Substorm topology in the ionosphere and magnetosphere during a flux rope event in the magnetotail

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- Main subject of this presentation:

  Analyse

  ionospheric electrodynamics, *auroral signatures*, and *magnetosphere-ionosphere coupling*

  for

  a *flux rope event (FLR)* in the magnetotail current sheet with an *associated traveling compression region (TCR)* in the lobe

- Main data sources:

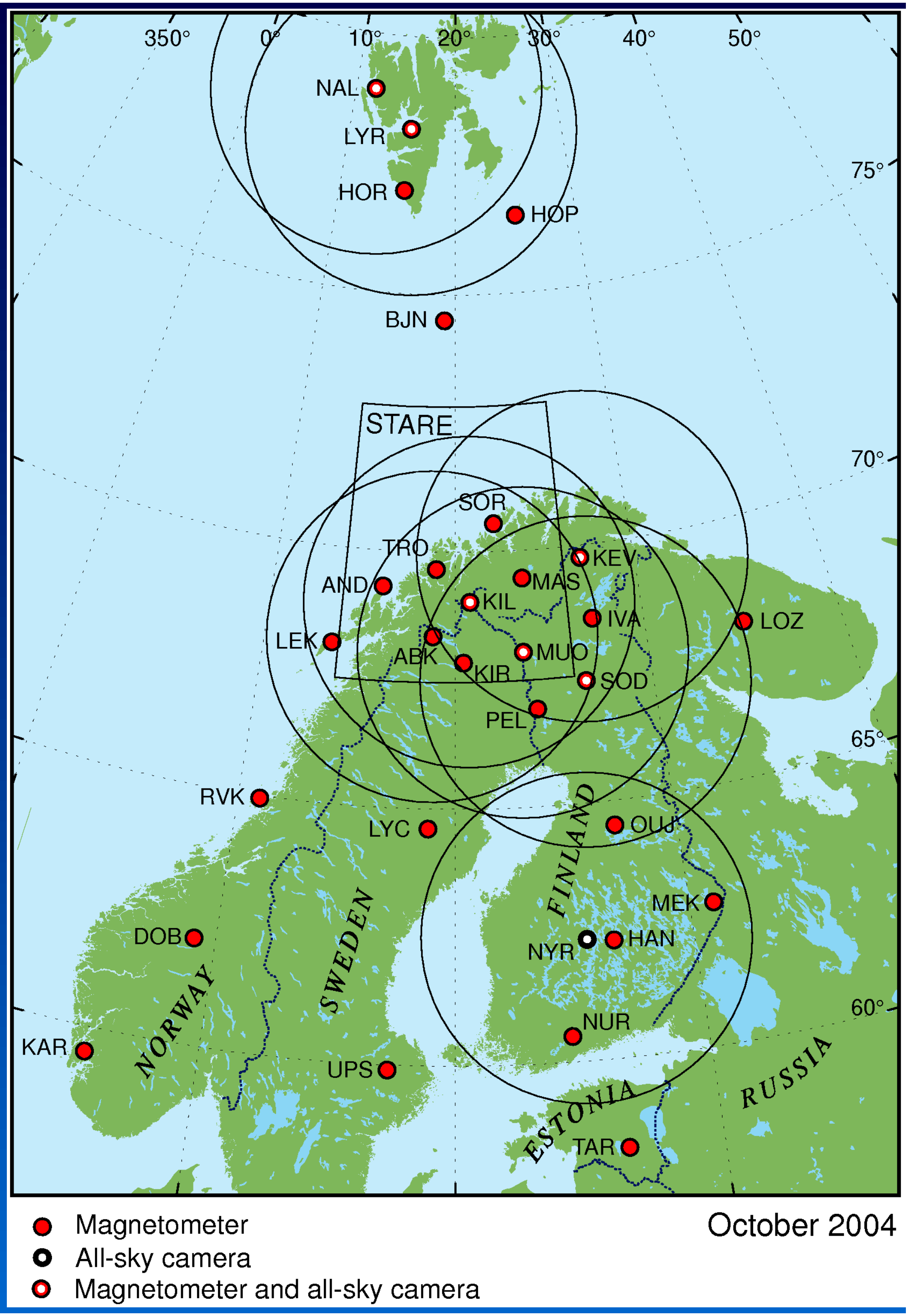
  Magnetosphere: Cluster spacecraft
  Ionosphere: MIRACLE observation network

- The *MIRACLE network* consists of:

  - IMAGE magnetometers
  - STARE radar
  - all-sky cameras

- A large number of other relevant instruments exists in Northern Fennoscandia, for example:

  - EISCAT
  - SuperDARN radars
  - riometers
  - other optical instruments
  - ...



2) Cluster/MIRACLE event study:

- Analysis of topological correspondances in the ionosphere and magnetosphere during a flux rope event in the magnetotail

- Data: Cluster FGM, CIS; IMAGE satellite WIC; MIRACLE, EISCAT
- Event: August 13, 2002, ~ 2300 UT
- Analysis techniques: Cluster: Curlometer (Dunlop et al., JGR, 2002)
  MIRACLE: 2D and 1D SECS techniques for upward continuation of magnetic fields (Amm and Viljanen, EPS, 1999; Vanhamäki et al., EPS, 2003)
- Reference: Amm et al., Ann. Geophys., 2005 (submitted).

- Main open question:
  - Are there any topological correspondences in the ionosphere to the flux rope event in the magnetotail, and if yes which ones?

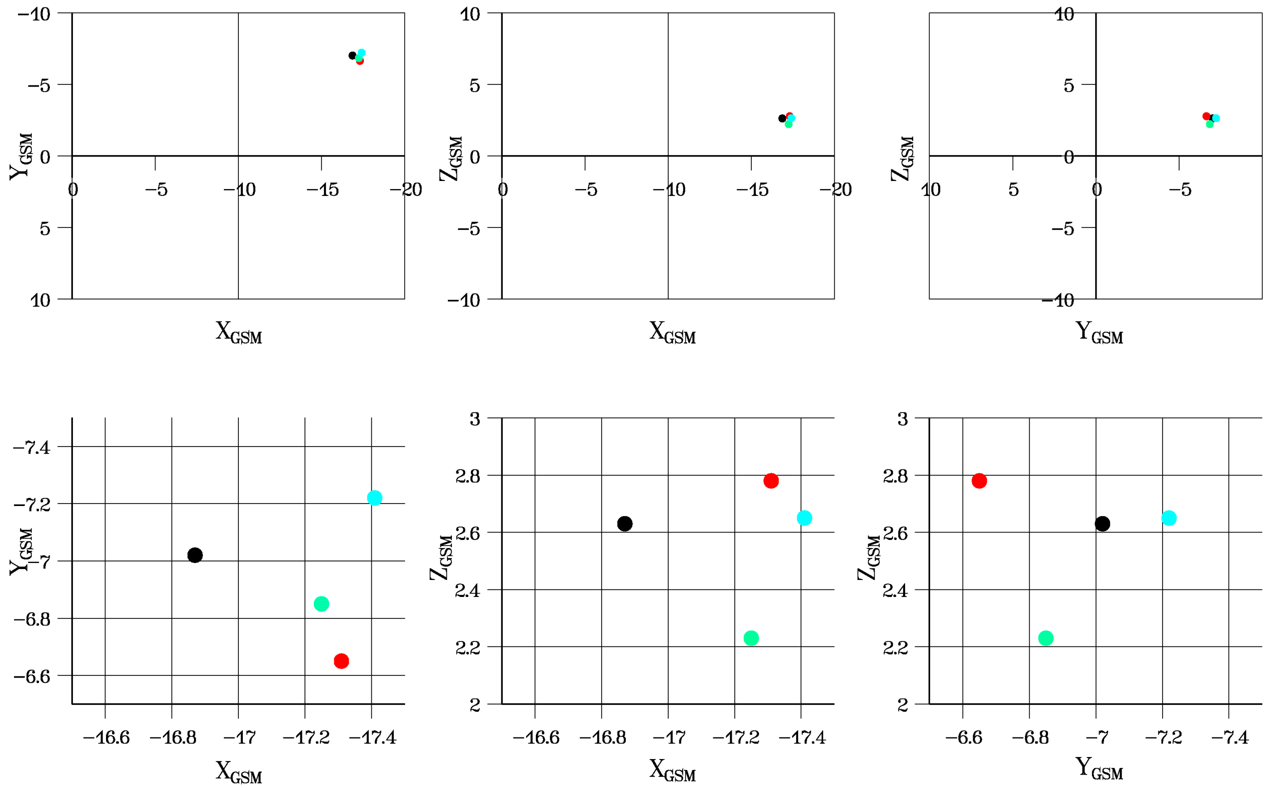
- Ionospheric signatures of a flux rope? Aren't those magnetically closed and force-free structures?

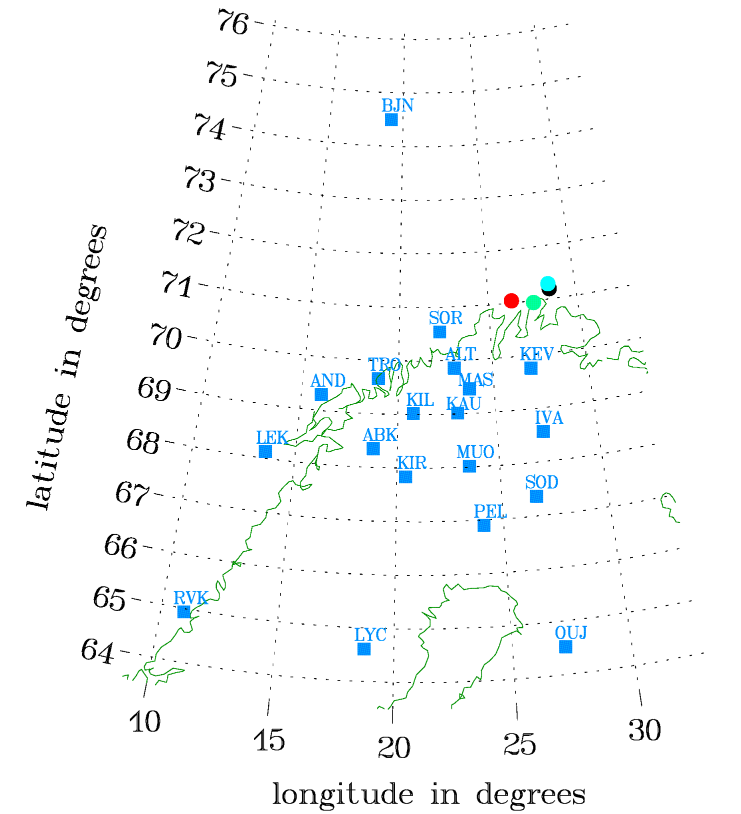
☞ *Ideally* yes, but:

- The ideal solutions imply perfect symmetry and extend to infinity
  ⇒ once that symmetry is broken, especially at the ends of the structure in symmetry direction, they must be either not force-free or/and not closed
  ⇒ current may "leak" into/ out of structures

- For topological correspondences, regions do not necessarily need to be magnetically connected
  (e.g., a TCR is a topological correspondence to a flux rope in the magnetosphere)

- Cluster configuration and mapping to the ionosphere:

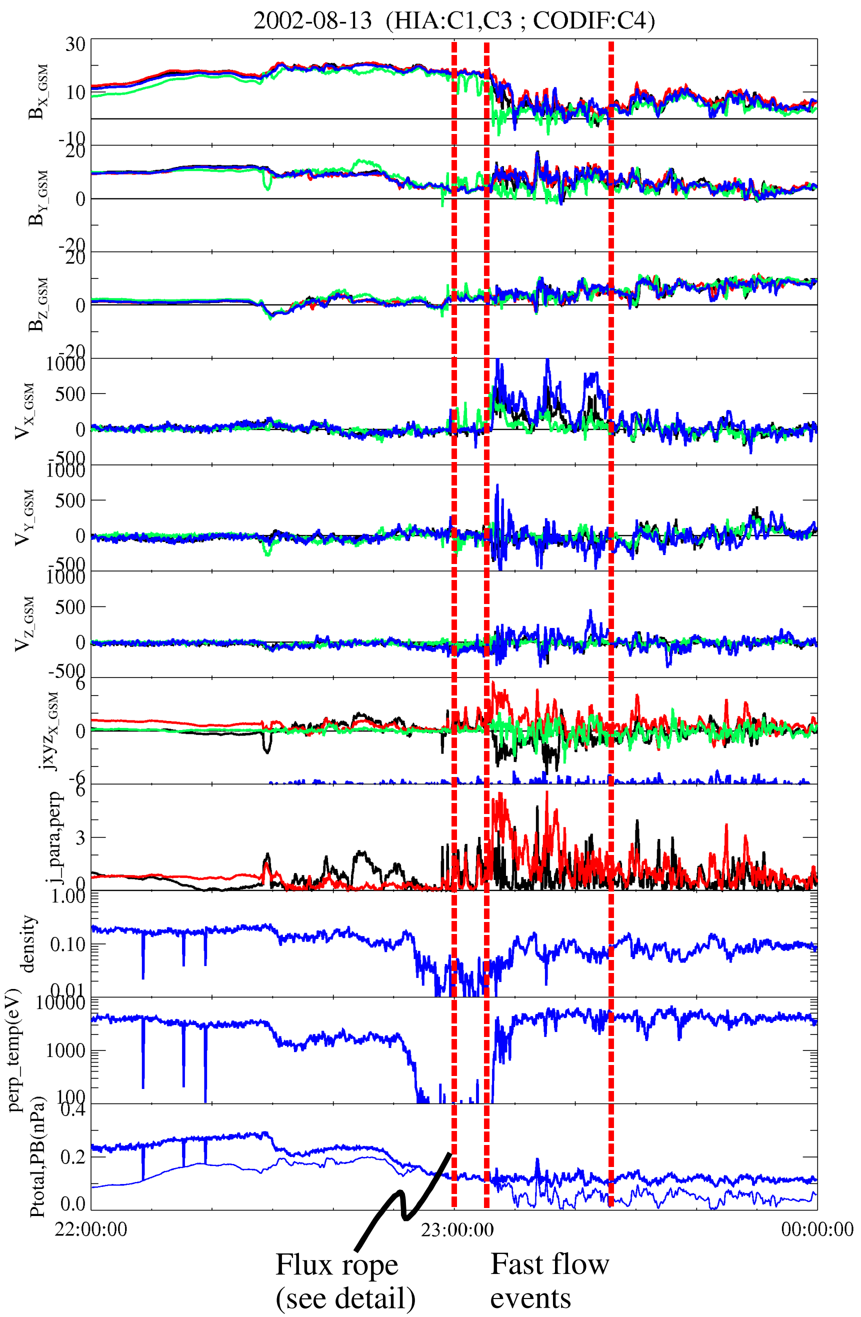




- Cluster 3 most equatorward, in plasma sheet boundary layer (PSBL); Cluster 1,2,4 in northern lobe

- Selected Cluster data, overview (longer period around event):

- Plasma sheet thinning and exit of Cl 1,2,4 into the PSBL and lobe starting from ~ 2230 UT
- Flux rope event at ~ 2300 UT
- Dipolarisation and plasma sheet expansion at onset of fast flow event ~ 2306 UT



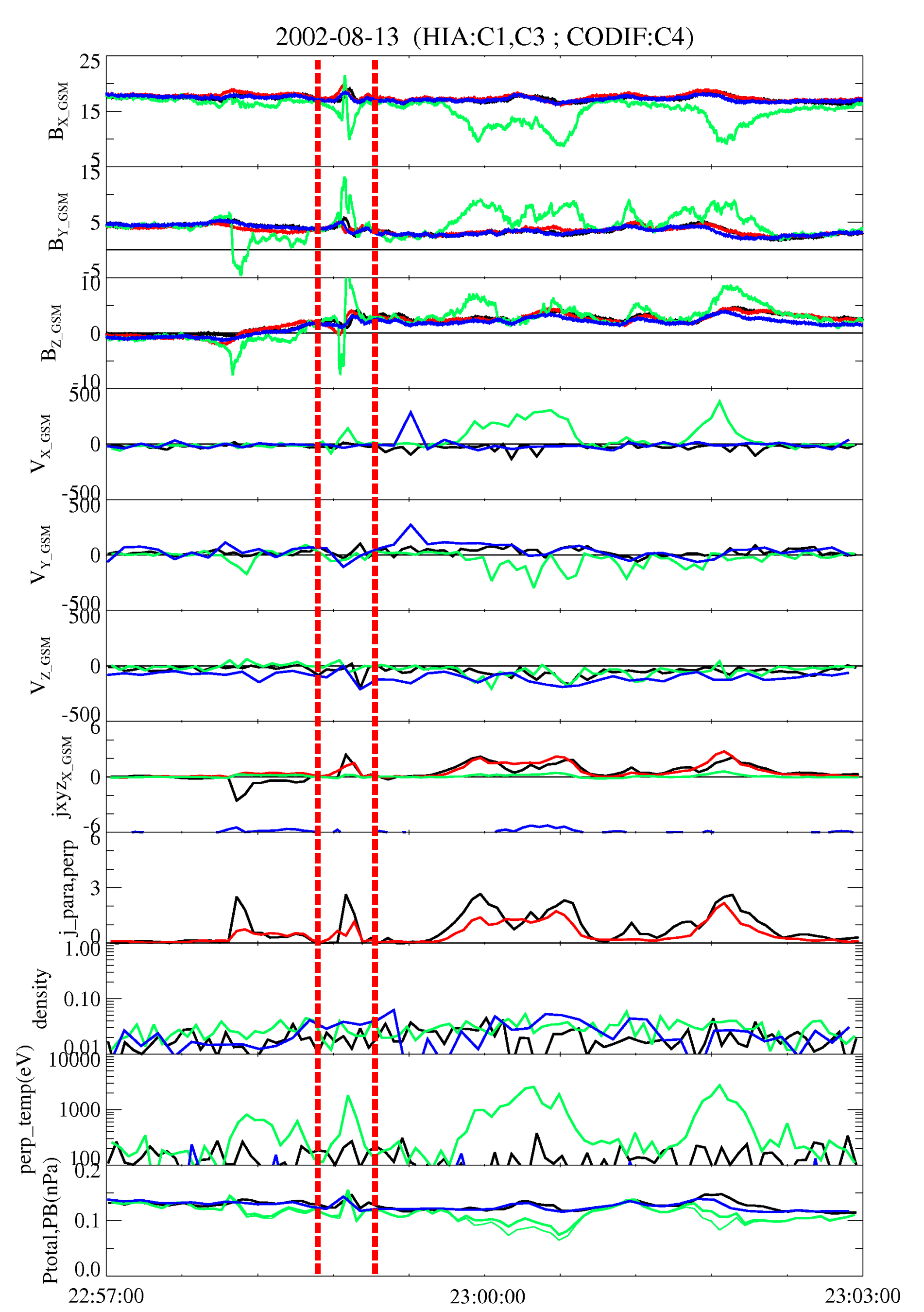
- Selected Cluster data, closeup around flux rope event:

a) Cluster 3:
- bipolar “first south-then north” variation in BZ
- Maximum in |B|, increase in V_X
- duration ≈ 30 s

⇒ typical earthward moving flux rope signatures

b) Cluster 1,2,4:
- earthward moving traveling compression region (TCR) in the lobe

c) Result of curlometer technique:
- Downward FAC at time of flux rope event

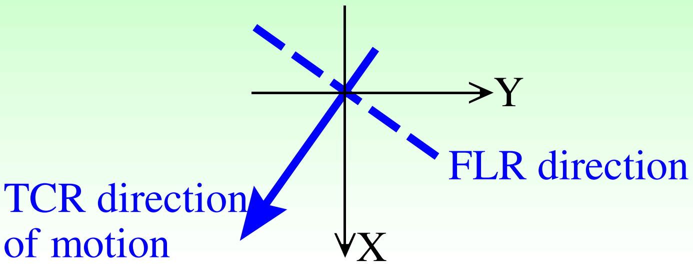


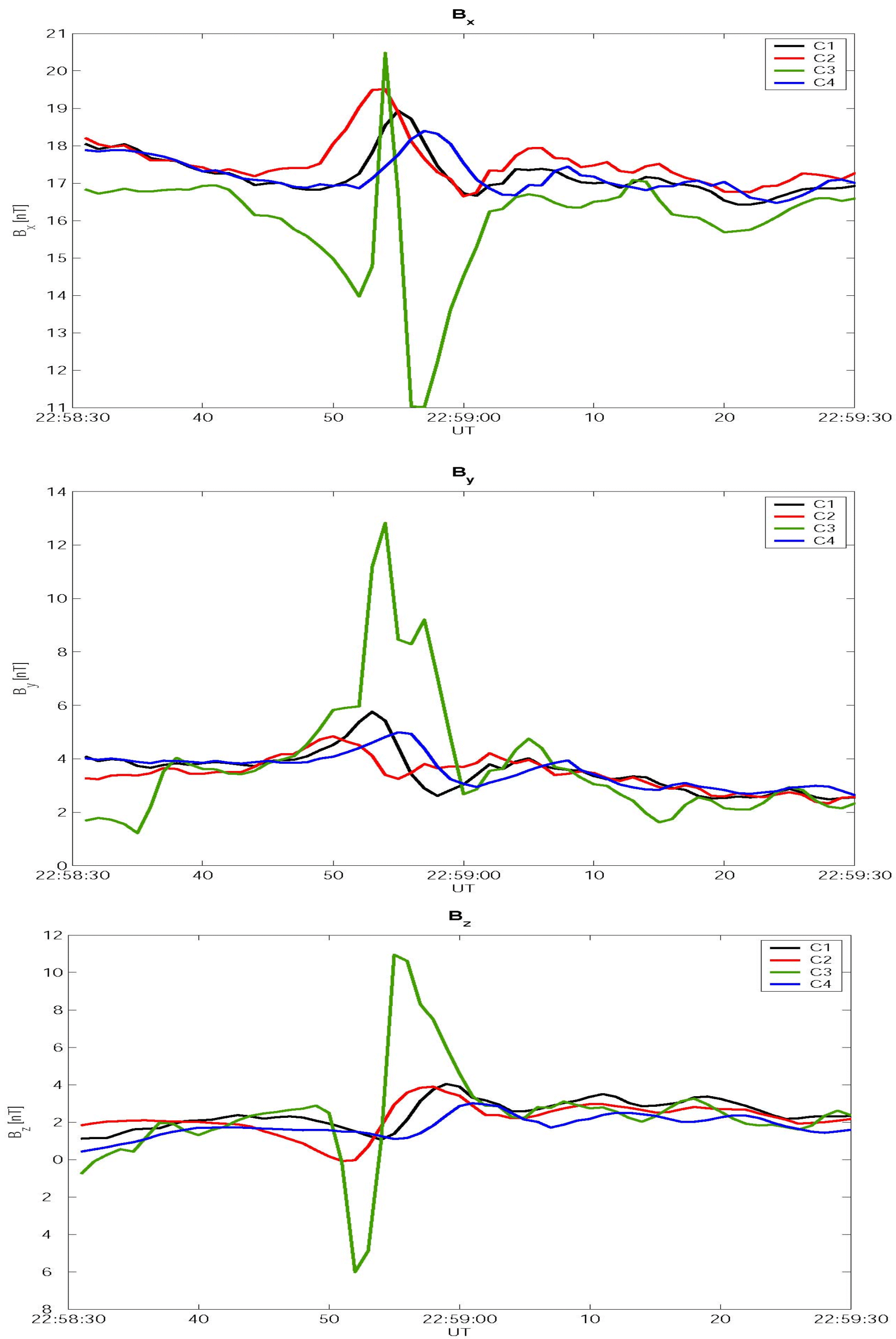
Flux rope event

- Cluster high-resolution (1-sec) magnetic field data, closeup around flux rope event:

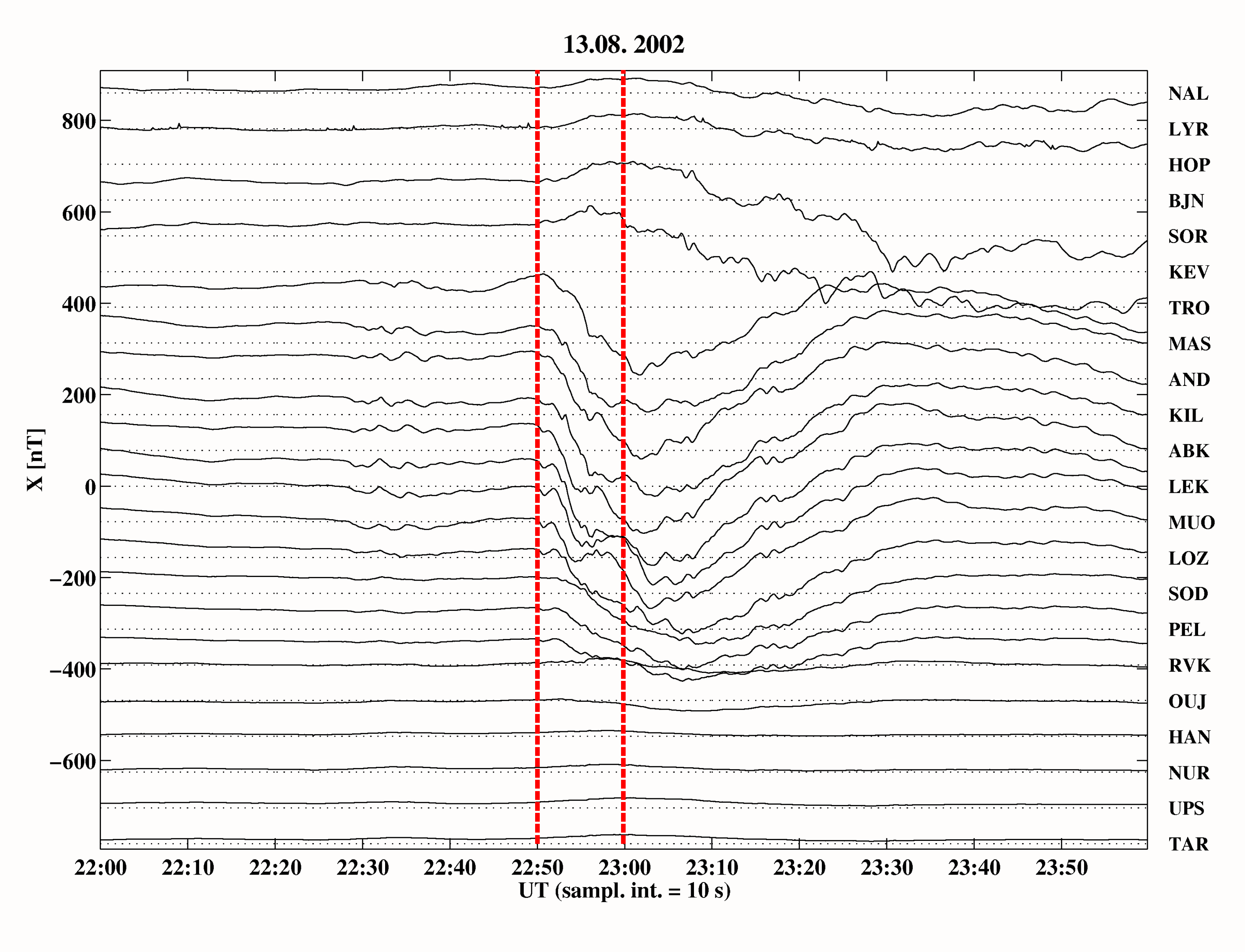
a) Cluster 3:
  - General decrease in X: Signature of plasma sheet (boundary layer) entry
  - From spike in +Y and +X direction: ⇒ (apparent) FLR direction ≈ 42° clockwise from +Y (seen from +Z direction), <u>but</u> s/c not directly in center of FLR

b) Cluster 1,2,4:
  - TCR motion with ≈ 1200 km/s in +X and -Y direction
    ⇒ FLR direction (as 90° rotated TCR direction of motion) ≈ 29° clockwise from +Y (seen from +Z direction)



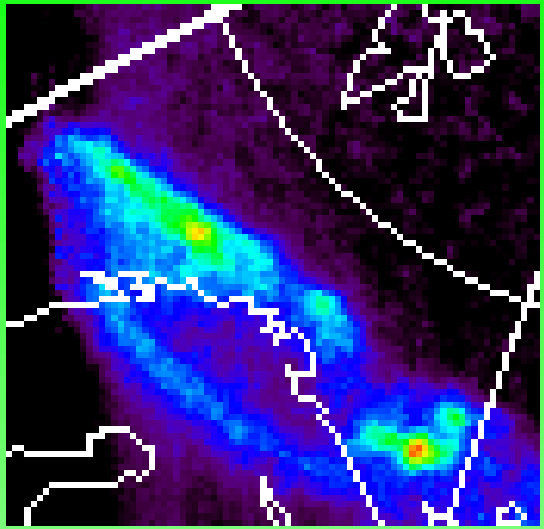


- IMAGE magnetograms:

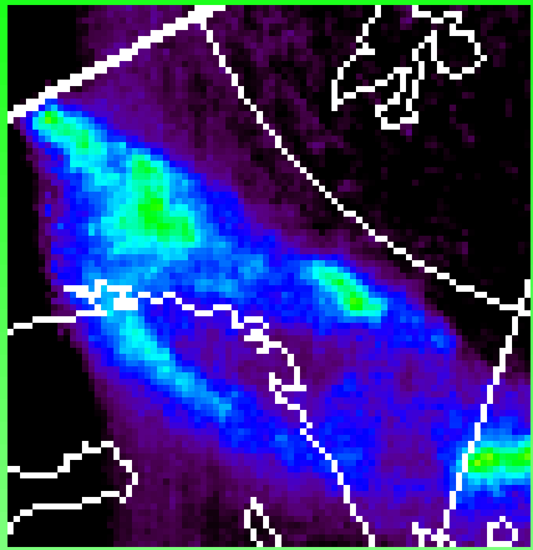


- Flux rope event observed during late substorm expansion phase (also weak electron injection at LANL 2250 UT)

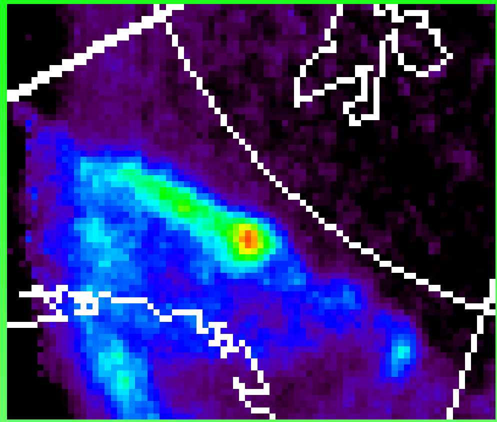
- 2D representations:
    a) auroral images from IMAGE/WIC



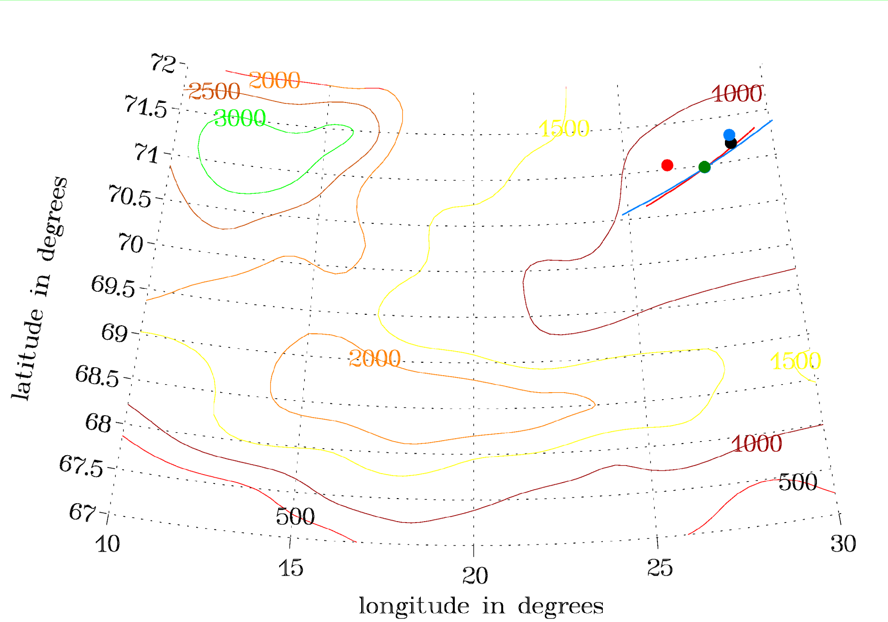
2256:38 UT



2258:41 UT



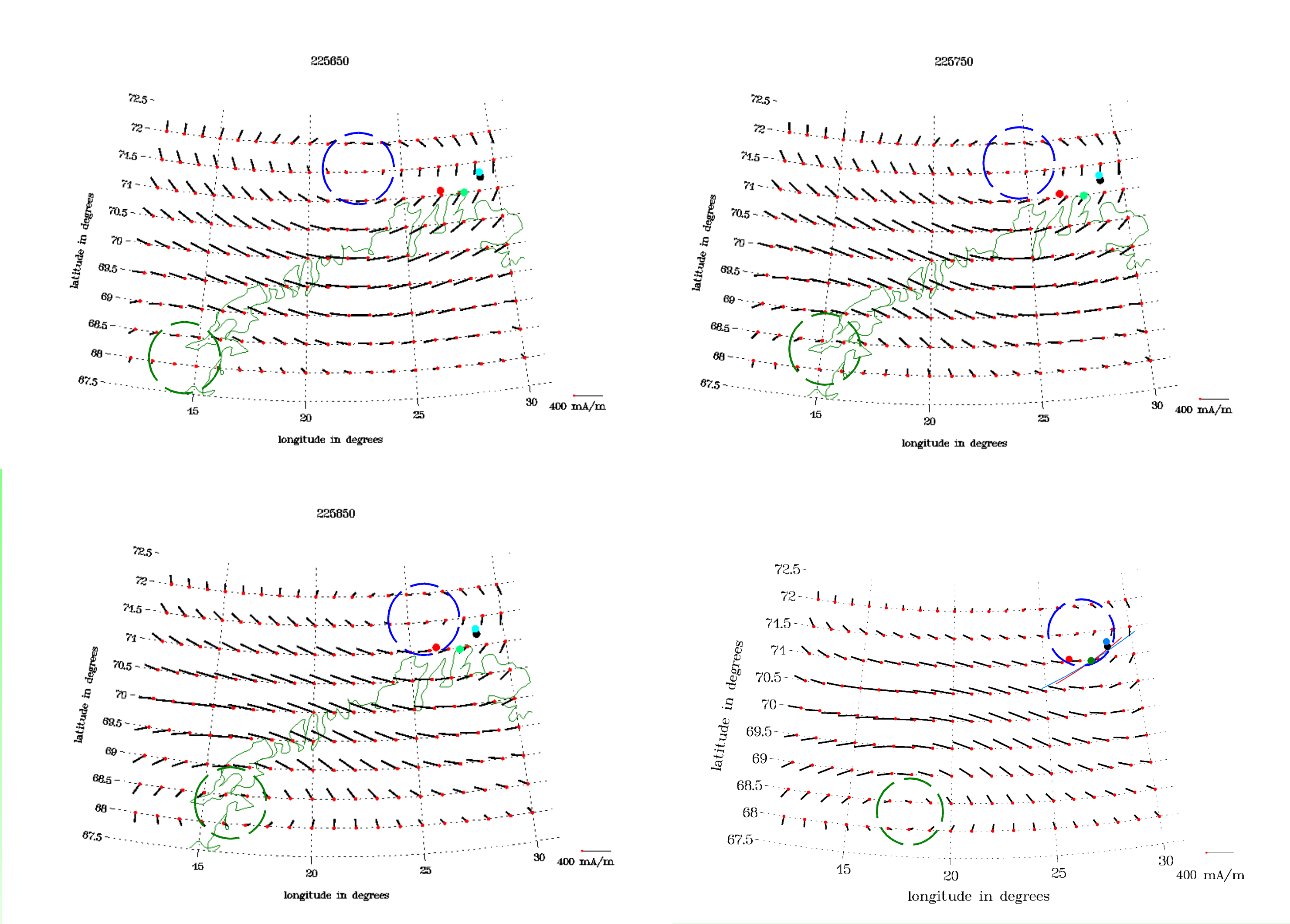
2300:43 UT



- Lens-shaped region of auroral FUV emission minimum at mapped FLR position, well aligned with mapped FLR orientation

blue: FLR direction from 90° rotated TCR motion;
red: FLR direction from Cluster3 magnetic field data

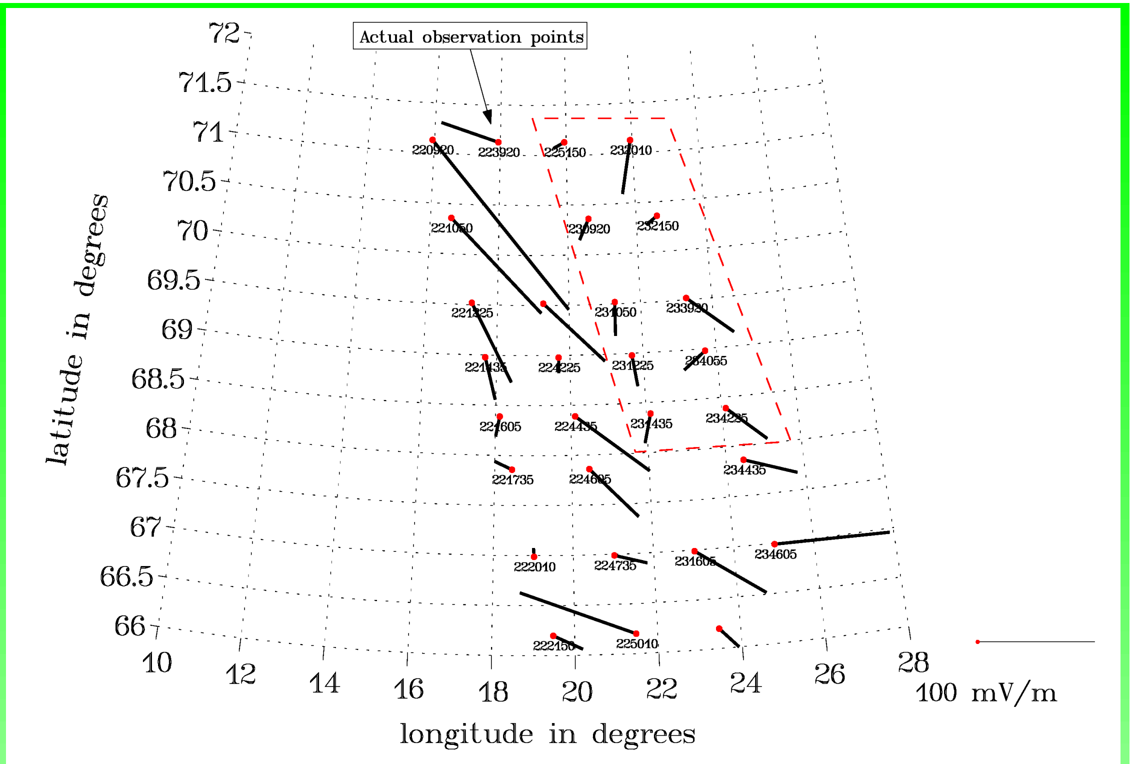
- 2D representations:
  b) equivalent currents (2D SECS method), only part which has curls within analysis area (background electrojet separated away)



- Leading clockwise (downward FAC) and trailing anticlockwise (upward FAC) current vortices, comoving with ≈ 2 km/s eastward ≅ mapped bulk velocity at Cluster 4, closest to vortex

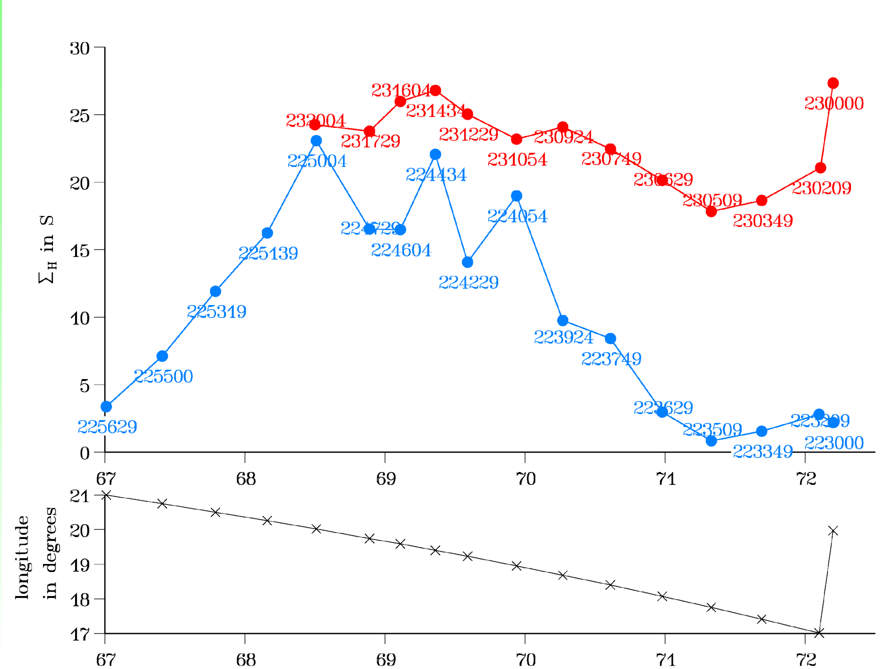
- Direction of tilt angle between current vortices well aligned with FLR direction
- Downward FAC vortex “hits” Cluster just when it also measures downward FAC

- Connection between FAC area, i.e., southwestward total current flow in the ionosphere, possible?
  ☞ look at electric field (EISCAT), superposed vector plot:



  - Electric field in relevant scan mainly in southward direction
    ⇒ yes, possible

- (Hall) conductance structure as determined from EISCAT scans before and after intensification:



  - Hall conductance drop visible still 5 min after FLR area has passed EISCAT beam

- Conclusions from August 13, 2002, FLR event:

Topological correspondences in the ionosphere to FLR encounter in magnetotail:

- A lens-shaped auroral emission minimum with decreased conductance at FLR footprint, well aligned with the FLR orientation
- A downward FAC area colocated with the auroral emission minimum, moving eastward at ≈ 2 km/s, corresponding to the mapped bulk velocity of the closest Cluster spacecraft
- Comoving with the leading downward FAC area a trailing upward FAC area at lower latitudes; the tilt angle between the two FAC area corresponds well to tilt angle of FLR; electric field is consistent with current flow from downward to upward FAC region
- No topological correspondence to fast TCR movement in the ionosphere

Possible interpretation:

- Do the FAC regions demarcate the “edges” of the FLR in symmetry direction?
- In this case, ≈ parallel current directions in FLR and in ionosphere
  ⇒ competing current closure process?

- Some general conclusions:

  - Cluster/ MIRACLE studies (and Cluster/ ground-based studies in general) are a powerful tool to study the *spatio-temporal ionosphere-magnetosphere coupling*

  - Ionospheric signatures of magnetospheric features do frequently exist, but *often advanced data analysis methods are needed to recognize and analyse them*

- Small advert in the end... :

- Want to see more Cluster/ ground-based studies?

⇒ *Interim review of Cluster/ground based research in latest Annales Geophysicae issue!*

Amm et al., Ann. Geophys., 23, 2129 -2170, 2005.

Annales Geophysicae, 23, 2129–2170, 2005
SRef-ID: 1432-0576/ag/2005-23-2129

Annales Geophysicae

Coordinated studies of the geospace environment using Cluster, satellite and ground-based data: an interim review

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Received: 21 December 2004 – Revised: 18 April 2005 – Accepted: 3 May 2005 – Published: 15 September 2005

Abstract. A little more than four years after its launch, the first magnetospheric, multi-satellite mission Cluster has already tremendously contributed to our understanding about the coupled solar wind - magnetosphere - ionosphere system. This is mostly due to its ability, for the first time, to provide instantaneous spatial views of structures in the system, to separate temporal and spatial variations, and to derive velocities and directions of moving structures. Ground-based data have an important complementary impact on Cluster-related research, as they provide a larger-scale context to put the spacecraft data in, allow to virtually enlarge the spacecrafts' field of view, and make it possible to study in detail the coupling between the magnetosphere and the ionosphere in a spatially extended domain. With this paper we present an interim review of cooperative research done with Cluster and ground-based instruments, including the support of other space-based data. We first give a short overview of the instrumentation used, and present some specific data analysis and modeling techniques that have been devised for the combined analysis of Cluster and ground-based data. Then we review highlighted results of the research using Cluster and ground-based data, ordered into dayside and nightside processes. Such highlights include, for example, the identification of the spatio-temporal signatures of the different modes of reconnection on the dayside, and the detailed analysis of the electrodynamic magnetosphere-ionosphere coupling of bursty bulk flows in the tail plasma sheet on the nightside. The aim of this paper is to provide a "sourcebook" for the Cluster and ground-based community that summarises the work that has been done in this field of research, and to identify open questions and possible directions for future studies.

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Keywords. Ionosphere (Auroral ionosphere) – Magnetospheric physics (Magnetosphere-ionosphere interactions; General or miscellanous)

1 Introduction

The terrestrial magnetosphere is a cavity carved out of the solar wind by the terrestrial magnetic field. To zeroth order it is a consequence of the high solar wind conductivity, and its dimensions reflect a stress balance between the solar wind dynamic pressure and the magnetic pressure inside the cavity. The magnetosphere is coupled to the solar wind across its outer boundary - the magnetopause - and to the Earth's upper atmosphere via the ionosphere and thermosphere. Key processes at work at the magnetopause are magnetic reconnection, particle entry, and large- and small-scale waves that arise at and around this boundary. Electric currents couple the magnetosphere and ionosphere, and large-scale convection within the magnetosphere drives ionospheric currents, and has significant effects on the motion of the neutral atmosphere at thermospheric altitudes. The energy that powers