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ELEC-E9550 – Magnetism and applications

Space weather Instrumentation

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Lecture content

- Brief space weather overview
- Basic measuring principles
- Ground-based instruments
  - *Vector magnetometers*
  - *Scalar magnetometers*
  - *All-sky cameras*
  - *Incoherent scatter radars*
  - *Neutron monitors*
- Ground-based infrastructure
  - *IMAGE magnetometer network*
  - *Greenland magnetometer network*

Lecture content

- Space based instrumentation
  - *Magnetometers*
  - *X-ray instruments*
  - *Plasma instruments*
  - *Mass spectrometers*
- Space platforms
  - *ACE*
  - *DSCOVR*
  - *SDO*
- Space weather services
  - *NOAA SWPC*
  - *Finnish Meteorological Institute*
- Aurora Propulsion Technologies
  - *Plasma brake*
  - *E-sail*

Lecturer introduction

- Hello I am Pyry Peitso, researcher at Aurora Propulsion Technologies and part-time doctoral student at Aalto University
- Current work consists of plasma brake modelling, along with small satellite, mainly CubeSat, engineering and ESA project applications
- Background in space weather and space weather instrumentation
- Worked on Aalto-1 and AuroraSat-1 CubeSat missions as well as the ARO (Aurora Resistojet One) CubeSat propulsion system

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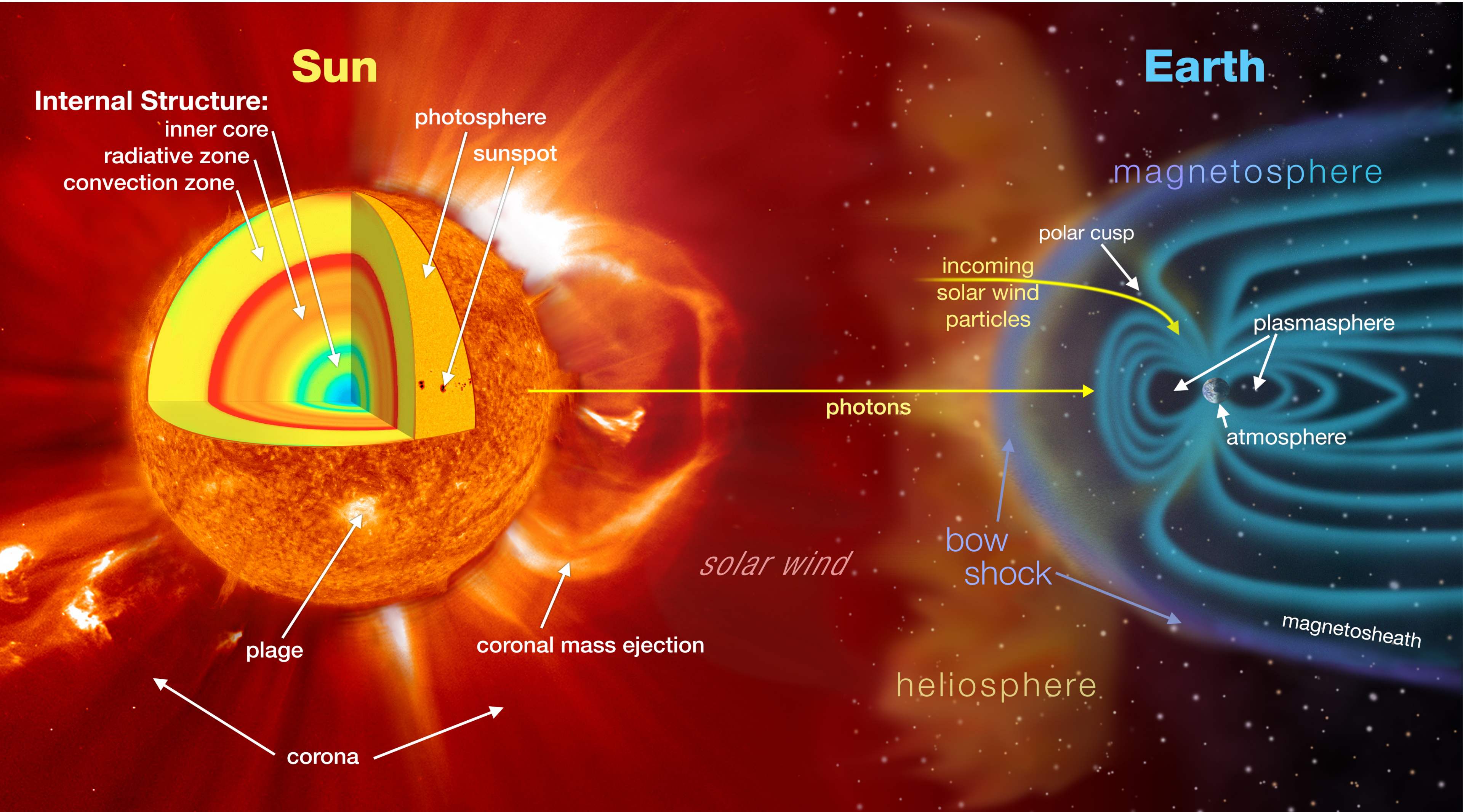
Why?



Economic factors

The Economic Impact of Space Weather: Where Do We Stand?

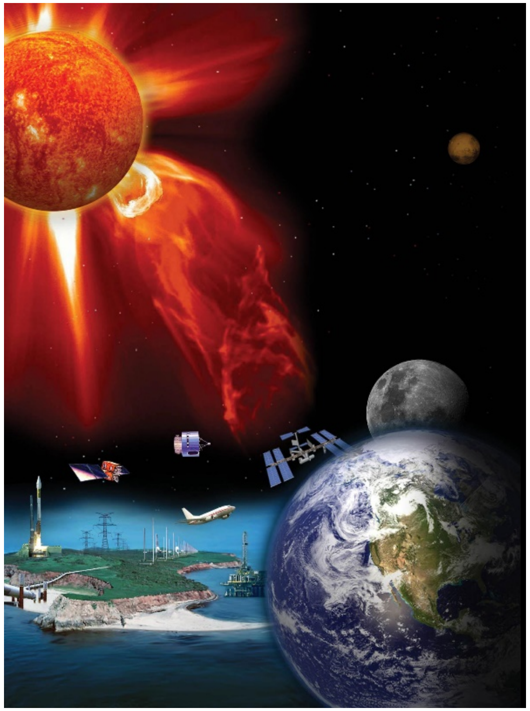
J.P Eastwood, E. Biffis, M.A. Hapgood, L. Green, M.M. Bisi, R.D. Bentley, R. Wicks, L-A. McKinnel, M. Gibbs and C Burnett, *Risk Analysis*, Vol 37, No 2., 2017

- ”[f]or a 1989 Quebec-like event, the global economic impacts would range from $2.4 – $3.4 tn over a year”

Space weather overview

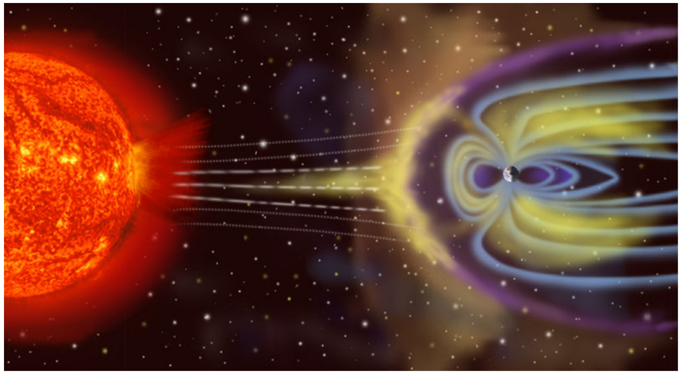
Definition of space weather

- Space weather refers to (mostly) solar originated effects
- Auroras only cosmetic effect
- Satellite errors, surface degradation
- Geomagnetically induced currents in infrastructure
- Power failures due to magnetic field fluctuations in electric power systems
- Communication disruptions and blackouts



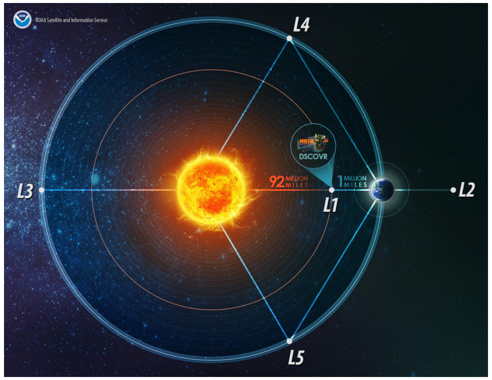
Basic space weather value chain

- Solar eruption releases charged particles
  - *CME, flare*
- Solar wind propagates particles throughout the interplanetary space
- Particles enter the Earth’s Magnetosphere
- Current systems enhanced, magnetic field disturbed
- Ionospheric conditions change, affects propagation of radio waves



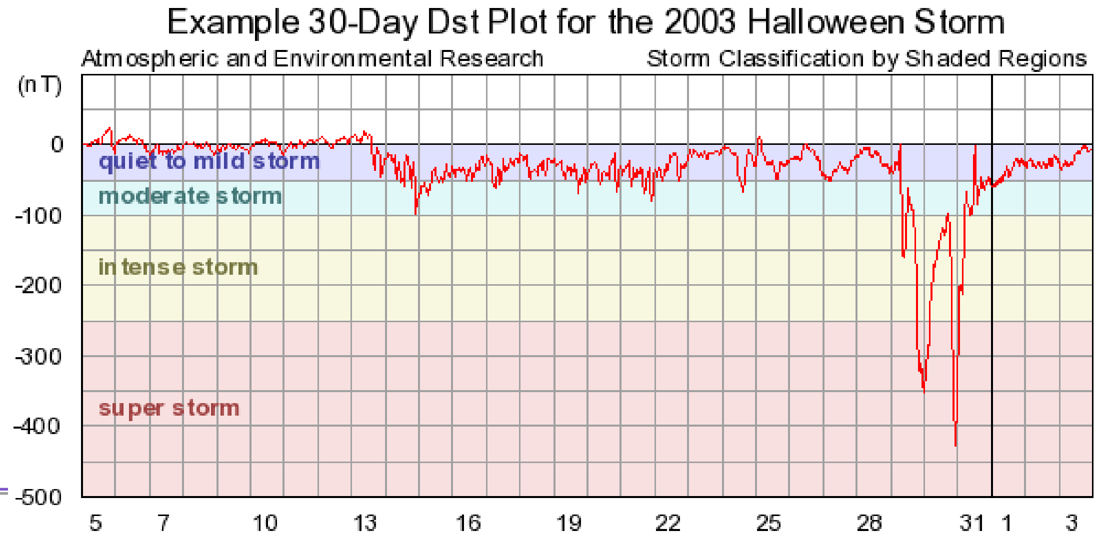
Space weather observations

- How to observe these effects?
- Solar surface can be monitored for eruptions
  - *Space based as well as terrestrial observations*
- Solar wind conditions can be observed with *in situ* equipment, though these are rare and expensive
- Terrestrial effects can be easily observed on the Earth surface
- Ionosphere can be measured using terrestrial radars



Activity indices

- Measurements from multiple sources are often combined into easy to interpret activity indices
- Disturbance storm time (Dst) index is one common measure of space weather activity
- It measures the strength of the ring current near the Earth's equator, and is often used as a proxy for global geomagnetic storms



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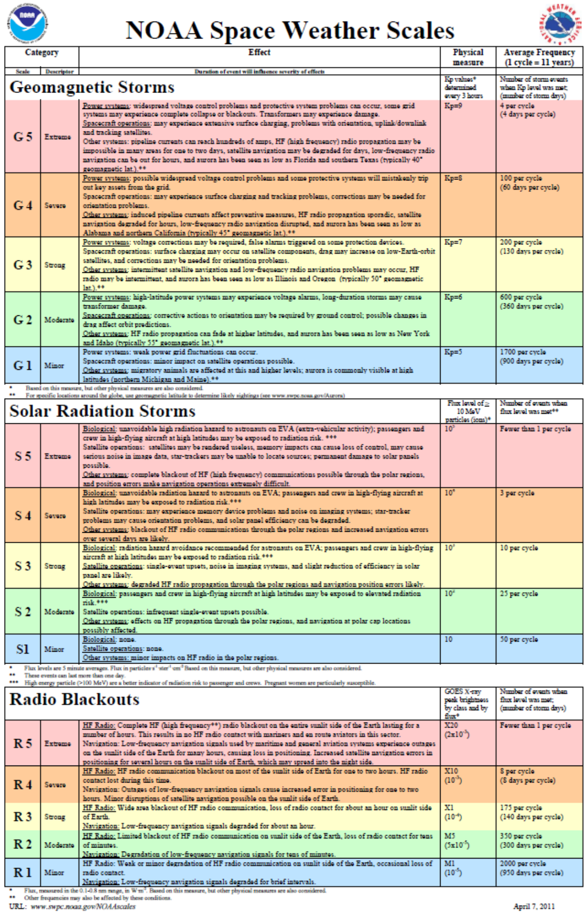
NOAA Space Weather Scales

- *De facto* standard for space weather classification
- Three alert classes, G for geomagnetic storms, S for solar radiation storms and R for radio blackouts
- Scale goes from 0 to 5, normal situation is 0 for all three cases
- Alert class of 5 has been reached for all three, extreme events are off the scale



Basic measuring instruments and principles

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What are we actually measuring

- Space weather manifests itself in numerous different ways
- The Sun is responsible for (almost all) space weather phenomena
  - *Direct observations of solar eruptions*
- This is mostly through different current systems caused by charged particles
- Changes in different magnetic fields are an easy, economic and straightforward way to measure these changing circumstances
  - *Surprisingly large amounts of information can be gleamed from a rather unsophisticated instrument from the 19th century*
- Several overlapping systems -> effects sometimes difficult to differentiate -> lots of open scientific questions -> good field for research!

Tesla [T]

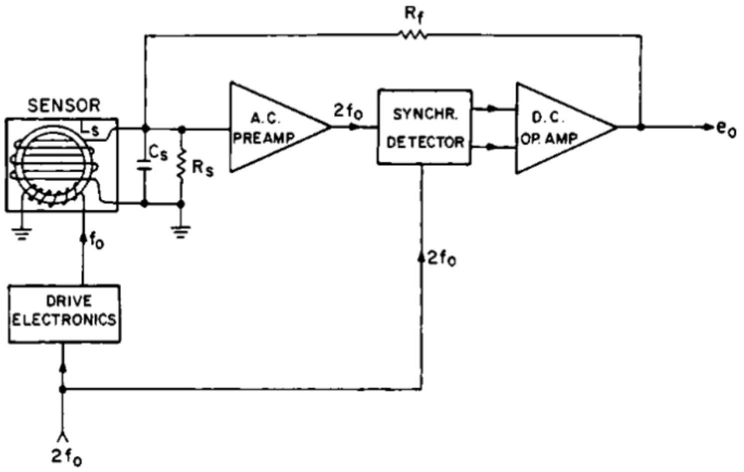
- Magnetic field flux density is measured in a rather unintuitive unit, the tesla (T), in base SI units kg s^{-2} A^{-1}
- Fields in the order of magnitude of teslas have been achieved in laboratories, Earth field is in the range of 10000s of nanoteslas (nT), while neutron stars could have fields in the strength of 10^{10} T
- Nanotesla is the basic unit of space weather, rule of thumb is that 5 nT change in the interplanetary magnetic field z-direction (IMF) signifies that *Something Is Up*
- Changes at the Earth surface are typically in the scale of hundreds of nanoteslas, in case *Something Is Up*

Magnetometer operating principles

- Fluxgate magnetometer is the most widely used space weather instrument
- Developed in the 19th century, historical measurements quite useful even today
- Notable application in submarine detection
- Danish FGM-FGE fluxgate magnetometer, with supporting electronics depicted

Magnetometer operating principles

- Ferromagnetic core is driven to saturation by a periodic current
- Current creates magnetic field -> induces a new current into the ferromagnetic core
- Measure the asymmetry between the original current and the induced current -> determine the external magnetic field
- Artificial magnetic fields, i.e. almost anything done by humans, disrupts measurements -> magnetometers deployed far from cities and such

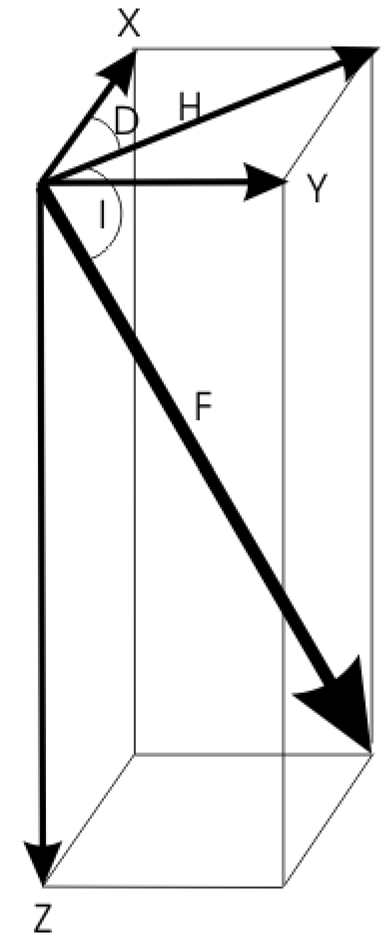


Magnetometer operating principles

- Rugged and simple instrumentation, basic setup requires electricity, rudimentary heating and instrument cover and data logging capabilities
- Due to the nature of the phenomena, long timeseries and high time resolution (seconds) is preferred
- Change of the magnetic field is often more useful than the absolute value, due to Earth base field’s rather significant differences across the globe
- When looking at different measurements remember that in addition to 10000 nT size changes across the globe, the poles also drift in early timescales

Vector vs scalar

- Vector instruments measure different components of the magnetic field
- Either XYZ or HZD, these can also be calculated from each other
- Scalar instruments measure the absolute value of the magnetic field
- Used mostly for calibration purposes due to increased emphasize on accuracy



All-sky cameras

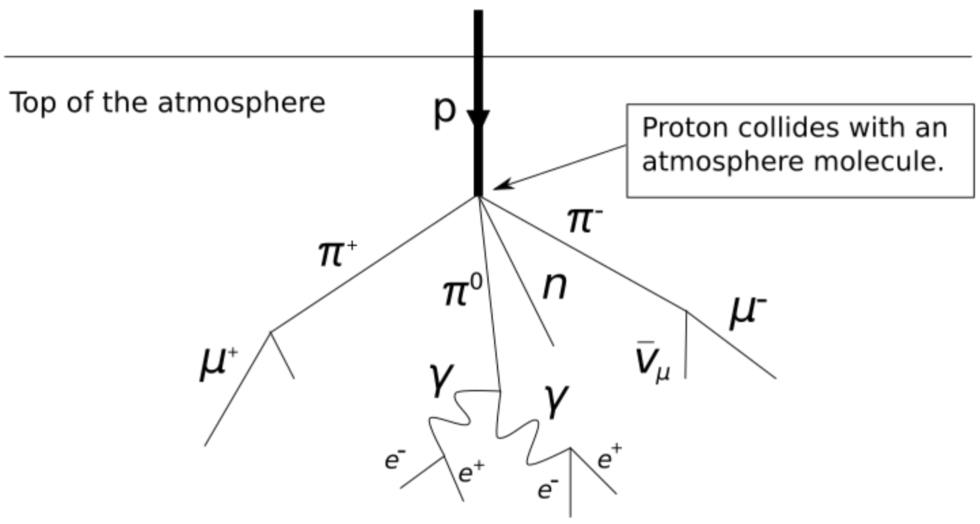
- Sometimes called whole sky cameras
- Specialized cameras used to photograph auroras, fisheye lens allow for a very wide field of view
- Usually take automatic images throughout the the night, so rather large data volume

Incoherent scatter radars

- High power ground based radars
- Work by beaming a signal to the ionosphere, where it is scattered
- The resulting scattered signal is measured and the results are compared to the original signal sent
- Allows for study of wide range of ionospheric parameters, such as electron density and temperature, ion temperature, mass, plasma drift velocity etc.
- EISCAT (European Incoherent Scatter Scientific Association) located partly in Finland

Neutron monitors

- Instrument to measure hadronic component in atmospheric secondary radiation related to cosmic rays
- Actually measures showers of secondary particles from cosmic ray interaction with Earth magnetic field
- Study of cosmic rays allows for indirect studies of solar activity



Magnetometer networks

- Magnetometer measurements are usually conducted by large chains of stations
- Calibration of measurements synchronized across the whole chain
- Usual products are activity indices, in addition to single station measurements
- Location of magnetometer chain gives information about different current systems around the Earth, measurements from the equator look significantly different compared to measurements from polar regions

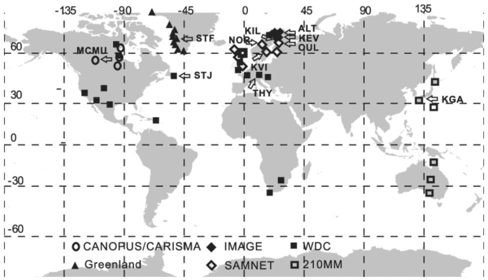
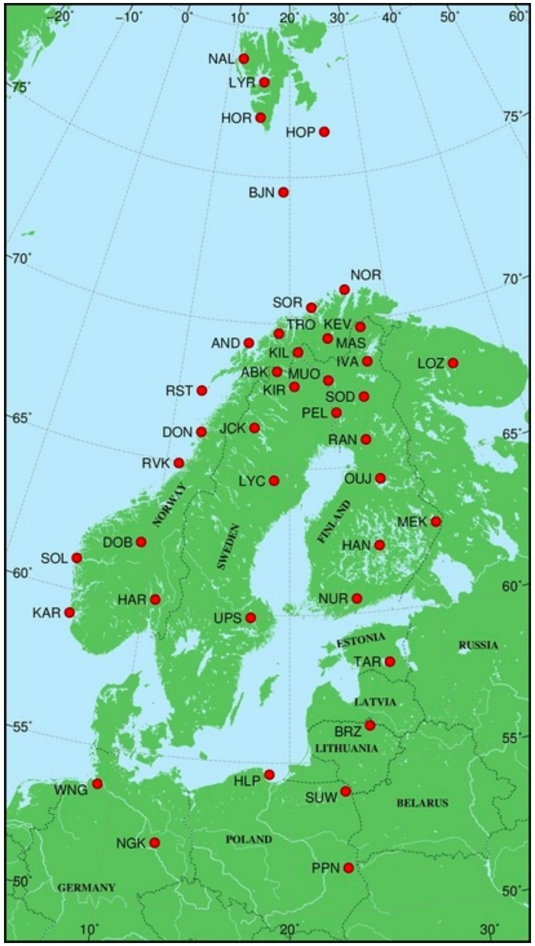


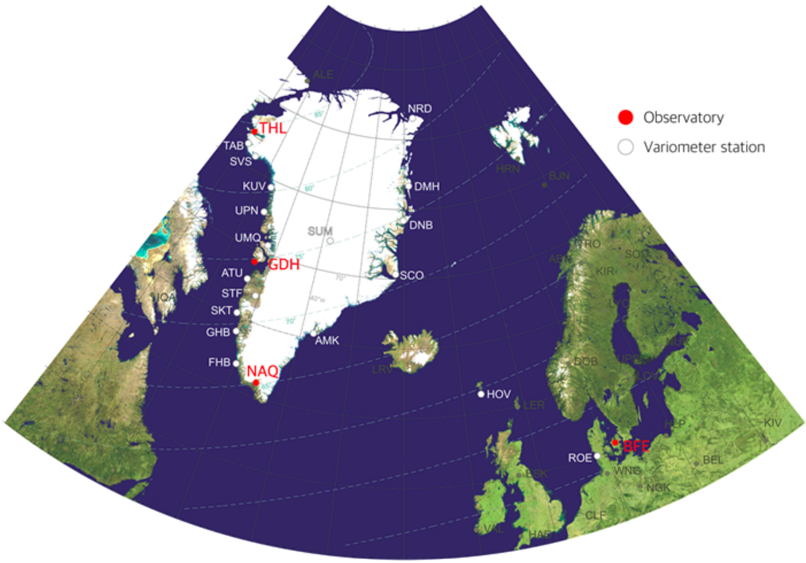
IMAGE magnetometer network

- International Monitor for Auroral Geomagnetic Effects (IMAGE)
- 41 stations maintained by 8 institutes
- Main objective to study auroral electrojets as well as moving current systems, the large latitudinal coverage making IMAGE well suited for this
- High quality data and long time series available



Greenland magnetometers

- Danish Technical University (DTU) operated 19 station network located in Greenland
- Compared to IMAGE, stations are situated more poleward, allowing for measurements of different current systems, such as quite direct solar wind interaction at the polar cap regions
- High quality data, with also long time series available though not as long as IMAGE stations



End of part I

Coming next: space based instrumentation

Space based instruments

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