Intense magnetic spikes in geomagnetic storms: Occurrence characteristics, physical mechanisms and consequences for space weather impacts in terms of GIC's and GNSS disturbances.

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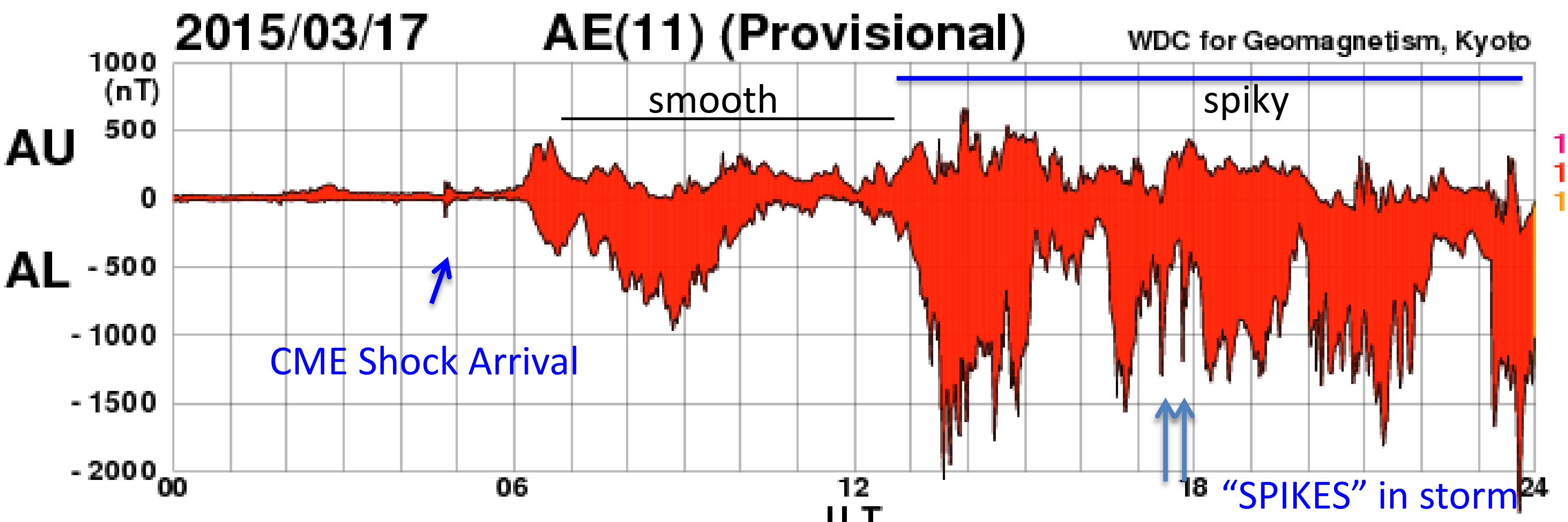
Haris Haralambous - *Fredericks University, Nicosia, Cyprus*

A talk in two parts

First part – what we have learned:

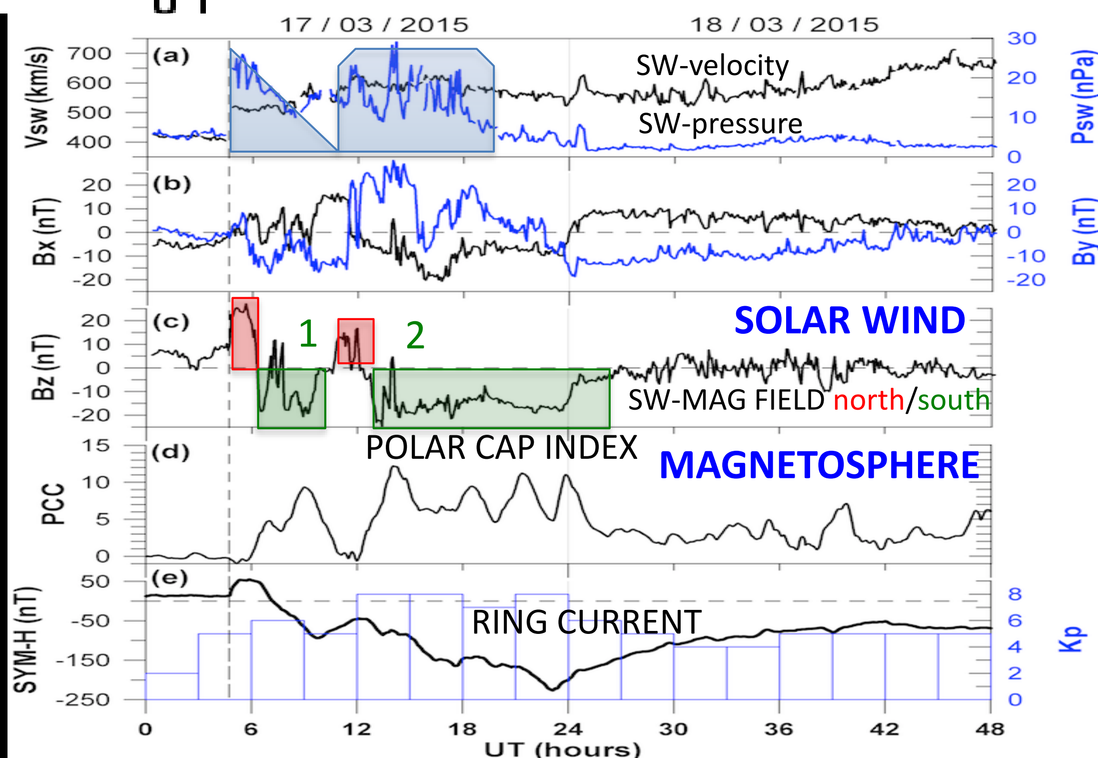
The characteristics and causes for large dB/dt – spikes in storms

“The Perfect Storm”: St. Patrick’s Day 17. March 2015: Combined CIR & CME effects



TOP: Auroral Electrojet Indices (AE = AU+AL) showing “smooth” and “spiky” parts of a magnetic storm

RIGHT: Solar Wind Data …and Pc - Dst indices



What about those storm-spikes in a statistical sense?

At first glance they can occur at random at any night-side local time from dusk to dawn
(A. Schillings, H. Opgenoorth et al. – Journal Space Weather paper under final review)

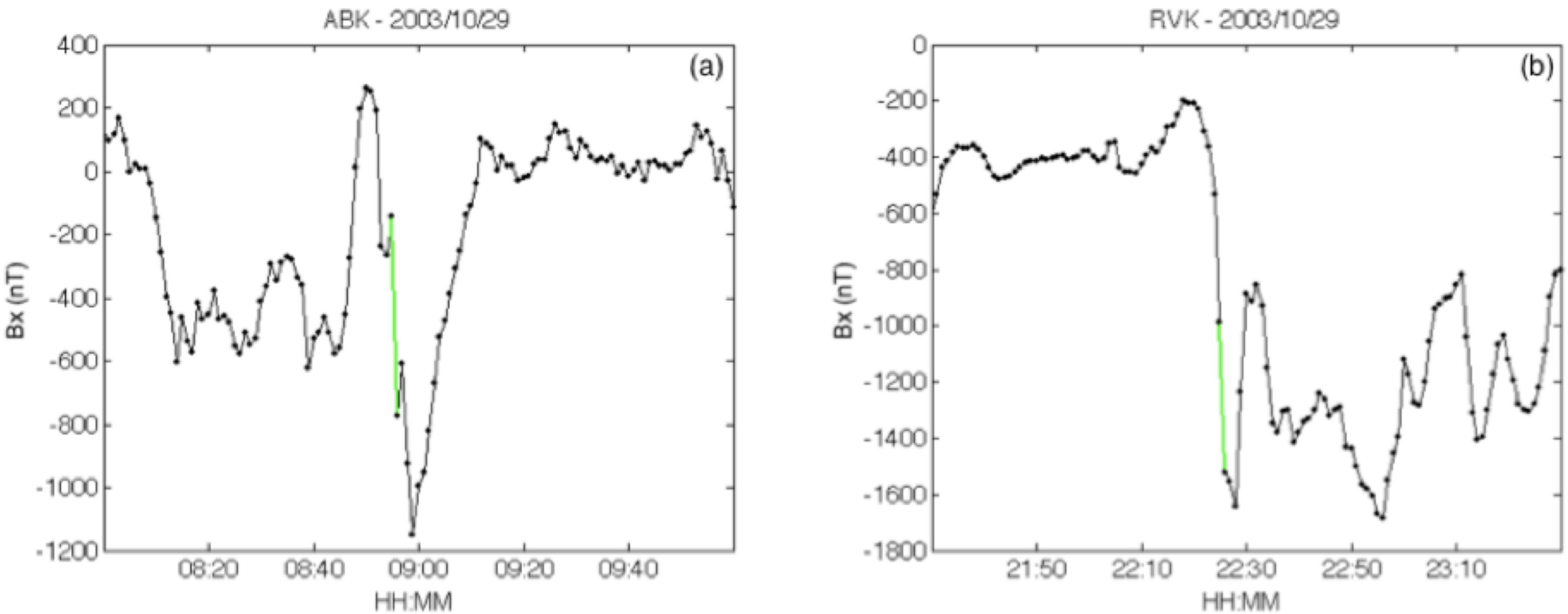
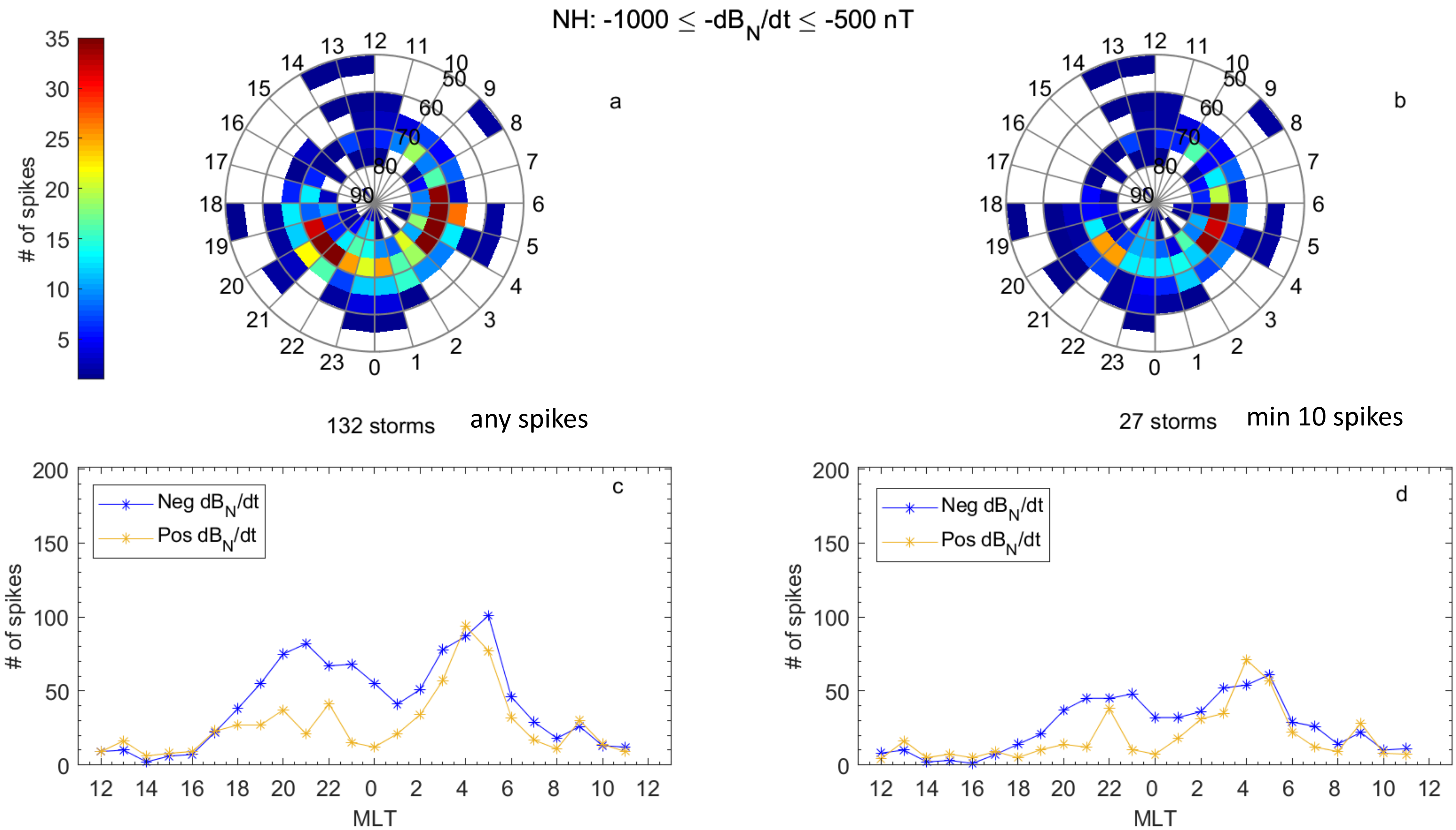


Figure 1 : Examples of selected spikes (dBx/dt) appear in green on the plot.

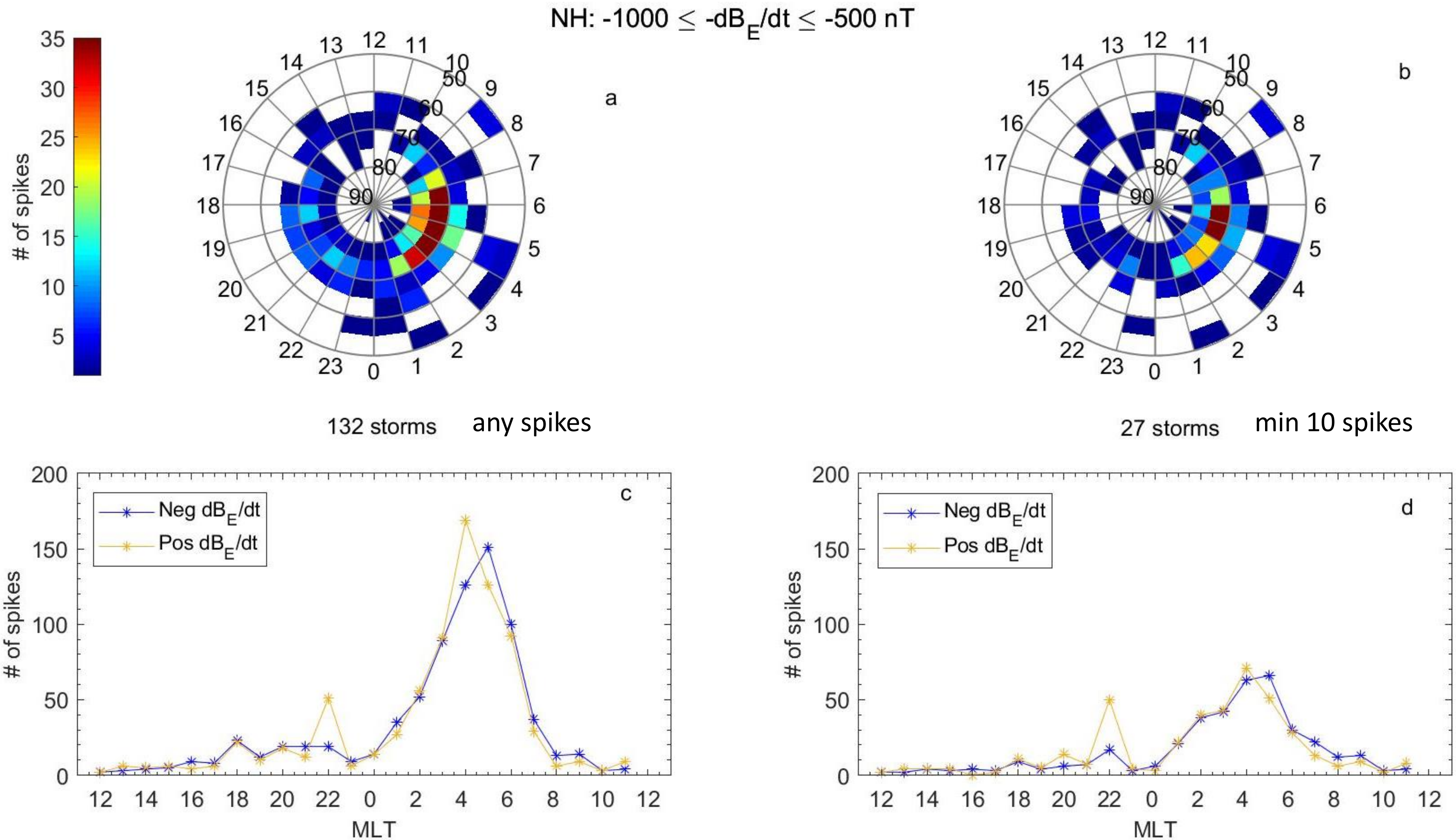
Statistical study using SuperMAG data since 1980 for more than 300 storms (27 major storms)
Automated spike detection dB/dt > 500nT/min, visual selection of good data

X - Component (N)



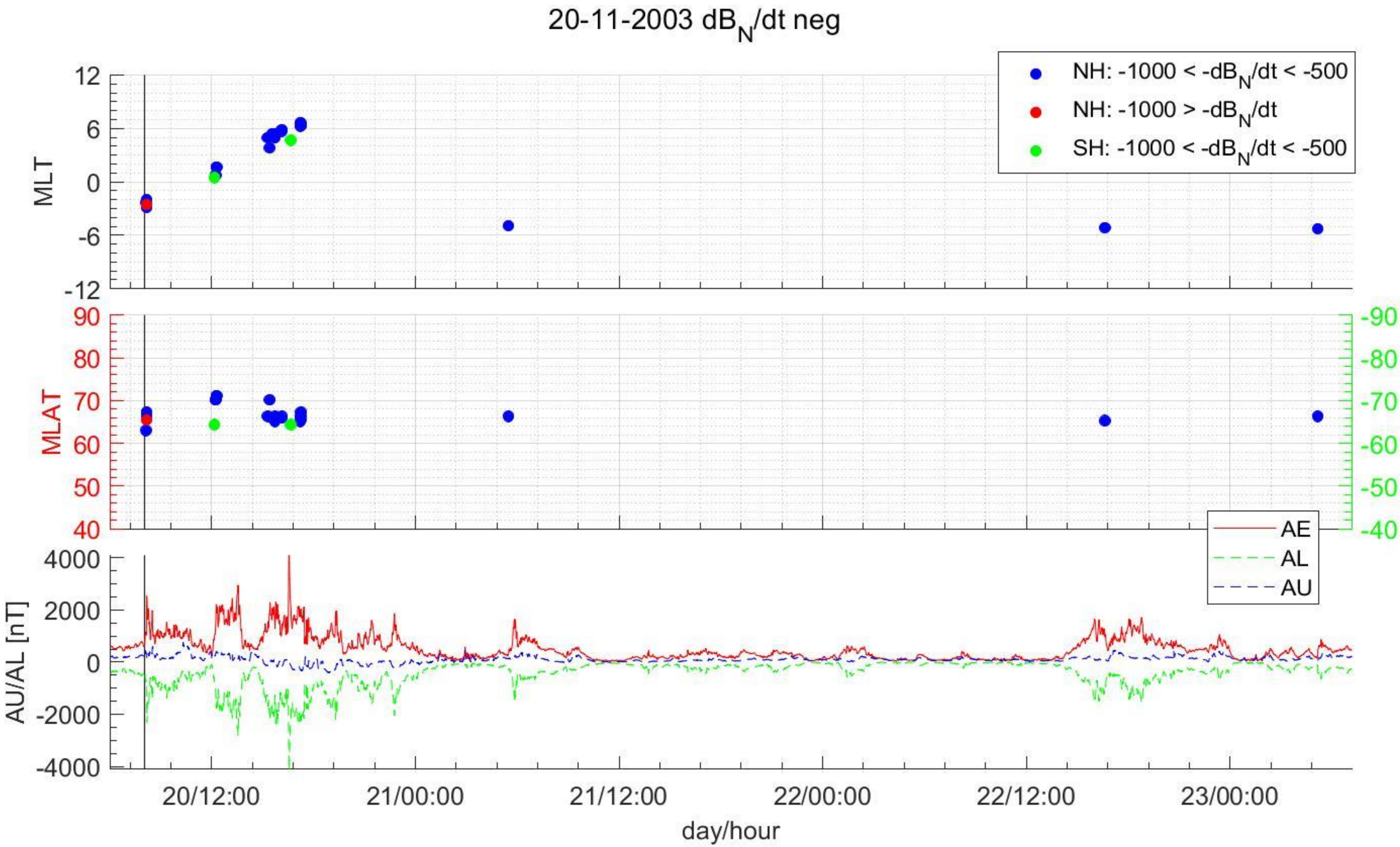
TWO HOTSPOTS: **– Bx:** in **pre-midnight sector** (few +Bx) and **+/- Bx** in **morning sector**)

Y - Component (E)



ONE HOTSPOT in Morning sector for + / – By (only a few pos By at premidnight –> WTS?)

MLT and MLAT development of series of spikes in storms: from premidnight to dawn



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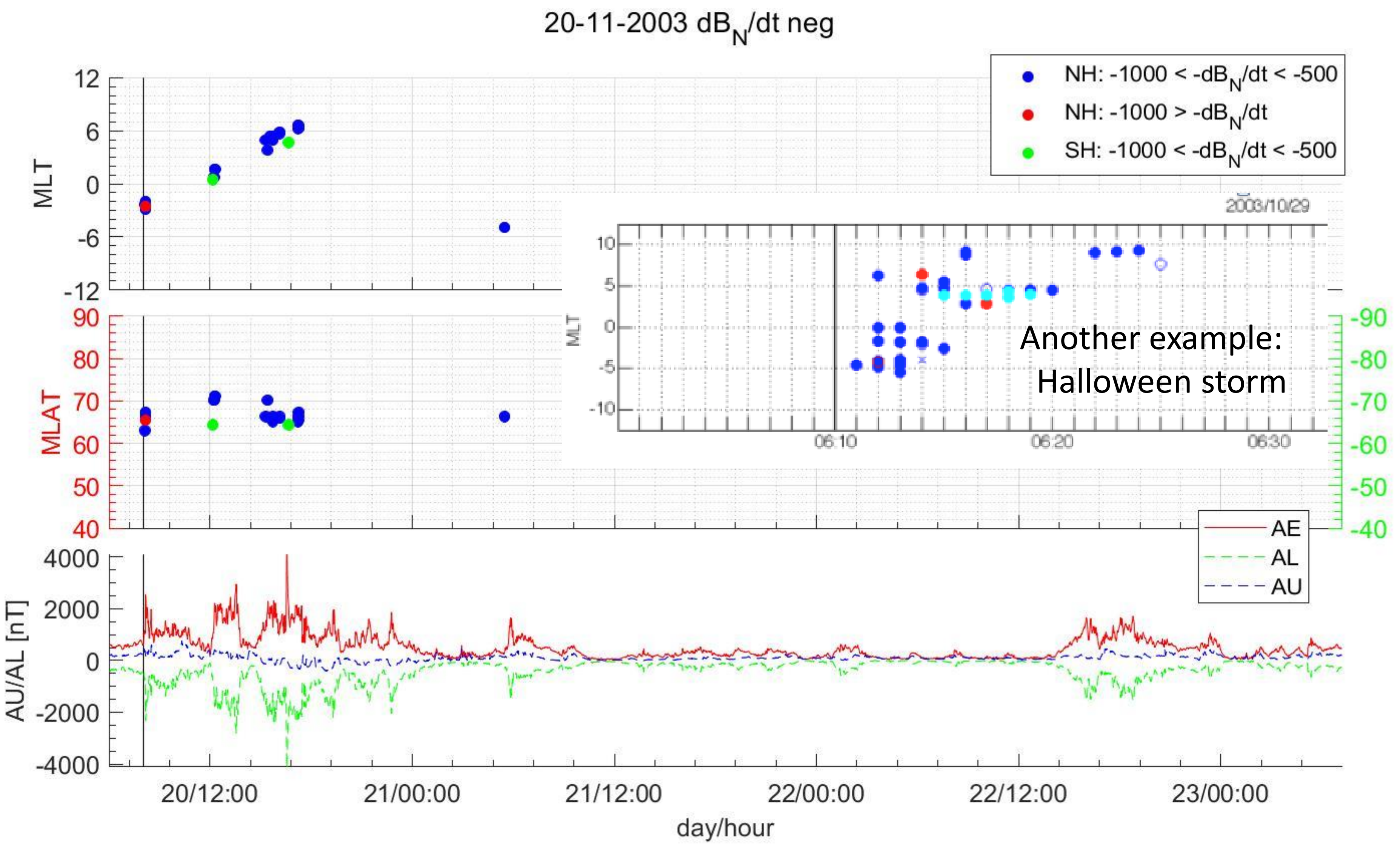
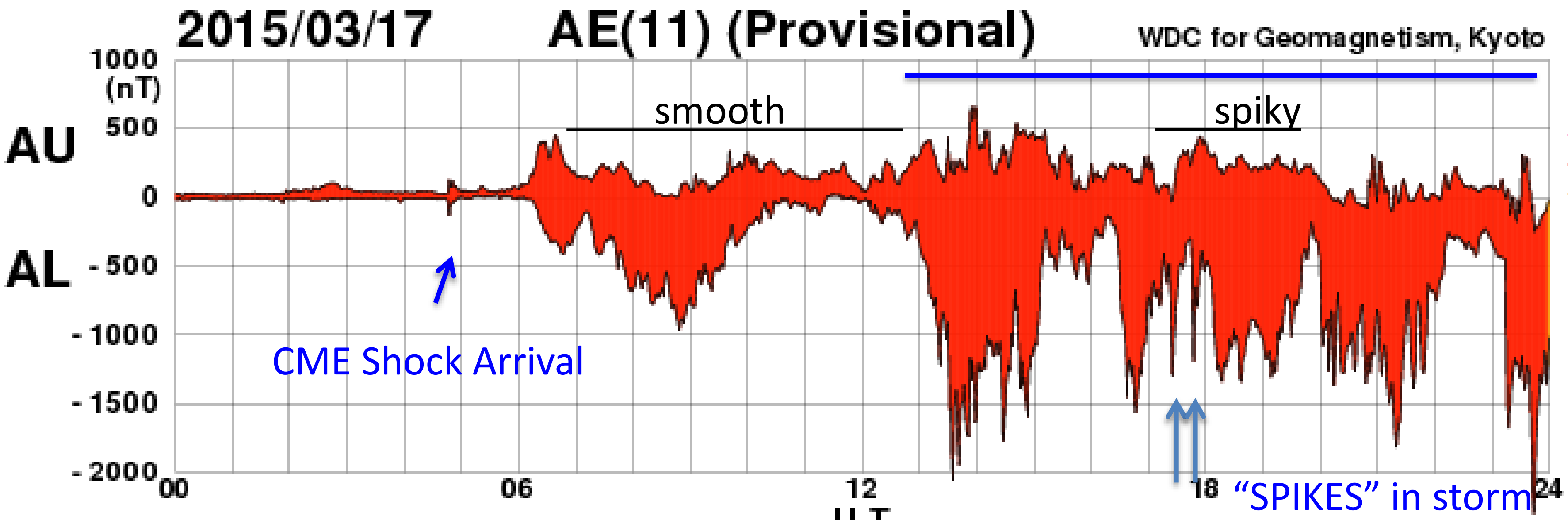


"The Perfect Storm": St. Patrick's Day 17. March 2015: Combined CIR & CME effects

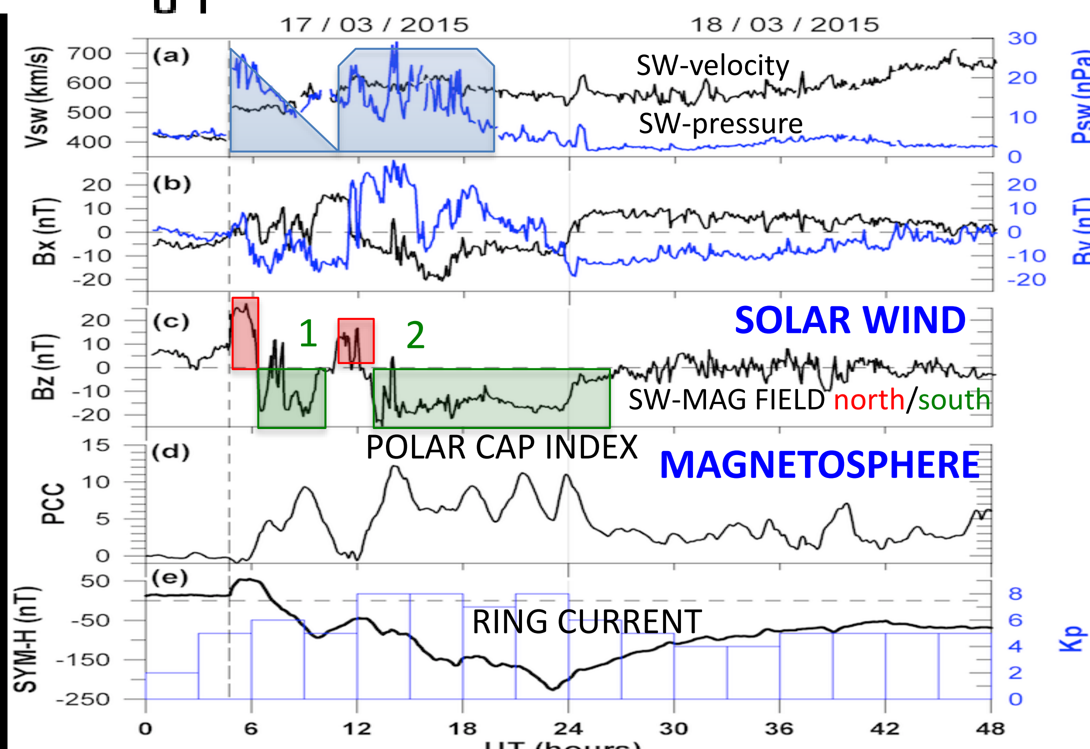


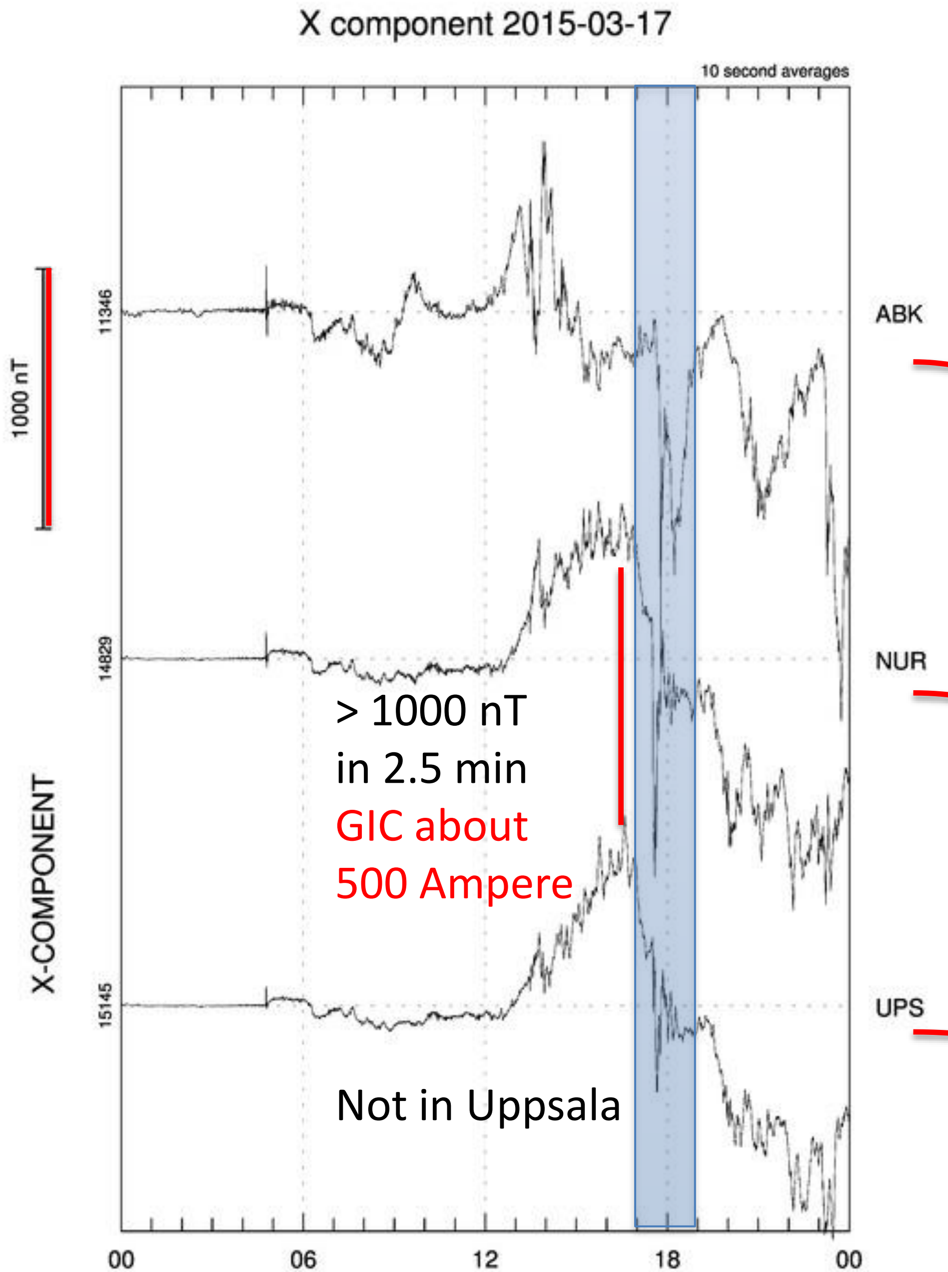
TOP: Auroral Electrojet Indices (AE = AU+AL)

Now we look closer at individual spikes at 1730 UT

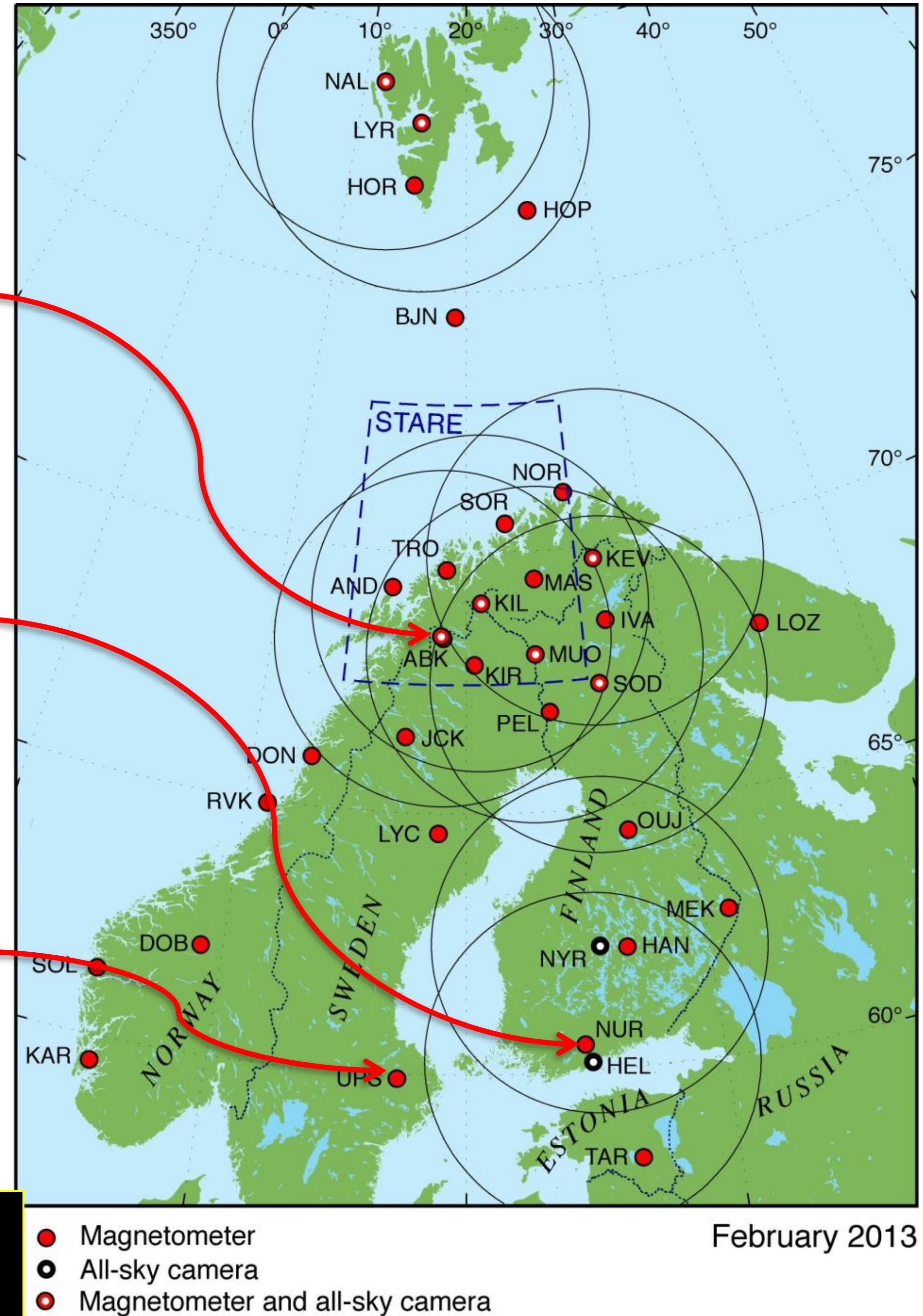
RIGHT: Solar Wind Data

…and Pc - Dst indices

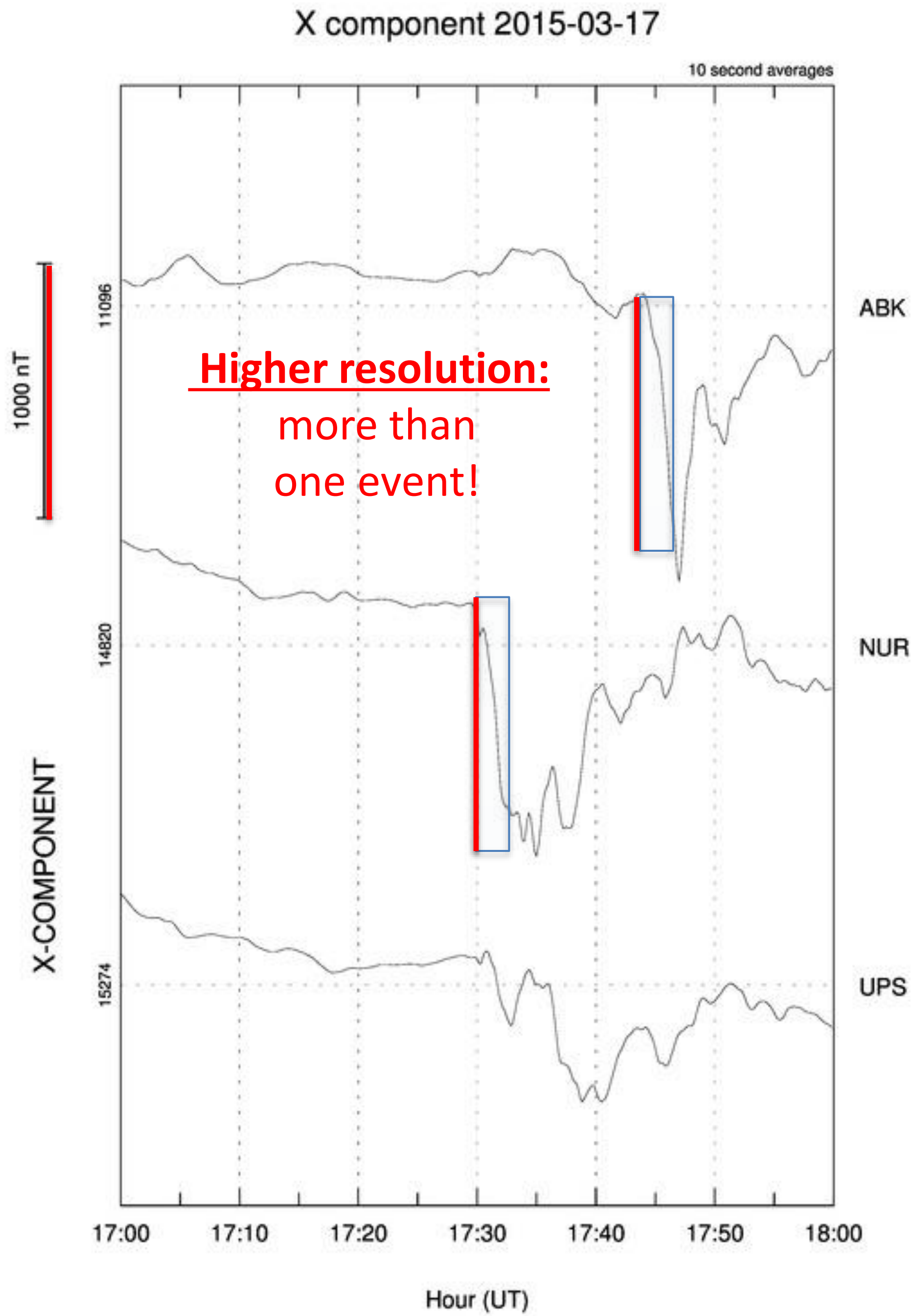




MIRACLE NETWORK: FMI, IRF, Univ. of Tromsö

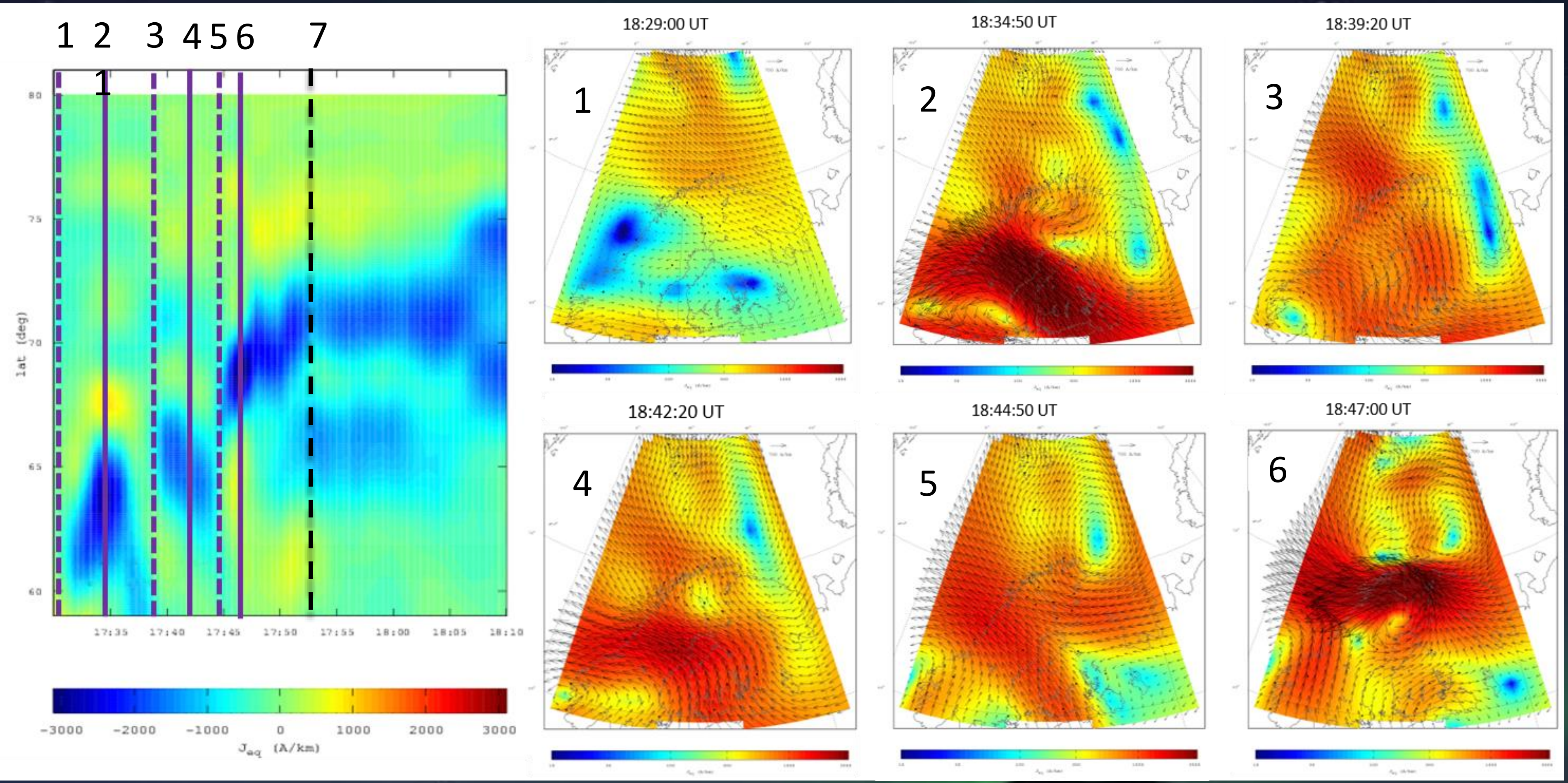


Note: dB/dt-spikes in Halloween storm 2003 were similar: 2000 nT in 5 min over Malmö!!



ST PATRICK'S Storm NOTE: scale 1000 nT

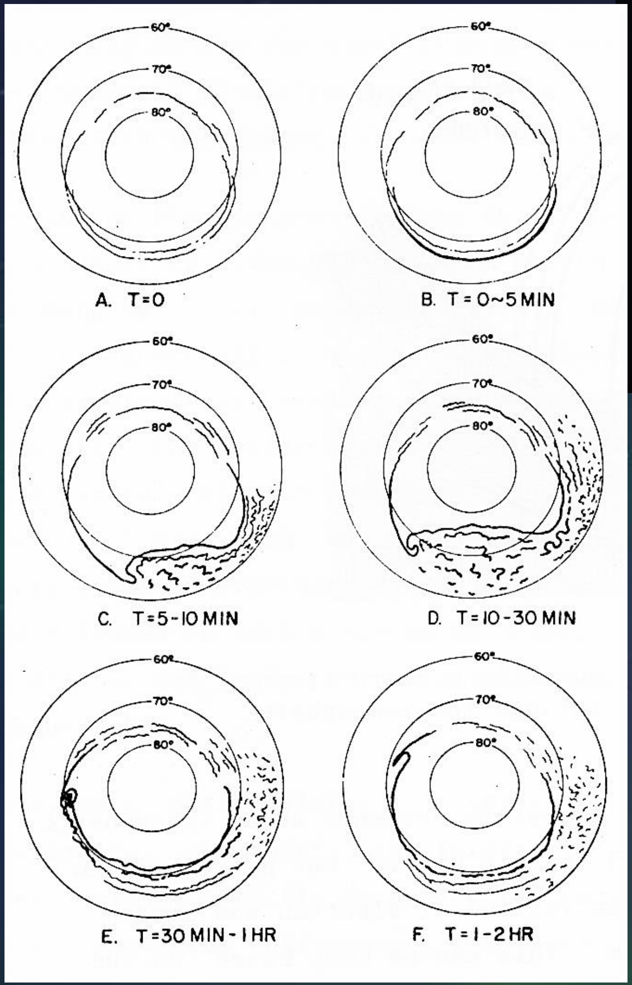
The three successive examples of "spikes" on 17. March, 2015

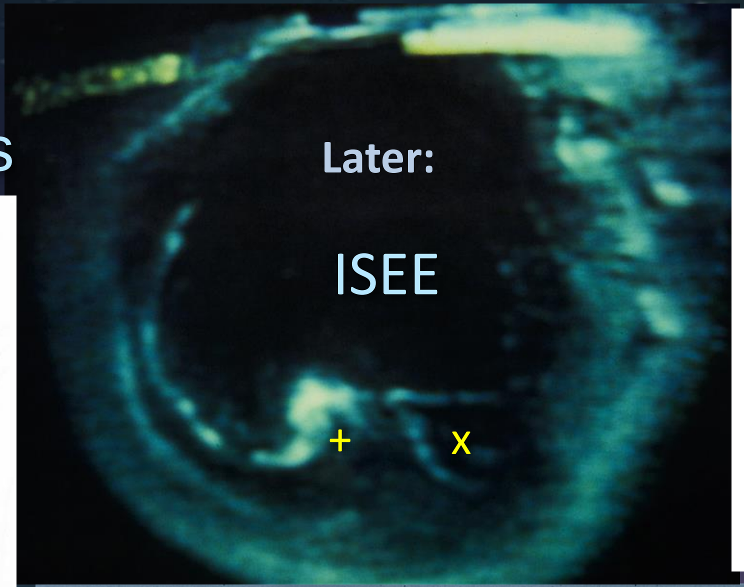


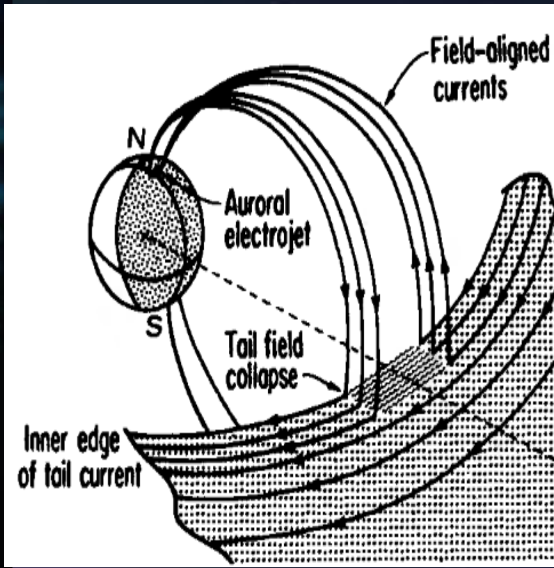
3 events in < 18 mins for entire sequence – 6 mins on average - much shorter than substorms !

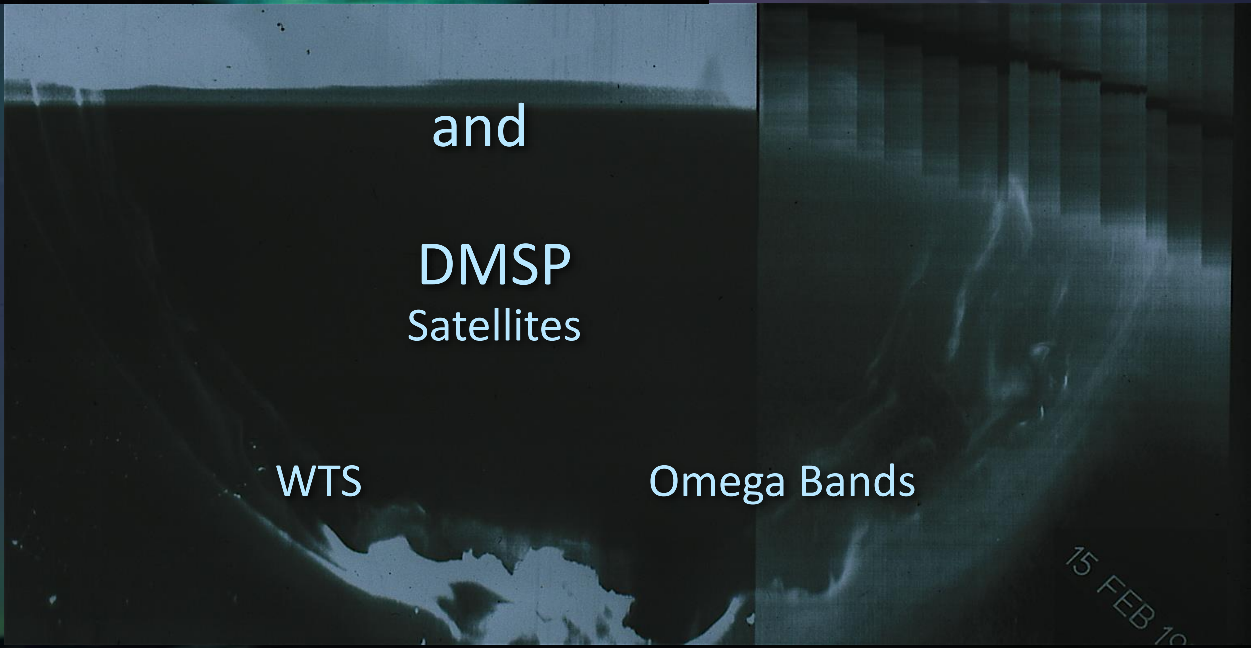
HISTORY: the understanding of aurora and substorm as a global phenomena emerged from the IGY

First: Akasofu, 1964
from All-Sky Cameras









Magnetic signatures of localized field-aligned currents seen from ground

Localised Substorm Onset

see Opgenoorth et al. 1980 and 1983, *Baumjohann et al.* 1983

The "Fukushima Theorem" - Untiedt et al. 1979

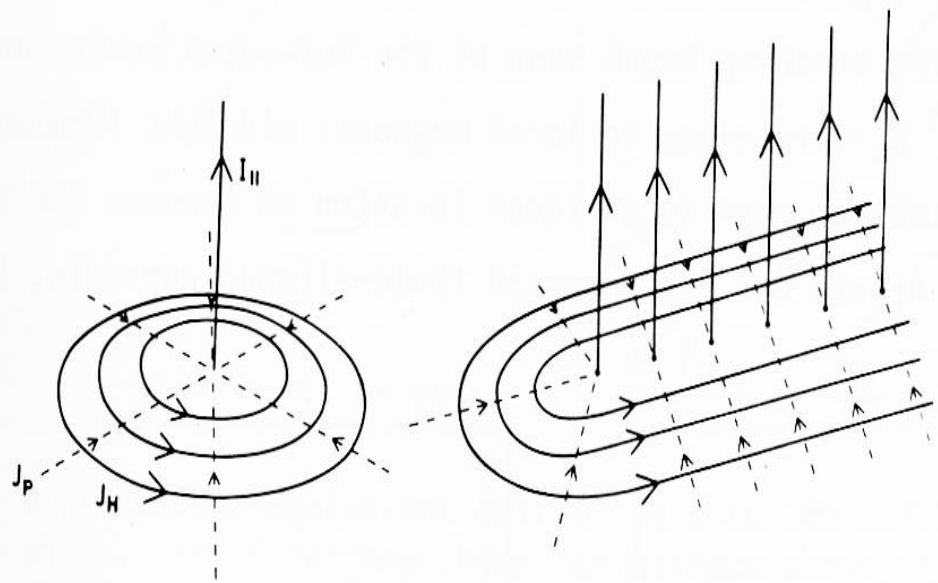
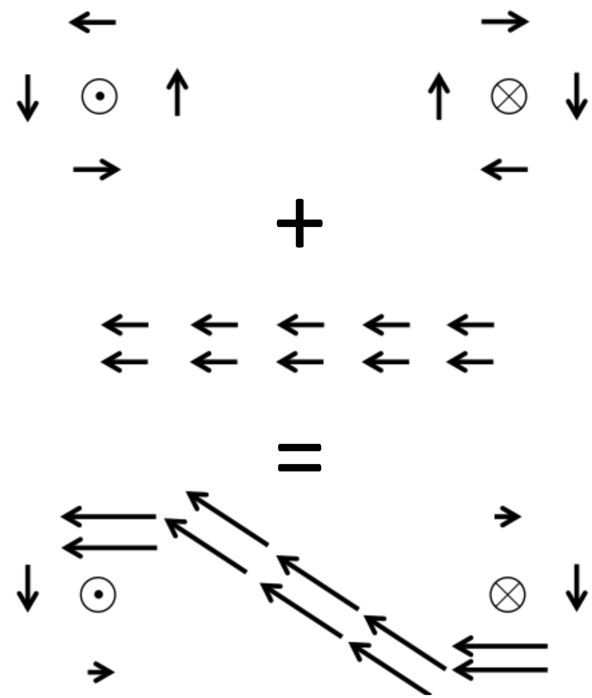
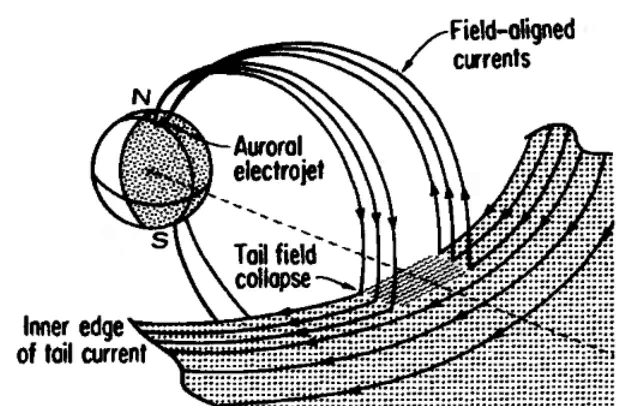


Fig. 24. Schematic view of a current system (right) which might explain the pattern of the equivalent current vectors shown in Fig. 26b. It is composed of elemantary systems (Fukushima, 1971) of the sort shown left. J_P and J_H denote Pedersen and Hall currents, respectively.

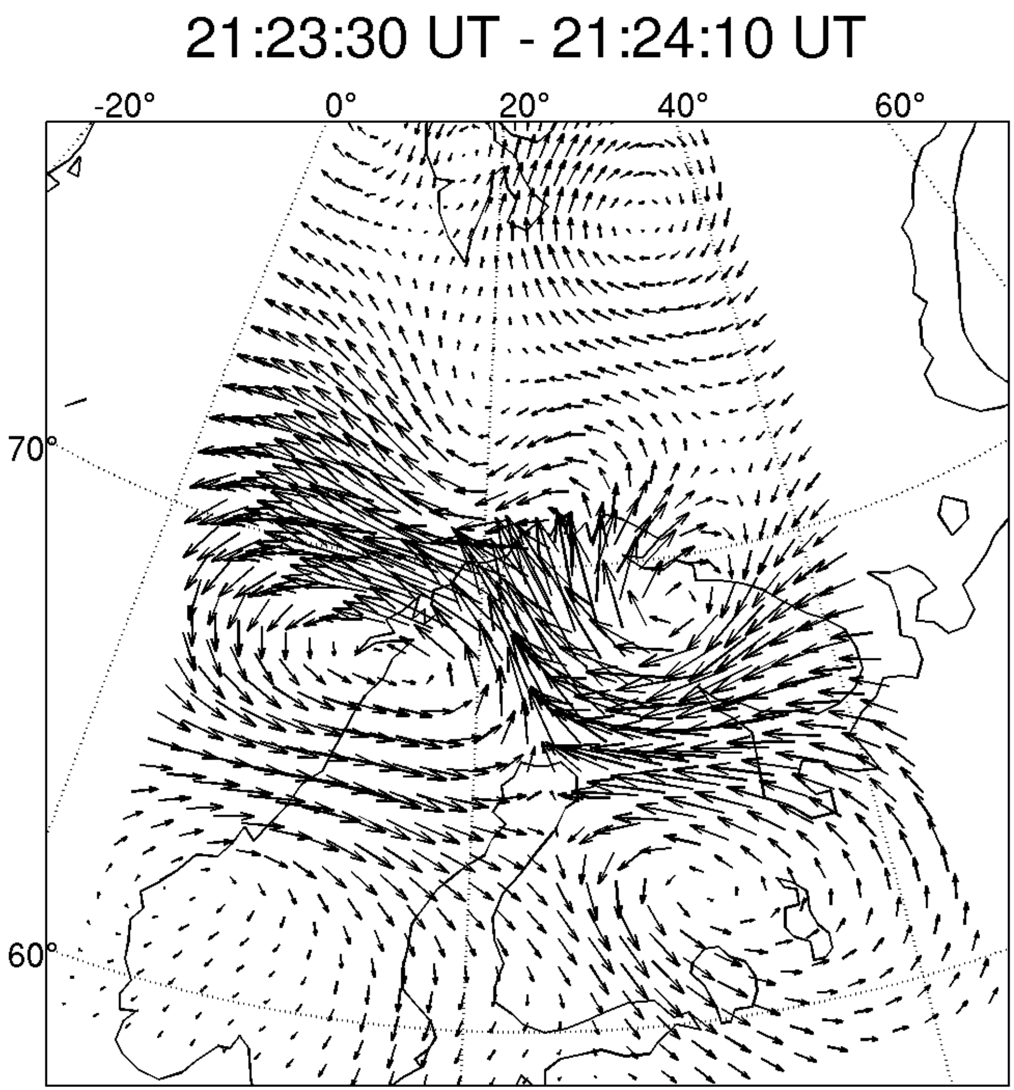


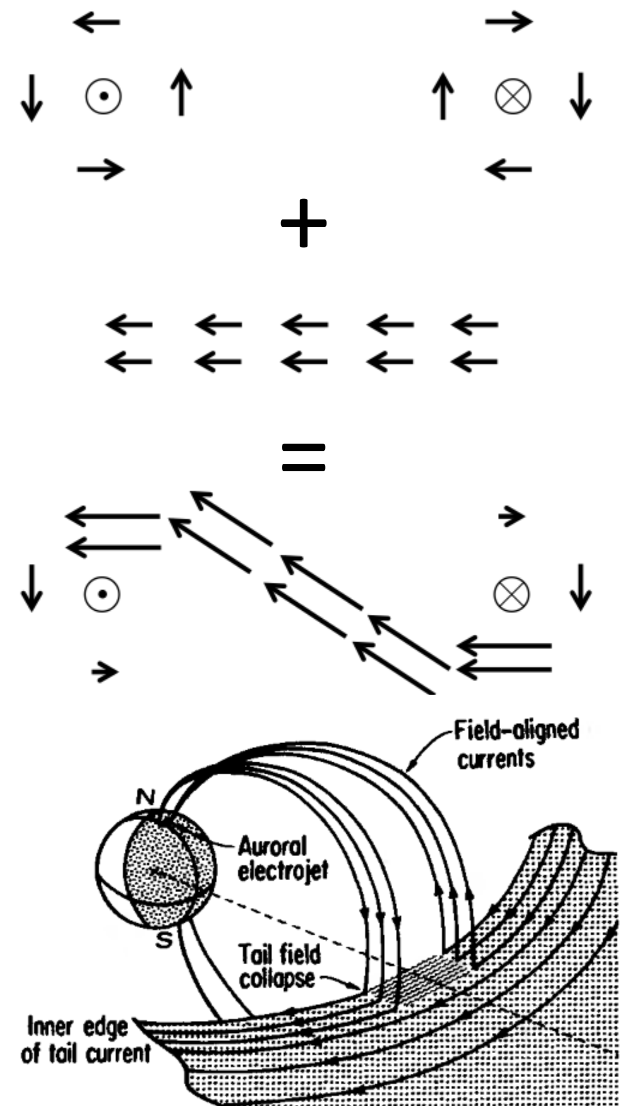


Pattern of (**Differential**) Equivalent Ionospheric Current

Localised Substorm Onset

from Palin et al. 2016; see also Opgenoorth et al. 1980,1983, *Baumjohann et al.* 1983





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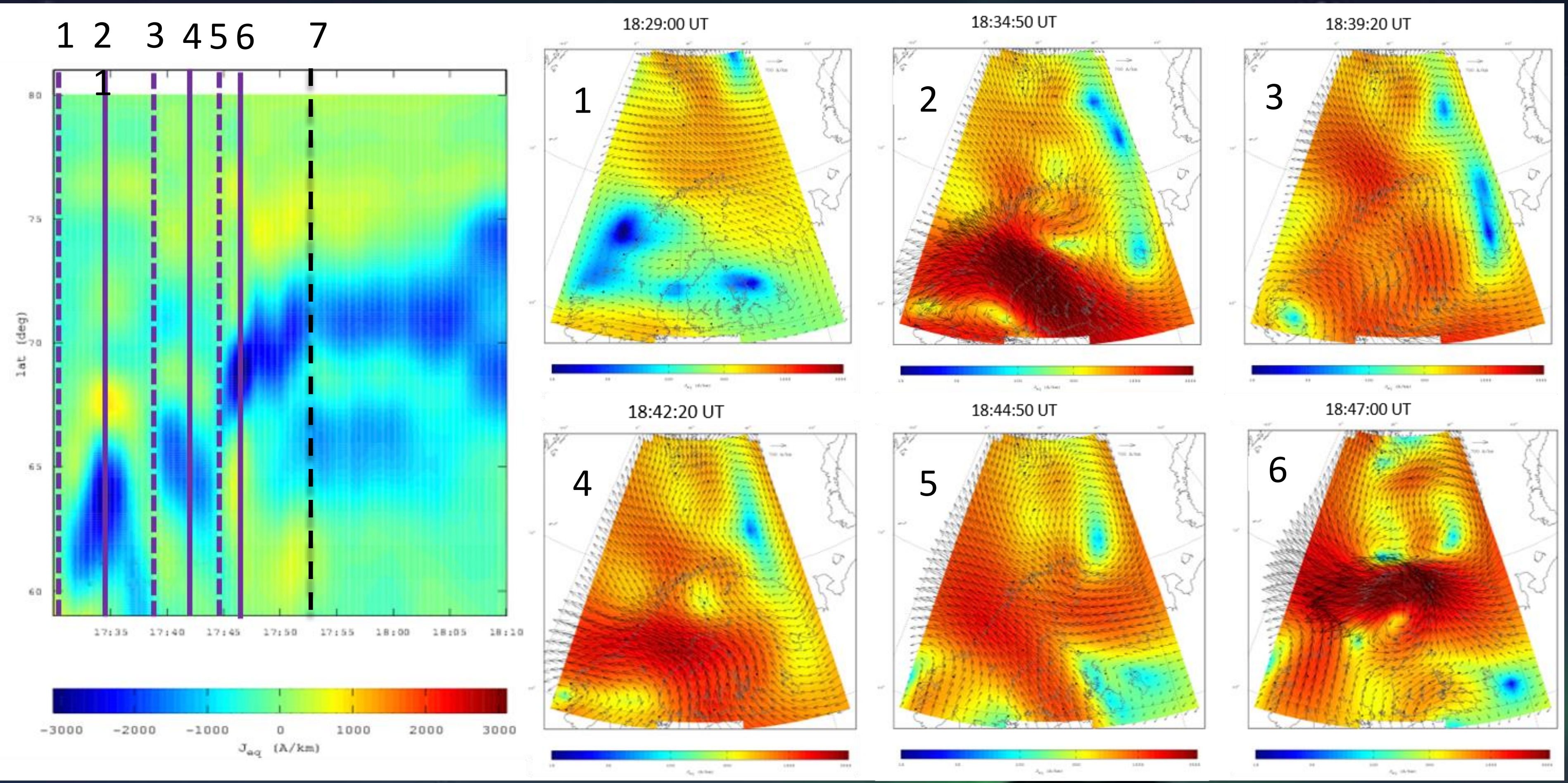
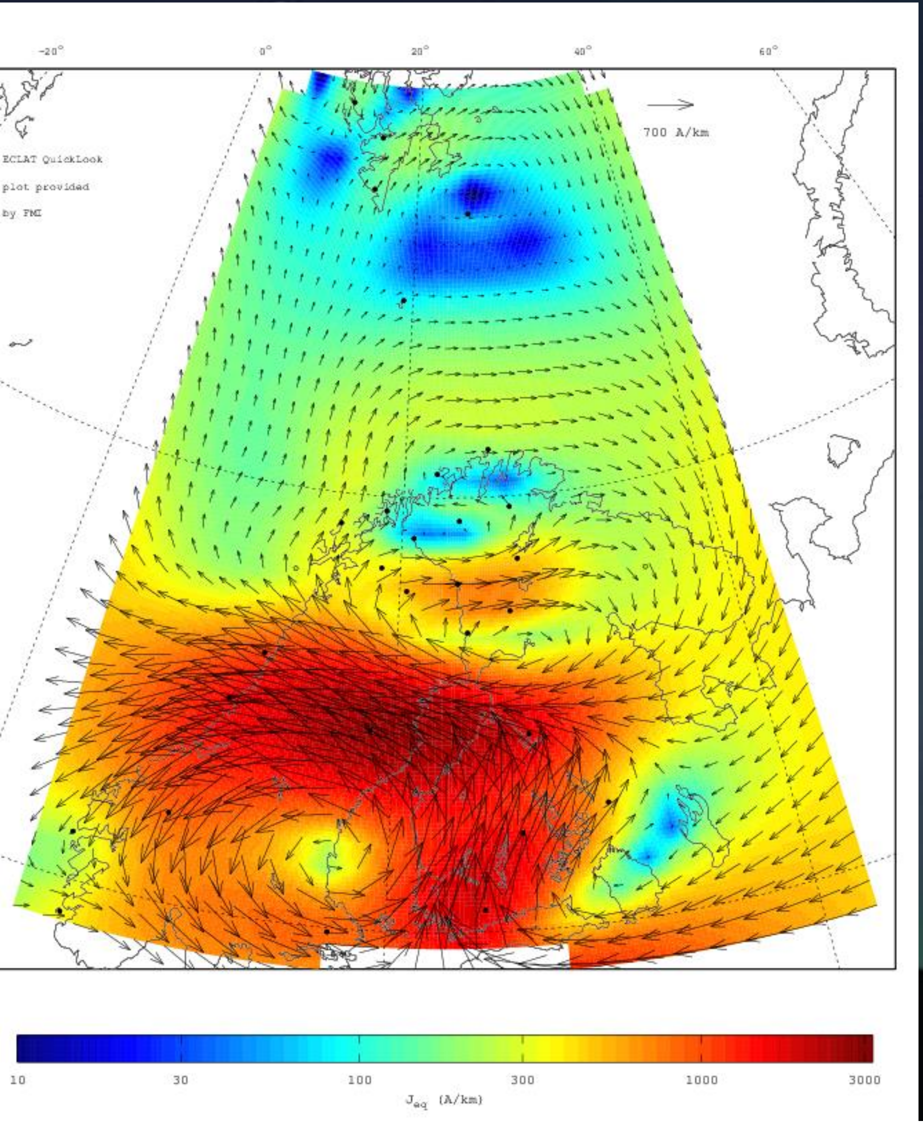
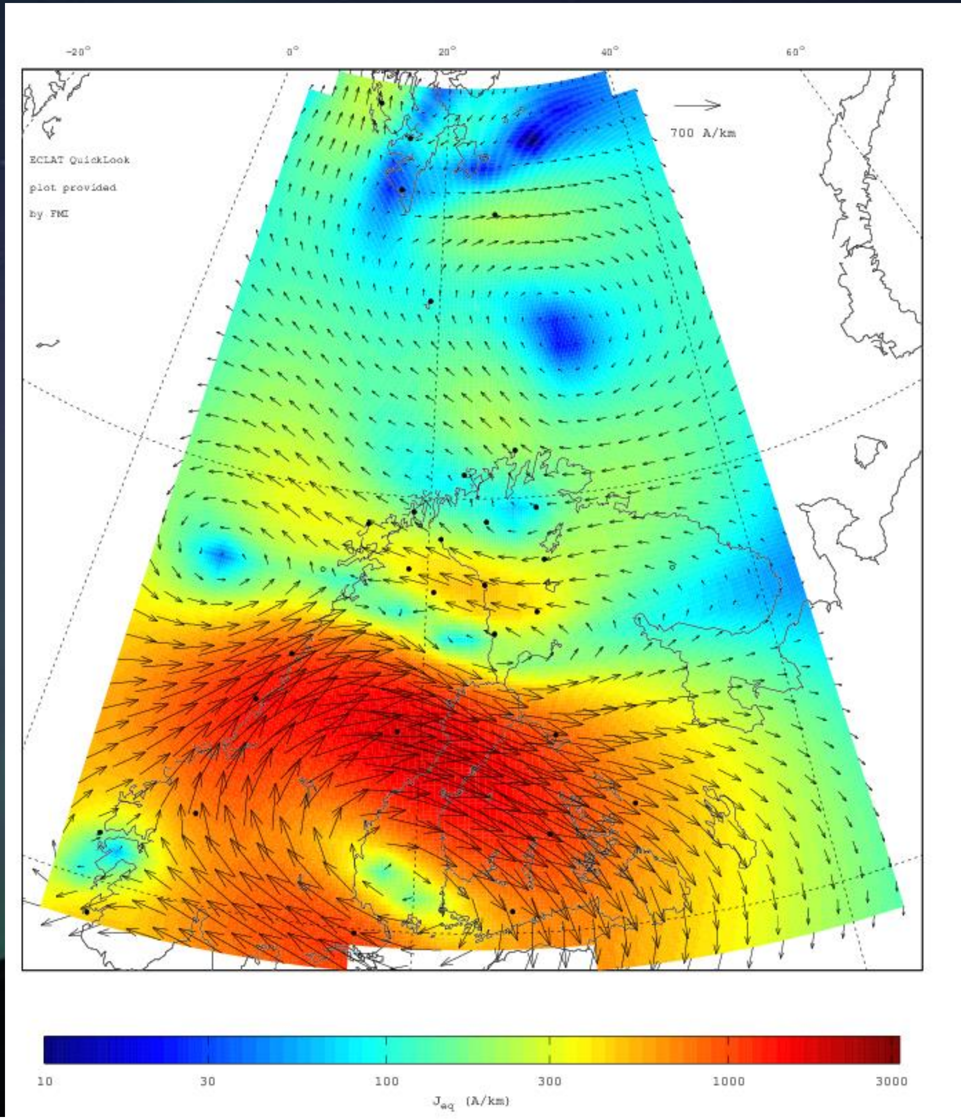


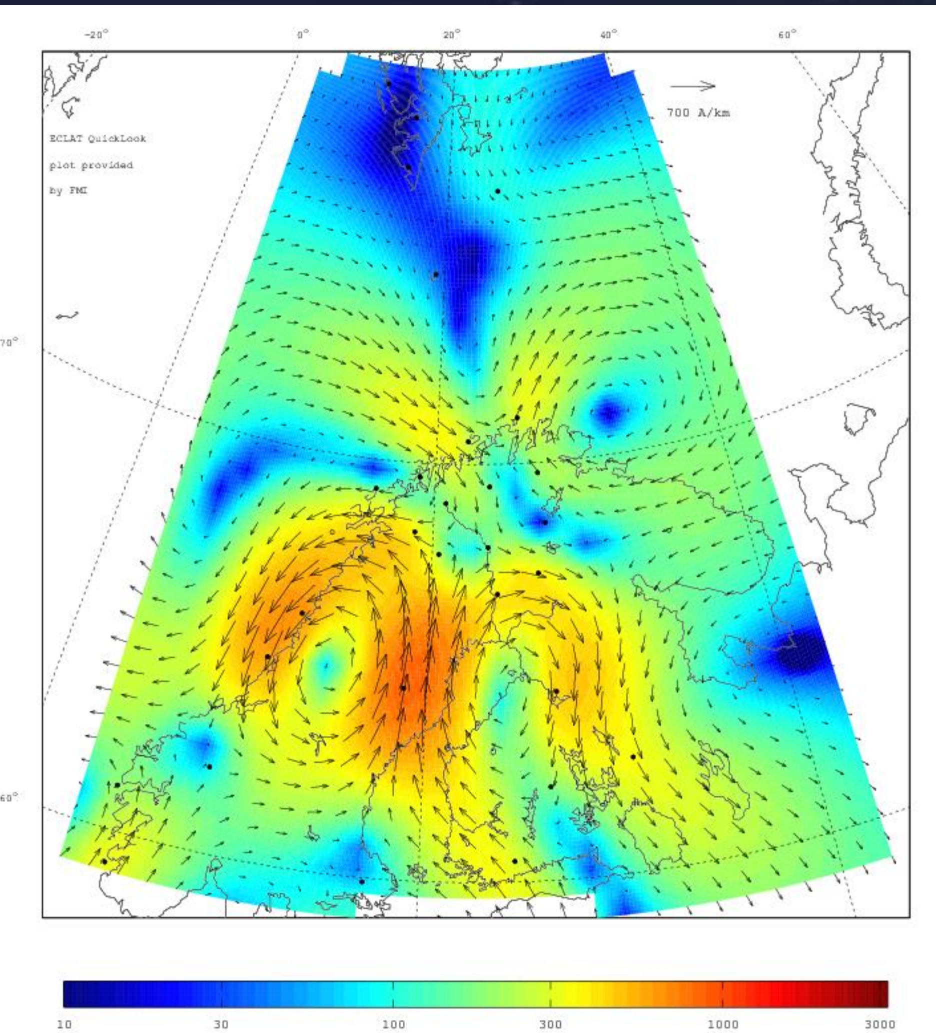
3 events in < 18 mins for entire sequence – 6 mins on average - much shorter than substorms !

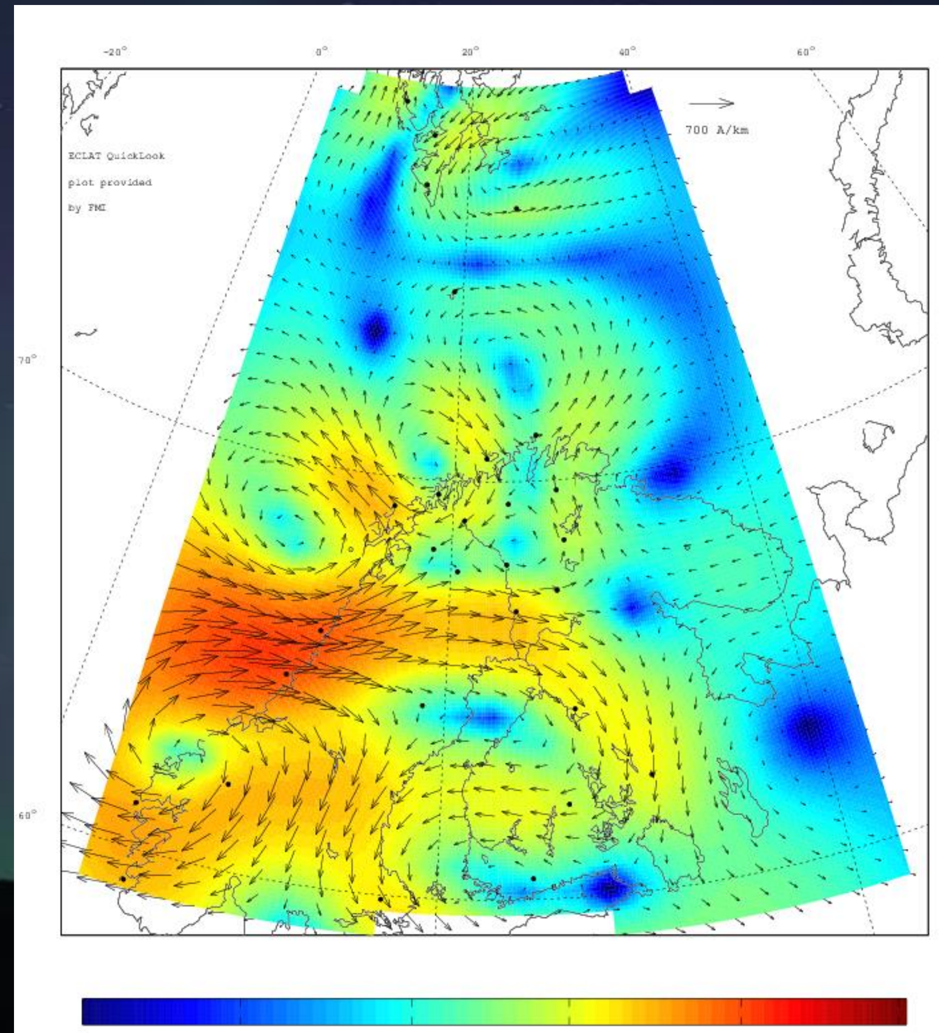
Differential equivalent current vectors for built-up and dis-appearance of first spike



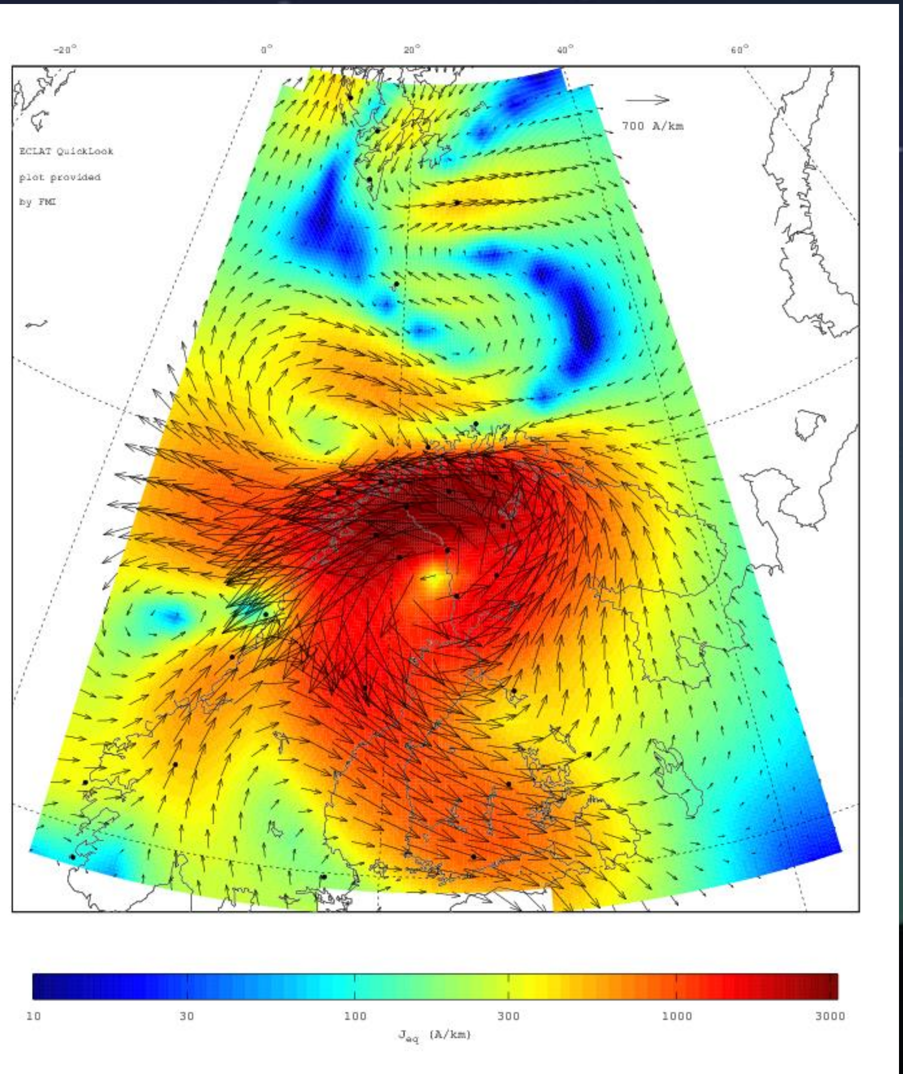


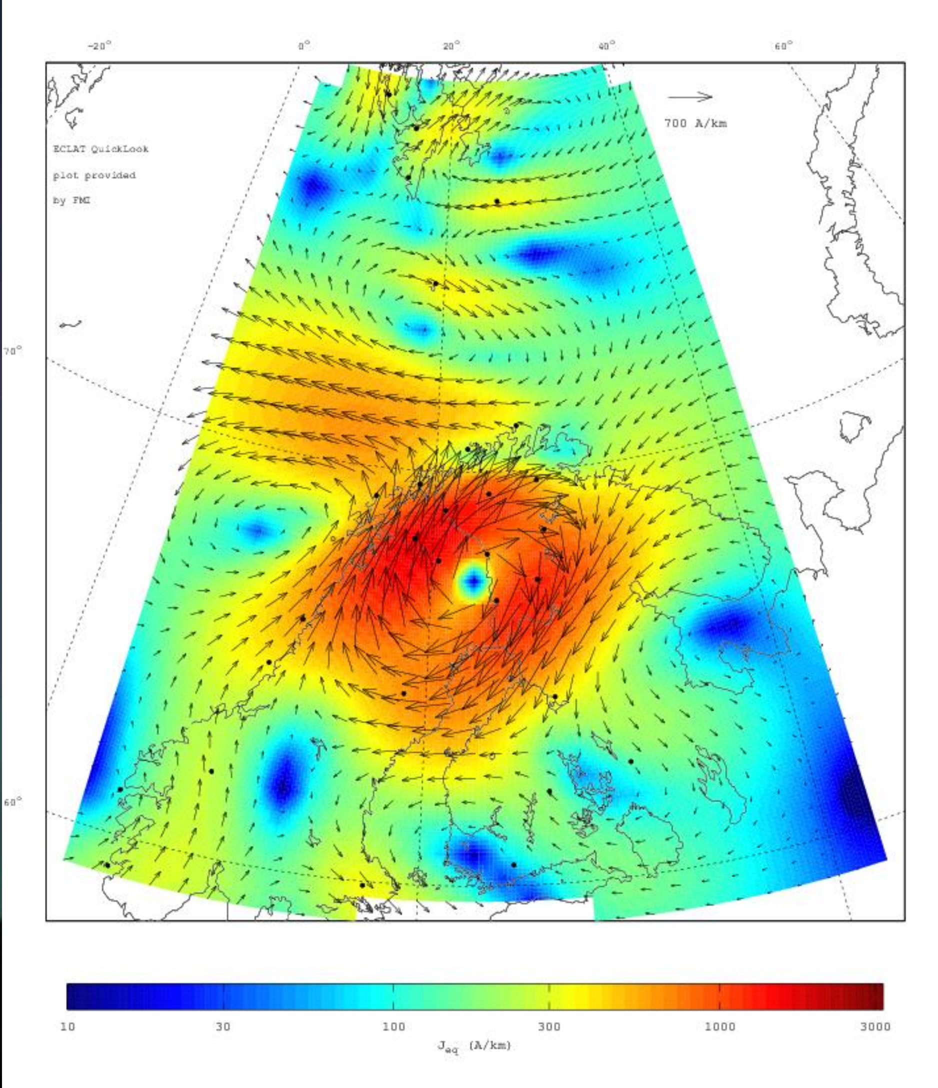
Differential equivalent current vectors for built-up and dis-appearance of second spike





Differential equivalent current vectors for built-up and dis-appearance of third spike





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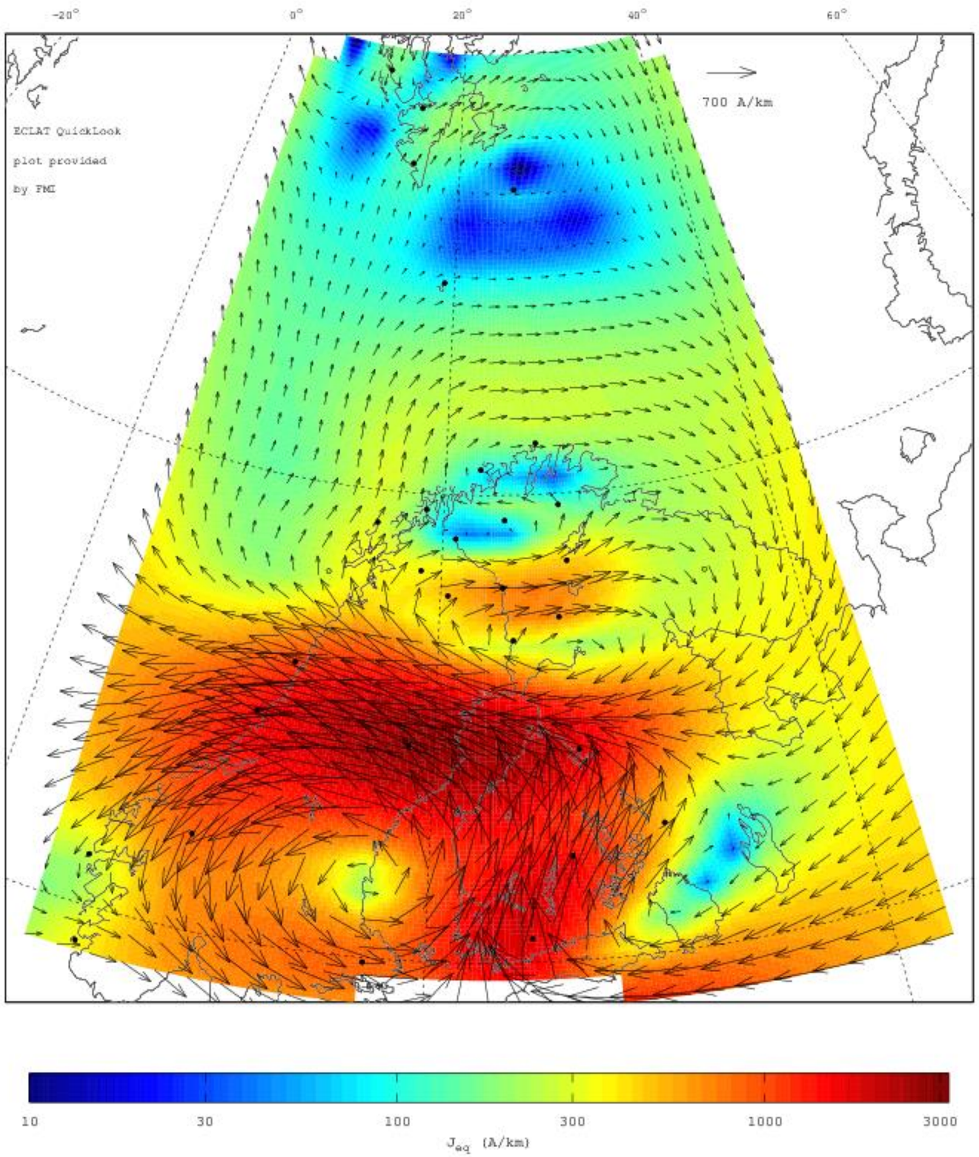
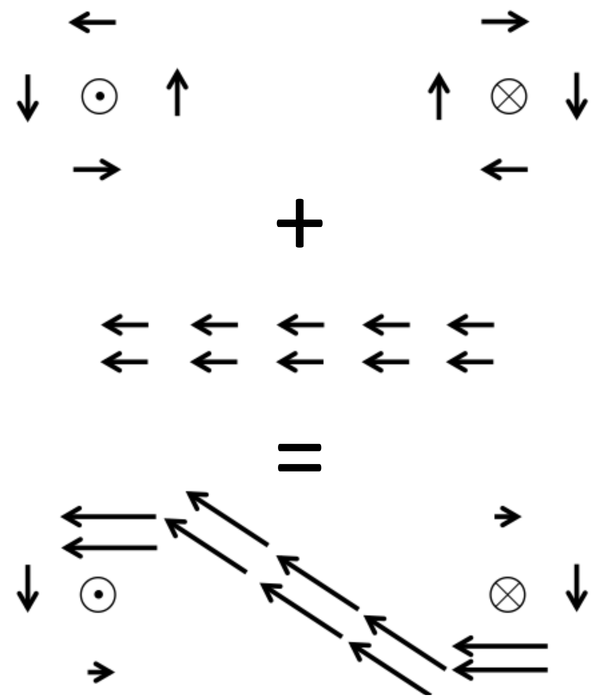
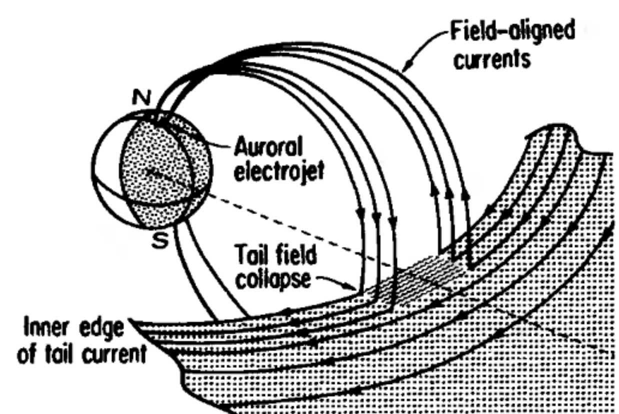
from Palin et al. 2016; see also Opgenoorth et al. 1980,1983, *Baumjohann et al.* 1983





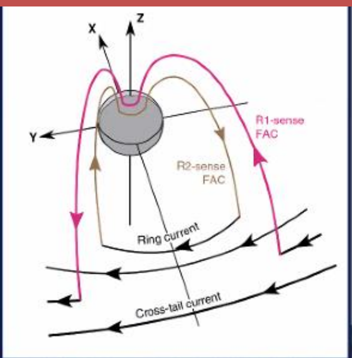


Such studies are at the heart of modern magnetospheric physics
Better scientific understanding will improve potential to predict

Large Scale Current Circuits vs. Wedgelets

Large scale re-routing of cross tail current

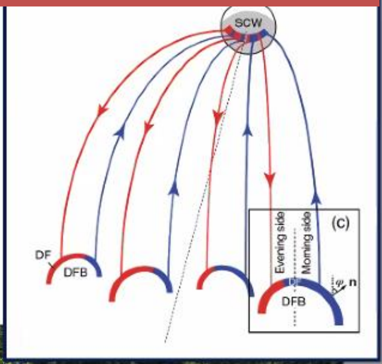
Many small wedge-lets from BBFs in tail



Sergeev et al.

vs

Liu et al.

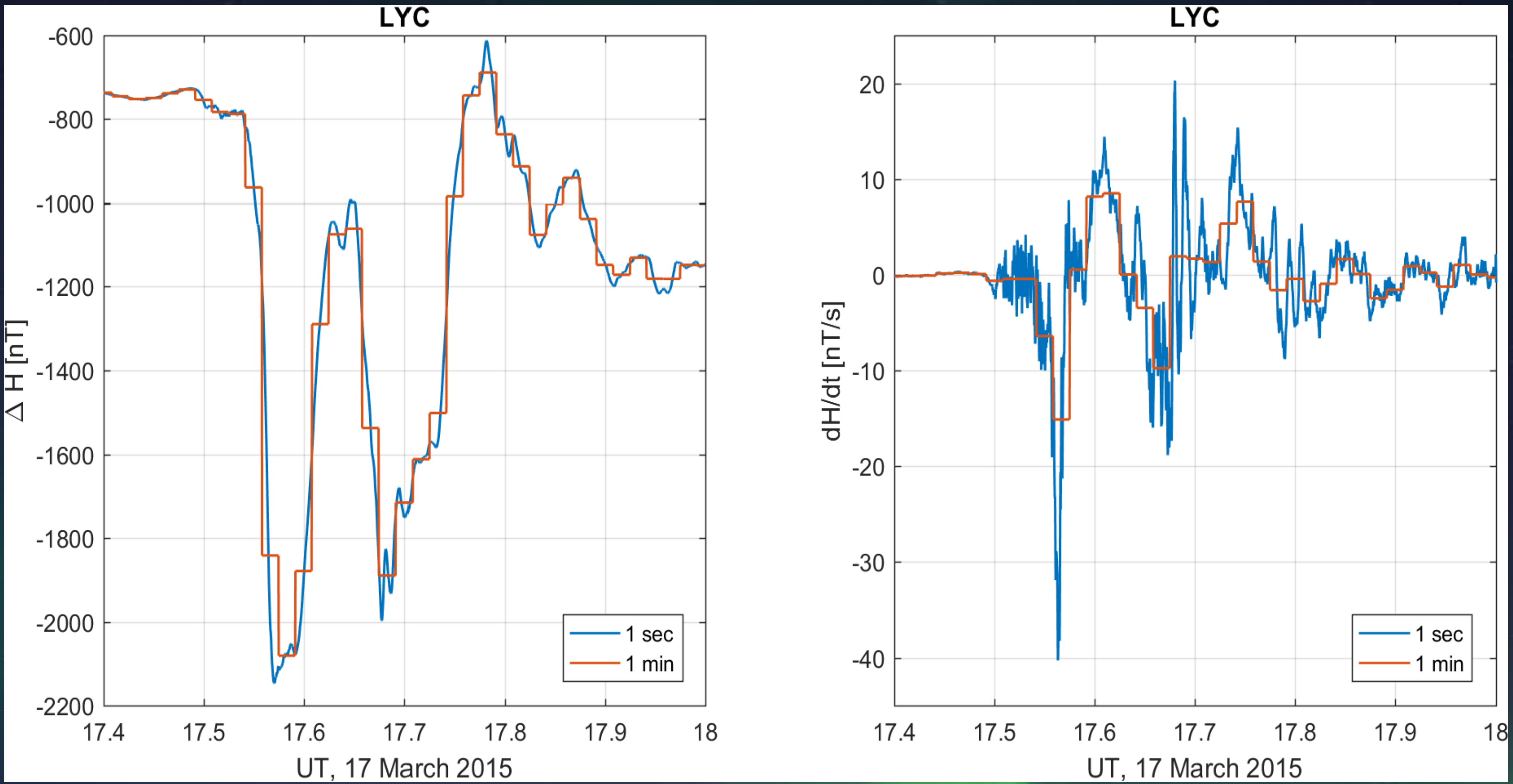


OR

See also Palin et al. 2015, 2016
Angelopulous et al. 2020, etc.

Slide borrowed from talk by Jesper Gjerlöv, ISWAT workshop, 2021

Obvious shortcoming of this study – too few instruments in sub-auroral latitudes
...and too coarse temporal resolution(1 min) to catch the true dB/dt spikes



Insufficiency not only restricted to instrument overage, and station density, but even in temporal resolution !

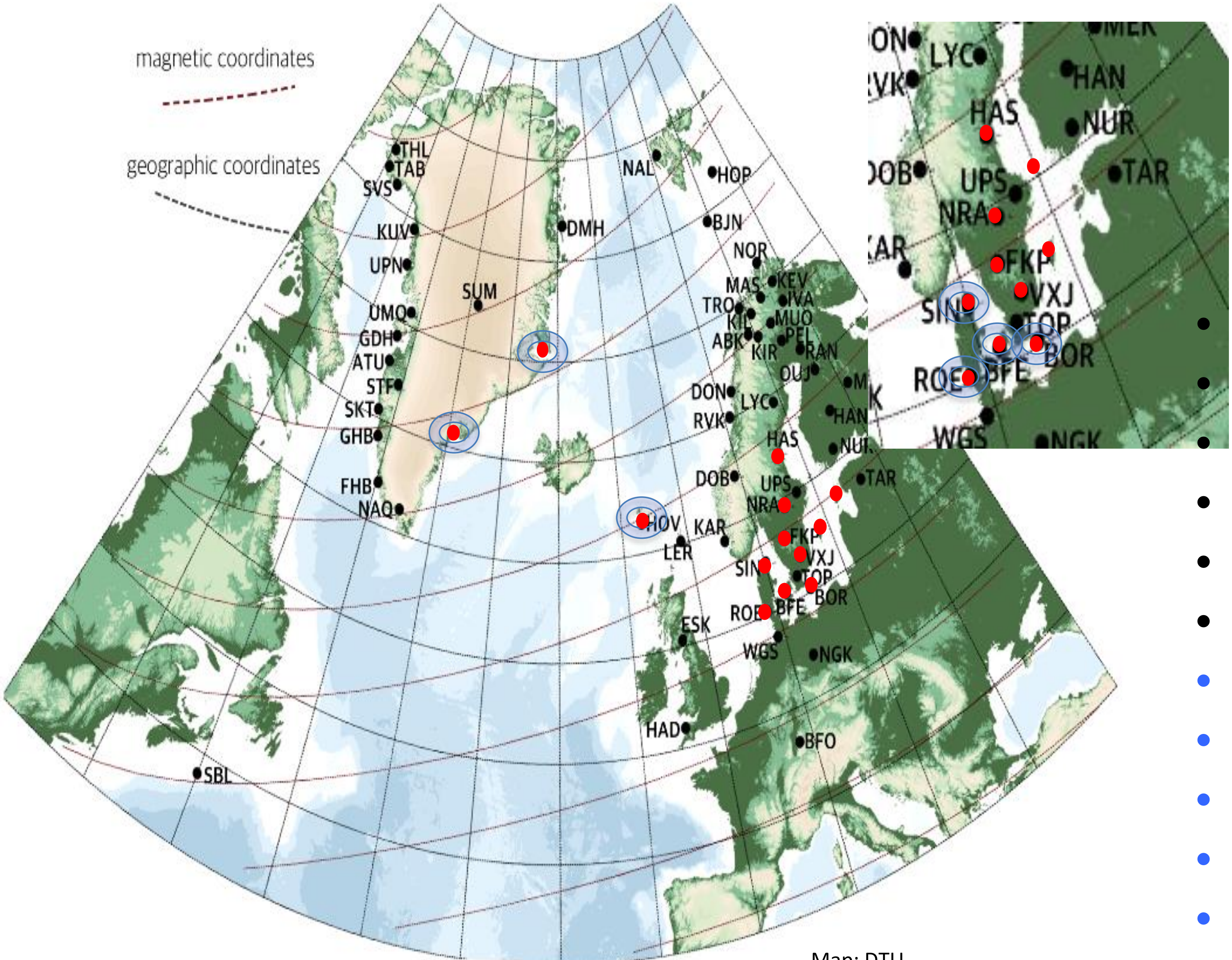
Second Part: Future opportunities

Additional space weather effects indirectly related to dB/dt and GICs:

Strong flow channels = strong electric fields - adjacent to storm-time current systems

Coordinated observations between

MAGSWEDAN: ESA funded Magnetometer network
14 stations with 1 sec temporal resolution
(DTU Denmark and SGU Sweden)
and
CY-DARN: a new sub-auroral SuperDARN Radar
on Cyprus - overlooking MAGSWEDAN
(Leicester, UK, and Nicosia, Cyprus)



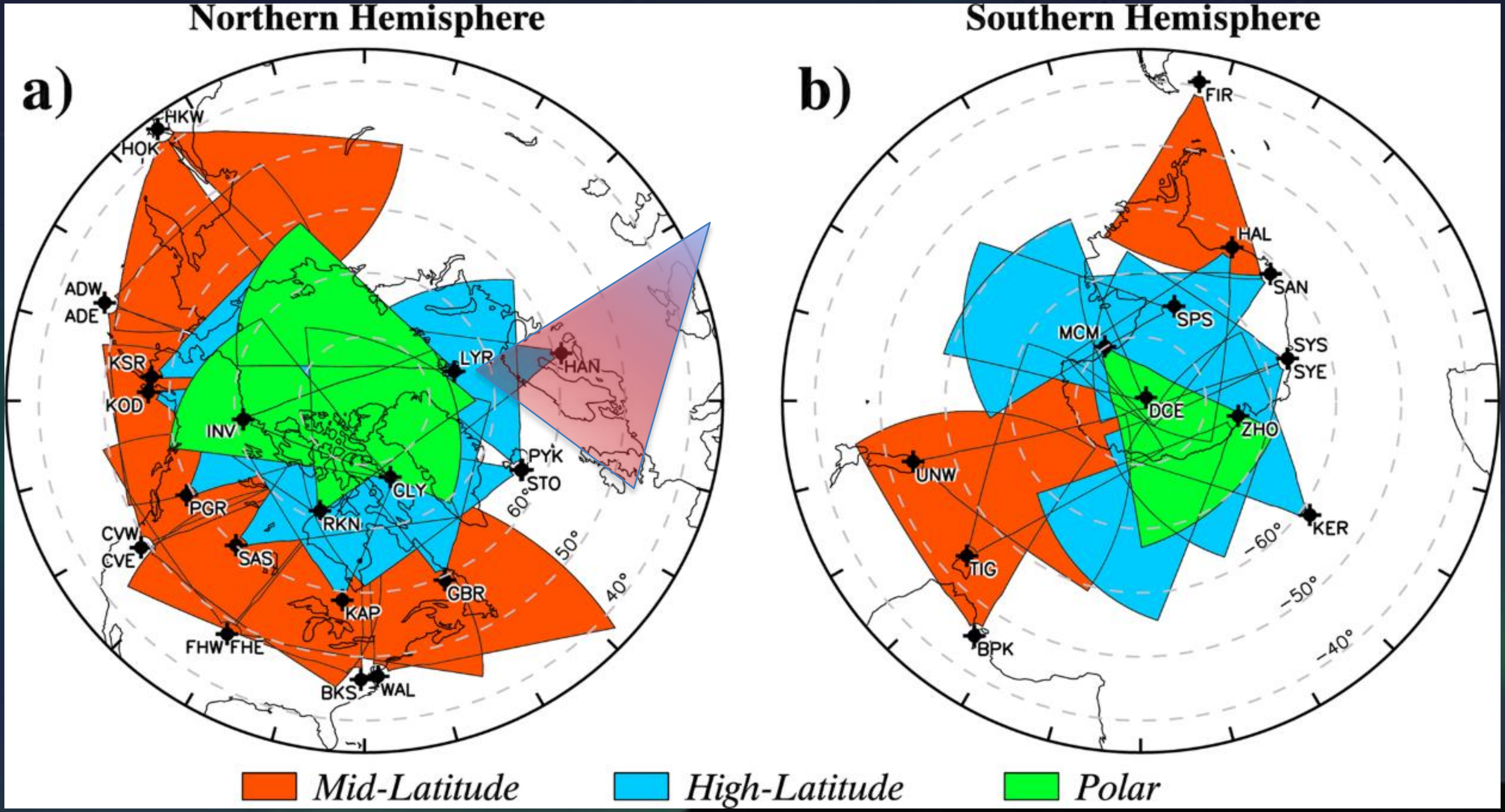
Map: DTU

THE NEW MAGSWEDAN MAGNETOMETER NETWORK
(operative as of autumn 2021)

- Växjö
- Falköping
- Nora
- Hassela
- Åland
- Gotland
- Sindal
- Bornholm
- Rømø
- Brorfelde
- Hov -Farør
- Greenland East 1 & 2

SuperDARN Radars' Fields of View:

recent extension into sub-auroral latitudes (red)
and the planned CYDARN (shaded pink)

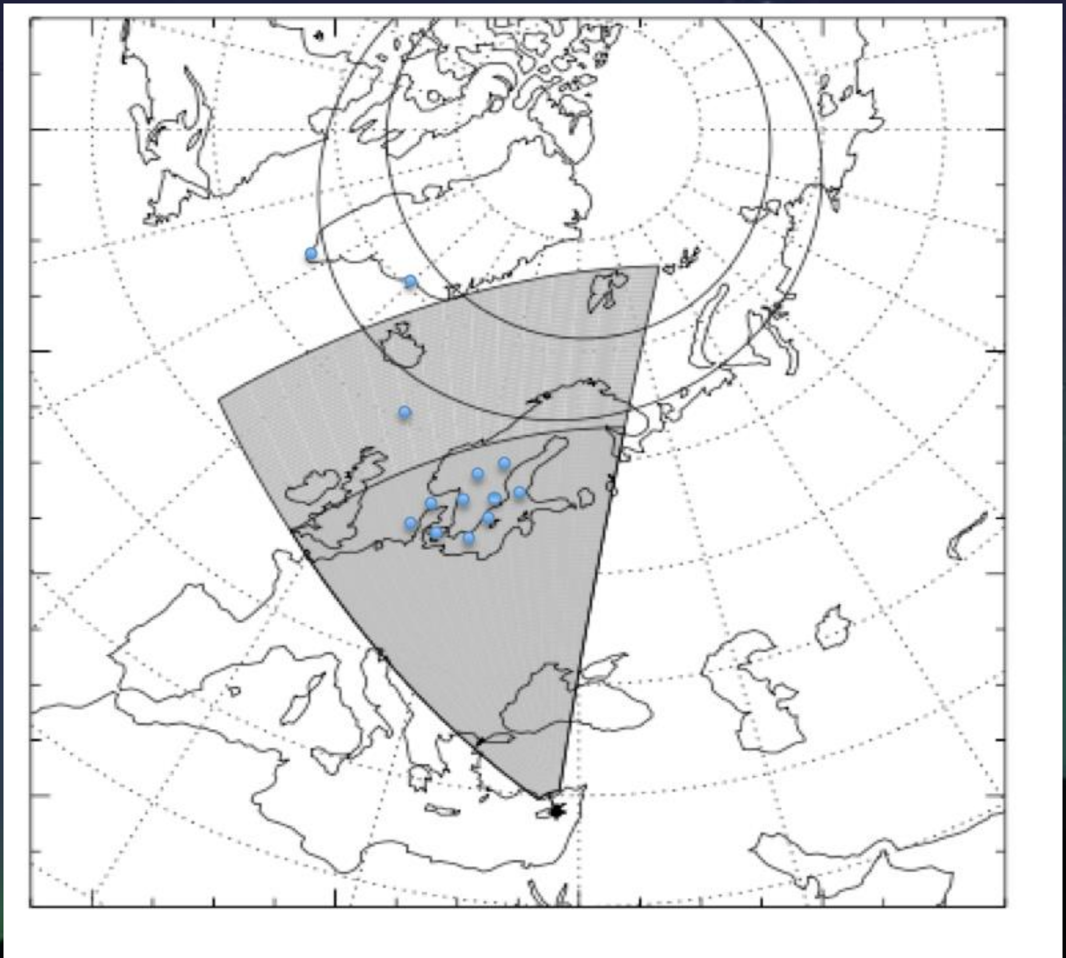


The CY-DARN Project - supporting the MAGSWEDAN network

Radar, site, license and funding exist

MoU with CSEO close to completion

Installation as soon as Covid permits



New Interest: SAPS – Sub-Auroral Polarisation Streams

strong convection channels causing ionospheric instabilities

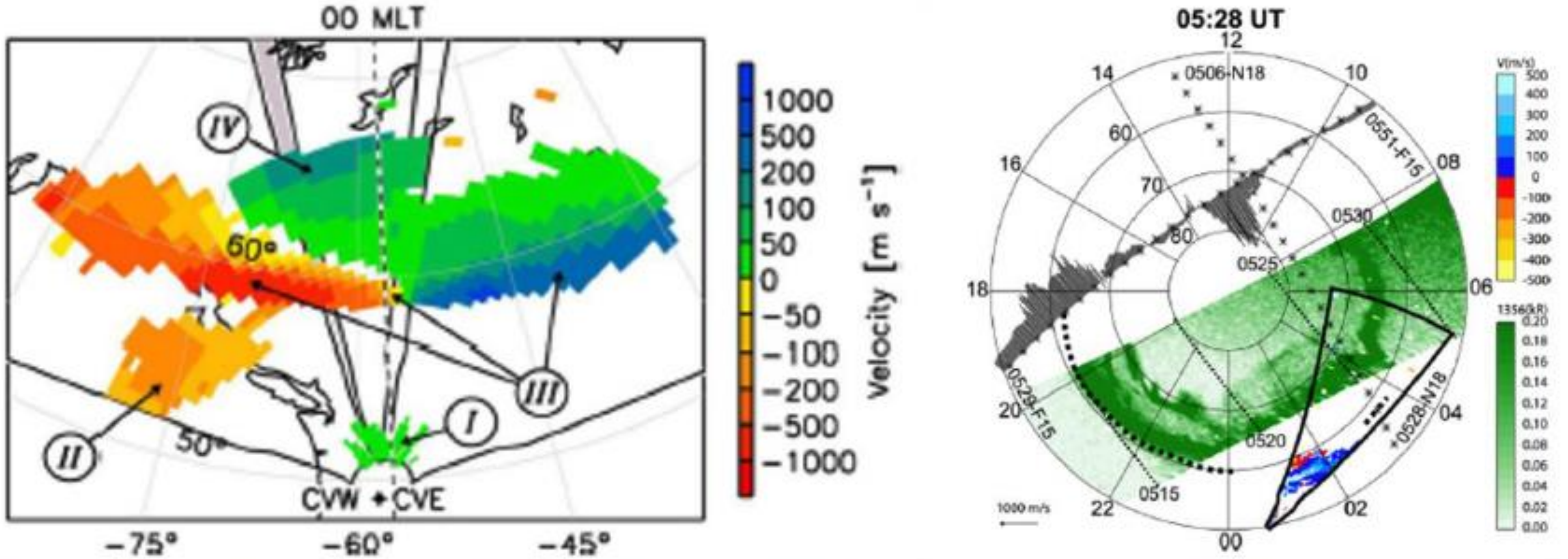
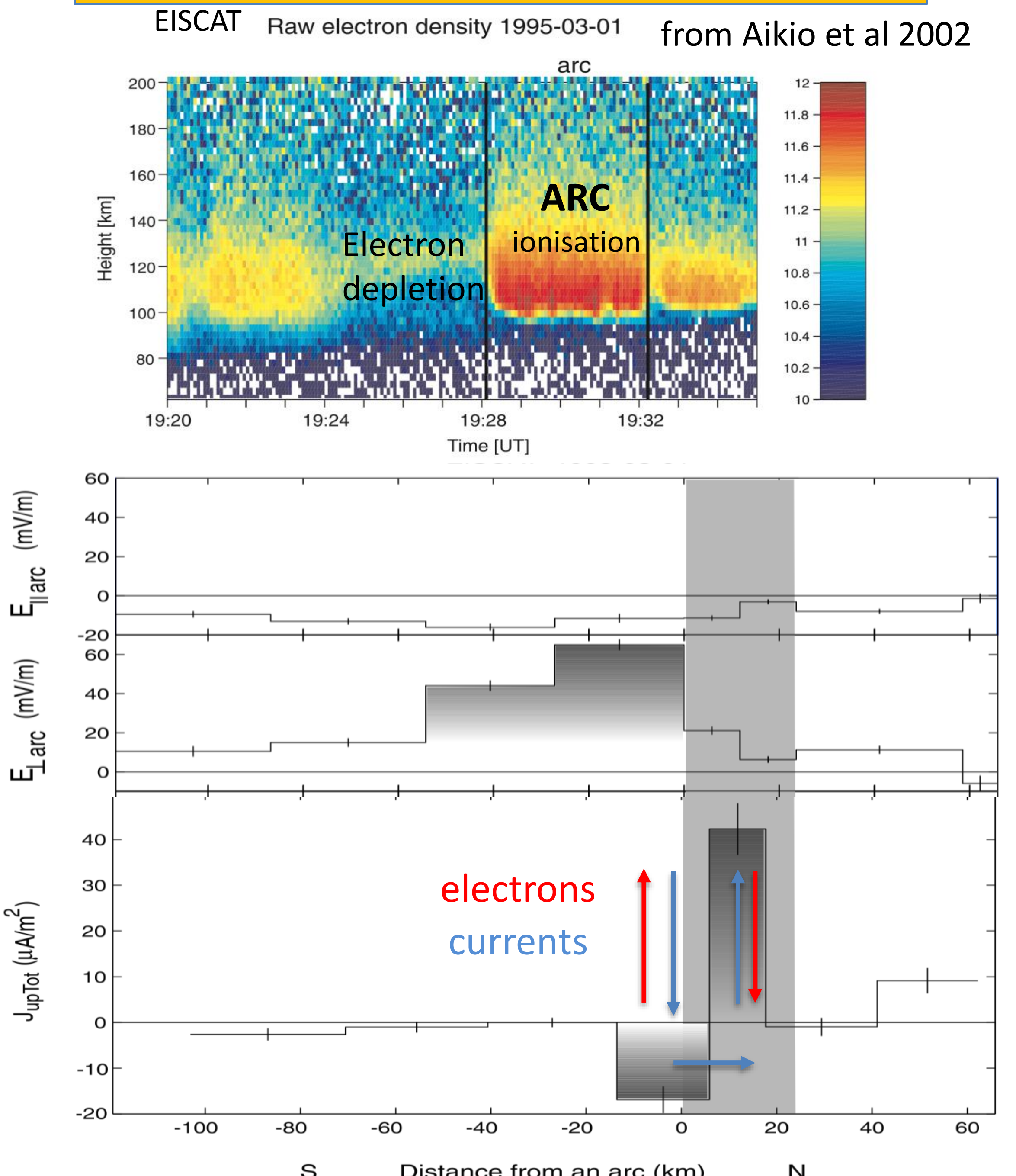


Fig. 5: Left panel: Field of view from one SuperDARN radar. SAPS event observed around 60° latitude (annotation III), clear high plasma velocity (color scale) associated with the narrowed in latitude but extended in longitude structure. Clausen et al., 2012 [36]. Right Panel: Example of SAPS structure enclosed in the triangle below the nothern light (green auroral image). Satellites are passing close to the SAPS region (grey lines and stars). Oksavik et al. (2006) [37].

The physics behind fast flows adjacent to aurora



First paper to note large perpendicular electric fields, fast flows, high ion temperature and decreased electron density adjacent to auroral arcs was

Opgenoorth, H. J., I. Häggström, P. J. S. Williams, and G. O. L. Jones, Regions of strongly enhanced perpendicular electric fields adjacent to auroral arcs, J. Atmos. Terr. Phys., 52, 449–458, 1990.

Later followed up by Anita Aikio, Oulu, Finland in a series of papers in JGR and elsewhere…

Main characteristics - shown on left

Arcs are longitudinally extended narrow regions of high conductivity, caused by precipitating electrons.

We plan to study future magnetic storm events expanding to sub-auroral Scandinavia with imultaneous MAGSWEDAN and CY-DARN data to find the physical causes for GNSS anomalies

Questions ?