VALIDATING THE SPACE WEATHER MODELING FRAMEWORK (SWMF) FOR APPLICATIONS IN NORTHERN EUROPE:

Ground magnetic perturbation validation

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OUTLINE

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- Simulation and Validation set up
- ΔB validation results
- $\frac{dB}{dt}$ validation results
- Summary

SWMF Coupling

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GM-BATSRUS
IE - Ridley
IM-Rice Convection

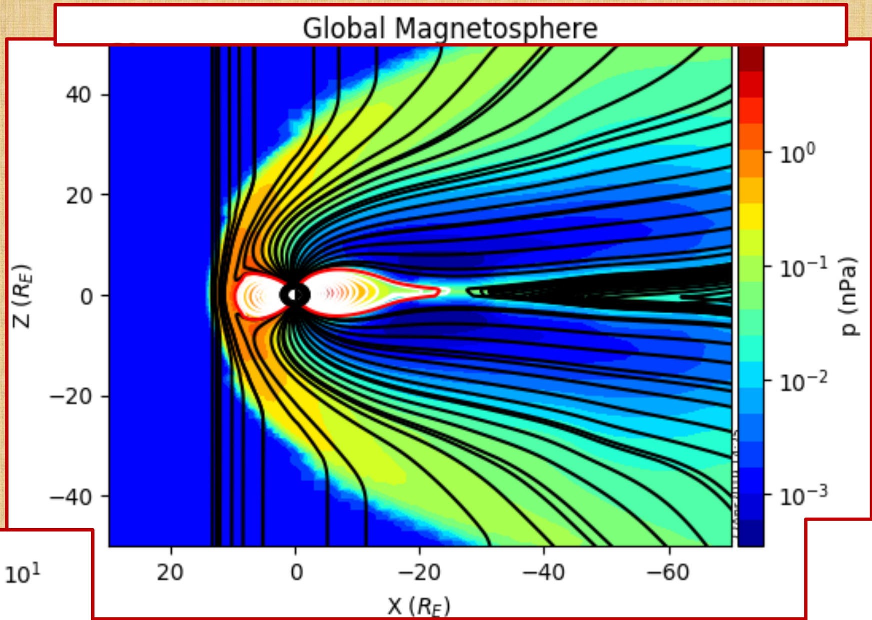
Density & Pressure

Magnetic Field & Plasma

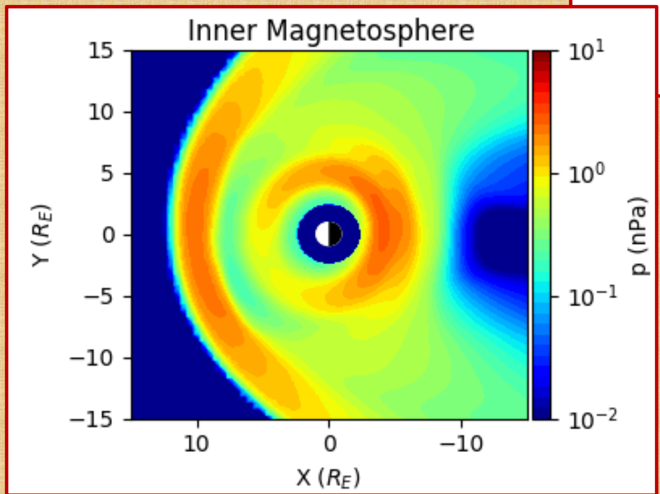
Electric Field

Current Density

GM

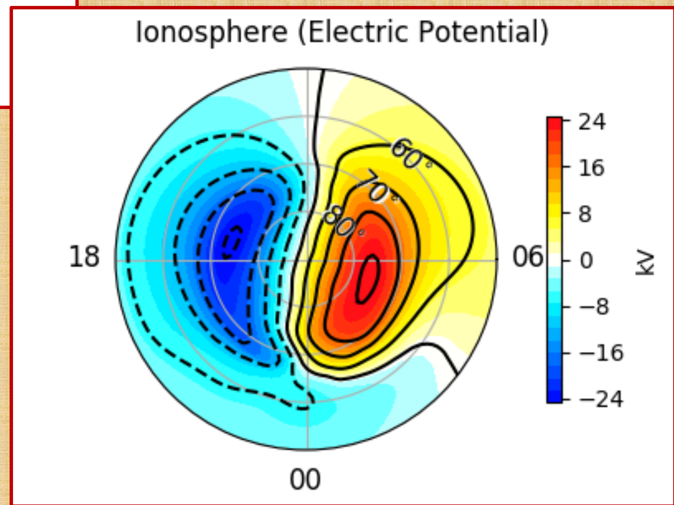


IM



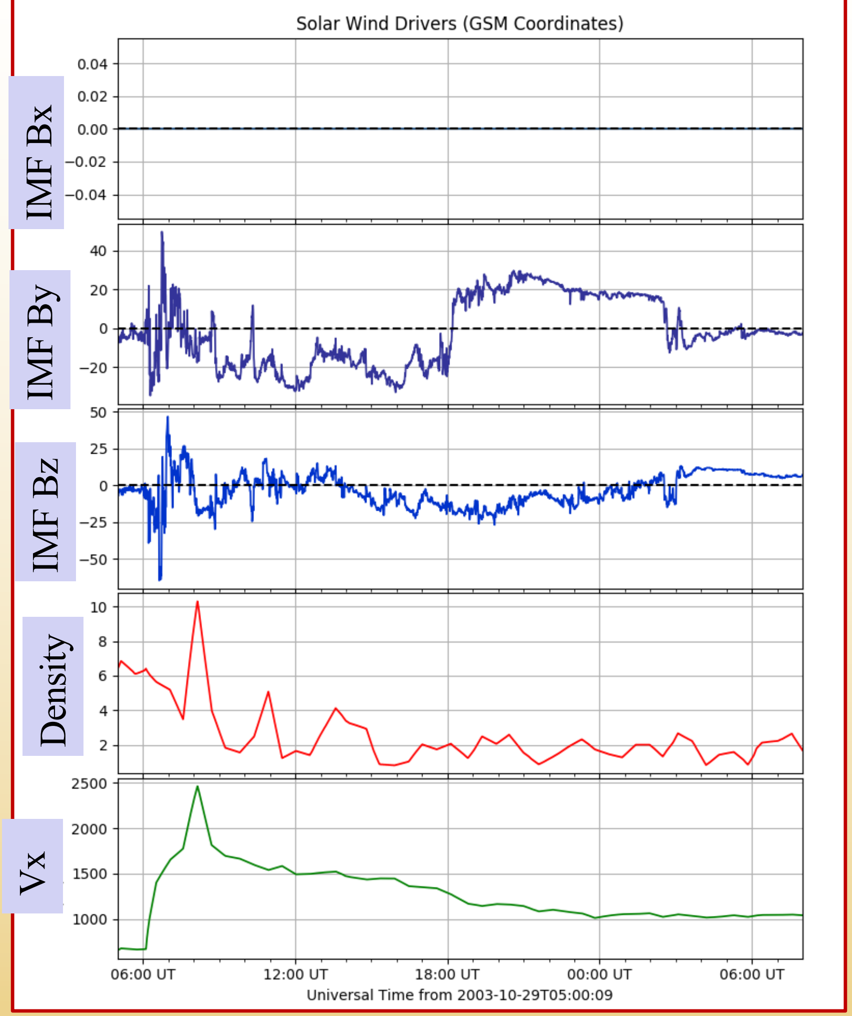
Electric Potential

IE



SWMF input

Halloween storm 2003



- Solarwind data from ACE or WIND at L1
  - Velocity Vx, Vy, Vz [km/s]
  - IMF Bx=0, By, Bz [nT]
  - Density [n/cc]
  - Temperature [K]

- F10.7 flux
- Coordinates of ground magnetometers, i.e., Virtual magnetometer locations

Storm Events

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Event	Date	F10.7	AE index	SYM-H
1	31 Aug 2001	192.2	959	-46
2	31 Aug 2005	85.6	2063	-119
3	14 Dec 2006	90.5	2284	-211
4	05 April 2010	79.3	2565	-67
5	05 Aug 2011	112.5	2611	-126
6	22 Jan 2012	136.6	1028	-79
7	29 Oct 2003	275.4	4056	-391
8	16 March 2015	113.2	2298	-234

Ground Magnetometer Stations

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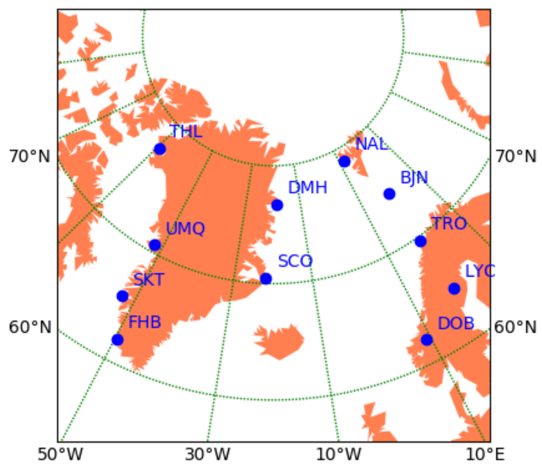
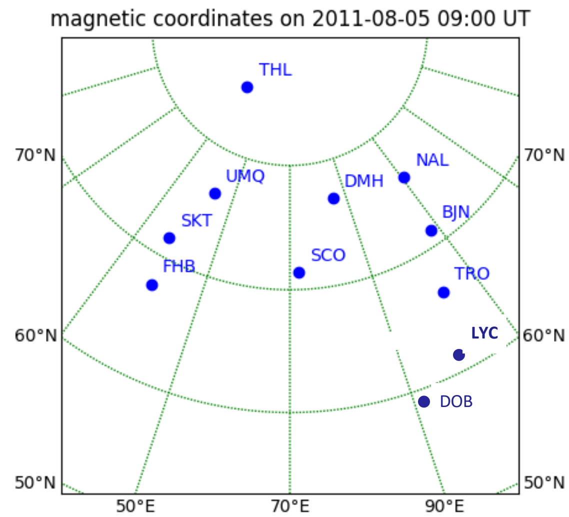
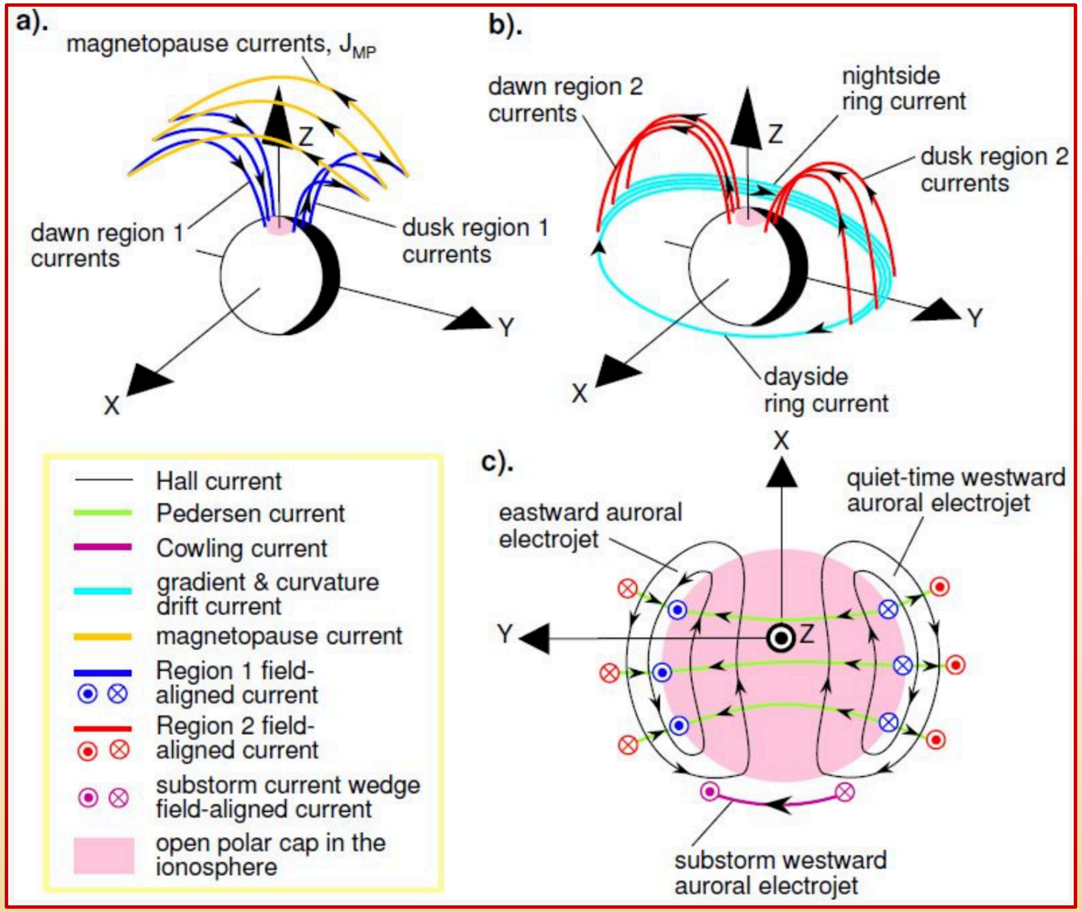
Station Name	Station Code	Geomagn. latitude	Geomag. longitude
Thule	THL	85.0	30.8
Danmarkshavn	DMH	77.0	85.4
Uummannaq	UMQ	76.5	43.1
Ny Ålesund	NAL	76.0	110.6
Sukkertoppen	SKT	71.6	37.3
Scoresbysund	SCO	71.4	72.2
Bjornåya	BJN	71.3	108.0
Fredrikshp	FHB	67.6	39.0
Tromsø	TRO	66.5	102.9
Lycksele	LYC	61.3	99.3
Dombås	DOB	59.1	90.1

- Magnetic latitude range 59º – 85º
- Spanning ~ 5 MLTs





M-I Currents



Lockwood, M. Living Rev. Sol. Phys. (2013) 10: 4. https://doi.org/10.12942/lrsp-2013-4

- Magnetic pertubations on the ground can be calculated from Ampere´s law

i.e.,

$$\Delta B_n = \frac{\mu_o}{2} J_e$$

$$\Delta B_e = \frac{-\mu_o}{2} J_n$$

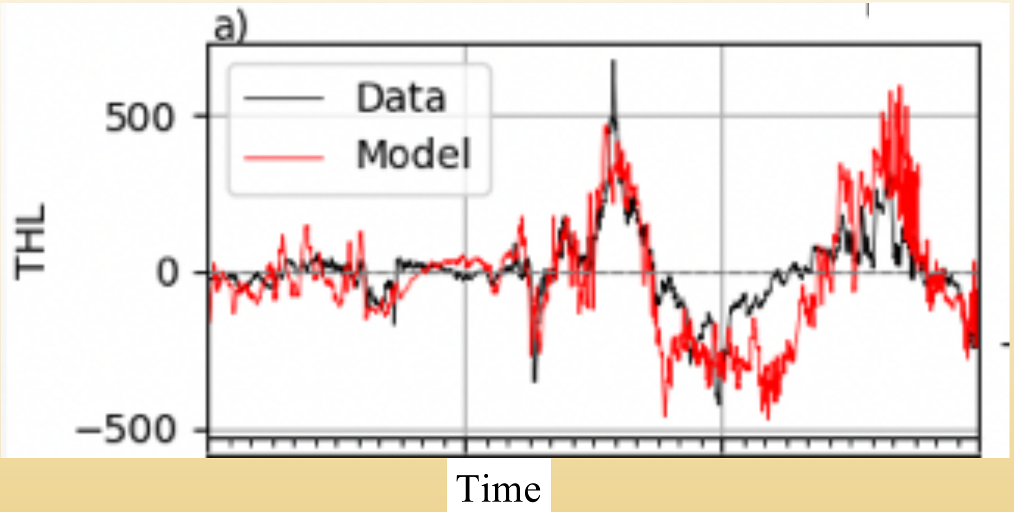
n: northward (x)
e: eastward (y)

- SWMF ΔB calculates contributions from
  - MHD currents
  - FAC
  - Perdersen currents
  - Hall currents

Model Performance Evaluation

ΔB:

- Normalised root mean sqaure (nRMS) error
- Correlation coefficient (Corr.)



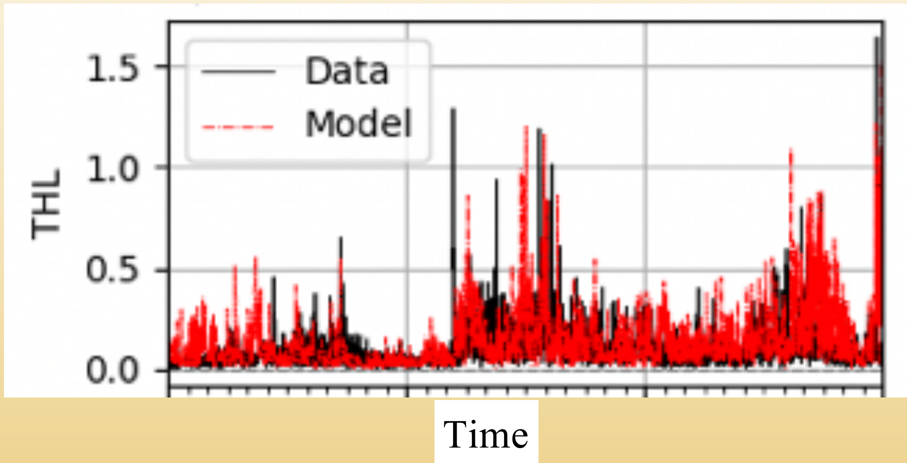
$\frac{dB}{dt}$:

POD – Probability of Detection

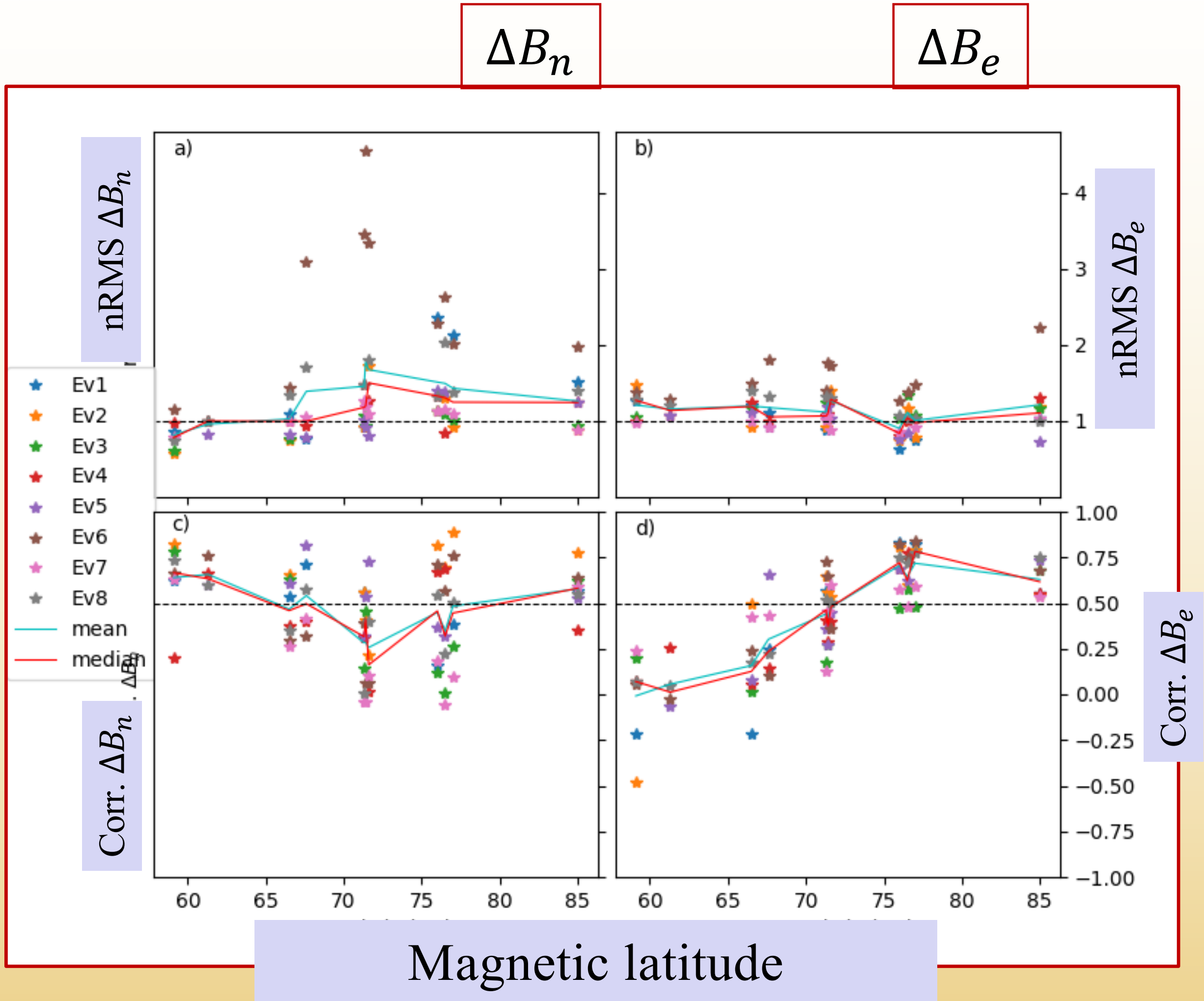
POFD – Probability of False Detection

HSS – Heidke Skill Score

FB – Frequency Bias



nRMS error for ΔB

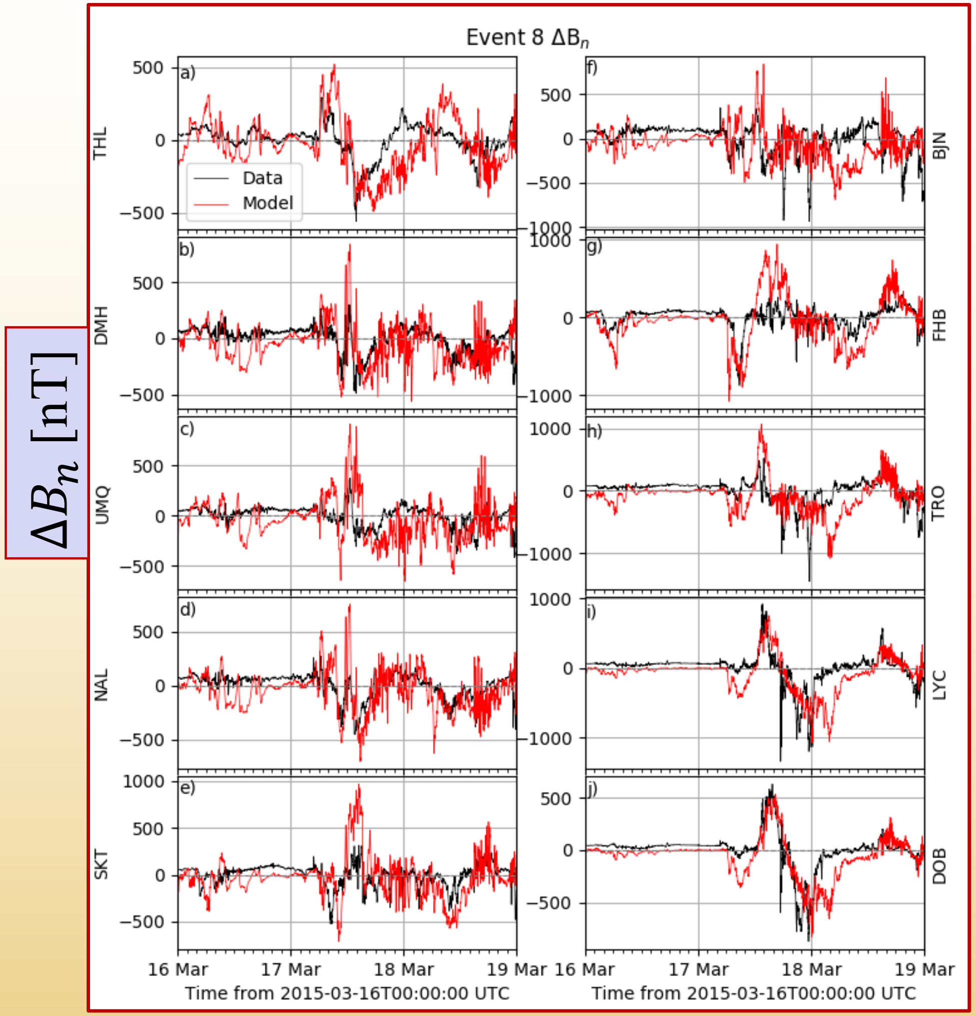


$$nRMS = \frac{\sqrt{< (\Delta B_p - \Delta B_o)^2 >}}{\sqrt{< (\Delta B_o)^2 >}}$$

p: predicted
o: observed

- ➢ $nRMS = 0$, Prediction exactly the same as observation
- ➢ $nRMS \leq 1$, Prediction in good agreement with observation
- ➢ $nRMS > 1$ Model misses observations significantly
- ➢ For ΔB_n ; better perfarmance at lower latitudes (below 70)
- ➢ For ΔB_e ; better performance at higher latitudes (above 70)
- ➢ Performance is the same for the polar cap station THL (~85), relatively good for both components

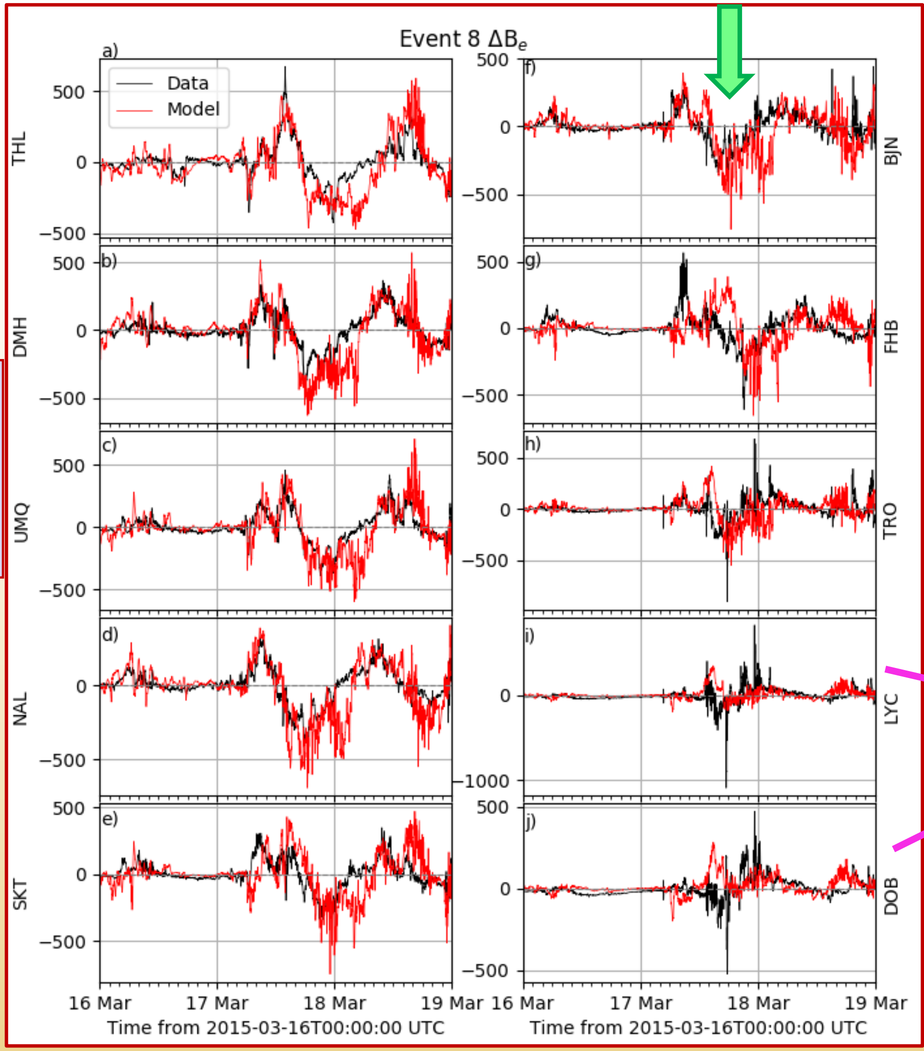
Event 8: ΔB_n



- nRMS error above 1 for the high latitude stations (THL-TRO)
- The model overshoots in magnitude especially at these latitude
- Model tends to capture the start and expansion phase of the perturbations better than the recovery
- Misses brief large perturbations at lower latitude stations (LYC and DOB)

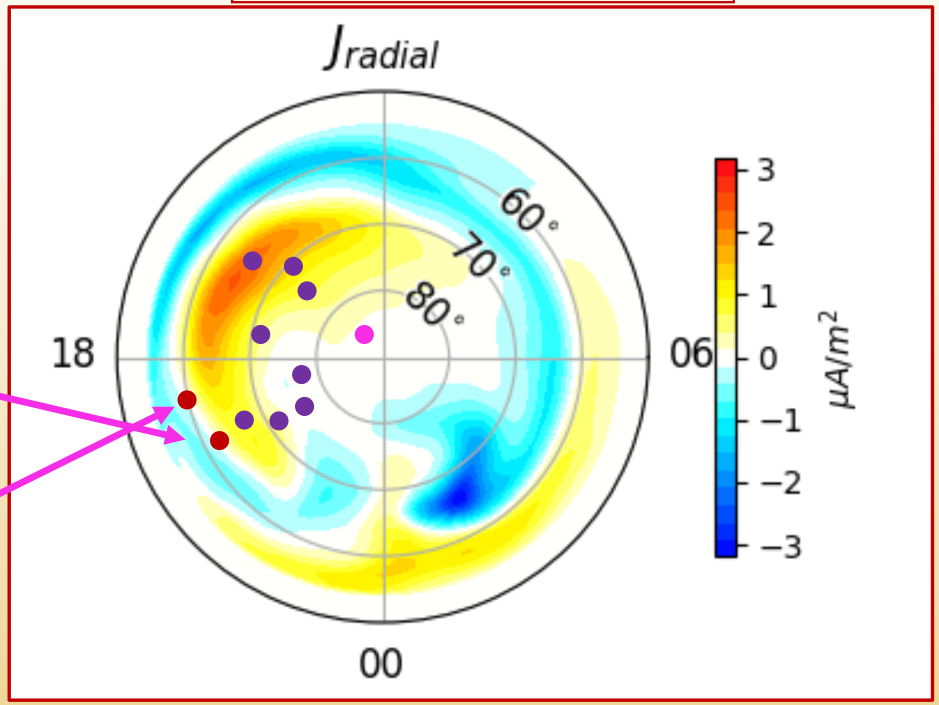
Event 8: ΔB_e

ΔB_e [nT]



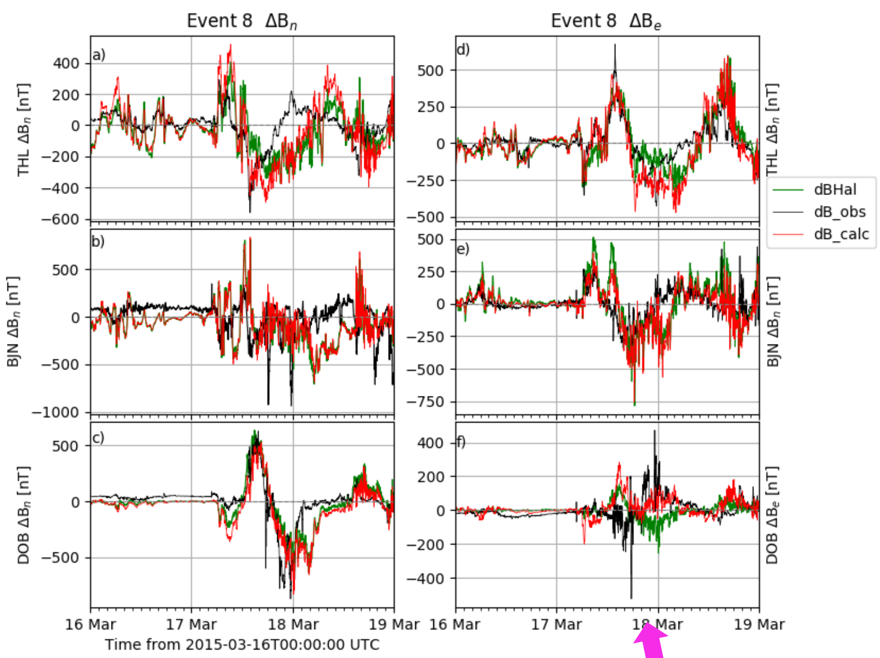
- Prediction improves with increasing latitude
- Magnitude captured better than for ΔB_n

Event 8 at 18:00 UT

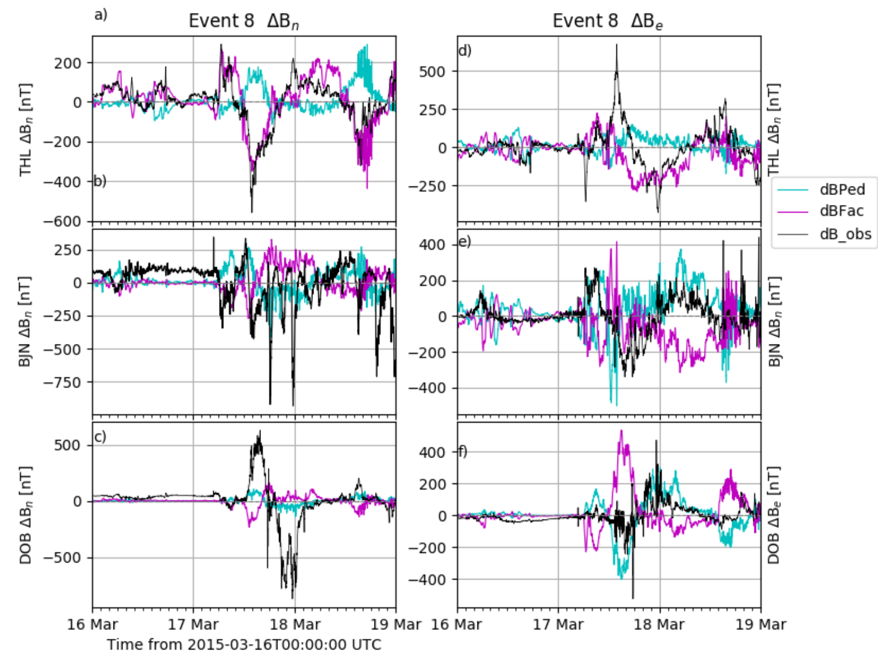


Event 8: ΔB due different sources

From Hall currents

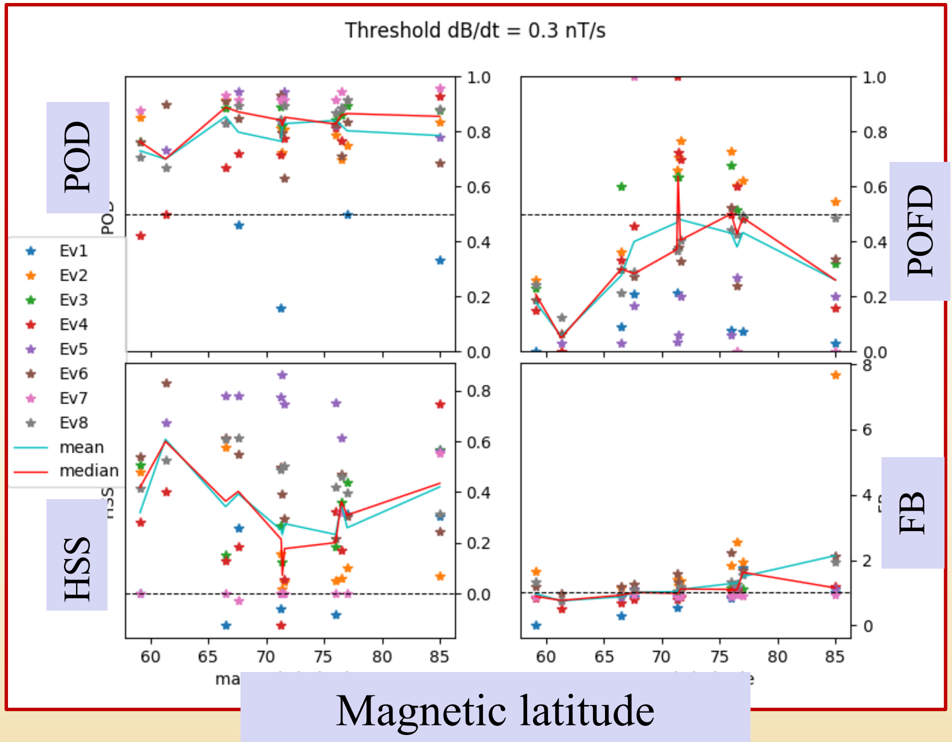


From Pedersen and FACs



- Opposite direction of perturbations ⟹ misplacement of current with respect to station
- Hall current dominate but other sources contribute. FAC and Pedersen do not completely cancel

dB/dt Metrics : $Th = 0.3nT/s$



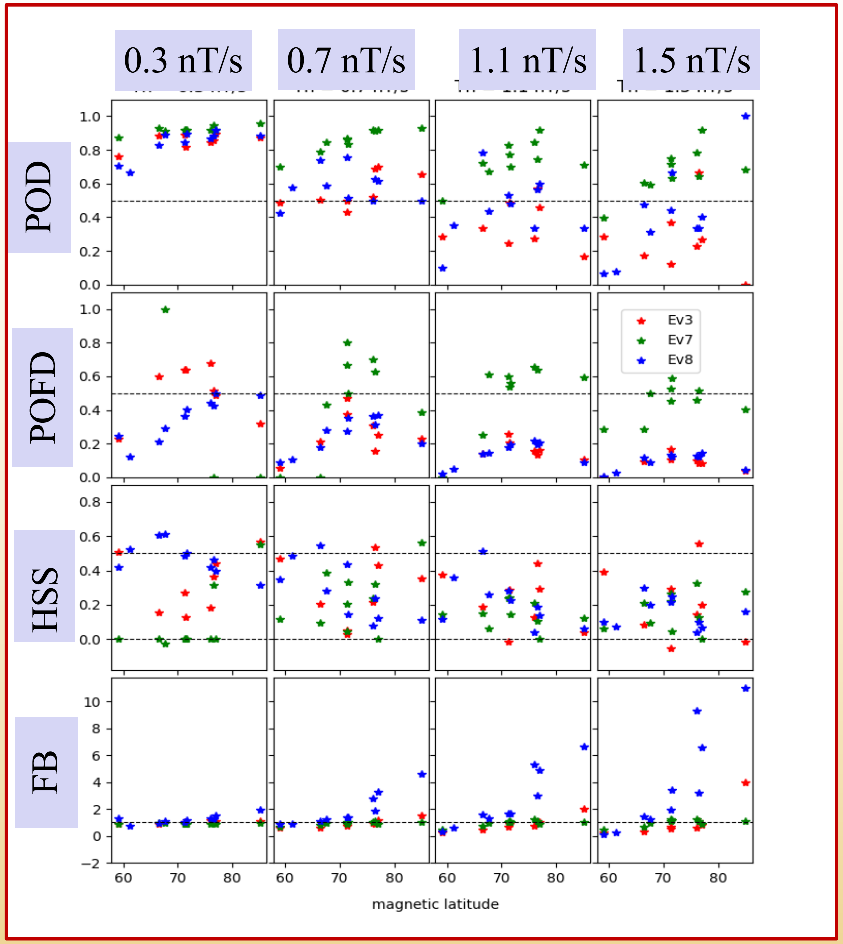
POD – Probability of Detection (Perfect score 1)
POFD – Probability of False Detection (Perfect score 0)
HSS – Heidke Skill Score (Perfect score 1)
FB – Frequency Bias (Perfect score 1)

- Forecast window of 20 minutes
- Threshold 0.3 nT/s
- H=hits, M=misses,
- N=correct no-event, F=false alarm
- {H,M,N,F} used to calculate metrics

Results

- Performs well with respect to POD
- Better than a guess (HSS>0)
- Also has the skill to predict (max HSS >0.8)
- Tends to predict events faster than nature at > 70^0 latitude (FB>1)
- High POFD at auroral (>65 <80) latitudes

dB/dt Metrics at different Thresholds



- Most intense events (3, 7, 8)
- For increasing threshold;

  POFD decreases

- However,

  POD decreases (still some POD>0.5)
  HSS slightly decreases

- The rate at which events are predicted tends to divert more from nature (FB>1 & FB<1)

Event 8 dB/dt

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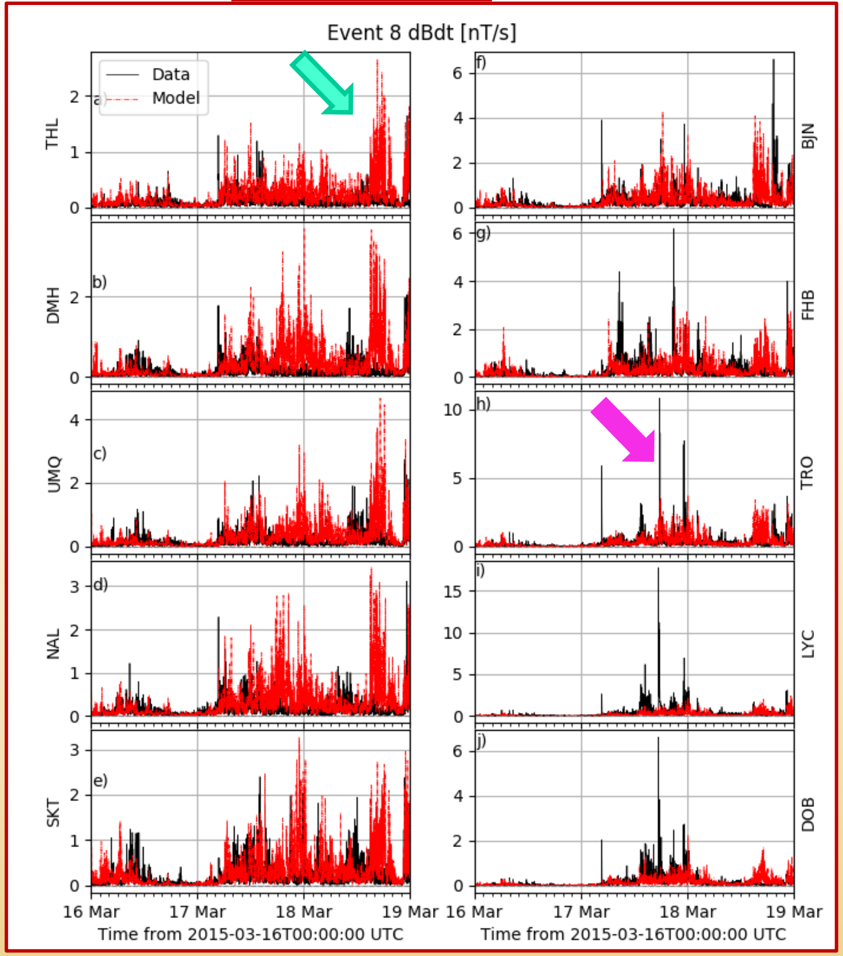
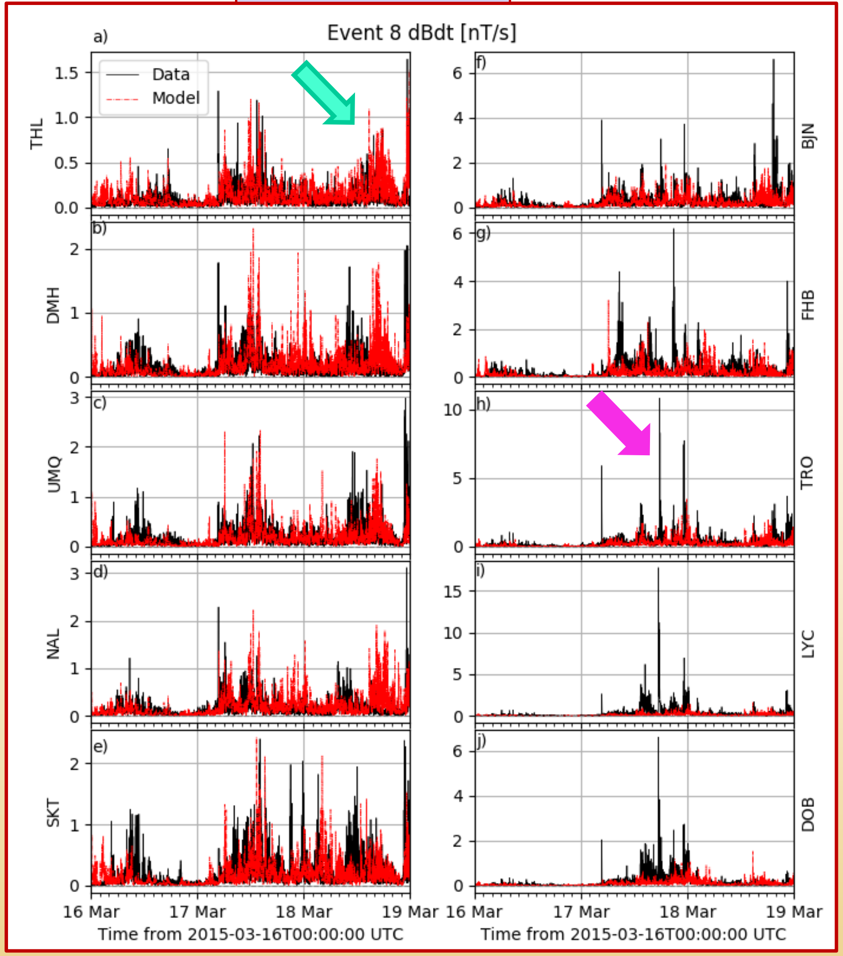
Sokolov scheme



Rusanov scheme



Summary

- SWMF tends to capture the general trend of the geomagnetic perturbations on the ground
- It performs better at high latitudes (i.e., > 70°) capturing most of the perturbations both in trend and magnitude, particularly at the start and expansion of large perturbations
- SWMF sometimes overestimates the magnitude of the perturbations at high magnetic latitudes particularly ΔB_n
- It just manages to predict high dB/dt threshold crossing but performance score decreases for such predictions
- Sometimes SWMF underestimates the intense (e.g., 16nT/s) brief perturbations which could be connected to very localised current structures and/or misplacement of the current with respect to the virtual station.

- Relatively precise predictions can be acheived using the SWMF, particularly at high latitudes

THANK YOU!

Acknowlegment

We acknowledge ;

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