© Mehtapress 2014
J.Phy.Ast.

Print-ISSN: 2320-6756
Online-ISSN: 2320-6764

Journal of
Physics & Astronomy

WWW.MEHTAPRESS.COM

Review

Jyh-Woei Lin

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

Received: November 30, 2013
Accepted: February 28, 2014

***Corresponding author's Name & Address**

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

Ionospheric precursor of 2008 Wenchuan earthquake using two-dimensional principal component analysis: A review

Abstract

Two-Dimensional Principal component analysis (2DPCA) has been used to examine ionospheric total electron content (TEC) during the time period from 07 to 12 May, which was in 5 days before China's Wenchuan earthquake (UT) (M_w=7.9) at 06:28:00 on 12 May 2008 (UT) with the epicenter of |(31.119°N, 103.258°E). A TEC precursor represented with larger principal eigenvalue was detectable during the time period from 02:00 to 04:00 UT on 09 May over the epicenter with the duration time approximately 2 hours.

Key Words

Two-dimensional principal component analysis (2DPCA); Total electron content (TEC); Wenchuan earthquake; Precursor.

INTRODUCTION

The ionospheric anomalies were researched prior to China's May 12, 2008 Wenchuan earthquake by a number of researchers[3,5,6,15,26]. Lin[10] applied principal component analysis (PCA) to ionospheric total electron content (TEC) to investigate TEC-anomaly precursors to 12 earthquakes of Me"5.0 in a local region of 23.00 - 24.00° N, 120.00 - 121.50° E for 1 January 2002 to 31 December 2003. These earthquakes were previously investigated by Liu et al.[16] who showed statistically that earthquake-related TEC anomalies could be detected within 5 days of all these earthquakes. Lin[10] helped establish criteria for using Principal Component Analysis (PCA) in the detection of earthquake related TEC anomalies. For PCA to be considered effective in detecting earthquake-related TEC anomalies the earthquake must be of Me"5.0; other possible causes of TEC anomalies must be eliminated such as geomagnetic activity and detection occur within the earthquake preparation zone. The advantage of PCA over other statistical methods, such as deviations from predetermined median values for TEC, is that PCA is a mathematical method and is independent of non-earthquake effects[10]. Two-Dimensional Principal Component Analysis (2DPCA) is applied to the TEC data during the time period from 07 to 12 May, which is in 5 days before China's Wenchuan earthquake because the TEC precursors were usually detectable in 5 days before the large earthquakes[14]. The TEC data type is the integrated value over the full 2 hour-period in the examined time period. This earthquake occurred on 12 May at 06:28:00 (UT) with the epicenter of |(31.119°N, 103.258°E).

TEC DATA SOURCE

The source of the TEC data is the FORMOSAT-3 satellite system, which generates 2500 GPS-occultation density profiles per 24 hours. The GPS TEC data is from IGS[11].

METHOD

Theory of 2DPCA

2DPCA is a procedure which can detect anomalies for a two-dimensional data from its original domain to 2DPCA domain. Its concept is introduced[12,13]. Using 2DPCA Small Sample Size (SSS) (small two-dimension)

problem can be avoided[12,13].

TEC data processing

The TEC data for the previous time period is examined by 2DPCA; however after the data processing, only a TEC anomaly related to this earthquake is detectable in a time period such as Figure 1a. The procedure of TEC data processing in Figure 1a in this time period is represented in the study. The TEC data in other examined time period are done with the same data analysis by 2DPCA but not shown in this study because earthquake-related TEC anomaly is not detectable. Figure 1a shows the GIM in the previous time period for observing. Actually, the true TEC data is processed by 2DPCA. This global region is divided into 100 smaller areas, 36° in longitude and 18° in latitude to detect more detailed TEC information, and therefore each area at least includes 9 estimated TEC data. For analysis, in each area the 9 TEC data are taken. These 9 TEC data form the input matrix B[12] (it belongs to SSS data) of dimensions 3 x 3 for Eq. (1) using 2DPCA to remove SSS data problem and detect a clear TEC anomaly related to the earthquake. This allows for principal eigenvalues to be computed for each of the 100 smaller areas.

RESULTS

It can be readily seen that the earthquake-associated TEC anomaly exists at the time 02:00-04:00 UT on May 09 (Figure 1b) as indicated by the region representing larger eigenvalues. In the other examined time period, any earthquake-associated TEC anomaly is not detectable. Figure 2 shows the Kp indices for the corresponding time periods (07 to 12 May, 2008) and the Kp indices (< 4) represents a relatively geomagnetic quiet time for this time period.

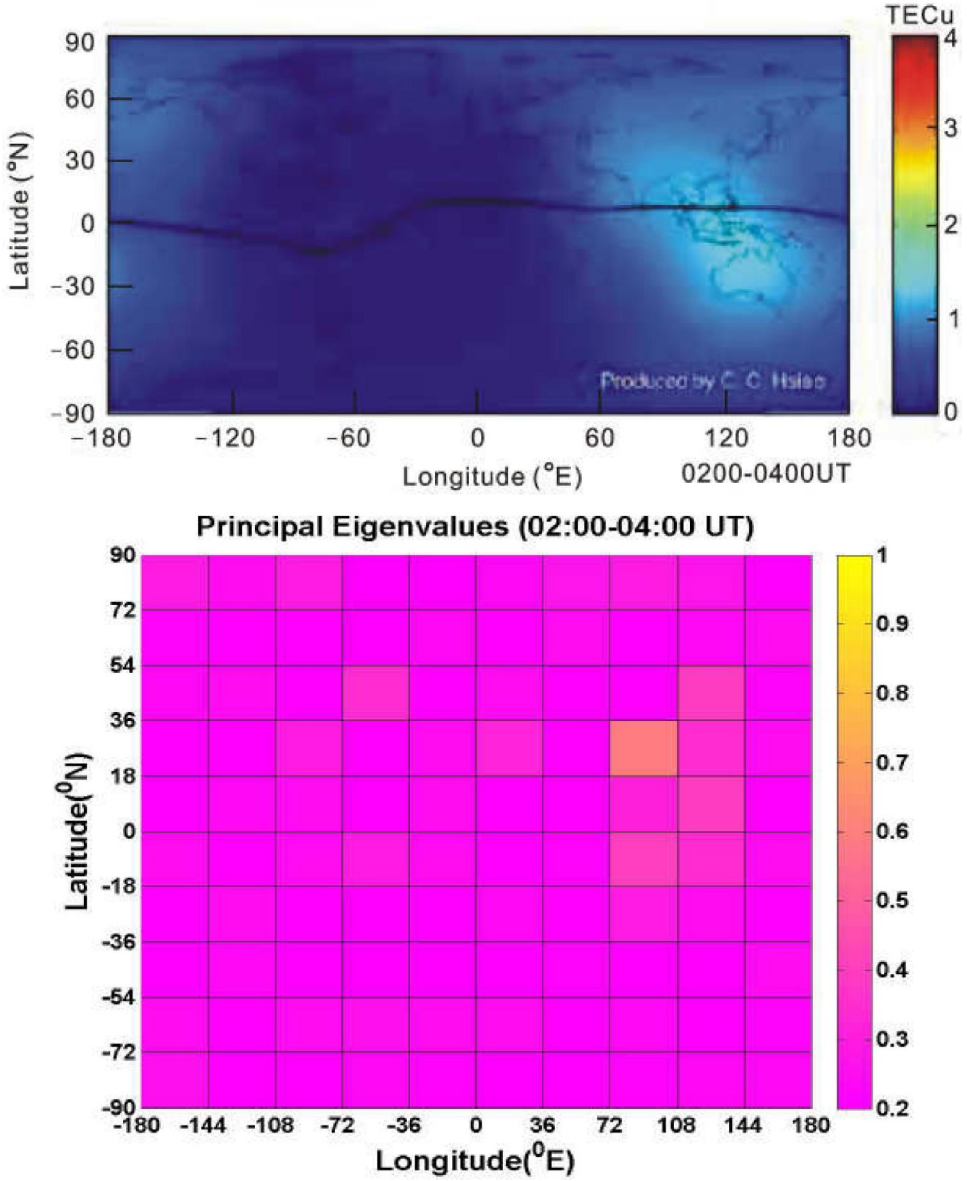

Figure 1 : (a) The GIM on 09 May, 2008 for the time period 02:00-04:00 UT; (b) The figures give a color-coded scale of the magnitudes of principal eigenvalues.

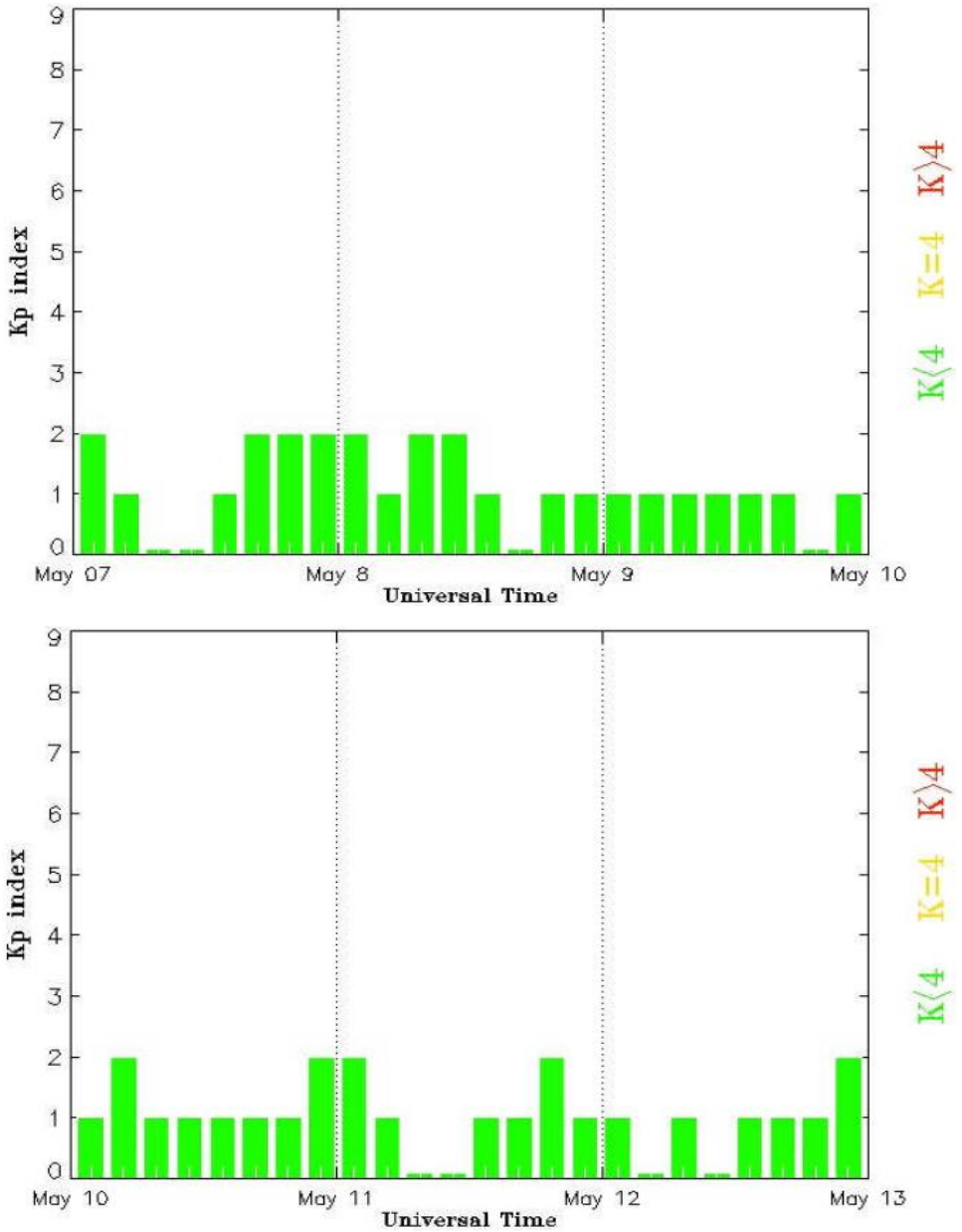

Figure 2 : The Kp indices from 07 to 12 May 2008 (NOAA / NWS Space Weather Prediction Center).

DISCUSSION

The results (TEC anomalies) fit the criteria for detection of earthquake-associated TEC anomalies by 2DPCA discussed in the introduction. The large principal eigenvalue given in Figure 1b are around the epicenter. The earthquake-associated TEC anomaly releases in 02:00-04:00 UT on 09 May before China's Wenchuan earthquake. This is a strong indication that 2DPCA is suitable for detecting earthquake-related TEC anomalies for large earthquakes.

Some possible causes of TEC anomalies and their association with earthquakes are introduced. Pulinets and Boyarchuk[19] suggest radon emanating from active faults and cracks before earthquakes ionizing the near ground atmosphere to produce large vertical electric fields. The VAN group[23] 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. 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. Gravity waves causing such TEC precursor should not be possible because vibration in the earth's surface before this earthquake should be very small and usually causes TEC anomaly just after earthquake. Moreover, the previous caused reasons of TEC precursor usually endure a long time. Therefore, true mechanism to cause TEC anomaly by the earthquake

is not easy to be determined.

CONCLUSIONS

A TEC anomaly as the TEC precursor believed to be earthquake related were found for the time period 02:00-04:00 UT on 09 May before Wenchuan earthquake. The duration time of the TEC precursor was approximately 2 hrs.

ACKNOWLEDGEMENTS

The author is grateful to: FORMOSAT-3/COSMIC Data Users Workshop and NOAA / NWS Space Weather Prediction Center for the useful information.

REFERENCES

[1] H.K.Ekenel, B.Sankur; Multiresolution face recognition. Image and Vision Computing, **23**, 469-477 (2005).
[2] K.Fukunnaga; Introduction to Statistical Pattern Recognition. Academic Press, 38-40 (1991).
[3] H.K.Jhuang, Y.Y.Ho, Y.Kakinami, J.Y.Liu, K.I.Oyama, M.Parrot, K.M.Hattori, M.Nishihashi, D.Zhang; Seismo-ionospheric anomalies of the GPS-TEC appear before the 12 May 2008 magnitude 8.0 Wenchuan earthquake. International Journal of Remote Sensing, **31**, 3579-3587 (2010).
[4] 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).
[5] S.Jin, W.Zhu, E.Afraimovich; Co-seismic ionospheric and deformation signals on the 2008 magnitude 8.0 Wenchuan earthquake from GPS observations. International Journal of Remote Sensing, **31**, 3535-3543 (2010).
[6] Y.Kakinami, J.Y.Liu, L.C.Tsai, K.I.Oyama; Ionospheric electron content anomalies detected by a FORMOSAT-3/COSMIC empirical model before and after the Wenchuan earthquake. International Journal of Remote Sensing, **31**, 3571-3578 (2010).
[7] 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).
[8] H.L.Kong, E.K.Wang, X.Teoh, J.Li, G.Wang, R.Venkateswarlu; Generalized 2D principal component analysis for face image representation and recognition. Neural Networks, **18**, 585-594 (2005).
[9] M.A.Kramer; Nonlinear principal component analysis using autoassociative neural networks. AIChe Journal, **37(2)**, 233-243 (1991).
[10] 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).
[11] J.W.Lin; Nonlinear principal component analysis in the detection of ionospheric electron content anomalies related to a deep earthquake (> 300 km, M 7.0) on 1 January 2012, Izu Islands, Japan, J.Geophys.Res., **117**, A06314 (2012).
[12] J.W.Lin; Ionospheric anomaly related to M = 6.6, 26 August 2012, Tobelo earthquake near Indonesia: Two-dimensional principal component analysis. Acta Geod Geophys, **48**, 247-264 (2013).
[13] J.W.Lin; Ionospheric precursor for a deep earthquake (~378 km) near Papua New Guinea occurred on 7 July 2013, =7.2 in the environment of geomagnetic storm using two-dimensional principal component analysis (2DPCA). NGRK Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards, (2014).
[14] 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).
[15] 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**, (2009).
[16] J.Y.Liu, H.F.Tsai, C.H.Lin, M.Kamogawa, Y.I.Chen, C.H.Lin, B.S.Huang, S.B.Yu, Y.H.Yeh; Coseismic ionospheric disturbances triggered by the Chi-Chi earthquake. Journal of Geophysical Research, **115**, A08303 (2010).
[17] O.A.Molchanov, M.Hayakawa; Subionospheric VLF signal perturbations possibly related to earthquakes. Journal of Geophysical Research, **103**, 17489-17504 (1998).
[18] R.Muellerschoen, B.Iijima, R.Meyer, Y.Bar-Sever, E.Accad; Real-Time Point Positioning Performance Evaluation of Single-Frequency Receivers Using NASA's Global Differential GPS System Jet Propulsion Laboratory, California Institute of Technology, ION GNSS Meeting, Long Beach, CA, September 2004, (2004).
[19] S.Pulinets, K.Boyarchuk; Ionospheric Precursors of Earthquakes. Springer-Verlag, Berlin, Heidelberg, 315 (2004).
[20] H.Ringberg, J.Rexford, A.Soule, C.Diot; Sensitivity of PCA for traffic anomaly detection. SIGMETRICS '07 Proceedings of the 2007 ACM SIGMETRICS international conference on Measurement and modeling of computer systems, (2007).
[21] P.Sanguansat; Principal Component Analysis, Published by InTech, Janeza Trdine 9, 51000 Rijeka, Croatia, 300 (2012).
[22] US-TEC Technical Document; Based on the MAGIC code written by Paul S.J.Spencer, Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado 80309-0216, (2004).
[23] 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).
[24] S.Wu, Y.Bar-Sever; Real-Time Sub-cm Differential Orbit Determination of Two Low-Earth Orbiters with GPS Bias Fixing Jet Propulsion Laboratory, California Institute of Technology. TX, USA, Sept. 2005, (2005).
[25] D.Y.Ying, X.Lu, J.Dang; A Voice Activity Detector for Robust Speech Recognition. Spring Meeting of ASJ, 1-2 (2007).
[26] 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).