Modelling GICs in Sweden – verification and extreme event analysis

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Improved predictions for extreme solar storms

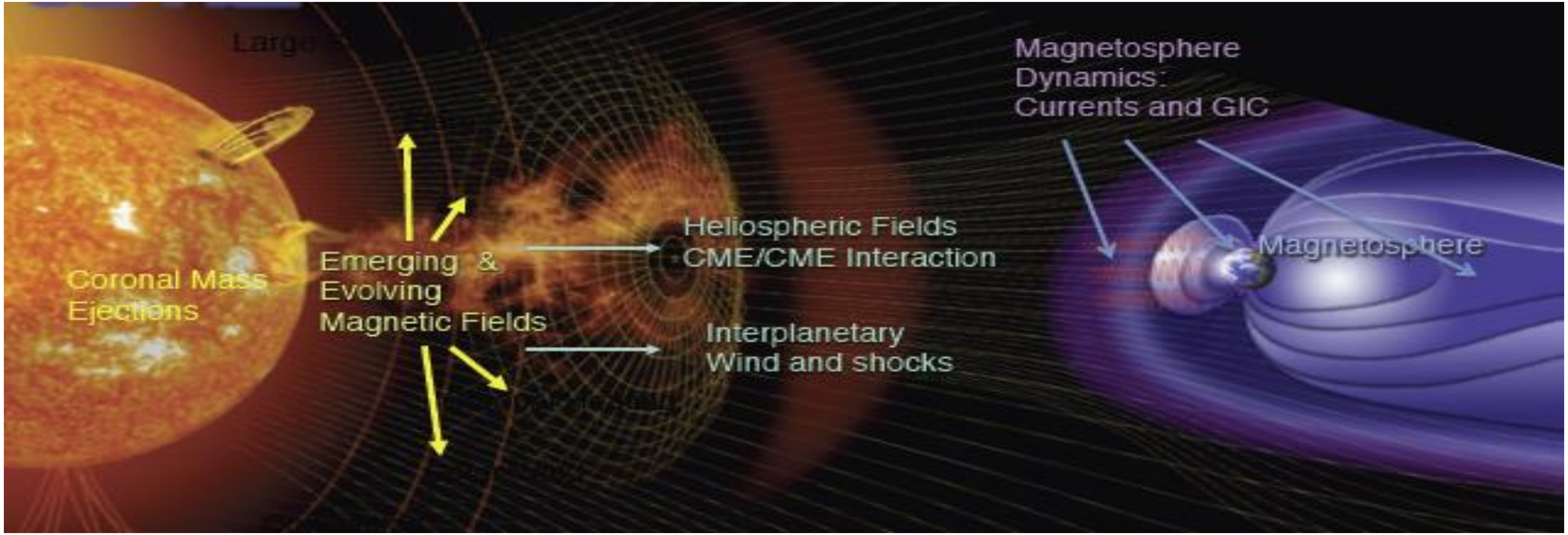
- Research Project finansed by MSB
- Consortium Stockholm University (Solar physics), Swedish Institute for Space Physics (IRF), FOI
- Four parts in the space weather chain

Solar eruption (SU)
Increased knowledge for the magnetic fields in the eruption

Solar wind (IRF)
CME interaction

Magnetosphere (IRF)
Energy transfer in the Earth magnetosphere (dB/dt)

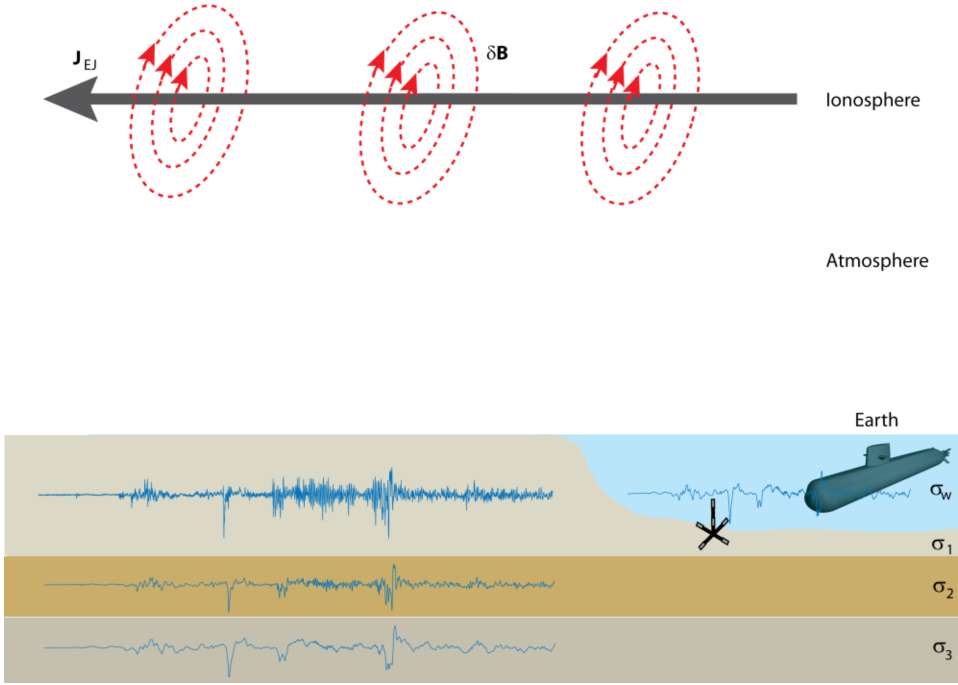
Earth (FOI)
Effect of Earth geology



End-user susceptibility

Effects

- Characteristics of the background electromagnetic noise important for detection of anomalous fields in electromagnetic sensors (mines, surveillance systems etc.)
- Historic example: Dolores Knipps presentation about mine self-sterilization in the Haiphong harbor during the Vietnam war…

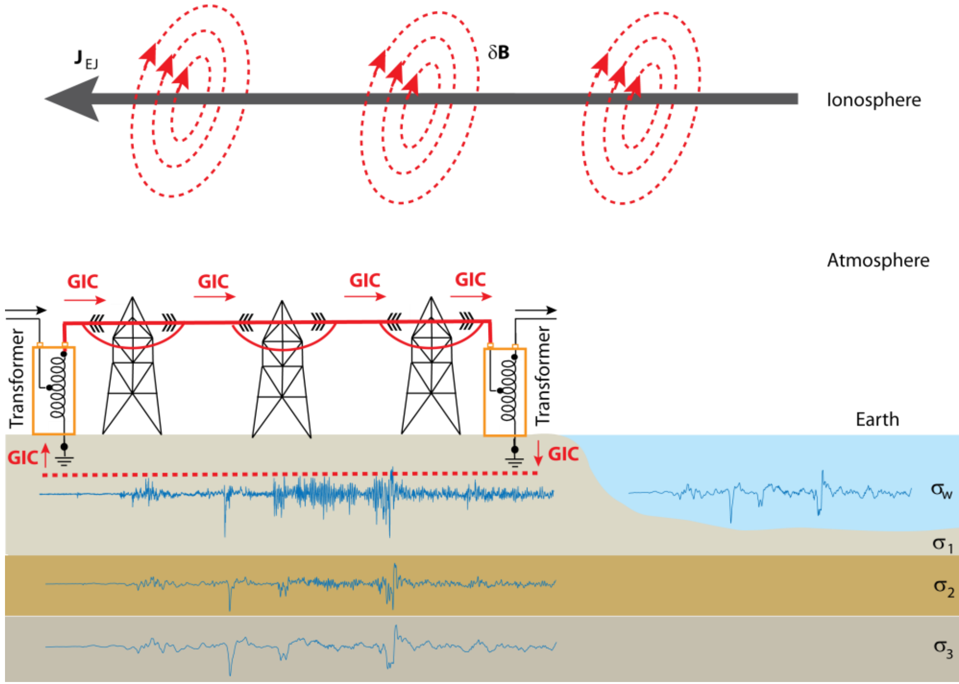


End-user susceptibility

Effects

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

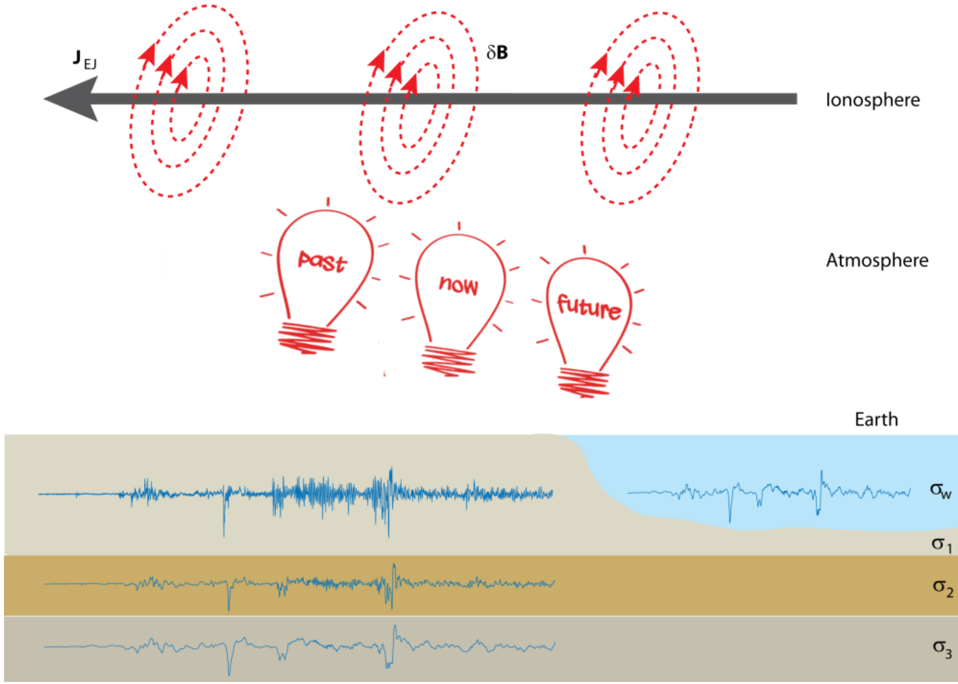
- Can affect the power system as GIC pass through the coils of the transformer and into the transmission lines
    - Core saturation, may lead to breaker trip
    - Voltage dropout
    - Heating of transformer parts



WP4 Goals

To improve forecasting capability for GIC estimations in Sweden by:

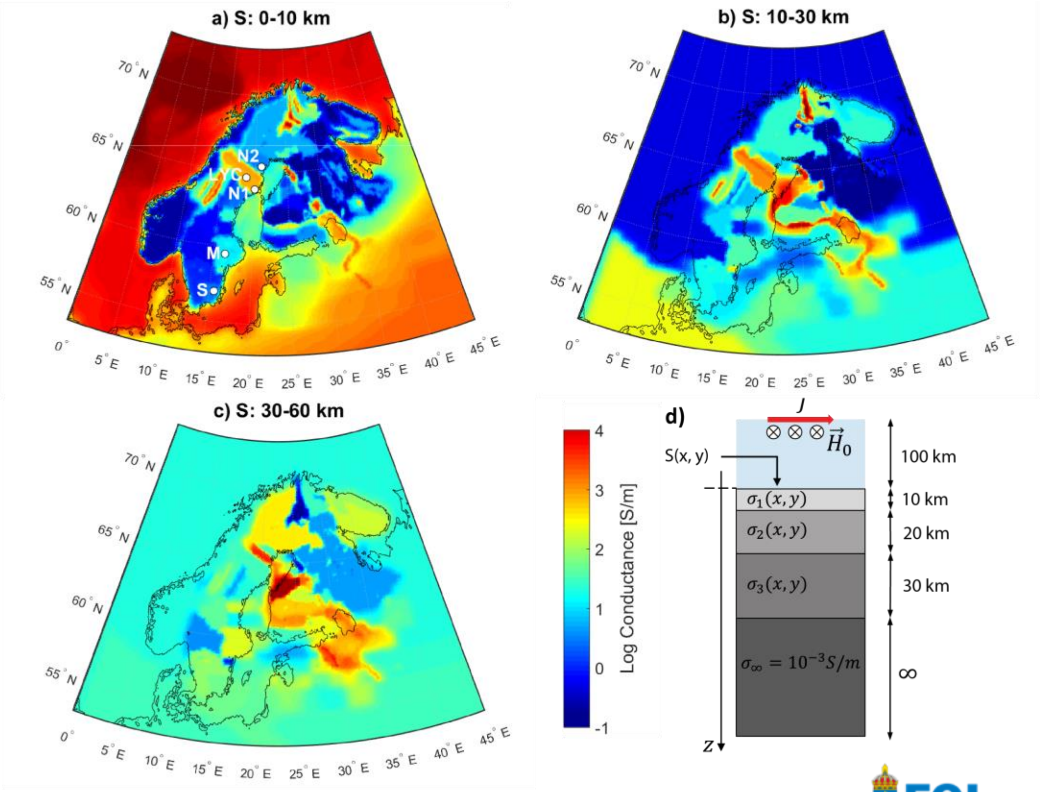
- Identifying the requirements of Swedish end-users for GIC predictions
    - Acting as the link between the scientific community and the end-users to ensure relevant research and validate models
- Studying the specific Swedish conditions for GICs
    - Increase understanding of how GIC are influenced by Swedish geology
- Analyzing the necessary components needed to tailor a GIC forecasting model for Swedish conditions



What do we need?

Necessary components to model GICs

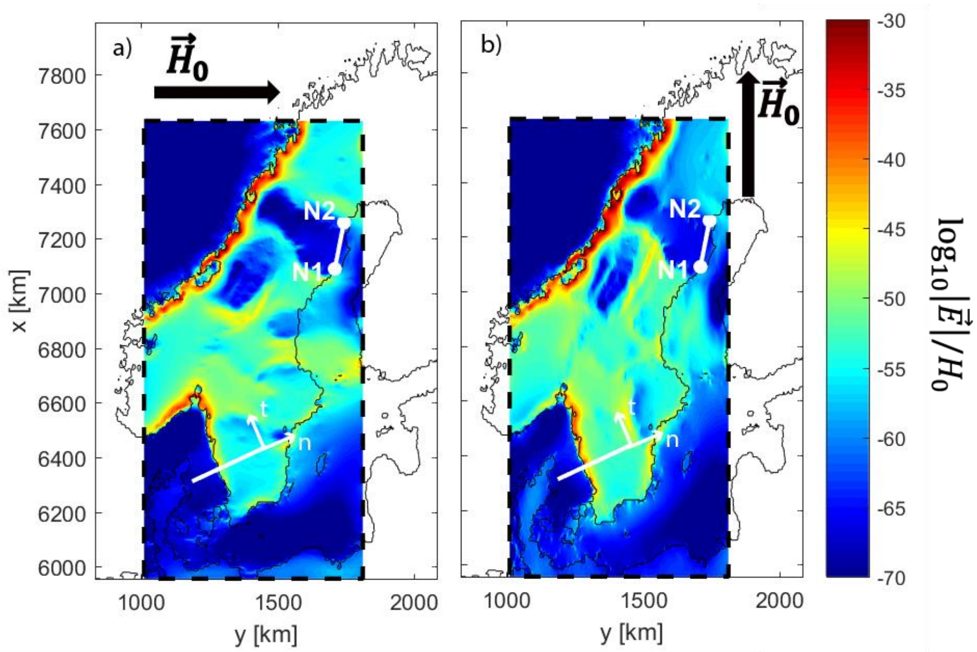
- Magnetic disturbances (WP3)
- Power grid topology (industry/operators)
- Earth conductivity (FOI)
  - Large lateral gradients across the country, coastal areas
  - Earlier studies assumption of 1D conductivity structure
  - Importance of 3D at coastal areas or inland conductivity gradients?
  - Differences between models and large uncertainties
  - Cooperation with LTU, 3D model over Fennoscandinavian crustal conductivity SMAP



FOI

3D modelling of GIC in Sweden

- 3D modelling of the geoelectric field with SMAP (COMSOL multiphysics)
- Uniform magnetic field variation with unit amplitude (|H| = 1A/m, f = 0.0001 - 1Hz)
- Conclusions
  - Clear coastal enhancements (also inland)
  - Hazard area in southern Sweden (lower conductivity and coastal effect)
  - Modelling of GICs in arbitrary network based on observed or modelled magnetic field variations
  - Verified with observations in northern transmission line (*Rosenqvist et al., Space Weather Journal, 2019*)
  - Southern transmission line near the coast?



Induced voltage: $V = V_{H_x}\left[\frac{H_x}{H_0}\right] + V_{H_y}\left[\frac{H_y}{H_0}\right]$

$$V_{H_x} = \int_C \vec{E}_{H_x} \cdot \hat{n}\, ds$$

$$V_{H_y} = \int_C \vec{E}_{H_y} \cdot \hat{n}\, ds$$

Current calculated from: $I(\omega) = V(\omega)/Z$

GIC measurements 2018 on FT58

Current shunt GIC measurements on transmission line in cooperation with Svenska Kraftnät in Maj 2018

Blue circle – current shunt in Horred

Red circle – earthing in Ringhals

Yellow circle – toplinecurrent

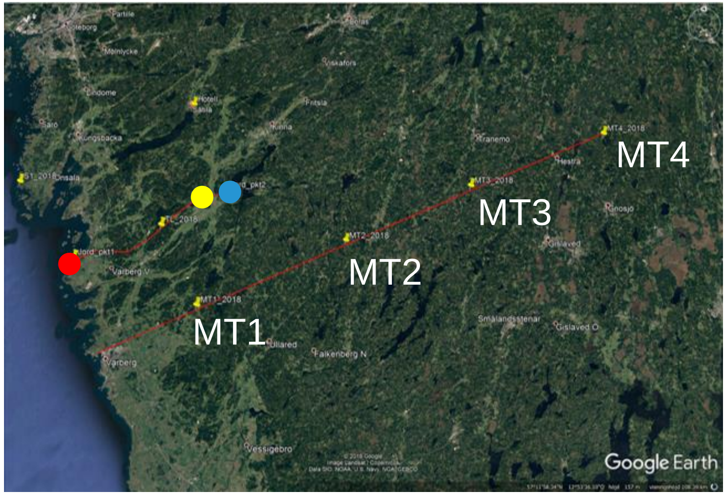
MT1 – Magnetotelluric station 1

MT2 – Magnetotelluric station 2

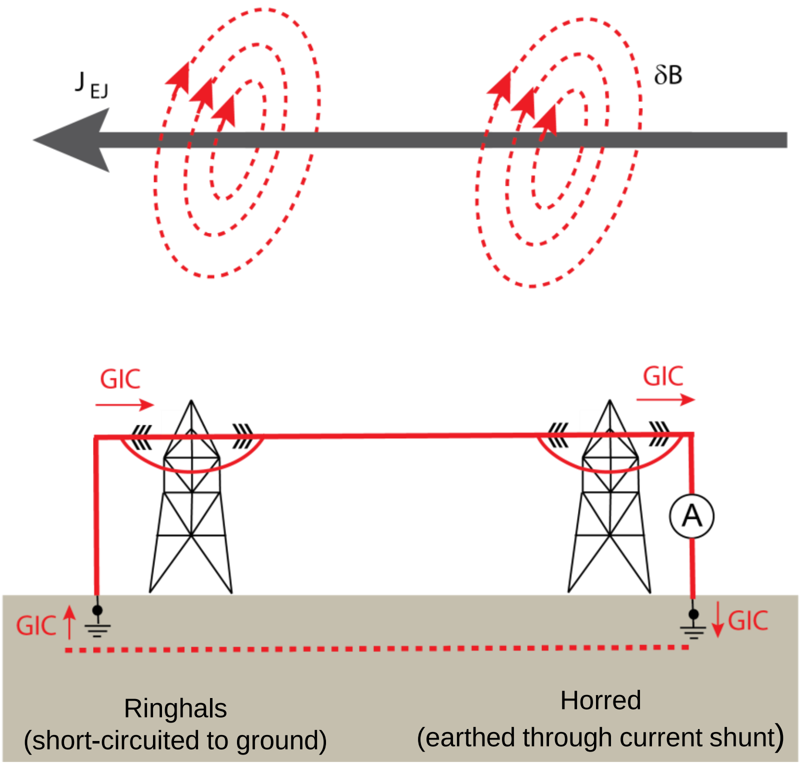
MT3 – Magnetotelluric station 3

MT4 – Magnetotelluric station 4

TOR – Fluxgatemagnetometer in Tomerstorp

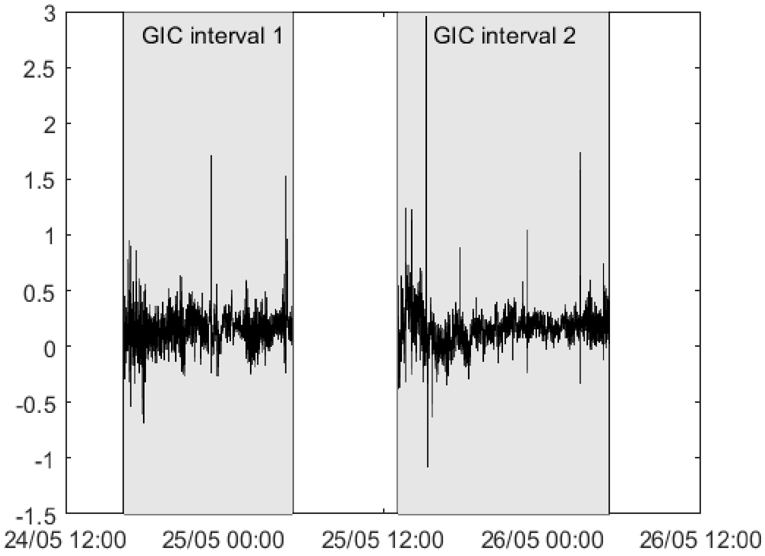


Experimental setup

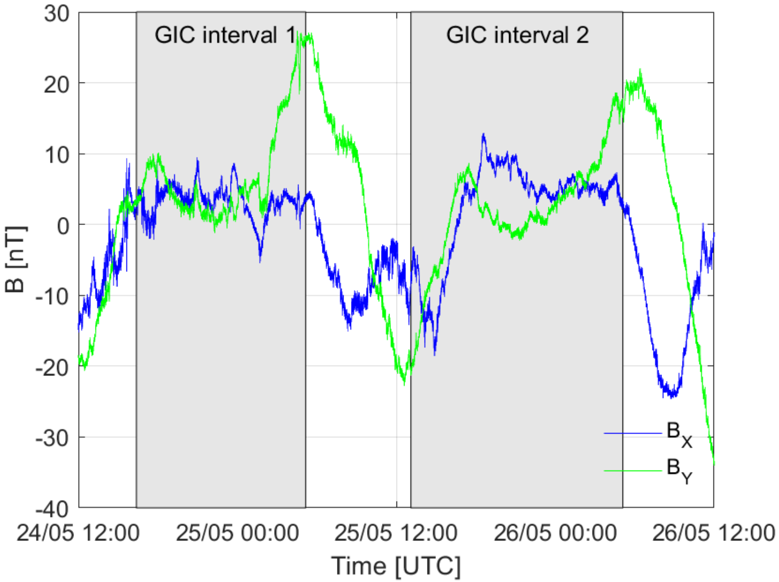


FOI

Observations

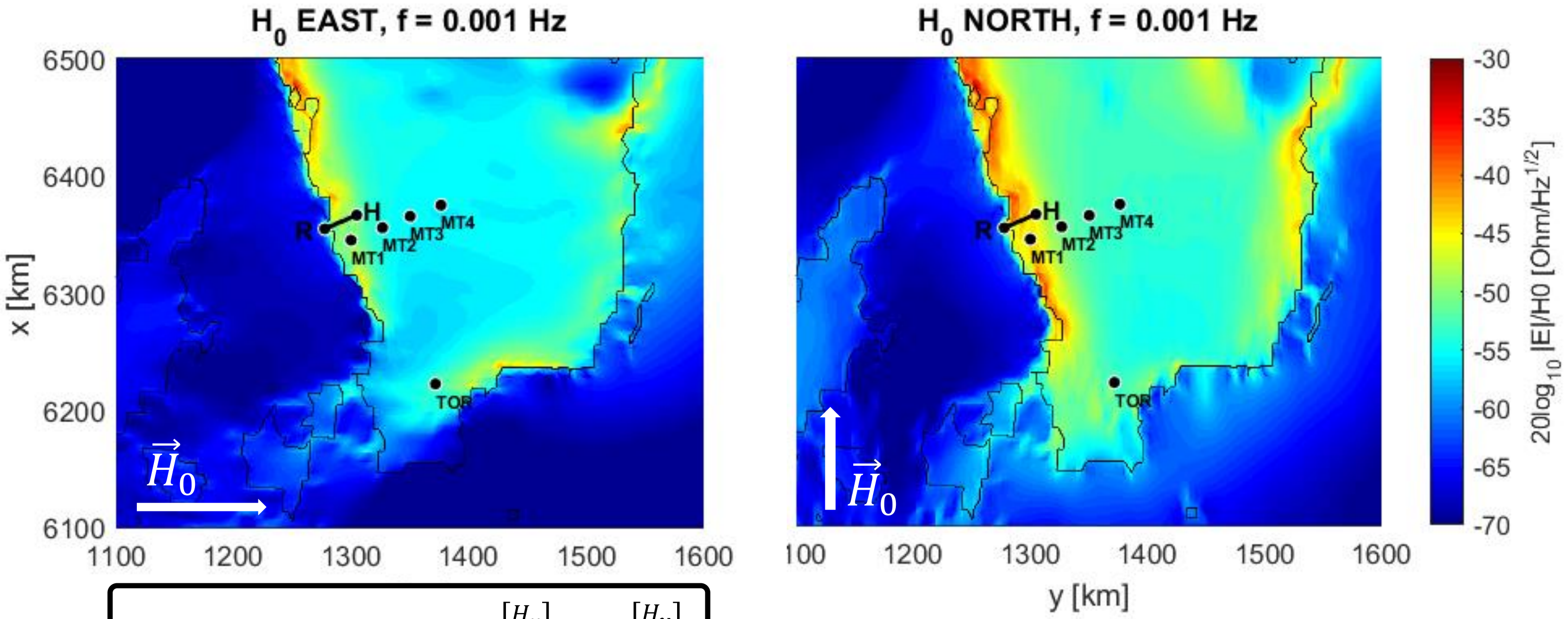


Current measured in Horred



Magnetic field from TOR

Calculation of GIC in FT58



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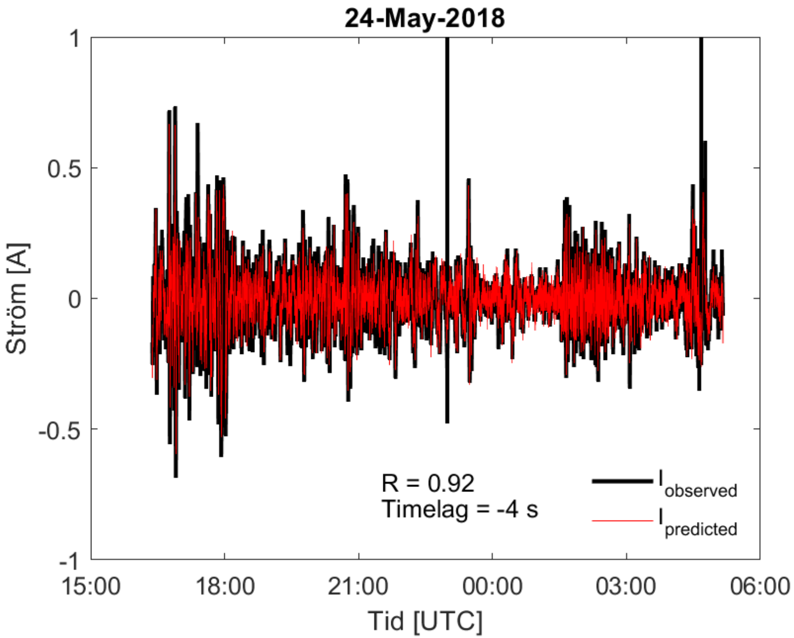
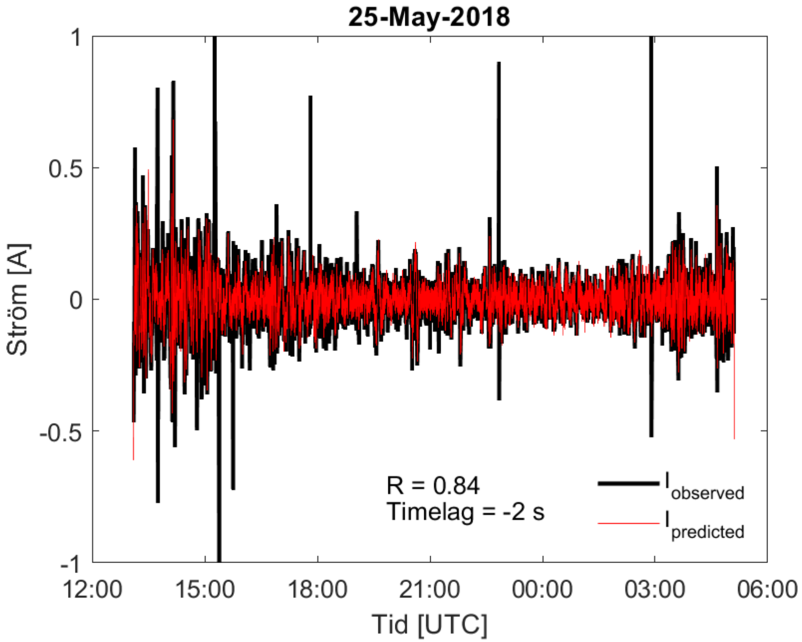
Model verification FT58 (mHz – 1 Hz)



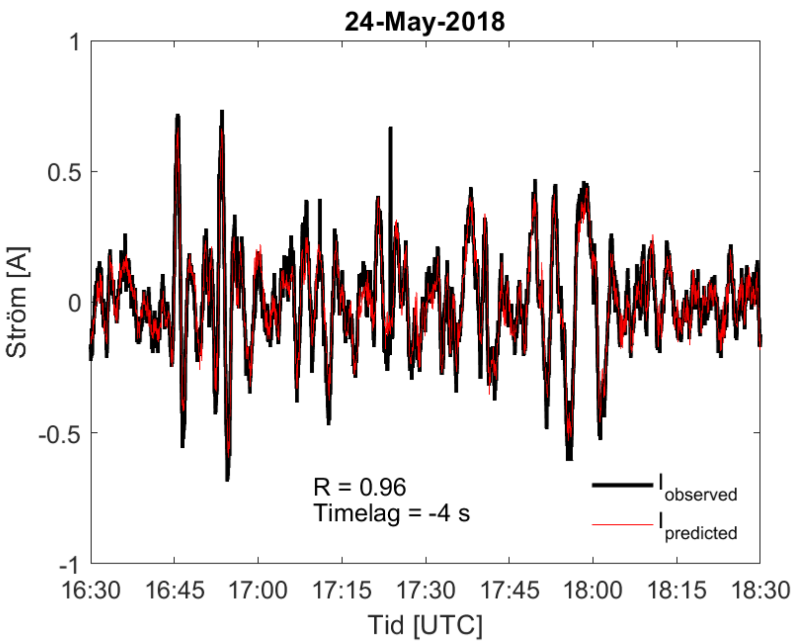
GIC interval 1



GIC interval 2

FOI

Model verification FT58 (mHz – 1 Hz)



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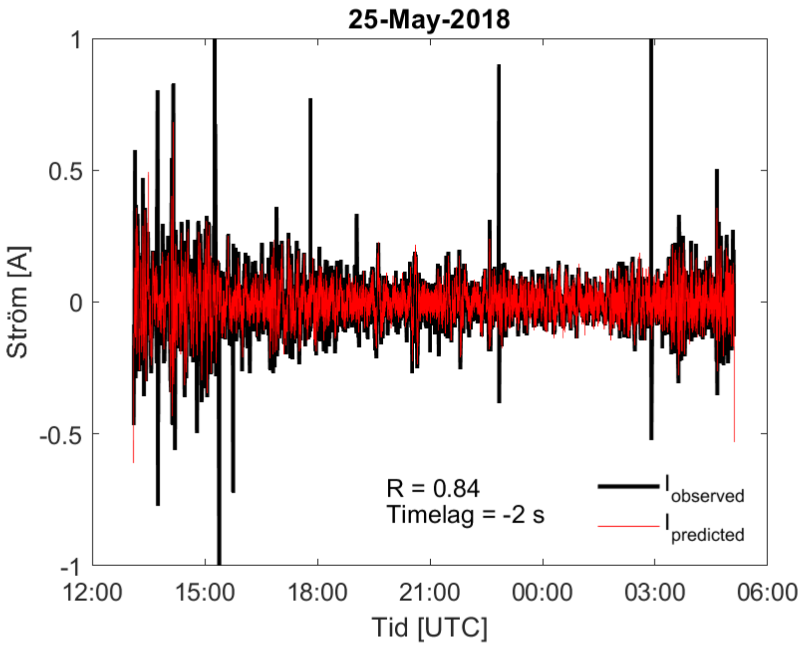
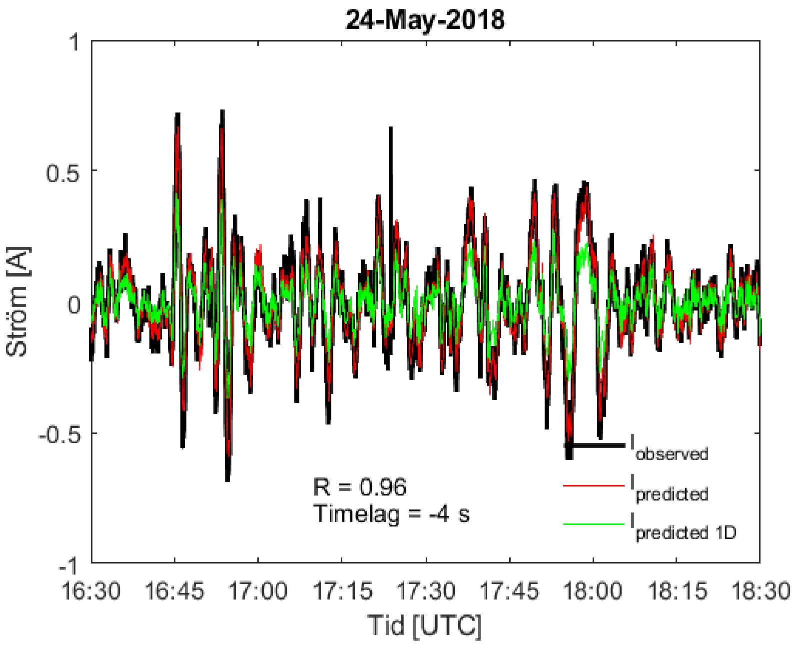


GIC interval 2

FOI

1D versus 3D



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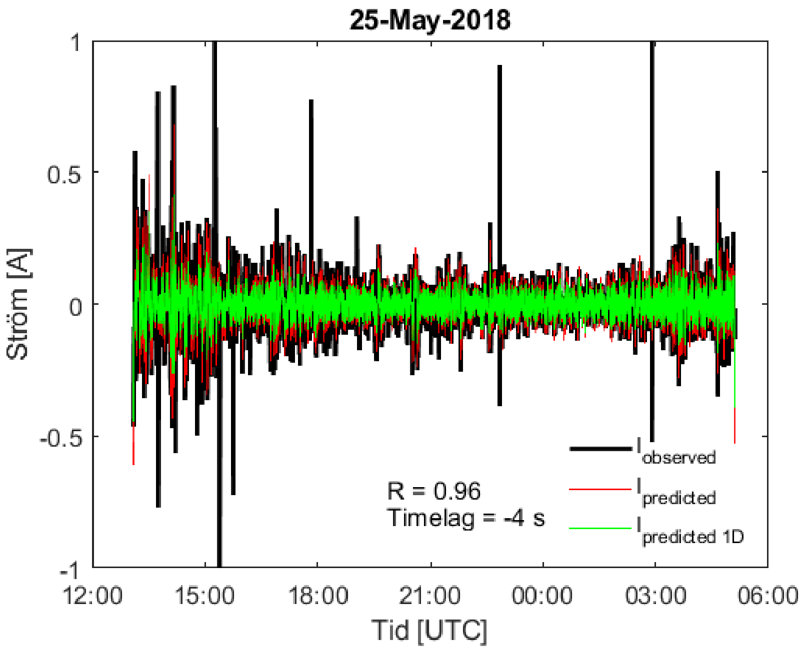


GIC interval 2

FOI

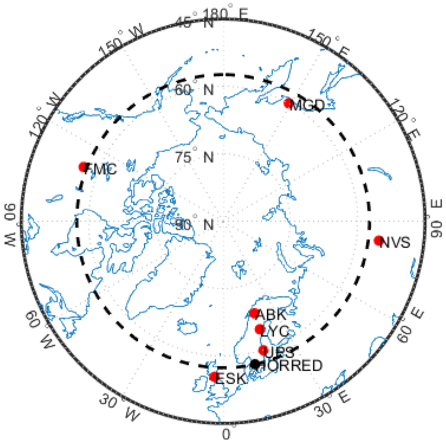
Analysis of major storms

- GIC scales linearly against magnetic variations
- Extrapolation for high activity during historical storms
- List of 13 historical magnetic storms (NASA/CCMC)
- Analyse peak GIC for the FT58 transmission line during the 13 storms based on magnetic recordings from similar latitude (~57 degrees)

Table 2
List of Events in the Current dB/dt Test Suite (1–6), New Events Recommended for Inclusion by the Working Group (7-8), and Other Events Considered by the Working Group (9–13)

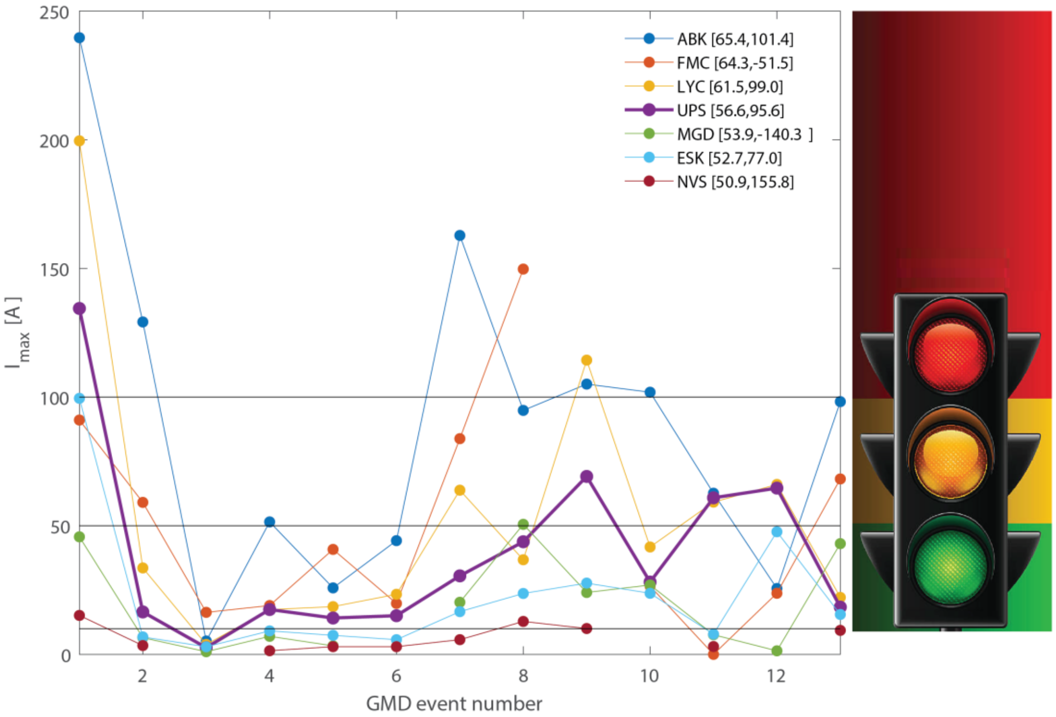
#	Event start	Extent (hr)	F10.7 (sfu)	Kp	AE (nT)	SYM-H (nT)
1	29 Oct 2003 06:00 UT	24	275.4	9°	4056.0	−391.0
2	14 Dec 2006 12:00 UT	36	90.5	8^{+}	2284.0	−211.0
3	31 Aug 2001 00:00 UT	24	203.0	4°	959.0	−46.0
4	31 Aug 2005 10:00 UT	26	86.0	7°	2063.0	−119.0
5	05 Apr 2010 00:00 UT	24	79.0	8^{-}	2565.0	−67.0
6	05 Aug 2011 09:00 UT	24	113.0	8^{-}	2611.0	−126.0
7	17 Mar 2015 02:00 UT	34	116.0	8^{-}	2298.0	−234.0
8	22 Jul 2004 06:00 UT	162	178.4	9^{-}	3632.0	−208.0
9	07 Nov 2004 00:00 UT	60	138.1	9^{-}	3360.0	−394.0
10	30 Mar 2001 12:00 UT	48	257.2	9^{-}	2407.0	−437.0
11	17 Mar 2013 00:00 UT	48	124.5	7^{-}	2689.0	−132.0
12	06 Apr 2000 12:00 UT	48	178.1	9^{-}	2481.0	−320.0
13	15 May 2005 00:00 UT	24	105.2	8^{+}	2051.0	−305.0

Note. AE = auroral electrojet. For each, the start time, duration over which data-model comparisons should be made, maximum F10.7 solar flux, Kp, AE, and minimum SYM-H values are shown in each column from left to right, respectively.



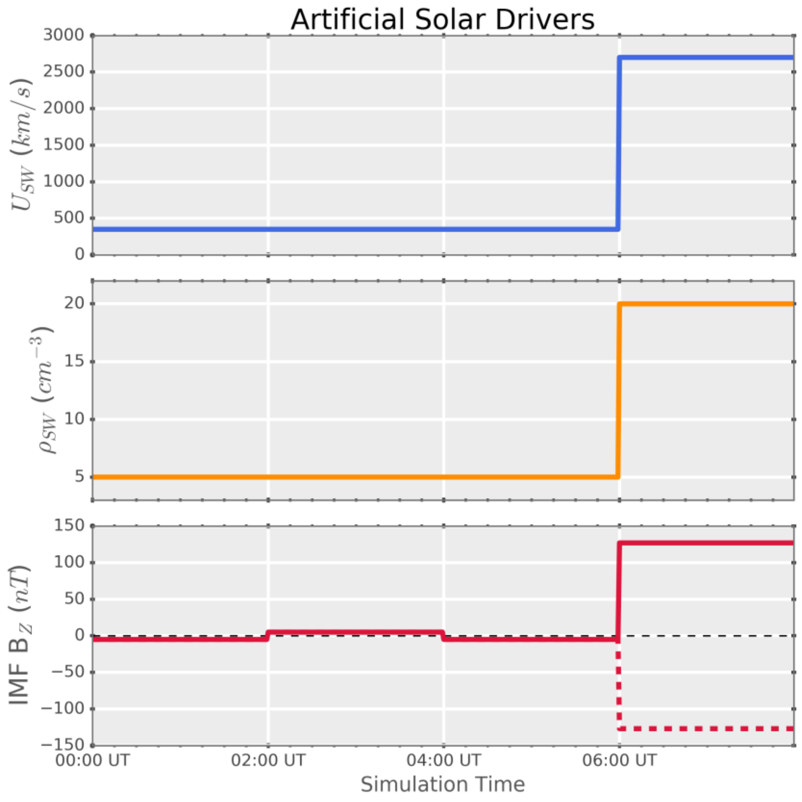
Analysis of major storms

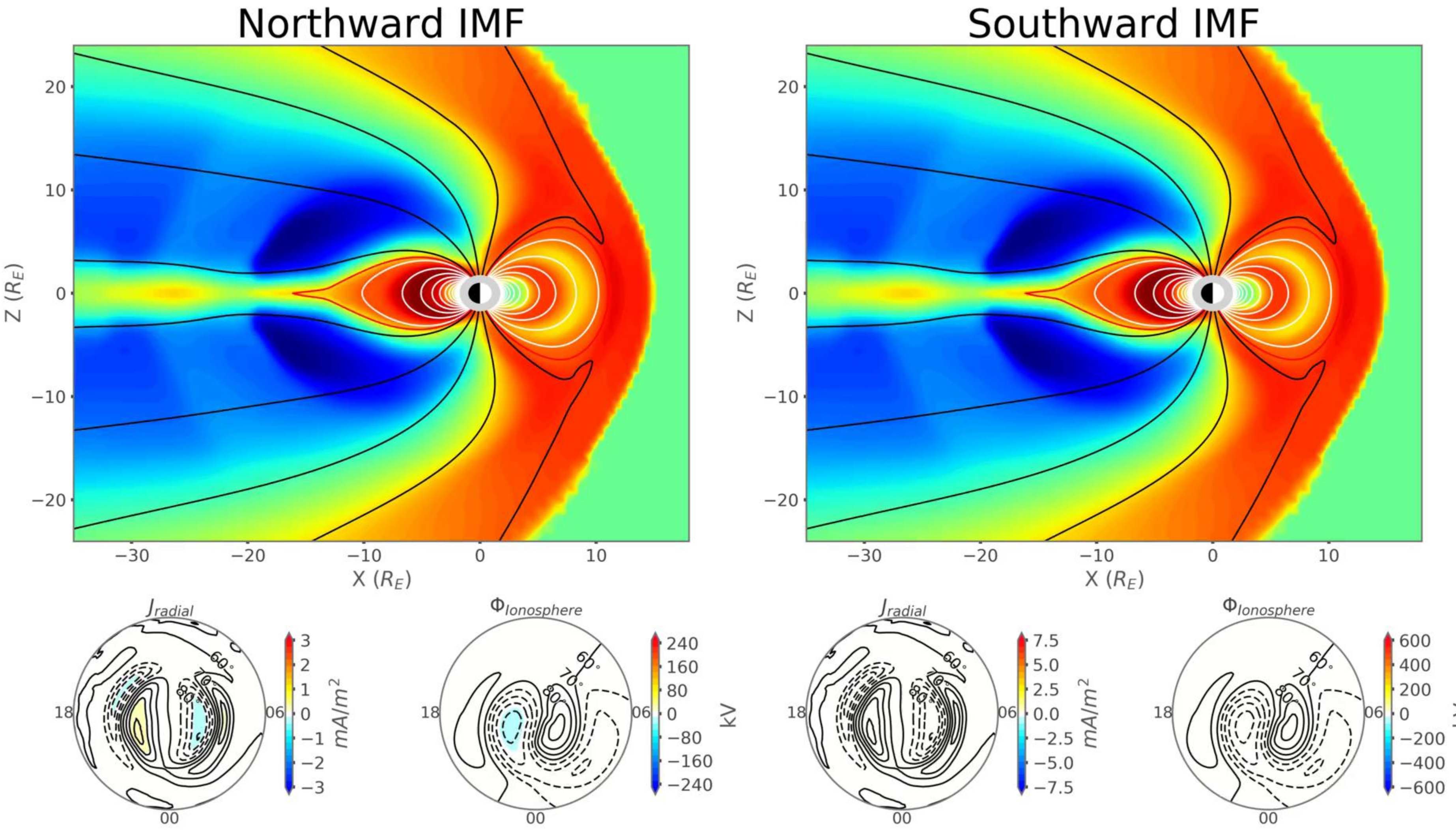
- Classification:
  - Small: 10-50 A
  - Medium 50-100 A
  - Large > 100 A
  - Note: Individual for each grid…
- GIC > 100 A (peak) for only one of the 13 storms at relevant MLAT (3 medium, 8 small)
- Peak GIC strongly dependent on MLAT (expected)
- For higher MLAT (ABK) 5 events are classified as ”large”



A hypothetical extreme storm

- Tsurutani & Lakhina, 2014 GRL
- CME velocity 2700 km/s
- Density 20 cm^{-3}
- Empirical scaling of IMF Bz to 127 nT
- Expected results:
  - Magnetopause compressed to 5 R_E
  - $\Delta H \approx 245\ nT$, dB/dt $\approx 30\ nT/s$
- Modelled with Space Weather Modelling Framework (SWMF)

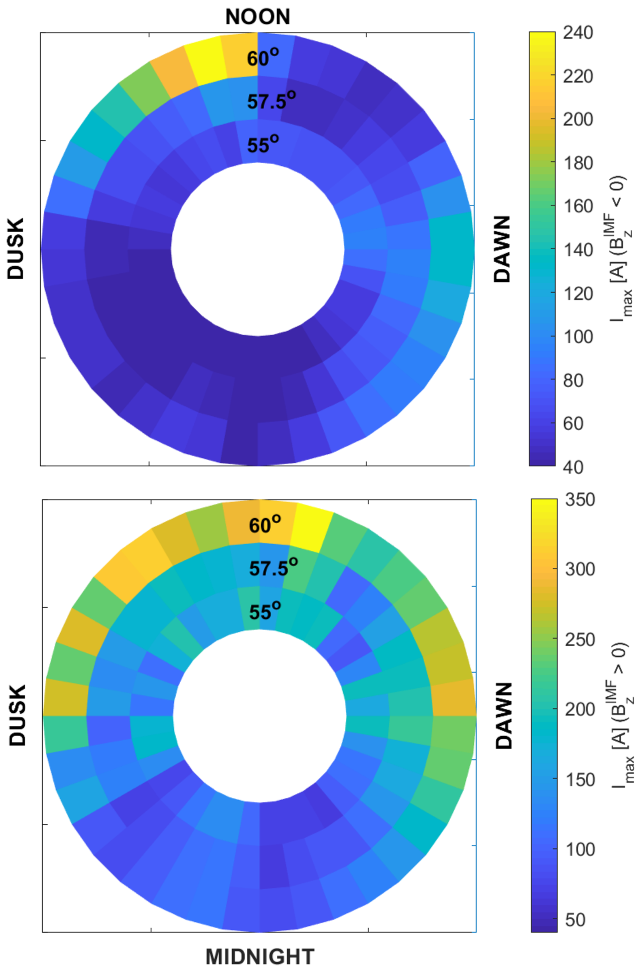




Northward IMF
Southward IMF
Z (R_E)
X (R_E)
20
10
0
−10
−20
−30
−20
−10
0
10
J_{radial}
$\Phi_{Ionosphere}$
60°
70°
80°
18
06
00
mA/m^2
kV
3
2
1
0
−1
−2
−3
240
160
80
0
−80
−160
−240
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
600
400
200
0
−200
−400
−600

Results extreme storm

- GICs in FT58 for magnetic disturbances around latitude 57 degrees for the ”sudden storm commencement”
- Peak current strongly dependent on MLT
- GIC > 240 A (peak) for IMF > 0
- GIC > 400 A (peak) for IMF < 0



Conclusions

- GIC-SMAP model validated at two Swedish sites with excellent agreement
- Unique method with existing 3D conductivity model and measurements of transmission line impendence (no “tuning” to achieve best fit to observations)
- 1D model underestimates current by ~ 50 %
- Model tailored for Swedish conditions and permits modelling of GICs for arbitrary networks
- A tool to investigate potential hazard for extreme space weather events
    - Only one “major” GIC event during historical storms in this particular line
    - A hypothetical event peak GIC could exceed 400 A (for FT58)