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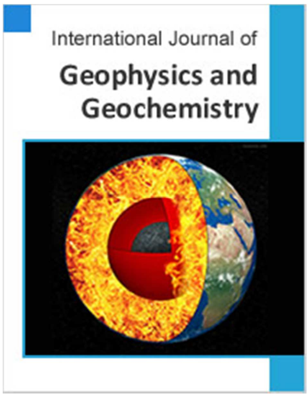

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Wavelet Based Semblance Analysis

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Abstract
Wavelet analysis is a tool for analyzing localized variations of power within a time series. By decomposing a time series into time-frequency space, the wavelet transform has been used in a variety of fields and was found advantageous compared to the conventional tools like Fourier analysis for a time series. Wavelet based semblance analysis compares two time series on the basis of their phase as a function of frequency. Based on the wavelet transform, an efficient methodology for measuring the periodicity of a time series of the Earth's magnetic field observed over the Indian subcontinent is presented in this paper.

1. Introduction

The magnetic field and its secular variations observed on the Earth's surface are a complex function of space and time. The identification of regular patterns in the geomagnetic field relies not only on the acquisition of new experimental data but also on the application of more effective methods of analysis [1]. Fourier analysis has been widely used to interpret the observational results of atmospheric waves in the middle atmosphere, assuming these are monochromatic waves. When a data series includes different kinds of localized or intermittent frequencies, the Fourier spectrum is usually a complex mixture which is difficult to interpret. The wavelet transform is an alternative to the Fourier transform and can be used to analyze time series that contain non-stationary power at different frequencies [2].

Wavelet transform began to be used in geophysics since the early 1980s for the analysis of seismic signals. In geophysics, the power of wavelets for analysis of non stationary processes that contain multi scale features, detection of singularities, analysis of transient phenomena and signal compression is being exploited for the study of several mechanisms. Wavelet analysis is becoming a common tool for analyzing localized variations of power within a time series. By decomposing a time-series in to time- frequency space, one is able to determine both the dominant modes of variability and how those modes vary in time [3].

Wavelet analysis has also been applied to many areas of signal processing. It localizes spectral information (unlike Fourier analysis), which makes it especially suitable for the analysis of non stationary features [4]. Wavelet analysis is often very effective because it provides a simple approach for dealing with local aspects of a signal [5]. With the help of wavelet analysis we could bring out more details about the periodicity of daily variations in the geomagnetic field. The fundamental purpose of wavelet analysis outlined here is to identify the periodic events in the geomagnetic time-series that were analyzed. We use semblance analysis for this purpose.

Semblance is a measure of the cross correlation of two datasets. It is frequently useful to be able to compare different data sets to see what they have in common and where they differ. One method of comparing two data sets is semblance analysis. The semblance S is the cosine of the difference between the Fourier phase angles of the two data sets, at each frequency *f*. It can take values from -1 to +1, where a value of +1 implies perfect phase correlation, 0 implies no correlation, and -1 implies perfect anti- correlation [6]. In this paper, we compare the daily variation of Earth's horizontal intensity of magnetic field at different places in India to get information about the periodicities. These are verified using the MATLAB tool box.

2. Semblance Analysis Using the Wavelet Transform

The wavelet transform method gives detailed information on the time localization of each frequency component. In this work, the wavelet technique is utilized to study the presence of periodicities in the Earths horizontal intensity of magnetic field. The wavelet transform is a powerful tool for the analysis of non-stationary data sets. It can also use a variety of basis functions whose mathematical properties can be chosen depending on the data to be processed. The cross wavelet transform between two datasets is defined as

$$CWT_{1,2}=CWT_1.CWT_2$$

where CWT_1 and CWT_2 are the continuous wavelet transforms of datasets 1 and 2 respectively. The cross wavelet transform is a complex quantity having an amplitude given by [7]

$$A = CWT_{1,2}$$

and local phase θ

$$\theta = \tan^{-1}(J\ (CW_{1,2}) / R\ (CW_{1,2}))$$

where R and J indicate the real and imaginary parts.

Semblance is then defined as

$$S = Cos^n(\theta)$$

3. Data

In this work we use the data published by the Indian Institute of Geomagnetism, Mumbai, for the horizontal component of earth's magnetic field at 1 hour intervals from January to December, 2002 for the stations Alibag (Geographic latitude = $18^0 37^{'} N$, Geographic longitude = $72^0 52^{'} E$ Geomagnetic latitude = $10.02^0 N$ and denoted by ABG), Ettaiyapuram ($09^0 10^{'} N$, $78^0 01^{'} E$, $0.13^0 N$, ETT), Hyderabad ($17^0 25^{'} N$, $78^0 33^{'} E$, $8.29^0 N$, HYD), Sabhawala ($30^0 22^{'} N$, $77^0 48^{'} E$, $21.25^0 N$, SAB) and Visakhapatnam ($17^0 41^{'} N$, $83^0 19^{'} E$, $8.17^0 N$, VIS) spanning almost the entire country. The data consists of hourly values of the H-component with, obviously, 24 values for a day; these form the raw data for the wavelet analysis. Wavelet based semblance analysis was done for the pair of stations ABG-VIS, ETT-TVI and SAB-TVI for the months January, April and June coming respectively in D season (December solstice), E season (Equinoctial months) and J season (June solstice) [8].

4. Results

In Figure 1 Data 1 are the H- values of ABG for the month of January and Data 2 are the same for Visakhapatnam. Below Data 1 and Data 2, real part of the complex CWT of the data set is shown. White (bright red in color version) indicate a large positive amplitude and black (dark blue) indicate a large negative amplitude. It is seen that alternate white and black spots are seen at 24 units indicating a 24 hour periodicity in data 1 and data 2. Bottom Panel shows power spectrum of ABG (left) and VIS (right). There is strong evidence for 24 hour periodicity. The small peak indicates a 12 hour periodicity also. Figures 2 and 3 are similar plots respectively for the months April and June for the same pair of stations ABG-VIS. In all the three cases 24 hour and 12 hour periodicities of the data can be seen.

Similar figures are drawn for the pair of stations ETT-TVI (Figures 4-6) and SAB-TVI (Figures 7-9). In all the cases the 24 hour and 12 hour periodicities can be seen. From this we can conclude that the horizontal intensity of magnetic field varies with a 24 hour periodicity. This 24 – hour periodicity was observed earlier by Fourier analysis [9]. In addition we have, in this study, confirmed the existence of a 12 hour periodicity also.

As is evident from the Figures, the power in the 12 - hour peaks are almost an order of magnitude smaller than the power in the 24 - hour peaks. Also the power in the 24 - hour peaks at the equatorial stations Ettaiyapuram and Tirunelveli, are much greater than the power in the peaks for the off equatorial stations Alibag, Visakhapatnam and Sabhawala.

The movement of conductive air across the lines of the earth's magnetic field is responsible for the daily variations of the geomagnetic field. However, lunar and solar tides have also been proposed as the cause for the movement of air in the upper atmosphere [10, 11]. This, in turn, has been associated with the dynamo current in the E-region of the earth's ionosphere. Due to the presence of a non-conducting layer, the strong vertical polarization field opposes the downward flow of electric current. This field gives rise to an intense Hall current, popularly known as the equatorial electro-jet (EEJ) [12]. The EEJ flows along the dip equator in the E-region of the ionosphere, within a latitudinal region of $\pm\ 3^o$, and is responsible for variations of the earth's magnetic field. As indicted above the power present in the 12-hour periodicities at the equatorial stations were much greater than the off-equatorial ones. This could be due to the decreasing influence of the equatorial electro-jet as one moves away from the equator.

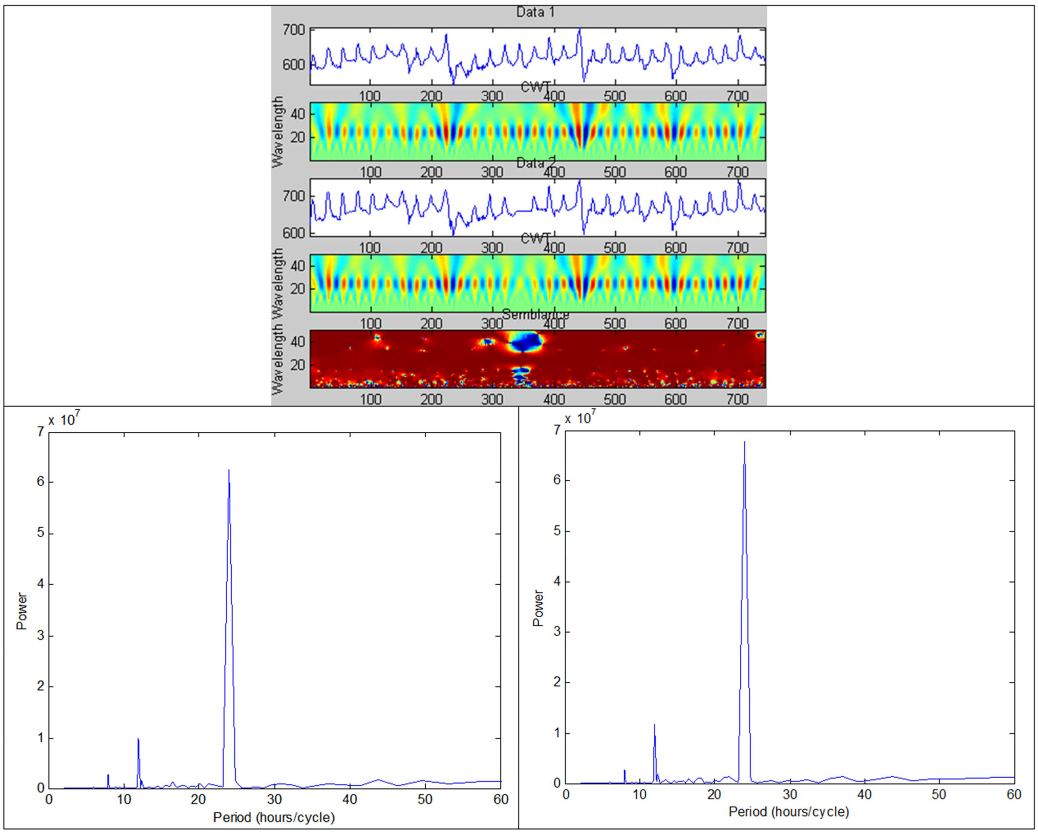

***Figure 1.** ABG – VIS January.*

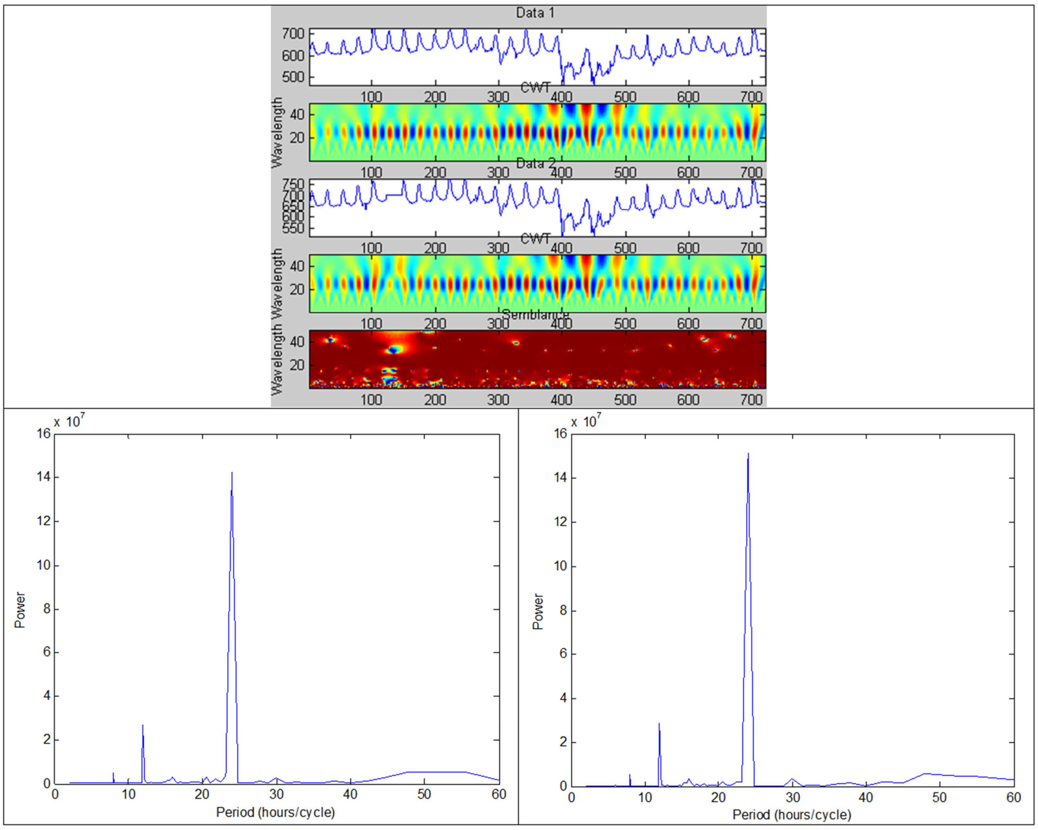

***Figure 2.** ABG – VIS April.*

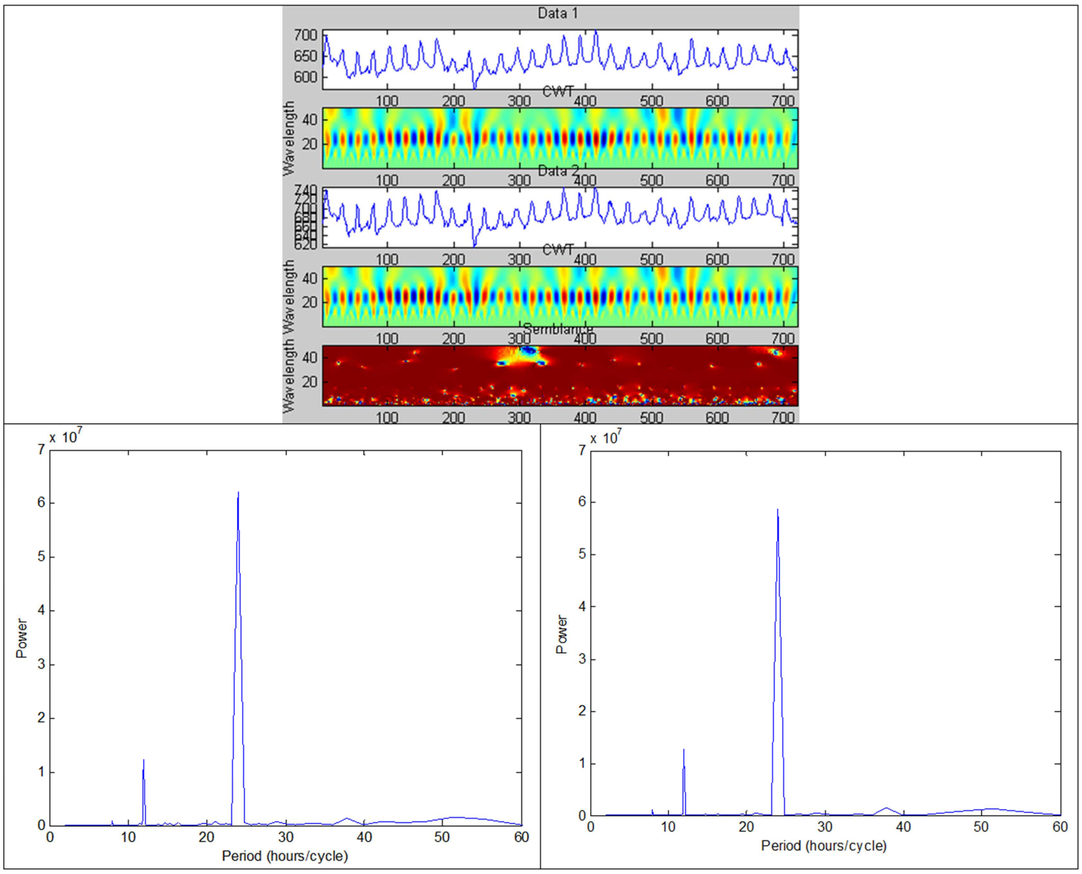

Figure 3. *ABG – VIS June.*

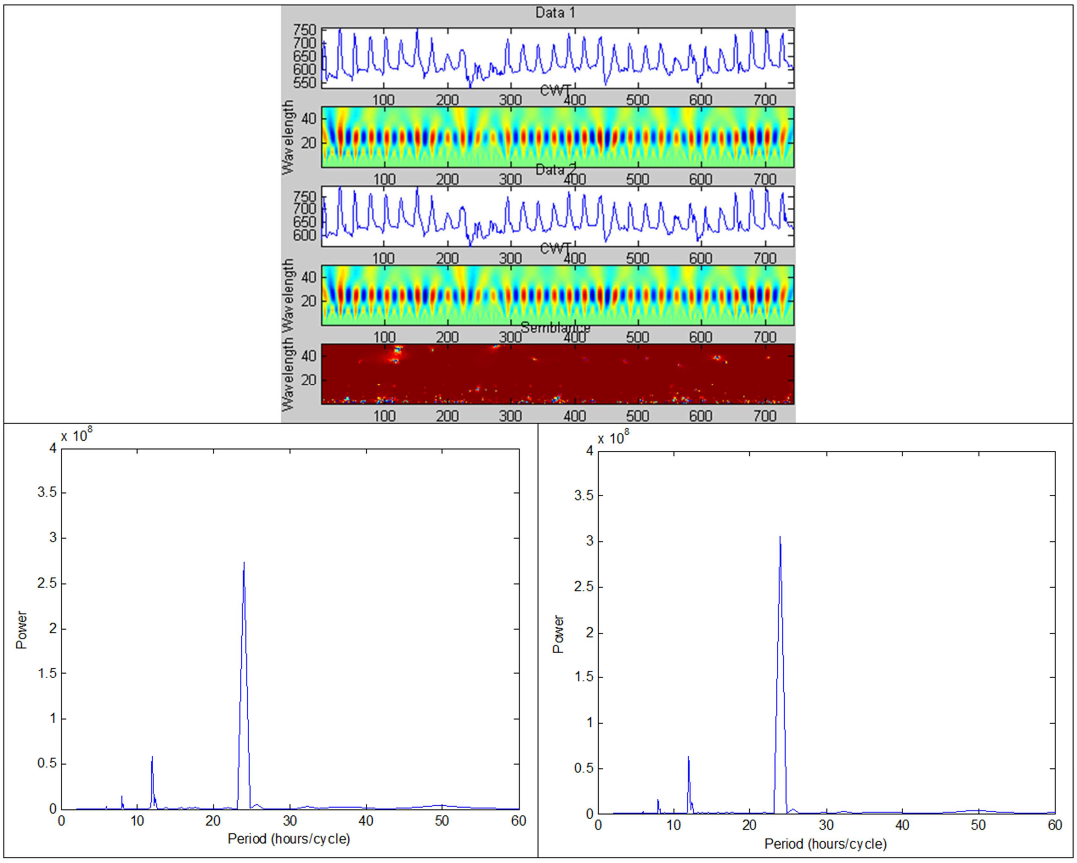

Figure 4. *ETT- TVI January.*

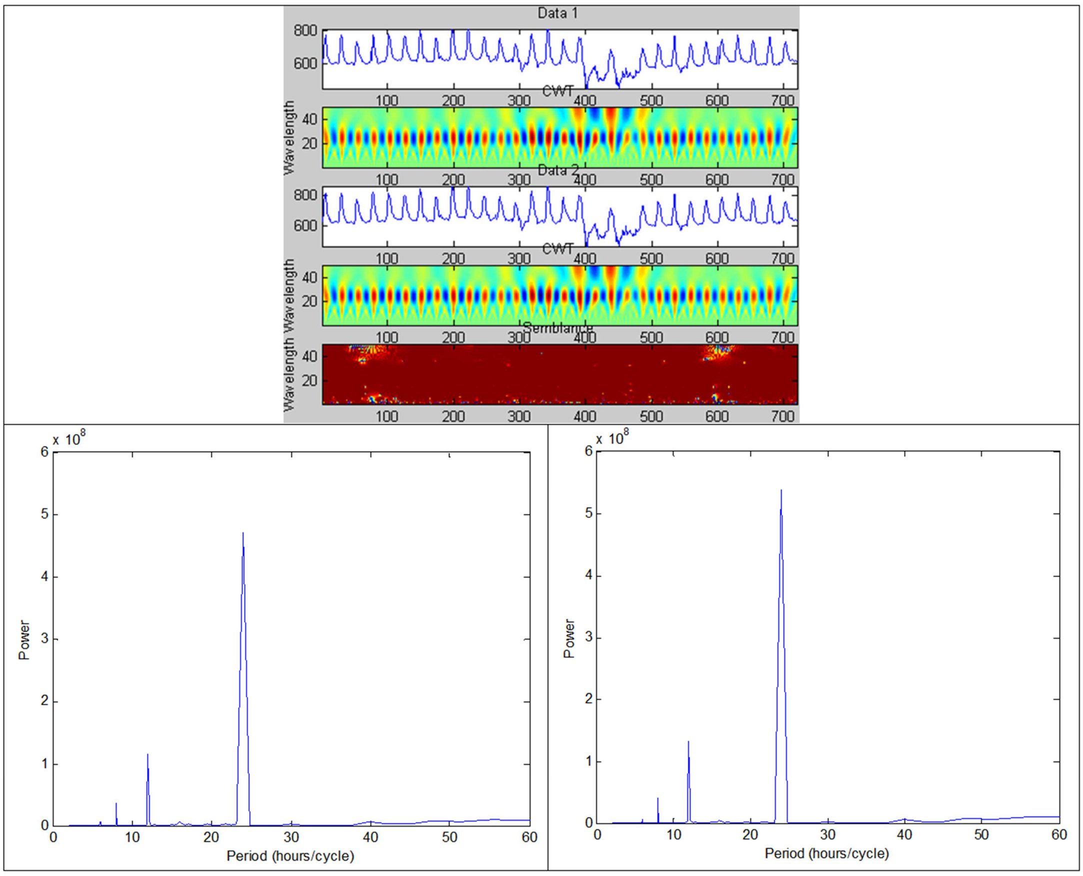

Figure 5. *ETT- TVI April.*

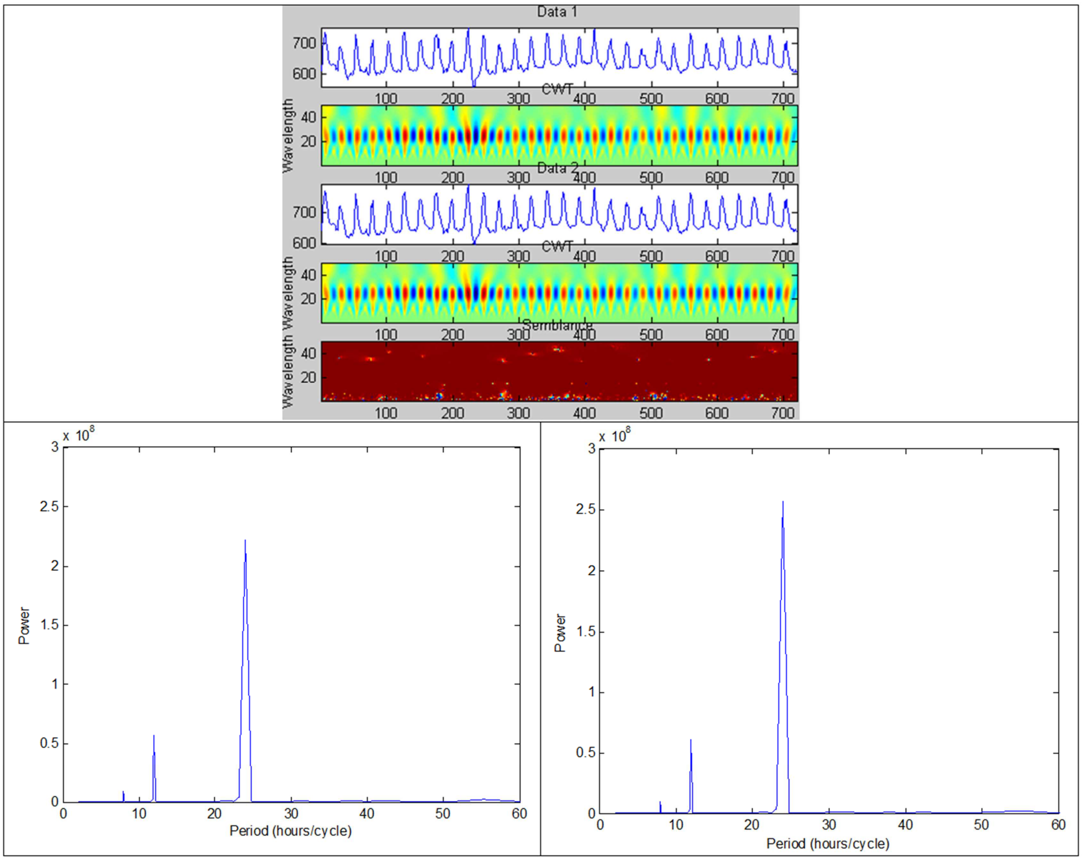

Figure 6. *ETT- TVI June.*

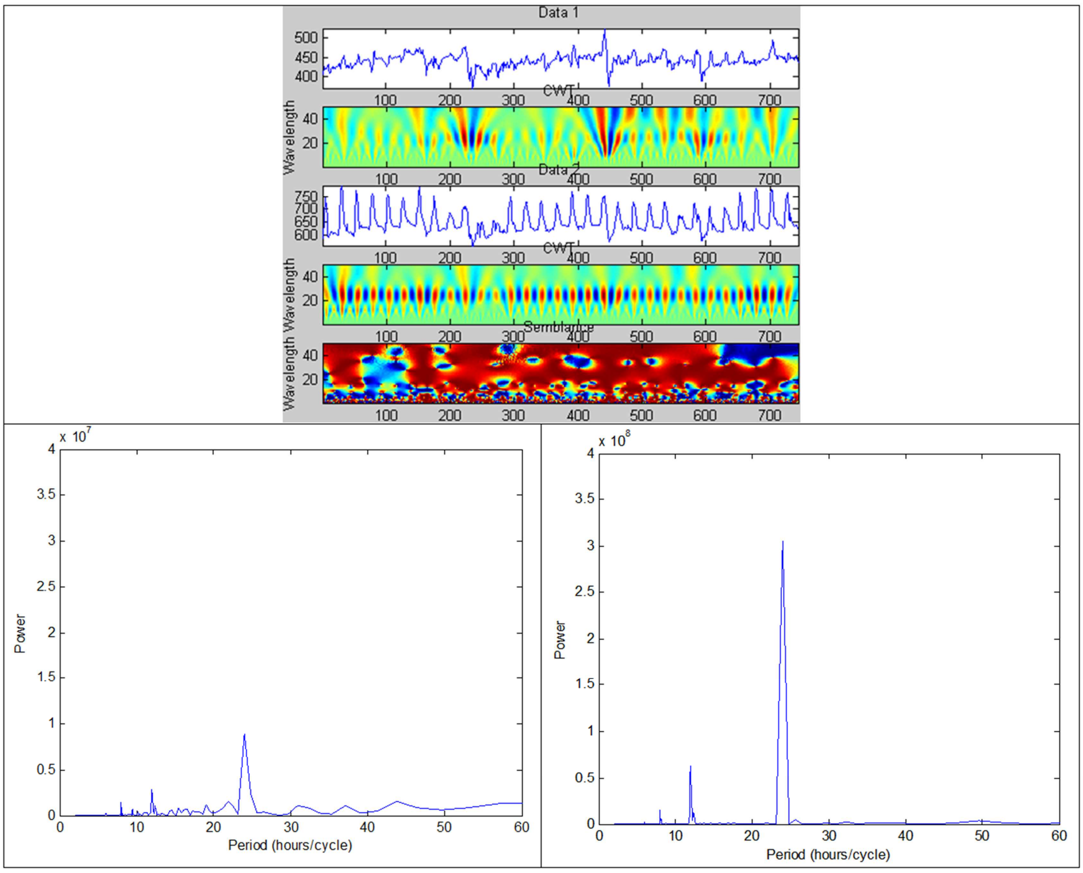

Figure 7. *SAB- TVI January.*

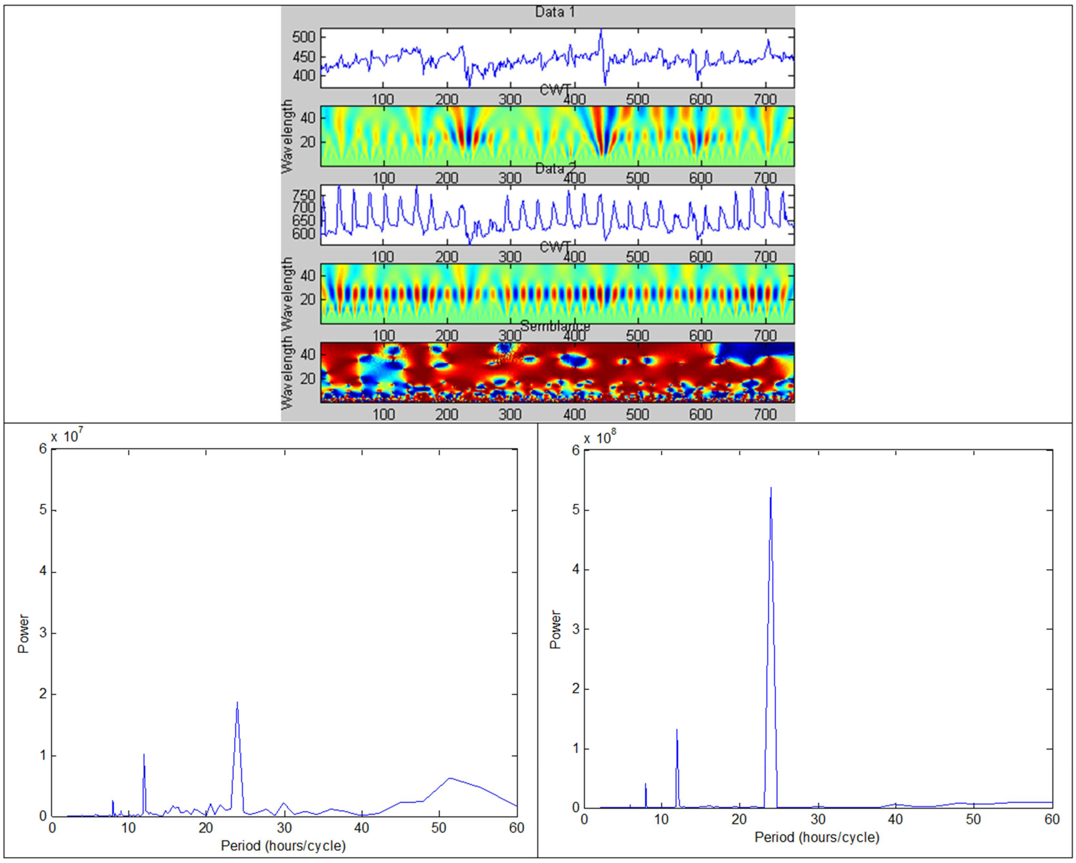

Figure 8. *SAB- TVI April.*

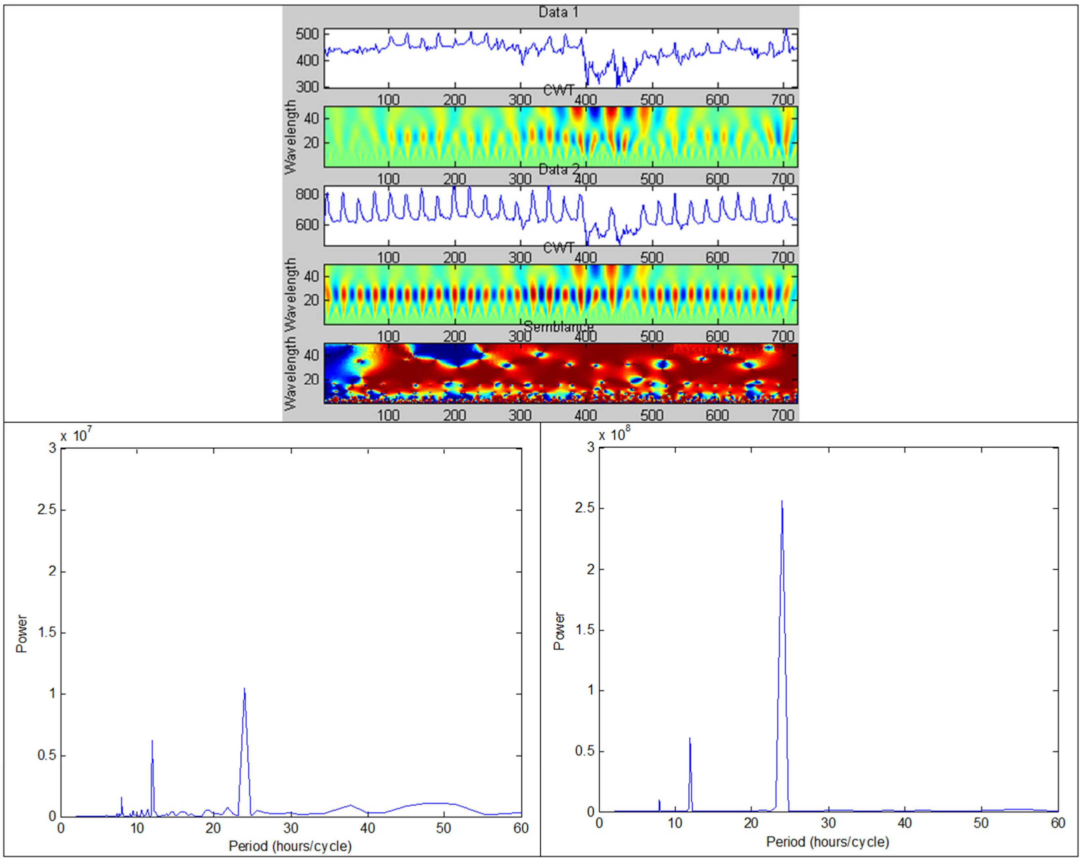

Figure 9. *SAB- TVI June.*

5. Conclusion

The wavelet method presented in this work provides an excellent means of finding the strength of quasi periods in the Earth's horizontal intensity of magnetic field. Also the power present in the 12-hour periodicity sub-harmonic is very much less than the 24-hour periodicity wave.

Figure Captions

Figure 1. Data 1 and Data 2 in the upper panel are the H-values of Alibag and Visakhapatnam in January 2002 (D season). Bottom panel shows the power spectrum of Alibag (left) and Visakhapatnam (right) January 2002 (D season).

Figure 2. Data 1 and Data 2 in the upper panel are the H-values of Alibag and Visakhapatnam in April 2002 (E season). Bottom panel shows the power spectrum of Alibag (left) and Visakhapatnam (right) in April 2002 (E season).

Figure 3. Data 1 and Data 2 in the upper panel are the H-values of Alibag and Visakhapatnam in June 2002 (J season). Bottom panel shows the power spectrum of Alibag (left) and Visakhapatnam (right) in June 2002 (J season).

Figure 4. Data 1 and Data 2 in the upper panel are the H-values of Ettaiyapuram and Tirunelveli in January 2002 (D season). Bottom panel shows the power spectrum of Ettaiyapuram (left) and Tirunelveli (right) in January 2002 (D season).

Figure 5. Data 1 and Data 2 in the upper panel are the H-values of Ettaiyapuram and Tirunelveli in April 2002 (E season). Bottom panel shows the power spectrum of Ettaiyapuram (left) and Tirunelveli (right) in April 2002 (E season).

Figure 6. Data 1 and Data 2 in the upper panel are the H-values of Ettaiyapuram and Tirunelveli in June 2002 (Jseason). Bottom panel shows the power spectrum of Ettaiyapuram (left) and Tirunelveli (right) in June 2002 (J season).

Figure 7. Data 1 and Data 2 in the upper panel are the H-values of Sabhawala and Tirunelveli in January 2002 (Dseason). Bottom panel shows the power spectrum of Sabhawala (left) and Tirunelveli (right) in January 2002 (D season).

Figure 8. Data 1 and Data 2 in the upper panel are the H-values of Sabhawala and Tirunelveli in April 2002 (E season). Bottom panel shows the power spectrum of Sabhawala (left) and Tirunelveli (right) in April 2002 (E season).

Figure 9. Data 1 and Data 2 in the upper panel are the H-values of Sabhawala and Tirunelveli in June 2002 (J season). Bottom panel shows the power spectrum of Sabhawala (left) and Tirunelveli (right) in June 2002 (J season).

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