What Can Ground Magnetometers Tell Us?

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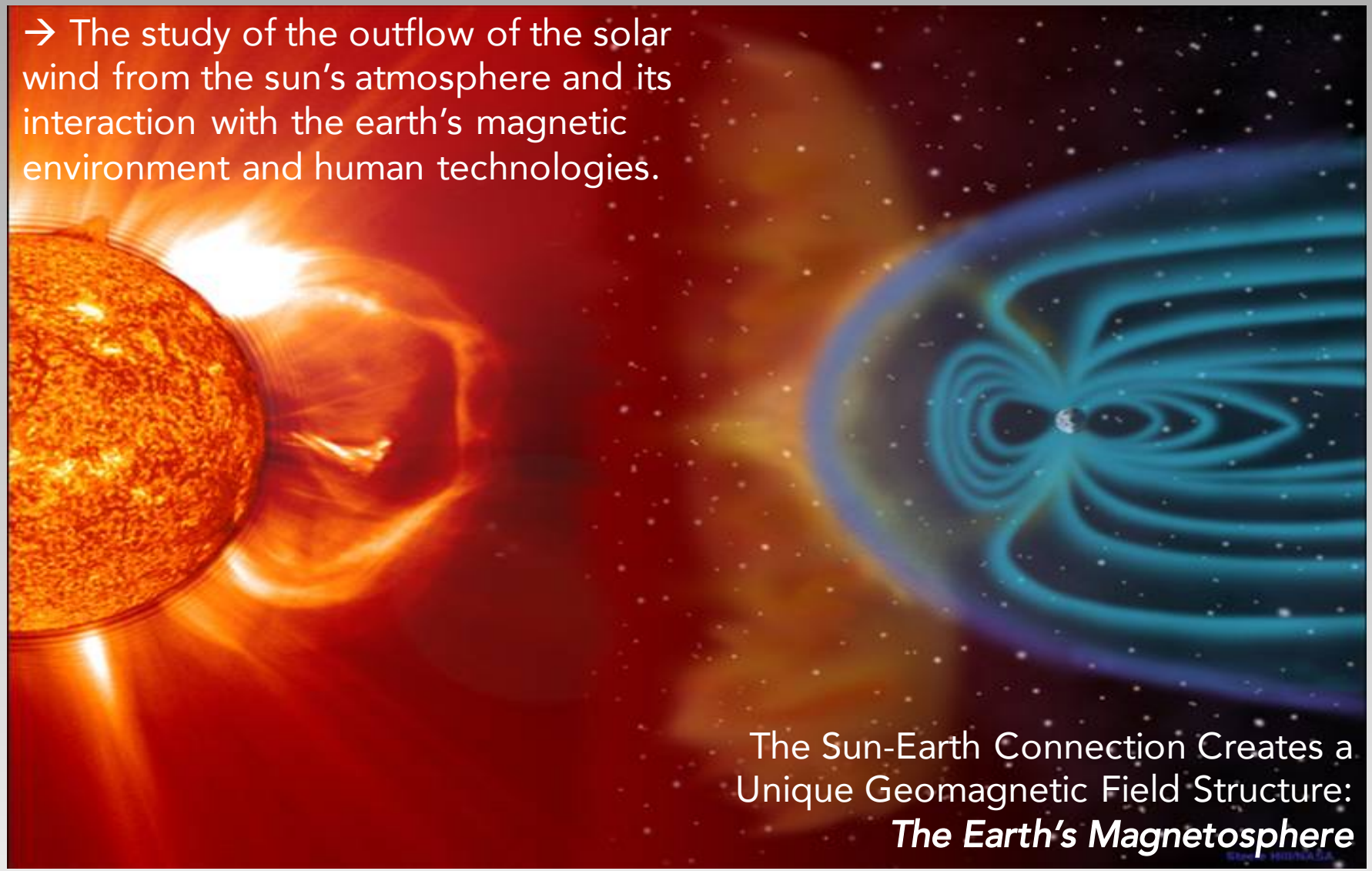
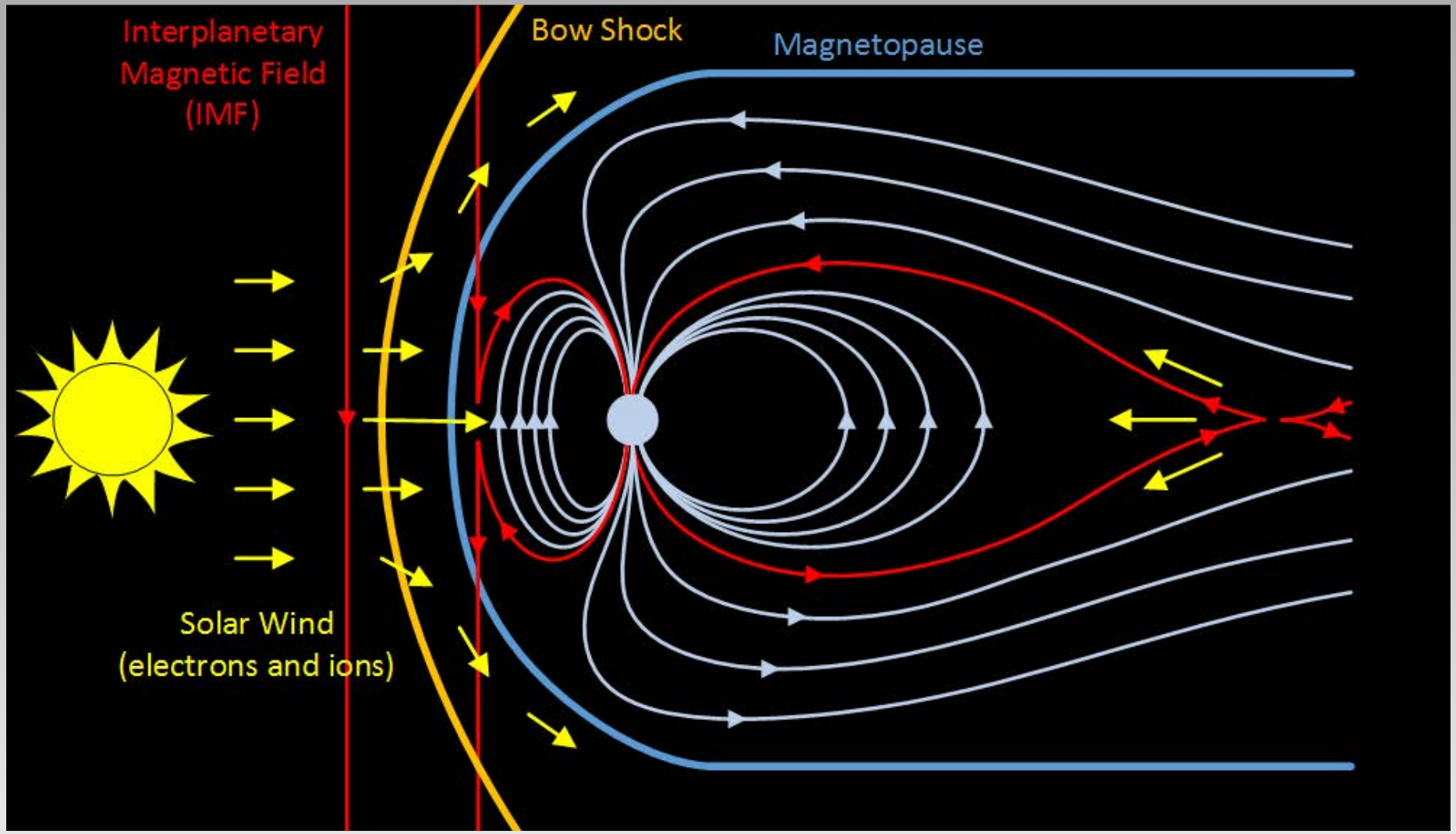
B4/22

What is "Space Science"?



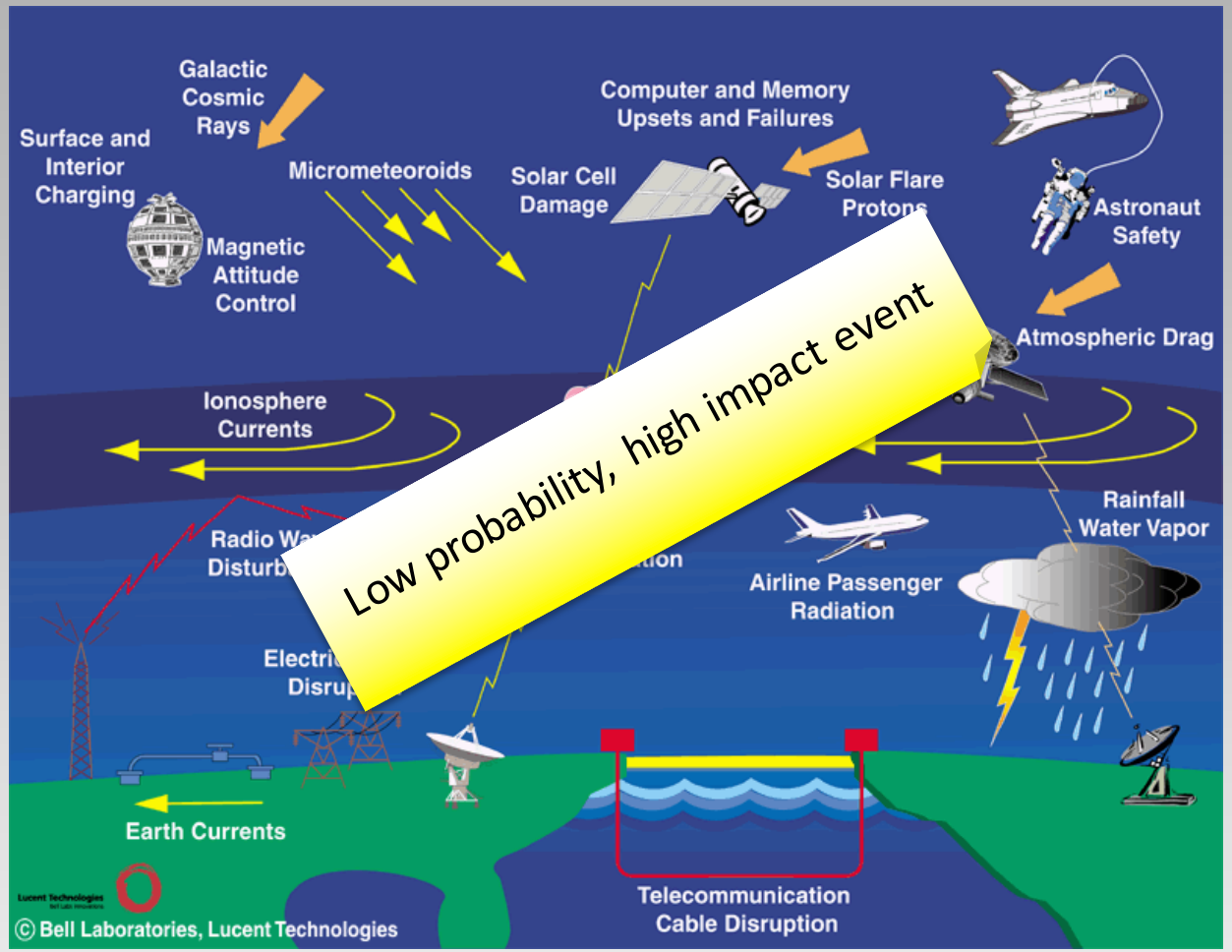
The Sun-Earth Connection



- IMF and the earth's magnetic fields are coupled by magnetic reconnection.

Why Care?

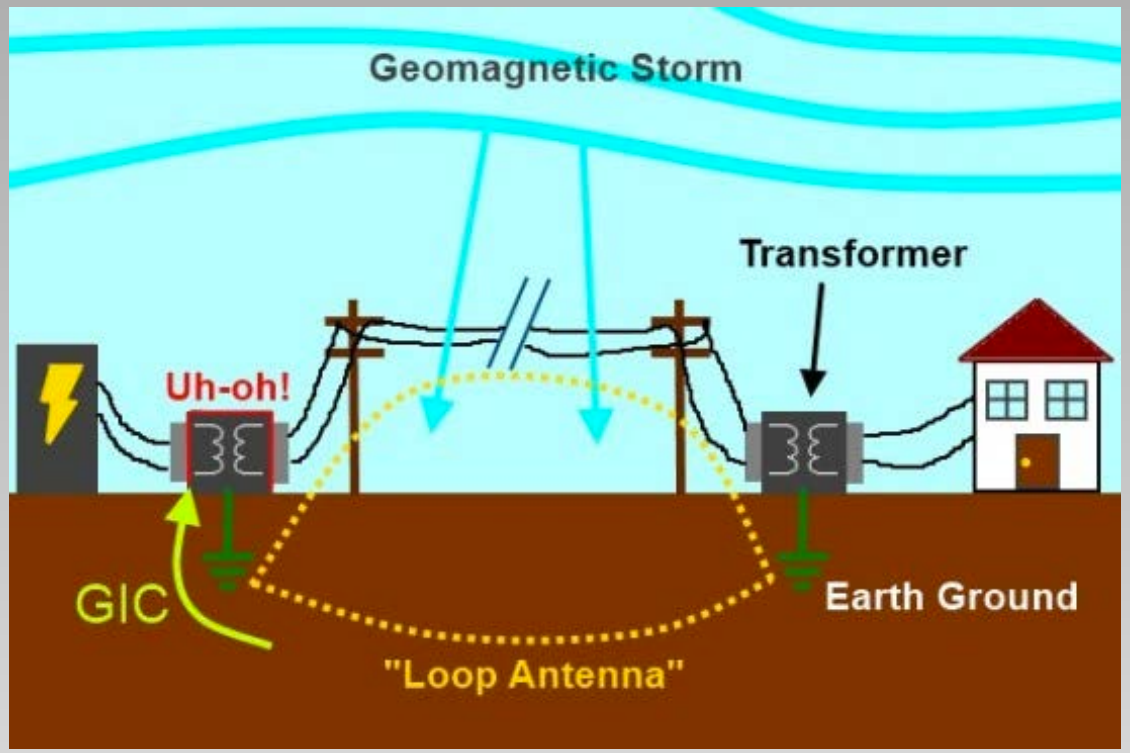
- Space is not benign!
- Perturbations to the geospace environment can have huge impacts on society:

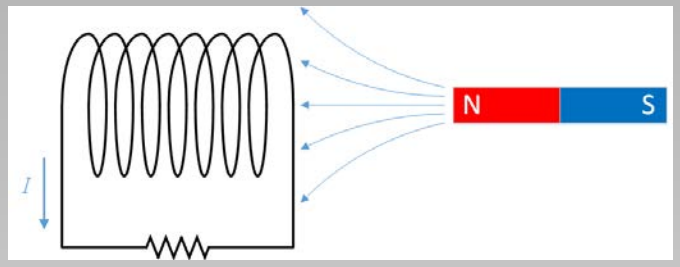


→ "Space Weather"

- Spacecraft damage
- Atmospheric drag
- Power disruption
- Human Health (radiation)
- Deviation of airplanes
- Degraded navigation
- Disrupted communication
- Radar clutter
- Confused pigeons!

Ground Effect of Space Weather





$$\nabla \times \mathrm{E} = -\frac{\partial \mathrm{B}}{\partial t}$$

- **Faraday's law of induction**: Changing magnetic fields creates voltage.
- Geomagnetically induced current (GIC)
- Affects transmission lines, oil/gas pipelines railways, etc.

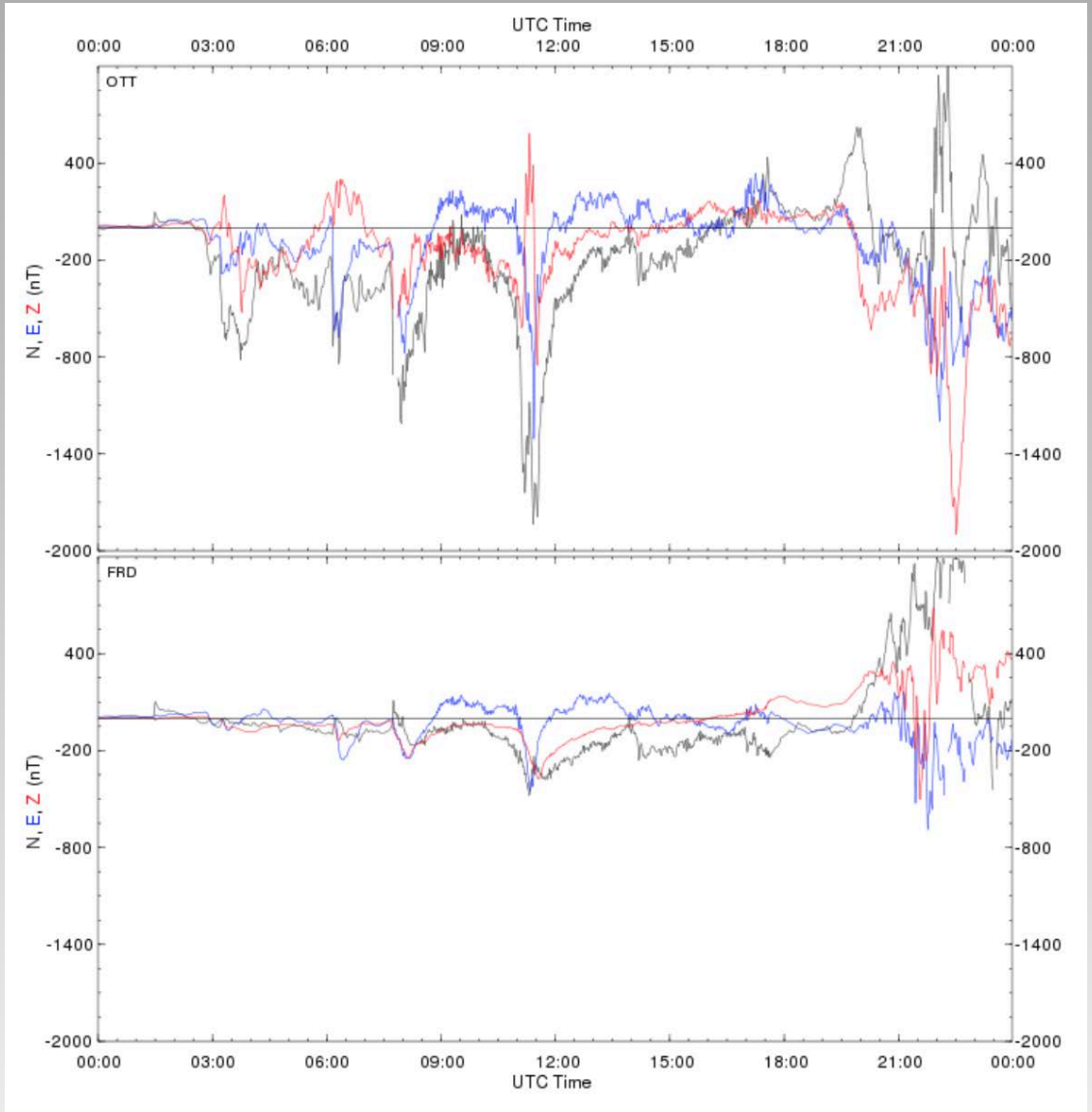
Carrington Event (September 3, 1859)

- The biggest solar storm on record.
- Named after British astronomer Richard Carrington, who witnessed the megaflare and was the first to realize the link between activity on the sun and geomagnetic disturbances on Earth.
- Northern lights were reported as far south as Cuba and Honolulu, while southern lights were seen as far north as Santiago, Chile.
- Arching and sparking of telegraph keys were reported from a wide range of stations, including "eastern U.S., England, Scandinavia, Belgium, France, Switzerland, Prussia, Wurtemburg, Austria, Tuscany, …"

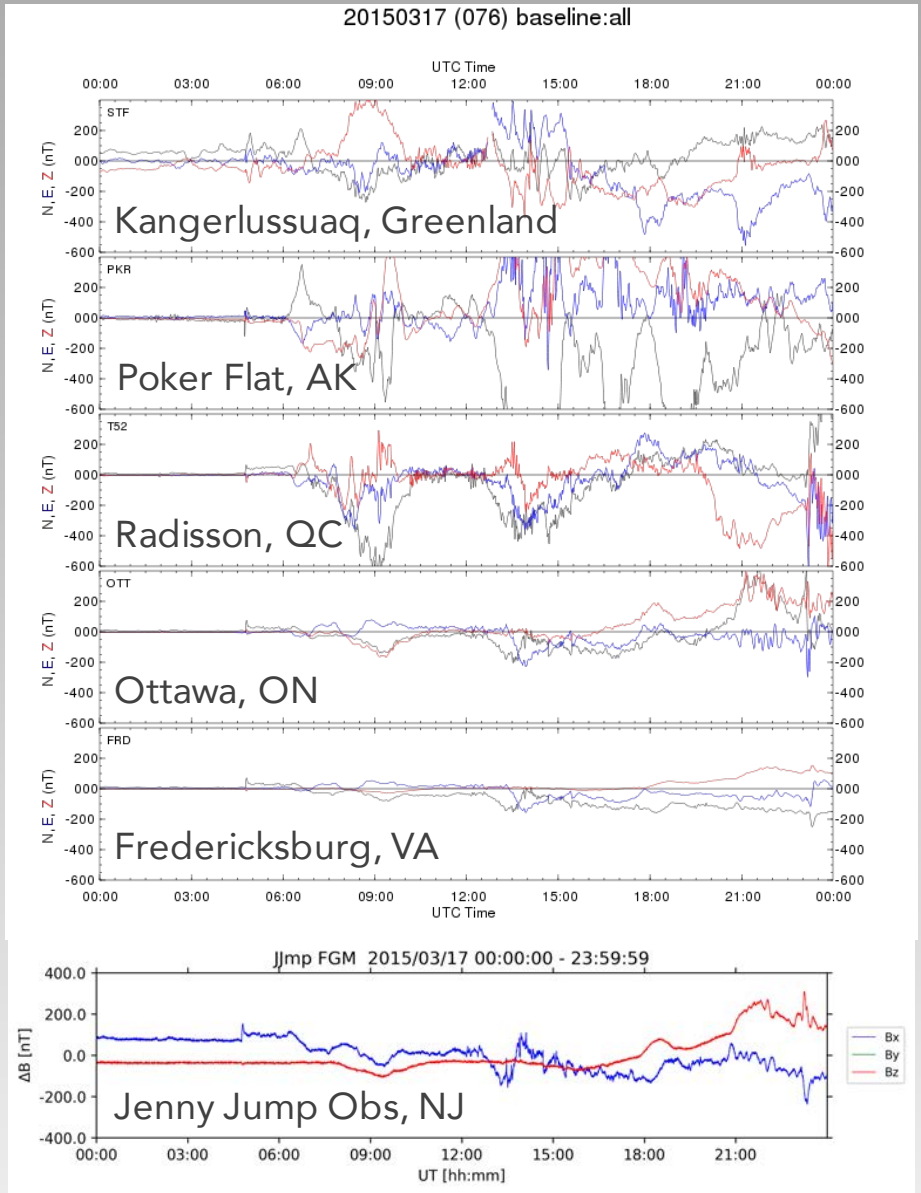
March 13, 1989 Magnetic Storm

- A geomagnetic storm occurred in March 1989 caused the collapse of the entire Hydro-Quebec's electricity transmission system and several at the Salem nuclear plant in NJ, leaving 6 million people without power for more than 9 hours.
- It could takes longer to replace large transformers in case of larger storms.

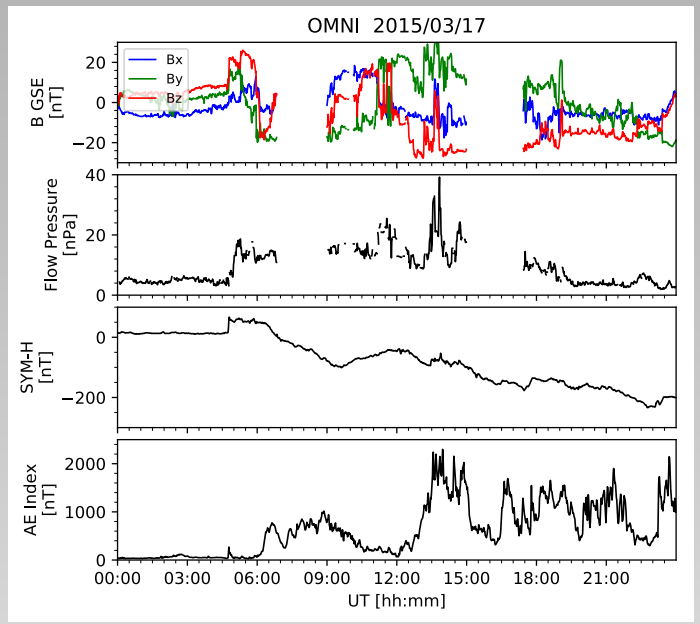
March 13, 1989 Magnetic Storm



Geomagnetic Storm Observed by Ground Magnetometers

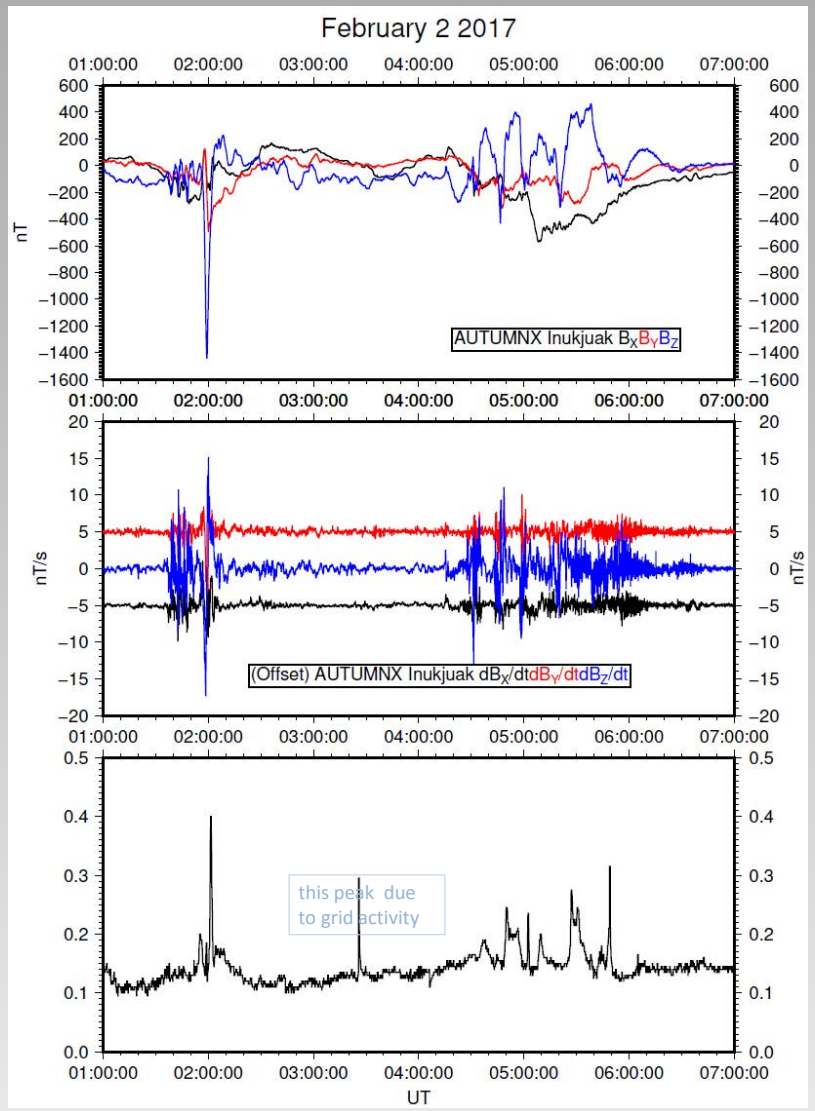


Solar Wind Data



- Several hundreds of nT changes at low/mid latitudes are typical during geomagnetic storms.

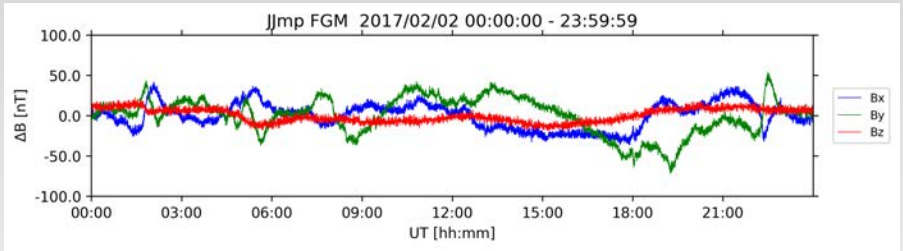
"Magnetic Impulse Event" Observed by Ground Magnetometers



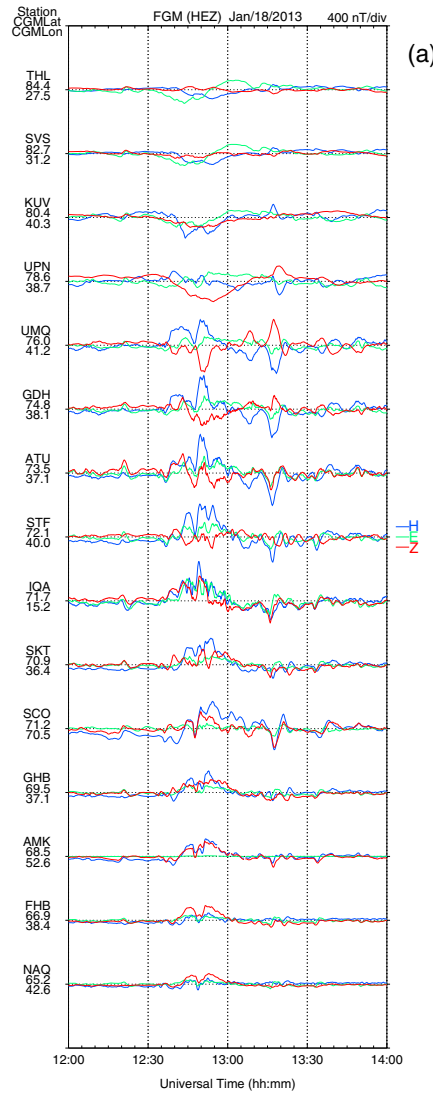
[*Connors et al.* 2017, AGU]

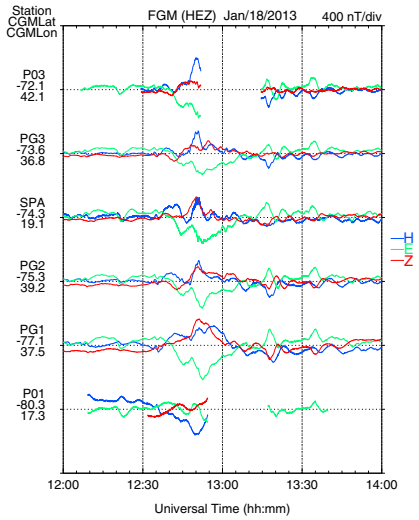
- Inukjuak (INUK) **B** and d**B**/dt correlate with harmonic distortion from Hydro-Québec measurements.
- A few tens of d**B**/dt could cause geomagnetically induced currents (GIC).

Jenny Jump Obs, NJ

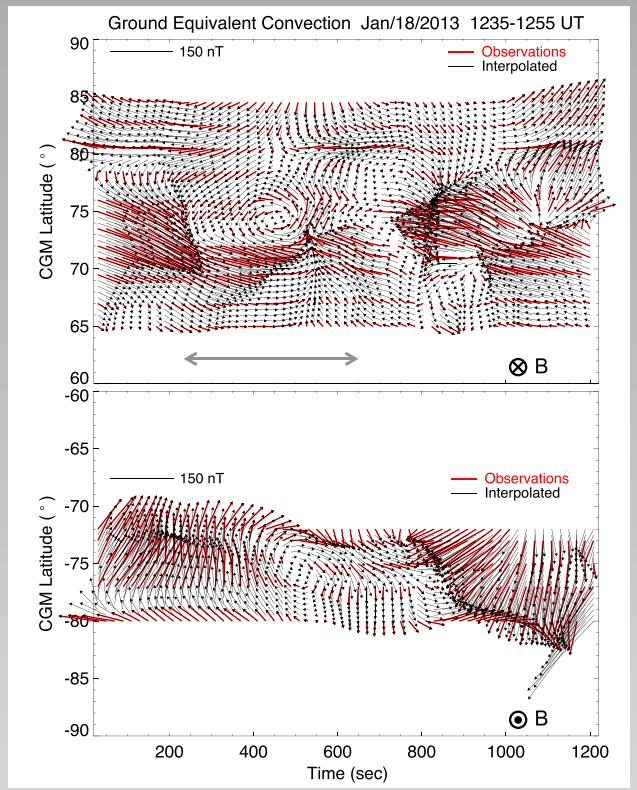


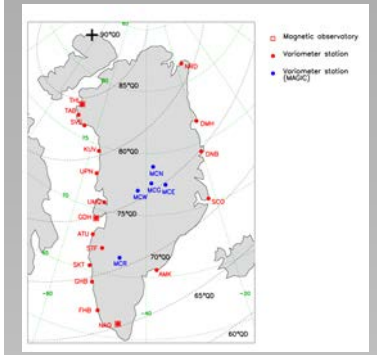
Example of M-I-T Coupling Study Using Magnetometer Network

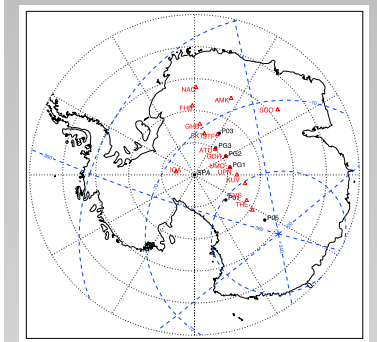




[*Kim et al.* 2015, JGR]

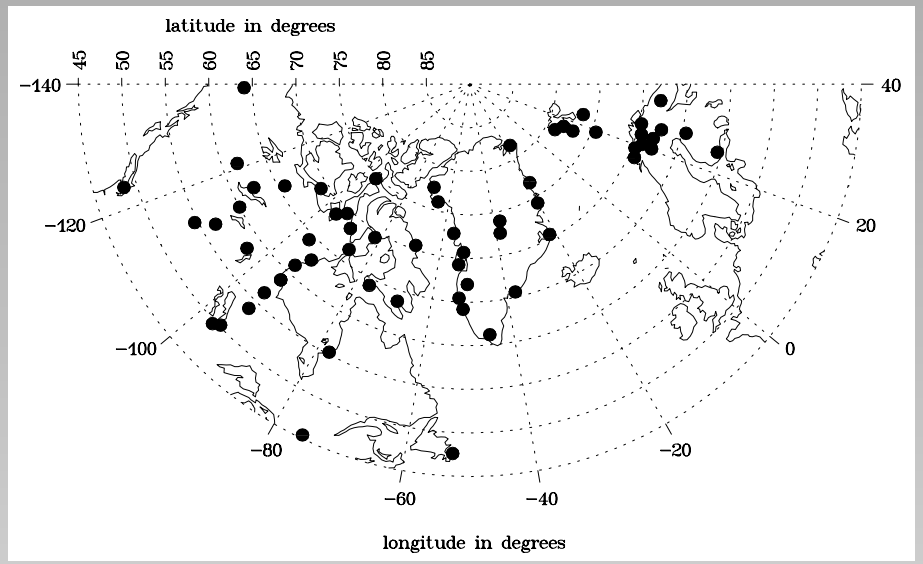


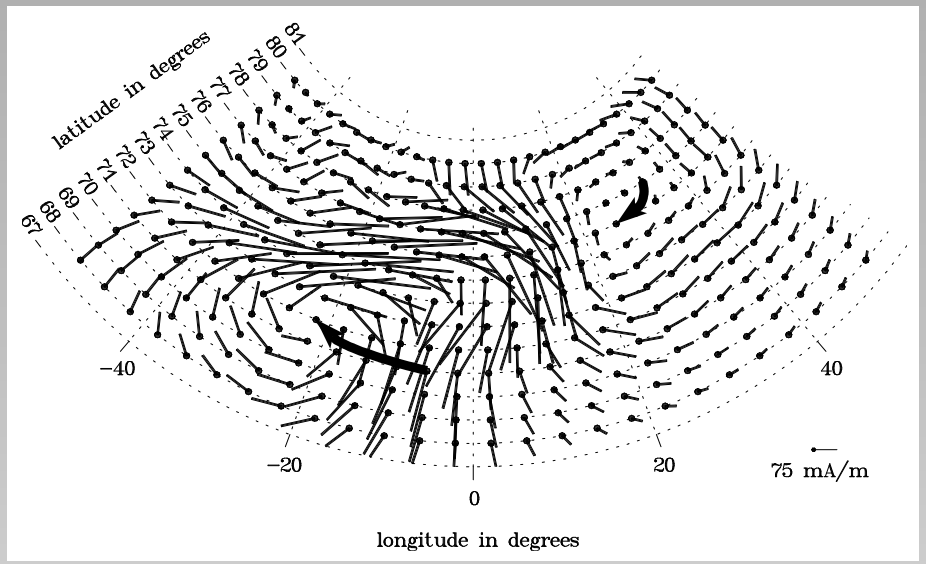




- Ground observations of "Traveling Convection Vortices (TCVs) due to sudden increases in solar wind pressure.
- Shows how the magnetosphere and ionosphere respond to the solar wind flow dynamics.

Example of M-I-T Coupling Study Using Magnetometer Network



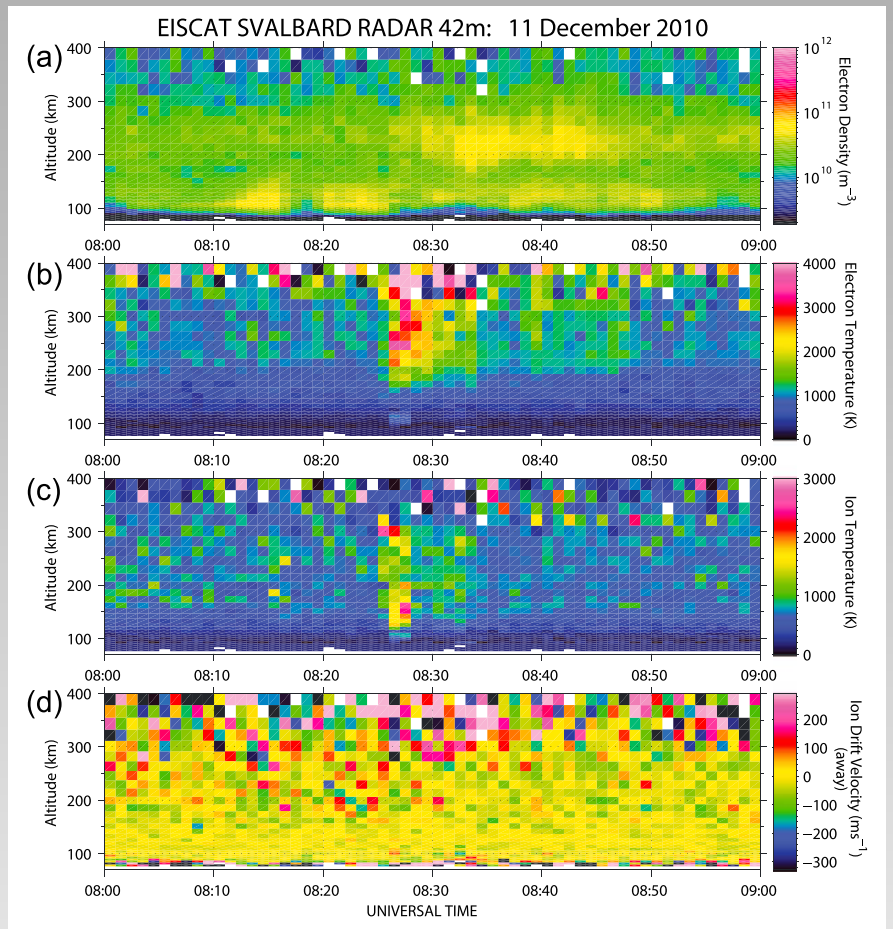


[*Amm et al.* 2002, JGR]

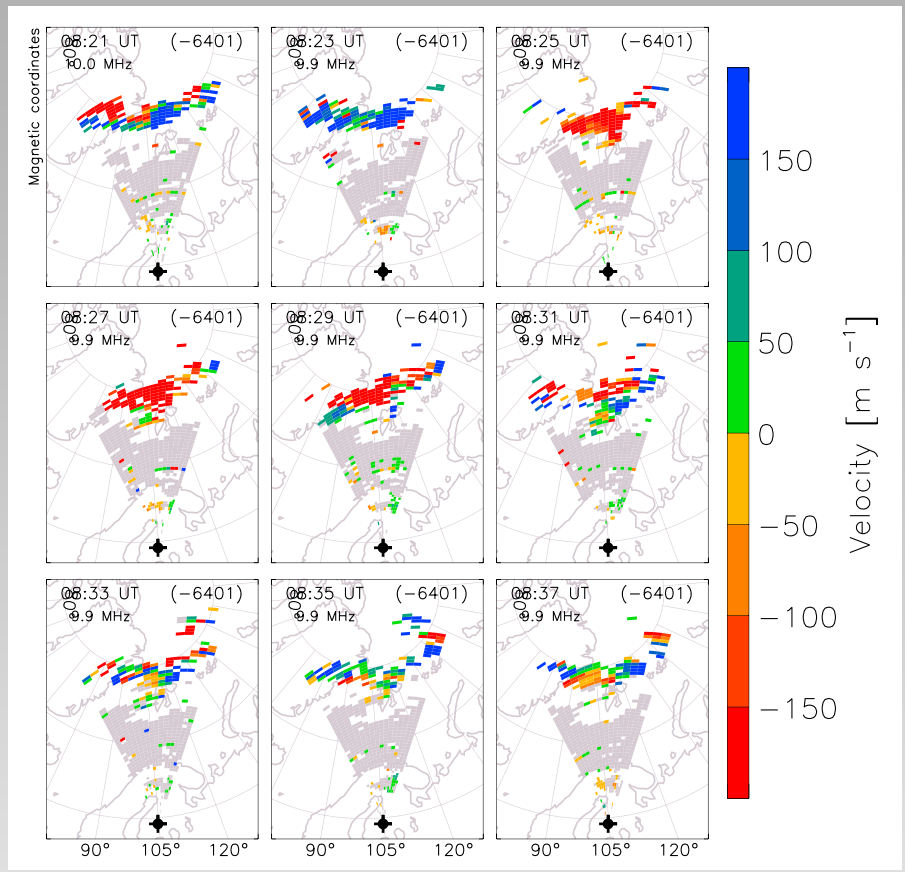
- TCVs over Canada, Europe and Greenland.
- Need more extensive, denser array for finer-scale investigation.

Example of M-I-T Coupling Study Using Magnetometer Network

EISCAT Svalbard Radar (500 MHz)



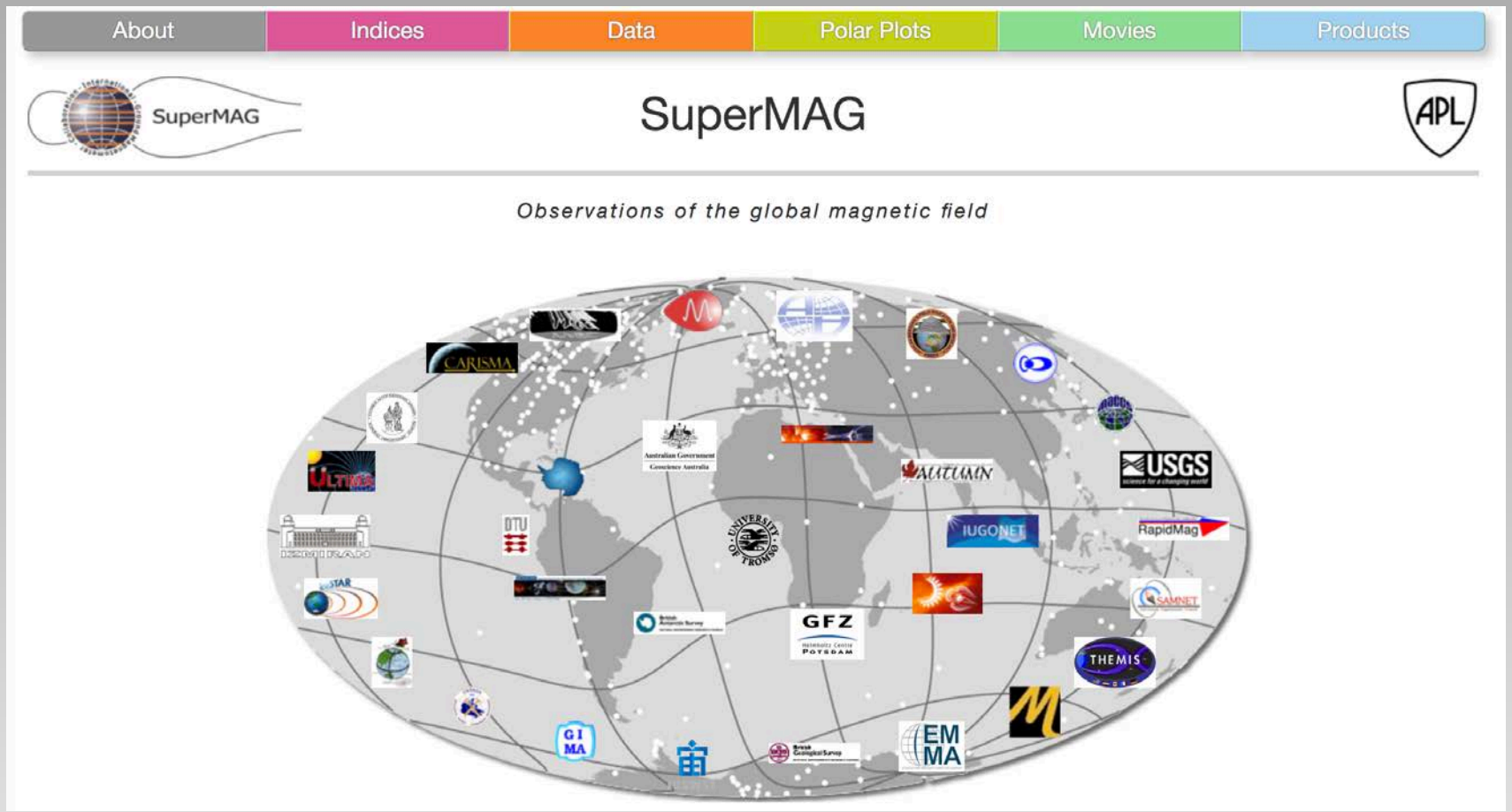
SuperDARN HF Radar



[*Kim et al.* 2017, JGR]

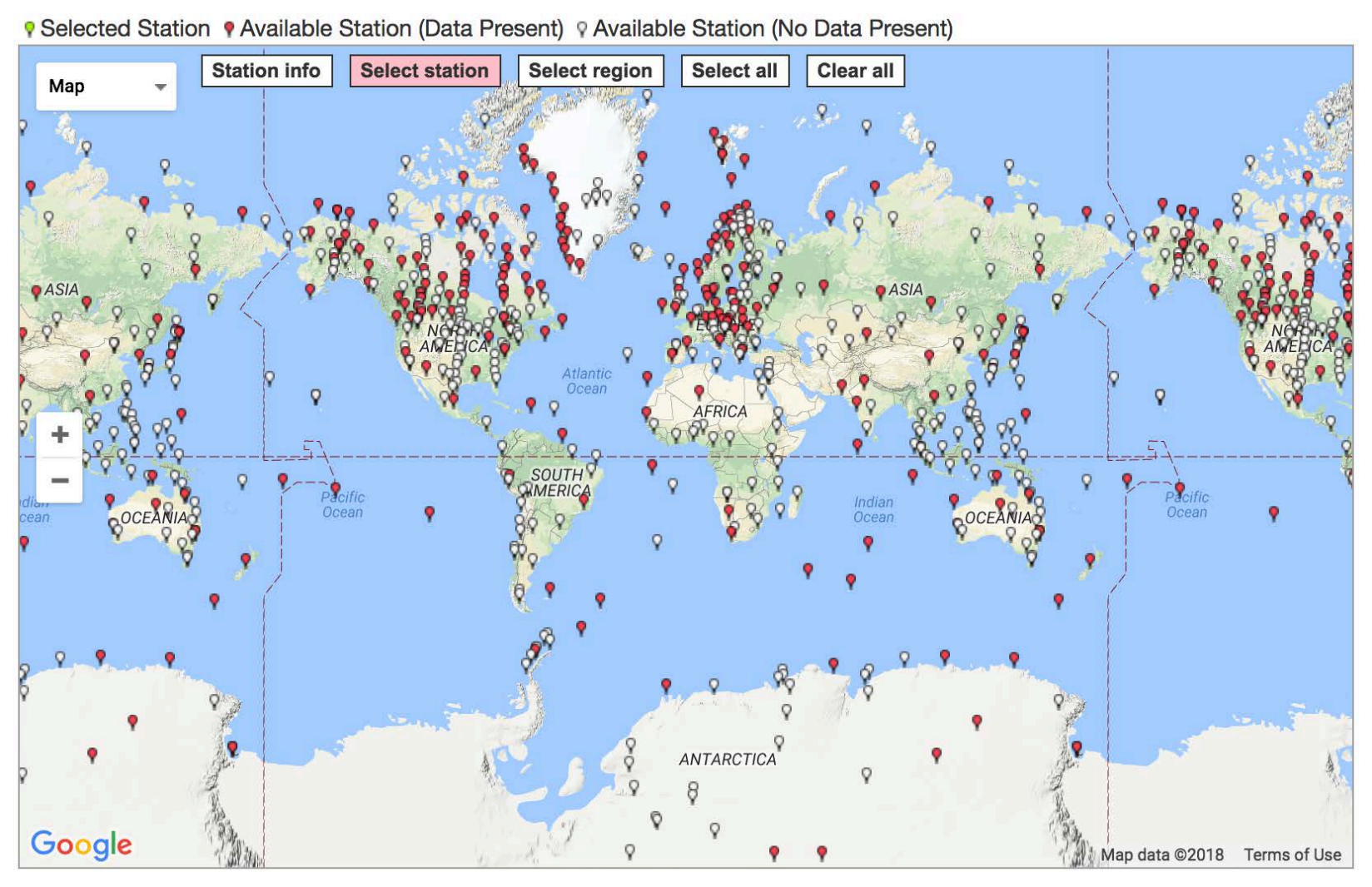
- Transient solar wind-magnetosphere phenomena impact lower ionosphere.

Example of Magnetometer Network Array: SuperMAG



- "SuperMAG is a worldwide collaboration of organizations and national agencies that currently operate more than 300 ground based magnetometers. SuperMAG provides easy access to validated ground magnetic field perturbations in the same coordinate system, identical time resolution and with a common baseline removal approach."

Example of Magnetometer Network Array: SuperMAG



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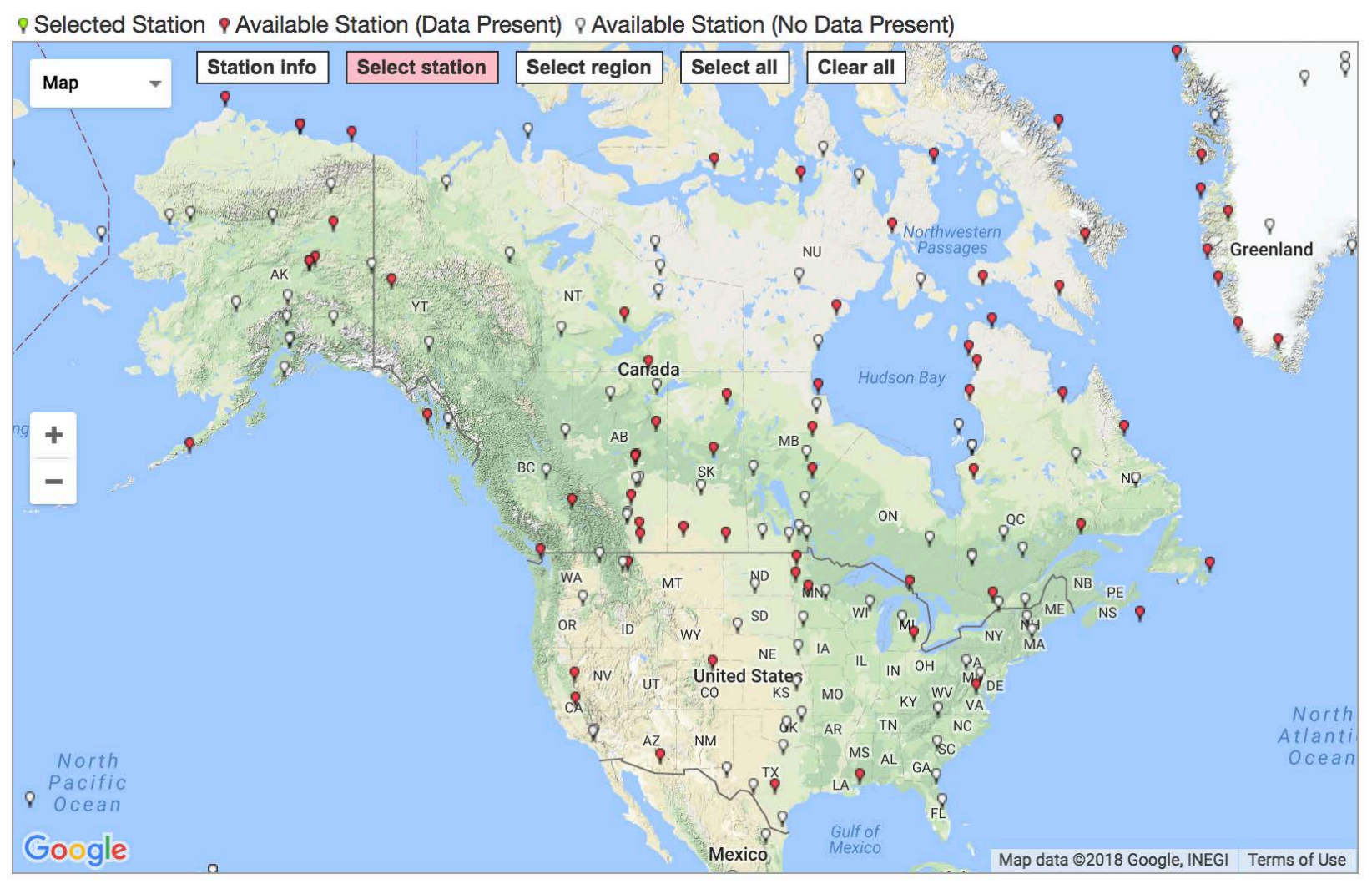
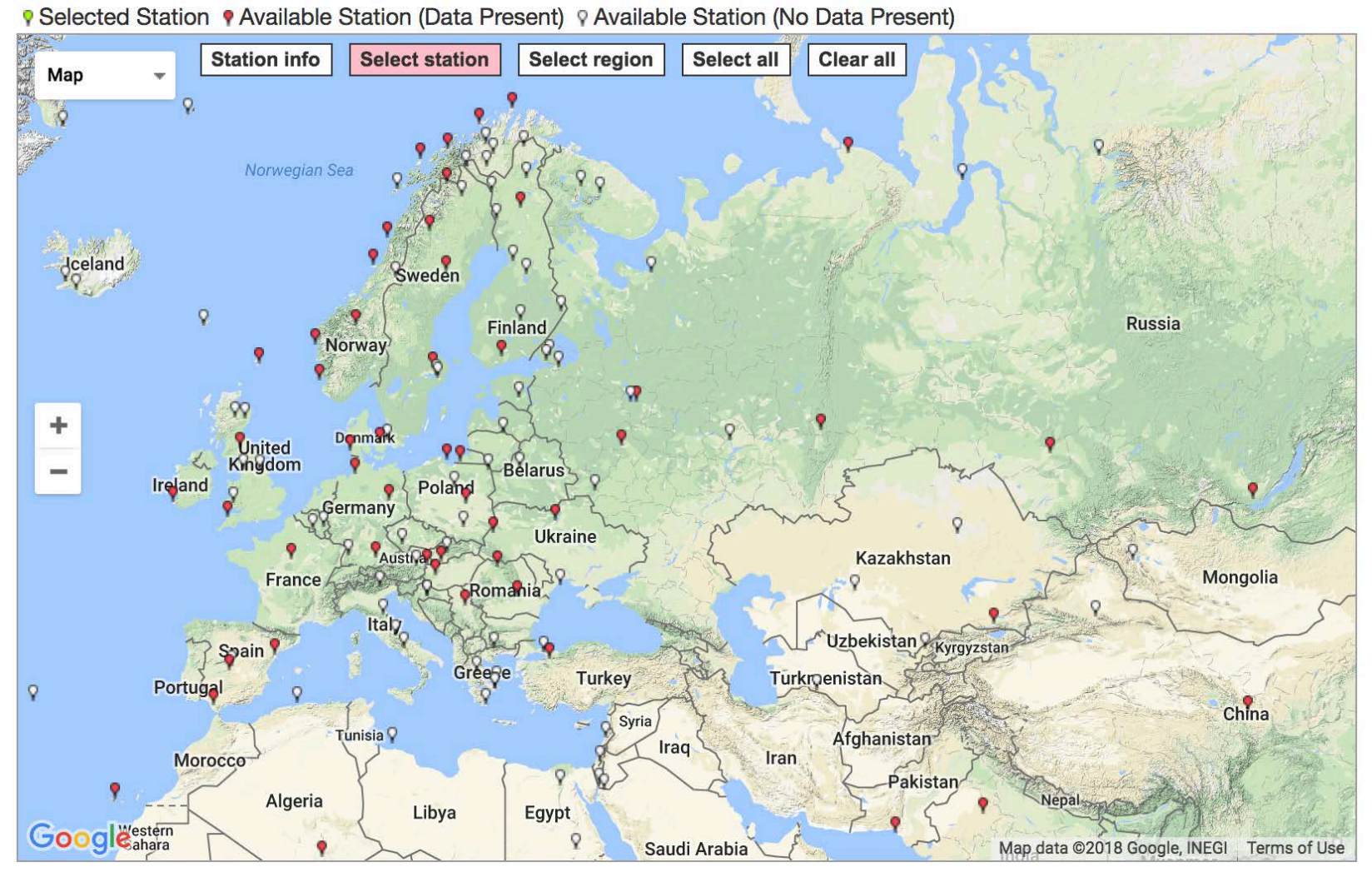


Example of Magnetometer Network Array: SuperMAG

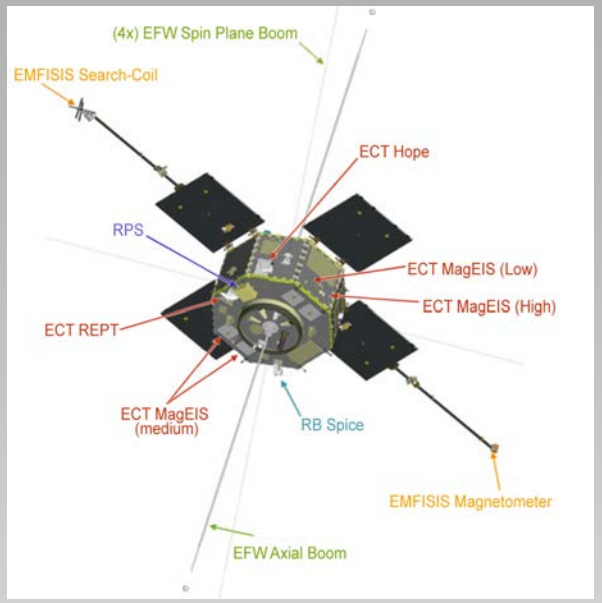


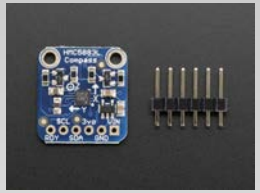
Magnetometry

- Besides auroral observations, magnetic field measurements are one of the traditional way of observing the space weather phenomena on the ground.
- Magnetic field sensor - "magnetometer".
- Wide application: metal detection, non-contact switch, non-destructive testing, oil/coal exploration, military, space research, etc.
- Induction type magnetometers are widely used for space applications.

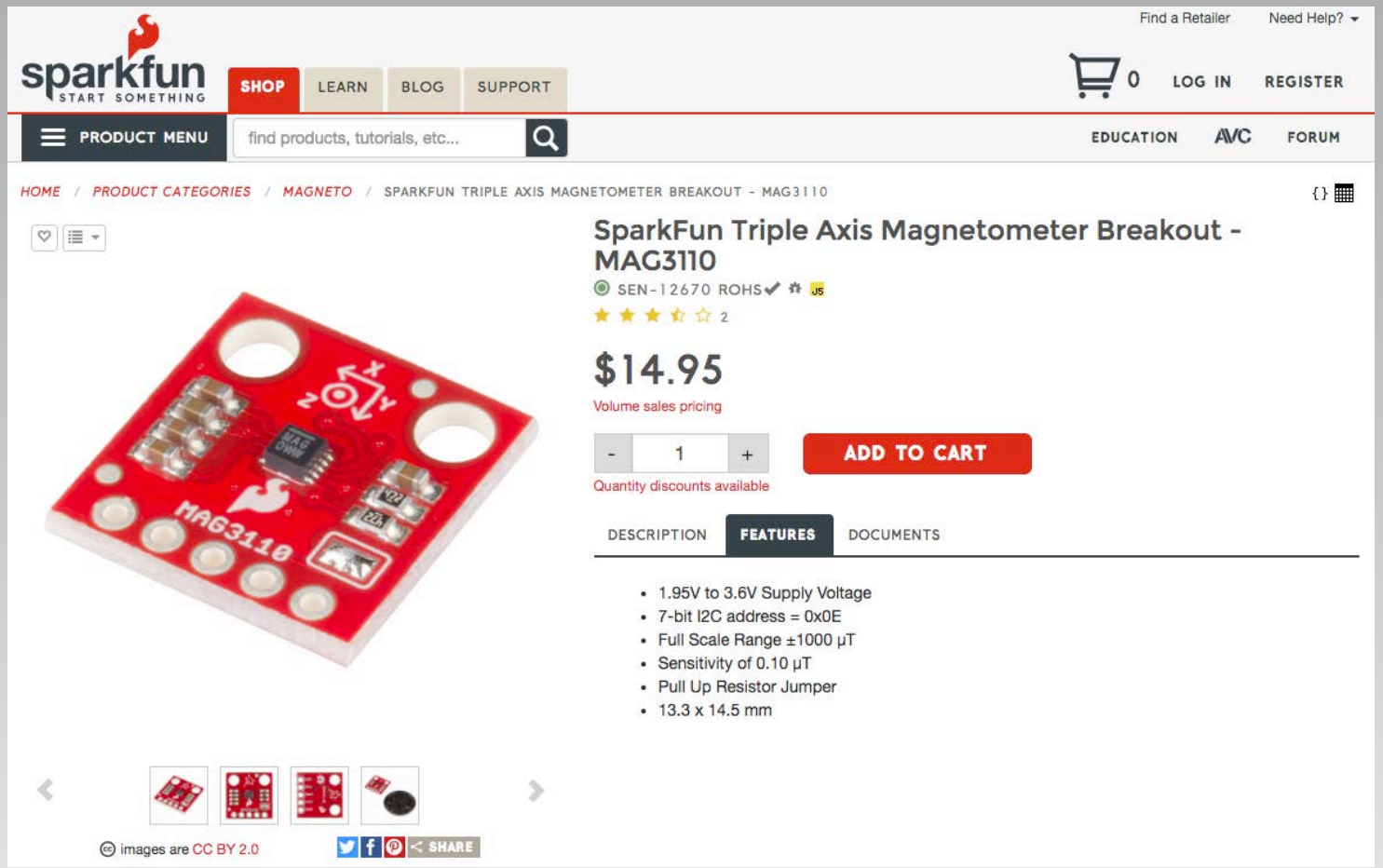
Magnetometers

- **Scalar Magnetometers**
  - Proton precession
  - Overhauser effect, etc.
- **Vector Magnetometers**
  - Hall effect
  - Magnetoresistive
  - Fluxgate
  - Search-coil
  - SQUID (Superconducting Quantum Interference Device), etc.





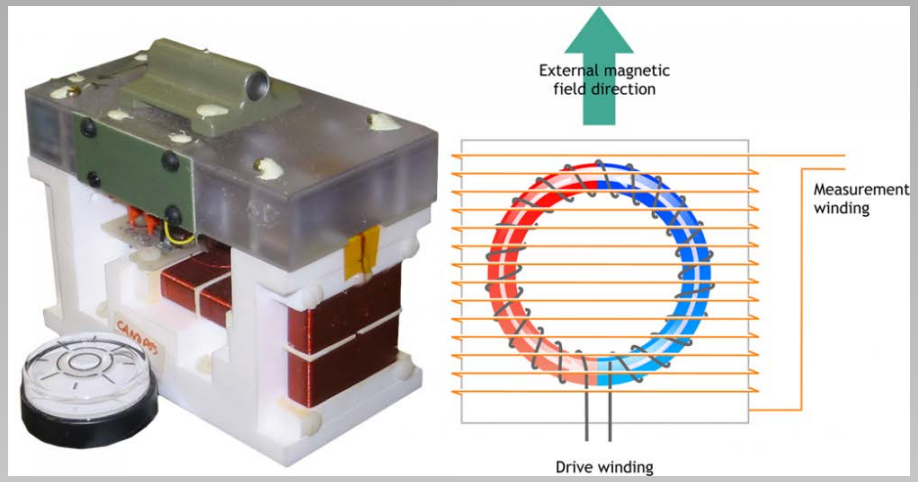
Magnetoresistive Magnetometer

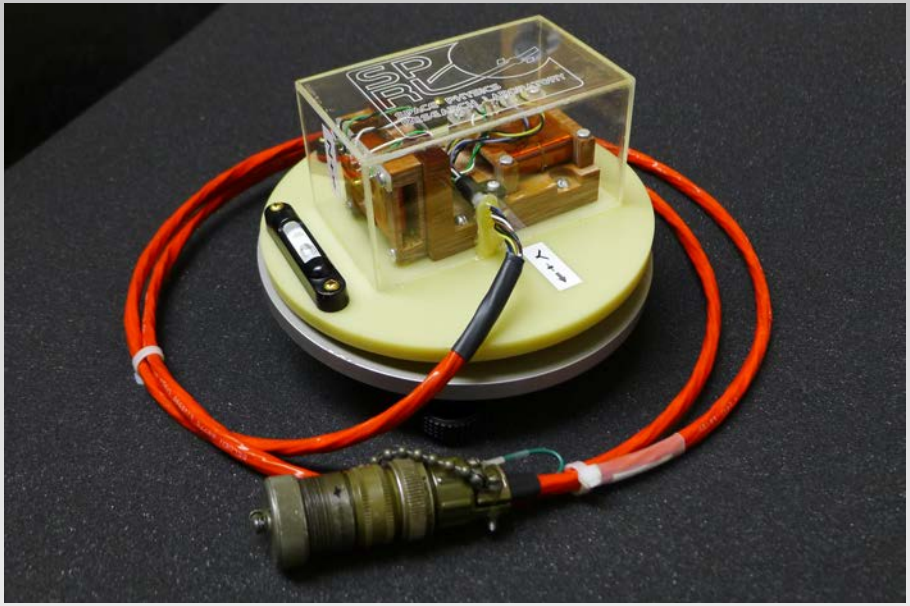


- One of the cheapest kinds but not appropriate for space weather observations: very low resolution (~100 nT).

Fluxgate Magnetometer

- Measures DC magnetic fields.
- Freq. response (DC - ~ tens of Hz).
- Compact/light-weight.
- Reliable physical structure.
- Direction-sensitive (vector field measurement).
- Widely used for space research (both in space and on the ground).
- Baseline drift due to temperature, long-term drift.

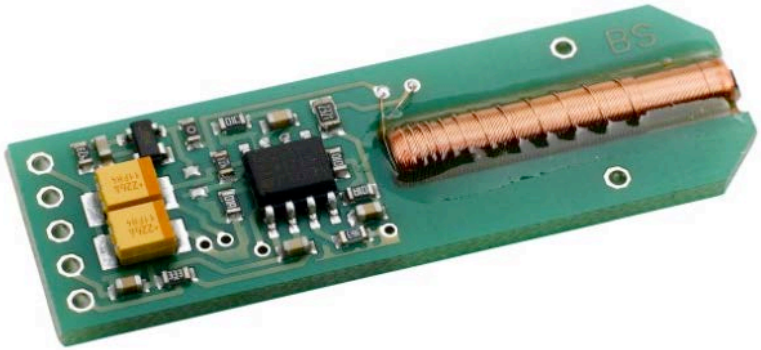




Low-Cost Off-the-Shelf Fluxgate Magnetometer

Stefan Mayer Instruments
Fluxgate Magnetometers & more

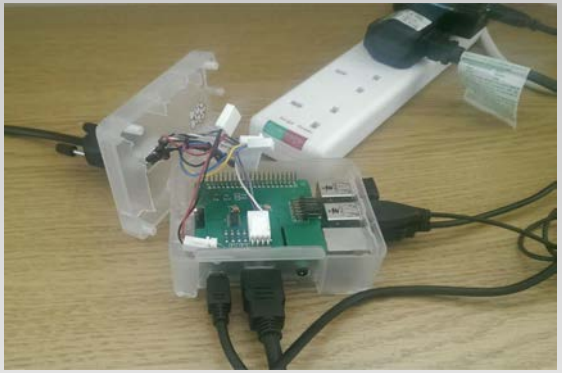
Miniature Magnetic Field Sensor FLC 100



Complete miniature fluxgate magnetometer can be used in any application where the sensitivity of Hall- or MR-magnetometers is not sufficient, e. g. measurement of the earth's field, detection of AC field from power lines, vehicle detection, compass navigation, and many others. Due to its low price and low power consumption ideally suited for multi-sensor array systems.

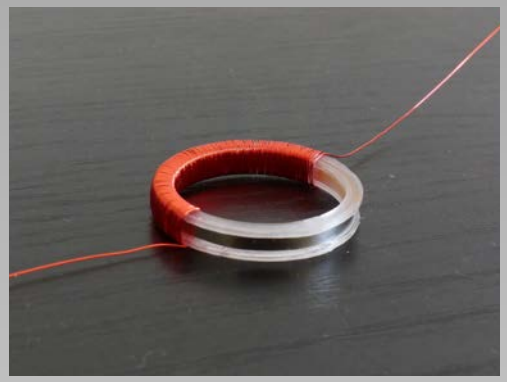
- Measurement range: ±100 µT
- Single 5 V supply voltage
- Only 2 mA current consumption
- Low noise: < 5 nT_{pp} (0.1 to 10 Hz)
- Frequency range: DC to 1 kHz (-3 dB)
- Custom versions available

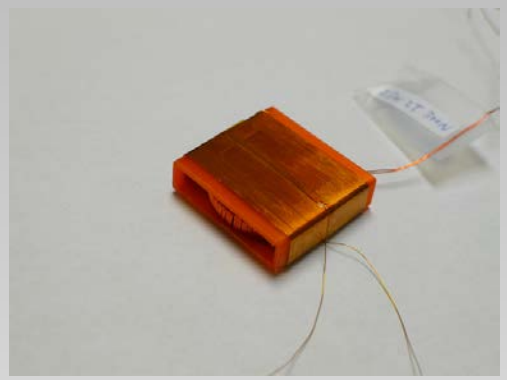
Download data sheet here: Data sheet FLC 100

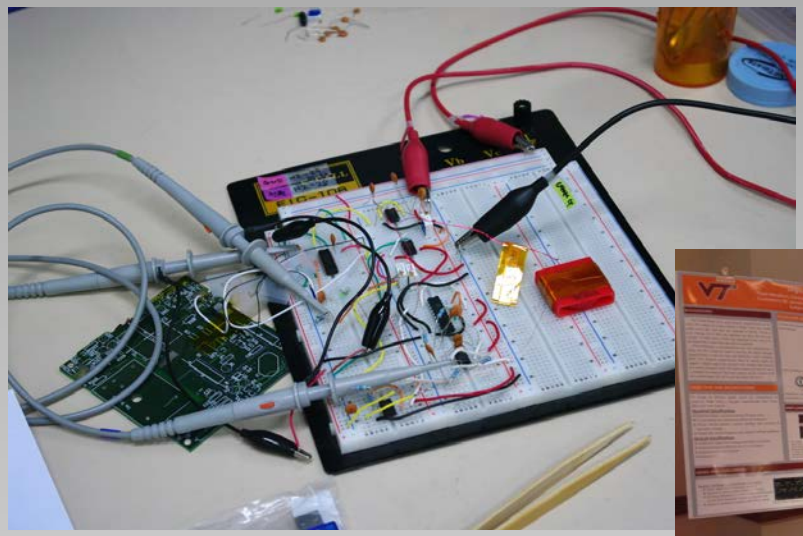


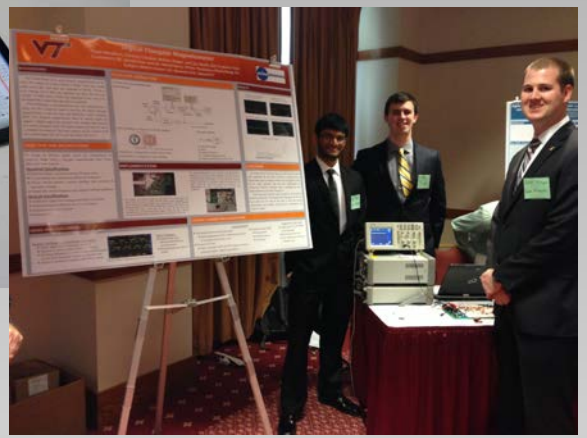
- "Raspberry Pi Magnetometer" by British Geological Survey (BGS)

In-House Fluxgate Magnetometer





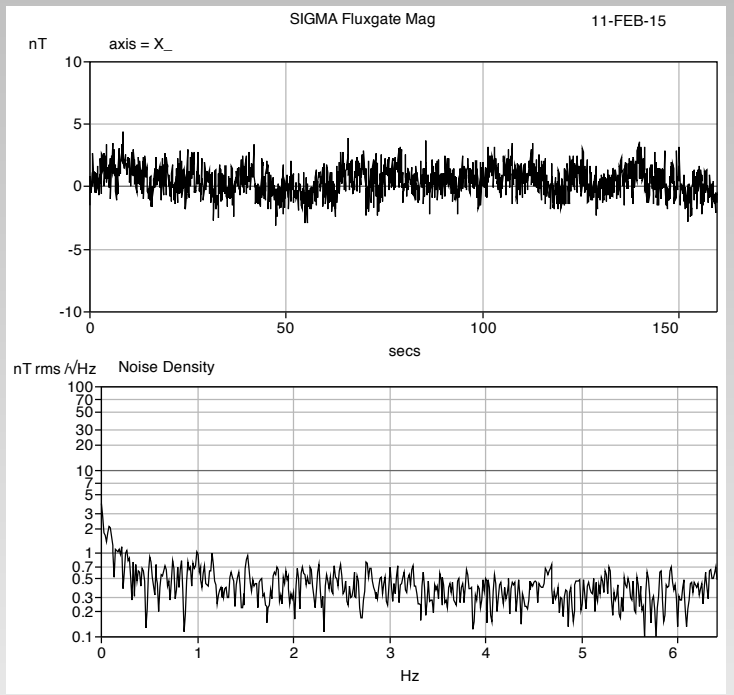




- Prototype fluxgate magnetometer as part of Virginia Tech ECE independent study project.
- Sensor: magnet wire, amorphous metal alloy ribbon, 3-D printed bobbins. Coils are wound by hand → Great Hands-on experience!
- Electronics: can be either analog or digital. Most components are inexpensive.

In-House Fluxgate Magnetometer

- Challenges
  - Material/parts could be very low; however, labor-intensive (machining, coil-winding, electronics fabrication, test/calibration).
  - Quality control: calibration, installation, EMI issues, etc.



Summary/Open Discussion

- Magnetometer is one of the critical instruments for space weather research.
- Data acquisition/handling is relatively straightforward (especially for ground-based observations).
- Affordable off-the-shelf options are available. Relatively simple, in-house design/fabrication is also possible, great opportunity for citizen scientists and space weather community.
- Space weather research using widely-spaced magnetometer array
  - What science?
  - Magnetic latitude
  - Spacing
  - Sensor performance: resolution, sensitivity, noise level, etc.
  - Quality control: calibration, installation, EMI issue, etc.
- *No one else has done this!*
- *Ground version of CubeSats!*
- **Contact: Hyomin Kim, CSTR/NJIT, hmkim@njit.edu**