Unraveling the Ionospheric Storm-Enhanced Density Formation, Interhemispheric Asymmetry and Role in Plasmaspheric Refilling Using GITM-SAMI3

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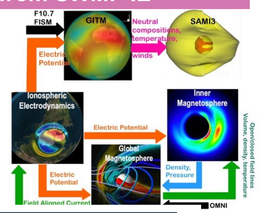
1. Introduction

- During geomagnetic storms, ionospheric storms consist of large-scale variations of ionospheric electron density. Ionospheric responses are complex because it has EM-coupling with the SW-magnetosphere and collisional-coupling with the thermosphere.
- SEDs are electron density enhancements (positive phase) that often occur in the mid-latitude regions from post-noon to dusk sector during storm times. Occasionally, SEDs extend northwestward to higher latitudes and form a SED plume.
- The plasmasphere is eroded during a storm and refills during quiet times with different time scales. Plasmaspheric plume and refilling reflect the interplay among magnetosphere, ionosphere and thermosphere.
- Understanding these storm-time density variations are crucial for modern technology and communication.

2. Methodology

April 2023 storm by GITM-SAMI3 with high-latitude driver from SWMF-IE

- 1st southward Bz turning: 04/23/18--21 UT due to ICME sheath
- Northward Bz period: 04/23/21 -- 04/24/01:40 UT
- 2nd southward Bz turning: 04/24/01:40 – 11:00 UT
- Minimum Dst reached -233 nT at 04:00 UT on 04/24



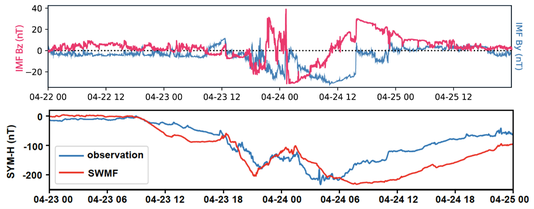


Fig 1. Solar Wind Conditions

3.1 Model-Data Comparison

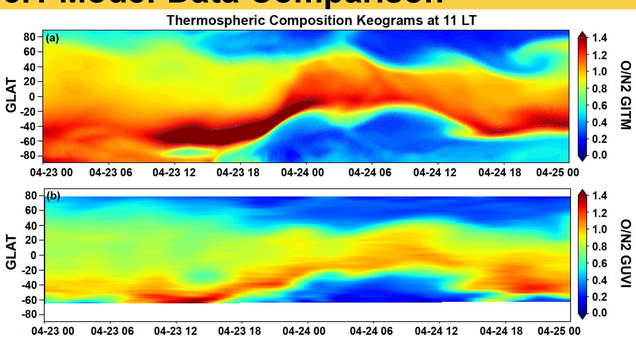


Fig 2. O/N2 from Model and Gold Observation

- With limited satellite TEC observation, we compared the keograms of O/N2 from model and GOLD at 11 local time.
- The comparison showed a good alignment that southern O/N2 enhancement moved equatorward after 18 UT, April 23rd, representing the negative phase of ionosphere.

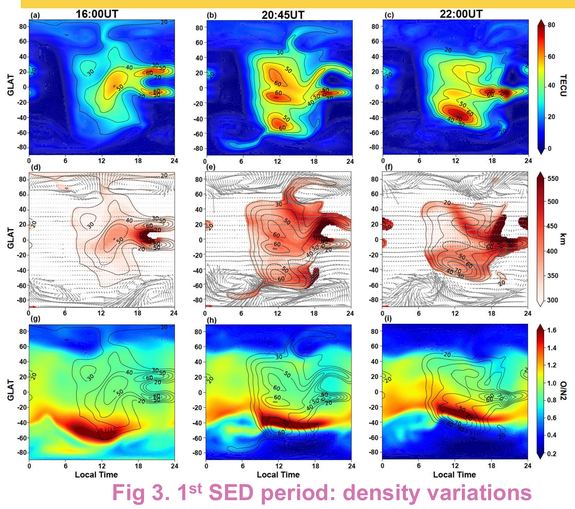


Fig 3. 1st SED period: density variations

Storm (04/23/20:45 UT)
- Bifurcated EIA; Plumes at both hemispheres; Southern SED is separated from EIA; Enhanced O/N2 overlapped southern SED

Northward Bz (04/23/22:00 UT)
- Weakened EIA; Southern SED merged with EIA; Strong equatorward wind surge signatures; Southern O/N2 enhancement moves equatorward

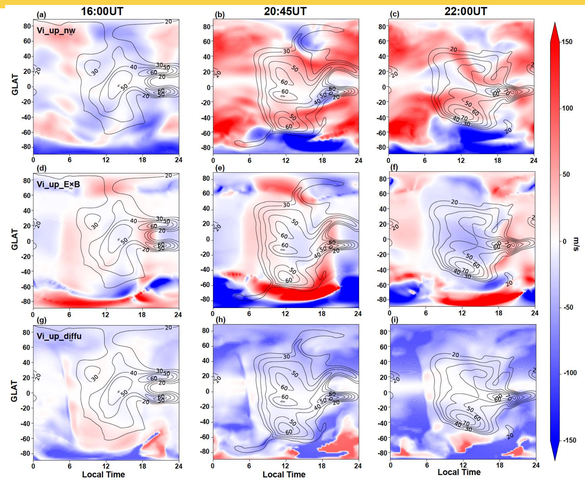


Fig 4. 1st SED period: upward drifts

Storm (04/23/20:45 UT)
- Strong neutral wind component was upward 100 m/s at SED and downward at plumes. E-field component was upward poleward edge of SED

Northward Bz (04/23/22:00 UT)
- Large wind surge propagated southward and lift plasma up
- Convection E-field retreats with downward drifts at mid-latitudes

3.2 Results: 1st Southward Bz Period

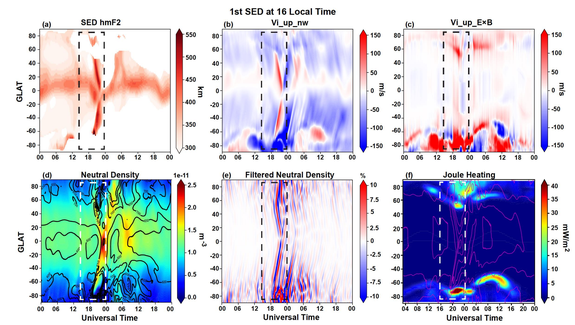


Fig 5. 1st SED period: keograms

- SED hmF2 and neutral wind induced ion drift showed equatorward propagation. E field induced drift is hemispheric asymmetry.
- Similar equatorward neutral density perturbation (TAD)
- average perturbed ~12% with 2h period
- More Joule Heating in the south hemisphere

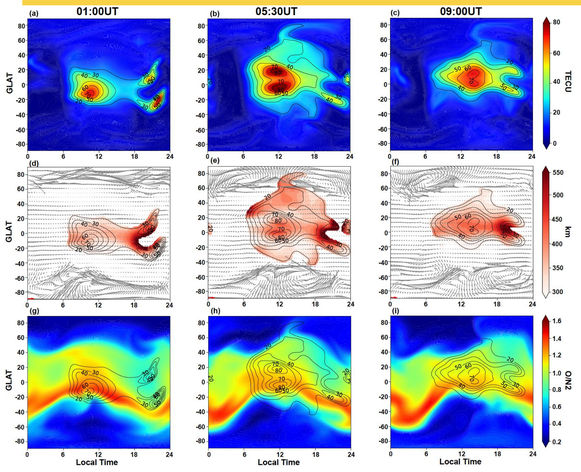


Fig 6. 2nd SED period: density variations

Pre-southward turning (04/24/01 UT):
- One peak EIA; Negative phase of O/N2 reduction

Storm peak (04/24/05:30):
- Bifurcated EIA but closer; Weak northern SED with plume, and southern SED did not grow; O/N2 at noon further decreased

Recovery phase (04/24/09:00 UT):
- SED and plumes decayed; ON2 ratio existed only at equatorial region at dayside

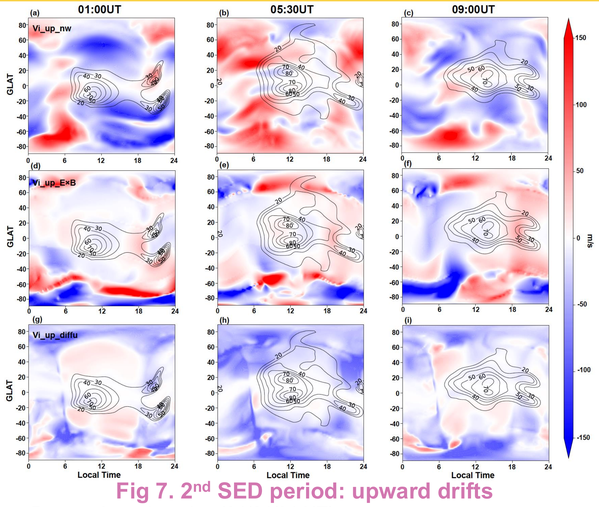


Fig 7. 2nd SED period: upward drifts

Pre-southward turning (04/24/01 UT):
- Strong downward neutral wind induced ion drift.

Storm peak (04/24/05:30):
- Moderate neutral wind component at northern SED. Strong uplifting by E field was confined at auroral latitude.

Recovery phase (04/24/09:00 UT):
- Neutral wind component became downward.

3.3 Results: 2nd Southward Bz Period

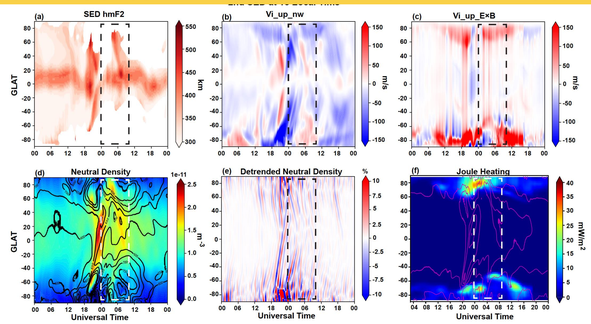


Fig 8. 2nd SED period: keograms

- SED hmF2 was higher in the north. E-field induced ion drift remained hemispheric asymmetric.
- Weaker propagating TAD only in north with perturbation at ~5%/
- More Joule heating in the northern hemisphere.

4. Conclusions

SED Formation:
- Equatorward neutral wind induced upward ion drift was the primary driver at mid-latitudes; E fields dominated at the high latitudes.
- Thermospheric composition changes were important

SED IHA:
- **Pre-storm modulation:** seasonal effect with small negative Bz prior to the storm lead to enhanced O/N2 in the south hemisphere.
- **Storm reinforcement:** had more enhanced O/N2 in the south hemisphere due to neutral circulation induced by auroral zone energy input. Thus, sufficient plasma production was provided to the isolated southern SED.
- **Magnetic pole offset and UT effects:** strong convection with Joule heating further expanded and pushed enhanced O/N2 to lower latitudes during magnetic cloud, which limited the southern SED growth.

Effects of IT preconditioning by thermospheric composition even within one ICME

5. Future Work on Plasmasphere

Fig 9. Magnetic equatorial plane of inner magnetosphere and plasmasphere

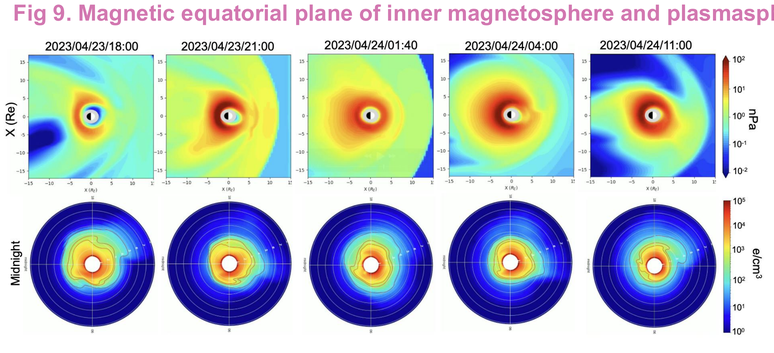
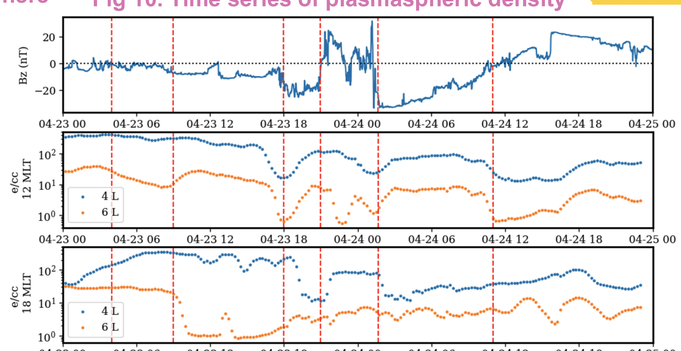


Fig 10. Time series of plasmaspheric density



- Day-night asymmetry of ring current are well corresponded with southward Bz periods.
- Three times of strong nightside plasmasphere erosions occurred at 4/23/09 UT, 4/23/18 UT and 4/24/01:30 UT.
- The most persisted dayside plasmaspheric plume was formed at ~ 4/24/04 UT and corotated until 4/24/13 UT.

Acknowledgements:
NASA LWS 80NSSC20K0190,
NASA HSR 80NSSC20K1313,
NASA 80NSSC23K0407