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

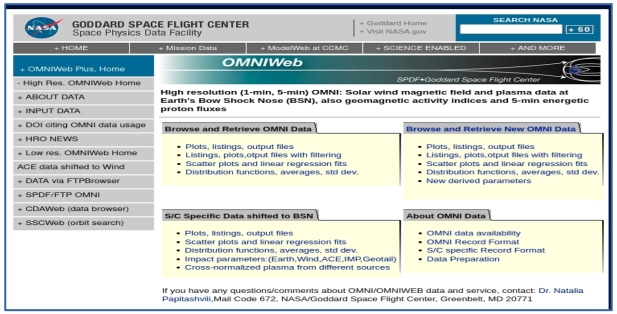
- To analyze multi-instrumental data to investigate the behavior of equatorial/low latitude ionosphere during the geomagnetic storm of November 3-5, 2021.

- 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

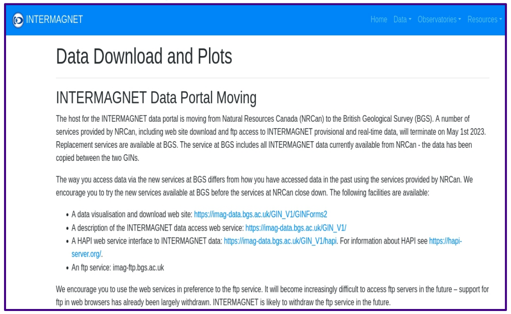
Solar wind parameters and magnetic indices



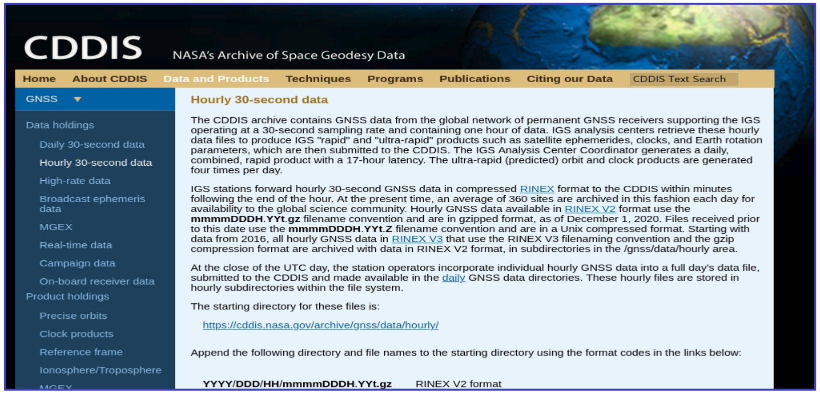
GNSS receivers and magnetometers used

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	$5.91°N$	$52.93°W$

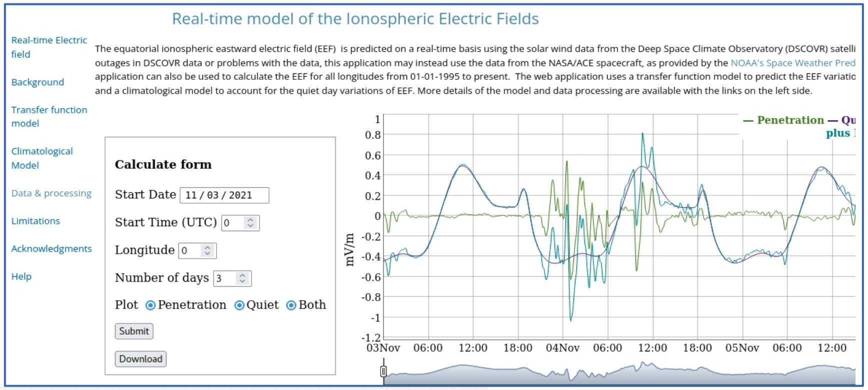
Geomagnetic field data

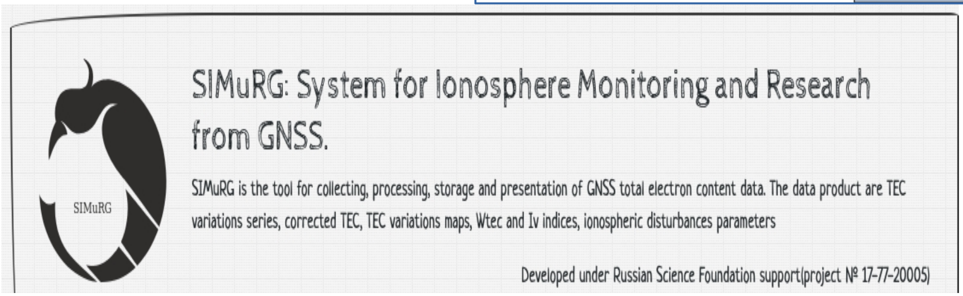


UQRG-GIM, vTEC and TEC



Penetration Electric field

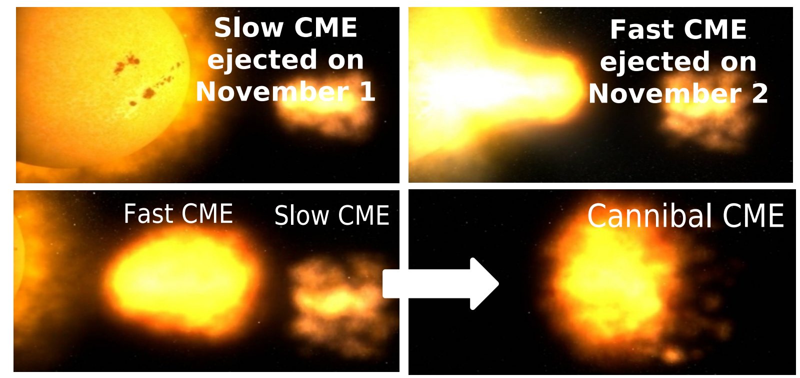


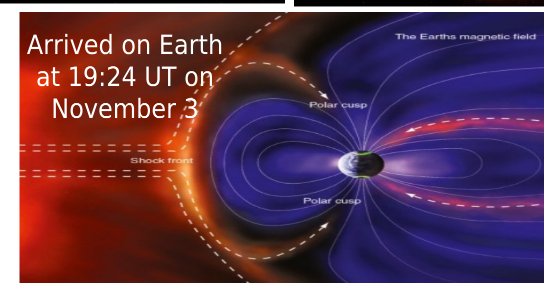


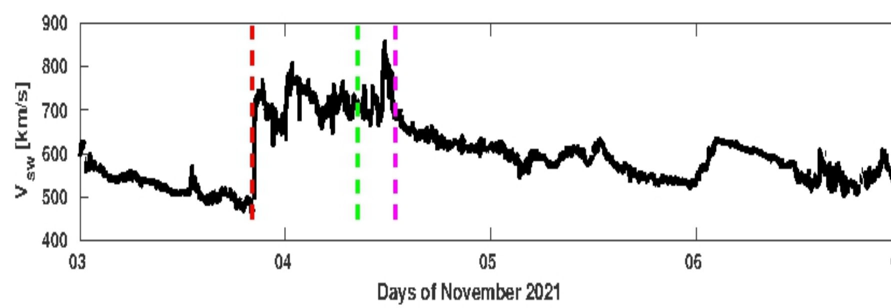
Case Study

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.



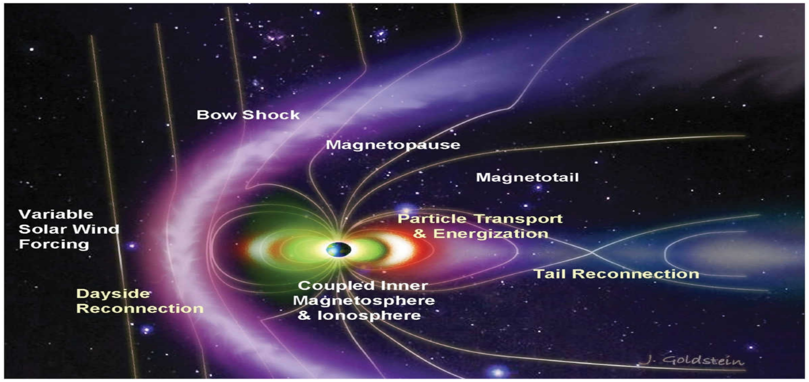




Magnetic Field Signatures

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.

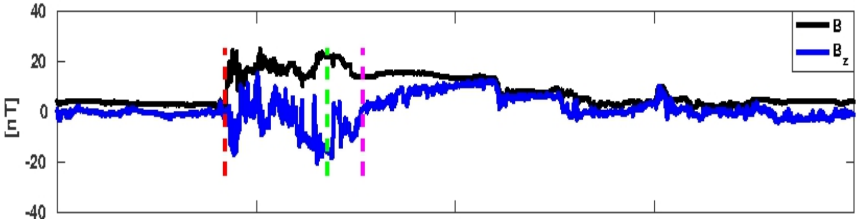


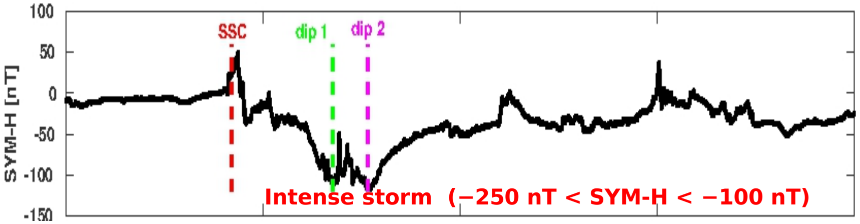
Southward IMF Bz:

- 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 Bz:

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



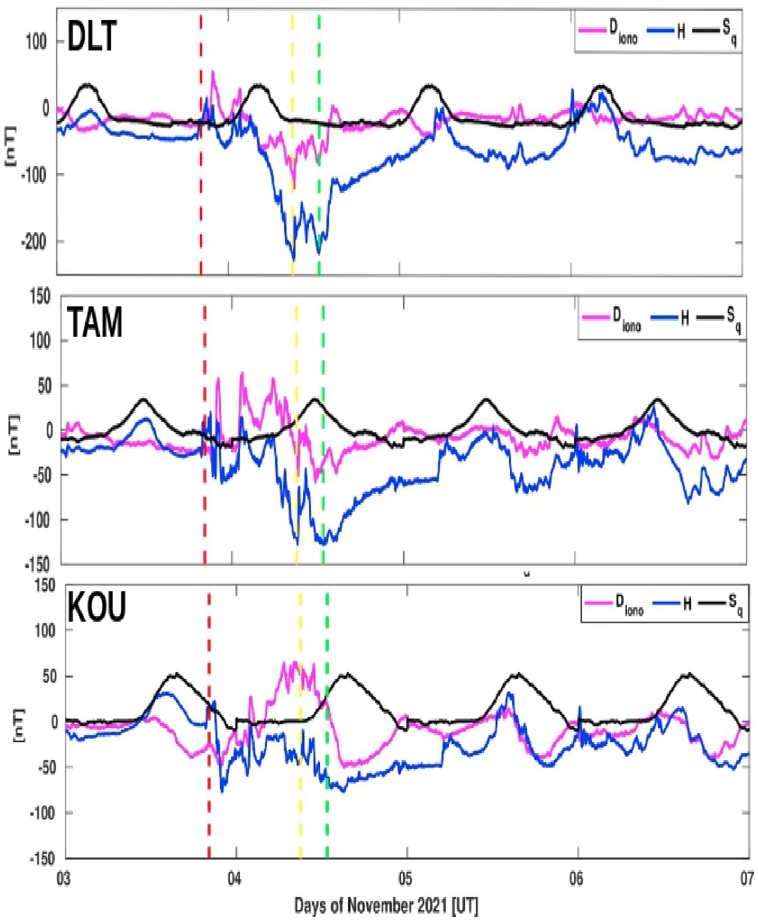


Geomagnetic Field Variation

- 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:

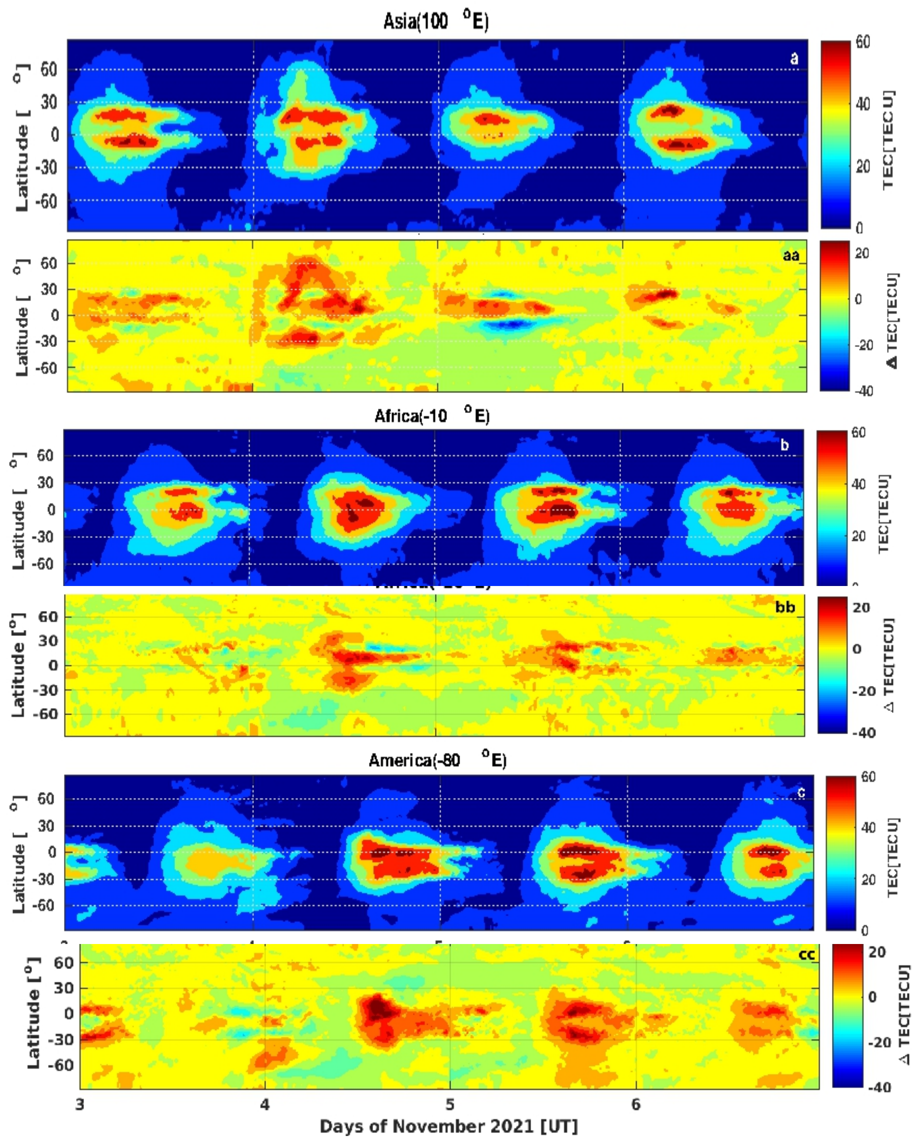
- Enhanced EIA with asymmetric distribution of vTEC in the crests.
- On November 5, a strong decrease in the ionization level in the crests.

African sector:

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

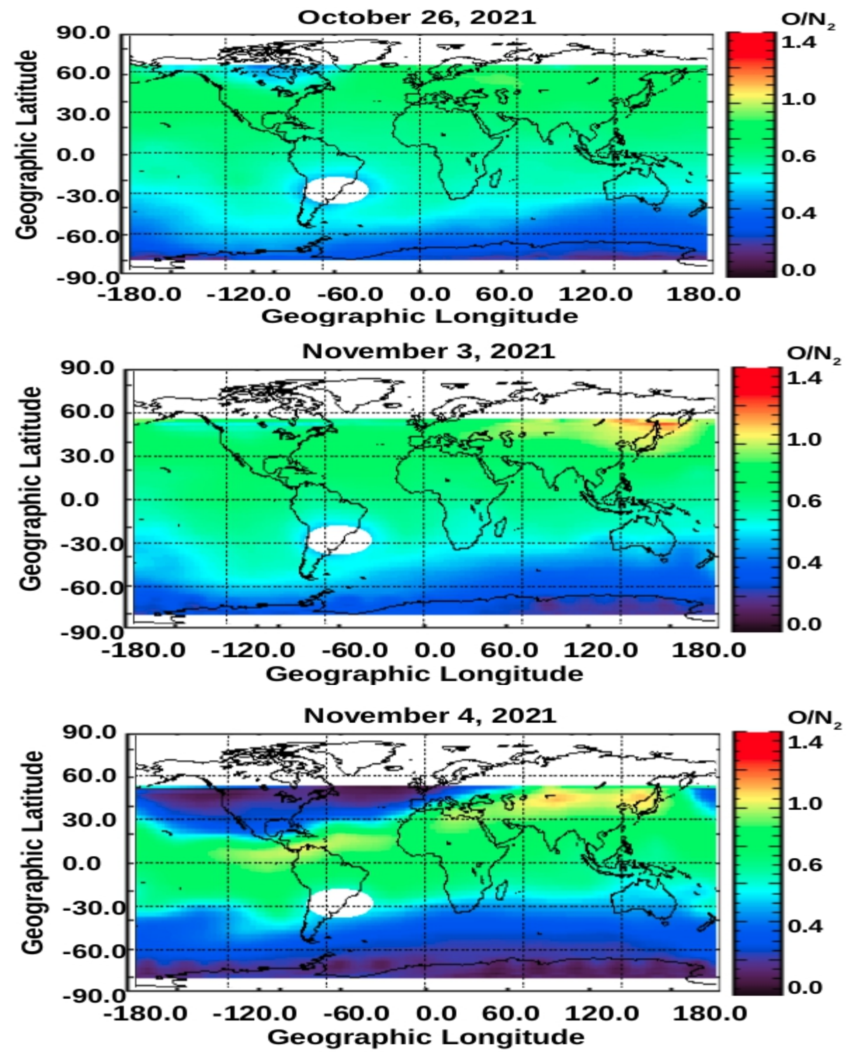
American Sector:

- A strong increase in vTEC in the equatorial zone/northern low latitude. The ionization level extends beyond 30º 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.

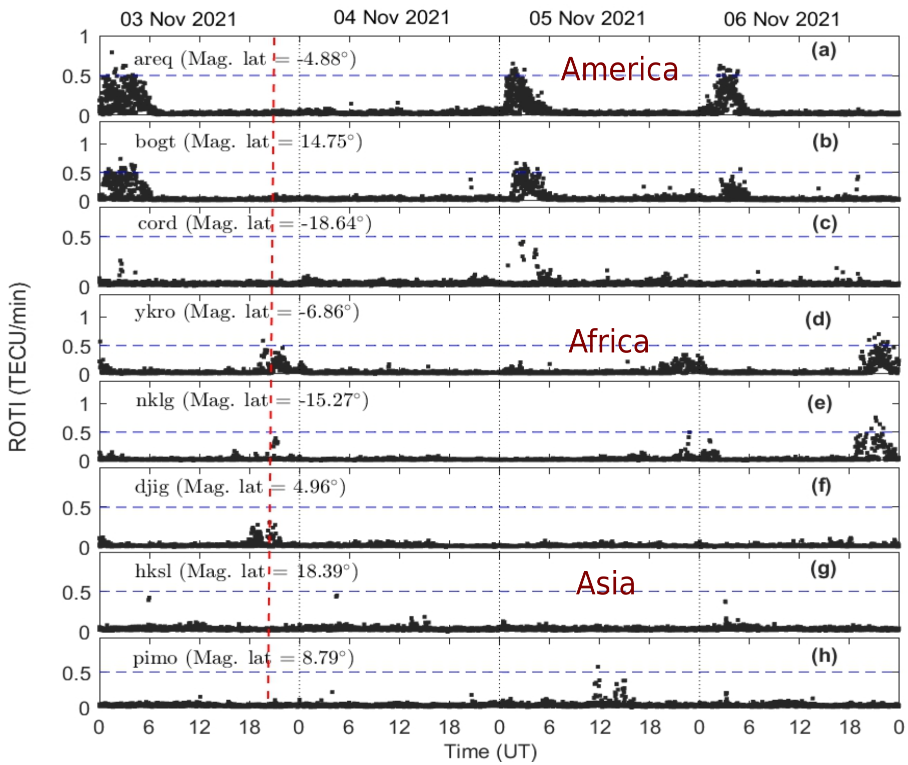


Overview: Equatorial Plasma Irregularities

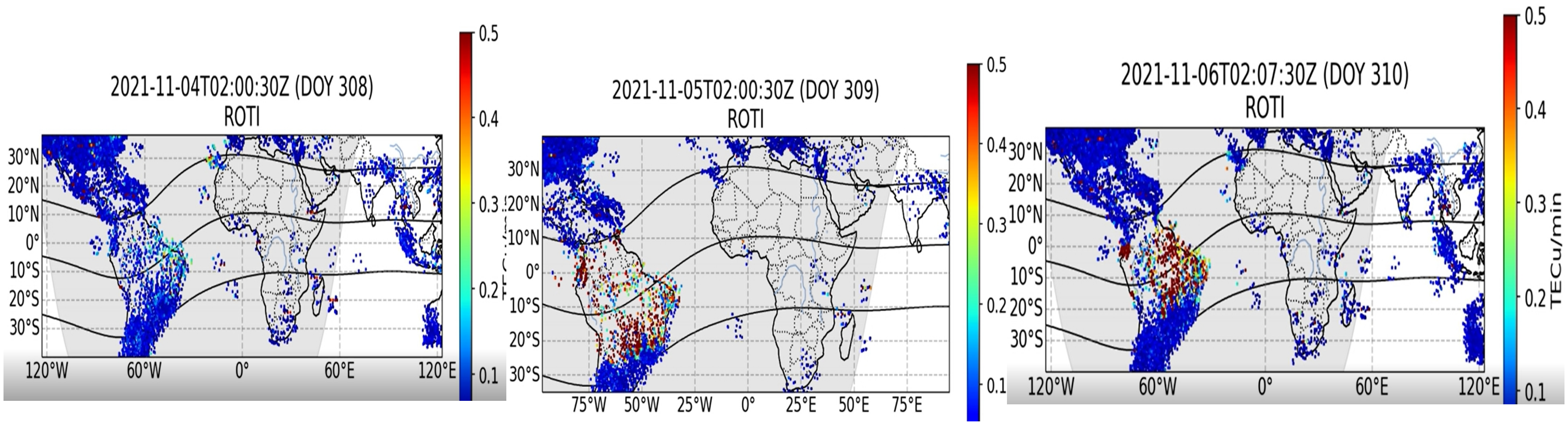
- Ionospheric irregularities are small scale structures which can severely degrade radio communication and navigation systems.
- Development of EPIs is closely related to Rayleigh–Taylor instability whose growth rate is proportional to plasma density gradient and the vertical drift velocity.
- The EPIs can be classified as: weak (0.25 < ROTI < 0.5 TECU/min); moderate (0.5 < ROTI < 1TEC/min) and strong (ROTI > 1TEC/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



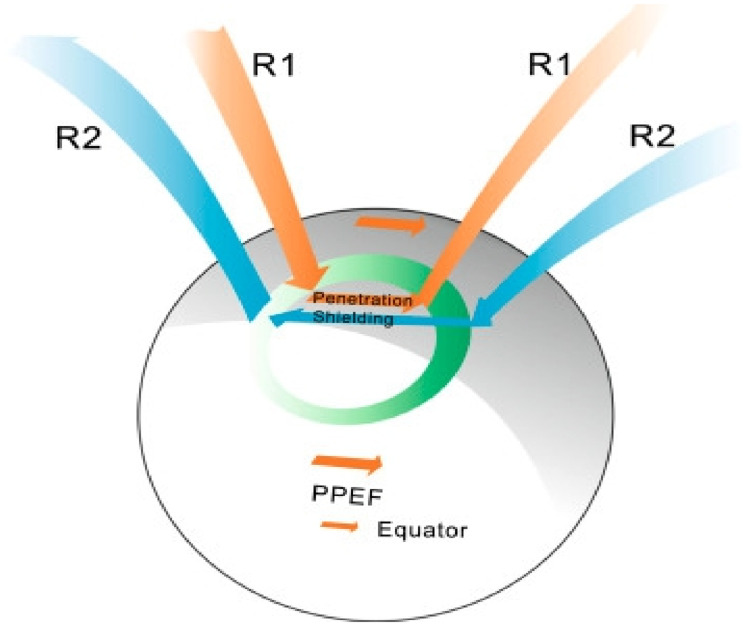
Role of Maximum Ring Current

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 occuring 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 Aligned Currents.
- Penetration or undershielding electric field is associated with R1 FAC and shielding electric field is associated with R2 FAC.



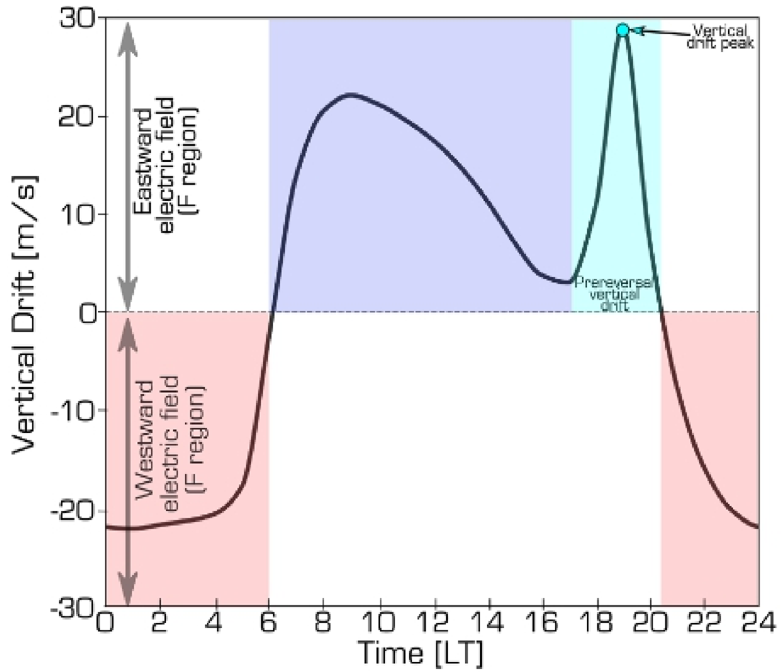
- Under shielding condition: FAC R1 >FAC R2 & IMF Bz<0: Eastward/Westward in the dayside/nightside.
- Over shielding condition: FAC R2 <FAC R1 & IMF Bz>0: Westward/Eastward in the dayside/nightside.

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.

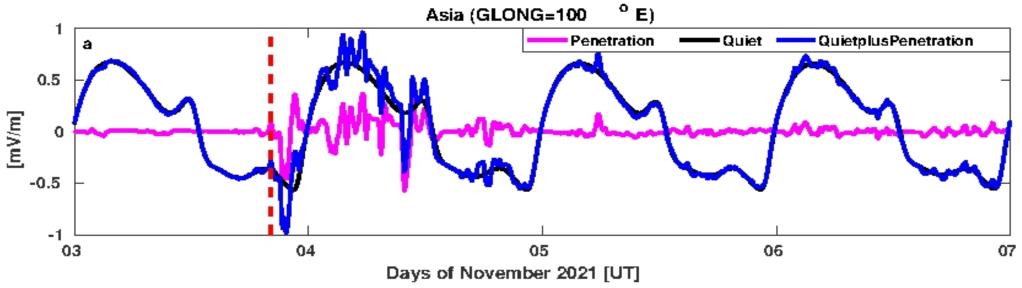


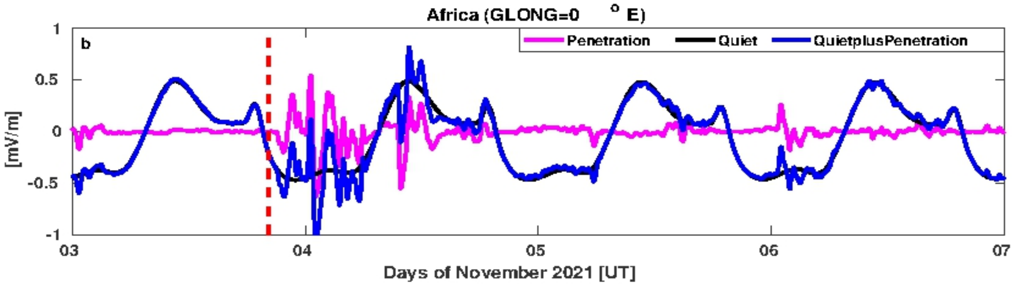
https://doi.org/10.1590/jatm.v13.1237

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

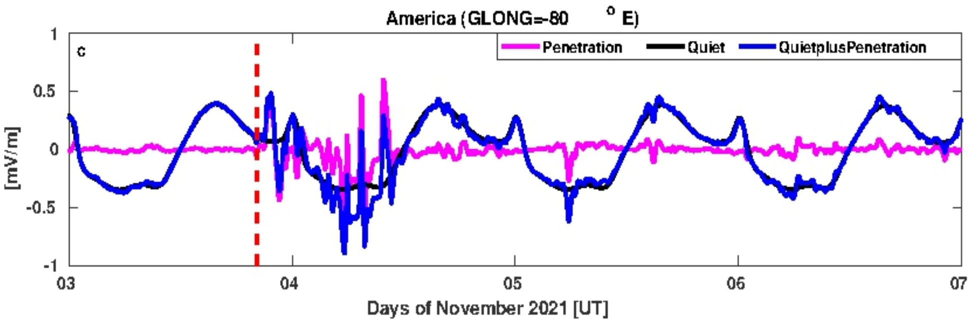
PEF	UT	Day
W	21:45	Nov. 3
E	22:35	Nov. 3
E	3:35	Nov. 4
E	6:30	Nov. 4
W	9:50	Nov. 4
E	10:40	Nov. 4

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.

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