

**Longitudinal Dependence of
Ionospheric
Irregularities to Maximum Ring
Current and PPEF
during the Storm of 4 November
2021**

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Outline

- Objectives
- Case Study: November 4, 2021 storm
- Methodology: Data Sources used
- Observations:
 - Magnetic Signatures
 - Plasma Density Variations: GIMs and ROTI
 - Thermospheric Neutral Composition
- Summary

Objectives

- To analyze multi-instrumental data to investigate the behavior of equatorial/low latitude ionosphere during the geomagnetic storm of November 3-5, 2021.
- Special attention on the storm-time ionization level and the occurrence of ionospheric plasma irregularities over different longitudes.
- To investigate the role of different physical factors such as the local time of the occurrence of maximum excursion of the ring current, and the under shielding electric field (Prompt Penetration Electric Field (PPEF)).

Data Sources

Solar wind parameters and magnetic indices

The screenshot shows the OMNIWeb website interface. It features a search bar at the top right with the text "SEARCH NASA" and a "GO" button. Below the search bar, there are several navigation tabs: "HOME", "Mission Data", "ModelWeb at CCMC", "SCIENCE ENABLED", and "AND MORE". The main content area is divided into several sections: "OMNIWeb", "Browse and Retrieve OMNI Data", "Browse and Retrieve New OMNI Data", and "S/C Specific Data shifted to BSN". Each section contains a list of data types and formats available for retrieval, such as "Plots, listings, output files", "Listings, plots/output files with filtering", "Scatter plots and linear regression fits", and "Distribution functions, averages, std dev".

GNSS receivers and magnetometers used

| Instrument Type | Station | Sector | Geographic Latitude | Geographic Longitude |
|-----------------|---------|---------|---------------------|----------------------|
| GNSS | MRO | Asia | 26.70° S | 116.64° E |
| GNSS | BRUN | Asia | 4.97° N | 114.95° E |
| GNSS | HKSL | Asia | 22.37° N | 113.93° E |
| GNSS | MFKG | Africa | 25.81° S | 25.54° E |
| GNSS | NKLG | Africa | 0.35° N | 9.67° E |
| GNSS | MAS | Africa | 15.63° N | 15.63° W |
| GNSS | IQQ | America | 20.27° S | 70.13° W |
| GNSS | QUI | America | 0.14° N | 78.47° W |
| GNSS | SCUB | America | 20.01° N | 75.70° W |
| Magnetometer | DLT | Asia | 11.94° N | 109.1° E |
| Magnetometer | TAM | Africa | 5.53° N | 22.79° W |
| Magnetometer | KOU | America | 5.91° N | 52.93° W |

Geomagnetic field data

The screenshot shows the INTERMAGNET website interface. It features a "Data Download and Plots" section with a "Data Download and Plots" button. Below this, there is a "INTERMAGNET Data Portal Moving" section with a paragraph of text explaining the move from NRCAN to BGS. There are also several links for data visualization and download, such as "A data visualization and download web site: https://mag-data.bgs.ac.uk/GN_V3/GNForms" and "A description of the INTERMAGNET data access web service: https://mag-data.bgs.ac.uk/GN_V3/".

UQRG-GIM, vTEC and TEC

The screenshot shows the CDDIS website interface. It features a "Home About CDDIS Data and Products Techniques Programs Publications Citing our Data CDDIS Text Search" navigation bar. The main content area is titled "Hourly 30-second data" and contains a paragraph of text explaining the CDDIS archive and the data products available. There is also a link to the starting directory for the files: "https://cddis.nasa.gov/archive/gnss/data/hourly/".

Penetration Electric field

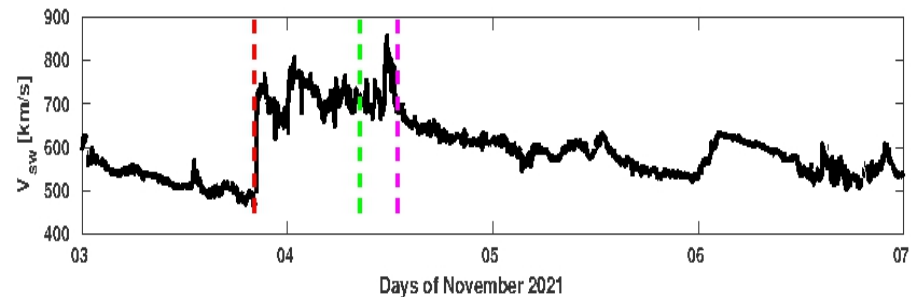
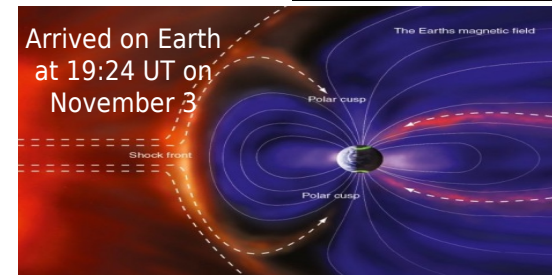
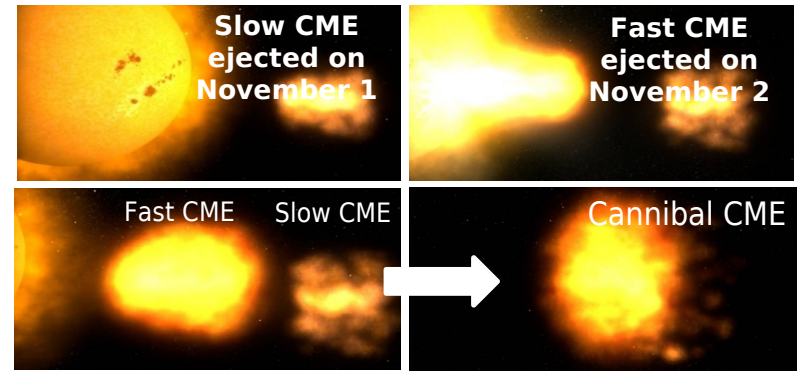
The screenshot shows a "Real-time model of the Ionospheric Electric Fields" application. It features a "Calculate form" section with input fields for "Start Date" (11/03/2021), "Start Time (UTC)" (0), "Longitude" (0), and "Number of days" (3). There are also radio buttons for "Penetration" and "Quiet" and a "Submit" button. To the right of the form is a line graph showing the "Penetration - Quiet" electric field (mV/m) over time. The graph shows a fluctuating signal with a peak around 12:00 on 03Nov and another peak around 12:00 on 05Nov.

The SIMuRG logo is a stylized black and white graphic of a globe with a lightning bolt. To the right of the logo, the text reads: "SIMuRG: System for Ionosphere Monitoring and Research from GNSS. SIMuRG is the tool for collecting, processing, storage and presentation of GNSS total electron content data. The data product are TEC variations series, corrected TEC, TEC variations maps, Wtec and Iv indices, ionospheric disturbances parameters". At the bottom right, it says "Developed under Russian Science Foundation support/project № 17-77-20005".

Case Study

Geomagnetic storm of November 3-5, 2021

- A cannibal CME resulting from the superposition of slow/ fast CMEs that are erupted on November 1 and 2 from active regions of Sun.
- It contains complex and enhanced magnetic fields.
- Arrived on Earth at 19:24UT on November 3 when a shock was observed in the solar wind parameters.



Magnetic Field Signatures

Interplanetary shock:

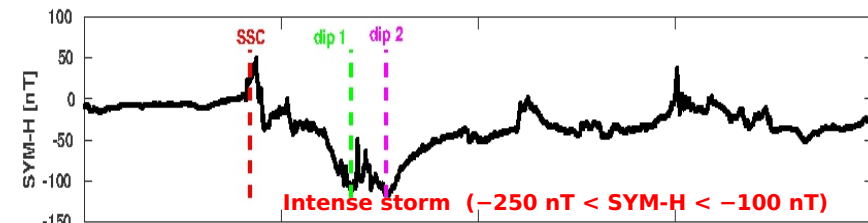
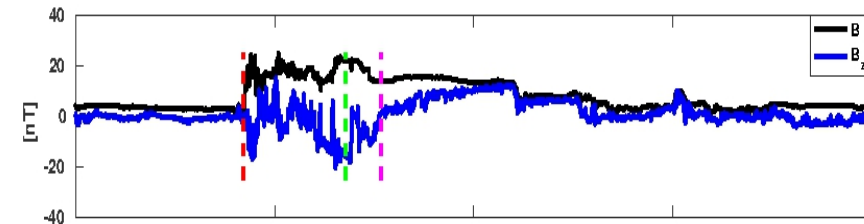
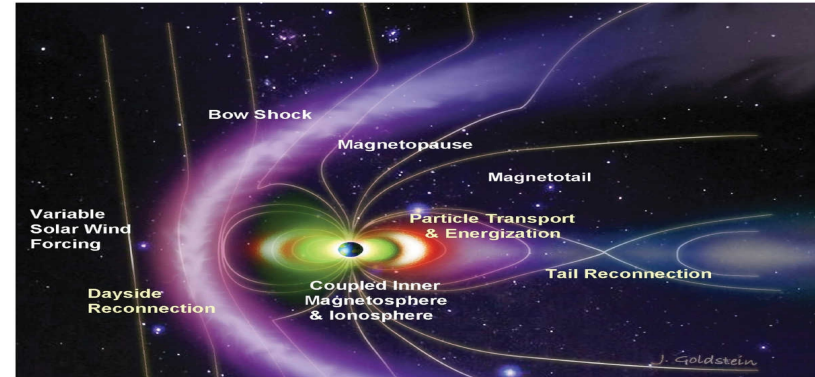
It compresses the magnetosphere, and causes increase of the horizontal component (H) of the geomagnetic field. This is the *Sudden Storm Commencement (SSC)* at 19:46 UT on November 3, 2021.

Southward IMF B_z :

- The magnetic re-connection occurs due to anti-parallel magnetic fields.
- The intensification of the ring current.
- A strong depression of H at the ground magnetometers.
- This is the *main phase* which persists for ~ 16 hr.

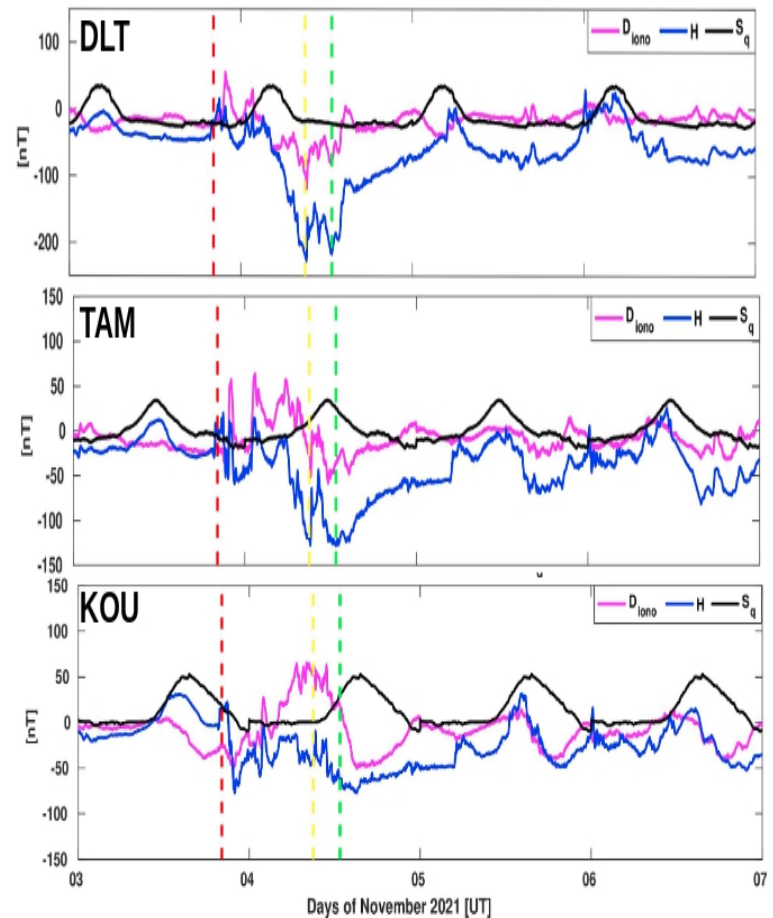
Northward IMF B_z :

- Parallel magnetic fields.
- Decrease in Ring Current
- Increase in H .
- The *recovery phase* starts at 12:44 UT.



Geomagnetic Field Variation

- A strong decrease in the horizontal component 'H' is observed in Asian sector followed by African and American sectors.
- D_{iono} represents the variation of the magnetic field associated with the ionospheric currents during the storm.
- Dayside sectors show negative and nightside exhibits a large positive value of D_{iono} during the main phase.



Equatorial Ionization Anomaly (EIA)

Asian sector:

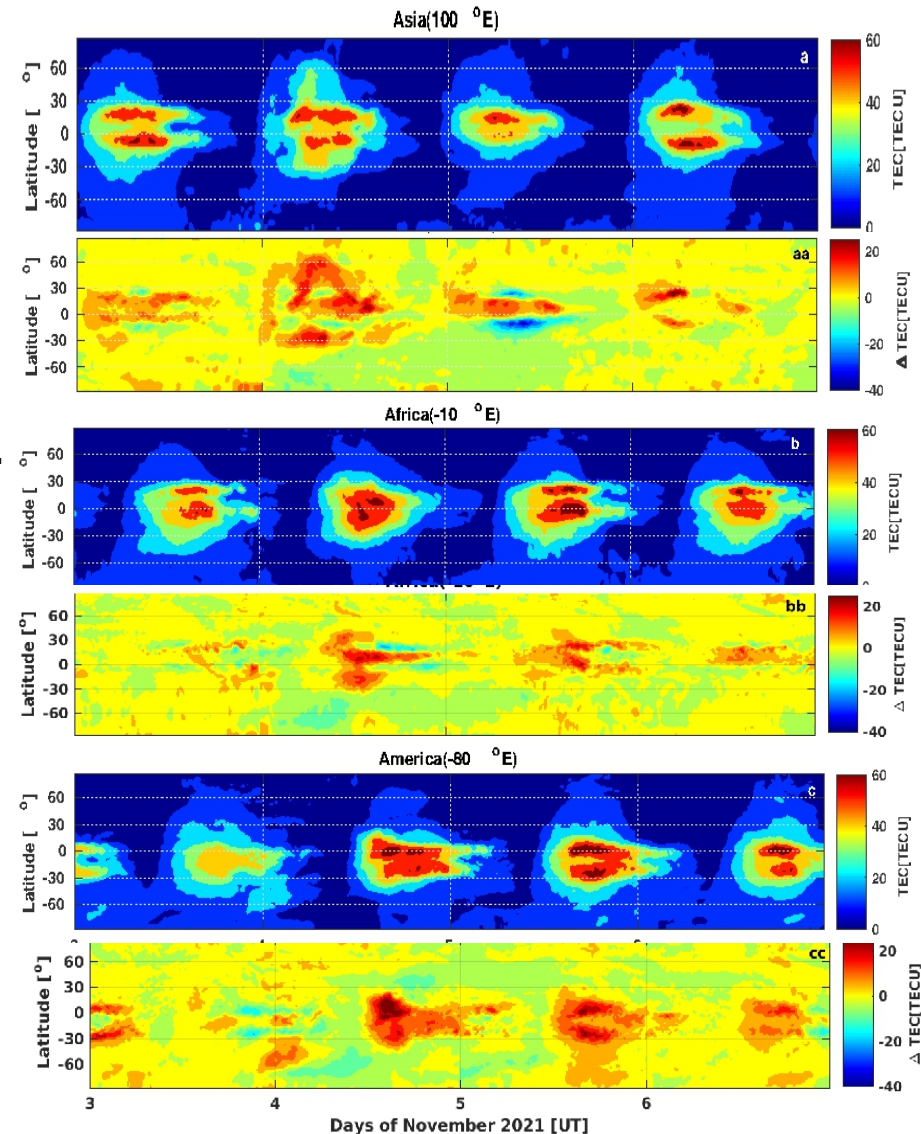
- Enhanced EIA with asymmetric distribution of vTEC in the crests.
- On November 5, a strong decrease in the ionization level in the crests.

African sector:

- A strong increase in the equatorial zone.
- On November 5, the higher ionization in the crests.

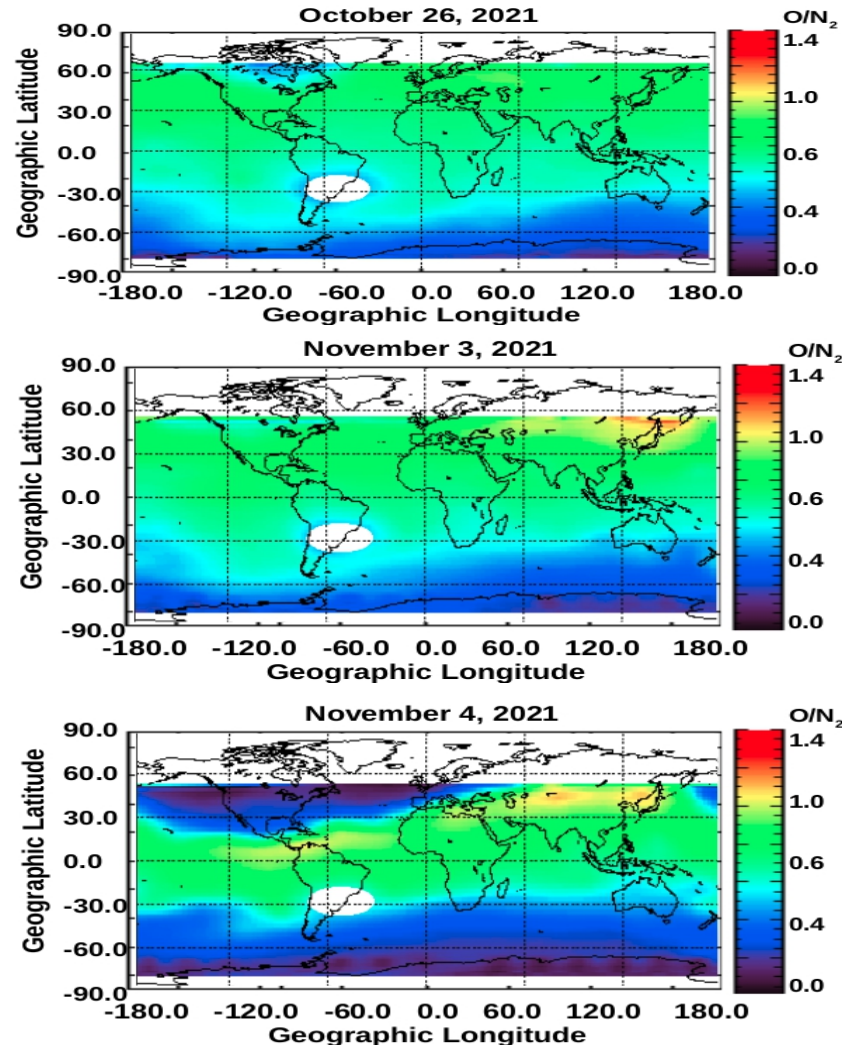
American Sector:

- A strong increase in vTEC in the equatorial zone/northern low latitude. The ionization level extends beyond 30° on south-side.
- On November 5, the enhancement mostly occurs in the EIA crests.



Neutral Composition

- Quiet-time O/N₂ pattern is uniform.
- Storm-time meridional wind can change the O/N₂ composition.
- From the SH (summer) move O faster than N₂ to the NH (winter).
- The downwelling of disturbed neutral composition occur in the NH (winter hemisphere) during storms.
- O/N₂ in the NH become larger than in the SH, which leads to enhanced plasma density in the NH.
- Storm-time meridional winds and neutral composition can cause asymmetry in the EIA.

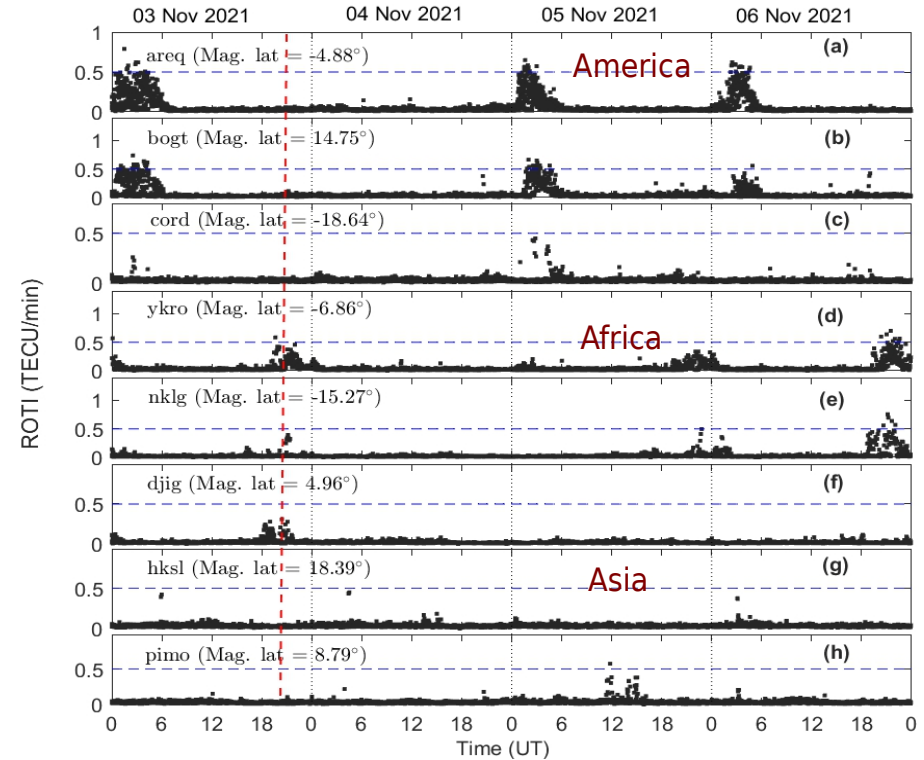


Overview: Equatorial Plasma Irregularities

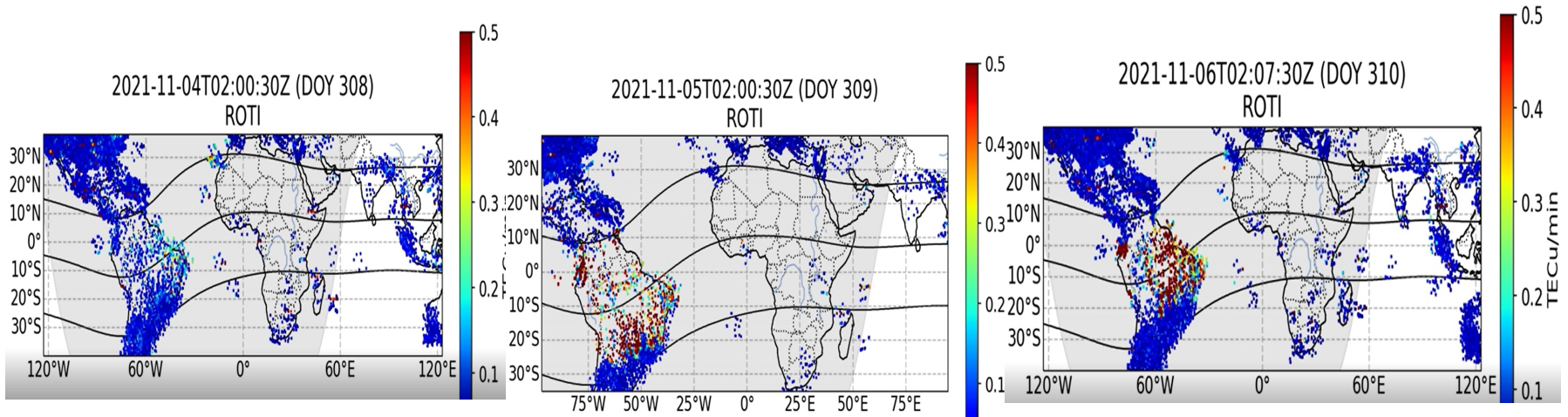
- Ionospheric irregularities are small scale structures which can severely degrade radio communication and navigation systems.
- Development of EPIs is closely related to Rayleigh–Taylor instability whose growth rate is proportional to plasma density gradient and the vertical drift velocity.
- The EPIs can be classified as: **weak** ($0.25 < \text{ROTI} < 0.5$ TECU/min); **moderate** ($0.5 < \text{ROTI} < 1$ TECU/min) and **strong** ($\text{ROTI} > 1$ TECU/min) (Ma & Maruyama, 2005).
- The impact of geomagnetic storms is to either enhance the generation or inhibition of the ionospheric plasma irregularities.

Ionospheric Irregularities

- During storm phase, the ionospheric plasma irregularities are strongly inhibited.
- After recovery, the post-midnight irregularities reappear over America.



SiMURG Results



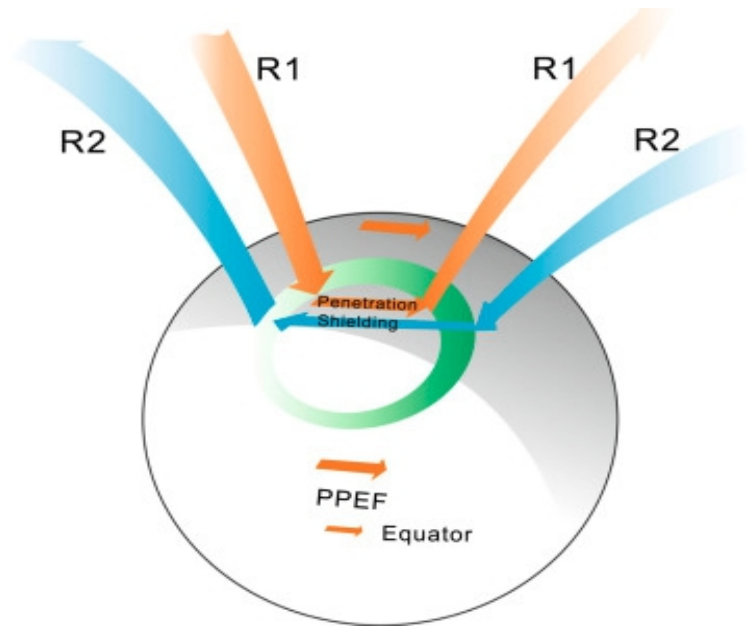
Role of Maximum Ring Current

Aaron's Criteria:

- The maximum occurs around sunset or shortly after sunset, has insignificant effect on the development of irregularities that night. (Asian sector (LT=19:44UT) follows this criteria).
- If maximum occurs in the early afternoon, the ionospheric irregularities would be inhibited. (African sector (LT=11:44UT) follows this criteria)
- The maximum occurring during local midnight to post midnight supports the generation of ionospheric irregularities. (American sector (LT=4:44UT) doesn't follow the criteria).

Role of Penetration Electric Field

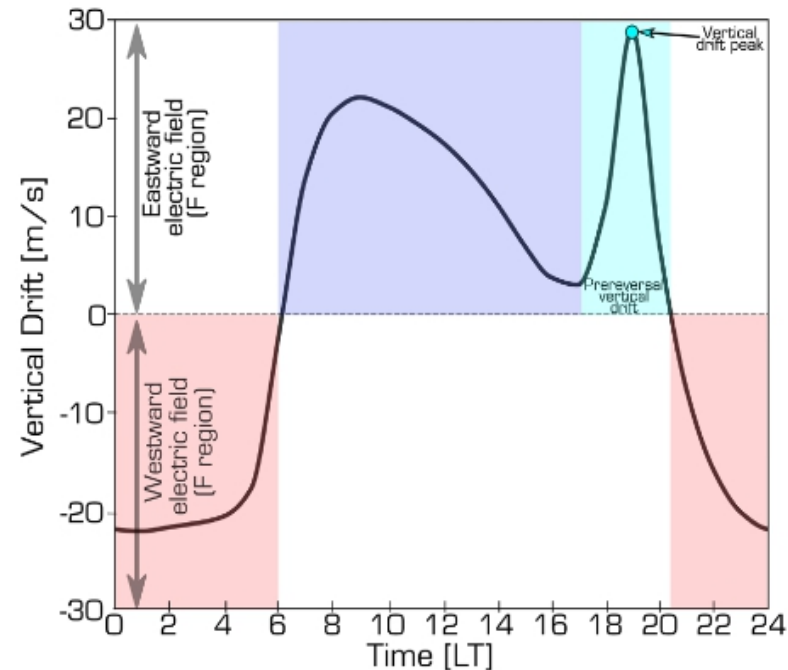
- Magnetospheric electric fields communicate with the ionosphere through R1 and R2 Field Aigned Currents.
- Penetration or undershielding electric field is associated with R1 FAC and shielding electric field is associated with R2 FAC.



- Under shielding condition:
 $FAC R1 > FAC R2$ & IMF $B_z < 0$: Eastward/Westward in the dayside/nightside.
- Over shielding condition:
 $FAC R2 < FAC R1$ & IMF $B_z > 0$: Westward/Eastward in the dayside/nightside.

PPEF/PRE Effects

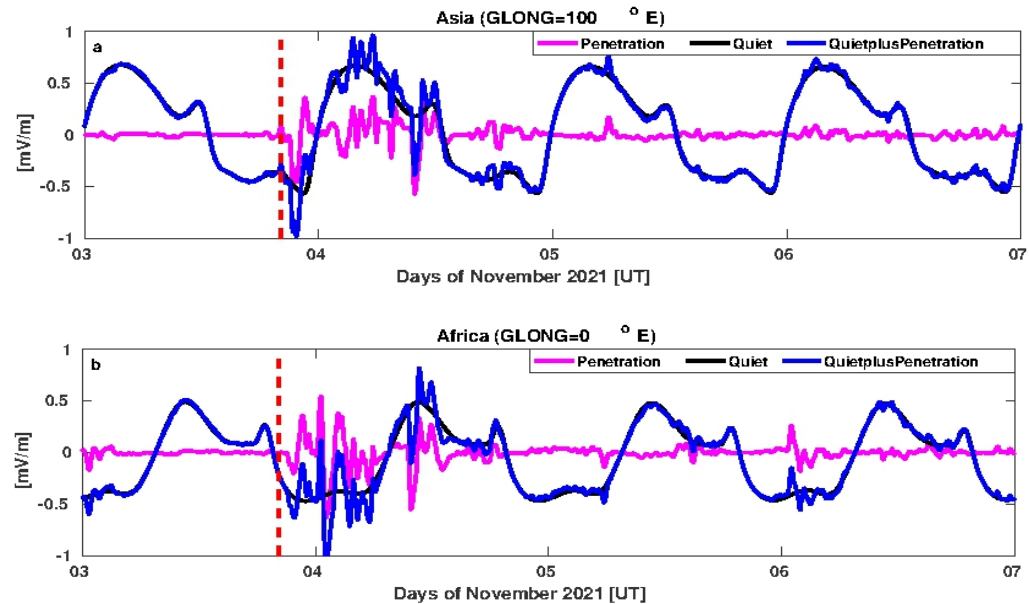
- During southward IMF Bz, the IEF penetrates into equatorial/ low-latitude ionosphere, as PPEFs or under shielding electric field.
- Nighttime/daytime (Westward/Eastward) PPEF may suppress (favor) the upward drift of a plasma which affects the generation of ionospheric irregularities through RT-instability.
- Pre-reversal enhancement (PRE) favors the post-sunset EPIs.



<https://doi.org/10.1590/jatm.v13.1237>

PPEF & EPIs over Asia/Africa

- In Asian sector, injection of strong westward PEF occurred around dawn and a small eastward PEF observed an hour before main phase.
- In African sector, a strong westward PEF is injected in nighttime.



PEF Over Asia/Africa

Asian Sector

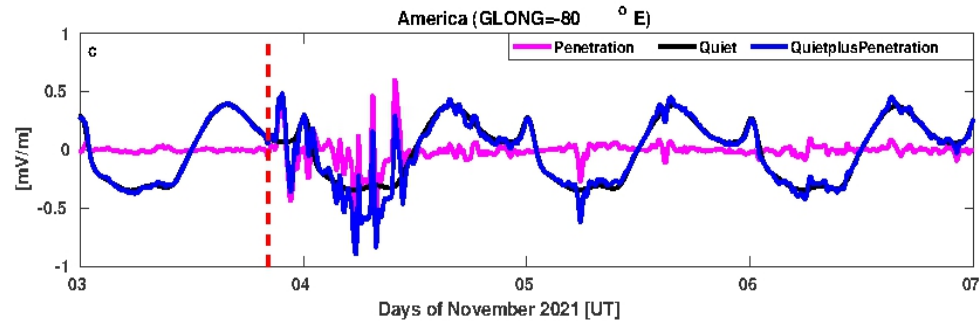
| PEF | UT | Day |
|------------|--------------|---------------|
| W | 21:45 | Nov. 3 |
| E | 22:35 | Nov. 3 |
| E | 3:35 | Nov. 4 |
| E | 6:30 | Nov. 4 |
| W | 9:50 | Nov. 4 |
| E | 10:40 | Nov. 4 |

African Sector

| PEF | UT | Day |
|------------|--------------|---------------|
| W | 21:50 | Nov. 3 |
| E | 22:40 | Nov. 3 |
| E | 00:35 | Nov. 4 |
| W | 1:15 | Nov. 4 |
| E | 2:20 | Nov. 4 |
| W | 9:50 | Nov. 4 |

PPEF and EPIs over America

- Injection of strong Eastward PPEF occurred around 21:00 UT on Nov. 3 and at 7:30 and 9:30 UT on November 4.
- PEF conditions do not favor the occurrence of post-midnight ionospheric plasma irregularities during the main phase.
- The post-midnight ionospheric plasma irregularities reappear over this sector after the storm-recovery.



| PEF | UT | Day |
|-----|-------|--------|
| E | 21:30 | Nov. 3 |
| W | 22:30 | Nov. 3 |
| W | 5:35 | Nov. 4 |
| W | 7:50 | Nov. 4 |

Summary

Multi-instrumental data is used to investigate the longitudinal variation in the occurrence of equatorial and low latitude ionospheric plasma irregularities during the geomagnetic storm of 4 November 2021.

During storm phase, the ionospheric irregularities are strongly suppressed in the three sectors.

The occurrence of ionospheric irregularities reappear over American sector after the recovery phase of the storm.

The longitudinal variability in the development/inhibition of ionospheric irregularities during geomagnetic storm are potentially associated with local time occurrence of maximum ring current and the injection of PEFs during different phases of the storm.

ACKNOWLEDGEMENTS

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