GMW

cpi
COMPUTATIONAL PHYSICS, INC.

Webinar: Long Term Magnetic Field Monitoring for Space Weather Monitoring and GIC Forecasting

Ludovic Letourneur, PhD
Senior Applications Engineer
GMW Associates

Jenn Gannon, PhD
GMD Lead
Computational Physics, Inc.

Mike Henderson
Owner and Principal Engineer
GIC Magnetics

Agenda

- Induction due to space weather and impact on man made installations. *Jenn Gannon, CPI*
- Details on fluxgate magnetometer benefits for monitoring of the Earth's field variations. *Ludovic Letourneur, GMW*
- Hardware integration: Data transfer and processing. *Mike Henderson, GIC Magnetics*
- Use of data for GIC monitoring/prediction: Application to power networks and link to upcoming regulations. *Jenn Gannon, CPI*
- Use of magnetic data for magnetic storm monitoring and application to the oil & gas directional drilling industry. *Ludovic Letourneur, GMW*
- What's next: Integration of electric current information to the data stream. *Ludovic Letourneur, GMW*
- Questions and Answers

Space Weather and Infrastructure

Jennifer Gannon
Computational Physics, Inc.
gannon@cpi.com

Space weather is all about magnetic fields.

Space weather is the interaction between the Sun and the Earth.

- Aurora
- Van Allen radiation belts
- Magnetosphere, ionosphere
- Solar wind
- Solar activity (flares, sunspots, etc)

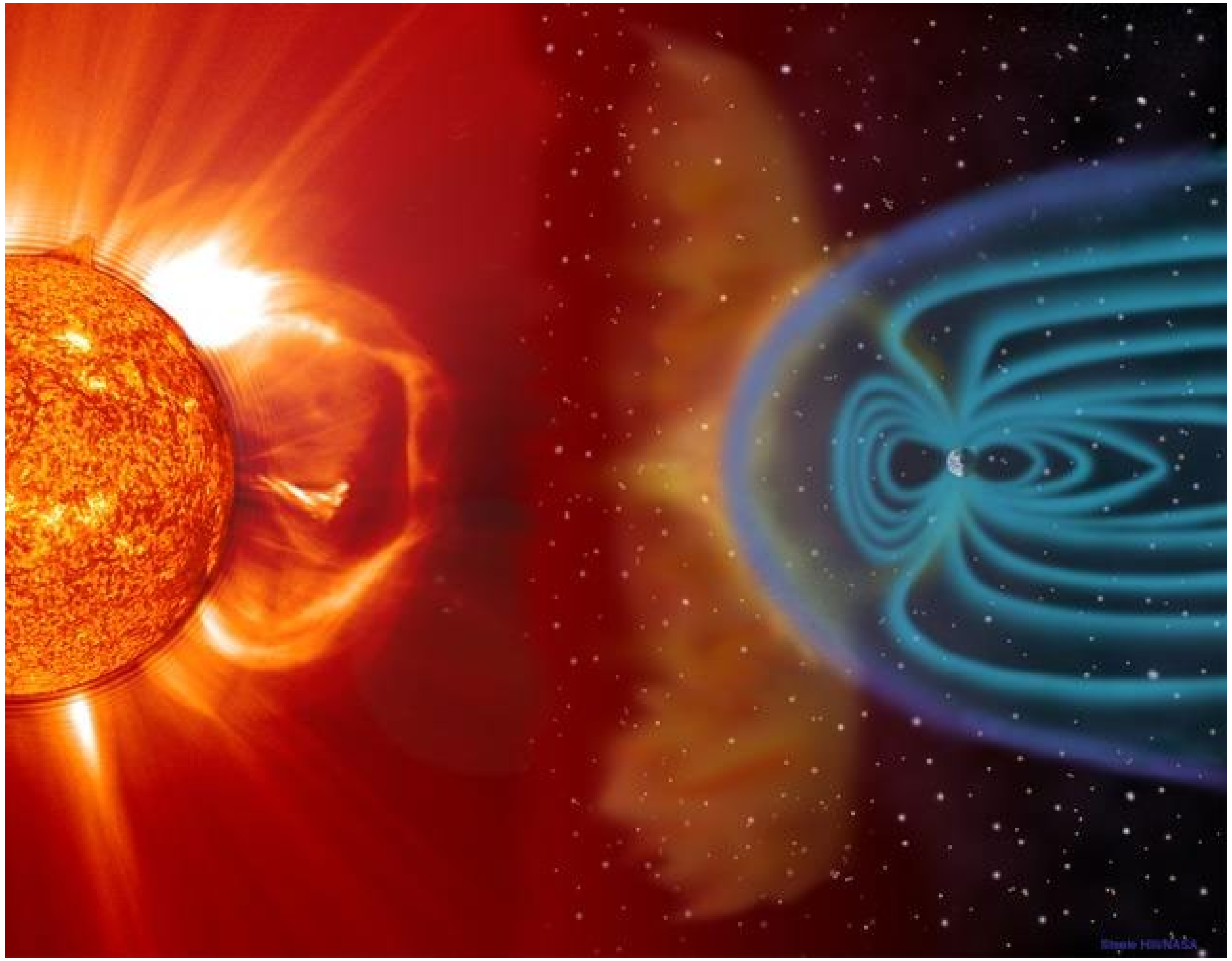
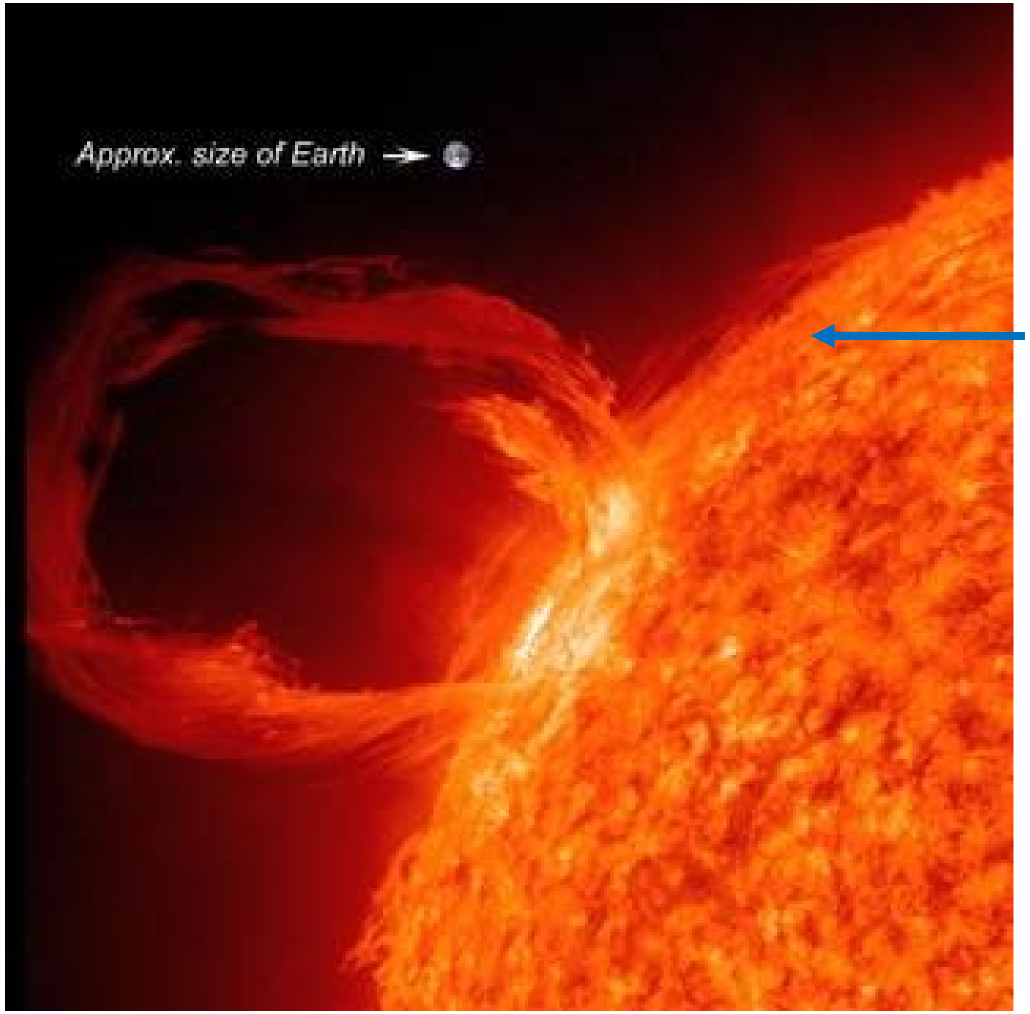


Image credit: NASA

There are different solar effects that produce GMDs.



Prominence

CME

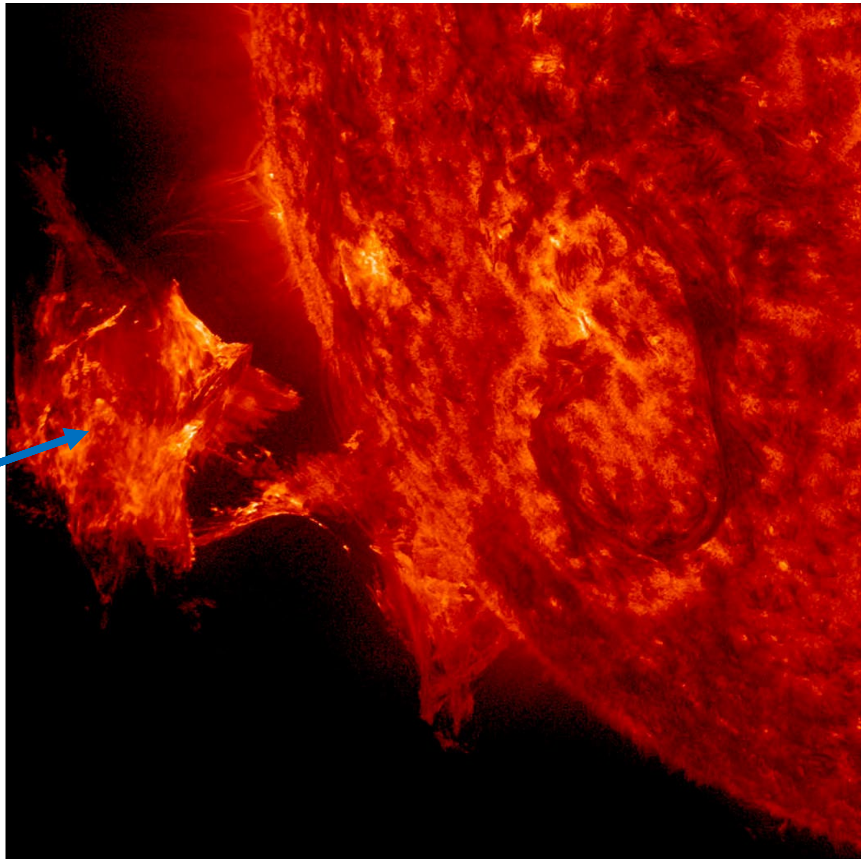
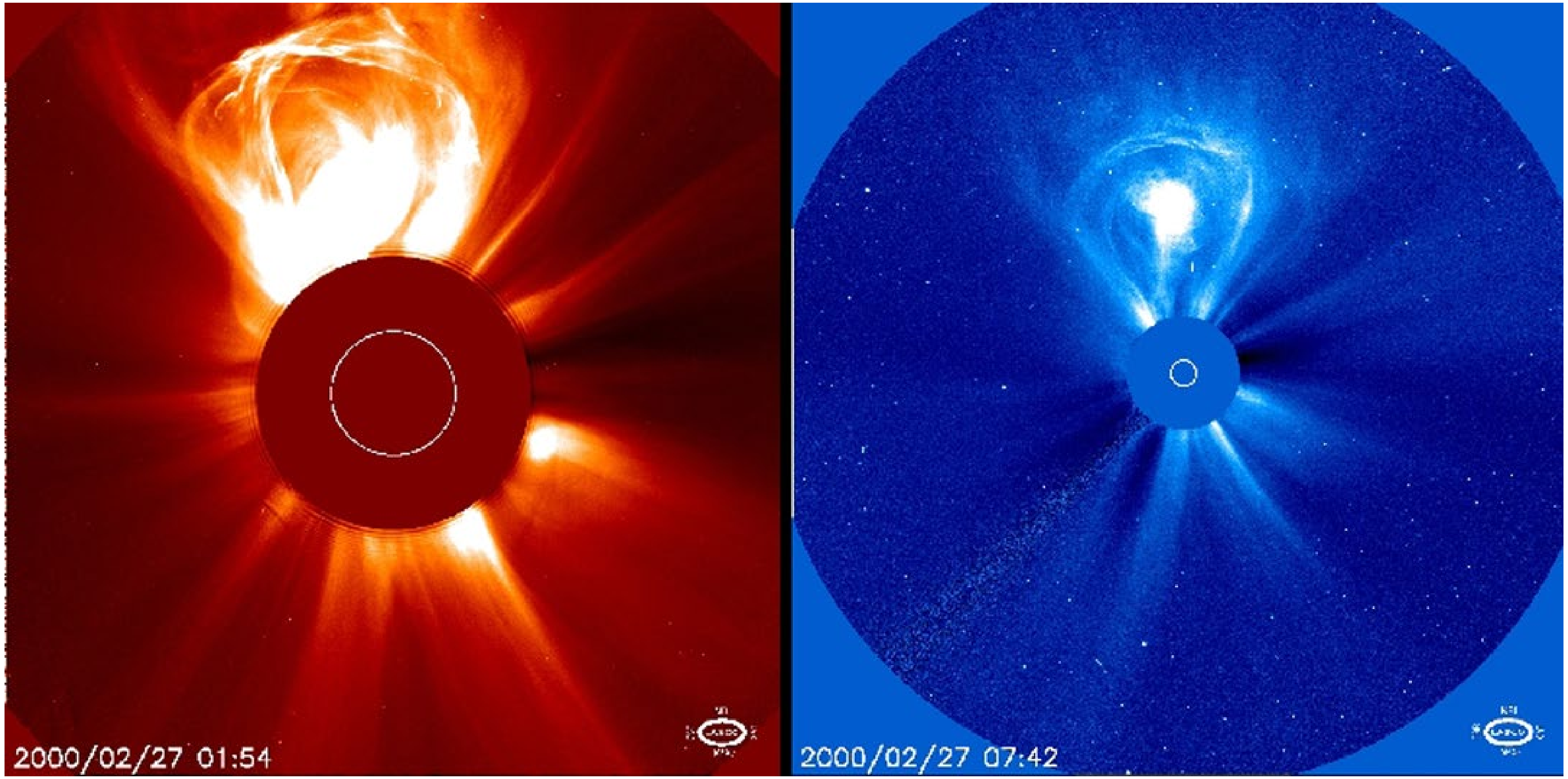


Image credit: NASA

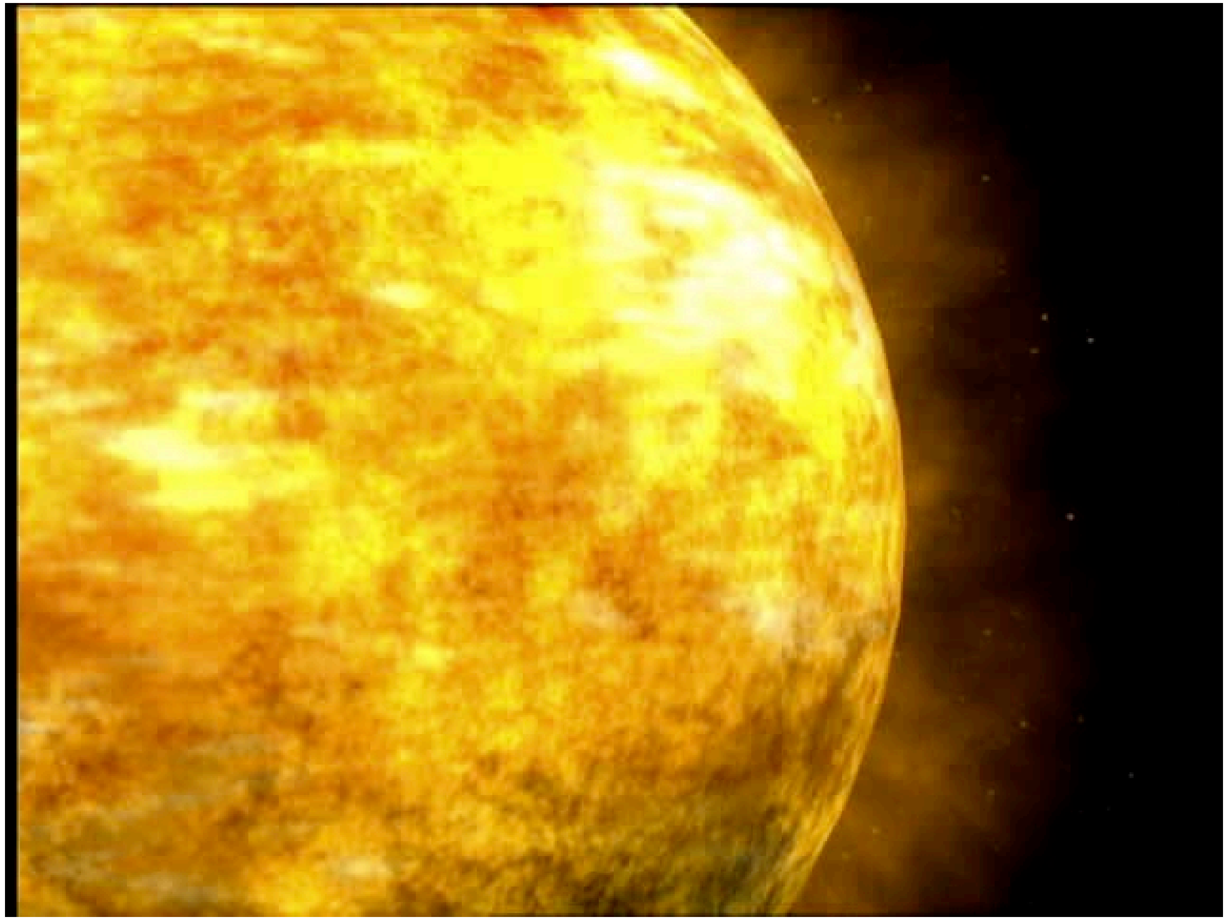
CMEs cause the largest GMDs.



- Fast speed in the solar wind
- High density plasma
- Very large relative to the Earth
- Uncertainty in direction (towards/away from Earth)

Image credit: NASA

During a geomagnetic storm, the magnetic field changes rapidly.



The Earth’s magnetic field is our shield against plasma from the Sun.

Earth and solar wind magnetic fields in the same direction (both North) -> compression.

Earth and solar wind magnetic fields in the opposite directions -> reconnection.

Image credit: NASA

A Geomagnetic Storm is a reconfiguration of fields.

- ”Active” geomagnetic field – actually a fairly specific definition

- Small storms happen regularly.

- The effect is a rapidly changing magnetic field on the ground.

Image credit: NASA

Changing magnetic fields interact with the Earth to produce electric fields.

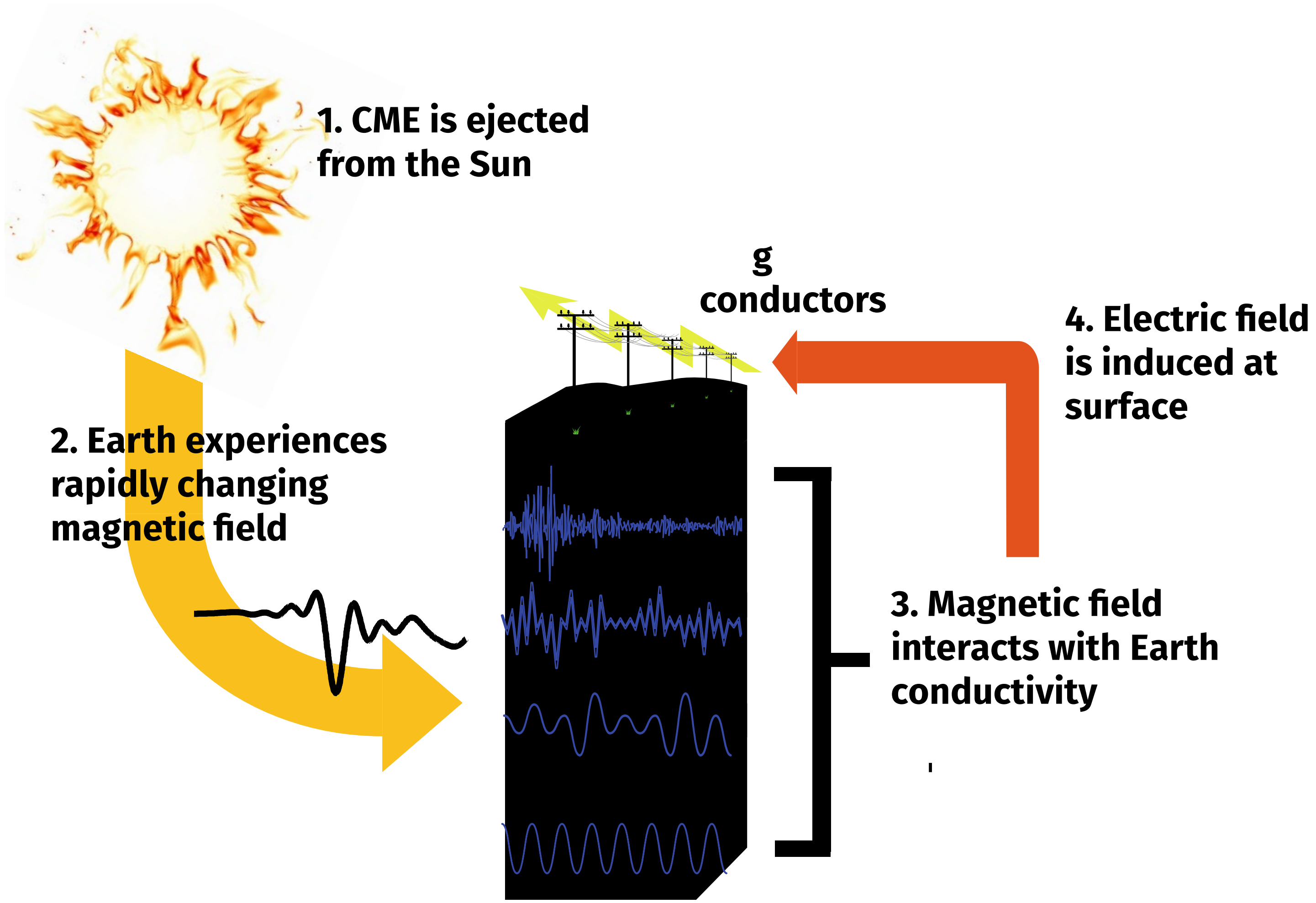


Image: CPI

Introduction to Fluxgate Magnetometers

Presented by:

Ludo Letourneur
Senior Sales Engineer
GMW Associates
ludo@gmw.com

GMW Associates

Fluxgate sensors measure the amplitude of the magnetic field along the axis of the fluxgate element rather than just the total amplitude of the magnetic field – decompose the field along North, East and Down component.

From Boteler, D. H. (2019). A 21st century view of the March 1989 magnetic storm. *Space Weather*, *17*, 1427–1441. https://doi.org/10.1029/2019SW002278

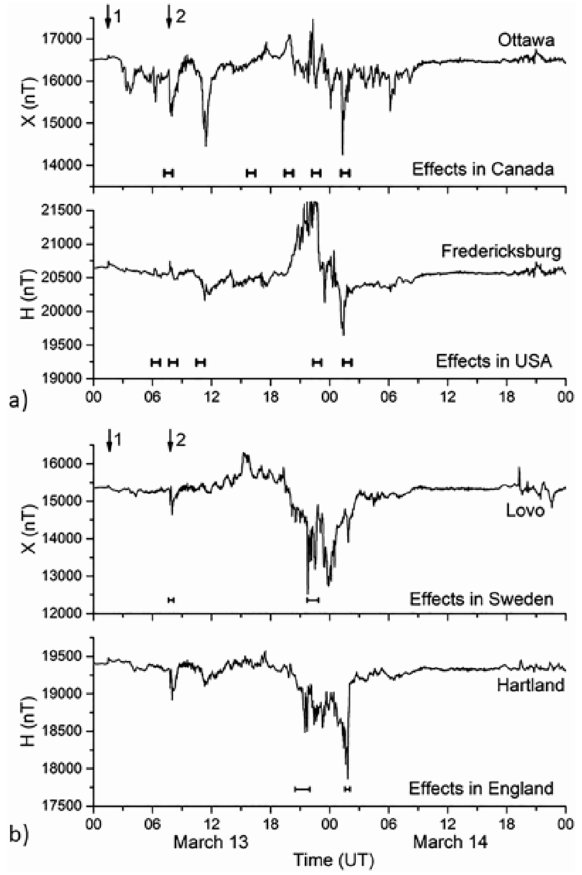
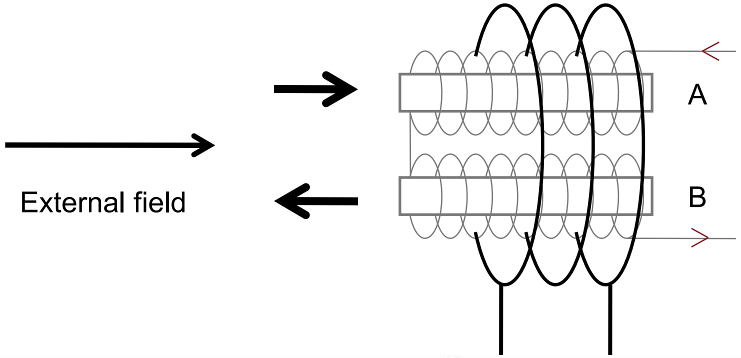


Figure 8. Magnetic disturbances and effects on power systems during 13–14 March 1989 in (a) North America and (b) Europe (the different vertical scales). Horizontal bars indicate the times of power system effects. Black arrows indicate the times of the storm sudden commencement.

Fluxgate are perfect to measure Earth's field amplitude and variations from sub-nT in amplitude – typically the amplitude change seen in Space Weather from nT to hundreds or even thousands of nT at ground level.

The fluxgate principle date back from the mid 1930’s and aims to measure the magnetic flux density – B in the direction of the fluxgate.
Three-axis achieved by combining three fluxgate elements orthogonally from one another.

Multiple fluxgate designs exists – ring core, single linear cores, twin cores.



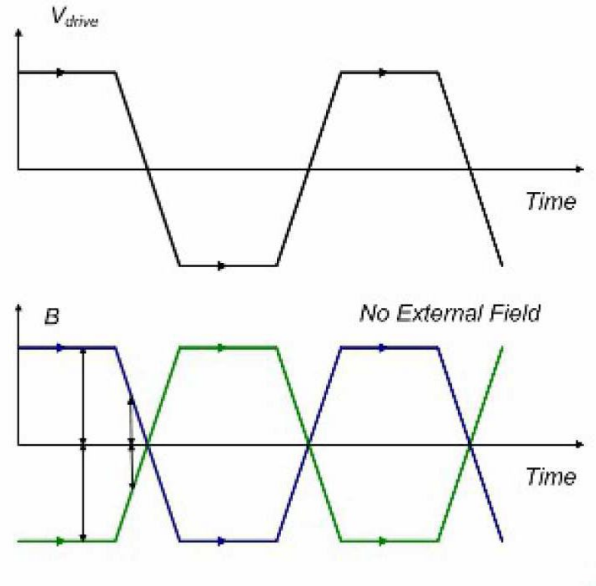


Fig. 2a: Drive Waveform

Fig. 2b:
B generated by each half core
with no external field

Bartington uses a twin core setup. Benefits includes better immunity to excitation signal.

Frequency of measurement(~3kHz) dependent on the sensor’s excitation frequency (~16kHz)

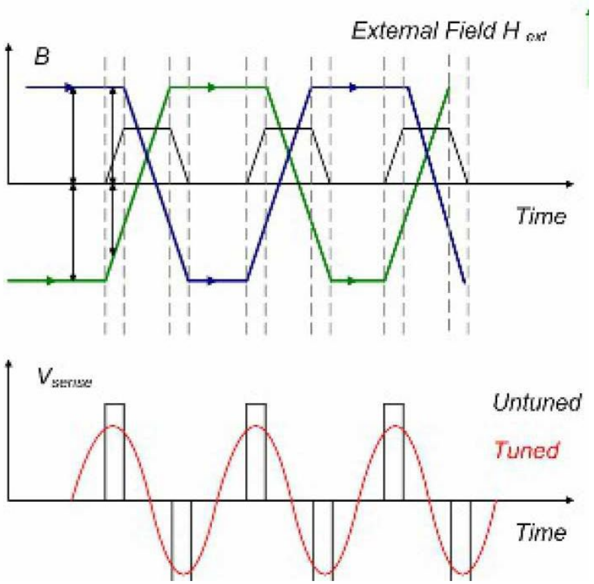
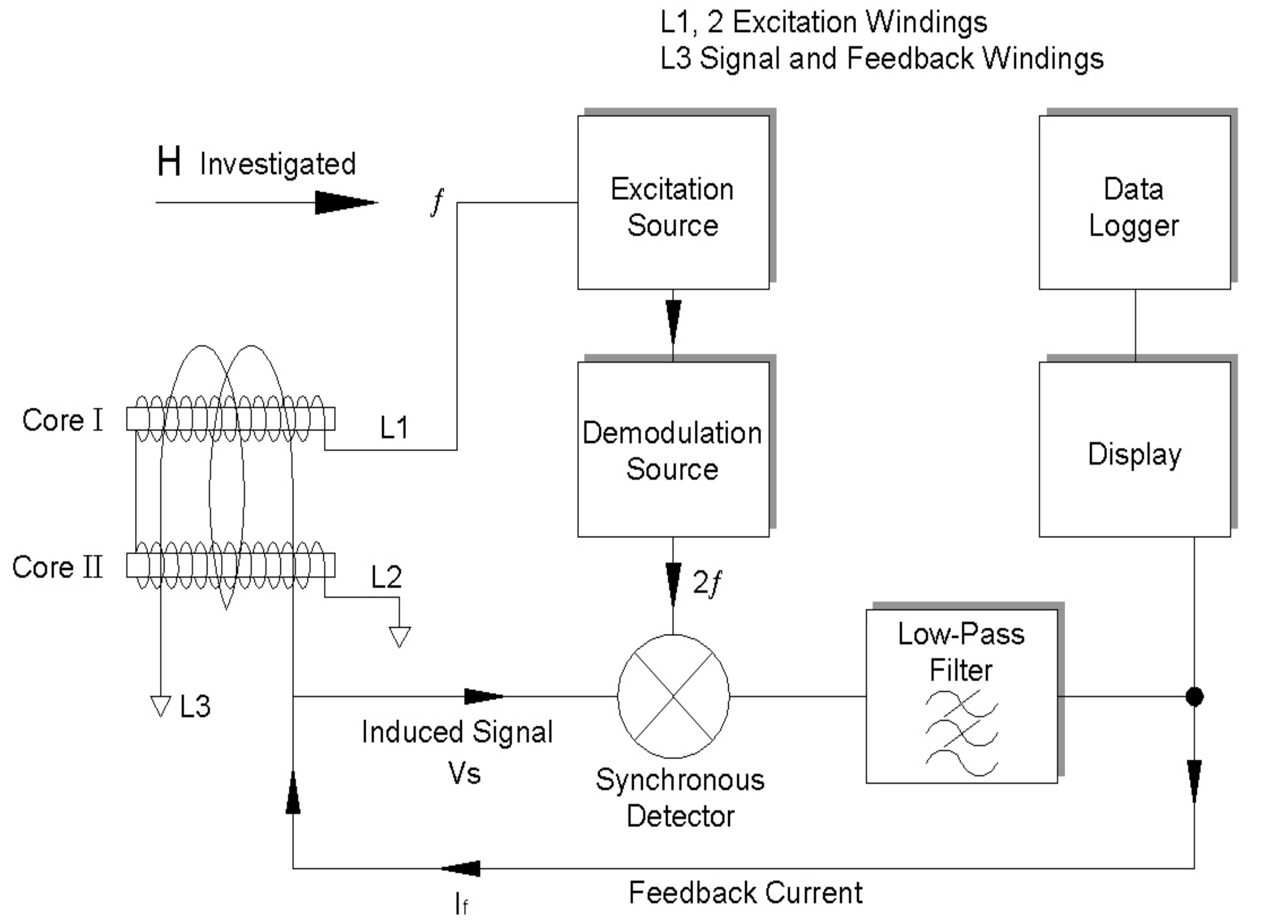


Fig. 2c:
B generated by each half core
in external field

Fig. 2d:
Voltage induced in the sense winding (black)
Resultant voltage if the sensor is tuned (red)

GMW Associates

Fluxgate run in closed-loop mode – the induced voltage is used to provide a feedback current into the pick up coil. This 'cancel out' the external field so that the fluxgate is always in a null mode (no induced voltage). The external field is directly proportional to the feedback current read across a precision scaling resistor



Fluxgate in closed-loop offer excellent linearity mainly dependent on the Op-Amp used to drive the current in the feedback loop.

GMWAssociates

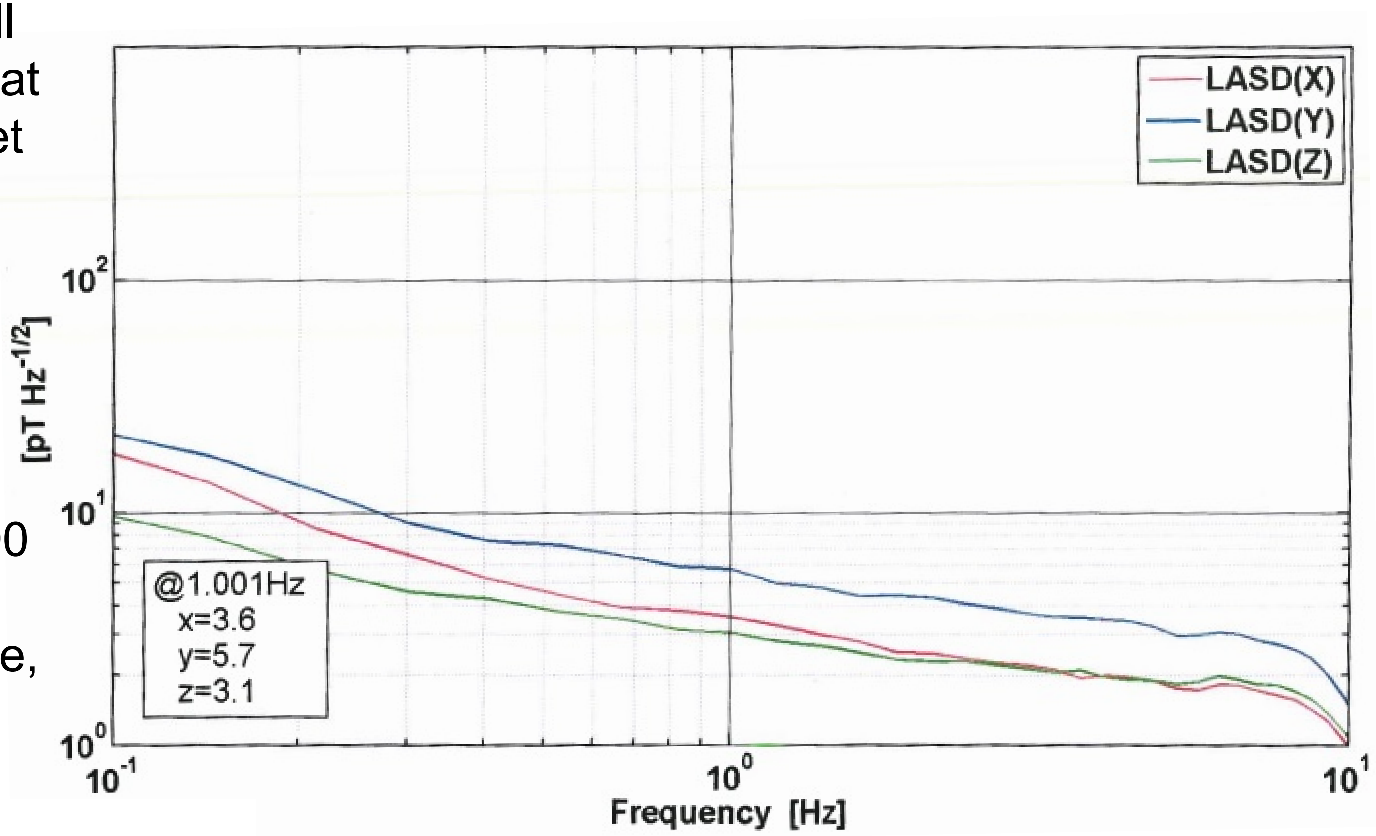
Noise on the Bartington fluxgate is typically less than 10pT. Care needs to be taken siting the magnetometers away from human-made interferences and insulate them from temperature variations

Due to their offset, the sensors have some small errors for absolute measurements but are ideal at measuring small field variations over time. Offset are extremely stable over time once warm up period has passed.

Mag-13 are best suited – low offset, noise

For low power setups use Mag649
For cost over performance is important - Mag690

Both these options have higher offsets and noise, as well a higher orthogonality error.



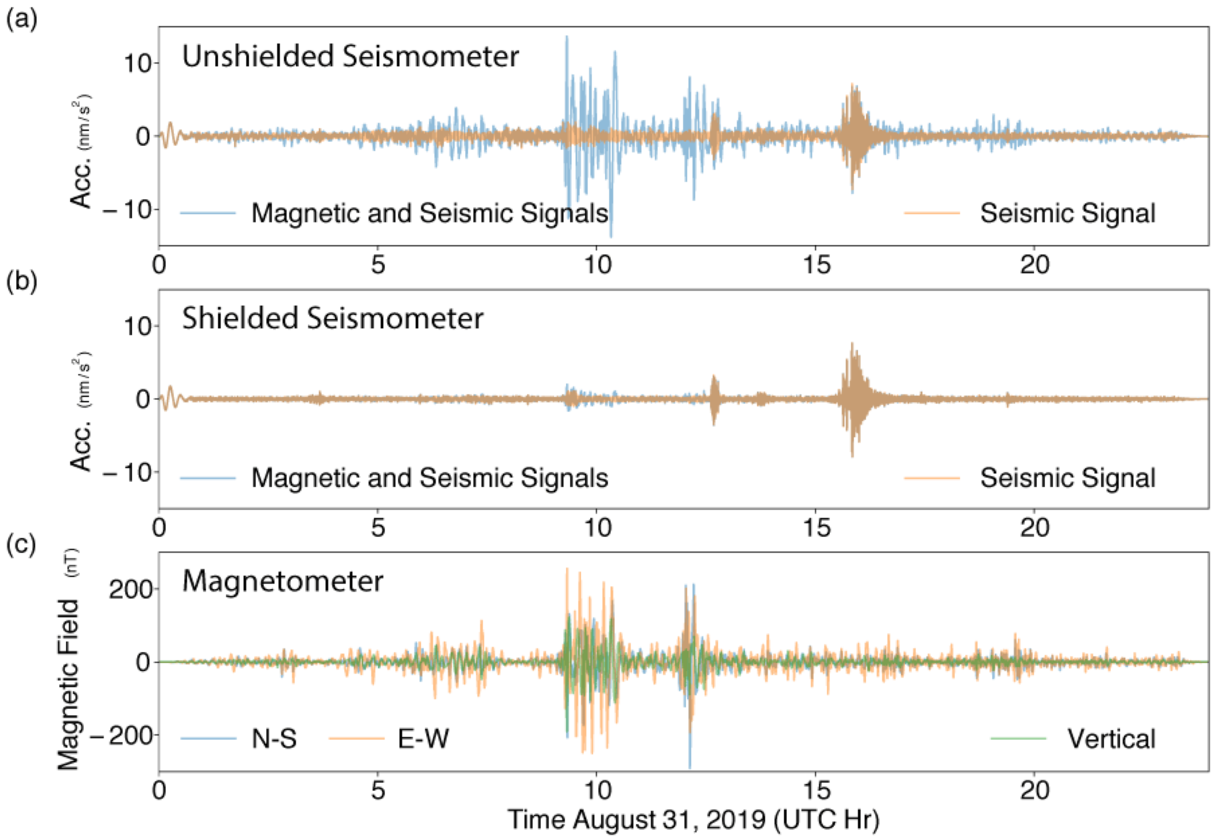
Noise plot of Mag-13 Low noise

GMWAssociates

Example of use: Bureau of Meteorology - Australia
https://www.sws.bom.gov.au/World_Data_Centre/2/3/1
Image from the Bureau of Meteorology – link above.

USGS: This is part of a joint magnetic/seismic survey and using the magnetic data to correct the effect space weather has on the seismic network.

https://pubs.geoscienceworld.org/ssa/bssa/article-abstract/110/5/2530/587721/Magnetic-Field-Variations-in-Alaska-Recording?redirectedFrom=fulltext



Data from USGS – Adam Ringler
https://www.usgs.gov/natural-hazards/earthquake-hazards/science/auroras-and-earthquakes-strange-companions?qt-science_center_objects=0#qt-science_center_objects

Integration of Fluxgate Magnetometers into Measurement Systems

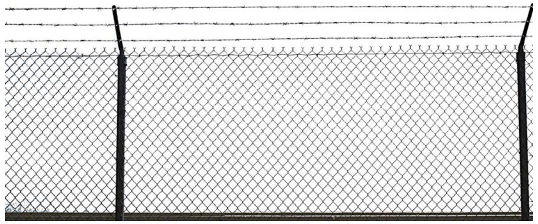
Mike Henderson

GIC Magnetics

Not just a sensor …

Magnetometers used for GIC estimation need to be **physically remote**, and are **highly sensitive**

You need to keep the sensor away from iron

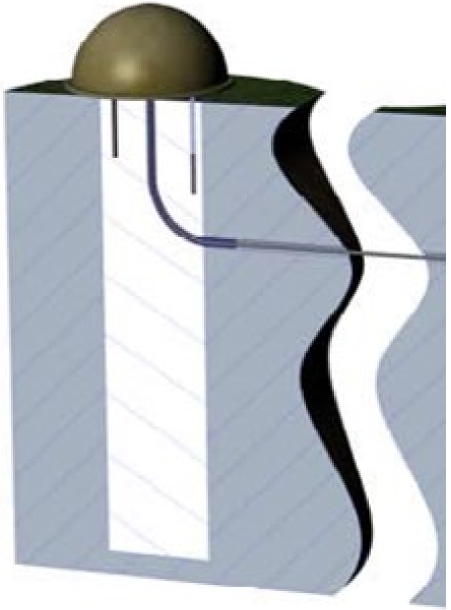


Stationary metal

Moving metal

Large moving metal

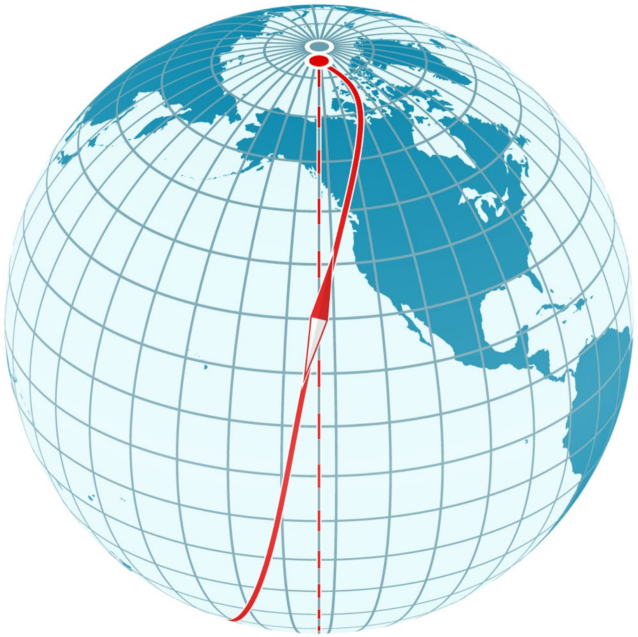
You need to mount the sensor carefully



No vibration

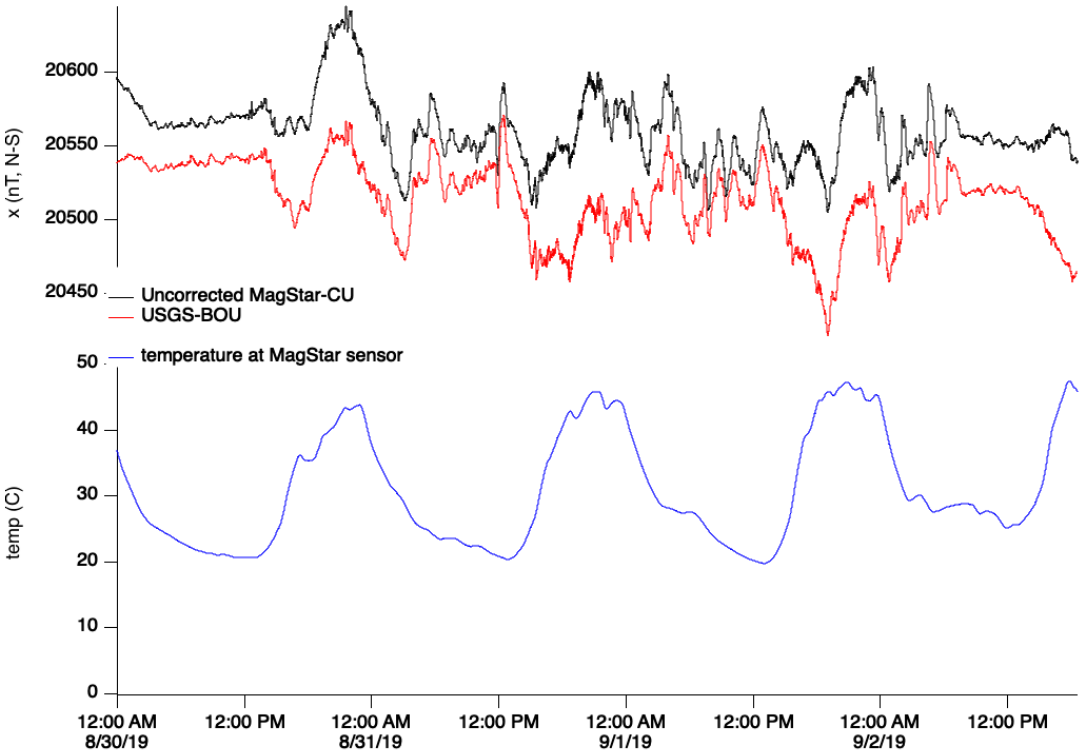
Level

Oriented
True North

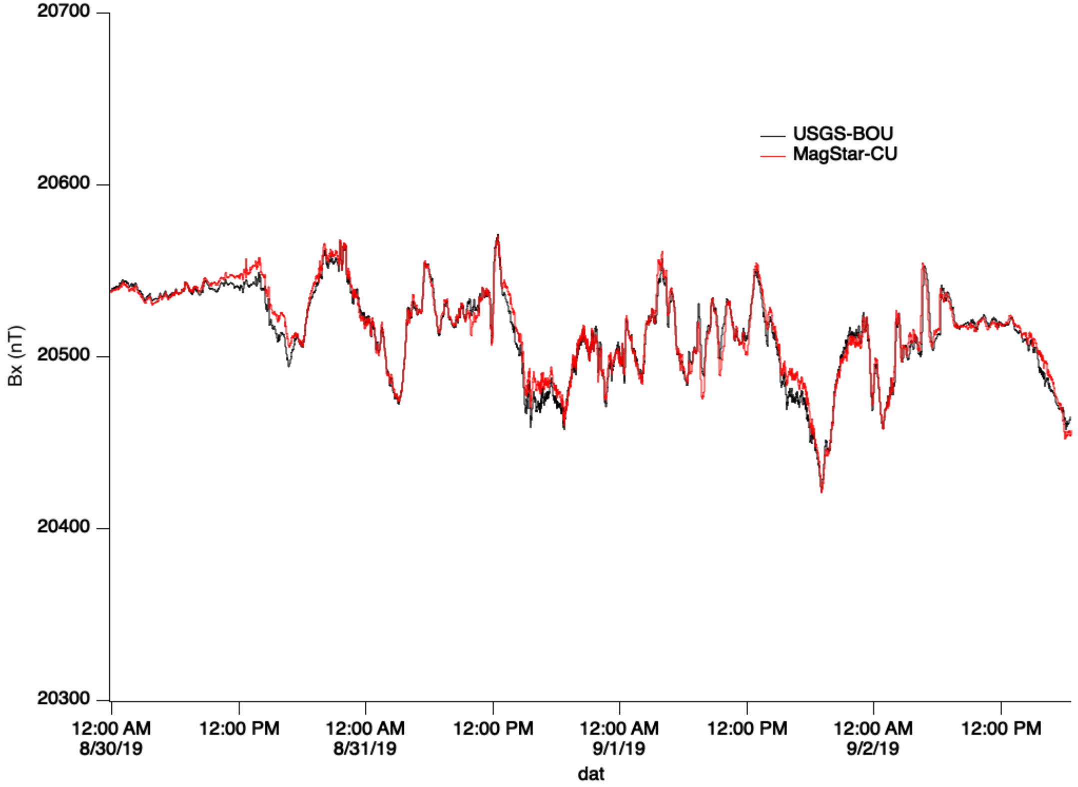


You need to handle temperature changes

Raw

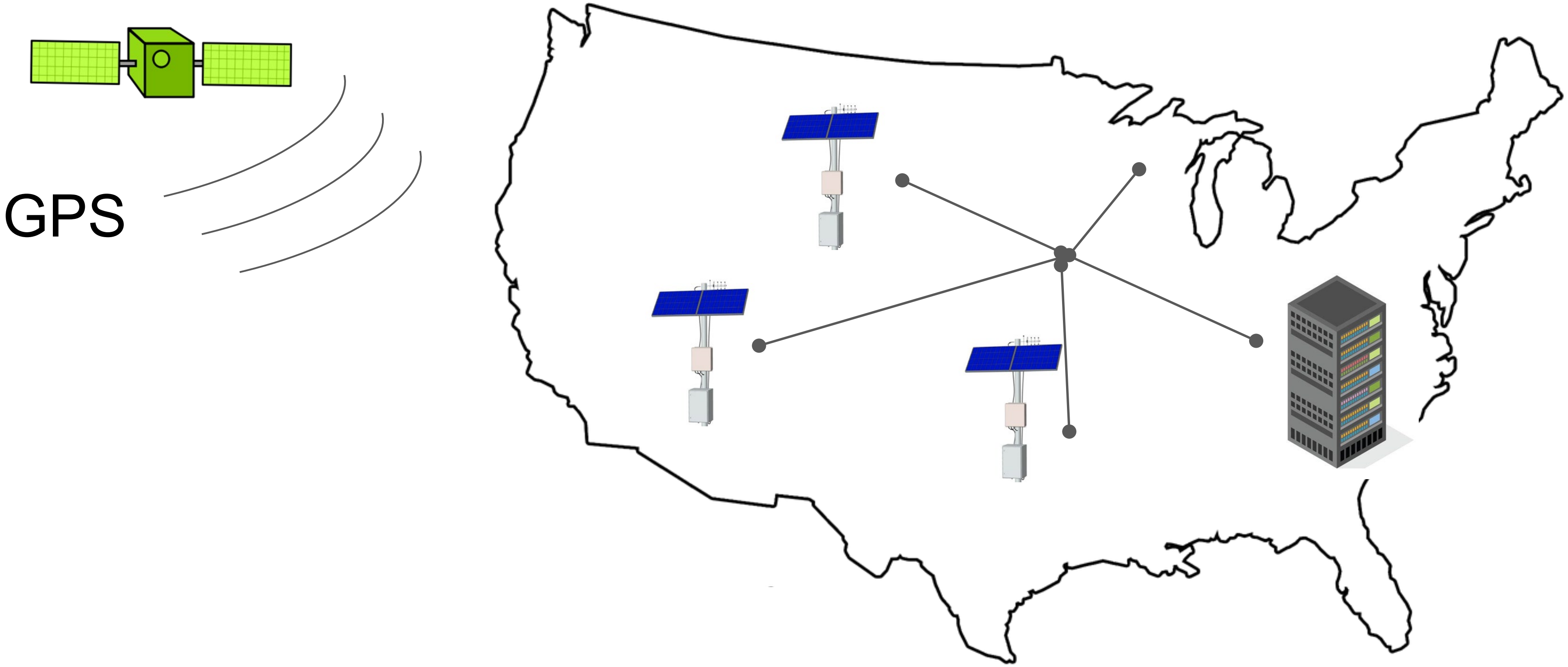


Calibrated to USGS Observatory



GIC Magnetics

You need to time align the data

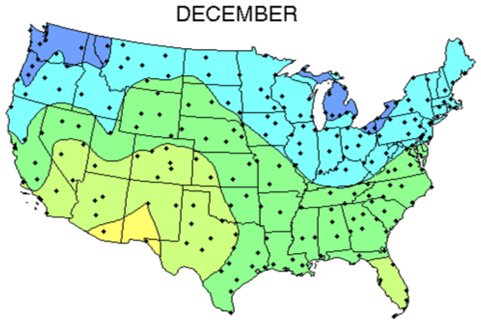


Timestamp data **at the sensor** to avoid network timing jitter

You need to power the system

6 Watts ...

continual operation in mid winter ...



... **360 Watt** solar (22 ft²)

You need to get the data to a server

Physical security can be difficult to guarantee at remote sites

Mitigate security risks of a **physically compromised** station

Cellular or point-to-point ethernet link

If cellular, M2M accounts

You need to store the data

Things to consider:

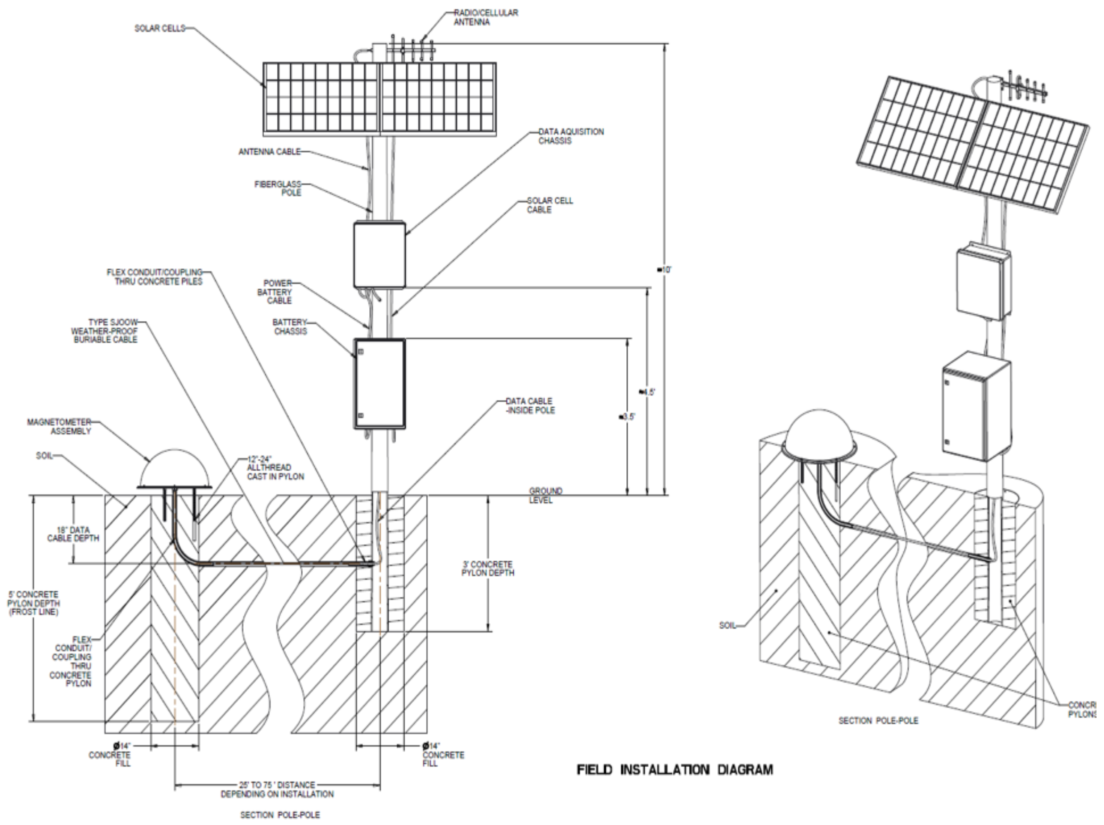
- Probably want read-only access for most people
- Data rate for 1 station = 8 GB per year

Permanent, autonomous sensor stations

MagStar

Purpose-built magnetometer station
for GIC estimation

Featuring **Mag13-MSS**



GIC Magnetics

Impacts on Power Systems and FERC Regulations

Jennifer Gannon
Computational Physics, Inc.
gannon@cpi.com

FERC TPL-007 Regulation (Magnetic Fields)

⇒ **Measure magnetic field and geomagnetically induced currents (GICs) -- July 2021**

Why? Know local hazard conditions and use in model validation.

⇒ **Model validation of power system model -- July 2022**

Why? Accurate models mean that planning scenarios are accurate.

TPL-007 Model Validation Steps

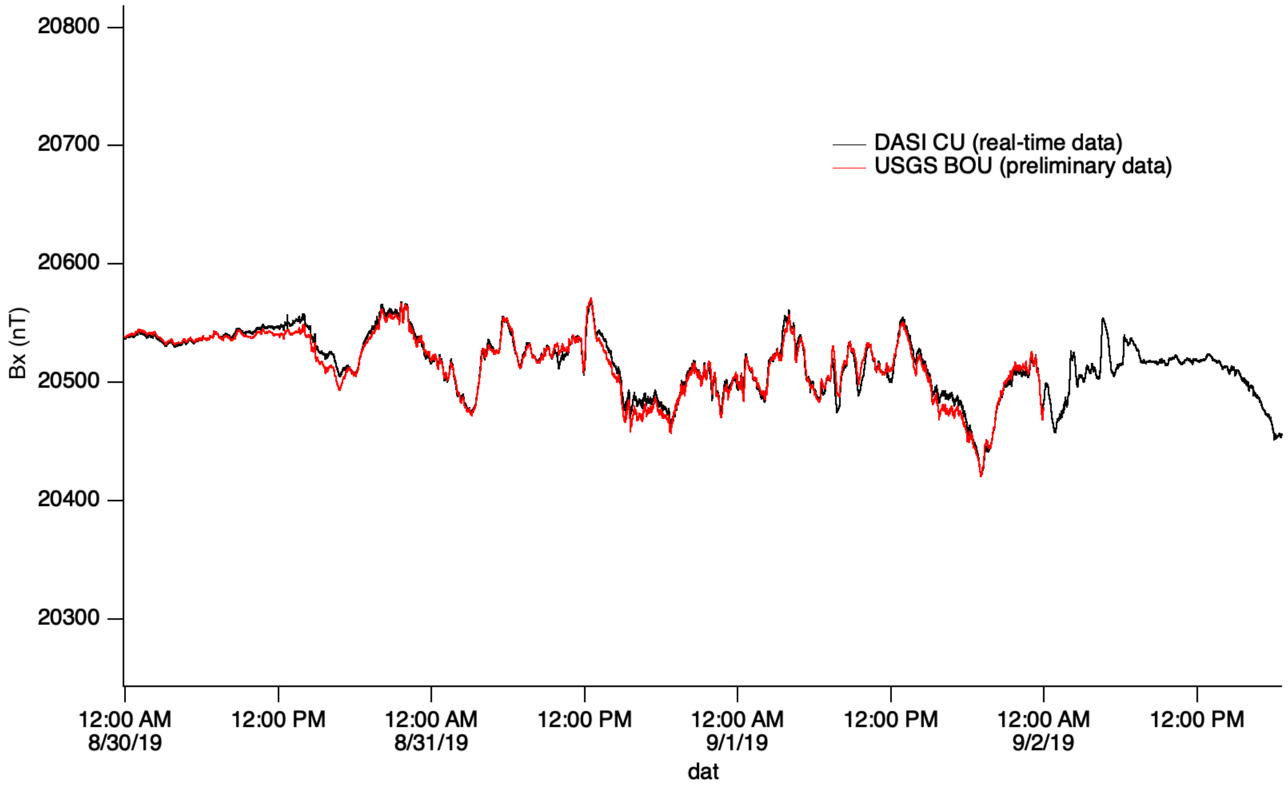
1. Measure **magnetic field** and **GIC** at the same time.
2. Calculate **electric field** from magnetic field and earth model.
3. Estimate **GIC** using electric field as input to system models.
4. Compare measured and modeled GIC

Reference: EPRI Model Validation Guide (with examples): Guidance for Validation of GIC models, EPRI Technical Update, EPRI, Palo Alto, CA, 2020 : 3002017897.

1. Measure magnetic field (and GIC)

Best practices for magnetic field data:

- 10 second (or shorter) cadence measurements
- Remove spikes and bad data
- Magnetic field measurements taken within 150 – 200 miles of GIC measurements



2. Calculate the electric field

There are multiple ways to do this:

- Scaling factors:
  - Used for scaling electric field from another location.
- Uniform electric field
  - Updated EPRI ground response transfer functions recommended
  - Every electric field point will be the same across your region, and will point in the same direction
- Non-uniform electric field
  - Most useful in high-response regions (Maine, mountain regions, Minnesota). *(CPI's AVERT model - http://gmd.cpi.com)*

EPRI earth response models: Improving conductivity models for Geomagnetically Induced Current Estimation, EPRI Technical Update, EPRI, Palo Alto, CA, 2018: 3002014856.

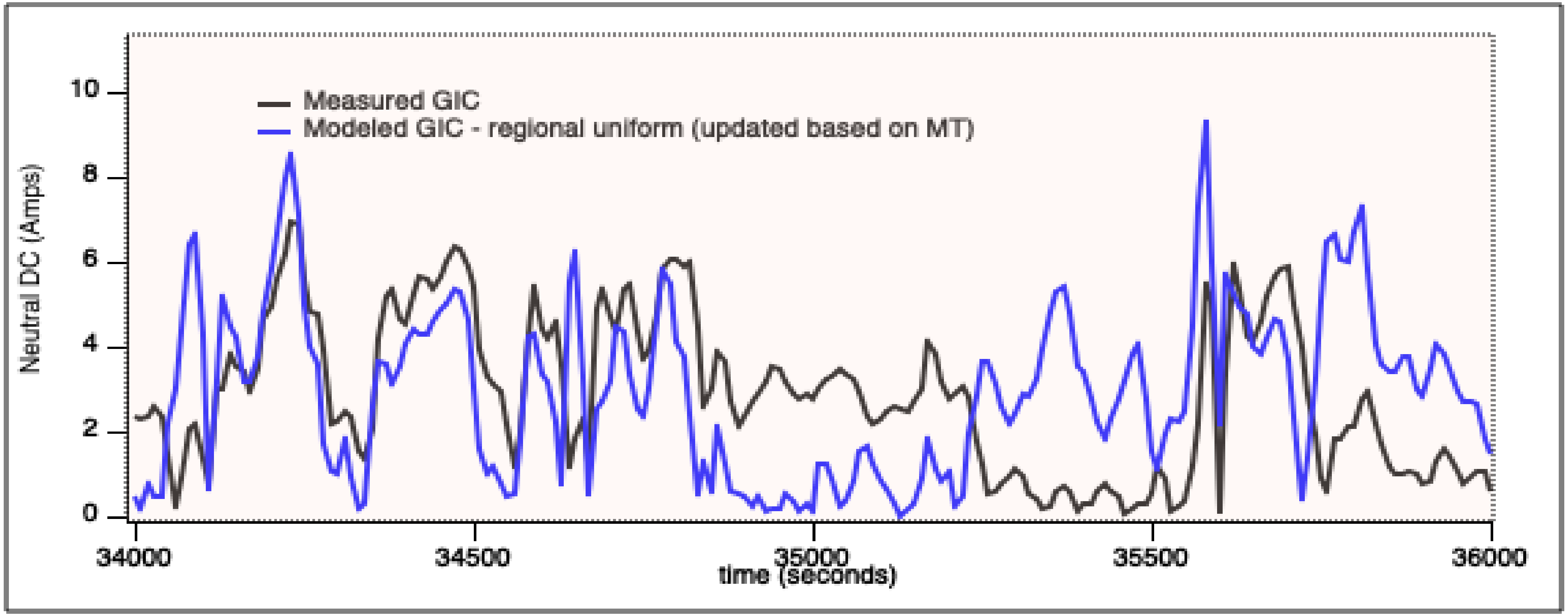
3. Estimate GIC using electric field as input to system model

- System models, like PowerWorld or PSSE, can use electric field inputs to model GICs
- Note that some system modeling software uses DIFFERENT NOTATION for N-S and E-W!!

4. Compare measured and modeled GIC

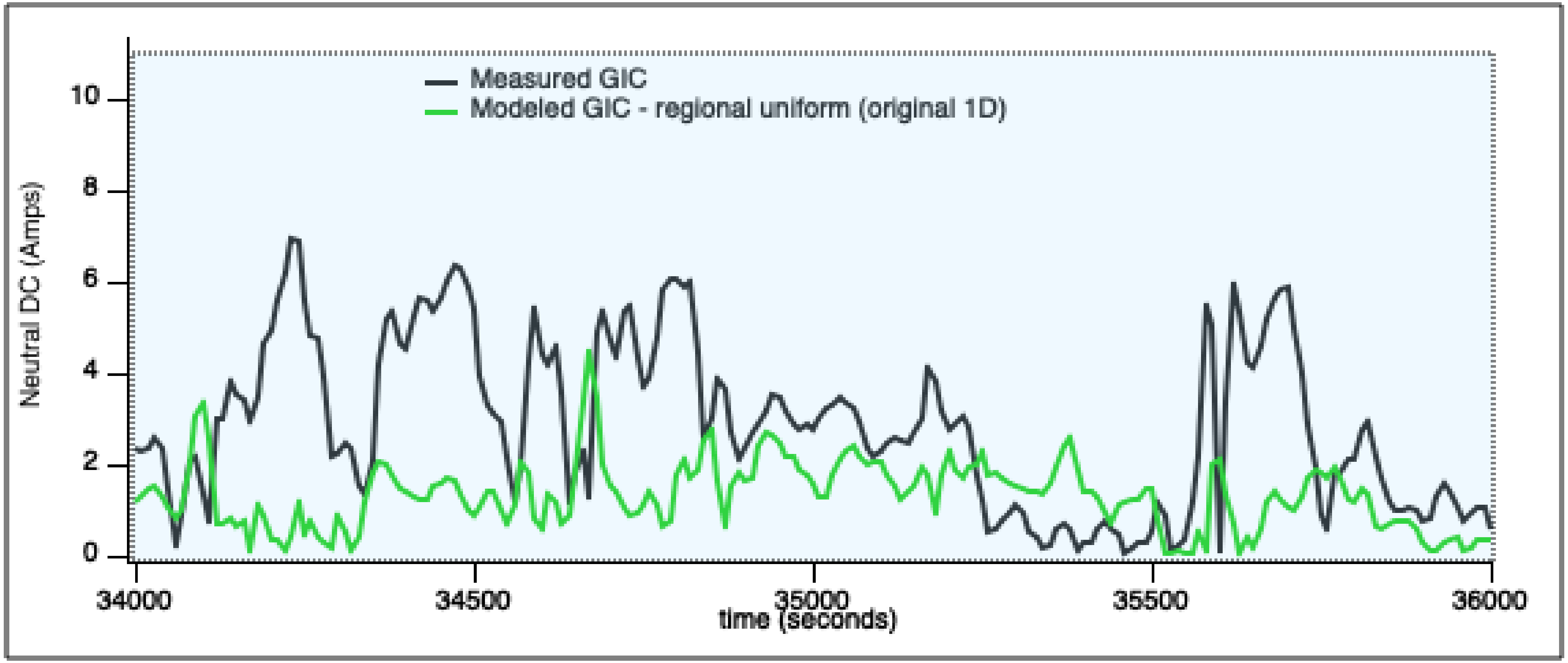
- Make sure you have a good data
- Don’t expect a perfect, point by point match.

Estimating GIC – Decent match



Reference: EPRI Model Validation Guide (with examples): Guidance for Validation of GIC models, EPRI Technical Update, EPRI, Palo Alto, CA, 2020 : 3002017897.

Estimating GIC – Not as good.



Reference: EPRI Model Validation Guide (with examples): Guidance for Validation of GIC models, EPRI Technical Update, EPRI, Palo Alto, CA, 2020 : 3002017897.

Top causes of GIC estimation errors

1. **Inaccurate/outdated substation grounding values**

   Solution: update/improve system model.

2. **Magnetic field is inaccurate in intensity <u>or direction</u>**

   Solution: use local magnetometer. Make sure you have good data!

3. **Local geologic complexities**

   Solution: improve electric field calculations or ground conductivity models.

Resources

Feel free to reach out to me with questions, I'm happy to help, if I can: gannon@cpi.com

EPRI Model Validation Guide (with examples): Guidance for Validation of GIC models, EPRI Technical Update, EPRI, Palo Alto, CA, 2020 : 3002017897.

EPRI earth response models: Improving conductivity models for Geomagnetically Induced Current Estimation, EPRI Technical Update, EPRI, Palo Alto, CA, 2018: 3002014856.

Find your geomagnetic latitude on a map: http://gmd.cpi.com/resources.html or http://magneticlatitude.com .

Magnetic Storm monitoring

Application to the Oil & Gas Directional Drilling industry

Presented by:

Ludo Letourneur
Senior Sales Engineer
GMW Associates
ludo@gmw.com

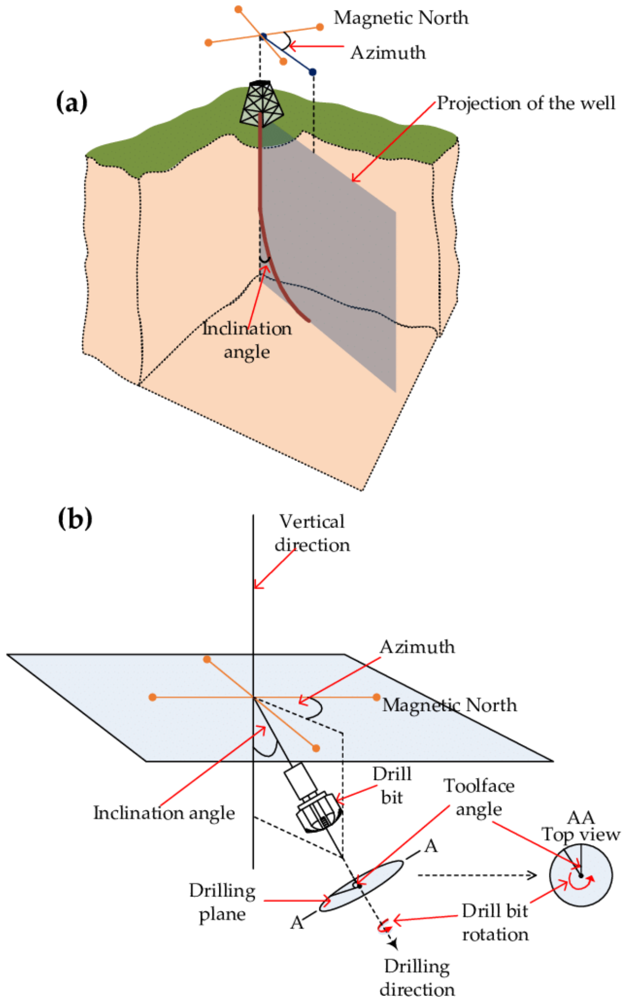
GMW Associates

Rapid change of field during geomagnetic storms impact accuracy of magnetometers used in directional drilling package.

- Change in amplitude can lead to temporary change in field azimuth and inclination – data which are relied on to direct the drilling tool in the borehole.

- Having local ground magnetometer data can help determine periods of heavy disturbances. Corrections or alert can be obtained/raised from the magnetometer data.

- Proximity to the drilling site is essential as the further from the site you are, the less useful the data become – geomagnetic storms can see their effect decrease relatively rapidly especially when travelling further away from the poles.

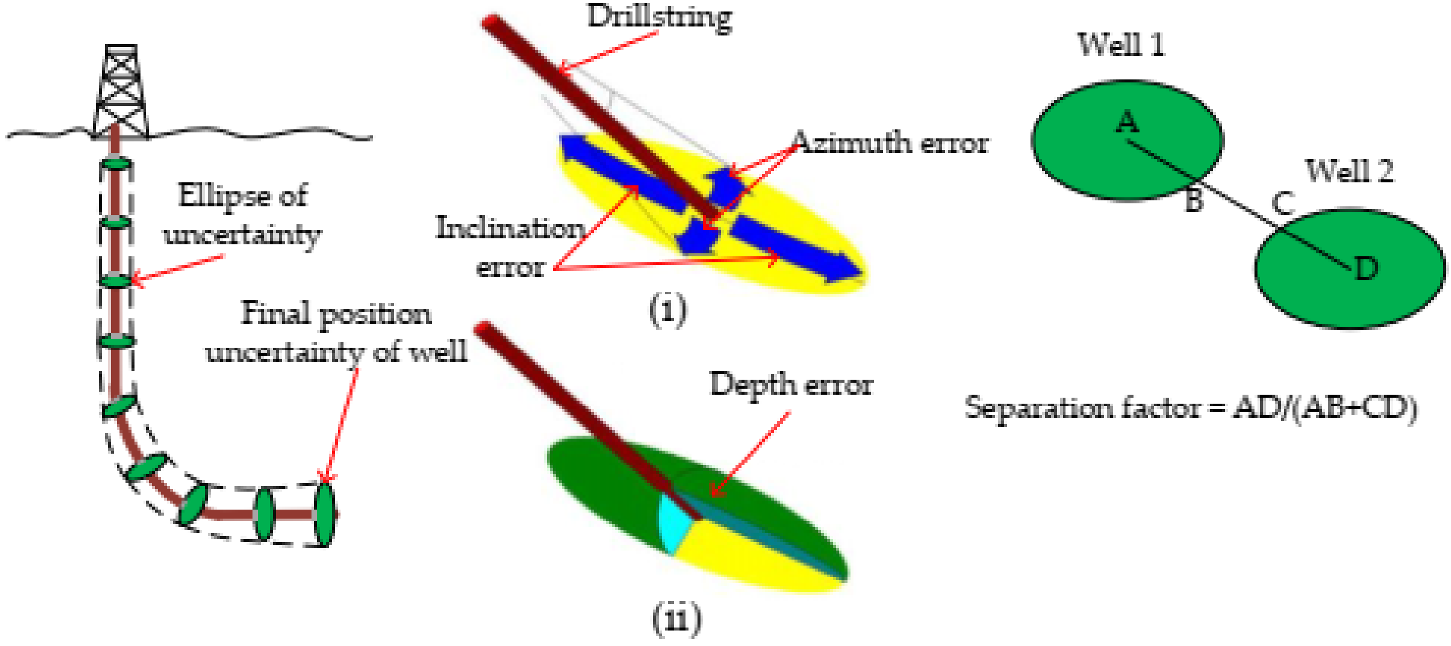


From Gooneratne et al., 2017. Downhole Applications of Magnetic Sensors. Sensors, 17, 2384.

GMW Associates

For directional drilling – sensors typically have a 50nT precision and aim to achieve ~0.1 degrees in directional accuracy.

- Magnetic anomalies from storms can be in the range or in excess of hundreds of nT
- The angular range that can be observed could be up to 0.2-0.5 degrees in excess of the desired accuracy.
- Increased error can lead to
  - an increased risk of collision
  - less optimal intersection with the target reservoir



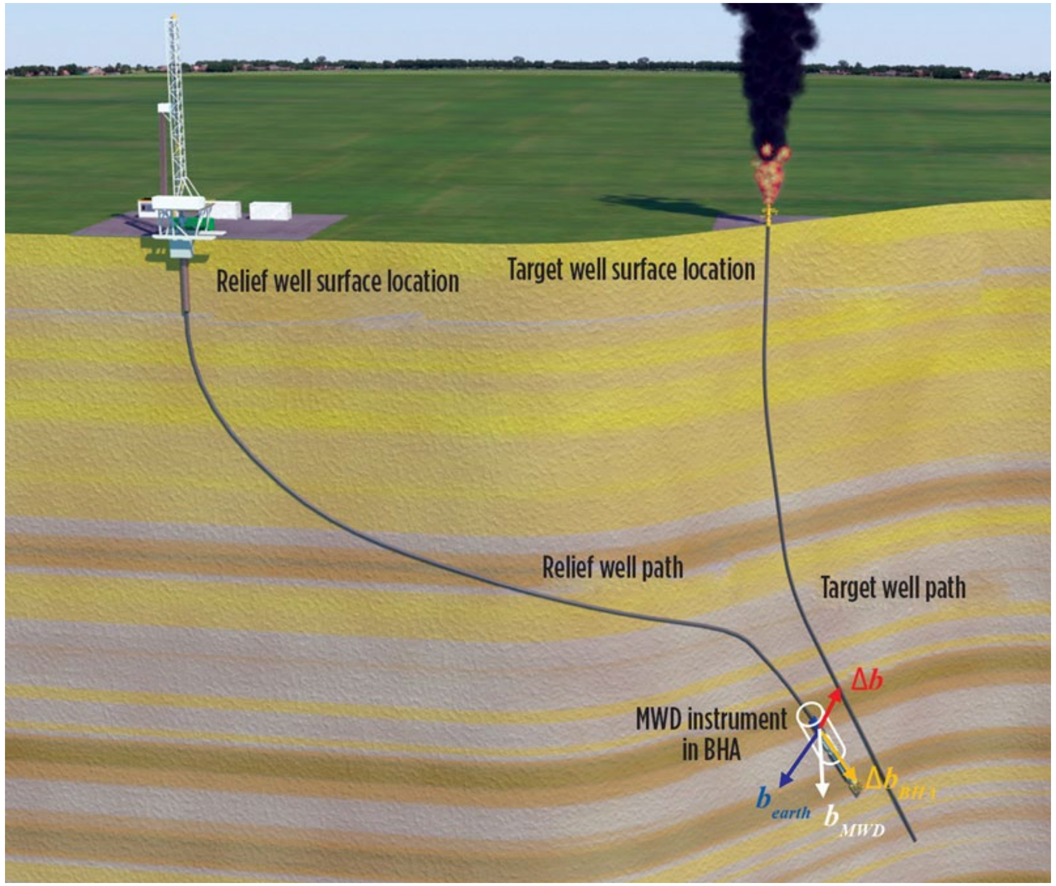
From Gooneratne et al., 2017. Downhole Applications of Magnetic Sensors. Sensors, 17, 2384.

GMWAssociates

Impact on magnetic ranging: Magnetic ranging is the technology used to accurately position multiple wells in relation to one another (or intersect wells)

- Active ranging uses an AC source and will therefore be more immune to the geomagnetic storm.

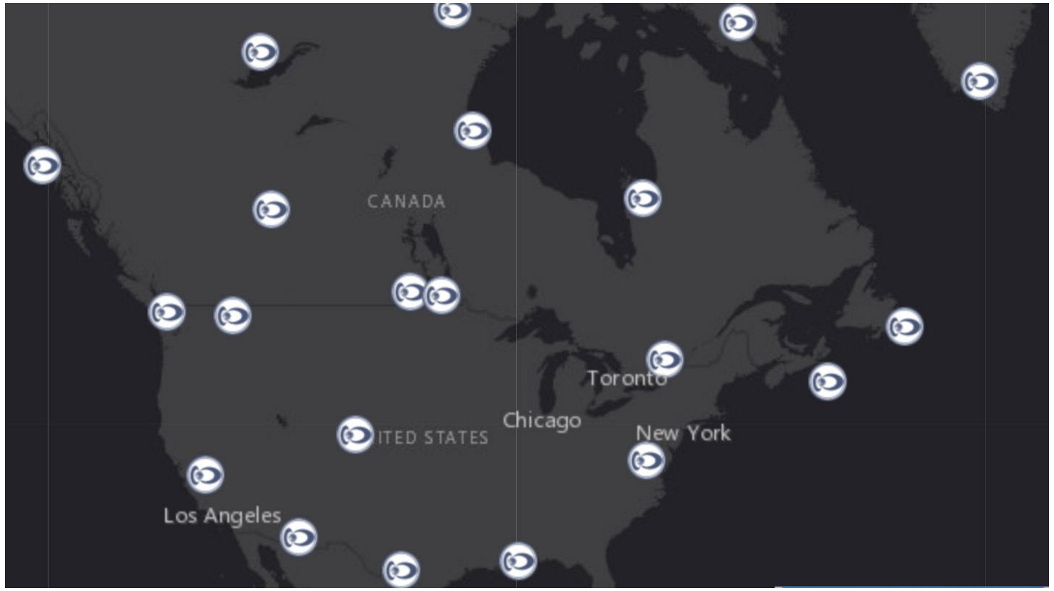
- Passive ranging uses well casing as the 'magnetic source' – this is purely DC and will be greatly affected by geomagnetic storms



From Roggeband et al., 2020. Passive-magnetic ranging capability for relief wells in salt formations. World Oil, Vol 12, n241.

External data can help determine whether variations observed are due to instrument error or are external field changes – proximity of the external sensor is important – magnetic observatories in the US or Canada are not always close to production basins

- Data can be used to determine go/no go for drilling operation.
- Data can also be used for correcting the data from the drilling tool.



The use of fluxgate magnetometers for Space Weather monitoring

MagStar

MagStar network managed by Computational Physics Inc (CPI)
Image courtesy of CPI.
Map of Intermagnet observatory

GMW Associates

Next step with the system

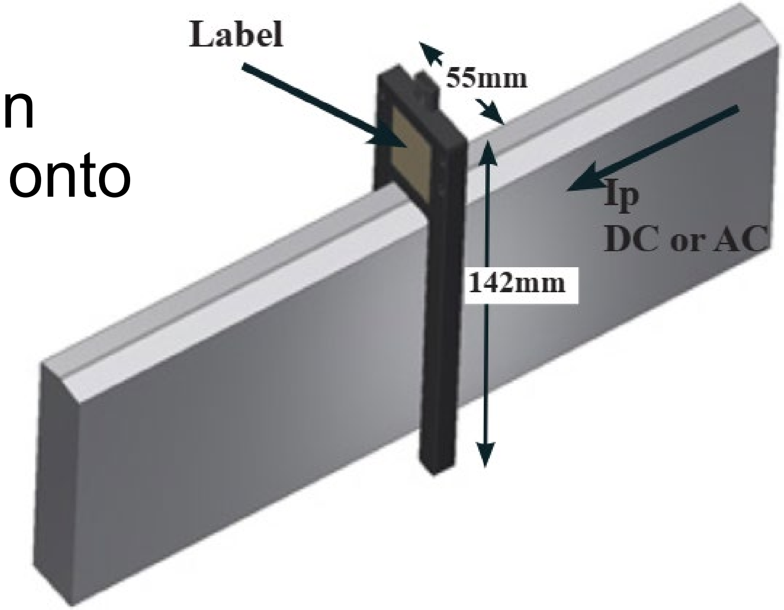
Presented by:

Ludo Letourneur
Senior Sales Engineer
GMW Associates
ludo@gmw.com

GMW Associates

Magnetic data used to monitor the space weather data are fed into models of network and conductivity to provide prediction of GIC amplitude.

- An additional set of data would be to provide directly a reading of the current on transformer ground
- Clip-on and slip-on design allow for easy retrofitting onto conductors.
- Hall-effect CT



Slip-on and clip-on GMW current transducers. DC operation.

GMW Associates

Questions?

Please enter any questions into the chat box, thank you!

Ludovic Letourneur, PhD
ludo@gmw.com
Senior Applications Engineer
GMW Associates

Jenn Gannon, PhD
gannon@cpi.com
GMD Lead
Computational Physics, Inc.

Mike Henderson
mphend@gicmagnetics.com
Owner and Principal Engineer
GIC Magnetics