J.Phy.Ast.
Print-ISSN: 2320-6756
Online-ISSN: 2320-6764

Journal of
Physics &
Astronomy

WWW.MEHTAPRESS.COM

Full Paper

Lin Jyh-Woei

Dept. of Earth Science, National Cheng Kung University, No.1 University Road, Tainan City, (TAIWAN)
E-mail : pgjwl1966@gmail.com

Received: January 15, 2013
Accepted: March 1, 2013

***Corrresponding aurhor's Name & Addess**

Lin Jyh-Woei
Dept. of Earth Science, National Cheng Kung University, No.1 University Road, Tainan City, (TAIWAN)
E-mail : pgjwl1966@gmail.com

Ionospheric precursor detection for the M=7.6, 05 September 2012, Costa Rica earthquake under large geomagnetic storm activity: Two-dimensional principal component analysis

Abstract

Two-dimensional principal component analysis (2DPCA) is performed to detect ionospheric total electron content (TEC) anomaly related to earthquake undergoing geomagnetic storm activity. The time period of examined TEC data are 5 day before the M=7.6 Costa Rica earthquake at 14: 42:07 on 05 September 2012 (UT). A TEC precursor of this earthquake with large principal eigenvalues (>0.5) (Lin 2010) is found nearby the epicenter during the time period from 20:05 to 20:10 on 03 September 2012 (UT) with the duration time of at least 5 minutes by using 2DPA while TEC anomaly related to other smaller earthquakes is not detectable. TEC anomaly caused by the geomagnetic storm activity during the examined time period results in the small principal eigenvalues, therefore the detection of TEC precursor is regardless of the geomagnetic storm activity.

Key Words

Two-dimensional principal component analysis (2DPCA); Ionospheric total electron content (TEC); Geomagnetic storm activity; Costa Rica earthquake.

INTRODUCTION

Recently, the natural precursor (e.g. VHF transmitter signals) before the earthquakes was widely studied[2,3,8,14,24,29]. Some works researched the ionosphere total electron content (TEC) anomalies related to the large earthquakes. Liu et al's work[15] 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.[13] 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[23] 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[16] 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 in this study, two-dimensional principal component analysis (2DPCA) is performed to detect TEC anomaly related to earthquake undergoing geomagnetic storm activity. The time period of examined TEC data are from 14:40 on 31 August 2012 (UT) to 14: 40 on 05 September 2012 (UT), which are 5 day before the M=7.6 Costa Rica earthquake at 14: 42:07 on 05 September 2012 (UT) with the epicenter of (9.996°N, 85.318°W) and the depth at 40.2km (U.S. Geological Survey). Such 5-day time period TEC data are used because the TEC precursors usually revealed in 5 day before the large earthquakes[12]. The TEC Data and the global ionospheric TEC map (GIM) used in this study are acquired from the NASA Global Differential GPS system (GDGPS).

METHOD

Theory of 2DPCA

2DPCA performing is essentially PCA on the rows of the data if each row is viewed as a computational unit. For 2DPCA, let data be represented by a matrix C with the dimension of n x m. Linear projection of the form is considered as followed[10,26],

$$\mathbf{y = Cx} \quad (1)$$

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 the mean.

$$\mathbf{W_x = E(y - Ey)(y - Ey)^T} \quad (2)$$

Here W is the covariance matrix of the project feature vector.
The trace of W is defined;

$$\mathbf{J(x) = tr(W_x)} \quad (3)$$

$$\mathbf{tr(W_x) = tr\{x^T S x\}}, \text{ where } \mathbf{S = E[(C - EC)^T (C - EC)]} \quad (4)$$

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

$$\mathbf{w = \frac{1}{m}\sum_{k=1}^{m}(C_k - \overline{C})^T(C_k - \overline{C})},$$

$$\text{Where } \mathbf{\overline{C} = \frac{1}{m}\sum_{1}^{m} C_k} \quad (5)$$

The vector x maximizing Eq.4 corresponds to largest (principal) eigenvalue of W which represented the main characteristics of data. PCA assigns large principal eigenvalues i.e., principal eigenvalues > 0.5 in a normalized set to the earthquake related TEC anomalies[11]. 2DPCA is another version of PCA. Therefore large principal eigenvalue of 2DPCA (> 0.5 in a normalized set) also indicates TEC anomaly related to earthquake. Small sample size data (SSS data) problem (called SSS problem) is caused by using PCA[5]. Such SSS problem causes larger data reconstruction error when data in PCA domain is transformed back to its original domain and therefore principal eigenvalue is not very precise to represent main characteristics of data. SSS problem is expected to be removed by using 2DPCA. More detailed information about 2DPCA is given by the studies of Fukunnaga[5] and Kong et al.[10].

TEC data processing

The previous examined TEC data are processed by using 2DPCA and PCA (according to the formula of Lin's work[11]) and TEC anomaly related to earthquake is not detectable. Only for the TEC data during the time period from 20:00 to 20:15 UT on 03 September 2012, the TEC anomaly related to the Costa Rica earthquake can be found by using 2DPCA. Therefore the procedure of the TEC data processing for this time period is represented in this study. Figure 1(a) shows the GIMs during the time period from 20:00 to 20:15 UT on 03 September 2012. The TEC data of each GIM 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 the GDGPS system is 5 and 2.5 degrees in latitude and longitude, respectively (Hernández-Pajares et al. 2009), therefore the 8 TEC data are included in each grid. The 8 TEC data form the matrix C of dimensions 2 x 4 of Eq. (1). The matrix C belongs to the SSS data because of the low dimension, and SSS problem will be caused when PCA is performed. This should be the reason why TEC anomaly related to earthquake can not be found by using PCA. Figure 1(b) shows the magnitudes of 600 principal eigenvalues corresponding to Figure 1 (a). Representative of large principal eigenvalues in this shows the existence of a TEC anomaly with a large principal eigenvalue (>0.5) given nearby the epicenter during the time period 20:05 to 20:10 UT on 03 September 2012. It is a TEC precursor for the Costa Rica earthquake.

BACKGROUND ON TEC AND EARTHQUAKES

This section introduces some possible causes of TEC anomalies and their association with earthquakes. Pulinets and Boyarchuk[22] suggest radon emanating from active faults and cracks before earthquakes ionizing the near ground atmosphere to produce large vertical electric fields. Molchanov and Hayakawa[17] suggest gravity waves arising from fine vibrations in the earth's surface leading to gas release that results in lower atmospheric turbulence and eventual ionospheric perturbations. Such fine vibrations could also be responsible for gravity waves causing such anomalies and substantial post-earthquake research has been conducted in this area[6].

The VAN group[31,32] in Greece has been looking at the possibility of such TEC anomalies being caused by stressed rocks producing electric fields. This area of research looks at pressure stimulated currents creating electric fields in non-homogenous crustal rocks producing seismic electric signals which they attempt to recognize as earthquake precursors. Another area of study is that of p-holes. These charge carriers are defect electrons in the O^{2-} sub-lattice that are chemically equivalent to O^- in a matrix of O^{2-} [4,14]. They occur in stressed igneous and metamorphic rock. Pulinets and Boyarchuk[22] suggested such lower atmosphere electric fields could travel into the

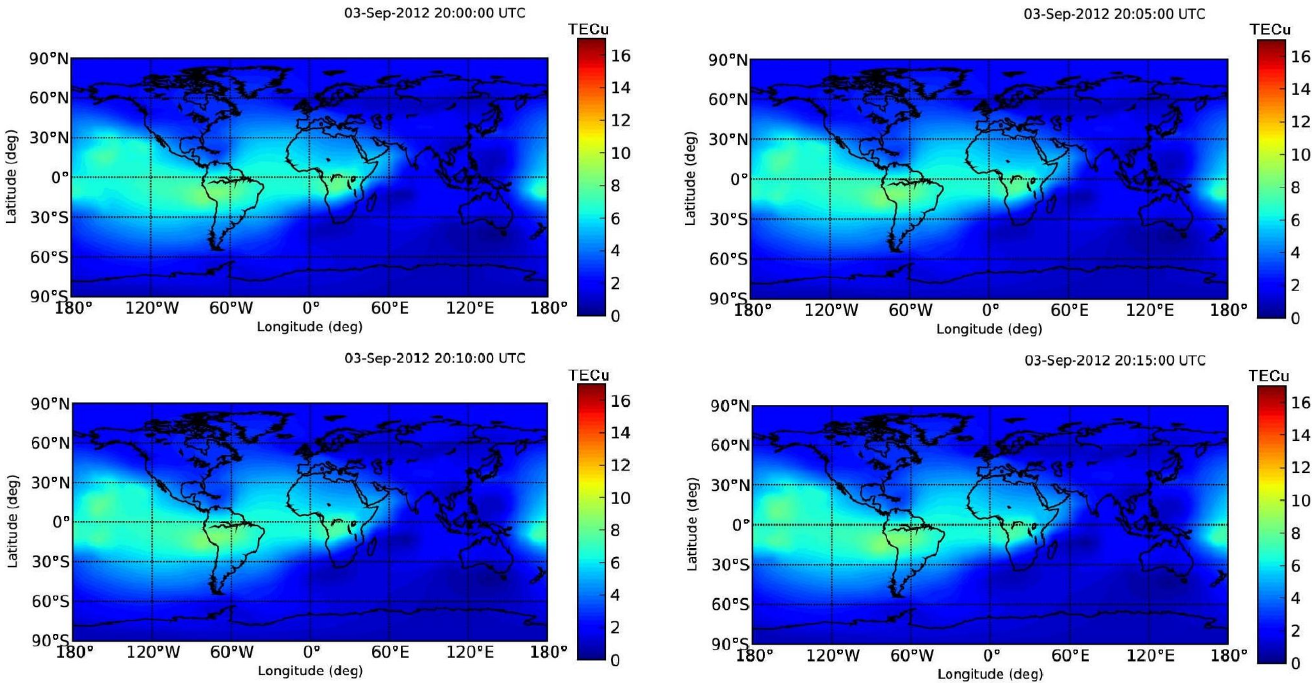

Figure 1(a) : This figure shows the GIMs during the time period from 20:00 to 20:15 UT on 03 September 2012.

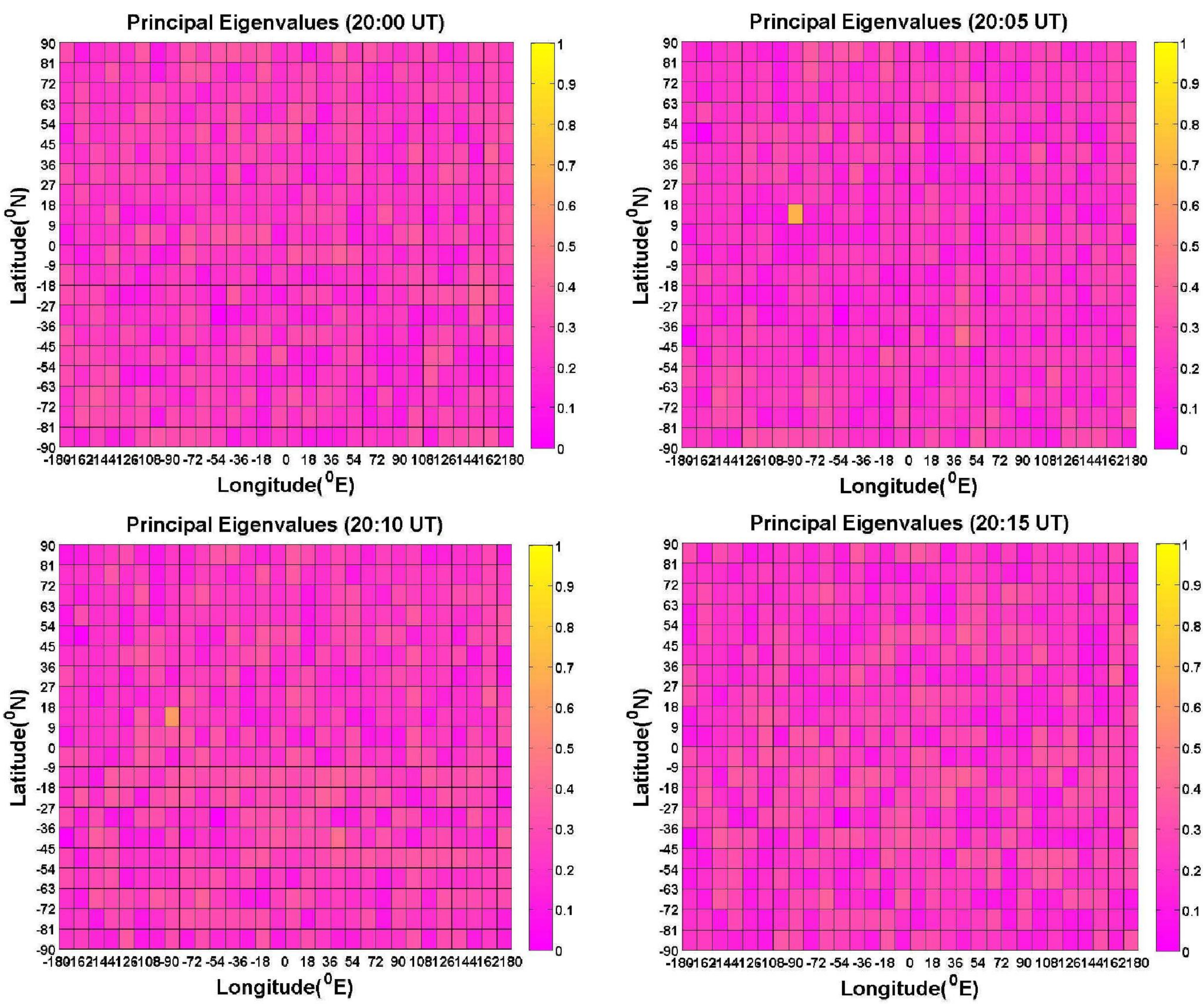

Figure 1(b) : The figures give a color-coded scale of the magnitudes of principal eigenvalues of 2DPCA corresponding to Figure 1(a). The color within a grid denotes the magnitude of a principal eigenvalue corresponding to Figure 1(a).

ionosphere unimpeded along geomagnetic lines causing TEC anomalies.

DISCUSSION

2DPCA is able to detect a TEC precursor of the Costa Rica earthquake during the time period from 20:05 to 20:10 UT on 03 September 2012 with the duration time of at least 5 minutes. TEC anomaly related to other smaller earthquakes during the examined time period is not detectable. The large geomagnetic storm activity occurred during the examined time period according to the Dst indices in Figure 2. TEC anomaly caused by such storm activity results in the small magnitudes of principal eigenvalues. Therefore, the factor of the geomagnetic storm activity can be eliminated when detecting the previous TEC precursor of the Costa Rica earthquake by using 2DPCA.

Gravity waves causing such TEC precursor should not be possible because vibration in the earth's surface before this earthquake should be very small when such vibration is assumed as precursor. However, true mechanism to cause TEC anomaly by the earthquake is not easy to be determined although some reasons are introduced in Section 3.

CONCLUSION

A TEC precursor has been detectable for the Costa Rica earthquake occurred at 14: 42:07 on 05 September 2012 (UT) during the time period from 20:05 to 20: 10 UT on 03 September 2012 and the duration time was at least 5 minutes. The detection of TEC precursor was regardless of the geomagnetic storm activity.

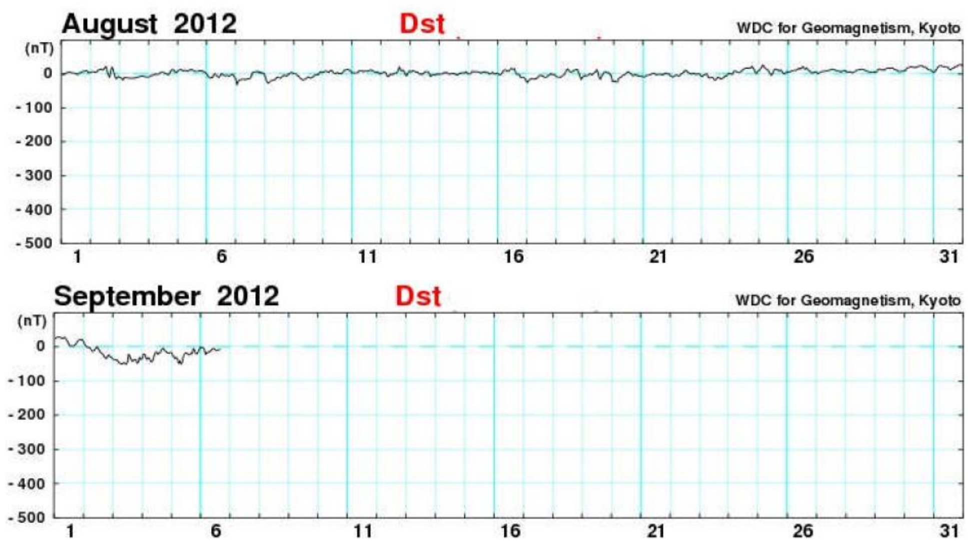

Figure 2 : This figure shows the Dst indices from 01 August to 06 September 2012 (UT) (WDC for Geomagnetism, Kyoto).

ACKNOWLEDGEMENTS

The author is grateful to: NASA Global Differential GPS system (GDGPS) and WDC for Geomagnetism, Kyoto for his useful references Data.

REFERENCES

[1] M.Akhoondzadeh, M.R.Saradjian; TEC variations analysis concerning Haiti (January 12, 2010) and Samoa (September 29, 2009) earthquakes, Adv.Space Res., **47**, 94–104 **(2011)**.

[2] E.Astafyeva, K.Heki; Vertical TEC over seismically active region during low solar activity, Journal of Atmospheric and Solar-Terrestrial Physics, **73(13)**, 1643-1652 **(2011)**.

[3] T.Dautermann, E.Calais, J.Haase, J.Garrison; Investigation of ionospheric electron content variations before earthquakes in southern California, 2003–2004, J.Geophys.Res., **112**, B02106 **(2007)**.

[4] F.T.Freund; Rocks that crackle and sparkle and glow strange pre-earthquake phenomena, Journal of Scientific Exploration, **17(1)**, 37-71 **(2003)**.

[5] K.Fukunnaga; Introduction to statistical pattern recognition, Academic Press, 38-40 **(1991)**.

[6] R.Garcia, F.Crespon, V.Ducic, P.Lognonné, Three-dimensional ionospheric tomography of post-seismic perturbations produced by the Denali earthquake from GPS data, Geophysical Journal International, **163**, 1049-1064 **(2005)**.

[7] M.Hernández-Pajares, J.M.Juan, J.Sanz, R.Orus, A.Garcia-Rigo, J.Feltens, A.Komjathy, S.C.Schaer, A.Krankowski; The IGS VTEC maps: A reliable source of ionospheric information since 1998. J.Geod., **83**, 263–275 **(2009)**.

[8] M.Kamogawa; Preseismic lithosphere-atmosphere-ionosphere coupling, Eos.Trans.AGU, **87(40)**, 417 **(2006)**.

[9] M.O.Kechine, C.C.J.M.Tiberius, H.Van Der Marel; Real-time kinematic positioning with NASA's global differential GPS system, GNSS conference, St.Petersburg, Russia **(2004)**.

[10] H.Kong, L.Wang, E.K.Teoh, X.Li., J.G.Wang, R.Venkate swarlu; Generalized 2D principal component analysis for face image representation and recognition, Neural Networks, **18**, 585–594 **(2005)**.

[11] J.W.Lin; Ionospheric total electron content (TEC) anomalies associated with earthquakes through Karhunen-Loéve Transform (KLT), Terrestrial, Atmospheric and Oceanic Sciences, **21**, 253-265 **(2010)**.

[12] J.Y.Liu, Y.I.Chen, Y.J.Chuo, C.S.Chen; A statistical investigation of pre-earthquake ionospheric anomaly, J.Geophys.Res.Space Phys., **111**, A05304 **(2006)**.

[13] J.Y.Liu, Y.I.Chen, C.H.Chen, C.Y.Liu, C.Y.Chen, M.Nishihashi, J.Z.Li, Y.Q.Xia, K.I.Oyama, K.Hattori, C.H.Lin; Seismoionospheric GPS total electron content anomalies observed before the 12 May 2008 Mw=7.9 Wenchuan earthquake, Journal of Geophysical Research, **114**, A013698 **(2009)**.

[14] J.Y.Liu, Y.I.Chen, S.A.Pulinets, Y.B.Tsai, Y.J.Chuo; Seismo-ionospheric signatures prior to M e"6.0 Taiwan earthquakes, Geophys.Res.Lett., **27**, 3113–3116 **(2000)**.

[15] J.Y.Liu, Y.J.Chuo, S.J.Shan, Y.B.Tsai, Y.I.Chen, S.A.Pulinets, S.B.Yu; Pre-earthquake ionospheric anomalies registered by continuous GPS TEC measurements, Ann.Geophys., **22**, 1585–1593 **(2004)**.

[16] J.Y.Liu, H.Le, Y.I.Chen; Observations and simulations of seismoionospheric GPS total electron content anomalies before the 12 January 2010 M7 Haiti earthquake, J.Geophys.Res., **116**, A04302 **(2011)**.

[17] O.A.Molchanov, M.Hayakawa; Subionospheric VLF signal perturbations possibly related to earthquakes, Journal of Geophysical Research, **103**, 17489-17504 **(1998)**.

[18] M.T.A.H.Muella, E.R.De Paula, I.J.Kantor, L.F.C.Rezende, P.F.Smorigo; Occurrence and zonal drifts of small-scale ionospheric irregularities over an equatorial station during solar maximum–Magnetic quiet and disturbed conditions, Advances in Space Research., **43(12)**, 1957-1973 **(2009)**.

[19] G.Ouyang, J.Wang, J.Wang, D.Cole; Analysis on temporal-Spatial variations of Australian TEC, International Association of Geodesy Symposia, **133(4)**, 751-758 **(2008)**.

[20] Plotnikov, I.Ya, E.S.Barkova; Advances in space research nonlinear dependence of Dst and AE indices on the electric field of magnetic clouds, Advances in Space Research, **40(12)**, 1858-1862 **(2007)**.

[21] S.A.Pulinets, K.A.Boyarchuk, V.V.Hegai, V.P.Kim, A.M.Lomonosov; Quasielectrostatic model of atmosphere-thermosphereionosphere coupling, Advances in Space Research, **26(8)**, 1209–1218 **(2000)**.

[22] S.Pulinets, K.Boyarchuk; Ionospheric precursors of earthquakes, Springer-Verlag, Berlin, Heidelberg, 315 **(2004)**.

[23] S.A.Pulinets, K.G.Tsybulyaa; Unique variations of the total electron content in the preparation period of haitian earthquake (M7.0) on January 12, Geomagn, Aeron., **50(5)**, 686–689 **(2010)**.

[24] H.Rishbeth, Ionoquakes: Earthquake precursors in the ionosphere? Eos Trans. AGU, **87(32)**, 316 **(2006)**.

[25] S.Sarkar, S.Choudhary, A.Sonakia, A.Vishwakarma, A.K.Gwal; Ionospheric anomalies associated with the Haiti earthquake of 12 January 2010 observed by DEMETER satellite, Nat.Hazards Earth Syst.Sci., **12**, 671–678 **(2012)**.

[26] P.Sanguansat; Principal component analysis, Published by Intech, Janeza Trdine 9, 51000 Rijeka, Croatia., 300 **(2012)**.

[27] Tim, Fuller-Rowell; USTEC: A new product from the space environment center characterizing the ionospheric total electron content, GPS Solutions, **V9.3**, 236-239 **(2005)**.

[28] S.Uyeda, M.Kamogawa, H.Tanaka; Analysis of electrical activity and seismicity in the natural time domain for the volcanic-seismic swarm activity in 2000 in the Izu island region, Japan, Journal of Geophysical Research, **114**, B02310 **(2009)**.

[29] Y.Yasuda, Y.Ida, T.Goto, M.Hayakawa; Interferometric direction finding of over-horizon VHF transmitter signals and natural VHF radio emissions possibly associated with earthquakes, Radio Sci., **44**, RS2009 **(2009)**.

[30] B.Zhao, T.Yu, M.Wang, W.Wan, J.Lei, L.Liu, B.Ning; Is an unusual large enhancement of ionospheric electron density linked with the 2008 great Wenchuan earthquake? Journal of Geophysical Research, **113**, A11304 **(2008)**.

[31] P.Varotsos, M.Lazaridou; Latest aspects of earthquake prediction in Greece based on seismic electric signals, I.Tectonophysics, **188**, 322 **(1991)**.

[32] P.A.Varotsos, N.V.Sarlis, M.Lazaridou, P.Kapiris; Transmission of stress induced electric signals in dielectric media, Journal of Applied Physics, **83**, 60-70 **(1998)**.