Multi-Instrument Analysis of Low Latitude Ionospheric Perturbations During Intense Geomagnetic Storm in the descending phase of solar cycle 24

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OVERVIEW

The **26 August 2018 geomagnetic storm (Dst ≈ −174 nT)** produced significant ionospheric disturbances over **Varanasi (25.3176°N, 82.9739°E)**. This study demonstrates that storm-time electrodynamic processes affected the **entire ionosphere from the D-region to the F-region**. While satellite and TEC measurements indicate **F-region uplift and enhanced ionization**, VLF observations show a **decrease in D-region electron density**, revealing strong vertical coupling of the ionosphere during geomagnetic storms. These results highlight that storm-time disturbances simultaneously impact all ionospheric layers.

INTRODUCTION

Geomagnetic storms are large-scale disturbances in the Earth's magnetosphere caused by enhanced solar wind–magnetosphere coupling, often triggered by coronal mass ejections (CMEs) or high-speed solar wind streams. These storms significantly modify the ionosphere–thermosphere system through changes in electric fields, particle precipitation, and neutral winds, leading to strong variations in ionospheric electron density and plasma dynamics.

DATA SOURCES

We have used the Automatic Whistler Detector (AWD) VLF receiver situated at Banaras Hindu University (BHU), Varanasi. IGS data are available at https://cddis.nasa.gov/archive/gnss/data/daily. DMSP data are available from the Madrigal Database http://cedar.openmadrigal.org. COSMIC data are available at https://www.cosmic.ucar.edu/what-we-do/cosmic1/data. SWARM data are available at https://vires.services. Planetary Vx, Bz, Kp and Dst indices are extracted from Kyoto website http://wdc.kugi.kyoto-u.ac.jp/dstdir/.

RESULTS

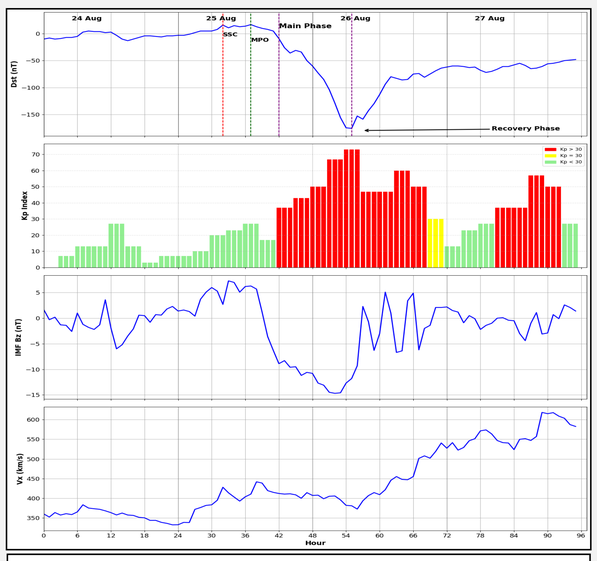

Figure 1: Temporal variation of geomagnetic indices and solar wind parameters during the **25–27 August 2018** storm. The Dst index reached a minimum of **-175 nT** with a maximum Kp index of **7+**, signifying an intense geomagnetic storm. The southward excursion of **IMF Bz (~-15 nT)** and increased solar wind speed (**Vx > 600 km/s**) illustrate the solar forcing responsible for the observed magnetospheric-ionospheric coupling.

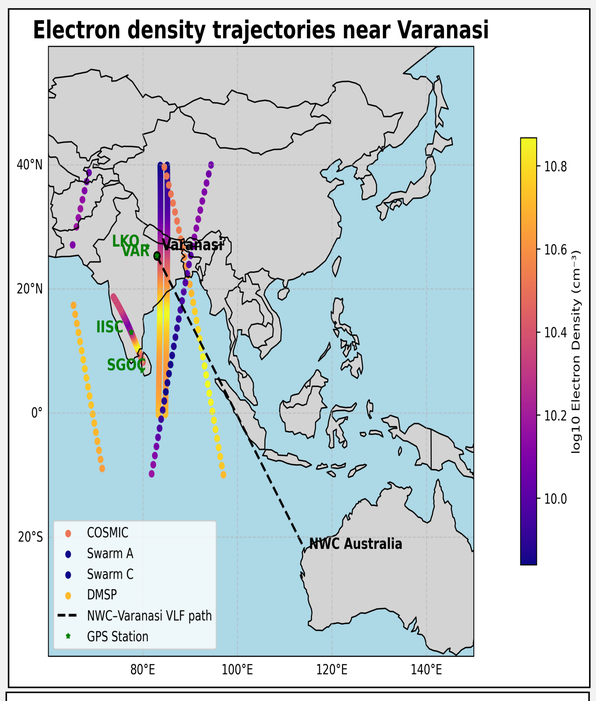

Figure 2: Spatial distribution of COSMIC, Swarm A/C, and DMSP satellite trajectories over the low latitude station, with the electron density (cm^{-3}) illustrated by the color bar, also showing variations of NWC-Varanasi VLF propagation path and different IGS stations.

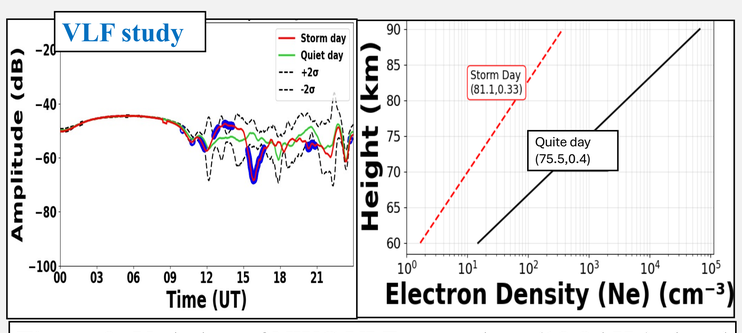

Figure 3: Variation of NWC VLF transmitter (19.8 kHz) signal amplitude recorded at Varanasi. The green line represents the five quiet day mean, while the black dashed lines indicate the ±2σ variability limits. The red line shows the storm day amplitude, where excursions beyond ±2σ (highlighted in blue) reveal storm-induced D-region perturbations and corresponding shifts in the electron density profiles.

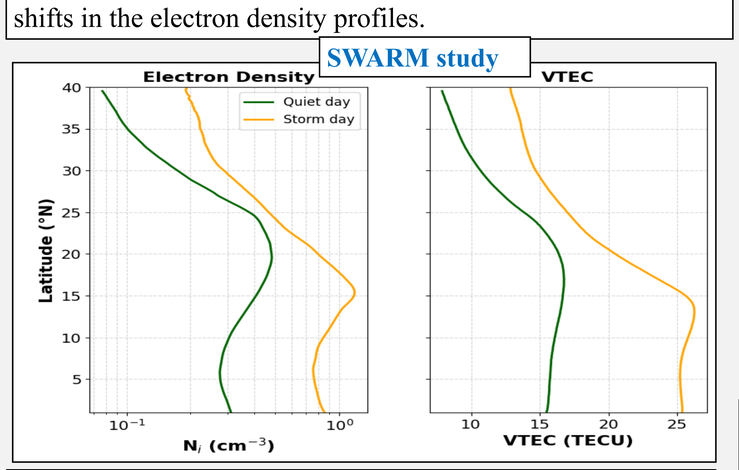

Figure 5: Latitudinal variation of ionospheric parameters derived from SWARM, comparing quiet-day (green line) and storm-day (orange line) conditions during the 26 August 2018 geomagnetic storm. The left panel shows the variation of N_i, while the right panel presents VTEC along the satellite track.

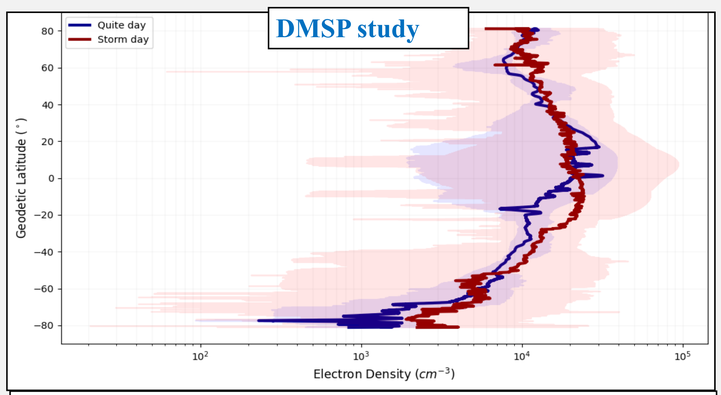

Figure 6: Latitudinal variation of electron density (Ne) derived from the DMSP, comparing quiet-day (dark blue) and storm-day (dark red) conditions during the 26 August 2018 geomagnetic storm. The storm day shows enhanced electron density and a partial filling of the equatorial depletion, indicating storm-time plasma redistribution.

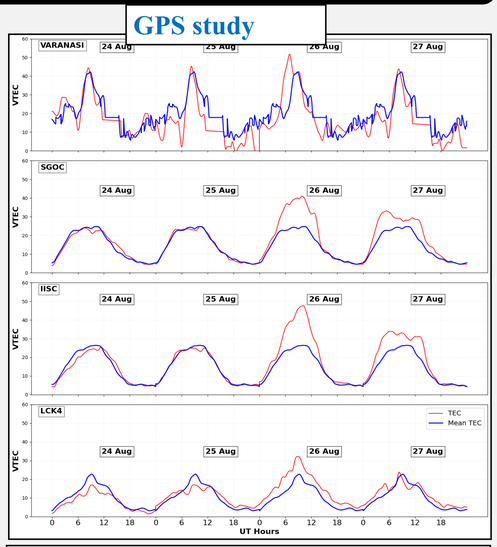

Figure 4: Temporal variation of Vertical Total Electron Content (VTEC) observed at four low latitude IGS stations—Varanasi, Shamshabad (SGOC), Bengaluru (IISC), and Lucknow (LCK4)—during 24–27 August 2018. The red line represents VTEC variations on the geomagnetic storm day (26 August 2018), while the blue line indicates the mean VTEC calculated from five geomagnetically quiet days.

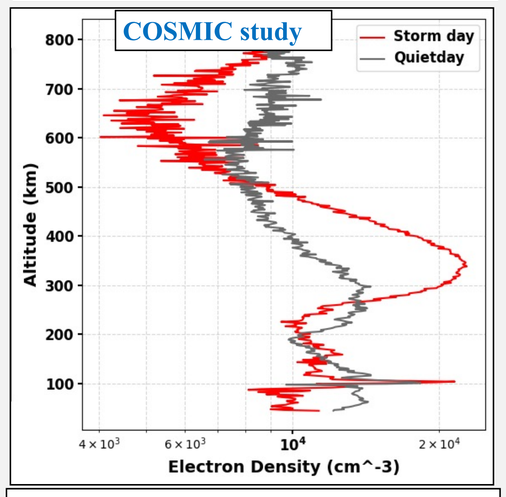

Figure 7: Altitude variation of Ne derived from COSMIC observations, comparing quiet-day (grey line) and storm-day (red line) conditions during the 26 August 2018 geomagnetic storm. The profile shows enhanced density in the F-region (≈250–500 km), depletion at higher altitudes (>600 km), and noticeable fluctuations near ~100 km, indicating the storm-time response of the ionosphere from the D-region to the F-region.

CONCLUSION

- **Multi-instrument observations reveal storm-time coupling across the entire ionosphere (D–F region)** during the **26 August 2018 geomagnetic storm** over **Varanasi**, demonstrating that geomagnetic disturbances simultaneously impact both the lower and upper ionosphere.
- VLF observations from the NWC VLF Transmitter–Varanasi path show clear amplitude perturbations, indicating modifications in the D-region electron density.
- GNSS-TEC measurements reveal enhanced TEC during the storm, suggesting a positive ionospheric storm effect in the low-latitude region.
- Satellite observations from SWARM, DMSP, and FORMOSAT-3/COSMIC confirm storm-time changes in electron density and plasma redistribution across different altitudes, indicating a positive ionospheric storm effect and strengthening of low-latitude ionospheric dynamics.

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