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*Pc*1 Biotropic Geomagnetic Pulsations Observed with a Hall Sensor Magnetic Field Detector

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Abstract—Data obtained with a Hall sensor magnetic field detector have been used to record the spectral components of the geomagnetic field. An analysis of the spectral characteristics of geomagnetic oscillations has shown that the variations identified in the vicinity of the strong magnetic storm on November 4, 2021, are oscillations of the "pearl" type, i.e., *Pc*1 biotropic geomagnetic pulsations. Pearls were also observed in the vicinity of some weak magnetic storms in 2021–2022, including in the absence of magnetic disturbances. At the same time, they were not observed during the passage of some strong magnetic storms. Thus, it is not entirely correct to state that the human body is adversely affected only in magnetically disturbed periods.

Keywords: *Pc*1 pulsations, magnetic storms, biotropicity, pearls

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INTRODUCTION

Statement of the Problem

Pulsations in the ELF spectral range (hydromagnetic hiss and oscillations of increasing frequency) are excited due to the kinetic instability of the distribution of energetic particles that fill the earth's magnetosphere. By contrast, the generation of longwave pulsations (natural oscillations of the magnetosphere) is a hydrodynamic type of instability, occurring, for example, when the solar wind flows around the magnetosphere. The theory of cyclotron instability of protons in the outer radiation belt is the most developed in the linear approximation. Considered by many researchers as the source of pearls, this instability is caused by the anisotropy of the distribution of energetic protons with respect to velocity.

*Pc*1 geomagnetic pulsations are hydromagnetic waves of natural origin in the range of 0.2–5 Hz. The central frequency of these waves varies depending on the level of geomagnetic activity: 0.5–0.7 Hz at very low geomagnetic activity (for $Kp < 2$) and in the range of 1.0–1.2 Hz (for $Kp = 2$–3) (Feigin et al., 2015). These pulsations can be successfully used, for example, for diagnosing the earth's magnetosphere, electromagnetic sounding of the crust, and geological exploration.

On the recorder tape, the magnetogram looks like a string of pearl necklaces. In view of this, Kleimenova and Troitskaya (1992) proposed the term *pearls* for similar temporal quasi-monochromatic series in the *Pc*1 range with an amplitude of $\sim 10^{-2}$–10^{-1} nT. The effect of such weak magnetic fields on biological systems is the subject of research in magnetobiology. Its modern development is accompanied by a number of objective difficulties associated with a significant lag between theory and experiment.

Academic interest in this issue is constrained by the lack of a clear physical explanation of experimental data and an evident imbalance in the representation of physical and biological sciences in magnetobiology: the involvement of physicists in solving problems of magnetobiology is extremely insignificant. Nevertheless, the problem of the adverse (biotropic) impact of magnetic storms on the biosphere and human health has been discussed in the scientific literature for more than 50 years.

The action of weak magnetic fields in the *Pc*1 range is below the threshold for activating protective biological mechanisms and, therefore, can accumulate at the subcellular level. These pulsations can be biotropic (unfavorable in terms of the quality of impact on the human body). Kleimenova and Troitskaya (1992) suggested that the biotropic effect of magnetic storms depends on the wave structure and spectrum of geomagnetic pulsations, which represent the so-called fine structure of a magnetic storm. This implies a stricter assertion that not every magnetic storm is biotropic, and only a detailed analysis of the spectral portrait of a magnetic storm can describe the detrimental nature of its impact.

RESEARCH METHODOLOGY

Since data on the state of the earth's geomagnetic field are obtained using expensive stationary groundbased and satellite magnetometers, the monitoring of the fine spectral structure of the geomagnetic field is very difficult. To overcome these difficulties in solving applied problems, Kubov and Slivinsky (2014) proposed a simple and economical method for monitoring the earth's geomagnetic field with the help of Hall sensors. With appropriate automation, this measuring system provides a cost-effective and technically accessible real-time recording of local perturbations in the geomagnetic field both for research purposes in university laboratories and as a preventive measure to alert the general population about current unfavorable conditions.

We have shown that this method can be used for recording the amplitude of the earth's geomagnetic field with a time step of 1-s in real time, followed by data archiving and their spectral processing. The studies were performed at the stand of the Ukrainian Radio Engineering Institute (UREI) in Nikolaev.

Since 2015, the readings of the Hall sensor magnetic field detector have been archived with a time step of 0.1 s (a sampling rate of 10 Hz). This rate allowed the amount of processed signal information to be increased by an order of magnitude compared to 1-s processing conditions under the same time intervals. This allows us to hope for the identification of pearls with amplitudes of an order of magnitude smaller than units of a nanotesla due to a respective increase in the coherent accumulation of signal information in the process of spectral processing.

Under the passage of a long-term strong magnetic storm that occurred on March 17, 2015, the readings of the magnetic field detector were archived at the URTI stand continuously for several months. Spectral processing of the signal information made it possible to successfully identify *Pc*1 geomagnetic pulsations of the pearl type. A detailed description of the observation results can be found in (Slivinsky, 2015).

RESULTS AND DISCUSSION

For various reasons, no regular recordings of the geomagnetic field at the UREI facility had been conducted for some time after 2015. Data archiving on some time intervals resumed in 2019 and was adapted, if possible, to the times of magnetic storms. However, due to low solar activity (and, accordingly, the rare occurrence of magnetic storms) and frequent hardware and software failures (including due to the COVID-19 pandemic), such events were recorded extremely rarely. Nevertheless, in the vicinity of the long and strong magnetic storm of November 4, 2021, there was an archival recording at the UREI stand from 11:00 to 17:00 local time. Figure 1 shows the recorded variations in the earth's magnetic field according to the data of the Magnetic Observatory of the Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Russian Academy of Sciences, Troitsk, Moscow (IZMIRAN).

The record stored at the UREI stand from 09:00 to 15:00 local time consisted of n = 248902 0.1-s readings. At the first stage, the spectrum with a Fourier base of order n was calculated. Since only the real part of the Fourier transform was considered, the number of filters at the base of the Fourier spectra shown in Figs. 1 was $n/2$.

If the spectral density maximum was observed in a filter with number f, period T of the corresponding oscillation was estimated using expression $T(\mathrm{s}) = 0.1(n/f)$. Figure 2 shows the calculated spectrum for the time interval from 12:00 to 18:00 local time on November 4, 2021.

According to Fig. 2, the highest values of spectral density according to the estimated signal-to-noise ratio S/N (denoted as circles) belong to filters with numbers $f_1 = 5570$, $(S/N) \approx 1.5$; $f_2 = 69457$, $(S/N) \approx 1.2$; and $f_3 = 106122$, $(S/N) \approx 3.65$. The corresponding estimates of the oscillation periods are $T_1 = 0.1(n/f_1) = 4.46$ s ($1/T_1 = 0.22$ Hz), $T_2 = 0.1(n/f_2) = 0.358$ s ($1/T_2 = 2.79$ Hz), and $T_3 = 0.1(n/f_3) = 0.2345$ s ($1/T_3 = 4.26$ Hz). Thus, according to the definition of sign sufficiency, the identified oscillation periods can belong to geomagnetic pulsations of the *Pc*1 group. For a more detailed analysis, Fig. 3 shows the spectral structure of signal T_3 with the largest amplitude of spectral density.

According to Fig. 3, the structure of T_3 has a clearly expressed multiplet character, which may indirectly indicate the presence of the necessary sign of pearl-type signals within the multiplet group.

At the second stage, the sufficiency of the sign of detection of signals of the pearl type was confirmed by dividing the saved record from 12:00 to 18:00 local time into seven 1-h intervals. The results of the spectral analysis for each 1-h interval are shown in Table 1. In addition, three more 1-h intervals were involved (19, 20, and 21 h).

According to Table 1, there is a frequency drift, which characterizes the sufficiency of detecting the sign of signals of the pearl type. The series of these pearls consist of discrete tones with both increasing and decreasing frequencies. It should be noted that, at 12, 13, and 21 h (denoted by dashes), there were indeed no *Pc*1-type pulsations.

In this study, we additionally identified geomagnetic pulsations of the *Pc*1 type in the observation series of the IZMIRAN Magnetic Observatory for the time period from May 2021 to February 2022 (Table 2).

According to Table 2, the largest values of spectral density (on the basis of estimates for the signal-to-noise ratio S/N) fell on geomagnetic disturbances on February 4, 2022. The dynamics of geomagnetic disturbances on February 4, 2022, is shown in Fig. 4.

Figure 5 shows the spectral density for this event. This is nothing less than some kind of a choir of pearls.

On some days, despite the presence of magnetic disturbances during strong magnetic storms, there were no

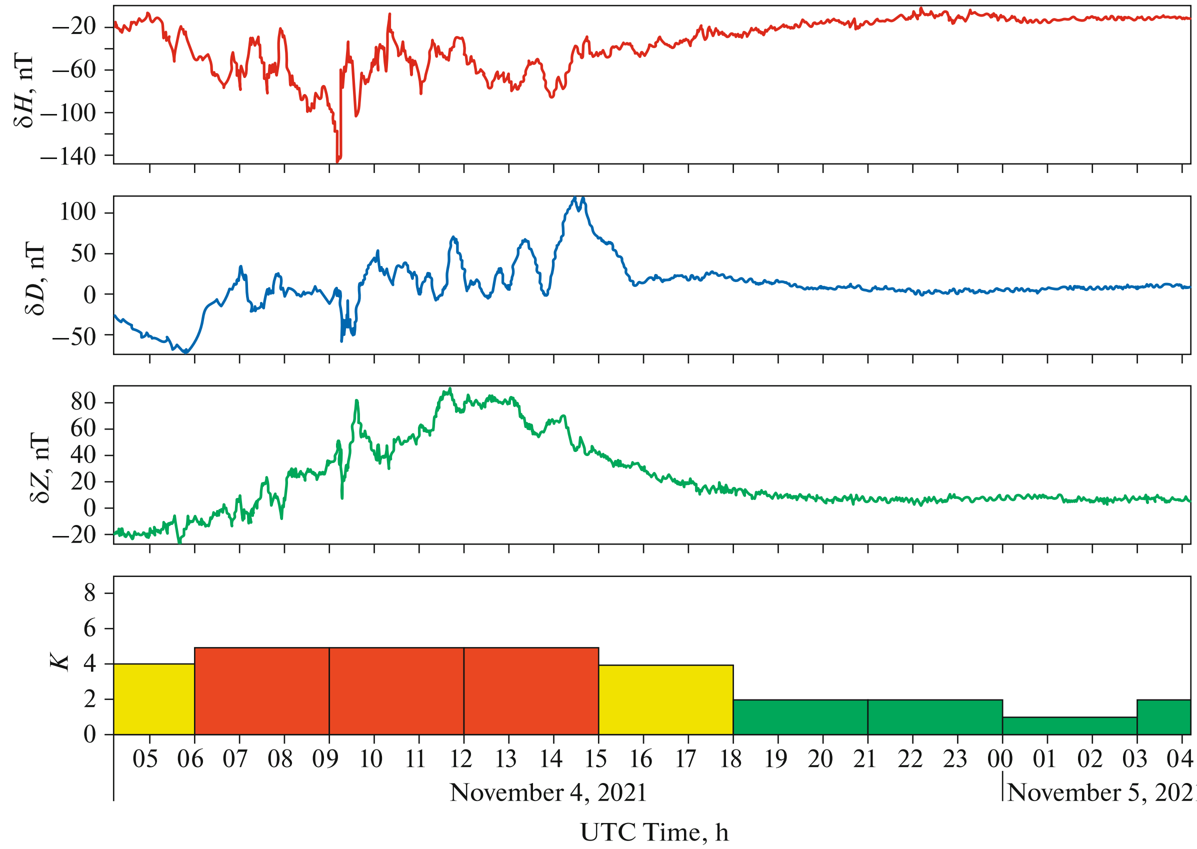

Fig. 1. Measurements of variations in the earth's geomagnetic field in the vicinity of the long-term magnetic storm on November 4, 2021, according to data of the IZMIRAN Magnetic Observatory.

*Pc*1-type pulsations. For example, Fig. 6 shows the change in the geomagnetic field in the vicinity of the January 18, 2022, event (see also Table 2).

Thus, the earlier assumption that not every magnetic storm is biotropic is confirmed, and only a detailed analysis of the spectral portrait of a magnetic storm can characterize its adverse effect on the human body. Indeed, *Pc*1 oscillations were observed for a quiet geomagnetic field on January 20, 2022 (see Fig. 6) (according to Table 2). However, during this day, a strong proton flare was observed (Fig. 7).

In conclusion, it should be noted that geomagnetic oscillations with *Pc*1-type pulsations are grouped mainly in the frequency range of ~3–4 Hz.

Table 1. Dynamics of estimates for periods, frequencies, and amplitudes of oscillations for spectral density maxima at 1-h intervals in the vicinity of the November 4, 2021, magnetic storm

Local time, h	Oscillation period, T, s	Oscillation frequency, $1/T$, Hz	Amplitude of signal-to-noise ratio S/N
12	–	–	–
13	–	–	–
14	**0.234495**	**4.2644**	**≈7.3**
15	**0.234452**	**4.2625**	**≈5.2**
16	**0.234541**	**4.2636**	**≈4**
17	**0.234541**	**4.2636**	**≈4.9**
18	**0.234547**	**4.2635**	**≈4.9**
19	0.234563	4.2632	≈5.9
20	0.234556	4.2633	≈2.8
21	–	–	–

The time interval from 12:00 to 18:00 local time taken for analysis is in bold.

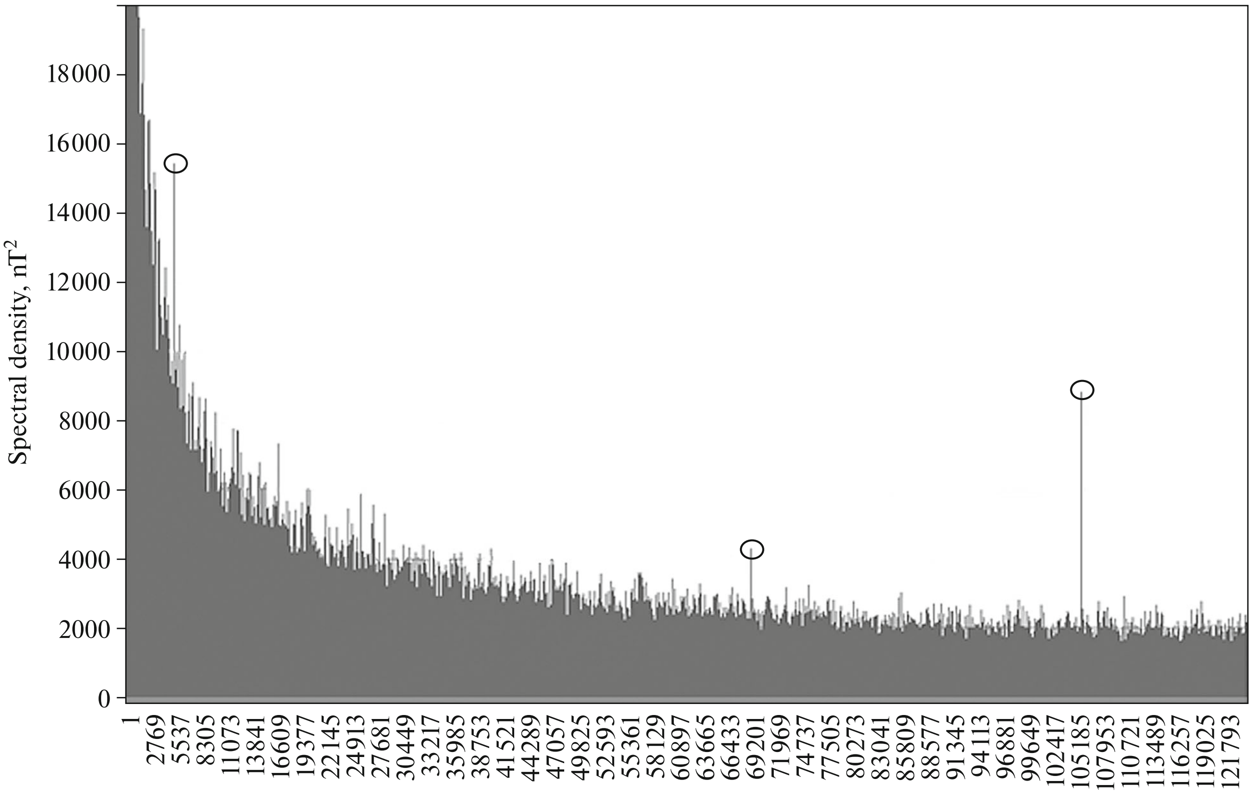

Fig. 2. Calculated spectrum of the geomagnetic field on November 4, 2021, from 12:00 to 18:00 local time. The maximum values of spectral density are shown by circles.

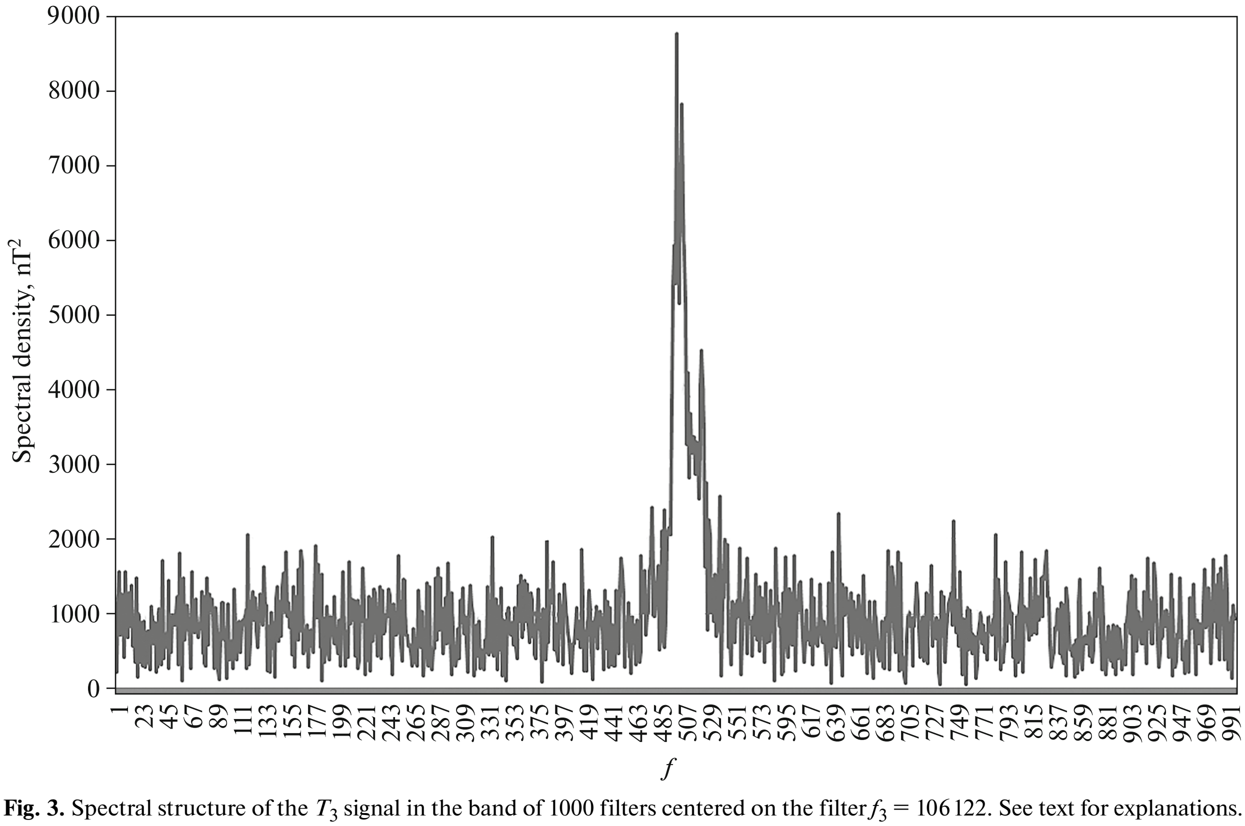

Fig. 3. Spectral structure of the T_3 signal in the band of 1000 filters centered on the filter $f_3 = 106\,122$. See text for explanations.

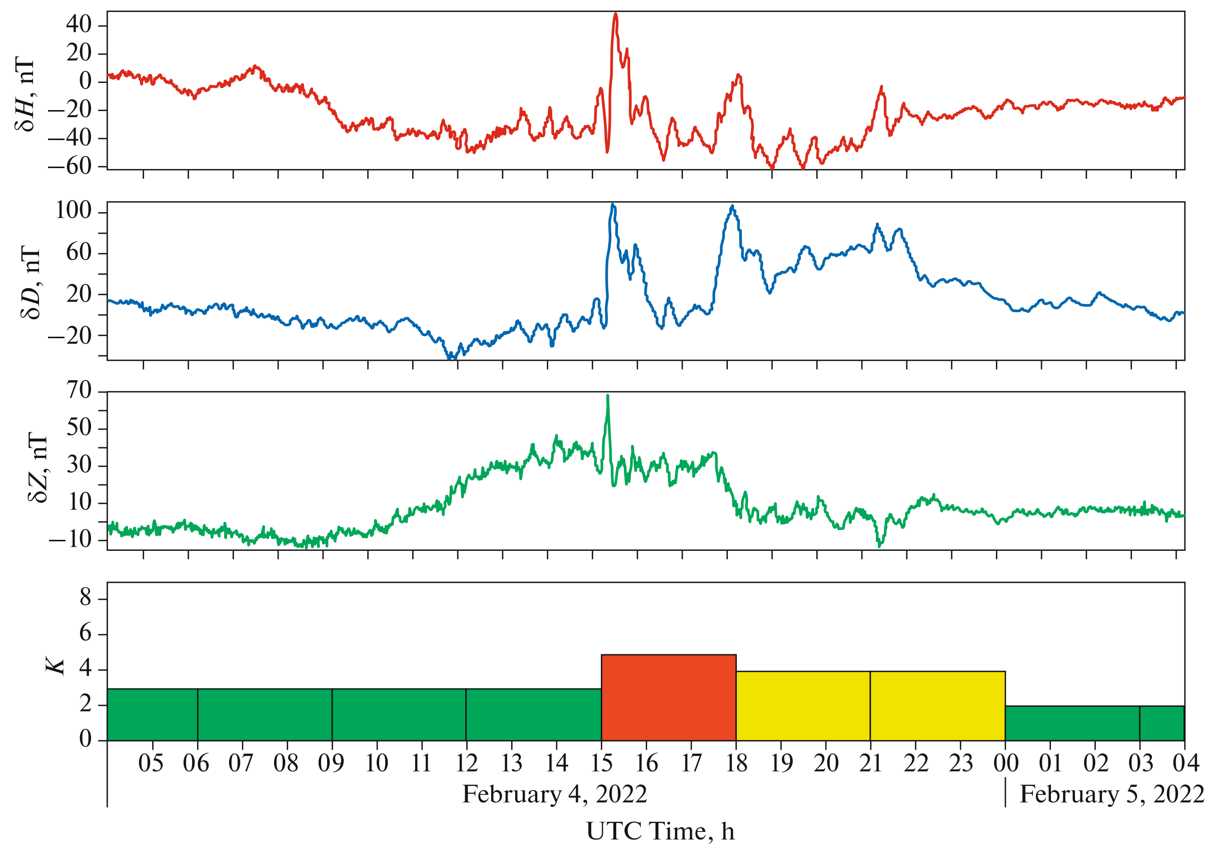

Fig. 4. Dynamics of geomagnetic field variations on February 4, 2022, according to data of the IZMIRAN Magnetic Observatory.

Table 2. Spectral characteristics of geomagnetic oscillations with *Pc*1-type pulsations from May 2021 to February 2022

Data	Local time	Oscillation period, s	Frequency, Hz	Amplitude of signal-to-noise ratio *S*/*N*
May 12, 2021	13–18 h	–	–	–
May 26, 2021	19–21 h	–	–	–
Oct 31, 2021	13–16 h	0.2345	4.264	≈2.35
Nov 21, 2021	15–18 h	0.3044	3.285	≈1.8
Jan 8, 2022	19–24 h	0.2797	3.356	≈2.63
Jan 14, 2022	16–22 h	–	–	–
Jan 15, 2022	18–22 h	–	–	–
Jan 15, 2022	00–03 h	0.2233	4.482	≈1.7
Jan 16, 2022	18–22 h	0.2350	4.255	≈18.2
Jan 18, 2022	02–05 h	–	–	–
Jan 19, 2022	00–06 h	0.3319	3.012	≈1.56
Jan 20, 2022	16–22 h	0.2694	3.712	≈2
Jan 21, 2022	18–22 h	0.2348	4.259	≈17.4
Jan 29, 2022	14–17 h	0.2348	4.258	≈2.32
Feb 2, 2022	02–05 h	0.2531	3.951	≈1.68
Feb 2, 2022	18–20 h	0.2476	4.038	≈1.4
Feb 3, 2022	05–11 h	–	–	–
Feb 3, 2022	12–18 h	0.2476	4.038	≈1.7
Feb 3, 2022	18–20 h	0.2348	4.258	≈15.1
Feb 4, 2022	17–20 h	0.2348	4.258	≈21.06
Feb 5, 2022	20–23 h	0.4900	2.04	≈1.63
Feb 6, 2022	20–23 h	0.2489	4.01	≈2.23
Feb 10, 2022	17–20 h	0.2347	–	≈1.9

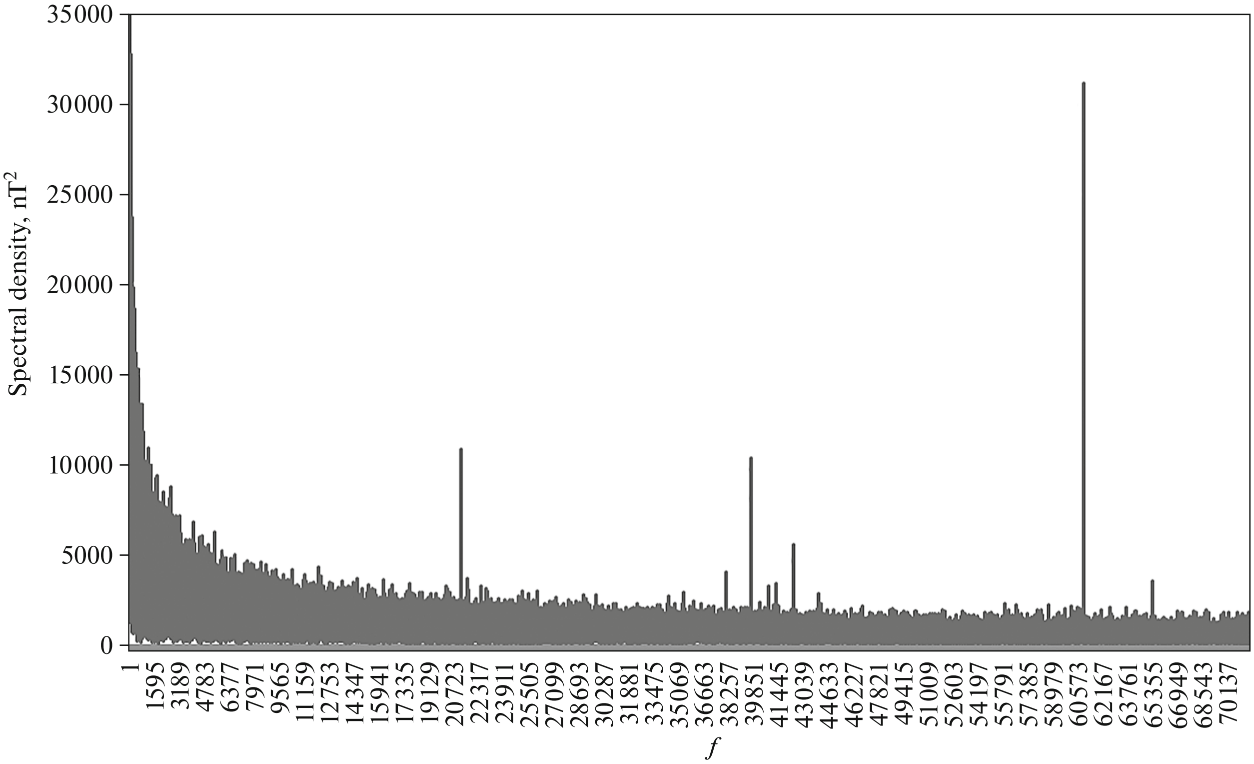

Fig. 5. Spectral density of geomagnetic disturbance on February 4, 2022.

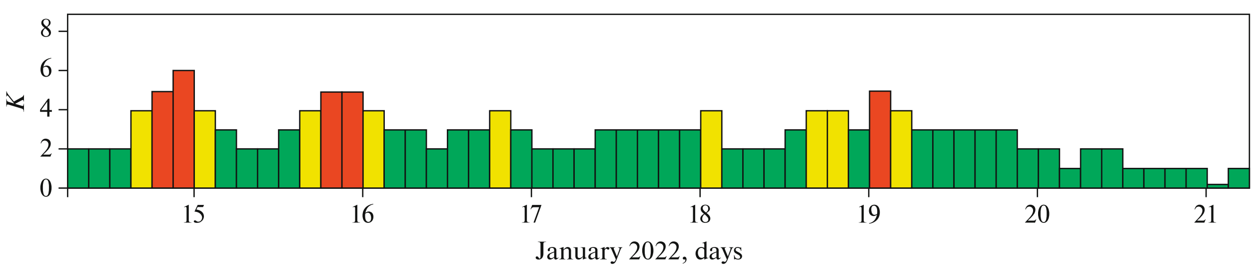

Fig. 6. Geomagnetic activity from January 14, 2022, to January 21, 2022, according to data of the IZMIRAN Magnetic Observatory.

CONCLUSIONS

Experimental data obtained during many studies have reliably established that the number of exacerbations of cardiovascular diseases increases with the growth of geomagnetic field disturbance on days in the vicinity of magnetic storms (Kleimenova, 2007, 2013; Kleimenova and Kozyreva, 2008; Kleimenova and Troitskaya, 1992; Breus et al., 2005; Ptitsyna et al., 1998; Rapoport et al., 2006; Samsonov et al., 2013; Temuryants et al., 1992). The same researchers found no influence of geomagnetic activity on the biosphere at the energetic level, because variations in the magnetic field amplitudes do not exceed 2–5% of the earth's magnetic field even during very strong magnetic storms, which is many orders of magnitude lower than the level of natural and anthropogenic electromagnetic noise.

At the same time, there is little heliobiological data on the spectral characteristics of the geomagnetic field, which can be considered a factor of the adverse environmental impact on biological objects, i.e., as a biotropic factor. It is known that *Pc*1 geomagnetic pulsations have biotropic features to the maximum extent. Since the amplitudes of *Pc*1 are fractions of a percent of the magnitude of the earth's magnetic field, there are some difficulties in detecting them. However, an increase in the sampling rate to 10 Hz compared to the signal information processing conditions described in (Kubov and Slivinsky, 2014) leads to the fact that the amount of signal information subject to spectral processing at the same time intervals increases by an order of magnitude. This allows one to hope that a corresponding increase in the coherent accumulation of signal information will make it possible to identify geomagnetic field oscillations with amplitudes an order of magnitude smaller than units of a nanotesla.

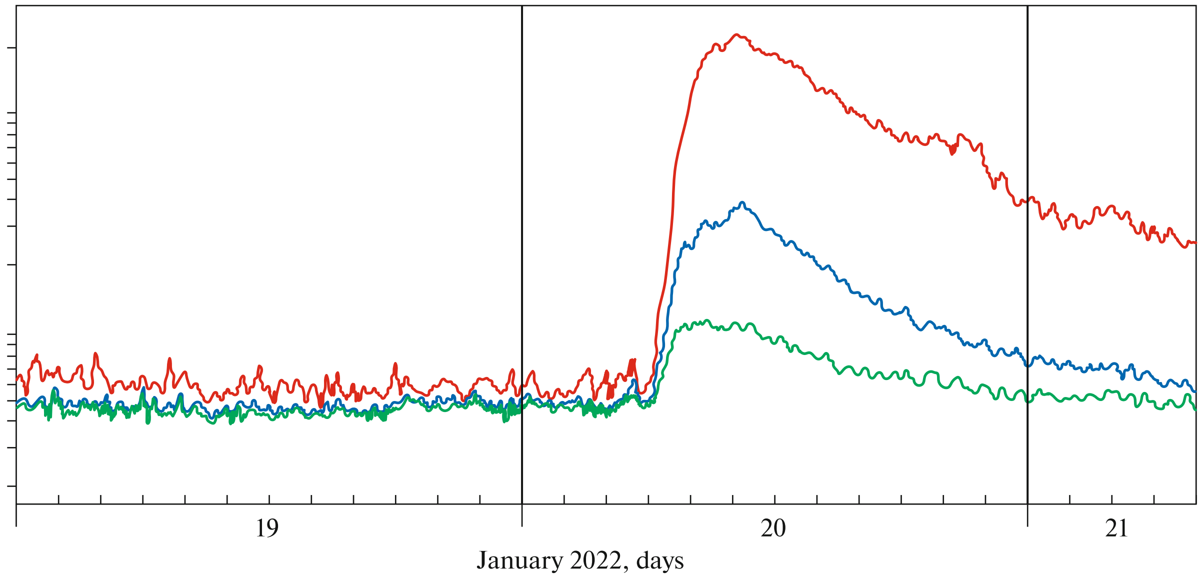

Fig. 7. Change in the earth's magnetic field in three components for January 19–21, 2022.

Our earlier analysis of the features of the spectral characteristics of geomagnetic oscillations in the vicinity of the strong magnetic storm on March 17, 2015 (Slivinsky, 2015), and in the vicinity of the long-term strong magnetic storms on November 4, 2021, and February 4, 2022 (see the present study), showed that the geomagnetic pulsations revealed in both cases are of the pearl type, i.e. *Pc*1 geomagnetic pulsations.

The results of this study indicate that the modified measuring system described in (Slivinsky, 2015), with appropriate automation, can provide a real-time economical and technically simple recording of local biotropic disturbances of the magnetic field of the *Pc*1 type, both in scientific research and as a preventive measure to alert the general population about possible unfavorable influences caused by disturbances of the magnetic field of the *Pc*1 type.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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