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Ionospheric Anomalies related to the (Mw=7.3), 16 April 2016 Kyushu Earthquake using Two-Dimensional Principal Component Analysis

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Abstract

Two-dimensional principal component analysis (2DPCA) were used to examine the ionospheric total electron content (TEC) data during the time period from 00:00 on 11 April to 00: 25 on 16 April (UT) 2016, which were 5 days before the Mw=7.3 Kyushu earthquake at 00:25:06 on 16 April 2016 (UT) with the epicenter (32.782°N, 130.726°E) and the depth of 10km. From the analysis result of 2DPCA, a TEC precursor was found localized nearby the epicenter during the time period from 06:20 to 06:25 on 11 April 2016 (UT) with the duration time of at least 5 minutes. The past studied by other researchers discusses potential reasons for TEC anomaly due to large earthquake mainly including radon gas release, P-type semiconductor effect (electric fields) and shock-acoustic waves for the TEC anomaly However, the possible reasons of the TEC anomaly related to this earthquake should be radon gas release and P-type semiconductor effects before the earthquake. Shock-acoustic wave was impossible reason because before this earthquake, large ground surface vibrations that formed shock-acoustic waves were not detected.

1. INTRODUCTION

The potential for ionospheric total electron content (TEC) anomalies being associated with large earthquakes has been widely researched ([1,2 4, 13]. The cause of TEC anomalies before large earthquakes is not known though there are many potential causes makes an extensive list of possible causes ([1, 2, 4, 13], including radon gas release causing lower atmospheric electric fields which travel up into the ionosphere along geomagnetic lines while suggests P-type semiconductor effect as the cause of lower atmosphere electric fields before earthquake [4]. The shock-acoustic waves could possible factors and however they caused the TEC anomaly after earthquake [2]. Principal component analysis (PCA) is a statistical procedure [3, 10] that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. The number of principal components is less than or equal to the number of original variables. This transformation is defined in such a way that the first principal component has the largest possible variance (that is, accounts for as much of the variability in the data as possible), and each succeeding component in turn has the highest variance possible under the constraint that it is orthogonal to the preceding components. The resulting vectors are an uncorrelated orthogonal basis set. PCA is sensitive to the relative scaling of the original variables. Principal component analysis (PCA), which is a type of remote sensing tool [3], has been used to detect the ionospheric total electron content (TEC)

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precursors regardless of non-earthquake TEC disturbances from [8] about PCA. From his work, PCA assigns large principal eigenvalue to the earthquake related TEC anomaly (TEC precursor). When a matrix with the high dimension is transformed into the PCA domain and this matrix will be simultaneously reduced to the low dimension with minimum loss of data information in the transformed process. Therefore computing time is saved and principal eigenvalue can represent main characteristics of data [8]. In this paper, two-dimensional principal component analysis (2DPCA) is performed to detect TEC anomaly related to three large earthquakes. The researched earthquake is Kyushu earthquake at 00:25:06 on 16 April 2016 (UT) with the epicenter (32.782°N, 130.726°E) at the depth of 10km. The examined ionospheric total electron content (TEC) data are during the time period from 00:00 on 11 April to 00: 25 on 16 April (UT) 2016, which are 5 days before the Mw=7.3 Kyushu earthquake. The TEC precursors were usually found in 5 day before the large earthquakes [9] and therefore this examined period is selected. TEC is derived from dual frequency code and carrier phase measurements provided by Global Navigation Satellite Systems (GNSS). SWACI uses GPS measurements from various European GNSS networks such as the International GNSS Service (IGS), European Reference Frame (EUREF), Norwegian Mapping Authority (NMA), and ascos distributed by the Federal Agency of Cartography and Geodesy (BKG) Frankfurt. The global TEC maps were mainly created by using data provided by the International GNSS Service Real-Time Pilot Project (IGS-RTPP).

2. Method

2. 1 2DPCA

The meaning of TEC is defined as the integral of the electron density along the ray path between satellite and receiver. Thus, TEC provides the number of electrons per square meter. The most frequently used unit [6] is 1TEC = $1x10^{16} electrons / m2$

For 2DPCA, let TEC data be represented by a matrix B with the dimension of m x n. Linear projection of the matrix B is considered as followed ([3, 7, 15],

$$y = Bx$$
(1)

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

$$W_x = E(y - Ey)(y - Ey)^T$$
(2)

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

The trace of W_x is defined;

$$J(x) = tr(W_x)$$
(3)

$$tr(W_x) = tr\{x^T S x\},$$

where $S = E[(B - EB)^T (B - EB)]$ (4)

The matrix W_x is called covariance matrix. The alternation criterion is expressed by $J(x) = tr(x^T W x)$, where the data inner-scatter matrix Wx is computed in a straightforward manner by

$$w_x = \frac{1}{m}\sum_{k=1}^{m}(B_k - \overline{B})^T(B_k - \overline{B}),$$

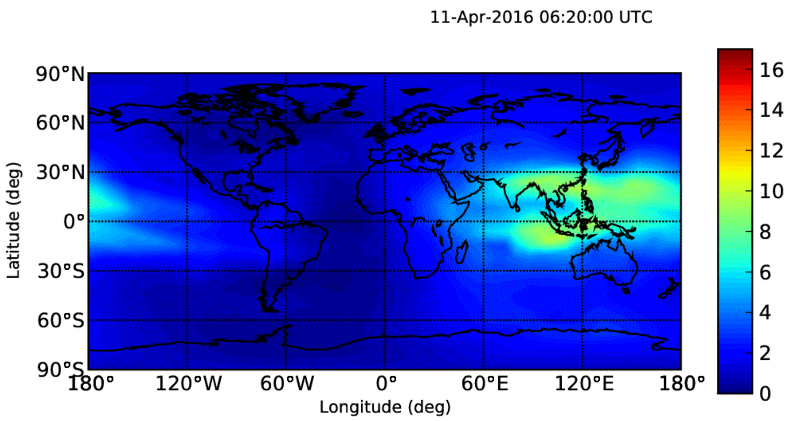
where

$$\overline{B} = \frac{1}{m}\sum_{1}^{m} B_k \qquad (5)$$

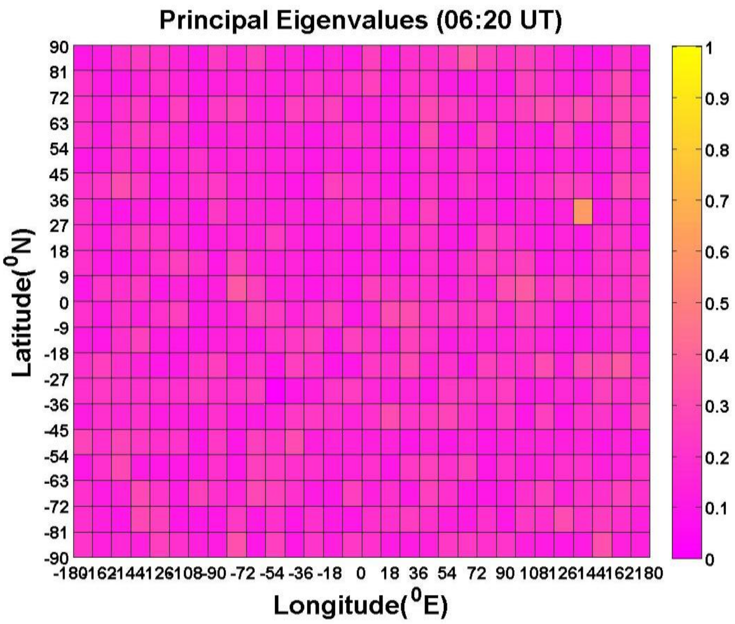
The vector x maximizing Eq.4 corresponds to largest (principal) eigenvalue of W_x which represented the main characteristics of data. 2DPCA is another version of PCA. Therefore large principal eigenvalue of 2DPCA also indicates earthquake-related TEC anomaly. If the PCA is used to transform a matrix with low dimension into the PCA domain and then the dimension of this matrix in the PCA domain will be too small after reducing and become small sample size (SSS) data. Therefore the SSS problem will be caused by using PCA. The SSS problem causes larger data reconstruction error when data in the PCA domain are transformed back to their original domain and corresponding principal eigenvalue is not very precise to represent main characteristics of data. The SSS problem can be removed when performing 2DPCA due to different algorithm from the PCA.

2.2 TEC Data Processing using 2DPCA

The previous examined TEC data are processed 2DPCA and no earthquake-related anomaly is found. Only during the time period from 06:20 to 06:25 on 11 April 2016 (UT) related to the Kyushu earthquake. Therefore the procedure of TEC data processing during this time periods is represented in this study. Figure 1(a) shows the Global ionospheric TEC maps (GIM) at that time of 06:20 on 11 April 2016 (UT). The TEC data in Figure 1(a) are divided into 600 smaller grids 12° in longitude and 9° in latitude, respectively. The resolution of the TEC data for this GPS system is 5 and 2.5 degrees in latitude and longitude, respectively [6], and therefore the 4 TEC data in each grid are selected to compute. These 4 TEC data form the matrix with the dimensions 2 x 2 in Eq.1 in order to perform 2DPA. Figure 1(b) gives the corresponding magnitudes of principal eigenvalues of 2DPCA. A TEC anomaly with a large principal eigenvalue is given nearby the epicenter of the Kyushu earthquake during. It is a TEC precursor for this earthquake. The corresponding magnitudes of principal eigenvalues of Figure 2(a) at that time 06:25 on 11 April 2016 (UT) using the previous processing is shown in Figure 2(b). Figure 3 shows the AE indices and DST indices from 01 to 30 April 2016 (UT). From these indices in this figure, 23, April was Geomagnetism quiet day. It could proof the previous TEC anomaly really related to this Kyushu earthquake.

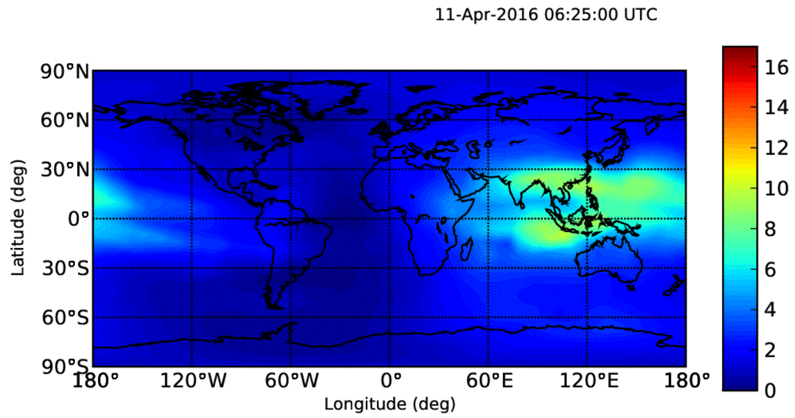


(a)

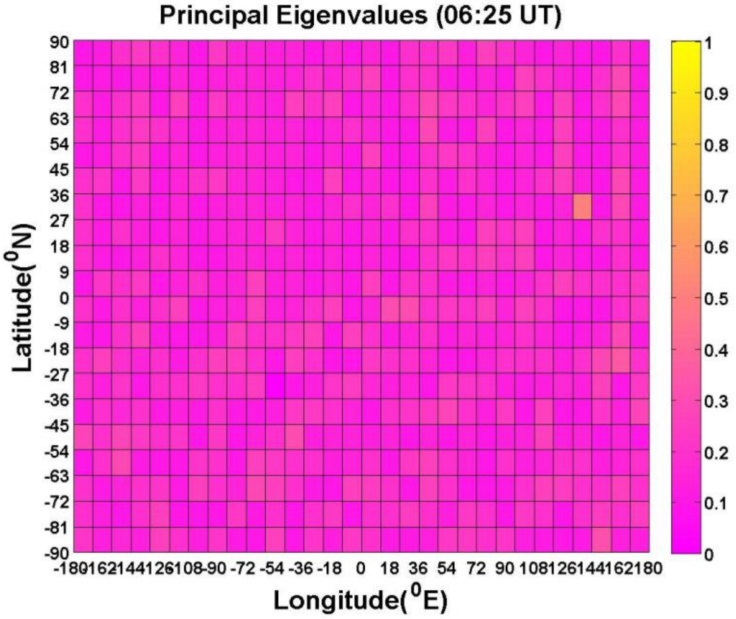


(b)

Figure 1. *a) The figure shows the GIM at that time of 06: 20 on 11 April 2016 (UT). b) The figure give a color-coded scale of the magnitudes of principal eigenvalues of 2DPCA corresponding to Figure 1a. The color within a grid denotes the magnitude of a principal eigenvalue corresponding to Figure 1a, so that there are 600 principal eigenvalues assigned for 600 grids in each small map, respectively.*



(a)



(b)

Figure 2. *a) The figure shows the GIM at that time of 06: 25 on 11 April 2016 (UT). b) The figure gives a color-coded scale of the magnitudes of principal eigenvalues of 2DPCA corresponding to Figure 2a. The color within a grid denotes the magnitude of a principal eigenvalue corresponding to Figure 2a, so that there are 600 principal eigenvalues assigned for 600 grids in each small map, respectively.*

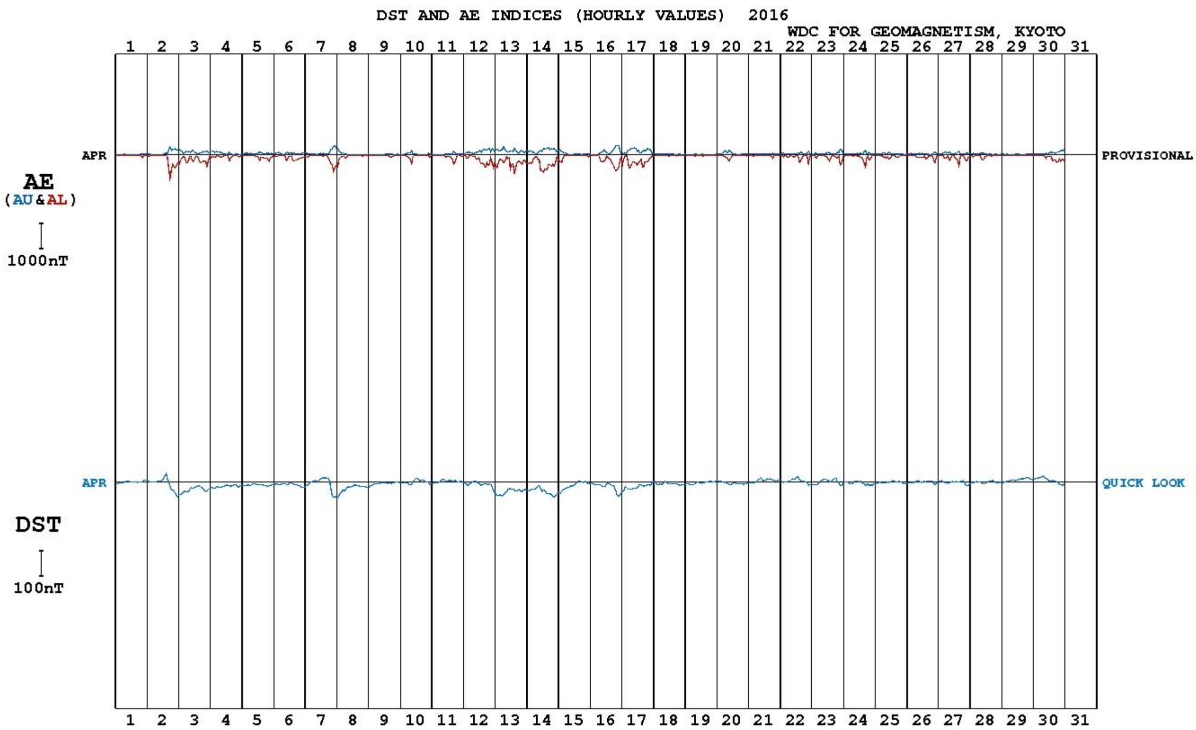


Figure 3. *The figures show the AE indices and DST indices in April 2016 (UT) (World Data Center for Geomagnetism, Kyoto).*

3. Discussion

The earthquake TEC disturbance with the obvious possibility of acoustic shock waves creating ionospheric disturbance due to large ground surface vibrations and the natural amplifier effect of decreased density with height in the atmosphere. However, before the earthquake, large ground surface vibrations should be impossible to occur. Therefore, the possible reasons should be radon gas release and P-type semiconductor effects. 2DPCA is able to detect a TEC precursor nearby the epicenter of Kyushu earthquake during the time period from 06:20 to 06: 25 on 11 April 2016 (UT) with the duration time of at least 5 minutes. 2DPCA has the ability to detect the clear TEC anomalies related to the large earthquakes in this study. 2DPCA has shown its credibility to estimate the duration time of the earthquake-associated TEC anomaly. An argument always exists; principal eigenvalue could not indicate true ionospheric variations or situation. However, if a mathematical index can indicate an ionospheric precursor and then the aim of earthquake precursor research is already to be satisfied. More detailed corresponding precursor research can be examined from the reports of VAN group (Varotsos, Caesar Alexopoulos and Kostas Nomikos) and some studies [4, 5 ,11-14, 16]

4. Conclusion

A TEC precursor has been detectable for the Kyushu earthquake during the time period from 06:20 to 06 25 on 11 April 2016 (UT) and its duration time was at least 5 minutes. In other examined time period 5 days before Kyushu earthquake, the TEC anomaly related to this earthquake, there was no TEC anomaly to be detectable. According to the previous discussed possible factors to cause TEC anomaly because of larger earthquake in the section introduction, Radon gas release and P-type semiconductor effects before the earthquake should be the possible reasons.

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CONFLICTS OF INTEREST

No conflict of interest was declared by the author.

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