IONOSPHERIC RESPONSE OF INTENSE GEOMAGNETIC STORMS OVER INDIAN LOW LATITUDE REGION

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Introduction

- **Geomagnetic storm** is a temporary disturbance of the Earth‘s magnetosphere caused by a solar wind shock wave and/or cloud of magnetic field that interacts with the Earth's magnetic field.
- During the geomagnetic storms, the energy inputs from the magnetosphere render dramatic effects into the upper atmospheric environment. One of such effects is the changes in ionospheric electron density (or TEC) which perturb communication and navigation systems.
- Geomagnetic storms have serious effects on various ground- and space-based technological systems operating over high, low and equatorial zone.

Geomagnetic Storm

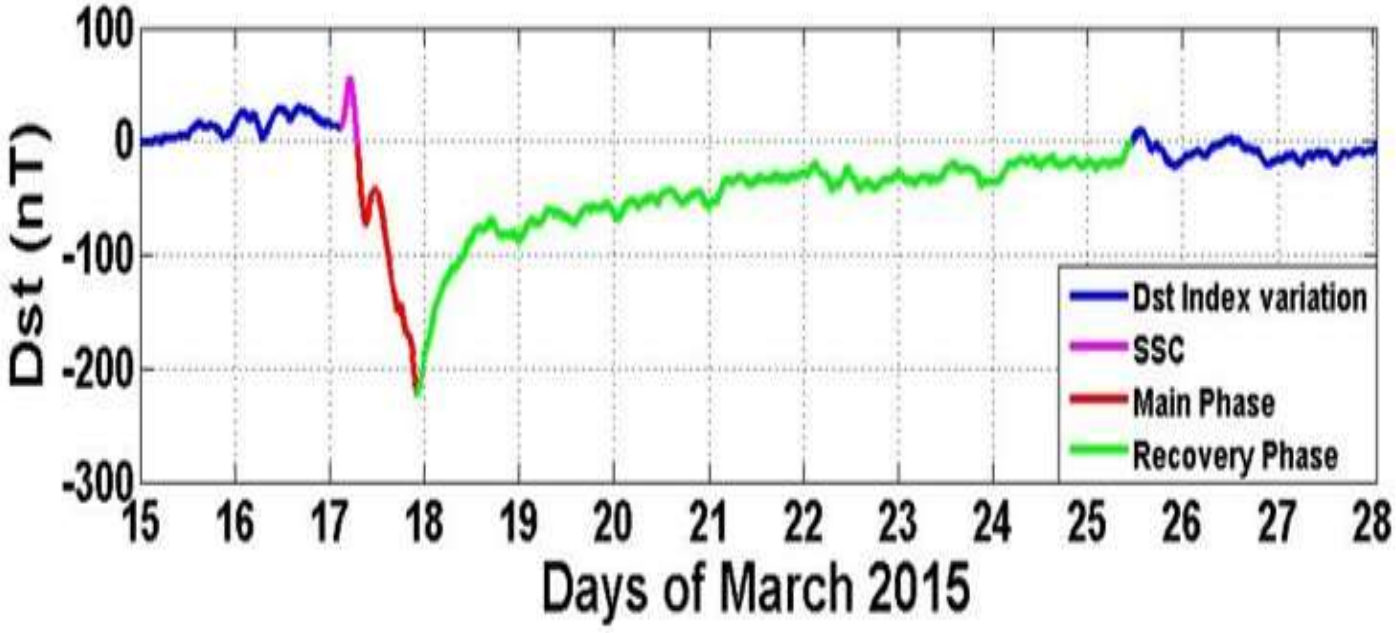
Phases of Geomagnetic Storm:

- **Initial Phase** (1/2 hrs-few hrs)
- **Main Phase** (few hrs-several hours)
- **Recovery Phase** (10 hrs- week)

Classification of Storm:

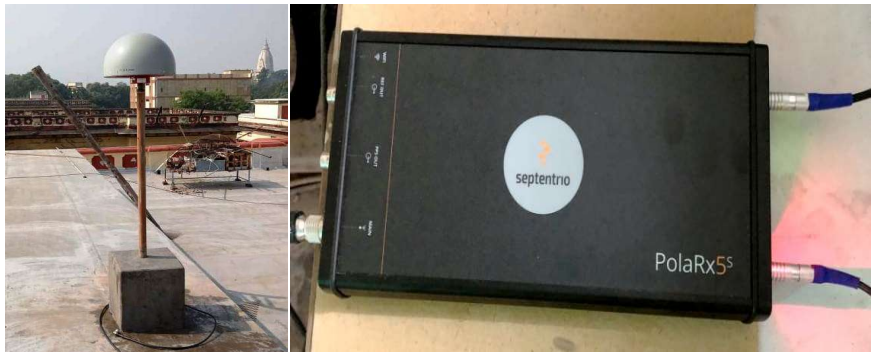
(Loewe & Prolss, 1997, J. Geophys. Res. 102, 14209)

- **Weak Storm (** -30 nT > Dst_{min} > -50 nT)
- **Moderate Storm (** -50 > Dst_{min} > -100 nT)
- **Intense Storm** (Dst_{min} < -100 nT)



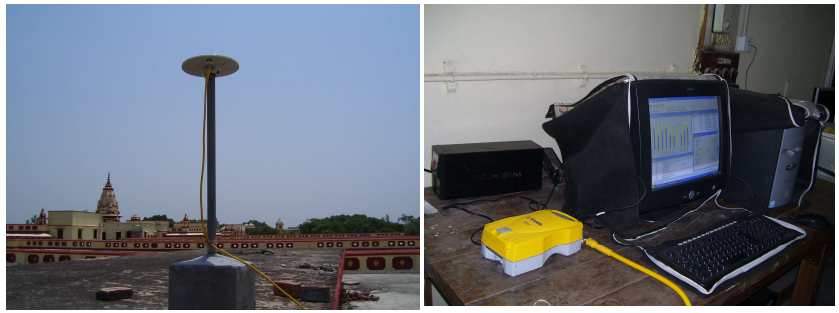
Instruments installed at BHU, Varanasi

- A multi-frequency GNSS receiver Septentrio PolaRx5S which is the world's leading ionospheric GNSS receiver having 544 channels is purchased and installed at our low latitude station Varanasi (Lat. 25.31° N, Long. 82.97° E, Magnetic dip Lat. 16.2°N) dated October 2020.



GNSS Antenna & Septentrio (PolaRx5s) Receiver

- It provides phase, code and carrier-to-noise ratio at up to 100 Hz for GPS/GLONASS/GALILEO L-band frequencies which is compatible with scintillation and TEC monitoring file formats.



GPS Antenna & Trimble (5700) Receiver

Ionospheric Error & TEC

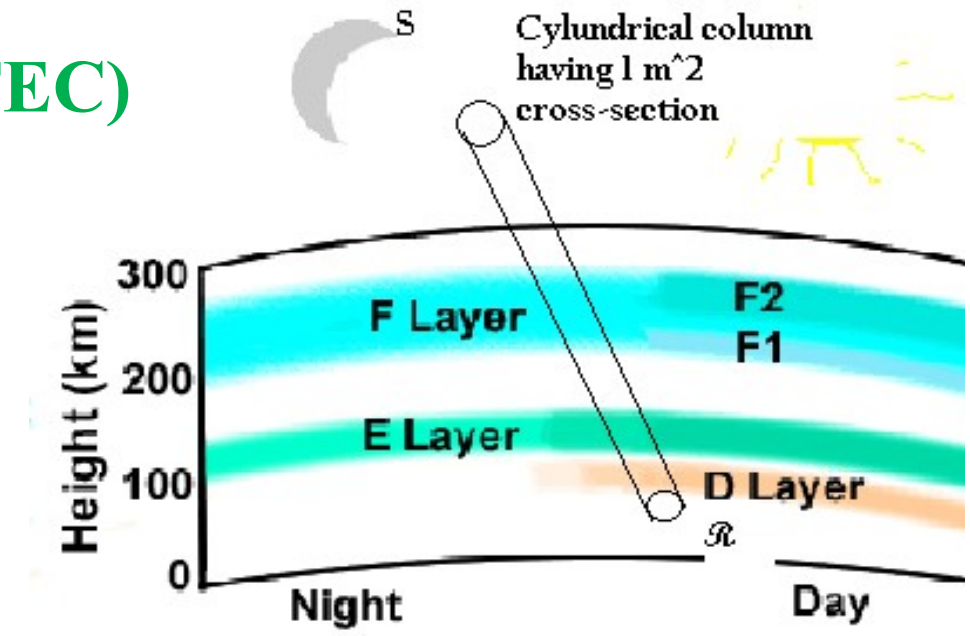
- The ionospheric delay in GPS signal is frequency dependent.
- The ionospheric delay in GPS signal is proportional to TEC of the ionosphere.

Total Electron Content (TEC)

$$TEC = \int_{R}^{S} Nedl$$ **Unit: electrons/m^2**

Ne = electron density

1 TEC Unit = 10^{16} electrons/m^2



which is defined as total number of free electrons in column of 1 m^2 cross-sectional area along the ray path from the satellite to receiver.

Results

- To study the effect of geomagnetic storm on Ionosphere, we have analyzed GPS data recorded at Indian low latitude stations: Varanasi & Lucknow and Equatorial stations: Bangalore & Hyderabad:

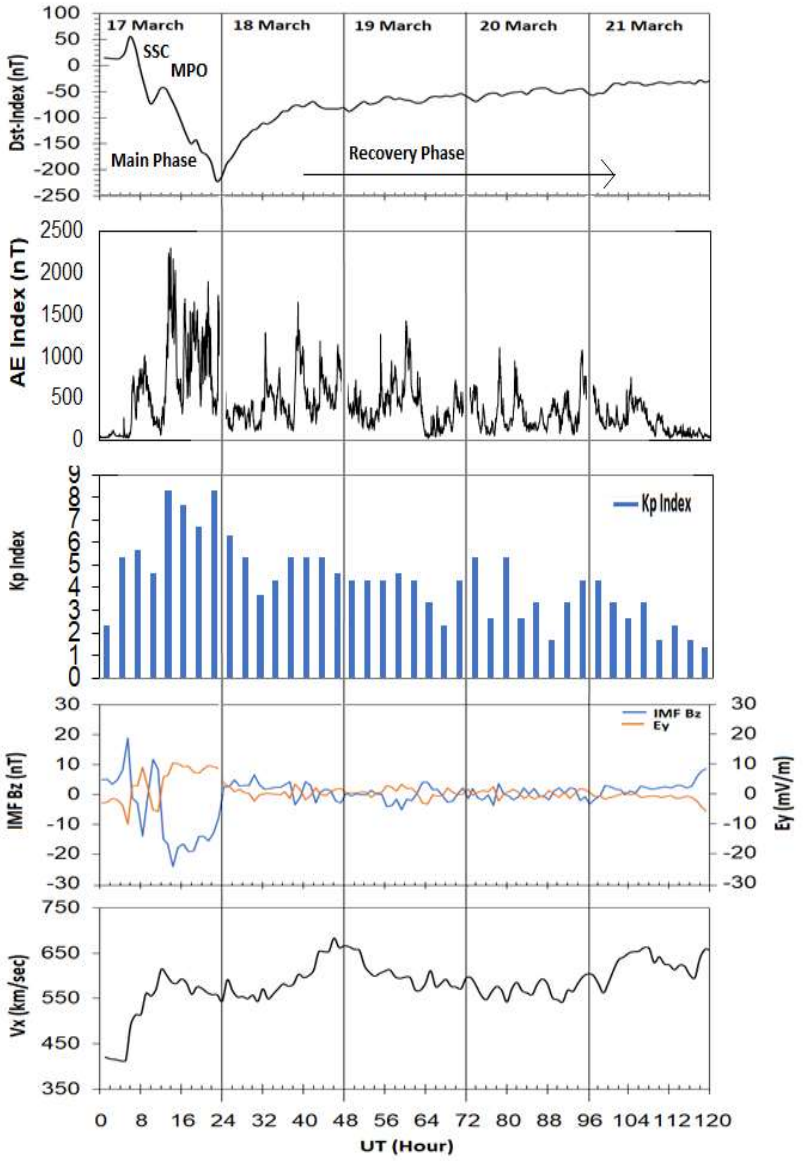
GPS Stations	CODE of station	Geo. Lat.	Geo. Long.
Varanasi	BHUP	25.32º N	82.98º E
Lucknow	LCK3	26.83º N	80.92º E
Bangalore	IISC	12.97º N	77.58º E
Hyderabad	HYDE	17.38º N	78.45º E

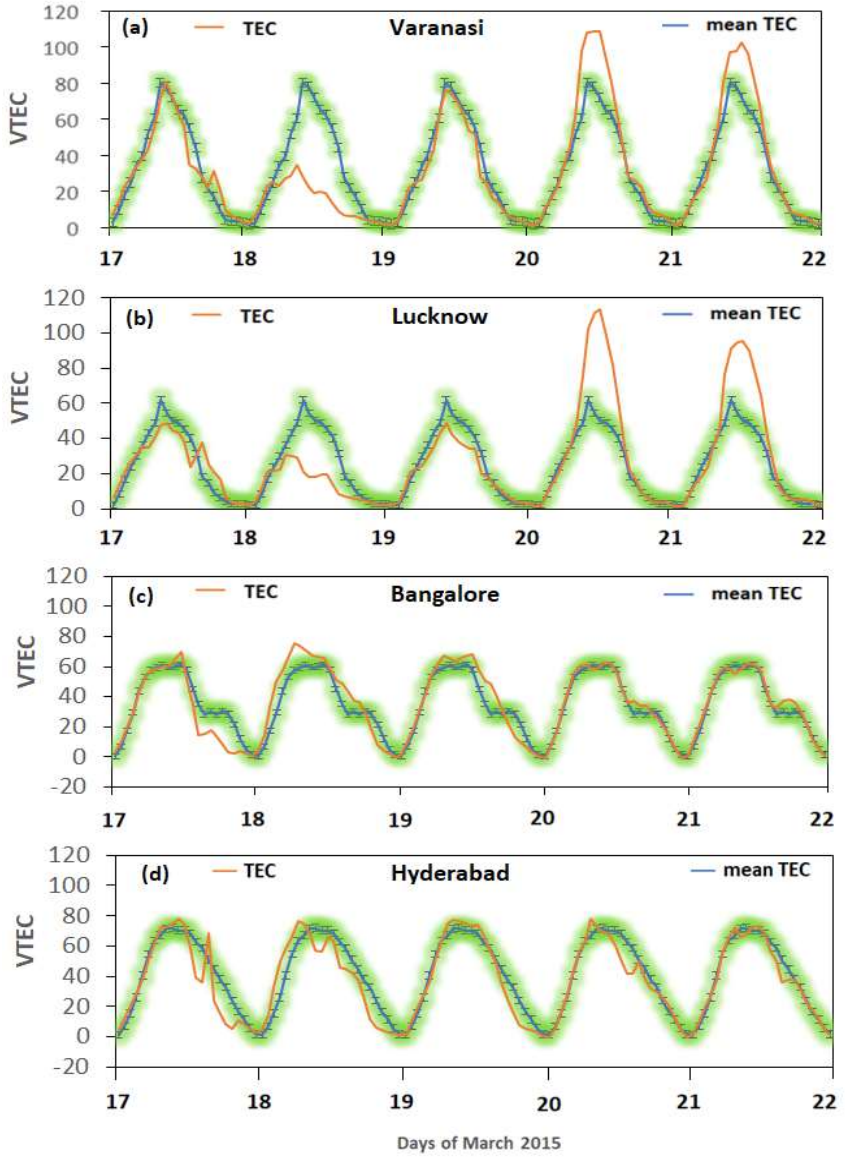
- Variations of:
  - Dst-index,
  - z-component of interplanetary magnetic field (IMF Bz),
  - y-component of interplanetary electric field (IEF Ey),
  - Solar wind speed, Density and
  - VTEC, quiet mean VTEC and DTEC.

Details of the selected storms and associated perturbation in TEC

Date of storm	Date of SSC	Dst (nT)	Peak Dst local time	Maximum Change in TEC during storm period
17 March 2015 (2300 UT)	17 March (0400 UT)	- 234	Night	Decrease (~43 TECU) Increase (~ 54 TECU)
26 September 2011 (2300 UT)	26 September (0700 UT)	-118	Night	Increase (~ 22 TECU)
15 July 2012 (1800 UT)	14 July (17:00 UT) and 15 July (0000 UT)	-139	Night	Increase (~ 10 TECU)
19 February 2014 (0800 UT)	18 February (1400 UT)	-116	Day	Increase (~13 TECU)
20 December 2015 (2200 UT)	19 December (1700 UT)	-170	Night	Increase (~35 TECU)

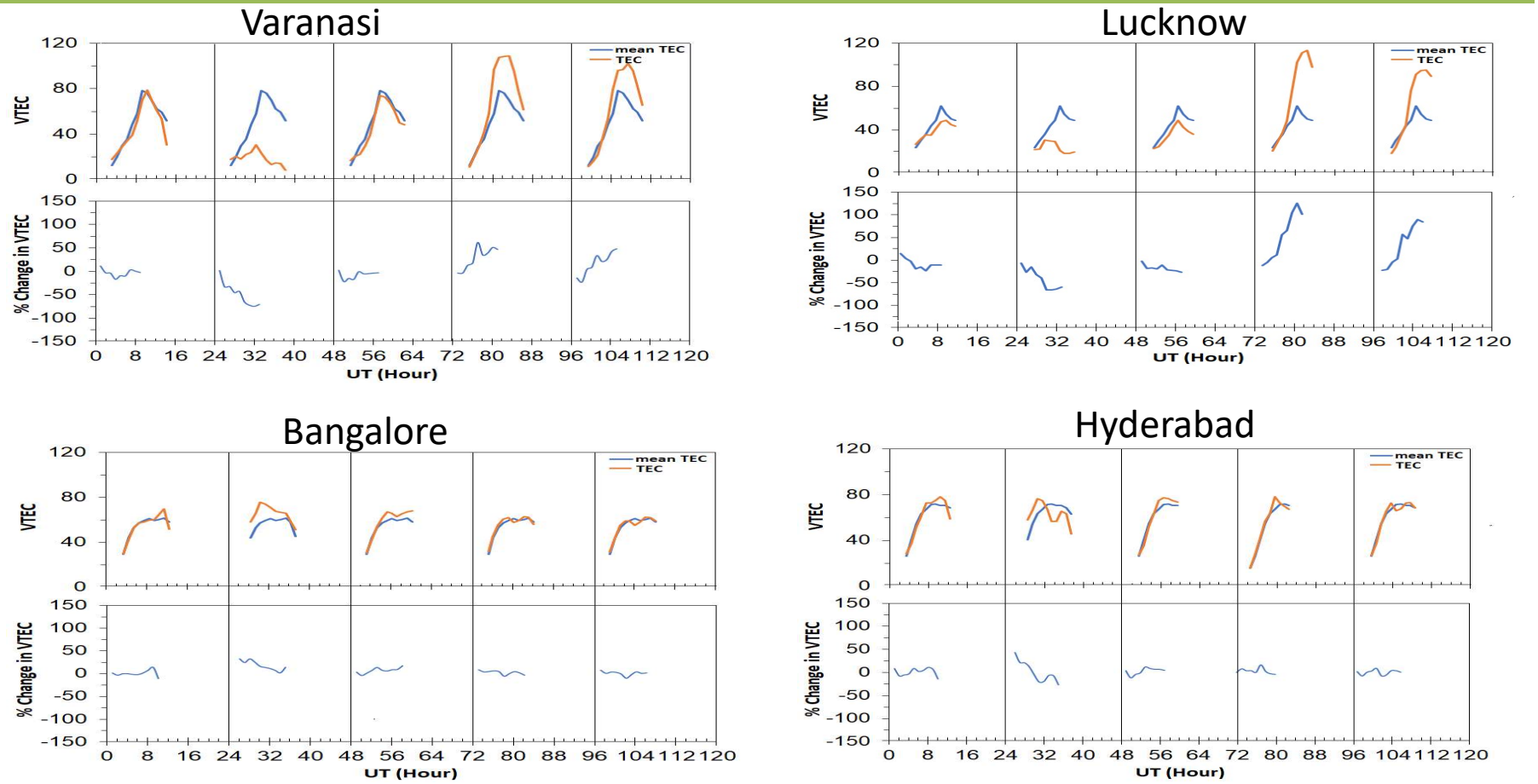
St. Patrick's Day Geomagnetic storm





(Chaurasiya, Singh et al., *Astrophysics and Space Science*, **367**, 103, 2022)

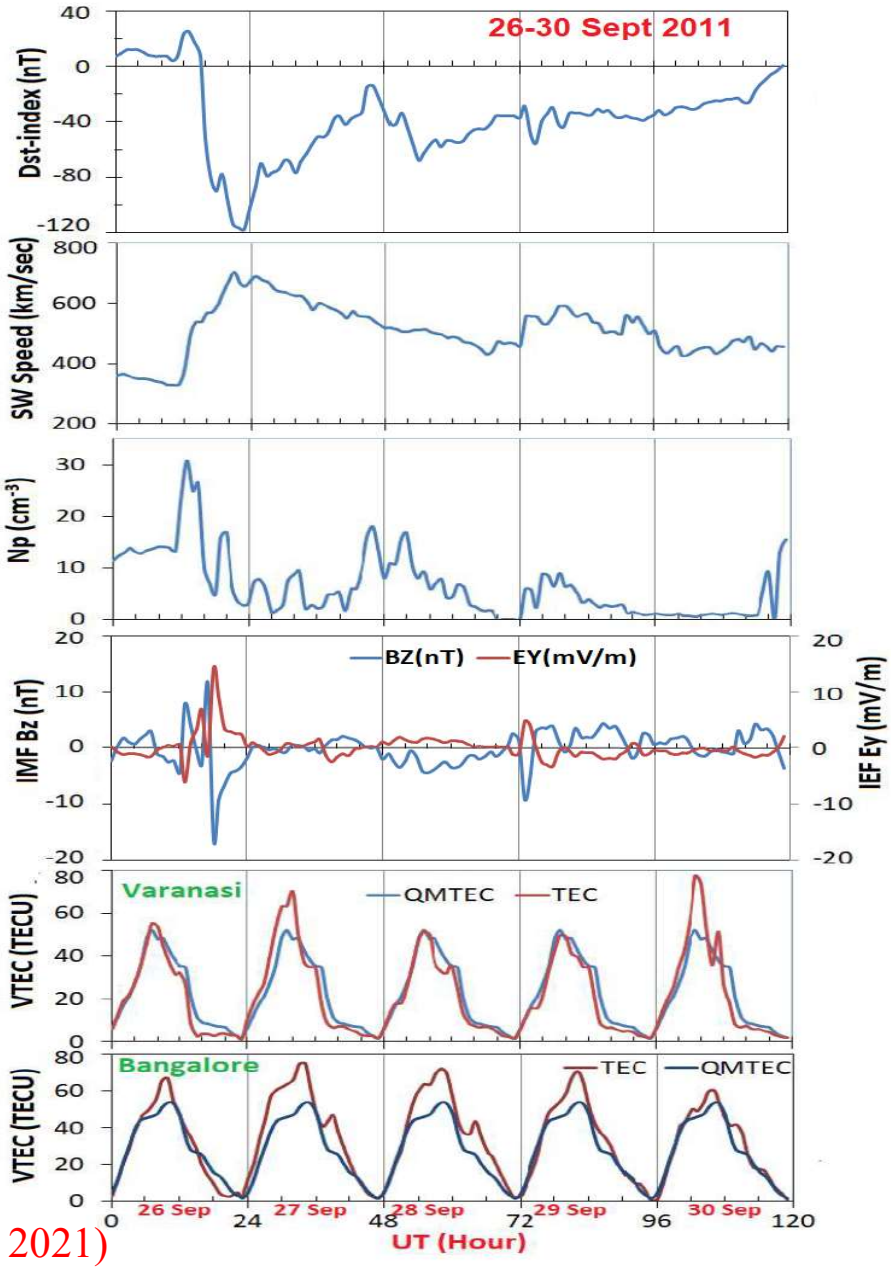
St. Patrick's Day Geomagnetic storm



A negative storm effect during daytime is observed at EIA station (Varanasi & Lucknow) whereas a positive storm effect is noticed in equatorial region Bangalore on 18 March. A strong positive storm effect at EIA stations in the daytime during 20-21 March has been observed at Lucknow (~63 TECU) & at Varanasi (~37 TECU) where as the equatorial and low latitude stations were found unaffected.

Geomagnetic Storm of 26 September 2011

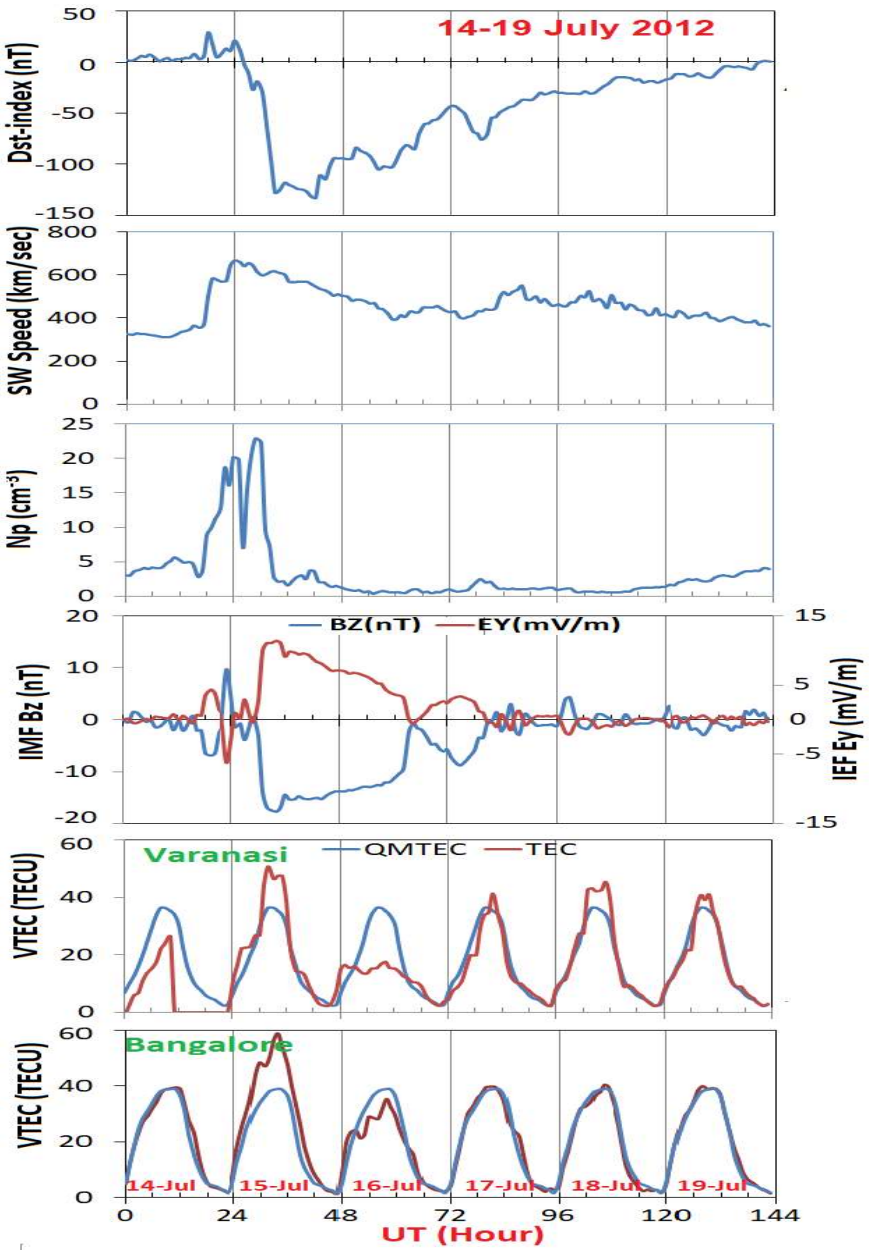
- The SSC at 17:00 UT then Dst decreases rapidly to -118 nT (23:00 UT).
- Solar wind speed and density jumped from 333 to 704 km/sec and 13.2/cm^3 to 30.7/cm^3 respectively, indicating the arrival of a possible interplanetary shock leading to the formation of a geomagnetic storm.
- The IMF Bz turned southward at 1700 UT and remained southward until 24:00 UT on 26 Sept. During this, IEF Ey turned eastward changed by 15.71 mV/m.
- On 27 September VTEC increases with maximum enhancement **~22 TECU**. Enhancement in VTEC (**~25 TECU**) is noted in daytime on 30 Sept.
- Such enhancement could be storm induced wind lifting effect because electric field was too weak to produce such enhancement.



(Singh, et al., *J. of Astrophysics and Astronomy*, **42**, 99, 2021)

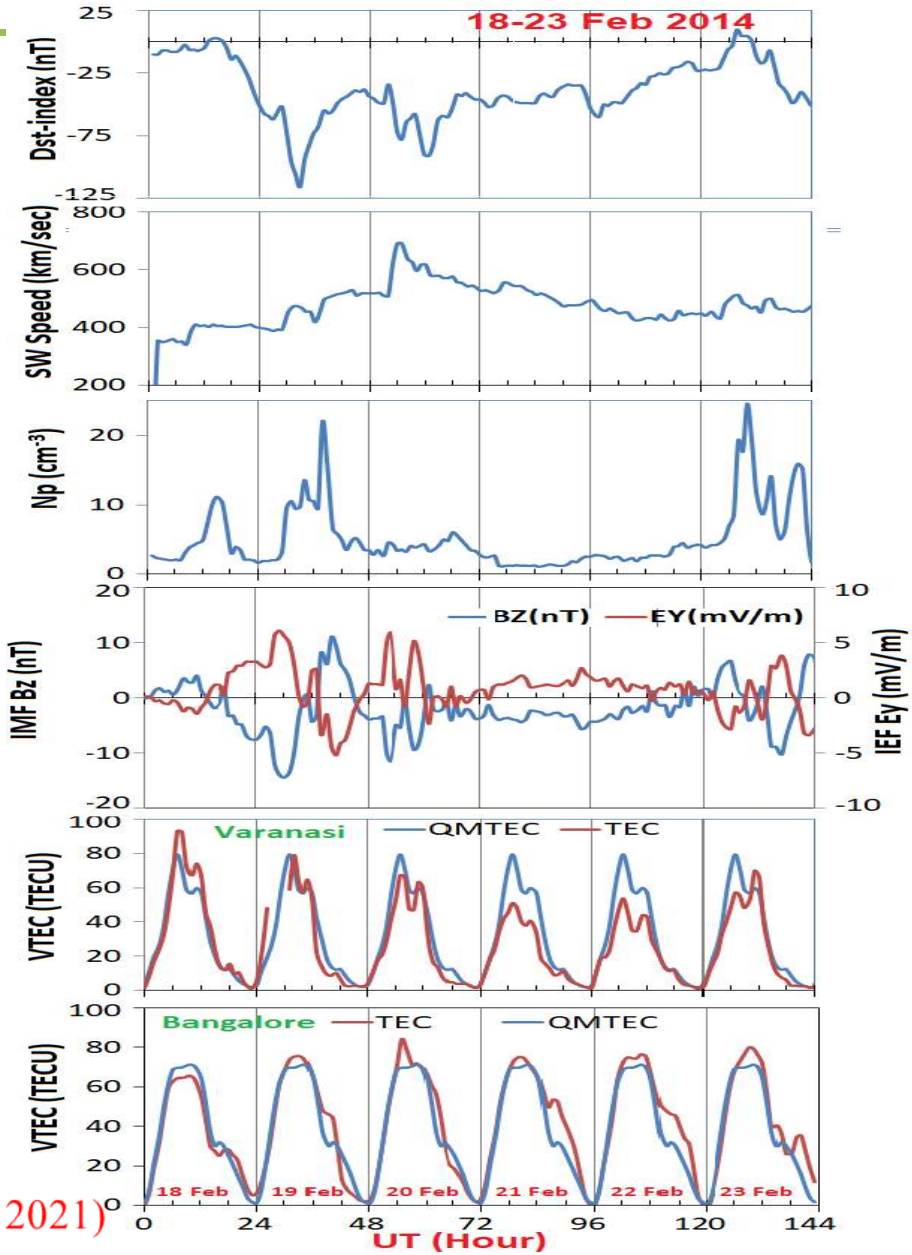
Geomagnetic Storm of 15 July 2012

- Storm onset at 00:00 UT on 15 July 2012 with Dst_{min}= -133 nT at 1800 on the same day.
- IMF Bz turned southward during 0600-0900 UT on 15 July consequently IEF Ey became eastward & significantly changed by 11.45mV/m.
- An enhancement in VTEC (**20 TECU**) was observed on 15 July in daytime hours during 0700-1200 UT which is probably associated with PP electric field.
- On 16 July VTEC decreased during 0300-1400 UT by ~ **20 TECU** from normal value. During this time interval IEF Ey was eastward and could not produce depression in VTEC hence such depression may be caused by DDEF effect.
- Further on 17 July, 18 July and 19 July an enhancement in VTEC was observed during the daytime hour could be resulted from the storm-induced neutral wind effect.



Geomagnetic Storm of 19 Feb 2014

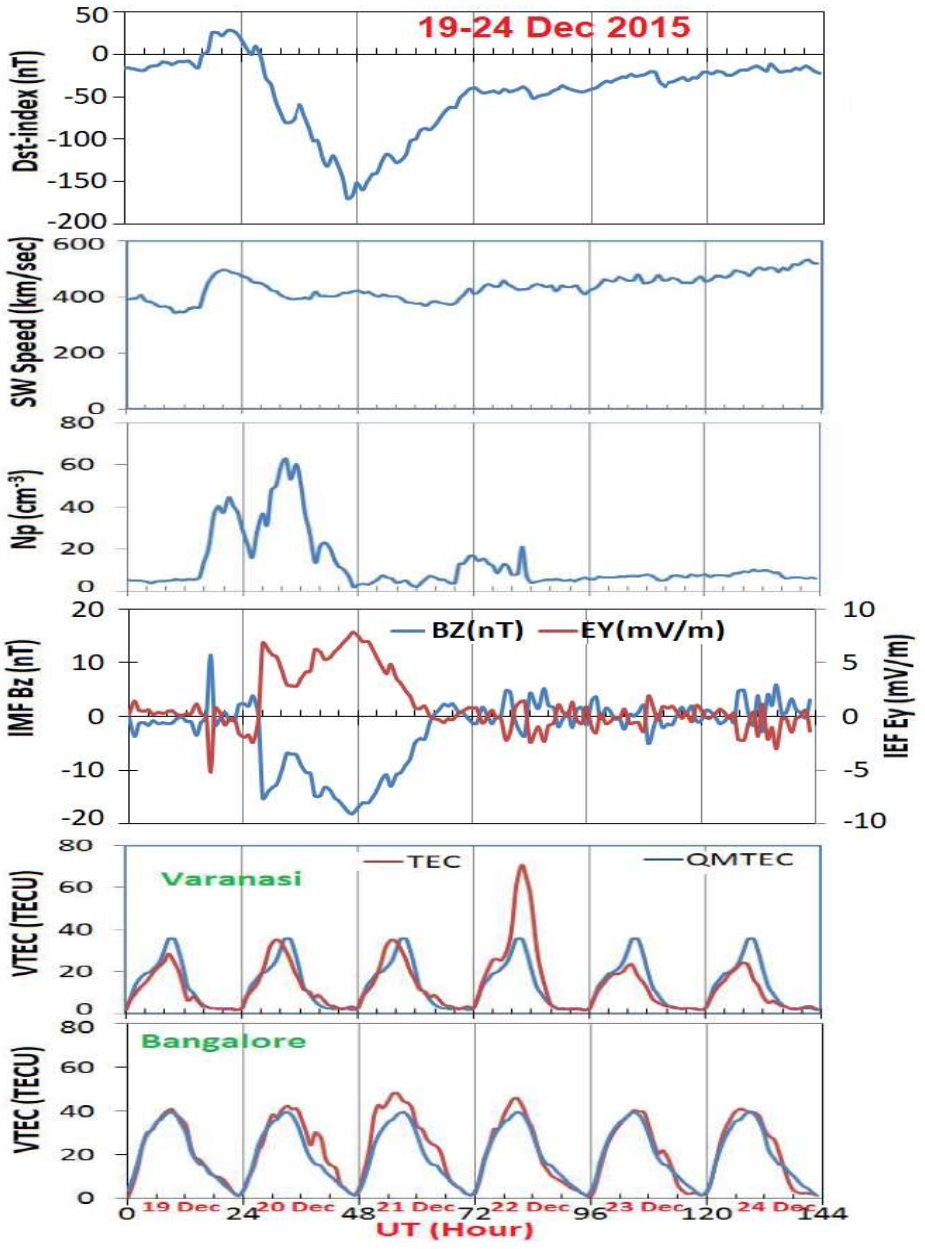
- The SSC was at 1400 UT on 18 Feb. with Dst_{min}= -116 nT at 0900 UT on 19 Feb. Dst-index again showed a dip on 20 Feb at around 1200 UT (Dst_{min} = -91 nT).
- IMF Bz turned southward between 1700 UT on 18 Feb and 0600 UT on 19 Feb and IEF Ey turned eastward and changed by 6.29 mV/m. IMF Bz turned southward again at 1600 UT on 19 Feb and remained southward until 0500 UT on 21 Feb which resulted IEF Ey to turned eastward and changed by 10 mV/m.
- An enhancement in VTEC is noticed during daytime hour on 18 and 23 Feb. Depression in VTEC is also noticed during 19-22 Feb in daytime hour. The reduction in VTEC during the daytime hour may be due to the DDEF effect.



(Singh, et al., *J. of Astrophysics and Astronomy*, **42**, 99, 2021)

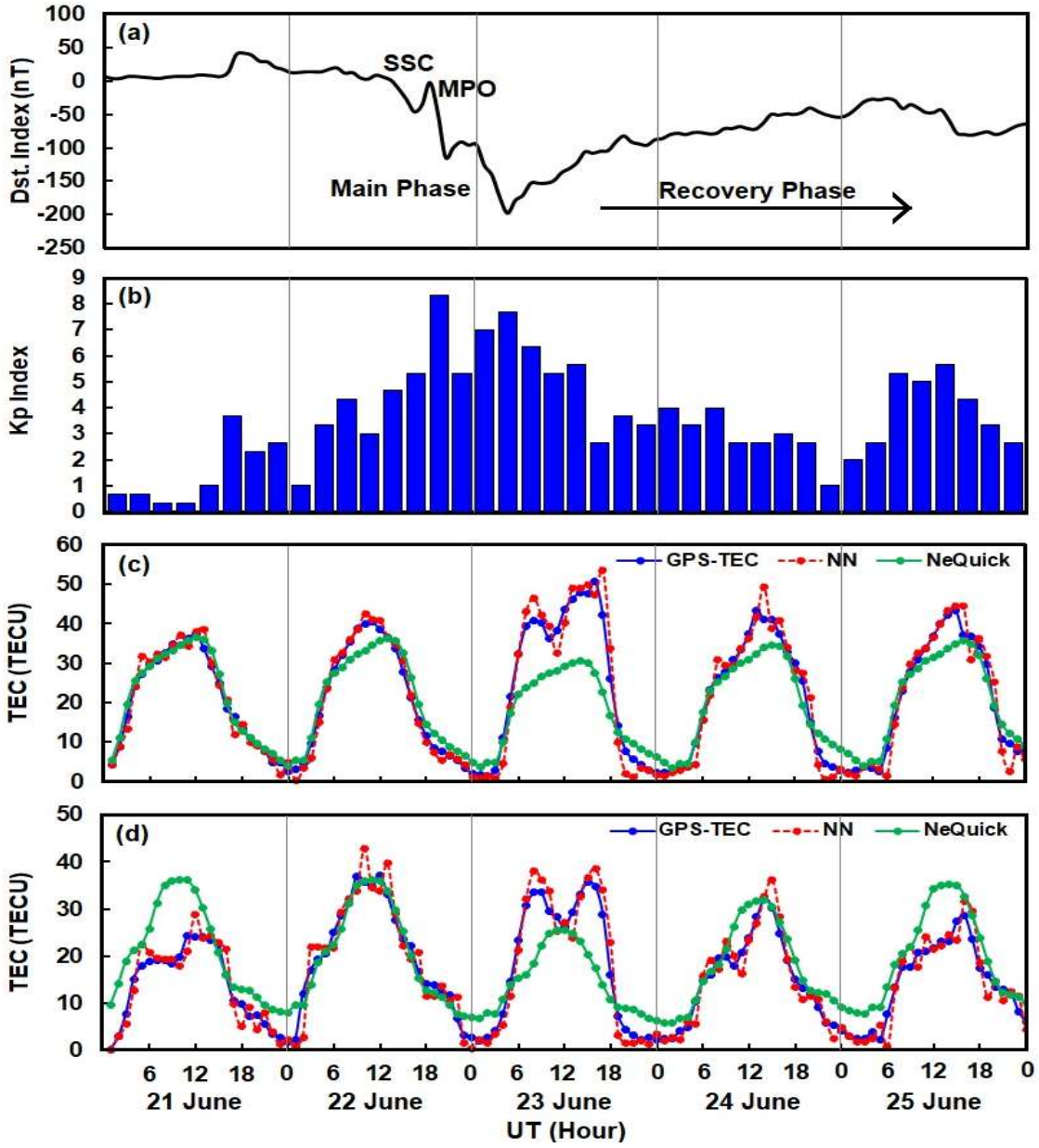
Geomagnetic Storm of 20 December 2015

- The SSC at 1700 UT on 19 Dec having Dst_{min}= -166 nT at 2300 UT on 20 Dec. After this recovery started.
- IMF Bz turned southward for a longer time between at 0200 UT and remained so until 2300 UT on 20 Dec. During this time interval IEF Ey turned eastward and enhanced by 10.3 mV/m.
- A small reduction in VTEC during daytime were seen on 19, 23, 24 Dec where as enhancements were observed on 20 Dec (10 TECU), 21 Dec (10 TECU), 22 Dec **(~35 TECU**).
- An enhancement in VTEC on 20 Dec could be alteree by eastward turning of IEF Ey where as enhancement on 21 and 22 Dec could be caused by storm induced wind lifting effect.



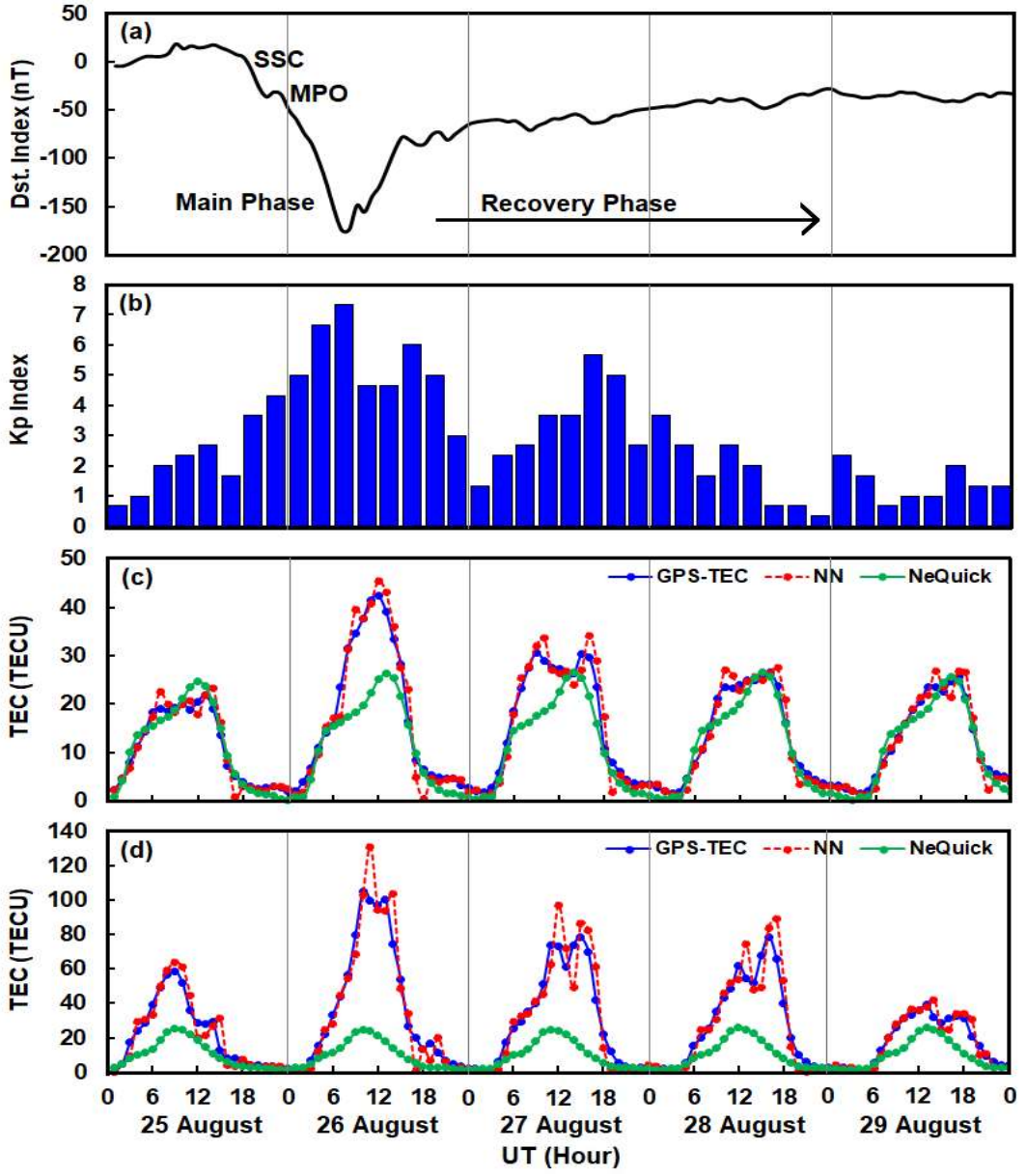
TEC forecasting with Neural Networks during Intense Geomagnetic Storm of 23 June 2015

- SSC:09:00 UT and MPO:12:00 on March 22, 2015. Dst-index dropped to -198 nT at 05:00 UT on June 23.
- The Kp index peaked to 8.33.
- TEC calculated via the NN is in accordance with the GPS-TEC values made across Bangalore and Lucknow.
- The NeQuick-TEC is underestimated during the entire event in Bangalore and Lucknow, except for June 21, 2015.
- NN model is better for predicting TEC values than the NeQuick model.



TEC forecasting with Neural Networks during Intense Geomagnetic Storm of 26 August 2018

- SSC: 10:00 UT, MPO: 1600 UT Dst-index: -175 nT at 07:00 UT on August 26.
- The Kp index peaked to 7.67
- TEC calculated using NN is in excellent accordance with the observed GPS-TEC values made across Bangalore and Lucknow during August 25–29, 2018.
- In Bangalore and Lucknow, the NeQuick-TEC is underestimated throughout the entire event.
- NN model is better for predicting TEC values than the NeQuick model.



Conclusions

- During Intense geomagnetic storms, ionospheric TEC is found to increase as well as decrease. Storm time perturbation in TEC as high as 54 TECU from quiet mean TEC can result in 5-6 m error in GPS-L1 signal and hence affect the navigation system.
- Storm induced electric field responsible for electrodynamical drift as well as storm induced mechanical effect from neutral wind have been used to explain the observed results.
- However yet it is not possible to separate contribution from individual factors particularly at equatorial and low latitude region where electrodynamics is less studied and more complex and therefore need further investigation.
- NN model is better for predicting TEC values than the IRI-NeQuick model during intense geomagnetic storm periods.

Acknowledgements

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THANK YOU