VOLUME 17 January 2020 eISSN : 2382-5340 ISSN : 2091 - 0762

Journal of Physical Sciences

BIBECHANA

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Professor, Physics
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Published by
Department of Physics
Mahendra Morang Adrash Multiple Campus
T.U., Biratnagar

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ISSN 2091-0762 (Print), 2382-5340 (Online)

Journal homepage: http://nepjol.info/index.php/BIBECHANA

Publisher: Department of Physics, Mahendra Morang A.M. Campus, TU, Biratnagar, Nepal

Variation of Total Electron Content (TEC) in the quiet and disturbed days and their correlation with geomagnetic parameters of Lamjung Station in the year of 2015

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Article Information:

Received: November 06, 2019

Accepted: December 14, 2019

Keywords:

Total Electron Content

Geomagnetic parameters

GPS

ABSTRACT

Total Electron content (TEC) is measured using a dual frequency GPS receiver in Lamgung (LMJG) Station located at 84.57° longitude and 28.17° latitude of the year 2015 as it is considered as geo-magnetically active year. In this study, diurnal variation of VTEC has been studied separately for quiet and disturbed days and, for the effective study of the case the PRN wise data of VTEC have been also used. The maximum VTEC is seen from 0700 LT to 1100 LT (LT=UT+5.45). PRN wise VTEC is studied taking the lower bound (LB) and upper bound (UB). The correlation of VTEC with Dst index, Kp index and Solar flux have been studied. Positive correlation has been found in disturbed days with Kp index and solar flux but negative correlation with Dst index. Dst index shows positive correlation in quiet days but Kp index shows negative correlation.

DOI: https://doi.org/10.3126/bibechana.v17i0.26249

1. Introduction

Total Electron Content (TEC) is one of the important tools to study ionosphere which holds many unsolved mysteries of our planet. Nowadays, Global positioning system (GPS) has become a great aid to study the characteristics of ionosphere [1-4]. The GPS-TEC is the total number of electrons in a vertical column of 1 m^2 cross-section from the height of the GPS satellite (~ 20,000 km) to the receiver on the ground. It is measured in TEC Unit (TECU) and 1 TECU is equal to 1×1016 el m^{-2} [5, 6]. The ionospheric delay which is proportional to TEC is the highest contributor of GPS positional errors [7, 8]. Since, the use of GPS based devices are increased, the importance of TEC is also increased.

The delay in radio signals produced by GPS satellite occurs in the atmosphere [2, 9]. GPS satellite has 32 PRN (Pseudo Random Noise). A GPS receiver receives 32 different waves of data or signals released from GPS satellite. Normally, the value of VTEC is taken as average of the values of VTEC received by 32 PRN but for precise analysis value of each PRN is taken. It basically helps to learn about scintillation of TEC [10-12].

TEC is important tool to indicate the changes in the atmosphere [3, 13, 14]. Study on both quiet and disturbed days is important. So, many studies on disturbed days [15-19] and study on quiet day since Shuster (1889) have been performed.

Retrieval of Data

To process the data obtained from GPS satellite, Chauhan et al., [5] and Arikan et al., 2003 have given different methods for calculation of TEC. In our study, the method given by Chauhan et al. [5] is followed.

Using a dual frequency receiver having L1=1575.42MHz and L2=1227.60MHz in one station which include L1/L2 GPS antenna, the TEC measurements have been carried out through combined frequencies of pseudo- range and carrier phase measurements. The formula for calculation of TEC given by [5] is:

$$TEC = [9.483*(PR_{L2}-PR_{L1} - \Delta_{C/A\text{-}P,\ PRN}) + TEC_{RX} + TEC_{CAL}]\ TECU$$

where, PR_{L2}, is the L2 pseudo-range in meters; PR_{L1}, the L1 pseudo-range in meters; and $\Delta_{C/A\text{-}P,\ PRN}$, the input bias between SV C/A- and P-code chip transition in meters. There are 32 offset values (one for each satellite) which added to the C/A code pseudo-range measurements. TEC_{RX} is the TEC result due to internal receiver L1/L2 delay and TEC_{CAL} is the user defined TEC offset [5, 8].

As Slant TEC depends upon ray path geometry through the ionosphere, an independent and equivalent VTEC of elevation angle is calculated [3]. The above-mentioned GPS equipment provide slant TEC data at a sampling rate of 60 s. From this data, vertical TEC (VTEC) values are obtained at different ionospheric pierce point (IPP) locations by using a mapping function, i.e.

$$S(E) = \frac{1}{\cos(Z)} = \left\{1 - \left(R_E * \frac{\cos(E)}{R_E + h_s}\right) \wedge 2\right\} \wedge -0.5$$

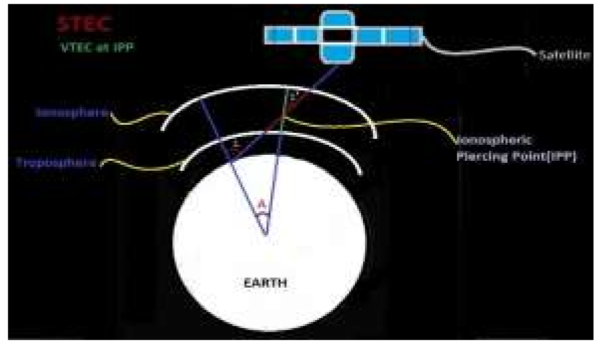


Fig: Conversion of STEC to VTEC

where, R_E, is the mean radius of the earth in km; h_s, the ionosphere (effective) height above the earth's surface; Z, the zenith angle; and E, the elevation angle in degrees [5]. Rama Rao et al. (2006) observed that the IPP (Ionospheric Pierce Point) altitude of 350 km is valid for the satellite elevation angle greater than 50°.

2. Method of study

UNAVCO provided the data of TEC obtained from GPS satellite. The GPS data is available the form of RINEX (Receiver Independent Exchange Format) which are further processed into ASCII files.

Data of every 60 sec of TEC has been converted into hourly data. Average value of VTEC has been taken into study in both cases, average VTEC of 32 PRN and VTEC of each PRN. The value of Kp index provided from NASA's Omniweb data explorer was given in the multiple of 10. So, In this paper, the value of Kp index's value is given in multiple of 10 and is represented as Kp*10. Data of values of Dst index, Kp index and Solar Flux were obtained from NASA's OmniWeb data explorer (https://omniweb.gsfc.nasa.gov/vitmo/iri2012_vitmo.html).

The station taken into study is LMJG (Lamjung). The details of the station is

Satellite	LMJG
Location	Lamjung
Latitude (degree)	28.17
Longitude (degree)	84.57
Elevation (m)	2025.2

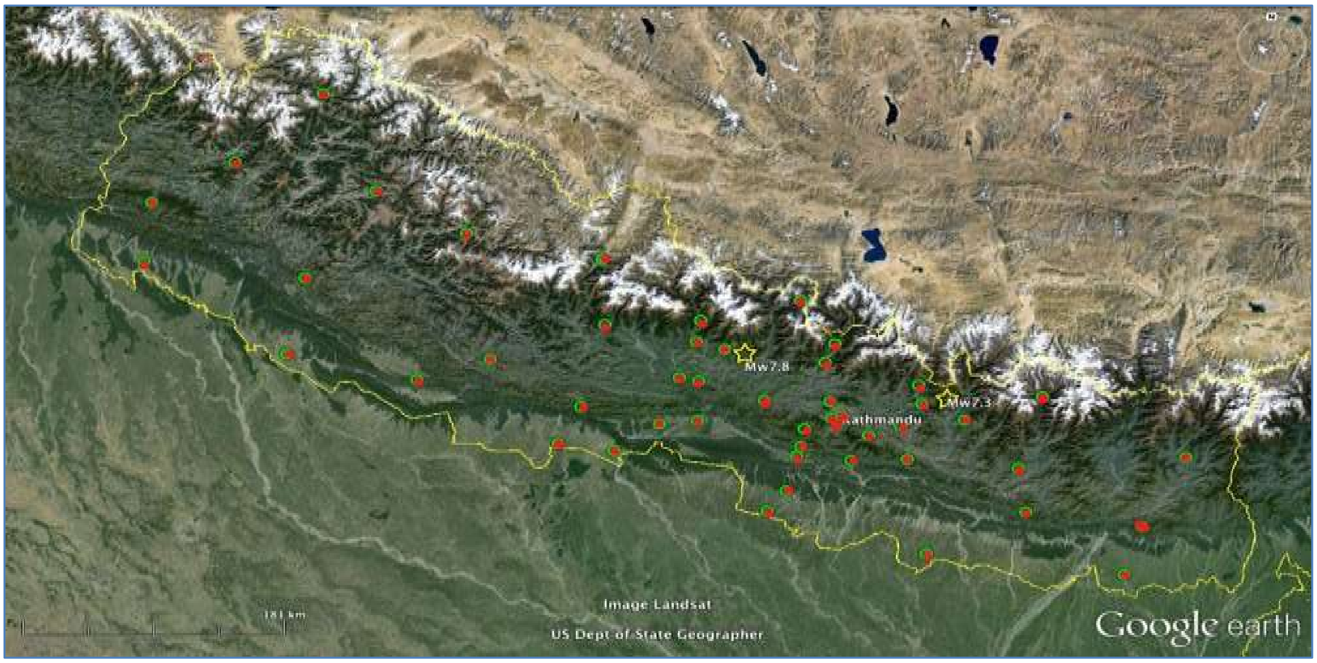


Fig: Map of Nepal showing GPS station taken in our study Source: www.unavco.org/highlights/nepalfield

3. Results and Discussions

In this Paper, VTEC variation of LMJG has been studied on daily basis. The study has been performed separately for quiet and disturbed days. Furthermore, the VTEC value of each PRN has also been studied on daily basis.

Data of VTEC of all months were not available due to the technical problems at the station. Data of May to July was available with few missing days.

Diurnal Variation of VTEC

Diurnal variation of TEC has been studied separately for quiet and disturbed days of three stations of the year 2015. Graphs of each quiet and disturbed days are presented for each month showing daily change. Generally, the diurnal variation of TEC is minimum a pre-dawn, a steady increase in the early morning followed by afternoon maximum then gradual decrease after the sunset.

The variation for peak value of TEC differs each and every day and also the time of the peak value.

The value of TEC was greater for quiet days than disturbed days which is opposite to the general result i.e. the higher value of VTEC in Disturbed days than Quiet days. There were many geomagnetic events that took place on 2015 which affected the value of TEC like Solar flare, St.Patrick's day and high EUV.

Quiet Day Variation

Fig. 1 (a) and Fig (b) show the daily variation of average VTEC and the variation of VTEC with PRN of May of quiet days of the year 2015 respectively. Data of each day of this month have been plotted.

Considering the variation of average VTEC, the trend of diurnal variation of minimum a pre-dawn, a steady increase in the early morning followed by afternoon maximum then gradual decrease after the sunset seems to be followed. The highest value of VTEC has been found to be 49.17 TECU at 1000LT.

In case of PRN wise variation, all the values of VTEC seems to lie between Upper bound (UB) and Lower bound (LB). However, PRN 9 recedes the value of lower bound (LB). This shows that there has been abnormal event in the values of VTEC received by the PRN 9. It has been found that the PRN 9 was exactly below the GPS satellite which resulted in abnormal value of VTEC.

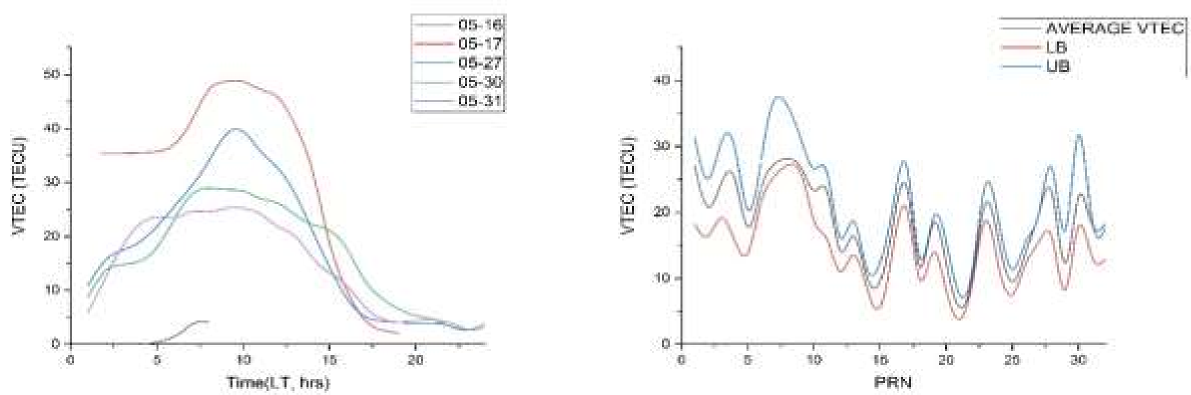


Fig. 1: (a) (b)

Fig. 2 (a) and (b) show the daily variation of average VTEC and the variation of VTEC with PRN of June of quiet days of the year 2015 respectively.

In the study of variation of average VTEC, the trend of diurnal variation of minimum a pre-dawn, a steady increase in the early morning followed by afternoon maximum then gradual decrease after the sunset seems to be followed. The highest value of VTEC has been found to be 58.34 TECU at 0900LT.

In case of PRN wise variation, all the values of VTEC seems to lie between Upper bound (UB) and Lower bound (LB). This shows that there has not been any abnormal event in quiet days of June.

Fig. 2 (a) and (b) show the daily variation of average VTEC and the variation of VTEC with PRN of July of quiet days of the year 2015 respectively.

In the study of variation of average VTEC, the trend of diurnal variation of minimum a pre-dawn, a steady increase in the early morning followed by afternoon maximum then gradual decrease after the sunset seems to be followed. The highest value of VTEC has been found to be 57.63 TECU at 0900LT.

In case of PRN wise variation, all the values of VTEC seems to lie between Upper bound (UB) and Lower bound (LB). This shows that there has not been any abnormal event in quiet days of July.

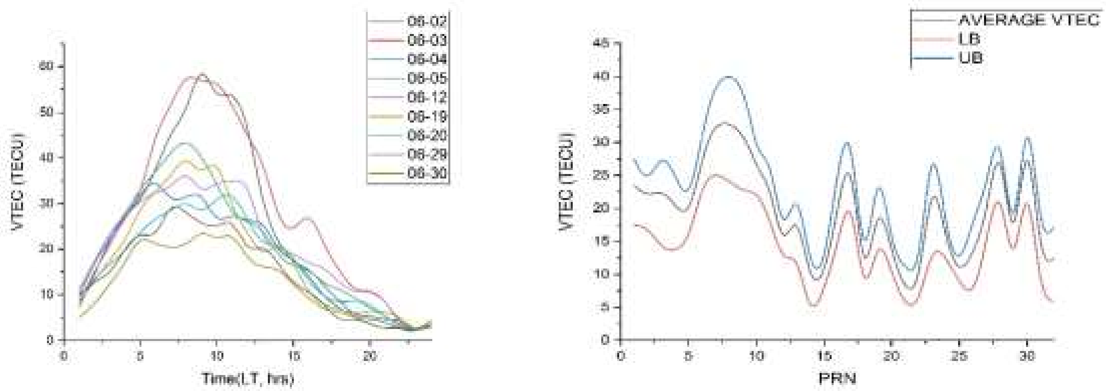


Fig. 2: (a) (b)

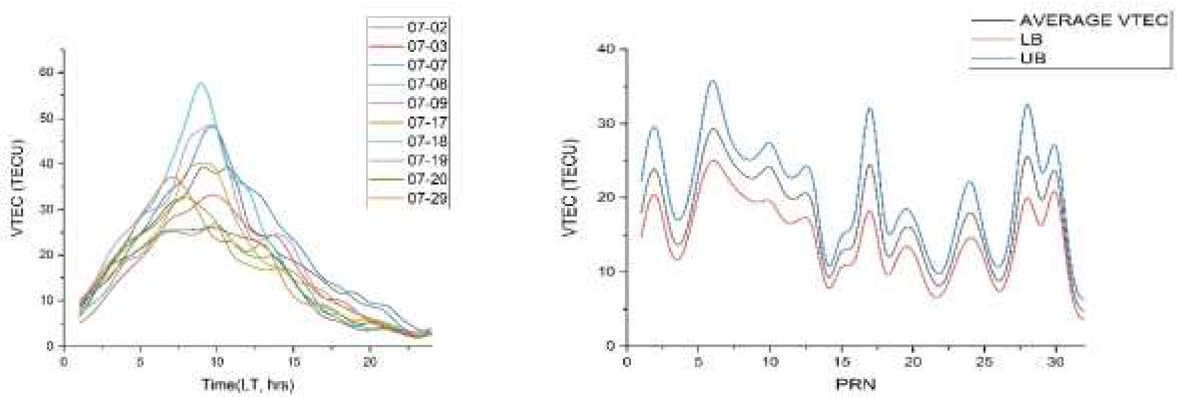


Fig. 3: (a) (b)

Disturbed day variation

Fig. 4 (a) and (b) show the daily variation of average VTEC and the variation of VTEC with PRN of May of disturbed days of the year 2015 respectively. Data of each day of this month have been plotted. The graphs similar to Quiet days has been observed.

In the study of the variation of average VTEC, the trend of diurnal variation of minimum a pre-dawn, a steady increase in the early morning followed by afternoon maximum then gradual decrease after the sunset seems to be followed. The highest value of VTEC has been found to be 27.02 TECU at 0900 LT.

In case of PRN wise variation, all the values of VTEC seems to lie between Upper bound (UB) and Lower bound (LB). This shows that there has not been any abnormal event in disturbed days of May.

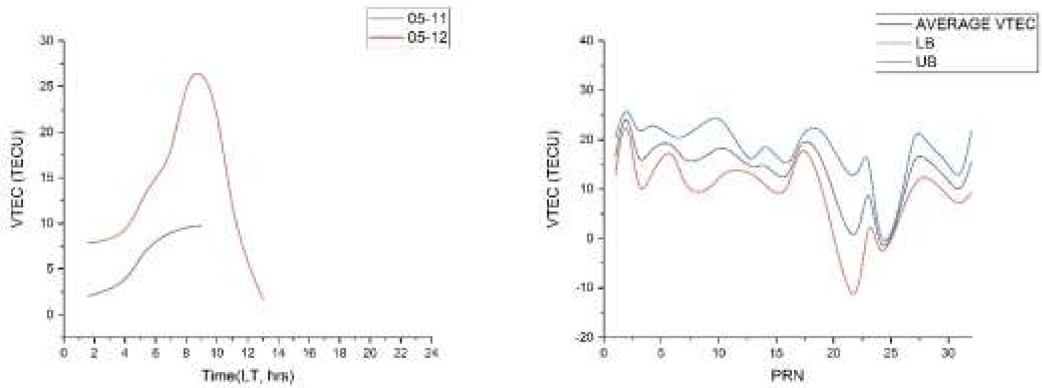


Fig. 4 (a) (b)

Fig. 5 (a) and (b) show the daily variation of average VTEC and the variation of VTEC with PRN of June of disturbed days of the year 2015 respectively. Data of each day of this month have been plotted. The graphs similar to Quiet days has been observed.

In the study of the variation of average VTEC, the trend of diurnal variation of minimum a pre-dawn, a steady increase in the early morning followed by afternoon maximum then gradual decrease after the sunset seems to be followed. The highest value of VTEC has been found to be 44.22 TECU at 1100 LT.

In case of PRN wise variation, all the values of VTEC seems to lie between Upper bound (UB) and Lower bound (LB). This shows that there has not been any abnormal event in disturbed days of June.

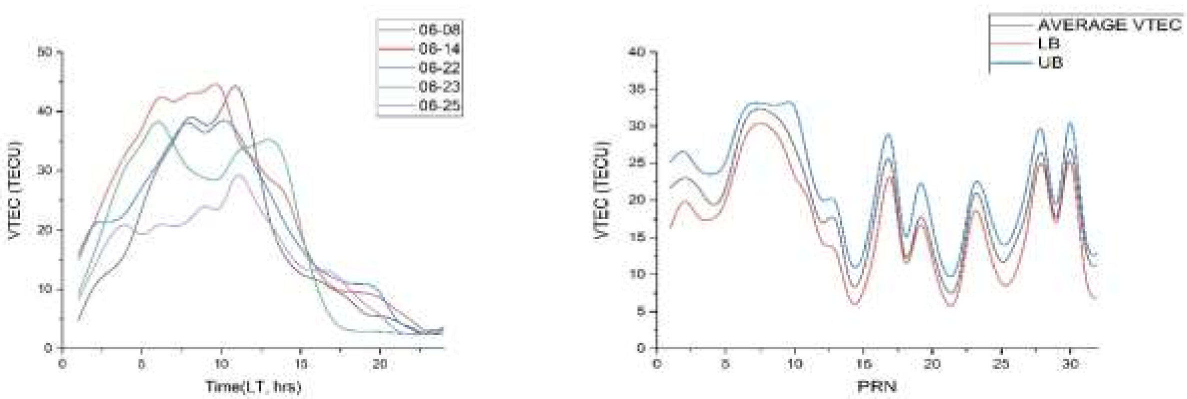
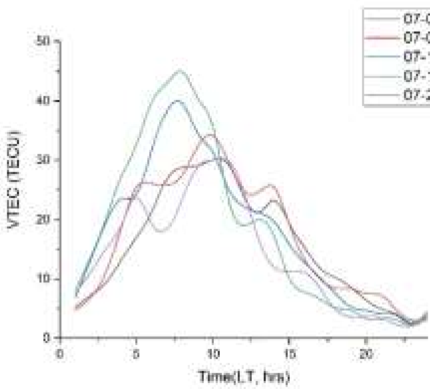


Fig. 5: (a) (b)

Fig. 6 (a) and (b) show the daily variation of average VTEC and the variation of VTEC with PRN of July of disturbed days of the year 2015 respectively. Data of each day of this month have been plotted. The graphs similar to Quiet days has been observed.

In the study of the variation of average VTEC, the trend of diurnal variation of minimum a pre-dawn, a steady increase in the early morning followed by afternoon maximum then gradual decrease after the sunset seems to be followed. The highest value of VTEC has been found to be 44.91 TECU at 0800 LT.

In case of PRN wise variation, all the values of VTEC seems to lie between Upper bound (UB) and Lower bound (LB). However, PRN 31 recedes the lower bound (LB) value of VTEC. This shows that there has been abnormal event in the values of VTEC received by the PRN 31. PRN 31 position has been found just below the GPS- satellite which resulted in abnormal value of VTEC.



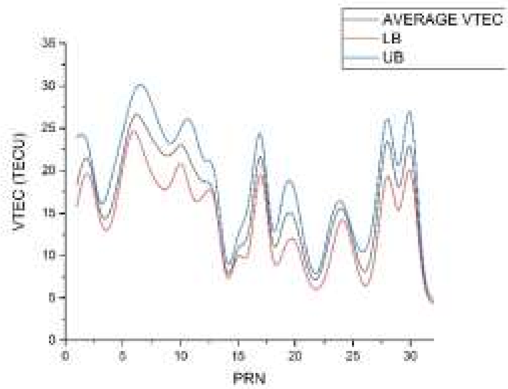


Fig. 6: (a) (b)

Solar Activity Dependence of TEC

Solar activity greatly affects TEC. Mainly, Solar radiations are the cause of solar activity. Solar indices like F10.7, Sunspot Number (SSN), EUV Flux and many more are parameters that are used to represent solar activity. In our study, Dst index, Kp index and 10.7 cm Solar Radio flux (sfu) are taken into study the effect where Kp index's value is given in the multiple of 10. Since, one parameter may not be enough to find the correlation between different seasons of LMJG; so, Dst and Kp were taken into study for both quiet and disturbed days.

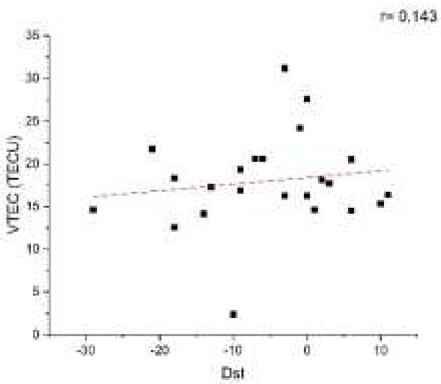
The correlation has been calculated from the average GPS- TEC data of all seasons in a combined manner.

Quiet Day Variation

Fig.7 (a) and (b) show the correlation of GPS- TEC with Dst index and Kp index respectively of LMJG station of quiet days of the year 2015. The correlation with Dst index has been found to be 0.143 nT whereas the correlation with Kp index has been found to be -0.128. It shows that Dst index correlates well but Kp index doesn't correlate with GPS- TEC of LMJG station.

Disturbed Day Variation

Fig. 8 (a), (b) and (c) Show the correlation of GPS- TEC with Dst index, Kp index and 10.7 cm Solar Radio flux (sfu) of LMJG station of disturbed days of the year 2015. The correlation with Dst index has been found to be -0.109 nT, 0.454 with Kp index and 0.096 with Solar flux. This shows that Kp and Solar flux correlate well with GPS- TEC of LMJG station but Dst doesn't correlate with Dst index. Soalr flux and Kp index support the occurrence of disturbed days as the correlation is positive whereas F10.7 was taken for disturbed days only as it has no significance in quiet days.



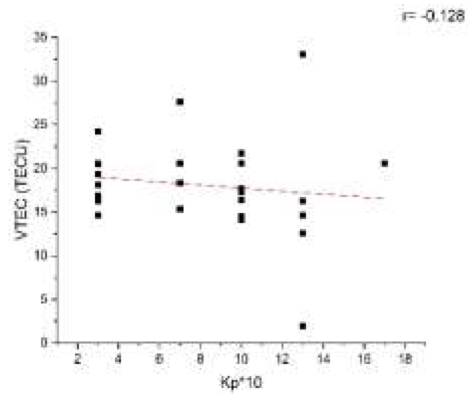
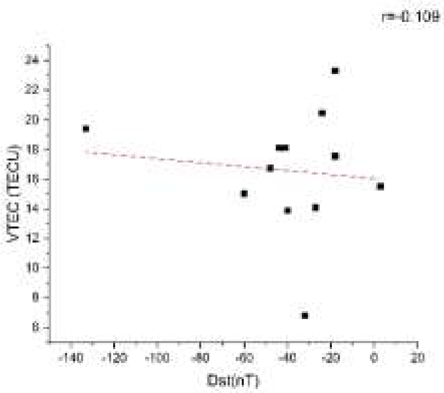


Fig. 7: (a) (b)



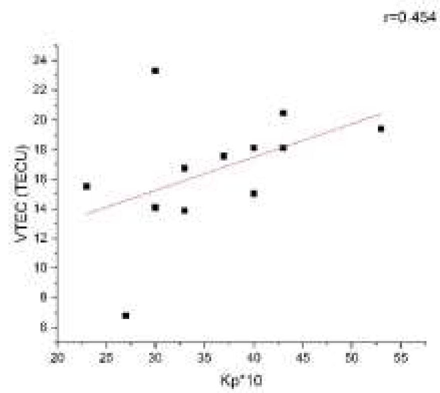
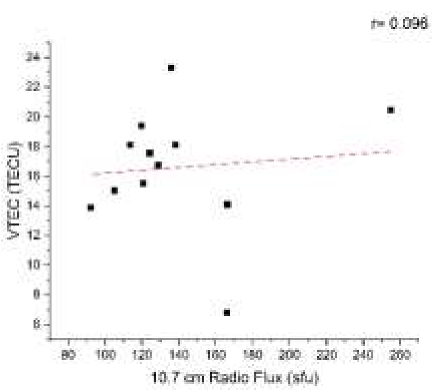


Fig. 8: (a) (b)



(c)

4. Conclusion

Variation of average VTEC and PRN wise VTEC have been studied on daily basis separately for Quiet and Disturbed days of LMJG station of the year 2015. Although, the data available was limited but the variation has been found positive. Average TEC varies from 0100 LT to maximum TEC from

0900 LT to 1000 LT on quiet days and from 0800LT to 1100 LT on disturbed days showing pre-dawn minimum and steep rise in the morning and peak value around 1000LT and then gradual decrease after sunset. In case of PRN wise TEC variation, average VTEC has been found to lie between Upper and Lower bound except in two cases in May of quiet day and in July of disturbed day; this showed the geo- magnetic event in PRN 9 and PRN 31 in the latter case. Overall. Dst index, Kp index and Solar Flux correlated well with GPS-TEC on both quiet and disturbed days. Different value of GPS- TEC on quiet and disturbed days explained the difference in geo- magnetic events between these days.

Acknowledgement

We would like to thank UGC for the support of this work and also like to thank NASA's OmniWeb data explorer for Dst , Kp*10 indices and solar flux values. We would also like to thank UNAVCO for providing the data of the station.

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