Ionospheric Precursor before a 547 km deep Indonesia Nebe Earthquake on 27 February 2015, Mw=7.0 using Two-Dimensional Principal Component Analysis (2DPCA)

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ABSTRACT

In this study, the ionospheric Total Electron Content (TEC) data of 5 days before Indonesia Nebe earthquake occurred at 13:45:05 (UT) on 27 February 2015 (M_w =7.0) with the depth of 547km and the epicentre of 7.277°S, 122.534°E were examined to detect TEC precursor by using Two-Dimensional Principal Component Analysis (2DPCA) because such TEC precursor could not be found by observation analysis. Results have shown that a TEC precursor was highly localized and increased in intensity during the time period from 05:55 to 06:00 (UT) on 26 February 2015. The duration time of TEC anomaly was at least 5 minutes. Possible reason of the TEC precursor over the epicenter before this earthquake should be radon gas release.

Keywords: Total Electron Content (TEC), Indonesia Nebe Earthquake, TEC Precursor, Two-Dimensional Principal Component Analysis (2DPCA), Radon Gas Release

INTRODUCTION

Ionospheric total electron content (TEC) earthquake-associated anomalies have been widely researched (Hegai et al., 2006; Liu et al. 2011; Liu et al. 2009; Liu et al. 2008; Liu et al. 2006; Liu et al. 2001; Lognonné et al. 2006; Marchand et al. 2008; Pulinets et al. 2000 Pulinets et al 2002; Pulinets et al. 2004; Pulinets, 2007; Singh, et al., 2010; Xia et al. 2011a; Zhao et al. 2008). TEC anomalies indicating depletion and enhancement of the TEC anomalies near the earthquake preparation zones before large earthquakes may be useful in the earthquake prediction studies (Liu, 2001; Xia et al. 2011ab; Zhao et al. 2008). Le et al. (2011) surveyed 736 earthquakes (M≥6.0) globally for statistical association with pre-earthquake TEC anomalies. This study found that the probability of anomalous TEC behavior being associated with earthquakes depended on the following factors: earthquake magnitude, earthquake depth, and the number of days the anomaly existed before these earthquakes. Xia et al. (2011b) also investigated pre-earthquake related TEC anomalies in the Tibetan Plateau region. They investigated 20 earthquakes (M>5) in the Tibetan Plateau using a 15-day running median as normal TEC levels. They found for the period 11 days before these earthquakes TEC enhancement occurred for 17/20 (85%) of the earthquakes over the earthquake preparation zones and depletions occurred for 13/20 (65%). Their papers make the interesting finding that the prevalence of enhancements or depletions varies with focal depth and not magnitude. Pulinets et al. (2002) showed that for earthquakes of an equivalent magnitude, the dispersion factor for TEC increased threefold for deep focus earthquakes (depth 60-300 km) at the Chungli ionosonde in Taiwan for the period 1978 to 1986. They assumed that the increased scale of the disturbance zone for deep-focus earthquakes would generate a vertical electrical disturbance of 200 to 250 km in diameter at the earth’s surface

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that is large enough to create notable ionospheric disturbance. Pulinets (2004) makes an extensive list of possible causes, including radon gas release causing lower atmospheric electric fields which travel up into the ionosphere along geomagnetic lines while Freund (2003) suggests P-type semiconductor effect as the cause of lower atmosphere electric fields. The TEC anomalies are most likely caused by acoustic shock waves traveling from the earth's surface into the ionosphere after the earthquake (Artru et al. 2001; Garcia et al. 2005; Lognonné et al. 2006; Marchand et al. 2008; Pulinets et al. 2000). In this study, Two-Dimensional Principal Component Analysis (2DPCA) is used to detect TEC precursor before Indonesia Nebe earthquake occurred at 13:45:05 (UT) on 27 February 2015 (M_w=7.0) with the depth of 547km and the epicentre being 7.277°S, 122.534°E. The interesting aspect about this earthquake is 547 km depth. The earthquake-associated TEC precursor should be not easy to recognize before the earthquake using any observation analysis. The TEC data of 5-day time period before the first Miyako earthquake were processed because TEC precursors have usually been identified during this period before large earthquakes (Liu et al., 2006). NASA Global Differential GPS system (GDGPS) and the TEC data are derived using data from ~100 real-time GDGPS tracking sites, augmented with additional sites that are available on 5 minutes basis, probing the ionosphere. The GDGPS System produces two dimensional total electron content (TEC) values on a 2°×2° global grid every 5 minutes (Yoaz and Byron 2014). The integrated electron density data along each receiver-GPS satellite link is processed through a Kalman filter in a sun-fixed frame to produce the global gridded TEC maps.

METHOD

For 2DPCA, let two-dimensional TEC data in an area (an area is 12° and 9° in longitude and latitude in this study) represented by a matrix *A* (the dimension of *n* x *m*). Linear projection of the form is considered as followed (Sanguansat 2012),

$$y = Ax \tag{1}$$

Here x is an n dimensional project axis and y is the projected feature of TEC data on x called principal component vector.

$$S_x = E(y - Ey)(y - Ey)^T \tag{2}$$

Here S_x is the covariance matrix of the project feature vector.

The trace of S_x is defined;

$$J(x) = tr(S_x) \tag{3}$$

$$tr(S_x) = tr\{x^T G x\},$$

$$G = E[(A - EA)^T (A - EA)] \tag{4}$$

The matrix G is called covariance matrix. Vector x maximizing Eq. (4) corresponds to the largest eigenvalue of G, which is the dominant component of the TEC data in a given area, and is therefore referred to as the principal eigenvalue. If the magnitudes of the principal eigenvalues in two TEC data sets are the same, then their principal spatial characteristics, patterns, and underlying conditions should also be the same. 2DPCA can be removed small sample signal size (SSS) problem. The PCA converts the measurements into one-dimensional

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data before covariance matrix calculation. The covariance matrix of PCA is based on an input matrix with the dimension of *m x n*, which is reshaped from one-dimensional data (length of *m* multiplying *n*). Reshaping data will cause computing error because PCA is a tool to deal with one-dimensional data. That proclaims the spatial structure and information can not be well preserved due to some original information loss when inverting to original dimension under the condition of the matrix being small sample size (SSS). Such information loss is called SSS problem (such loss is a low dimensional data problem). However, the covariance matrix in 2DPCA is full rank for a matrix of low dimension. The curse of dimensionality and SSS problem (low dimensional data problem) can be avoided by 2DPCA. Therefore, 2DPCA can be performed to detect the Miyako earthquake-related and the induced-tsunami TEC anomalies using non-dense two dimensional TEC data from the GDGPS network System (non-dense TEC data in an area) in this study.

TEC data Processing

TEC data of 5 days before Indonesia Nebe earthquake occurred were examined to detect TEC precursor by using 2DPCA. TEC data of previous examined time periods were processed by 2DPCA and TEC precursor of Nebe earthquake was not detectable. Only during the time period from 05:55 to 06:00 (UT) on 26 February 2015 was the TEC precursor of the corresponding information from the Nebe earthquake because a largest principal eigenvalues was in an area incl. epicentre. Therefore, the TEC data processing procedure for these time periods is shown in this study.

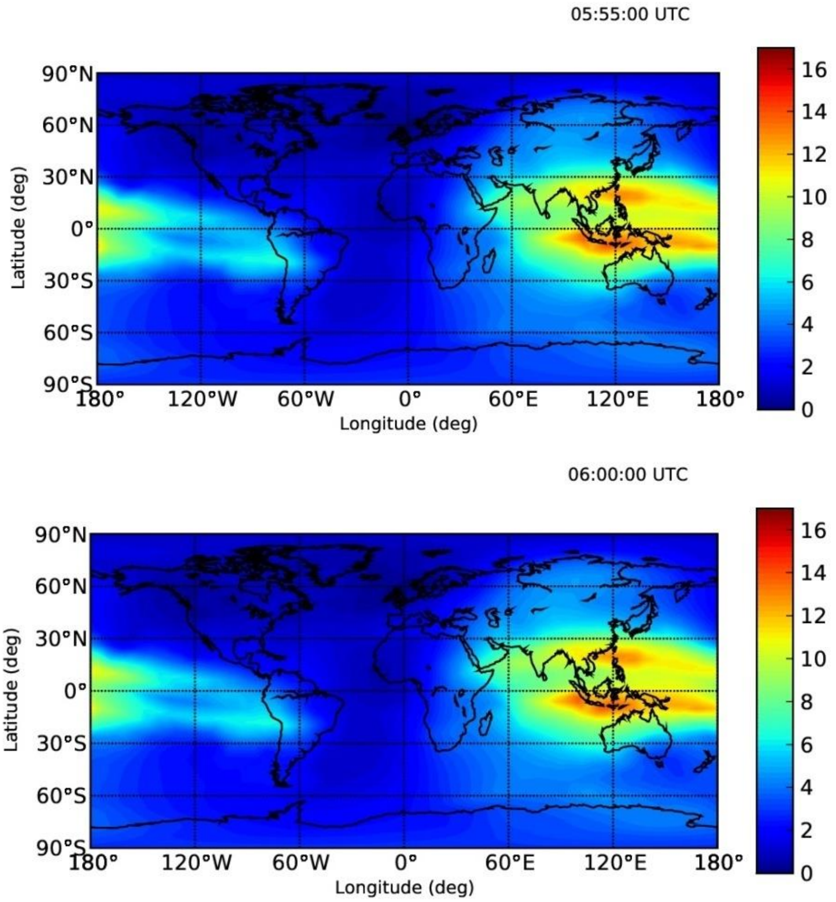

Figure 1(a). The figure set shows the GIMs during the time period from 05:55 to 06:00 (UT) on 26 February 2015

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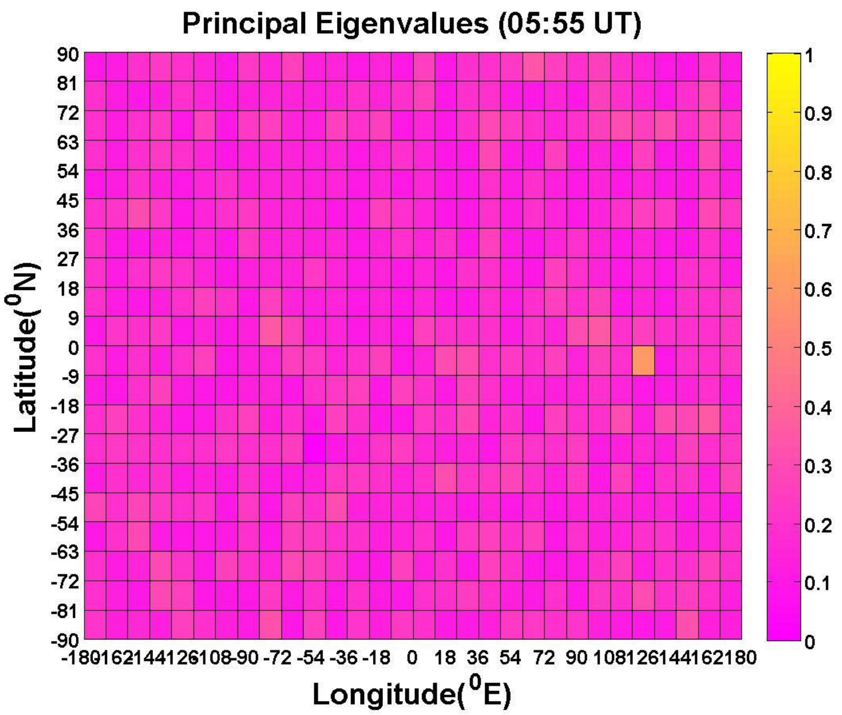
Figure 1(a) shows the GIMs during the time period from 05:55 to 06:00 (UT) on 26 February 2015. The TEC data for the global region in Figure 1(a) are divided into 600 grids 12° and 9° in longitude and latitude, respectively. The terminology grid is used instead of area in this study for convenience. Thus, the size of each grid is 12° in longitude and 9° in latitude. Such small grids as analysis regions are reasonable according to the results of past some studies (Artru, et al. 2001; Lognonné et al. 2006; Hobara & Parrot 2005) because TEC were anomalies usually spread widely from the epicenters of large earthquakes. Section one referred to the contents regarding the spatial resolution of the TEC data for the GDGPS system. A grid includes about 24 TEC data, and there are 6 TEC data in Longitude and 4 TEC data in Latitude of each grid. A substantial amount of computing time is needed when performing 2DPCA to 24 TEC data in a grid. However, the effects of 2DPCA are almost the same as the effects using 4 TEC data. That allows that performing 2DPCA is not distorted taking 4 TEC data (low dimensional data) instead of 24 TEC data (high dimensional data) in each grid. Therefore the 4 TEC data were used in each grid. When performing a quantitative analysis, the four TEC data were in a grid form; a matrix A as an input for Eq. (1) with the dimensions of 2×2 as a small sample signal size (SSS) in each grid of Figure 1(a).

Eq. (2) through (4) was performed and the principal eigenvalue G was estimated. The largest principal eigenvalue in a grid incl. the epicentre of this earthquake was assigned to the principal spatial characteristics of the TEC data in a grid which is the TEC precursor. This allows the principal eigenvalues to be computed for each of the 600 grids in the world. Therefore, Figure 1(b) can be explained as a result in a principal eigenvalue in a grid which was represented by the TEC principal spatial characteristics of this grid. However, each grid was filled with a uniform colour for ease of presentation.



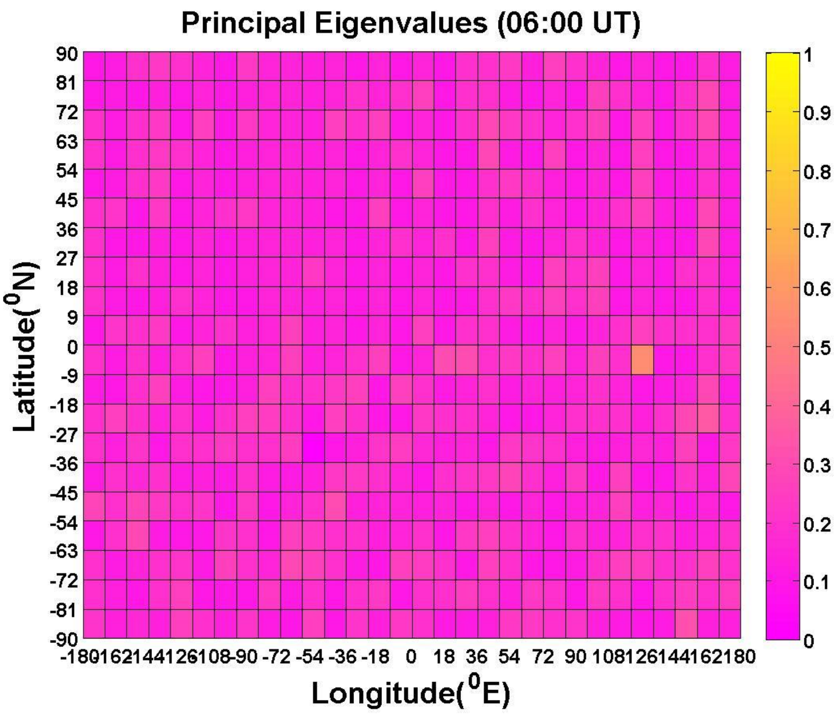


Figure 1(b). The figure set gives a color-coded scale of the magnitudes of principal eigenvalues corresponding to Figure 1(a) with 2DPCA. The color within a grid denotes the magnitude of a principal eigenvalue corresponding to Figure 1(a), so that there are 600 principal eigenvalues assigned.

DISCUSSION

2DPCA was able to detect a TEC anomaly over the epicenter before the Nebe earthquake at 13:45:05 (UT) on 27 February 2015 (M_w=7.0) with the depth of 547km and the epicentre being 7.277°S, 122.534°E. A TEC precursor was detected during the time period from 05:55 to 06:00 (UT) on 26 February 2015. The duration time was at least 5 minutes. The 2DPCA accurately describes the earthquake related TEC precursor, and it is worth considering caused reasons. Accordingly, past researches of TEC disturbance suggested three possible explanations for earthquake associated precursors. One is acoustic shock waves (Jin et al. 2010). Since the earthquake was very deep it is not likely those acoustic shock waves from fine topside vibrations would be responsible for the TEC anomaly although it may remain a possibility. But it usually occurred after the earthquake (Lin, 2011; Liu, 2011). The area of study has been into post earthquake TEC disturbance with the additional obvious possibility of acoustic shock waves creating ionospheric disturbance due to ground surface vibrations and the natural amplifier effect of decreased density with height in the atmosphere. This is impossible that in the case of such a deep earthquake much of its shaking would have attenuated by the time its waves reached the surface before this earthquake. The other possibility is the presence of an electric field creating large scale ionospheric density irregularities either from radon gas release and P-type semiconductor effects due to stress variance in rocks near the focus of the earthquake (Liu et al. 2004; Pulinets and Legen'ka, 2003; Pulinets 2004; Freund 2003). As mentioned in the introduction, much pre-earthquake research has pointed to shallow earthquakes being associated with recognized TEC anomalies (Le 2011), although Pulinets (2004) thought that large deep earthquakes could provide the necessary preparation zone to create the 200 km diameter lower atmosphere electric field necessary for ionospheric disturbance. In terms of a possible electric field being generated in the lower atmosphere radon release rather than p-type semiconductor effects would seem to be more likely (Pulinets 2004). P-type semiconductor effects would not be able to travel through the heterogeneous rocks that exist between the surface and 300 km down, while P and S type waves would have attenuated so greatly as to not create adequate rock compression at the surface to generate the p-type semiconductor effect. Radon gas release on the other hand could occur through micro-cracks formed in the crust and the earth's surface. Radon gas can lead to lower atmospheric electric fields and these can travel unimpeded into the ionosphere along geomagnetic lines (Pulintes 2004). Radon can affect the ionosphere in this work due to the earthquake. The reason may be; radon, which is concentrated in both water and soil gasses deep in the earth, can be released with high initial speed because of high pressure environments in the time period of this deep earthquake preparation zone formed process. Therefore the ionosphere at height >150km is affected although radon has large atomic weight. This seems like the most reasonable explanation for the observed TEC precursor. Figure 2 shows the Kp indices from 00:00 (UT) on 25 to 15:00 (UT) on 27 in February 2015. February 26 was geomagnetic quiet days with $K_p < 4$.

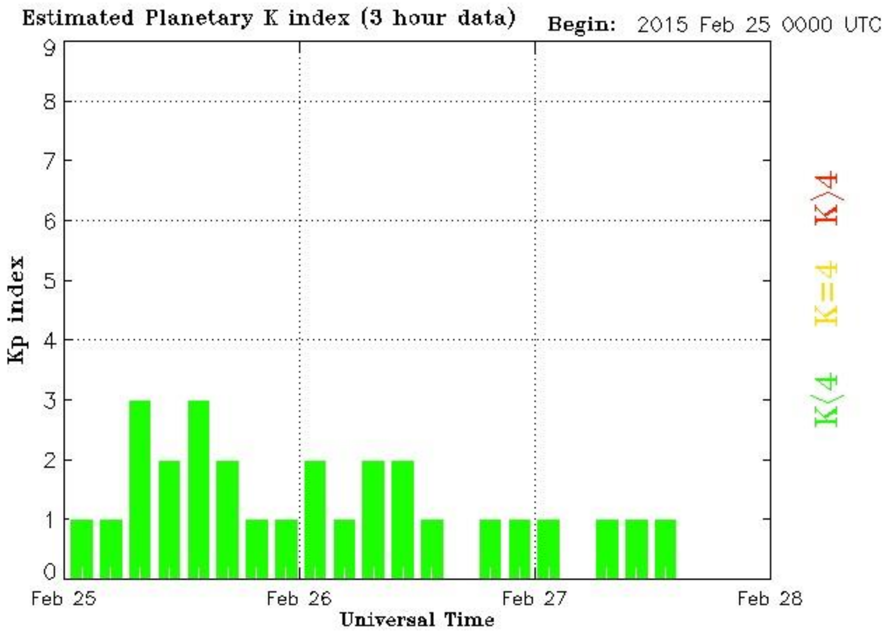


Figure 2. This figure shows the Kp indices from 00:00 (UT) on 25 to 15:00 (UT) on 27 in February 2015 (Space Weather Prediction Center).

CONCLUSION

2DPCA was used to detect a highly localized TEC precursor that occurred before Indonesia Nebe earthquake occurred on 27 February 2015 (M_w=7.0). A TEC precursor was detected over the epicenter during the time period from 05:55 to 06:00 (UT) on 26 February 2015. The duration time was at least 5 minutes. The TEC precursor's distribution could be indicative of radon gas release.

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