Abstract

Background/Objectives: Ionospheric total electron content perturbations generated by earthquake occurred in Indonesia are analyzed. Methods/Statistical analysis: The vertical total electron content data on the earthquake day is detrended such that it can be analyzed using statistical signal processing algorithms. Modified periodogram algorithm is implemented on both the disturbed and undisturbed vertical total electron content data. Findings: From the power spectral densities of modified periodogram, the time of occurrence of earthquake is observed and it is noted that it is matching with the actual time of occurrence of event considered. Application/Improvement: This analysis aids in developing an early warning system for earthquakes.

Keywords: Atmospheric Sciences, Earthquakes, Global Positioning System, Statistical Signal Processing

1. Introduction

Electromagnetic detection of earthquakes well before their occurrence helps in rescuing mankind. The study of many large earthquakes all over the world has reported an increase in ionospheric total electron content before and during their occurrence. These disturbances are caused by the generation of vertical electric field in the lower atmosphere. The ion molecular reactions in the lower atmosphere act as the origin for the development of vertical electric field\textsuperscript{1–4}.

Radon, greenhouse gases and large amount of metal ions are released from the earth’s crust before the occurrence of the earthquake. The atmospheric constituents are ionized by radon. The metal ions attach with the free electrons to form negative ions. Coulomb’s force of attraction plays an extensive role in formation of ion clusters. The vertical electric field thus generated perturbs the dynamic upper atmosphere. These perturbations are mapped on to the Global Positioning Systems (GPS) signals propagating through the ionosphere\textsuperscript{5–7}.

The dispersive nature of the ionosphere introduces time delay in the GPS signals. The time delay in the GPS signals is measured as Slant Total Electron Content (STEC). For a dual frequency GPS receiver STEC is calculated using equation (1).

\[
\text{STEC} = \frac{1}{40.3} \left[ \frac{f_1^2 + f_2^2}{f_1^2 + f_2^2} \right] (\rho_1 - \rho_2) \tag{1}
\]

where \(f_1\) and \(f_2\) correspond to the frequencies of GPS L\(_1\) and L\(_2\) signals.

The change in the values of STEC is due to the movement of satellite. Ground based GPS receiver tracks many satellites at a particular instant of time. In order to reduce the errors which are caused due to the interference of one or more satellites STEC values are converted to Vertical Total Electron Content (VTEC). VTEC is calculated using equation (2).

\[
\text{VTEC} = \text{STEC} \times (\cos(\xi)) \tag{2}
\]

where, \(\xi\), is the difference between 90\(^\circ\) and zenith angle of the satellite at Ionospheric Pierce Point (IPP). IPP’s are the points where the GPS signal interacts with the ionosphere\textsuperscript{6}.

Spectral resolution gives the clear idea of the change in energy disturbances in the ionosphere. So, in the present work an attempt is made to estimate the spectrum...
of the VTEC data on the earthquake day using modified periodogram. Modified periodogram is applied on both the disturbed and undisturbed VTEC data on the earthquake day. This method is asymptotically biased and it gives a better estimate of the signal compared to periodogram.

2. Event Considered

Earthquake has occurred on 25th January 2014 in Kroya, Central Java, Indonesia (7.986°S, 109.265°E) at 10:44 hours Local Time Coordinate (LTC) i.e., 5:14 hours Universal Time Coordinate (UTC) with a depth of 66 km. On Richter scale a magnitude of 6.1 was recorded on the earthquake day. Australian Pacific plate and the east coast of Pupa New Guinea are dominated by the general northward subduction of the Australian plate. The location map of the earthquake is shown in Figure 1. The location map of the earthquake is taken from http://earthquaketrack.com/quakes/2014-01-25-05-14-18-utc-6-1-66.

3. Data

International Global Navigation Satellite system (IGS) network provides RINEX data. RINEX data is converted into VTEC using equation (1) and equation (2). The VTEC values are collected for the IGS station named BAKO, situated at Bakosurtanal, Cibinong, West Java, Indonesia (-6.49°N, 106.85°E). This station is situated 314 km away from the epicenter of the earthquake. The VTEC data on the earthquake day is considered for analysis. The VTEC plot of PRN number 18 and the satellite ray path are shown in Figures 2 and 3.

4. Methodology

Energy distribution of VTEC data in frequency domain for seismo-ionospheric perturbations is useful to unravel their source mechanisms. The disturbances in the signals can be analyzed using many statistical signal processing algorithms. In this research work modified periodogram is explored. The algorithm is realized for a synthetic signal of known normalized frequency. The synthetic signal x(n) is given as:

\[ x(n) = 2\cos(2\pi f_1 n) + z(n) \]

where \( f_1 = 0.5, n = 0:N-1, N = 128 \) and z(n) is a zero mean white Gaussian noise. The PSD of the synthetic signal is shown in Figure 4. The advantage of this method is it uses a rectangular window on the data. The application of the rectangular window reduces the bias on the estimate of the signal.

Figure 4 clearly show that the peak is at 0.5 normalized frequency which is assumed in the synthetic signal. It is understood that modified periodogram is able to estimate the frequencies of the signal; therefore, it is applied for the analysis of VTEC data representing the earthquake. The VTEC data on the earthquake day consists of 1041 points. As the PRN 18 data is not available before 9 hours LTC,
the VTEC data is divided into disturbed and undisturbed sets. From the VTEC plot of PRN 18 on the earthquake day it is understood that the perturbation is seen for 3 hours consisting of 255 points. The undisturbed data is considered up to 16 hours consisting of 486 points. The VTEC data after 17 hours is not considered as it represents the post sunset perturbations in this low latitude region. Figures 5(a) and 5(b) represent the detrended disturbed and undisturbed VTEC data.

Modified periodogram is first implemented on the disturbed and undisturbed VTEC data. The PSDs for them are given in Figures 6(a) and 6(b). It is observed that six peaks are seen in the disturbed VTEC with normalized frequencies of 0.302, 0.3242, 0.5156, 0.5977, 0.791, and 0.9668 with PSDs of 23.14dB, 22.44dB, 26.27dB, 23.96dB, 29.06dB, and 35.23dB respectively. In the PSD of the undisturbed data no peaks are observed. Spectral resolution of the PSD can be increased by the implementation of multi resolution analysis.

So, the VTEC data is divided into sets of 127, 62, 30 and 15 data points each. In the first bisection peaks are observed in the first set at normalized frequencies of 0.2734, 0.6953, 0.8105, and 0.8262 with PSDs of 22.81dB, 28.05dB, 30.6dB and 29.37dB respectively. In the second set a single peak is observed at normalized frequency of 0.2109 with PSD of 18.38. The PSD plot of first bisection is given in Figure 7. The next fragmentation of the data into 62 points, peaks are observed in the four sets with normalized frequencies of 0.2441, 0.8164, 0.3398, 0.7871, 0.2227 and 0.6895 with PSDs of 15.22dB, 30.05dB, 25.84dB, 29.73dB, 7.832dB, and 29.51dB respectively. The PSDs of the four sets are given in Figures 8 and 9.
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Figure 7. PSD for data with 127 points each.

Figure 8. PSD for first two sets with 62 points each.

Figure 9. PSD for second two sets with 62 points each.

In the last fragmentation of the data with 30 points each peaks are observed in first six sets. The PSD of this division are given in Figures 10, 11 and 12 representing two sets each. The last division of 30 points is similar to that of the undisturbed data. The peaks in the first three sets of 30 points are observed at 0.8145, 0.441, 0.8418, 0.3203 and 0.7813 with PSDs of 28.56dB, 12.86dB, 24.25dB, 12.81dB and 23.49dB respectively. In the last three sets of 30 points peaks are observed at normalized frequencies of 0.8984, 0.668, 0.375 and 0.8203 with PSDs of 18dB, 19.67dB, 13.09dB and 25.19dB respectively.
5. Conclusion

Modified periodogram could identify the seismic perturbations in ionosphere. It is clearly observed that the ionosphere was distributed during and before the occurrence of the earthquake. The PSD plots of data fragmentation into sets of equal parts resulted in the certainty of the time of occurrence in the disturbance. It is clearly observed the PSDs have modest initial value, reached a maximum and finally attained a low value. The analysis is consistent with the lithosphere-atmosphere-ionosphere coupling mechanisms. Thus energy and momentum are deported from lower to upper atmosphere before and during the occurrence of the earthquake.

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