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

Nadia Imtiaz Theoretical Physics Division PINSTECH, PAKISTAN

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Plasma Density Variations: GIMs and ROTI

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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

Geomagn	etic	field	data
Geomagn	etit	neiu	uata

The host for the INTERMAGNET data portal is moving from Natural Resources Canada (INRCan) to the British Geological Survey (IBGS). A number of services provided by INRCan, Including web site download and to parcess to INTERMACHET provisional and reletime data, all terminate on Mag 1at 2023. Replacement services are available all BCS. The service all BCS Endback all INTERMACHET fraductionary services than been on

The way you access data via the new services at BGS differs from how you have accessed data in the past using the services provided by NRCan. We encourage you to try the new services available at BGS before the services at NRCan close down. The following facilities are available:

A HAPI web service interface to INTERMAGNET data: https://map.data.bos.ac.uk/GIN_V1/hapi. For information about HAPI see https://hapi.

We encourage you to use the web services in preference to the ftp service. It will become increasingly difficult to access ftp servers in the future – support for ftp in web browsers has already been largely withdrawn. INTERMAGNET is likely to withdraw the ftp service in the future.

Data Download and Plots

A data visualisation and download web site: https://imag-data.bgs.ac.uk/GIN_V/L/GINForms2
 A description of the INTERMAGNET data access web service: https://imag-data.bgs.ac.uk/GIN_VL

copied between the two GINs.

· An ftp service: imag-ftp.bgs.ac.uk

+ OMNIWeb Plus, Home	OMNIWe	ь		- 6
High Res. OMNIWeb Home	SPDF+Goddard Space Flight C			light Center
+ ABOUT DATA	High resolution (1-min, 5-m	In) OMNI: Solar wind I	magnetic field and	plasma data at
+ INPUT DATA	proton fluxes	(Sit), and geomagnet	ie activity indices a	nd 5-min energeue
+ DOI citing OMNI data usage	Browse and Retrieve OMNI	Data	Browse and Retriev	e New OMNI Data
+ HRO NEWS				
+ Low res. OMNIWeb Home	 Plots, listings, output files Listings, plots, otput files y 	with filtering	 Plots, listings, output files Listings, plots, otput files with filtering Scatter plots and linear regression fits 	
ACE data shifted to Wind	 Scatter plots and linear re 	gression fits		
+ DATA via FTPBrowser	· Distribution functions, ave	rages, survey.	 New derived par 	ameters
+ SPDF/FTP OMNI				
+ CDAWeb (data browser)				
+ SSCWeb (orbit search)	S/C Specific Data shifted to I	BSN (About OMNI Data)	
	 Plots, listings, output files 		OMNI data avai	ability
	 Scatter plots and linear re Distribution functions, ave 	rages, std dev.	 S/C specific Rec 	ormat ord Format
		-		

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

UQRG-GIM, vTEC and TEC

CDDIS	NASA's Archive of Space Geodesy Data
Home About CDDIS	Data and Products Techniques Programs Publications Citing our Data CDDIS Text Search
	Hourly 30-second data
Data holdings Daily 30-second data Hourly 30-second data High-rate data	The CDDIS archive contains GNS5 data from the global network of permanent GNS5 receivers supporting the IGS operating at a 30-second sampling rate and containing one hour of data. IGS analysis centers retrieve these houry data files to produce IGS "rapid" and "ultra-rapid" products such as satellite ephemerides, clocks, and Earth vortation parameters, which are then submitted to the CDDIS. The IGS Analysis Center scatters as daily, control to the standard standard standard products and a satellite ephemerides, clocks, and Earth vortation parameters, which are then submitted to the CDDIS. The IGS Analysis Center scatters as daily, control to the standard standard products and products and clock products are generated for times per day.
Broadcast ephemeris data MGEX Real-time data	IGS stations forward hourly 30-second GNSS data in compressed RINEX format to the CDDIS within minutes tollowing the end of the hour. At the present time, an average of 300 sites are archived in this fastion each day for mmmmbDDH Yt ga filename convention at are in gapped format, as in Eucocate 1, 2020. Files received prior to this date use the mmmbDDDH Ytt Z intername convention and are in a Unix compressed format. Starting with data from 2016, all hourly GNSS data in RINEX V3 finant, in subdirectories in the darsadarburdy area.
Campaign data On-board receiver data Product holdings	At the close of the UTC day, the station operators incorporate individual hourly GNSS data into a full day's data file, submitted to the CDDIS and made available in the <u>ally</u> GNSS data directories. These hourly files are stored in hourly subdirectories within the file system.
	Ine starting directory for these tiles is: https://cddis.nasa.gov/archive/gnss/data/hourly/
Reference frame	Append the following directory and file names to the starting directory using the format codes in the links below:
	YYYY/DDD/HH/mmmDDDH.YYt.gz RINEX V2 format





SIMuRG: System for Ionosphere Monitoring and Research

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

Developed under Russian Science Foundation support(project № 17-77-20005)

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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.



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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.





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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:

- 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.



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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.



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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.

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Ionospheric Irregularities

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

2021-11-04T02:00:30Z (DOY 308)

ROTI

0°

30°I

20°

10°N 0°

10°S

20°S

30°S

120°W

60°W

SiMURG Results

75°W 50°W

25°W

· 0.5

0.4

0.3.!20

0.2

120°E

60°E

20°S

0.1 30°S



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 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 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 postmidnight ionospheric plasma irregularities during the main phase.
- The post-midnight ionospheric plasma irregularities reappear over this sector after the storm-recovery.



UT	Day
21:30	Nov. 3
22:30	Nov. 3
5:35	Nov. 4
7:50	Nov. 4
	UT 21:30 22:30 5:35 7:50

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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