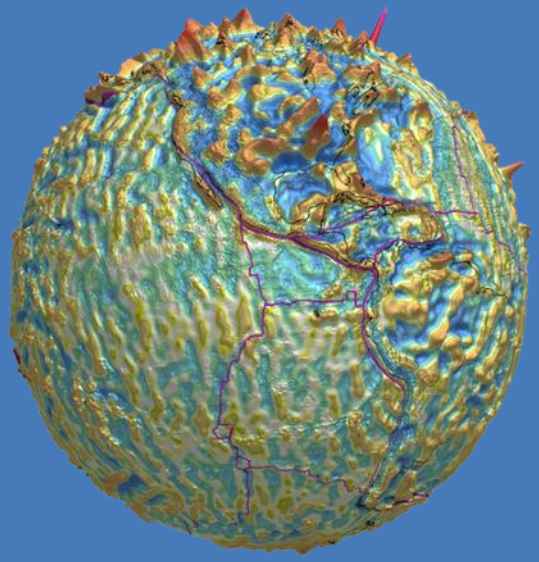
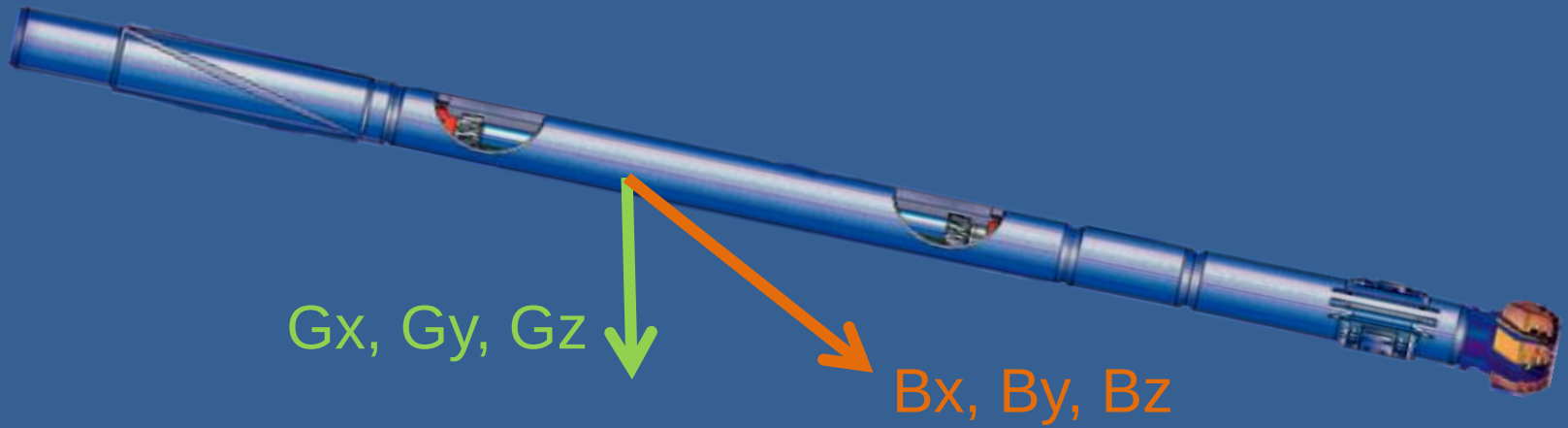
On-Site Disturbance Field Measurement:



A portable real-time disturbance field monitoring station

Motivation

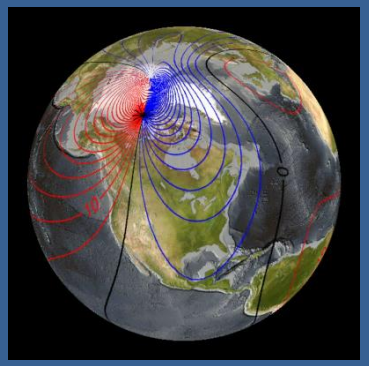
- MWD wellbore azimuth is determined relative to the geomagnetic field



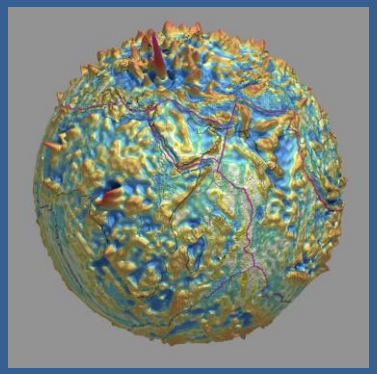
- Converting magnetic azimuth to true azimuth requires knowledge of the direction of the geomagnetic field, at the point of measurement downhole
- Since Earth's magnetic field varies spatially and with time, referencing against it requires measurement of the spatial and temporal variations

Magnetic Field Components

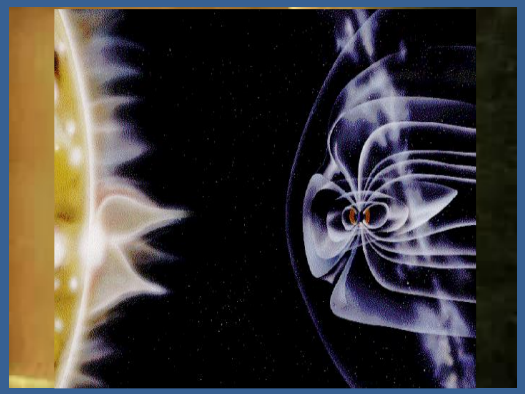
Main Field



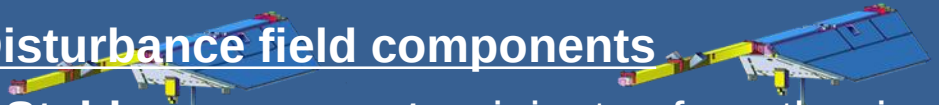
Crustal Field



Disturbance Field

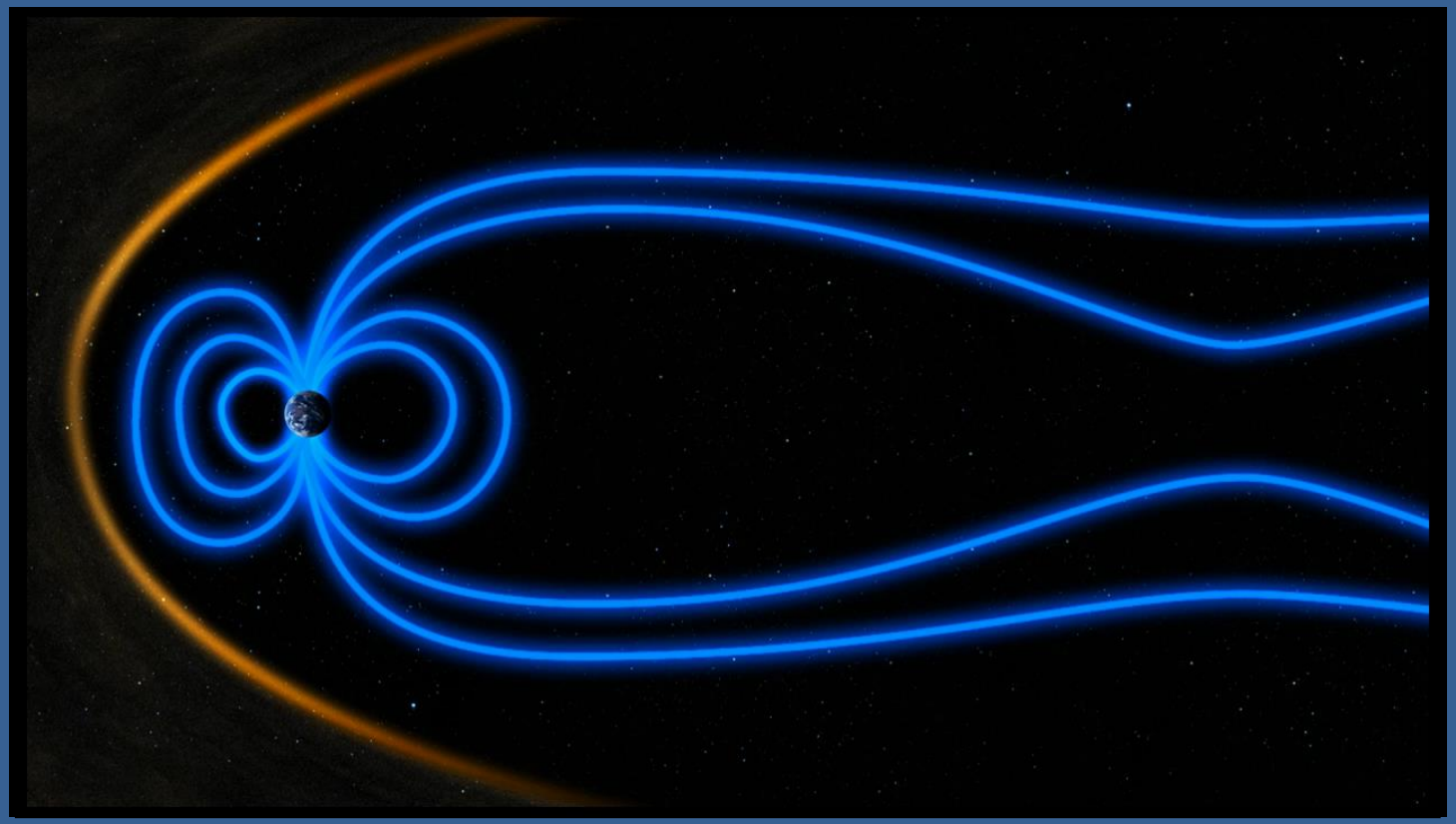


Disturbance field components



- **Stable component:** originates from the ring current; varies with solar cycle
- **Seasonal component**: periods of months to 1 year, accounted for by global measurements and subsequent modeling
- **Rapid variations**: solar storms, diurnal variations, auroral events – short timescale typically less than 2 weeks, events with large magnetic swings

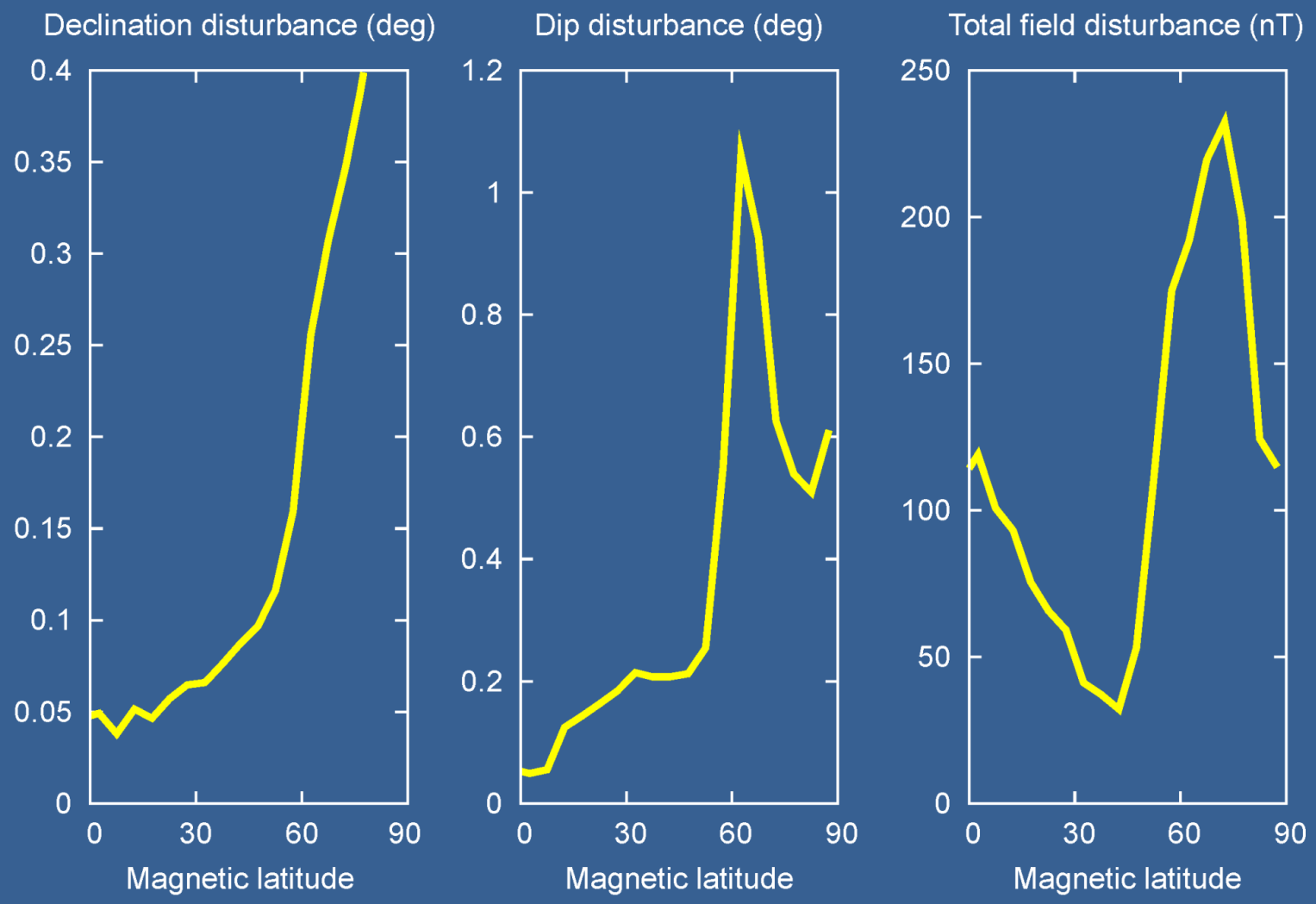
Source of Disturbance Field



- The solar wind deforms Earth's fields steadily and impulsively
- This requires disturbance field monitoring to capture time variation

Disturbance Field Averages

(1-sigma, magnetic storm*) *Defined here as Kp ≥ 6



Disturbance Field Averages

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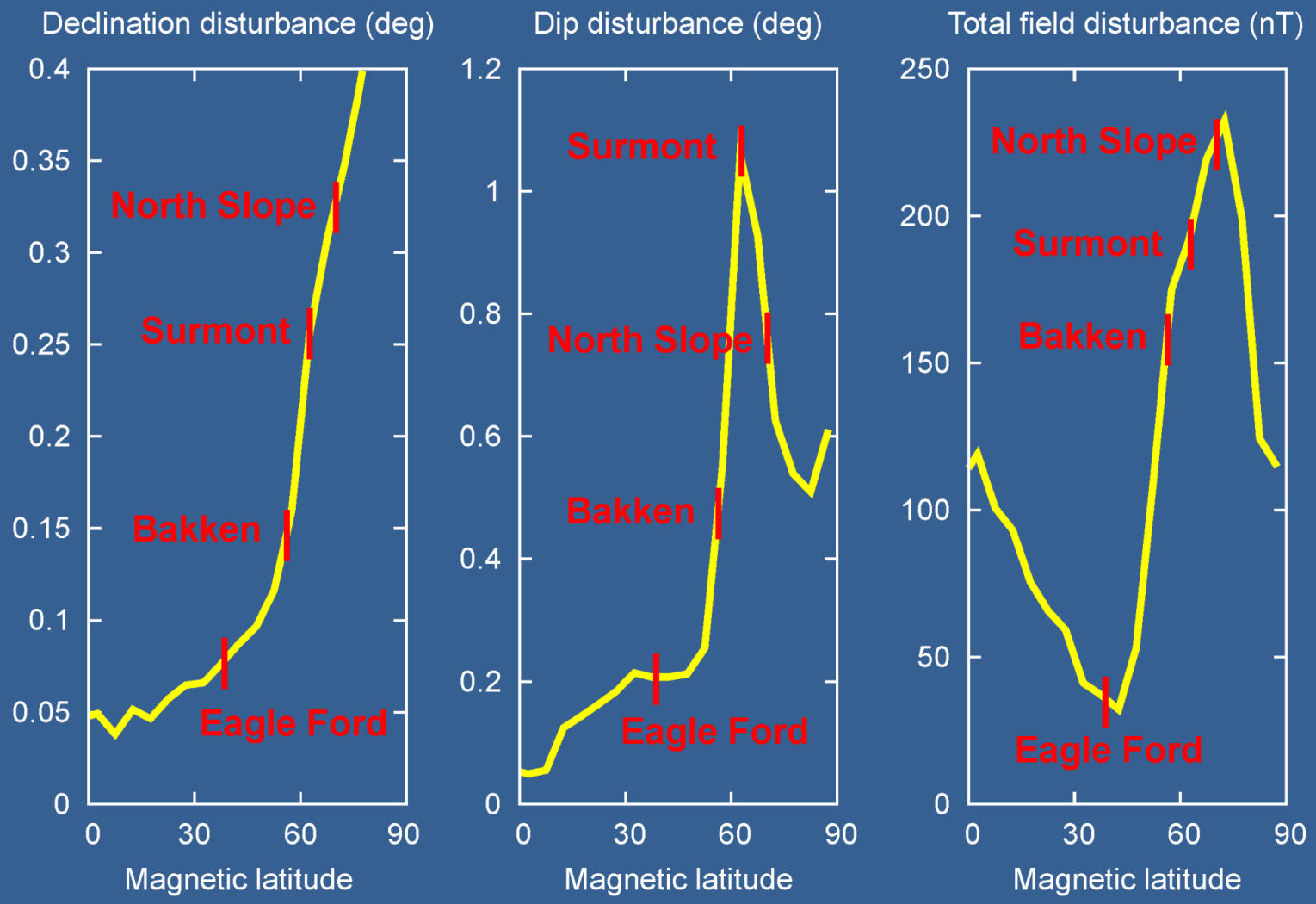
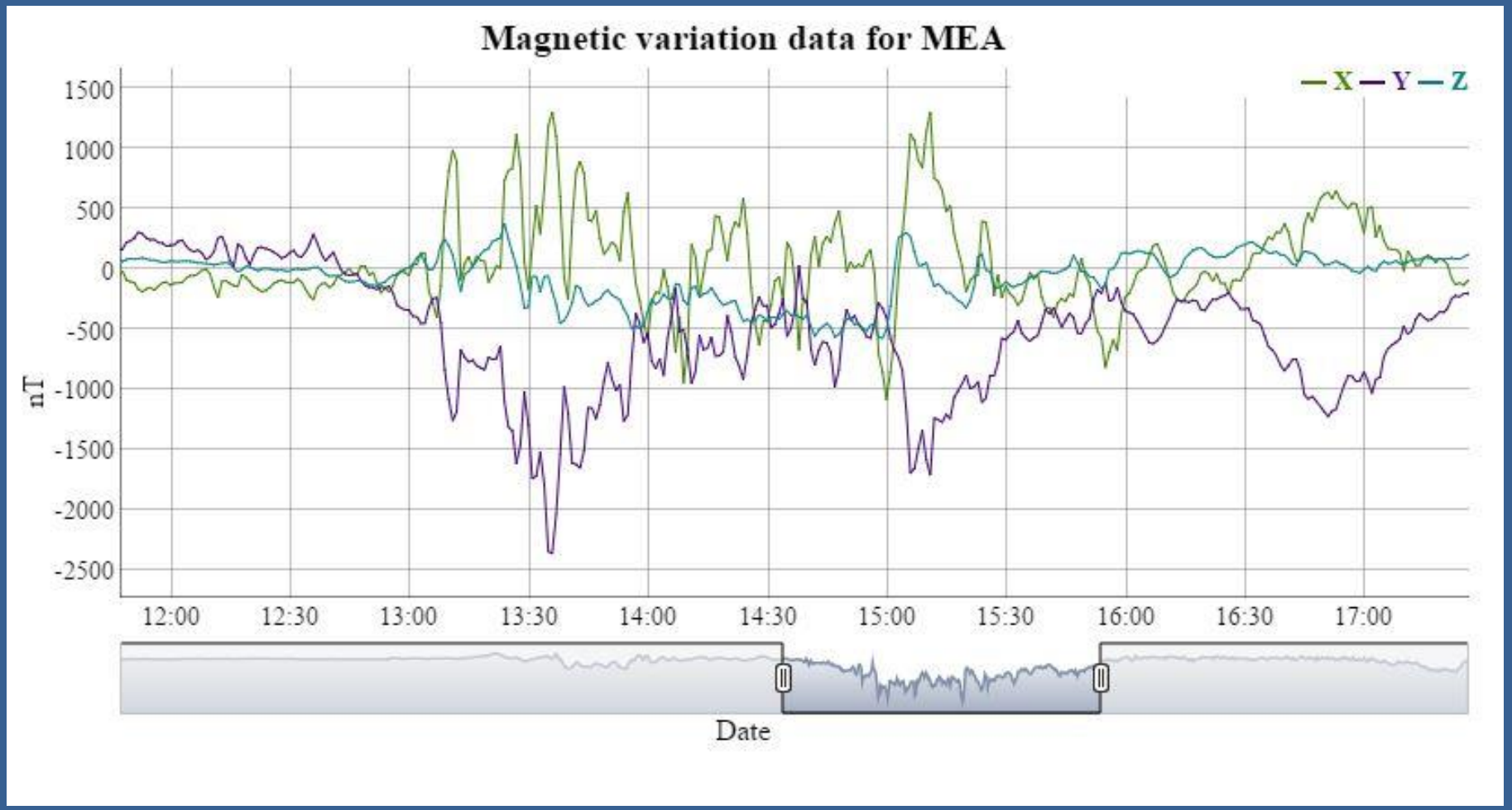


Typical Storm-Time Disturbances

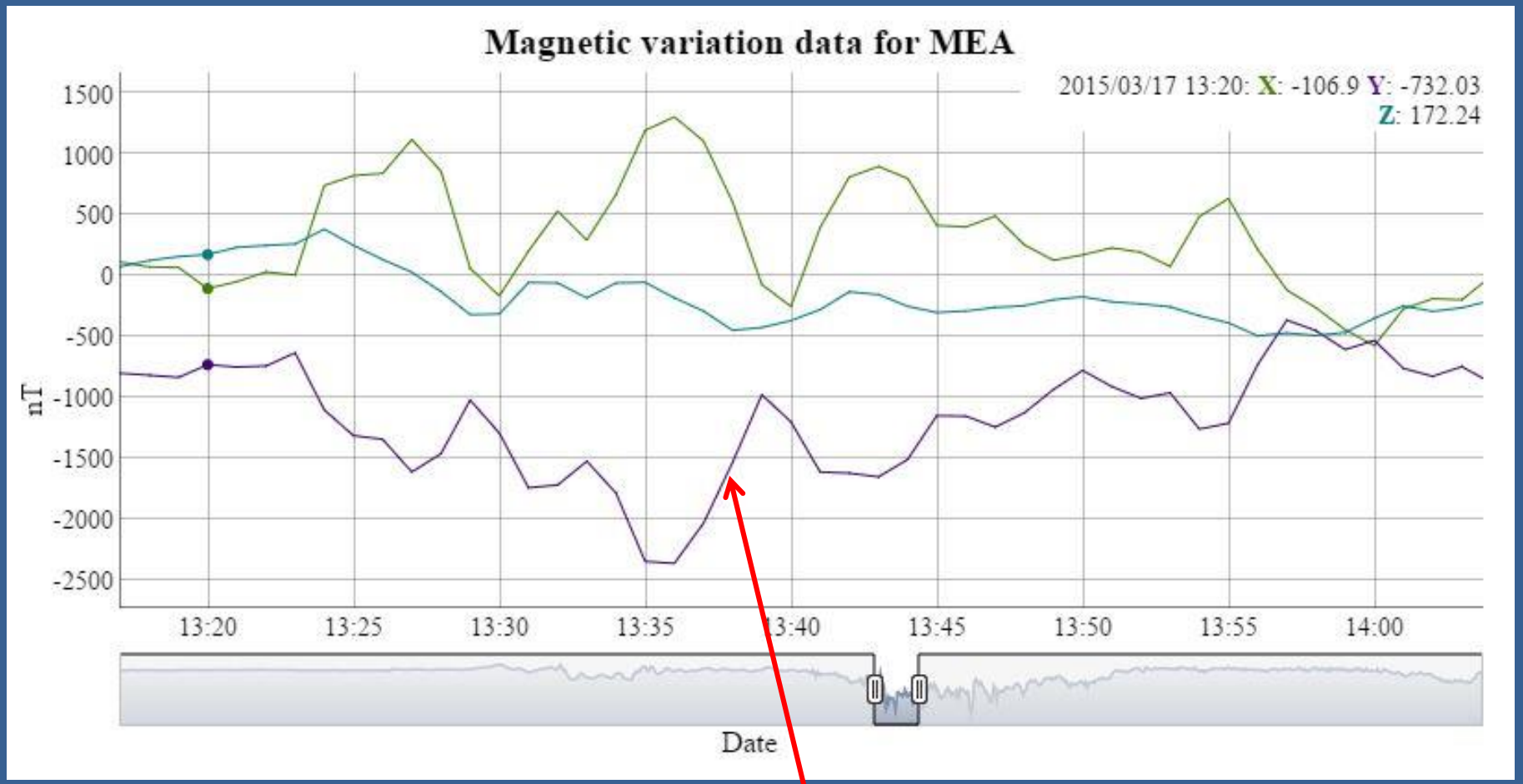
Alberta



Meanuk, 17-Mar-2015

Typical Storm-Time Disturbances

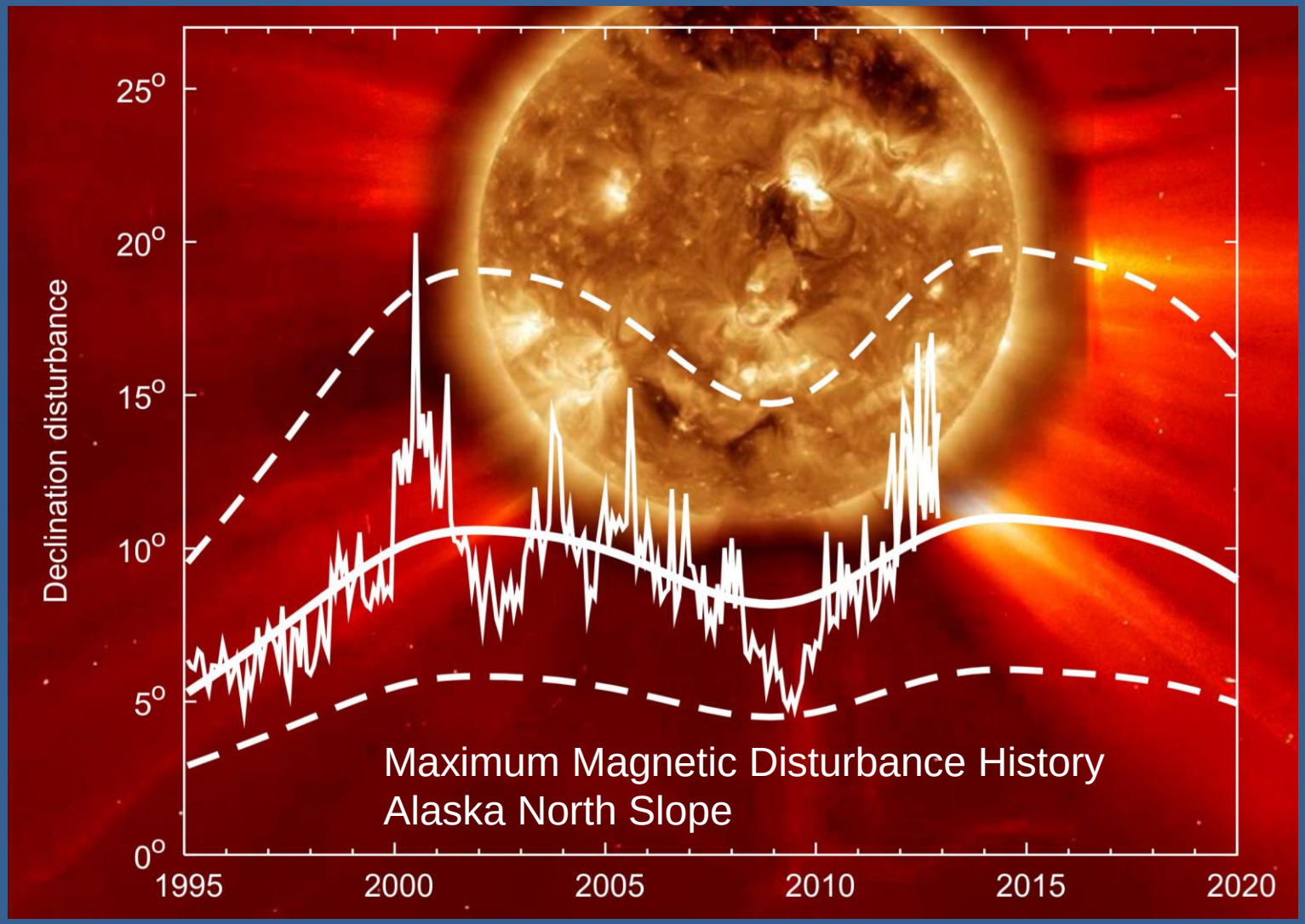
Alberta
1-minute averages



Meanuk, 17-Mar-2015

Field changes by 500 nT from 1 minute to next

Disturbance Fields Maximums

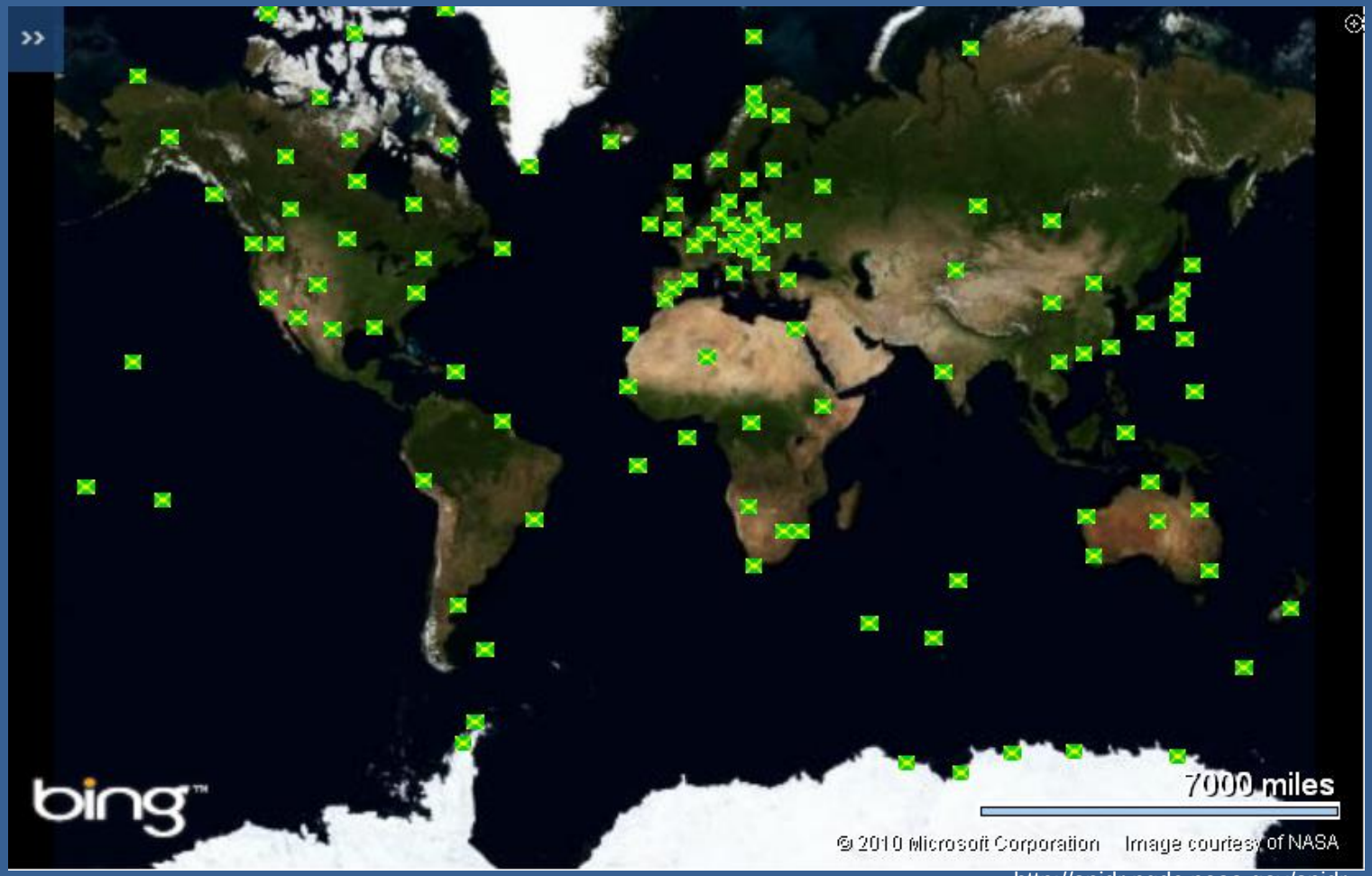


Impact on Wellbore Position and QC

- Systematic disturbance field contributions do change your well trajectory
  - See Maus, S. *Systematic and Random Contributions to the Disturbance Field (IFR 2).* ISCWSA Proc., 2014.
- By correcting for the disturbance field you will have fewer surveys failing QC
- With disturbance field monitoring drilling can continue through magnetic storms, reducing down time

Fixed Magnetic Observatories

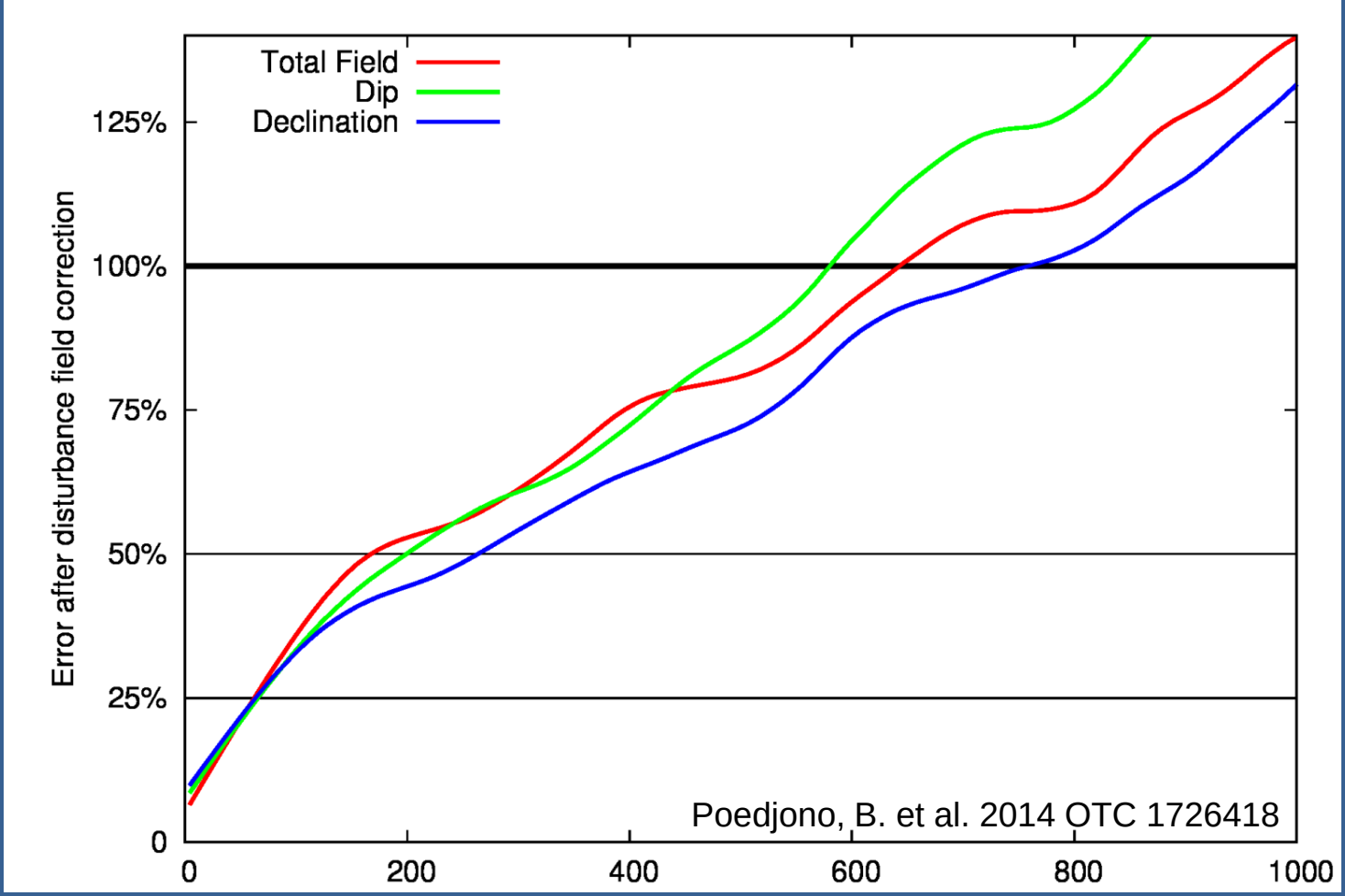
- A network of observatories provide sparse coverage of the globe
- These require interpolation to be used for IIFR service



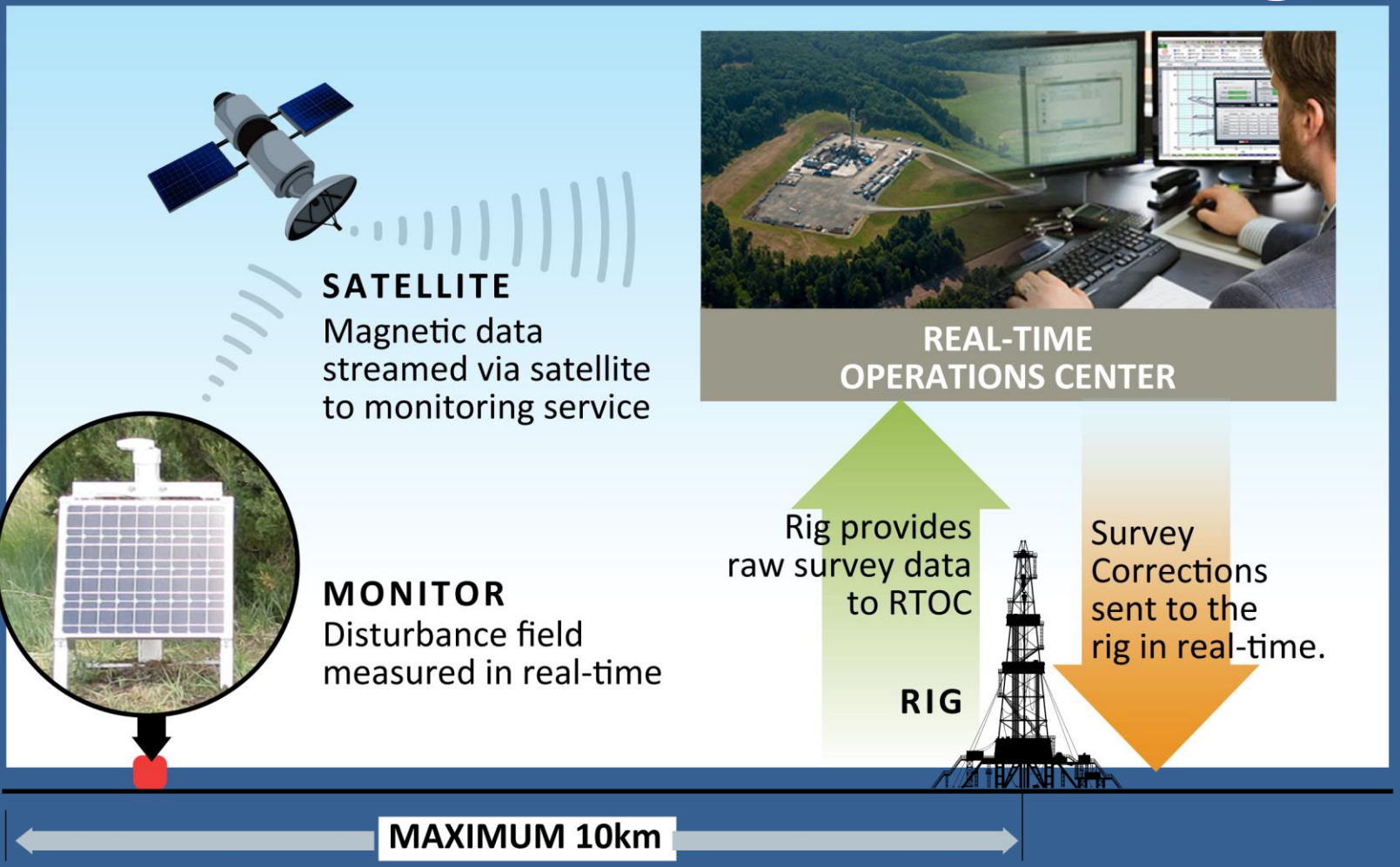
http://spidr.ngdc.noaa.gov/spidr

Benefit of On-Site Measurement

Assuming only 1 nearby station is used for the IFR2 correction:

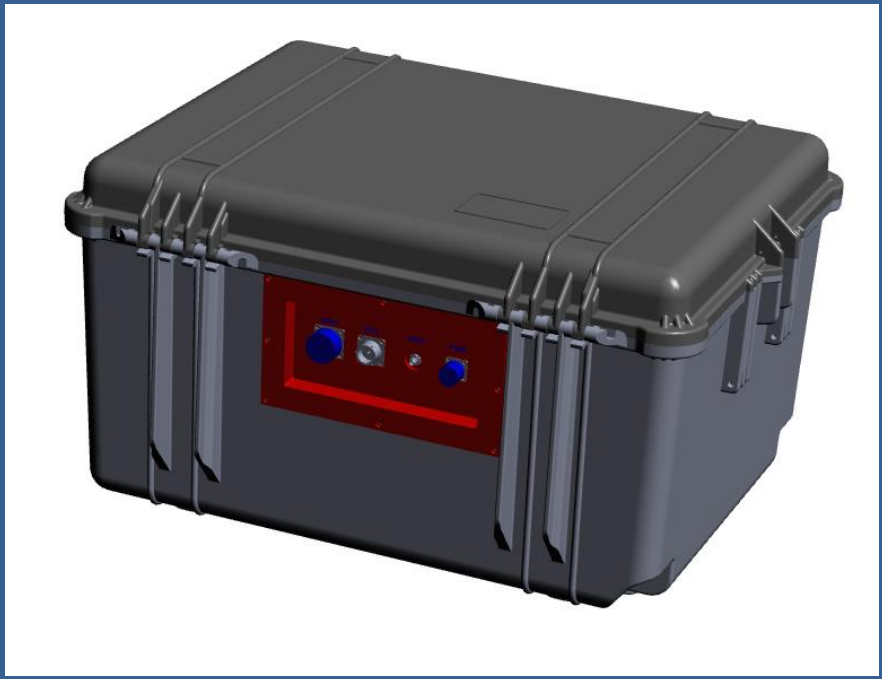


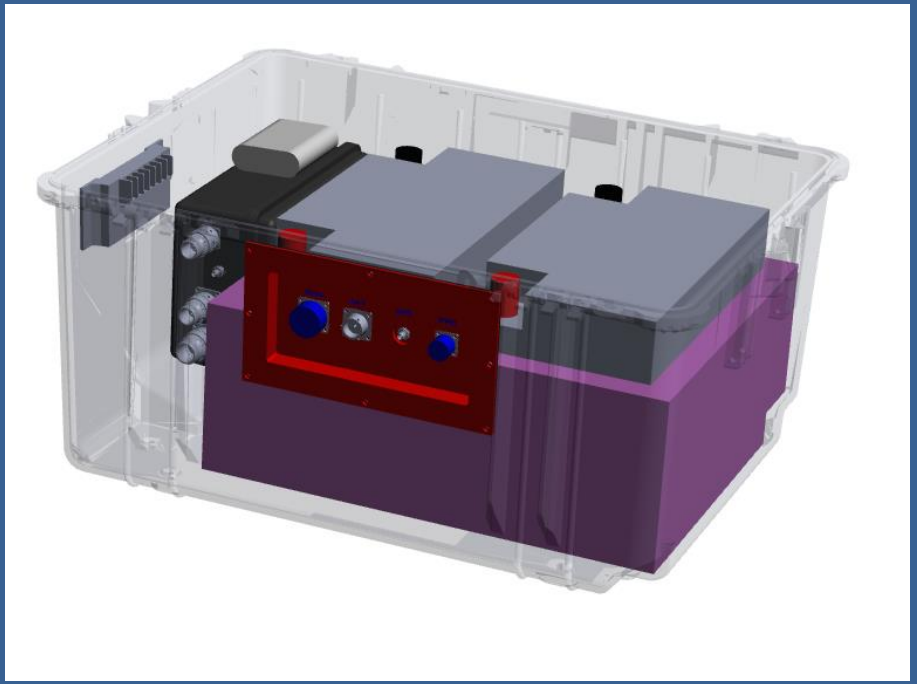
Local and Real-time Disturbance Field Monitoring



Monitoring Station Hardware

- Ruggedized hardware for reliable field operation
- Remote data collection, control, and health monitoring for ease of operation





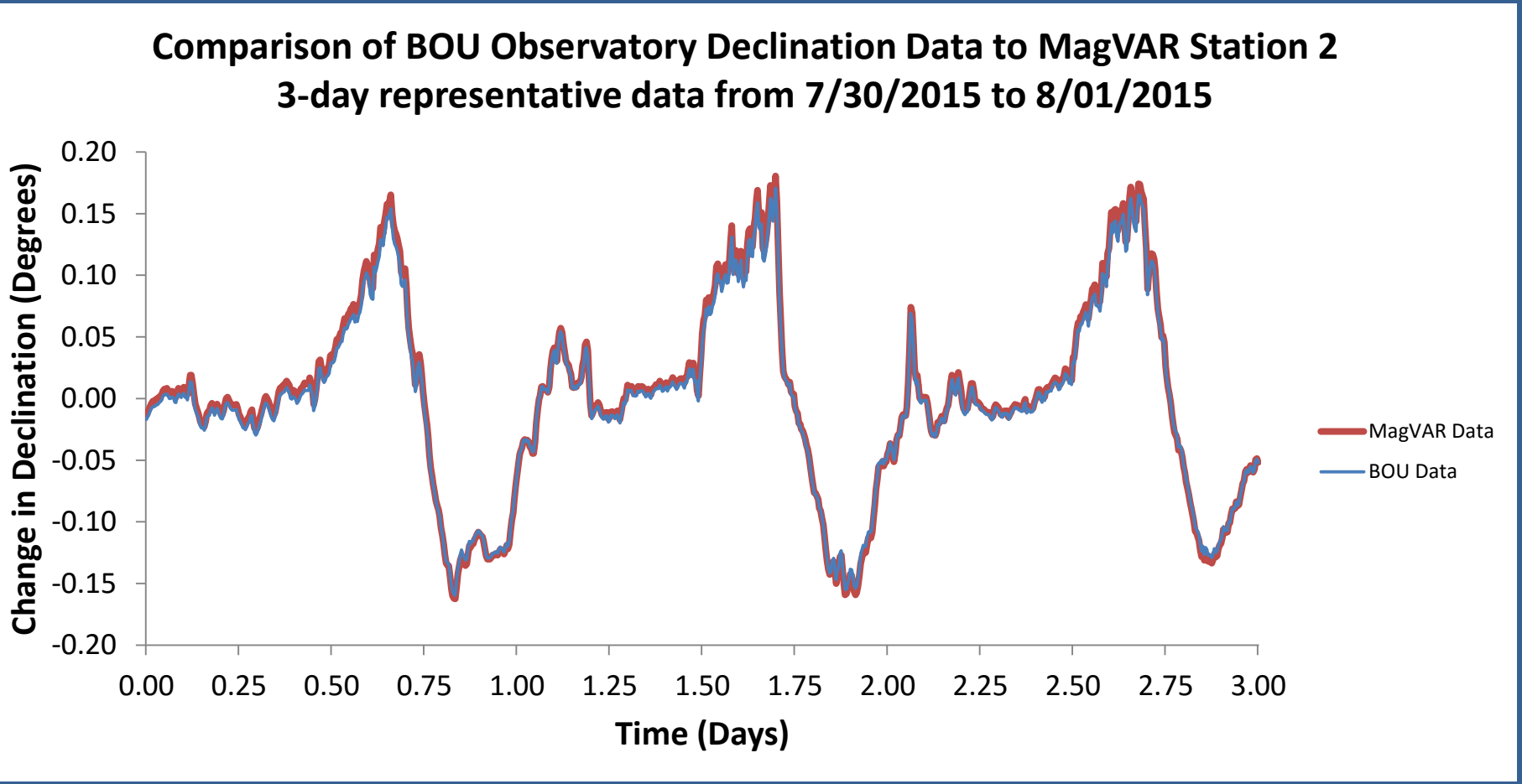
Validation Deployments

Bakken, North Dakota

Loveland, Colorado

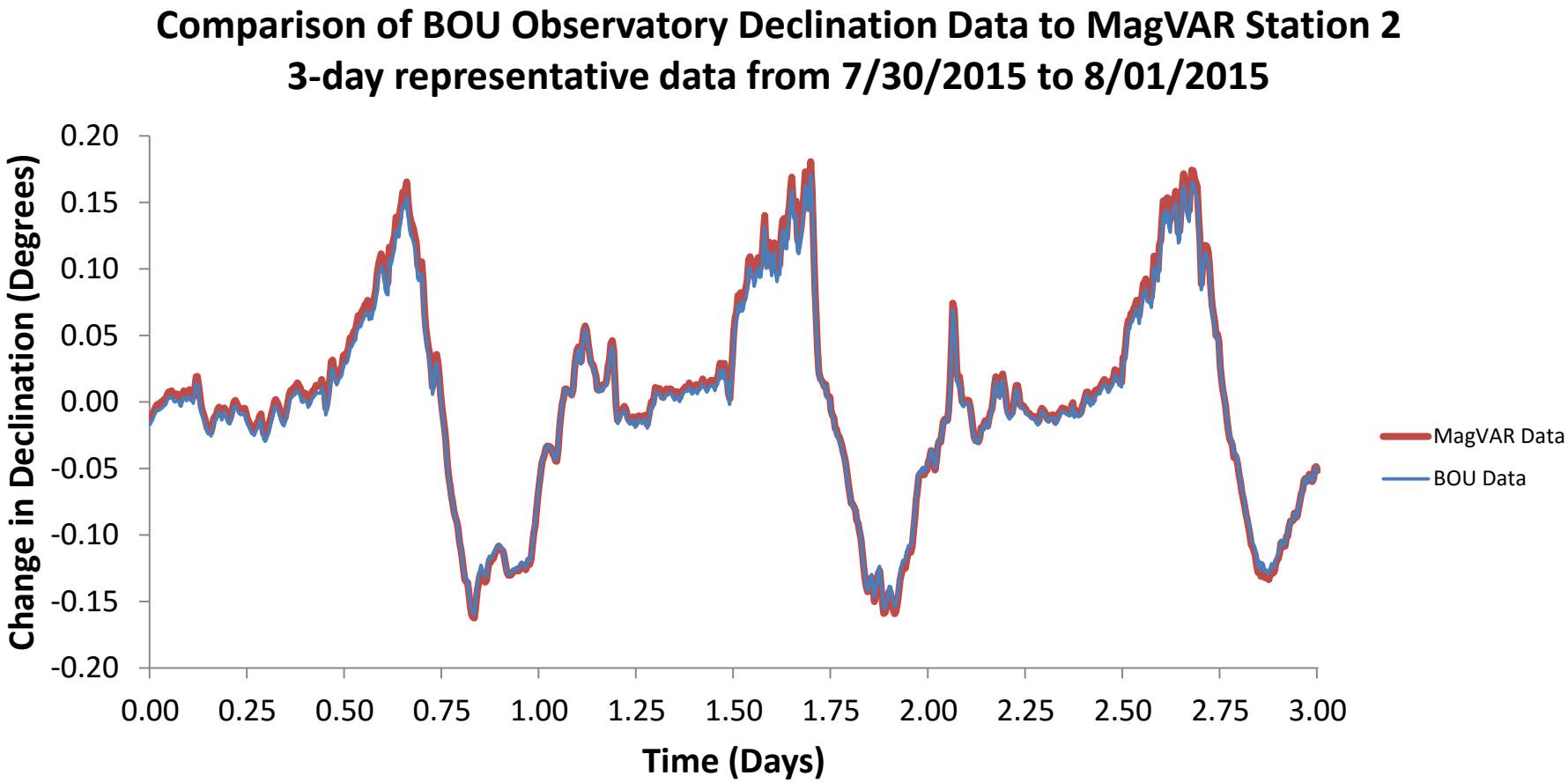
Validation: Boulder Observatory

Declination Validation with Boulder Observatory



Validation: Boulder Observatory

B_{total} Validation with Boulder Observatory

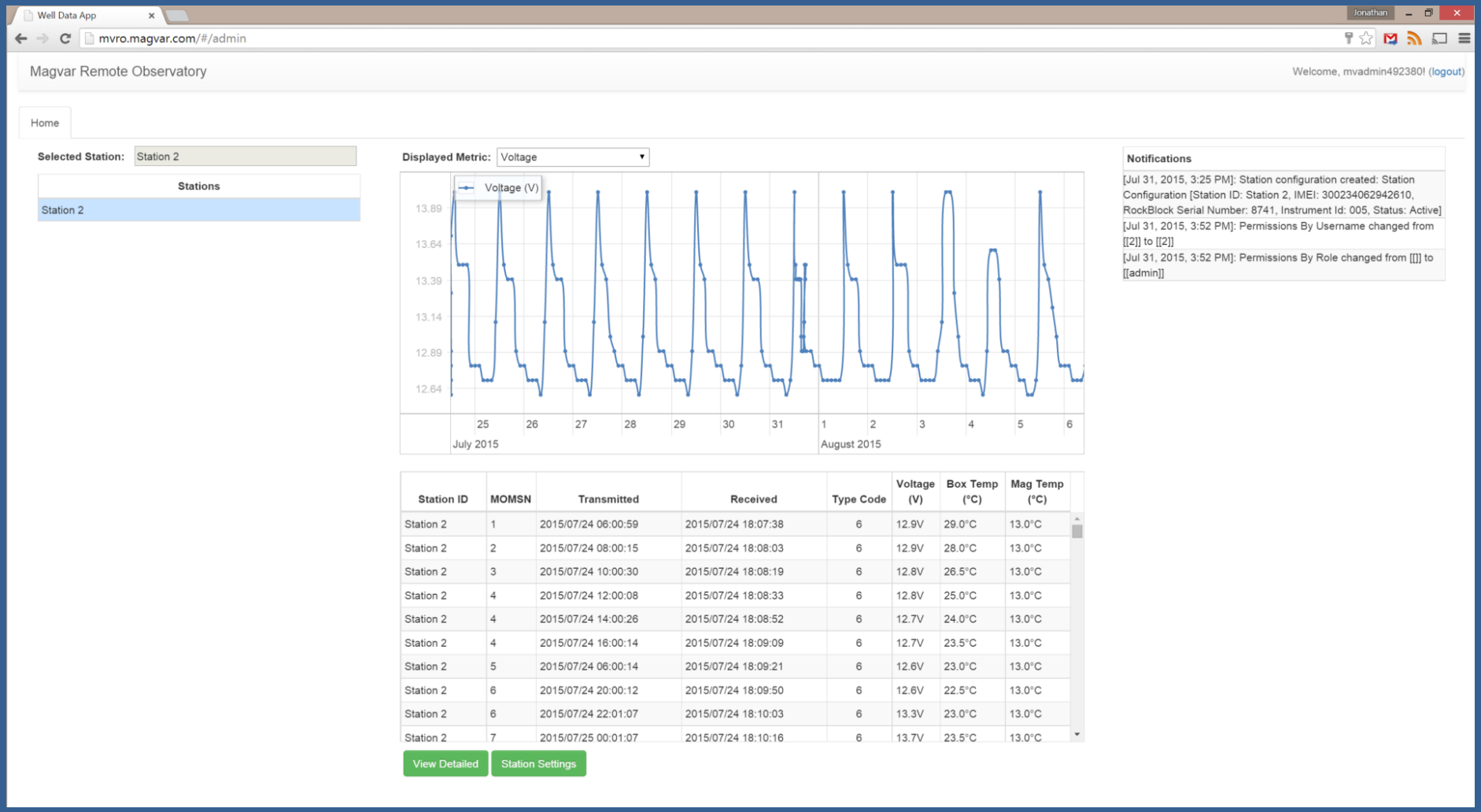


Validation: Boulder Observatory

Summary:

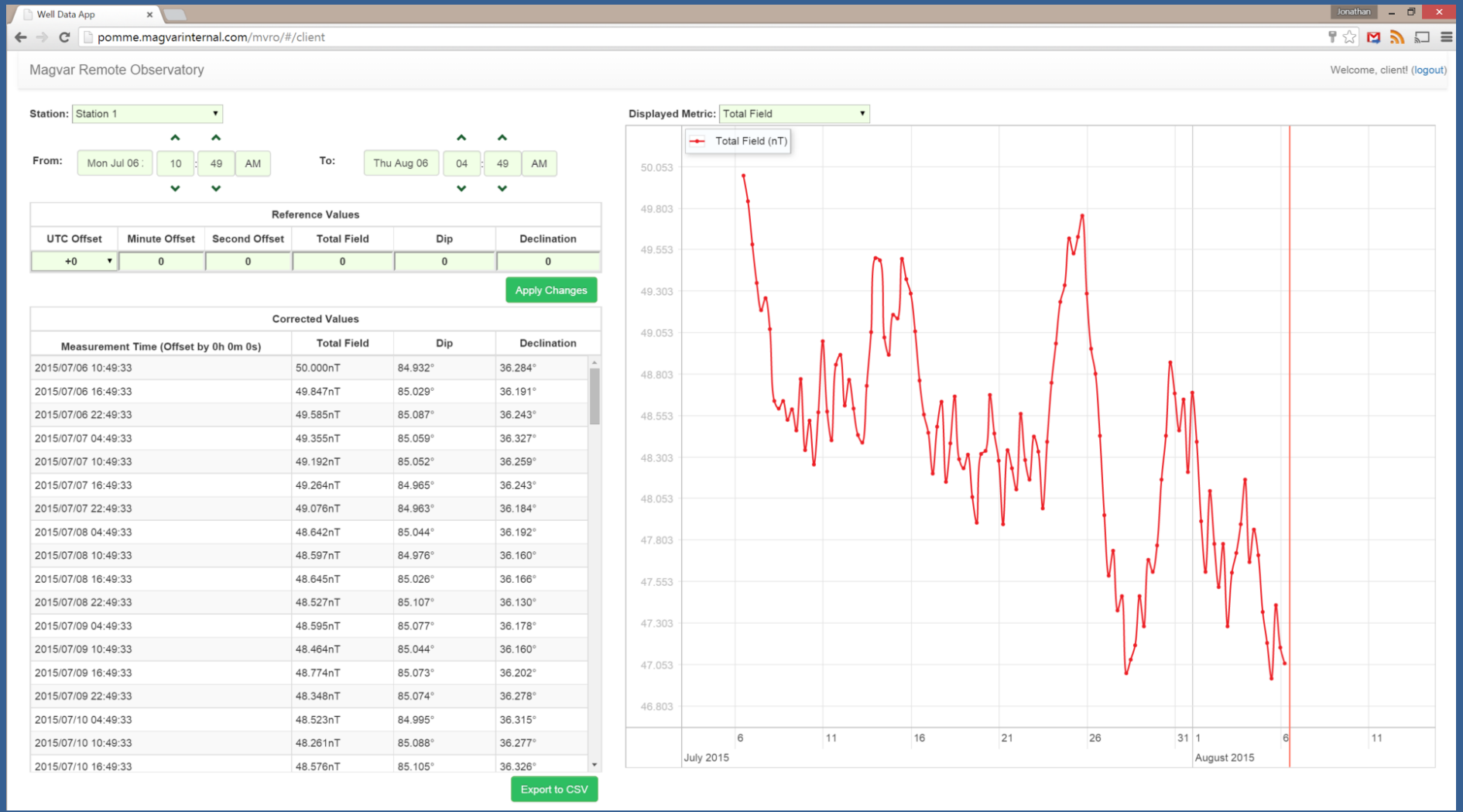
- *MagVAR data shows good agreement to observatory data*
- *MagVAR data has higher cadence (1 second) than the observatory network (1 minute)*
- *MagVAR stations are deployed on-site, rather than using a signal from possibly hundreds of miles away*

Raw Data Web Monitor



Station ID	MOMSN	Transmitted	Received	Type Code	Voltage (V)	Box Temp (°C)	Mag Temp (°C)
Station 2	1	2015/07/24 06:00:59	2015/07/24 18:07:38	6	12.9V	29.0°C	13.0°C
Station 2	2	2015/07/24 08:00:15	2015/07/24 18:08:03	6	12.9V	28.0°C	13.0°C
Station 2	3	2015/07/24 10:00:30	2015/07/24 18:08:19	6	12.8V	26.5°C	13.0°C
Station 2	4	2015/07/24 12:00:08	2015/07/24 18:08:33	6	12.8V	25.0°C	13.0°C
Station 2	4	2015/07/24 14:00:26	2015/07/24 18:08:52	6	12.7V	24.0°C	13.0°C
Station 2	4	2015/07/24 16:00:14	2015/07/24 18:09:09	6	12.7V	23.5°C	13.0°C
Station 2	5	2015/07/24 06:00:14	2015/07/24 18:09:21	6	12.6V	23.0°C	13.0°C
Station 2	6	2015/07/24 20:00:12	2015/07/24 18:09:50	6	12.6V	22.5°C	13.0°C
Station 2	6	2015/07/24 22:01:07	2015/07/24 18:10:03	6	13.3V	23.0°C	13.0°C
Station 2	7	2015/07/25 00:01:07	2015/07/24 18:10:16	6	13.7V	23.5°C	13.0°C

Disturbance Field Data Access



Summary and Conclusions

- Disturbance field monitoring at high latitudes is highly beneficial
- Proximity of measurement to drill site is of importance
- Validation studies show that quality is on par with fixed observatories
  - Absolute level needs to be provided by a complete model
- A portable disturbance field monitoring station with satellite uplink allows for ready deployment anywhere on the globe