Impact of Ionospheric Density Structures on Ion Upflow Flux during the April 2023 Geomagnetic Storm

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Motivation

- Earth's ionosphere is a crucial source of heavy ions (O+, etc.) for magnetospheric dynamics.
- During a geomagnetic storm's positive phase, strong mid-to-high-latitude density structures (storm-enhanced density, SED plumes) may form.
- Transport of high-density structures into regions with enhanced precipitating particle fluxes or enhanced convection flows can generate large ion upflow fluxes.
- Case study: CME-driven storm from April 23 and April 24, 2023.

Question 1: How do ionospheric high-density structures appear and evolve during geomagnetic storms?

Question 2: How do these structures affect ion upflow flux?

Datasets

Parameter	Source
IMF components and SYM-H (1)	High Resolution OMNI
Ionospheric total electron content (TEC) (2) (3)	Madrigal GNSS / VISTA algorithm
Thermospheric O/N2 ratio (2)	TIMED GUVI
Ionospheric field-aligned currents (FAC) (3)	AMPERE / Iridium satellite
Ionospheric ion density / velocity (4)	DMSP satellites F16, F17, F18

Results

1 Storm Parameters

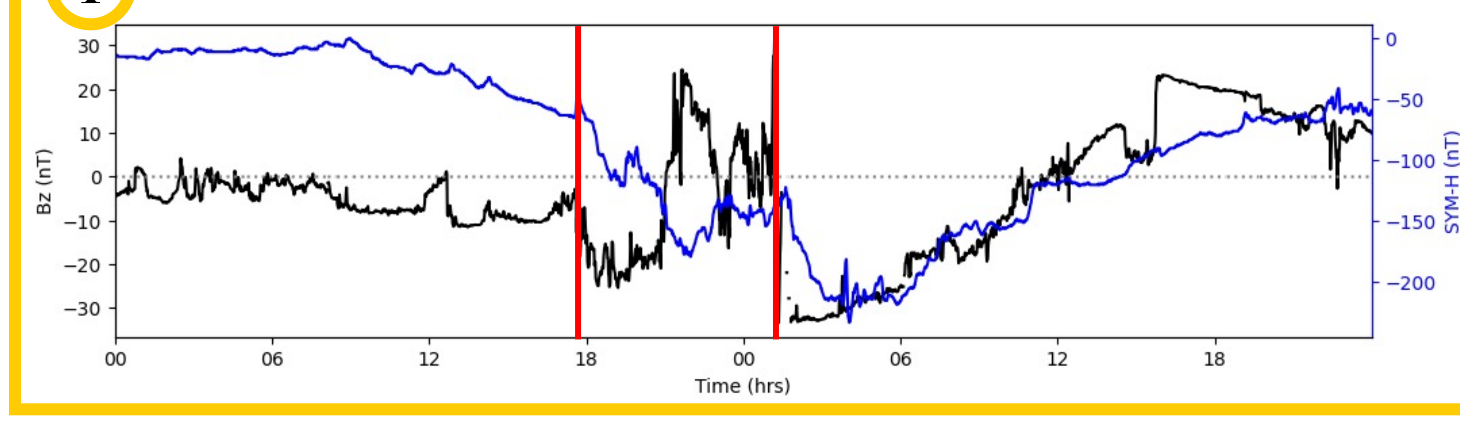


Figure 1: IMF B_z (black) and SYM-H index (blue) on April 23-24, 2023. Vertical lines mark the two major southward turnings of B_z.

2 Simultaneous Development of TEC and O/N2

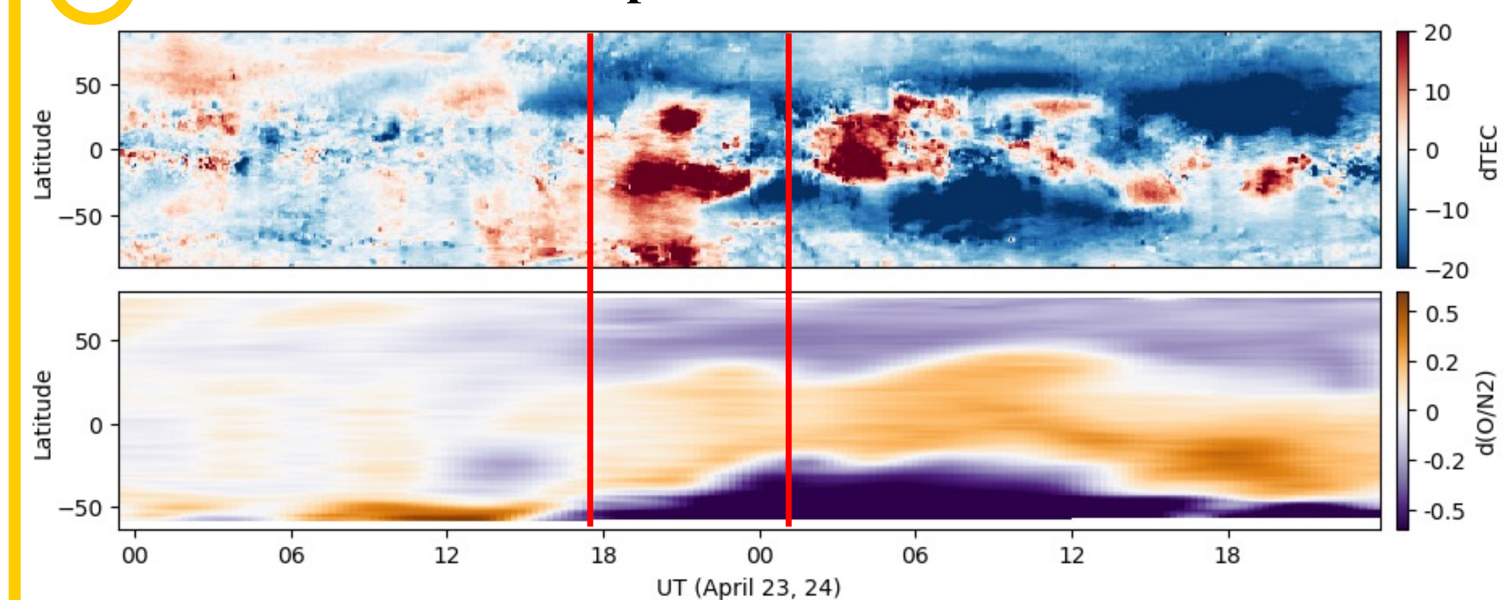
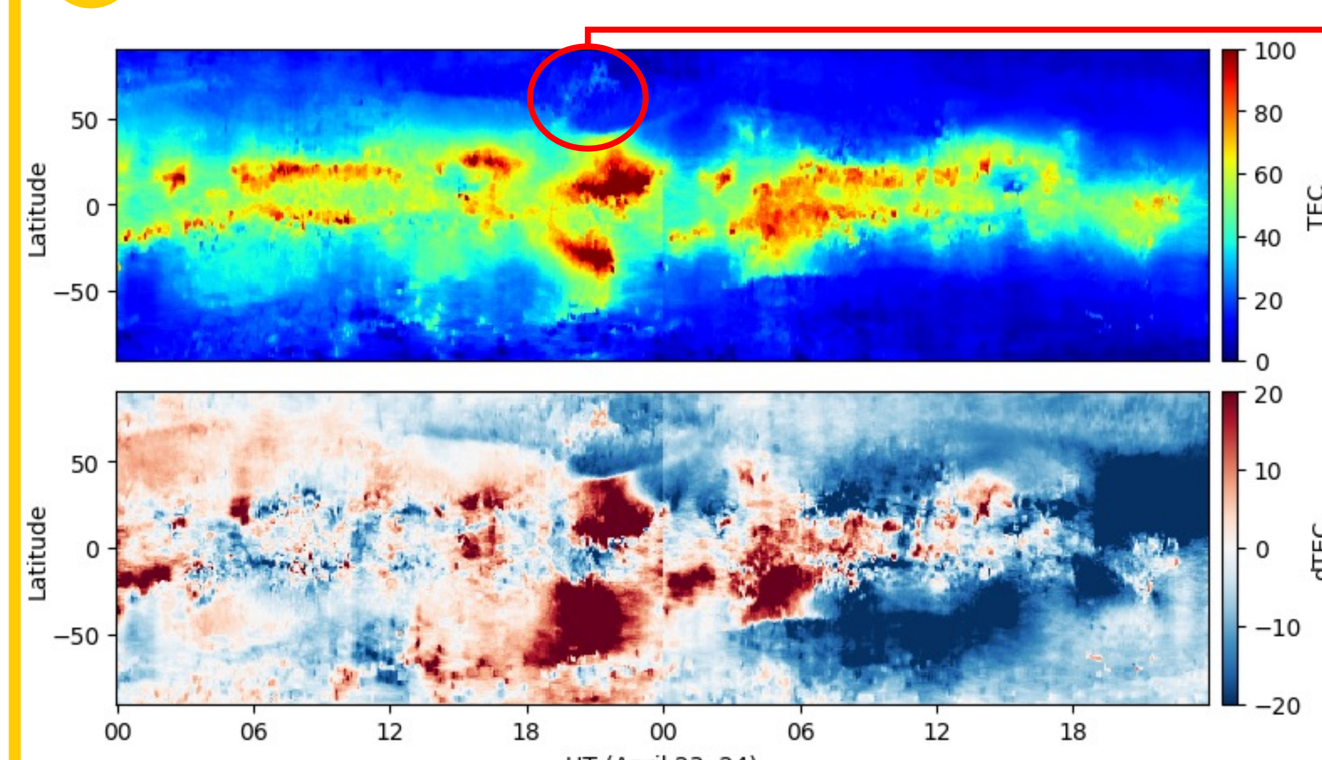


Figure 2: (top) TEC at 11 LT with quiet-time background subtracted and (bottom) O/N2 ratio with background subtracted. Vertical lines mark same times as in Figure 1.

1. We see **two separate positive phases** that follow the two southward turnings of IMF B_z.
2. The negative phase is initiated at high latitudes after the first southward turning, which modulates the effect of the second turning (and minimum SYM-H period). The second positive phase is confined to lower latitudes.
3. There are **clear hemispheric asymmetries** in dTEC and d(O/N2). The positive phase and O/N2 ratio are both larger in the southern hemisphere.

3 Storm-Enhanced Density Plumes



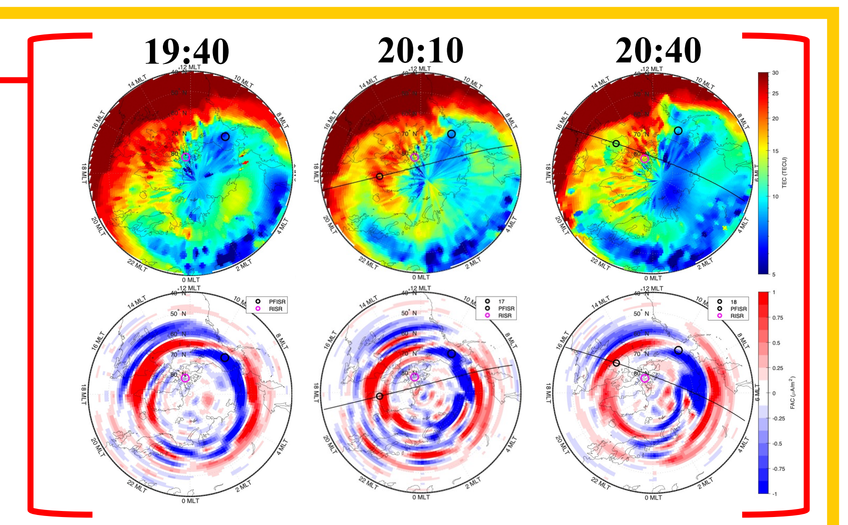


Figure 3: (top) TEC and (bottom) dTEC at 16 LT. Polar-view plots show the evolution of (top) an SED plume and (bottom) concurrent FACs.

1. Multiple high-density structures formed in the ionosphere, including **two SED plumes** in the afternoon sector (~20 UT April 23 and ~00 UT April 24).
2. The first plume extended to the nightside over the pole while the second plume was regionally confined due to the high-latitude negative phase.

4 Ion Upflow Flux

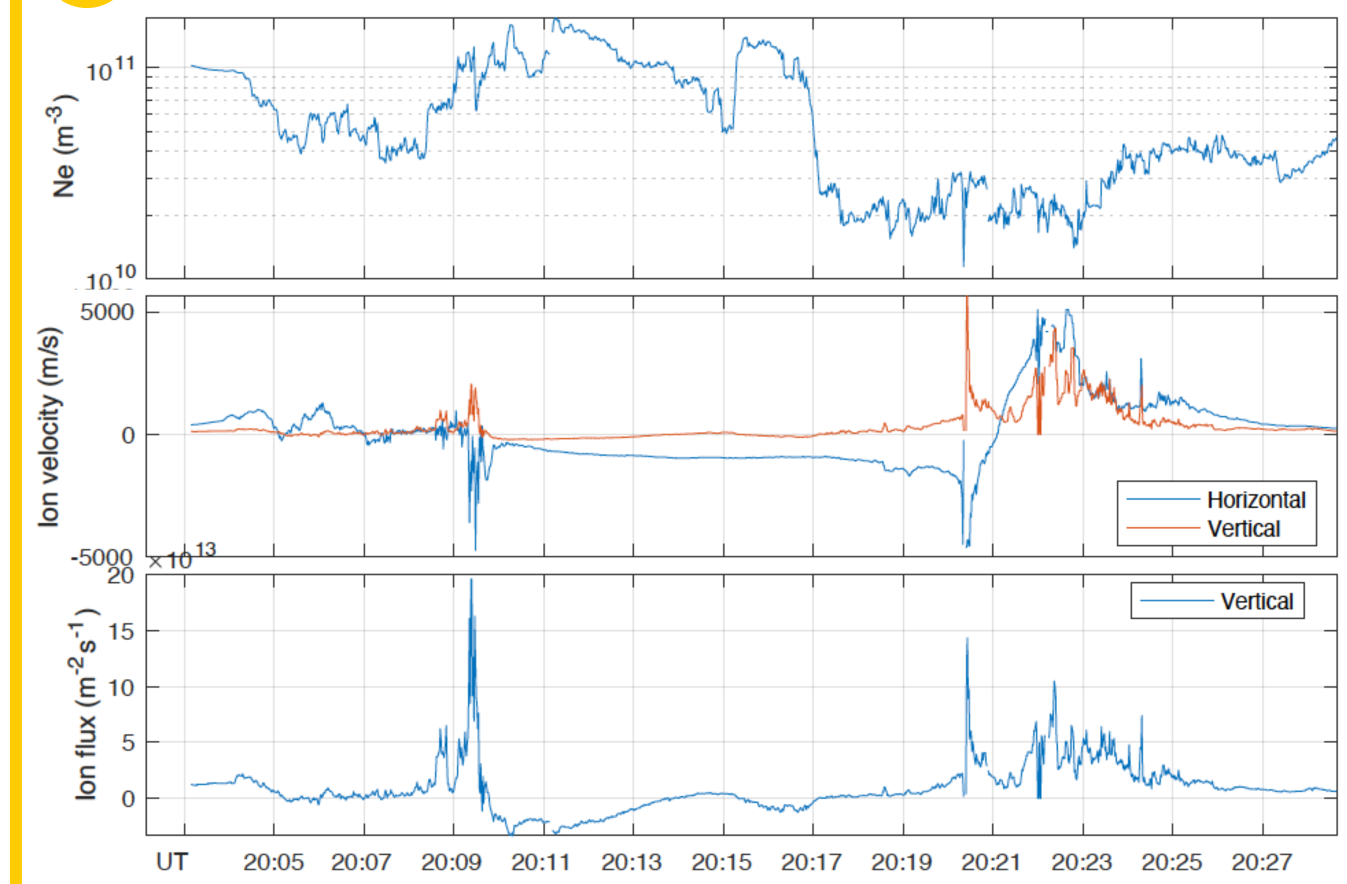


Figure 4: Plasma density, ion velocity, and ion flux measured by DMSP F17 around 20:00 UT on April 23.

We see a **large positive ion flux** when the satellite passes over the SED plume highlighted in Figure 3 (~20:10 UT).

Conclusions + Future Work

- The thermospheric composition has an important effect on the state of the storm-time ionosphere and should be considered alongside IMF / SYM-H.
- The dynamics and extent of structures like SED and SED plumes are strongly influenced by the storm phase.
- Ionospheric density structures can contribute to significant upward ion fluxes in the high-latitude regions.

Continuing work:

- Investigate other storms, including CIR-driven storms, and perform a statistical analysis of upflow events.
- Integrate more TEC data products (JASON, GOLD, COSMIC-2) into the VISTA algorithm to improve tracking of high-density structures.

Acknowledgements

- NASA grants 80NSSC20K0190 and 80NSSC20K1313
- University of Michigan Rackham Merit Fellowship

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