IJCTA, 10(5) 2017, pp. 149-155

Analysis of Seismo-Ionospheric Perturbations Using Welch Method on GPS Tec for Earthquakes

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Abstract: Investigation of coseismic perturbations hastens diagnosis of percussive signatures of earthquakes in ionosphere. Perturbations observed in time delays introduced in the signals traversing through ionospheric in terms of total electron content, for the earthquake occurred at Banten, Indonesia were investigated. Non parametric method Welch, is applied on the detrended perturbed and unperturbed vertical total electron content (VTEC). Welch power spectral densities could identify coseismic perturbations in ionosphere.

Keywords: Statistical Signal Processing, Perturbations, Earthquake.

1. INTRODUCTION

Electrostatic and magnetic field anomalies are observed in the signals derived from a French micro satellite named DEMETER before the occurrence of earthquakes[1-3]. These anomalies cause seismogenic perturbations in ionosphere. Many researchers have statistically analyzed these perturbations in ionosphere [4].

Anterior to the occurrence of the earthquake, the epicenter zone is subjected to mechanical transformations and active geochemical processes. Radon a radioactive element, noble, greenhouse gasses along with wide range of tiny metal particles are emanated during and prior the occurrence of the earthquake [3,5]. Radon, the radioactive element expends its energy and ionize the lower atmosphere resulting the development of vertical electric fields coupling the lithosphere, atmosphere and ionosphere [6,7].

Due to change in the velocity of the signals in the atmosphere delays introduced in signals traversing through ionosphere. Electrons present in ionosphere are disturbed due to changes in the solar activity, seismic perturbations, thunderstorms etc. The pseudorange of GPS receiver with single frequency ‘ρ_{L_1}’, is

$$\rho_{L_1} = (40.3 \times S_1)/\nu_{L_1}^2 \tag{1}$$

where ‘S_1’ slant total electron content. GPS receiver with dual frequency, it is

$$\rho_{L_1} - \rho_{L_2} = (40.3 \times S_1) \times [(1/\varphi_{L_1}^2) - (1/\varphi_{L_2}^2)] \tag{2}$$

where ‘φ_{L_1}’, and ‘φ_{L_2}’, represent GPS ‘L_1’ and ‘L_2’, signals. So, STEC is given by

$$S_1 = \left[\frac{(\rho_{L_1} - \rho_{L_2})}{40.3}\right] \times \left[\frac{\varphi_{L_1}^2 \times \varphi_{L_2}^2}{\varphi_{L_1}^2 - \varphi_{L_2}^2}\right] \tag{3}$$

Along the satellite ray path the S_1 values are recorded by the GPS receiver. Thus V_1 is the product of S_1 and $(\cos(\theta))$ given by

$$V_1 = S_1 \times (\cos(\theta)) \tag{4}$$

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where 'θ' is difference between 90° and the satellite zenith angle at a height of 350 km from surface of earth. Usually GPS data of different stations situated in arbitrary geometric structure is considered analysis. This combined data of ground based GPS receiver contains modeling errors and may not have equal sampling periods over the complete data record. Now for the application of advance statistical signal processing techniques on GPS TEC we need to have GPS data with less modeling errors and uniform sampling period for which we are considering single ground based GPS receiver [8-11].

The analysis was carried out on V_1 data of an earthquake using Welch method. The analysis is done for disturbed and undisturbed sets of VTEC data on earthquake day. Non parametric methods use the statistical properties of the given data sets. Welch estimates the power spectral density (PSD) using ensemble averages of the signal.

Event considered for this research work as occurred on 30th January 2014 in Banten Java, Indonesia (6.424°S, 106.393°E) 3:34 hours Greenwich mean time i.e. at 9:04 hours in Indonesia. The quake occurred at a depth of 147 km with M = 4.12 on Richer scale. The epicentral area of earthquake occurrence is shown in Figure 1. http://earthquaketrack.com/quakes/2014-01-30-03-34-40-utc-4-1-147 and is represented in Figure 1. International global navigation satellite systems (IGS) stakes GPS data located around the world. It provides good data base of GPS V_1 data. It is noticed that V_1 data of satellite 18 was perturbed on earthquake day. The V_1 on earthquake day is represented in Figure 2.

2. METHODOLOGY

A large number of signal processing algorithms are applicable to identify disturbances in the given data [12-15]. Welch, a non parametric method is explored [16] in the present work. Welch algorithm is realized and applied for a signal containing known normalized frequencies 0.16 and 0.8. The equation of synthetic signal is given as

$$X_1(n) = 2 \times \cos(2 \times \text{pi} \times \tau_1 \times n) + 2 \times \cos(2 \times \text{pi} \times \tau_2 \times n) + w(n) \tag{5}$$

where $\tau_1 = 0.16$ and $\tau_2 = 0.8$, $w(n)$ is white Gaussian noise having zero mean, $n = 0$ to $M - 1$ and $M = 128$ points. Figure 3 represents the PSD of synthetic signal using Welch algorithm. Figure 3 clearly represents the peaks at 0.16 and 0.8 normalized frequencies. It is understood that Welch algorithm is able to analyze the spectral components and hence it is applied to analyze the VTEC data representing the earthquake signal.

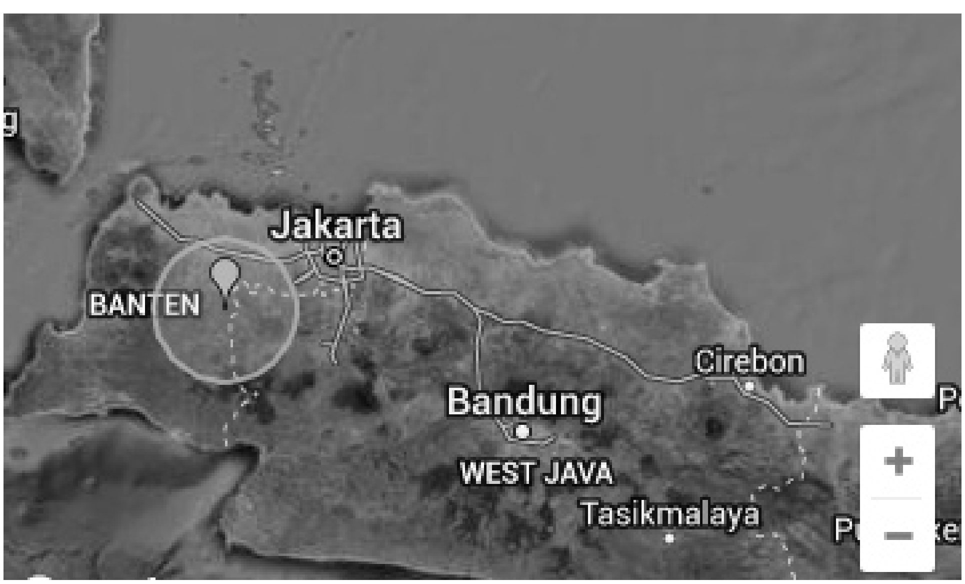

Figure 1: Region of earthquake occurrence

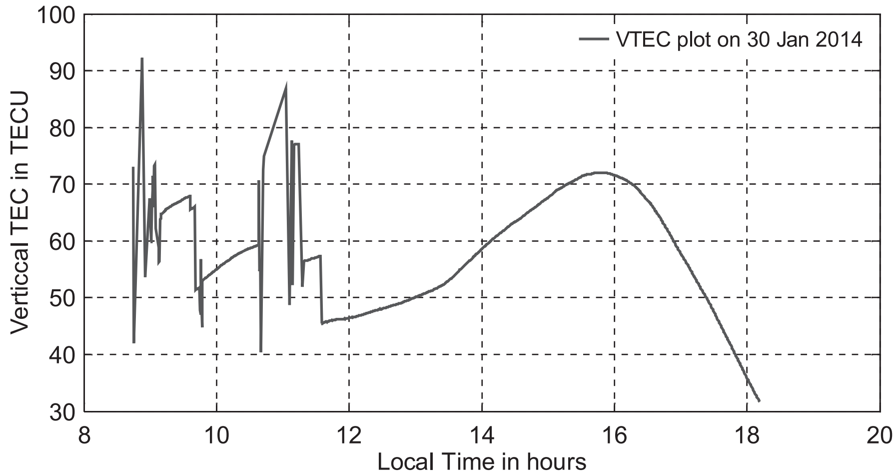

Figure 2: Plot of V_1 on earthquake day

The satellite PRN number 18 is visible for the GPS receiver situated in the region of earthquake occurrence from 8:00 hour's local time to 22:00 hour's local time. The V_1 data is divided into disturbed and undisturbed segments. The data of PRN 18 consists of 1043 data points with a set 261 disturbed points and a set 519 undisturbed points. The detrended disturbed V_2 data set is and undisturbed V_3 data set are shown in Figure 4 and Figure 5. Perturbation in V_1 is observed for 3 hours on the earthquake day. The PSDs of V_1 and V_2 using Welch algorithm are given in Figure 6 and Figure 7.

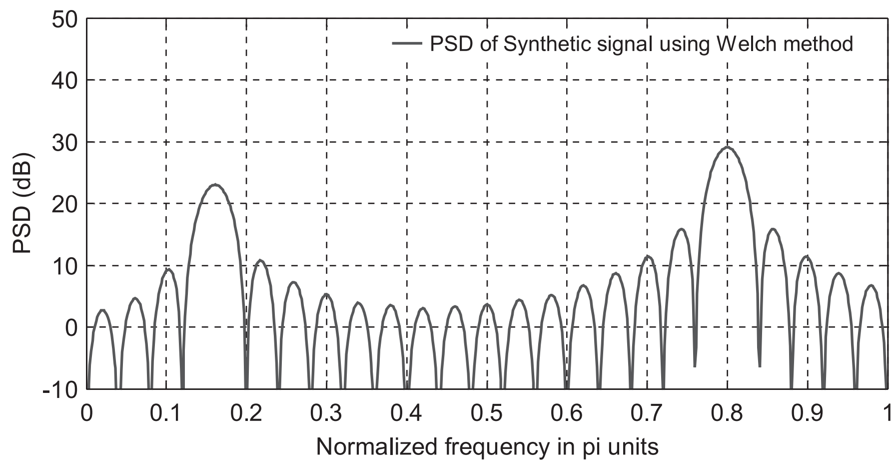

Figure 3: PSD of synthetic signal using welch algorithm

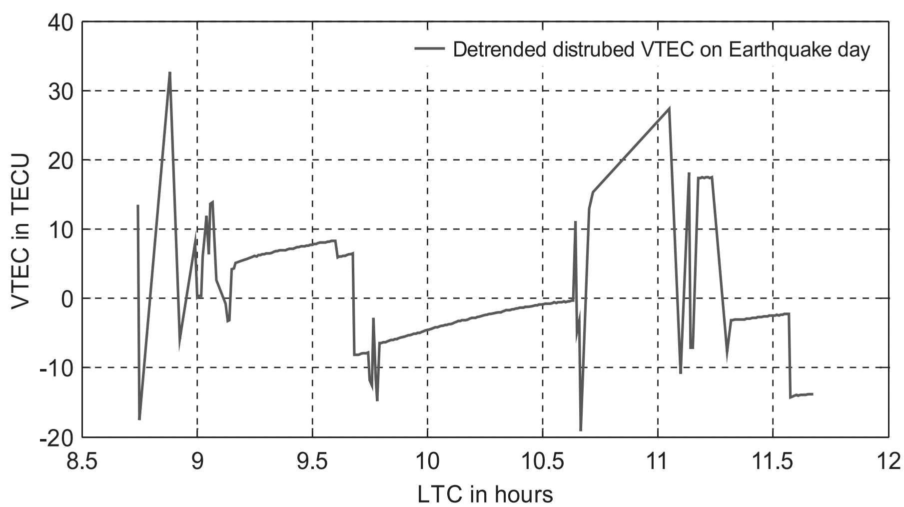

Figure 4: Represents detrended disturbed V_1 data

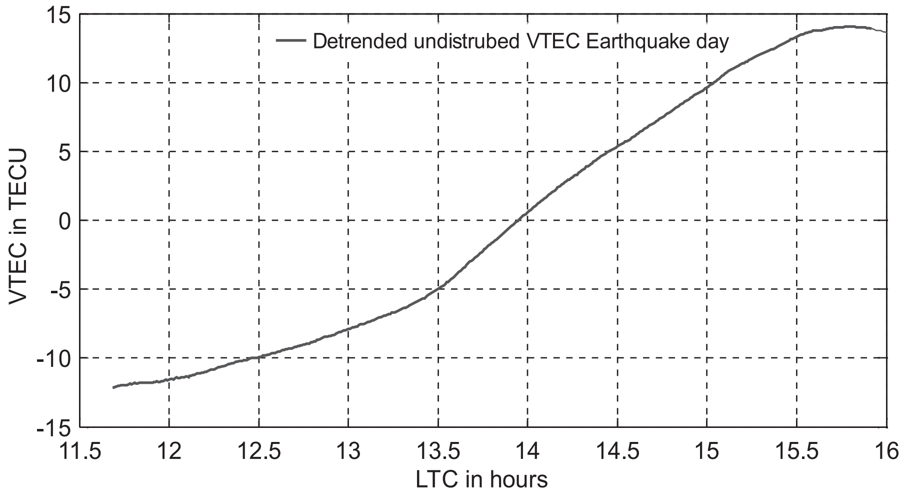

Figure 5: Represents detrended undisturbed V_1 data

The assessment of PSD of disturbed and undisturbed data is carried out by using Welch algorithm. In this method the V_2 data is fragmented into L number of segments with length M. Each segment is having D number of overlapping points. The overlapping is said to be 50% if D = M/2. The overlapped xsegments are windowed to calculate the PSD.

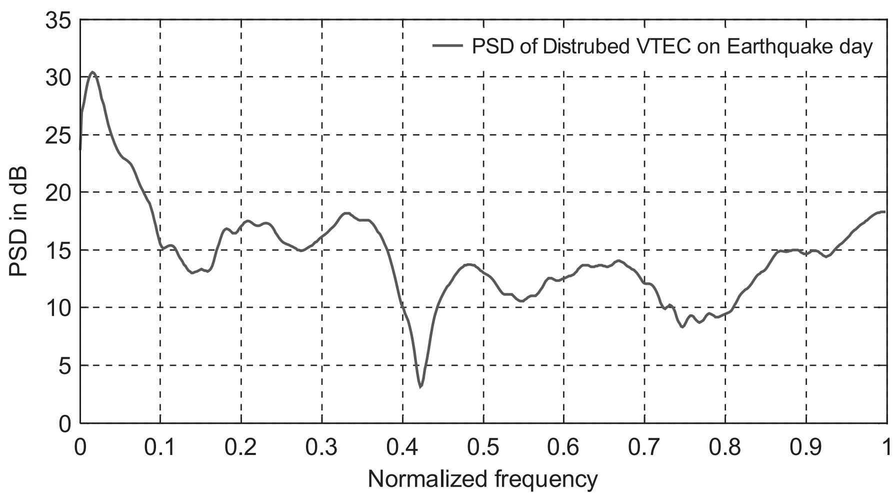

Figure 6: PSD of disturbed V_2 data

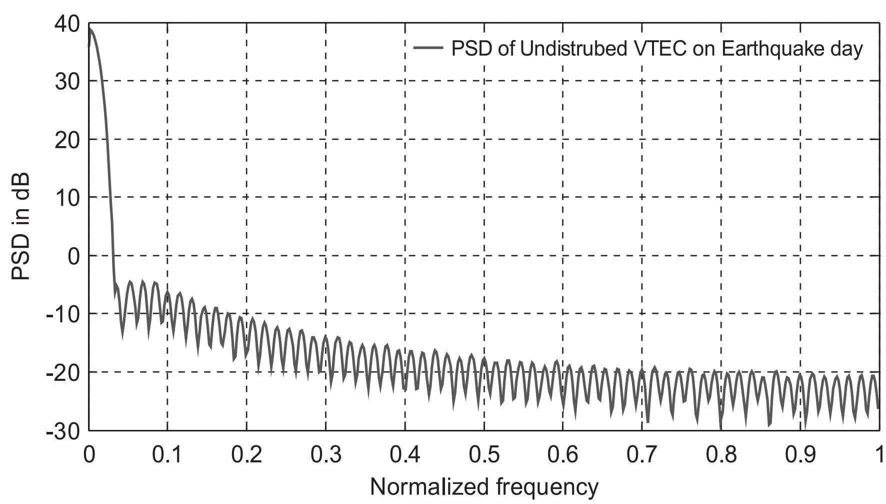

Figure 7: Power spectral density of V_3

In V_2 data peak is observed at normalized frequency 0.4223 with PSD of 3.17dB, and no peaks are noticed in V_3. It has a negative PSD value. Multi resolution analysis is carried out on V_2 to increase the precise time of occurrence of the perturbation. So, the V_2 data is tailored into sets of 130, 65 and 32 data points each.

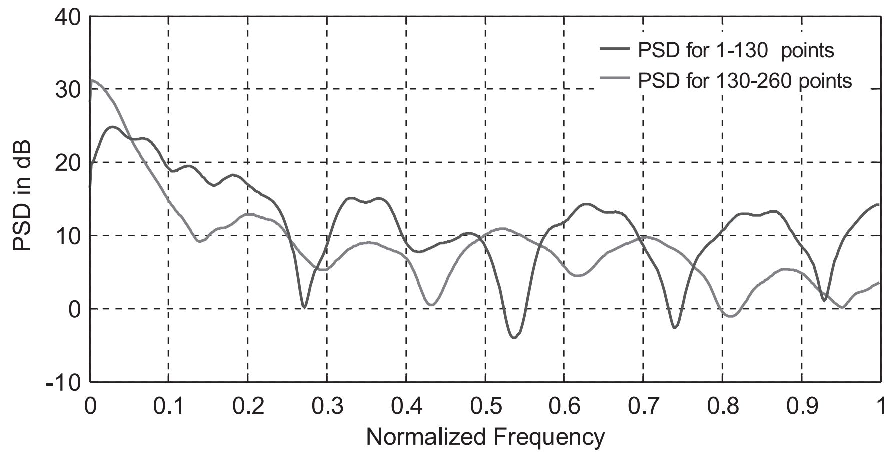

Figure 8: PSD of V_2 with 130 points each

Welch, a non parametric algorithm is implemented on all fragmented data sets. The PSD of first bisection of the data is given in Figure 8. In this division peaks are noticed in two sets of 130 data points. Peaks are observed at normalized frequencies of 0.436 and 0.8152 with PSDs of 0.6666 dB and -0.9647dB in first set and in second set peaks are observed at normalized frequencies 0.2717, 0.5357 and 0.7429 with PSDs of 0.1421dB, -4.002 dB and -2.298 dB. In this segmentation of 130 data points each positive peaks represent the increase of energy in the ionosphere and the negative peaks represent the abating of the energy in the ionosphere.

The fragmentation of VTEC into 65 data points each is shown in Figure 9. In this split up the energy has abated in the first, second and third sets. Peaks are observed in fourth set of 65 data points at normalized frequencies 0.4282, 0.7351 and 0.9286 with PSDs of 10.07 dB, 14.25 dB and 14.94dB respectively.

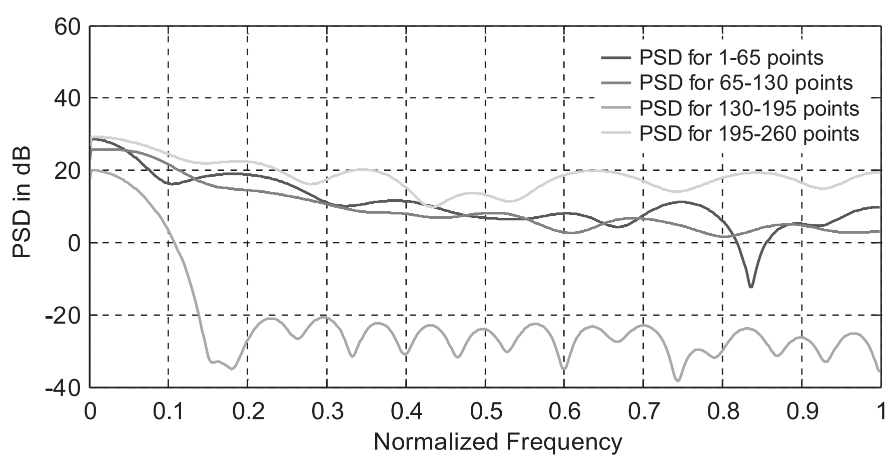

Figure 9: PSD of V_2 with 65 data points

A further split up VTEC into 32 data points a peak is observed in the first set at a normalized frequency of 0.653 with PSD of 3.874 dB and in the third set the energy is decreasing. In the second and fourth set no perturbation is observed in the VTEC data. It is observed that the data has abated in the four sets.

3. DISCUSSION

Multi resolution analysis of VTEC data using welch algorithm has shown that energy in the ionosphere has been increased during the occurrence of perturbations. The energy in the VTEC data has abated as there a change in satellite position. This analysis shows that the lower and upper atmospheres are coupled during earthquake. Thus a transformation of energy and momentum has taken place from lower atmosphere to upper atmosphere.

4. CONCLUSION

Welch algorithm is enforced on perturbations observed in V_2 data on earthquake day. The algorithm could identify seismo-ionospheric anomalies in ionosphere. These disturbances have a high PSD value at the beginning. So it may be concluded that the ionosphere is perturbed before and during the occurrence earthquake, which is in correlation with the occurrence time of the perturbation in VTEC.

Acknowledgments

We are very much thankful to Department of Science and Technology, Government of India for financially funding this research work through sonsored projects SR/AS-04/WOS-A/2011 and SR/S4/AS-9/2012. The authors would also thank President, K L University for their continuous support and assistance.

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