Ionosphere Thermosphere Storm on 2023 March Strom Using Observations and TIEGCM Driven with Data Assimilated Electric Potential and Aurora

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Abstract

We investigate the thermospheric response to the March 23–24, 2023 geomagnetic storm (Kp = 8) using GOLD, PFISR, and TIEGCM simulations driven by data-assimilated auroral energy and high-latitude electric fields. Lattice Kriging is used to assimilate auroral energy inputs from THEMIS/ASIs and DMSP/SSUSIs, and electric fields derived from line-of-sight ion drifts measured by PFISR and SuperDARN. Compared to the default TIEGCM run, the assimilation run better captured storm-time responses: a) E-region enhancement in electron density, (b) elevated neutral temperature, and (d) high-latitude O/N₂ depletion. The transportation of electron density is consistent with meridional wind associated with electric field variability. We show that data assimilation of high latitude drivers significantly improves TIEGCM's ability to represent storm-time dynamics.

Methodology

Aurora
- Observation (DMSP/SSUSI & THEMIS/ASIs)
- Empirical Model (Zhang & Paxton,2008)

E- field
- Observation (SuperDARN & PFISR)
- Empirical Model (SuperDARN SHF)

Lattice Kriging
y(x)= μ(x) + g(x)+e(x)
μ(x): background mean
g(x): cov x basis function
e(x): error

Auroral Map

TIEGCM model
Resolution:1.25x1.25x1/8
(lat x long x scale height)
Temporal: 2 minutes

Potential Map

NE, TE, O/N$_2$

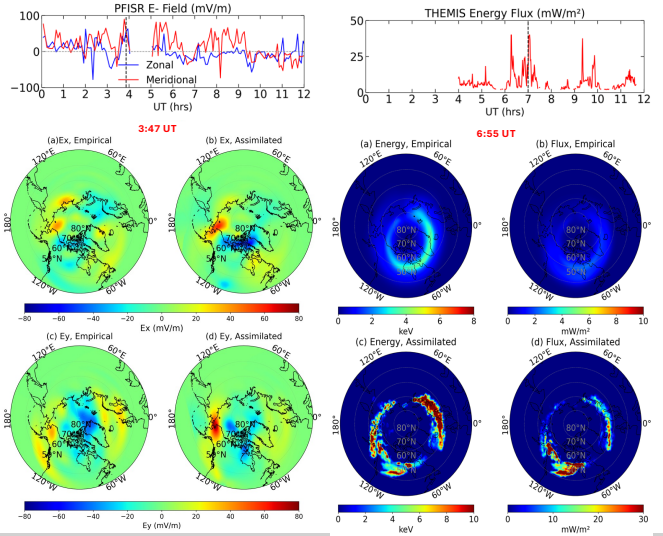
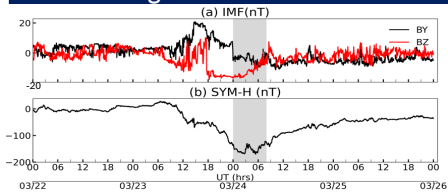


Figure: Comparison of empirical and assimilated high-latitude inputs (Aurora and electric field) on the March 24, 2023. Time corresponds to black dotted line in top figures of PFISR electric fields and THEMIS auroral energy flux.

➢ **Data-assimilated aurora and electric field maps display finer spatial structures and mesoscale features; compared to empirical models.**

Geomagnetic Storm of March 23-24, 2023



- IMF Bz turned south (–17nT) on 18 Ut of March 23 and remain south for ~10 hrs.
- Dst dropped to -169 nT around 02 UT, Mar 24

Figure: Geomagnetic indices from March 22 to March 25

PFISR Observation

➢ Electron density decreased on the storm day compared to the quiet day -- a **negative ionospheric response** to geomagnetic storm at Poker Flat

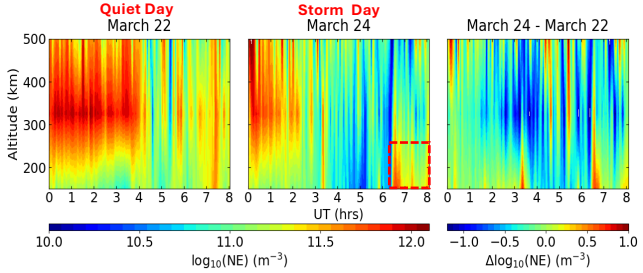


Figure: PFISR observation of electron density on March 22, March 24 and the difference between March 24 and March 22. LT=UT- 8hrs

GOLD Observation

➢ Neutral temperature increased to ~1200 K in high latitudes during the storm day, over 200 K higher than on the quiet day

➢ O/N₂ ratio decreased by more than 0.4 in high-latitude regions, indicating significant composition changes.

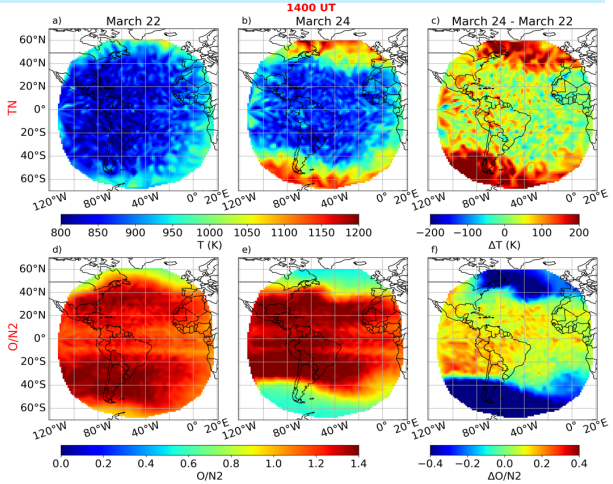


Figure: GOLD observations of TN and O/N₂ ratio on March 22 and March 24 , along with the respective differences showing storm-day values relative to the quiet day at 14:00 UT.

Results : TIEGCM Simulation

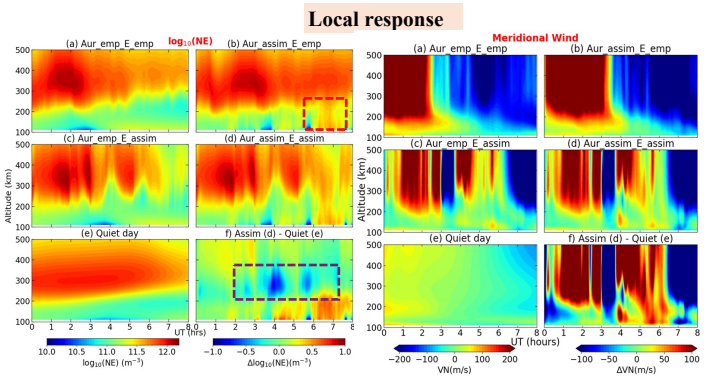


Figure: Electron density and meridional wind derived from TIEGCM simulation at PFISR location

➢ Aurora assimilation in TIEGCM captures **enhancements in E-region electron density.**

➢ **Negative ionospheric response** is partially captured.

➢ Electric field assimilation drives variability in meridional wind, which can redistribute plasma and potentially move electron density in or out of localized region

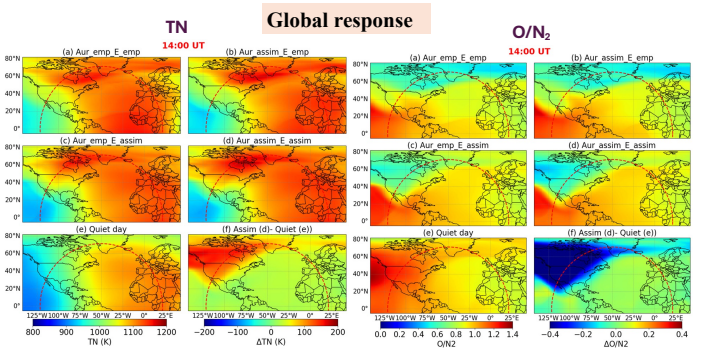


Figure: Neutral temperature and O/N₂ ratio from the TIEGCM simulation. The red curve indicates the field of view of the GOLD.

➢ The assimilation run of TIEGCM captures enhanced neutral temperature (~1200 K) and reduced O/N₂ ratio (~0.4) in high-latitude

➢ Electric field drives the transport of neutral species, resulting in strong O/N₂ depletion extending up to 20^{0}N, while temperature enhancement arises from both forcings.

➢ **Future work:** Investigate the roles of neutral winds, Joule heating, and circulation patterns in driving O/N₂ depletion and temperature enhancement.

Conclusions

➢ Data assimilation of aurora and electric fields improves the IT responses of TIEGCM compared to the default model run.

➢ Horizontal winds driven by electric fields can transport electron density locally, while E-region density enhancement is due to aurora.

➢ O/N2 depletion in high latitude region is mainly driven by electric field, whereas neutral temperature is induced by both aurora and electric field.

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