Ionospheric Observation over Turkey by using Turkish Permanent GPS Stations

Kutubuddin ANSARI, and Ozsen CORUMLUOGLU

***Abstract*—The ionosphere is the atmospheric part that is ionized by solar radiation and plays an important role in atmospheric electricity and forms the inner frame of the magnetosphere. It has a practical significance because it influences radio propagation to distant places on the Earth. The present study investigates variation of the ionospheric electron density over low latitude Turkish region from five ground based Turkish Global Positioning System (TGPS) network stations for the period from January 2015 to December 2015. The electron density in terms of Total Electron Content (TEC) is estimated from the parameters of Turkish Permanent GPS Stations (TPGN) including International GPS Services (IGS) observation at different locations of Turkey and compared with standard International Reference Ionosphere (IRI), Global Ionosphere Map (GIM) and Standard Plasmasphere Ionosphere Model (SPIM) predictions. The slant Total Electron Content (sTEC) is derived from the dual pseudo range and the phase observation delays. It is assumed that a thin ionospheric shell is located at an altitude of 350 km above the Earth sTEC has been converted in to vertical Total Electron Content (vTEC) and it has been plotted to analyze its diurnal, monthly and seasonal variation behavior.**

***Keywords*—TPGN, CCC, TECU**

I. Introduction

Ionosphere is an important atmospheric layer for the High Frequency (HF) with satellite communications systems. It lies between 100 and 1,000 km altitude and contains gases ionized by solar radiation [1]. Solar events and geomagnetic storms have significant effects on the inner variability of this layer. This variability must be continuously observed and if possible, predicted due to importance of aforementioned objects [1]. The ionospheric TEC is also important for precise positioning, navigation and measurement of electric wave field [2]. The dual frequency radio signals of the Global Positioning System (GPS) at an altitude of 20,200 km allow the measurement of the total number of free electrons, known as TEC, along ray path from GPS satellite to receiver [3]. The TEC is measured in a unit called TECU, where 1TECU=1×10^{16} electrons/m^2.The ground and space-based GPS are utilized nowadays in continuously measuring electron density of ionosphere in terms of TEC from the amplitude and phase of received signals due to continuous operation of GPS satellites around the globe [4]. The present paper illustrates the regular variations and disturbances in the ionospheric electrons above the Turkish region from ground based GPS observations. The measured TEC is correlated with solar activity and geomagnetic indices and compared with International Reference Ionosphere (IRI) model. The Cross Correlation Coefficient (CCC) of measured vTEC has been calculated with IRI model during quiet days. Finally, TEC predictions from Global Ionosphere Map (GIM) model and international Standard Plasmasphere Ionosphere Model (SPIM) have also been discussed in this study.

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II. The GPS Data and Methodology

The observation data from five permanent GPS stations across Turkish region for the duration January 2015-December 2015 are processed to estimate TEC at different latitudes. The geographic co-ordinates of the stations are given in table 1. The distribution of GPS stations are shown in fig. 1. To avoid the effect of geomagnetic disturbances due to earth and solar events, only the days with geomagnetic Ap indices below 20 nanotesla (Ap < 20nT) are considered. For the dual frequency (L1, L2) observation, TEC in the slant direction can be calculated from the pseudo range (P) and phase observations (ϕ) as:

$$TEC = \frac{1}{40.3}\left(\frac{f_1^2 f_2^2}{f_1^2 - f_2^2}\right)(P_2 - P_1) \qquad (1)$$

$$TEC = \frac{1}{40.3}\left(\frac{f_1^2 f_2^2}{f_1^2 - f_2^2}\right)(\phi_1 - \phi_2)$$

Here, P_1 and P_2 are pseudoranges and ϕ_1 and ϕ_2 are phases of carriers L1 and L2 respectively. Putting the values of both frequencies, the expression for the total electron content in terms of TECU (1 $TECU = 1\times10^{16}$ electrons/meter^2) is given by [5]:

$$TEC = 9.52\,(P_2 - P_1) \qquad (2)$$

To reduce the effect of pseudorange noise on TEC data, GPS pseudoranges are smoothed by carrier phase leveling. The value of TEC consists of both the sTEC along a satellite receiver ray path and instrumental bias (B) [1].

$$sTEC = TEC + B \qquad (3)$$

The instrumental biases are considered to be constant over several days [6].Since sTEC is related to vTEC, by assuming that the ionosphere is thin shell, vTEC at a given point is calculated with the mapping function [7] as:

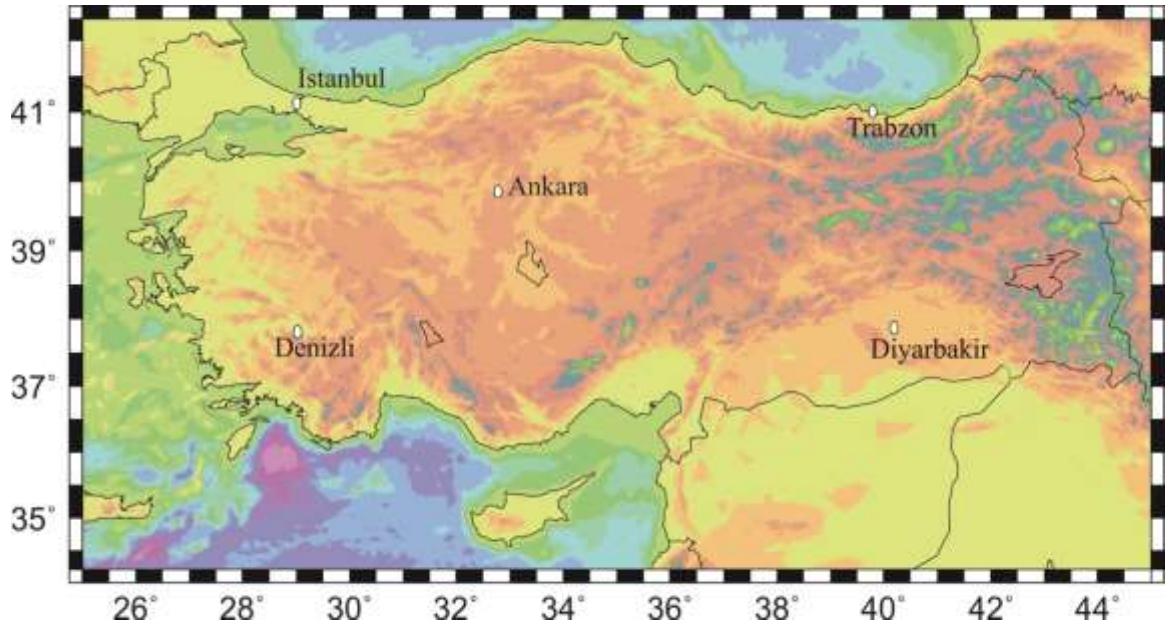

Fig.1. Turkish GPS stations across Turkish region during 2015

$$vTEC=sTEC\times\sqrt{1-\left(\frac{R_E\cos\alpha}{Re+h_{max}}\right)^2}$$

Where α is the elevation angle, R_E the radius of the earth (R_E=6378 km) and h_{max} (=350 km) is the height of the ionospheric shell above the surface of the earth. To avoid the multipath, change in satellite geometry and other atmospheric effects, an elevation angle of greater than 20° is chosen for all the stations

TABLE I: GEOGRAPHIC CO-ORDINATES OF GPS STATIONS ACROSS THE TURKISH REGION WITH HEIGHT

GPS Station	Code	Station	Location	Height (m)
Istanbul	ISTA	IGS	41.104°N, 29.019°E	147.268
Ankara	ANKR	IGS	39.887°N, 32.758°E	976.039
Denizli	DENI	TPGN	37.762°N, 29.092°E	471.150
Diyarbakir	DIYB	TPGN	37.954°N, 40.187°E	773.707
Trabzon	TRBN	TPGN	41.005°N, 39.711°E	085.424

III. The Result and Discussion

The fig. 2 shows variations of geomagnetic Kp, Ap and Disturbance storm (Dst) indices along with international sunspot number. There is a normal correlation between the parameters throughout the period. Here, we examined the diurnal variation of ionospheric TEC during the quiet and geomagnetic storm days and its monthly and seasonal variations estimated from GPS observations. The ionospheric variability is investigated using CCC between vTEC of TGPS and vTEC of IRI model. At final stage the results are compared with global ionosphere maps and standard model outputs in the analysis.

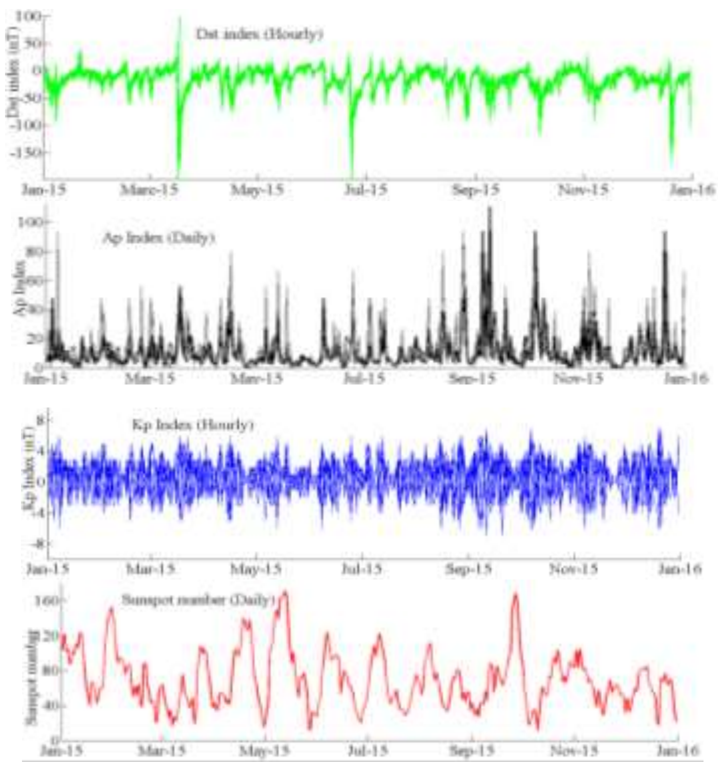

Fig.2. Variations of Sunspot number, geomagnetic Kp, Ap and Dst indices during January 2015 to December 2015

The diurnal variation

The diurnal variation of TEC at different stations for a disturbance storm day (15 April 2015, ΣKp = -30) and for quiet day (16 October 2015, ΣKp =13) is shown in fig. 3. It can be observed from the figure that the TEC gradually increases with sunrise, attains a peak at around 10:00 UT and then minimum value after midnight. The graphs in fig. 3 also clearly show that regardless of magnetic storm, daily TEC follows a similar trend like other daily TEC trend after solar elevation reaches to a certain low level daily especially after evening time. On the other hand, after TEC reaches to its highest level in a magnetic storm day, it stay at that high level for a while and then shows a sharp drop towards the normal daily level at evening time instead of a steady decrease seen in TEC in quite days. It is probably because the land part (Turkey) cannot expose direct sun light any more at those hours of a day. The daily maximum value of TEC remains for a longer duration towards Ankara while the longer night time minima is observed over stations Trabzon. In general, the effect of a geomagnetic storm on the ionosphere is observed that the diurnal maximum value of TEC at all stations was enhanced due to this strong geomagnetic storm. The enhancement in TEC is seen to be severe at Denizli, followed by Ankara and Diyarbakir, and this enhancement is more on the storm day than on the previous and succeeding quiet days.

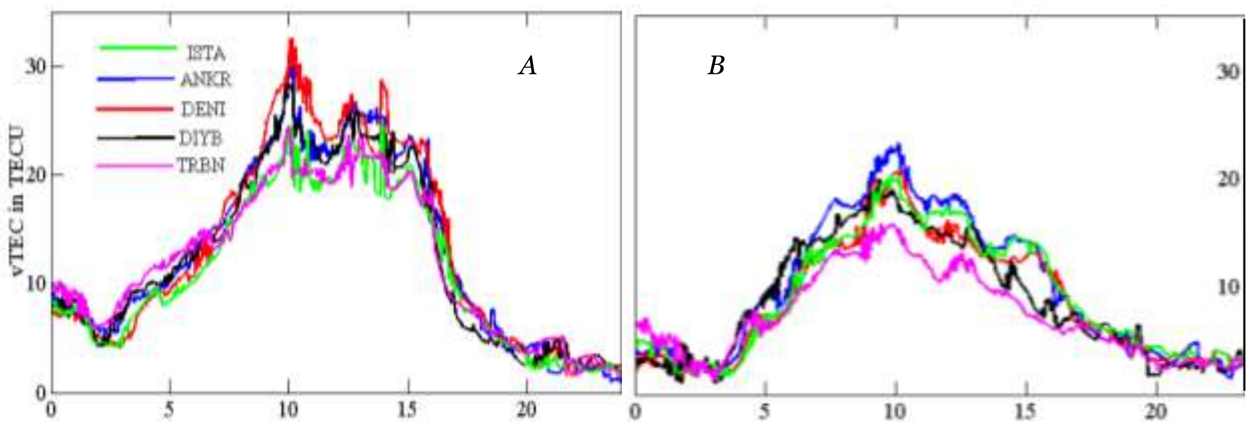

Fig. 3: Diurnal variation of TEC over different GPS stations across Turkish region for storm day (A) and for quiet day (B).

The Monthly and Seasonal variation

The monthly and seasonal variation of TEC for each month from January 2015-December 2015 at all stations was studied to observe the ionospheric changes. The TEC at all the stations are plotted along with monthly changes (Fig 4). The higher value of daily maxima of TEC are observed during months of March, April, May and June while the months of January, November and December are depicting lower values of TEC. To investigate the seasonal variations in TEC, the seasons are categorized as March equinox, June solstice, September equinox and December solstice. Maximum value of TEC was observed during the March equinox and June solstice, and the September equinox shows slightly higher value than the December solstice at all stations.

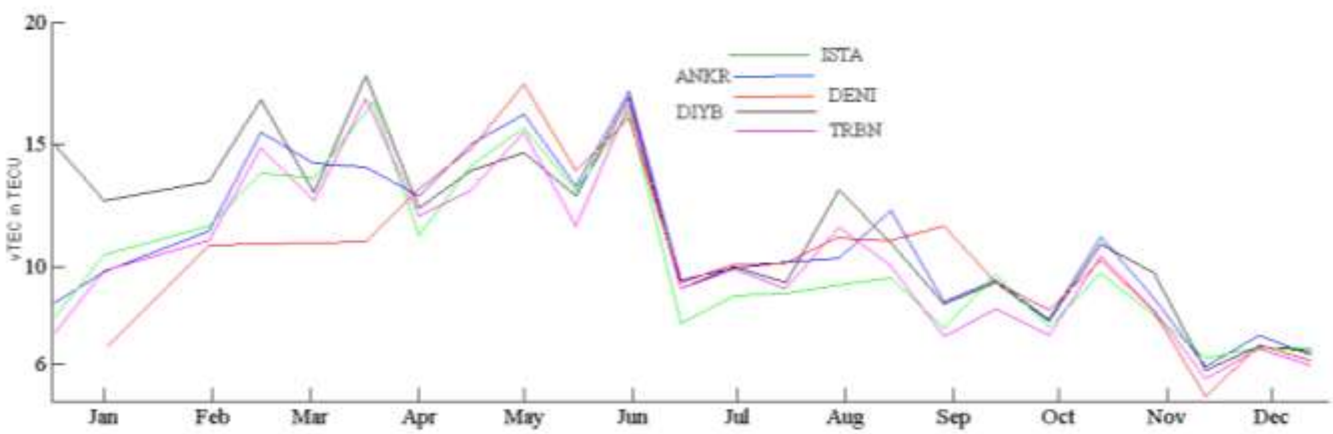

Fig.4. The Monthly and Seasonal variation of TEC over different GPS stations across Turkish region

The Cross Correlation Coefficient (CCC)

Cross Correlation Coefficient (CCC) defined the correlation between the two sets of vectors, vTEC of TGPS and vTEC of IRI model in this study, and are compared for quiet day's period 26 October to 28 October-2015 over Turkey. For all the selected IGS (Istanbul and Ankara) stations CCC metrics are calculated. The metric values can be seen in Fig. 5, blue (circle), red (triangle) and green (square) graphs belong to the PRN (Pseudo Random Noise) 9, 16 and 25 respectively. It is obviously seen from the graphs that for magnetically quiet days without any disturbance, IRI- model data are very similar with the data provided from TGPS-TEC. The general trend in CCC metric graphs for different stations and for the given satellites is very similar for these days also.

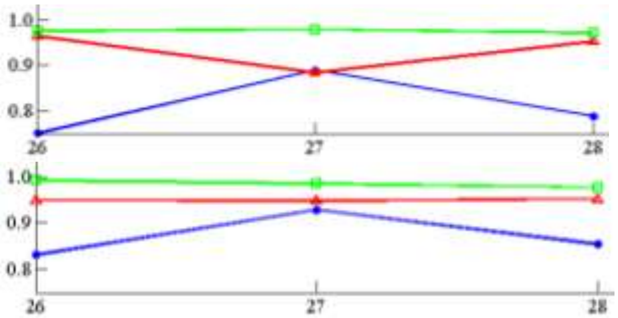

Fig. 5. CCC metrics of Istanbul (first) and Ankara (second)

The Model Comparison

The IRI is an empirical standard model sponsored by the Committee on Space Research and the International Union of Radio Science which provides the ionospheric informations at the altitude range 50 km to 2000 km, but the predictions are most accurate in northern mid-latitude regions due to dense network of monitoring stations [8]. The SPIM is developed under International Standardization Organization (ISO) by merging IRI below 1000 km and the plasmasphere region of the Russian Standard Model of Ionosphere (SMI) up to 20,000 km [8]. The measured TEC is compared with GIM published by IGS, SPIM predictions and IRI-2015 for quiet days. The comparison plots during quiet period 26-28 October 2015 (Fig-5) shows that the measured TEC (black curves) agree with the IRI-2015 predictions (blue curve). The GIM (red curves) and the SPIM (green curves) model overestimated the TEC values and show much higher values at all stations than the local measurements and IRI outputs. This concluded that GIM and SPIM predictions need further improvement for TEC predictions.

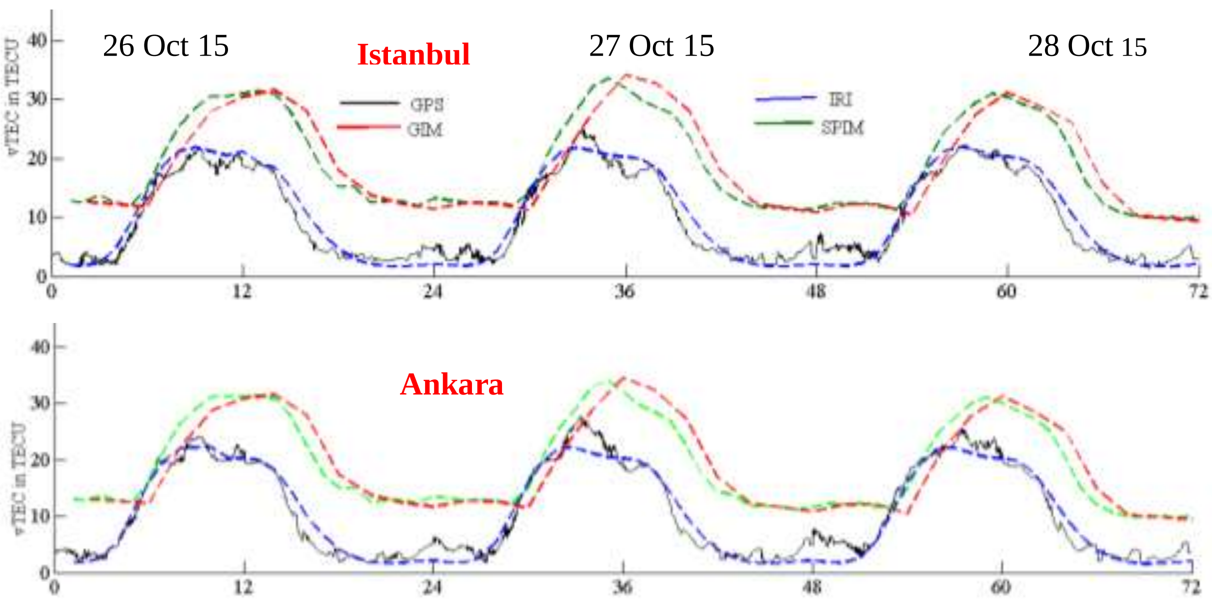

Fig.6. Comparison of GPS derived TEC with IRI-2015 and GIM and SPIM model predictions during quiet period (26-28 October 2015)

IV. Conclusion

In this study, ionosphere over Turkey was investigated using TGPS-TEC values and comparison model has been presented to better understand the ionosphere over the low latitude Turkish region for quiet and storm days. The TEC has maximum variation in storm days compare to quiet days. As a monthly of TEC has higher value average 17 TECU during months of March, April, May and June and as a seasonal variation TEC has maximum value 18 TECU during the March equinox and June solstice. The cross correlation coefficient method observed that for quiet days the difference between data sets is small which means the observed and modelled vTEC data are very similar. These similarities of data can be used to detect the ionospheric events. As the International standard models are still lacking reliable results over this region, further studies are needed for developing a suitable model.

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