Tourism sector

Why:

Navigation, positioning and exploration activities

GNSS navigation and HF communication (S&R, Avinor etc.)

GNSS navigation and HF communication

Ground Induced Currents and GPS timing (NVE/Statnett)

Damages to systems (Statsat/Telenor)

GNSS positioning

Aurora forecasts

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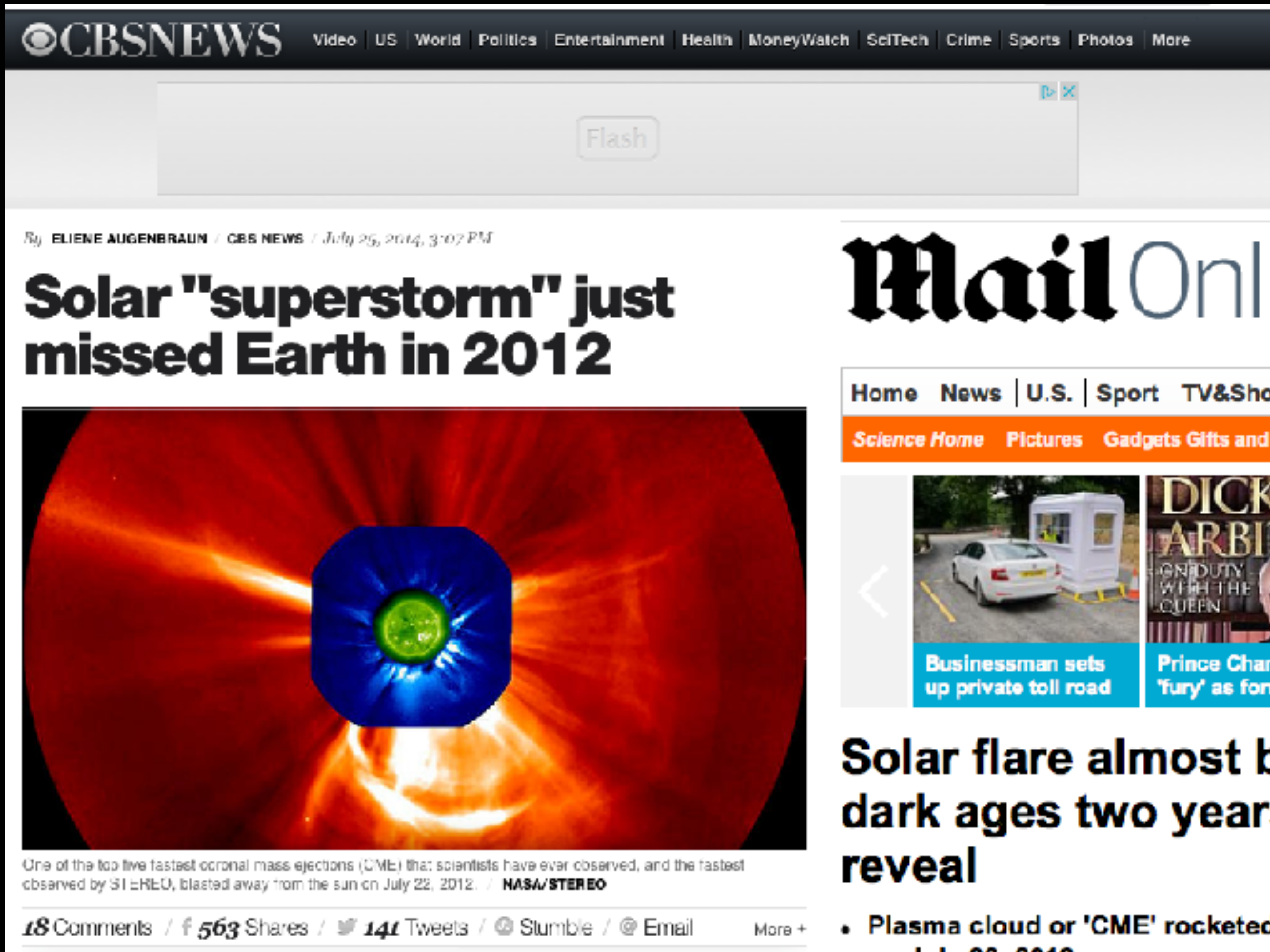
Extreme Solar Weather Has Happened Before

Morse Telegraph Table
Photo from www.telegraphlore.com

- 1847 – "Anomalous current" noted on telegraph line between Derby and Birmingham. First recorded impact of solar weather on technology.
- August 28-29, 1859 – Telegraph service disrupted worldwide by geomagnetic superstorm.
- September 1-2, 1859 – Carrington-Hodgson event is largest geomagnetic storm in 500 years.
- May 16, 1921 – The "Great Storm" disrupted telegraph service, caused fires, burned out cables. **Storms like this may occur roughly every 100 years.**
- March 13, 1989 – Geomagnetic storm collapsed Quebec power grid. Northeast U.S. and Midwest power grid came within seconds of collapse.
- October 19 – November 7, 2003 – "Halloween Storms" interrupted GPS, blacked out High Frequency (HF) radio, forced emergency procedures at nuclear power plants in Canada and the Northeastern United States, and destroyed several large electrical power transformers in South Africa.



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Flash

By ELIENE AUGENBRAUN / CBS NEWS / July 25, 2014, 3:07 PM

Solar "superstorm" just missed Earth in 2012

One of the top five fastest coronal mass ejections (CME) that scientists have ever observed, and the fastest observed by STEREO, blasted away from the sun on July 22, 2012. / NASA/STEREO

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Businessman sets up private toll road

Prince Charles' 'fury' as former

Diana's favourite DJ Mike Smith dies at

Best hotel in Britain is Birmingham's

Solar flare almost blasted Earth back to the dark ages two years ago, NASA scientists reveal

- Plasma cloud or 'CME' rocketed away from the sun as fast as 3000 km/s on July 23, 2012
- Had the eruption occurred just one week earlier, the blast site would have been facing Earth
- Direct hit could cause widespread power blackouts, disabling everything that plugs into a wall socket.
- Total economic impact could have exceeded $2 trillion or 20 times greater than the costs of a Hurricane Katrina

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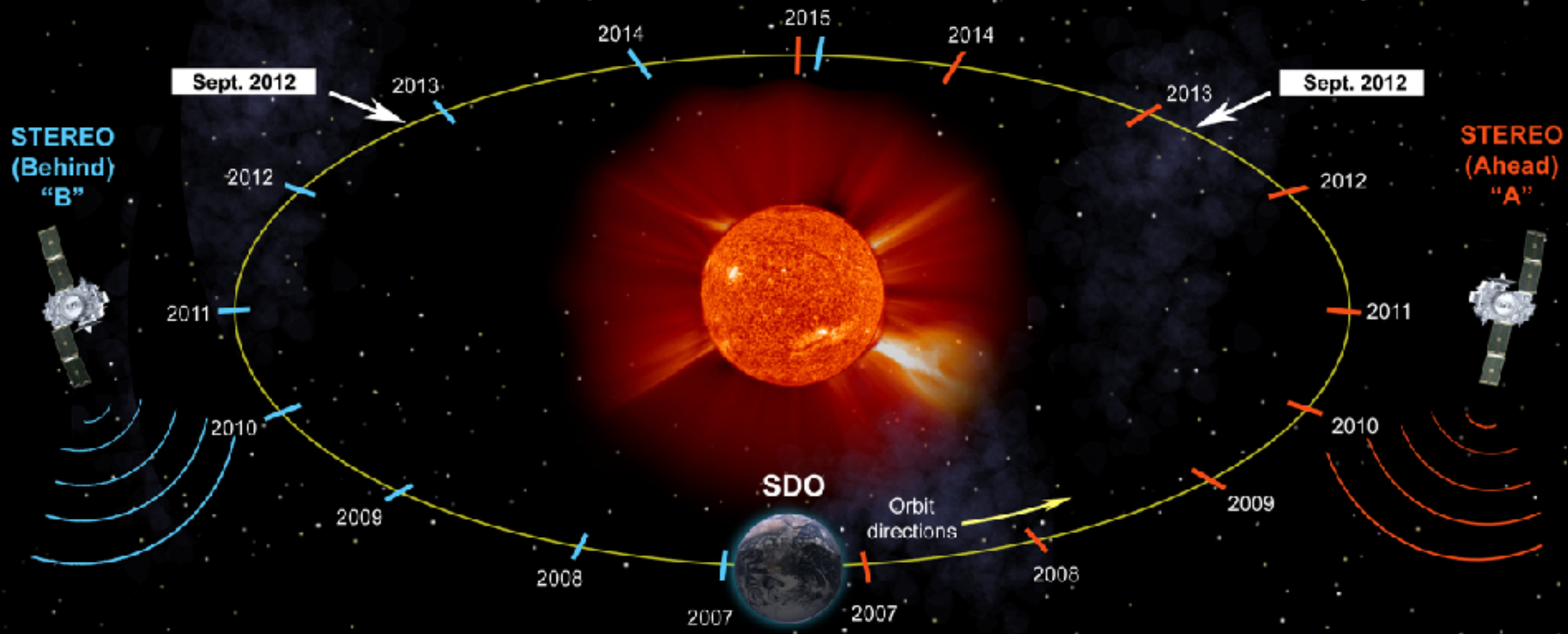
NASA's STEREO (with SDO) Sees the Entire Sun



The two **STEREO** spacecraft reach equidistant positions between themselves and Earth on Sept. 1, 2012.

Drawing gives the relative orbital positions of both STEREO spacecraft for each year from June 2007 to June 2015.
(Not to scale)

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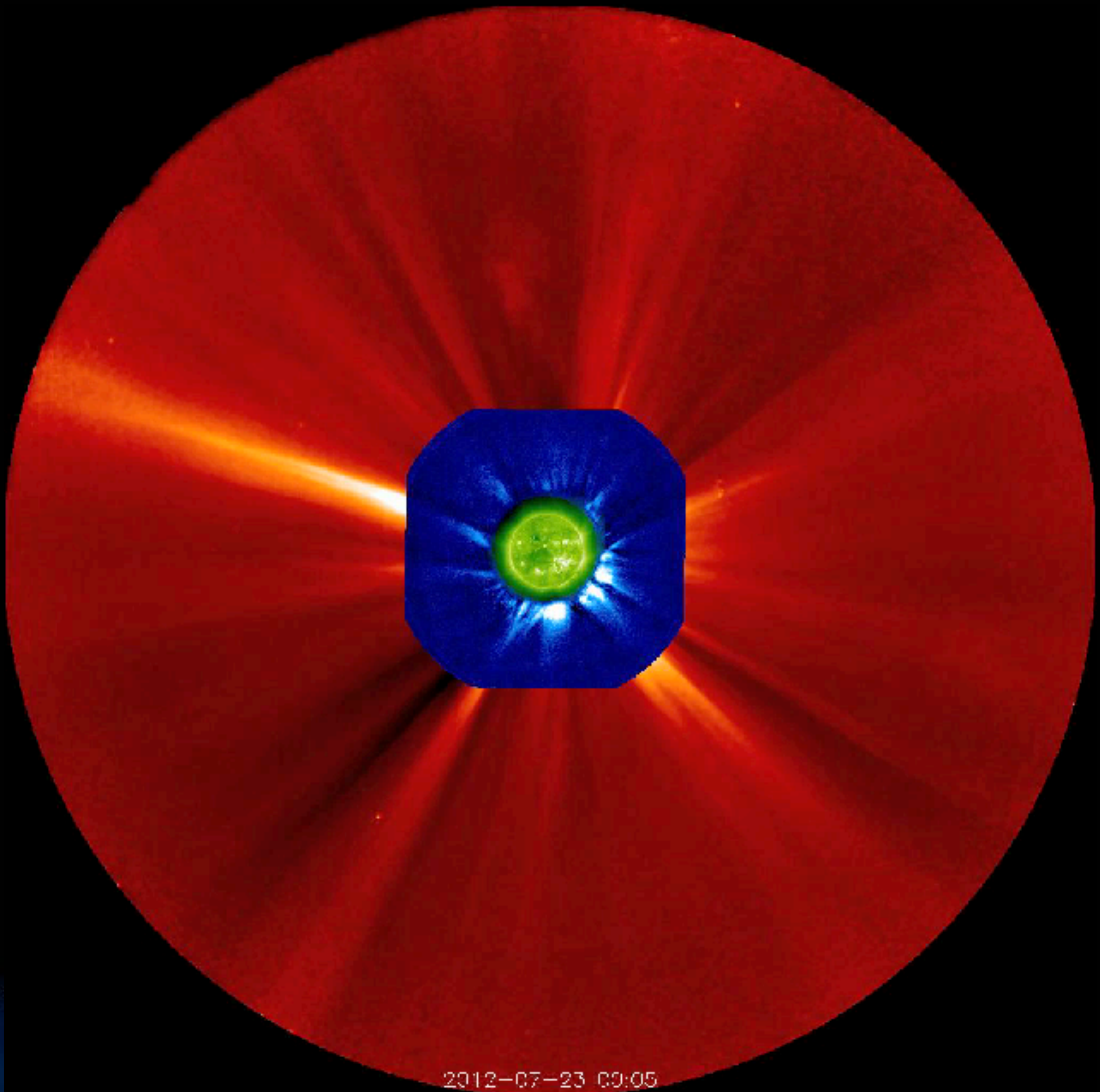
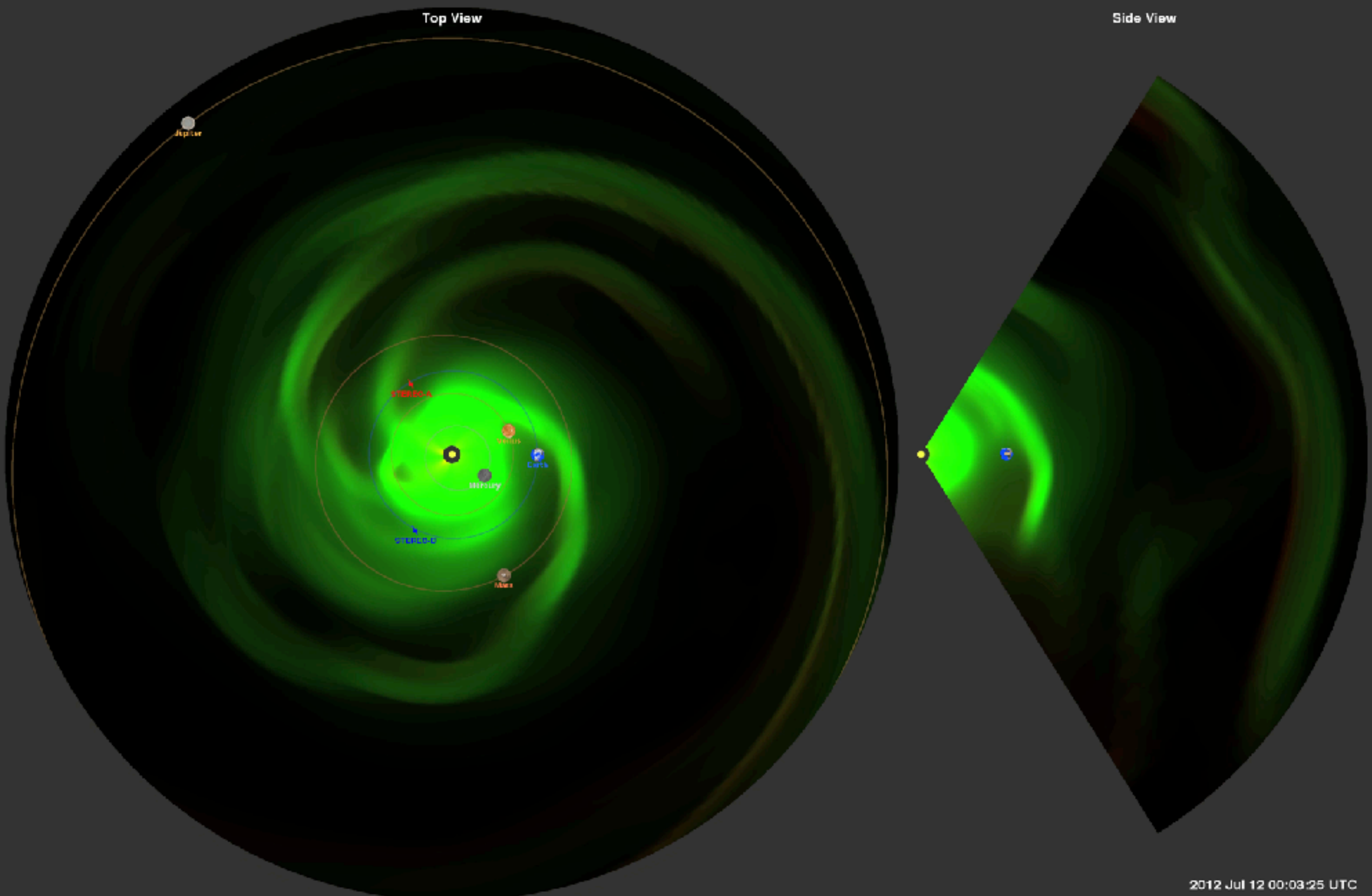
Superstorm 2012



Superstorm 2012



Solar storms on talks shows

Summary

Several Norwegian agencies and companies are aware of their needs within space weather and ask about national services.

With the expected increased oil and gas activities in the Barents Sea, more traffic through the North West passage, more GNSS-users on land and ocean as well GNSS-usage in aviation the demands for reliable space weather services will also increase.

However, until now very little coordination towards an operative national system

Today Norway also have its own small satellites that are affected my space weather and space debris. As well as satellites with space weather instrumentation.

Our goal is to be in the front on Arctic Space Weather part of the European development.

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