# Substorms are a major cause of large geomagnetically induced currents

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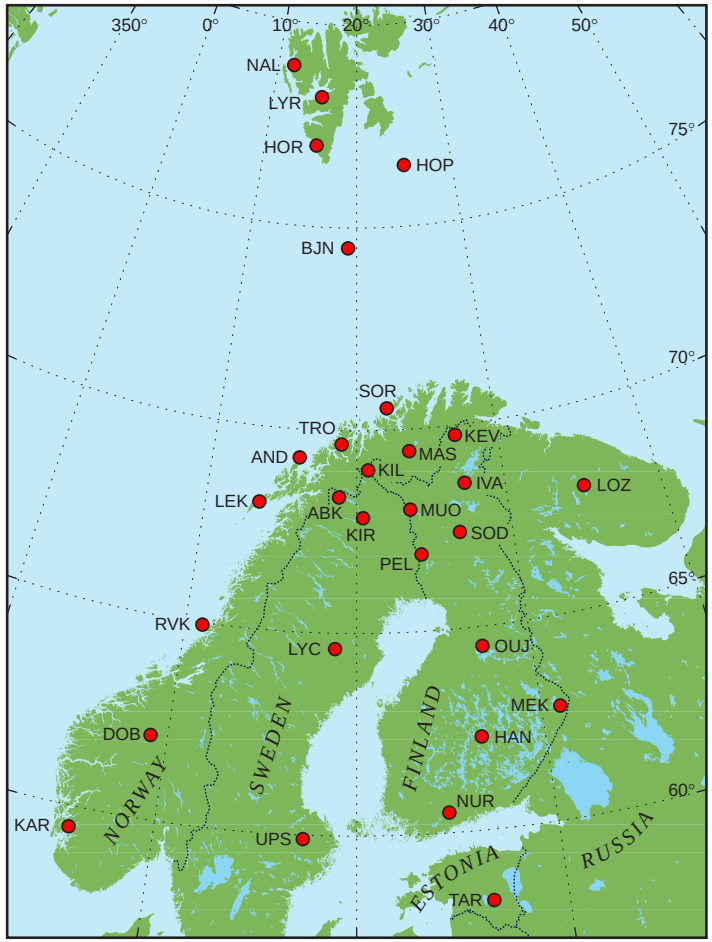
- **Substorm:**
  Negative bay > 100 nT with a clear onset when the IL index rapidly decreases at least 100 nT within 10 min ($IL(t) = \min\{B_x(t)\}$)
- **Data:** 833 substorms in 1997 and 1999
- **Two categories:**
  non-storm (Dst>-40 nT) (696 events)
  storm-time (Dst<-40 nT) (137 events)
- $d\mathbf{H}/dt$ is a good activity indicator of geomagnetically induced currents (GIC)

IMAGE Magnetometer Network




October 2004

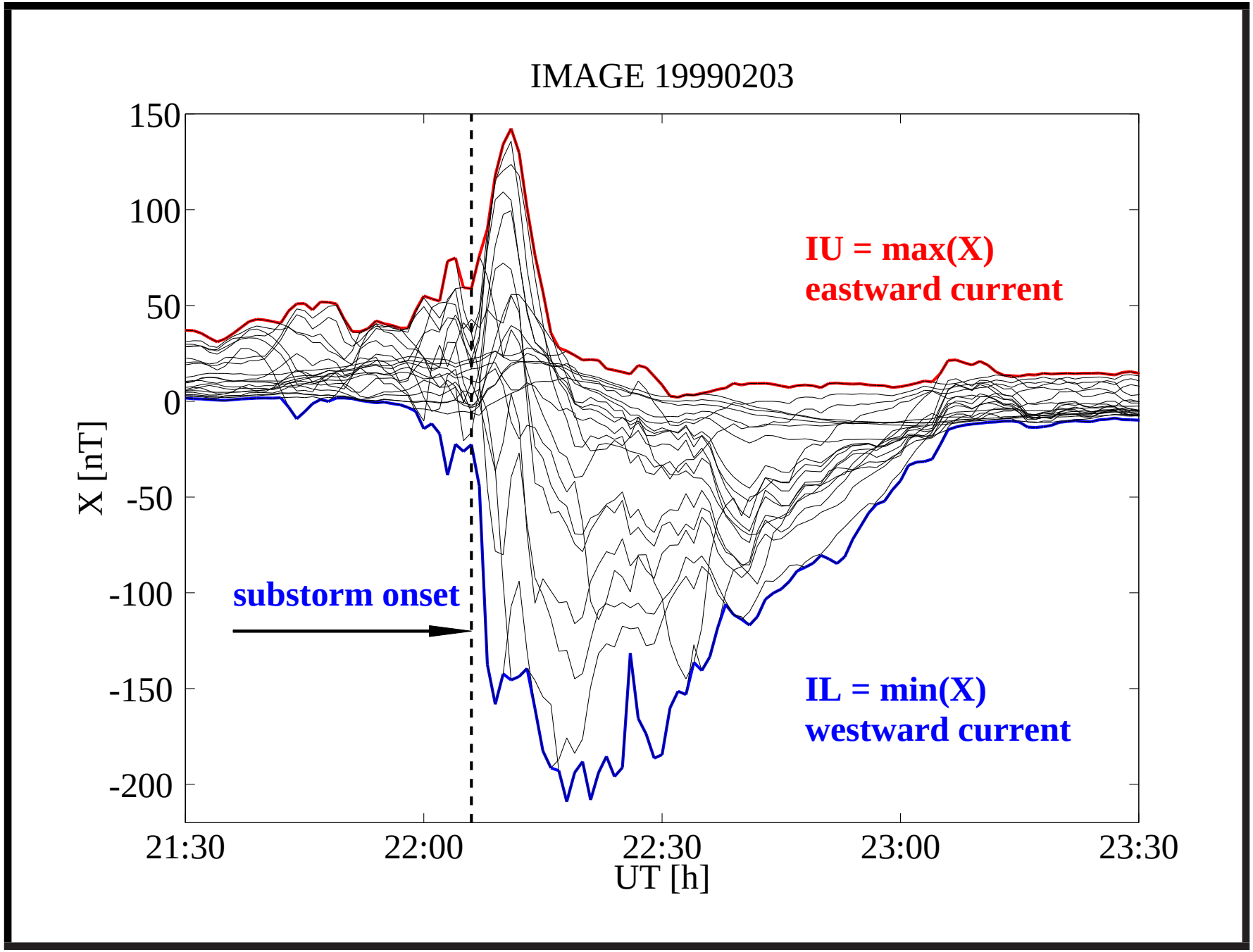
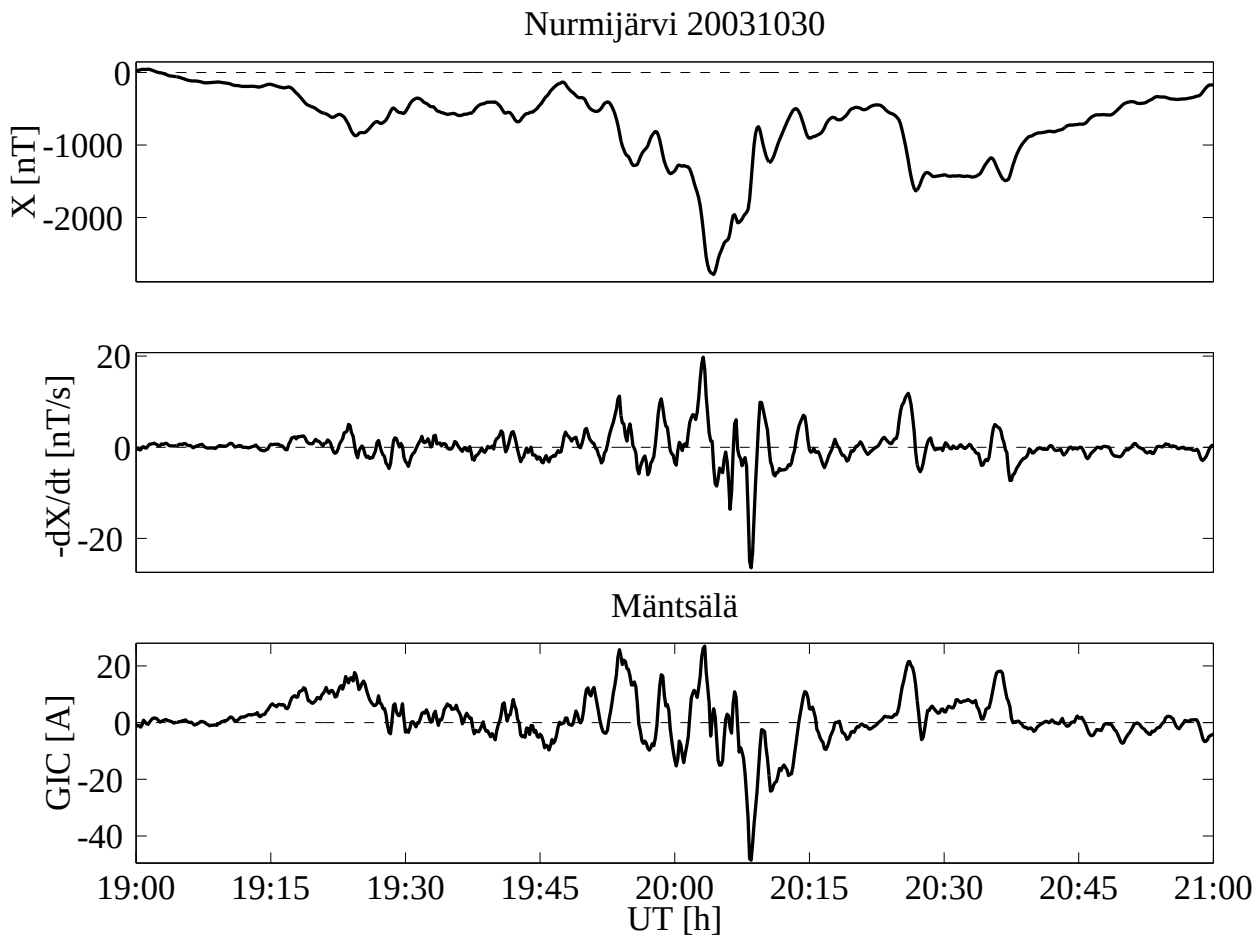


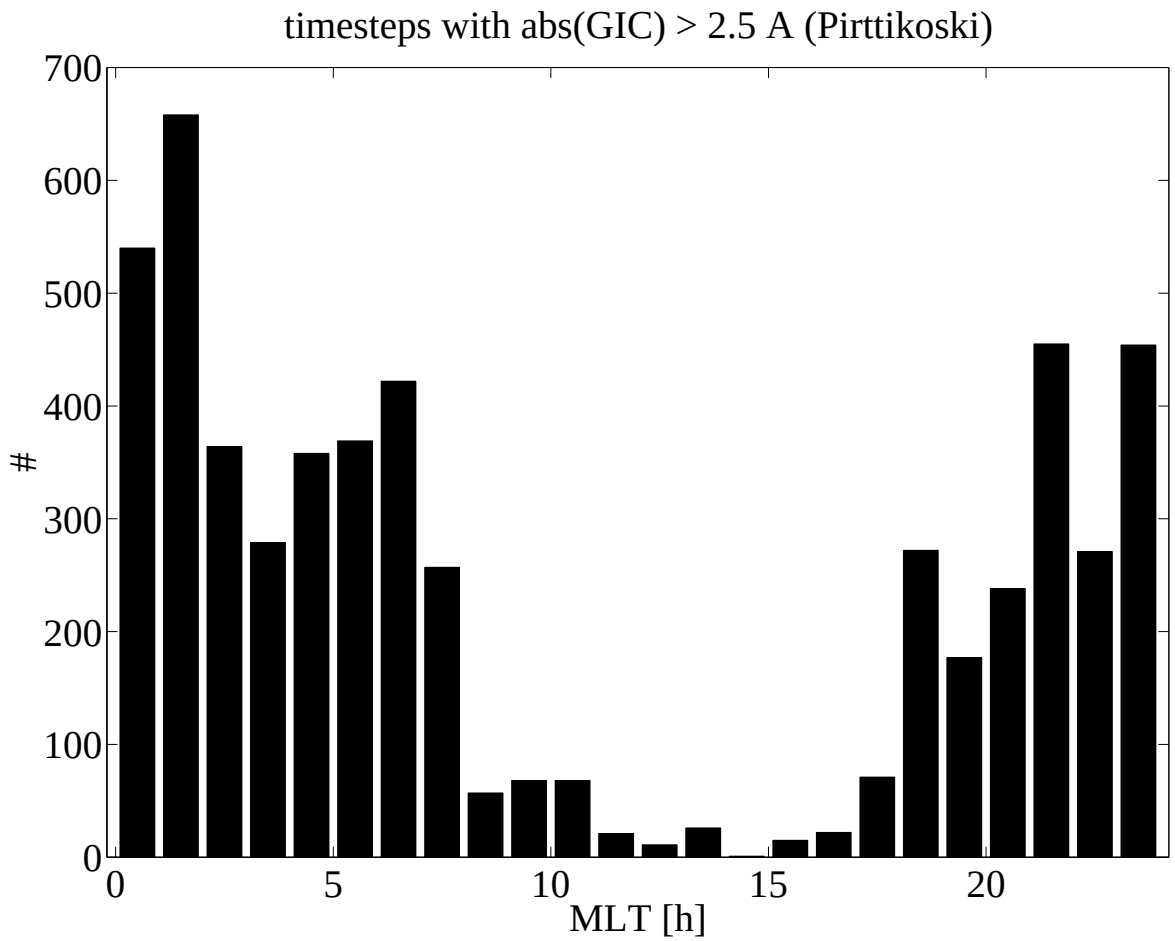
IMAGE 19990203
150
100
50
0
-50
-100
-150
-200
X [nT]
21:30
22:00
22:30
23:00
23:30
UT [h]
IU = max(X)
eastward current
IL = min(X)
westward current
substorm onset

## *There are large GIC during substorms*



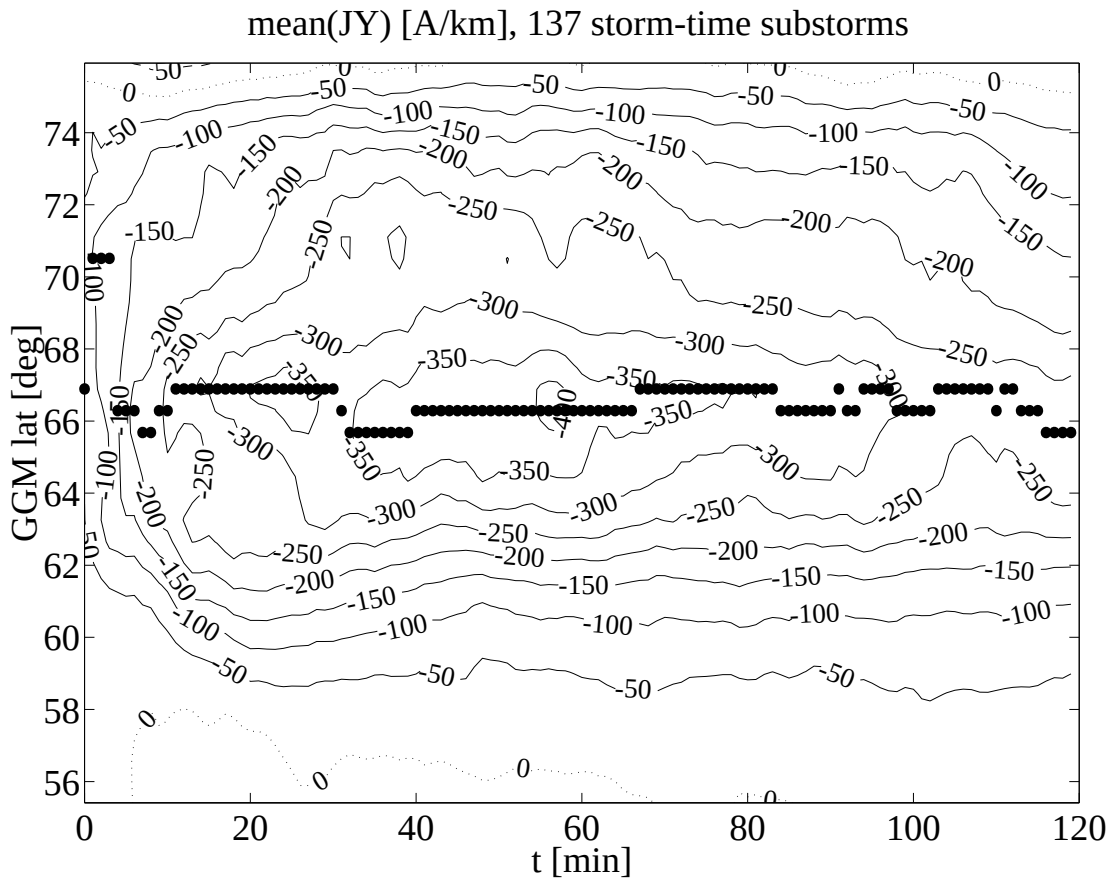

$X$ **and** $dX/dt$ **at Nurmijärvi, and GIC along the natural gas pipeline.**

## *Large GIC occur often during substorms*



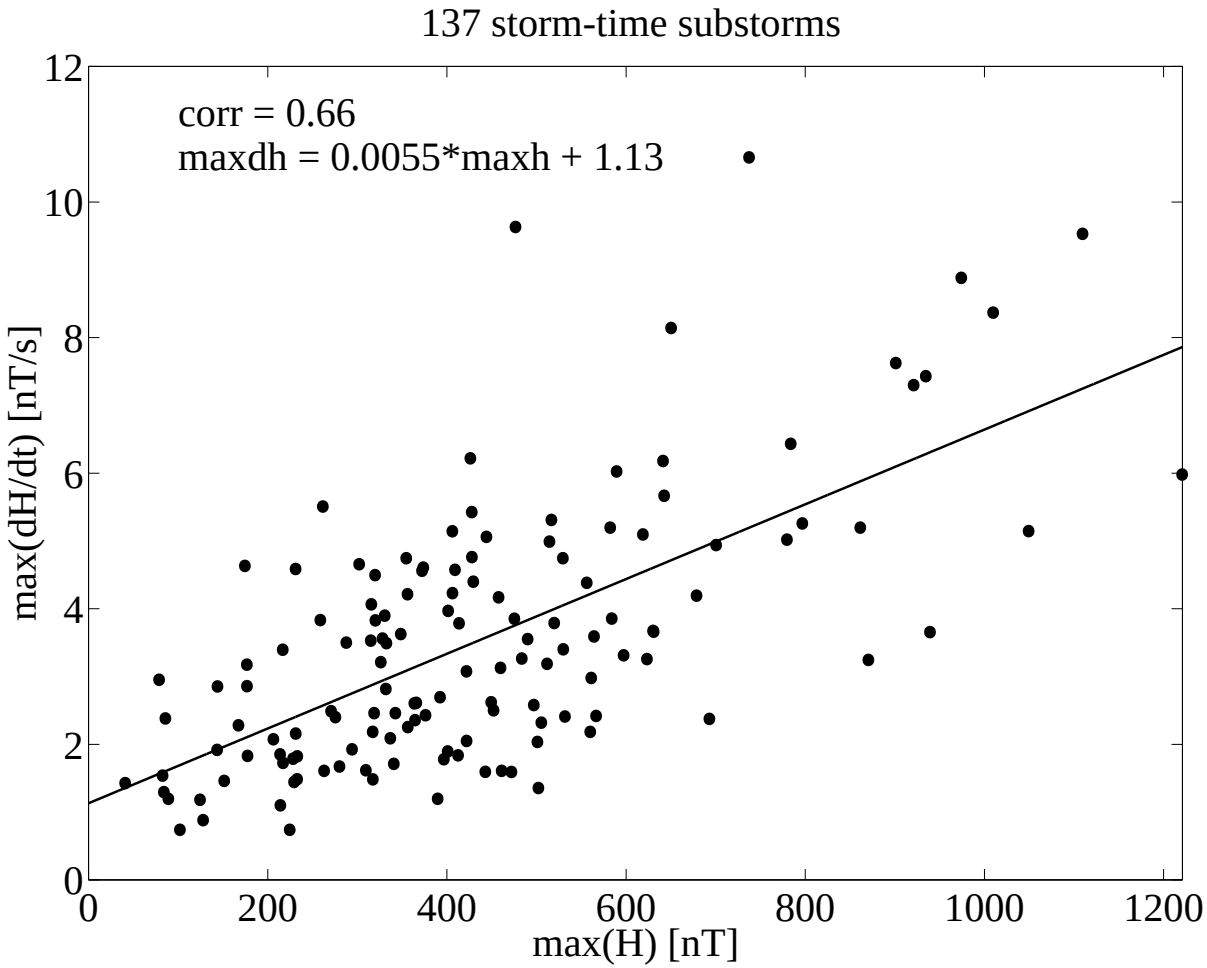

**Number of observations in 1999-2000 of |GIC| > 2.5 A (10 s data) at the Pirttikoski transformer in northern Finland (CGM lat. 63 deg N).**

## *Peak time of large dH/dt is a few minutes after the onset*




**Average eastward equivalent current density after the onset.**
**Dots show the location of the maximum westward current density.**
**There is a rapid intensification and southward transition after the onset.**

## *dH/dt increases as a function of the electrojet amplitude*




**max($|d\mathbf{H}/dt|$) versus $|\mathbf{H}|$ at the maximum times of $|d\mathbf{H}/dt|$.**

***Ionospheric (equivalent) currents look often smooth without any prominent rapid changes in geometry***

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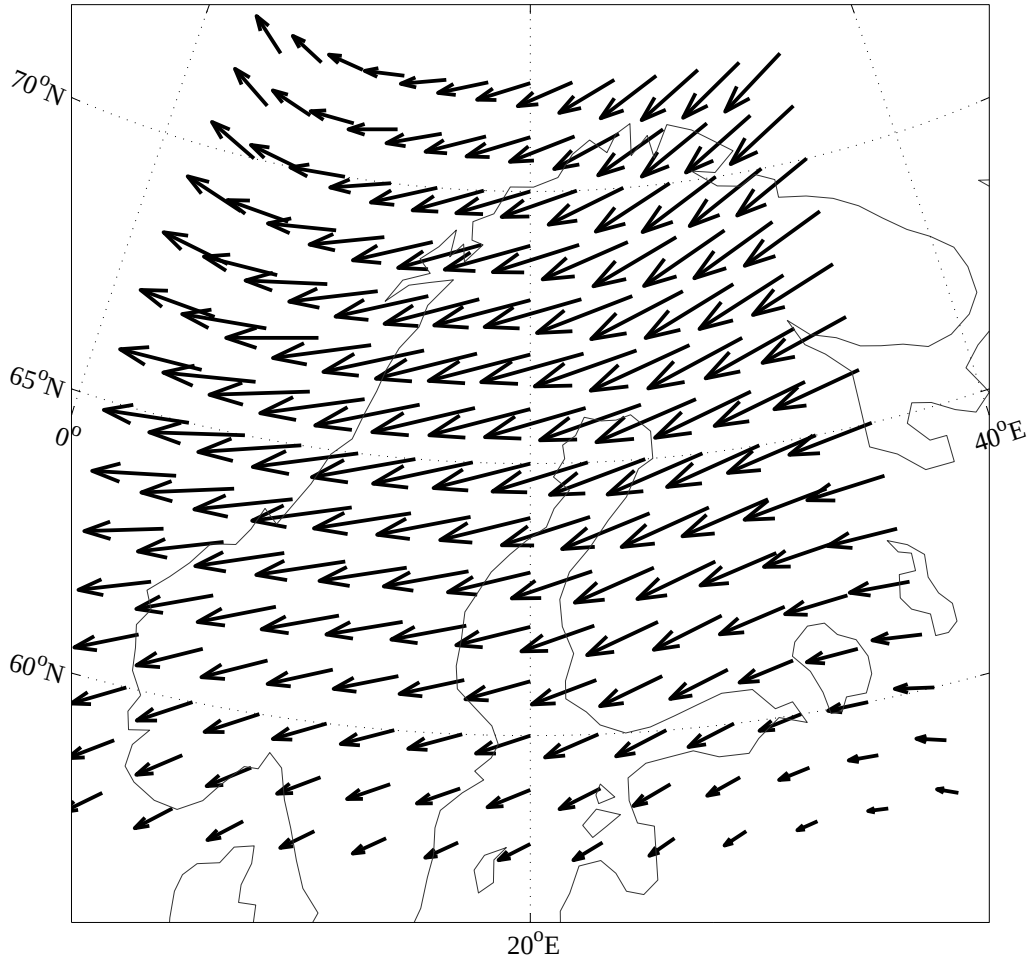
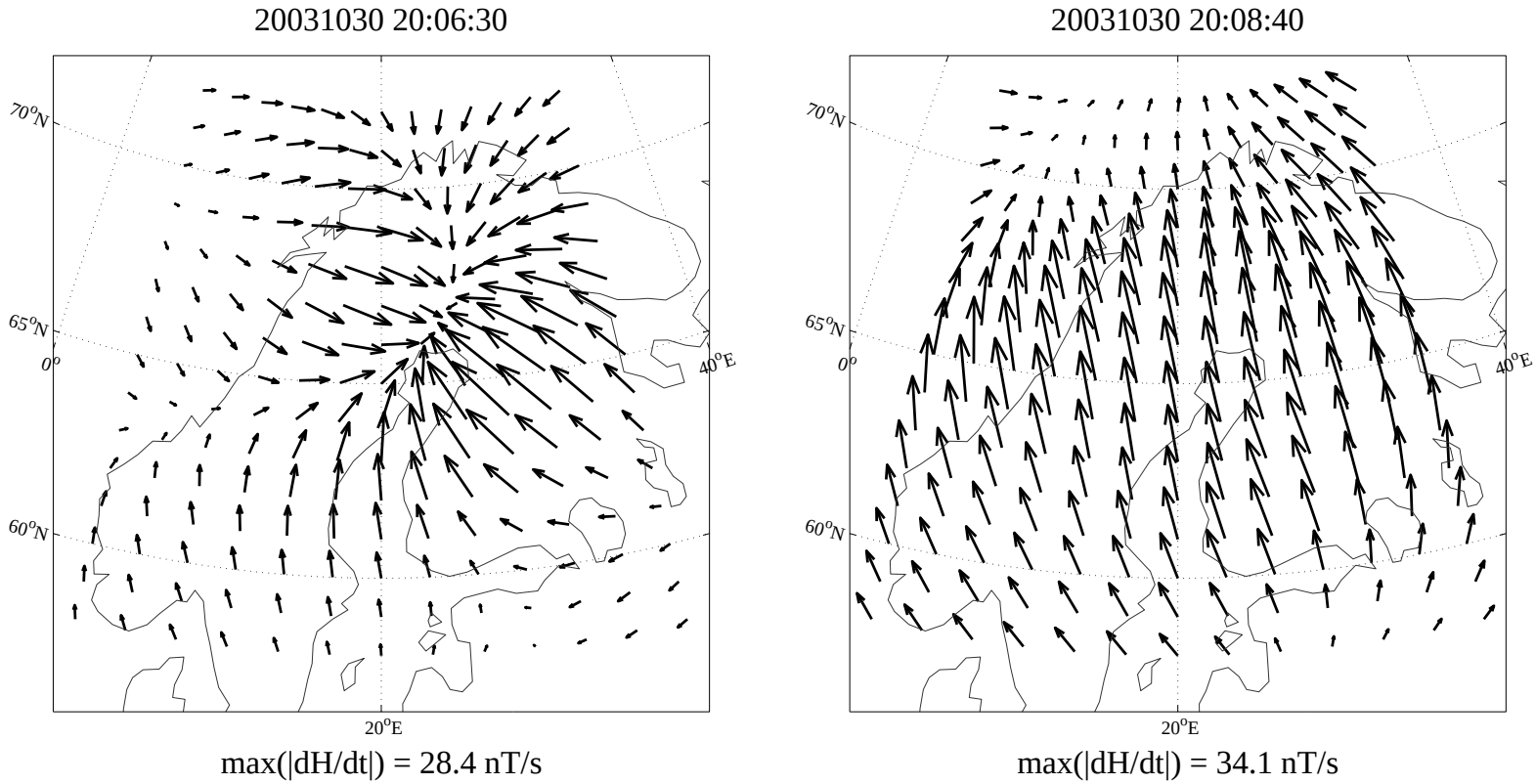



max(|H|) = 3843 nT

## *Two nearby timesteps may have very different* $d\mathbf{H}/dt$*:*




**→ completely different ground electric fields and GIC**

**Note: further complexity due to a nonuniform conductivity of the earth.**

## *Can we predict $d\mathbf{H}/dt$ (or GIC) during substorms?*

- Ionosphere has a short memory of $d\mathbf{H}/dt$ (less than 2 minutes)
- Preference for any particular direction or length scale of $d\mathbf{H}/dt$ decreases during substorms
- It may be impossible to predict $d\mathbf{H}/dt$ in a deterministic way

Pulkkinen et al., 2006: Spatiotemporal scaling properties of the ground geomagnetic field variations. JGR, doi:10.1029/2005JA011294.

However, there is some hope to estimate GIC levels even with quite incomplete knowledge of $d\mathbf{H}/dt$:

Pulkkinen et al., 2006: Estimation of geomagnetically induced current levels from different input data. Space Weather, 4, S08005, doi:10.1029/2006SW000229.

## Conclusions

- A few minutes after the onset is the most probable time of large $d\mathbf{H}/dt$ and GIC during (storm-time) substorms.
- The probability of large $d\mathbf{H}/dt$ increases with increasing $|\mathbf{H}|$. For a given $|\mathbf{H}|$, there seems to be a fairly well-defined lower limit of $\max(|d\mathbf{H}/dt|)$.
- Large $d\mathbf{H}/dt$ can occur due to two very different spatial structures:
  - intensification of the main electrojet $\rightarrow$ smooth $d\mathbf{H}/dt$ pattern
  - small-scale radiply varying structures $\rightarrow$ complicated $d\mathbf{H}/dt$ pattern

**Future work:** study all substorms of a complete sunspot cycle (1996–2006).

**Reference:** Viljanen et al., 2006: Relation between substorm characteristics and rapid temporal variations of the ground magnetic field. Ann. Geophys., SRef-ID: 1432-0576/ag/2006-24-725.