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Reasearch article

Solar Wind High Speed Stream as a Proxy for the Variation of Ionosphere over Ethiopia

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ABSTRACT

Equatorial ionospheric irregularity is a nuisance for technologies that depend on trans-ionospheric propagating radio waves. Significant efforts are being carried out to understand the EEJ irregularity. However, the African equatorial ionosphere that shows unique phenomena as observed by Low Earth Orbiting (LEO) satellite is the least investigated due to the lack of ionospheric monitoring instruments. To study the ionospheric variations and solar wind speed at high stream over Ethiopia, GPS data from a year of 2010 to 2014 for all days at Bahir Dar (110 N, 380 E) stations using a dual frequency f1(1575:42 MHz) and f2 (1227:60 MHz). The TEC data were downloaded from UNAVCO. By employing dual-frequency GPS observations, it is possible to calculate the estimates about GPS derived ionospheric TEC. The multi-day oscillations can cause a few units of TEC (TECu) change in the TEC. These oscillations were persistent for the entire five-year periods. The annual characteristic of TEC has solar wind speed, interplanetary magnetic field and kp index. The daily peak occurs at about DOY [48, 296, 463, 655, 860, 1206] and 1411 around low latitude (equatorial) regions. The distribution of HSS from 2010- 2014 that have an amplitude of [671,693, 700, 716] and [757] respectively. TEC and solar wind speed are correlated highly during solar maximum.

Key words: Ionosphere, Total Electron Content (TEC), Solar Wind Speed (SWS), Bahir Dar

INTRODUCTION

Since The Space Weather, which can be defined as the collective, often violent, changes in the space environment surrounding Earth, plays an important role on space-based assets for navigation, communication, military reconnaissance and exploration [1]. Solar wind speed generally, and Solar wind high speed streams (HSSs) emanating from solar coronal holes specifically, are the main cause for recurrent, moderate geomagnetic activity, which can last more than one solar rotation [2].

The variation of the plasma density with altitude, the ionosphere also shows significant variations with time of day, latitude, longitude, season, solar activity, and geomagnetic activity [3]. The ionosphere is as a whole electrically neutral, where there are sufficient number of free electrons that can largely affect the propagation of radio waves [4]. Hence, acting as a dispersive medium, the ionosphere has great influence on the satellite navigation and communication. This influence is directly proportional to the density of free electrons which could change the phase and strength of electromagnetic radio frequency waves [5].

Solar activity dependence of TEC has also been studied by a large number of researchers [6]. [7] studied day-to-day variability of quiet-time ionosphere using foF2 data. He observed oscillations of day-to-day variation with peak spacing of 7 days at several locations and he indicated that in the absence of solar or geomagnetic effects, planetary waves dominate the day-to-day variability. [8] studied the ionospheric variability using the foF2 parameter over the Brazilian low and equatorial latitudes and comparing their results with IRI model. [9] studied the variations in TEC with different solar indices, i.e. EUV, F10.7 solar flux and smoothed sunspot number (SSN) for summer, winter and equinoxes. They concluded that TEC exhibited nonlinear relationship with SSN in general and linear variations with EUV and F10.7 solar flux. According to [10] they analyze total electron content (TEC) and the corresponding GPS scintillation using two GPS SCINDA receivers located at

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Makerere University, Uganda (Lat:0.30 N; Lon:32.50 E) and at the University of Nairobi, Kenya (Lat:1.3o S; Lon:36.8o E), both in East Africa effects on the geomagnetic storm of the 24-25 October 2011 on the ionospheric total electron content at the two East African stations. The response of the ionosphere to intense magnetic storms has been studied using total electron content (TEC). [11] proposed the TEC data recorded by a series of GPS receivers at a longitude 35oE covering a wide range of latitudes 32oS to 68oN is analyzed to study spatio-temporal modifications of the vertical TEC (vTEC) during storms on 07 March and 09 July. [12] analyzes the response of Ethiopia ionosphere to geomagnetic storm by considering the change in the daily peak of total electron content. The demands of developing countries (such as the African countries) to use modern technology for their better development are tremendously increasing. As a result, they are becoming the users of different types of devices (such as GPS) for various applications. Hence, this work investigates the pattern of GPS-TEC [13] In line with the implication of the technology and lack of scientific investigation in the area the present study was aimed to analyze the effect of solar wind high speed stream on GPS ionospheric total electron content over Ethiopia using Bahir Dar stations in the year of 2010 to 2014.

METHODOLOGY

Data source

The observational data used are described as follows. To study the ionospheric variations and solar wind speed at high stream over Ethiopia, GPS data from a year of 2010 to 2014 for all days at Bahir Dar (110 N, 380 E) stations using a dual frequency f1(1575:42 MHz) and f2 (1227:60 MHz). The TEC data are downloaded from UNAVCO data home page: http://facility.unavco.org/data/gnss/perm-sta.php

The data on solar wind parameters such as plasma flow, pressure/solar wind pressure (PSW), solar wind speed (Vsw), interplanetary electric field (IEF)Esw, the H-component of symmetric current (SYM-H), H component of asymmetric ring current (ASY-H) indices, the auroral electro jet (AE) are downloaded from the database available with coordinated data analysis web pagehttp://cdaweb.gsfc.nasa.gov/ist public/

It contains the values of the interplanetary magnetic field (IMF) and solar wind parameters measured by various spacecraft (ISEE3, IMP8, etc.) near the earths orbit. The correction of time delay of about 51 minutes between locations of the spacecraft and the magnetopause is incorporated in the temporal evolutions of solar wind parameters. The TEC used in this study is obtained from database maintained by NASA JPL insert table.

Methods of analysis

The total electron content (2010 to 2014) and solar wind speed (2010 to 2014) phases were considered. The GPS-TEC data were inferred from the dual frequency GPS receivers. According to [14] we apply a more wavelet analysis to the TEC data to observe the time evolution of the periodicities over the two stations. and the Comparative analysis has shown high correlation between total electron content and solar wind speed for the year of 2015. The details on the calculation of correlation coefficient and wavelet power spectrum are presented in the next subsections.

TEC from dual-frequency GPS receivers

By employing dual-frequency GPS observations, it is possible to calculate the estimates about GPS derived ionospheric TEC. According to different findings [15], the GPS receiver measurements are important to estimate the electron density along a ray path between a GPS satellite and receiver on the ground. In addition to eliminating ionospheric errors in the estimation of TEC, dual-frequency GPS receivers can provide integral information about the ionosphere and plasma sphere by computing the differential of the code and carrier phase measurements [15;16). As a result, the GPS-TEC estimated by the dual-frequency receivers is proposed as an input to an assimilative model of the ionosphere [17]. Thus, the GPS data recorded in the dual-frequency receivers have been utilized for this study, and the GPS-TEC data were obtained employing pseudo range and carrier phase measurements given as follows. The TEC from the pseudo range measurement is given by [18].

$$TEC_p = \frac{1}{40.4}\left[\frac{{f_1}^2{f_2}^2}{f_1^2 - {f_2}^2}\right](p_2 - p_1) \tag{1}$$

Similarly, the TEC from carrier phase measurement can be given as,

$$TEC_\phi = \frac{1}{40.4}\left[\frac{{f_1}^2{f_2}^2}{f_1^2 - {f_2}^2}\right](\phi_2 - \phi_1) \tag{2}$$

where f1 and f − 2 are frequencies transmitted by GPS satellites which are obtained from the fundamental frequency, fo = 10.23 MHz as: (f1 = 154; fo = 1; 575: 42MHz) (f1 = 154; fo = 1; 575: 42MHz) (f2 = 120; f0 = 1; 227: 60MHz) and (P2 − P1 and (φ2 − φ1) are the differential code and phase measurements, respectively.

The integrated TEC from the receiver to satellite as shown is proportional to the accumulated effect by the time the signal arrives at the receiver. This affects the GPS range observables: a delay is added to the code measurements and advance to the phase measurements [19]. The GPS data in the receivers are recorded in the Receiver Independent Exchange (RINEX) format and is then converted to GPS observable files using a suitable model.

These GPS observables are either code pseudo ranges (P) or carrier phase (φ) measurements. By cross-correlating the f1 and f2 modulated carrier signals which are generally assumed to travel along the same path through the ionosphere, the receiver obtains the time delay of the code and the carrier phase difference. These are used to calculate the pseudo range and differential carrier phase which result in the determination of the slant code TEC and slant phase TEC, respectively. Although there is relatively much noise, TEC from code pseudo range measurements is free of ambiguity. On the other hand, in spite of the ambiguity, TEC from carrier phase measurements has relatively less noise [19]. To solve this problem, the pseudo range noise is reduced by smoothing GPS pseudo range data with carrier phase measurements. This technique is called carrier phase smoothing or carrier phase levelling [20]. For accurate TEC estimation, the [21]) approach was followed by removing differential instrument biases as satellites, and receivers for the GPS observables are biased on the instrumental delays [22]. As a result, even though it is not completely absolute TEC, linearly combining both the code pseudo range and the carrier phase measurements for the same satellite pass is supposed to increase the accuracy of TEC [23]. Hence, this resultant absolute TEC is the so-called GPS-derived slant TEC (STEC) along the signal path between the satellite and the receiver. As the STEC measurements are taken from different GPS satellite observed at arbitrary elevation angles, the GPS signals cross largely different portion of the ionosphere. To compare the electron contents for paths with different elevation angles, the STEC must be transformed into equivalent VTEC by dividing it by the secant of the elevation angle at a mean ionospheric height as shown in Equation 5. According to [22], this height usually ranges from 250 to 350 km at mid-latitudes and from 350 to 500 km at equatorial. Hence, in this study, the height of maximum electron density, hm = 350 km, has been taken, because at this height the ionosphere is assumed to be spatially uniform and simplified to be a thin layer; hence, this is considered as the height of maximum electron density at the F2 peak [22]. Moreover, it is worth converting STEC to VTEC as the VTEC is considered as a more compact parameter to characterize the TEC over a given receiver position and used as a good indicator for the overall ionization of the Earths ionosphere [24]. Hence, the relationship between STEC and VTEC in terms of the zenith angle χ at the ionospheric piercing point (IPP) and the zenith angle χ at the receiver position can be given by:

$$VTEC = STEC(\cos\chi') \qquad (3)$$

Where

$$\chi' = \arcsin\lfloor\frac{R_e}{R_e + h_m}\sin\chi\rfloor \qquad (4)$$

Substituting Equation 3.4 into Equation 3.3 and rearranging, we get:

$$VTEC = STEC\{\cos\lceil\arcsin\lfloor\frac{R_e}{R_e + h_m}\sin\chi\rfloor\rceil\} \qquad (5)$$

Here, Re is the Earths

Substituting Equation 3.4 into Equation 3.3 and rearranging, we get:

Here, Re is the Earths radius in kilometers. [(1.1 and 10.1186)]

The correlation coefficient

The cross correlation between two series provides the degree of similarity between them, along with the displacement between them in time. The correlation between two series, solar wind speed(sws) and total electron content(TEC), is given by

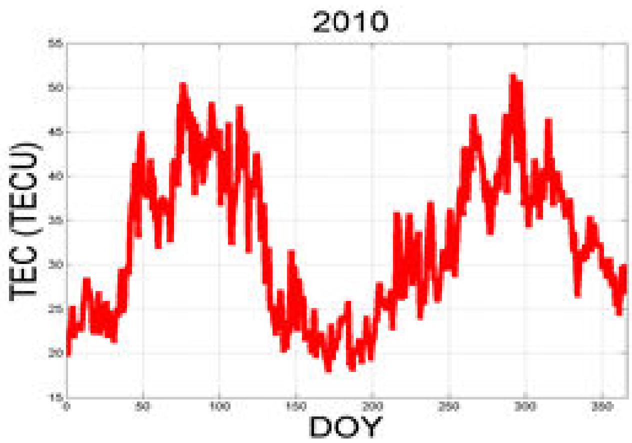
$$R = \frac{\sum(sws_i - sws).\sum(TEC_i - TEC)}{\sqrt{(\sum(sws_i - sws))^2.(\sum(TEC_i - TEC))^2}} \qquad (6)$$

where R is the correlation coefficient. The correlation coefficient defines how well correlated the two series are, varying from −1 to1.

RESULTS AND DISCUSSIONS

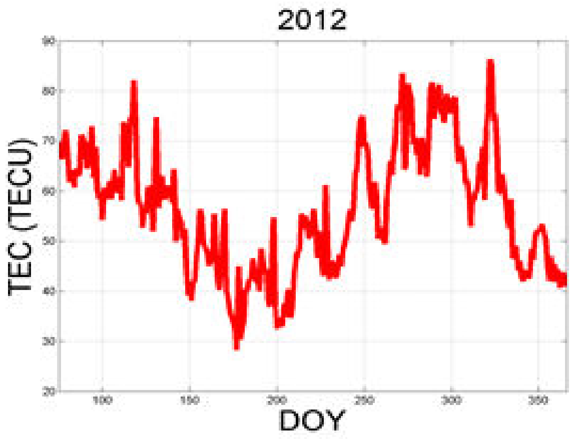
The Annual variation of Ionospheric TEC, SWS, and geomagnetic indices(kp)

The annual, semi-annual, and 27-day variations of the TEC are clearly seen in Fig. 1;

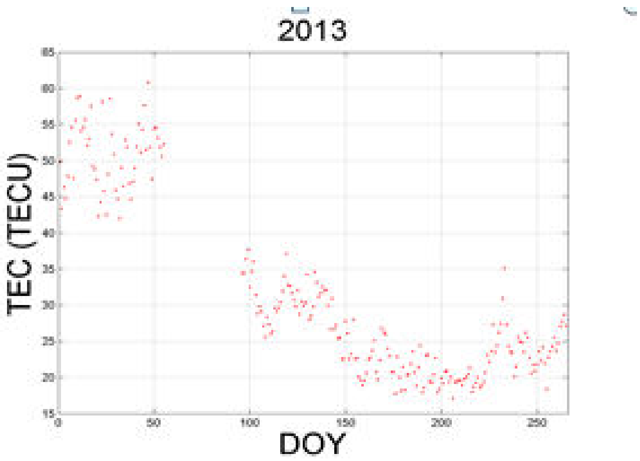


2010

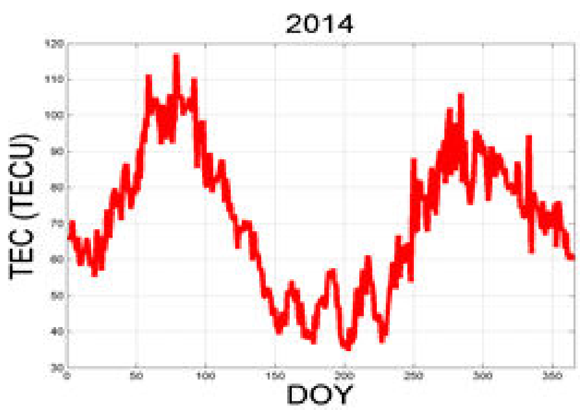
2011



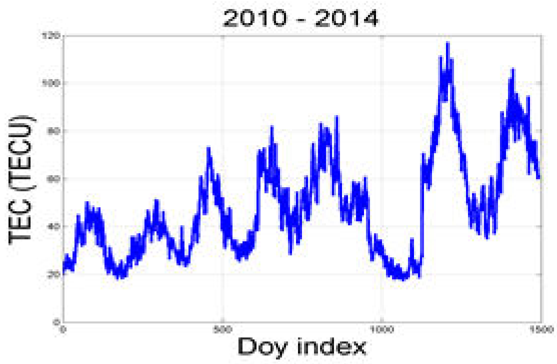
2012



2013



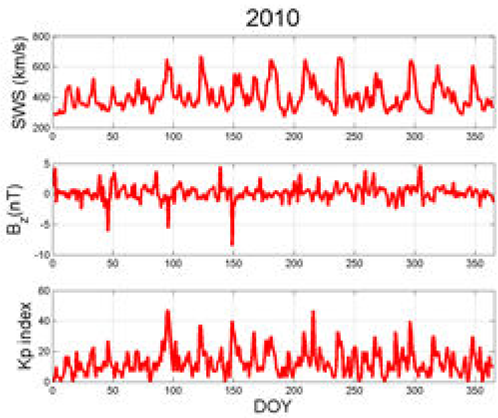
2014



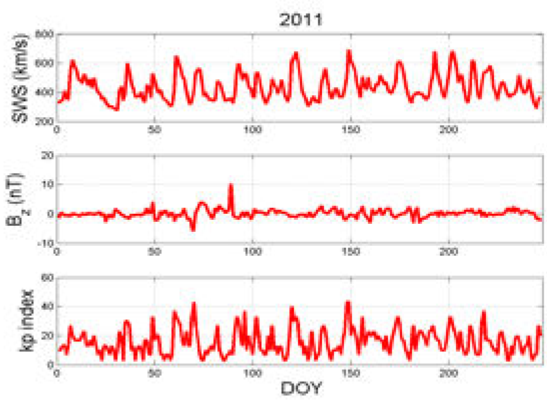
2010-2014

Figure 1: The temporal variations of TEC in the year of 2010, 2011, 2012, 2013, 2014.

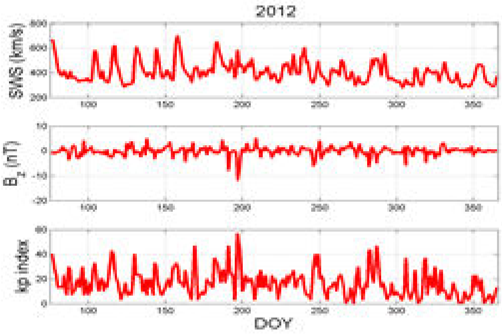
The annual characteristic of TEC has solar wind speed, interplanetary magnetic field and kp index. The left and right-hand panels in Fig.2



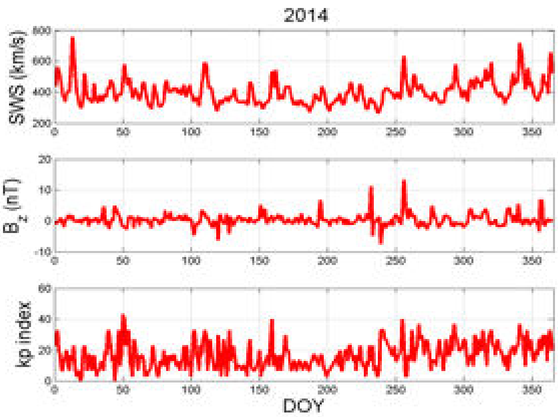
2010



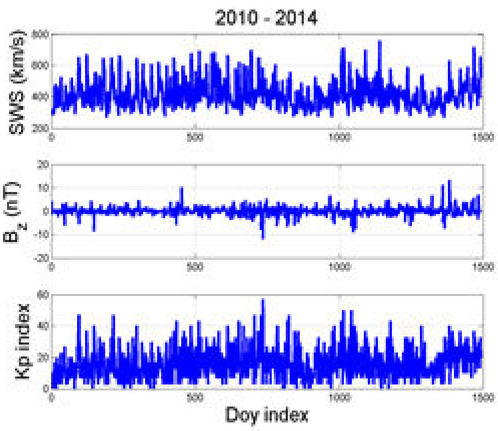
2011



2012



2014



2010-2014

Figure 2: The temporal variations of TEC, solar wind parameters (SWS and IMF Bz) and geomagnetic indices(kp) in the year of 2010, 2011, 2012, 2013, 2014

TEC during HSS

The variations in TEC values during specific HSS are presented by fig.3 in the year 2010 to 2014. As indicate in the histograms the magnitude of TEC has responded for specific HSS values. The top panel of fig.3 shows the higher and lower values of solar wind parameter whereas the bottom panel illustrates the corresponding values of TEC in the year 2010 to 2014. All most in all cases except 2013, As the SWS increases the value of TEC has responded positively. We think that because of the TEC does not decrease the same amount as the electron density, the volume of the electrons and therefore the size of the ionosphere increases. This is probably related to the size of the magnetosphere growing because of the smaller solar wind pressure. It can be seen from the histograms showing the distribution of HSS from 2010- 2014 that have an amplitude of 671,693, 700, 716 and 757 respectively.

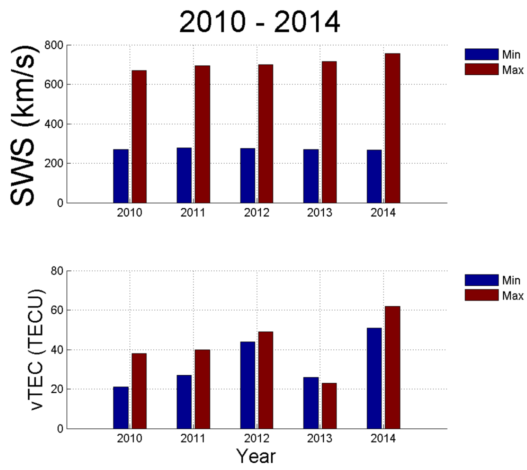
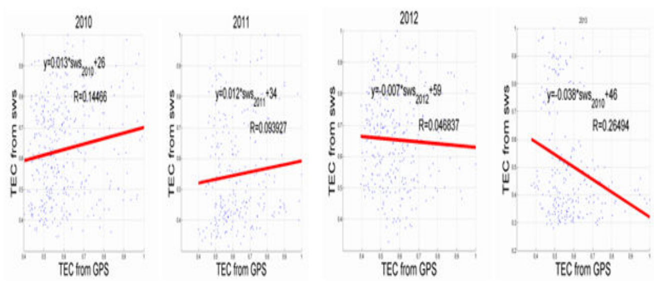


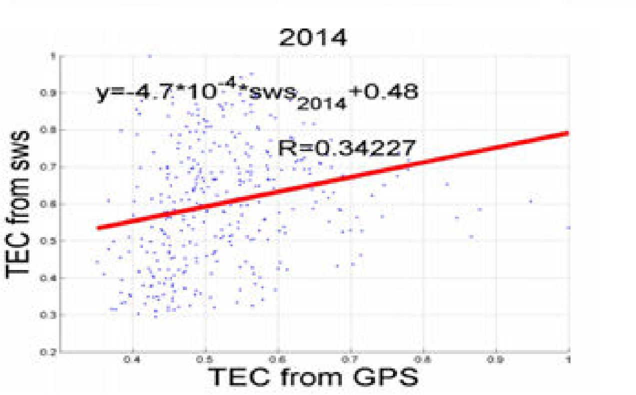
Figure 3: Number of HSSs in 2010 - 2014

Statistical analysis of TEC and SWS

The study investigates the relationship between the ionospheric GPS-TEC, solar wind parameter and geomagnetic indices by applying the cross-correlation analysis. In particular, these correlation relations illustrate the linear dependence between total electron content (TEC) and solar wind speed (SWS). The result revels that the linear least-square fit parameters a and b, the correlation coefficient (R) are presented. A given x-y correlation corresponds to the linear form Y (i) = a∗swsi+b, where swsi is the value of the SWS that occurred in a year and Y (i) is the value of TEC which is obtained from SWS. The computed correlated coefficients are r = 0.16, 0.094, 0.07, 0.27 and 0.34 for the year 2010, 2011, 2012, 2013 and 2014 respectively. Generally, correlation coefficients are higher in 2014. This illustrates the ionospheric TEC and solar wind speed are correlated highly during solar maximum (Figure 4).



2010 2011 2012 2013



2014

Figure 4: Correlation GPS- TEC and solar wind speed in 2010, 2011, 2012 2013 and 2014

CONCLUSION

The annual, semi-annual, and 27-day variations of the TEC are clearly seen. There was a peak of the solar wind speed higher than 600km/s and there was not associated response of the magnetic indices, kp. Thus, the ionospheric variation shows clear correlation to changes in solar activity, such as the relation between F10;7- index and TEC. Due to the TEC does not decrease the same amount as the electron density, the volume of the electrons and therefore the size of the ionosphere increases. The task of this study was to analyzed the solar cycle variation of HSSs and their typical features represented by the solar wind parameters. In a first step HSS were defined according to their velocity distribution and then described with help of a superposed epoch analysis and two particular examples the decrease in the velocity and the proton density during an HSS and the correlation between the magnetic field and the proton density. Further the occurrence of HSSs and fast solar wind periods was illustrated. As the SWS increases the value of TEC has responded positively

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