Investigation of Total Electron Content Variations Before the Aegean Sea Earthquake (24.05.2014 Mw 6.9) Study Area and Tectonic Summary of Earthquake
Investigation of Total Electron Content Variations Before the Aegean Sea Earthquake (24.05.2014 Mw 6.9)

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Abstract
Global Positioning System (GPS) satellites have been used as sensors with the development in space and satellite techniques. Total Electron Content (TEC) variations in the ionosphere before, during and after the earthquake can be identified by means of GPS observations. Thus, the effects of earthquakes over TEC variations can be monitored. In this study, the effects of the Aegean Sea Earthquake (Mw 6.9), occurred off Aegean Sea in 24 May 2014 at 09:25:03 UT, was investigated and pre-seismic TEC variations were examined. 42-days (between DoY 115 and 156) vertical TEC (VTEC) variations of CORS-TR (Continuously Operating Reference System-Turkey) stations at study area, ANV, IPSA and YENC, were determined and used to monitor the ionospheric TEC variations before the earthquake. In order to investigate these pre-earthquake ionospheric anomalies, two indices related to the space weather conditions which are solar activity index (F10.7) and geomagnetic activity index (Dst) were investigated by eliminating the ionospheric anomalies that arise from solar activities and geomagnetic storms. Potential causes of these activities were discussed. The observations, which showed a significant increase in VTEC, started 8-9 days before the earthquake. This study concludes that the observed possible anomalies in GPS-TEC were related to the earthquake. Keywords: Ionosphere, Total Electron Content, VTEC, Earthquake, Aegean, GNSS.

Study Area and Tectonic Summary of Earthquake
The May 24, 2014 M 6.9 earthquake south of the island of Samothraki, Greece, occurred as the result of strike-slip faulting at shallow depths beneath the northern Aegean Sea (Figure 1). Preliminary analysis of the mechanisms for the event indicate slip occurred on either a SSE-NNW trending left-lateral fault, or on a WSW-ENE trending right lateral structure (URL-1).

Space Weather Conditions
To determine whether there was a correlation between TEC response and solar/geomagnetic activity changes, we analyzed Solar Activity Index (F10.7 cm) and Geomagnetic Activity Index (Dst) (Figure 2a, b).

Obtaining VTEC
To obtain STEC, the differential code biases are also needed to be known. In order to take the advantage of reduced noise in carrier-phase based LA measurements in STEC computations, the LA data is usually fitted to the Pn by means of various algorithms in the literature as Lanly and Roth (1988), Jakowski et al. (1996), Kosjajthy and Langley (1996), Otsuka et al. (2003) and Liu et al. (2012) explain.

Analysis of VTEC Variations
Theoretically, the median (M) of 7 days (1-7 May 2014) of GPS-TEC is calculated to find the median (M) values. Then, the (first) or lower (or upper) quartiles are calculated to provide the information denoted by LQ and UQ, respectively. Assuming that the GPS-TEC values are in normal distribution with mean (m) and standard deviation (σ), the expected values of M and LQ or UQ are m and 1.34 σ, respectively (Klotz and Johnson, 1983). The lower bound (LB) and upper bound (UB) are calculated as LB=M-1.5(m-LQ) and UB=M+1.5(UQ-μ) respectively. The GPS-TEC data is analyzed per day. Each particular day is said to be anomalous if peak values are greater or smaller than with respect to other peak values in data set higher than UB and LB. A strong earthquake of Mw 6.9 occurred in the Aegean Sea at 09:25:03 UT on 24 May 2014 (http://earthquake.usgs.gov/). Based on the methodology explained above, GPS-TEC data for 42 days (25 April - 5 June, 2014) was processed and analyzed (3).

For each CORS-TR and IGS Sates, the differences (STEC) between the daily variation of VTEC and the UB are determined for 42 consecutive days between the dates 25 April - 5 June 2014. As a consequence, an abnormal peak values were found within the daytime. For all sites, STEC peak values were about 10-15 TECU started approximately 10-12 days before the earthquake. However, solar activity values are high between the dates 8-15 May, 2014. Hence, the peak values between this time interval may lead to misinterpretation of seismo-ionospheric effects of the Aegean Sea Earthquake. For this reason, it is reasonable to consider the peak values for the days after 15 May 2014 as pre-earthquake ionospheric precursors. It can be clearly seen in Figure 4 that the ionospheric VTEC increased before the earthquake. After the seismic event, the STEC values tend to decrease over time (Figure 4).

Conclusions
In the study, the ionospheric anomalies before the Aegean Sea Earthquake have been investigated by means of GPS data. The results showed that it may be possible to detect the characteristics of pre-earthquake ionospheric disturbances using GPS-TEC several days prior to a major earthquake. The abnormal variation in GPS-TEC started on 10-12 May 2014. Because the solar activity between the dates 8-15 May 2014, the peak values for the days after 15 May 2014 may be considered as the pre-earthquake ionospheric precursors. The significant increase in TEC may be attributed more to the pre-earthquake ionospheric activity than the solar or geomagnetic activity. The development of GNSS technology and assimilation techniques enables us to further improve the detection level of the ionosphere. In the near future, the GPS-TEC will be very valuable to discover the mechanism of seismo-ionospheric coupling. This study only focuses on demonstrating the ionospheric variability characters prior to the Aegean Sea earthquake. The physical mechanism of seismo-ionospheric effects of this earthquake will also be studied in the future works.

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References