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Performance analysis of Bartlett and Welch Methods for Earthquake Signatures Using GPS TEC

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Abstract: Ionospheric total electronic content perturbations for a catastrophic event took on 17th January 2014 in Indonesia are analyzed. Quake struck with a 4.7 on Richter scale. The natural calamity took place at 3:34 hours Greenwich mean time i.e., at 9:04 hours local time. The vertical total electron content data on earthquake day is taken from the International Global Navigation Satellite System Service station, BAKO, Java, Indonesia. The variation in the spectrum of signals with and without disturbances in the received signals is analyzed using Bartlett and Welch methods. It is clearly observed that the seismic perturbations are identified using both the methods.

Keywords: Non parametric methods, Earthquakes, Ionosphere.

1. INTRODUCTION

Ionosphere acknowledges to large number of disturbances. solar wind, plasma energy particles from sun, tides, gravity waves and a large number of electromagnetic waves from atmosphere below it[1], [2], [3]. Investigations for a large number of earthquakes occurred during quiet geomagnetic and solar activity have reported significant perturbations in ionosphere[4]. The coupling of lithosphere-troposphere-ionosphere leads to the perturbations in upper atmosphere leading to appreciable changes in the total electron content (TEC) observed before large earthquakes.

The ionosphere induces delay in signals propagating through it. The pseudorange in meters for a dual frequency GPS receiver, it is given by

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

where 'f_{L_1}', and 'f_{L_2}', frequencies correspond to GPS 'L_1' and 'L_2', signals. GPS receiver with dual frequency STEC is given by

$$\text{STEC} = \left[\frac{(\rho_{L_1} - \rho_{L_2})}{40.3}\right] \times \left[\frac{f_{L_1}^2 \times f_{L_2}^2}{f_{L_1}^2 - f_{L_2}^2}\right] \tag{2}$$

These STEC values are recorded along the satellite trace and are converted to vertical profile as

$$V_1 = \text{STEC} \times \cos(\alpha) \tag{3}$$

where $\alpha = 90°$ – satellite zenith angle at an altitude of 350 Km and V_1 is the vertical total electron content. V_1 data of a GPS receiver is free of modelling errors and has constant time period over the entire record which is the essential condition to be met for estimating spectrum of GPS TEC [5].

Non parametric methods estimate the signal using the statistical properties of the given data. These techniques do not rely upon variations in statistical parameters of data. They can be applied on all sorts

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of data categories with short data lengths. In existing case study we analyzed V_1 data for earthquake precursors using Bartlett and Welch methods. The earthquake epicentral region is shown in Figure 1. http://earthquaketrack.com/quakes/2014-01-30-03-34-40-utc-4-1-147. The earthquake has occurred on 17^{th} day of year 2014. It is recognized that V_1 data of satellite 18 is perturbed on event occurrence day. The V_1 plot of this particular satellite is shown in Figure 2.

Figure 1: Location map of the earthquake

2. METHODOLOGY

A large number of algorithms are there to identify disturbances in the received GPS signals[6-16]. In the present research work Bartlett and Welch non parametric methods are explored. Estimation the signal below detection level is possible by using non-parametric methods.

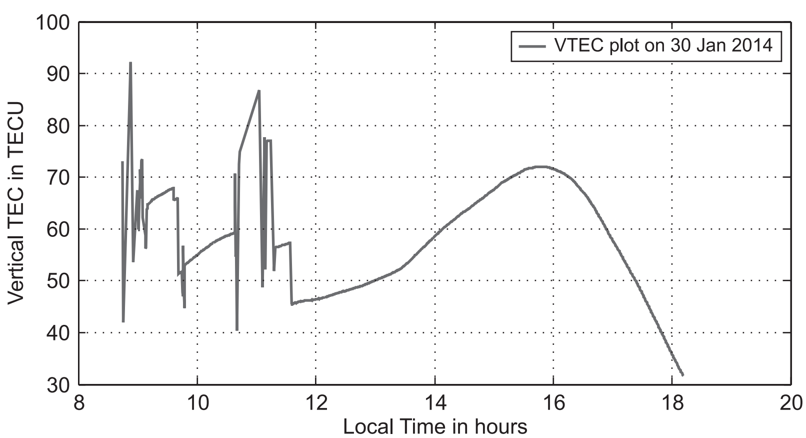


Figure 2: VTEC plot of PRN 18 on earthquake day

These methods are realized for a synthetic signal of known normalized frequencies 0.2 and 0.8. The synthetic signal $X_2(n)$ is given as

$$X_2(n) = 2 \times \cos(2 \times pi \times \alpha_1 \times n) + 2 \times \cos(2 \times pi \times \alpha_2 \times n) + u(n) \tag{5}$$

where $\alpha_1 = 0\ 1$ and $\alpha_2 = 0.5$, $u(n)$ is noise having zero mean, $n = 0$ to $N - 1$ and $N = 128$ points. The PSD of synthetic signal is given in Figure 3 and Figure 4.

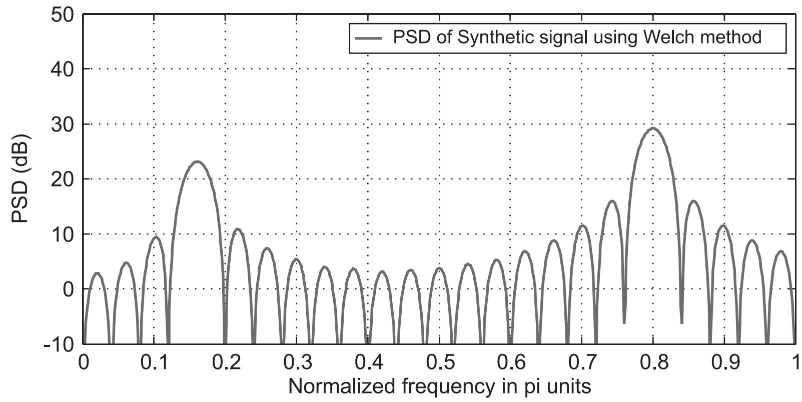


Figure 3: PSD for synthetic signal using Welch method

3. RESULTS

Figure 3 and Figure 4 shows clearly that the peaks are at 0.16 and 0.8 normalized frequencies. It is understood that Welch and Bartlett algorithms are able to analyze the spectral components and hence they are applied on V_1 data representing the earthquake signal. Bartlett method considers the ensemble averages of data to spectrum estimation. The advantage of this method is that the variance is reduced. Welch method data is fragmented into L number of segments of length M with D number of overlapping points. The overlapping is said to be 50% if D = M/2. The overlapped segments are windowed to calculate the PSD.

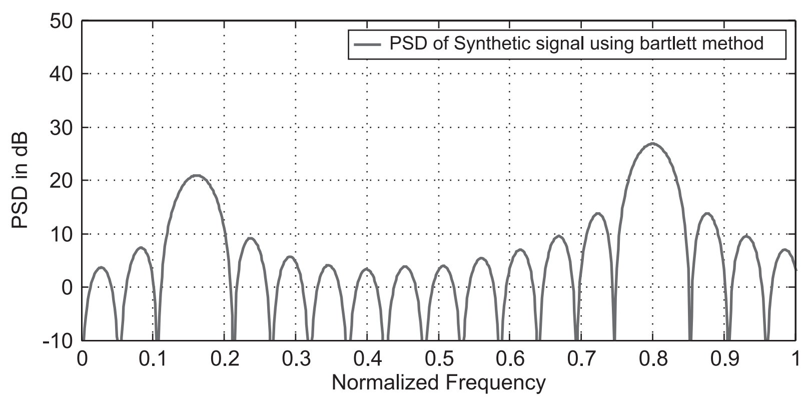


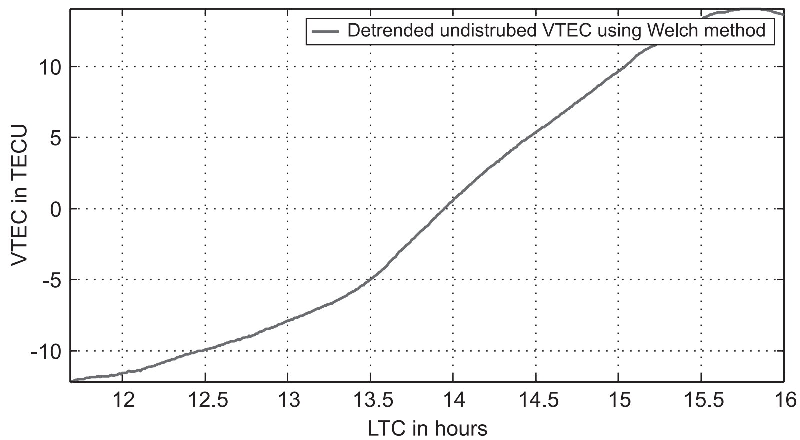
Figure 4: PSD for synthetic signal using Bartlett method

The V_1 data consists of 1043 points. The perturbed and unperturbed V_1 consists of 260 and 519 points respectively. The reason for removing the remaining 262 points is the post sunset enhancements. The algorithms are realized on the undisturbed and disturbed data sets. The detrended disturbed (P_1) and undisturbed (P_2) sets are represented in Figure 5(a) and 5(b) respectively. The PSDs of the P_1 and P_2 for welch method are represented in Figure 6(a) and 6(b) and for bartlett are represented in Figure 7(a) and 7(b).

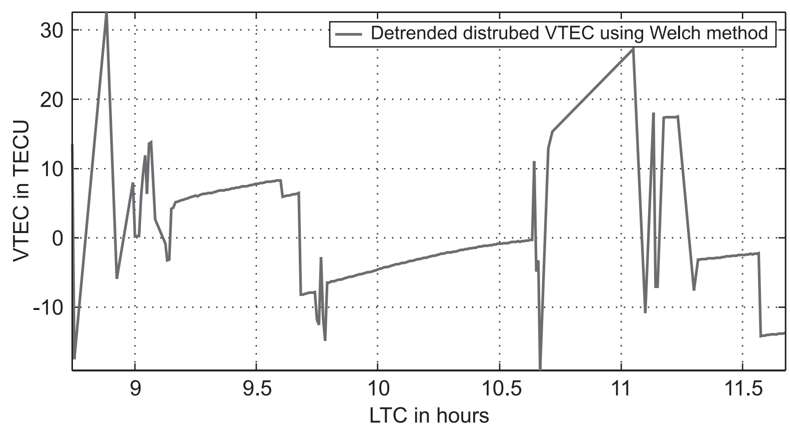
In the PSD of P2 data using Welch method a peak is noticed at normalized frequency 0.4223 with PSD of 3.17dB. In the PSD of disturbed data using Bartlett method two peaks are noticed at normalized frequencies of 0.2813 and 0.457 having same PSD of 10.2 dB. The PSDs of both methods for disturbed and undisturbed data are given in Table 1.

The methods are also applied on the first bisection of the data to increase the certainty during time of occurrence of the perturbations. The PSDs of this bisection for both the methods are given in Figure 8 and Figure 8(a) and 8(b). From the figures it is inferred that the Welch method is able to represent all the normalized frequencies. In Welch method for the first set of data with 130 points, peaks are appearing at normalized frequencies 0.2972, 0.4301 and 0.6217 with PSDs of 5.24 dB, 0.5191 dB and 4.467 dB respectively. In the second set of data with 130 points, peaks are observed at 0.2698 and 0.9306 with PSDs of 0.1421 dB and 1.27 dB respectively.

In Bartlett method for first set of data with 130 data points a peak has appeared at normalized frequency of 0.4219 with PSD of 9.513 dB. In the second set of data with 130 points peaks are noticed at 0.2813 and 0.4531 with PSDs of 11.14dB and 10.63 dB respectively. The negative peaks are not given here because they represent the decrease of energy in the ionosphere during the perturbations.

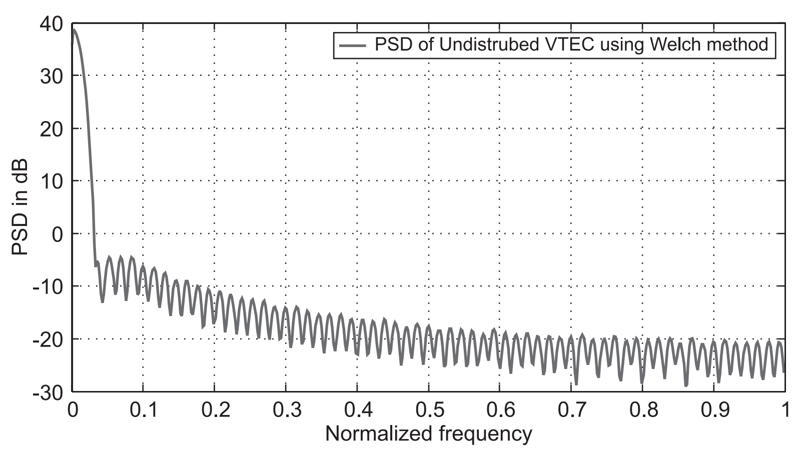


(a)

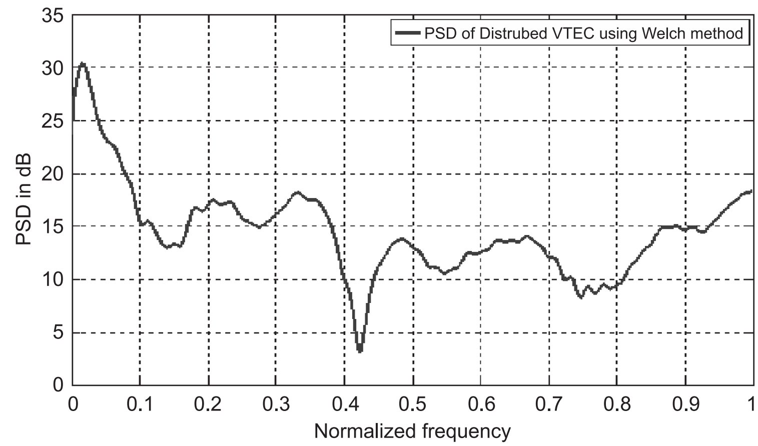


(b)

Figure 5: (a) and (b) Detrended P_1 and P_2 on earthquake day

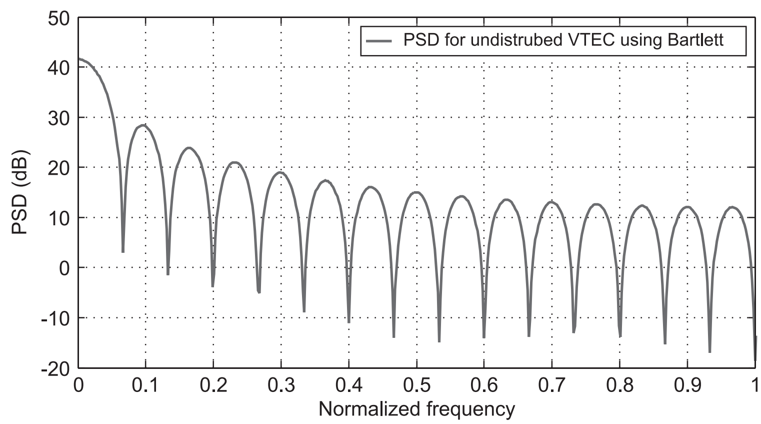


(a)

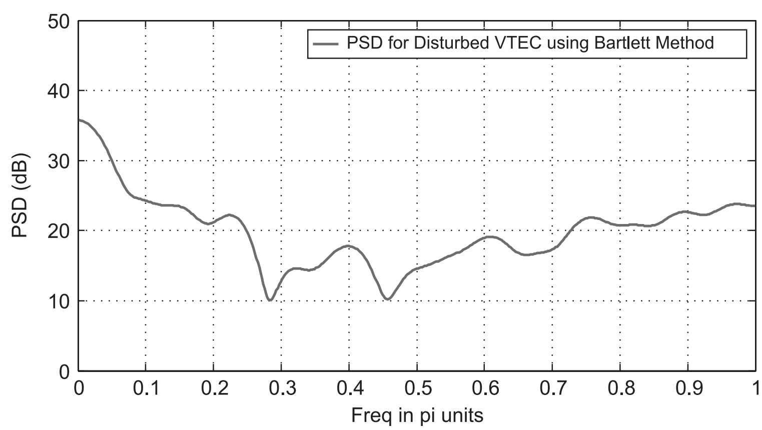


(b)

Figure 6: (a) and (b) Power spectral density of P_1 and P_2 using Welch method



(a)

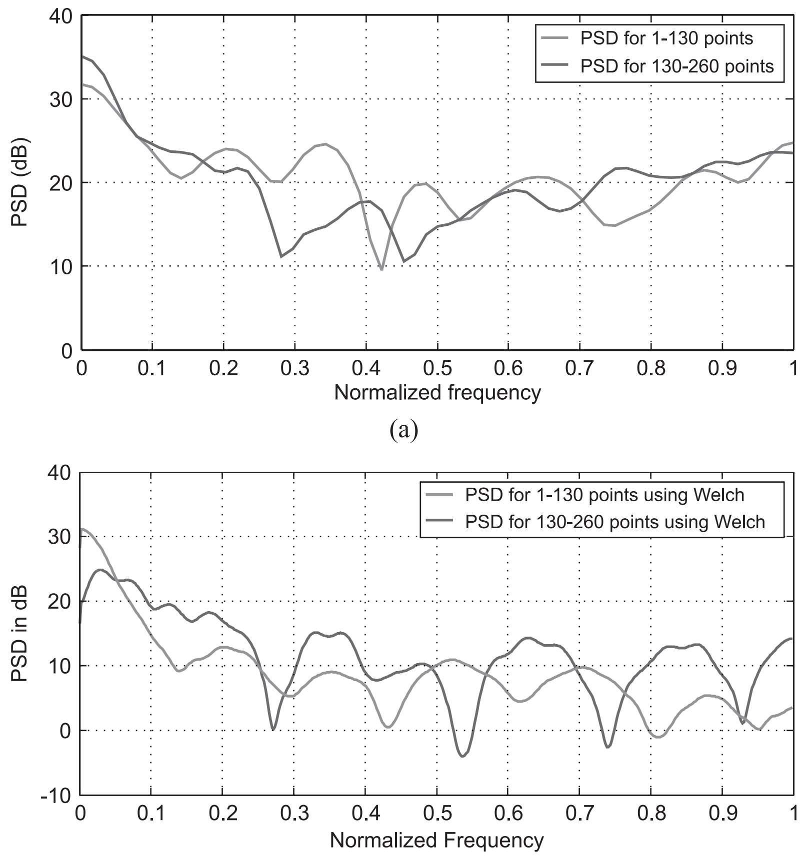


(b)

Figure 7: (a) and (b) Power spectral density of P_1 and P_2 using Bartlett method

Table 1
PSD of disturbed and undisturbed VTEC using Welch and Bartlett

S.No.	*Method*	*Disturbed VTEC*		*Undisturbed VTEC*
		Normalized Frequency	*PSD in dB*	
1	Welch	0.4223	3.17	No peaks are observed
2	Bartlett	0.2813	10.2	No peaks are observed
		0.457	10.2	No peaks are observed



(b)

Figure 8: (a) and (b) Power spectral density of P_1 and P_2 using Bartlett and Welch methods for 130 points.

4. DISCUSSION

The analysis of VTEC data using Welch and Bartlett methods has identified the seismic perturbations in the ionosphere during the earthquake. These perturbations are in congruence with coupling mechanism of lithosphere-atmosphere-ionosphere. The vertical electric field generated in the earthquake zone disturbs the dynamic upper atmosphere. In the analysis the earthquake considered is nearer to the epicenter.

5. CONCLUSIONS

From the analysis of VTEC data on earthquake day it may be concluded that the observed ionospheric perturbations represent the impending earthquake. The distance between the earthquake epicenter and the BAKO IGS station also cornerstone the results obtained in this analysis. Welch method can represent the perturbations more precisely than Bartlett method as it applies windowing on the data.

Acknowledgments

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