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IDENTIFICATION OF LONG-PERIOD MHD FLUCTUATIONS IN THE MAGNETOSPHERE AS PRECURSORS OF FLARES BY METHODS OF WAVELET AND SKELETON ANALYSIS

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1. Introduction

It was observed earlier [*Bystrov et al*, 1979] that a few days before the expansion of a Solar flare can be observed long-period (20 minutes or more) geomagnetic pulsations in the components of the geomagnetic field of ground-based observatories. In [*Smirnova*, 2010] showed that indeed for 2-3 days before the Solar flare enhancement of long-period pulsations of H-component of the geomagnetic field in comparison with quiet periods is observed. There is also pointed out that the correlation coefficient of the spectral density of X-ray radiation and the horizontal component of the magnetic field can reach 93%. This allowed the claim on the effect of the spectral composition of ionizing radiation from the Sun to pre-flare spectrum of growing geomagnetic fluctuations. Unfortunately, this conclusion on the consideration of a narrow range of oscillation periods for one event of extreme flare is based. In addition calculated the correlation coefficient is not accurately set moments of synchronization of processes on terrestrial observatories. A major factor limiting consideration of direct communication fluctuations of Solar ionizing radiation and geomagnetic pulsations is the inertia of the ionosphere [*Barkhatov et al.*, 2004] is observed.

In our study using large experimental data, which includes data from 20 extreme X-ray flares is performed by wavelet analysis of geomagnetic pulsations at different scales within a five-day interval before each flare. Feature of the data is the use of wavelet-skeleton technology allows maximum eliminate uncertainty in the interpretation of results. The study aims to establish the possibility of using evidence obtained synchronization skeletons as precursors of a powerful Solar flares. It is necessary to test the hypothesis of the electromagnetic impact of Solar radiation on the physical processes in the Earth's magnetosphere.

The study was performed with minute data for the horizontal component of the geomagnetic field of six observatories Leirvogur, Valentia, Kanoya, Hatizyo, Kakioka, Memambetsu in a wide range of coordinates (latitude geom. 31^0-64^0) derived from the resource *http://wdc.kugi.kyoto-u.ac.jp*. Were analyzed in simultaneous minute data about the power of X-rays and the data on the Solar wind - the flow velocity, density, the magnitude of the IMF granted resource *http://spidr.ngdc.noaa.gov/spidr*. The study of each case included a flare interval of observations containing 4.5 days (6480 min) before register the flare and 0.3 days (500 minutes) after register. Thus, each analyzed interval contains 6980 minutes of simultaneous observations of the geomagnetic field, parameters of the solar wind and the power of X-rays. The main criteria for the selection of such events was magnetically quiet environment for the entire five-day observation period (|Dst|<20nT) and analyzed all flares have been attributed to the extreme power class X (W> 10-4 W/m^2). According to these criteria, 20 flares were analyzed according to the catalog *http://vso.nso.edu/cgi/catalogui*. The date of the analyzed flares of class X: 07.09.2005, 16.07.2004, 02.11.2003, 28.10.2003, 19.10.2001, 23.07.2002, 13.12.2001, 17.03.2003, 26.02.2004, 07.11.2004, 24.09.2001, 03.08.2002, 06.04.2001, 28.12.2001, 21.04.2002, 31.10.2002, 09.06.2003, 15.06.2003, 13.08.2004, 30.10.2004.

2. Selection tool for spectral analysis

The task of registering pulsations at a certain frequency in the horizontal component of the geomagnetic field can generally be reduced to the construction of the dynamic amplitude and frequency of the Fourier spectrum of the magnetogram with each participating in the experiment observatory. However, this approach does not allow to say exactly at what point in time there was of interest to us harmonica in the analyzed signal. This is due to the fact that the Fourier transformation algorithm operates with infinite harmonic functions, which leads the result of using, or to a good localization of the wide frequency band in time or for good specificity narrow bandwidth indefinitely in a wide time interval. As a result of the registration of interest to us, the harmonics can be determined with great inaccuracy. In addition, we have set our task need to check the fact of registration of the same type of long-period harmonics on all the analyzed stations at a specific time in the presence of a quantitative objective calculation of the consistency of the spectra obtained.

Such study may be performed under an alternative approach to the spectral signal processing - wavelet transform. Its advantage in the first definition of the basis decomposition of the analyzed signal in the form of a finite function which selected for a specific numerical experiment is provided. Secondly, wavelet analysis allows to obtain the spectrum at a specific frequency band at a particular time interval, which makes it possible to limit the search features of the original signal. Third, the use of post-processing technique results of wavelet analysis to

obtain the wavelet-skeleton spectra makes it easier for an objective comparison of the spectrums. So much for the successful evaluation of consistency spectral pattern should contain only the key features that reflect the sets of wavelet-skeleton spectrums.

In a study of the basic wavelet function is selected Daubechies of the fourth order. Scale wavelet transform coefficients in the frequency range considered in the maximum period of 5, 10, 15, 30, 60, 90, 120, 180, 240, 300 and 360 min. The resulting pattern of wavelet transforms processed by the search algorithm to represent the local maxima of the results of the calculation in the form of wavelet-skeleton spectrum. The resulting matrix skeleton range of each parameter of each event is a matrix with elements 0 and 1, where 1 corresponds to the local maximum at a particular frequency at a particular time. Then, by plotting each point of skeleton exactly corresponds to one pixel in the image. Such an approach to the construction of wavelet-skeleton spectral sets for the purposes of calculating the objective characteristics of the spectra comparison of pairs of skeleton was used.

3. The algorithm of the comparative analysis of skeleton spectrums

In our paper, a search of synchronization moments fluctuations of horizontal component of the geomagnetic field over the entire latitudinal range of the considered magnetic stations during the five days before an intense flare was made. The presence of regions synchronization during this time may serve as a indication of flare. Interpretation of the results of the comparative analysis of the primary skeleton sets calculated in the work on the basis of data from the observatories participating in the experiment. It is complicated by a long duration of the observed range, which prevents finding moments of synchronization of fluctuations. To solve this problem, after calculating the skeleton of the spectra and their comparison the overall picture with a Gaussian filter with a high contrast ratio, which contributes to visualize the degree of correlation of the vibrational modes at different observatories was treated.

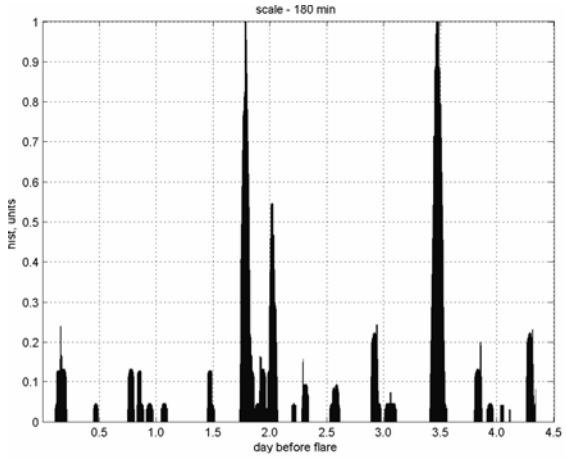

Fig. 1 The total amount of the normalized histogram moments synchronization of oscillations at all stations for all the analyzed flares by period 180 min. On the horizontal axis represents time in days before the flare of class X. The moment of registration of flare is located at left.

To avoid subjective judgments obtained in the analysis of skeleton sets required numerical evaluation. To do this, the study proposed an original algorithm for comparative analysis of the spectra with the calculation of skeletons objective characteristics registering moments of synchronization of oscillatory modes at all stations. Earlier, it was noted that the construction of graphs skeleton every point exactly corresponds to one pixel in the image. This method for constructing the wavelet-skeleton spectral sets suitable for the purposes of calculating the objective characteristics of the spectra comparison of pairs of skeleton. Further processing of the data will explain step by step.

1. We calculate the wavelet-skeleton patterns of the horizontal component of the geomagnetic field in the selected frequency bands registered for five days before to each analysis flare, which is then stored in the form of matrices with 1 and 0 elements.
2. The resulting 6 matrices (one on each station) with single (skeleton point) and zero (no point) elements for a specific frequency range used in the operation of column subtraction with record values of the difference in absolute value.
3. The picture with markers, marking the moments of complete synchronization of oscillations at the stations, a Gaussian filter with high contrast is treated. At this stage the individual, not grouped markers will be screened out (blown out), and the existing group of markers will be highlighted. The non-zero values of the differences are not considered at all, which allows to reduce the dimension of the problem to a minimum. As a result, the intensity of diffuse objects in the picture with markers shows the density of synchronization.

4. For obtained in the previous step one-dimensional picture of the intensity distribution histogram is calculated in black on a scale from 0 (completely white) to 1 (completely black).

5. For all analyzed flares, and for each of the analyzed scale fluctuations are calculated histogram of the intensity distribution groups moments of complete synchronization of oscillations. The histograms corresponding to one scale are summarized and linked to the timeline. For ease of interpretation, the results expanded time axis so that the origin of the abscissa corresponds to the flare time. Histogram for oscillations with a period of 180 minutes presented on Fig. 1. Here clearly shows that there are extremes of 2 and 3.5 days before the expansion of the flare. This corresponds to the sync moments of the horizontal component of the geomagnetic field in the studied events.

In order to test the alternative hypothesis by impact of Solar wind parameters (flow velocity, density, and the magnitude of IMF) on the Earth's magnetosphere in the pre-flare intervals are calculated cumulative histogram of the intensity distribution groups moments of complete synchronization of oscillations in these parameters. An example of an appropriate analysis for the period of oscillation 180 min in Fig. 2 is shown.

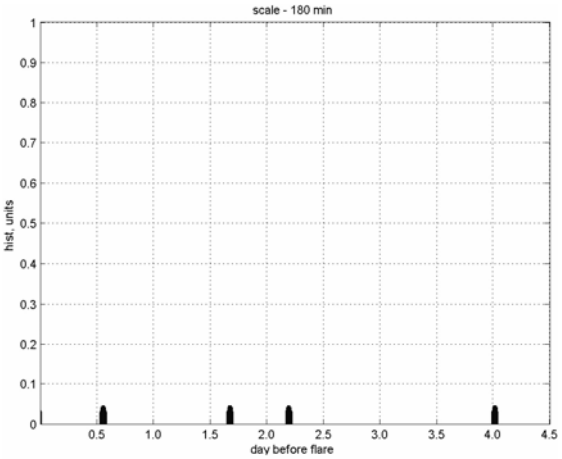

Fig. 2 The total amount of the normalized histogram moments synchronization of oscillations for near-Earth parameters for all the analyzed flares by period 180 min. On the horizontal axis represents time in days before the flare of class X. The moment of registration of flare is located at left.

4. Interpretation and verification of the results

The resulting cumulative histogram of the normalized moments of horizontal sync component of the geomagnetic field in a wide geographic range in different ranges of periods for its extremes the connection with the phenomena of X-ray flares was demonstrate. With the increasing analyzed periods availability of extrema becomes more prominent. Extremes of histograms for oscillations with a period of 180 minutes, the most informative - they are marked with 2 and 3.5 days to extreme flare.

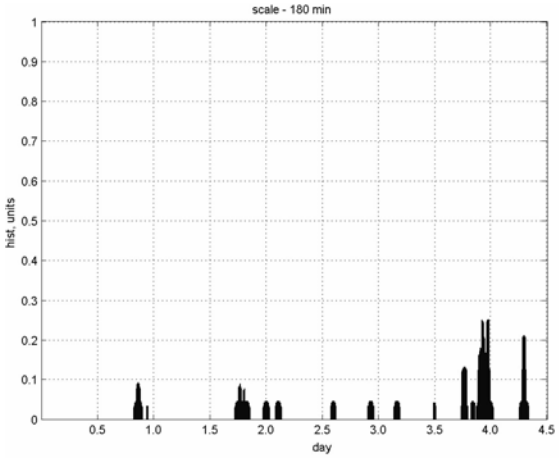

Fig. 3 The total amount of the normalized histogram moments synchronization of oscillations at all stations for period of 180 minutes, when within 5 days there has been an flares of class M or X not observed. The y-axis represents the number of occurrences of the histogram moments of complete synchronization of oscillations at all stations. On the horizontal axis represents time in days.

Test results of the numerical analysis at 20 five-day intervals 2001-2005 was performed. During which Solar flares class M or X were not observed. By the method proposed in the study for all intervals and analyzed undisturbed for each analyze scale of oscillations histogram of intensity groups moments of complete synchronization of oscillations recorded on magnetic observatories were calculated. The histograms corresponding to the same scale as summarized and linked to the timeline.

As seen in the histogram shown (see Fig. 3) previously detected extremes (see Fig. 1) is not observed, which indirectly confirms the validity of the developed method in the study and allows us to offer following hypothesis. The mechanism of occurrence and further synchronization in large geographical limits may be an increase of the ionospheric conductivity and hence the enhancement of ionospheric current system oscillations by Solar ionizing electromagnetic radiation before extreme flare. Fluctuations in the intensity of this radiation in geomagnetic pulsations from the periods of the order of an hour or more, which can be associated with the corresponding inertia of the ionosphere [*Barkhatov et al*., 2004] are shown.

An alternative possibility of a long-period geomagnetic fluctuations may be the impact of the magnetized Solar wind flow changes as a result of oscillatory processes in the Solar atmosphere. To test this hypothesis were made total histogram moments synchronization of oscillations in the parameters of the Solar wind and IMF (Fig. 2). The resulting histograms reflect moments synchronization of oscillations in the velocity of the Solar wind, its density and the magnitude of IMF, which are often observed in the oscillations with periods of about 30 minutes. Indeed, such is the characteristic time scale restructuring of the oscillatory process in the Solar wind [*Kepko and Spence*, 2003; *Barhatov et al*., 2013]. However, histograms do not contain the results previously mentioned extremes, and can not indicate future flare. Thus, according to our study only mechanism of occurrence and sync of further geomagnetic pulsations in the wide geographic range may be an increase of the ionospheric conductivity with increasing vibrational ionospheric current systems by solar ionizing electromagnetic radiation before extreme flare.

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