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Study of Seismic Precursors by Wavelet Analysis

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Abstract

In this study we analyzed the NmF2 data by wavelet analysis at the time of strong seismic event. We used Ionosonde data for analysis. Data of maximum electron density of F2 layer (NmF2) was collected from NOAA space environment center. With the help of Mat-Lab software wavelet analysis performed. Results of the study showed some unusual perturbations in NmF2 parameter few days before earthquake. This fact can be used as precursory phenomena. It may be due to the emission of energy from the earth rock which propagate upward and perturb the F-region of ionosphere. This study may be useful for earthquake prediction.

Keywords: NmF2, ionosphere; earthquake; ionospheric precursors, wavelet analysis.

Introduction

Earthquake is one of the most destructive of all natural hazards and it has long been a dream of scientists to achieve effective prediction. The detection of electromagnetic perturbations prior to fault ruptures or volcanic eruptions has often been proposed as a simple and effective method for monitoring crustal activities and electromagnetic phenomena have been considered promising candidates for short-term earthquake prediction. So far, a lot of evidence of seismo-electromagnetic precursory signatures in a wide frequency range from DC to VHF has been reported[1-2]. Meanwhile, abundant indoor/outdoor experiments and numerical simulations[3-7] have confirmed the existence of this seismo-electromagnetic phenomenon. Because of skin depth, passive ground-based observation of ULF (ultra low frequency) geomagnetic signatures is considered to be the most promising method for seismomagnetic phenomena study. In order to verify electromagnetic phenomena preceding large earthquakes, a sensitive geomagnetic network has been installed in Japan[8] and plenty of data associated with moderate-large earthquakes have been accumulated. So far, there have been many reports on the ULF electromagnetic phenomena associated with the 2000 Izu Islands earthquake swarm. Different kinds of methodologies have been performed, such as principal component analysis[9-10], fractal analysis, polarization analysis[14-16] and direction-finding analysis[11-13]. In previous studies, the most significant results were found in H (NS) component by PCA and fractal analysis. In addition, we have found that there is a remarkable enhancement of energy in the Z (vertical) component at the period around 100s during the earthquake swarm using wavelet transform. After comparing the results with those at a reference station and geomagnetic activities, it is highly suggested that the anomalous enhancement of energy might be one of seismomagnetic phenomena[10] associated with the 2000 Izu Islands earthquake swarm.

Material and Methods

In this study data of foF2 were obtained from NOAA Space Environment Center and data of Dst index collected from WDC Koyoto Japan and OMINI web data server.

Maximum peak electron density (NmF2) is defined by
$$NmF2 = 1.24 \times (foF2)^2 \quad (1)$$

Where foF2 is the critical frequency of F2 layer

We have analyzed 30 days data records of NmF2, before and after the seismic shock.

Continuous Wavelet Transform (CWT): The wavelet transform was introduced at the beginning of the 1980s by *Morlet and Grossman,* who used it to evaluate seismic data. They modified the Gabor transform, also known as Windowed Fourier Transform, to produce the continuous wavelet transform. The idea was to change the width of the window function accordingly to the frequency of the signal being considered. The CWT, also called the *integral wavelet transform* (IWT), finds most of its applications in data analysis, where it yields an affine invariant time-frequency representation.

In order to be called wavelet a function must satisfy the following conditions: i. The integral of the wavelet function, usually denoted by Ψ, must be zero $\int_{-\infty}^{\infty} \psi(t)dt = 0$

This condition is known as the admissibility condition and assures that the wavelet have a mean zero. i. The energy must be unitary i.e, $\int_{-\infty}^{\infty} |\psi(t)|^2 dt = 1$
The second condition assures that the function is localized in both, physical and Fourier, spaces (time and frequency), i.e., the

Heisenberg relation must be satisfied. The CWT of a time series is defined by the integral transform,

In wavelet analysis,a Signal (S) is segregated into an approximation (A) and a details (D) as:

$S=A_1+D_1=A_2+D_2=A_3+D_1+D_2+D_3$

The approximations are the high –scale, Low frequency components of the signal. The details are the low scale, high-frequency components. The approximation is then itself split into a second-level approximation and details, and the process is repeated. For n-level decomposition, there are n+1 possible ways to decompose or encode the signal.

For the wavelet analysis we use the wavelet Biorthogonal. In following figure displays the characteristic of wavelet Biorthogonal. Fast numerical algorithms were developed to represent periodic functions in bi-orthogonal multi resolution analysis in two dimensions. They have showed that, in the Fourier domain, the decomposition and reconstruction algorithms had a matrix representation in terms of permutations and block diagonal matrices.

Results and Discussion

Analysis of ionospheric data for several strong earthquakes in Japan revealed the common feature of ionospheric anomalies observed before earthquakes. These anomalies are expressed in the form of sharp changes of NmF2 approximately 2 to 12 days before the seismic shock. We present six cases of earthquakes in which ionospheric perturbations were observed before the earthquake. Results related to these earthquakes are described below:

Japan: Hokkaido Earthquake occurred on Dec.14, 2004: During the month of December 2004, an earthquake occurred in Hokkaido (Japan). The intensity of this earthquake was 5.8 and focal depth 10 kilometers. Anomalous variation in NmF2 signal observed before two days from the main seismic shock. Results related to this earthquake are shown from figures 1 to 3. Figure 1 shows the continuous wavelet transform of NmF2. Figure 2 shows the retained energy percent in the signal. In this figure the left most graph shows how the threshold (vertical yellow line) has been chosen automatically (60.5) to balance the number of zeros in the compressed signal (purple curve that decreases as the threshold increases). This threshold means that any signal element whose value is less than 60.5 will be set to zero when we perform the compression. Threshold controls are located to the right (red box). The automatic threshold of 60.5 results in a retained energy of only 63%. In this cause the retained energy percentage is 97%. This may cause unacceptable amount of distortion, especially in the peak values of the oscillating signal. Figure 3 shows the NmF2 variation pattern and its wavelet analysis. It shows the signal characteristics at different levels.

Conclusion

The main idea we present in this paper is that the joint multi resolution wavelet analysis of self-potential signals and support data related to environmental forcing can represent a suitable basis to extract environment-induced electrical fluctuations. Wavelet transform translates the complexity of mixed global behaviours and transient patterns described by the electrical signals in simpler time sequences of coefficients over several resolutions or scales. We focused on hourly self-potential variability driven by earthquake by exploiting hourly measures as support data. Such data, transformed in the wavelet domain, were used to mark the time-scale regions where earthquakes act influencing self-potential variability. We showed that in these regions excited wavelet coefficients of the signal are detectable. Moreover, these coefficients can be filtered out, removing distortions with a mildly invasive technique. We think that our methodological approach is promising. However, there liability of the recovering procedure is strictly related to the quality of the support data and their ability to represent the actual mechanisms we are interested in.

In the analysis, wavelet techniques are basically used in two ways: as an integration nucleus of the analysis to get information about the processes and as a characterization basis of the processes. Some selected papers, here shortly described, reveals applications in a wide range of phenomena. Ranging from issues related to atmospheric-ocean interactions to nearby space conditions, all aspects are related to the atmosphere as a whole.

Several authors have discussed the problem of choosing the Daubechies orthogonal wavelet functions for turbulent signals, for example[19-20]. They have found that the best choice is a function that produce less unbalance on the signal energy, i.e., in which less coefficients are needed to represent the signal. These authors have developed a threshold procedure, that they denominate as Lorentz threshold, to identify the most relevant coefficients[21] has defined a coherence wavelet function using a Morlet wavelet to study the interactions between the wind and the oceanic waves[22] have discussed the practical applicability of such information in characterizing the cross correlation, since there are some difficulties in the analysis of the resulting information. In this study, the conventional treatment given to the Fourier analysis affects the temporal localization of the wavelet analysis.

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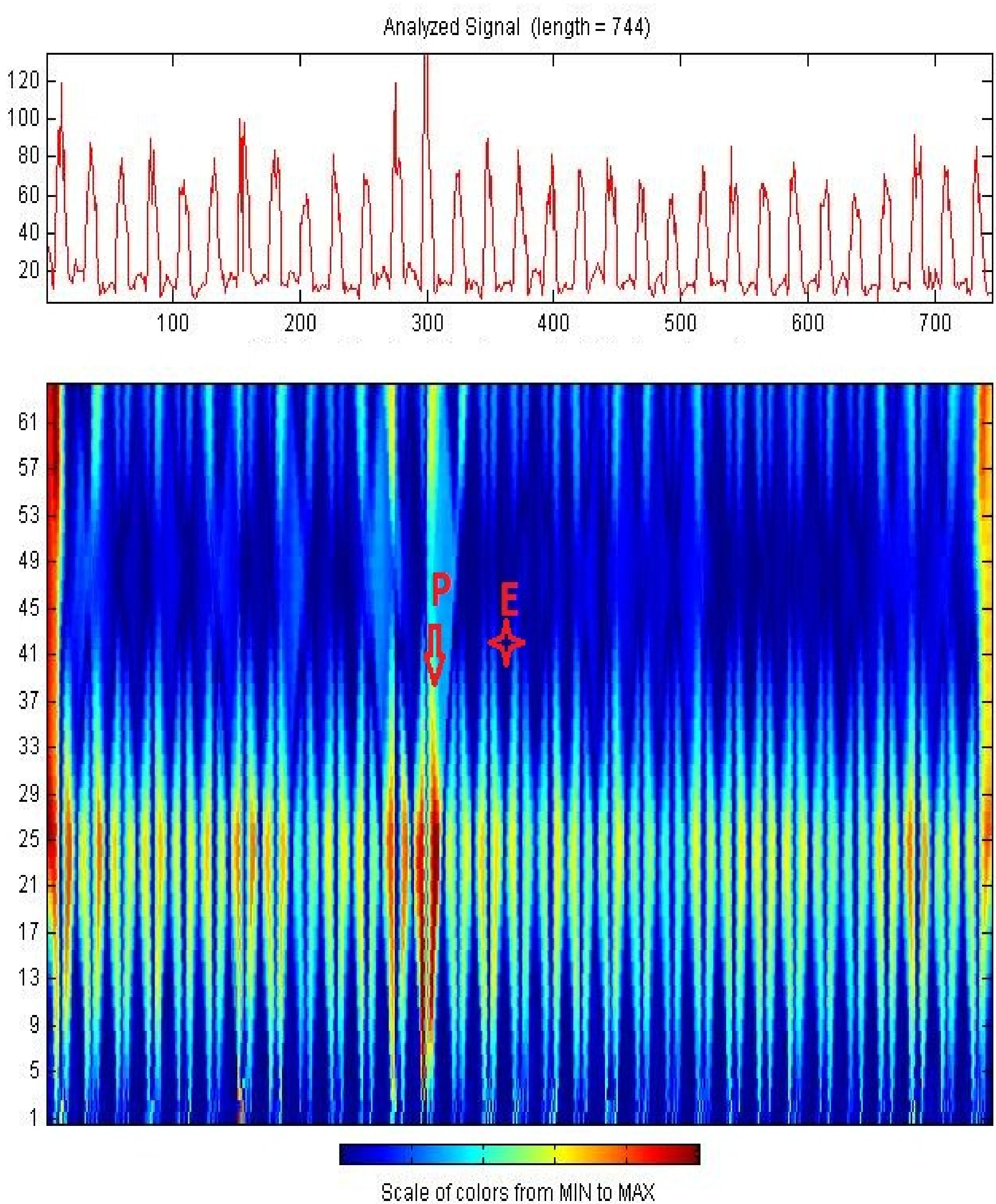

Figure-1
The continuous wavelet transform of NmF2

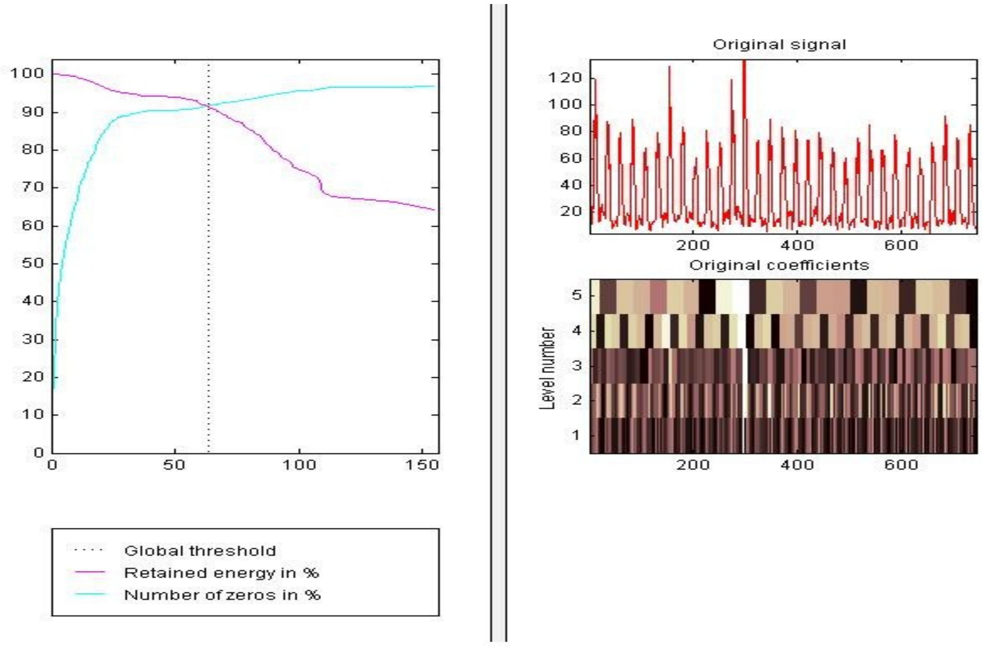

Figure-2
The retained energy percent in NmF2 signal

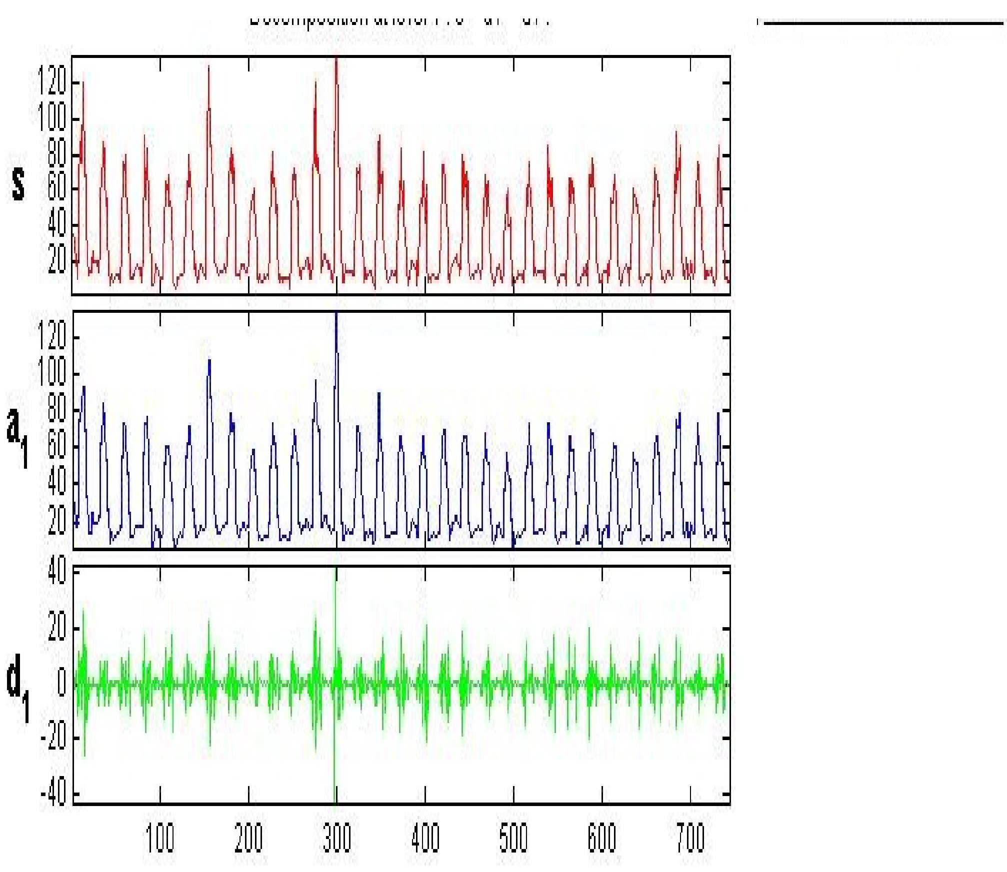

Figure-3
Variation of NmF2 over Wakanai Station

References

1. Johnston M., Review of electric and magnetic fields accompanying seismic and volcanic activity, *Surv. Geophys*., **18**, 441–476, doi:10.1023/A: 1006500408086 **(1997)**
2. Hayakawa M., Hattori K. and Ohta K., Observation of ULF geomagnetic variations and detection of ULF emissions associated with earthquakes, Review, *Electr. Eng. Jpn*., **162(4)**, 1–8, doi:10.1002/eej.20637 **(2008)**
3. Molchanov O.A. and Hayakawa M., Generation of ULF electromagnetic emissions by micro-fracturing, *Geophys. Res. Lett*., **22(22),** 3091–3094, doi: 10.1029/95GL00781 **(1995)**
4. Huang Q. and Ikeya M., Seismic electromagnetic signals (SEMS) explained by a simulation experiment using electromagnetic waves, *Phys. Earth Planet*. *In*., **109**, 107–114 **(1998)**
5. Huang Q., One possible generation mechanism of co-seismic electric signals, *Proc. Jpn. Acad. Ser. B*, **78(B7),** 173–178 **(2002)**
6. Huang Q.H., Controlled analogue experiments on propagation of seismic electromagnetic signals, *Chinese Sci. Bull*., **50**, 1956–1961 **(2005)**
7. Huang Q.H. and Lin Y.F., Selectivity of seismic electric signal (SES) of the 2000 Izu earthquake swarm: a 3D FEM numerical simulation model, *Proc. Jpn. Acad*., **86**, 257–264, doi:10.2183/pjab.86.257 **(2010)**
8. Hattori K., Takahashi I., Yoshino C., Isezaki N., Iwasaki H., Harada M., Kawabata K., Kopytenko E., Kopytenko Y., Maltsev P., Korepanov V., Molchanov O., Hayakawa M., Noda Y., Nagao T. and Uyeda S., ULF geomagnetic field measurements in Japan and some recent results associated with Iwateken Nairiku Hokubu earthquakes in 1998, *Phys. Chem. Earth*, **29**, 481–494, doi:10.1016/j.pce.2003.09.019 **(2004a)**
9. Uyeda S., Hayakawa M., Nagao T., Molchanov O., Hattori K., Orihara Y., Gotoh K., Akinaga Y. and Tanaka H., Electric and magnetic phenomena observed before the volcano seismic activity in 2000 in the Izu Island Region, Japan, *PNAS* 99: 7352-7355 **(2002)**
10. Hattori K., Serita A., Gotoh K., Yoshino C., Harada M., Isezaki N. and Hayakawa M., ULF geomagnetic anomaly as sociated with 2000 Izu Islands earthquake swarm, Japan, *Phys. Chem. Earth*, **29**, 425-436, doi: 10.1016/j.pce.2003.11.014 **(2004b)**
11. Gotoh K., Hayakawa M., Smirnova N. and Hattori K., Fractal analysis of seismogenic ULF emissions, *Phys. Chem. Earth*, **29**, 419–424, doi:10.1016/j.pce.2003.11.013 **(2004)**
12. Telesca L. and Hattori K., Non-uniform scaling behavior in Ultra Low Frequency (ULF) earthquake-related geomagnetic signals, Physica A, 384, 522–528 **(2007)**
13. Telesca L., Lapenna V., Macchiato M. and Hattori K., Investigating non-uniform scaling behavior in Ultra Low Frequency (ULF) earthquake-related geomagnetic signals, *Earth Planet. Sci. Lett*., 268, 219–224, doi:10.1016/j.epsl.2008.01.033 **(2008)**
14. Ismaguilov V.S., Kopytenko Yu. A., Hattori K. and Hayakawa M., Variations of phase velocity and gradient values of ULF geomagnetic disturbances connected with the Izu strong Ionosphere before Great Earthquakes, *Geomagn. and Aeronomy*, **33,** 658-662 **(2001)**
15. Ismaguilov V.S., Kopytenko Yu. A., Hattori K., Voronov P.M., Molchanov O.A. and Hayakawa M., ULF magnetic emissions connected with under sea bottom earthquakes, *Nat. Hazards Earth Syst. Sci*., **1**, 23–31, doi:10.5194/nhess-1-23 **(2001)**
16. Kotsarenko A., Molchanov O., Hayakawa M., Koshevaya S., Grimalsky V., P´erez Enr´ıquez R. and L´opez Cruz-Abeyro J.A., Investigation of ULF magnetic anomaly during Izu earthquake swarm and Miyakejima volcano eruption at summer 2000, Japan, *Nat. Hazards Earth Syst. Sci*., **5,** 63–69, doi:10.5194/nhess-5-63-2005 **(2005)**
17. Ismaguilov V.S., Kopytenko Yu. A., Hattori K. and Hayakawa M., Variations of phase velocity and gradient values of ULF geomagnetic disturbances connected with the Izu strong Ionosphere Before Great Earthquakes, *Geomagn. and Aeronomy,* **33,** 658-662 **(2001)**
18. Kopytenko Y., Ismaguilov V., Hattori K. and Hayakawa M., Determination of hearth position of a forthcoming strong EQ using gradients and phase velocities of ULF geomagnetic disturbances, *Phys. Chem. Earth*, **31**, 292–298, doi:10.1016/j.pce.2006.02.004 **(2006)**
19. Katul G.G., Albertson J.D., Chu C.R., Parlange M.B., Wavelets in Geophysics, in: Ch. Intermittency in Atmospheric Surface Layer Turbulence: the Orthonormal Wavelet Representation Wavelet Analysis and Its Applications, **4,** 81–105 **(1994)**
20. Vidakovic B., Statistical Modeling by Wavelets, Probability and Statistics, Wiley, New York **(2000)**
21. Liu J.Y., Tsai H.F. and Jung T.K., Total electron content obtained by using the global positioning system, *Terr. Atmos. Oceanic Sci*. **7,** 107-117 **(1996)**
22. Torrence C. and Compo G.P., A practical guide to wavelet analysis, Bulletin of the American Meteorological Society, **79(1),** 61–78 **(1998)**