DYNAMICAL FRACTAL ANALYSIS OF THE ACOUSTIC ULTRA-WIDEBAND SIGNAL CAUSED BY THE CHELYABINSK METEOROID

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ABSTRACT

The non-linear paradigm clams, that many processes in open, non-linear, dynamical systems, which caused by the non-stationary, powerful sources, are appeared to be short-time, non-linear, ultra-wideband and fractal ones. The acoustic signals created by the Chelyabinsk meteoroid fall were shown to be namely ones of them. Using a new fractal analysis method called as 'Dynamical Fractal Analysis', the fractal properties of these signals were investigated. The corresponding numerical characteristics were estimated and discussed.

1. INTRODUCTION

Being formulated in the late 1970s by prof. L. F. Chernogor, the non-linear paradigm claims, that many processes in open, non-linear, dynamical systems, which caused by impact of a non-stationary, powerful source, are appeared to be short-time, non-linear, ultra-wideband (UWB) and fractal ones [1 – 3]. The Chelyabinsk meteoroid fall is namely such source, and the Earth – atmosphere – ionosphere – magnetosphere (EAIM) system is namely such system. Therefore, it is not surprising, that using so called 'System Spectral Analysis', the acoustic signals generated in the EAIM system by the Chelyabinsk meteoroid fall were shown to be UWB ones [4, 5]. Moreover, the corresponding perturbations in the EAIM system were appeared to be global. This fact is fully explained by the phenomenon of appearance of the large-scale and global perturbations in the EAIM system caused by a non-stationary, powerful source influence. This phenomenon had been discovered in the former Soviet Union in the late 1980s by the scientific group led by prof. L. F. Chernogor [1 – 3].

At the same time, according the non-linear paradigm, the acoustic UWB signals listed above may be the fractal UWB (FUWB) signals. Therefore, the theme of the paper seems to be actual, topical and interesting.

The purpose of this paper is to investigate the fractal properties of these signals with usage of a new fractal analysis method, which is able to research a non-stationary fractal structure of a signal.

2. CHELYABINSK METEOROID FALL EVENT

The space body fall took place in Chelyabinsk region (Russia) February 15, 2013 and is known as 'Chelyabinsk meteoroid'. One of a large number of very complex processes in the EAIM system

generated during this event is the infrasonic waves. Being very powerful, these acoustic signals were detected by the stations of both the international system of monitoring of nuclear tests and the geophysical observatories. It is necessary to point, that amplitude and spectrum of the infrasound signals carry a lot of information about the source of the waves and the atmosphere parameters (see, for example, [6 – 9]).

The infrasonic signals generated by the Chelyabinsk meteoroid fall and investigated in this paper were detected by the sensitive microbarographs of the IS27 station (Germany) placed in the Antarctica.

Overcame the distance about 15500 km, first of them (the direct signal) was registered February 15, 2013 between 17.30 UT and 18.15 UT. The second signal (the reverse signal) passed a greater distance (about 25000 km) and therefore was received some later (February 16, 2013 between 02.50 UT and 03.35 UT). At the Figure 1, a and the Figure 2, a both the signals are shown.

3. DYNAMICAL FRACTAL ANALYSIS METHOD BASES

If a signal has complex, non-stationary fractal structure, the Hurst exponent calculated for whole signal is not able to describe this. at all [10]. The usage of a time domain window is needed. But a Hurst exponent value estimated in such way will depend from the window width. We propose a new idea to choice a window width, which may be considered as an optimal (in some sense) for a signal or for its part. First, it is necessary to estimate the fractal dimension D_H based on the Hurst exponent (in bounds of Generalized Brownian Motion Model they connected with $D_H = 2 - H$) with sliding time domain window with changing width T. In such way we obtain D_H distribution at the time-period plane (t, T). Second, we use module, angle and angle skeleton of the complex valued spectral function (SF) of the analytic wavelet transform (AWT) [11]. Researching the time-period structures of the signals, some fixed T values are obtained. Third, for these T values the dependences $D_H(T)$ are boiled and D_H values for each signal or each signal part are estimated. Thus, such approach we call as 'Dynamical Fractal Analysis' (DynFA).

4. ANALYSIS RESULTS AND DISCUSSION

According to the SSA result [4, 5], there are two UWB processes with changing mean frequency (ChMF) in both the direct (Figure 1, a) and the reverse (Figure 2, a) signals. In the direct signal the first ChMF UWB process started approximately at 17.41 UT ($t = 675$ s), its duration was $\tau = 600 - 660$ s, its wideband index was $\mu = 0,8$, the dynamical wideband index (for window width $\Delta t_w = 270$ s) was changed in bounds $\mu_d = 0,6 - 0,3$ with time, the disturbance periods of the signal were $T = 35 - 90$ s, the mean period T_0 was decreased approximately linearly from 65 s to 40 s. This information obtained in the SSA with the non-linear transforms usage can be seen at the Figure 1, h, but with bad quality due to much worse time-frequency resolution of the AWT. The DynFA shows, that the fractal dimension D_H of this process vary in bounds $1,38 - 1,59$ (Figure 1, d).

For the second ChMF UWB process started first of them started approximately at 17.52 UT ($t = 1300$ s), we had $\tau = 900 - 960$ s, $\mu = 0,8$, $\mu_d = 0,2 - 0,3$, $T = 20 - 60$ s, the mean period T_0 was decreased approximately linearly from 50 s to 30 s. With DynFA we obtain, that $D_H = 1,51 - 1,78$ (Figure 1, f).

For the first ChMF UWB process started approximately at 03.03 UT ($t = 785$ s) in the reverse signal, we obtained $\tau = 600 - 900$ s, $\mu = 0,7$, $\mu_d = 0,35 - 0,3$, $T = 20 - 40$ s, the mean period T_0 was decreased approximately linearly from 32 s to 22 s. The DynFA results show that $D_H = 1,45 - 1,77$ (Figure 2, f).

Second ChMF UWB process started approximately at 03.10 UT (t = 1190 s) had τ = 1500 s, μ = 0,8, μ_d = 0,5 – 0,2, T = 28 – 70 s, the mean period T_0 was decreased approximately linearly from 55 s to 30 s. The DynFA gives D_H = 1,61 – 1,77 (Figure 2, f).
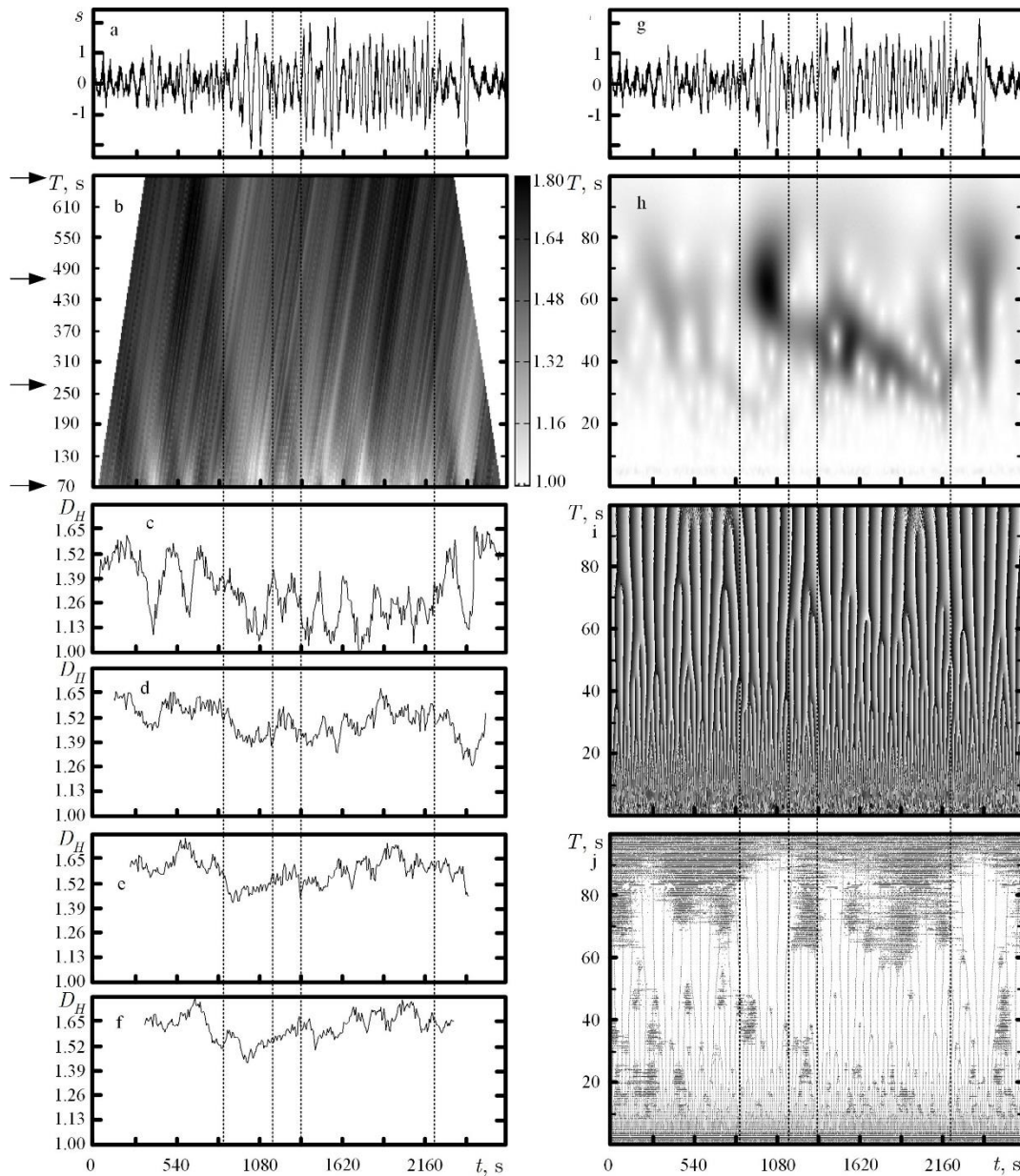

Figure 1. The DynFA results of the acoustic UWB signals generated by the Chelyabinsk meteoroid fall for direct signal (February 15, 2013): (a), (g) The signal in time domain; (b) The signal fractal dimension D_H based on the Hurst exponent at the time – period plane (t, T); (c) The signal fractal dimension D_H with time t for the time-domain window with fixed width T = 70 s; (d) The same for T = 270 s; (e) The same for T = 470 s; (f) The same for T = 670 s; (h) The AWT SF module obtained with complex Morlet wavelet cmor1-1.5; (i) The AWT SF angle obtained with complex Morlet wavelet cmor1-1.5, (j) The AWT SF angle skeleton obtained with complex Morlet wavelet cmor1-1.5. The dotted lines help to divide a signal investigated at some parts, for each of the fractal dimensions D_H values are estimated. The arrows show the fixed T values, for which $D_H(T)$ dependences are built.

Most likely, the first UWB process in each signal pair may be explained by generation and propagation of the explosive shock wave. Second UWB process may be connected with generation and propagation of the ballistic wave.

It is important to point, that the signals analyzed contain a lot of information about as their source, as the state of the environment along the signal propagation path.
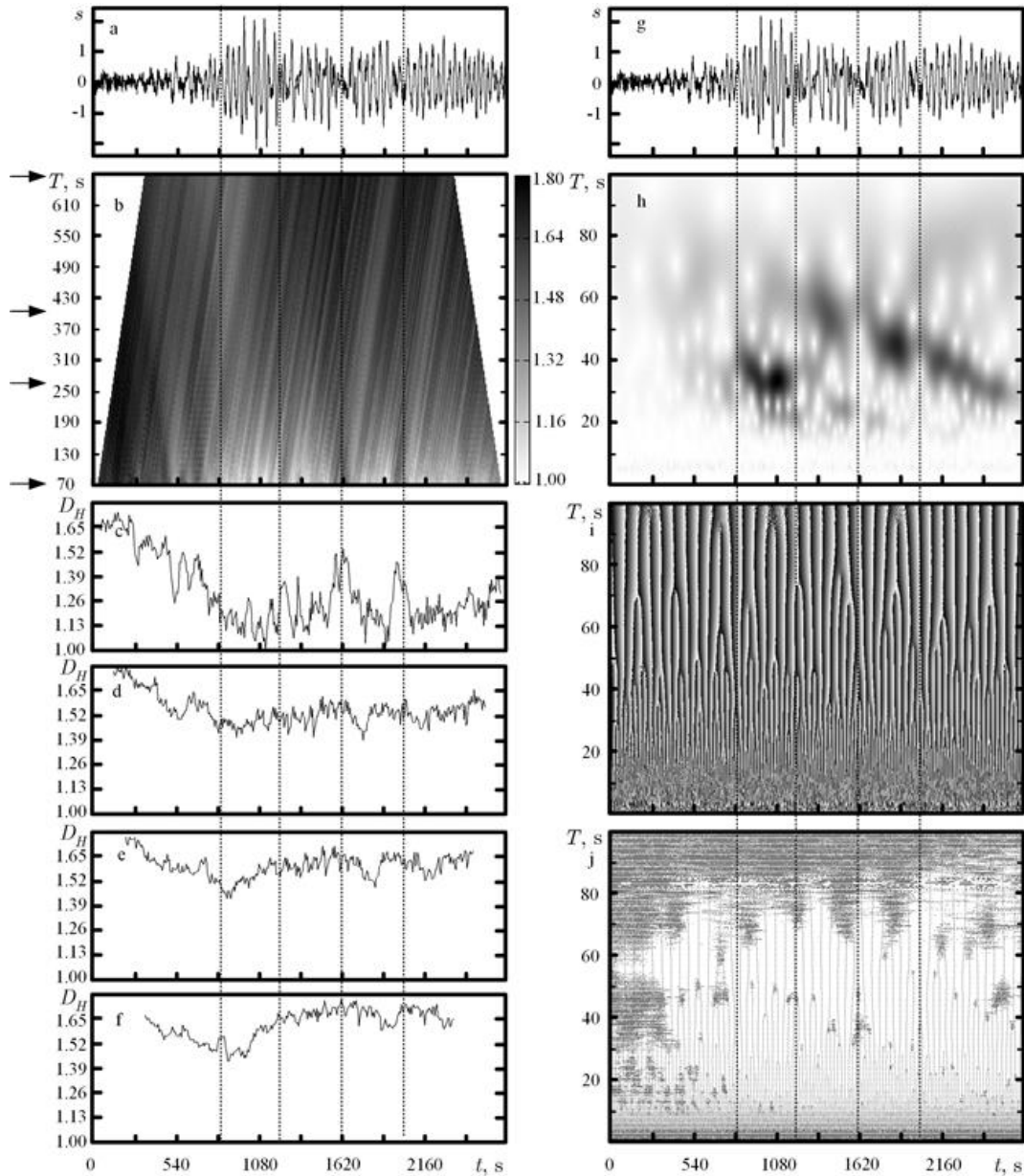

Figure 2. The DynFA results of the acoustic UWB signals generated by the Chelyabinsk meteoroid fall for reverse signal (February 16, 2013): (a), (g) The signal in time domain; (b) The signal fractal dimension D_H based on the Hurst exponent at the time – period plane (t, T); (c) The signal fractal dimension D_H with time t for the time-domain window with fixed width $T = 70$ s; (d) The same for $T = 270$ s; (e) The same for $T = 470$ s; (f) The same for $T = 670$ s; (h) The AWT SF module obtained with complex Morlet wavelet cmor1-1.5; (i) The AWT SF angle obtained with complex Morlet wavelet cmor1-1.5, (j) The AWT SF angle skeleton obtained with complex Morlet wavelet cmor1-1.5. The dotted lines help to divide a signal

investigated at some parts, for each of the fractal dimensions D_H values are estimated. The arrows show the fixed T values, for which $D_H(T)$ dependences are built.

5. CONCLUSIONS

The acoustic UWB signals generated by the Chelyabinsk meteoroid fall were found to be the fractal ChMF UWB processes with complex, non-stationary fractal structure.

Using a new fractal analysis method created specially and called as the 'Dynamical Fractal Analysis', the non-stationary fractal properties of the acoustic signals generated by the Chelyabinsk meteoroid fall were investigated and corresponding numerical characteristics were estimated.

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