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Search for Periodicities in Galactic Cosmic Rays, Sunspots and Coronal Index Before Arrival of Relativistic Protons from the Sun[1]

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Abstract—Using different approaches and techniques of wavelet analysis we analyze variations (oscillations) of galactic cosmic rays, solar spot number, and coronal index of solar activity before ground level enhancements of solar cosmic rays. Obtained results are discussed in frames of recent ideas about periodicity phenomena in the photosphere, and corona of the Sun, interplanetary medium, and cosmic rays.

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INTRODUCTION

Solar proton events (SPE) are registered at the Earth orbit rather frequently and represent one of the important manifestations of solar activity (SA) [1, 2]. Until recently they usually were considered as the stochastic process caused in main by solar flares. At the same time, their clause relations to centers of solar activity, coronal mass ejections (CMEs) and shock waves is not subjected to doubt [2, 3]. At last, it is possible to state, that frequency of SPE occurrence to some extent follows the 11-years cycle of solar activity [1, 4, 5].

The majority of SPEs are observed in nonrelativistic range of energies (from ≥10 MeV up to ≤500 MeV for protons). Oscillations of various characteristics of such events were widely studied in the past [1, 4, 6]. Thus many periods, intrinsic to other SA parameters, in particular periods about 5 months and ~2 years in length have been detected.

On average once a year relativistic solar protons with energy from 500 MeV up to ≥10 GeV arrive to the Earth. Events of such type received a title of ground level enhancements of solar cosmic rays (SCR), or Ground Level Enhancements (GLEs). In total for the period 1942–2006 70 GLEs were fixed [2]. The widely known event of 23 February, 1956 (GLE05 in the numeration accepted nowadays) remains till now the largest one for the whole history of observations.

The majority of GLE events are observed preferentially on a rising or descending section of a curve of 11-years cycle of solar spots. They are rare in a maximum of a cycle and, in practice, are absent during solar minimum [1, 5]. Thus on a hum noise of quasi-periodic as a whole variations there are possible the strong fluctuations of frequency of occurrence of separate GLEs [1, 2, 4, 5]. The study of characteristics of SPEs (and, in particular, GLE) gives valuable information about properties of a source, processes of acceleration and transport of the accelerated particles, about fundamental properties of the Sun as a star [1, 2], for example, about maximal abilities of the solar accelerator (or accelerators), about the structure and dynamics of magnetic fields in the solar atmosphere, about magnetic parameters of interplanetary medium.

On the other hand [6], there is an actual task of prediction and providing of radiation safety for the crews and electronic equipments onboard spacecraft (SC), especially at the stages of planning and realization of interplanetary missions.

In connection with noted above fundamental and applied problems of Sun-Earth physics, in the present paper an attempt is undertaken to investigate behavior of series of cosmophysical parameters on the eve of GLE with the help of up-to date technique of the wavelet-analysis [7].

[1] The article was translated by the authors.

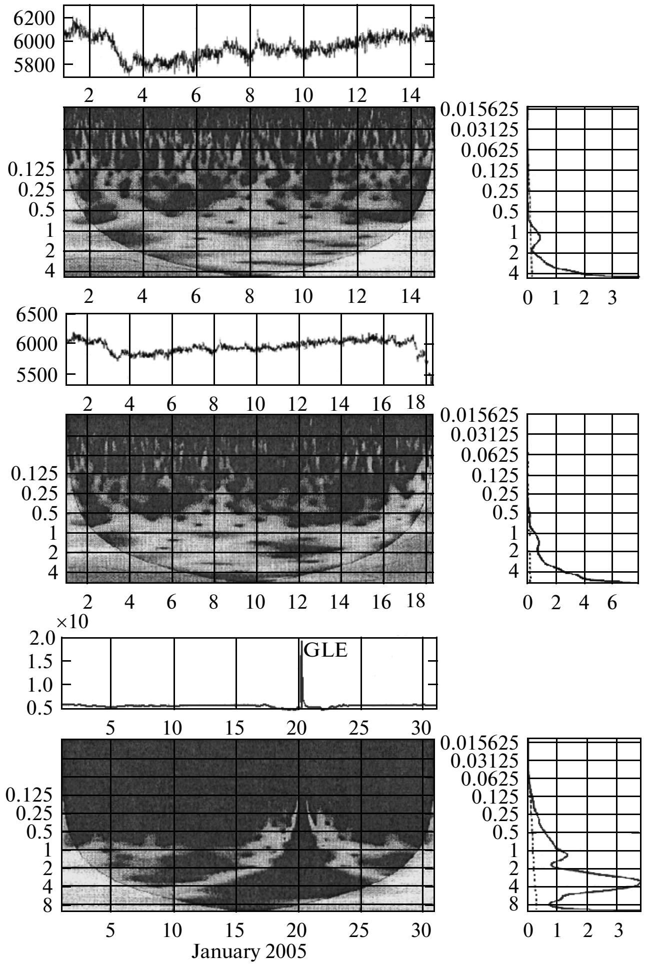

Fig. 1. Temporal profiles of intensity and wavelet-spectra of oscillations of GCR and SCR 5 days prior to event GLE on January, 20, 2005 (the left-hand panel, the upper pair of graphs), for 2 days (a middle pair), and in a day of GLE itself (the lower pair) in view of arrival of powerful SCR flux. Graphs of intensity and the wavelet-diagrams built at a various time resolution on the data of neutron monitor station Oulu (in units of the neutron monitor count rate); the *x*-axis shows real time (days of January, 2005); periods of oscillations (*y*-axis) are presented in days. On the right panels appropriate power spectra of oscillations in arbitrary units (*x*-axis) are shown from top to down depending on period in days (*y*-axis). The dashed line shows a power of red noise at a confidence level of 95%.

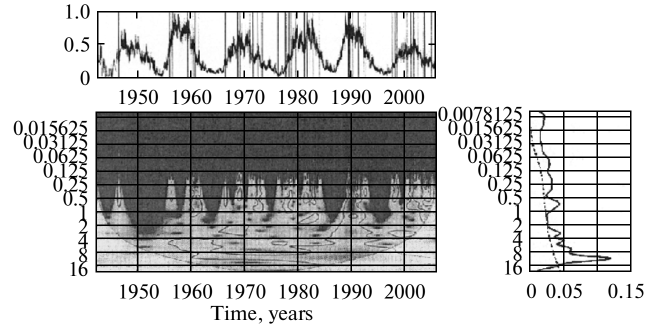

Fig. 2. Oscillations of frequency of GLE events. On the left-hand panel above are time series PWM (it built by a method [12] on dates of detecting of 70 events GLE in 1942–2006, thin verticals), imposed on the broken-up curve of number of solar spots. Below is the wavelet -diagram for a spectrum of oscillations (on the y-axis are periods in shares of year). On the right panel the spectrum of a power of oscillations in arbitrary units (*x*-axis) is shown depending on period in shares of year (*y*-axis). The dashed line shows a power of red noise at a confidence level of 95%.

1. OBSERVATIONAL DATA AND METHODS OF ANALYSIS

As is noted in [8], magnetic activity of the Sun frequently differs by nonlinear, short-term and random behavior. For this reason we used methods of the wavelet-analysis [9–12] to compare behavior of indicators of SA and cosmic rays to mathematical models. For the analysis four outstanding GLEs have been selected: 23 February 1956 (GLE05), 14 July 2000 (GLE59), 28 October 2003 (GLE65) and 20 January 2005 (GLE69) (DataBase at World Data Center C, Japan; DataBase at World Data Center B, Russia).

First of all evolution of a power spectrum of GCR fluctuations 50 days prior to the moment of concrete GLE has been investigated. Thus for the analysis of event GLE05 the data of the neutron monitor on a mountain Climax (Canada) were used. For three remaining GLE the data of Oulu (Finland) station were analyzed. To find singularities in behavior of SCR fluxes, fit in the capacity of prognostic indications, we analyzed the data of observations inside a time intervals of separate GLEs. Further the coherent wavelet-analysis has been applied to daily average values of number of solar spots (http://sidc.oma.be/sunspot-data/) and to the data about the coronal index CI (http://www.ngdc.noaa.gov/stp/SOLAR/solintro.html). The significance level of a wavelet-spectral power was estimated in view of recent developments in deriving theoretical wavelet-spectra for processes of white and red noise [9]. It is important to note, that the power of red noise grows with decrease of frequency [13].

2. RESULS

For illustration of effectiveness of the wavelet analysis results both for a separate GLE, and for their complete series for all time of observations are presented below. In Fig. 1 the evolution of a spectrum of GCR oscillations several days prior to GLE on January, 20, 2005 is shown. On the upper left panels intensity of cosmic rays, including the increase of SCR flux within the day of given GLE is presented. The lower panels reflect wavelet-spectra of oscillations. By the more dark color periodicities with a larger power (or with a high degree of coherence) are shown. The lighter coloring corresponds to low-power oscillations (or with a low level of coherence). A mask of the U-tube form contours the area of coherence with a confidence level of 95%. On the right panels from up to bottom are shown appropriate power spectra of oscillations in arbitrary units (*x*-axis) in dependence on a period in days (*y*-axis).

From Fig. 1 it may be seen that frequencies of oscillations evolve in time: starting from a low value many days prior to the event, the frequency rises gradually in accordance with approaching of the event date. During a day of the event all these periods (frequencies) are presented simultaneously. As a whole the wavelet-analysis shows, that each of GLE is characterized by its own set of periods. the majority from which, however, is inside an interval from 15 min till 10 h.

In Fig. 2 results of the wavelet-analysis for dates (days) of detection of GLE events are presented. In addition to well-known earlier periods of SA (0.3, 0.5, 0.7, 1.3, 3.5, 7 and 11 years), periods by duration 2.5, 5–8, 11, 22–30 and 60 days are revealed.

Also anomalities in a power spectrum of SA before GLE have been detected. It is revealed, that anomalities are the positive if GLE has amplitude >100%, and the negative at amplitude ≤100%.

3. DISCUSSION AND CONCLUSIONS

The majority of the periodicities retrieved by us are common for SCR, solar spots and a coronal index, i.e. synchronization of oscillations in various layers of the solar atmosphere: from the photosphere up to the corona takes place. It can testify that the generation SCR affects rather large areas in the atmosphere of the Sun. More disputable result of our work is conclusion about a possibility to find uniform criterion for a prediction of SCR events, built on the basis of specific behavior of GCR oscillations several weeks (days) prior to a GLE event.

More recently authors [14] have applied the wavelet-analysis to searching periodicities in behavior of a solar flare index (SFI) during 21–23 cycles of SA. In all cycles of SA on a significance level, at least 90%, a period ~27 days have been found which has an apparent origin (period of solar rotation). Besides, the following well-defined periods have been obtained: 152 days for cycle 21; 73 days for cycle 22; 62 days for cycle 23. In this context, it is interesting the property of GLEs to be clustered preferentially on rising and descending sections of a curve of 11-years cycle of solar spots [4, 5]. On the data of ground based observations for 1942–1990 it has been shown [15], that the solar flares causing GLEs, are forbidden essentially during a transition phase of cycle when there is a change of sign of the global magnetic field of the Sun near to periods of SA maxima. Authors [15] consider that lack of GLE in a maximum of SA is caused by not the depressing of SCR generation because of the strong magnetic fields, but a decline of effectiveness of a acceleration of particles during structural reorganization of fields of the Sun in a transition period. Moreover, the structure of large-scale magnetic fields in a corona strongly varies during a cycle. Therefore, to separate effects of acceleration of SCR and their escape from the solar atmosphere, it is necessary to investigate this structure for individual GLE events [1, 2]. More detailed account of a procedure and our results can be found in [16].

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