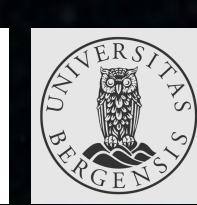
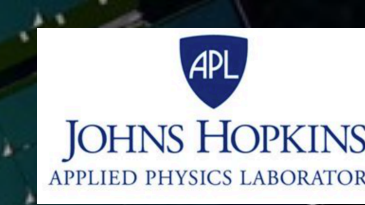




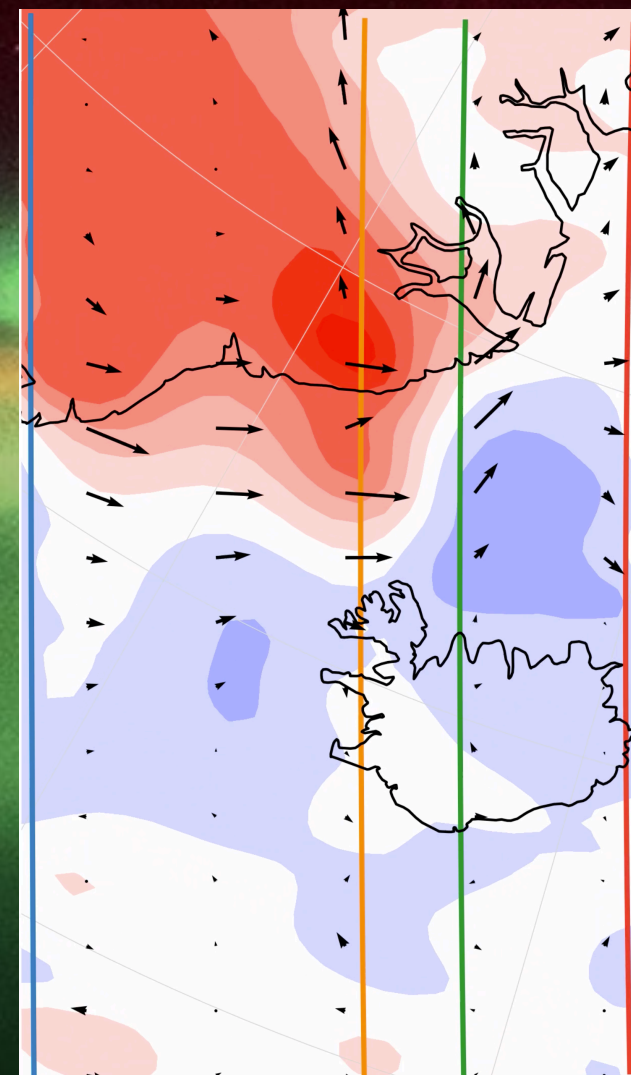
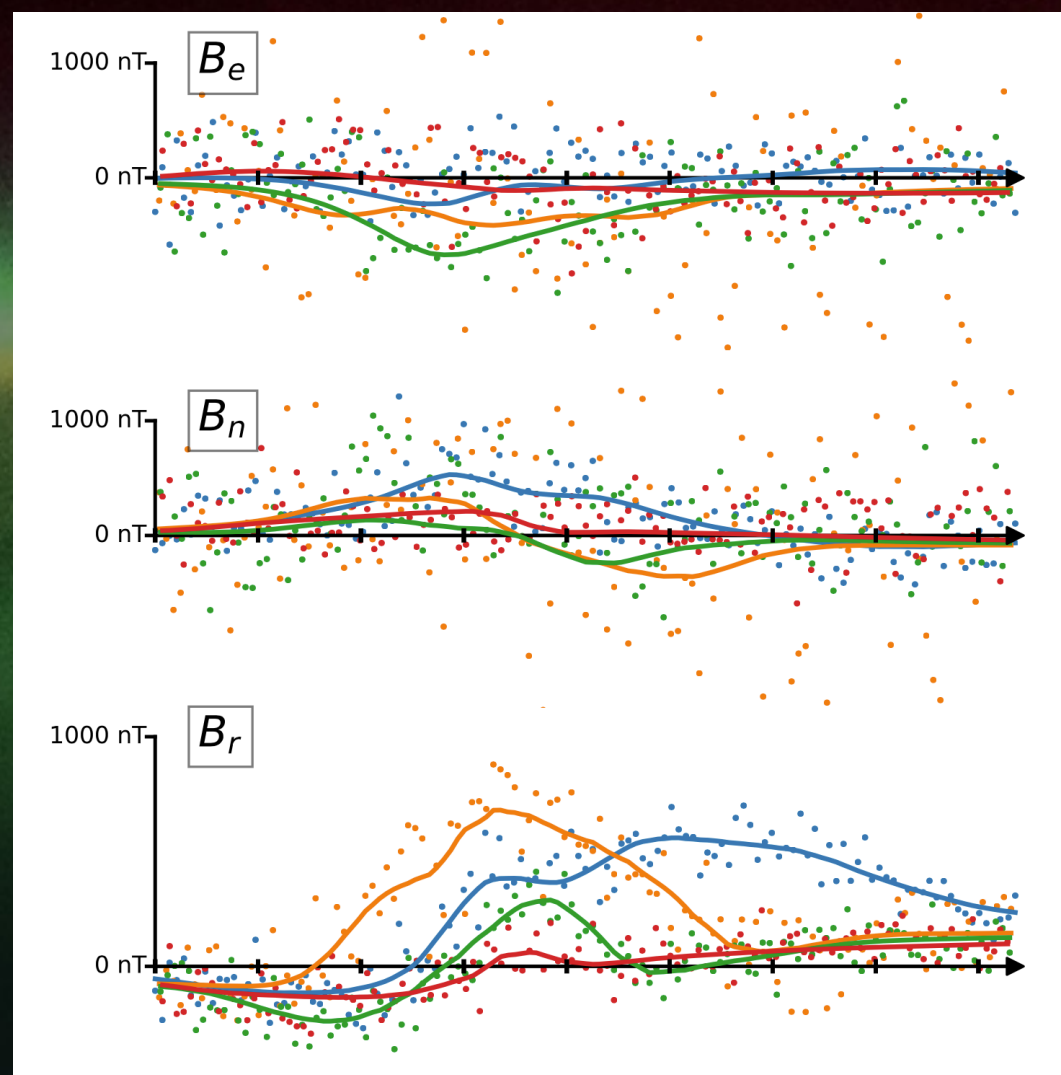
Electrojet estimates from mesospheric magnetic field measurements

Karl Laundal (karl.laundal@uib.no),
J. H. Yee, V. G. Merkin, J. W. Gjerloev, H. Vanhamäki, J. P. Reistad, M. Madelaire, K. Sorathia

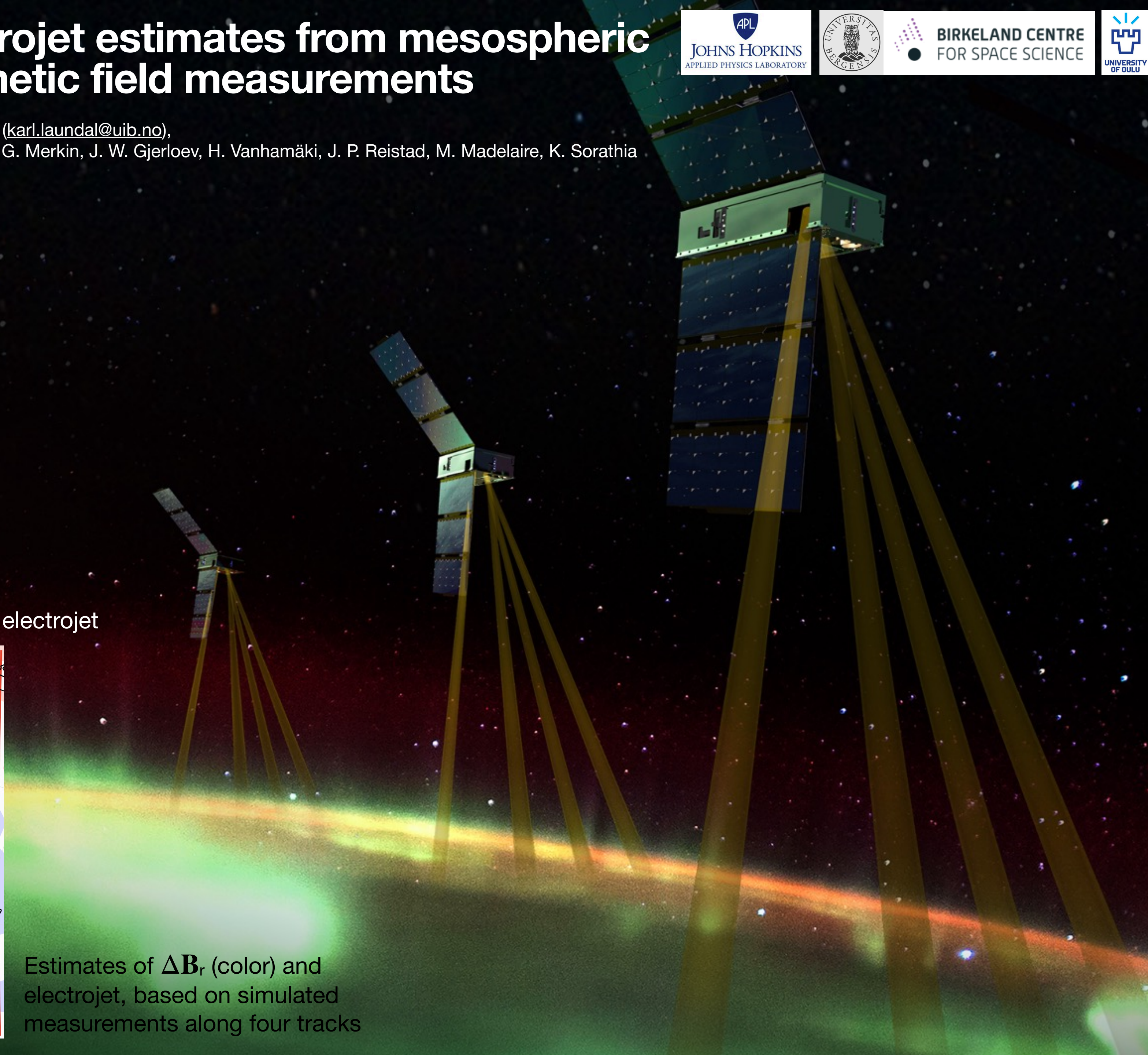


- A NASA mission to reveal spatial structure and temporal evolution of the auroral electrojet. Launch planned in 2024
- Will give *remote* multipoint measurements of mesospheric (80-85 km) magnetic field disturbances, using the **Zeeman effect**
- We present a technique to calculate **electrojet maps** from EZIE measurements of $\Delta \mathbf{B}$
- We demonstrate the technique in an Observing System Simulation Experiment (OSSE)

Noisy multipoint measurements $\rightarrow$ Continuous maps of $\Delta \mathbf{B}$ and electrojet

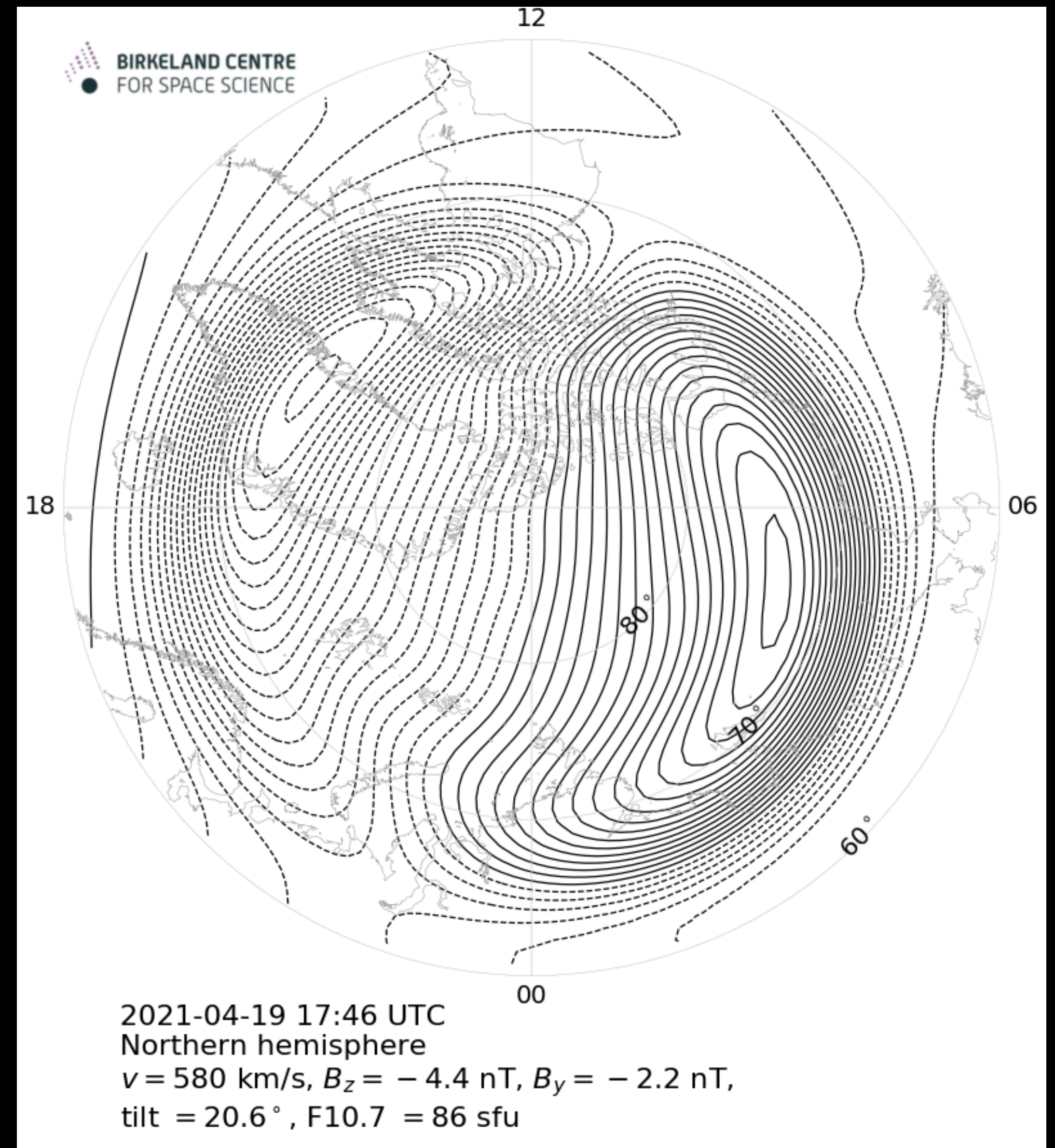


Estimates of $\Delta \mathbf{B}_r$ (color) and electrojet, based on simulated measurements along four tracks



The auroral electrojet

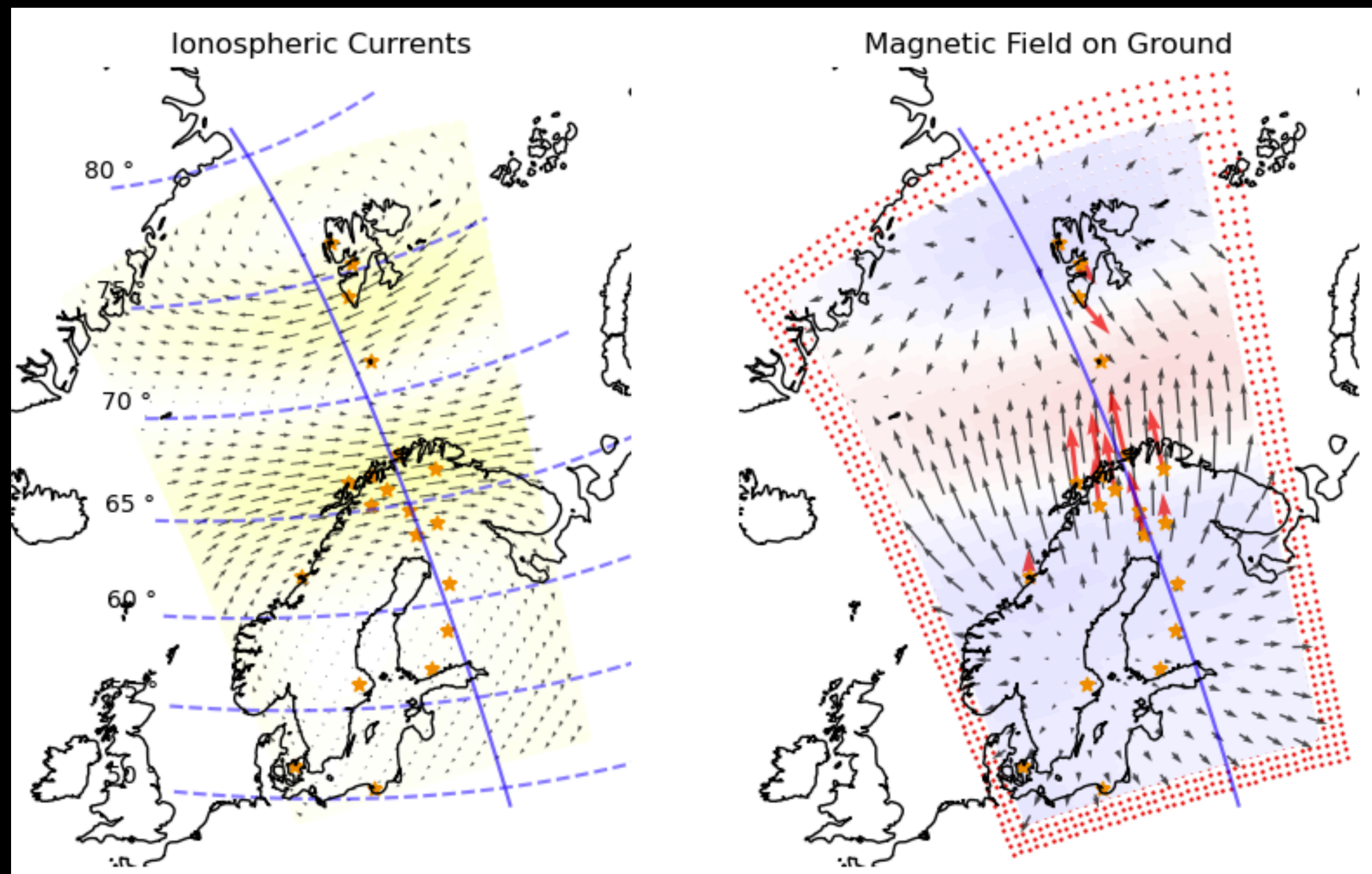
- An equivalent current system that explains ground magnetic field perturbations
- Equal to the divergence-free part of the true horizontal current system
- Confined to a relatively thin sheet at 100-120 km
- Investigated with ground magnetometers for more than 100 years
- Prominent feature: The westward electrojet, a westward equivalent current in the post-midnight region. Associated with plasma flow towards the dayside and high conductivity due to energetic diffuse particle precipitation.



Electrojet derived from Swarm satellite data. Contours represent current streamlines. 15 kA between each contour line.
<https://birkeland.uib.no/data/amps/>

Spherical Elementary Current Systems

- A mathematical analysis technique to represent ground magnetometer measurements and associated equivalent currents / electrojets
- Used extensively since first developed, by Amm (1997)
- A good choice for regional analyses with high data density



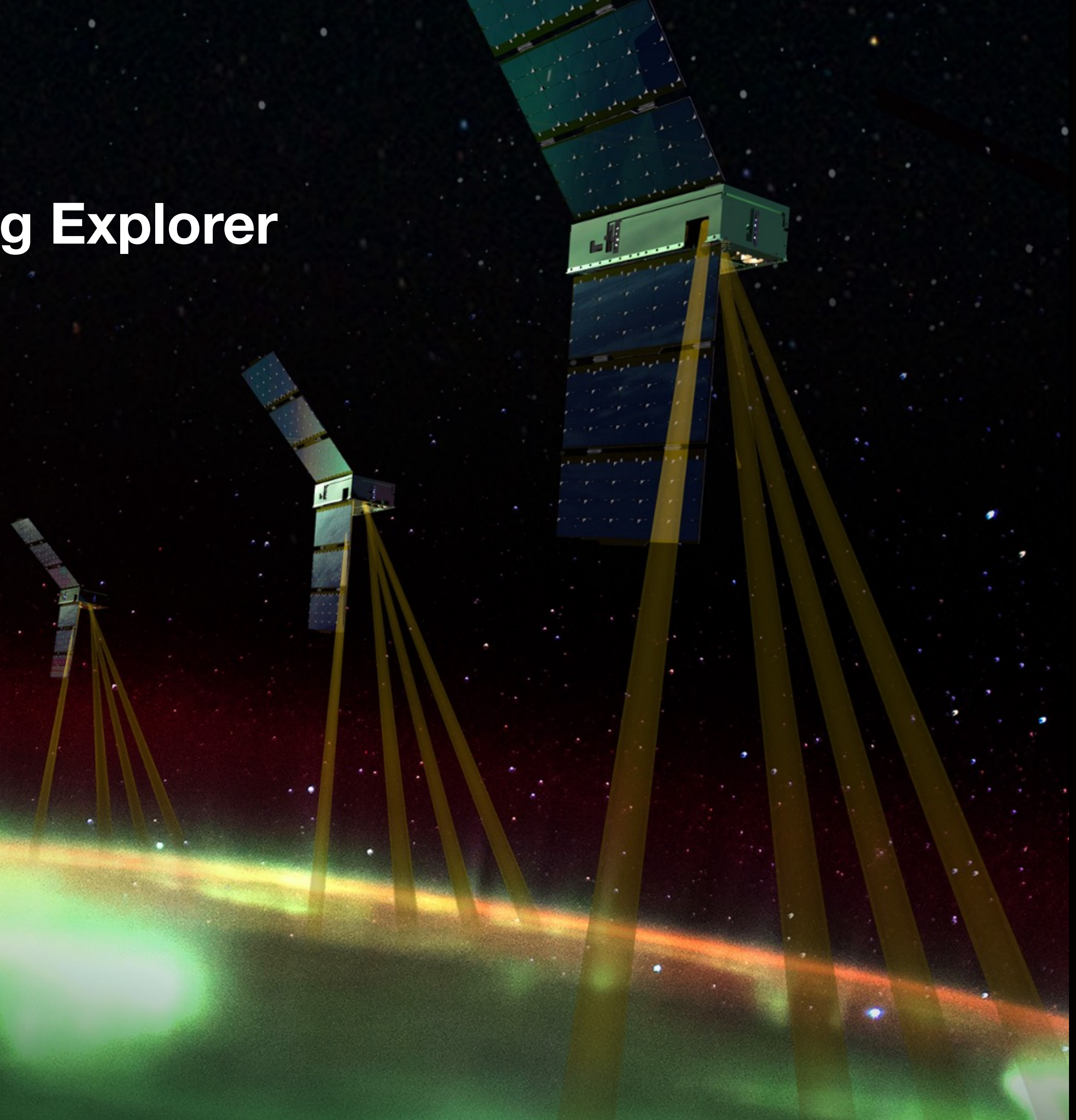
Electrojet currents (left), estimated using spherical elementary current systems and IMAGE magnetometers. The right plot shows magnetometer measurements in red and the SECS magnetic field representation in black.

From master thesis by Simon Walker, University in Bergen (2020)

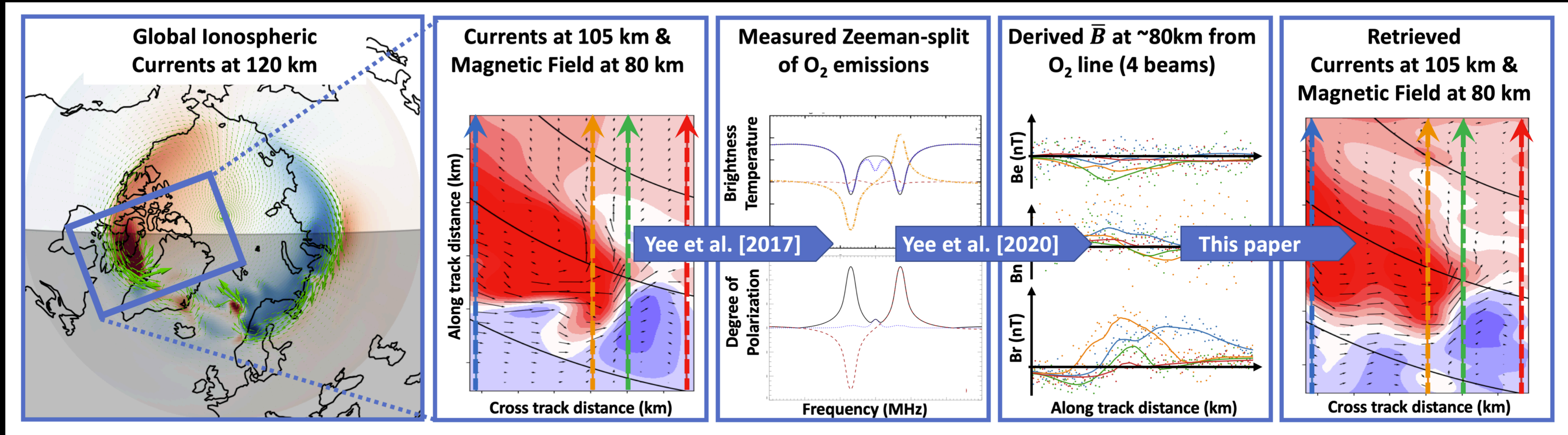
EZIE

The electrojet Zeeman Imaging Explorer

- Three satellites to fly in a pearl-on-a-string formation
- Each will carry four antennas to measure microwave radiation from mesospheric O₂.
- These emissions are strongly affected by the Zeeman effect, which depends on the magnetic field.
- Result: **High density measurements of ΔB at ~80 km altitude along four tracks along satellite trajectory**



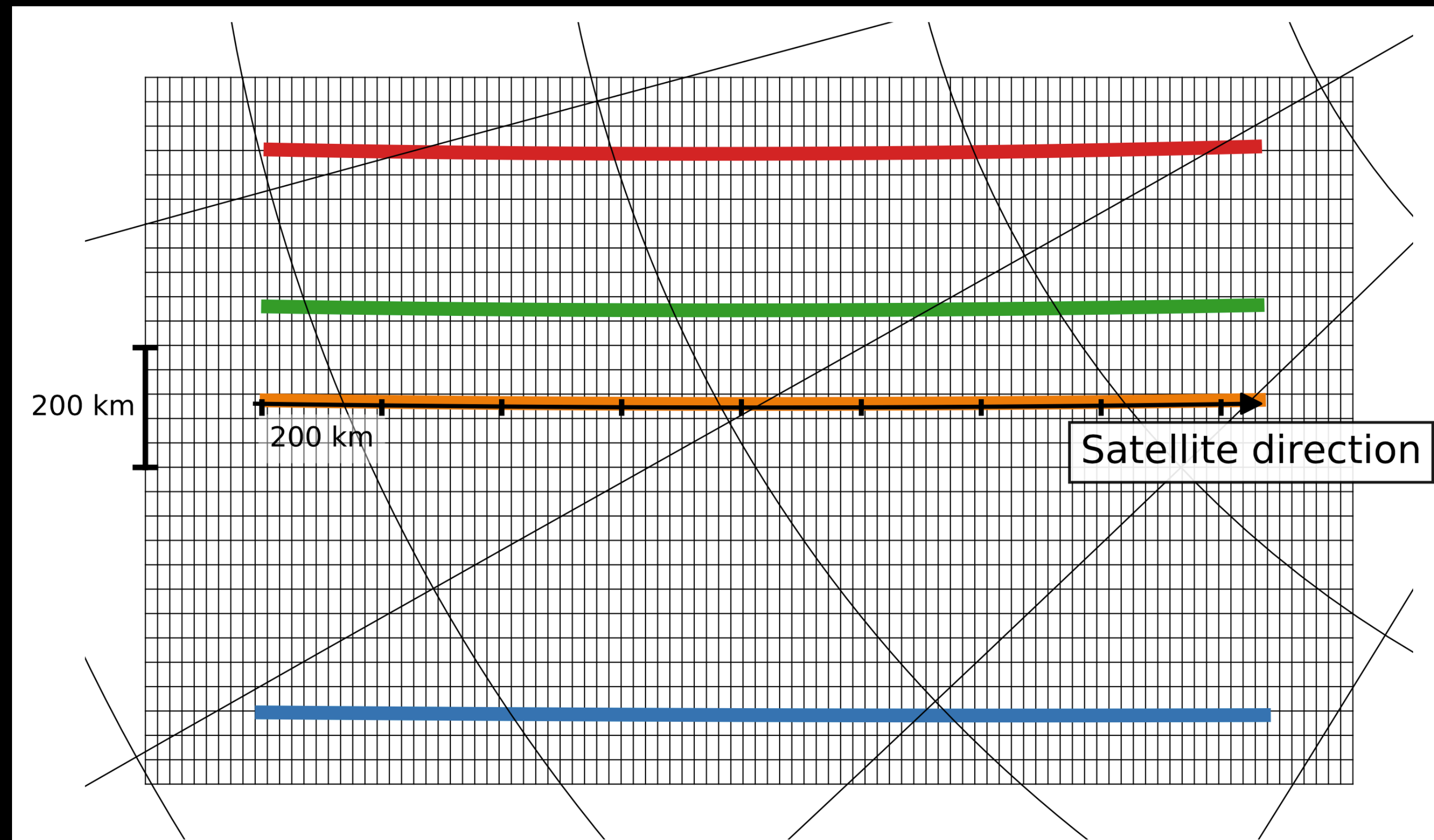
An Observing System Simulation Experiment for EZIE



1. High-resolution GAMERA simulations [Sorathia+2020] provide realistic $\Delta\mathbf{B}$ at 80 km
2. Atmospheric radiative transfer give polarized emission spectra from mesospheric O₂ - including Zeeman effect. Sampled from realistic measurement track, with realistic measurement noise added
3. An inversion is performed to retrieve $\Delta\mathbf{B}$ including variances
4. A second inversion is performed on the simulated $\Delta\mathbf{B}$ measurements to retrieve map.
Step 4 is the topic of this presentation

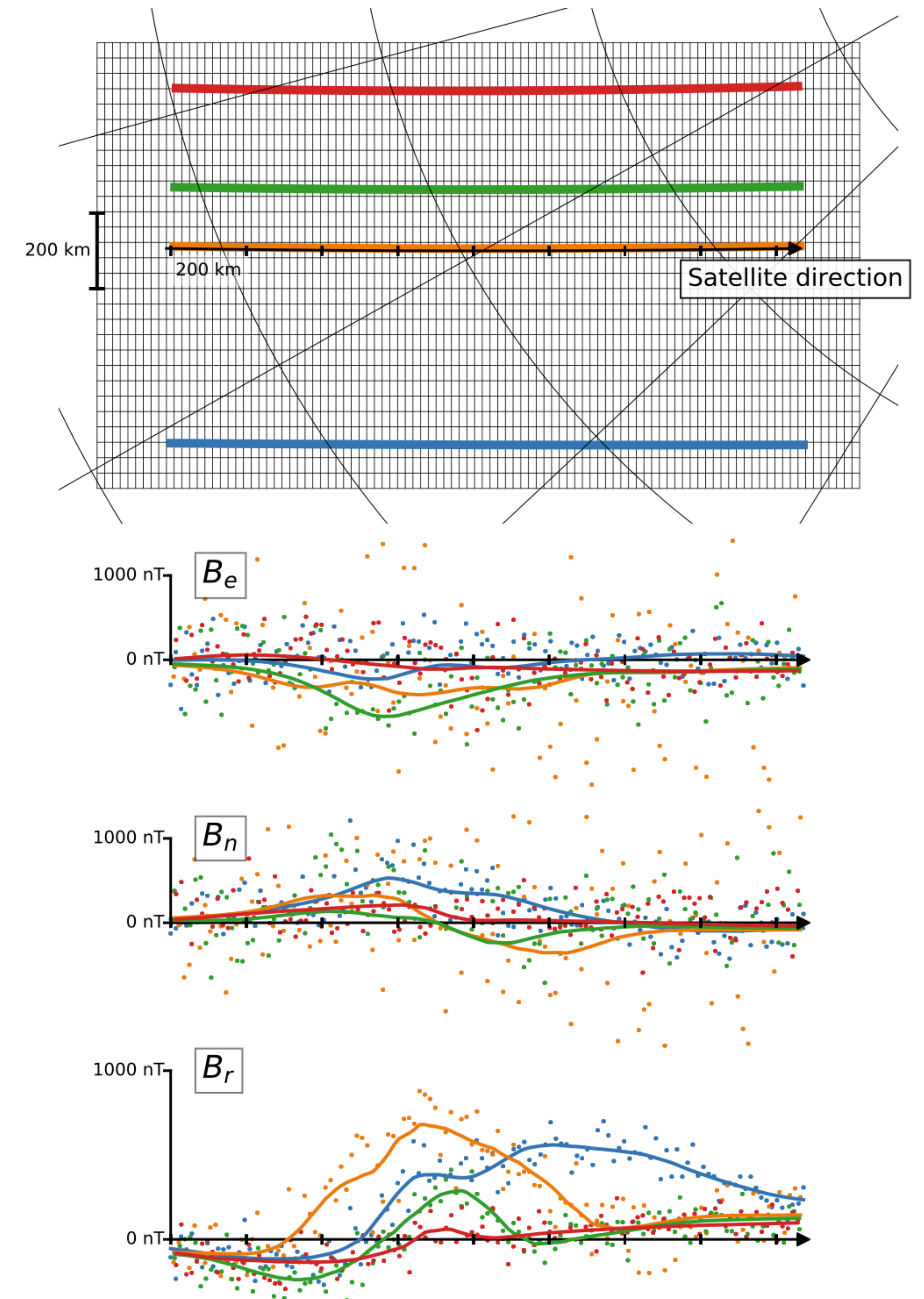
Measurement geometry

- EZIE will make measurements along four tracks, covering about 1000 km across-track.
- The colored lines consist of measurement points collected by a single satellite during 4 minutes.
- The grid shows the placement of SECS basis functions (will get back to this)



Simulated data

- The simulated data points (dots) are color coded to match the measurement track
- The lines are MHD simulation outputs - what would be measured with a perfectly accurate instrument
- Notice the quite large scatter. The horizontal components are more noisy than the radial component. The noise is correlated between the components
- The error covariance matrix is known

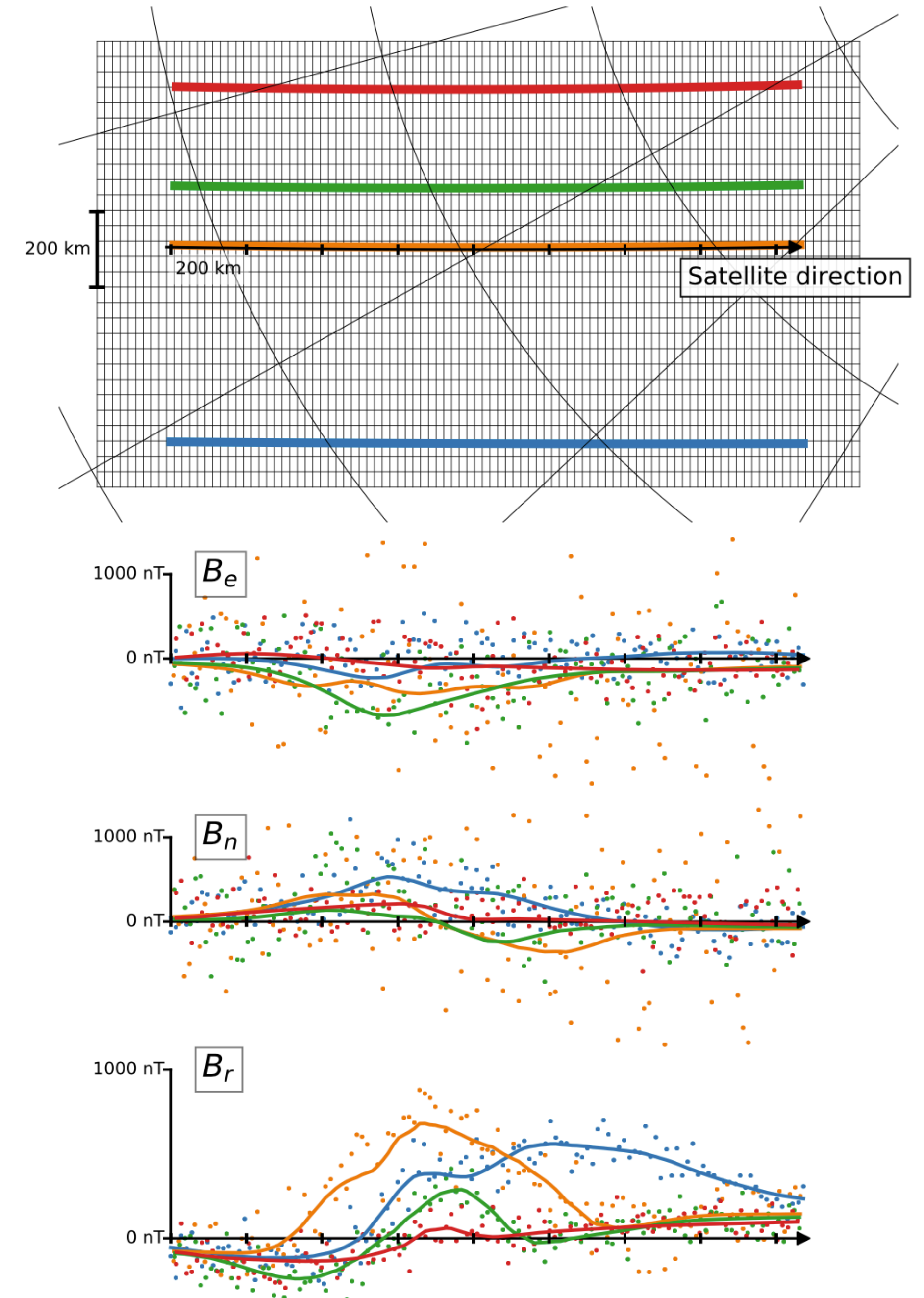


Electrojet inversion

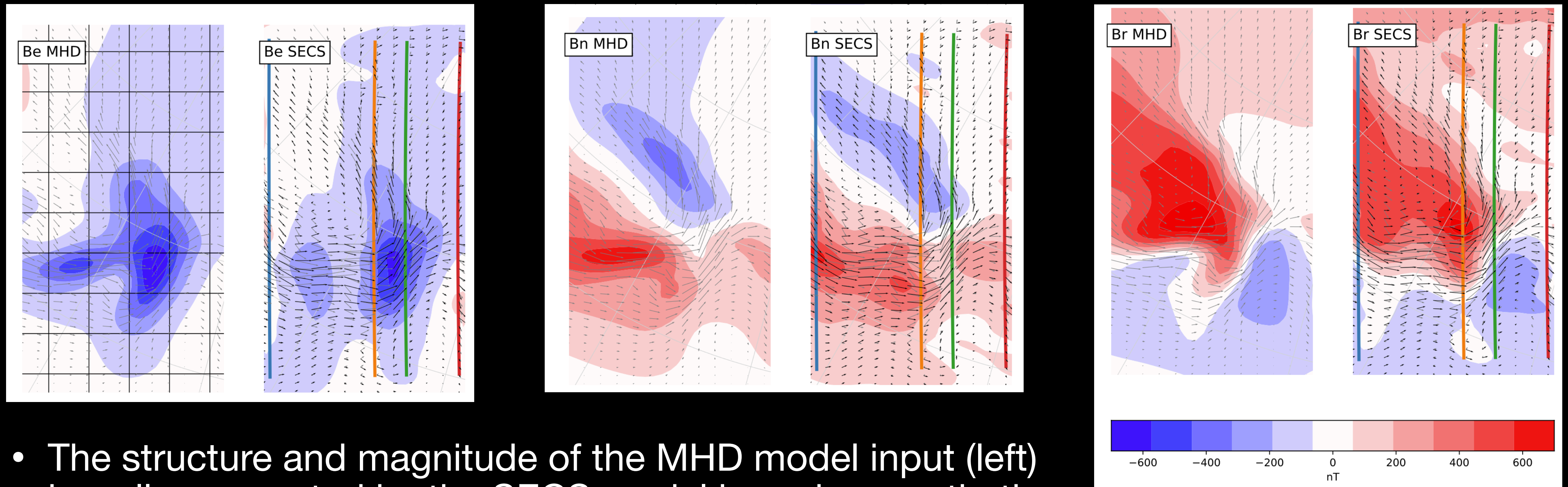
- The magnetic field at the measurement location can be related to SECS pole amplitudes S_j (as many poles as there are grid points) by the following equation:

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int_S \frac{\left[\sum_{j=1}^K \frac{S_j}{4\pi R_I} \cot \left(\frac{\theta_{\mathbf{r}'\mathbf{r}_j}}{2} \right) \hat{\phi}_j \right] \times \hat{\mathbf{r}}'}{\|\mathbf{r} - \mathbf{r}'\|^2} dS$$

- The resulting set of linear equations is solved for S_j by minimising a combination of data-model-misfit, model amplitude, and gradients in the magnetic east-west direction



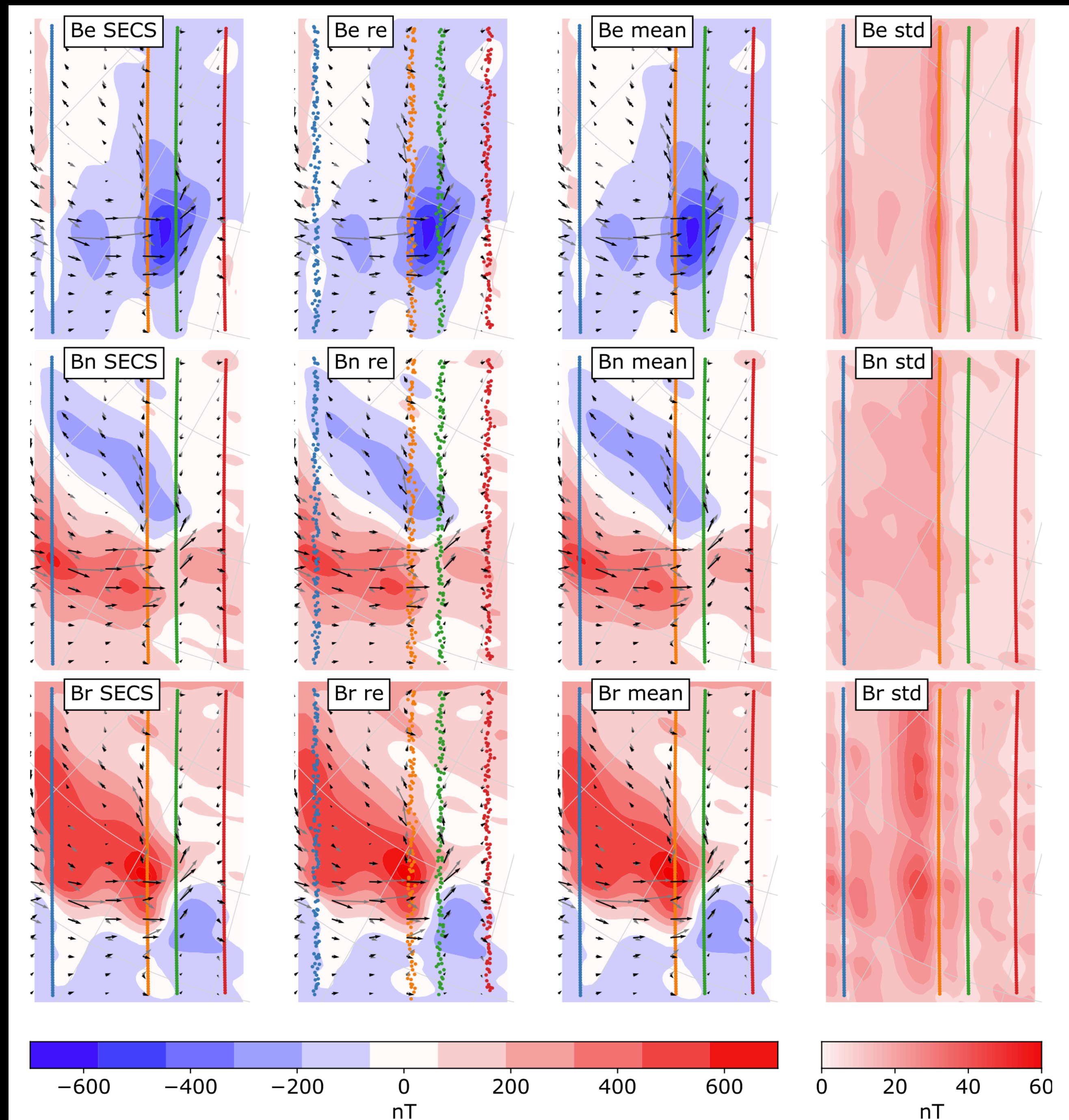
Results



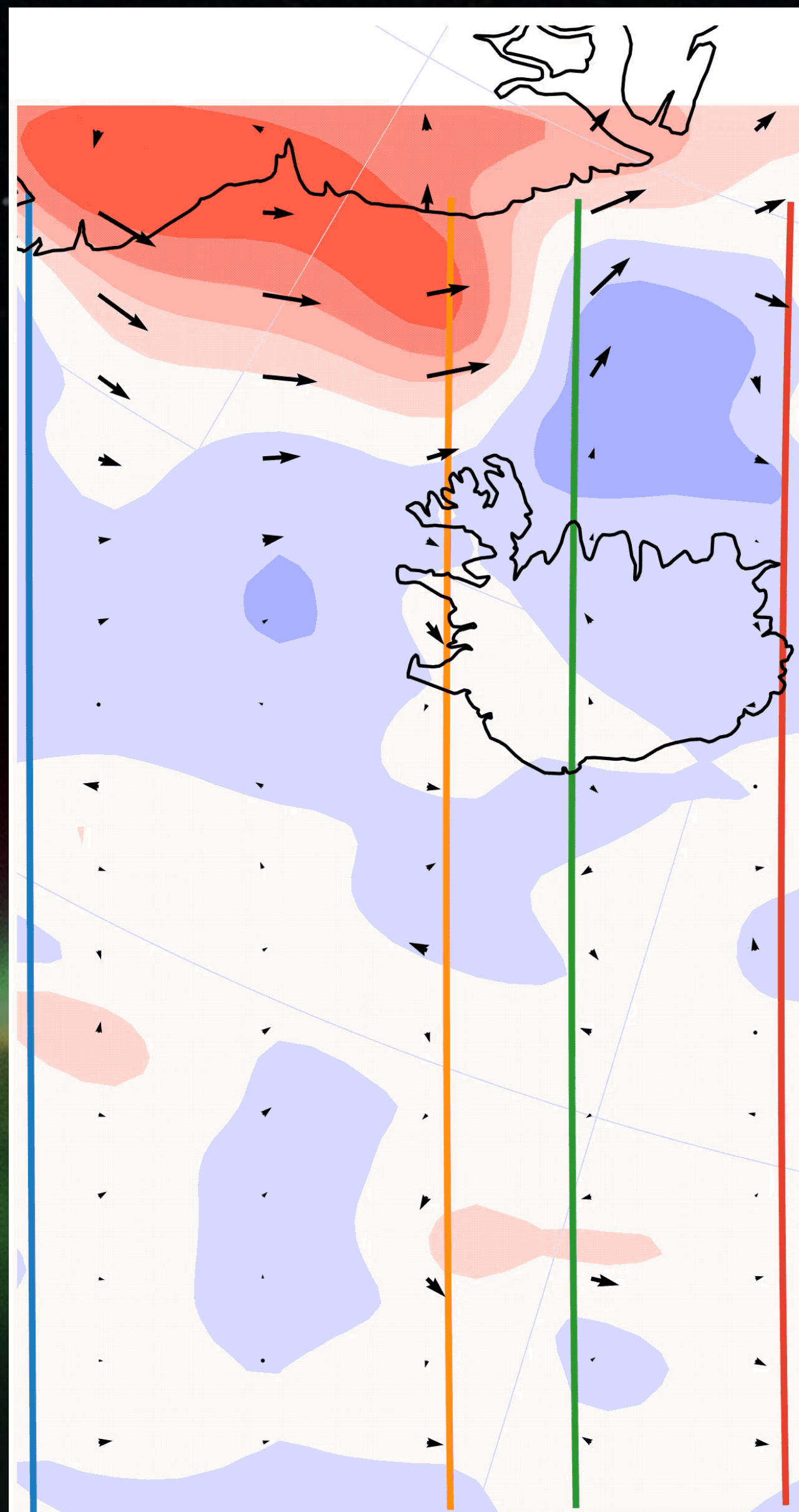
- The structure and magnitude of the MHD model input (left) is well represented by the SECS model based on synthetic data
- Even the very noisy horizontal components are accurately retrieved

Effects of field-of-view

- The measurements are based on radiation coming from a field-of-view. Above we treated them as point measurements. What are the effects of this?
- To explore this, we drew measurements from spatial probability distributions to mimic the fields of view, and investigated the resulting models.
- The columns correspond to
 1. MHD model output
 2. An example random model (notice scattered data points)
 3. The mean of all models
 4. The standard deviation of all models



Conclusions



EZIE will give maps of the electrojet and associated magnetic field in a 1000 km wide band along satellite tracks - thanks to unprecedented spatial coverage and a novel inversion scheme for SECS analysis

For details, see preprint at
<https://www.essoar.org/doi/10.1002/essoar.10504160.1>

