Magnetic environment: science of GIC

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This presentation is a contribution to

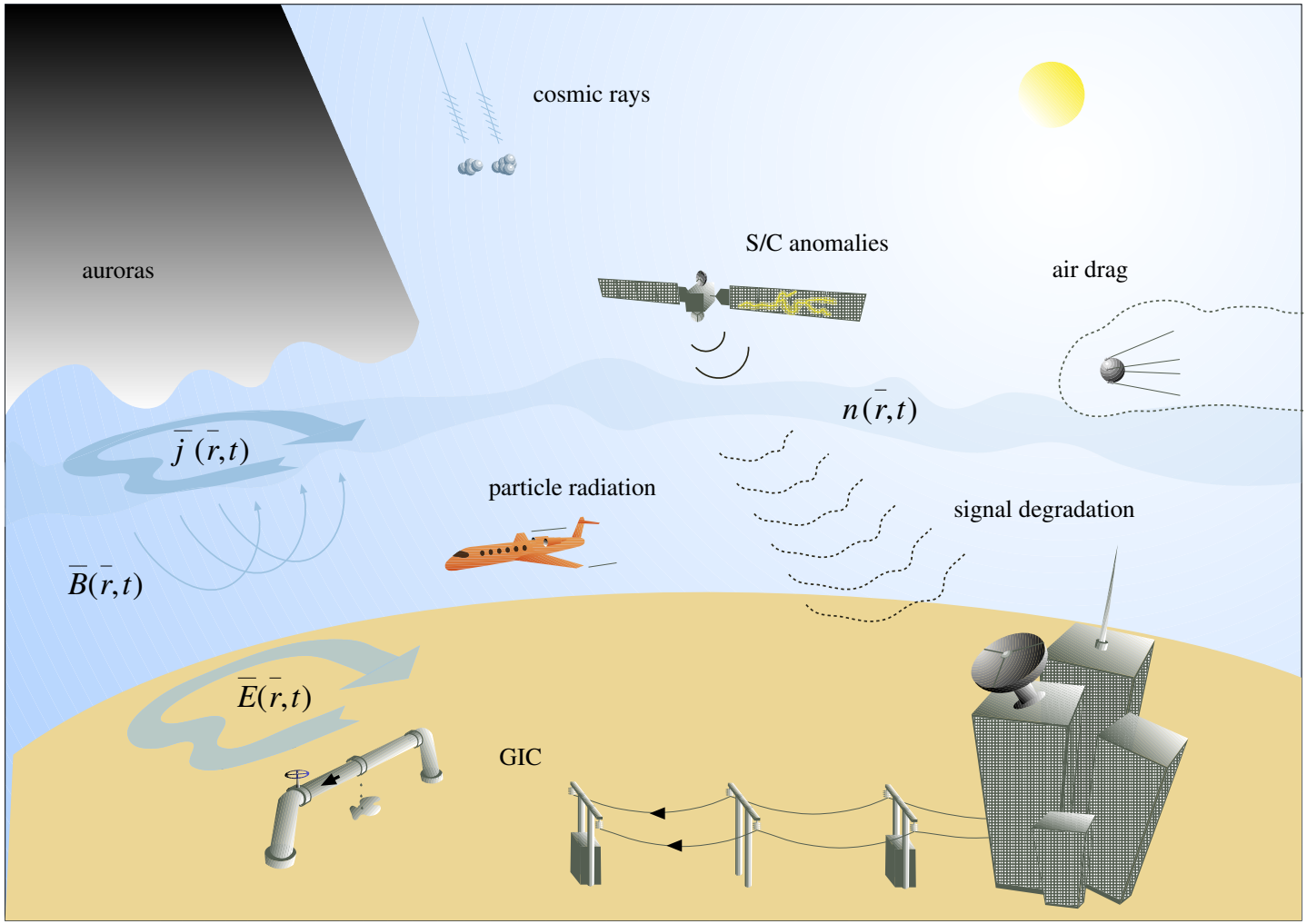
Contents

1) General scientific background

2) Operative calculation & some science

3) On-going and future science

Before the modern "space weather", there was GIC



GIC deals with the inductive coupling between the ionosphere and the earth

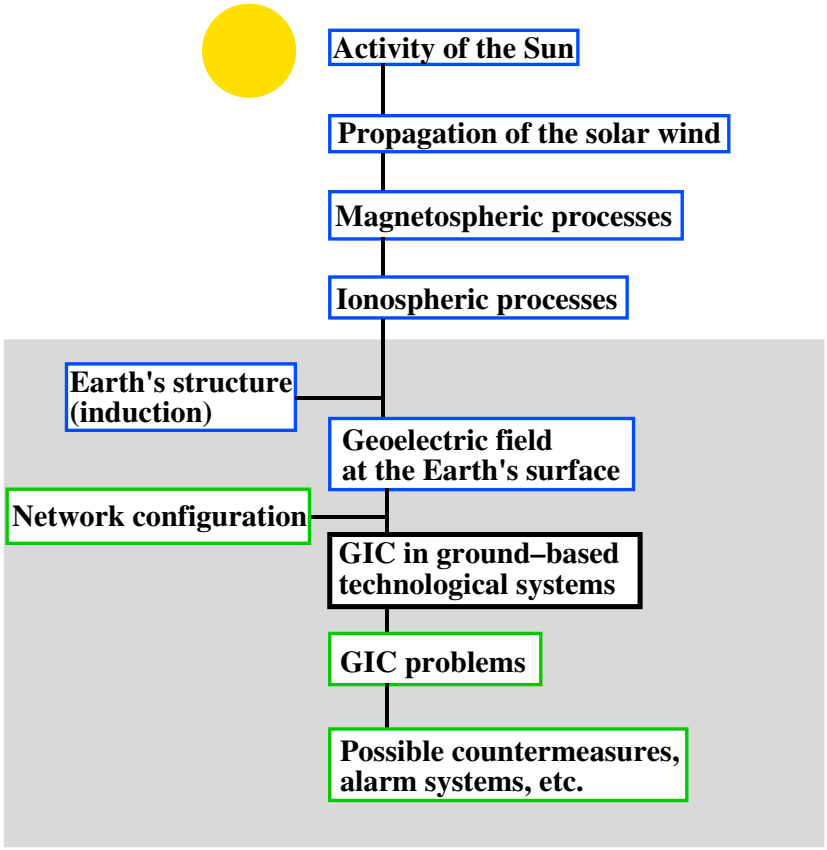


Figure 1: Schematic GIC chain. **"Science blocks" marked by blue.**

1. Modelling of the geoelectric field

- **Ionospheric currents or ground magnetic data**
- **Earth's conductivity**

These results also applicable in magnetotelluric studies.

2. Modelling of GIC

- Discretely grounded systems
- Continuously grounded systems

3. Analysis of GIC effects

GIC and dB/dt are closely related

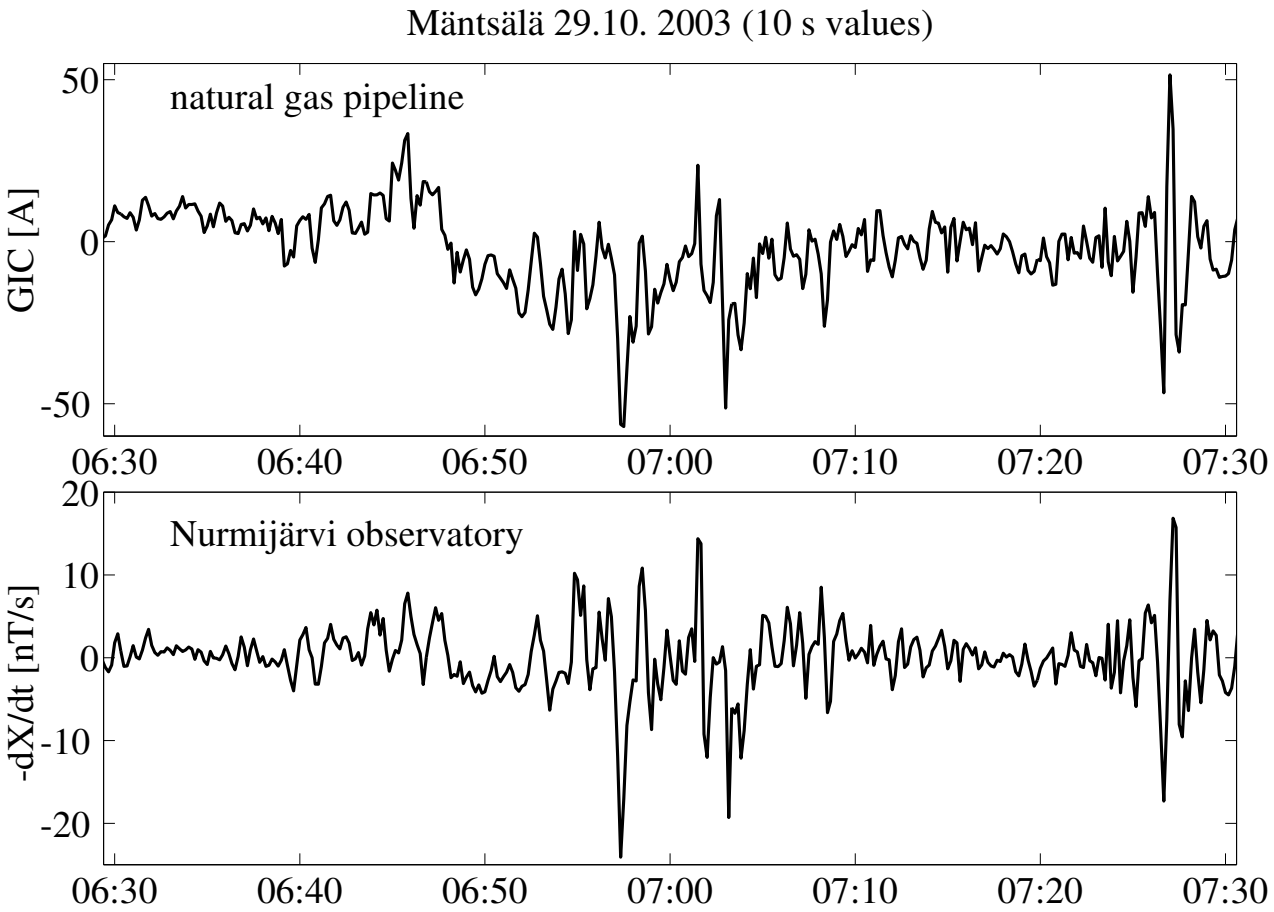


Figure 2: Largest GIC measured in the Finnish natural gas pipeline.

GIC is a manifestation of Faraday's law

Roughly speaking:

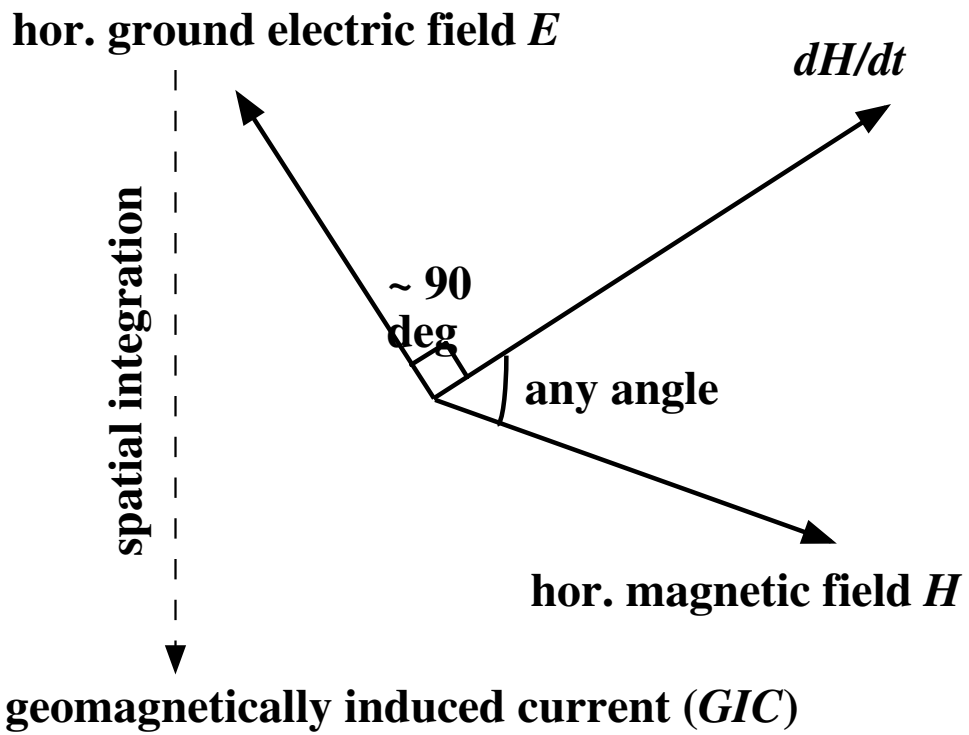


Figure 3: Measured: ground magnetic field variation.
To be determined: **E** and GIC.

Space currents cause the varying magnetic field

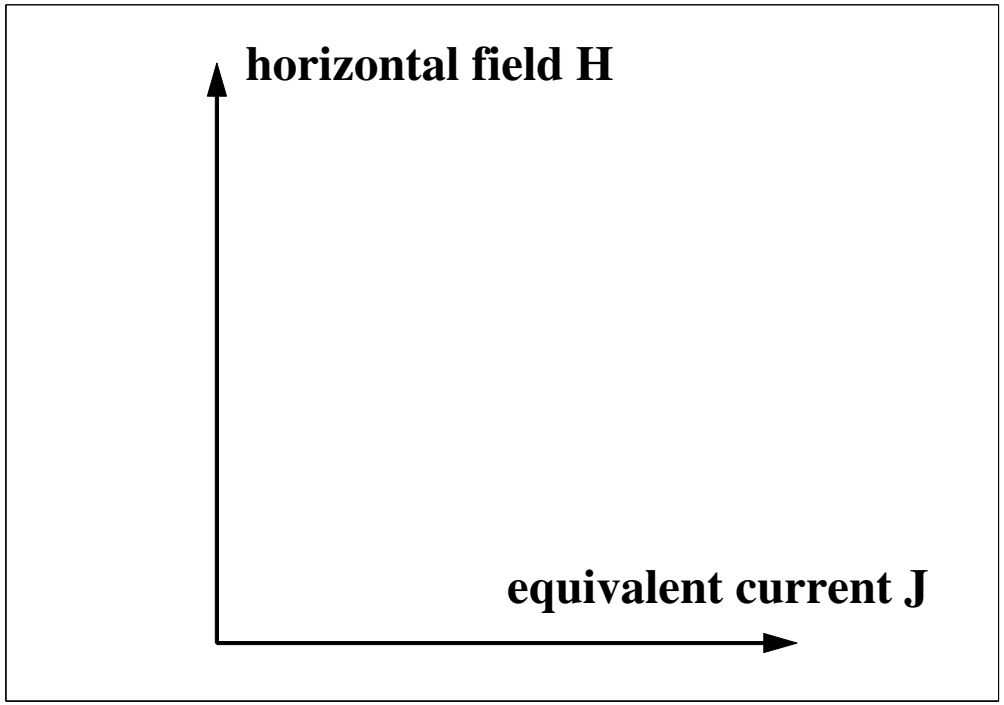


Figure 4: Potential theory states that the ground magnetic variation field can be explained by an equivalent current distribution at the ionospheric plane. Approximately, rotate **H** 90 degrees clockwise.

Ionospheric currents flow all the time

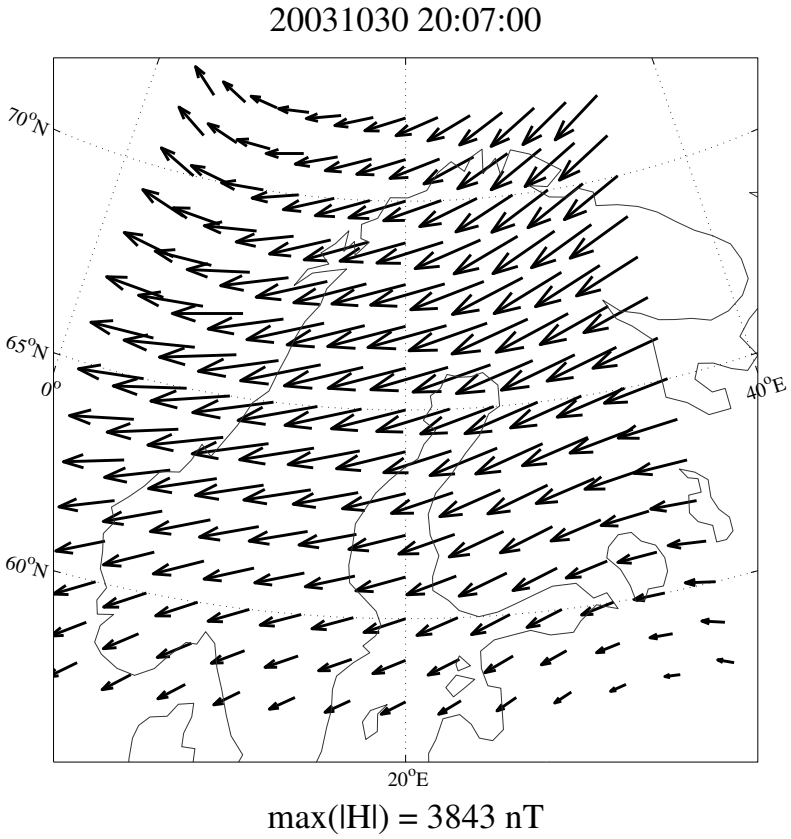
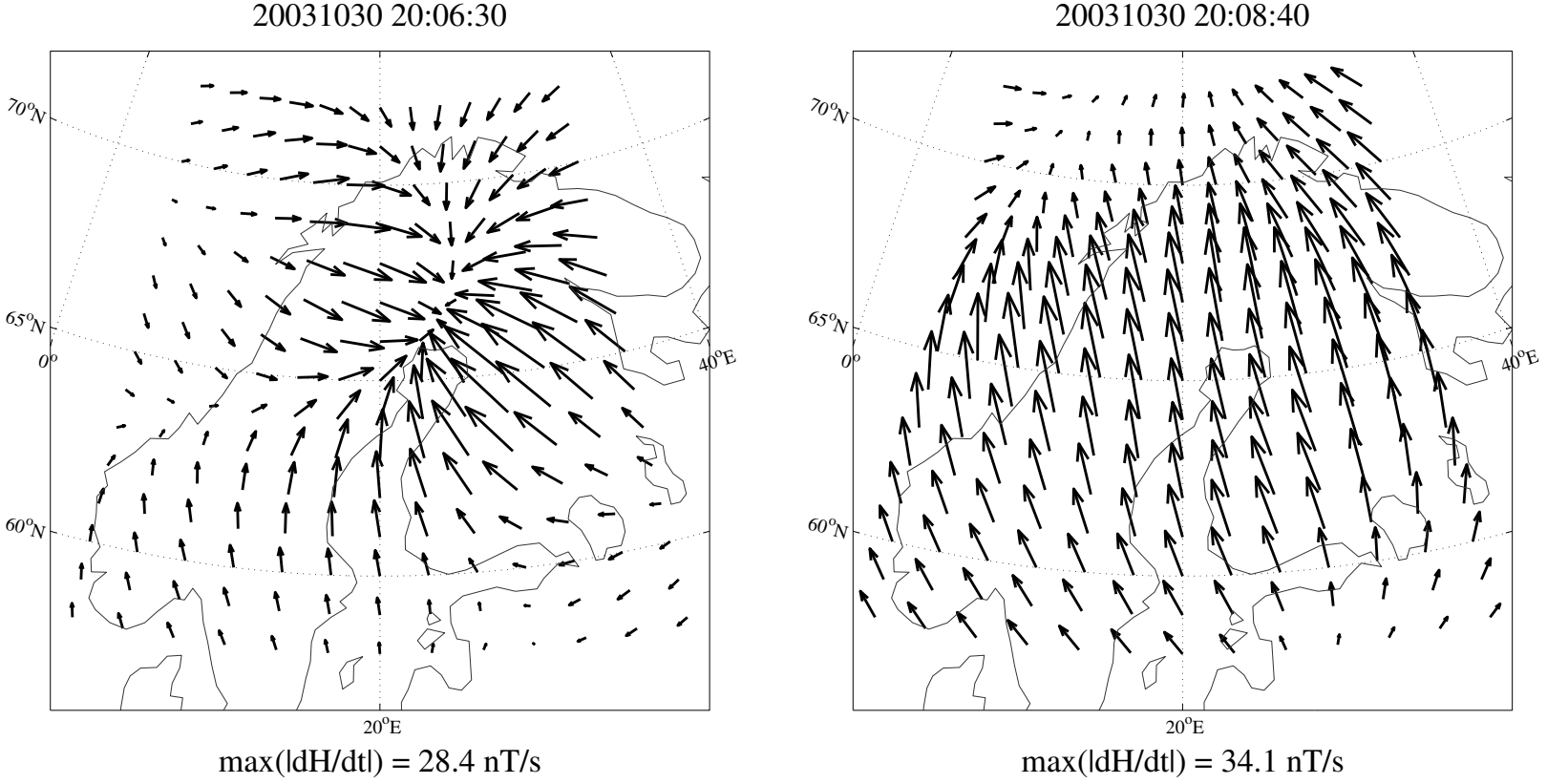


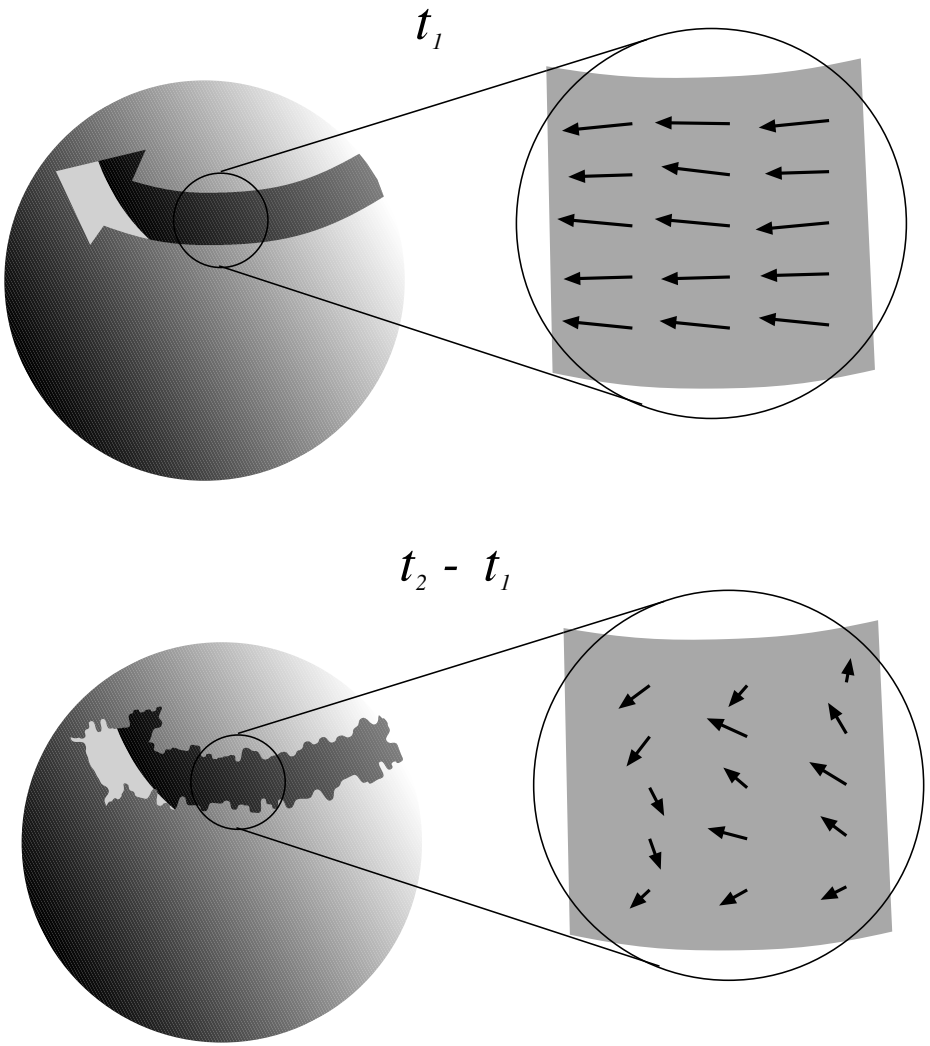
Figure 5: Interpolated and rotated ground **H** at 20:07:00 UT on October 30, 2003, at the time of the GIC blackout in southern Sweden.

Diversity of dB/dt is eye-catching

Two nearby timesteps, nearly identical patterns of ground **H**, but very different $d\mathbf{H}/dt$:



Small scales are important



Arising questions:

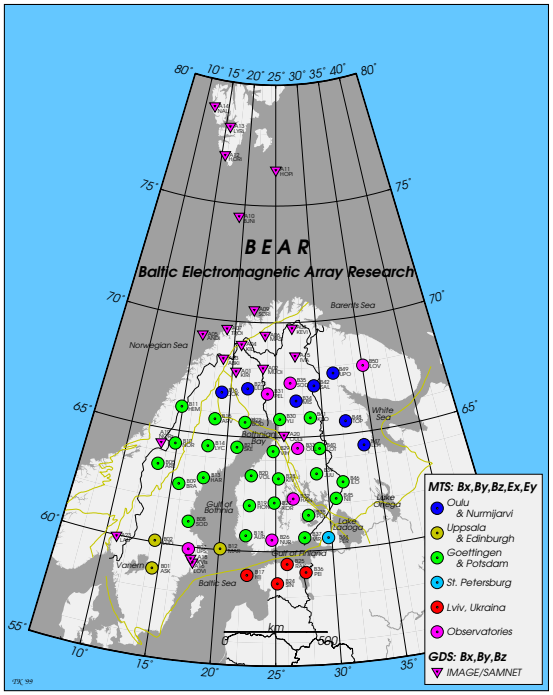
- Which ionospheric events cause large GIC?
  How do these events couple to magnetospheric and solar wind dynamics?
- What are the characteristic spatial and temporal scales related to these events?
  Are there any characteristic scales?
- Can we forecast such events?
  What features of these events can we forecast?

Earth has a remarkable effect on the geoelectric field

Ionospheric currents → primary field $\mathbf{E}_p$

Telluric currents → secondary field $\mathbf{E}_{hor,s} \approx -\mathbf{E}_{hor,p}$

Earth conductivity models are obtained from magnetotelluric studies.



Operative method - ground B

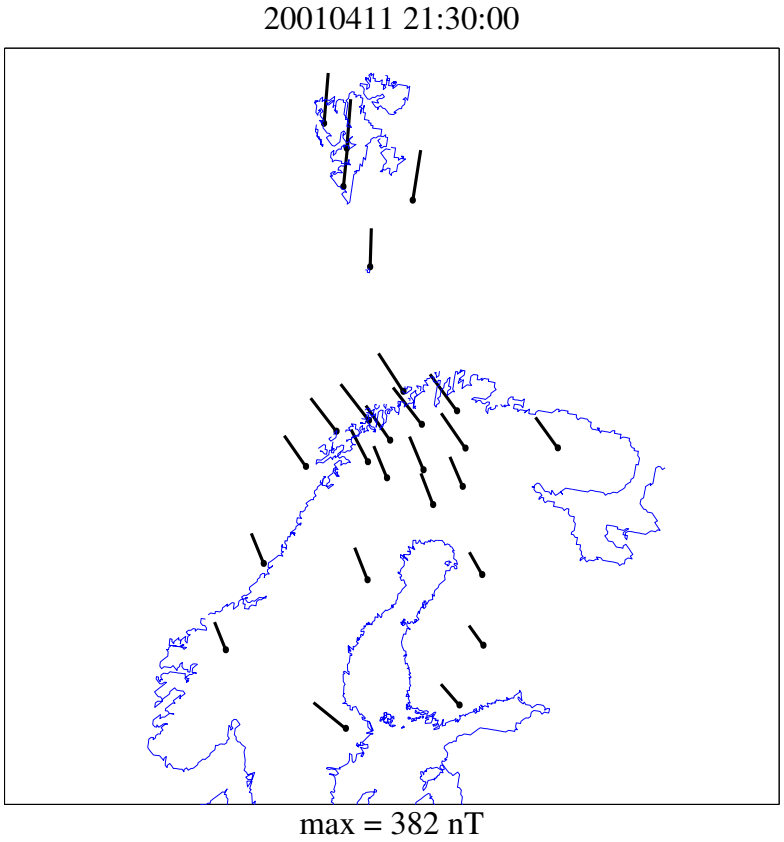


Figure 6: Measured ground horizontal field rotated 90 deg clockwise to mimic ionospheric equivalent currents.

Operative method - interpolated B

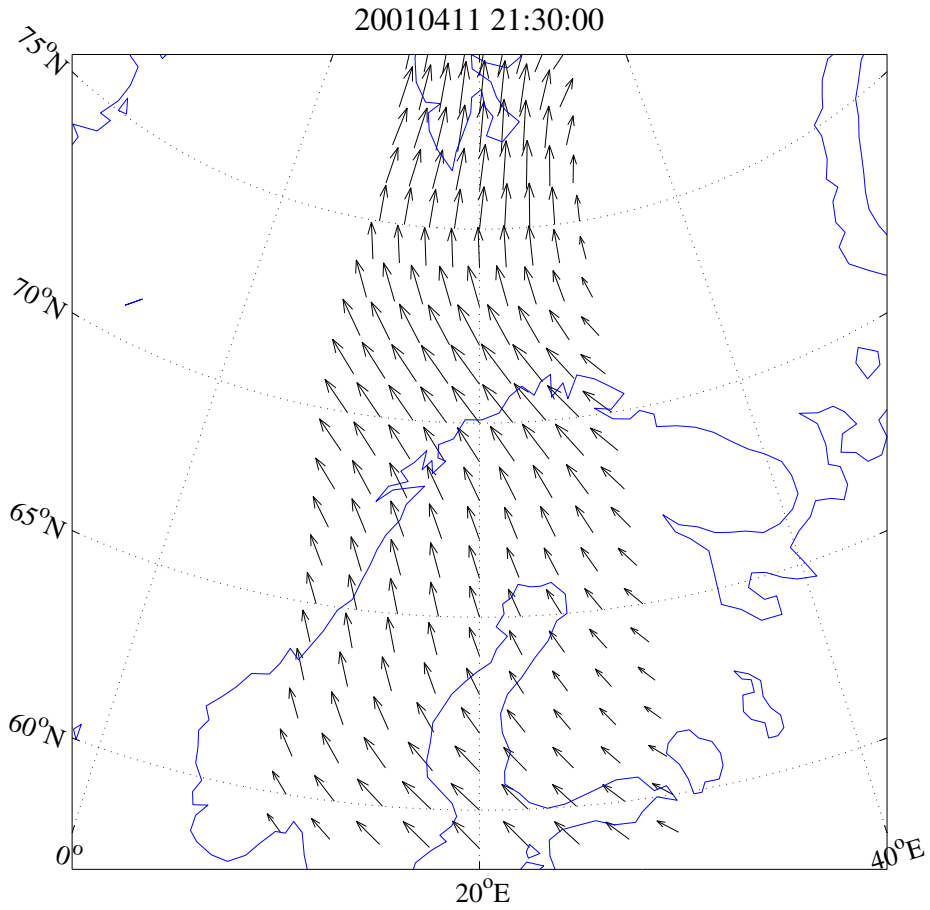


Figure 7: Use of equivalent currents is a robust interpolation method.

Operative method - earth's conductivity

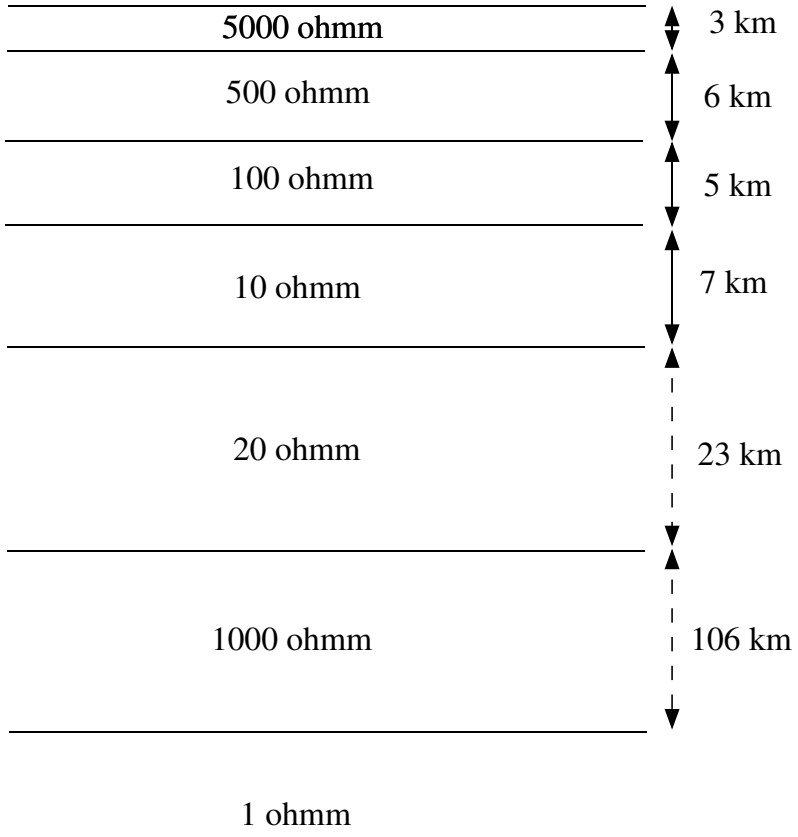


Figure 8: Rough model of southern Finland. The local magnetotelluric relationship $E(\omega) \sim Z(\omega) \cdot B(\omega)$ is the first approximation.

Operative method - geoelectric field

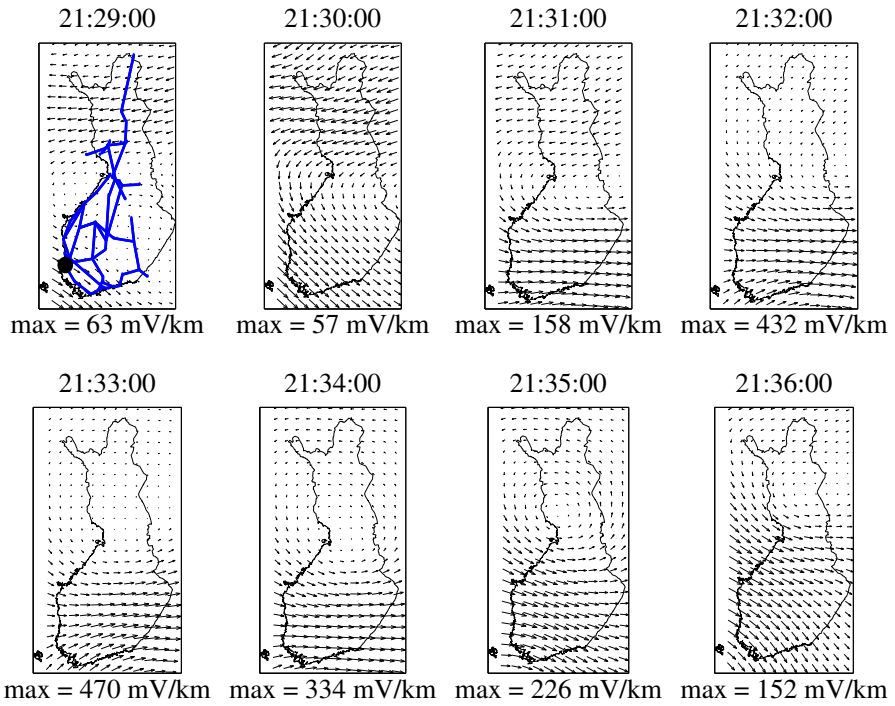
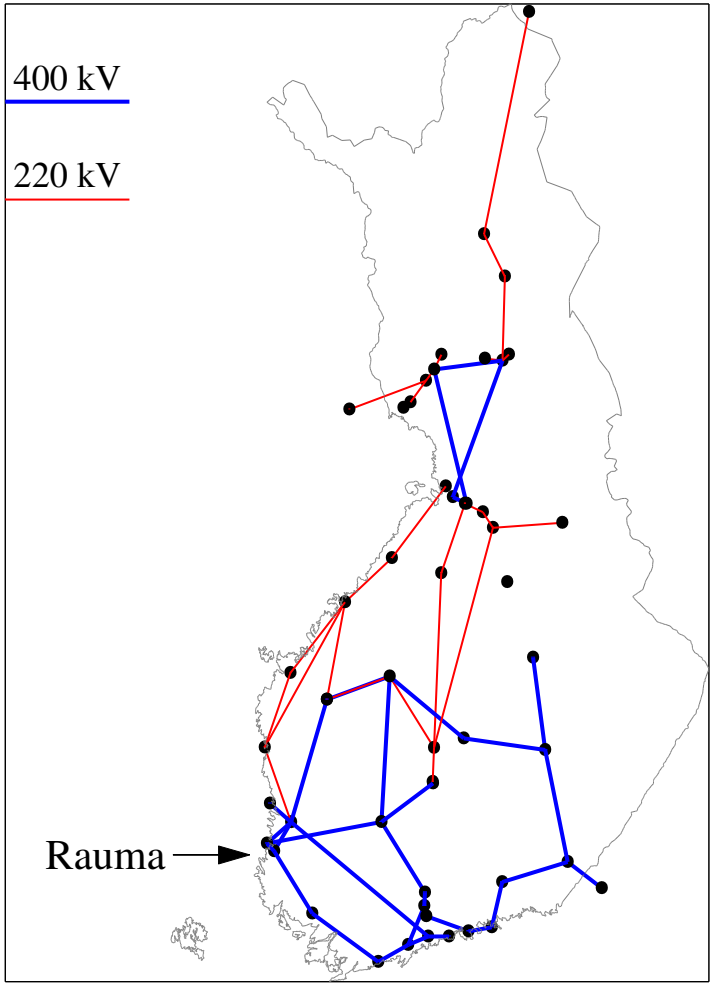


Figure 9: Snapshots of the calculated electric field.

GIC is basically a measure for the electric field *integrated* along the conductors. The conductor system defines the relevant scales.

Operative method - power grid



Operative method - GIC

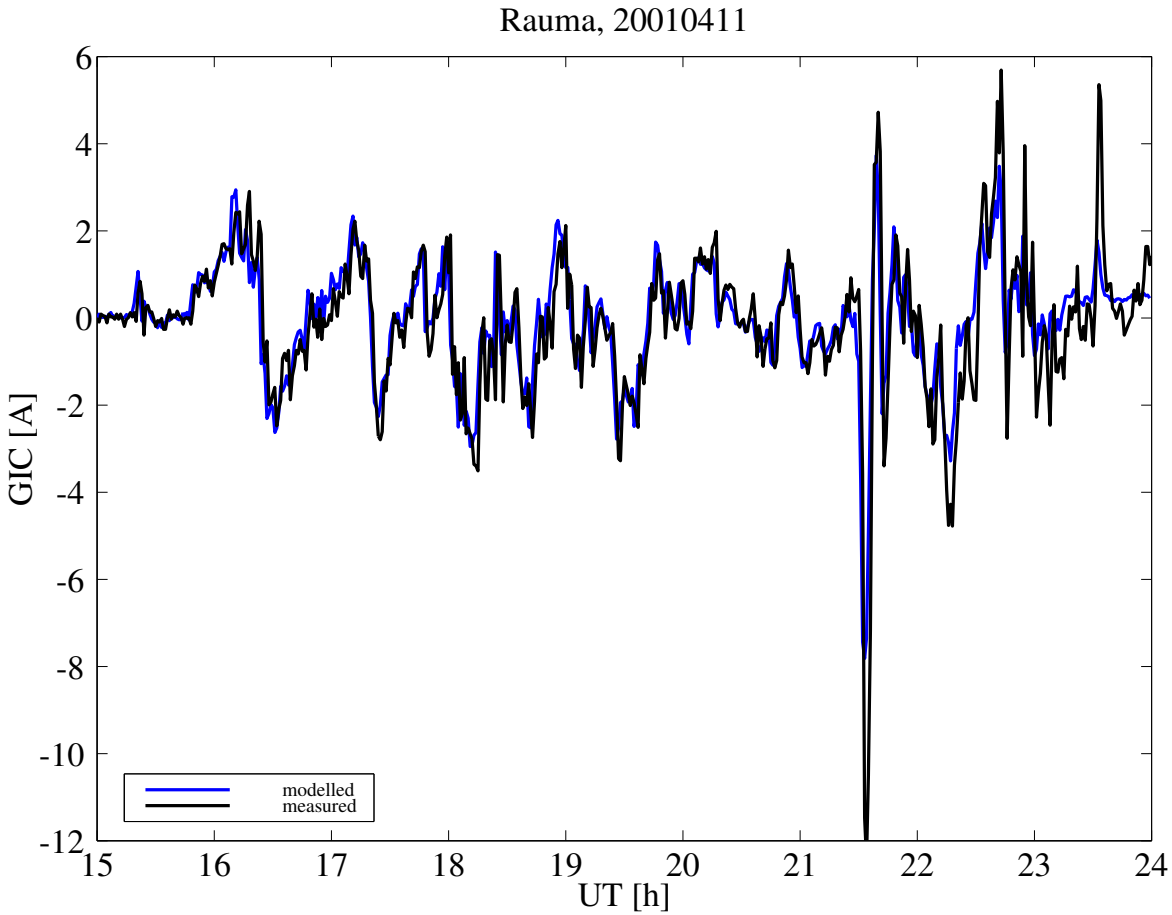
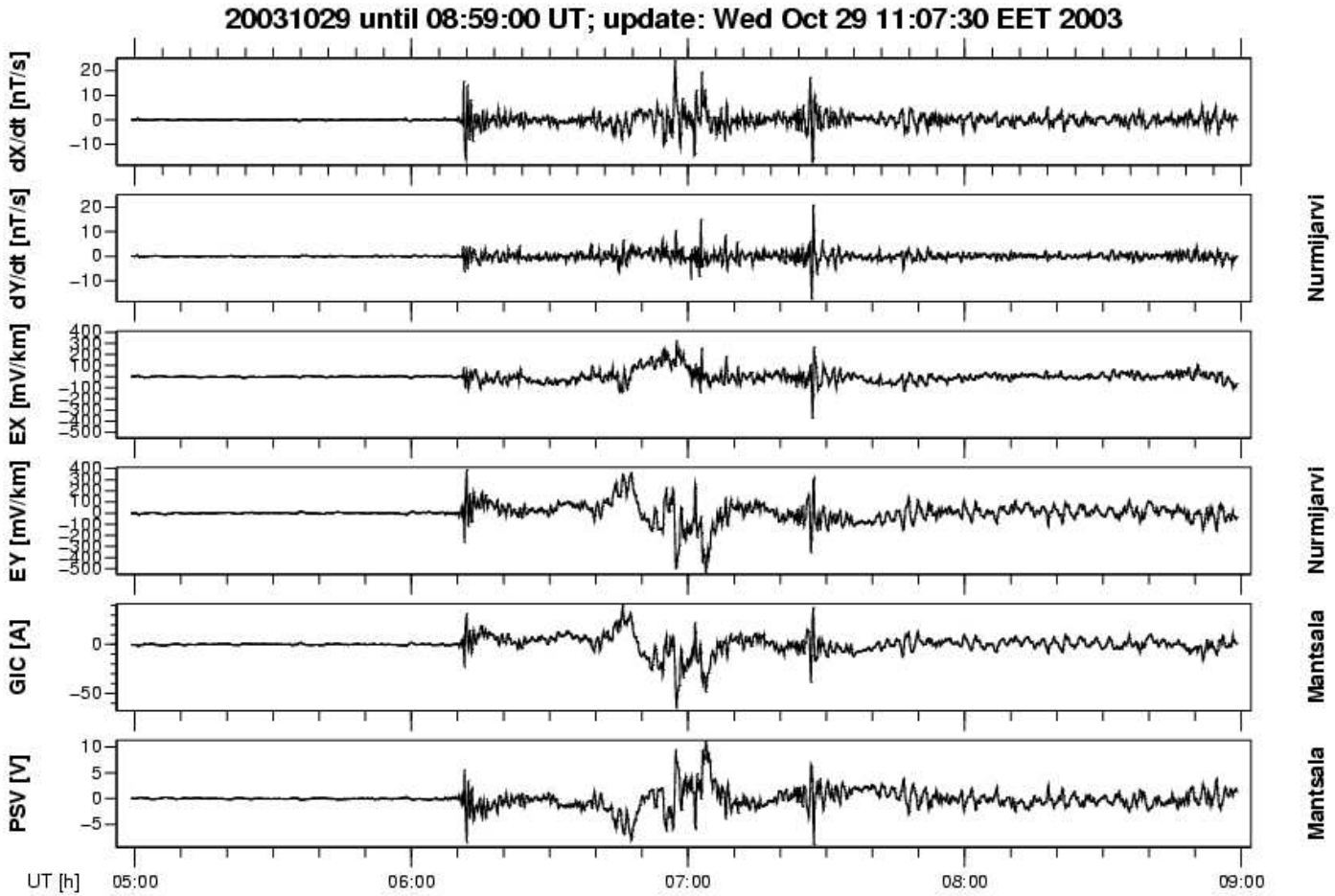


Figure 10: **Measured** and **modelled** transformer neutral GIC.

Operative method - ESA SDA Gasum Now!



Science is progressing

Classify quantitatively ionospheric currents causing large GIC. Apply pattern recognition methods originally used for auroral all-sky images.

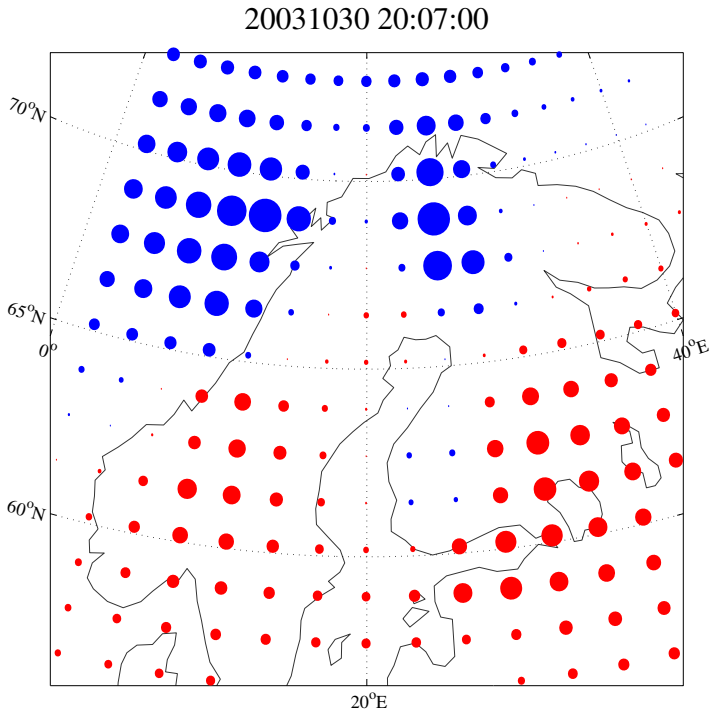


Figure 11: Scalar representation of equivalent currents.

Forecasting GIC is demanding

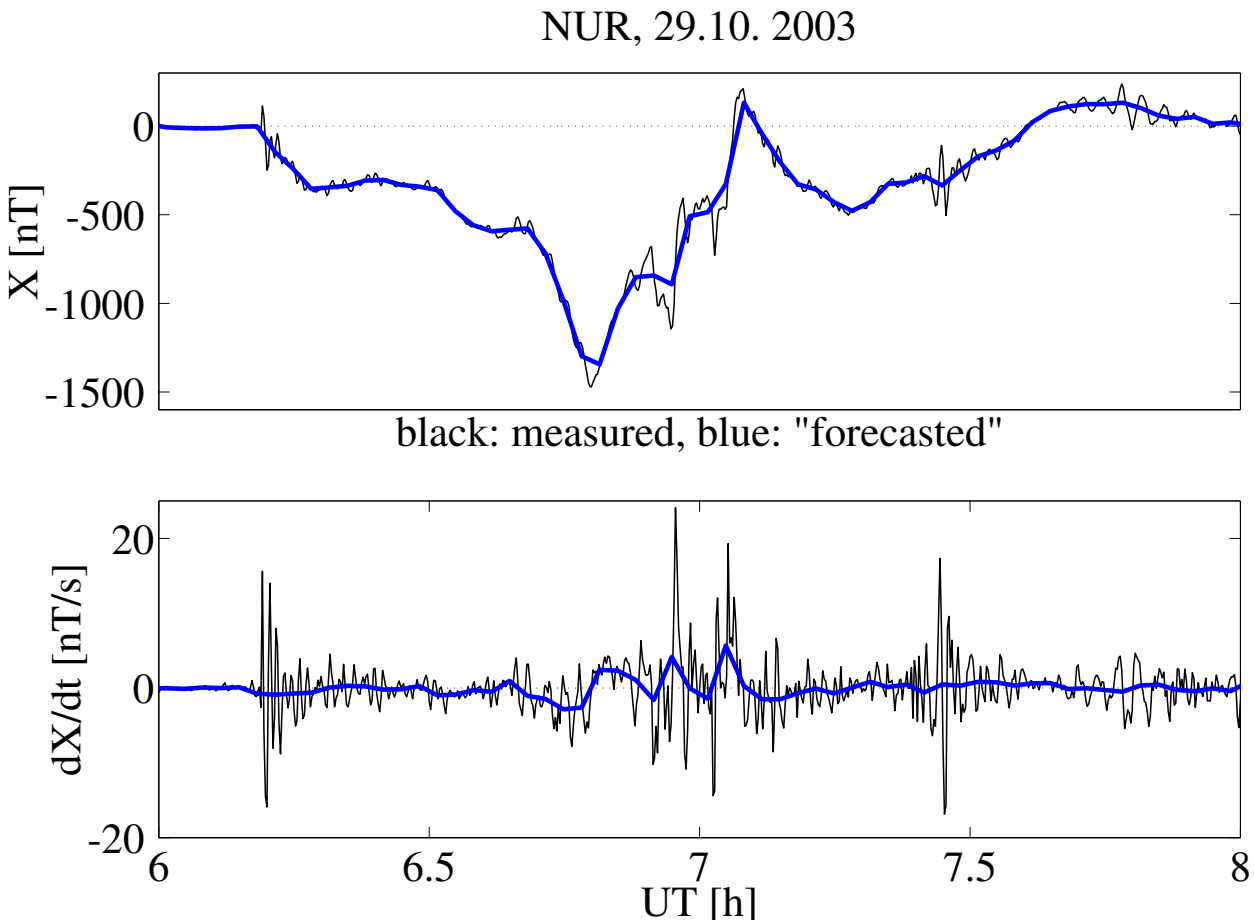


Figure 12: Artificial example: not enough to forecast **B** fairly accurately.

Summarising

- Recordings of the geomagnetic field reveal ionospheric (equivalent) currents
- Solid earth studies reveal the Earth's conductivity structure
- Ionospheric phenomena affecting GIC have highly varying spatial scales, which are determined by $d\mathbf{B}/dt$
- Operative nowcasting of GIC is well established
- Quantitative classification of GIC events is advancing
- Producing reliable GIC forecasts may require completely new ideas
- Producing GIC forecasts as accurately as forecasts for terrestrial weather may be impossible forever

There are many scientific challenges of a general interest

- Investigate the basic nature of spatio-temporal variability of our geomagnetic environment
- Understand how our geomagnetic environment couples to the large scale dynamics of the magnetosphere
- Understand implications of the coupling and apply new knowledge to science of GIC