Academic Journal of Science,
CD-ROM. ISSN: 2165-6282 :: 06(01):77–84 (2016)

SEASONAL, EQUINOX AND SOLSTICE VARIATIONS OF THE IONOSPHERE OVER TURKEY

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The ionosphere is a region of the upper atmosphere, from about 50 km to 1000 km altitude. Due to its space-time variability and dispersive nature, inhomogeneity and anisotropicity, ionosphere plays an important role in High Frequency (HF) and satellite signal propagation. Since it responds to solar EUV radiation, the ionosphere varies with multiple temporal scales such as the diurnal, seasonal, annual and 11-year cycle of solar activity. Ionosphere also varies with irregular temporal and spatial dynamic processes, known as ionospheric disturbances and anomalies. The Sun can vary the structure of the ionosphere in winter and summer seasons and special periods in a year such as equinoxes and solstices. The dynamic processes can cause density depression in the form of "bite-out" in the ionosphere. Total Electron Content (TEC) is an important observable that represents the variability characteristics of the ionosphere. TEC is proportional to the total number of electrons on a path crossing the atmosphere. TEC measurements can be obtained by Global Positioning System (GPS) using the network of world-wide receivers. In this study, by using IONOLAB-TEC (www.ionolab.org), GPS-TEC values are estimated for each chosen special periods of 10-30 days for winter and summer and before and after the equinoxes and solstices between May 2009 and September 2012. In this study, the behaviour of the ionosphere in the winter and summer and solstice and equinox periods are examined for the solar minima and maxima periods using Symmetric Kullback-Leibler Distance (SKLD), L2-Norm (L2N) and regression Analysis. It is observed that the days between March and September and June and December are different from each other during geomagnetically quiet periods. The difference between the same periods of the different years increases when a disturbance occurs in the ionosphere. The seasonal variability and anomaly structures are distinguished from each other by fusion of metric distance and correlation coefficient measures. Within-the-hour occurrence and duration of disturbances are examined by computing experimental probability densities of disturbances.

Keywords: Ionosphere, Total electron content, Disturbance.

Introduction

Space weather is a new concept that describes the conditions and the variations of the magnetic fields of Sun and Earth in the ionosphere and Earth's technological systems. The structure and the variability of the ionosphere related to the solar and geomagnetic activity are the decisive facts in the atmosphere. The ionosphere is the layer that extends between 50 and 100 km in the atmosphere. Ionosphere affects to the radio signals in the High Frequency and satellite communications because of its multi-scale spatially and temporally varying, dispersive, anisotropic and inhomogeneous structure. The most important parameter of the ionosphere is the electron density distribution which is a complex function of spatial and temporal variations of solar, geomagnetic, gravitational and seismic activity. The daily trend of the electron density distribution of the ionosphere is affected by disturbances during equinoxes, solstices, annual cycles, 11-year Solar Cycles and due to the dynamo effects from the Sun. An important measurable quantity about the electron density is the Total Electron Content (TEC) which is proportional to the total number of electrons on a line crossing the atmosphere. TEC measurements can be obtained by Global Positioning System (GPS) using the network of world-wide receivers. TEC measurements enable monitoring variations in the space weather. Some modern radio systems based on the propagation through the ionosphere need the information about the variations in TEC.

The trend of the electron density distribution in the ionosphere is disturbed during equinoxes and solstices, annual cycle and 11-year Solar Cycles, solar flares and due to the dynamo effect from the Sun. So seasonal and the daily variations are often observed in the ionosphere. In the 11-year cycles, the minima and the maxima are observed in the Sunspot Numbers (SSN). The numbers of these spots trigger the geomagnetic activity and affect many parameters such as electron density, critical frequencies of the ionospheric layers and TEC [Karatay, et al., 2010]. The electron density increases with the sunrise and decreases with the sunset. The maximum value is observed in the noon time. The structure of the ionosphere varies due to the dynamical processes from the electromagnetic drift and the neutral winds. The dynamic processes can cause density depression in the form of "bite-out" in the electron density distribution of the ionosphere [Zhang, et al., 2000, Lee, 2012].

The aim of this study is to investigate the variations in the ionosphere over Turkey due to solar and geomagnetic activity and the dynamical process using IONOLAB-TEC obtained from GPS stations. The variations and the difference between the solstice and equinox times in solar maxima and minima periods are analyzed using Symmetric Kullback-Leibler Distance Method. The statistical analysis method is presented in the following section.

The Method of Analysis

In GPS-TEC computations, Vertical Total Electron Content (VTEC) is defined as the sum of the free electrons estimated in the direction of the local zenith angle of the GPS receiver. Let

$$\mathbf{x}_{u;d} = \left[x_{u;d}(1) \ldots\ldots\ldots x_{u;d}(n) \ldots\ldots\ldots x_{u;d}(N) \right]^T \tag{1}$$

represent the set of VTEC data of length N for day d. Here, u indicates the receiver, n is the sample number ($1 \leq n \leq N$) and T is the transpose operator. In order to compare VTEC values obtained from different time intervals, data vectors in Equation 1 is normalized. The Probability Density Function (PDF) of TEC for station u and day d can be approximated as:

$$\hat{\mathbf{P}}_{u;d} = \mathbf{x}_{u;d} \left[\sum_{n=N_i}^{N_s} x_{u;d}(n) \right]^{-1} \tag{2}$$

where N_i and N_s denote the initial and final sample, respectively. Using these approximations described in Equation 2, the Symmetric Kullback-Leibler Distance (SKLD) for station u between days d1 and d2 can be defined as follows [Karatay, et al., 2010, Cover and Thomas, 2006]:

$$\mathrm{SKLD}(\hat{\mathbf{P}}_{u;d1};\hat{\mathbf{P}}_{u;d2}) = \mathrm{K}(\hat{\mathbf{P}}_{u;d1} \setminus \hat{\mathbf{P}}_{u;d2}) + \mathrm{K}(\hat{\mathbf{P}}_{u;d2} \setminus \hat{\mathbf{P}}_{u;d1}) \tag{3}$$

where $\mathrm{K}(\hat{\mathbf{P}}_{u;d} \setminus \hat{\mathbf{P}}_{v;d}), \mathrm{K}(\hat{\mathbf{P}}_{v;d} \setminus \hat{\mathbf{P}}_{u;d})$ functions are defined as:

$$\mathrm{K}(\hat{\mathbf{P}}_{u;d1} \setminus \hat{\mathbf{P}}_{u;d2}) = \sum_{n=N_i}^{N_s} \hat{P}_{u;d1}(n) \ln\left(\frac{\hat{P}_{u;d1}(n)}{\hat{P}_{u;d2}(n)}\right)$$

$$\mathrm{K}(\hat{\mathbf{P}}_{u;d2} \setminus \hat{\mathbf{P}}_{u;d1}) = \sum_{n=N_i}^{N_s} \hat{P}_{u;d2}(n) \ln\left(\frac{\hat{P}_{u;d2}(n)}{\hat{P}_{u;d1}(n)}\right) \tag{4}$$

where $N_i < n < N_s$. For the energy normalized TEC distribution, the L2-Norm can be given as [Karatay, et al., 2010, Papoulis, 1977]:

$$\mathrm{L2N}(\mathbf{x}_{u;d1};\mathbf{x}_{u;d2}) = \sqrt{\sum_{n=N_i}^{N_s}\left(\mathbf{x}_{u;d1}(n) - \mathbf{x}_{u;d2}(n)\right)^2} \tag{5}$$

Regression analysis is an analysis method used to measure the relation between two or more variables. Scatter diagram is a graph which marked the (x, y) binary sample data. Each (x, y) pair is a single point. The regression equation describes the relation between two variables. The regression equation of the monthly scatter diagram between two variables $\bar{X}_{u;d}$ and Sunspot Numbers is defined as follows [Arici, 1998]:

$$\hat{y} = b_i x + b_0 \tag{6}$$

where b_1 is the slope and b_0 is the secant. The coefficient of determination R^2 can be defined using Equation 6:

$$R^2 = \frac{\Sigma(\hat{y}-\bar{y})^2}{\Sigma(y-\bar{y})^2} \tag{7}$$

The observations and the conclusion are given in Section 2 and Section 3, respectively.

Observations

The statistical tool given in Section 2 is applied to IONOLAB-TEC data [http://www.ionolab.org] obtained from ankr (40°N, 32.7°E) in search for ionospheric disturbances and anomalies in winter and summer, solstice and equinox periods. In the first group of the study, 2009 and 2011 are chosen for investigating the ionospheric anomalies in the solstice and the equinox. The investigating periods are chosen as the time period from 10 days prior and after the solstice and equinox. In these periods, there is a significant geomagnetic disturbance on 26-28 September 2011. Kp and Ap values are 8 and 67, respectively [http://www.swpc.noaa.gov]. It is observed the difference between two equinox and solstice periods days in geomagnetically quiet 2009 are greater than those in geomagnetically disturbed 2011 when the equinox and the solstice times a year are compared with each other. The variations in the equinoxes between 2009 and 2011 are greater than in the solstices when the equinox and solstice periods are compared with each other. A similar result is demonstrated in Figure 1. It is observed that the days in an equinox or a solstice period in geomagnetically disturbed 2011 are similar to each other. Both equinox and solstice periods days in quiet 2009 are different from each other.

Secondly, a special time interval between 10 and 20 January, which the "bite-out" phenomenon is observed in noon times, is chosen for 2009, 2010, 2011 and 2012. There are no significant geomagnetic and solar activities in the periods of the interest according to the information provided from Kp and Ap indices. Only a small scale geomagnetic disturbance occurred on 20 January 2010. The maximum value of Kp index is approximately 5 and Ap is 14 in this date. IONOLAB-TEC values are compared with those of consecutive day for all years. The chosen years are also compared with each other for this time interval. It is observed that there is no significant variation in the consecutive days a year. In the years' comparison, it is observed that a few days in 2010 and 2011 are different from the other days due to the effect of the dynamic process. Because the chosen period between 2009 and 2011 is geomagnetically quiet periods and the chosen period is the same for all years, the differences in these days can be caused by the effect of the dynamic process. An example to this observation is provided in Figure 2. SKLD values vary from 0.00 to 0.004 in general. When the years are compared with 2010 and 2011, it is observed that SKLD values vary close to 0.12.

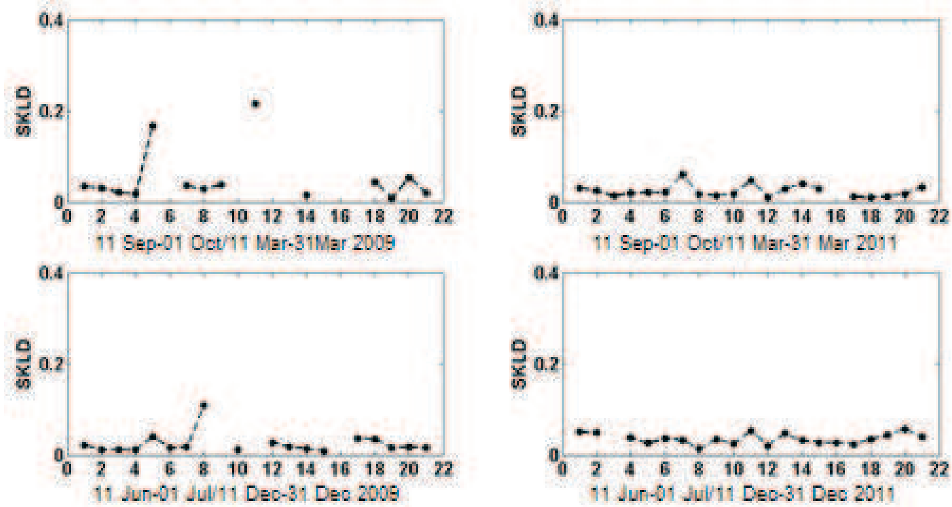

Figure 1. Comparison of the solstice and the equinox periods in a year with each other

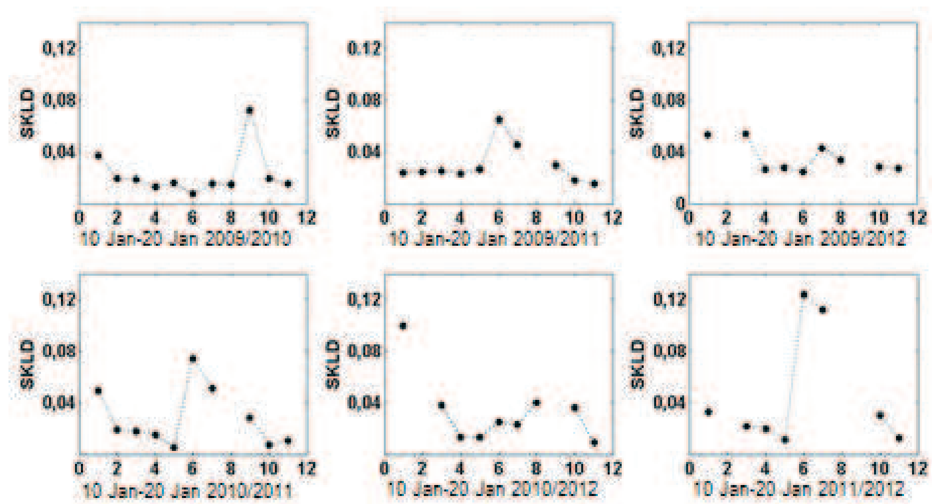

Figure 2. Comparison of the years with each other for days between 10 and 20 January

In the second group of the study, investigating periods are chosen 2009 and 2014 for the solar minimum and solar maximum years and Juna and March for the solstice and equinox months, respectively. The variation of the Sunspot Numbers (SSN) in 2009 and 2014 is given in Figure 3 [http://www.swpc.noaa.gov].

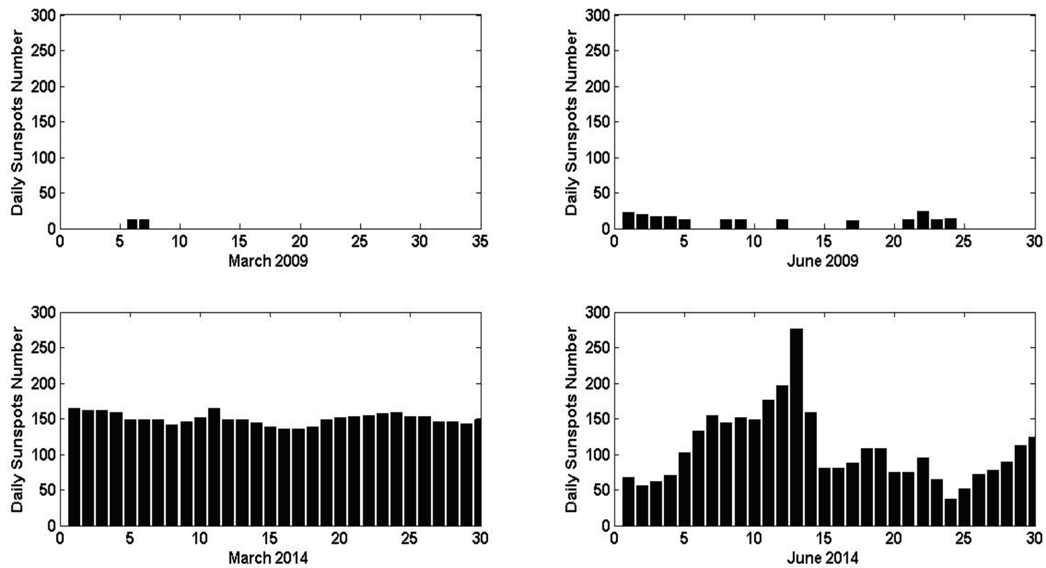

Figure 3. The daily Sunspots Numbers for March and June in 2009 and 2014.

In this group of the study, TEC values obtained for the same month in different years and for two months in the same year are comparing with each other using Equation 5, respectively. It is observed that the difference between the TEC values for the equinox increases in the solar maximum year 2014 and decreases in the solar minimum year 2009. When the equinox and solstice periods are compared with each other, it is observed that the L2N values between two periods in 2014 are greater than in 2009. An example to this observation is given in Figure 4.

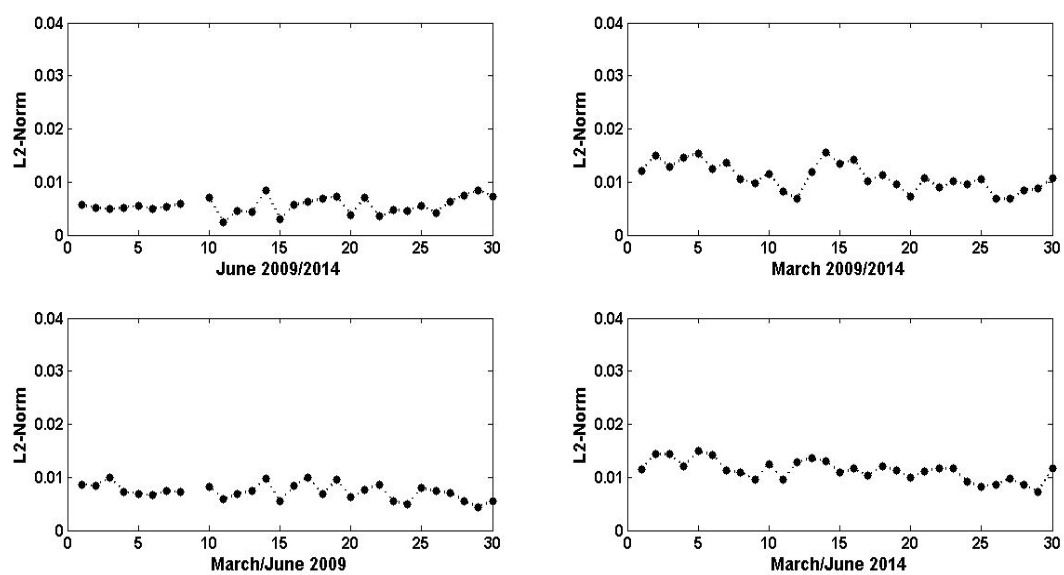

Figure 4. L2N values for June and March in 2009 and 2014

In the third group of the study, the daily mean values of TEC obtained for March and June in 2009 and 2014 are computed. The scattering diagram is obtained between the mean TEC and SSN. The monthly regression equation and the coefficient of the determination R^2 are computed using Equations 6 and 7, respectively. It is observed that TEC values, the positive linear relation between mean TEC and SSN and R^2 values increase depending on the increasing solar activity and SSN. The positive linear relation and R^2 values in June are greater than in March. This observation is shown in Figure 5.

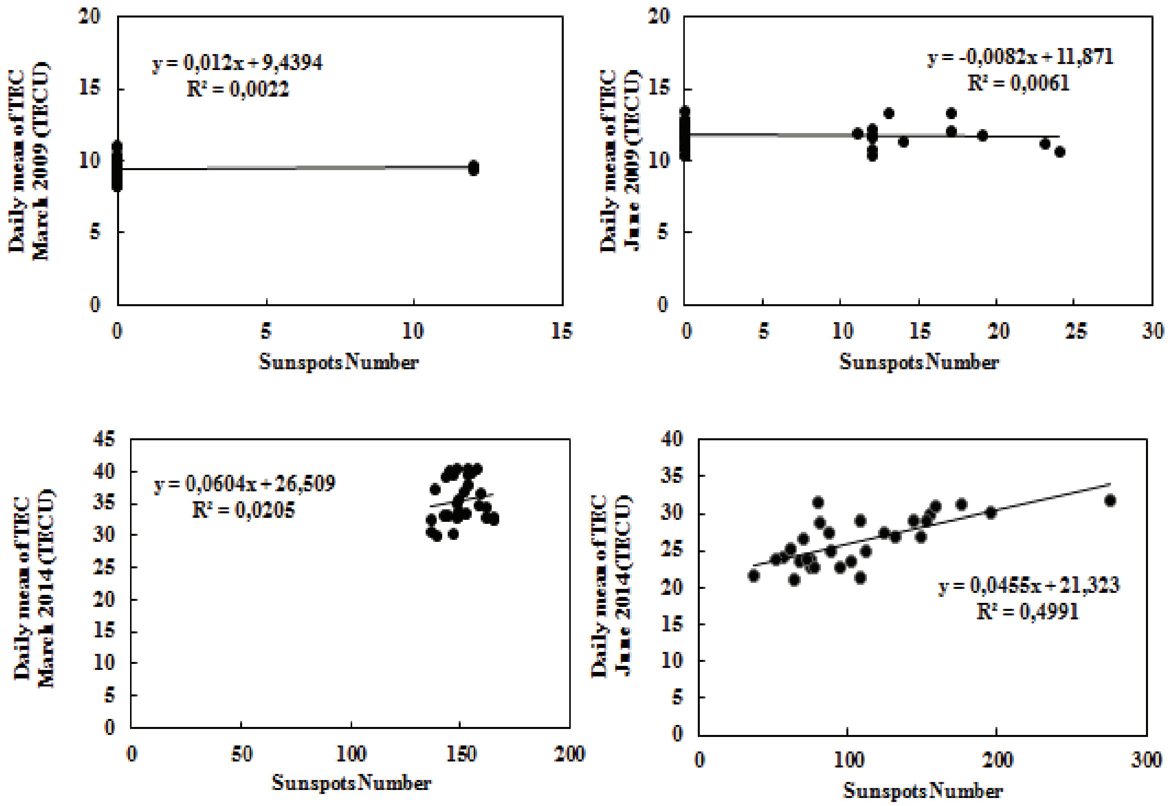

Figure 5. The scattering diagrams between the daily mean of TEC and SSN for March and June in 2009 and 2014.

Because the measurements made in limited and rare in the world have not obtained for Turkey until now, the effects of the solar and geomagnetic activity and the dynamic process on the ionosphere over Turkey have not been investigated much. The chosen GPS station, days and the time intervals are limited in this study. The time intervals and the conditions for the solar and geomagnetic activity that can be studied for Turkey could be defined with this study.

Conclusion

In this study, a disturbance and an anomaly due to seasonal, equinox and solstice variations are investigated by using IONOLAB-TEC estimates obtained from GPS station ankr. The behaviour of the ionosphere in these periods is examined for the solar minima and maxima periods using Symmetric Kullback-Leibler Distance (SKLD), L2-Norm and Regression Analysis Methods. It is observed that the days between March and September and June and December are different from each other during geomagnetically quiet periods. The difference between the same periods of the different years increases when a disturbance occurs in the ionosphere. The seasonal variability and anomaly structures are distinguished from each other by fusion of metric distance and correlation coefficient measures. Within-the-hour occurrence and duration of disturbances are examined by computing experimental probability densities of disturbances. TEC values and the regression determination coefficient increase when the Sunspot Numbers increase. The difference in the equinox days is greater than in the solstice days.

Acknowledgments

This study is sported by the joint TUBITAK 114E541.

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   http://www.ionolab.org

   http://www.swpc.noaa.gov/ftpdir/indices/old_indices