Ionospheric Anomalies around the Time of the Powerful Nabro's Eruption Triggered by June 12, 2011 Earthquakes

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Abstract

Ionospheric variability resulting from earthquake events is a known phenomenon as revealed by various seismo-ionospheric coupling studies. Variations resulting from seismo-ionospheric couplings are known to be much weaker, and noted to occur only locally in an area that is specified by the magnitude of the earthquake. Whereas disturbances generated by other sources like geomagnetic storms, exhibit a more global behaviour. For this study, GPS-TEC data of 31 days (15 days before and 15 days after the occurrence of June 12, 2011 earthquakes) were examined. There were 14 earthquakes within 6 hours of that day that triggered the eruption that occurred on the 19th and 20th. This eruption produced the highest level of sulfur dioxide emissions in the earth's atmosphere that was ever detected from space. Any correlation between the identified TEC anomalies and the earthquakes was examined. The results showed an anomaly which started two days before the earthquakes. There was a consistent decrease in the GPS-TEC two days before the earthquake. The day of the earthquake also witnessed the most anomalous decrease during the days understudy. The 19th day of June 2011 eruptions however reflected in the ionosphere through the decrease in electron concentrations.

Keywords

Ionospheric Variability, Seismo-Ionospheric Couplings, Earthquake, GPS-TEC Data, TEC Anomalies and Eruption

Subject Areas: **Atmospheric Sciences, Geophysics**

1. Introduction

Scientists in the field of seismo-ionospheric couplings acknowledge that a seismic electromagnetic anomaly is a

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climax of some processes which began a few days before the occurrences of the event and continued until a few days after. Pre-seismic electric field together with its polarity caused the electrons in the F-layer to penetrate into lower layers leading to the creation of anomaly in the ionospheric parameters. The penetration of this electric field into the ionosphere was first shown by [1], thereafter applied by [2] [3] to show the seismo-electromagnetic process. The explanation of the physical process is that gas emanations from the earth's crust (CO_2, Radon, light gases, etc.) prior to an earthquake lead to the destruction of neutral clusters of atmospheric plasma, thereby enriching the atmosphere with ions and producing an anomalous vertical electric field that penetrates through the ionosphere [4]-[6]. However, in all cases, it is only the perpendicular component, to the geomagnetic field lines, of the anomalous electric field that penetrates into the ionosphere [7]. This zonal component leads to plasma density anomalies, which are observed over the earthquake area [8]-[12]. GPS TEC measurements have added immerse contributions to the understanding of these seismo-ionospheric variations. [13] used TEC data around the time of 20 major earthquakes in Taiwan to describe the seismo-ionospheric precursors detected between 1 - 5 days prior to these earthquakes. Furthermore, [14] showed that the shape of the TEC profiles of the northern crest of the equatorial anomaly is largely depended on electric field generated during earthquake preparatory processes. While [15] successfully noticed an anomalous enhancement of the total electron content (TEC) 3 days prior to 12 May Sichuan earthquake.

The 2011 Eritrea-Ethiopia region earthquakes are series of moderate earthquakes near a sparsely populated part of the Eritrea-Ethiopia border, starting at 15:37 UTC on Sunday, 12 June 2011. As of 21:37 UTC (within 6 hrs), at least 14 earthquakes of magnitude 4.5 or greater have occurred in the region. The initial quake registered a magnitude of 5.1 M_w with a focal depth of 10 km, and was succeeded by multiple lighter tremors. Hours later, two consecutive magnitude 5.7 M_w earthquakes struck the region at 20:32 and 21:03 UTC, occurring at very similar depths according to Wikipedia. The subsequent tremors resulted in localized strong shaking, registering at VII (very strong) on the Mercalli scale near the epicenters. Until the eruption began, the volcano had no records of historical eruptions. However, on 19 June, the volcano produced the highest level of sulfur dioxide emissions in the earth's atmosphere ever detected from space according to Volcanic Ash Advisory Center. On 20 June, VAAC reported that the SO_2 eruption was still active.

2. Data Analysis

GPS-TEC data (hourly data) of 31 days (15 days before the day of the earthquake and 15 days after it) from Addis Abba station (9.02˚N and 38.46˚E) were used for this work. In order to identify the seismic signals from the GPS-TEC data: the median and the inter-quartile range of data were utilized to construct their upper and lower bound in order to separate seismic anomalies from the background of natural variations [16]. The upper and lower bound of the above days (15 days before and 15 days after) were calculated using the following equations:

$$\text{Upper bound}\left(\text{UB}\right) = \text{X} + 1.5\left(\text{UQ} - \text{X}\right) \quad (1)$$

$$\text{Lower bound}\left(\text{LB}\right) = \text{X} + 1.5\left(\text{LQ} - \text{X}\right) \quad (2)$$

where UB is upper bound, LB is lower bound, LQ is lower quartile, UQ is upper quartile and median is the X.

Any perturbations that are considered related to earthquake must first be above either the lower or upper bound. However, an anomaly is considered a seismic signal if and only if it persisted for at least 3hrs in a day [17]. This was done deliberately so as to address the disturbances due to geomagnetic storms and avoid large variability in day to day values [18]. However the data available for this study has some hours missing (On 11th day, from 17:00 hrs to the 10:00 hrs of the 14th day; and also from 15:00 hrs till 24 hrs of the 15th day of the data). Dst index together with the Kp index of the same period were used to check for any geomagnetic activity within the period of study.

3. Result

Figure 1 shows the variation in the TEC data over the period of study with the time some data were missing. The results showed that the before the earthquake, there were 99.73% lower anomalies (LB) and 8.1% of upper anomalies (UB). But after the earthquake, there were 99.16% lower anomalies (LB) and 2.2% of upper anomalies (UB). This clearly shows more upper anomalies occurred before the earthquake (E representing the time of the earthquake) as seen in **Figure 2**. **Figure 3** shows the Dst index around the time in question. It can be

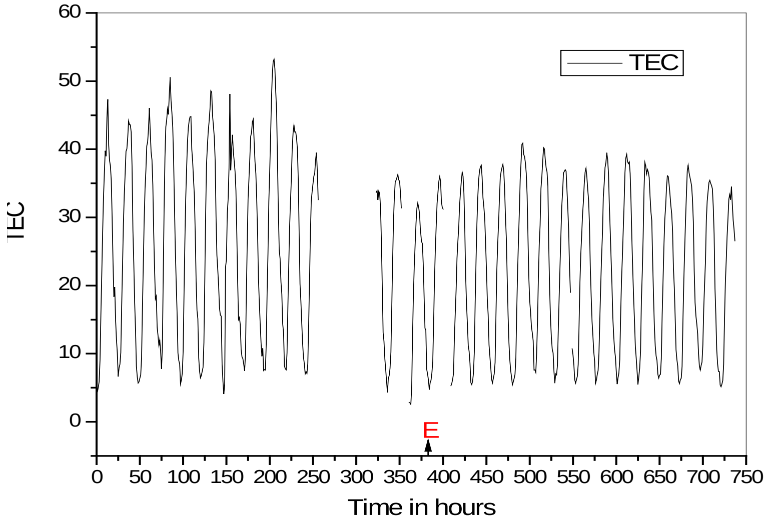

Figure 1. TEC variation from May 28th to June 27th, 2011.

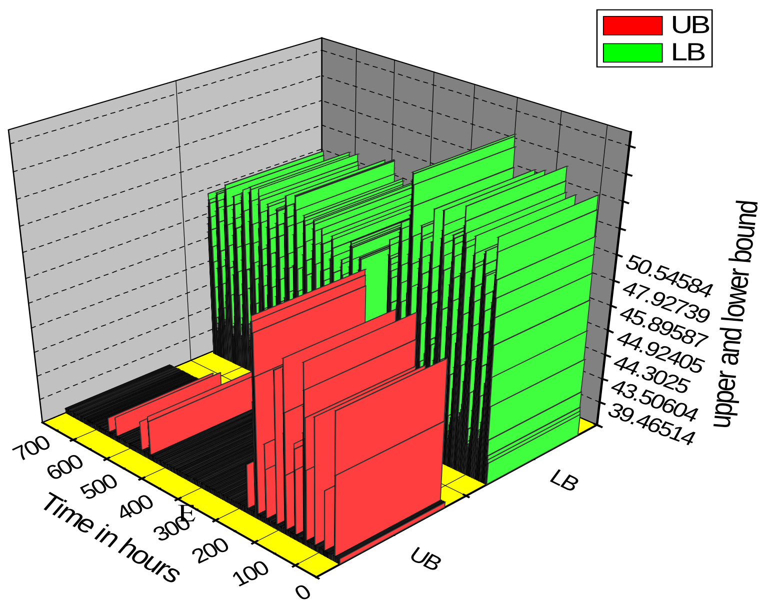

Figure 2. Upper and lower anomalies during the period under study.

seen that there were major magnetic activity only on the first day and the 9th day of the period under examination. This was also confirmed by **Figure 4** which shows the Kp index during the same period that was examined. However, **Figure 5** reveals the variation in TEC data before the day of the earthquake. It was noticed that there was a sudden significant decrease in the GPS-TEC in the afternoon of the day of the earthquake when compared with the other days (it is the lowest for the whole period under study). Another point that was obvious from the graph, is the steady decrease in the GPS-TEC in the early hours as clearly noticed 2(two) days before the earthquake from the data available; with the lowest TEC occurring on the day of the earthquake itself (June 12th 2011). Furthermore, there was a change in the situation after the day of the earthquake as the early hours GPS-TEC returned back to its familiar state. A closer look at the variation after the day of the earthquake as seen in **Figure 6** shows that, a sudden decrease in the GPS-TEC in the afternoon was noticed on the 23rd and 24th day of the data under study (represented by Er in the graph). These days coincided exactly with the 19th and 20th day of June, 2011. The value of *K*p index of geomagnetic activity did not exceed 3, therefore the condition around the two days can be characterized as quiet ones. **Table 1** shows the 14 earthquakes that occurred that day.

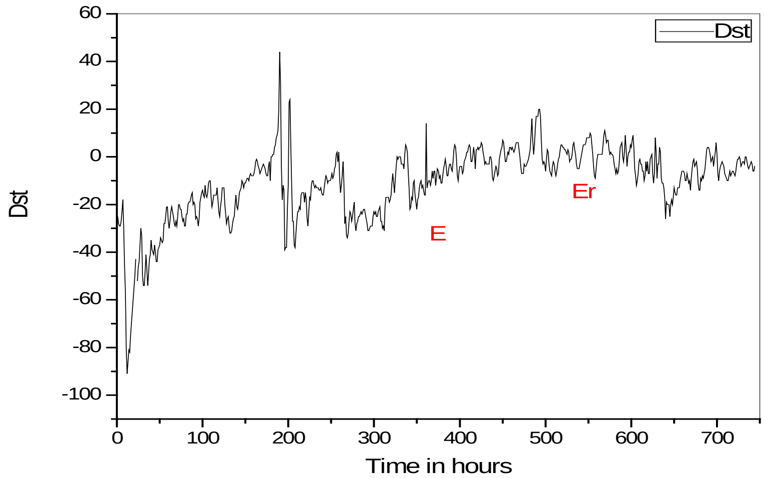

Figure 3. Dst index for the period of May 28 to June 27th, 2011.

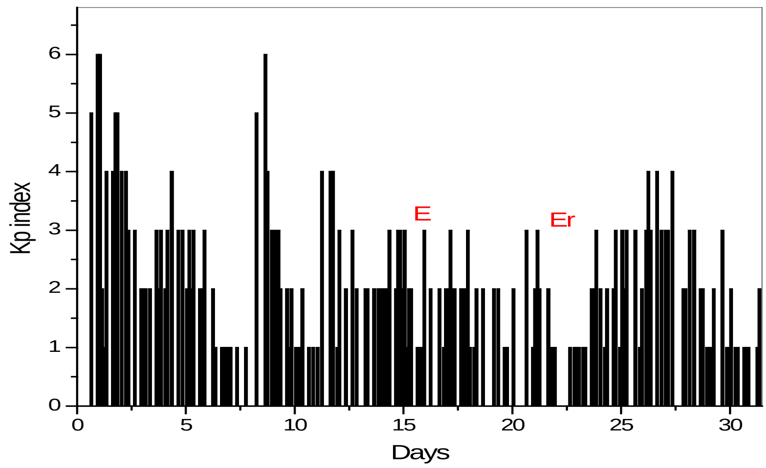

Figure 4. Kp index for the period of May 28 to June 27th, 2011.

Table 1. Characteristics of the 14 earthquakes that occurred on the 12th of June 2011.

Magnitude	Date and time in UTC	Focal length
M 4.5	2011/06/12 21.37	Depth 15.0 km
M 5.7	2011/06/12 21.03	Depth 9.9 km
M 5.7	2011/06/12 20.32	Depth 10.1 km
M 4.8	2011/06/12 19.44	Depth 9.9 km
M 4.7	2011/06/12 19.37	Depth 10.1 km
M 4.5	2011/06/12 18.01	Depth 10.1 km
M 5.0	2011/06/12 19.21	Depth 10.0 km
M 4.7	2011/06/12 17.47.21	Depth 10.0 km
M 4.8	2011/06/12 17.18.10	Depth 9.9 km
M 4.3	2011/06/12 16.33.12	Depth 10.0 km
M 4.8	2011/06/12 16.24.44	Depth 10.0 km
M 4.7	2011/06/12 16.12.03	Depth 10.0 km
M 4.5	2011/06/12 16.09.30	Depth 2.9 km
M5.7	June 12, 2011. 21.03.23	Depth 9.9 km

4. Discussion and Conclusion

This work studied the ionospheric anomaly associated with the Nabro's eruption that was triggered by the June 2011 earthquake by examining the GPS-TEC variation before and after the period. The fact that the upper anomalies were much more before the earthquake, suggested that pre-earthquake ionosphere had major contributions from the earthquake as described by [3] [18]. Moreover, the fact that the day of the earthquake experienced both the Sudden decrease in the early hours and also in the afternoon (with the Kp index around 3; clearly quiet day) shows plainly it was of seismic origin. [5] [16] showed that the eastward plasma E X B drift may cause the abnormal enhancement of TEC slightly shifting east of the epicenter. [5] [16] also stated that depending on the direction of the electric field on the ground surface (*i.e.*, up or down), negative or positive deviations in the electron concentration may be created, respectively. In the case of this work, it was negative deviation and that was why there was a decrease in electron concentration. The same reason was responsible for the continuous decrease of the electron concentration in the early hours noticed two days before the earthquake. It is most likely the decrease would have started some days earlier had the data been complete. On the other hand, the electron concentration sudden decrease in the afternoon on the 19th and 20th was in response to the emission of the highest levels of sulphur dioxide (SO_2) ever observed from Earth's orbit on the 19th, and it continued on

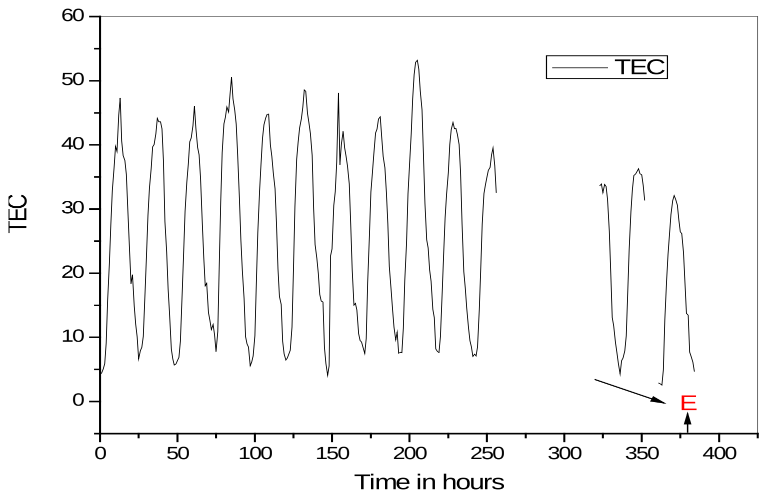

Figure 5. Variation of the TEC data from May 28th, 2011 till the day of the earthquake.

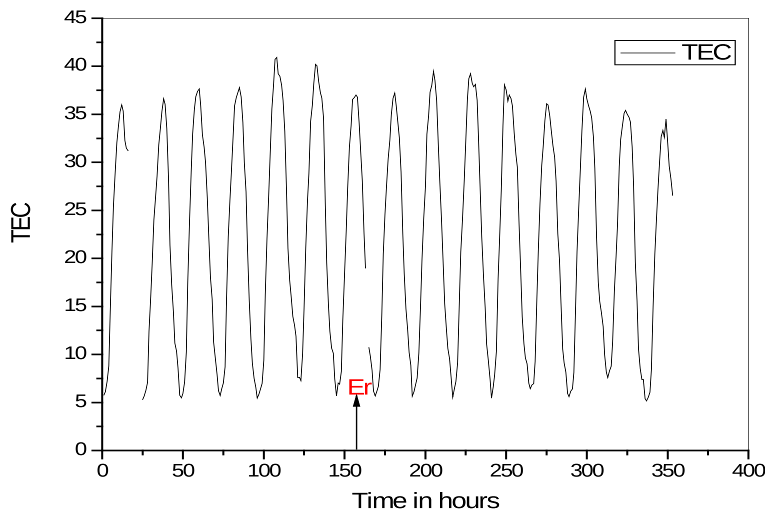

Figure 6. Variation of the TEC data from the day after the earthquake to the 27th of June, 2011.

the 20th even though not as much as the previous day. [19] stated that the most abundant gas typically released into the atmosphere from volcanic systems is water vapor (H_2O), followed by carbon dioxide (CO_2) and sulfur dioxide (SO_2). Volcanoes also release smaller amounts of others gases, including hydrogen sulfide (H_2S), hydrogen (H_2), carbon monoxide (CO), hydrogen chloride (HCL), hydrogen fluoride (HF), and helium (He). These gases spread from an erupting vent primarily as acid aerosols (tiny acid droplets), compounds attached to tephra particles, and microscopic salt particles. [20] however stated that, in addition to their destructive role regarding neutral clusters, they may also carry with them submicron aerosols, which, it is well known, will increase the intensity of the electric field due to the drop in air conductivity created by aerosols. However, the decrease in the electron concentration experienced was as a result of negative deviation at the ground surface. One other thing that was noticed which must be emphasized from the results is that the earthquake produced a decrease in the electron concentration both in the early hours and the afternoon period of the same day, while the Volcano (eruption) only produced a decrease in the afternoon on its day, but not as much decrease as that of the earthquake as seen from the graph. One major reason for the decrease in the afternoon not to be up to that of the earthquake might be attributed to the fact that the submicron aerosols release during volcanoes are much more than during earthquakes. These submicron aerosols will increase the intensity of electric field as revealed above. Moreover, since the surface experienced negative deviation, decrease in electron density was noticed.

Acknowledgements

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