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FRACTAL MODELING OF SANIMETER TIME SEQUENCES OF SOLAR RADIO RADIATION

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In this work, we used the data of solar observations obtained by various radio astronomy devices. Since these data show the unsteadiness of processes in the solar atmosphere, it is important to use the dynamic fractal analysis method. In other words, when studying the complex processes taking place on the Sun, we took into account synergetic approaches - nonlinearity and dissipativity in dynamical systems. It was found that if the found values of the fractal estimate $1 < D_t < 1.5$, obtained on the basis of the time series of fluctuations in the solar radio emission, then the existing series has a persistent (inertial) character. The practical application of the modern dynamic method of fractal analysis made it possible to determine the dynamic parameters (evolution of spots, forecast flare events and estimate their power, etc.) on the Sun.

Keywords: Solar radiation – Unsteady time series – Synergetic – Fractal analysis – Forecasting – Space weather.

1. INTRODUCTION

By the end of the 20th century, Russian radio-physicist O.I. Yudin, who studied solar radio emission, confirmed the existence of fluctuations associated with the physical processes occurring on the Sun during these radio emissions. Researcher at the Radio-physical Research Institute, located in Nizhny Novgorod in the 70s of the same century, prof. M.M. Kobrin (together with his collaborators) began to publish scientific results confirming that the dynamics of these fluctuations are associated with solar flares [1,2]. Despite the fact that these observations are carried out on radio astronomy telescopes with a diameter of $2 \div 100$ meters and operating at frequencies f $= 1 \div 17$ GHz in the territories of different countries, the results obtained currently contradict one another. The main reasons for

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this were partially explained in [3]. The application of the Fourier transform and its various modifications based on fluctuations of solar radio emission is the most important of these reasons, although these classical methods allow obtaining more realistic results in the study of stationary processes. Over the past few decades, researchers have discovered that there are a number of important events and processes in the world that cannot be interpreted only by the theory of oscillations and waves. Here, “chaos” is implied as an indicator of the transition to nonlinear systems in real evolutionary processes. Thus, in order to understand the essence of complex events and processes, it is necessary to accept the nonlinearity and dissipativity of dynamic systems. The theory of dissipative structure is understood as a complex of concepts of open physical systems and nonlinear dynamics. These are the main indicators for describing non-linear events that occur in the world. The causes of changes in action and evolution, according to this theory, are created by matter itself. Thus, regularity should be sought in their particular development [4]. Various dynamic and statistical methods are used to study time series reflecting stationary and non-stationary random processes. The “chaos” defined in the time series is intended for dynamic methods, and the “noise” is used in statistical methods. Each of these methods has its advantages and disadvantages. Over the past 30 years, specialists and experts in various fields of science have developed valuable scientific proposals and methods for studying the causes and evolution of processes occurring in living and non-living objects in the world. Some of them are widely covered in monographs and textbooks [5–7]. The study of time series based on our observations in any open systems consists in determining its structure and studying the future based on past data. Based on the aforementioned scientific works, in the proposed work by applying fractal analysis methods to time series obtained from radio astronomical observations of the Sun, an attempt is made to establish a forecast and diagnose a flaring process and its effect on the Earth’s atmosphere. In other words, by controlling the “chaos” of the process that we are exploring in dynamic methods (Fractal analysis, Wavelet and the Empirical model), the existence of deterministic randomness and its dynamics is investigated.

2. PROCESSING AND USE OF OBSERVATION DATA

As observational data, 12 isolated solar radio bursts with a power of $2 \leq K \leq 3$ were used. The observations were carried out on a 12-meter radio telescope at frequencies f = 1 GHz and f = 3 GHz at the Institute of the Ionosphere of the Republic of Kazakhstan in 2010-2015. Observations of the Sun continued regularly, from 08:00 to 18:00 (local time) at wavelengths of 10.7 and 27.8 cm. Given that the discrete amount of data received is $\Delta t = 5$ seconds, the amount of daily data is 7-8 hours is N = 5400-5700. It also allows you to observe the dynamics of long characteristic fluctuations, ranging from 5 to 70 minutes. The alleged radio flares and their observational data around them were processed using the dynamic Fourier transform (DFT) method and the fractal analysis method (FAM) [3, 9]. On the 24th cycle of solar activity, thanks to joint research, in addition to the proton events that took place on May 17 and January 6, 2014, three proton events were confirmed - January 27, March 7 and March 13, 2012 [9]. During these proton events, there was an increase in solar radiation on Earth. Proton event - is one of the most important and dangerous manifestations of space weather and requires a careful and comprehensive study. In addition, we also used the data of radio polarimeters operating at frequencies of 1.2.3 and 4 GHz, obtained in 2010-15, at the Nobeyama Radio Observatory (Japan). Information for mathematical processing is taken from the site "Http solar.nro.ac.jp". Time series are based on discrete values $\Delta t = 1min$. We studied time series associated with flare processes, which, in turn, were associated with the evolution of spots (field changes, increase in intensity) and variation in the range $5.5 \leq M \leq 8.7$. At present, the intensity of perturbations during proton events is estimated on a five-point scale from R1 (for the M-point flash) to R5 (M-12.5) for the brightest flash.

3. RESULTS OF PROCESSING DATA OF OBSERVATIONS AND THEIR ANALYSIS

Over the past 25 years, various modern methods have widely used such modern methods as fractal analysis, wavelet transform for time series analysis, which reflects the dynamics of non-stationary processes in physics, geophysics, radiophysics, biology, medicine and economics [3]. The application of the fractal analysis method to radio astronomy time series is reflected in [3,10]. Determining the degree of randomness of time series is the main essence of fractal analysis. There are various ways to determine the degree of fractal measurement. A simple R / S method for non-stationary time series was proposed by the English hydrologist Hurst [11].

In this method, the degree of fractal measurement - D_t is based on the H_t-Hurst exponent. In this work, using the modified fractal analysis, we analyzed the radio astronomy time series based on 12 powerful flashes and 5 proton events (3 days before the event, day of events, and two days after the event).

During the analysis of the solar flare process, the time series studied by us on the basis of local jumps, when the number of discrete points $100 \leq N \leq 300$ is relatively small, were of great importance for the study, we used the formula improved by Eric Neumann [12]:

$$H_t = ln(R/S)/ln(\pi + \frac{N}{2})(-0,0011^{*}lnN + 1.0136) \quad (1)$$

Here a=$\pi/2$ is a given positive constant.

Analyzing natural phenomena, Hurst came to the conclusion that, if the number of discrete values is insignificant, then the value a = 0.5 more realistically reflects the value of this constant. Then

$\pi = 2\text{a} = 2 \cdot 0.5 = 1$. We, in the following calculations, use formula (1), where, N is the amount of observation data of temporary data, S is the average square of the slope of the observation series, R is the magnitude of the span within the boundary. As a calculation point, Hurst used the formula $R = \sqrt{T}$, which he took from Einstein's work on the Brownian motion of particles, where T is an indicator of time. Estimates of the fractal dimension by the Hirst indicator D_t are determined by the following simple formula

$$D_t = 2 - H_t \quad (2)$$

Based on the time series obtained before, during and after the flash, the estimates for the fractal measurement D_t are determined $0.5 < H_t \leq 1$; $1 < D_t < 1.5$ The indicators allow us to conclude that time series based on radio astronomy oscillations are continuous time series. If $H_t \approx 0.5; 1 < D_t \approx 1.5, t$hen the process is defined as a random.

The results of statistical and dynamic processing of observation data are presented in the following graphs and tables:

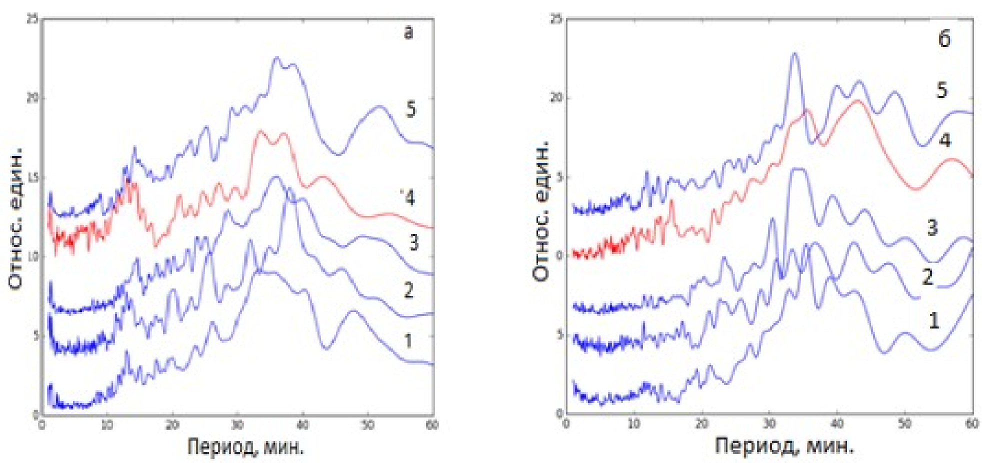

Fig. 1. (a, b) Averaged amplitude spectra of fluctuations of radio emission

Sun signal levels are 1 GHz and 3 GHz. Curves 4-Medium Solar flare spectrum. Curves below 4 days before the flash,Higher days after the outbreak. Each curve represents Averaged spectrum for 12 days.

It can be seen from the figures that in the power spectra shown for 1 (a), $t_x 10 \div 15$ minutes peaks with a characteristic change, and for $1(b) - t_x = 35 \div 40$ minutes peaks with a characteristic change prevail. Based on the results of observation at a frequency of 1 GHz, no correlation was found between power spectra and flare phenomena. From Figure 1 (b) it is clear that in the power spectrum based on the time series at a frequency f = 3 GHz, characteristic changes $t_x \approx 35 \div 40$ minutes prevail when approaching the flare phenomenon. The results obtained in this work were partially reflected in the model of “small sunspots” developed by A. Solovev and Yu. A. Kirichik [13]. In Table 1 it can be seen that as

Table 1. Time series around flash events, Hurst indicators and fractal analysis estimates based on the radio astronomy.

Days, months, year	3.03.2011	4.03.2011	5.03.2011	6.03.2011	7.03.2011 Flash day	8.03.2011	9.03.2011
Herst indicator H_t	0.827	0.825	0.828	0.814	0.766	0.825	0.830
Fractal dimension D_t	1.172	1.174	1.171	1.185	1.233	1.174	1.169

the day of events approaches (the day of the outbreak), randomness is replaced by smoother randomness.

Flash day	**Flash duration**	**During the event** D_t
	1) 04.54÷05.40	1.157
7.03.2011	2) 07.55÷08.41	1.171
	3) 09.00÷09.50	1.168

Based on the analysis of 5 proton events, we were able to conclude that an inverse relationship occurs between the estimation of the fractal dimension and the power of proton events.

Table 2. The relationship between the power of proton events and the estimation of fractal dimension on different days.

Date of proton events (day, month and year)	05.03.2012	09.03.2012	13.03.2012	07.03.2012
Power proton events	M 5.5	M 6.3	M 7.9	X 5.5; X 1.5 α-β-γ
Estimates of the fractal dimensions	1.272	1.260	1.246	1.193

4. CONCLUSION

The research presented in this work gives us the opportunity to draw the following scientific conclusions:

1. It was found that 1-3 days before an outbreak with a power of $2 \leq K \leq 3$ points, pulsations with characteristic change time of $t_x \geq 35$ min prevail.

2. It was found that the time series of fluctuations of solar radio emission, in accordance with a certain fractal value $1 < D_t < 1.5$ are continuous (inertial) time series. In other words, with the approach of flare processes, randomness is replaced by a more smoothly defined randomness.

3. The study of 5 proton events showed that the value of the calculated degree of fractal dimension is inversely proportional to the power of the proton event. More precisely, 1-3 days before the proton event $D_t(strong) D_t(week)$ The conditions are preserved.

4. It is established that when using the dynamic method of fractal analysis in radio astronomy time series, the control of the restrained randomness of the physical state caused by the processes occurring on the Sun and its interaction with the Earth's atmosphere is taken into account. This allows us to qualitatively and quantitatively evaluate the energy balance of the object we are studying. Thus, the modern dynamic method - fractal analysis, gives more realistic results in the study of unsteady processes occurring on the Sun.

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