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COMPARISON OF IONOSPHERIC VARIATIONS IN SEISMIC AND QUIET DAYS BY CORS-TR IONOLAB-TEC ESTIMATES

Secil Karatay*, Feza Arikan†, Orhan Arikan‡, Onur Lenk°, Bahadir Aktug° and Melih Sukru Aysezen°

*Department of Physics
Firat University
23100, Elazig, Turkey

†Department of Electrical and Electronics Engineering
Hacettepe University
06800, Beytepe, Ankara, Turkey

‡Department of Electrical and Electronics Engineering
Bilkent University
06800, Bilkent, Ankara, Turkey

°4General Command of Mapping
Cebeci, Ankara, Turkey

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Abstract. The variability of the ionosphere is important for radio communications and ionospheric studies. In this study, the variability of the ionosphere due to seismic activity is investigated by using Total Electron Content (TEC) estimates obtained from CORS-TR Global Positioning System (GPS) stations. Two earthquakes occurred on Northern Anatolian Fault in Turkey are chosen for the purpose. The TEC data set is investigated by using Cross Correlation Coefficient (CC), symmetric Kullback-Leibler Distance (KLD) and L2-Norm for seismically active days and geomagnetically quiet days. It is observed that CC values of quiet days are highly correlated for quiet days. CC values of earthquake days decrease down to 0.2 in earthquake days. KLD values of earthquake days are 10 times greater than those of the quiet days. In order to form a proper earthquake precursor alarm signal, more earthquakes with different properties have to be investigated in the future.

1 INTRODUCTION

Increased observations of the ionosphere in the literature show that there are several disturbances and variations in some parameters of the ionosphere before the strong earthquakes, especially in TEC and critical frequency of the ionosphere[1-8]. There have been some theories that try to explain the ionospheric anomalies associated with pre-seismic activity and their effects in the ionosphere and some statistical tools have been used to explain their causes by using some parameters like TEC and critical frequency of F2-Layer. TEC is defined as the total number of electrons on a line crossing the atmosphere. The unit of TEC is given in TECU where 1 TECU = 10^{16}el/m^2. Global Positioning System (GPS), with the network of the world-wide receivers, provides cost effective solutions in estimating TEC and also, in monitoring the variability of the ionosphere [9,10].

In statistics and information theory, Kullback-Leibler Divergence is a widely used measure of distance between two probability density distributions [6,7,8,11,12]. Similarly, L2-Norm is used to define the metric distance between two vectors [6,7,8,13]. In this study, the variability of GPS-TEC is investigated over two different time period data set using Cross Correlation Coefficient (CC), symmetric Kullback-Leibler Distance (KLD) and L2-Norm (L2N). These three statistical tools are used before in five earthquakes in Japan that occurred over magnitude 5.9 in Richter scale and Sichuan China earthquake with magnitude 7.9 [6-8]. In these studies, the distances of the GPS stations to the epicenters varied from 30 km to 2000 km. In Sichuan, China earthquake, only one GPS station was available. So, the TEC difference between the stations can not be investigated. In this study, two earthquakes with same seismic properties that occurred on Northern Anatolian Fault in Turkey are chosen for the purpose. It will be the first time in the literature that the magnitudes smaller than 5.9 will be investigated for possible pre-seismic activity in ionosphere. The GPS-TEC estimates are obtained as IONOLAB-TEC [9,10,17] using CORS-TR GPS stations that are placed over Turkey by General Command of Mapping. The distances between these GPS stations vary from 80 km to 100 km. Thus, it is possible to study many GPS stations that are close to epicenters for investigating any earthquake occurred in the different seismic zones of Turkey.

2 THE STATISTICAL ANALYSIS TOOLS

For this study, chosen statistical tools, CC, KLD and L2N, are applied on three different groups. In the first group, CC, KLD and L2N are applied between TEC values of neighboring GPS stations. In the second group, an Average Quiet Day TEC (AQDT) estimate is obtained for each GPS station and TEC values of seismic and quiet days are compared with this AQDT using CC, KLD and L2N. In the third group, TEC values for consecutive seismic and quiet days of each GPS station are compared with each other. These techniques are discussed in detail in [6-8]. Application of these statistical tools are given in Section 3.

3 APPLICATION OF STATISTICAL ANALYSIS TOOLS TO CORS-TR NETWORK

Two time intervals are chosen for the investigation. Firstly, the earthquake day periods are chosen as the time period from 10 days prior and after the earthquake day. Secondly, the quiet days are chosen such that there are no significant geomagnetic and solar activities in the region of the interest according to the information provided from Dst, Kp and Ap indices. There are no significant geomagnetic disturbances during the earthquake days periods. For this study, 30 July 2009 Erzincan (E1) [14] (M=5 Richter scale, depth=5 km, $Lat = 39.6^oN$, $Lon = 40.3^oE$, UT=1037) and 08 August 2009 anakkale (E2) [15] (M=4.2 Richter scale, depth=10 km, $Lat = 40.3^oN$, $Lon = 27.2^oE$, UT=0452) earthquakes are chosen. These earthquakes both occured on Northern Anatolian Fault. The queit days are chosen from 1 October to 15 October 2009. The second quiet days period for AQDT is chosen from 1 June to 20 June 2009 [16]. The raw data for corresponding GPS stations in the region of the interest are estimated by using data of CORS-TR network [9,10,17].

In the first group of the study, CC, KLD and L2N are applied between TEC values of stations bayb $(40.25^oN, 40.19^oE)$, bing $(39.08^oN, 40.83^oE)$, erzi $(39.74^oN, 39.50^oE)$ and rhiy $(39.90^oN, 38.77^oE)$ in E1 and ayvl $(39.31^oN, 26.88^oE)$, band $(40.33^oN, 27.99^oE)$, cana $(40.11^oN, 24.41^oE)$, tekr $(40.95^oN, 27.49^oE)$ and yenc $(39.93^oN, 27.24^oE)$ in E2. It is observed that CC values in quiet days are highly correlated and vary close to +1. CC values in earthquake days decrease down to +0.5. KLD values between the stations in earthquake days are 10 times greater than those from quiet days values. L2N values between the stations vary from 0 to 0.005 in both earthquake and quiet days. L2N is not an indicator in the first group of the analysis. A similar result is demonstrated in Figure 1. It is observed from figure that CC values of earthquake days (Figure 1a) have small correlation coefficients. KLD values of earthquake days (Figure 1b) are 10 times greater than quiet days (Figure 1e). The earthquake day is represented by the arrow in Figure 1.

In the second group, TEC estimates of each station for earthquake and quiet days are compared with an AQDT using CC, KLD and L2N. It is observed that CC values for both earthquake and quiet days vary between 0.8 and 1. KLD and L2N values for earthquake days are greater than quiet days. KLD and L2N values increase significantly in some of days before the earthquake day. An example to this observation is provided in Figure 2 for E1 and station rhiy. CC values are similar with each other in E1 and quiet days as shown in Figure 2a and 2b, respectively. KLD values increase significantly 2 and 6 days before the earthquake as shown in Figure 2b. Same increases are also shown in L2N values in Figure 2c. The earthquake day is represented by the arrow in Figure 2.

In the third group, the daily VTEC data of each station is compared with those of consecutive day for all earthquake and quiet days. It is observed that CC values vary close to +1 in quiet days. CC values in earthquake decrease down to 0.2. KLD values in consecutive earthquake days are 10 times greater than consecutive quiet days. Similarly, L2N values in consecutive earthquake days are 2 times greater than consecutive quiet days. A similar result is demonstrated in Figure 3 for E1 and nearest station to epicenter erzi. From Figure3, it is observed that CC values in E1 (Figure 3a) are low correlated. KLD and L2N values in E1 (Figure 3b and 3c) are significantly greater than those of values in consecutive quiet days (Figure 3e and 3f).

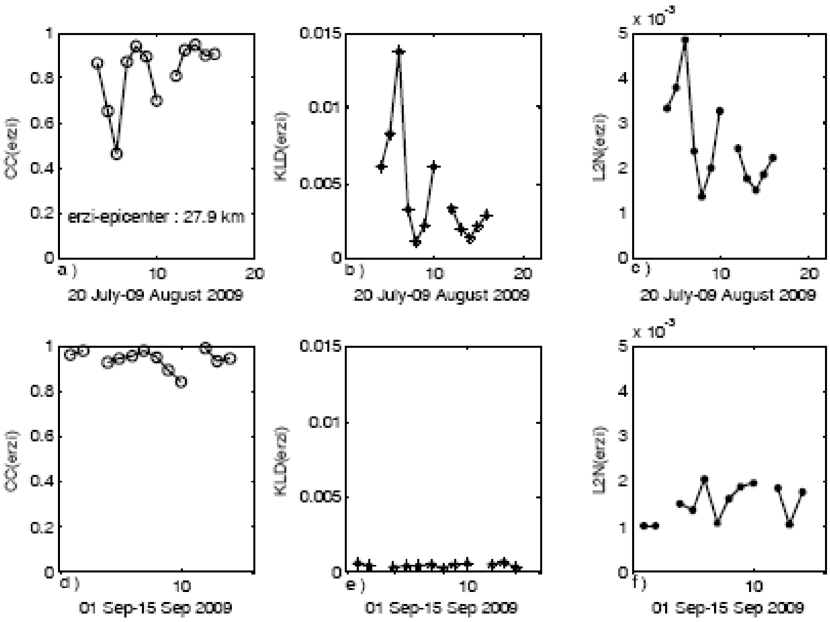

Figure 1: The values of a) CC, b) KLD and c) L2N in E2; d) CC, e) KLD and f) L2N in quiet days between stations ayvl and yenc.

4 CONCLUSIONS

In this study, a disturbance in the ionosphere due to seismic activity is investigated by using TEC estimates obtained from CORS-TR GPS stations. For the purpose, Cross Correlation Coefficient, Kullback-Leibler and L2-Norm methods are used. These statistical tools are applied on three major of group. Two earthquake with same seismic and geophysical properties occurred on Northern Anatolian Fault are chosen. It is observed that CC method between the neighboring stations can differentiate the earthquake days form quiet days as different from the previous studies [8,9,10]. KLD and L2N have similar results in the previous studies. In this study, KLD are better indicator of approaching seismic disturbance compared to L2N. In order to form a proper earthquake precursor alarm signal, more earthquakes with different properties have to be investigated in the future.

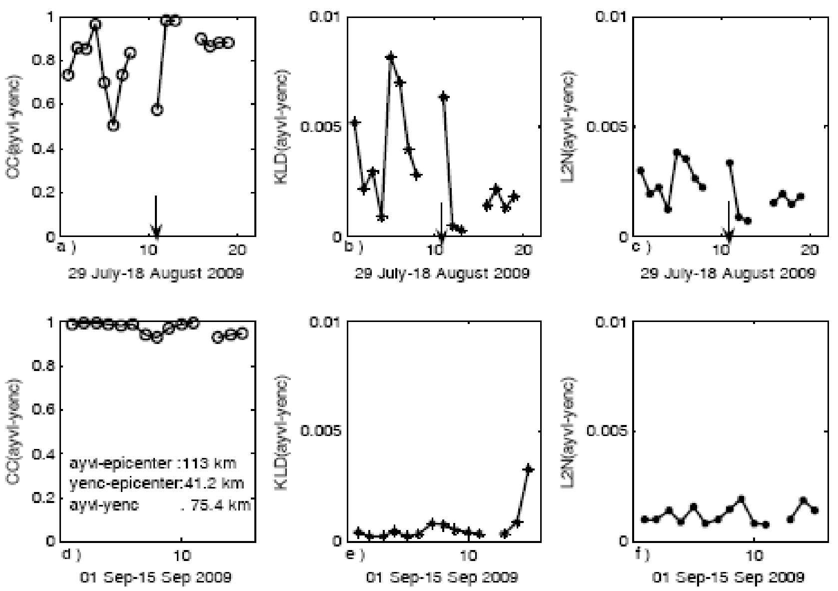

Figure 2: For rhiy, values of a) CC, b) KLD and c) L2N between days of E1 and AQDT; d) CC, e) KLD and f) L2N between quiet days and AQDT.

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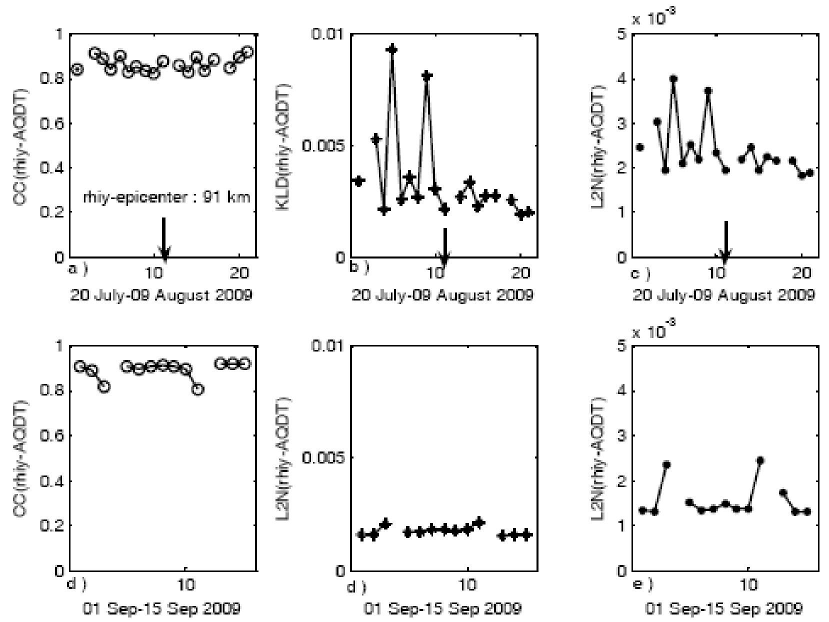

Figure 3: For erzi, values of a) CC, b) KLD and c) L2N in consecutive E1 days; d) CC, e) KLD and f) L2N in consecutive quiet days.

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