Aalto University
School of Electrical
Engineering

Instrumentation for geo- and space observations

Magnetism and applications 6.6.2023

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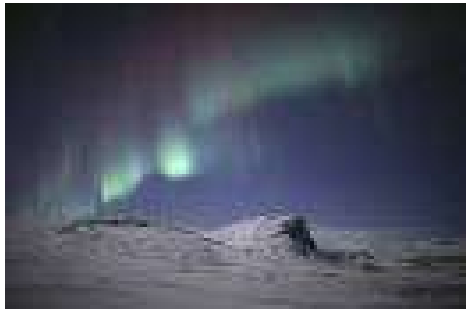
Today

Ground-based space weather measurements:

Magnetometers & all-sky cameras
Magnetic measurements
Geomagnetic activity indices

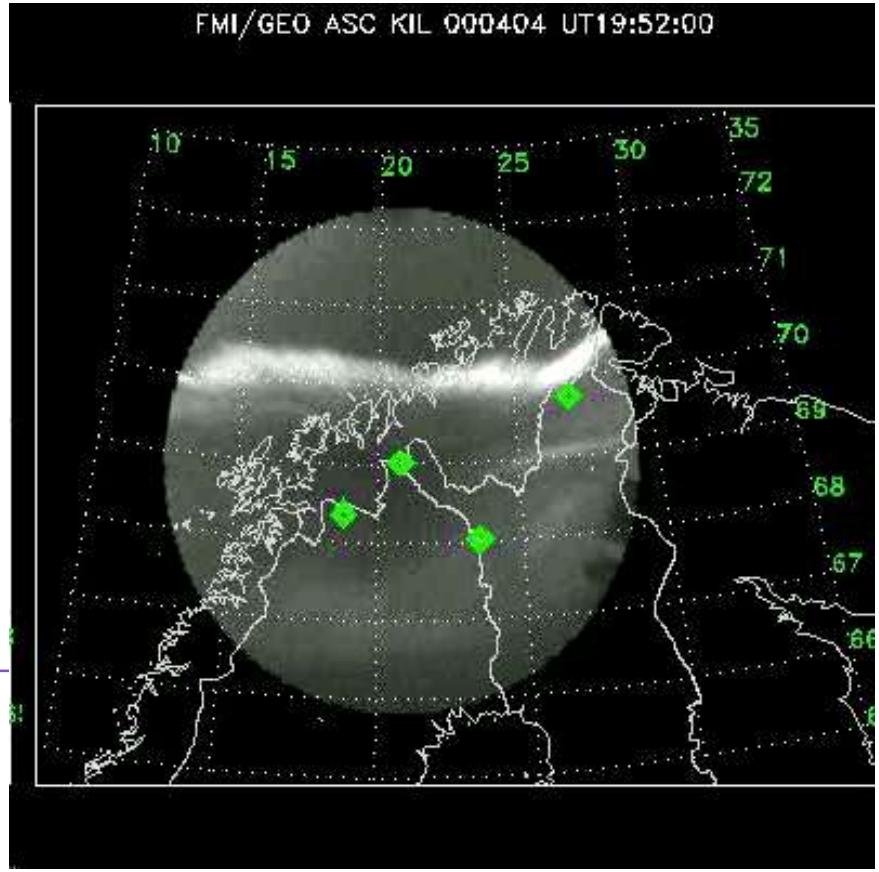
Brief history of magnetic measurements



- First scientific magnetometer 1832 (Gauss)
- First magnetic observatory 1840 (Toronto)
  - Summer 1844 also in Helsinki
- Famous solar storm, Carrington event of 1859
- First scientific satellite 1958 (Explorer I)
- First magnetotail observations 1965
- Continuous ground-based observations since 1966 (Kyoto AL)
- Solar wind observations since 1966, continuous L1 observations since 1997 (ACE spacecraft)

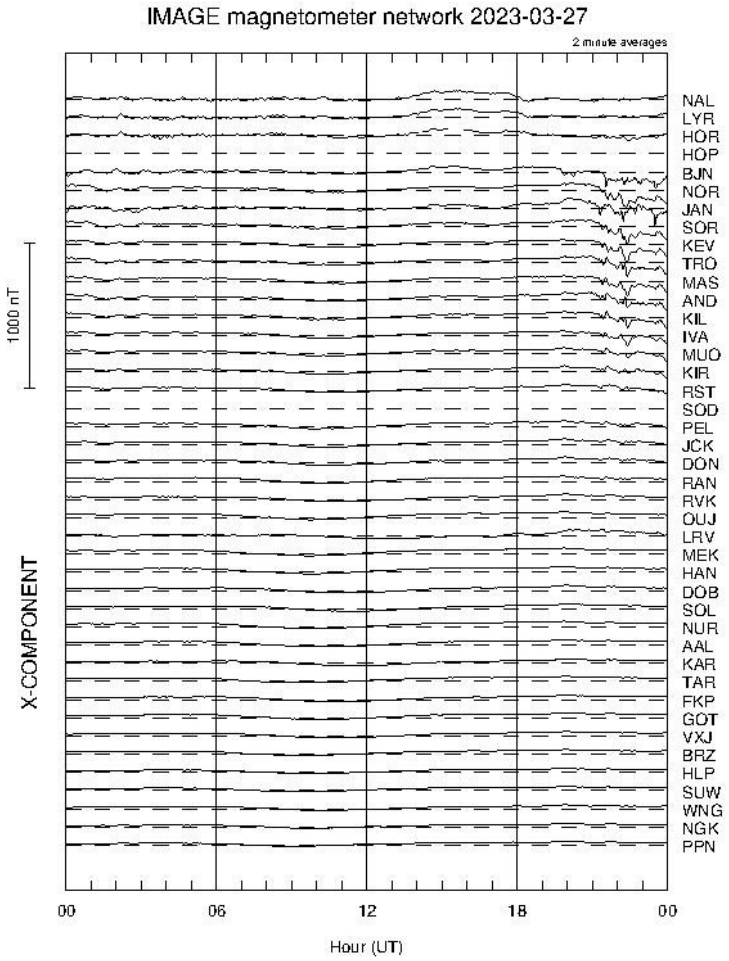
Detecting (geo)magnetic activity (and currents)

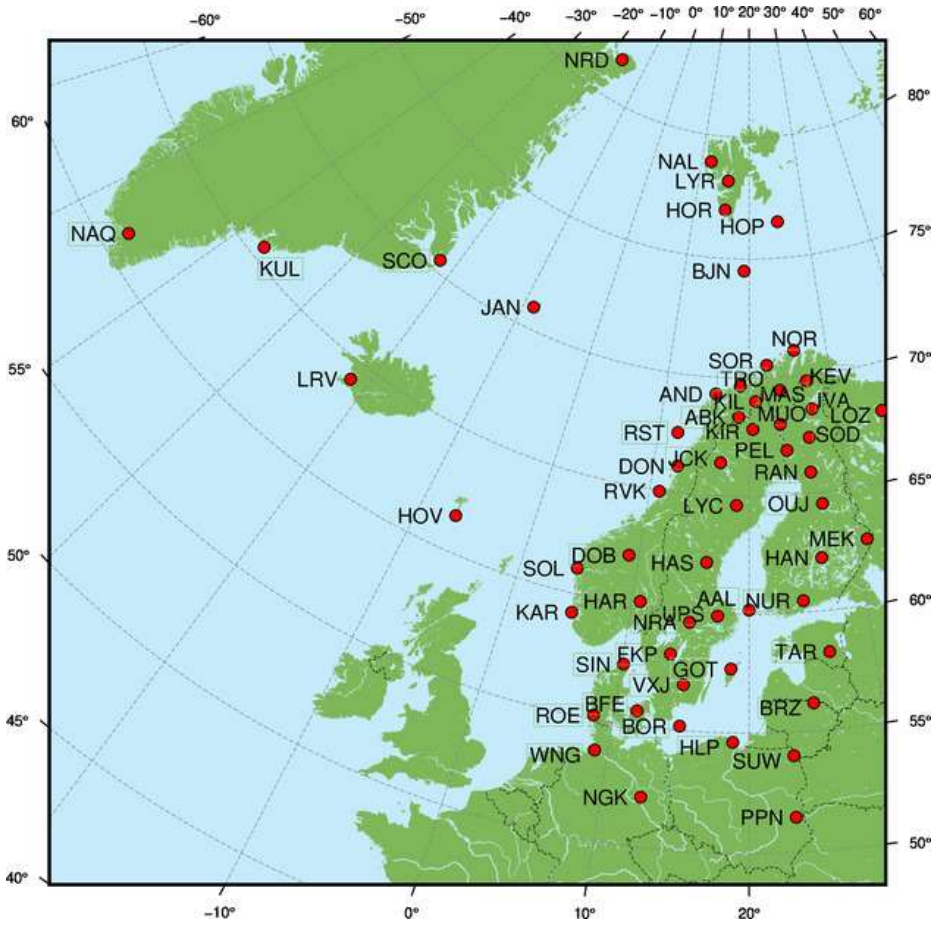
Geomagnetic activity can be detected by all-sky cameras, magnetometers, radars, riometers, ionosondes, satellites ...



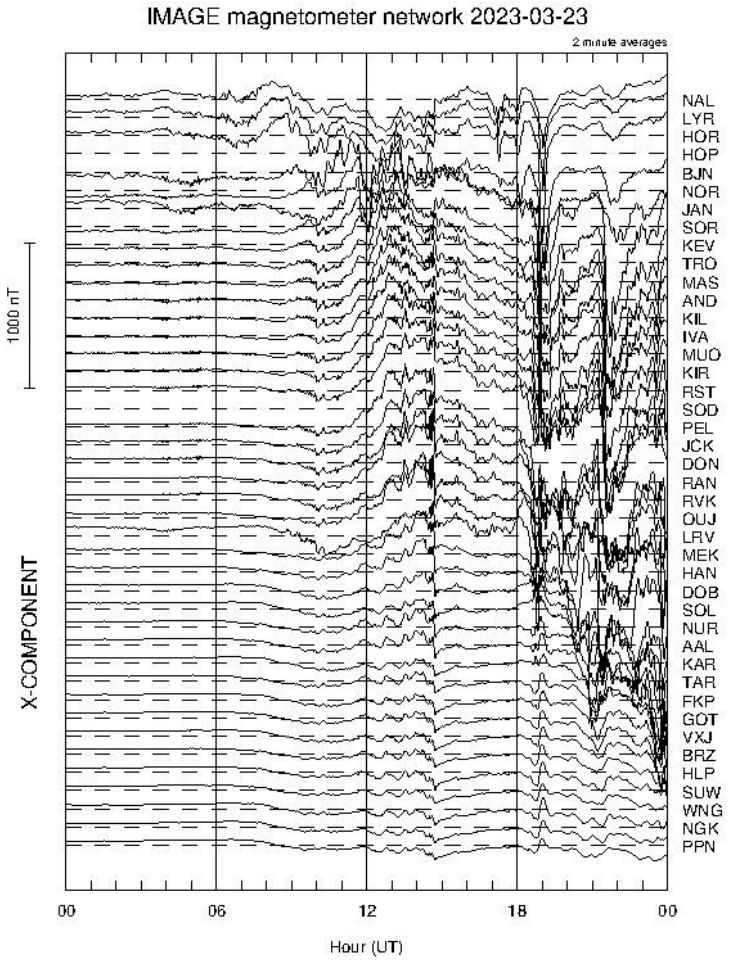
… or by an astronaut from a space shuttle

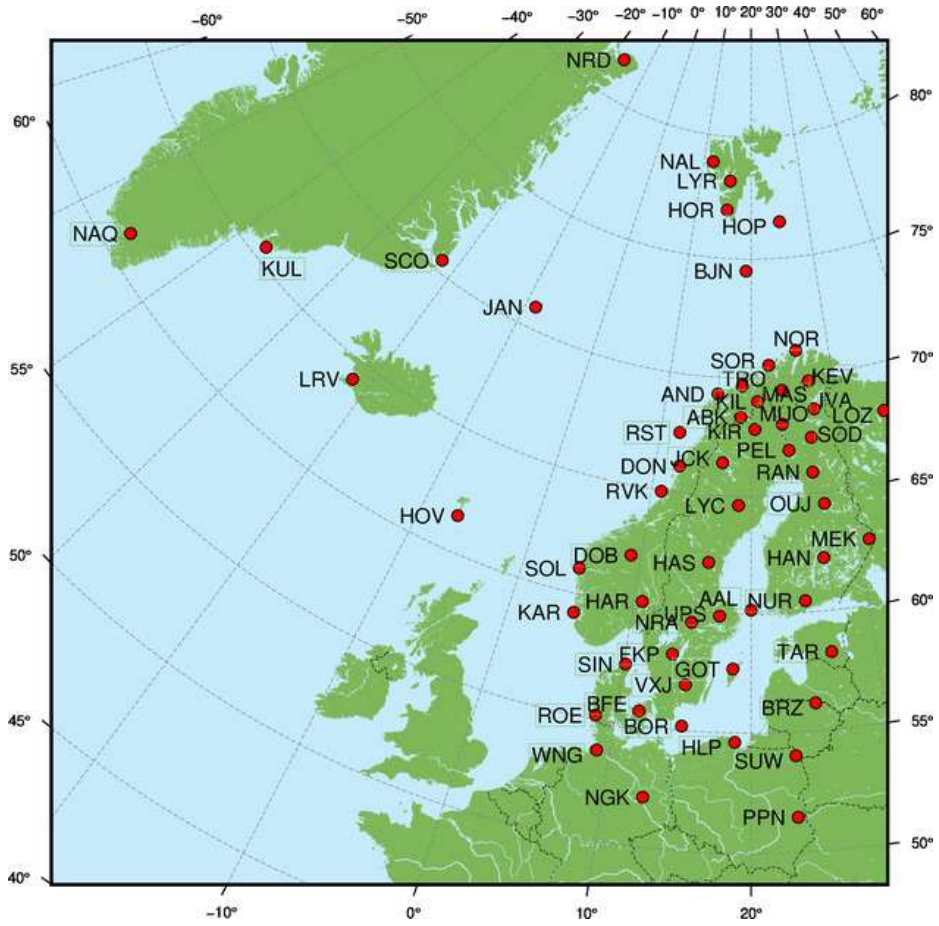
Geomagnetic activity detected by magnetometers



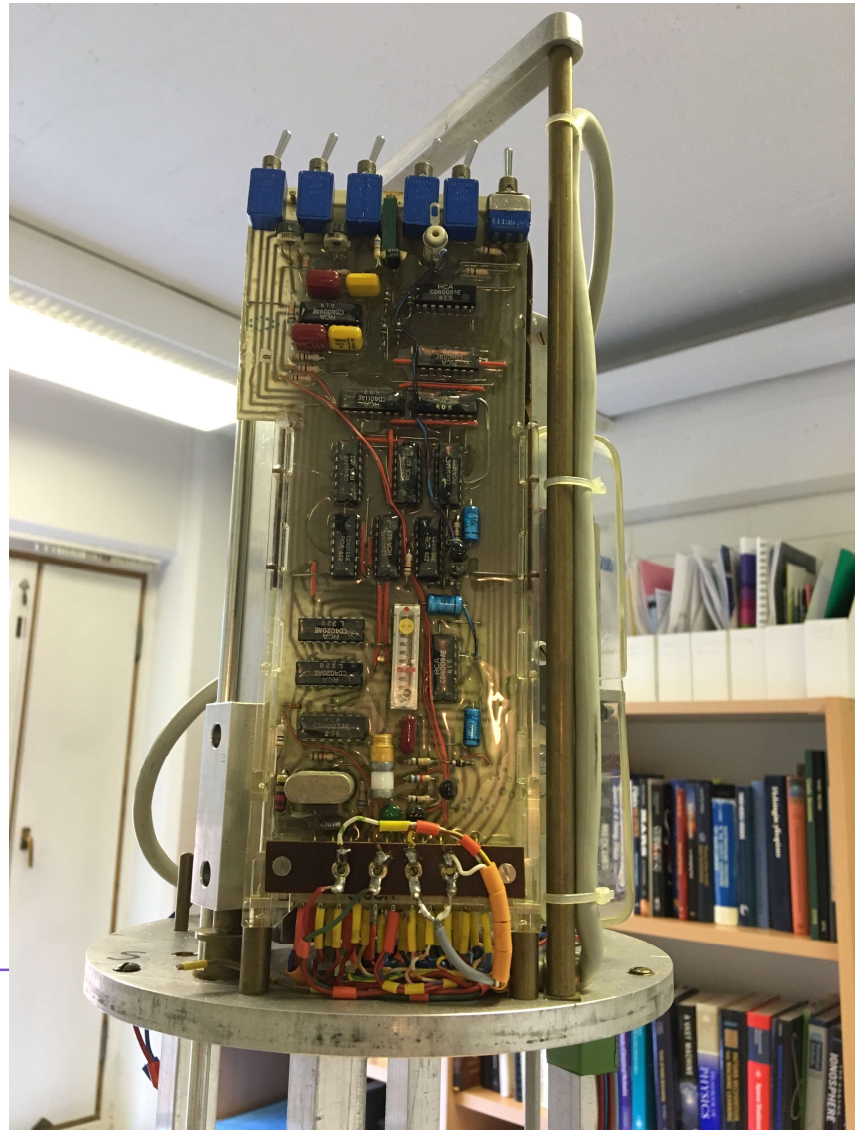


Geomagnetic activity detected by magnetometers





Analog magnetometer from 1960´s

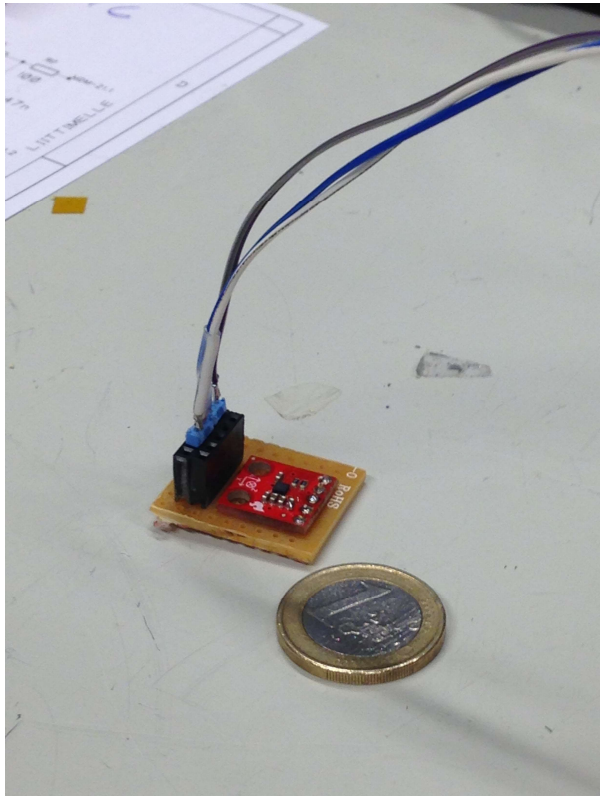


Modern ground-based magnetometers

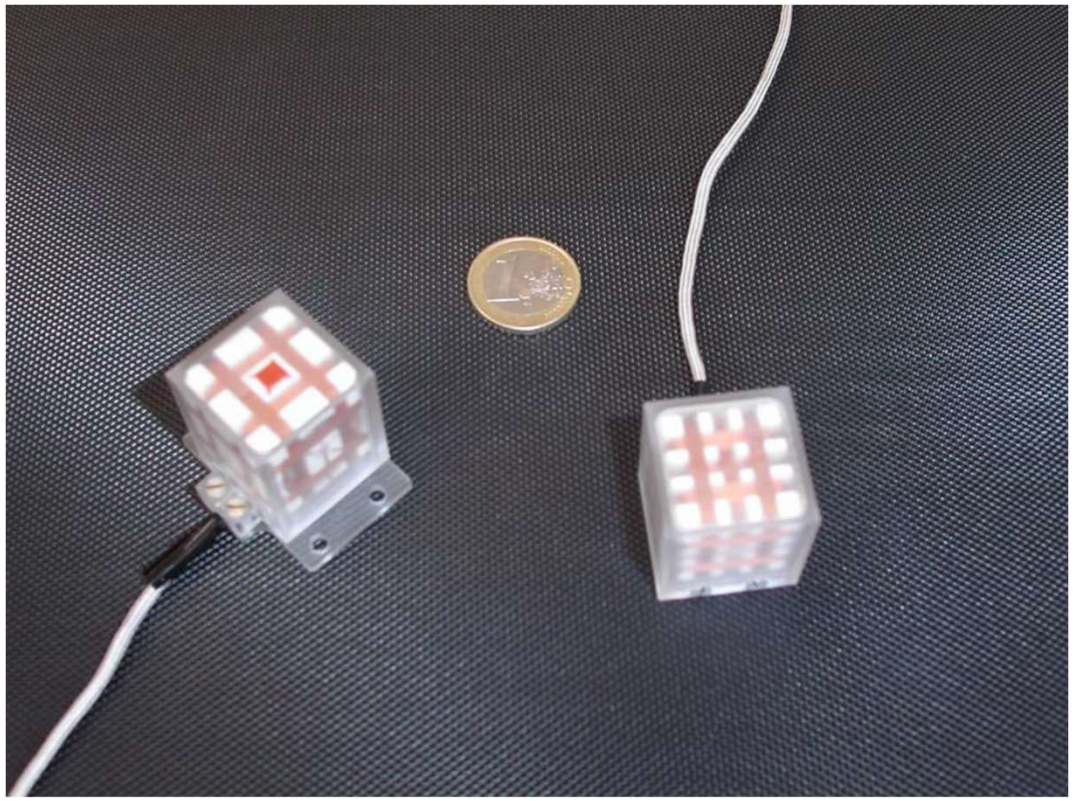
Flux gate magnetometer
for scientific measurements

Helicopter magnetometer
for magnetic surveys

Spacecraft magnetometers



Eija Tanskanen, 2016



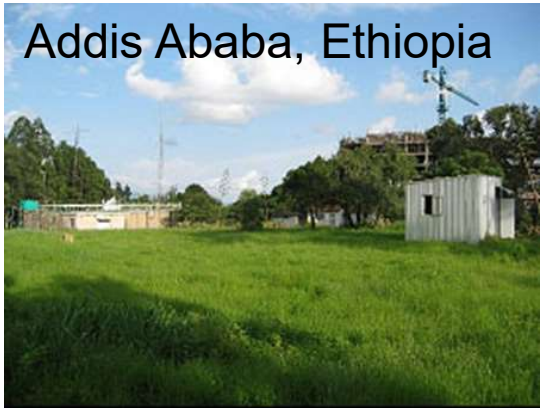
Ingo Richter, 2010

All-sky cameras

Observatories

Mawson, Antarctica

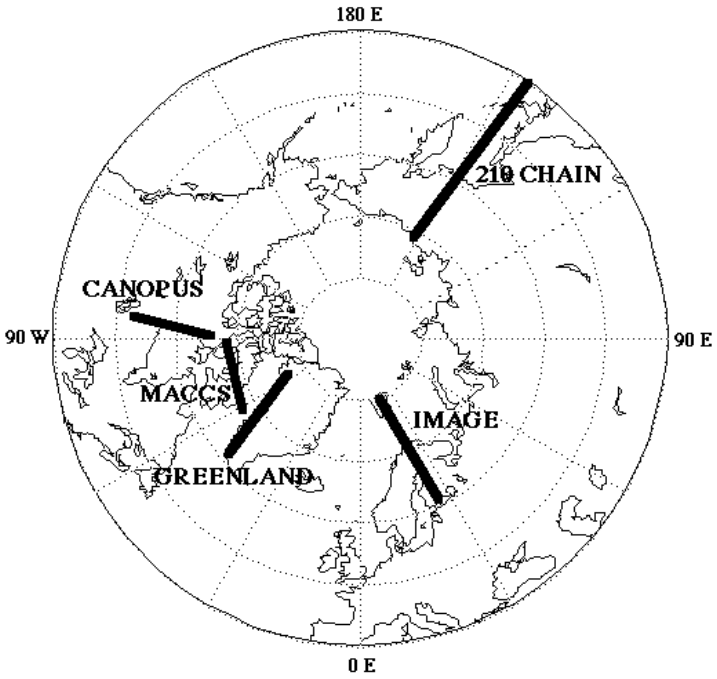
Nurmijärvi, Suomi



Dalat, Vietnam

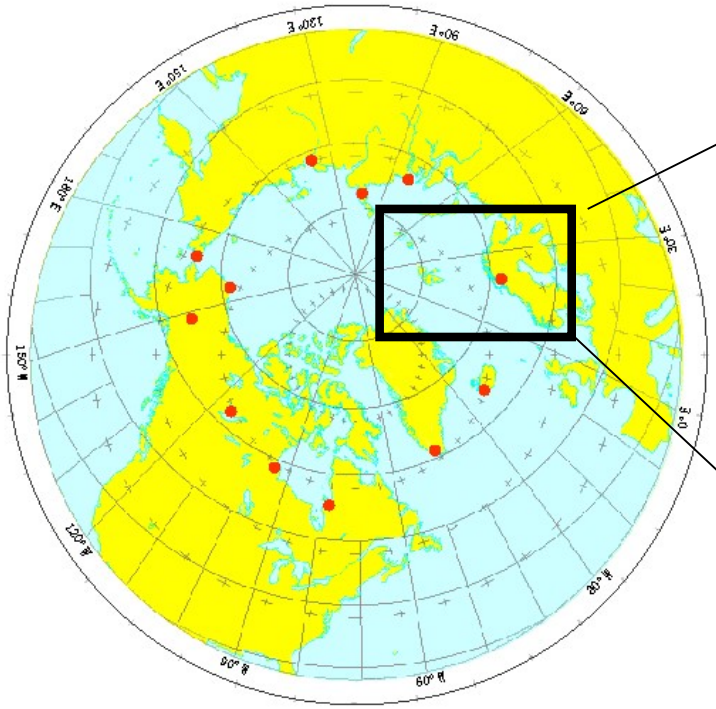
Magnetometer chains

- IMAGE network
- CARISMA (earlier CANOPUS)
- 210 CHAIN
- Greenland chain
- MAGDAS
- Scandinavian SME (only historical data).

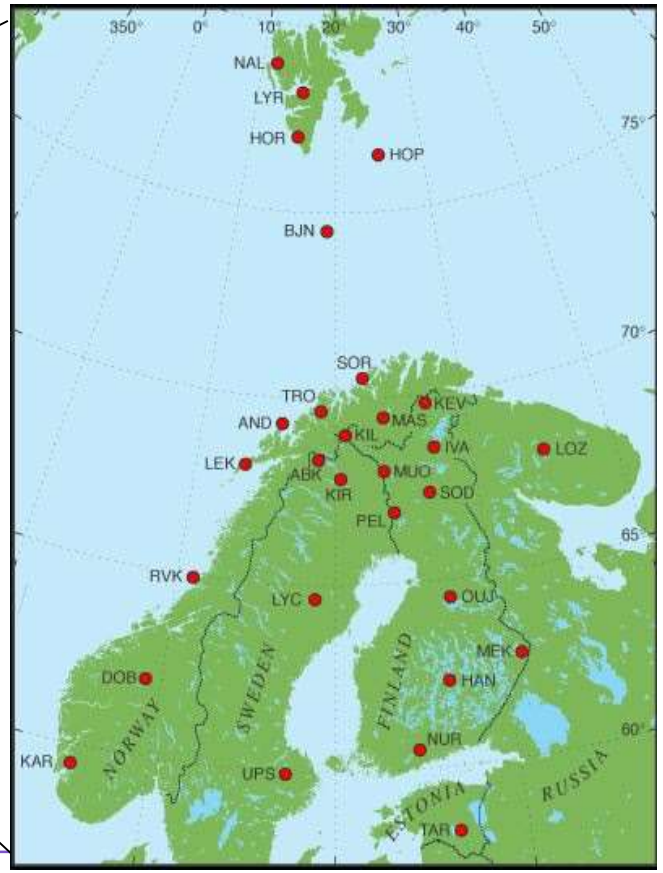


Magnetometer networks

12 Kyoto AL observatories

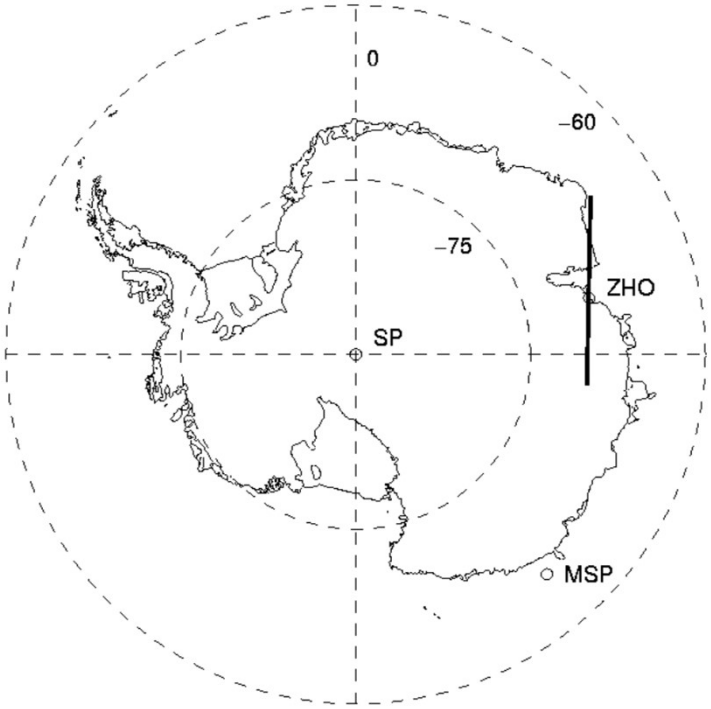


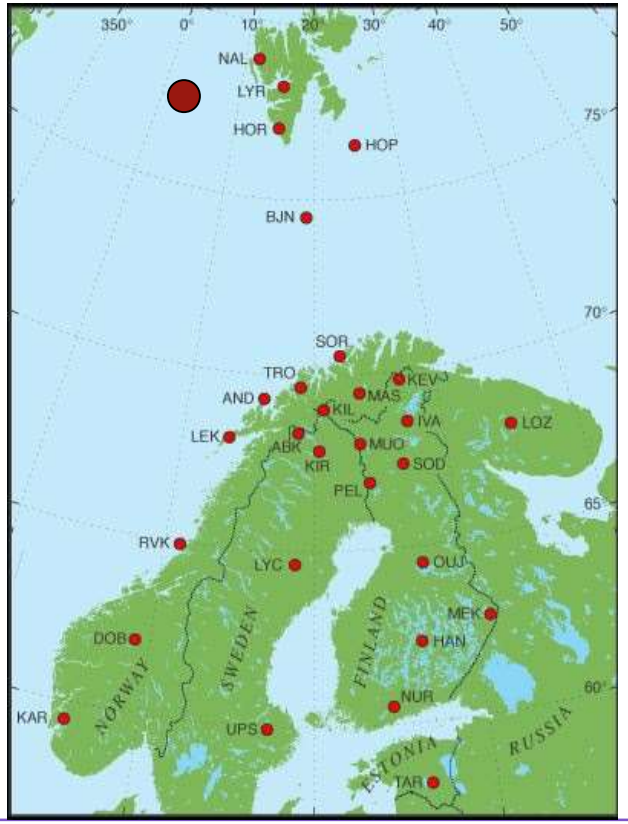
58 IMAGE observatories



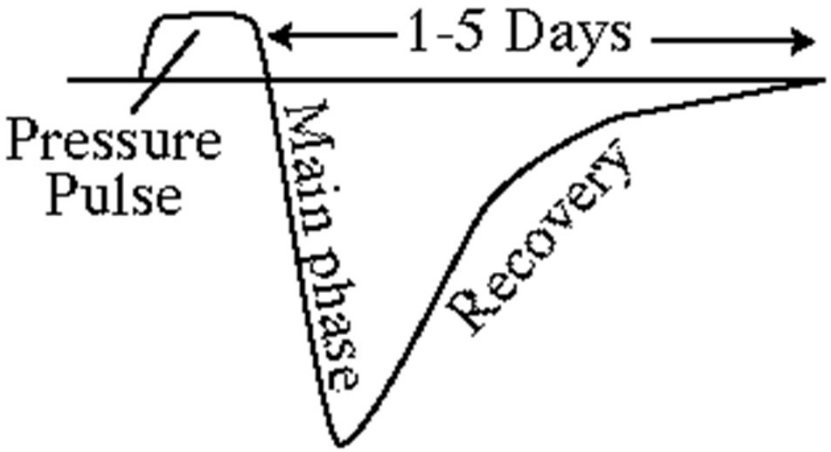
Courtesy of Häkkinen

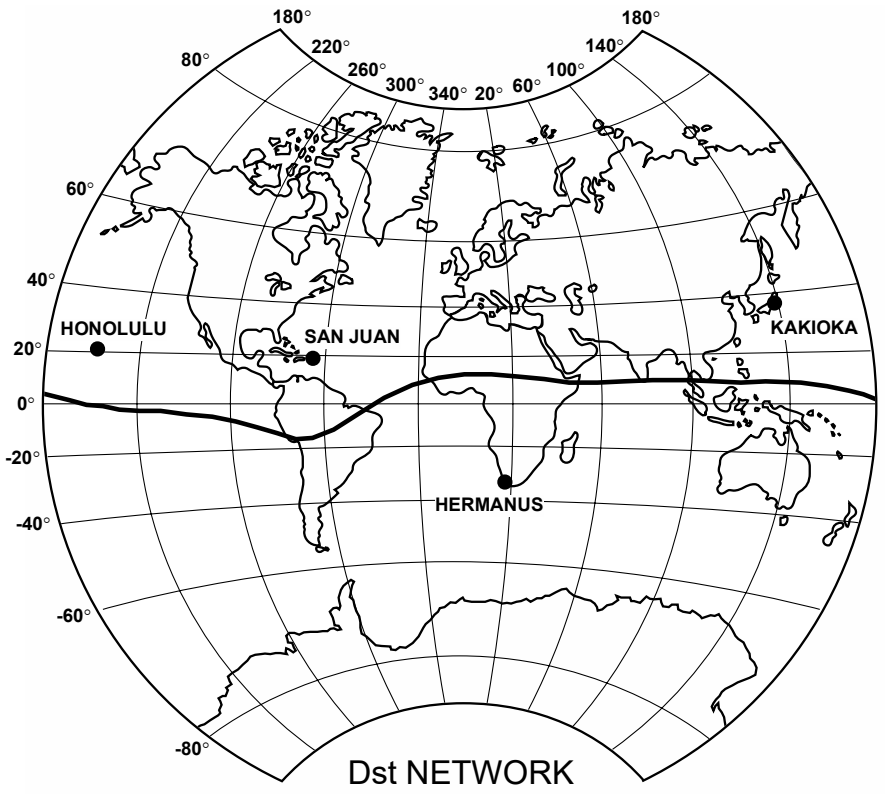
Conjugate magnetic measurements





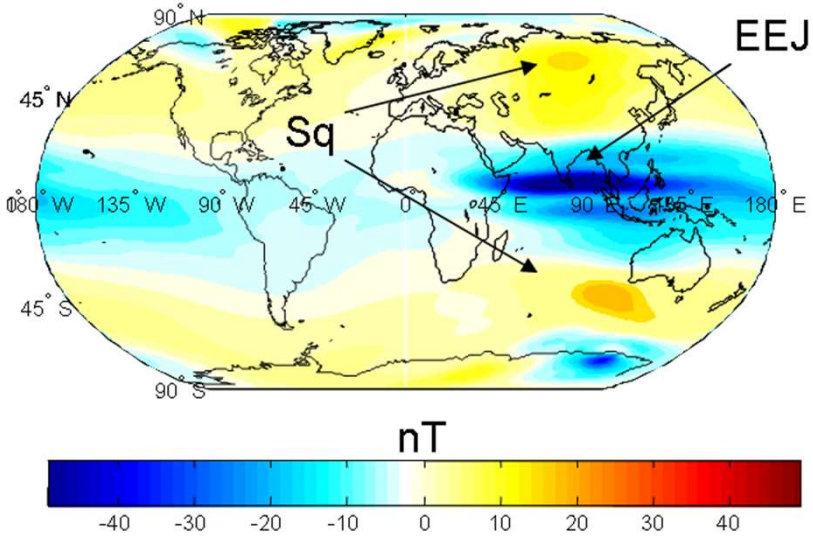
Geomagnetic storm signature & detection

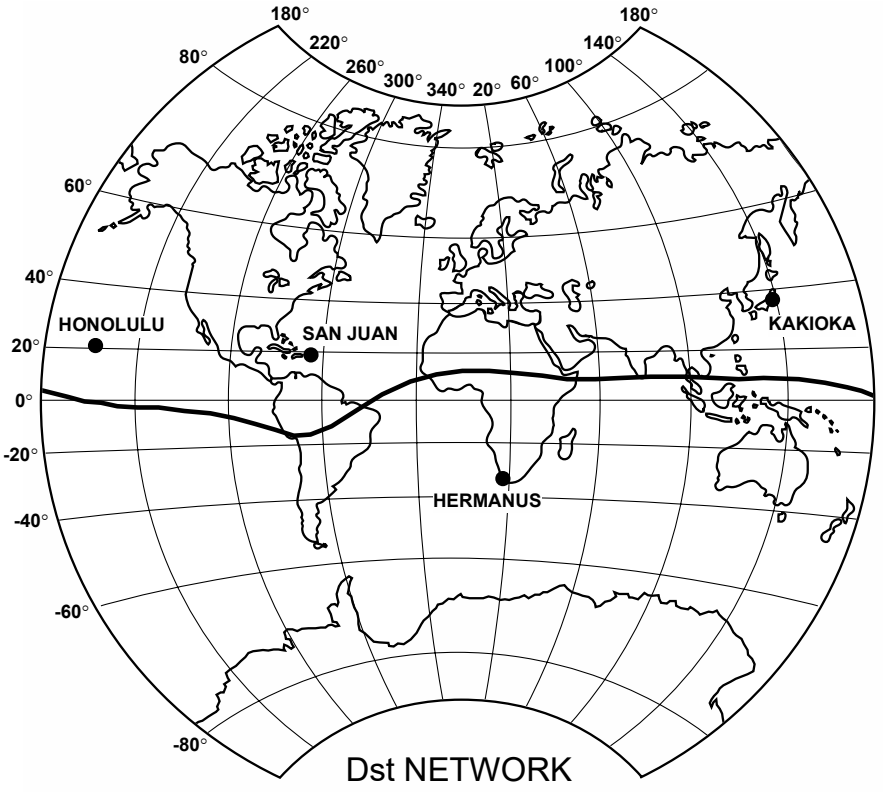




Geomagnetic storms detected by magnetometers close to magnetic equator, not exactly at the equator due to the equatorial electrojets.

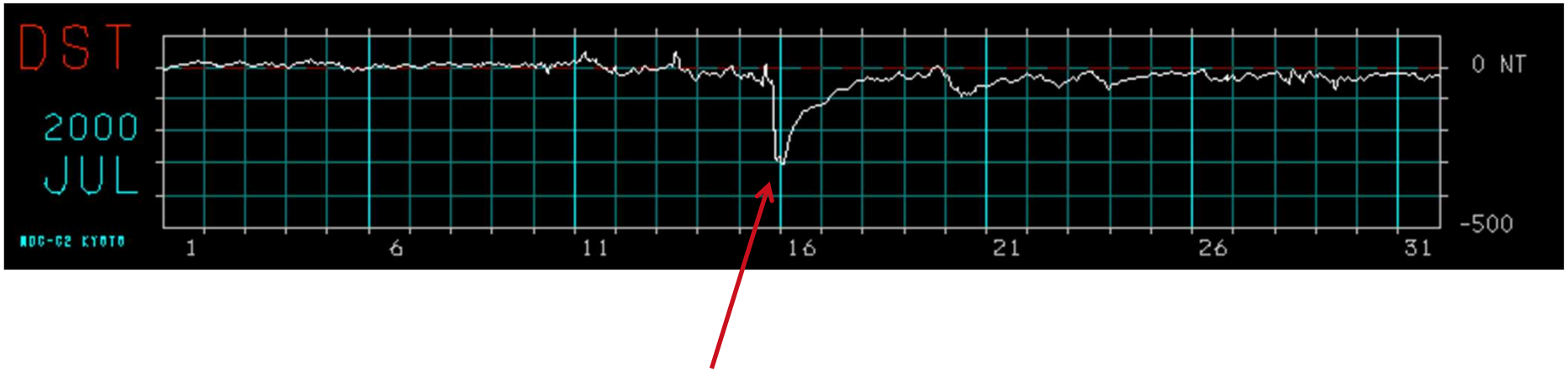
Equatorial electrojet





Geomagnetic storm index: Dst index

Formed as an envelope curve from the 12 equatorial magnetometers.

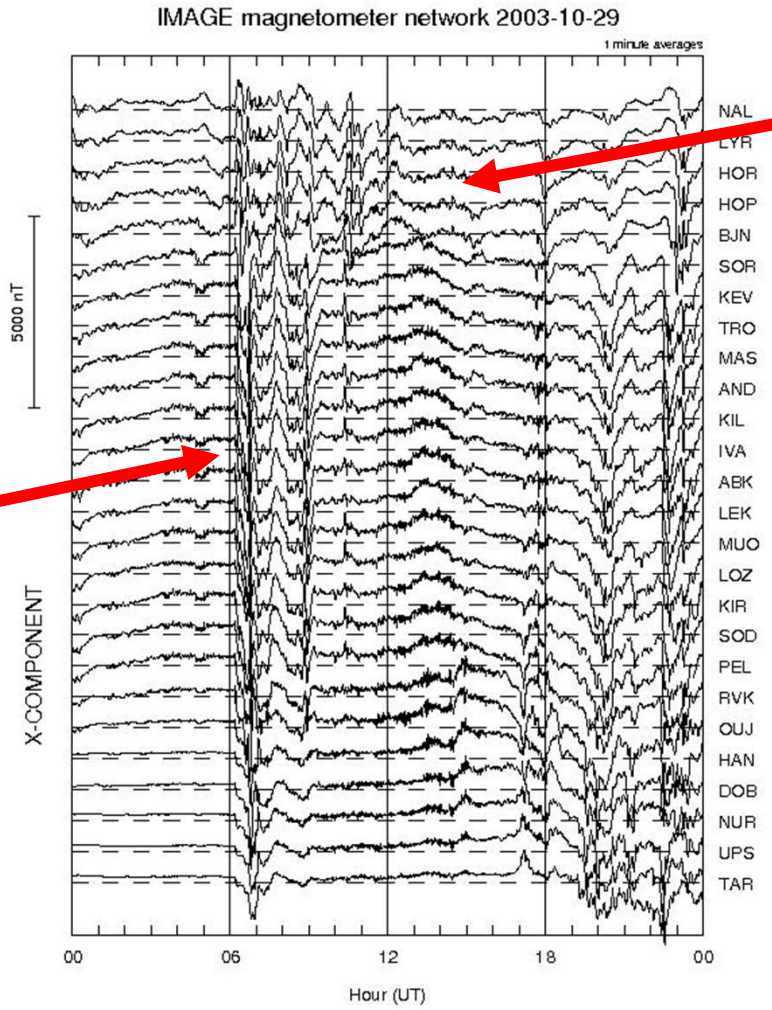


Geomagnetic storm starting on 15th July 2000
- with a peak amplitude 300 nT
- duration 5 days

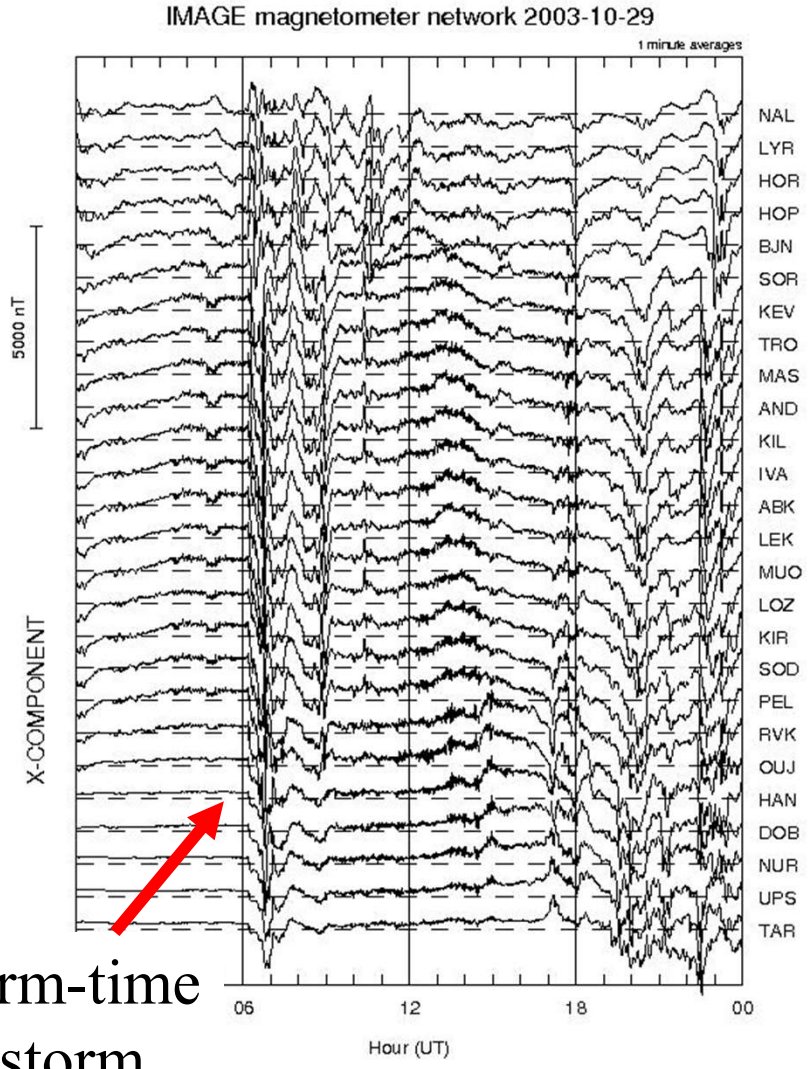
Geomagnetic activity at high-latitudes during storms

Pulsations

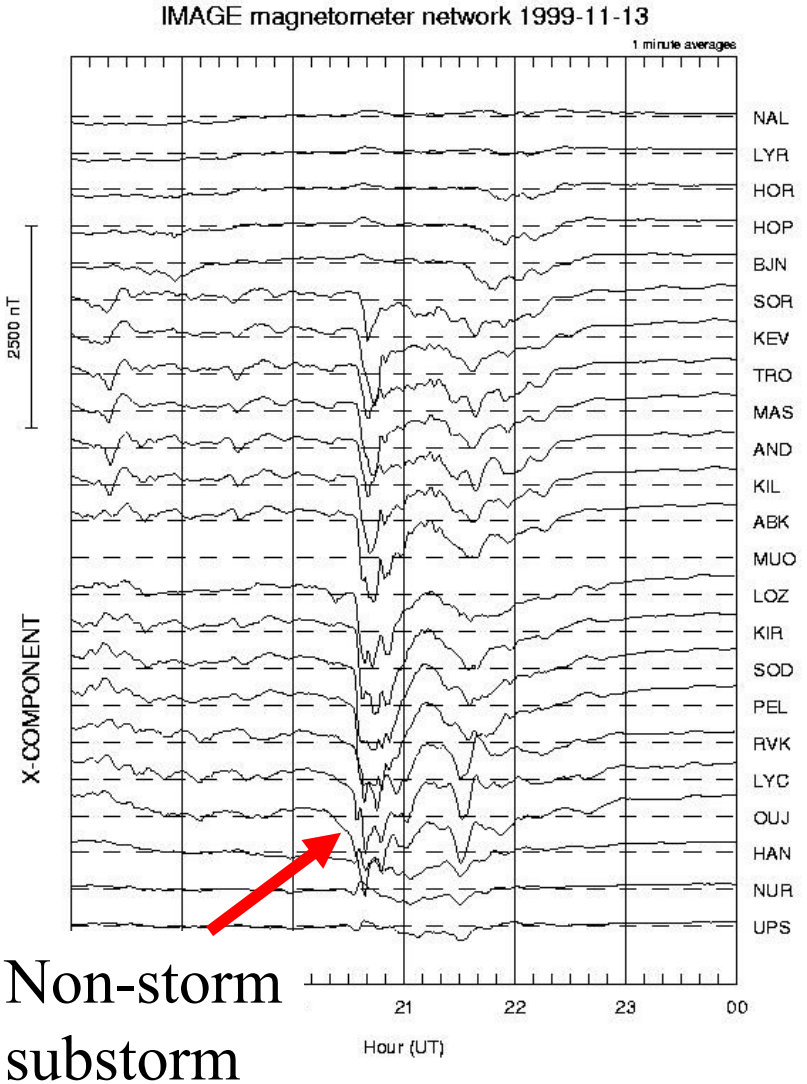
Storm-time substorms



Extreme and moderate activity



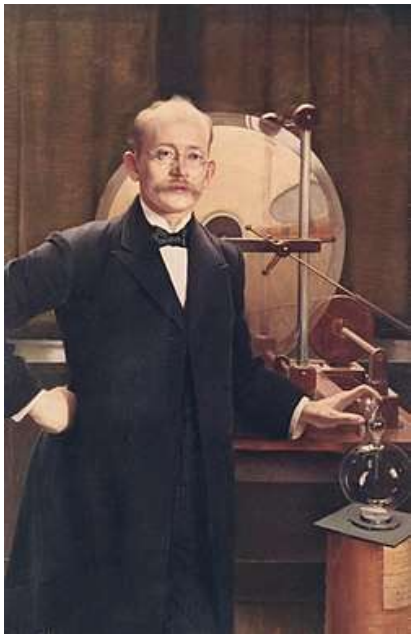
Storm-time substorm



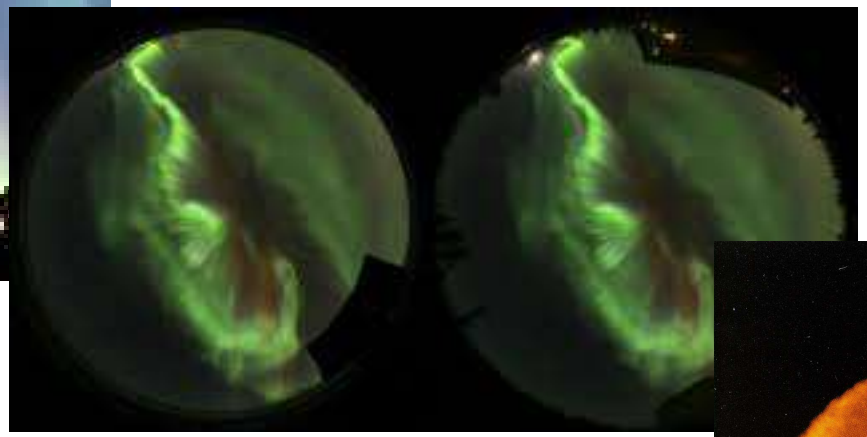
Non-storm substorm

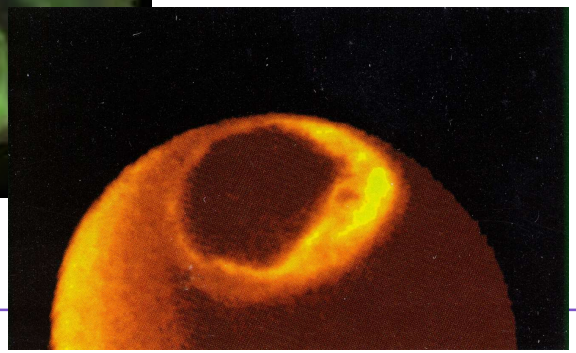
Magnetospheric substorm

- Magnetospheric substorms i.e. Birkeland's polar elementary storms, auroral substorms, etc.



Kristian Birkeland





One substorm definition

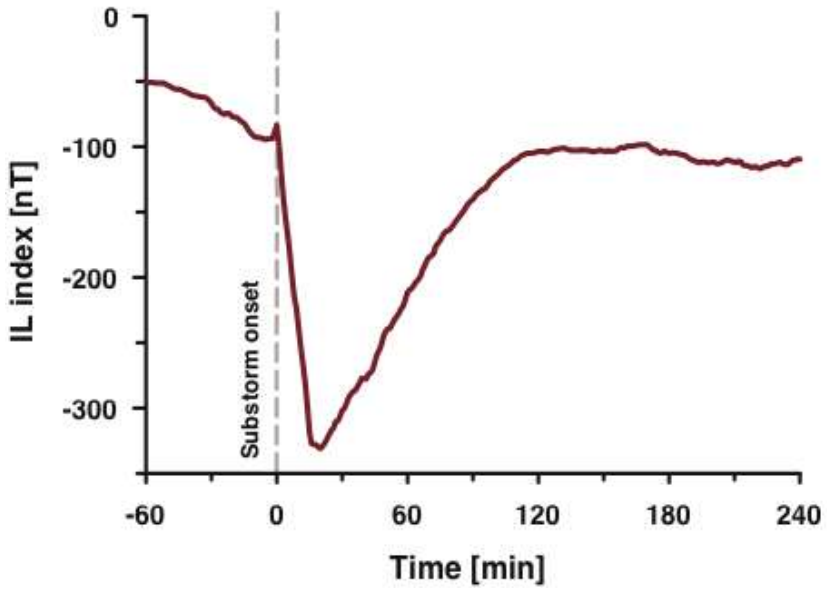
"Magnetic substorm is a transient process, in which a significant amount of energy is carried from the solar wind into the auroral ionosphere and magnetosphere".

McPherron et al. 1979

“Typical” auroral substorm

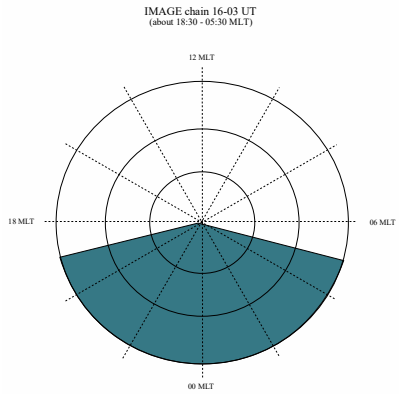
- All substorms are different, there is not “a normal” substorm. Statistical properties can be computed, but they need to be understood as average properties and not a single such substorm does not need to exist.

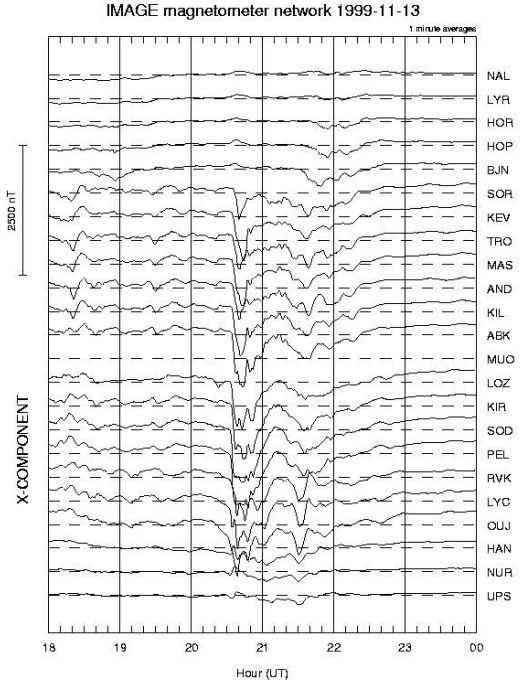
- A typical substorm signature: a negative bay in north-south (X) component of the terrestrial magnetic field.

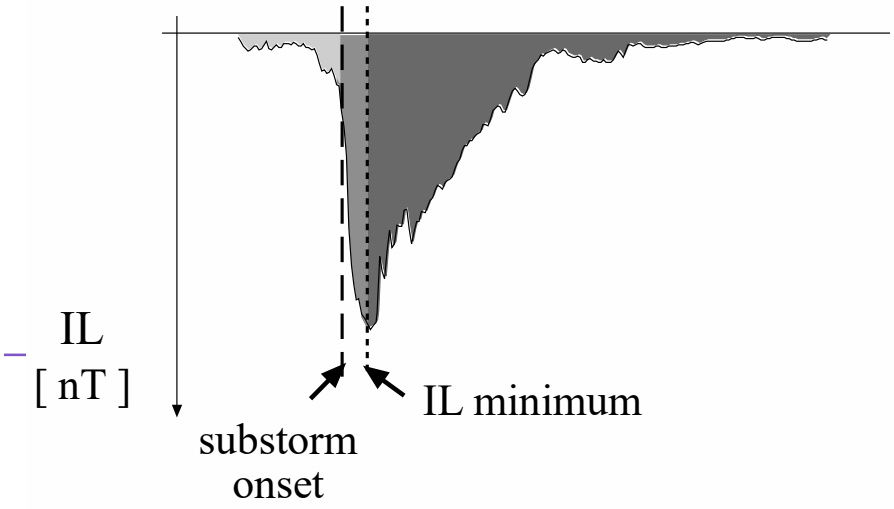


Westward electrojet index AL/IL/SML/CL

- Following AL description IL index is formed based on IMAGE ground-based magnetic measurements in UT-sector 16-03 UT.

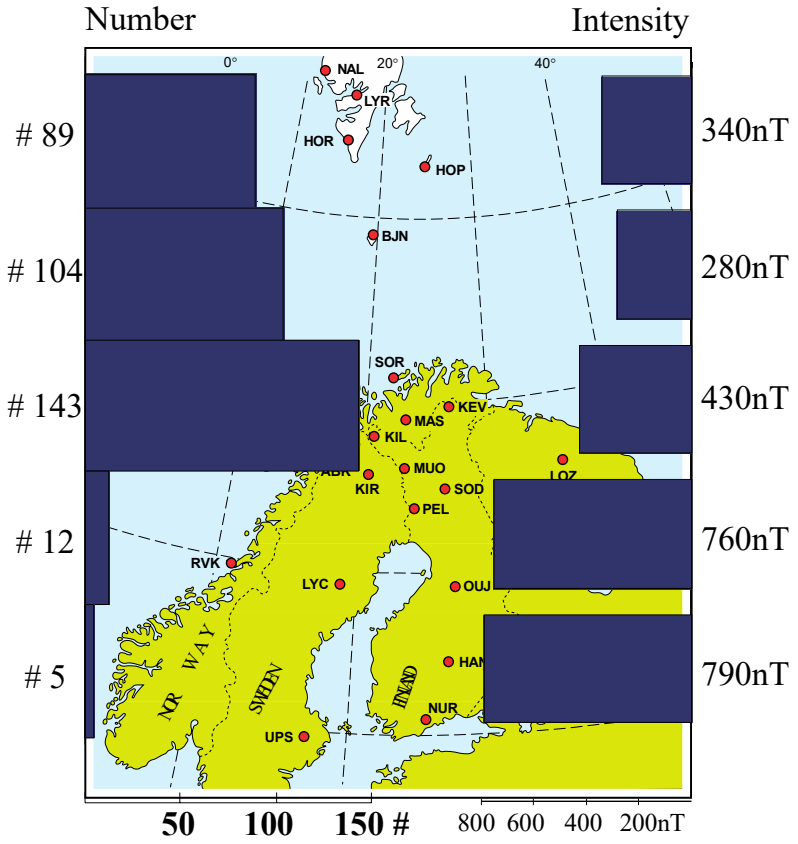






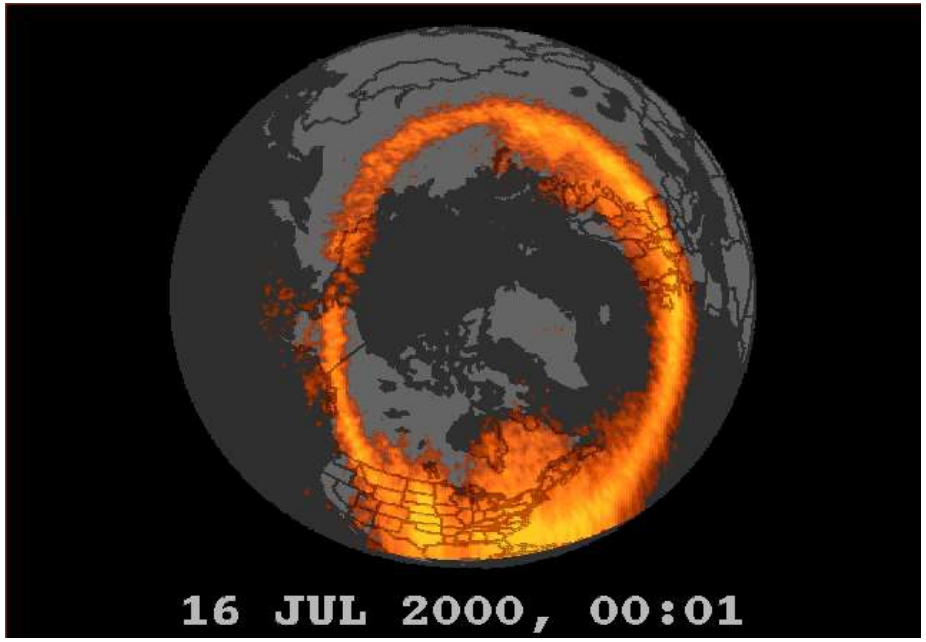
Latitudinal variation of substorms

- Substorms were categorized in the latitude bins according to the station where the maximum deviation of the X component was recorded
- Latitudinal zones from north to south (geogr. coord.)
  - north of 76°
  - 73° - 76°
  - 69° - 73°
  - 65° - 69°
  - south of 65°

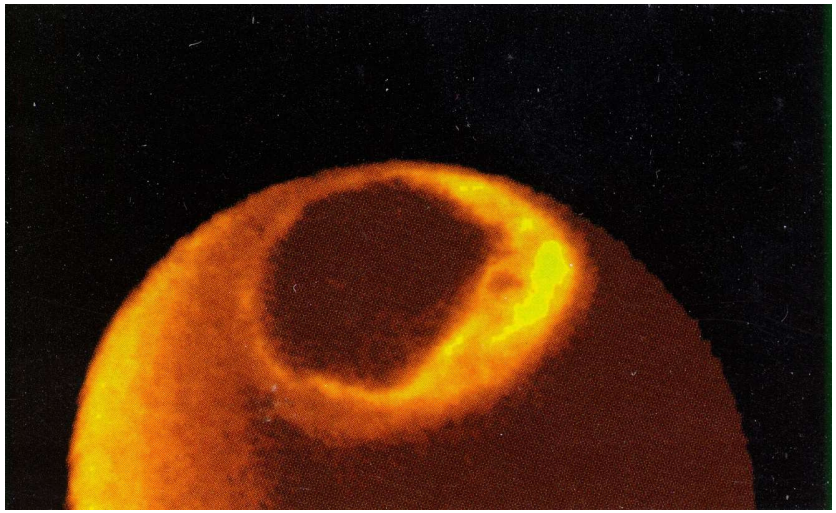


Auroral oval during a storm and a substorm

Storms

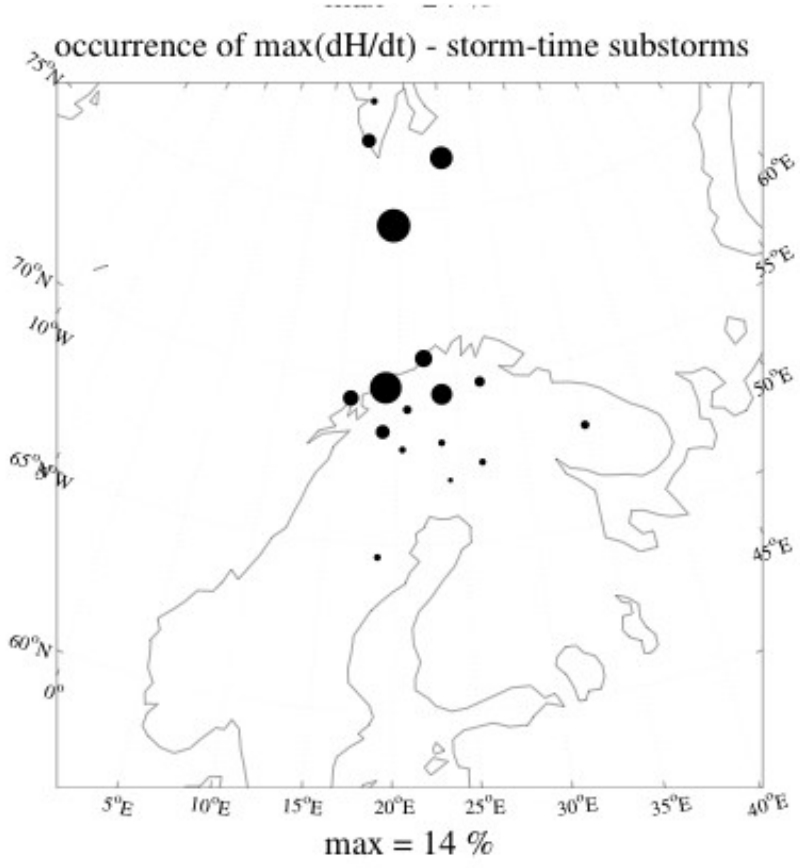


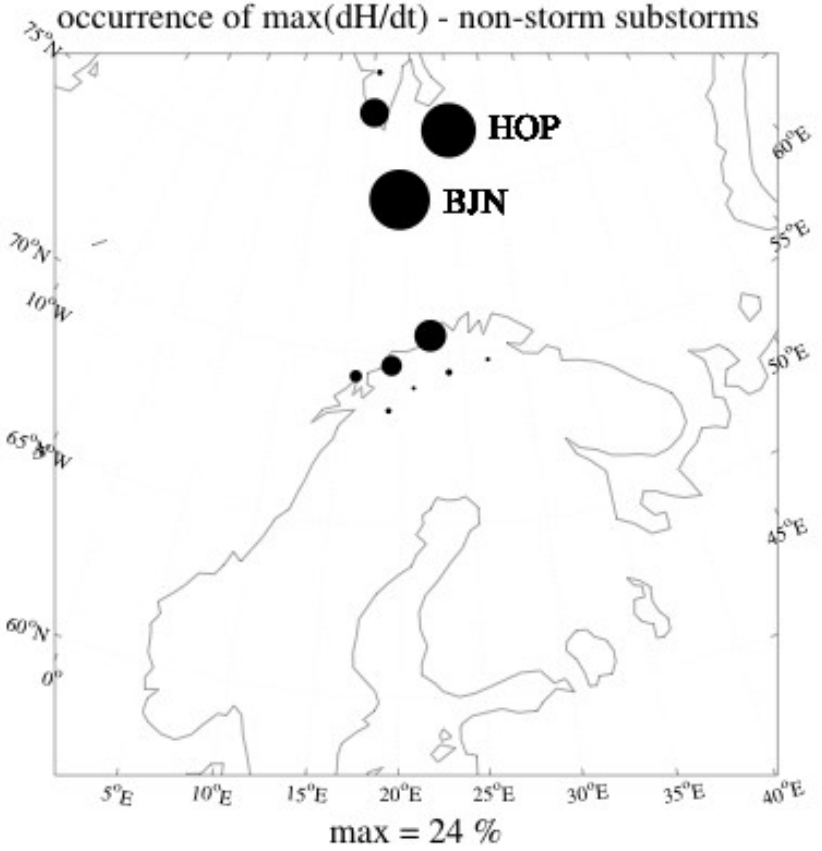
Substorms



Storm-time substorms and non-storm substorms

Site of maximum dH/dt i.e. substorm onset location is dramatically more north for non-storm than storm-time substorms.





Substorm morphology

Typical storm-time substorm is about twice as intense and carries about 2.5 times more energy into the ionosphere than a typical non-storm substorm.