62nd General Meeting
24th & 25th of September 2025
Anchorage, Alaska

Wellbore Positioning Technical Section

The Industry Steering Committee on Wellbore Survey Accuracy (ISCWSA)

CARISMA Data for Estimation of the Geomagnetic Disturbance Field in the Western Canada Sedimentary Basin

Xiong Li, Patrick Quist, Barry Wiggins, Bautista Puebla, and Jason Romero

Xcalibur SMART MAPPING

Speaker Bio

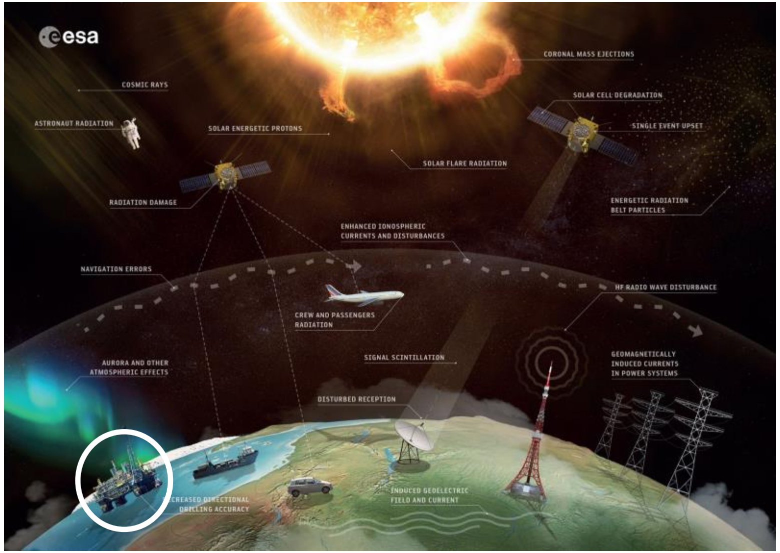
Xiong Li

- Chief Geophysicist, Xcalibur Smart Mapping
- Obtained a PhD in geophysics from Chinese Academy of Sciences in 1991
- Working on gravity and magnetics geophysics for resources exploration and other applications

Solar Wind, Magnetic Storm, Aurora, and Our Daily Life

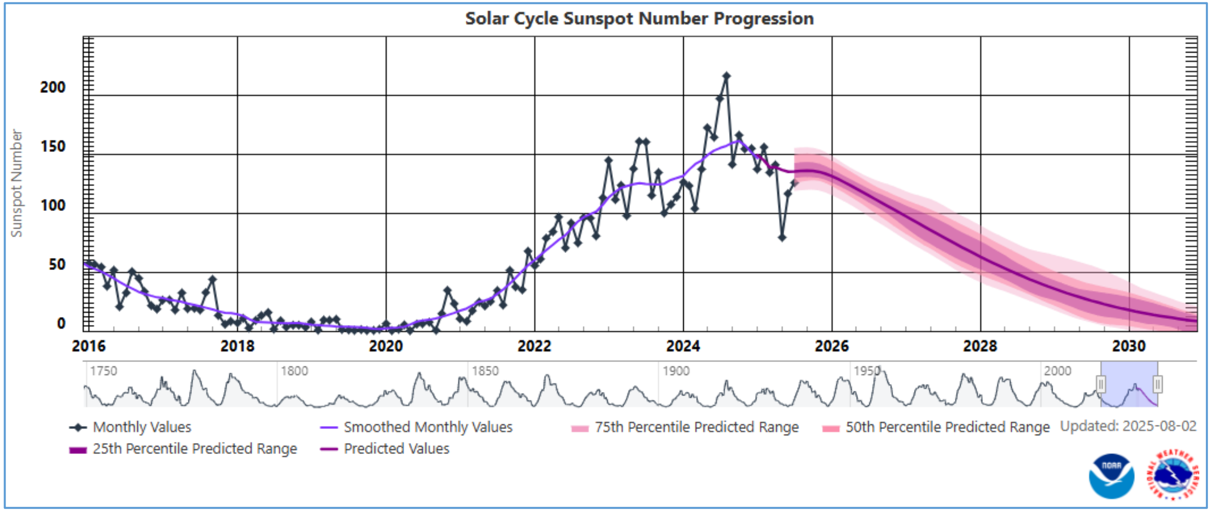
Aurora is beautiful

Magnetic storm can also be disastrous



https://www.esa.int/ESA_Multimedia/Images/2018/01/Space_weather_effects

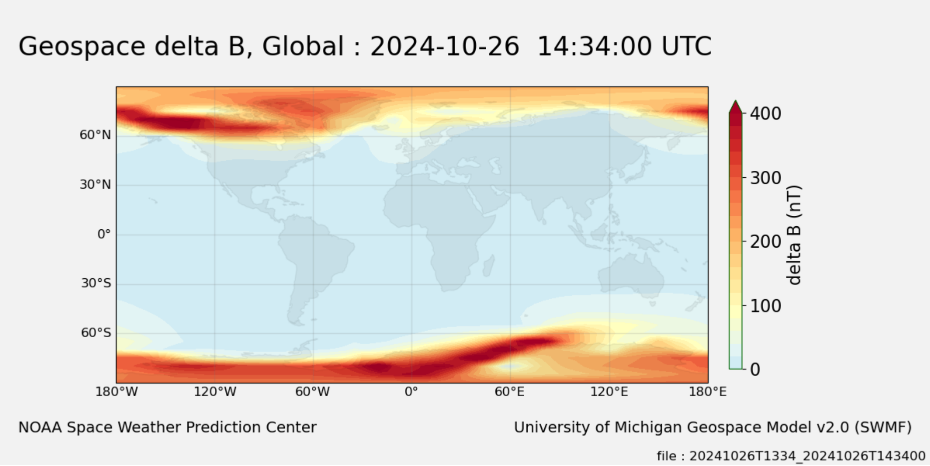
Solar Cycle 25

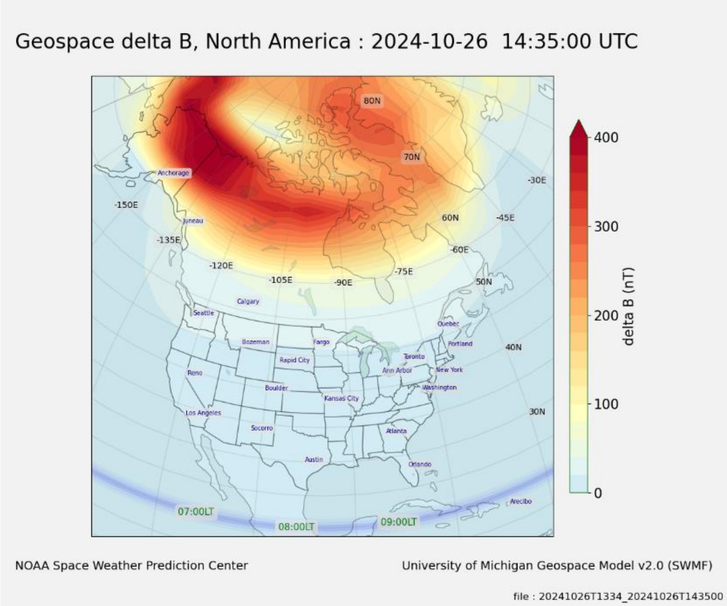


https://www.swpc.noaa.gov/products/solar-cycle-progression

- We are at solar (sunspot) maximum. Geomagnetic activity maximum generally lags the sunspot maximum by about 1–3 years.
- We are likely to experience more frequent occurrences of geomagnetic storms during the declining phase of the solar cycle.

Ground Magnetic Perturbations

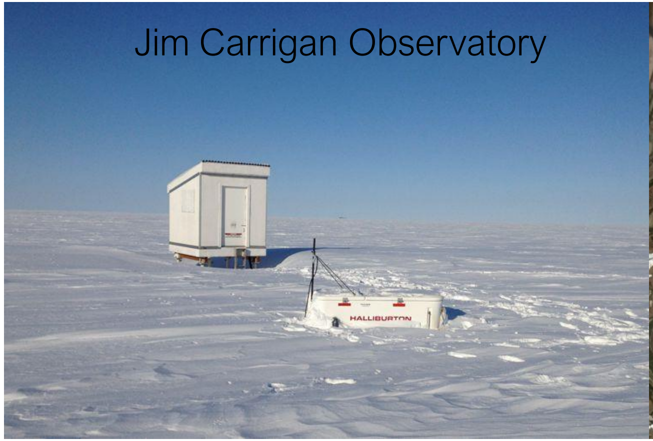




https://www.swpc.noaa.gov/products/geospace-ground-magnetic-perturbation-maps

Geomagnetic Observatories in Prudhoe Bay, Alaska

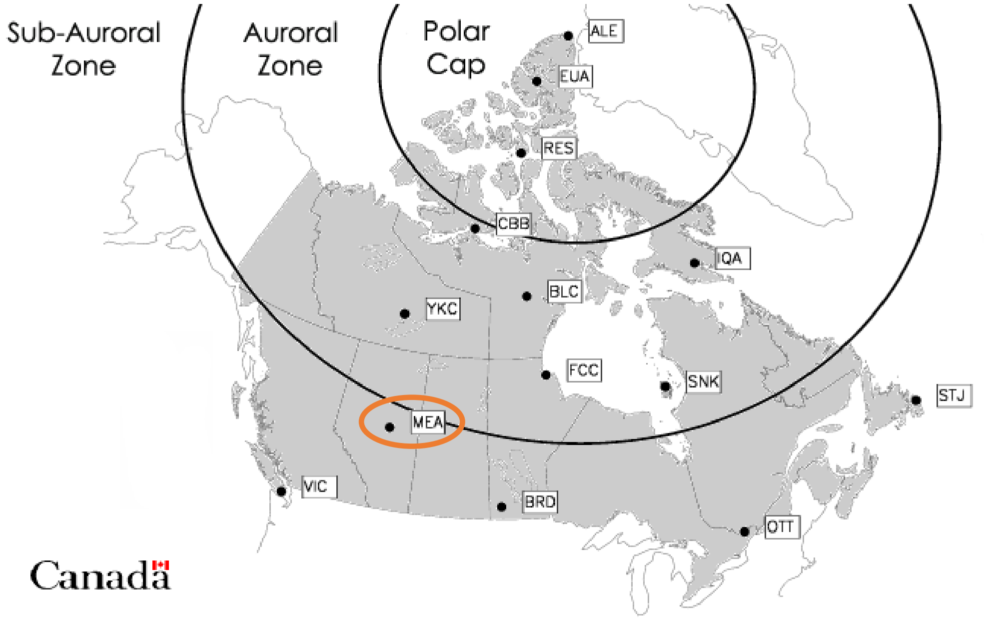
The most accurate way to correct for the geomagnetic disturbances is to install a continuously operating INTERMAGNET-standard vector magnetometer near the drilling rig. However, this option is often cost-prohibitive, particularly for remote or short-duration drilling programs.



https://geomag.bgs.ac.uk/operations/jimcarrigan.html

https://www.usgs.gov/media/images/deadhorse-geomagnetic-observatory-14

Geomagnetic Observatories in Canada

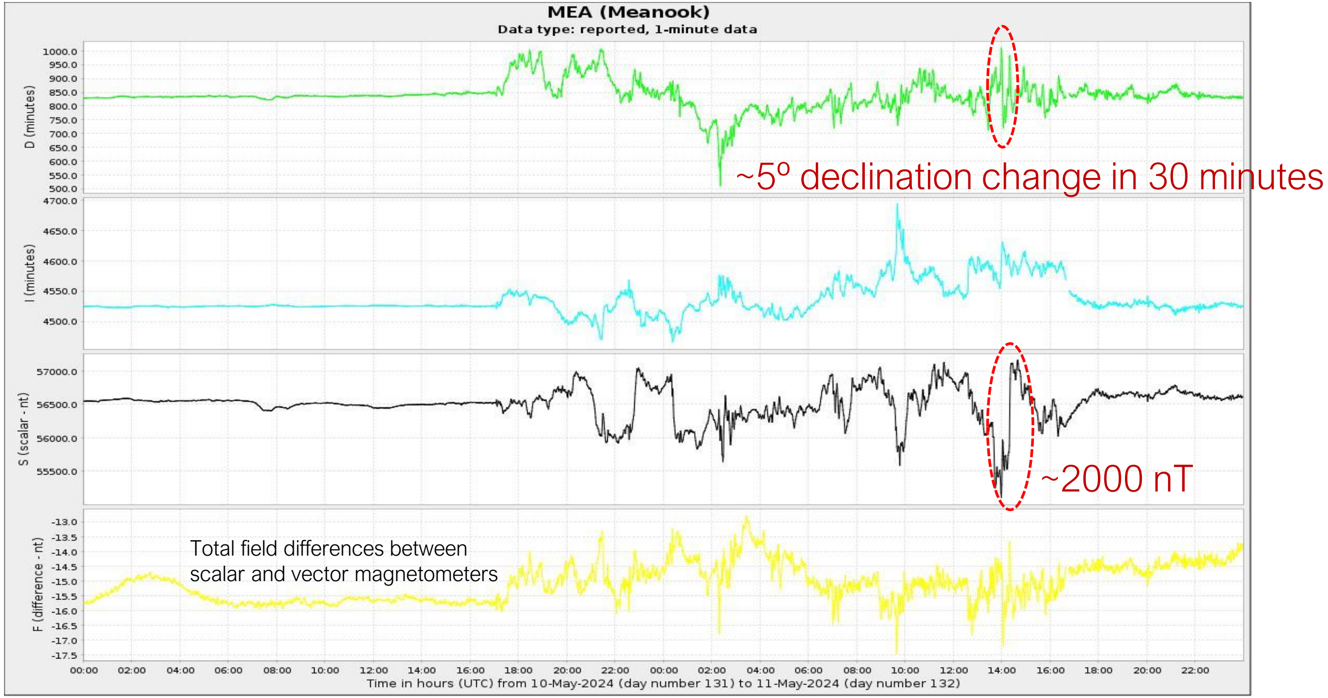


https://geomag.nrcan.gc.ca/obs/default-en.php

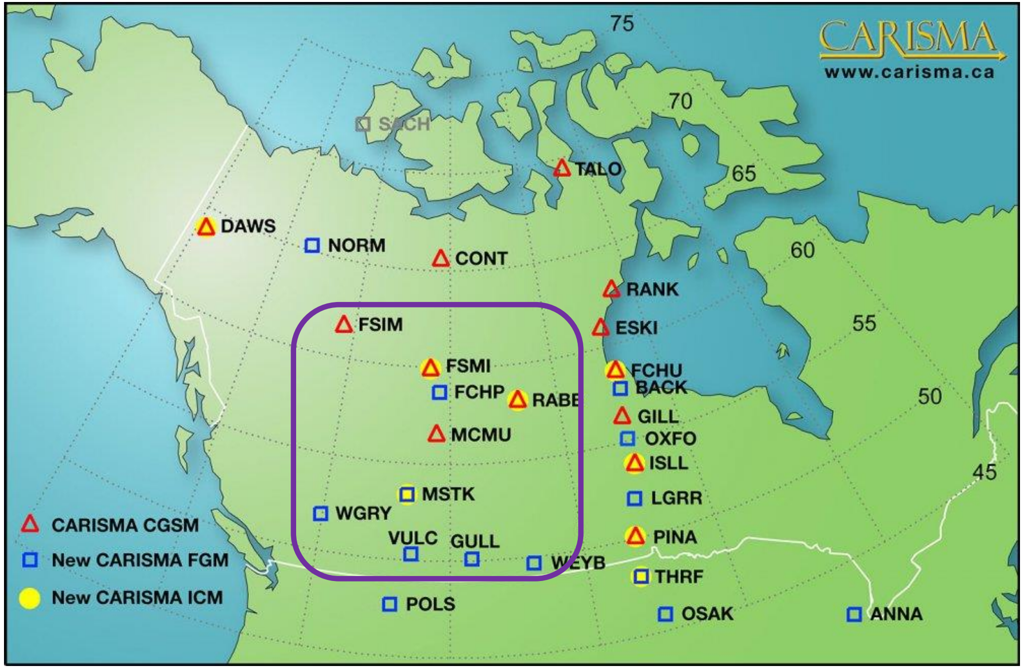
Meanook
Latitude: 54.616° N
Longitude: 113.347° W
Geomagnetic Latitude: 60.988° N
Geomagnetic Longitude: 50.211° W

IGRF20250101

The Strongest Magnetic Storm in 20 Years, on 10-11 May 2024

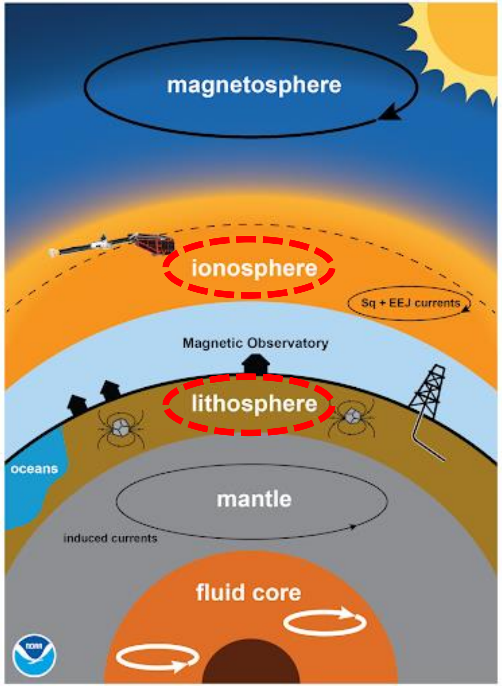


CARISMA and Its 10 Sites that Cover the Western Canada Sedimentary Basin

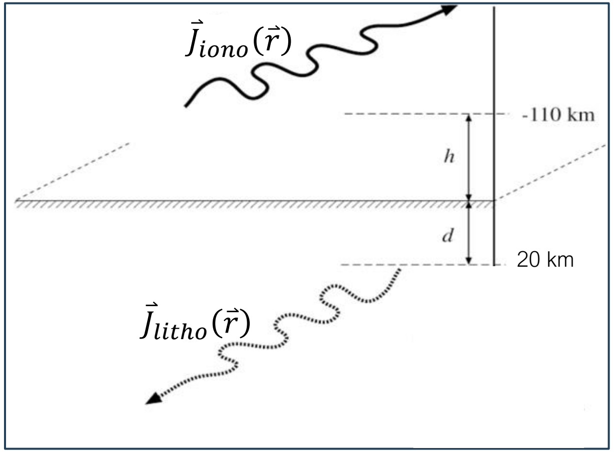


- CARISMA (Canadian Array for Realtime Investigations of Magnetic Activity) is the magnetometer (variometer) element of the Geospace Observatory Canada project.
- We use 10 CARISMA sites inside the purple box.
- 1-Hz real-time data are available. After a careful check, we conclude that 1-minute real-time data are good enough for IFR2, i.e., interpolation of the XYZ components of the disturbance field.

The Spherical Elementary Current System (SECS) Method – A Physics-based Method



https://www.ncei.noaa.gov/news/nceis-ionosonde-data-program-coming-end



- Geomagnetic storms driven by space weather create time-varying magnetic fields in the ionosphere which penetrate the ground creating induced electric fields.
- As a result of some simplifications, ground magnetic field disturbances can be obtained from an exclusively divergence-free system of equivalent currents at a specific height in the ionosphere (External Ionospheric Currents) and the elementary current systems at an appropriate depth in the lithosphere (Internal Telluric Currents).
- The amplitudes of SECS are determined by the best fit of the SECS' magnetic field to the measured magnetic field.
- The SECS method does not require any assumptions about the ionospheric and lithospheric conductivities.

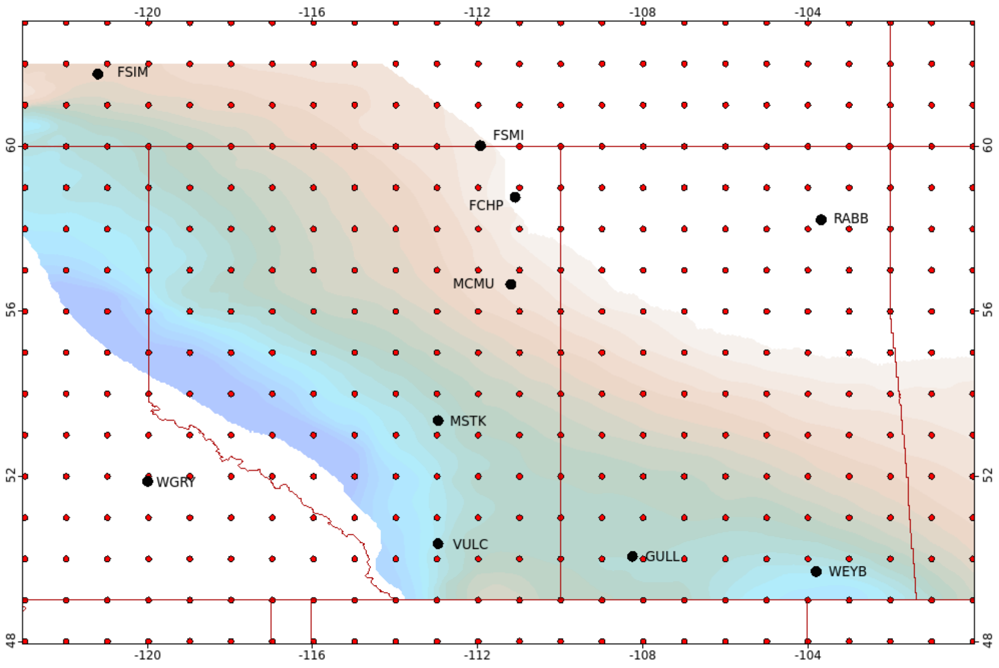
O. Amm, 1997, Ionospheric elementary current systems in spherical coordinates and their application: J. Geomagn. Geoelectr., 49, 947-955.

O. Amm, and A. Viljanen, 1999, Ionospheric disturbance magnetic field continuation from the ground to ionosphere using spherical elementary current systems: Earth Planets Space, 51, 431-440.

A. Pulkkinen, O. Amm, A. Viljanen, and BEAR working group, 2003, Separation of the geomagnetic variation field on the ground into external and internal parts using the spherical elementary current system method: Earth Planets Space, 55, 117-129.

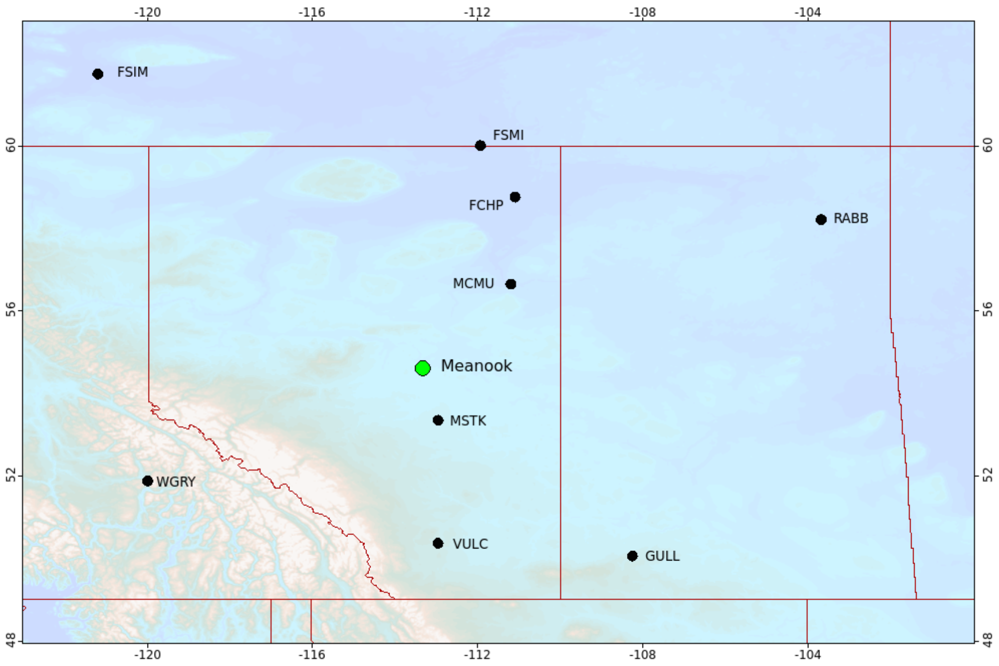
S. A. McLay, and C. D. Beggan, 2010, Interpolation of externally-caused magnetic fields over large sparse arrays using spherical elementary current systems: Annales Geophysicae, 28(9), 1795–1805.

The SECS Applied to 10 CARISMA Sites



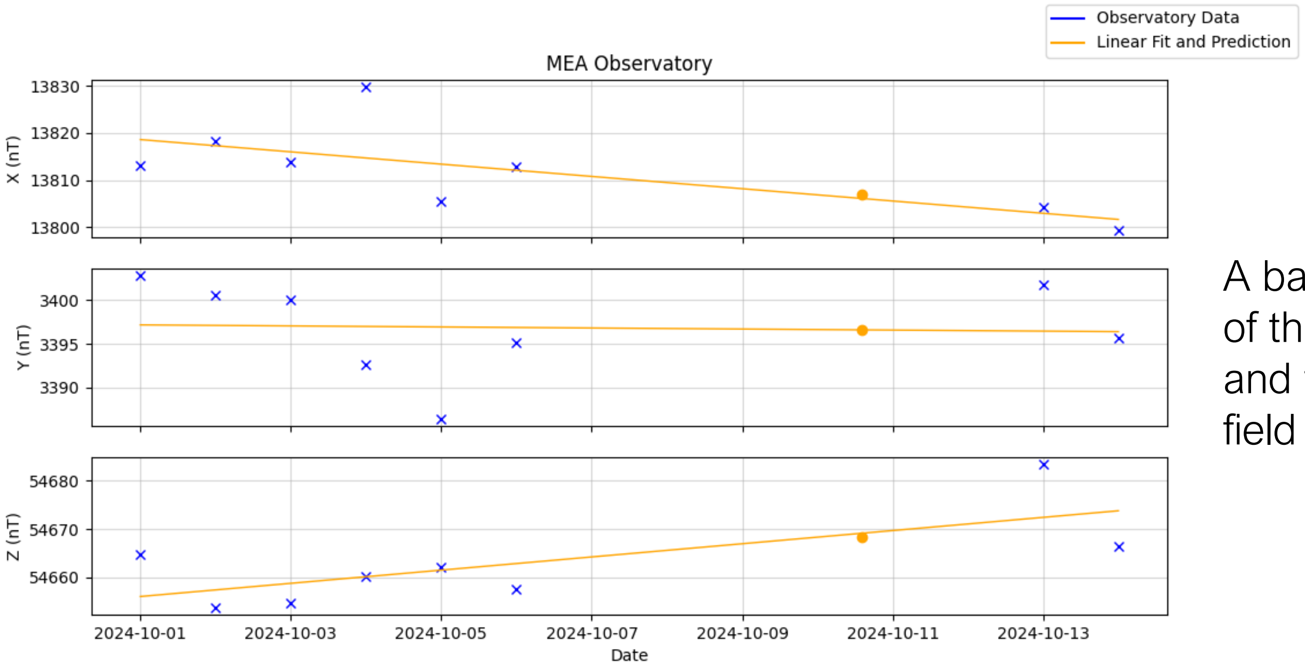
- We use 1-minute real-time data at 10 CARISMA sites (black dots).
- The SECS grid uses a grid spacing of 1º and has these latitude and longitude limits: 48º to 63 Nº, 123º to 100º W (red dots).
- We apply the SECS method to the 1-minute data to derive the Bx, By, and Bz components of the disturbance field at a drilling site.
- The background image shows basement depths of the WCSB.

Validation of the SECS Method



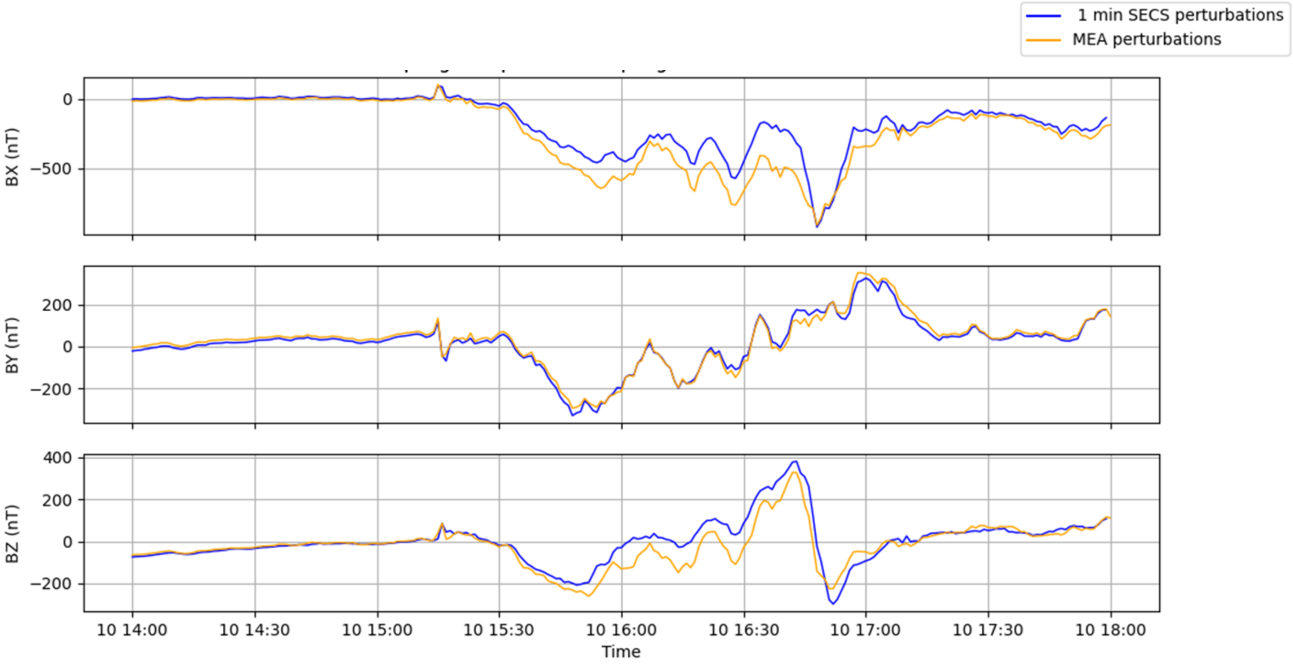
We use data at 9 CARISMA sites to estimate the disturbance field at the Meanook Observatory and compare to the truths. (Site WEYB didn’t work properly during the 4-hour on 10 Oct 2024).

Baseline Determination: A Linear Trend of Daily Means When Kp < 3

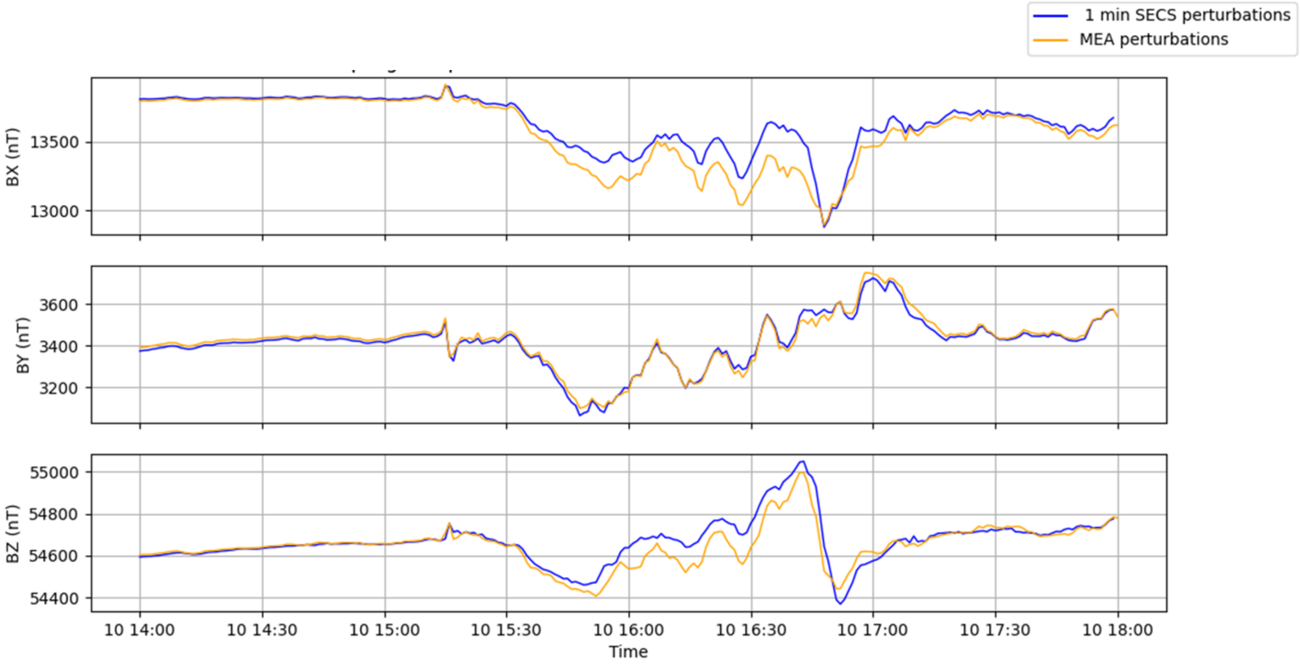


A baseline is a combination of the main magnetic field and the crustal magnetic field at a given location.

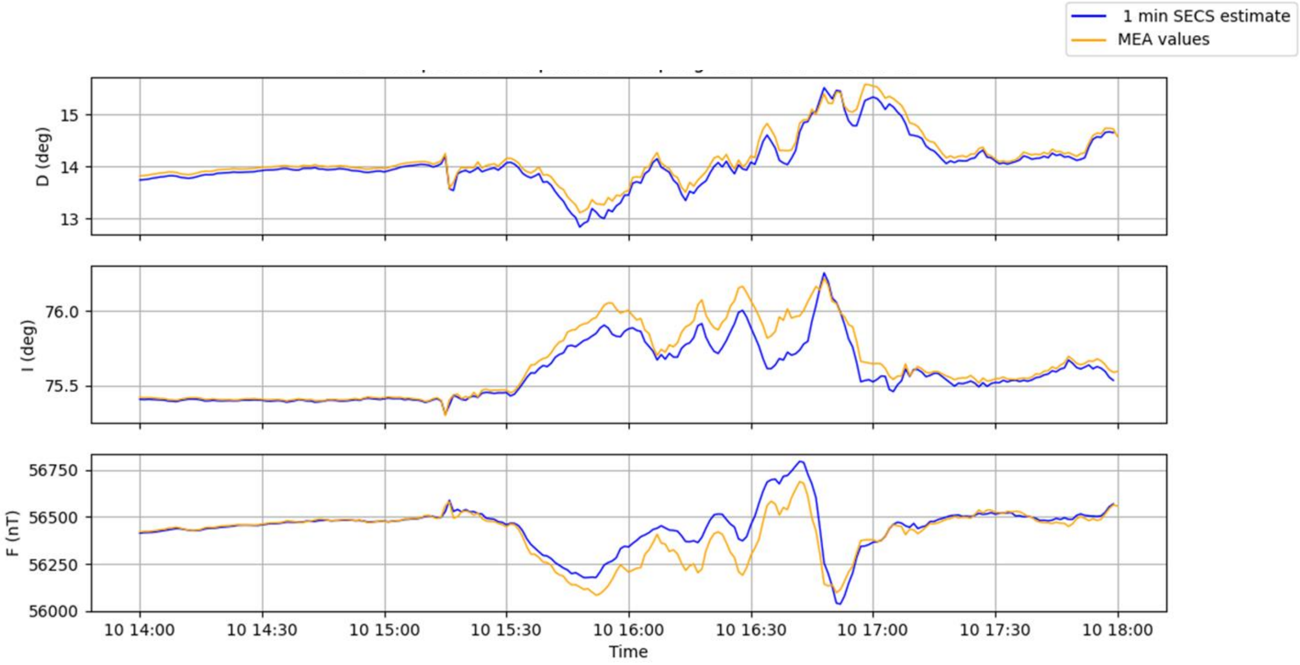
A Comparison of 4-hour Disturbance Field Data on 10 October 2024



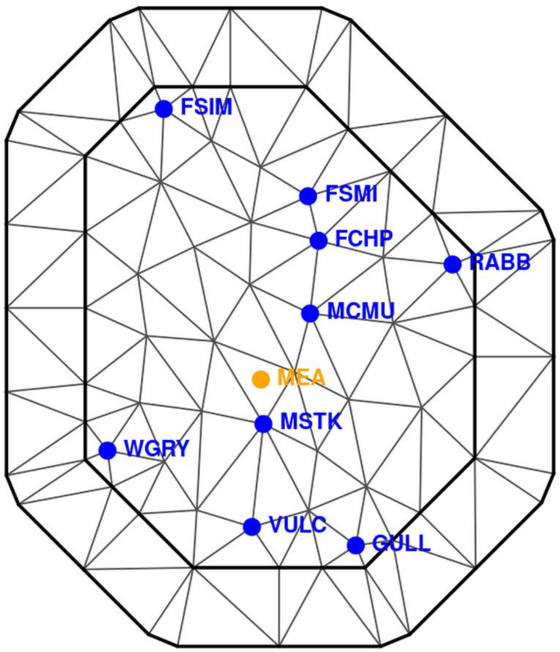
A Comparison of 4-hour Geomagnetic Field Data on 10 October 2024 (Baselines Restored)



A Comparison of 4-hour Geomagnetic Field DIF Data on 10 October 2024



The SPDE-INLA Method – A Statistical Modeling Approach

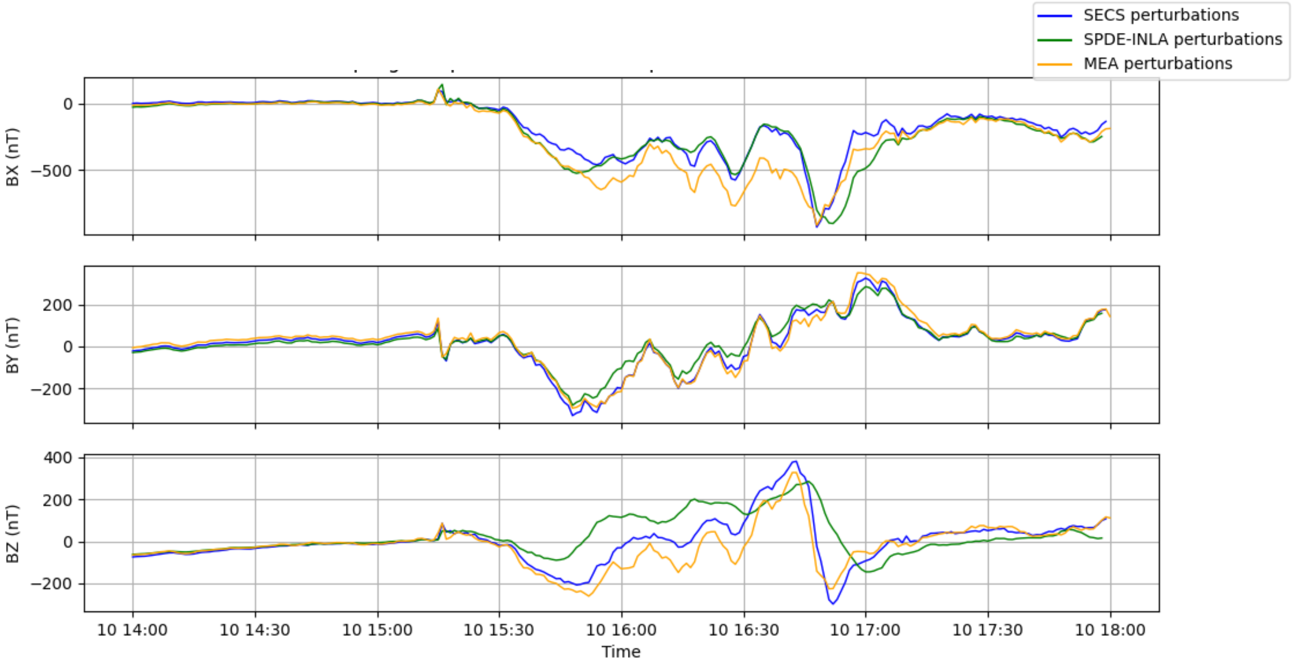


- The SPDE-INLA combines Stochastic Partial Differential Equation (SPDE) with the Integrated Nested Laplace Approximation (INLA).
- Spatially correlated magnetic disturbances are represented as a Gaussian Random Field (GRF). The SPDE represents a GRF as a solution to a differential equation. This allows the GRF to be approximated by a Gaussian Markov Random Field (GMRF) on a mesh, enabling efficient computation via sparse matrices.
- INLA is a Bayesian inference method that provides fast, accurate approximations to posterior distributions in latent Gaussian models, avoiding the heavy computation of MCMC (Markov Chain Monte Carlo).
- Together, SPDE and INLA allow for efficient modeling and prediction of spatially correlated data, even on irregularly spaced datasets.

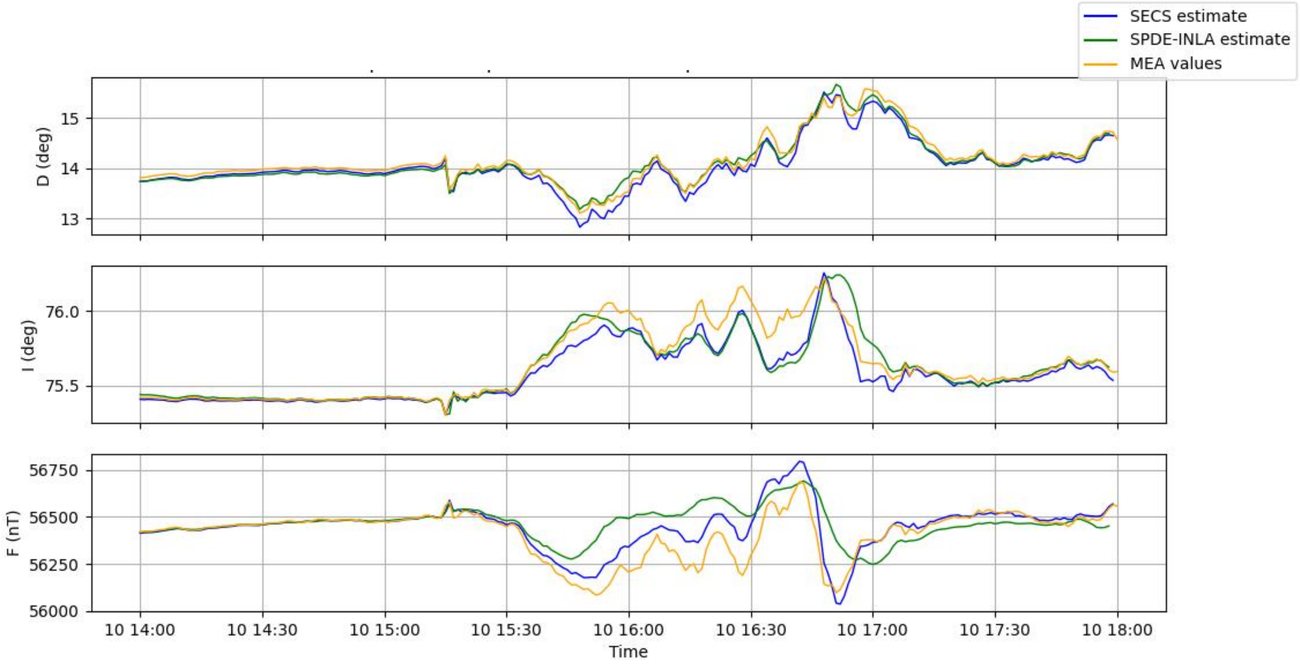
F. Lindgren, H. Rue, J. Lindstrom, 2011, An explicit link between Gaussian fields and Gaussian Markov random fields: the stochastic partial differential equation approach (with discussion): Journal of the Royal Statistical Society, Series B, 73, Part 4, pp. 423-498.

F. Lindgren, 2012, Continuous domain spatial models in r-INLA: The ISBA Bulletin, 19(4), 14–20.

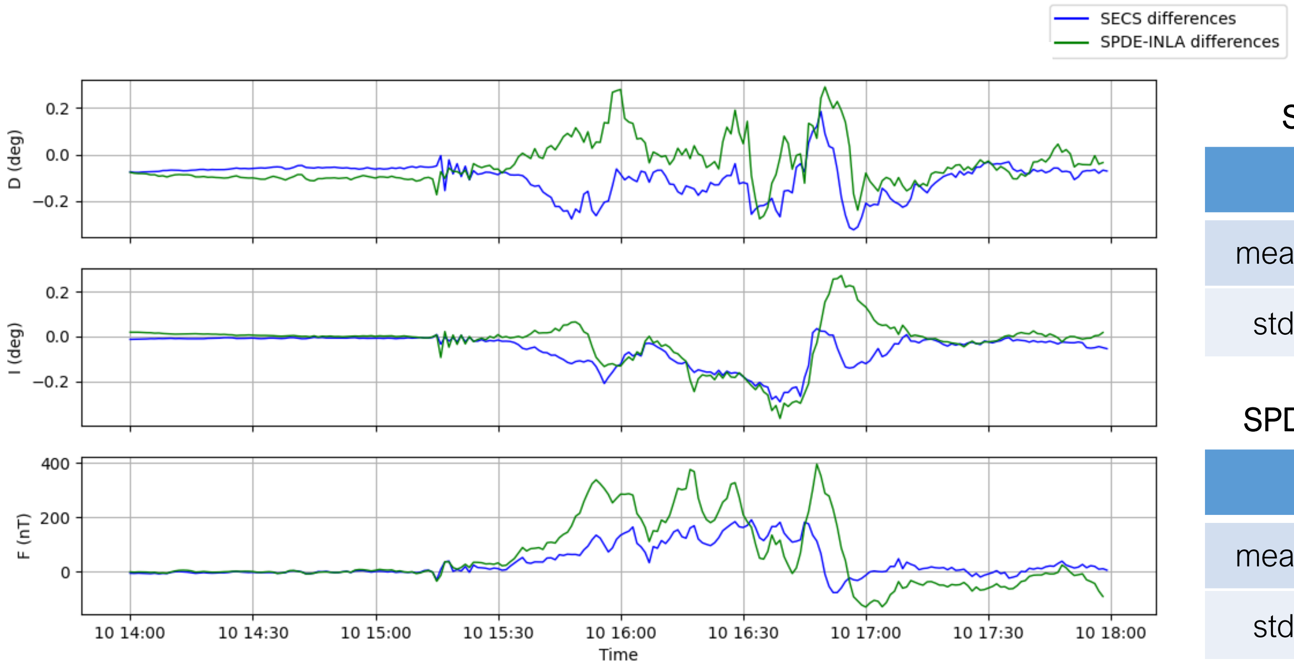
Disturbance Field Estimated by SECS and SPDE-INLA Methods



Geomagnetic Field DIF from SECS and SPDE-INLA Methods



DIF Differences between Estimates and Truths



SECS Result – Meanook Data

	Dec (°)	Inc (°)	TF (nT)
mean	-0.10	-0.06	35
std	0.07	0.07	59

SPDE-INLA Result – Meanook Data

	Dec (°)	Inc (°)	TF (nT)
mean	-0.04	-0.02	54
std	0.10	0.10	119

Summary

- The magnetic disturbance field during a magnetic storm is significant
- The spherical element current systems (SECS) method provides an effective interpolation of the disturbance field. So does the SPDE-INLA method
- Real-time CARISMA data can be used to estimate the disturbance field in the Western Canada Sedimentary Basin
- Our approach in no way is superior to continuously operating an INTERMAGNET-standard vector magnetometer near a drilling rig

Acknowledgments

- The CARISMA team at University of Alberta (Ian Mann and Andy Kale) for geomagnetic data
- roundLAB (Dukhwa Hong and Tyler Longeau) for encouragement

Xcalibur SMART MAPPING