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Total electron content anomalies before 12 January 2010 (Mw=7.0) Haiti earthquake using principal component analysis

Abstract

The aim of this study is to detect Total Electron Content (TEC) anomalies before (Mw=7.0) Haiti earthquake on 12 Jan 2010. Three earthquake-associated TEC anomalies appear at 15:00, 20:00 and 22:00 on 11 Jan 2010 (UTC), 1 day before this earthquake. The analysis results are examined using a mathematical tool called Principal Component Analysis (PCA). After more detailed analysis using PCA, each of three TEC anomalies lasts about 30 minutes.

Key Words

Total electron content (TEC); Haiti earthquake; Principal component analysis (PCA).

INTRODUCTION

Recently, the natural precursor (e.g. VHF transmitter signals) before the earthquakes was widely studied[2-4,7,13,17]. Some works researched the ionosphere total electron content (TEC) anomalies related to the large earthquakes. Liu et al's work[8] showed that the ionosphere (TEC) pronouncedly decreased in the afternoon period of 1200–1800 (LT) and especially evening period of 1800–2200 LT within 5 days prior to 20 M≥6.0 earthquakes in Taiwan during September 1999 to December 2002. Liu et al[6] studied the TEC anomalies associated with 35 M≥6.0 earthquakes that occurred from 1 May 1998 to 30 April 2008 in China. Related to the Haiti earthquake with the magnitude Mw=7.0 on 12 January 2010, Pulinets[12] found that the TEC increased for a few days prior to this earthquake. By the study of Akhoondzadeh and Saradjian[1], the interquartile method, wavelet transformation and Kalman filter method were used to identify the TEC anomaly (decreased TEC) appeared at 19:00 LT on 11 Jan before the Haiti earthquake. Liu et al's[9] research showed that the TEC anomaly (increased TEC) appears related to the Haiti earthquake specifically and persistently in a small region of the northern epicenter area.

From previous statements, increased and decreased TEC could not be a standard indication as an ionospheric anomaly related to the earthquake. Thus a mathematical tool called the principal component analysis (PCA)[5] will be used to proof TEC anomalies related to earthquake in this study. TEC data are from National Geophysical Data Center (NGDC). The TEC data are registered using a Kalman Filter assimilation model, currently about 80 CORS (Operating Reference Stations), 30 GPS/Met (Meteorology) and additionally, 15 IGS stations in America are ingested into the model. Its temporal resolution is 15-minutes and its spatial resolution is 1° and its RMSE (root-mean-square error) is about 2.4 TECu[15]. The TEC data is examined to detect anomaly related to the Haiti earthquake, which occurred at 21:53:09 (UTC) on 12 January 2012 (Mw=7.0, the depth=10km) with the epicenter at (N18.45°, W72.53°) in this study. The aim of this study is to estimate the duration time of earthquake-related TEC anomaly using PCA.

ANALYSIS METHODS

TEC variance observation

The TEC data from 12 Dec 2009 to 15 Jan 2010 are plotted shown in Figure 1. The curve shows no clear difference between TEC value and the mean TEC value, which is an average of past 10-day TEC value (e.g. the mean TEC value on 01 Jan 2010 is the average of past 10-day TEC value from 22 Dec 2009 to 31 Dec 2009), for the time period from 12 Dec 2009 to 10 Jan 2010. Except for 11 Jan, 1 day before the earthquake, the TEC value greatly increases and reaches 28.7 TECu. This is a peak value in the last 30 days. The TEC value drops to previous level on 12 Jan. For comparison the TEC value at 20:00 UTC from 12 Dec 2009 to 15 Jan 2010 is shown in Figure 2, and a clear peak value is on 11 Jan 2010. The mean TEC value at 20:00UTC in the last 30 days is 18.2 TECu with STD 2.5, and the peak value is at 20:00 UTC of 11 Jan, it reaches 28.7 TECu, almost 57.6% higher than the mean value.

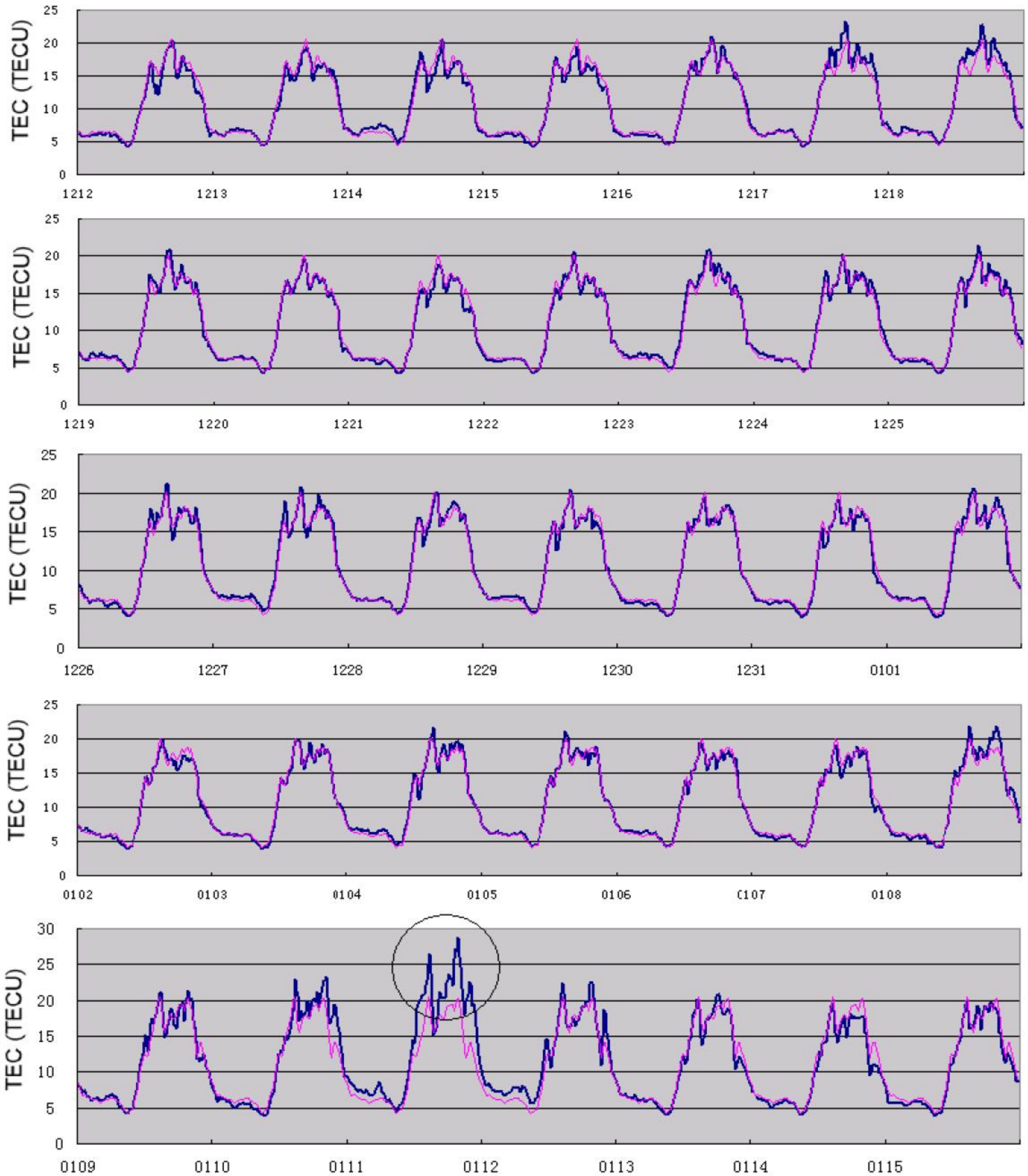

Figure 1 : This figure set shows the daily TEC variances from 12 Dec 2009 to 15 Jan. 2010. The blue line is daily TEC and the magenta line is the mean TEC. The position of circle is the time interval, in which the TEC anomalies are released. The mean TEC is an average of past 10-day TEC value. For example the mean TEC value on 01 Jan 2010 is the average of past 10-day TEC value from 22 Dec 2009 to 31 Dec 2009.

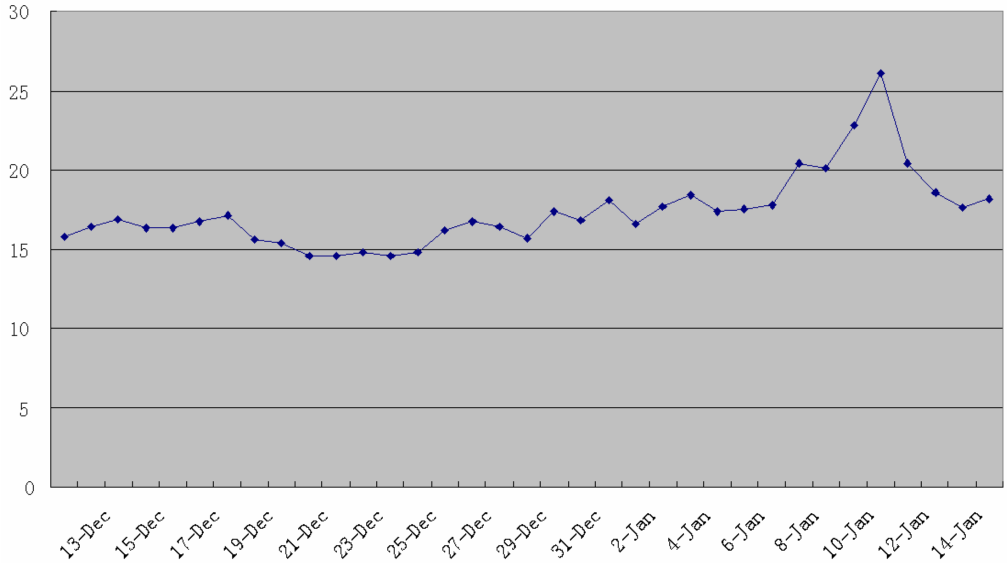

Figure 2 : TEC variances at 20:00 UTC from 12 Dec 2009 to 15 Jan 2010

The 3 peaks at 15:00, 20:00 and 22:00 UTC (10:00, 15:00 and 17:00 LT) are shown in Figure 3, respectively. A peak appears at 15:00, namely the afternoon time. It is similar to Liu et al's research[8] namely the TEC anomalies appeared in the afternoon period of 1200–1800 LT. However the result shows that the TEC anomaly appears at 15:00 LT, while Akhoondzadeh's method shows that the TEC anomaly appears at 17:00LT due to different source. The Kp (≦2) indices show that 11 Jan is a geomagnetic quiet day in Figure 4[10,11,16], and therefore the TEC anomalies with 3 peaks on 11 Jan should be associated with the earthquake. Similar results were shown in the work of Sarkar et al[14], a significant enhancement of electron density and electron temperature as a precursor near the epicenter on 11 Jan 2010, 1 day before the same Haiti eathquake, was shown by observing the plasma parameter variation registered by DEMETER satellite. According to previous interpretation, primary judged results show that the increased TEC should be the earthquake-associated anomalies in this day[6,18]. Principal component analysis (PCA) will be used to proof such earthquake-associated TEC anomalies in next section.

TEC data processing by PCA

PCA has previously been applied in the description of TEC anomalies associated with the earthquakes, which is proofed to be independent of long term TEC variances and non-earthquake effects (e.g. sun effect)[5]. Supposed the signal *s* is presented in a matrix *M* with *m* rows and *n* columns.

$$M = \begin{bmatrix} s_{1\times1} \cdots\cdots s_{1\times n} \\ \downarrow \\ s_{m\times1} \cdots\cdots s_{m\times n} \end{bmatrix} \quad (1)$$

$\tilde{J}(u) = u^T M M^T u + \lambda(1 - u^T u)$ is defined, and let $\nabla_u \tilde{J} = 0$, u is the unit vector, and then $MM^T u = \lambda u$, therefore there are m eigenvalues which are $\lambda_1 \geq \lambda_2 \geq ..... \geq \lambda_m$. The largest eigenvalue (principal eigenvalue) λ_1 represents the main characteristics of signal *s*.

The TEC data in this study are normalized under the same scale as the TEC data of Lin's work[5], so that principal eigenvalue with the magnitude > 0.5 in a normalized set is associated with earthquake information and indicate earthquake-associated TEC anomaly[5].

TEC data of a day have 96 data points to form a matrix *M* of Eq.1 (dimension, m (row) = 96, n (column) = 1) to get a principal eigenvalue for a day. The results of PCA from 01 to 15 January 2010 are shown in Figure 5. The principal eigenvalue gets to the maximum value on 11 January which reveals earthquake-associated TEC anomaly because the principal eigenvalue with the magnitude > 0.5 in a normalized set is associated with earthquake-related TEC anomaly.

For the 9-hour TEC data from 14:00 to 23:00 on 11 Jan (UTC), the TEC data are examined each 30 minutes. Each 30 minutes of TEC data have 2 measured data points which form a matrix *M* of eq.1 (dimension, m (row) = 2, n (column) = 1) to get a principal eigenvalues, and the results of PCA for this time period are shown in Figure 6(a). The larger principal eigenvalues (> 0.5) are at 15:00, 20:00 and 22:00 (UTC) which reveal the earthquake-associated anomalies as stated in last section.

For the same 9-hour TEC data, the TEC data are examined each 45 minutes. Each 45 minutes of TEC data have 3 measured data points to form a matrix *M* (dimension, m (row) = 3, n (column) = 1) to get a principal eigenvalues, and the results of PCA for this time period are shown in Figure 6(b). No large principal eigenvalues (> 0.5) are represented, so that the earthquake-associated TEC anomalies are not revealed.

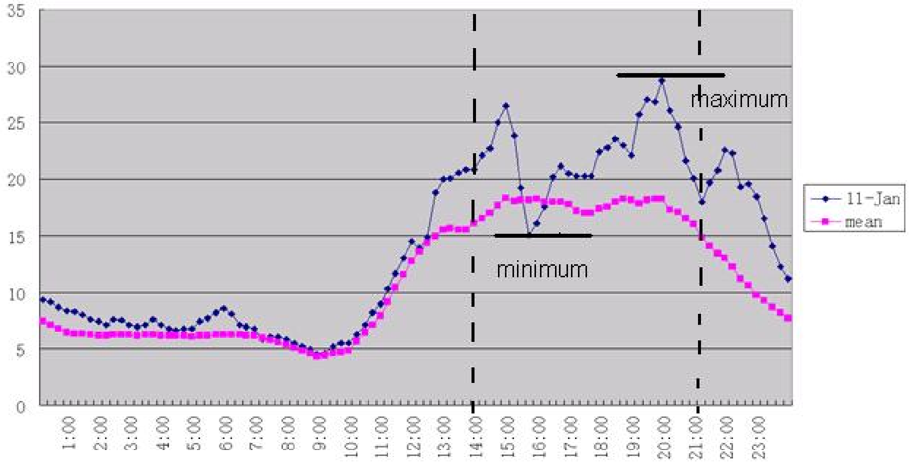

Figure 3 : TEC variances on 11 Jan 2010, 3 peaks are shown clearly compared with mean value from 12 Dec 2009 to 10 Jan 2010. The meaning of mean value is; for example, the value at 1:00 is the mean of TEC values at 1:00 from 12 Dec 2009 to 10 Jan 2010. The minimum and the maximum values in 14:00-21:00 are drawn with short black line.

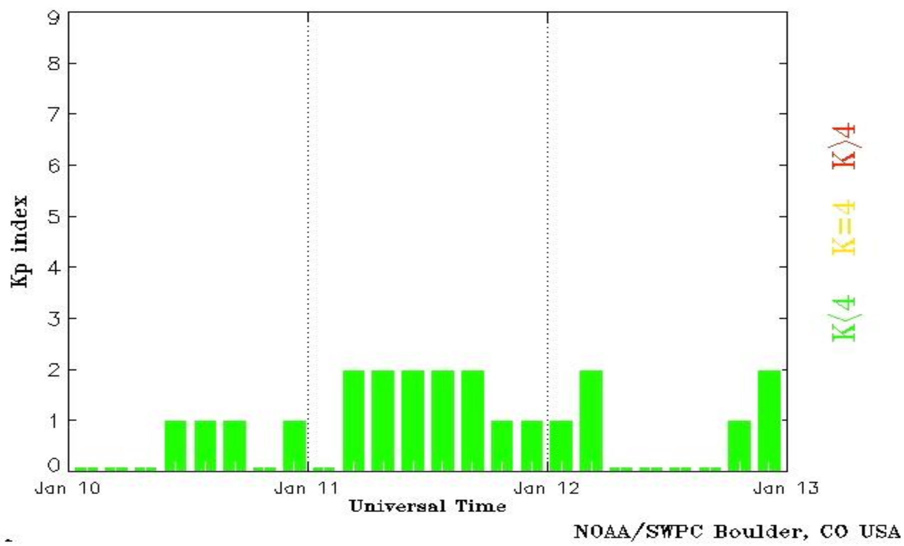

Figure 4 : This figure shows Kp indices from 10 Jan to 12 Jan 2010

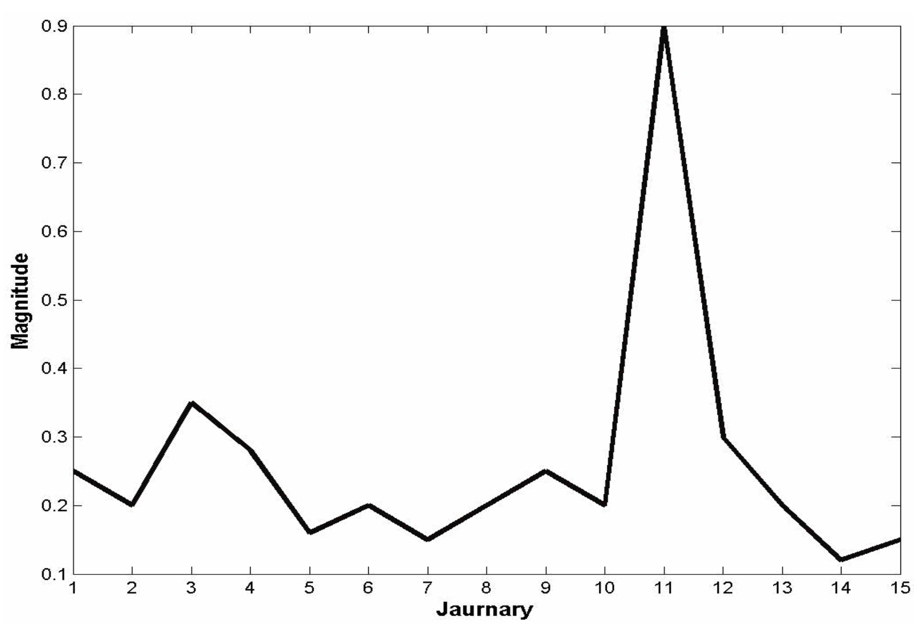

Figure 5 : This figure shows the principal eigenvalues of PCA in the time period from 01 to 15 Jan, 2010. The principal eigenvalue is the largest on 11 Jan.

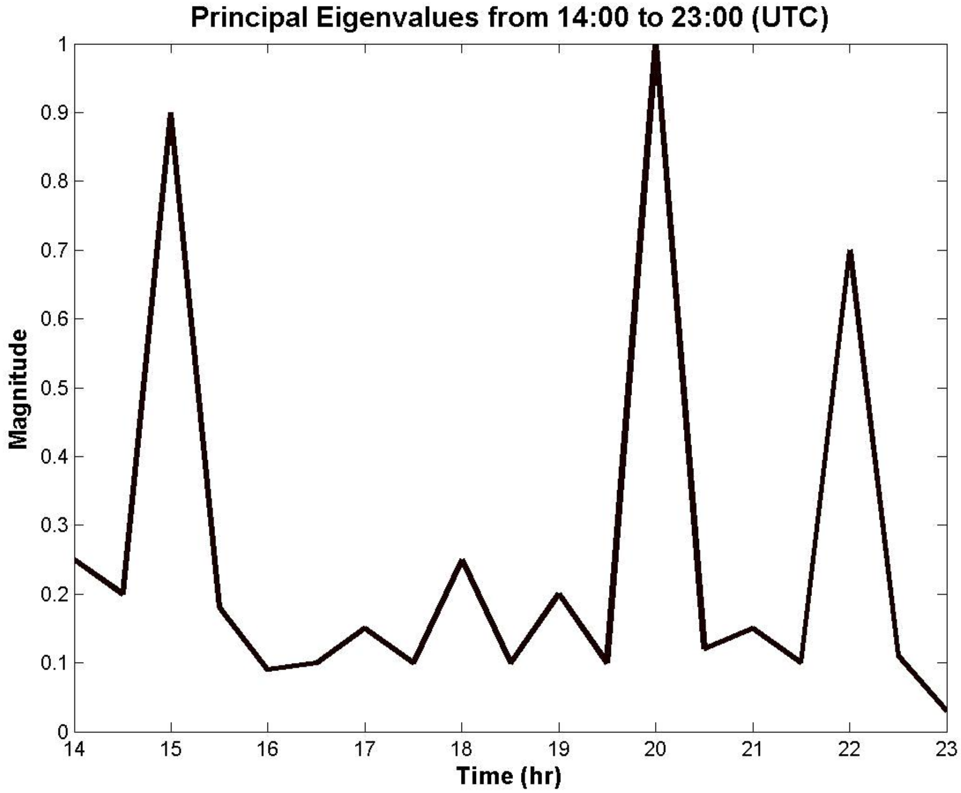

Figure 6(a) : This figure shows the principal eigenvalues of PA for the time period from 14:00 to 23:00 on 11 January 2010 (UTC). The principal eigenvalue with magnitude (>0.5) is associated with earthquake information to indicate earthquake-associated TEC anomaly[5].

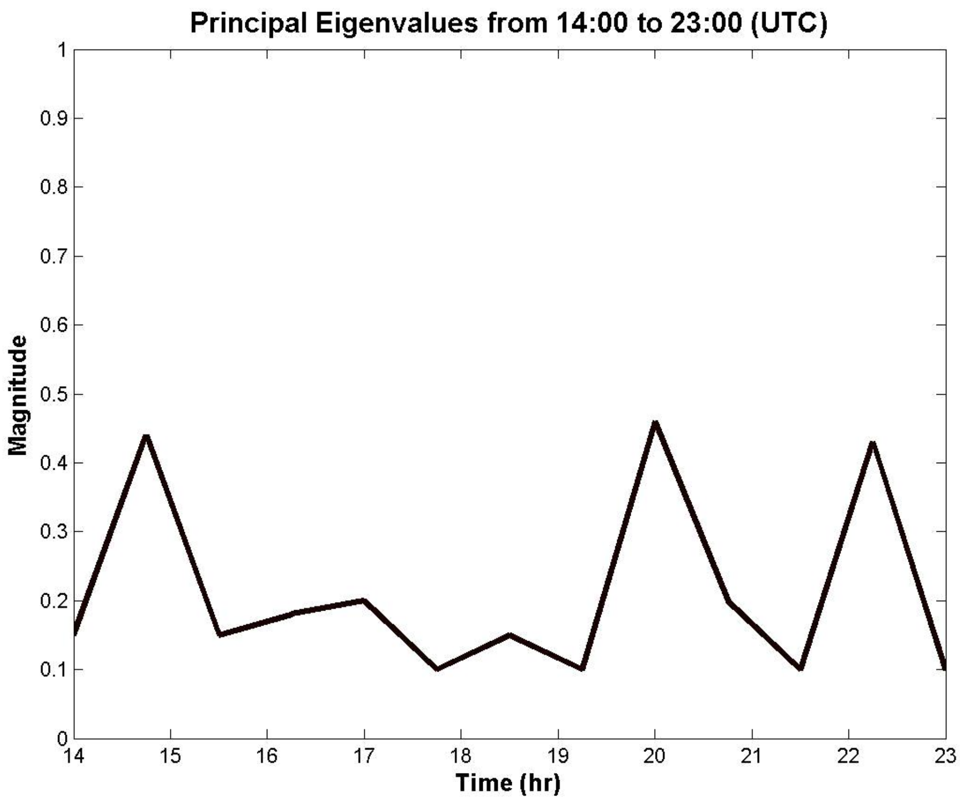

Figure 6(b) : This figure shows the principal eigenvalues of PCA for the time period from 14:00 to 23:00 on 11 January 2010 (UTC). No large principal eigenvalues (>0.5) are represented to indicate earthquake-associated TEC anomaly.

From previous results, the 3 TEC anomalies on 11 Jan are related to Haiti earthquake. Each of these TEC anomalies, the duration time is about 30 minutes by examining the difference between Figure 6(a) and 6(b).

DISCUSSION

Lin' work (2010) considered the TEC anomalies related to 12 M≧5 earthquakes and M=7.2 Chi-Chi earthquake in Taiwan using PCA. From the Figures 17 and 18 of that work, the seismogenic effects seemed to be independent of non-earthquake noises including space weather effects e.g. sun effect and long term TEC variance, therefore PCA is used to rationalize the observed results in the Section 2.1 of this study. It also shows a convincing result in Figure 5. Figure 5 shows the analysis results of PCA from 01 Jan to 15 Jan 2010. Different non-earthquake mechanisms such as atmospheric winds, tides, gravity waves, travelling ionospheric disturbances should exist during this time period, and however seismogenic effect is revealed on 11 Jan. Therefore the PCA can be used to detect the earthquake-related TEC anomaly without considering non-earthquake effects. From previous interpretation, However the PCA method has a weakness. That is; the principal eigenvalue can not interpret true TEC anomaly situation. It gives that a principal eigenvalue (> 0.5) is associated with an earthquake-related TEC anomaly.

CONCLUSION

The TEC anomaly appeared on 11 Jan, 1 day before the Haiti earthquake. The 3 earthquake-associated TEC anomalies have been found at 15:00, 20:00 and 22:00 UTC (10:00, 15:00 and 17:00 LT), and the largest anomaly appears at 20:00. Each of the 3 anomalies had the duration time about 30 minutes.

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