International Journal of Advance and Applied Research
www.ijaar.co.in
ISSN – 2347-7075 Impact Factor – 7.328
Peer Reviewed Bi-Monthly
Vol.11 No.5 May – June 2024

Response of the GPS-measured Total Electron Content (TEC) at Low Latitude during the Geomagnetic Storm

D. J. Shetti[1] & S. K. Chougule[1], P.D. Chougule[1]
[1]*Smt. Kasturbai Walchand College of Arts and Science, Sangli, India.*
Corresponding Author - D. J. Shetti
DOI - 10.5281/zenodo.12633627

Abstract:

GPS data from the IGS Hyderabad, Bangalore station were used to estimate the Total Electron Content (TEC) of the ionosphere during the geomagnetic storm that occurred on May 15, 2005. RD_RINEX slant TEC program and UNB Ionospheric Modelling Techniques were used to estimate TEC from these two-station data. Three consecutive days were used to analysed TEC and measure the rate of change of TEC (d(TEC)/dT). In this paper, the percentage variation during the period 14-16, May 2005 on day and night and the TEC response to a geomagnetic storm were discussed.

Keywords: Total Electron Content (TEC), Magnetic Storm, Ionosphere, Dst, Kp index

Introduction:

In order to study the F-region storm effects (both positive and negative) at equatorial and low-latitude regions, several authors have recently used the Global Positioning System(GPS) (Singh et al ,2021). Numerous studies (Prolss, 1995, Fuller et al., 1998, Buonsanto,1999, Danilov and Lastovicka, 2001) have examined the circumstances and the mechanisms that result in the complex spatial and temporal structure in the F region of the ionosphere during geomagnetic storms (Rajana etal, 2024).

Case studies of particular ionospheric storms have also been studied by many researchers (Ho et al,1998, Cander and Mihajlovic, 1998; Jokowski et al., 1999). The plasma distribution of the ionosphere significantly affects the ionospheric electric field disturbances during the magnetic storms observed at mid and low latitude stations on different time scales.

According to several researchers (Nishida ,1968; Vasyliunas ,1970, 1972; Jaggi and Wolf ,1973), and longer-lasting disturbance-wind dynamo effects (Spiro et al., 1988; Sastri, 1988), they are caused by both the rapid penetration of time-varying magnetospheric fields from high latitudes to low latitudes. A low mid-latitude station experienced a significant increase in total electron content (TEC) during the Bastille Day storm in July 2002 of about 250% compared to the quiet day conditions (Araujo-pradere, 2005). Season, solar activity, and magnetic activity have all been investigated in relation to nighttime improvements in TEC at low, mid, and high latitudes (Young et al., 1970). For all seasons, researchers found that the occurrence frequency (in percent) of TEC boosts during weak storms is higher than during quiet nights (Unnikrishnan et al. (2002). There is a strong correlation between the sun zenith angles and dTEC /dt (Wan et al. ,2005). Additionally, the TEC fluctuation rate and TEC increment are both proportional to the radiation flux and inversely proportional to the Chapman function.

In this research, we use GPS data from the IGS station in Hyderabad to analyse the response of the low latitude ionosphere to the various phases of the major geomagnetic storm that occurred on May 15–17, 2005.

GPS Data Processing:

The UNB Ionospheric Modeling Technique (UNB-IMT) and the RD_RINEX software are used to process the GPS data from the Hyderabad station. UNB was created in 1997 by Attla Komjathy at the "Department of Geodesy and Geomatics Engineering at the University of New Brunswick (UNB)". It produces ionospheric corrections by calculating TEC from GPS observables at both L1 and L2 frequencies. The software models the ionospheric measurements from a dual frequency GPS receiver with the single-layer ionospheric model (Komjathy, et al 1997), and it also estimates the coefficients of a linear spatial approximation of TEC over each station in addition to the satellite and receiver differential biases. Utah State University, Logan's Scherliess and Don Thompson created the RD_RINEX software. According to Scherliess et al. (2006), RD_RINEX is a program that converts RINEX observation and navigation files into the format required by the GAIM Kalman Filters. The software anticipates P1, P2, L1, and L2. Should P1 not be accessible, C1 will automatically take its place, provided it is available. Links that don't have at least two hours of data will not produce any output. No data are used that are less than 15 degrees above the horizon. The application makes an attempt to read the coordinates of the station from a file named gps_coord.dat.The coordinates from the RINEX file are used and considered reliable if the station isn't included in this file. Since this station consistently has all of the satellites in the file, we use the "brdc" navigation files. Occasionally, a single ground station can view all of the satellites visible to other stations. The brdc*n files were acquired from ftp.ngs.noaa.gov.

The Slant Phase TEC and Slant Code TEC are the program's outputs. Thus, we can derive Vertical Phase TEC and Vertical Code TEC by utilizing an appropriate geometrical mapping function.

Results and Discussion:

On May 15, the shock was observed at about 0600UT i.e. 1130LT (Local Time) [Pandey and Dashara 2005]. When compared to the third day (May 15, 2005), which shows an increase in VTEC values and a significant decrease in the Dst value that reached its lowest point (-256nT) at 0900 UT on the same day, Fig. 1 shows the first two days as quiet days that we use as reference days and are less influenced by the storm. The Kp index abruptly attained a value of 5 during the SSC and maxed at a value of 9, corresponding with the period of the lowest Dst value. The main phase has a short duration.

In Fig.2(a) and Fig.2(b), we also observe that the TEC value suddenly increases and then continues decreasing on May 15 2005 during day time hours and also into the night time but the enhancement is less pronounced relative to the day time hours.

Fig.2 (c & d) shows that the rate of loss of TEC also increases on 15 May 2005 relative to quiet day during day time while a slight increase in d(TEC)/dT is observed at night relative to the quiet night. The easiest way to express how the ionosphere reacts to geomagnetic disturbances is as ΔTEC%; this may be computed using the formula [Förster and Jakowski, 2000].

$$\Delta TEC\% = (TEC_{dist} - TEC_{quiet}) / TEC_{quiet} \times 100\%.$$

Fig. 2 (e & f) show the percentage deviation of storm time TEC values relative to the quiet day around day and night time hours. During the day time the deviation was 120% relative to the quiet day time while during the night time it was only 40% relative to the quiet night.

The dynamical connection between the high and low latitude regions is responsible for the increase in the TEC value caused by the equatorial F-region behavior under perturbed conditions, as opposed to quiet conditions. This can be mainly explained by two mechanisms:

1) Solar wind magnetospheric dynamo
2) Ionospheric disturbance dynamo

The first process is responsible for the polar cap potential variations, resulting in the rapid penetration of the electric field to low latitudes. The second mechanism, originating from changes in the global circulation due to Joule heating at auroral latitudes during magnetic storms, is described by Scherliess and Seger (1997).When hmF2 indicates a lower height value, the composition disturbance may be still another factor contributing to the augmentation of ground-based GPS TEC. The poleward disturbance zone causes the neutral species to downwell at low-middle latitude, which raises the [O] density in relation to N2 and O2 (Wan et al.,2005). At the maximal height of the F2 layer, the electron concentration is almost directly proportional to the [O]/[N2] ratio (Yizengaw et al, 2006, Pandey and Dashara, 2005).

Conclusions:

(a) During the main phase of the storm on May 15, 2005, the percentage deviation of TEC at Hyderabad was increased to 120 % relative to quiet day time values, however, the percentage deviation was reduced to 40% during the same night (Fig.2(e & f)).

(b) On May 15, 2005, both during the day and at about 03:30 hrs at night, the rate of loss of TEC (d(TEC)/dT) increased (Fig. 3(c &d)).

(c) Positive and negative effects of the storm on TEC could be explained by the generation of the eastward and west ward electric fields of magnetospheric origin which may lift the F-layer during day time enhancing TEC values and pushes the plasma down on the night side thereby reducing the TEC values.

Acknowledgements:

I am grateful to Prof. Langley of the Geomatics Engineering Department at the University of New Brunswick (UNB), Canada, for sharing a Unix/Linux-based FORTRAN code for the UNB ionospheric modeling technique with us. I also express my gratitude to D. Thompson of Utah State University's Center for Atmospheric and Space Science, Logan, for sharing the RD_RINEX code for educational purposes. Additionally, I am thankful to the IGS community for contributing ground-based GPS data and to the World Data Center for Geomagnetism in Kyoto, Japan, for providing the Dst and Kp index data.

References:

1. Araujo-Pradere, E. A. (2005). GPS-derived total electron content response for the Bastille Day magnetic storm of 2000 at a low mid-latitude station. Geofísica Internacional, 44(2), 211-218.
2. Buonsanto, M. J. (1999). Ionospheric storms - a review. Space Science Reviews, 88, 563-601.
3. Cander, Lj. R., & Mihajlovic, S. (1998). Ionospheric structure during the great geomagnetic storms. Journal of Geophysical Research, 103(A1), 391-398.
4. Danilov, A. D., & Lastovicka, J. (2001). Effects of geomagnetic storms on the ionosphere and atmosphere. International Journal of Geomagnetism and Aeronomy, 2, 209-224.
5. Förster M and Jakowski N (2000) Geomagnetic storm effects on the topside ionosphere and plasmasphere: A compact tutorial and new results. Surveys in Geophys 21: 47–87.
6. Fuller-Rowell, T. J., Codrescu, M. V., Roble, R. G., & Richmond, A. D. (1998). How does the thermosphere and ionosphere react to a geomagnetic storm? In B. T. Tsurutani et al. (Eds.), Magnetic Storms, Geophysical Monograph Series, Vol. 98 (pp. 203–225). AGU, Washington, D. C.
7. Ho, C. M., Mannucci, A. J., Sparks, L., Pi, X., Lindqwister, U. J., Wilson, B. D., Iijima, B. A., & Reyes, M. J. (1998). Ionospheric total electron content perturbations monitored by the GPS global network during two northern hemisphere winter storms. Journal of Geophysical Research, 103(A11), 26,419-26,420.

8. Jaggi, R. K., & Wolf, R. A. (1973). Self-consistent calculation of the motion of a sheet of ions in the magnetosphere. Journal of Geophysical Research, 78, 2852–2866.
9. Komjathy, A. (1997). Global Ionospheric Total Electron Content Mapping Using the Global Positioning System, Ph.D. dissertation, Department of Geodesy and Geomatics Engineering Technical Report No. 188, University of New Brunswick, Fredericton, New Brunswick, Canada.
10. Nishida, A. (1968). Coherence of geomagnetic DP 2 fluctuations with interplanetary magnetic variations. Journal of Geophysical Research, 73(17), 5549.
11. Pandey, R., & Dashora, N. (2005). Space weather studies at the crest of the equatorial ionization anomaly using GPS receiver. Retrieved from www.ips.gov.au/IP Hosted/coming.ursi
12. Prolss, G. W. (1995). Ionospheric F region storms. In H. Volland (Ed.), Handbook of Atmospheric Electrodynamics (pp. 195-248). CRC Press, Boca Raton, FL.
13. Rajana, S.S.K., Panda, S.K., Jade, S. et al. (2024). Impact of two severe geomagnetic storms on the ionosphere over Indian longitude sector during March-April 2023. Astrophys Space Sci 369, 3. https://doi.org/10.1007/s10509-024-04268-9
14. Sastri, J. H. (1988). Equatorial electric field of the disturbance dynamo origin. Annales Geophysicae, 6, 635.
15. Scherliess, L., Schunk, R. W., Sojka, J. J., Thompson, D. C., & Zhu, L. (2006). Utah State University Global Assimilation of Ionospheric Measurements Gauss-Markov Kalman filter model of the ionosphere: Model description and validation. Journal of Geophysical Research, 111, A11315. doi:10.1029/2006JA011712.
16. Singh, A., Rathore, V.S., Kumar, S. et al. (2021). Effect of intense geomagnetic storms on low-latitude TEC during the ascending phase of the solar cycle 24. J Astrophys Astron 42, 99. https://doi.org/10.1007/s12036-021-09774-8
17. Spiro, R. W., Wolf, R. A., & Fejer, B. G. (1988). Penetration of high-latitude electric-field effects to low latitudes during SUNDIAL 1984. Annales Geophysicae, 6, 39–50.
18. Unnikrishnan, K., Nair, R. B., & Venugopal, C. (2002). A comparative study of night-time enhancement of TEC at a low latitude station on storm and quiet nights including the local time, seasonal, and solar activity dependence. Annales Geophysicae, 20, 1843–1850.
19. Vasyliunas, V. M. (1972). The interrelationship of magnetospheric processes. In M. McCormac (Ed.), Earth's Magnetosphere Processes (pp. 29–38). Springer, New York.
20. Wan, W., Liu, L., Yuan, H., Ning, B., & Zhang, S. (2005). The GPS measured SITEC caused by the very intense solar flare on July 14, 2000. Advances in Space Research, 36, 2465–2469.

21. Yizengaw, E., Moldwin, M. B., Komjathy, A., & Mannucci, A. J. (2006). Unusual topside ionospheric density response to the November 2003 superstorm. Journal of Geophysical Research, 111.
22. Young, D. M. L., Yuen, P. C., & Roelofs, T. H. (1970). Anomalous night-time increase in total electron content. Planetary and Space Science, 18, 1165–1179.

Figure Captions:

Figure 1: From top to bottom panel shows the computed VTEC values for Hyderabad, the Dst (nT) index, and bottom panel showing the variation of Kp index on 13-17 May, 2005

Figure 2 (a & b): The VTEC variation for Hyderabad during day and night respectively on 13-17 May, 2005

Figure 2 (c & d): The d (TEC)/dT variation for Hyderabad during day and night respectively on 13-17 May , 2005

Figure 2 (e & f): The percentage deviation of TEC for Hyderabad during day and night respectively on 13-17 May, 2005

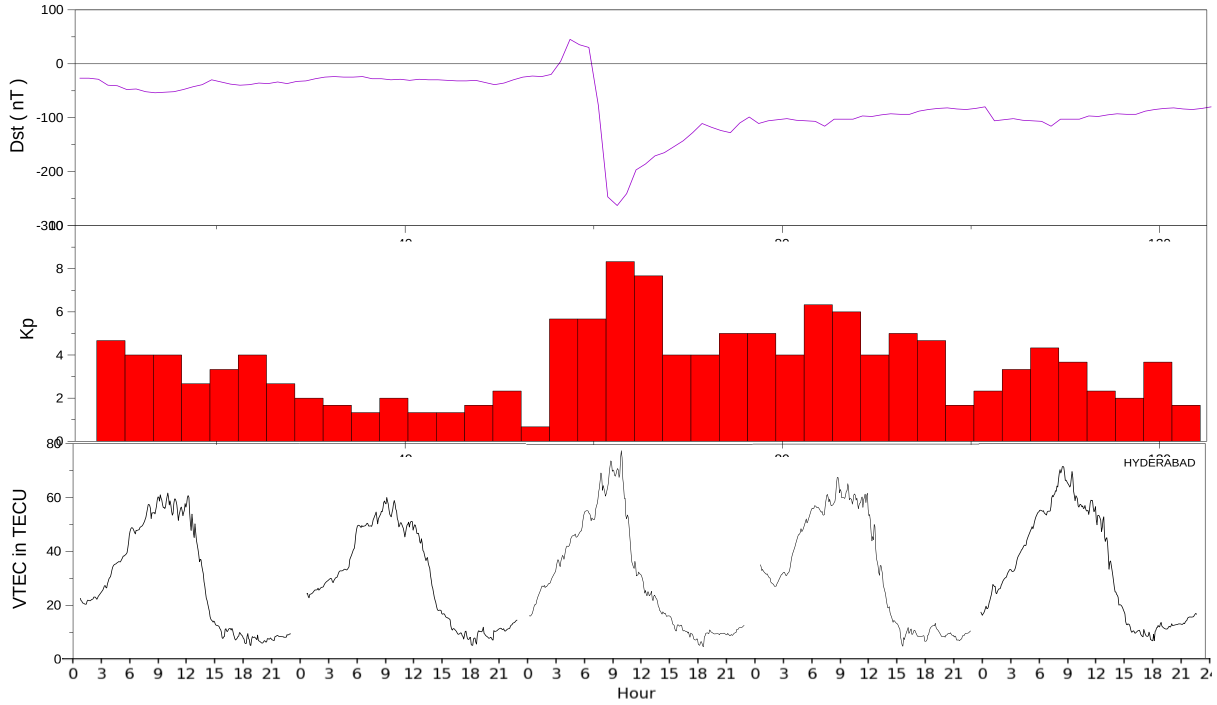

Figure 1

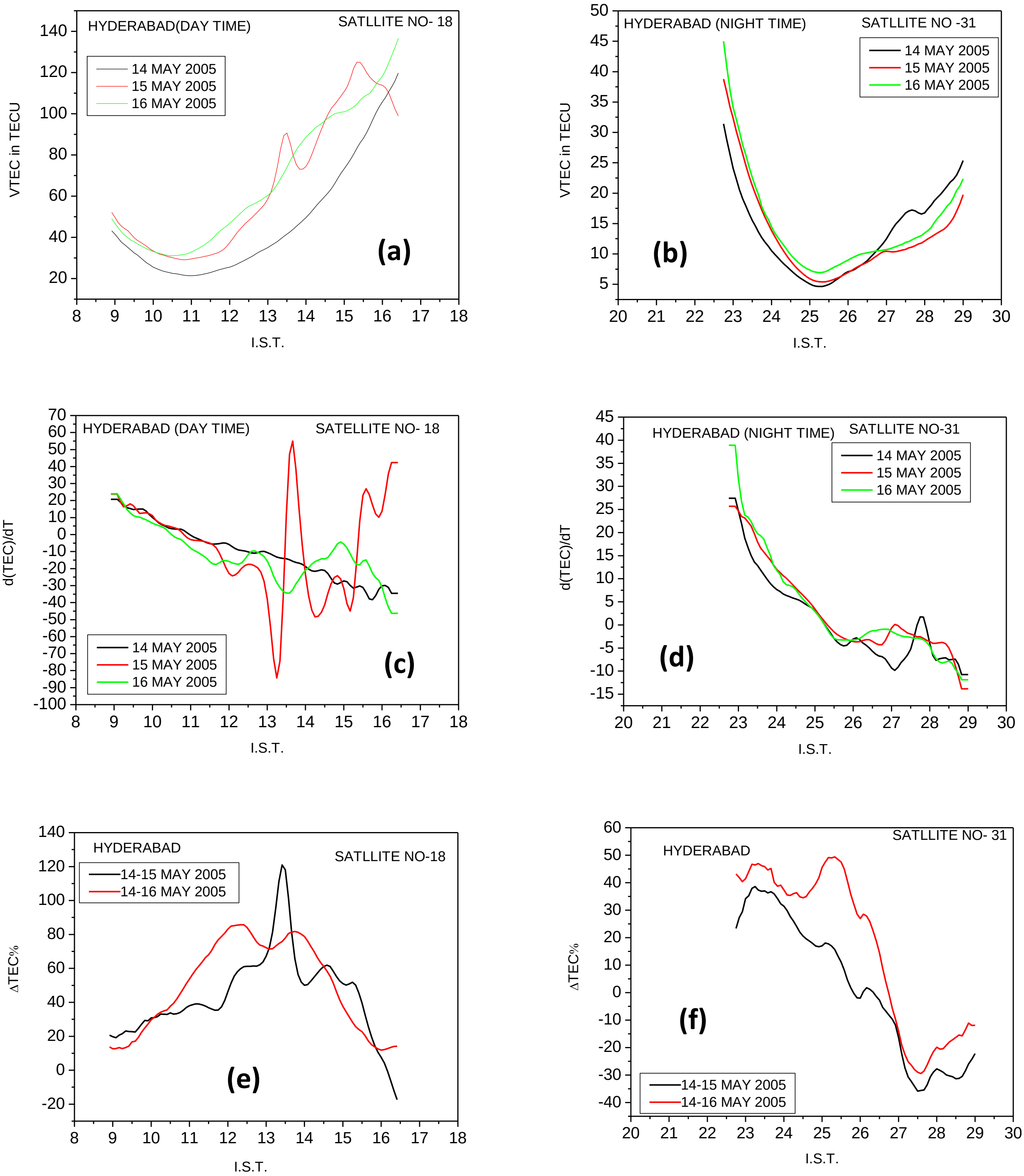
HYDERABAD(DAY TIME)
SATLLITE NO- 18
14 MAY 2005
15 MAY 2005
16 MAY 2005
VTEC in TECU
I.S.T.
(a)
HYDERABAD (NIGHT TIME)
SATLLITE NO -31
14 MAY 2005
15 MAY 2005
16 MAY 2005
VTEC in TECU
I.S.T.
(b)
HYDERABAD (DAY TIME)
SATELLITE NO- 18
14 MAY 2005
15 MAY 2005
16 MAY 2005
d(TEC)/dT
I.S.T.
(c)
HYDERABAD (NIGHT TIME)
SATLLITE NO-31
14 MAY 2005
15 MAY 2005
16 MAY 2005
d(TEC)/dT
I.S.T.
(d)
HYDERABAD
SATLLITE NO-18
14-15 MAY 2005
14-16 MAY 2005
ΔTEC%
I.S.T.
(e)
HYDERABAD
SATLLITE NO- 31
14-15 MAY 2005
14-16 MAY 2005
ΔTEC%
I.S.T.
(f)

Figure 2