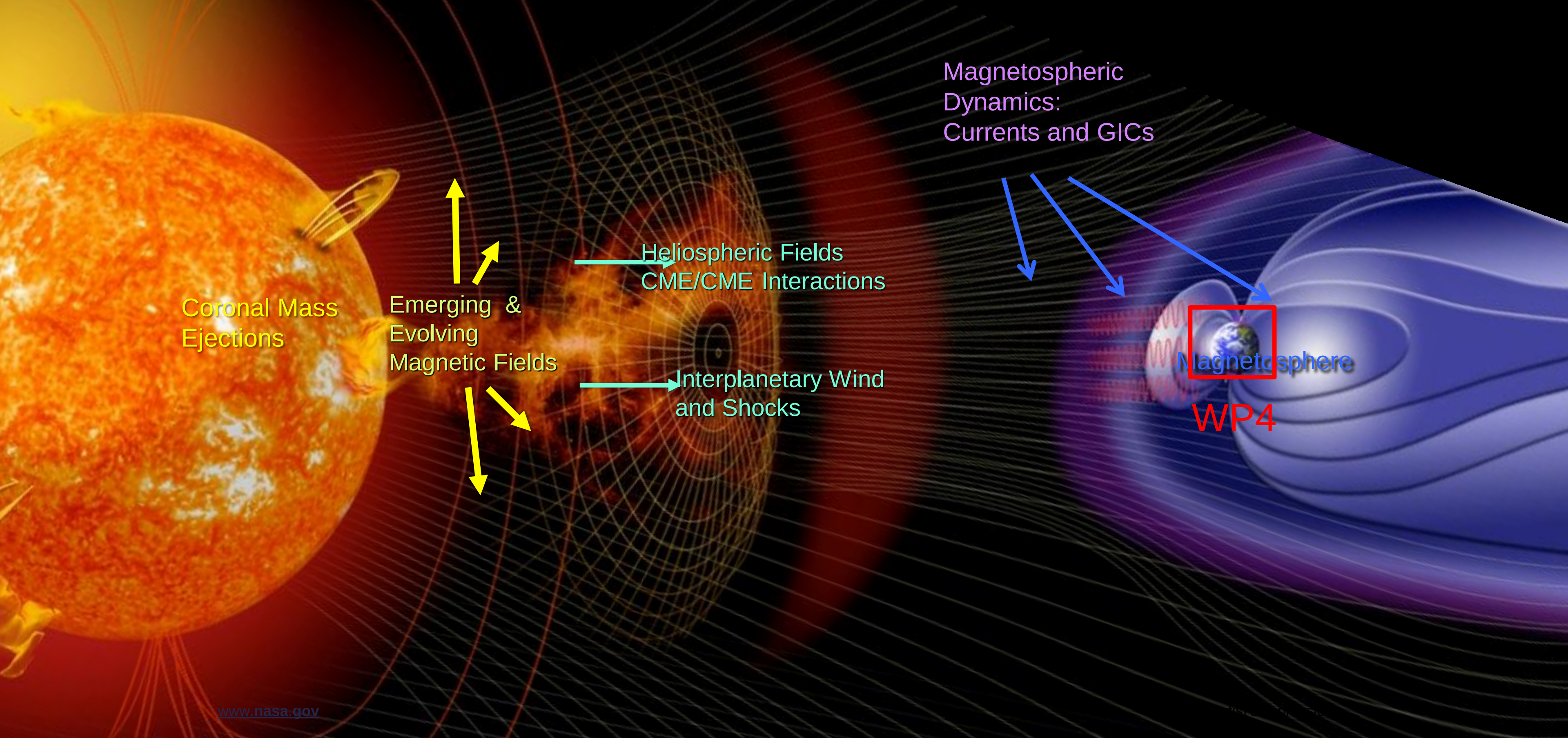
Requirements for GIC predictions in Sweden

Lisa Rosenqvist and Jan-Ove Hall

Uppsala, 2017-11-09

WP4 : Requirements for GIC predictions in Sweden



WP4 Goals

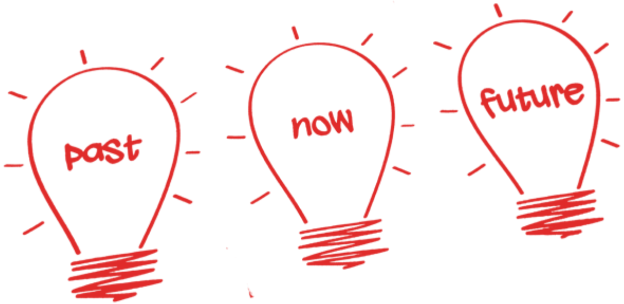
To improve forecasting capability for GIC estimations in Sweden by:

- Identifying the requirements of Swedish end-users, including Swedish power system utilities and the Swedish armed forces, with respect to a warning and forecasting system for geo-electric field disturbances and geomagnetically induced currents (GICs).

- Acting as the link between the scientific community and the end-users to ensure relevant research and validate model development

- Studying the specific conditions in Sweden for GICs driven by extreme space weather

- Analyzing the necessary components needed to tailor a GIC forecasting model for Swedish conditions

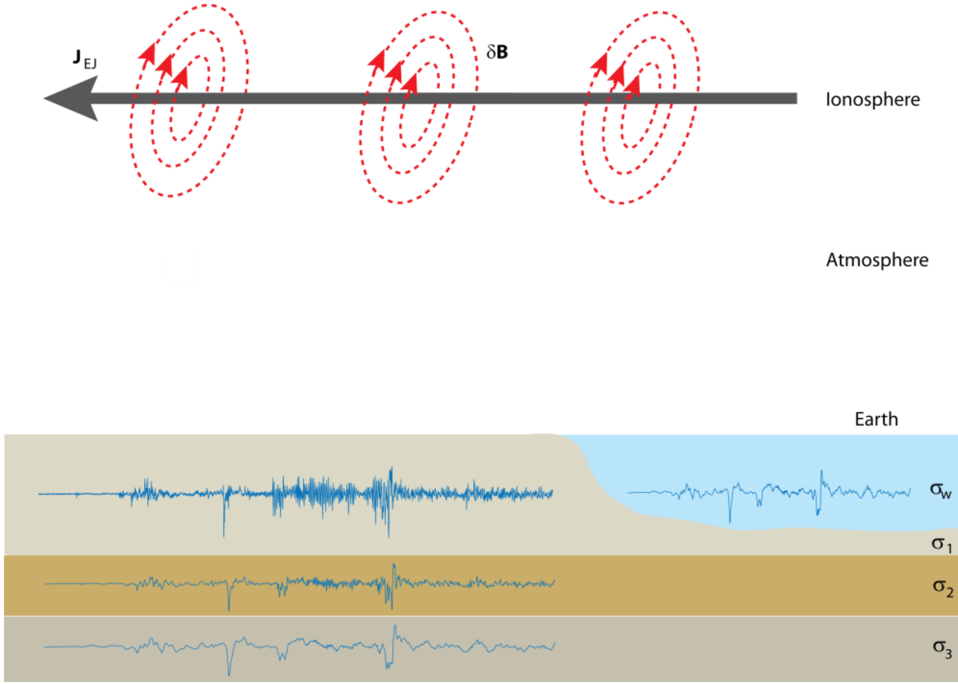


Cause and effects of GICs

Cause

- Solar activity give rise to geomagnetic activity in Earth magnetosphere (geomagnetic storms, substorms etc.)
- Currents in the ionosphere induce a time varying magnetic field
- The magnetic field interacts with conductive Earth and telluric currents arise
- Electric fields are induced in the ground

$$\left.\begin{aligned} \nabla \times \boldsymbol{E} &= -\frac{\partial \boldsymbol{B}}{\partial t} \\ \boldsymbol{J} &= \sigma \boldsymbol{E} \\ \nabla \times \boldsymbol{H} &= \boldsymbol{J} \end{aligned}\right\} \quad \boldsymbol{E} = \boldsymbol{ZH}$$

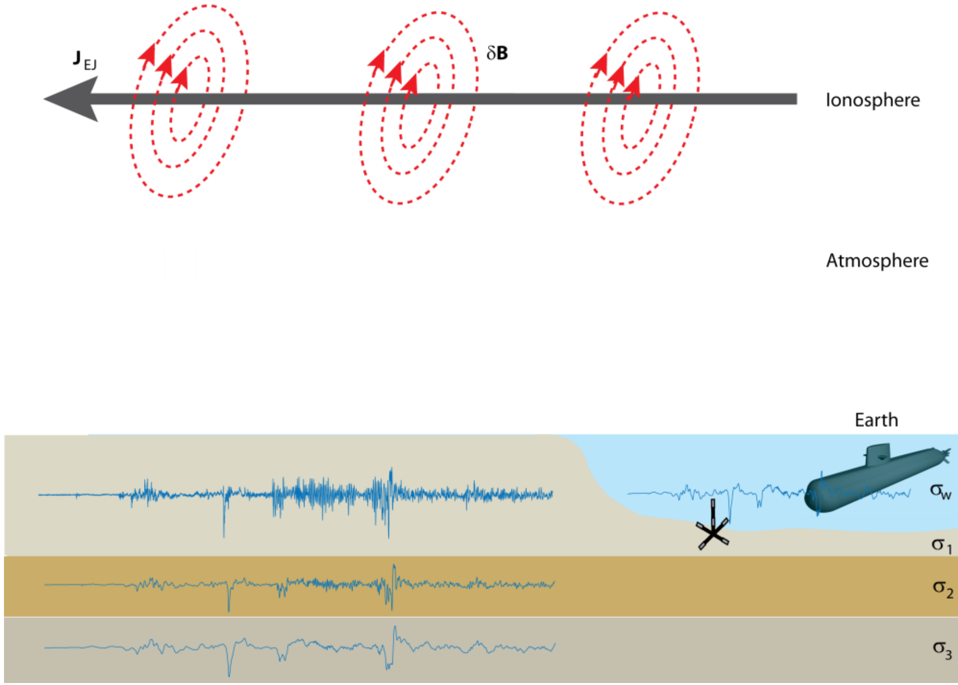


- Magnetotellurics (MT) to determine $Z(\sigma_W, \sigma_1, \sigma_2, \sigma_3 \ldots)$

Cause and effects of GICs

Effects

- Characteristics of the background electromagnetic noise important for detection of anomalous fields in electromagnetic sensors (mines, surveillance systems etc.)

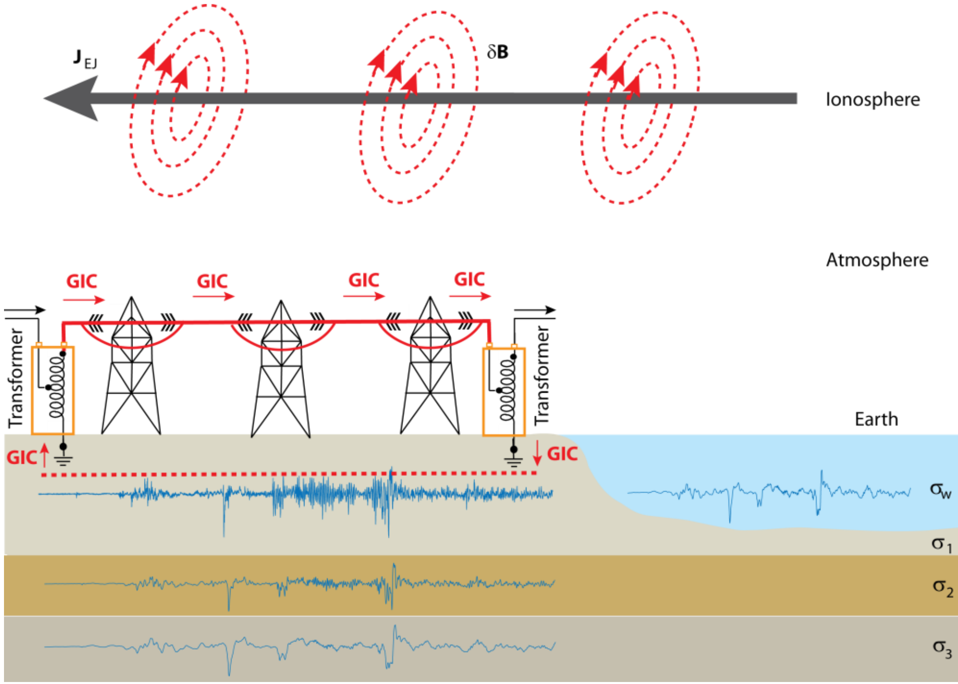


Cause and effects of GICs

Effects

- GIC arise in long conductors on Earth such as pipelines and power lines

- Can affect the power system as GIC pass through the coils of the transformer and into the transmission lines
    - Core saturation, may lead to breaker trip.
    - Voltage dropout
    - Heating of transformer parts



Cause and effects of GICs

Effects

- GIC arise in long conductors on Earth such as pipelines and power lines
- Can affect the power system as GIC pass through the coils of the transformer and into the tranmission lines
  - Core saturation, may lead to breaker trip.
  - Voltage dropout
  - Heating of transformer parts
- Quebec mars 1989 6 miljon people without power for nine hours (permanent transformer in figure)
- Power dropout in 2003 Malmö

FOI

Threat and protection

To what degree a storm affects the power system depends on different factors from two main groups:

- The strength and distribution of the geoelectric field
  - Strength and orientation of the magnetic variations (WP3)
  - Geomagnetic latitude (WP3)
  - Local geology, ground conductivity and proximity to coasts (WP4)
- Electrical system design
  - Orientation, resistance and length of transmission lines (NS, EW)
  - Design of the electrical system and its components

Protection

- Blocking of GIC, operator regulations, preparations and increased robustness, resistant transformers etc.
- Reliable forecasting systems for GICs

Threat and protection

To what degree a storm affects the power system depends on different factors from two main groups:

- The strength and distribution of the geoelectric field
  - Strength and orientation of the magnetic variations (WP3)
  - Geomagnetic latitude (WP3)
  - Local geology, ground conductivity and proximity to coasts (WP4)

Boundary between scientific community and power industry

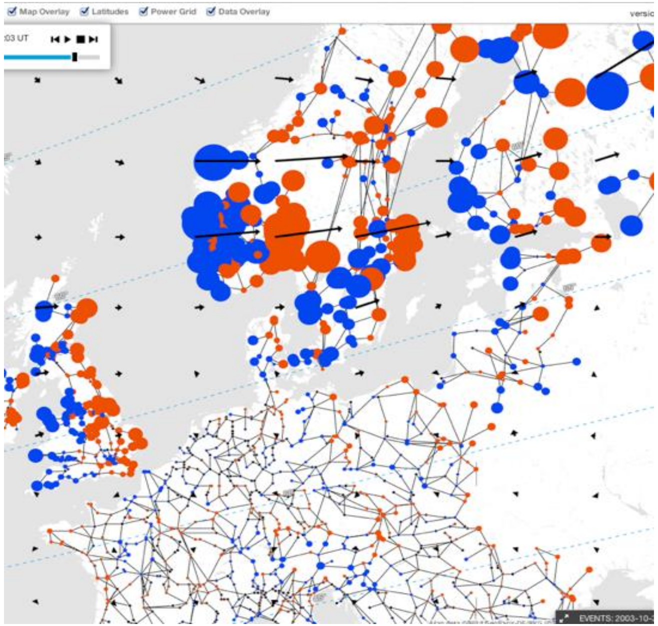
- Electrical system design
  - Orientation, resistance and length of transmission lines (NS, EW)
  - Design of the electrical system and its components

Protection

- Blocking of GIC, operator regulations, preparations and increased robustness, resistant transformers etc.
- Reliable forecasting systems for GICs

Swedish grid vulnerability

- The Swedish power system is robust and mostly unaffected for most geomagnetic disturbances. Only for severe or extreme levels of geomagenetic activity that occur ~ 1-2 times per decade (SvK, 2011) there may be a hazard for the power system performance
- The risk is largest in southern Sweden (Svk, 2001 in cooperation with Vattenfall, OKG) due to lower ground conductivity.
- GIC related problems in coastal areas, Oskarshamn and Malmö are affected by solar storms (SvK, 2011).
- The power system in southern Sweden is more vulnarable for extreme space weather (JRC, 2015) based on observations.
- The cause can be EITHER geology AND/OR power system design

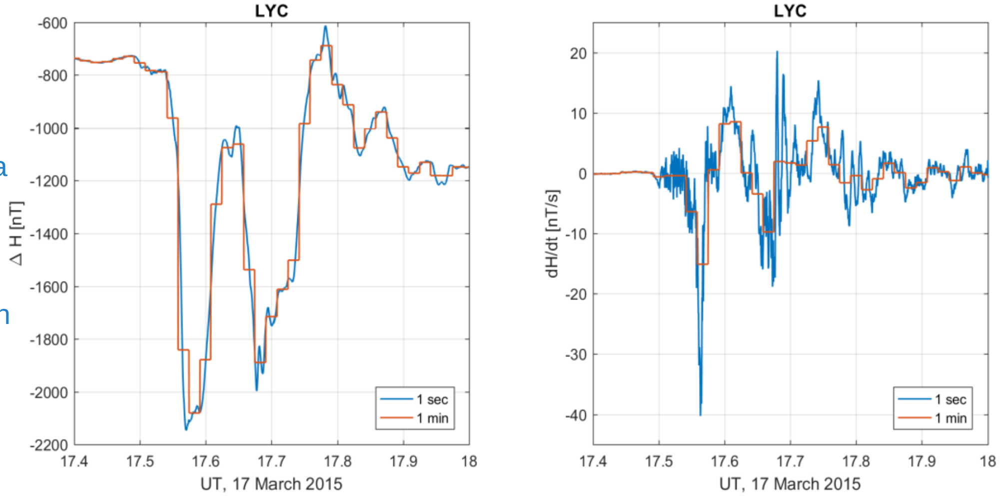


Electric field (arrows) and GIC connecting ground and grid (circles; blue and red for opposite directions), for the 2003/10/30 Halloween storm a few minutes before the failure in power delivery in Southern Sweden (Malmö). Courtesy Ari Viljanen, FMI.

What do we need?

Necessary components identified for GIC modelling

- Geomagnetic sampling rate and spatial coverage important (WP3)
  - Underestimation by > 200 nT from 1 min to 1 sec data (about 20 %) and dB/st by 25 nT/s (about 200 %)
  - Magnetic disturbances can be highly localized [Pulkkinen et al., 2016, Nqwira et. al., 2015]
  - Need for denser net of geomagnetic observations with higher resolution
- Earth conductivity model large source of error (WP4)
  - Differences between models up to an order of magnitude [Trichtchenko, 2016]
  - Uncertainties of models even larger (up to ~3 orders) [Trichtchenko, 2016]
  - Assumption of 1D conductivity structure inaccurate in regions of large lateral conductivity contrast [e.g. Puthe and Kuvshinov, 2013; Torta et al.,, 2017]

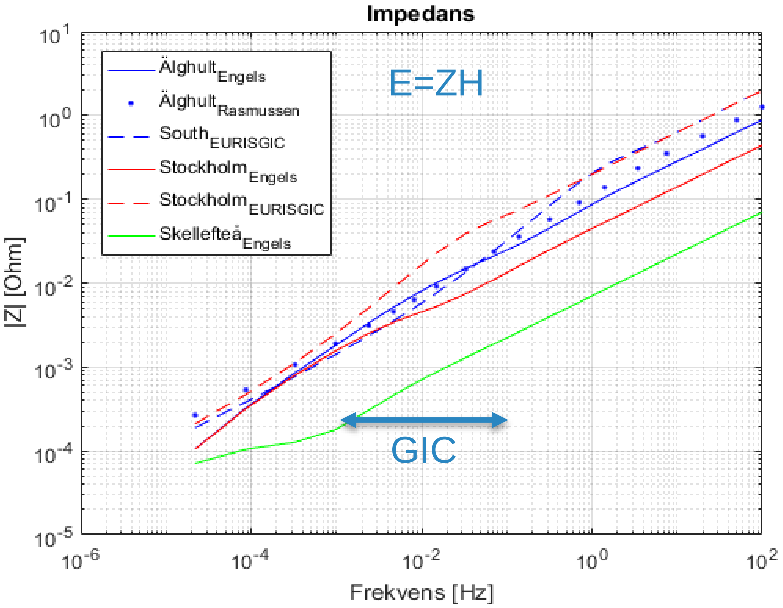


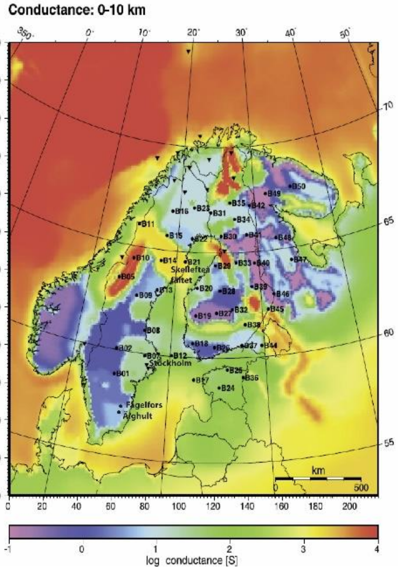
Comparison of the difference in the magnetic disturbances between one minute and one second data during the St. Patrick's storm on March 17, 2015. (credits: Nils Olsson, DTU, figure taken from an application by Opgenoorth et al. to ESA –SSA, April 2017)

What do we have?

Ground properties in Sweden

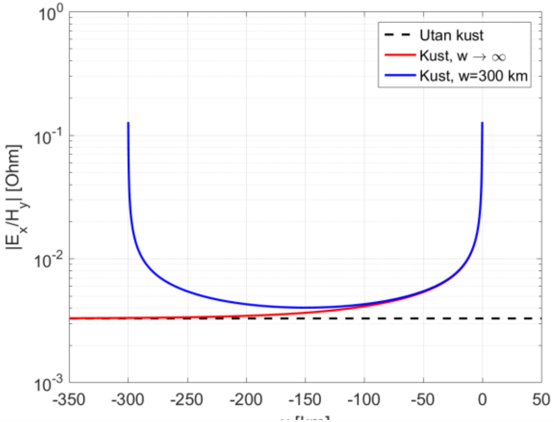
- Large variations in the country
    - From 0.1 till 0.0001 S/m
- Large differences between models
- Many earlier studies assume 1D conductivity structure
- Large lateral conductivity contrast in Sweden
    - Coasts on both sides
    - Local variability high

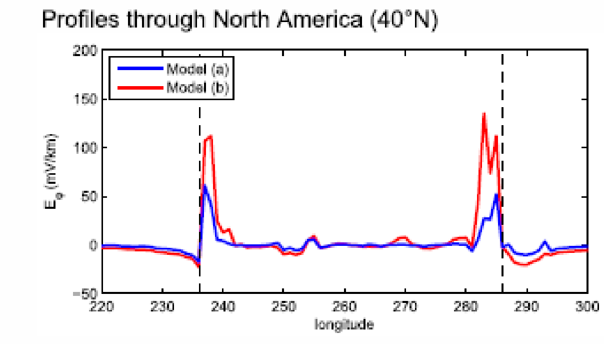




Coastal effect

- Simplified model of the coast effect in Sweden has been investigated
    - N/S incident magnetic field, E/W electric field
    - Two coast (300 km wide) corresponding to southern Sweden
    - 100 m water depth
    - Ground conductivity based on earlier MT measurements
- More than 10 times stronger geoelectric field close to the coasts
- Strength doubled 60 km from the coast
- Corresponds to a factor two amplifications of the current strength for an E/W conductor
- Results in agreement with 3D modelling results for North America [Puthe and Kuvshinov, 2013]





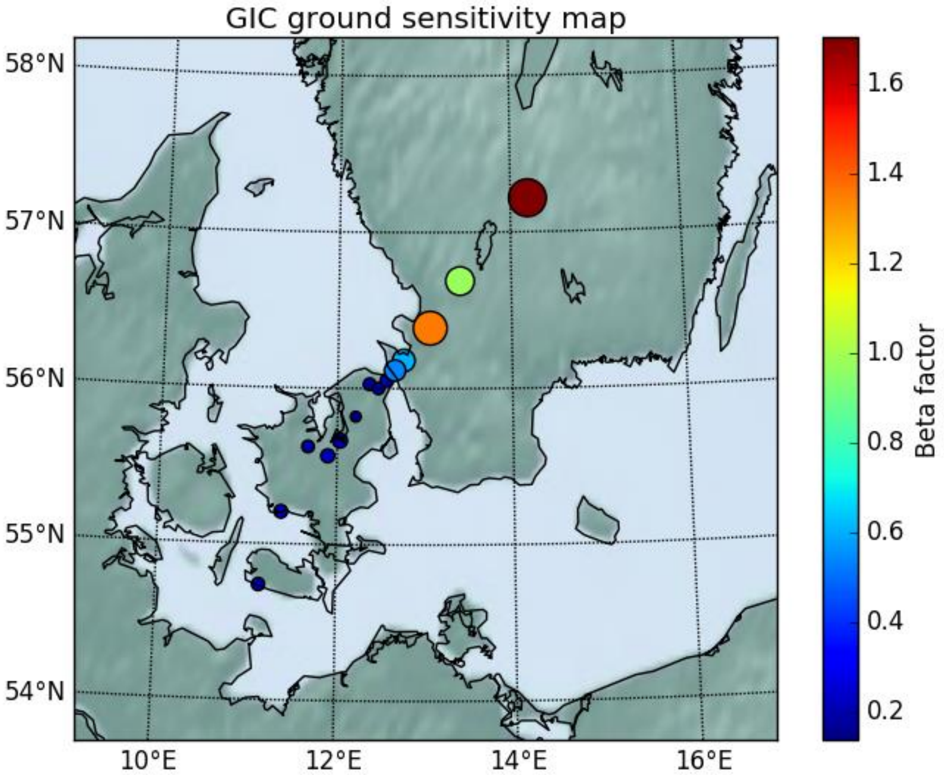
Geoelectric hazard map – local variablity

- NERC[1] Benchmark GMD Event – defined event for assessing system performance during low probability, high magnitude geomagnetic event
- Based on the March 1989 geomagnetic event that caused the Quebec blackout
- Regional geoelectric field peak amplitude to be used in calculating GIC in the GIC system model

$$E_{peak} = 8 \times \alpha \times \beta$$

- α - scaling factor account for geomagnetic latitude
- β - factor account for local earth conductivity structure (1 = Quebec event)

- Local variability in the beta factor for southern Sweden MT chain

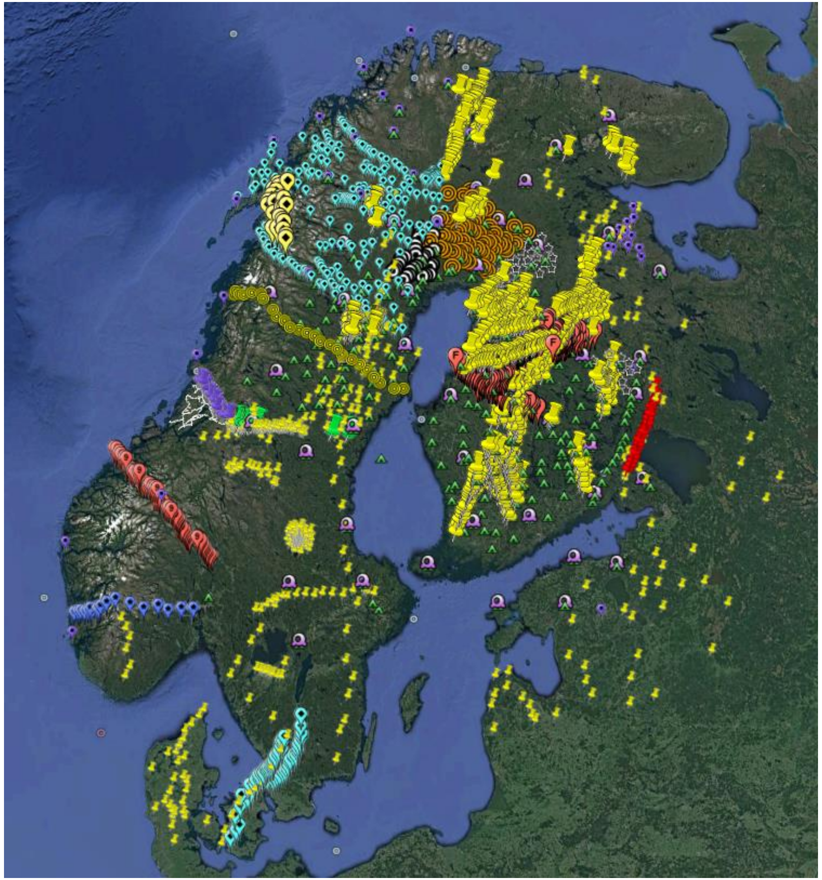


[1]North American Electric Reliability Corporation, Benchmark Geomagnetic Disturbance Event Description, May 12, 2016.

What can we provide?

- Improved GIC modelling relies on an accurate and reliable model of the **vertical and lateral** conductivity structure

- Joint project with Luleå Tekniska Universitet and Maxim Smirnov (Geoscience and environmental techniques)
    - **Improve and update** the current state of the art 3D conductivity model of Fennoscandinavia (SMAP)
    - Provide 3D magnetotelluric transfer functions from the sites that the model is based on
    - Joint field trials to test equipment, compare results and maximize coverage and output (October 2017)



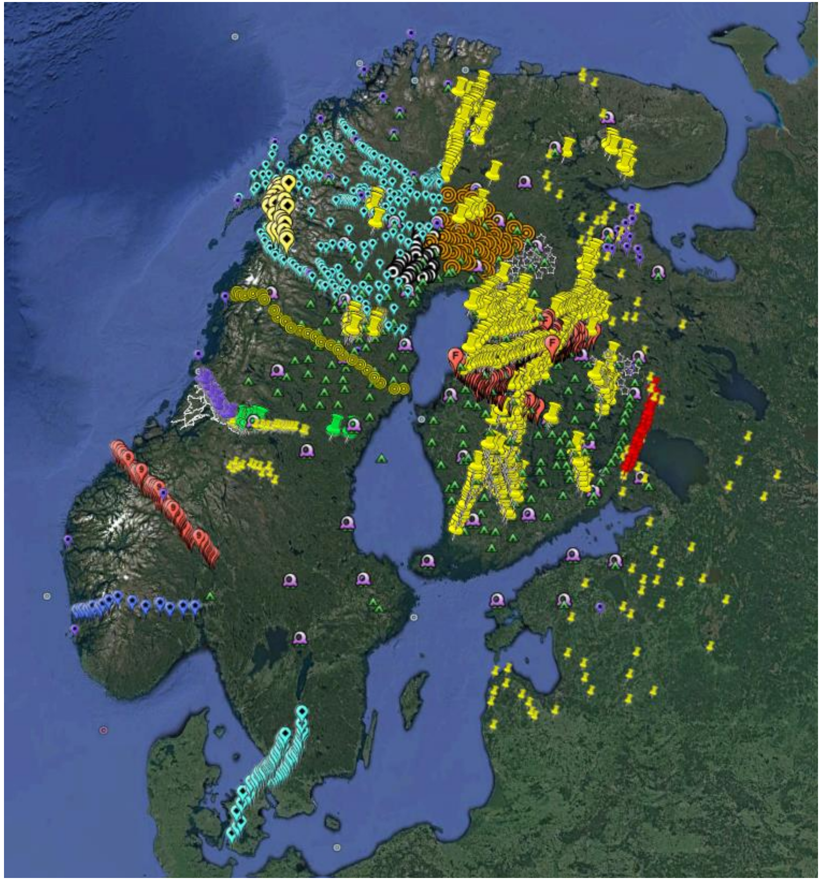
What can we provide?

- Improved GIC modelling relies on an accurate and reliable model of the **vertical and lateral** conductivity structure

- Joint project with Luleå Tekniska Universitet and Maxim Smirnov (Geoscience and environmental techniques)
    - **Improve and update** the current state of the art 3D conductivity model of Fennoscandinavia (SMAP)
    - Provide 3D magnetotelluric transfer functions from the sites that the model is based on
    - Joint field trials to test equipment, compare results and maximize coverage and output (October 2017)

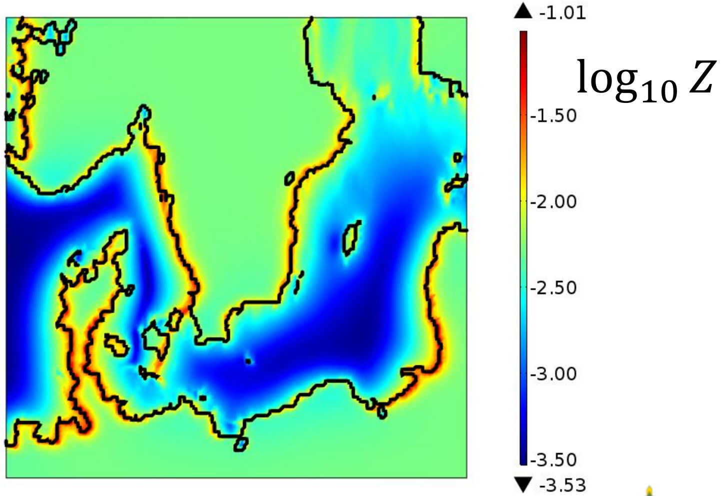
- Still large regions that are not characterized, especially in southern Sweden – a region identified as more vulnerable to GIC related problems

- Need for more observations in southern Sweden



What can we provide?

- Quantitative assessment of Swedish GIC hazard
  - 3D modelling study of Sweden based on updated SMAP (collaborations with LTU and ETH Zurich)
  - Improve the geoelectric hazard map based on magnetotelluric transfer functions from more sites
  - Can be used to identify critical sites where monitoring equipment can be installed and GIC model predictions can be improved by matching model and actual measurements [e.g. Wik et al., 2008]



What can we provide?

- Quantitative assessment of Swedish GIC hazard
  - 3D modelling study of Sweden based on updated SMAP (collaborations with LTU and ETH Zurich)
  - Improve the geoelectric hazard map based on magnetotelluric transfer functions from more sites
  - Can be used to identify critical sites where monitoring equipment can be installed and GIC model predictions can be improved by matching model and actual measurements [e.g. Wik et al., 2008]

500 km