Automated Regional Modelling (ARM) for characterization of the substorm current wedge

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Some characteristics of substorms may be determined through use of an electrojet forward modelling approach. These include the amplitude of cross-meridian electric current (0.2 to 1 MA typically), timescales (about 20 minutes to peak current and poleward extension), and amount of poleward motion (several degrees). An increase in the number of magnetic stations deployed in North America makes use of a full substorm current wedge system possible, reproducing well the perturbations observed both in the auroral zone and at subauroral stations. This provides good characterization not only of the aforementioned parameters, but also of the substorm longitudinal parameters including the central meridian. In principle, extension of near-Earth field-aligned currents into space is possible based on inversion results and field models. In practice, comparison with data from spacecraft such as THEMIS is complicated by processes in space such as plasma sheet changes at substorm onset

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How to invert ground magnetic data?

- A forward model based on characteristics of field-aligned and ionospheric (and induced) currents can be made
- The parameters of such a model can be adjusted so that ground magnetic fields from the model match those observed
- Pioneering work on this was done at U of Alberta in the 1970's by Rostoker and Kisabeth

Automated Forward Modelling

- Making the model to be matched to the data is referred to as "Forward" Modelling
- Doing the fit by hand takes a lot of time and perhaps does not allow the parameter space to be fully explored
- There is motivation to take the Forward approach and automate it
- A powerful and generally used inversion technique is the Levenberg-Marquardt approach (i.e. recently incorporated into MATLAB)
- The frequently encountered problem of sparse data can be overcome by working with meridian chains. This variant is loosely referred to as Automated Meridian Modelling
- For many applications (like THEMIS SCW) the appropriate scale is continental. This variant is Automated Regional Modelling (ARM)
- Generally data is too sparse to reliably apply AFM on a global scale

How does L-M work?

- L-M combines gradient descent plus a Newton solver in a space where an objective function is defined dependent on parameters
- In fitting data a suitable objective function is

$$\chi^2 = \sum_{i=1}^{N} \left(\frac{y_i - F(\mathbf{a}, x_i)}{\sigma_i} \right)^2$$

a is the parameter vector

(**x**,**y**) the N data points

and weighting is applied

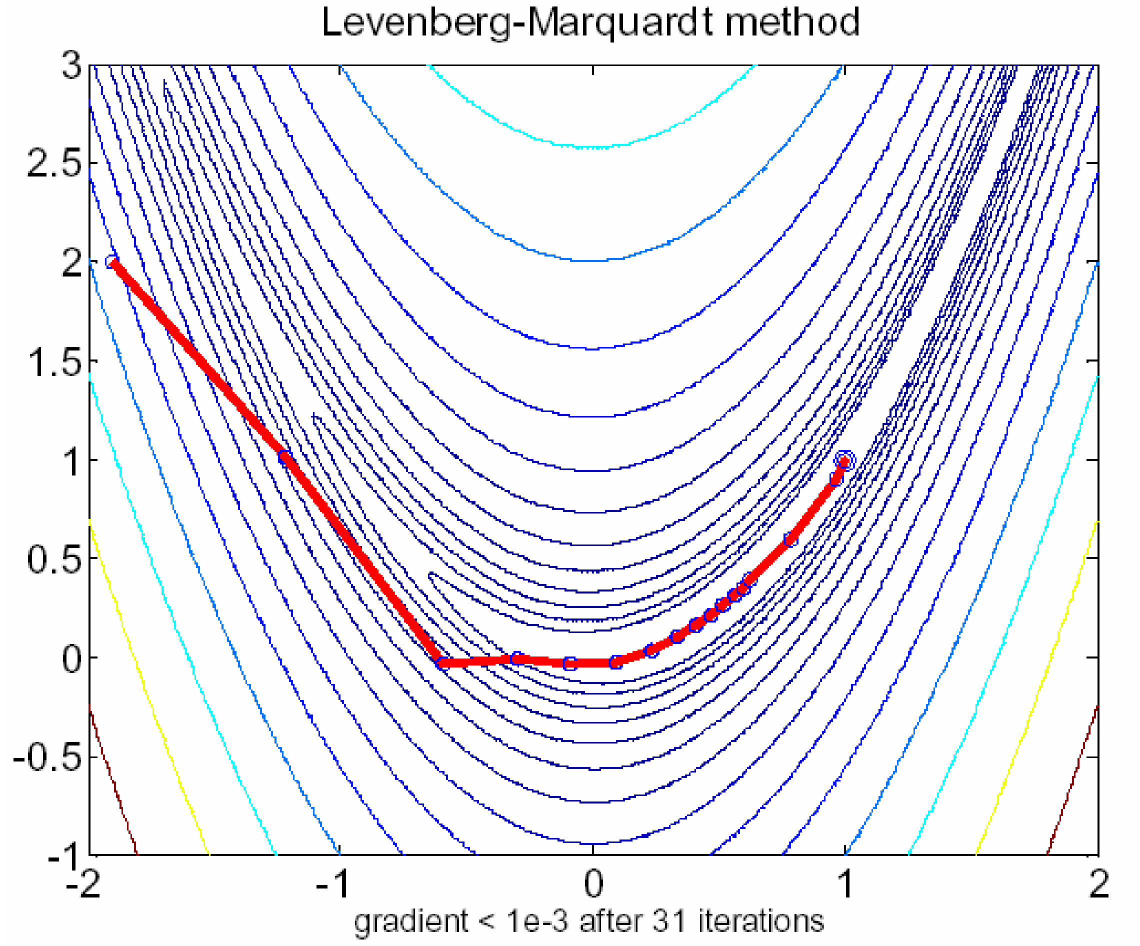
Far from minimum, following the gradient works BUT near it, the gradient is 0 and a quadratic form solution applies

L-M COMBINES these approaches

Initially follows gradients (more or less)

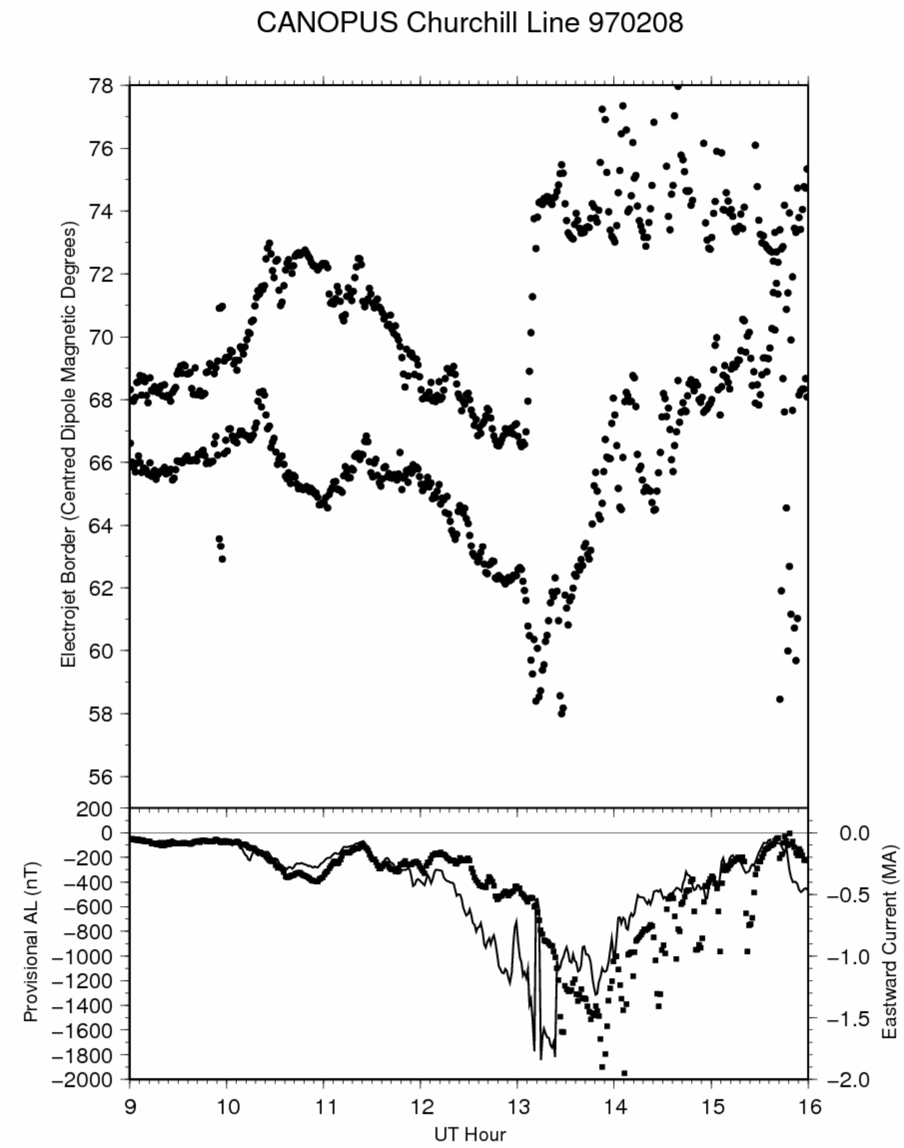
Then uses local curvature

Diagram: A. Zisserman, Oxford U.

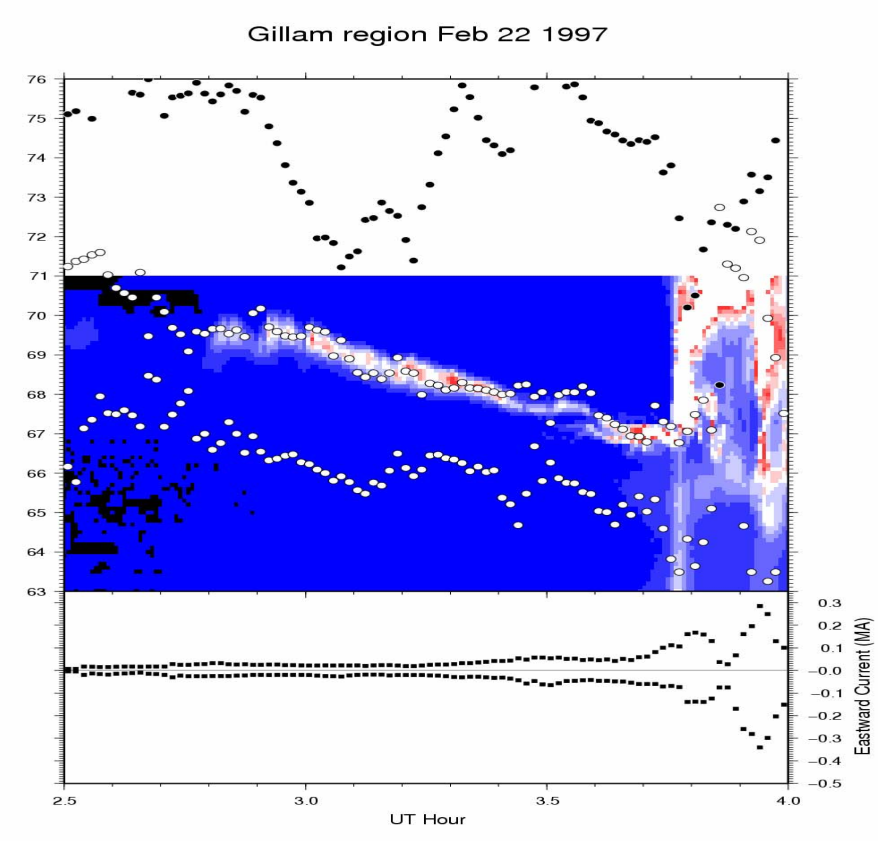


Meridian Modelling

- The AL (or AE) index can be misleading
- Here the AMM results are extremely clear for a substorm with strong growth phase
- AL or even the inverted current mislead as to onset time
- AL pre-onset shows Alaska conditions, post-onset shows Churchill



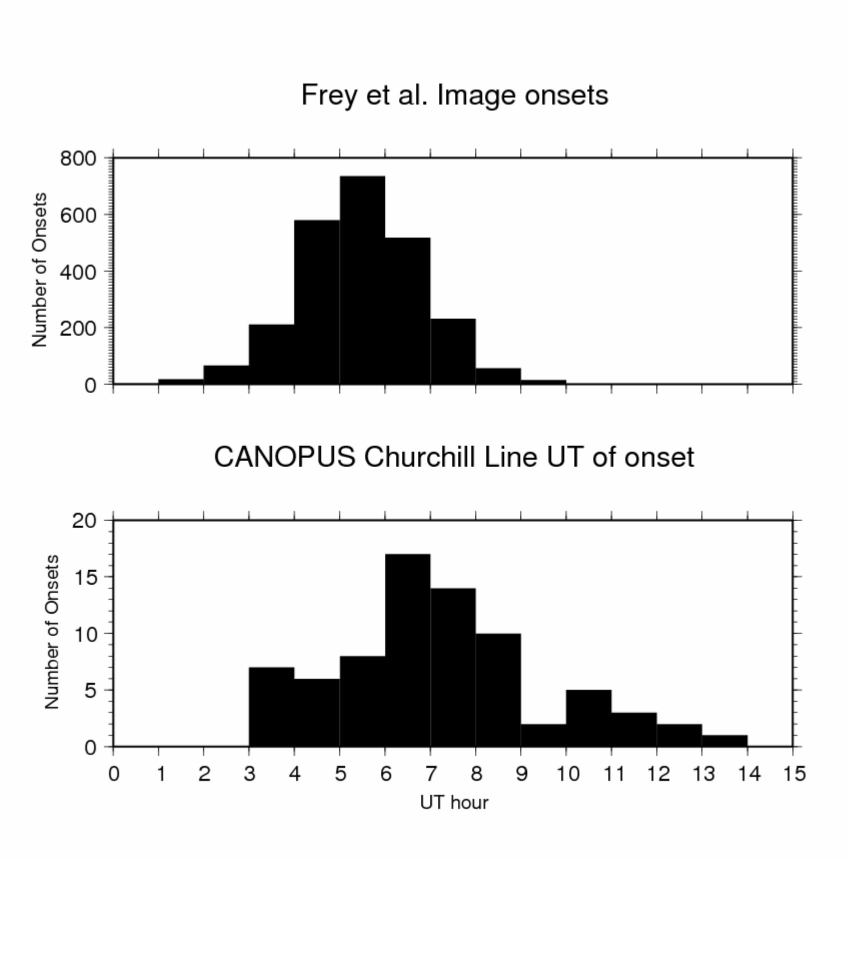
- In some cases, growth phase currents are strong enough to be tracked with AMM
- Here an eastward electrojet (white dots) tracks the equatorward motion of the growth phase arc



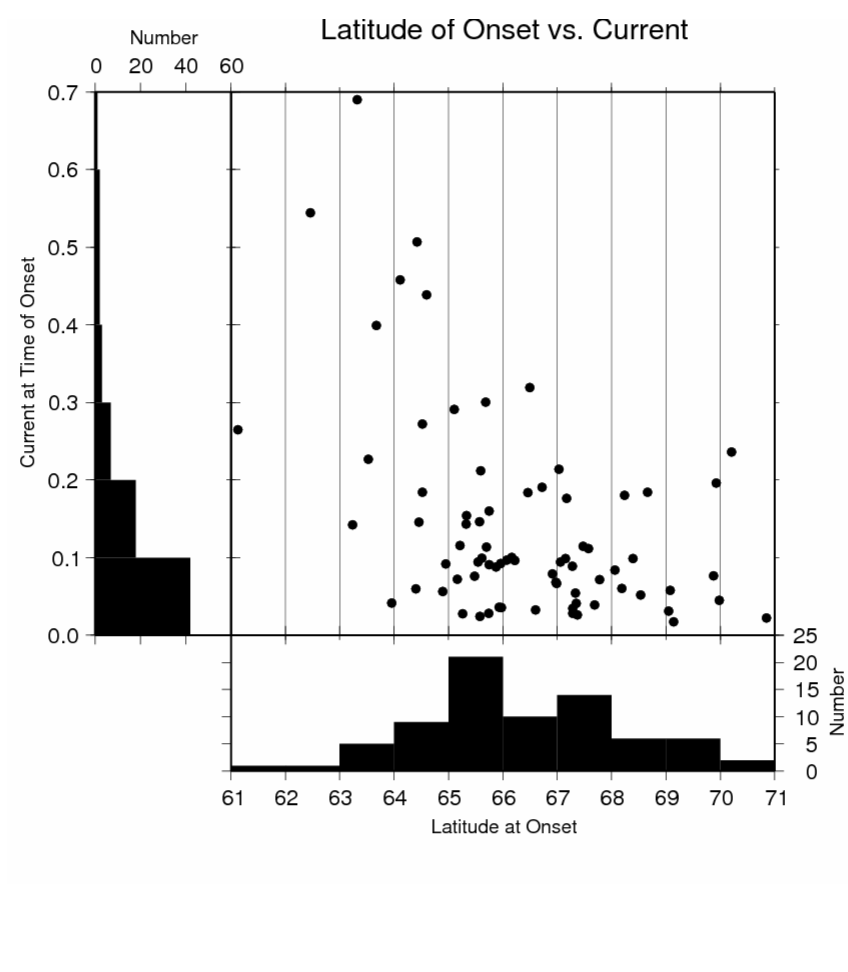
Statistical Properties of Substorms

- A large-scale inversion project was undertaken for 1997 Churchill meridian data
- Baselining the data is essential yet challenging
- About 65 onsets were found to be robustly inverted, comparable to the number of events in other statistical studies
- We have studied internal relations of parameters and not yet relation to external parameters such as solar wind

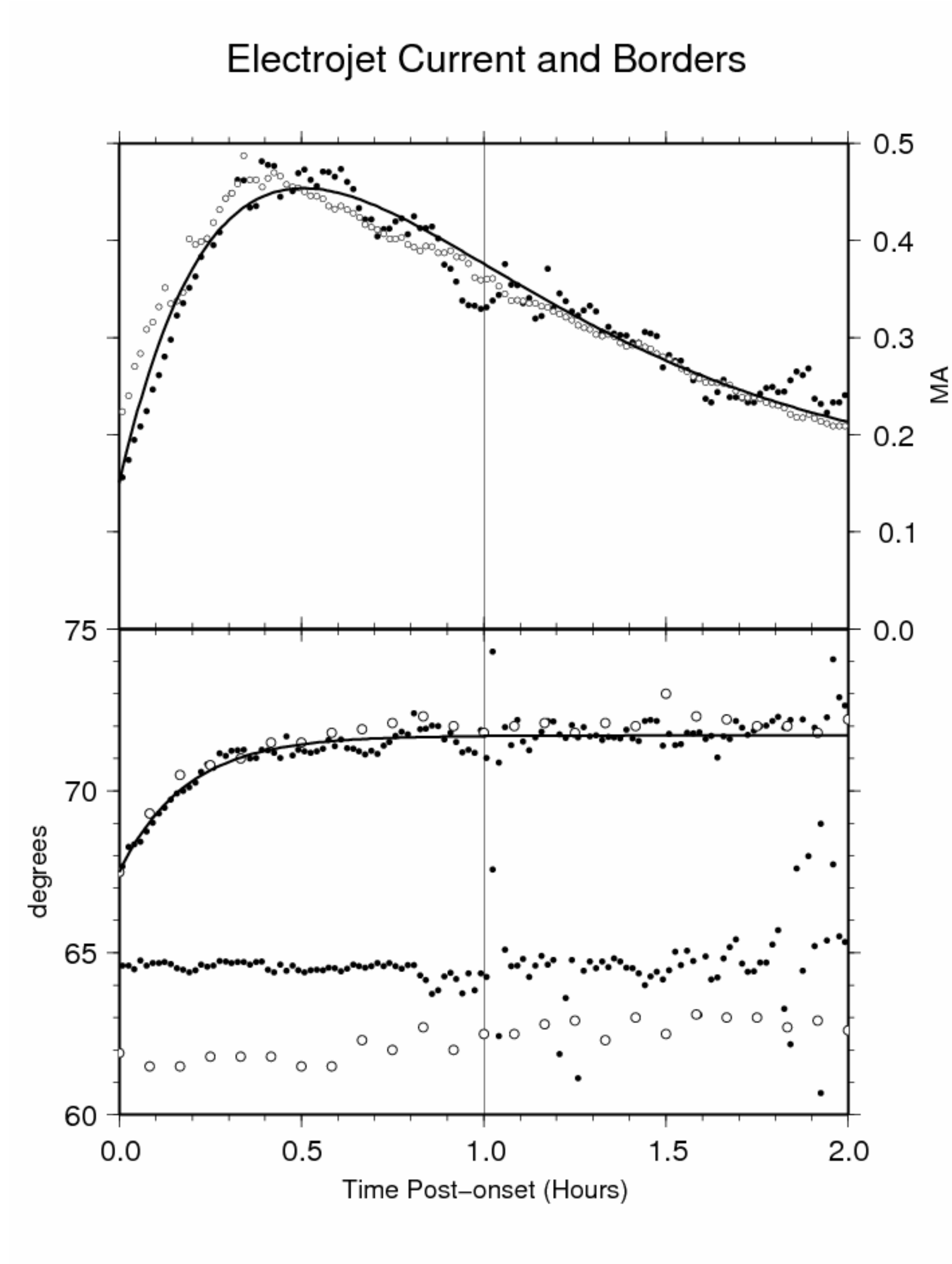
Frey et al. (2004) found Image FUV onsets skewed toward the evening sector. Our onsets straddle midnight. FUV onsets are due to bright evening sector auroras – the currents are in fact roughly symmetric around midnight.



Our results indicate a westward electrojet at time of onset of about 0.1 MA and also show the latitude at onset to increase with lesser current.



Post-Onset Average Behaviour

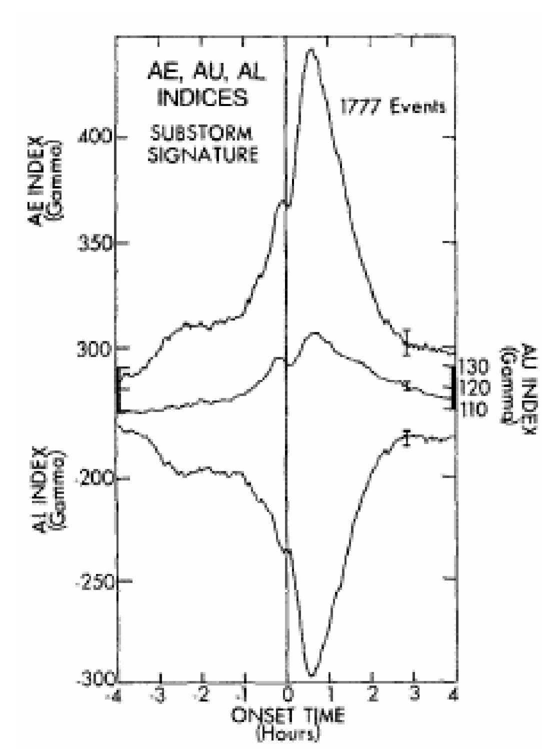


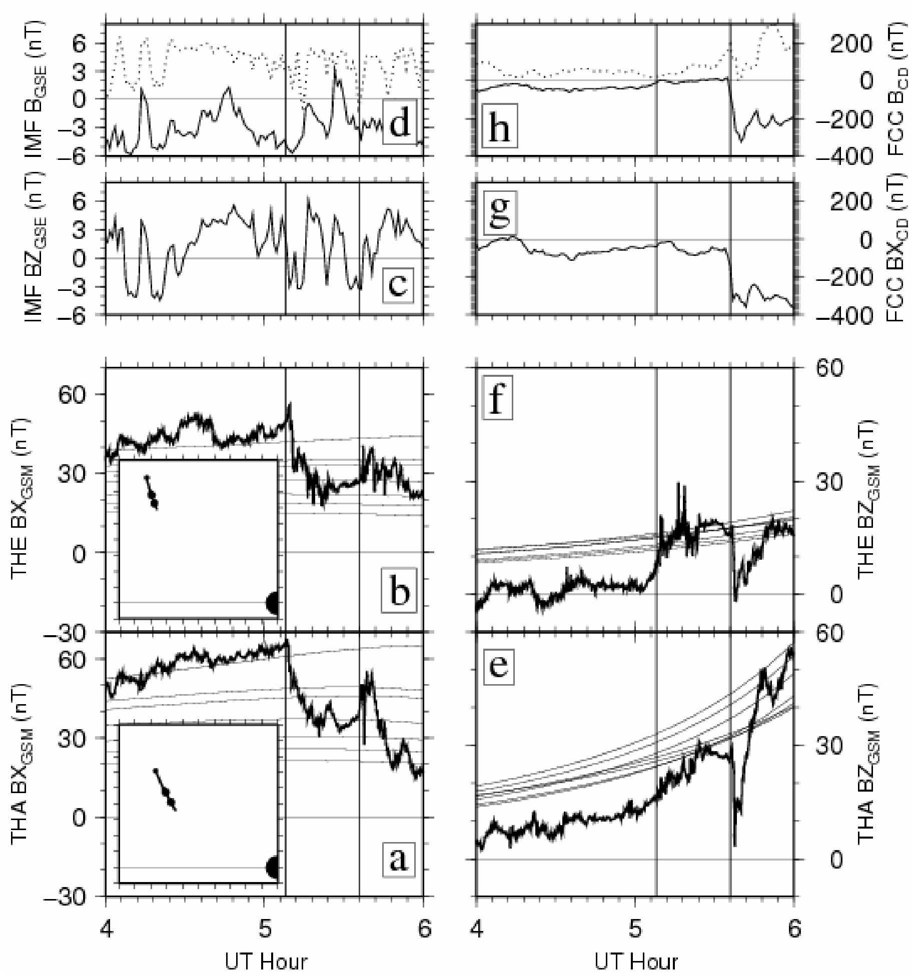
The current increases rapidly (20 min) to about 0.45 MA. Black dots show AMM current, open dots AE in MA as calibrated , and the solid curve the Weimer (1993) AE parametrization.

The electrojet poleward border (lower box) rises rapidly by about 5º (black dots AMM, open dots Frey et al., 2004). The equatorward border does not move. Frey's FUV width is wider than AMM gives.

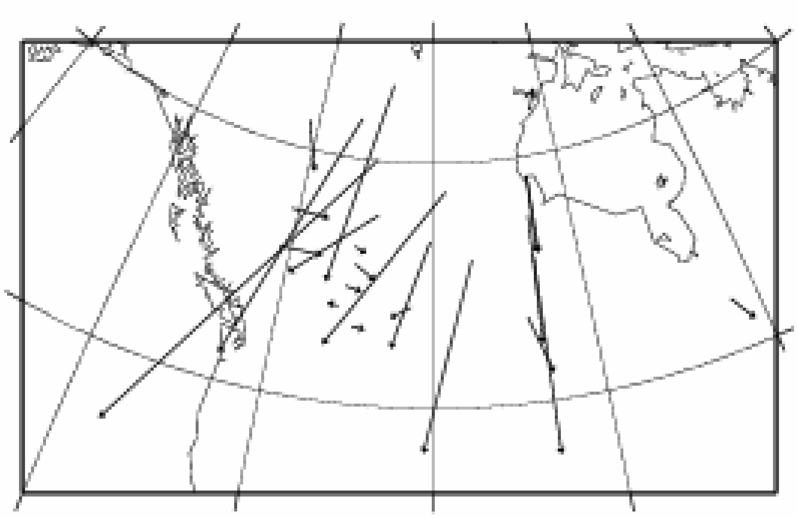
AE and AMM match on average and can be cross-calibrated. Weimer's *ate*$^{-bt}$+*c* parametrization is very good on average.

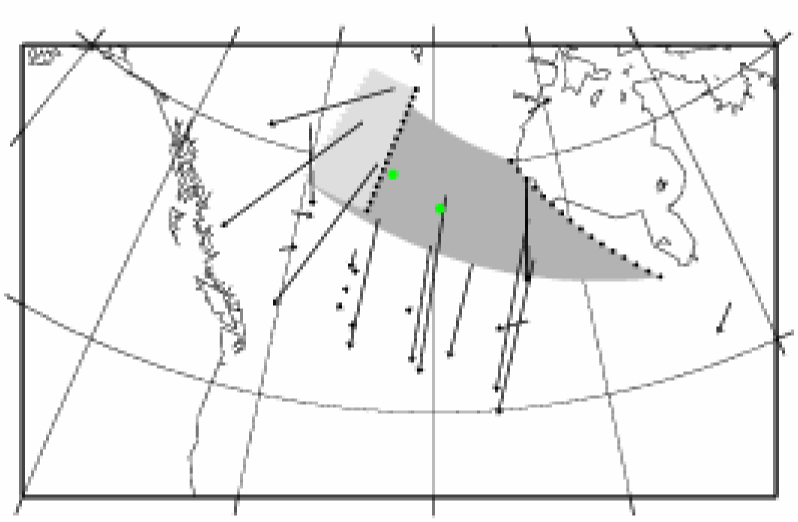
We note that Caan et al. had obtained similar results for AE in 1978 with a larger sample (right).





Observed (top) and modelled (bottom) perturbations arising from a westward electrojet (dark grey) and surge (light grey) system are shown below.



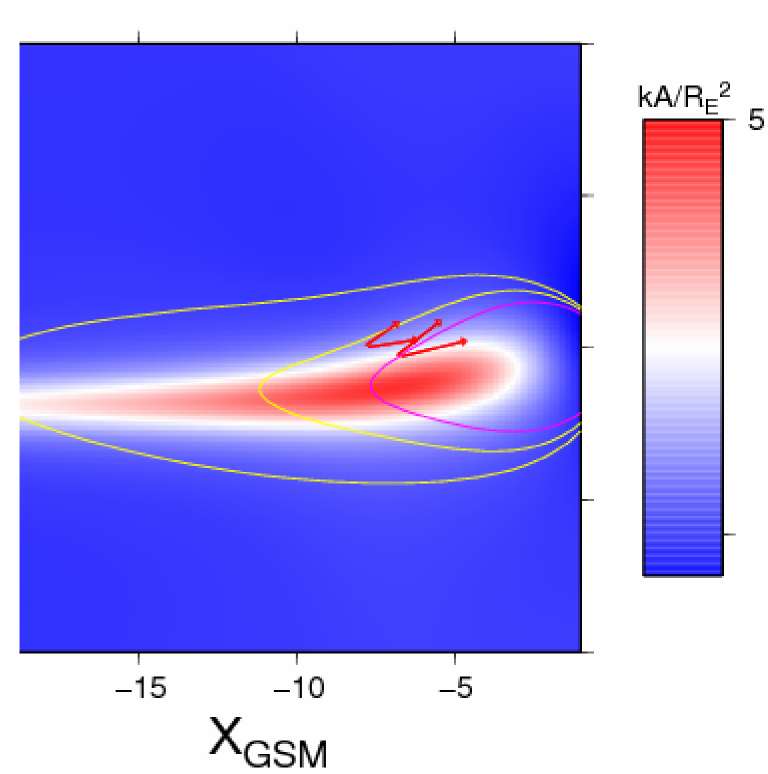


Mar. 13 2007 3D Model

At 5:07 UT, dipolarization was observed at THA and THE in the evening sector (positions in inset boxes of panels (a) and (b)). At 5:36 UT a second onset with large X (g) and Y (solid in (h)) perturbations also showed Z and Y (not shown) perturbations at THA and THE.

These are due to field-aligned currents of a “surge” current system (with northward ionospheric current).

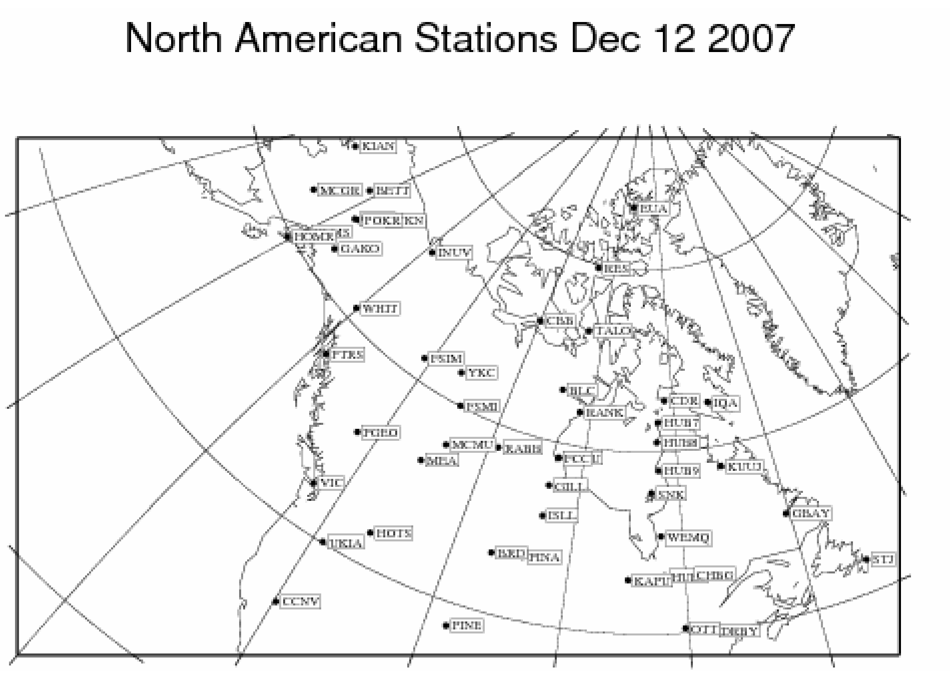
The T89 mapping goes from the surge to the spacecraft (see below).



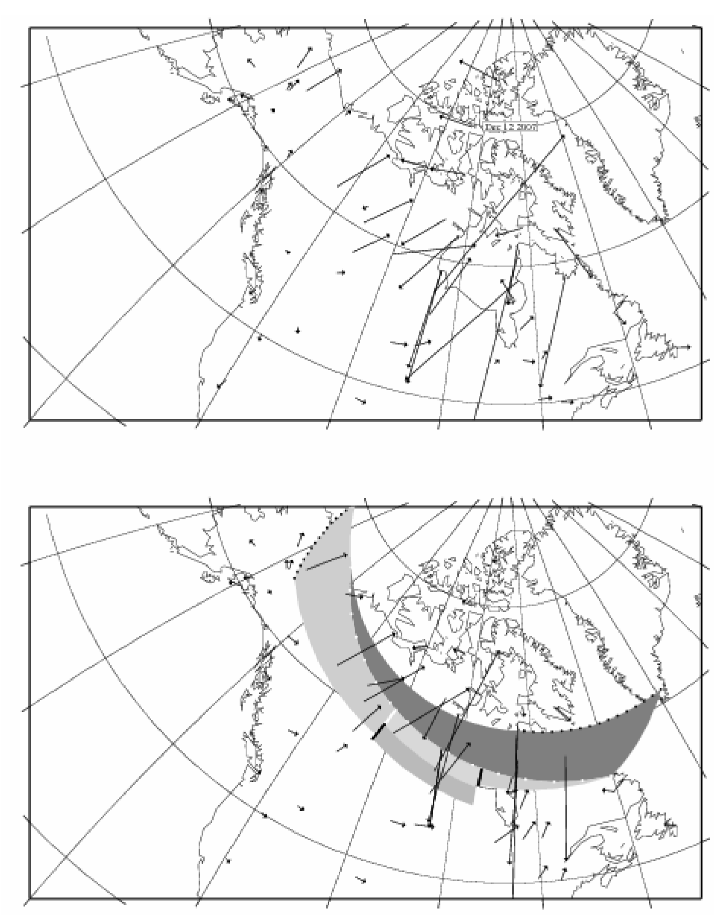
This simple current system (left) reproduces well the perturbations on the ground at this time (shortly after 5:07 onset). A similar system further east explains ground and space aspects of the 5:36 onset. The unique signature allows a verification of mapping: details depend on temporal evolution and spatial (mostly poleward) motion.

Dec. 12 2007 Two Electrojet 3D Model

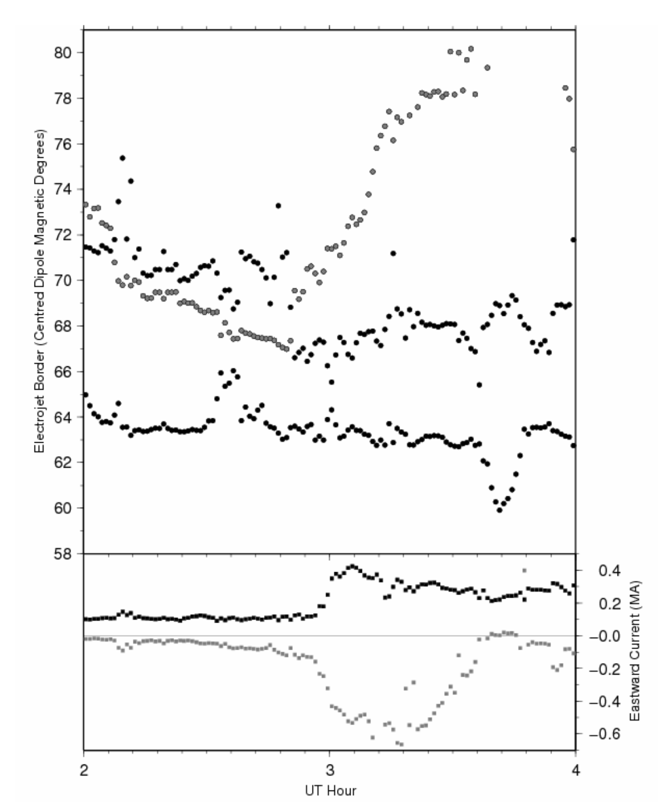
Expansion of ground magnetometer networks, largely in anticipation of THEMIS, allows regional modelling to be done for North America in a detailed way. The density of stations is essential to the smooth operation of the ARM routine. However, it remains true that a relatively small number of physical parameters can represent the current systems. In this case, the event is characterized by strong convection electrojets upon which a region of enhanced current is superposed, near where the opposed eastward (evening) and westward (morning) electrojets abut each other.



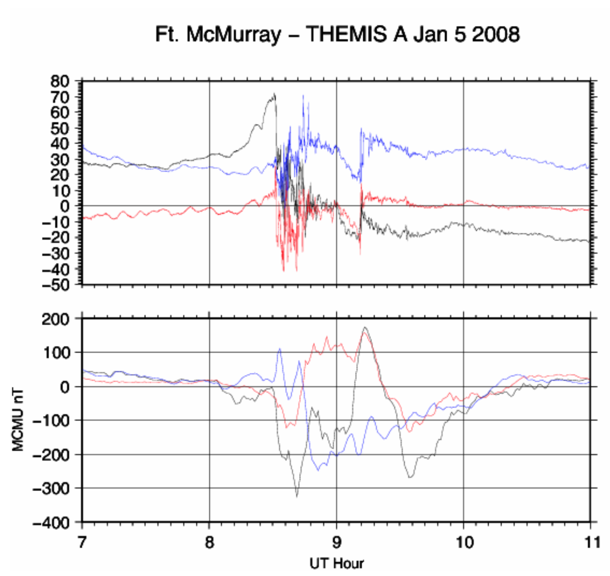
To our knowledge, the (left) magnetic dataset used is the largest ever from North America, notably through inclusion of GEONS, THEMIS, and Polaris East Hudson Bay instruments. Meridian chain inversion of the Churchill chain confirms the presence of two electrojets and at onset the westward electrojet borders move poleward and both electrojets intensify (below).



Despite (right) good characterization of Churchill line data by two electrojets, on the scale of North America both convection electrojets and an intense set at the onset point (near Gillam) are needed (left). Top panel data, bottom model, at 3 UT, just after onset.

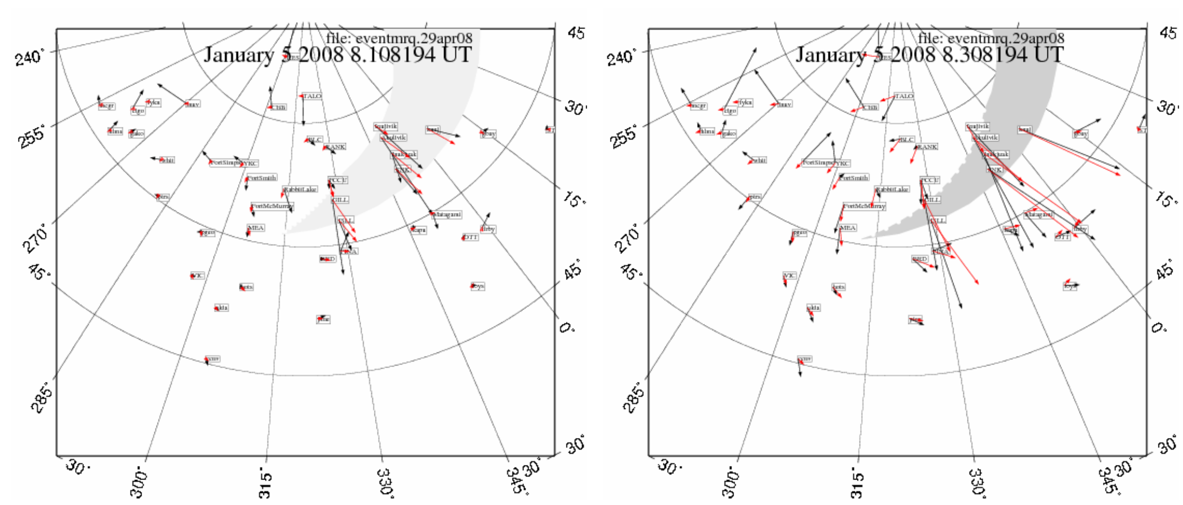


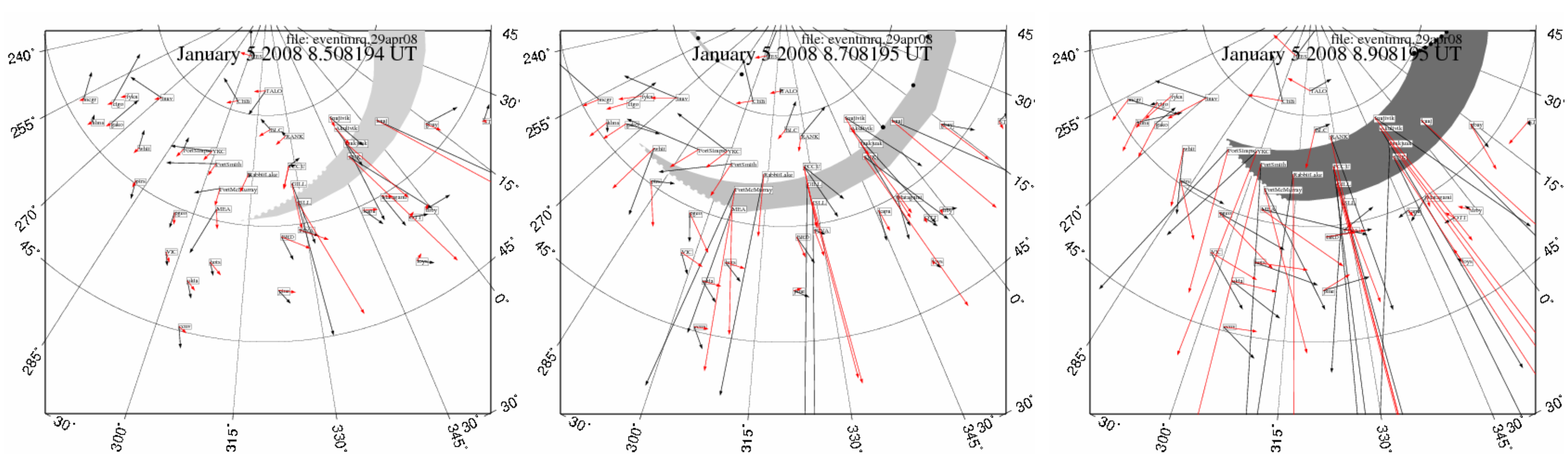
Jan. 5 2008 Temporal 3D SCW Model

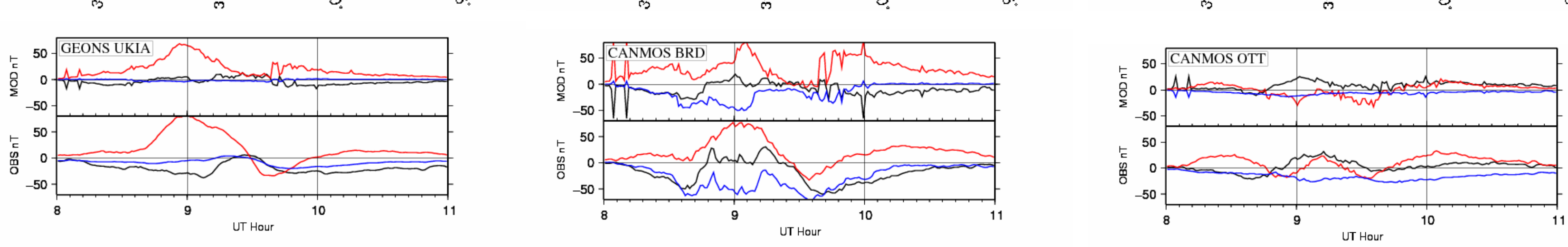


This event is characterized by westward expansion of the westward electrojet, with a weak eastward electrojet, and good conjugacy to THEMIS. An onset in the east at 8:00 UT was followed by another with westward expansion at 8:30 with effects seen at THEMIS A (left). Plasma data is not available but as for Mar. 13 event above, X changes may be due to plasma sheet effects.

Time evolution is shown here for 48 minutes. At 8.1 UT a local onset has taken place, growing in strength at 8.3 UT. Surge westward perturbations west of wedge at 8.5 UT, full onset in this region by 8.7 UT. Stengthens and expands poleward at 8.9 UT. Black is data, red model results.







Low latitude perturbations (bottom row of plots) are well reproduced by the simple single electojet model, (X black, Y red, Z blue; data on bottom, model on top). This and the perturbations at THEMIS show that field-aligned currents can be well determined by ARM and hold promise to explore ground-space mapping.

Overcoming sparse placement of magnetometers

Inversion techniques such as Automated Regional Modelling depend on data on the continental scale of Canada. Large gaps still exist in the deployment of magnetometers and some existing magnetometers do not operate for lack of funding.
It is **critically** important to fill the remaining gaps in support of THEMIS and the upcoming Canadian e-POP.

- An unfunded consortium including Don Wallis, George Sofko, Dieter Andre, Martin Connors, Gordon Rostoker, and others, has attempted to revive older EDA magnetometers
- These are used with $200 A/D cards and old computers. A recent upgrade to $400 seismic A/D with GPS is very worthtwhile
- Results are generally good but progress is slow
- Saskatoon SuperDARN site (mid-October) seen at right
- Fort Vermillion AB installed in December 2007

Athabasca University has installed several UCLA magnetometers in Alberta

AUTUMN
Athabasca University THEMIS UCLA Magnetometer Network

Ground Magnetometers

Inexpensive yet vital instruments

EDMO UCLA magnetometer being installed by Brian Martin for AUTUMN

Kanji Hayashi in La Ronge, Canada on field work for STEP

Conclusions

Automated Forward Modeling in regional and meridian forms allows determination of near-Earth electric currents, well quantified by a limited set of physically meaningful parameters.

In some cases a westward electrojet represents most perturbations well, but sometimes a more complex system is needed.

Good coverage in the conjugate region to THEMIS allows linking field-aligned currents in space and near the ionosphere.

Acknowledgements

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