DISTRIBUTION OF IONOSPHERIC IRREGULARITIES OVER INDIA DURING SEVERE SPACE WEATHER EVENT

Nilesh Desai

Deputy director, Space Applications Centre, ISRO

Introduction

- Space Weather Elements

  Space Weather is defined as the condition of the heliosphere driven by magnetic activities of the sun through solar wind, CME and solar flare etc.

  Primarily characterized by the solar wind parameters like its plasma content, momentum, pressure, etc. and by interplanetary magnetic field (IMF) carried by it.

- Effects on Equatorial ionosphere

  Their interplay with earth's magnetosphere leads to exchange of particles and energy

  Results in particle precipitation, induced electric fields and consequent currents, perturbation in geomagnetic fields

  Equatorial and high latitude ionosphere is mostly perturbed as a result in terms of electron density enhancement and irregularity formation

- Effect on GNSS

  Ionospheric perturbation leads to excess delay and scintillation in GNSS signals

Preamble

Metrics to quantify irregularities and its effects

- Variations in ionospheric Total Electron content occur as the ionosphere changes with time and signal changes its path with time, as well

- Overall Rate of TEC (ROT) along the signal path in terms of TEC (T) is

$$ROT = dT/dt = \partial T/\partial t + v \cdot \partial T/\partial s$$

- ROTI is Standard deviation in ROT values over a 5 minutes' window (Pi et al., 1997).

$$ROTI = \sqrt{< (ROT - < ROT >)^2 >} \quad \text{TECU/min}$$

- S4 is the index of amplitude scintillation and is given by

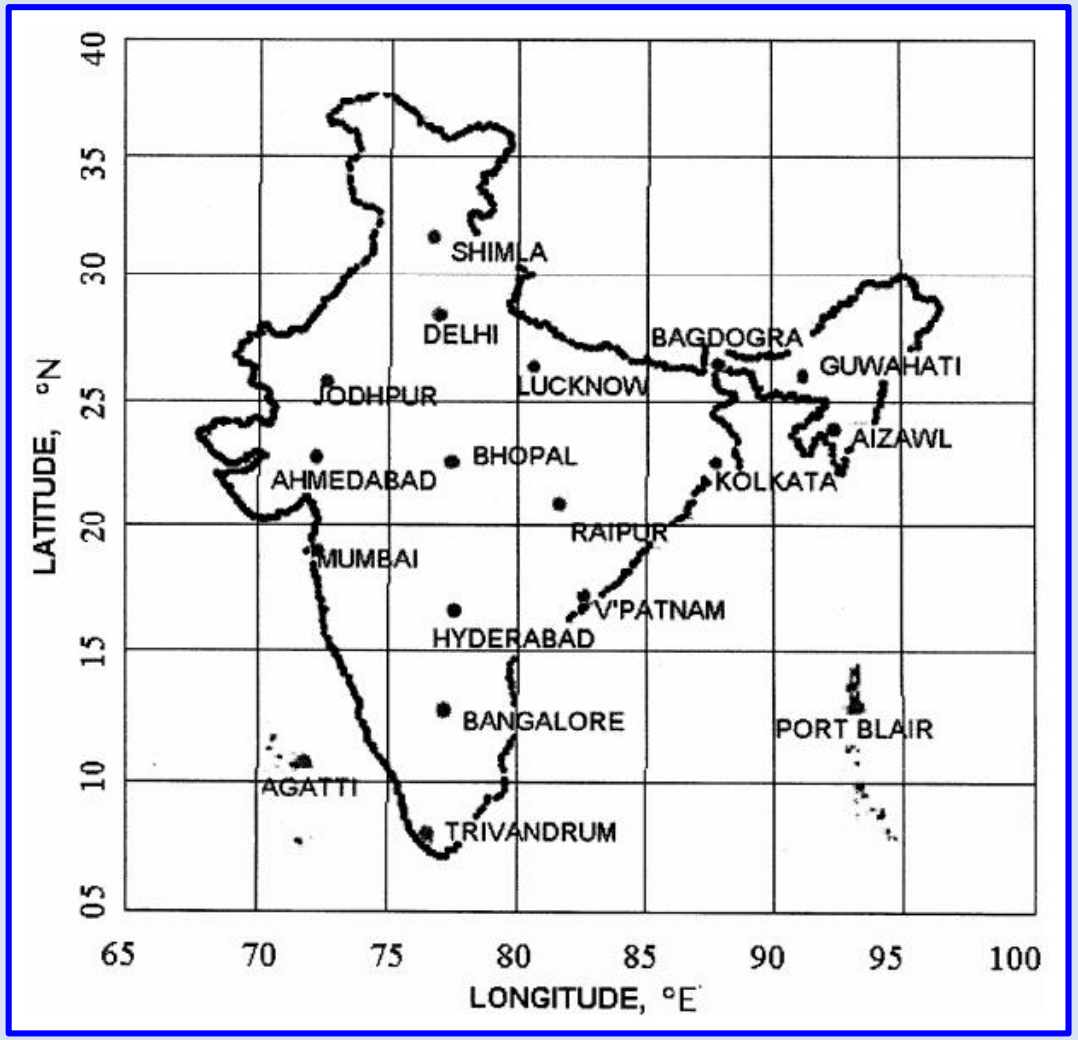
$$S_4{}^2 = \frac{<I^2> - <I>^2}{<I>^2}$$

- Correlation between ROTI and S4 has been established by many previous researchers

Preamble

Measurements of Data

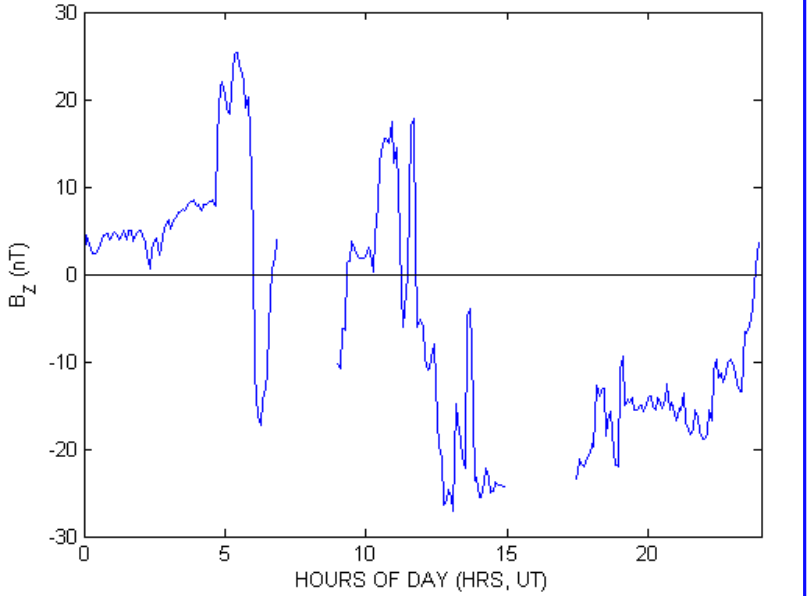
- TEC is measured using Indian GNSS Network of 18 Stations
- TEC data from the select TEC measuring receivers of the Indian GNSS is utilised
- Receivers provide the TEC values along the slant signal path in TEC units elevation, azimuth and time stamps at the interval of 30 seconds.
- Receivers are also capable of estimating the amplitude scintillation at L1 in terms of S4 index
- Measurements are recorded up to a lowest elevation of 25°.

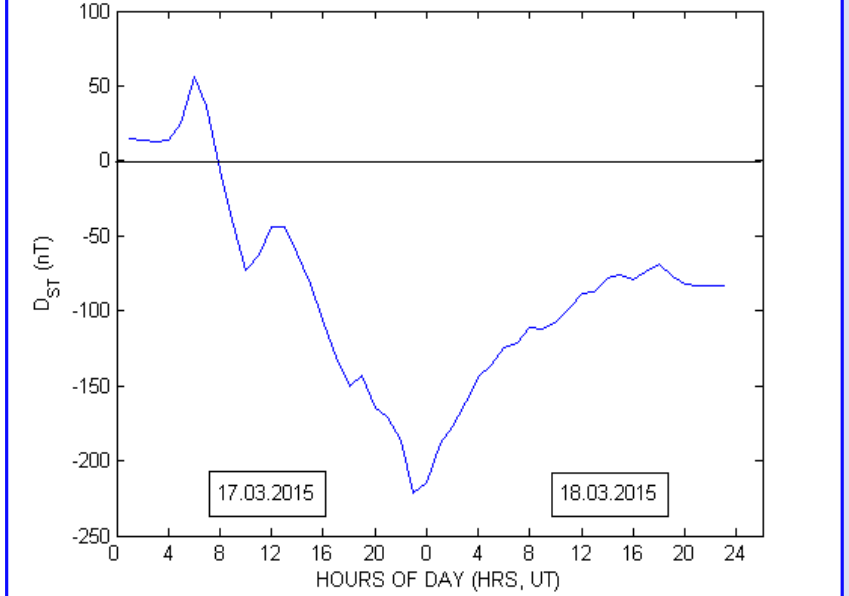


Preamble

St. Patrick's Day Geomagnetic Storm

- CME (Coronal Mass Ejection in Sun) occurred on March, 15, 2015
- Plasma shock impinged upon magnetosphere on March, 17, 2015 at ~0430 UT.
- Around 1200 hrs UT, IMF a G4 geomagnetic storm started. Most severe storm of cycle 24
- strong scintillation at equatorial latitudes were reported from Brazil and India





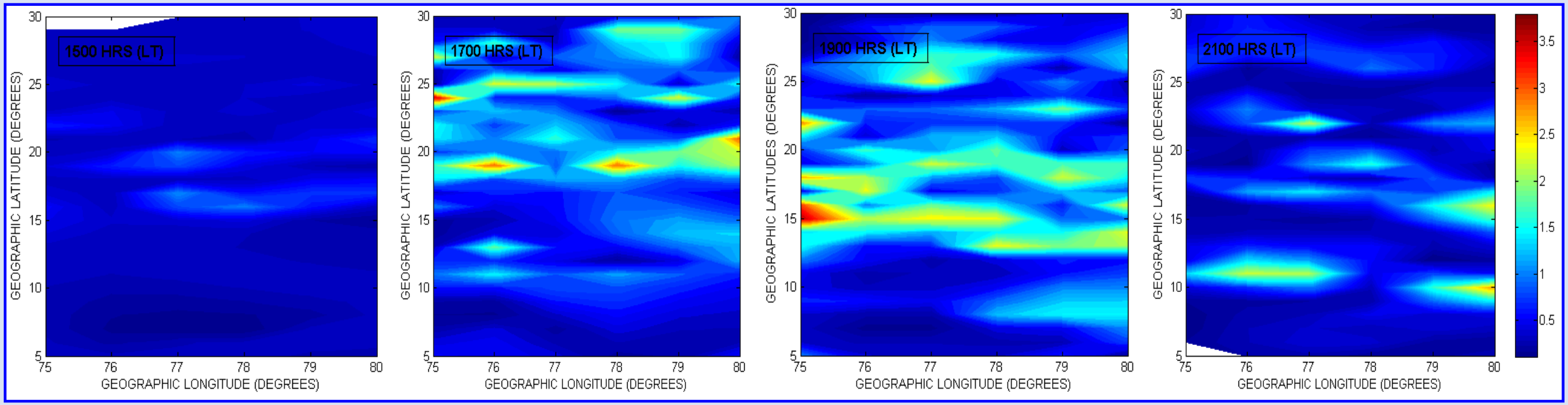
Min. IMF Bz = -30 nT

Induced Elec. Field = 200 mV/km

Min. D_{st} = -223 nT at 2300 hrs UT.

Results

Spatial plots of ROTI on Storm day for different snapshots

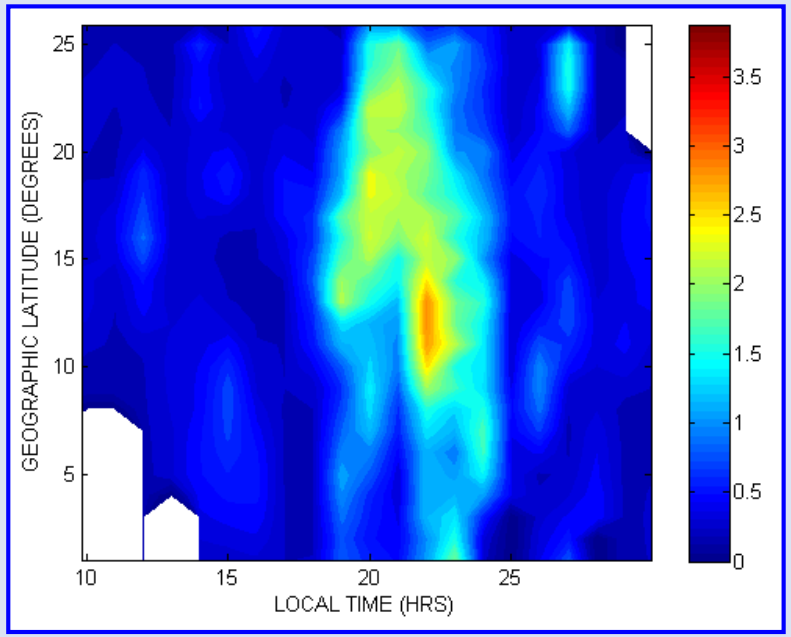


1500 hrs LT | 1700 hrs LT | 1900 hrs LT | 2100 hrs LT

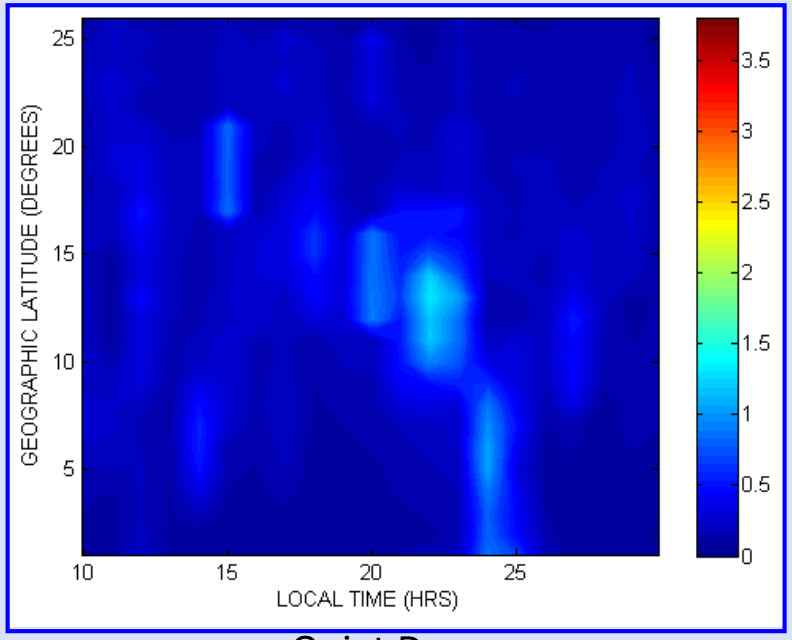
- Obvious escalations in irregularity intensity observed in ROTI on storm day
- Latitudinal regularity observed
- Occurrence most conspicuous under the crest
- Maximum occurrence observed around 1900 hrs

Results

Spatio-Temporal pots of ROTI for Storm and Quiet days



Storm Day
17.03.2015

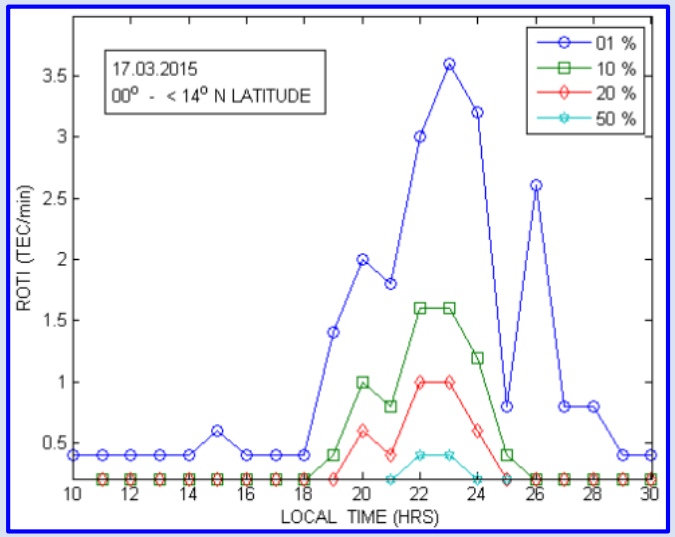


Quiet Day
10.03.2015

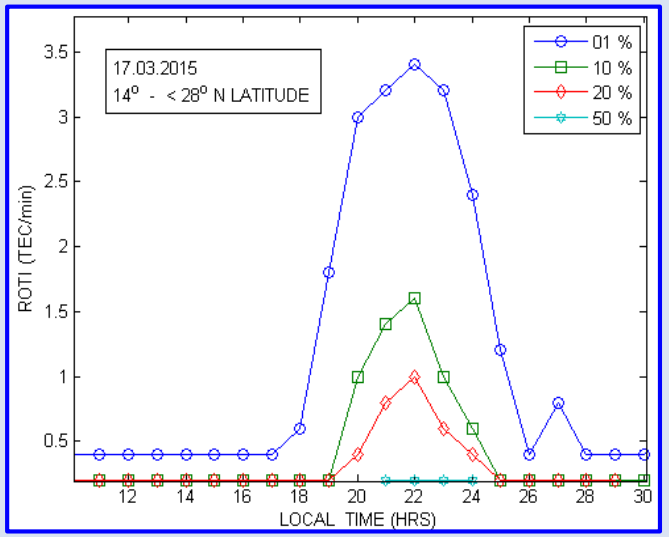
- Obvious escalations in spatial extent, intensity and duration of the ROTI for the storm day
- Compared to a quiet day, the intensity of the irregularity has increased by over 180% on the storm day while the spatial extent is over 300% more area in spatio-temporal plane

Results

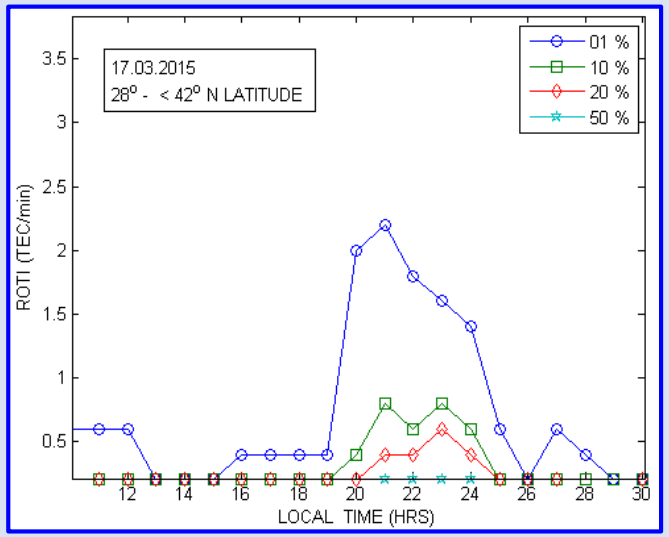
Statistical Occurrences of irregularities – Exceedance plots on Storm day



00° - <14°N



14°N - <28°N



28°N - <42°N

- Exceedance plots indicates the value of ROTI that is exceeded for a given probability of occurrence. Plots are shown for different percentages of exceedance over time.
- Equatorial and Crest region showed maximum values. 1% of cases at 22-23 hrs LT exceeded ROTI value of 3
- Intensity falls of at regions above crest region

Discussion and Conclusion

- Features of Spatio-temporal variations the equatorial ionospheric irregularities on storm day analysed in terms of ROTI

- The main conclusions of this study are the following:

  Intense storm generated irregularity compared with a nominal quiet day, and found

  - *Irregularity is much more extensive than that occurring during a normal quiet day in terms of intensity, spatial and temporal extent.*
  - *This enhancement continues till crest region, but in the hypercrest region, the enhancement factor is lesser.*
  - *Storm initiated large irregularities within 1 hour from the instant of the southward turning of the Interplanetary Magnetic Field (IMF) Bz.*
  - *Intense irregularity originates near the crest and shows movement towards both North and south*

Finally, we conclude severe storm can cause large magnitude of irregularities and hence scintillation over extensive areas and time, those otherwise considered to be unaffected over the Indian region.

References

- Abe, O.E., Villamide, X.O., Paparini, C., Ngaya, R.H., Radicella, S.M., Nava, B., 2017. Signature of ionospheric irregularities under different geophysical conditions on SBAS performance in the western African low-latitude region, Annales Geophysicae, 35, 1-9
- Acharya, R., Nagori, N., Jain, N., Sunda, S., Regar, S., Sivaraman, M.R., Badyopadhyay, K., 2007. Ionospheric Studies for the Implementation of GAGAN. Indian Journal of Radio and Space Science, 36, Oct-2007, 394-404
- Acharya, R and Majumder, S, 2018. Statistical relation of Scintillation index S4 with ionospheric irregularity index ROTI over Indian Equatorial region, Advances in Space Research (Communicated)
- Bagiya, M.S., Iyer, K.N., Joshi, H.P., Thampi, S.V., Tsugawa, T., Ravindran, S., Ravindran, R., Pathan, B.M., 2011. Low latitude ionospheric-thermospheric response to storm time electrodynamic coupling between high and low latitudes, Journal of Geophysical Research: Space Physics, 2011, 116, A01303.1 - A01303.17.
- Basu S, MacKenzie E, Basu Su, 1988. Ionospheric constraints on VHF/UHF communications links during solar maximum and minimum periods. Radio Science, 23(3), 363–378
- Basu, S., Groves, K.M., Quinn, J.M., Doherty, P., 1999. A comparison of TEC fluctuation and scintillations at Ascension Island, Journal of Atmospheric Solar Terrestrial Physics, 61, 1219–1226.
- Beach, T.L. and P.M. Kintner (1999), Simultaneous Global Position System observations of equatorial scintillations and total electron content fluctuations, Journal of Geophysical Research, 104(A10), 22553–22565.
- Blanc, M. and Richmond, A.D., 1980. The ionospheric disturbance dynamo, Journal of Geophysical Research, 85, 1669-1688.
- Fuller-Rowell, T.J., Cordrescu, M.V., Araujo-Pradere, E.A., 2001. Capturing the storm-time F region ionospheric response in an empirical model, in Space Weather, Geophysical Monograph No. 125, P. Song, H. Singer and G. Siscoe, Eds. AGU, Washington, D C, 2001, pp. 393-401.
- Ganeshan, A.S., Satish, S.V., Kartick, A., Srinivasan, N., Ramesh, G., 2016. GAGAN - Redefining Navigation over the Indian Region, Inside GNSS, Jan-Feb 2016, 42-48

References

- Gonzales, C. A., Kelley, M.C., Fejer, B.G., Vickrey, J.F., Woodman, R.F., 1979. Equatorial electric fields during magnetically disturbed conditions: 2. Implications of simultaneous auroral and equatorial measurements, Journal of Geophysical Research, 84(A10), 5803–5812
- Kelly, M.C., Fejer, B.G., Gonzales, C.A., 1979. An explanation for anomalous equatorial ionospheric electric fields associated with a northward turning of the interplanetary magnetic field, Geophysical Research Letters, 6(4), 301–304
- Kelly, M.C., 2009. Earth's Ionosphere: Plasma Physics and electrodynamics, 3rd Ed. Elsevier.
- Kikuchi, T., Hashimoto, K.K., Kitamura, T.I., Tachihara, H., Fejer, B., 2003. Equatorial counter-electrojets during substorms, Journal of Geophysical Research, 108(A11), 1406.
- Martyn, D.F., 1947. Atmospheric tides in ionosphere – I: Solar tides in the F2 region. Proceedings of the Physical society of London, A189, 241 – 260.
- NOAA, 2018. NOAA Space Weather Scales, SWPC, https://www.swpc.noaa.gov/. Accessed on Apr 19, 2018.
- Pi, X., A. J. Mannucci, U. J. Lindqwister, and C. M. Ho (1997), Monitoring of global ionospheric irregularities using the worldwide GPS network, Geophysical Research Letters, 24, 2283–2286, doi:10.1029/97GL02273.
- Raghunath, S. and Ventaka Ratnam, D., 2016. Detection of Ionospheric spatial and temporal gradients for ground based augmentation system, Indian Journal of Radio and Space Physics, 45, March 2016, 11-19.
- Solar Storm, 2015, https://www.space.com/28845-solar-storm-auroras-st-patricks-day.html, Accessed on 22.07.2018
- WDC, 2015. World Data Centre for Geomagnetism, Kyoto. Provisional AE index for 2015. http://wdc.kugi.kyoto-u.ac.jp/ae_provisional/201503/index_20150317.html, Accessed on 19.08.2018
- Hang, Z. and Liu, Z., 2016. Correlation between ROTI and Ionospheric Scintillation Indices using Hong Kong low-latitude GPS data, GPS Solutions, 20, 815–824

Thank You