ISSN 0016-7932, Geomagnetism and Aeronomy, 2017, Vol. 57, No. 2, pp. 199–206. © Pleiades Publishing, Ltd., 2017.
Original Russian Text © S.A. Riabova, A.A. Spivak, 2017, published in Geomagnetizm i Aeronomiya, 2017, Vol. 57, No. 2, pp. 217–225.

Geomagnetic Variation Peculiarities at Middle Latitudes of the East European Platform

S. A. Riabova* and A. A. Spivak**

Institute of Geosphere Dynamics, Russian Academy of Sciences, Moscow, 119334 Russia

**e-mail: riabovasa@mail.ru*

***e-mail: spivak@idg.chph.ras.ru*

Received May 27, 2016; in final form, July 20, 2016

Abstract—The results of instrumental observations of geomagnetic variations at the Mikhnevo midlatitudinal observatory of Institute of Geosphere Dynamics of the Russian Academy of Sciences (54.9595° N; 37.7664° E) are presented and discussed. The main periodicities of the local background variations of geomagnetic field are determined. Variations of ~ 27 days have been registered, as well as periodicities with periods of ~6–9, 12–14, 60 days, and a semiannual periodicity. It has been shown that the background geomagnetic variation periodicities have a sporadic and scaling character. An alternating effect of increasing and degradation periods in geomagnetic variation intensity (the intermittency effect) is found.

DOI: 10.1134/S0016793217020128

1. INTRODUCTION

The study of geomagnetic field variations is of great interest from the viewpoint of the opportunity to obtain information concerning the electrodynamic properties of the near-surface regions of the Earth's crust and the characteristics of dynamic processes in the bowels of the Earth. This is of great importance for the elaboration of modern approaches to the study of geodynamic modes of local regions of the Earth's crust, which is of doubtless interest for the elaboration of advanced methods of environmental diagnostics with the goal to select and justify the choice of sites destined for the construction of particularly important installations and objects and to provide their long-term, secure exploitation (Adushkin and Spivak, 2014; Kolesnik et al., 2009; Berdichevskii et al., 2003). With the emergence of new modern technologies, there has also been an increase in the practical importance of research on natural geomagnetic background variations in order to provide high-accuracy measurements and technological processes of high precision at the micro- and nanoscale level (biotechnology, production of electronic cells and microassemblies used in modern electronic and computer engineering).

The results of geomagnetic field instrumental observations carried out at different points have made it possible to distinguish the main periodicities of geomagnetic field: a 11-year cycle (Lamont, 1851; Schove, 1955), a 27-day periodicity (Broun, 1876; Maunder, 1905; Bartels, 1932, 1934), a periodicity related to the solar diurnal variations (Mielberg, 1874; Klausner, 2013), and lunar diurnal variations (Sabine, 1856; Winch, 1993).

With time the development of magnetic detectors and methods of data processing has made it possible to distinguish some other periodicities of the geomagnetic field. Among them, there are semiannual and annual variations (Russell and McPherron, 1973; Le Mouel et al., 2004) and periodicities with periods within an interval of 2–80 years (Currie, 1966). In (Malin et al., 1999), it is shown that the semiannual geomagnetic field variation is characterized by extrema in the vicinity of the days of equinoxes. Detailed spectral analysis with a high resolution demonstrated that the 27-day periodicity consists of three single peaks (Shapiro and Ward, 1966).

The consideration of shorter periods (those that do not exceed the 27-day period corresponding to the time during which the sun makes one rotation around its axis) has made it possible to distinguish periodicities with periods of 13–14 days and within an interval of 6–9 days (Courtillot and le Mouel, 1988; Fraser-Smith, 1972). However, it should be noted that the periodicities mentioned above have not been entirely confirmed in later studies: they are found in some papers (e.g., Singh and Prabhu, 1985)), while they are not found in others (e.g., in (Stimets and Londono, 1982)). In the geomagnetic field variations, one observes also micropulsations with characteristic periods from 1 to 2 min (Stewart, 1861), which are the subjects of systematic studies at the present time (La Cour and Laursen, 1930; Rolf, 1931; Guglielmi

Table 1. Technical characteristics of the LEMI-018 magnetometer

Characteristics	Parameter values
Number of orthogonal channels of registration	3
Interval of measurements of the entire magnetic field	±68000 nT
Resolution	10 pT
Operation temperature range	–20 to +60°C
Noise level within the frequency range 0.03–0.3 Hz	<15 rms pT
Long-temp zero drift	<±5 nT/year
Temperature drift	<0.2 nT/°C
Nonorthogonality of sensitivity	<30 angular minute
Sampling rate	1/s

and Troitskaya, 1973; Guglielmi et al., 2001; Guglielmi and Kangas, 2007).

The goal of this study is to determine the main periodicities with periods exceeding 12 h in the geomagnetic field variations at midlatitudes of the East European Platform.

2. USED DATA

In this work, we used as initial data the results of instrumental observations of geomagnetic field variations at the Geophysical observatory Mikhnevo (GO MHV) of the Institute of Geosphere Dynamics (IDG) of the Russian Academy of Sciences (RAS) over the period 2008–2015. The observatory is situated in the center of the East European Platform (54.9595° N; 37.7664° E) (Adushkin et al., 2005, 2016), in the south of Moscow region, far from big industrial objects in the area of influence of the underlying tectonic structure of the Nelidovo–Ryazan fault zone related to the Oka riverbed.

Ternary registration (the frame of references is as follows: the *X*-axis is directed to the geographic north, the *Y*-axis is directed to the east, and the *Z*-axis is directed vertically downwards) of the geomagnetic field (with components B_x, B_y, and B_z) was carried out in a stationary pavilion equipped for geomagnetic observations with a LEMI-018 fluxgate magnetometer, the electronic module of which provides for the transformation of data obtained by the fluxgate sensor, as well as data processing and storage with discretization of 1 s. The technical characteristics of the magnetometer are shown in Table 1. The data were transmitted to the computer and then to the main server of IDG RAS by means of the interface RS-232. The initial data for the analysis of variations were represented by numerical series with discretization of 1 min. The results of geomagnetic field registration at the GO MHV are presented on the IDG RAS website (http://idg.chph.ras.ru/mikhnevo.php).

3. DATA PROCESSING

The preparation of instrumental observation data for processing consisted of the identification and elimination of spikes and the filling of omissions (Aivazyan, 1983; Gvishiani et al., 2011). In this study, we used a method based on statistical estimations of a numerical series, taking into account the Tietjen–Moore's criterion (Aivazyan, 1983). For the purposes of this study, the use of a reconstruction based on the Fourier transform has shown itself as optimal in comparison with gravitational smoothing from the viewpoint of both the labor intensiveness and the quality of the results. The reconstruction of missing values in the series was made with the help of the linear interpolation with insignificant number of omissions (one to ten) over 1-minute intervals. In the case of longer intervals of missing values (more than ten omissions), the double Fourier transform was used in order to reconstruct the series (Grachev, 2004). As a result of such omission eliminations, equidistant data series were formed with a discretization of 1 min. Then, in order to distinguish the components of the numerical series of geomagnetic field data, series of data were formed with discretizations of 1 h and 1 day, the values of which were determined as the average within a chosen interval.

In order to choose the most appropriate method that would make it possible to distinguish the trend and periodic components of numerical series in the next stage, we made a preliminary analysis of the obtained numerical series based on testing of the hypothesis of normality, independence, and stationarity. In order to test the data normality, a graphical method (histogram) and an analytical method (Jarque–Bera's statistics (Jarque and Bera, 1987)) were applied. Histograms of the initial data with a theoretical normal curve (a curve constructed on the basis of the average value and root-mean-square deviation of the series) and the results of their analysis by the Jarque–Bera's criterion (Table 2) demonstrate a considerable deviation of the experimental data from the normal distribution. The independence test of data was made with the Wallis–Moore's phase-frequency criterion (Table 3) (Sachs, 1976). The analysis results show a regular character of the change in the geomagnetic field induction (the null hypothesis about the randomness of the time series data was rejected with a significance level equal to 0.05). The study of the used numerical series carried out on the basis of autocorrelation (correlogram) and partial autocorrelation functions (Ventsel, 1969) showed that the used numerical series are nonstationary.

Proceeding from the properties of the used numerical series, the separation of the trend component was carried out on the basis of singular spectral analysis with identification of the trend component by means of the low frequency method (Golyandina, 2004), as this method is applicable to both stationary and nonstationary series and does not presuppose knowledge of the parametric model of series. At the preliminary stage, we used spectral analysis based on the Fourier transform (Bloomfield, 2000) in order to obtain the main periodicities. Since the Fourier transform traditionally used in this case does not make it possible to distinguish sudden changes in nonstationary time series due to expansion coefficient averaging over the entire studied series (Yakovlev, 2003), the continuous wavelet transform (Meyer, 1993) was used in order to study the dynamics of the periodicities. The complex Morlet's wavelet (Astaf'eva, 1996; Mandrikova et al., 2013) was chosen as a mother wavelet, since it has a similarity of the chosen function shape to the shape of a registered continuous signal and allows one to separate the phase components and amplitude components in the results of wavelet transform. To construct wavelet spectra, it was taken into consideration that the procedure of wavelet transform applied to finite time series leads to errors in calculation of the wavelet spectra at the ends of time series. In order to distinguish the domain of edge effect influence, the cone of influence (a region in which the autocorrelations of wavelet transform values increase by a factor of e in each scale (Meyer, 1993)) was constructed.

4. PERIODICITIES OF GEOMAGNETIC VARIATIONS

As an example, one can see in Fig. 1 the results of registration of the magnetic induction component variations at GO MHV in 2010–2012 with a discretization of 1 min. The data presented in Fig. 1 demonstrate the presence of a trend component in the variations of magnetic induction components. Estimation based on singular spectral analysis with identification of the trend component by means of the low frequency method showed that the trend component for the horizontal X-component of geomagnetic field smoothly decreases during the analyzed period and is characterized by feebly marked minima in equinox periods and by maxima in solstice periods. The trend components of vertical Z- and horizontal Y-components of geomagnetic field have nearly a linear shape over six years.

In this study, local, long-period geomagnetic variations with periods $T \geq 12$ h have been investigated. At the first stage, the local background variations of geomagnetic field in its undisturbed state were determined. A characteristic example of diurnal variations of the magnetic field induction at GO MHV in the absence of disturbances (the local index of magnetic activity $K \sim 0$ during one day) is shown in Fig. 2. The diurnal geomagnetic field variation constitutes 10–15 nT in amplitude and is determined by S_q variation related to the variations of the current system evolving on the part of the Earth illuminated by the Sun.

Analysis of the data obtained over the whole period of observations shows a complex character of geomag-

Table 2. Jarque–Bera's criterion for numerical series of geomagnetic field

Component	Calculated value	Significance level
B_x	29.8	0.05
B_y	146.5	0.05
B_z	93.9	0.05

Table 3. Wallis–Moore's criterion for numerical series of geomagnetic field

Component	Calculated value	Significance level
B_x	2.9	0.05
B_y	4.2	0.05
B_z	3.4	0.05

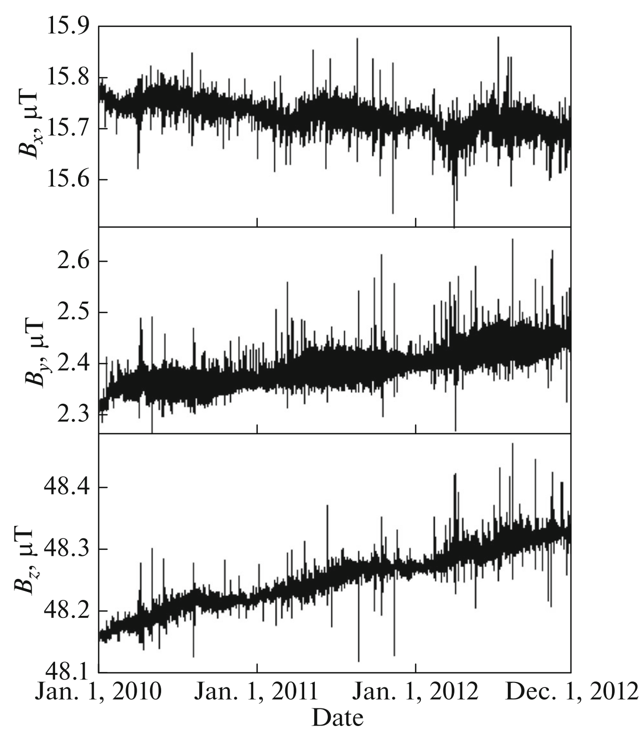

Fig. 1. Results of registration of geomagnetic variations at the GO MHV for the period 2010–2012.

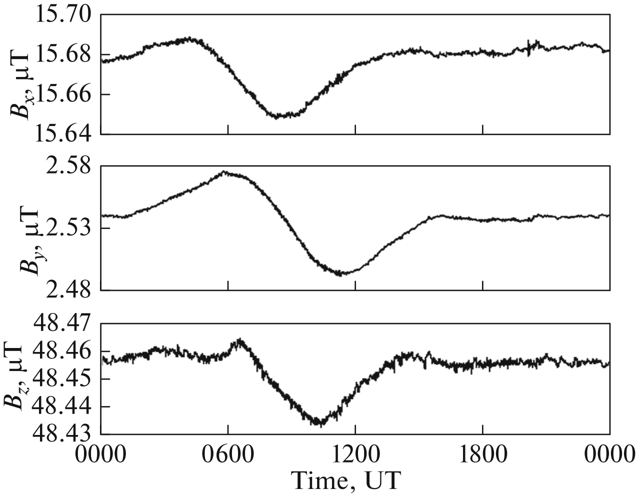

Fig. 2. Example of diurnal geomagnetic field variations in the absence of disturbances (background variations) at GO MHV on April 24, 2015.

netic variations at GO MHV. In particular, one can see in Fig. 3 the results of wavelet analysis of the data obtained in 2010–2015. The wavelet spectrum (Fig. 3c) shows the presence of variations with periods equal to about 27 days, periodicities with periods about 6–8 and 12–14 days, and a semiannual periodicity. More detailed information about periodicities in geomagnetic variations is presented by the results of wavelet analysis (the modulus and phase of wavelet transform) for the period 2010–2015 in Fig. 3a, 3b.

The complexity of geomagnetic variations is clearly shown in Fig. 4, where one can see the results of wavelet analysis of geomagnetic variations observed from February to August of 2011 within a range of periods from 0 to 4 days. It is clear from the represented pattent of the modulus of wavelet coefficients that in the background geomagnetic variations (quite powerful geomagnetic variations manifesting themselves relatively seldom and related to magnetic storms have duration from several hours to one day and do not form a periodic component), one can distinguish a number of clearly marked periodicities, starting from the semidiurnal one. It is important to emphasize that the intensity of periodic variations is not constant in time. The periods of high-amplitude variations (for example, February to the beginning of March and the beginning of August) alternate with periods of feebly marked periodicity (the second part of March, etc.). The noted peculiarity of geomagnetic variations is of certain interest for further studies and provides evidence of the complex processes of formation and degradation of the sources of geomagnetic variations at midlatitudes.

Another peculiarity of the observed periodicities of geomagnetic variations is their fractal character. In Fig. 5, one can see a fragment of the pattent of wavelet coefficient modulus, which was obtained as a result of wavelet analysis of the initial data within a range of periods from 0 to 120 h. It shows the hierarchic structure of geomagnetic variations in the form of a cascade process. One can clearly note the lines of local maxima. The scale fragmentation manifests itself as the emergence of particular "forks" in the coefficient distribution, i.e., the bifurcation of local maxima: each of the lines characterizing the position of local maxima bifurcates, forming two independent local maxima. This characteristic reproduces itself with increasing scale, which is evidence of a self-similarity and monofractality of the process (Astaf'eva, 1996). Various factors determine the disturbance of local geomagnetic field in different frequency ranges.

In order to determine the sources of geomagnetic disturbances, it is necessary to analyze, in particular, the change in the single spectral components of geomagnetic variations with time. Of special interest is to establish their periodicities. The analysis showed that, as in the case of geomagnetic variations averaged over the entire interval of periods, their single spectral components are characterized by periodicities. As an example, one can see in Fig. 6a–6c the amplitude

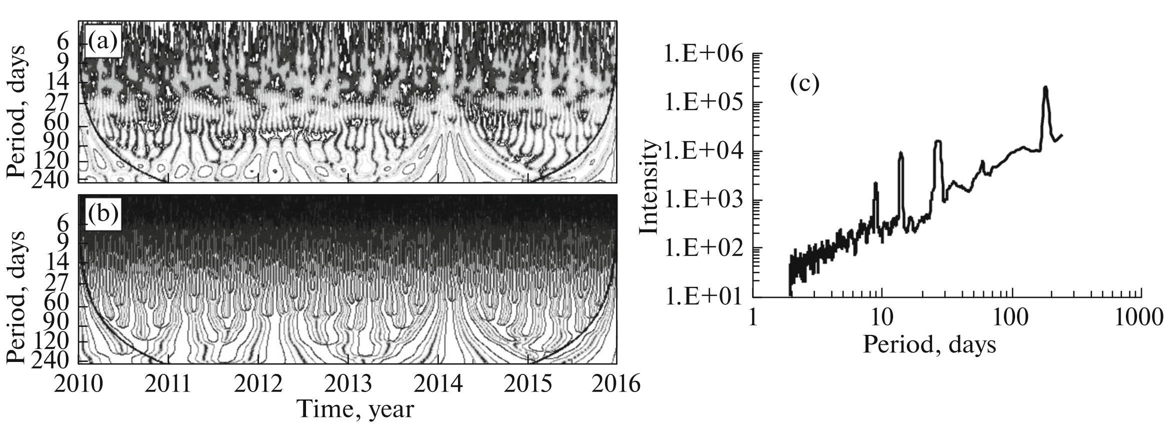

Fig. 3. Modulus (a) and phase (b) of wavelet transform coefficients and the wavelet spectrum (c) of geomagnetic variations (X-component) for 2010–2015.

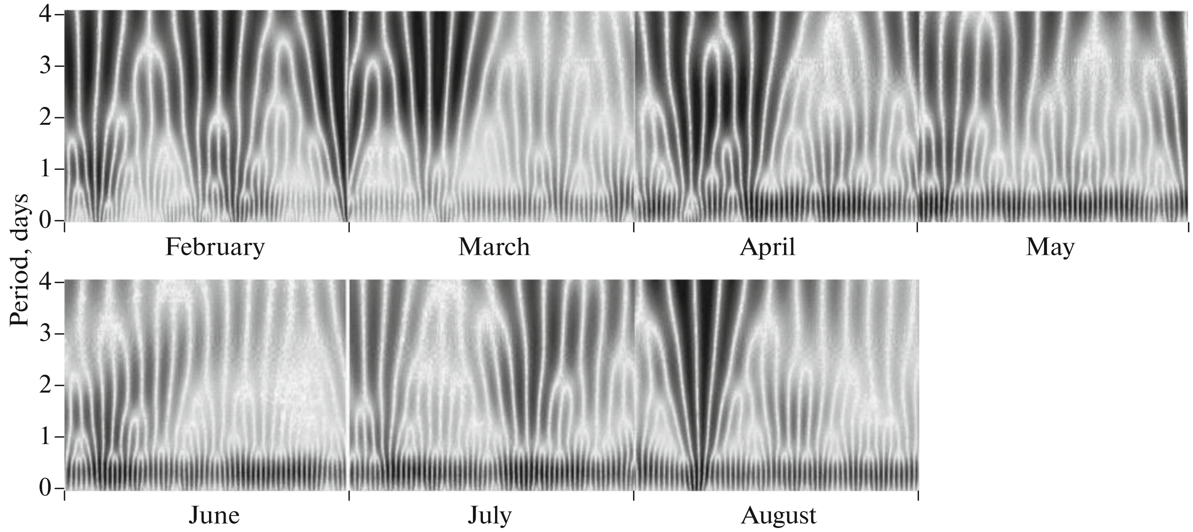

Fig. 4. Modulus of wavelet transform coefficients of geomagnetic variations (X-component) at GO MHV over the period of February–August 2011.

variations of spectral components with periods of 1, 14, and 27 days (data observed in 2010–2011). One can clearly distinguish several characteristic periods. For example, the graph presented in Fig. 6a clearly demonstrates the existence of an annual periodicity and also distinctly marked periodicities with periods less than a year. It is well seen in Fig. 6d, which shows a scan of envelope of the spectral component of geomagnetic variations with a period of 1 day for one of the time intervals of a duration of 60 days (on the graph, one can clearly distinguish periodicities multiples of about 14 days). A more complicated pattern is observed for spectral components with periods equal to 14 and 27 days (Figs. 6b, 6c). Thus, in the 14-day spectral component, one can distinguish periodicities of about 8 and 60 days, alongside an annual periodicity (Fig. 6b). The 27-day spectral component is characterized by periodicities of 14 and about 60 days (Fig. 6c). Figure 7, which represents the power spectral density of variations with a period of 1 day, demonstrates the existence of other periodicities with periods of about 8, 27, and 60 days.

As a whole, the variations of spectral components are characterized by the existence of several periodicities, the intensity of which changes with time. For example, Fig. 8 shows a general pattern of a diurnal harmonic of geomagnetic variations within a period range of 5–50 days. One can clearly distinguish not only periodicities of 6–8 days, 13–14 days, and about 27 days but also the epochs characterized by the emergence and degradation of some other periodicities.

5. DISCUSSION OF RESULTS

The obtained data show the existence of a trend and a number of periodicities in geomagnetic field variations under the conditions of the midlatitudinal geophysical observatory MHV. The behavior of the trend components during the analyzed period for the vertical and horizontal geomagnetic field components is determined by their secular variations (Yanovskii, 1932). The variation minima of the component B_x during the equinox periods and the maxima during the solstice periods are most probably related to the rotation of the Earth around the Sun (Kraev, 1965).

Among the found periodicities in geomagnetic field variations, those of 14 and 27 days are of particular interest. They are most probably related to movements in the Earth–Moon system. The existence of 14-day periodicity may be most likely explained by the characteristic period of the movement of the Earth–Moon system around its center of mass. The apparent 27-day periodicity traditionally associated with the

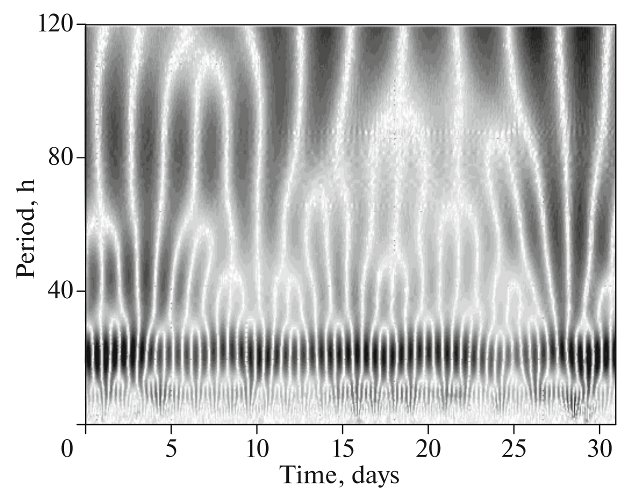

Fig. 5. Modulus of wavelet transform coefficients of geomagnetic variations (X-component) for May, 2011.

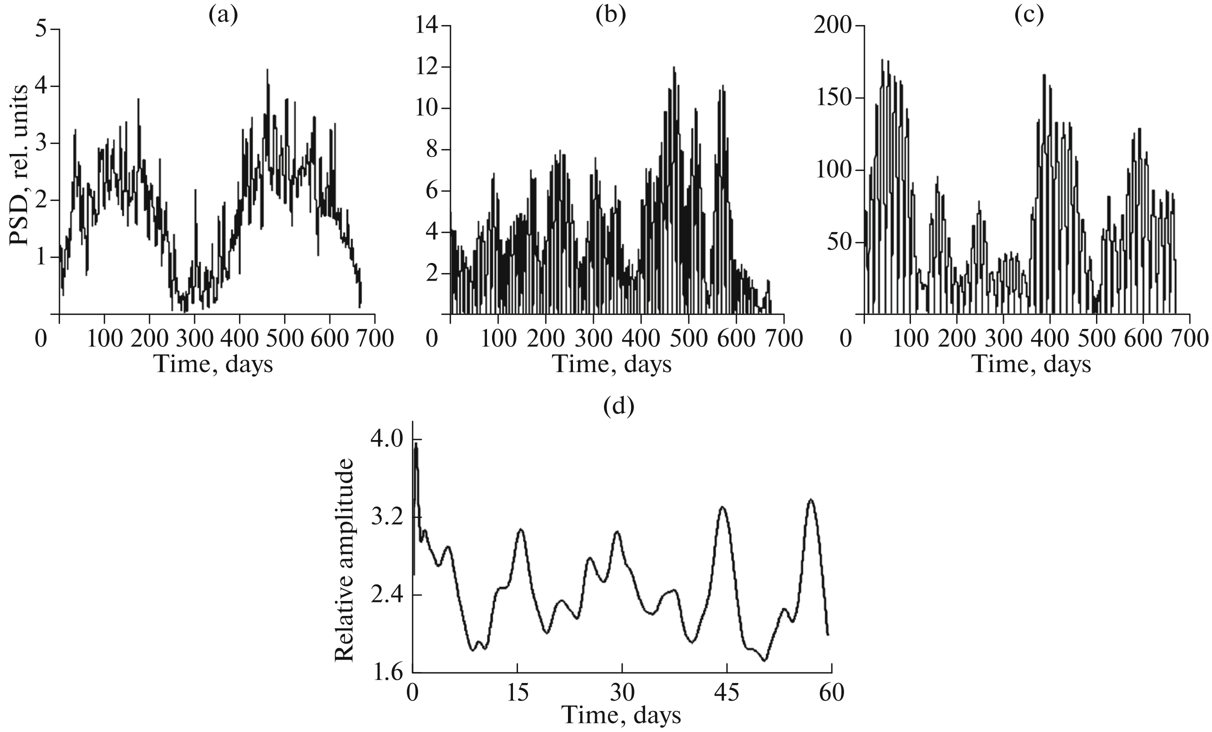

Fig. 6. Variations of spectral components of geomagnetic variations with periods (a) 1 day, (b) 14 days, (c) 27 days, and (d) the envelope of the spectral component of geomagnetic variations with a 1-day period.

rotation of the Sun around its axis may also have a component related to the period of the Moon's rotation around the Earth (the sidereal lunar cycle or the draconic lunar cycle close to it). As a mechanism of the lunar tide effect on geomagnetic variations on the Earth surface, one can consider, for example, the alteration in the systems of currents in the Earth crust due to the gravitational effect of the Moon, which causes a change in the hollowness of the earth matter in the tide bulge. It should be added that this effect becomes considerably stronger in zones of tectonic dislocations, where earth matter deformations are concentrated (Adushkin et al., 2012).

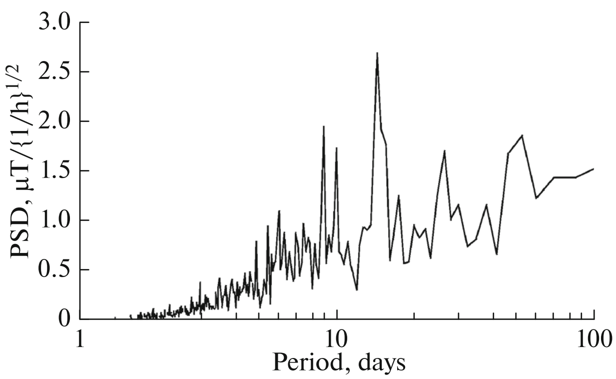

Fig. 7. Power spectral density of geomagnetic variations with a period of 1 day (Fourier spectrum).

To explain the semiannual geomagnetic field variation found in this study, one can turn to one of the main hypotheses existing at present: the equinox hypothesis relates semiannual variations to the change in the geomagnetic dipole orientation with respect to the Sun–Earth line, and the axial hypothesis relates the aforementioned periodicity to the change of the Earth's heliolatitude.

The question of the mechanism causing alternating (intermittent) increases and degradation of the geomagnetic field variations remains open and is a subject for further studies. It must not be ruled out that such a mechanism as endogenous, as well as exogenous, sources of geomagnetic field disturbances can be considered.

The analysis of self-similar properties of the geomagnetic field carried out on the basis of the wavelet-coefficient pattern is mainly of a qualitative character. It is planned to conduct later a consistent quantitative analysis of scaling on the basis of the maxima of wavelet transform modulus method.

The characteristics of geomagnetic variations found in this study allow one to suppose that they are most probably characteristic for the midlatitudes in general, i.e., one can expect that geomagnetic variations may be observed to have a sporadic and scaling character in other regions situated at midlatitudes.

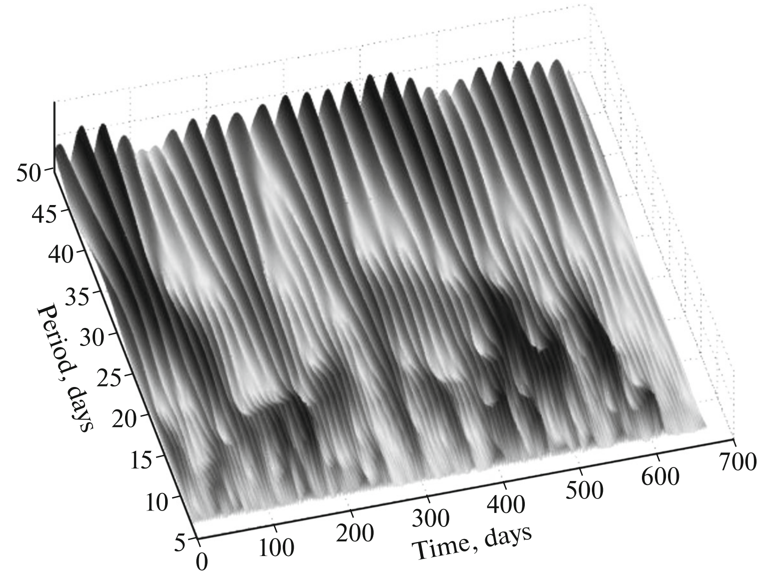

Fig. 8. Modulus of wavelet transform coefficients of the spectral component of geomagnetic variations with a period of 1 day (*X*-component).

It is necessary to note that the characteristics of geomagnetic variations found at the GO MHV are not of a local character. The geomagnetic field variations at the Borok geophysical observatory of the Institute of Physics of the Earth of RAS (58°04′ N, 38°14′ E) and at the Kiev magnetic observatory of the Institute of Geophysics of the National Academy of Sciences of Ukraine (50°43′ N, 30°18′ E), the data of which for the period from 2010 to 2012 have been also analyzed in this study, behave in an analogous manner.

6. CONCLUSIONS

The data obtained in this study prove that, in general, the amplitude of geomagnetic variations with periods of more than 12 h at midlatitudes and their single spectral components change in a complicated way with time and have a sporadic and scaling character. A number of periodicities in the geomagnetic field have been found, namely: diurnal, semiannual variations, those with periods of 12–14 days, about 27 and 60 days, and within the time interval of 6–9 days. The discovered effect of the alternation of periods of increasing and degradation (intermittency) in the intensity of geomagnetic variations attracts interest.

ACKNOWLEDGMENTS

This work was supported by Program IV.8.7 of the Department of Earth Sciences, RAS, "Intellectual analysis of geophysical data, geoinformatics, and mathematical geophysics," and the Russian Foundation for Basic Research (project no. 14-05-00073-a).

REFERENCES

Adushkin, V.V. and Spivak, A.A., *Fizicheskie polya v pripoverkhnostnoi geofizike* (Physical Fields in Near-Surface Geophysics), Moscow: Nauka, 2014.

Adushkin, V.V., Zetser, Yu.I., Gavrilov, B.G., Sanina, I.A., and Spivak, A.A., The *Mikhnevo* observatory measuring system of geophysical fields and processes of the interaction of geospheres, in *Dinamicheskie protsessy v sisteme vnutrennikh i vneshnikh vzaimodeistvuyushchikh geosfer* (Dynamical Processes in the System of Inner and Outer Interactions of Geospheres). Moscow: GEOS, 2005, pp. 13–18.

Adushkin, V.V., Spivak, A.A., and Kharlamov, V.A., Near-surface geophysics: Complex investigations of the lithosphere–atmosphere interactions, *Izv., Phys. Solid Earth*, 2012, vol. 48, no. 3, pp. 181–198.

Adushkin, V.V., Ovchinnikov, V.M., Sanina, I.A, and Riznichenko, O.Yu., *Mikhnevo*: from seismic station no. 1 to a modern geophysical observatory, *Izv., Phys. Solid Earth*, 2016, vol. 52, no. 1, pp. 105–116.

Aivazyan, S.A., Enyukov, I.S., and Meshalkin, L.D., *Prikladnaya statistika: Osnovy modelirovaniya i pervichnaya obrabotka dannykh* (Applied Statistics: Basics of Simulation and Primary Data Processing), Moscow: Finansy i statistika, 1983.

Astaf'eva, N.M., Wavelet analysis: Basic theory and some applications, *Phys.-Usp.*, 1996, vol. 39, no. 11, pp. 1085–1108.

Bartels, J., Terrestrial magnetic activity and its relations to solar phenomena, *J. Geophys. Res.*, 1932, vol. 37, pp. 1–52.

Bartels, J., Twenty-seven day recurrencies in terrestrial-magnetic and solar activity 1923–1933, *J. Geophys. Res.*, 1934, vol. 39, pp. 201–202.

Berdichevsky, M.N., Dmitriev, V.I., Golubtsova, N.S., et al., Magnetovariational sounding: New possibilities, *Izv., Phys. Solid Earth*, 2003, vol. 39, no. 9, pp. 701–727.

Bloomfield, P., *Fourier Analysis of Time Series: An Introduction*, New York: John Wiley and Sons, 2000.

Broun, J.A., On the variations of the daily mean horizontal force of the Earth's magnetism produced by the sun's rotation and the moon's synodical and tropical revolutions, *Philos. Trans. R. Soc. London*, 1876, vol. 66, pp. 387–404.

Courtillot, V. and Le Mouel, J.L., Time variations of the Earth's magnetic field: From daily to secular, *Ann. Rev. Earth Planet. Sci.*, 1988, vol. 16, pp. 389–476.

Currie, R.G., The geomagnetic spectrum—40 days to 5.5 years, *Surv. Geophys.*, 1966, vol. 71, no. 19, pp. 47–88.

Fraser-Smith, A.C., Spectrum of the geomagnetic activity index Ap, *J. Geophys. Res.*, 1972, vol. 77, no. 22, pp. 4209–4220.

Golyandina, N.E., *Metod "Gusenitsa"-SSA: analiz vremennykh ryadov* (Caterpillar-SSA: A Method for Analysis of Time Series), St. Petersburg: SPbGU, 2004.

Grachev, A.V., Recovery of gaps in experimental data, *Vestn. NNGU im. N. I. Lobachevskogo, Ser.: Radiofiz.*, 2004, no. 2, pp. 15–23.

Gvishiani, A.D., Agayan, S.M., Bogoutdinov, Sh.R., and Kagan, A.I., Gravitational smoothing of time series, *Tr. IMM UrO RAN*, 2011, vol.17, no. 2, pp. 62–70.

Guglielmi, A.V. and Troitskaya, V.A., *Geomagnitnye pul'satsii i diagnostika magnitosfery* (Geomagnetic Pulsations and Diagnostics of the Magnetosphere), Moscow: Nauka, 1973.

Guglielmi, A. and Kangas, J., Pc1 waves in the system of solar–terrestrial relations: New reflections, *J. Atmos. Sol.–Terr. Phys.*, 2007, vol. 69, pp. 1635–1643.

Guglielmi, A., Kangas, J., and Potapov, A., Quasi-periodic modulation of the Pc1 geomagnetic pulsations: An unsettled problem, *J. Geophys. Res.*, 2001, vol. 106, no. A11, pp. 25847–25856.

Jarque, C.M. and Bera, A.K., A test for normality of observations and regression residuals, *Int. Stat. Rev.*, 1987, vol. 55, no. 2, pp. 163–172.

Klausner, V., Papa, A.R.R., Mendes, O., Domingues, M.O., and Frick, P., Characteristics of solar diurnal variations: a case study based on records from the ground magnetic station at Vassouras, Brazil, *J. Atmos. Sol.–Terr. Phys.*, 2013, vol. 92, pp. 124–136.

Kolesnik, A.G., Kolesnik, S.A., and Pobachenko, S.V., *Elektromagnitnaya ekologiya* (Electromagnetic Ecology), Tomsk: TML-Press, 2009.

Kraev, A.P., *Osnovy geoelektriki* (Basics of Geoelectricity) Leningrad: Nedra, 1965.

La Cour, D. and Laursen, V., Le variometre de Copenhague, *Commun. Magnet. Copenhagen*, 1930, vol. 11, pp. 1–11.

Lamont, J.V., Ueber die zehnjährige Periode, welche sich in der Groösse der täglichen Bewegung der Magnetnadel darstellt, *Ann. der Physik*, 1851, vol. 160, no. 12, pp. 572–584.

Le Mouel, J.-L., Blanter, E., and Shnirman, M., The six-month line in geomagnetic long series, *Ann. Geophys.*, 2004, vol. 22, pp. 985–992.

Malin, S.R.C., Winch, D.E., and Işıkara, A.M., Semiannual variation of the geomagnetic field Earth, *Planet Space. Sci.*, 1999, vol. 51, no. 5, pp. 321–328.

Mandrikova, O.V., Bogdanov, V.V., and Solov'ev, I.S., Wavelet analysis of geomagnetic field data, *Geomagn. Aeron. (Engl. Transl.)*, 2013, vol. 53, no. 2, pp. 268–273.

Maunder, E.W., Magnetic disturbances, 1882 to 1903 as recorded at the royal observatory Greenwich, and their associations with sunspots, *Mon. Not. R. Astron. Soc.*, 1905, vol. 65, pp. 2–34.

Meyer, Y., *Wavelets: Algorithms and Applications*, Philadelphia: SIAM, 1993.

Mielberg, J., *Die magnetische Declination in St. Petersburg, Repertorium für Meteorologie, herausgeg. von der keiser. Akad. der Wissenschaft, St. Petersburg*, 1874, vol. 4, pp. 1–58.

Rolf, B., Giant micropulsations at Abisko, *Terr. Magn. Atmos. Electr.*, 1931, vol. 36, pp. 9–14.

Russell, C.T. and McPherron, R.L., Semiannual variation of geomagnetic activity, *J. Geophys. Res.*, 1973, vol. 78, pp. 92–108.

Sabine, E., On the lunar diurnal variation at Toronto, *Philos. Trans. R. Soc. London*, 1856, vol. 146, pp. 499–506.

Sachs, L., *Statistische Auswertungsmethoden. Berlin: Springer, 1972*; Moscow: Statistika, 1976.

Schove, D.J., The sunspot cycle 649 BC to 2000 AD, *J. Geophys. Res.*, 1955, vol. 60, pp. 127–146.

Shapiro, R. and Ward, F.W., Three peaks near 27 days in a high-resolution spectrum of the international magnetic character figure, *J. Geophys. Res.*, 1966, vol. 71, no. 9, pp. 2385–2388.

Singh, J. and Prabhu, T.P., Variations in the solar rotation rate derived from $Ca^{+}K$ plage areas, *Sol. Phys.*, 1985, vol. 97, pp. 203–212.

Stewart, B., On the great magnetic disturbances of 28 Aug. to 7 Sept. 1859, *Philos. Trans. R. Soc. London*, 1861, vol. 151, pp. 423–430.

Stimets, R.W. and Londono, C., Rotational modulation of ca k flux ratio and sunspot number, *Sol. Phys.*, 1982, vol. 76, pp. 167–180.

Venttsel', E.S., *Teoriya veroyatnostei* (Probability Theory) Moscow: Vysshaya shkola, 1969.

Winch, D.E., Solar and lunar daily geomagnetic variations, *Explor. Geophys.*, 1993, vol. 24, no. 2, pp. C. 147–150.

Yakovlev, A.N., *Vvedenie v veivlet-preobrazovaniya* (Introduction to Wavelet Transform), Novosibirsk: NGTU, 2003.

Yanovskii, B.M., *Zemnoi magnetizm* (Terrestrial Magnetism), Leningrad: LGU, 1978.

Translated by E. Smirnova