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Time Evolution of the Substorm Current Wedge from Ground and Space-based Magnetic Fields

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Abstract

Over the past several years, intensive efforts have resulted in a significant improvement in the ground instrumentation for auroral studies in North America. A major part of this is due to the THEMIS ground program, both in the U.S. and in Canada. The THEMIS Ground-Based Observatory network has fielded 10 additional magnetometers in Canada and Alaska. Further THEMIS magnetometers are part of the GEONS outreach effort, found in the continental U.S. and Alaska. Athabasca University initiatives and collaborations have made yet further magnetometer data available, most notably from the new AUTUMN network of instruments in central Alberta, and others in Quebec. Several stations of the University of Tokyo STEP network remain operational, and some have been upgraded. There is finally a dense enough set of magnetic data that techniques based on forward modeling, and most relevant to the opportunity afforded by THEMIS, Automated Regional Modeling (ARM), can be reliably used. These techniques specify where net field-aligned current (FAC) and ionospheric electric current flow are located. In some cases the Pedersen system can also be included based on data. Even when it is not, it can be considered collocated with electrojet locations given by ARM. The extension into space of the FAC (net or Pedersen) allows comparison with the perturbations observed at THEMIS. We present results from an event on March 13, 2007, during which THEMIS in its early orbital configuration was magnetically conjugate to central North America, clear weather prevailed, and a substorm took place whose perturbations were ideally suited for inversion using ARM. At about 5 UT, activations were detected from the ground with magnetic perturbations also detected from THEMIS. The ground perturbations are well represented by a three-dimensional substorm current wedge (SCW) system, and perturbations in space indicate radial propagation at a time when the electrojet expanded poleward. Little longitudinal propagation of the SCW is suggested by the ground data.

Athabasca University Geophysical Observatory (AUGO)

A comprehensive observatory ideally located for THEMIS conjunctions

54.72 N, 246.7 E
CGM (2005)
62.0, 306.5
L=4.55

Founded 2002
(UCLA mag 1998)

AUGO's Instrumentation

1. UCLA Fluxgate
2. THEMIS GBO Camera
3. KEO NORSTAR Camera

Guest instruments from STELAB:

1. Multispectal ASC including Hβ
2. 64 Hz induction coil
3. proton spectrometer

Ground Magnetometry

In a Sun-to-Mud approach, we are in the mud…

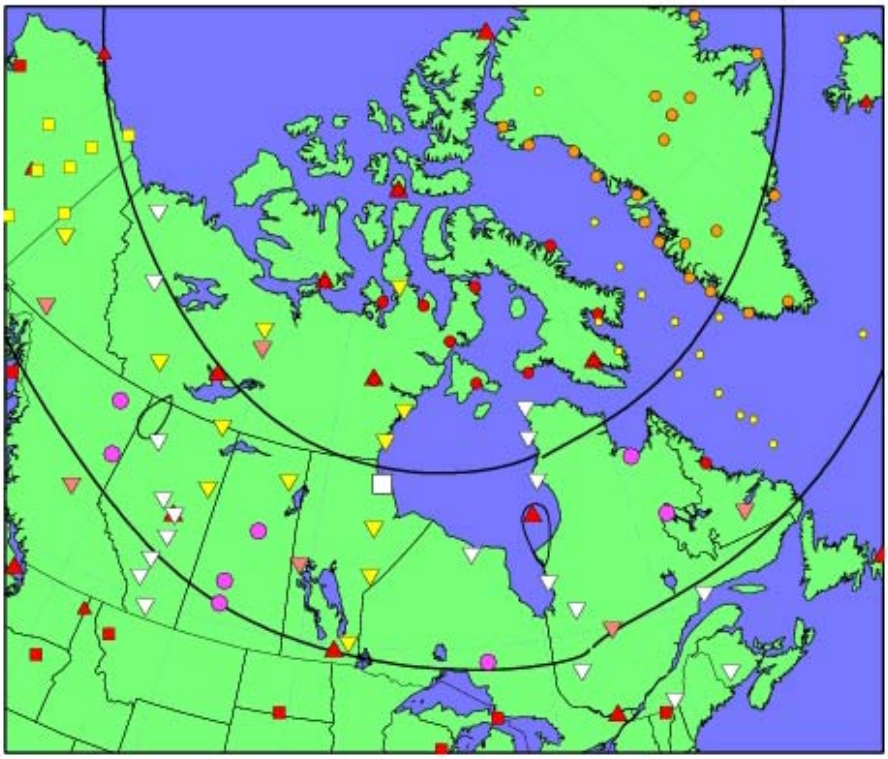
EDMO UCLA magnetometer installed by Martin Connors (Tom Sawyer-like technique applied to astronomer Brian Martin) in December 2004

Often the locales are less agreeable than San Francisco (Kanji Hayashi in LaRonge, Canada, mid-October 2004) but intensive fieldwork by teams from Athabasca University, UCLA, University of Calgary, University of Tokyo, and Northern Lakes College has greatly expanded North America's magnetometer networks

AUTUMN

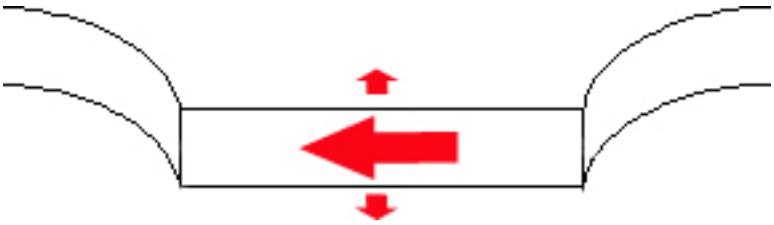
Athabasca University THEMIS UCLA Magnetometer Network

Magnetometers 2007

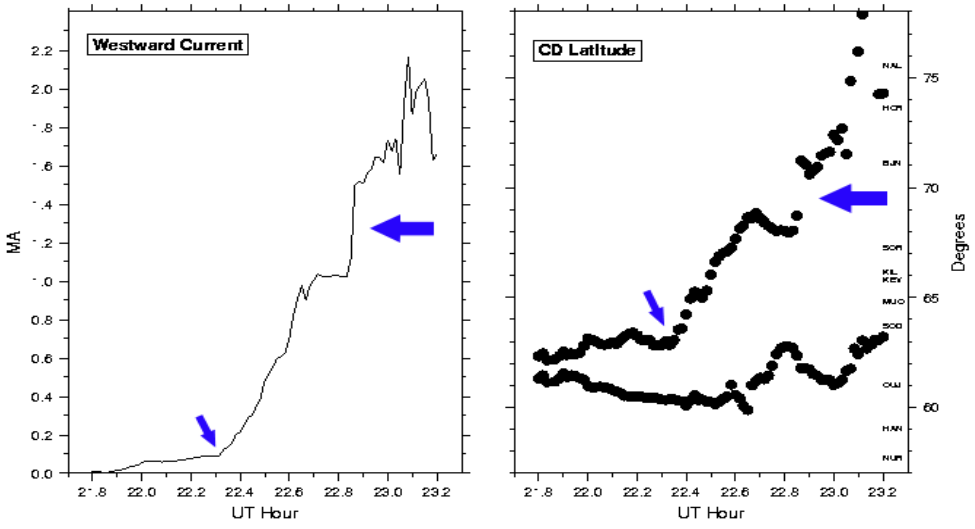


AUTUMN magnetometers cover Canada and are shown as white triangles. GBOs are brown triangles (some missing). STEP sites are purple. AUTUMN sites at Norman Wells, Peawanuck, Fredericton, Sept Iles are proposed, and new site Fort Vermillion (Dec. 2007 installed) is not shown. East coast Hudson Bay stations were installed in September 2007.

Automated Forward Modelling (AFM)



For meridian data, AFM adjusts current and borders. This is called Automated Meridian Modelling (AMM) and nominally uses only the X and Z ground perturbations.



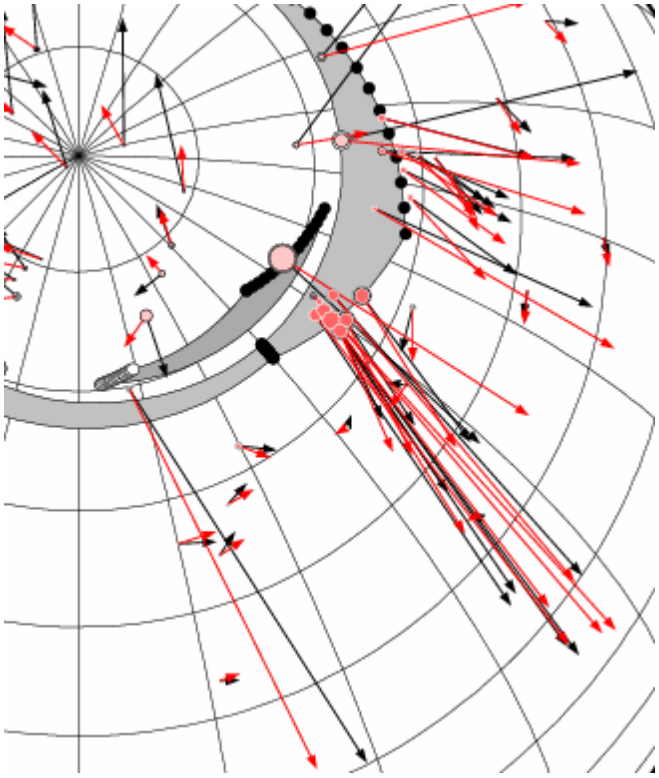
The method is however, much more general and can include field-aligned currents in realistic 3-d configurations. Midlatitude perturbations can be included as can a Dst-like parameter.

Array Interpretation from a distributed region is more difficult, complicated by problems of nonuniqueness. In a region such as North America, this is referred to as Automated Regional Modelling (ARM).

On the ground, one detects primarily the magnetic effects of the Hall currents associated with the auroral oval electric field

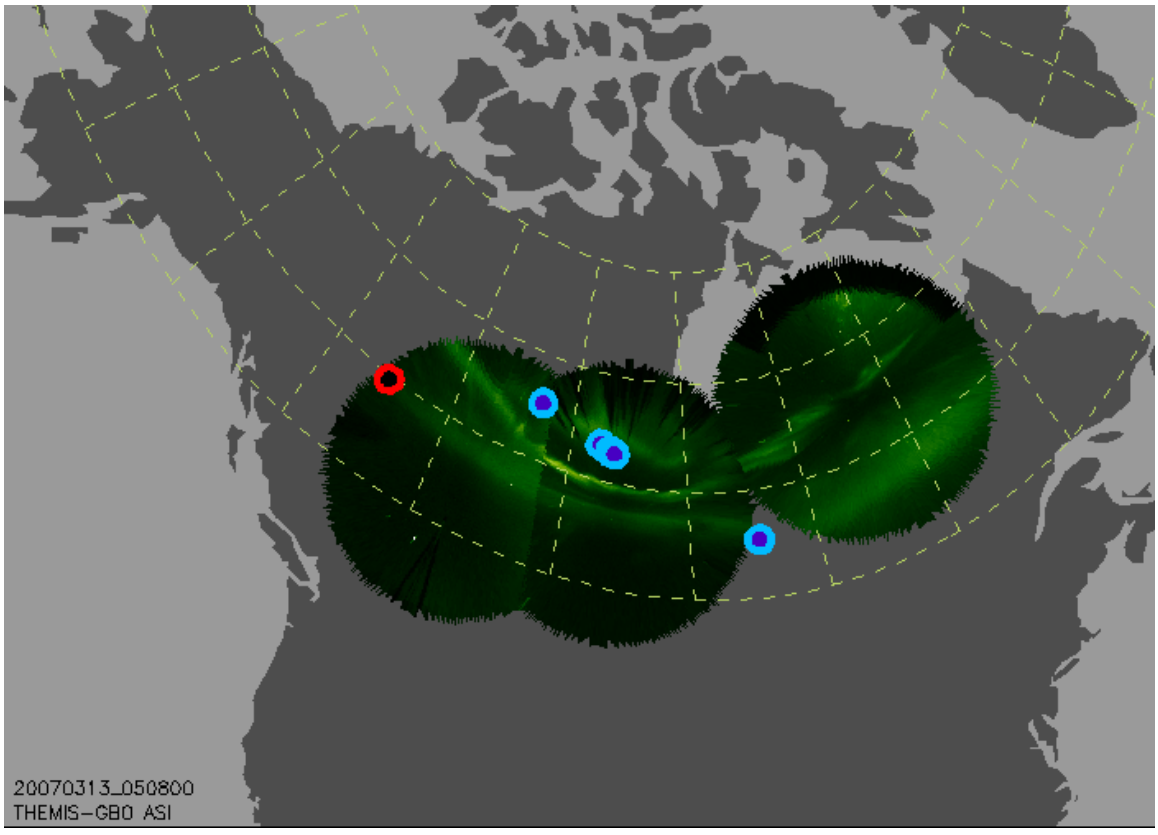
FAC effects CAN however also be detected from the ground.

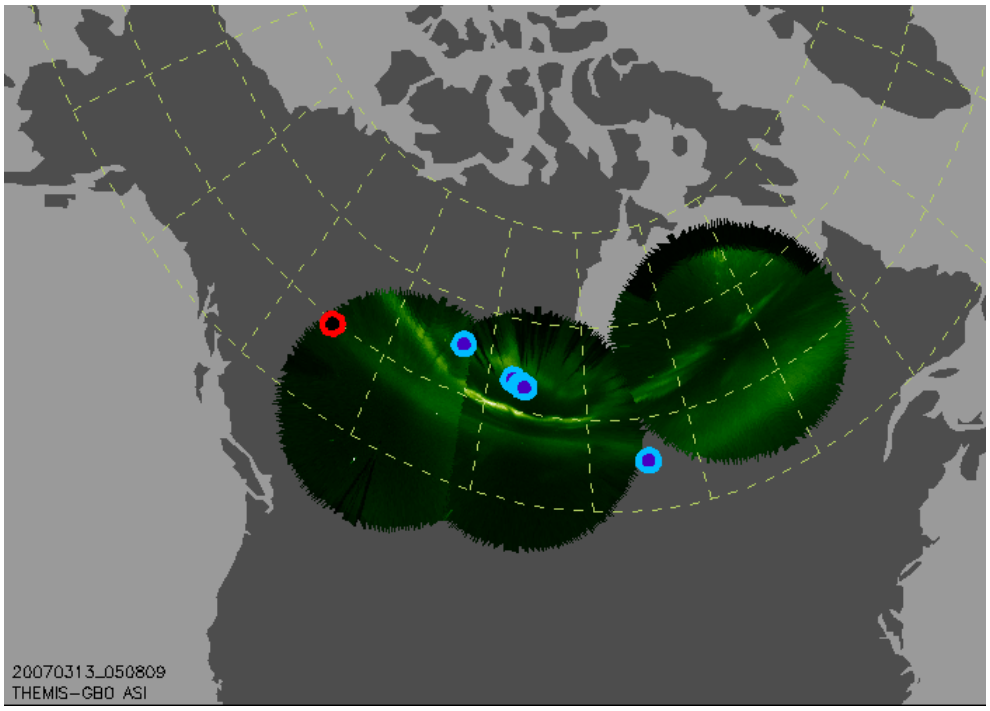
The figure shows a detailed model of the auroral oval on a global scale.



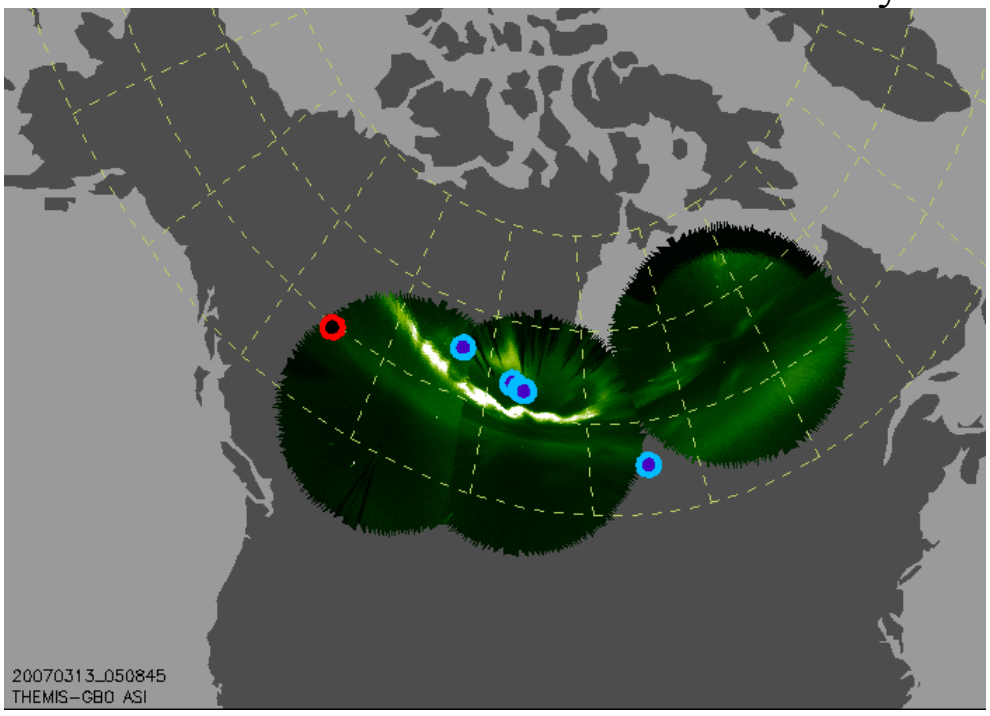
March 13, 2007 THEMIS Conjunction Event

Activations took place between 05:00 and 06:00 UT on March 13 2007, with several THEMIS satellites deployed in a line over central Canada with its THEMIS GBO cameras and many magnetometers. At 05:08:00 there was not much sign of activation. The cameras have 3s cadence.





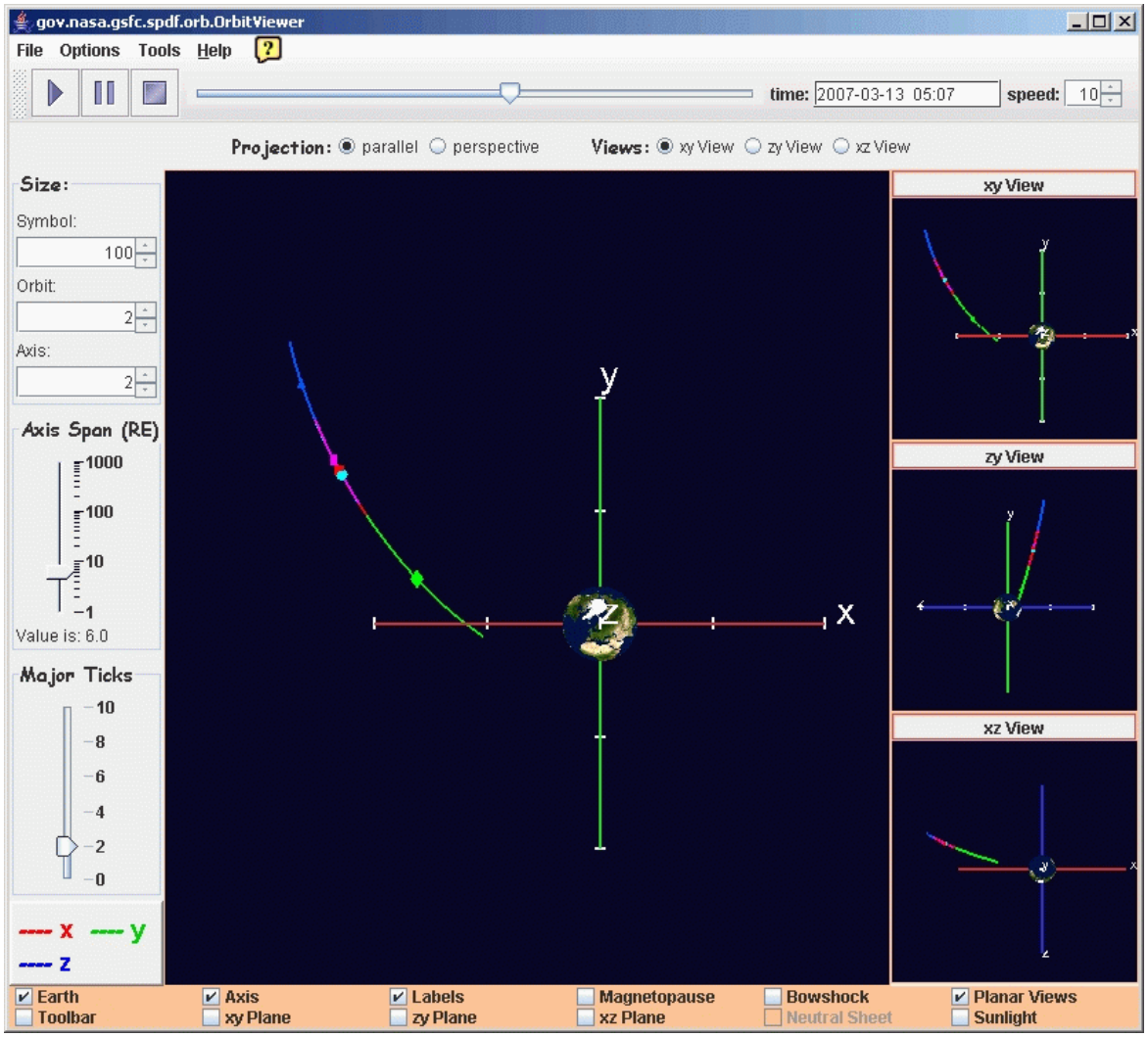
At 05:08:09 the activation was well under way.



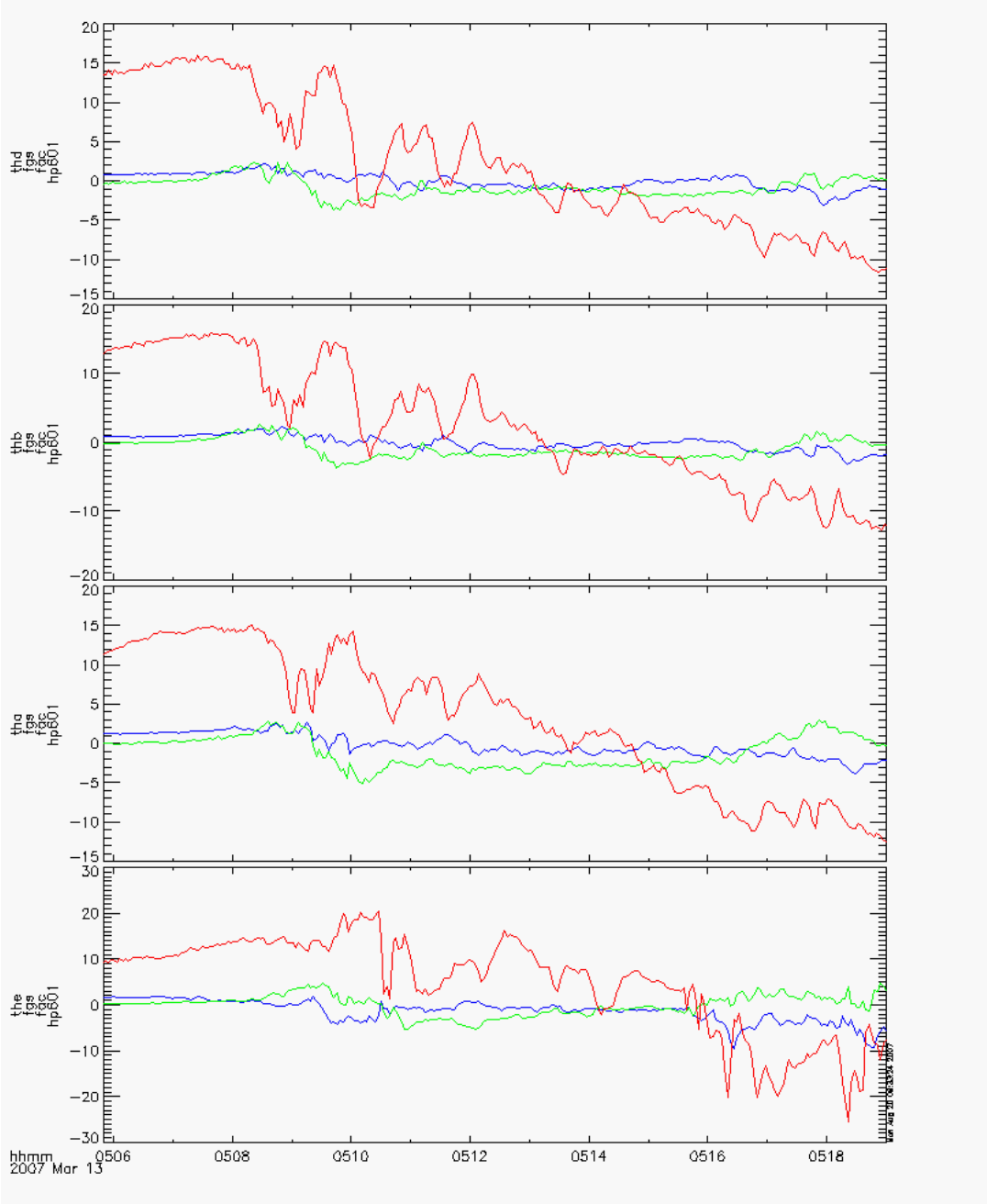
At 05:08:45 extensive vortical development had already taken place. The GBO network is a remarkable tool for identifying optical onset time and development of auroral features.

Magnetic Signatures

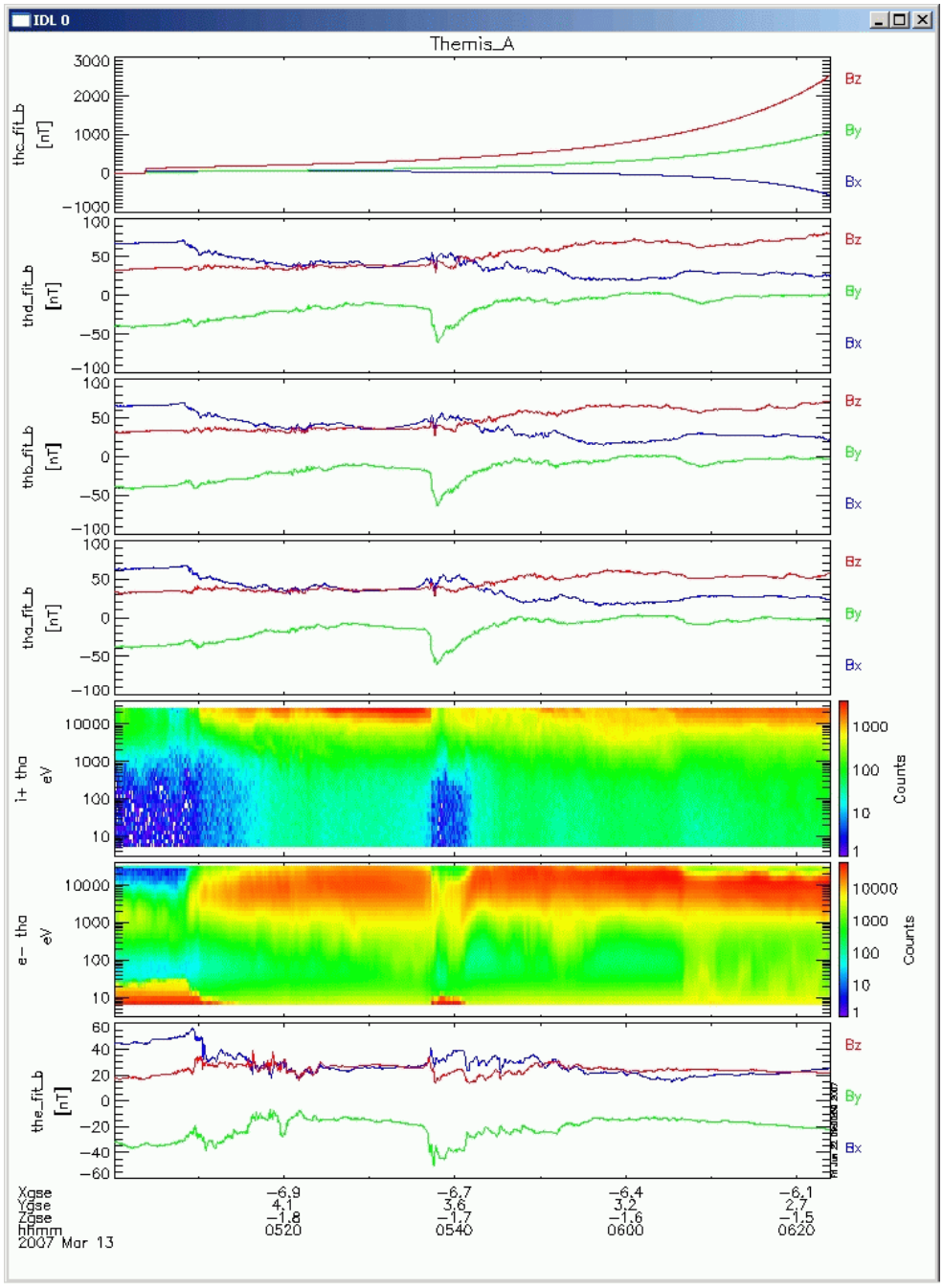
The magnetic signatures both in space and on the ground from the optically very bright 05:08:09 onset were modest. However they do show radial propagation outward.



Positions of spacecraft on Mar 13 2007 near 5:08 UT onset time. Scale is marked at 4 R_e intervals and dots are THEMIS C, D, B, A, and E, from lower right in main plot.



Radial and/or westward propagation of disturbance near 05:08 onset using field-aligned magnetic perturbations. X (blu) is toward Earth, Z (red) is along the field and Y (grn) westward.



Overview including second onset at 05:36. This onset appears suddenly at the location of the D, B, A, and E spacecraft. FAC signatures are very clear and particle data indicates exit from the plasma sheet.

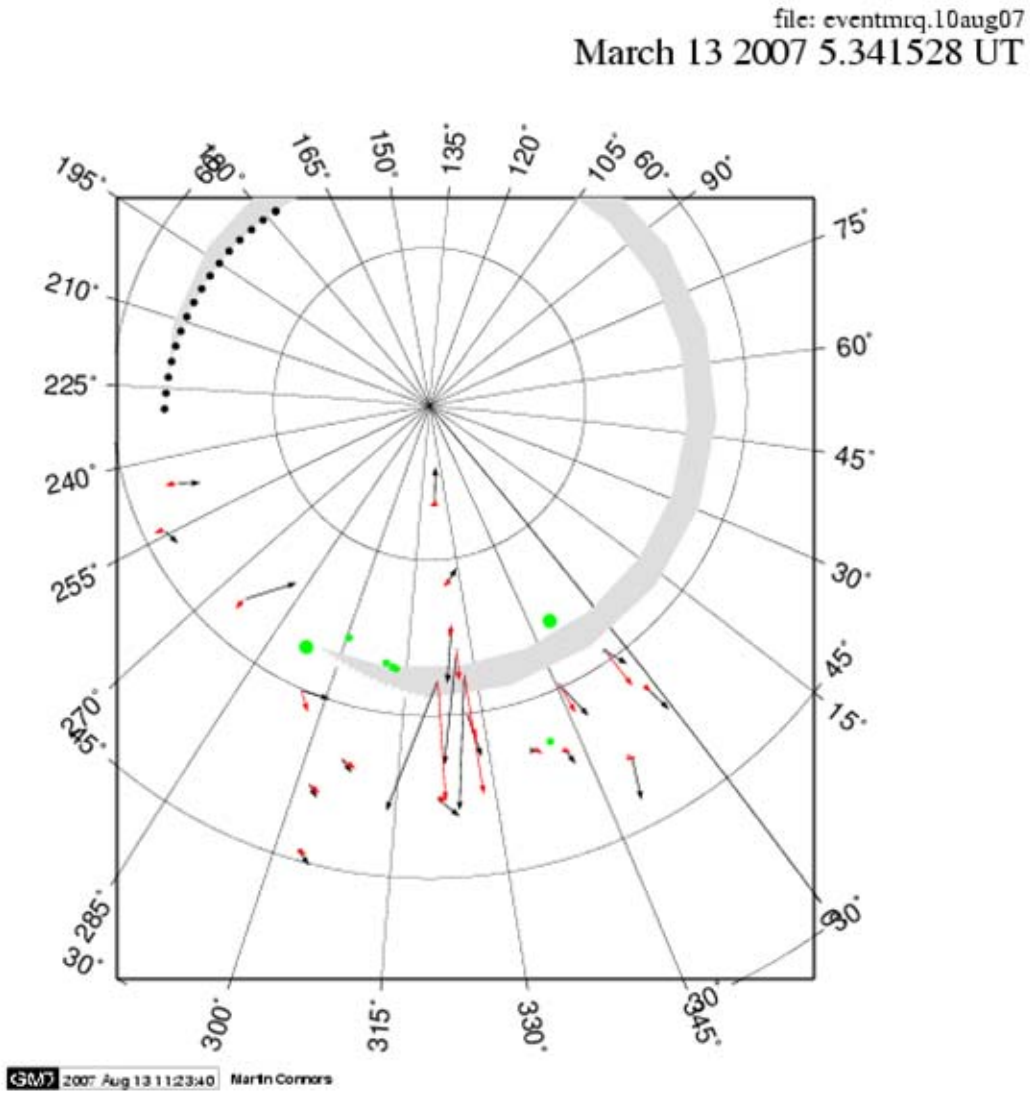
Automated Regional Modelling (ARM) preliminary results are based on local magnetic perturbations baselined with respect to March 18.

In all model runs, the electrojet was constrained to be in a substorm-current-wedge configuration, with downward field-aligned current (FAC) to the east, ionospheric current flow westward, and upward FAC to the west.

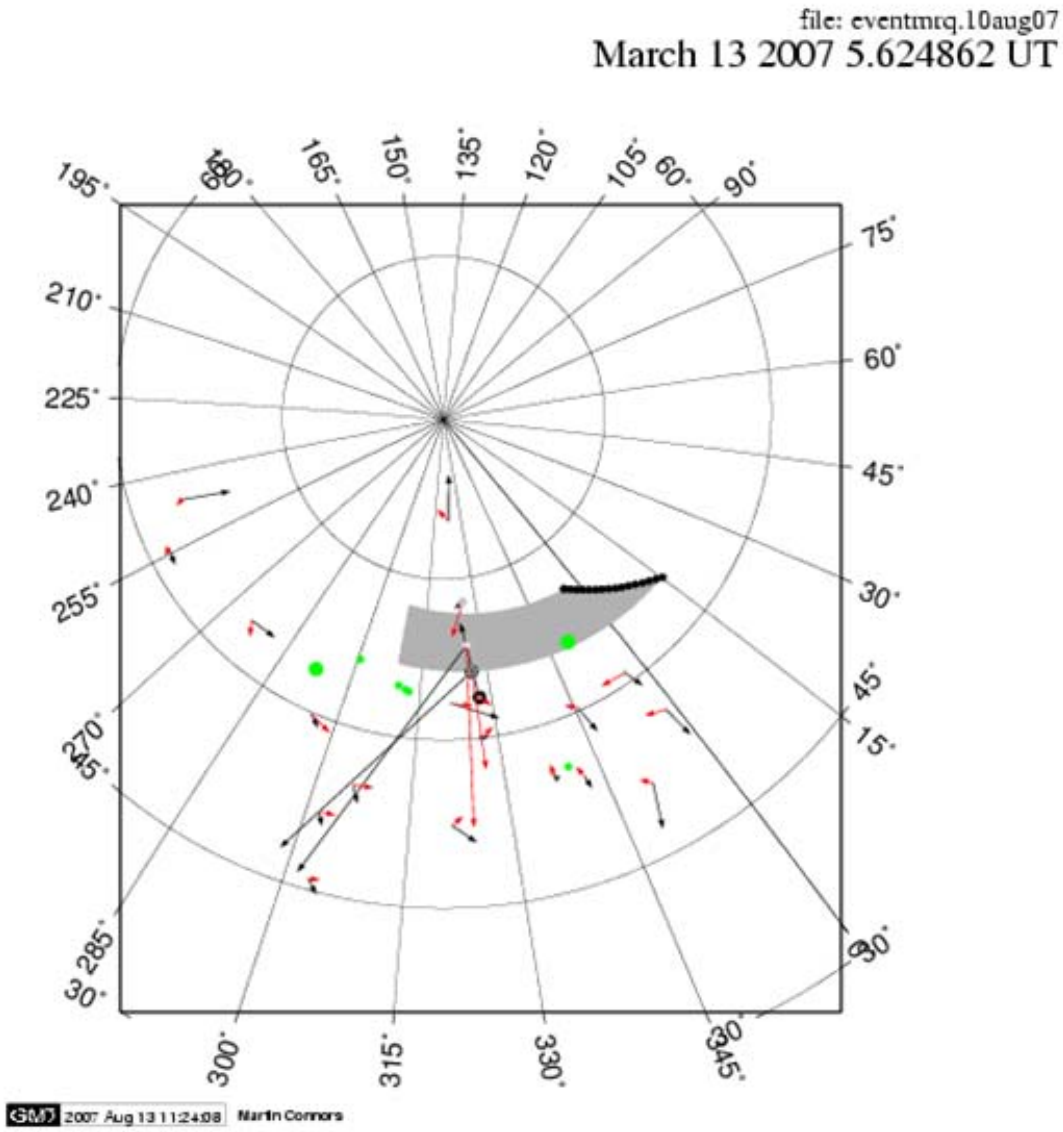
In the latter stages of the onset, this represented the magnetic perturbations at auroral and subauroral latitudes very well.

In the present model run Pedersen (north-south) currents and FAC sheets are not included, although the model can include them.

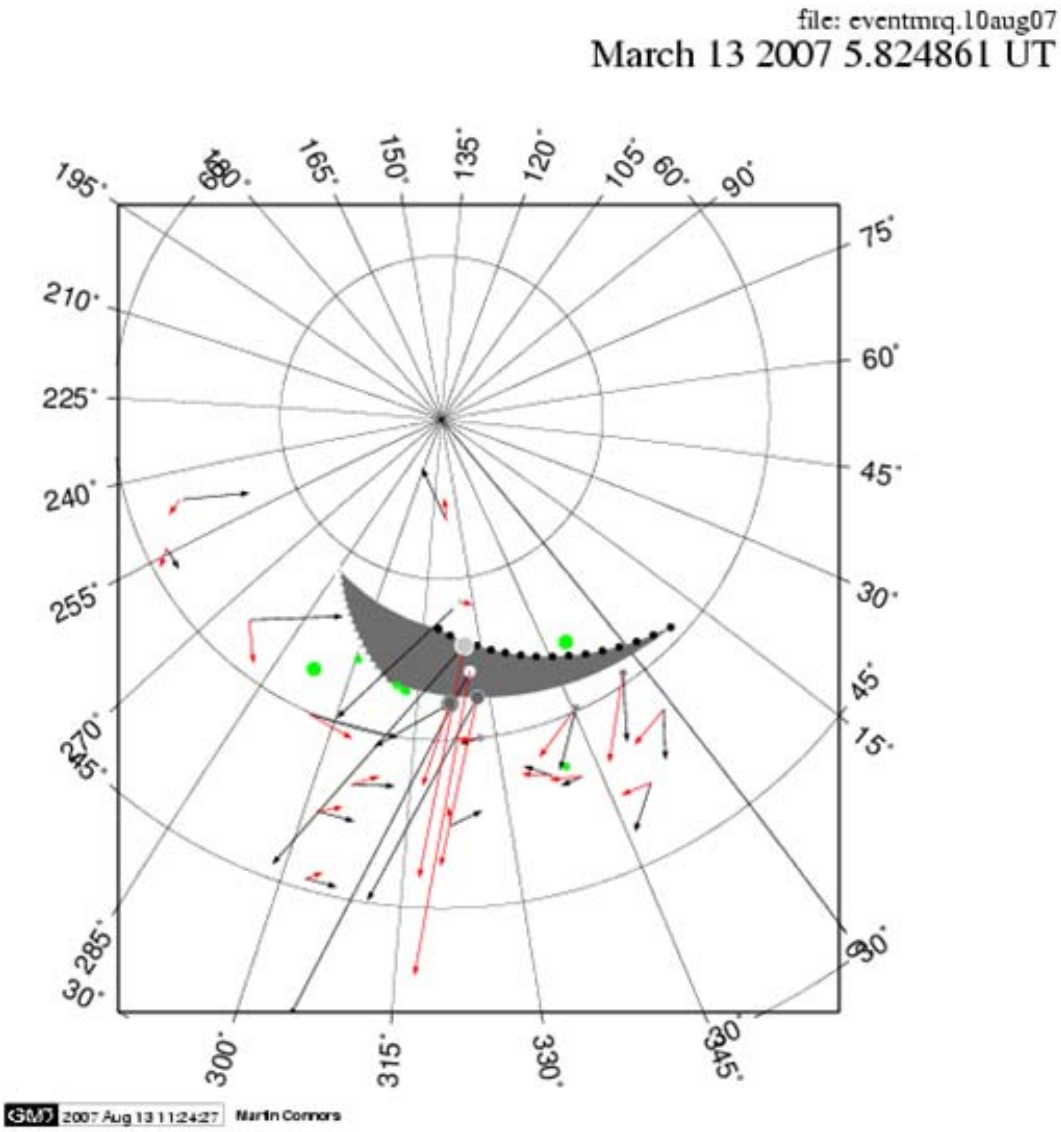
Model results are in red, observations in black.



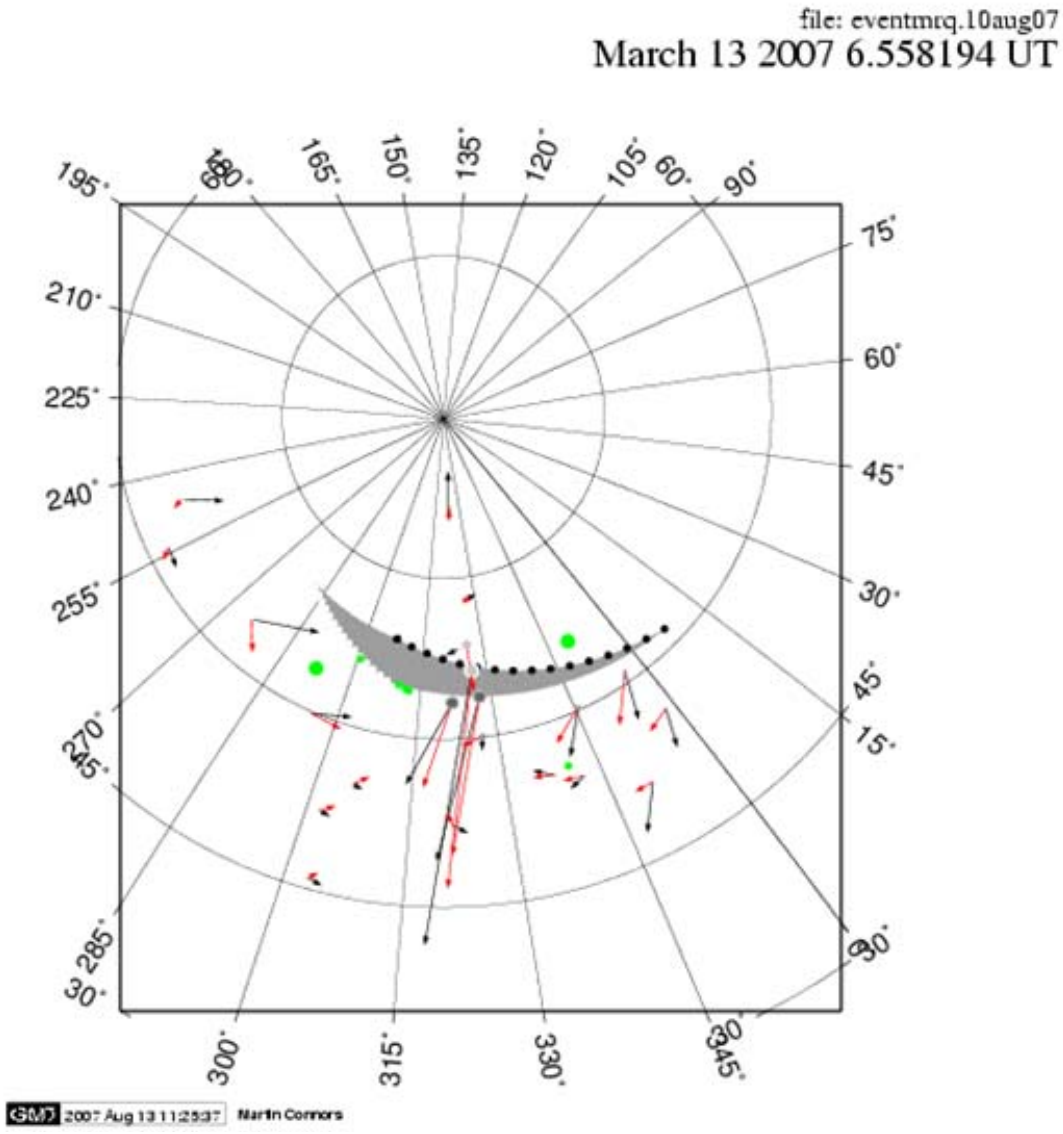
At 05:19.5 UT, after the initial onset, there is no indication of a narrow substorm current wedge. Perturbations in eastern North America are mainly southward. The eastward extension of the electrojet shown is poorly constrained and not indicative of reality.



A feature of the 05:36 onset (here shown at 05:37.5) is large westward perturbations in the auroral zone. These are not explained by the current simple SCW model. At this time, perturbations in eastern North America (NA) do not suggest a downward FAC there. These correspond to FAC signatures at THEMIS.

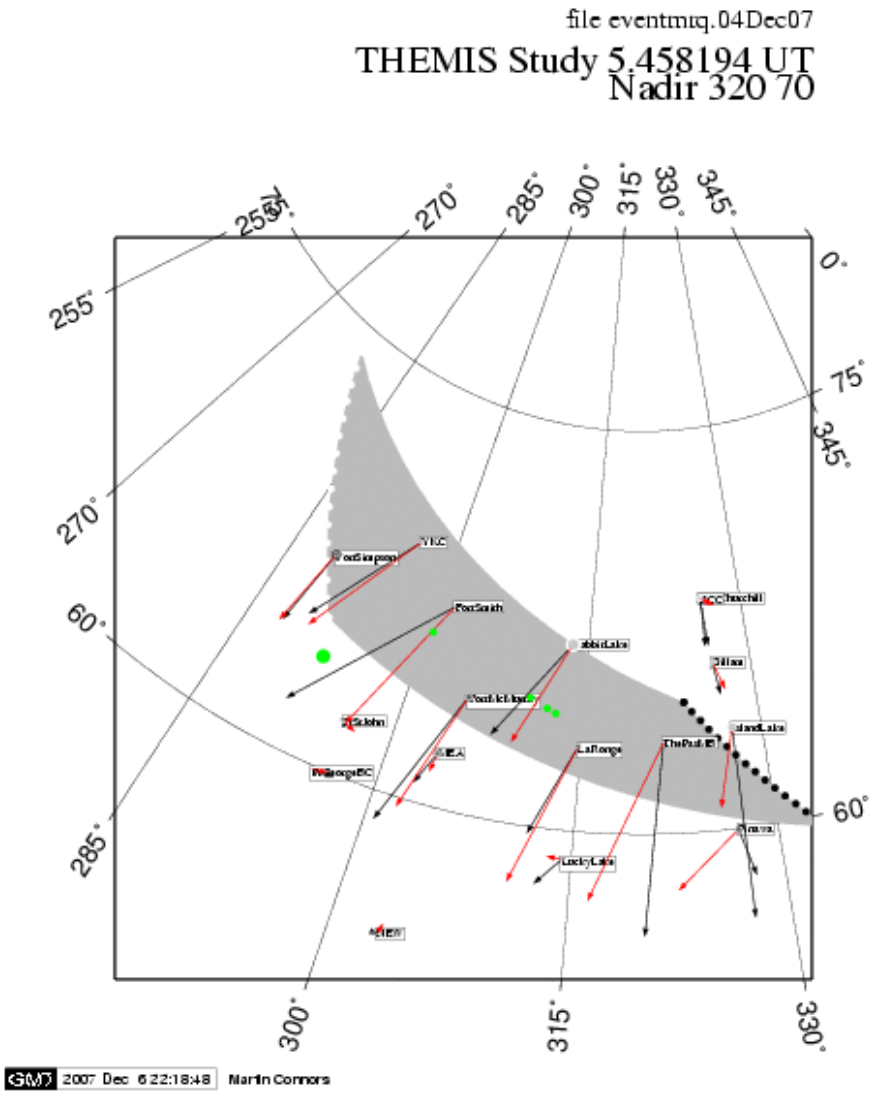


By 05:49.5 (13 minutes after onset), the SCW is well formed. Note westward perturbations under the downward FAC over eastern NA, eastward ones over western NA, and auroral zone currents comparable to those of the FAC. Westward perturbations on the ground and eastward ones at the spacecraft have died off.

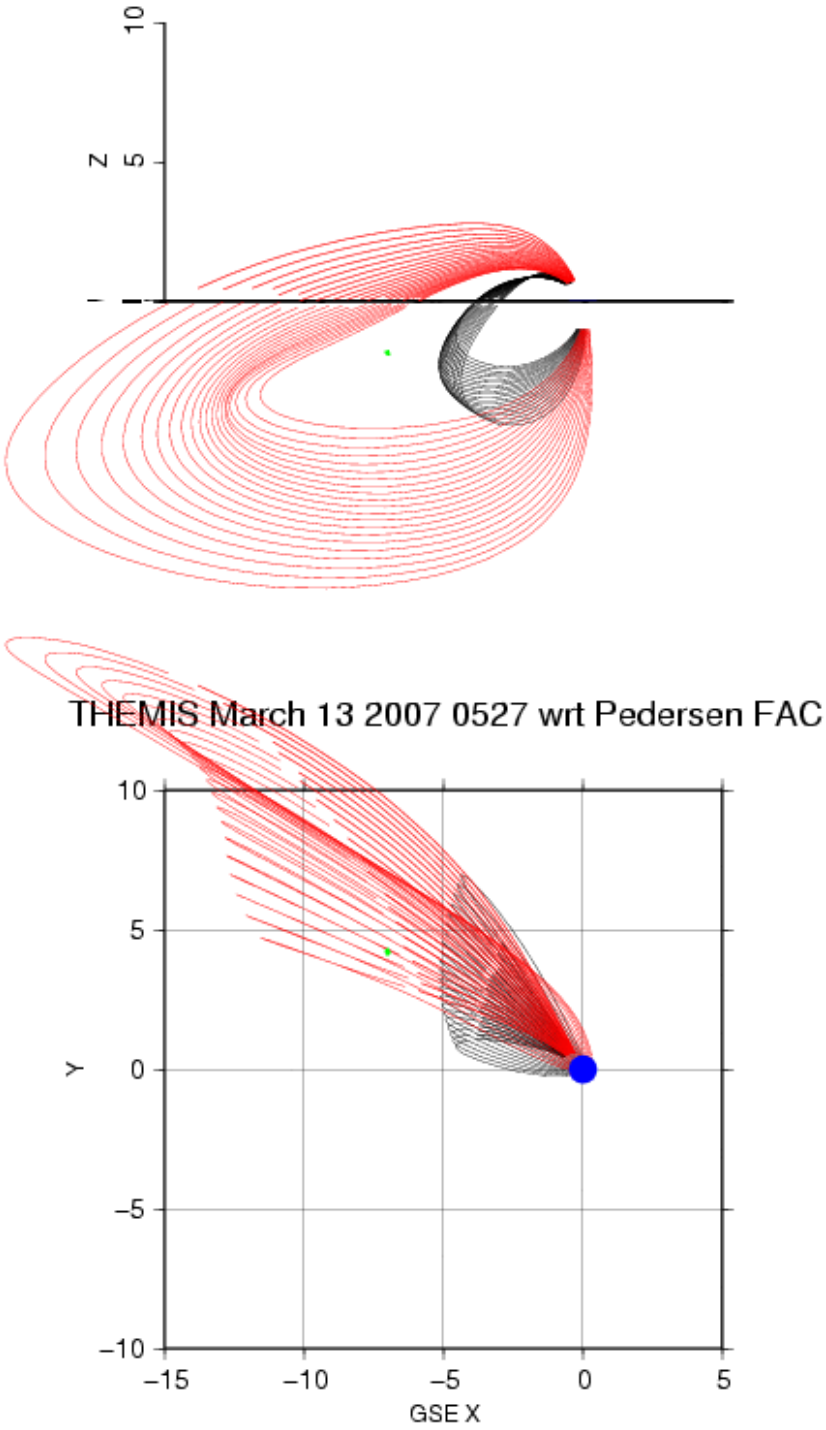


Nearly an hour after onset (6:33.5 UT), the same basic SCW pattern prevails but the intensity of currents has decreased.

Detailed view of late development of pseudo-breakup (05:27.5 UT)



There is very good agreement between the observed ground perturbations (black) and those arising from a simple model (FACs shown as dots).



The Pedersen FAC of the ARM model can be mapped to space with GEOPACK (Courtesy N. Tsyganenko and GSFC). THEMIS A (green) is between the FAC sheets. One could model the FAC flowing along these field lines.

Conclusions

- Within a month of launch, THEMIS already had a conjunction over North America in which optical and ground magnetic results could be compared with spacecraft data.
- In addition to an enhanced network of ground instruments, we have a new tool, Automated Regional Modelling (ARM), providing a simple view of current systems and explaining many aspects of ground perturbations.
- A simple SCW model explains many of the ground perturbations and should help studies of mapping to THEMIS.

Acknowledgements

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- Wessel and Smith for excellent GMT tools.