Long term ionospheric TEC variation over high latitude region during 24th solar cycle

Arun Kumar Singh[1],Rupesh M Das[1], Shailendra Saini[2]

1. CSIR-National Physical Laboratory, Dr. K. S. Krishnan Marg, New Delhi-110012, India
2. National Centre for Antarctic and Ocean Research, HeadLandSada, Vasco-da-Gama, Goa-403804, India

Abstract

The long term variation of Ionospheric Total electron content (ITEC) has been examined over high latitude region during inclination phase of 24th solar cycle and it has been observed that solar cycle, seasonal and geomagnetic activity has a prominent effect on ITEC. The ITEC data has been acquired with the help of Novatel make Global Ionospheric Scintillation and TEC monitoring (GISTM) system installed at Indian permanent scientific base "Maitri" [70˚46'00"S 11˚43'56" E], Antarctica. To investigate the vulnerability of Vertical Total Electron Content (VTEC) upon the sunspot numbers (SSN), linear and quadratic regression method has been used and it has been found that quadratic relation grant better correlation between VTEC and SSN. Further, during the investigation of ITEC seasonal variation, it is watched that VTEC and SSN follows better agreement during summer seasons as compared to winter and equinox seasons. However,an extraordniray agrrement has been noticed during the solar minimum phase (2010). Meanwhile, during the study of quiet days throughout the considered time frame i.e. 2010 to 2014, an improved correlation has been found between VTEC and SSN. During the long term study of ITEC, a saturation effect has been also observed during maximum phase (2014) of the 24th solar cycle.

Keywords: High latitude ionosphere; Ionospherictotal electron content; Sunspot number; linear regression, Quadratic regression.

1. Introduction

The earth's ionosphere is mainly consists of electrons and electrically charged atoms and molecules. The ionization at the ionospheric heights mainly depends upon the incoming solar and cosmic radiations. The Earth's ionosphere plays a very crucial role in radio wave propagation to establish long distance wireless communication link. The distance and frequency of communication of sky wave propagation depends upon the state of ionospheric condition. The state of the ionosphere mainly governed by time, background geophysical conditions and geographic locations; hence, required a real time monitoring for better frequency management. The measurement of Ionospheric Total Electron Content (ITEC) with the help of GPS receivers is one of the most popular techniques. Also, the study of ITEC helps the scientific community to understand the long as well as short term ionospheric variations which generally useful for effective use satellite based communication and navigations systems.The non-homogenous distribution characteristics of ionospheric ionization mainly depend on regional electro-dynamic properties. Therefore, the studies pertaining to regional level ionospheric aspects may provide better insight and highly informative concerning ionospheric modeling points of view. In view of this, many researchers studied the regular variations of solar radiation and its impact on Earth's ionosphere [Afraimovich et al., 2008; Balan et al., 1993]. These works have supplemented the skills and knowledge of scientific community across the globe for the betterment of societal and commercial utilization. It is to be noted that most of the studies and models, which are defining the ionospheric behavior on different latitudes and solar activity levels were based on ground based observation i.e. by using ionosonde data (Rishbeth, 1998; Yadav et al., 2010) and also limits up to equatorial, low and mid-latitudes. This limits the in-depth understanding of high latitude ionospheric region which is very important due to its sensitivity towards the changing near space environment system and largely influenced by the direct interaction with the energetic particles accompanied with the solar wind. However, few isolated studies have been carried out at higher latitudes (especially over southern hemisphere) due to difficult logistic requirements. In the present scenario, most of the ionospheric models have various limitations in order to predict the state of high latitude ionosphere. Therefore, the present work is the first attempt to examine and demonstrate the long-term behavior of high latitude ionospheric region which ultimately enhance the modeling capabilities of high latitude ionospheric region. The present study mainly focused on the associationbetween Sunspot number and the Ionospheric Total Electron Content (ITEC) during solar minima year 2010 to solar maxima year 2014 under different geomagnetic conditions.

2. Data and Methods

The presented work has been performed by using ITEC data acquired with the help of Novatel make dual frequency GPS receiver installed at Indian Permanent Research Base "Maitri", Antarctica (70°46′00″ S, 11°43′56″ E). The estimated VTEC is than segregated accordingly in view of quiet and disturbed background geomagnetic conditions as listed by world data center, Kyoto for the representative months of each seasons i.e. summer (January), winter (June) and Equinox (October). On the basis of that, the observed VTEC at around 00UT, 600UT, 1200UT and 1800UT were analyzed for each of the considered months. Further, the daily sunspot number (SSN) has been downloaded from world data center (http://www.ngdc.noaa.gov/wdc/wdcmain.shtml) to investigate the dependency of ionospheric ionization over solar activity. A linear/quadratic regression has been performed to establish a relation between SSN and VTEC by using equation 1 & 2.

$$VTEC = A_0 + A_1 * R \quad \text{----------------------------------- (1)}$$

Where, A_0 is the VTEC intercept of the regression line, A_1 is the Slope and R is the independent variable i.e. SSN.

$$VTEC = B_0 + B_1 * R + B_2 * (R)^2 \quad \text{--------------------------------- (2)}$$

Where, B_0, B_1 and B_2 are the second degree regression coefficients. The term B_2 is very important for defining the amplification or saturation effect.

Here by using the linear/quadratic regression methods, correlation coefficient (CC) has been estimated between VTEC and SSN forthe considered hours of representative months of different seasons.

3. Results and Discussion

The main aim of the present work is to establish a relationship between the Ionospheric TEC and SSN over southern hemispheric sub-auroral region. The study divided into two parts i.e. 1) The long term ionosphericvariation over sub-auroral region during the inclination phase of 24th solar cycle (2010-2014) and 2) Ionospheric TEC variation over sub-auroral region especially under quietgeophysical background conditions.

3.1 Long term dependency of Ionospheric TEC on SSN during the inclination phase of 24th solar cycle (2010-2014) over southern hemispheric sub-auroral region

Figure -1 shows the variation in the daily values of the SSN and VTEC, from the solar minimum year 2010 to the solar maximum year 2014 (inclination phase of 24th solar cycle) at four different representative hours i.e. 0000, 0600, 1200 and 1800UT. It is found that VTEC and SSN variations occur synchronously during the inclination phase of 24th solar cycle at all four observatory hours. Similar results have been observed by the Liu et al. (2009), in which they have analyzed 11 years (1998-2008) worth of TEC data and reported that the TEC data show strong annual, solar cycle and 27 days variation at low, middle and high latitude regions.The result is quite obvious because the first source of ionization of ionosphere is the solar radiation. The ionization in the ionosphere is directly related to extreme ultraviolet solar radiation intensity, which could be related to the ambient electron density. However solar radiation is not the only reason of electron density changes, it may occur due to the changes in neutral density, temperature and compositional changes, the ionospheric chemistry, neutral winds and the electric fields. It is also observed that during solar minima (during the year 2010) of the considered solar cycle the SSN and TEC follows an extraordinary agreement [Mansoori et al., 2013]. As the solar 2008 and 2009 were the solar minima year (Low SSN), so undersupply of solar extreme ultraviolet (EUV) irradiance was the reason of low VTEC values, which continues and taken as the main cause of low ionization during the year 2010.

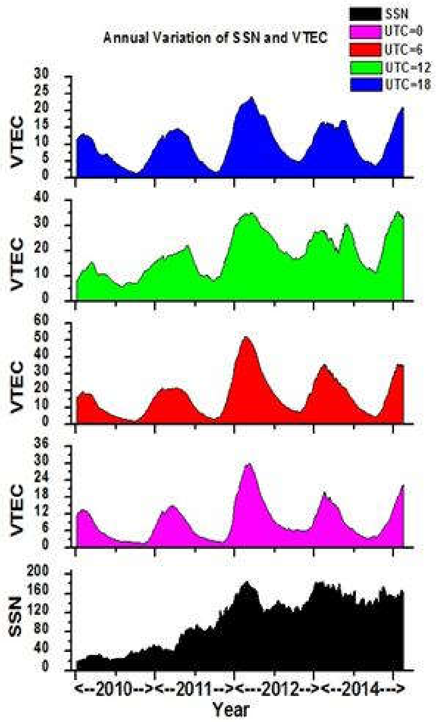

Figure1

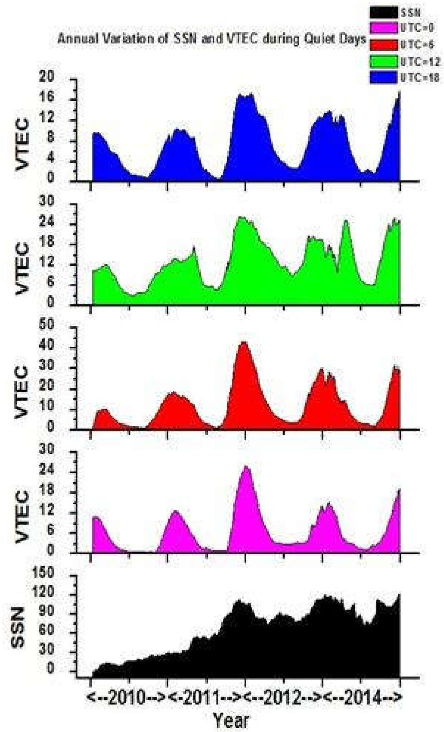

Figure2

3.2 TEC variation with SSN over sub-auroral region during quiet days

Figure-2 shows the variation in the daily values of the SSN and VTEC, from the solar minimum year 2010 to the solar maximum year 2014 (inclination phase of 24th solar cycle) during internationally defined quiet days for different representative hours i.e. 0000, 0600, 1200 and 1800UT. As it is well known that the selectionof the monthlyquiet days based upon the lowest Kp & Ap index values which is utilized as a proxy for geomagnetic activity. It means that the ionospheric perturbations are minimum due to stable background geophysical conditions. So ionospheric ionization process is much stable as compare to disturbed days and that is why total electron content follows a better agreement with the solar index (SSN) during quiet days. It is to be noted that the observed VTEC shows saturation effect during high solar maxima years especially under quiet background conditions. This might be due to significant amount of losses at the polar region and most essential loss is transportation loss [Foster, 1993]. The cause of transportation of plasma from high latitude region to mid-latitude region is the joules heating [Fuller-Rowell et al., 1994] on the polar region, which could be direct effect of the increased EUV irradiance at high SSN.

4. Conclusions

The investigation of solar cycle variation of vertical total electron content during different seasons over the high latitude region by using the long-term database of 24th solar cycle shows some interesting results.

The major results of this study as follows:

1) VTEC and SSN follow better agreement during summer seasons and extraordinary agreement during minimum phase (during theyear 2010) of thesolar cycle.
2) A significant correlation was observed between VTEC and SSN during quiet days of the years as compared to overall days of the years (2010-2014).

Acknowledgement

The authors would like to thanks, National Centre for Antarctic and Ocean Research, Ministry of Earth Sciences, Goa, India for providing all required logistic support to conduct the experiments.

References

1. E.L. Afraimovich, E.I. Astafyeva, A.V. Oinats, Y.V. Yasukevich,andI.V. Zhivetiev, “Global electron content: A new conception oftracking solar activity”, Ann. Geophys**, 26**, 2008, pp. 335 – 344.

2. N. Balan, G.J. Bailey, and B. Jayachandran, “Ionosphericevidencefor a nonlinear relationship between the solar e.u.v. and 10.7 cm fluxesduringan intense solar cycle”, Planet. Space Sci., **41(2),**1993, pp. 141 – 145,doi:10.1016/0032-0633(93)90043-2.

3. T.J. Fuller-Rowell, M. V. Codrescu, R. J. Moffett, and S. Quegan, “Response of the thermosphere and ionosphere to geomagnetic storms”, J. Geophys. Res, **99**, 1994, pp. 3893.

4. J.C. Foster, “Storm-time plasma transport at middle and high latitudes,” J. Geophys. Res,**98**, 1993, pp.1675–1689.

5. L. Liu, and Y. Chen, “Statistical analysis of solar activity variations of total electron content derived at Jet Propulsion Laboratory from GPS observations”, J. Geophys. Res, **114**, 2009, pp. A10311, doi:10.1029/2009JA014533.

6. A.A. Mansoori, P.A. Khan, P.K.Purohit and A.K. Gwal“Variability of TEC at mid latitude with solar activity during the solar cycle 23 and 24.” 2013 IEEE International Conference on Space Science and Communication (IconSpace) (2013): 83-87.

7. H. Rishbeth, “How the thermospheric circulation affects the ionospheric F2-layer”, J. Atmos. Sol. Terr. Phys., **60 (14),** 1998, pp. 1385–1402.

8. S. Yadav, R.S. Dabas, R.M. Das, A.K. Upadhayaya, S.K. Sarkar, and A.K. Gwal, “Variation of F-region critical frequency (foF2) over anequatorial and low-latitude region of the Indian zone during 19th and 20th solar cycle”, Adv. Space Res, **47(1),** 2011, pp. 124–137.