Earth's Natural Oscillations in Time Series of Geophysical Data

Boris Belashev
Institute of geology
Karelian research center of Russian academy of sciences
Petrozavodsk, Russia
belashev@krc.karelia.ru

Abstract—The time series of seismic noise, geomagnetic variations and exhalation of radon into the atmosphere were obtained by hardware-software complexes for conducting geophysical monitoring in the Republic of Karelia. Spectra for series recorded under low seismic and geomagnetic activity conditions were calculated and their major harmonic periods were determined. The similarity of the periods of the processes analyzed to the periods of the Earth's natural oscillations indicates the modulating role of the latter. A modulation mechanism, which takes into account radon transport by vesicles, was proposed for the exhalation of radon into the atmosphere.

*Keywords—seismic noise, geomagnetic variations, radon exhalation, power spectra, the Earth's natural oscillations, hydrogen degassing***.**

1. Introduction

The study of cyclicity helps to better understand the origin of a process and its connection with the environment. The cyclicity of a process is assessed by its spectrum. A spectrum is a sensitive indicator of differences, provides data on objects by means of local measurements and radiation emitted by objects.

The present study is based on geophysical monitoring data for the Republic of Karelia obtained by automated hardware-software complexes conducting instrumental monitoring of the region's lithosphere and magnetosphere [1].

The goal of our project is to study series of seismic noise, geomagnetic variations and the volumetric activity of radon showing the condition of the geophysical medium.

Microseisms are generated by earthquakes, standing sea waves, cyclones and production activities [2]. Their intensity is dependent on the characteristics of the place of recording [3].

Geomagnetic variations are attributed to solar activity, processes in the Earth core, magnetosphere perturbations, variations in electrical conductivity and the stressed state of the crustal surface [4].

The exhalation of radon into the atmosphere is sensitive to a geodynamic situation and the filtration properties of rocks. Radon increases the electrical conductivity of the subsurface layer of the atmosphere and provokes water vapour condensation and ozone formation near the earth surface [5]. Upon penetration into organisms, biologically active radioactive radon and its decay products provoke oncological diseases [6]. When assessing the ecological safety of territories, their radon survey is compulsory.

The local characteristics of series are often interpreted as precursors of dangerous phenomena [7, 8]. In this study, we focus our attention on their integral characteristics reflecting geophysical medium rhythms. The diurnal range of periods, related to a "biological clock" phenomenon, is of interest. The aim of our study is to reveal and analyze the cyclicity of the time series of the processes studied under low seismic and geomagnetic activity conditions.

The maximum entropy method, commonly used for analyzing complex signals, was employed for processing series [9]. The similarity of the periods of the processes analyzed to each other and to the periods of the Earth's natural oscillation periods is interpreted as evidence for the modulating and synchronizing role of the latter. The modulation of volumetric radon activity by the Earth's natural oscillations is interpreted with regard for the transport of radon by vesicles.

2. Materials and Methods

2.1 Reference data and data recording hardware.

Geomagnetic data were obtained at Petrozavodsk Geophysical Observatory. Located in the forest at the outskirts of Petrozavodsk, the observatory is mildly affected by human activities in the city [2]. Variations in horizontal east-west (E-W), north-south (N-S) and vertical (Z) Earth's magnetic field components were measured by a GI MTS-1 geophysical complex [10]. The reorientation of its sensitive element, a magnet made of samarium-cobalt alloy in a varying magnetic field is estimated by a light-emitting diode signal reflected from the mirror fixed to the magnet. The response of photodetectors is filtered at low frequencies, intensified ad redistributed between analog-to-digital converter and inductivity coils generating an inverse magnetic field. The complex has a frequency range of 0.001-8 Hz, a sensitivity of 0.1 nT and a dynamic measurement range of magnetic field induction of ±1800 nT. The discreteness of the reference series Bx (W-E), By(S-N) and Bz (Z) was 1s.

Microseismic data from PITK station meters, spatially oriented in vertical Z and horizontal east-west (E-W) and north-south (N-S) directions (coordinates: 61.671 N, 31.266 E, opening date: 03.06.2014), are presented in a similar way. Guralp GMC-6TD [11] seismodetectors are mounted on a concrete basement in a shielded pavilion built on amphibolized basalt in a tuffaceous-carbonate horizon. This station in Leppäsilta Town, located about 10 km from Pitkäranta, has the lowest noise level of all stations in the local Karelian network [12].

Volumetric radon activity in the air of basements was measured in the village of Tsarevichi, the City of Pitkäranta and Solomennoye Town, which is located at the suburbs of Petrozavodsk. Tsarevichi lies about 40 km from Petrozavodsk on a rocky isthmus between two small lakes. There are no industries in the village, and its roads are not fully used. The effect of human activities on the results of measurements in comparison with other areas chosen is considered as minimum.

Radon monitoring was conducted by a CPC-05 seismic station [13]. The station measures volumetric radon activity and air temperature, pressure and humidity with one-hour discreteness, storing measurement data in an internal memory. Extra devices in the station are responsible for remote, access to the Internet and data transmission to a ftp- server [14]. Data from all hardware-software complexes were supplied in an automatic mode to the ftp-сервер via the Internet and mobile connection at the Institute of Geology, KarRC, RAS, in Petrozavodsk. Radiation background at radon monitoring sites was measured manually using a SRP-68 gamma radiometer.

2.2 Correspondence with weak geomagnetic and seismic perturbation conditions.

Correspondence with weak geomagnetic and seismic perturbation conditions was checked by the intensity of the high-frequency component of microseisms and geomagnetic activity catalogues [15]. Series corresponding with horizontal Earth's magnetic field component values of less than 100nT and the daily Kp indices of global geomagnetic activity of less than 3 were chosen for analysis. An example of the control of Kp indices is shown in Table 1. Average daily Kp index values from 20.03 to 26.03 2016 not exceeding 2.5 are shown in the last line.

Table1. Kp indices in the time interval 20.03-26.03 2016.

Days Interval ,h	20. 03	21. 03	22. 03	23. 03	24. 03	25. 03	26.0 3
0-3	1	2	3	2	3	2	0.5
3-6	2	2	3	2	3	3	0.5
6-9	3	2	2	3	2	2	1
9-12	2	2	2	4	2	1	1
12-15	2	2	3	2	2	1	0.5
15-18	3	2	1	2	1	1	1
18-21	3	2	0.5	1	1	1	1
21-24	4	1	1	2	1	1	1
Mean	2.5	1..9	2.1	2.3	1.9	1.5	0.8

The duration of the series chosen for analysis varied from one to two weeks. Averaging data on seismic noise and geomagnetic variations in a one-hour discretization interval suppressed high-frequency fluctuations and the series obtained was interpreted as modulation functions. Some of the series were not tied to one time interval because of technical malfunctions in monitoring.

3. Methods for Data Processing and Data Analysis .

Time series spectra were obtained in the MATLAB computer mathematics system using Burg's maximum entropy method with a sliding window with length l = 40.

The method uses an autoregressive data model and shows an error in the current value as a linear combination of this and *l* preceding members of the series. For a Gaussian random process, the requirement of the maximum entropy functional of spectral power yields a signal power signal obtained by dividing output noise power by the square of the module of the spectral characteristics of the «bleaching» filter, if the conditions of Wiener-Khintchin theorem for *l + 1* autocorrelation function values are observed.

The estimate obtained for the spectral density of signal power is non-shifted and positive. The method has a high spectral resolution. The maximum entropy condition, consistent with minimum information, guarantees the absence of alien peaks in the spectrum.

The significance of spectral peak amplitudes was estimated on the basis of χ^2 statistics [16]. Peaks of amplitude A, significant with the confidence level α satisfy the inequality

$$2 \cdot s^2 / \chi^2_{2;1-\alpha/2} < A < 2 \cdot s^2 / \chi^2_{2;\alpha/2} \ ,$$

which uses the variance of s^2 series and the tabular statistical values χ^2 with two degrees of freedom of the spectral peak. Variations in harmonics with time are indicated by the amplitude spectra and waveletograms of series. Amplitude spectra were obtained using modified Scarlge transformation, which yields more precise harmonic parameters than Fourier transform

[17]. The waveletograms constructed are based on Morlet wavelet [16].

4. Results

Shown in Fig. 1 are seismic noise series yielded by three orthogonal meters at PITK station from 20.09 to 26.09 2016 and their power spectra.

Fig.2 shows geomagnetic variation series yielded by three orthogonal meters at the GI MTS-1 geophysical complex from 29.02 to 12.03 2016 and their power spectra.

Fig. 3 shows volumetric radon activity series recorded in three residential areas in different periods of time and their power spectra. Narrow spectral peaks (b, d) indicate their reliability and the resonance pattern of corresponding variations.

The values obtained for the periods of processes are summarized in Table 2.

The significance boundaries of the peak amplitudes for the spectra of volumetric radon activity series with a confidence level of α=0.05 and $\chi^2_{2;0.025} = 0.0506$, $\chi^2_{2;0.975} = 7.378$ are shown in Table 3. The periods of corresponding insignificant spectral components in Table 2 are indicated by asterisks.

Table 3. Significance limits of peak amplitudes (α=0.05).

Monitoring site Significance estimate	**Tsarevichi** Bq^2/m^6	**Solomennoye** Bq^2/m^6	**Pitkäranta** Bq^2/m^6
Variance	2260.2	1509.6	3499.3
Lower limit	612.7	409	949
Upper limit	89336	50644	138312

Intensive peaks in the spectra of seismic noise and geomagnetic variation series are consistent with a day, half a day and one-third of a day. Most of the peaks are close to the periods of the Earth’s own oscillations in the day range shown in the last columns of the Table 2 [19, 21].

The non-stationary pattern of the exhalation of radon into the atmosphere is shown by amplitude spectra in Fig.4 obtained with a sliding window by 60 counts and waveletograms in Fig. 5.

5. Discussion

The geophysical monitoring area is located in the Karelian Craton. The stability and aseismicity of this crustal fragment contribute to manifestation of lithospheric natural movements. On the contrary, the region’s magnetosphere is often unstable because of the proximity to Arctic latitudes and the aurora borealis zone. The duration of the weak perturbation intervals revealed in geomagnetic variation series is about one week (Table 1).

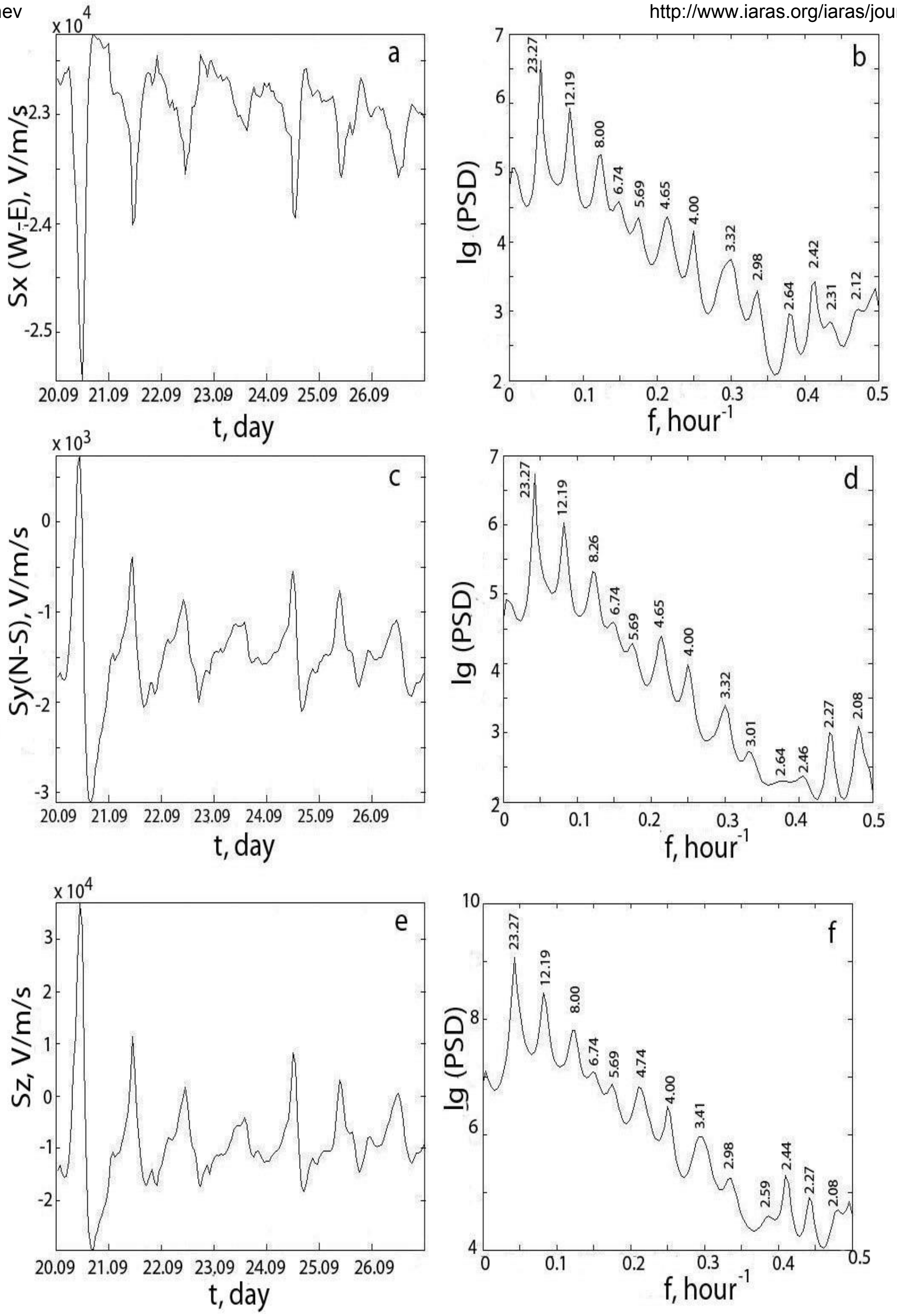

Fig. 1 Seismic noise series of three spatially oriented seismic meters with a one-hour discretization interval (a), (c), (e) and their power spectra (b, d, f), respectively

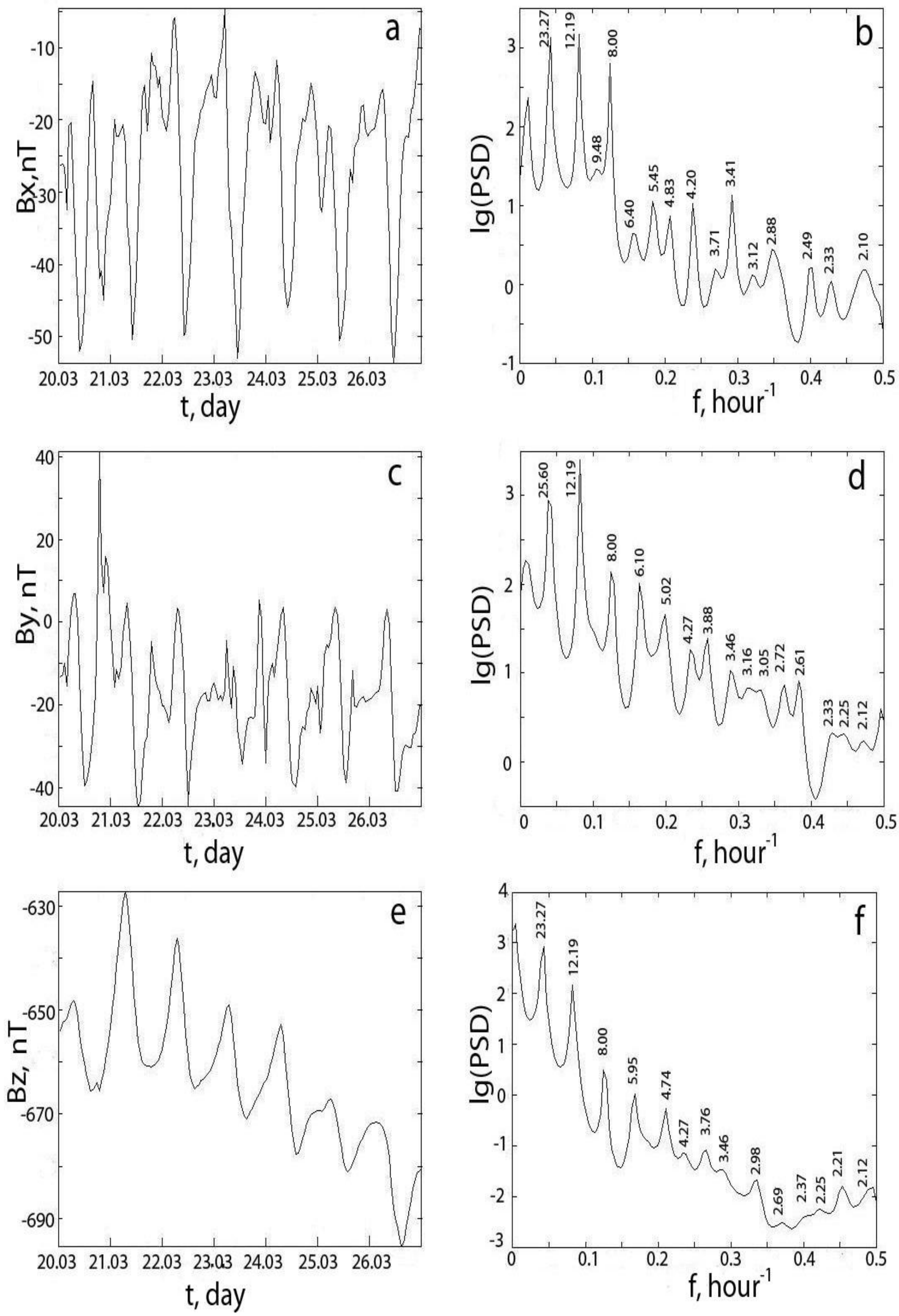

Fig. 2 Variations in three components Bx (a), By (c), Bz (e) of a geomagnetic field from 20- to 26.03.2016 with a one-hour discretization period and their power spectra (b, d, f), respectively.

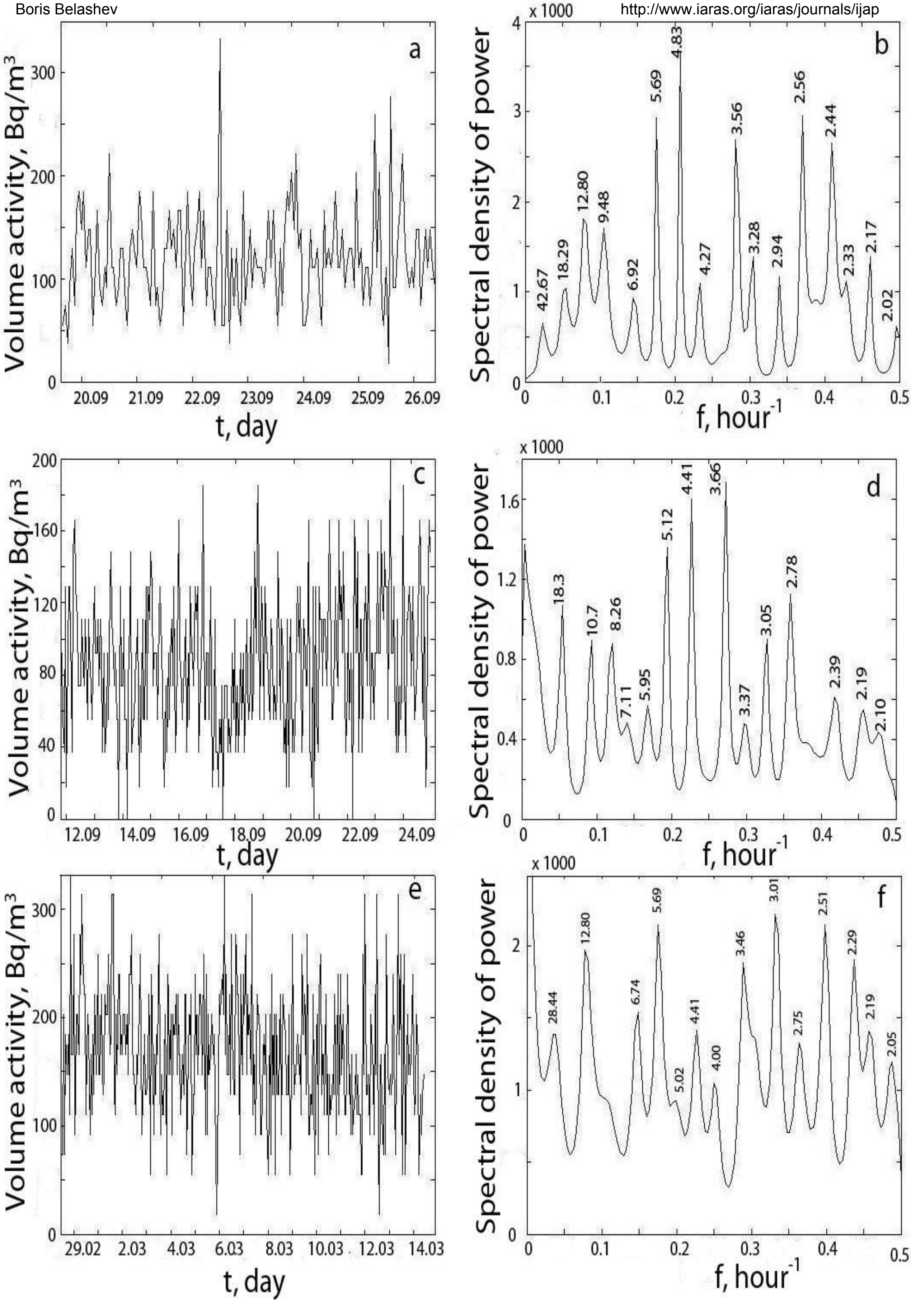

Fig. 3 Volumetric radon activity spectra recorded in the air of basements in the village of Tsarevichi from 20 to 26.09.2016 (a), in Solomennoye Town from 12 to 24.09.2014 (c) and the City of Pitkäranta from 29.02 to 14.03.2016 (e) with a one-hour discretization period and their power spectra (b, d, f), respectively.

Table 2. Periods in hours characterizing cyclicity of investigated processes and periods of Earth's natural oscillation

Seismic noise			Geomagnetic activity			Exhalation of radon in atmosphere			[19]	[21]	
N-S (Sy)	E-W (Sx)	Z (Sz)	N-S (By)	E-W(Bx)	Z(Bz)	Tsarevichi	Pitkäranta	Solomennoye	A	B	C
						42.67*					
23.27	23.27	23.27	23.27	25.60	23.27	18.29	28.44	18.3		23.37	$\Omega - 7\omega$
12.19	12.19	12.19	12.19	12.19	12.19	12.80	12.80	10.7		12.03	$\Omega - 4\omega$
8.26	8.00	8.00	8.00	8.00	8.00	9.48		8.26		8.07	$\Omega - 3\omega$
6.74	6.74	6.74	6.40	6.10		6.92	6.74	7.11			
					5.95			5.95	6.03	5.97	$\Omega - 2\omega$
5.69	5.69	5.69	5.45			5.69	5.69		5.67		
				5.02			5.02*	5.12			
		4.74	4.83		4.74	4.83			4.75	4.80	$\Omega - \omega$
4.65	4.65						4.41	4.41	4.35		
			4.20	4.27	4.27	4.27					
4.00	4.00	4.00					4.00		4.01	4.01	Ω
			3.71	3.88	3.76				3.76		
						3.56	3.48	3.66	3.60		
3.32	3.32	3.41	3.41	3.46	3.46			3.37	3.41	3.43	$\Omega + \omega$
				3.16		3.28			3.21		
3.01	2.98	2.98	3.12	3.05	2.98	2.94	3.01	3.05	3.06	3.00	$\Omega + 2\omega$
			2.88	2.72			2.75	2.78			
2.64	2.64	2.59		2.61	2.69	2.56	2..51			2.66	$\Omega + 3\omega$
2.46	2.42	2.44	2.49		2.37	2.44		2.39		2.40	$\Omega + 4\omega$
2.27	2.31	2.27	2.33	2.33		2.33	2.29				
				2.25	2.21	2.17*	2.19	2.19		2.18	$\Omega + 5\omega$
2.08	2.12	2.08	2.10	2.12	2.12			2.10			

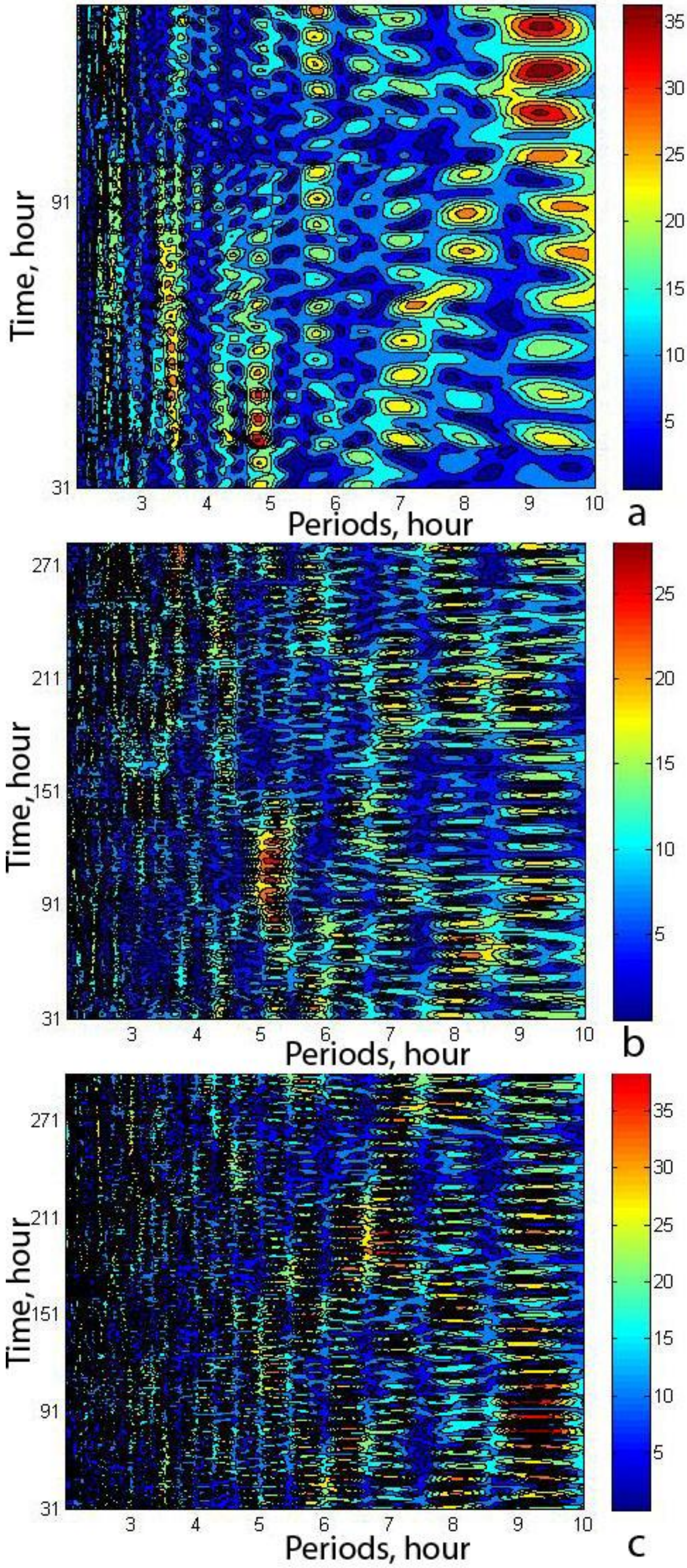

Fig. 4 Amplitude spectra of volumetric radon activity series recorded in the village of Tsarevichi (a), Solomennoye Town (b) and the City of Pitkäranta (c).

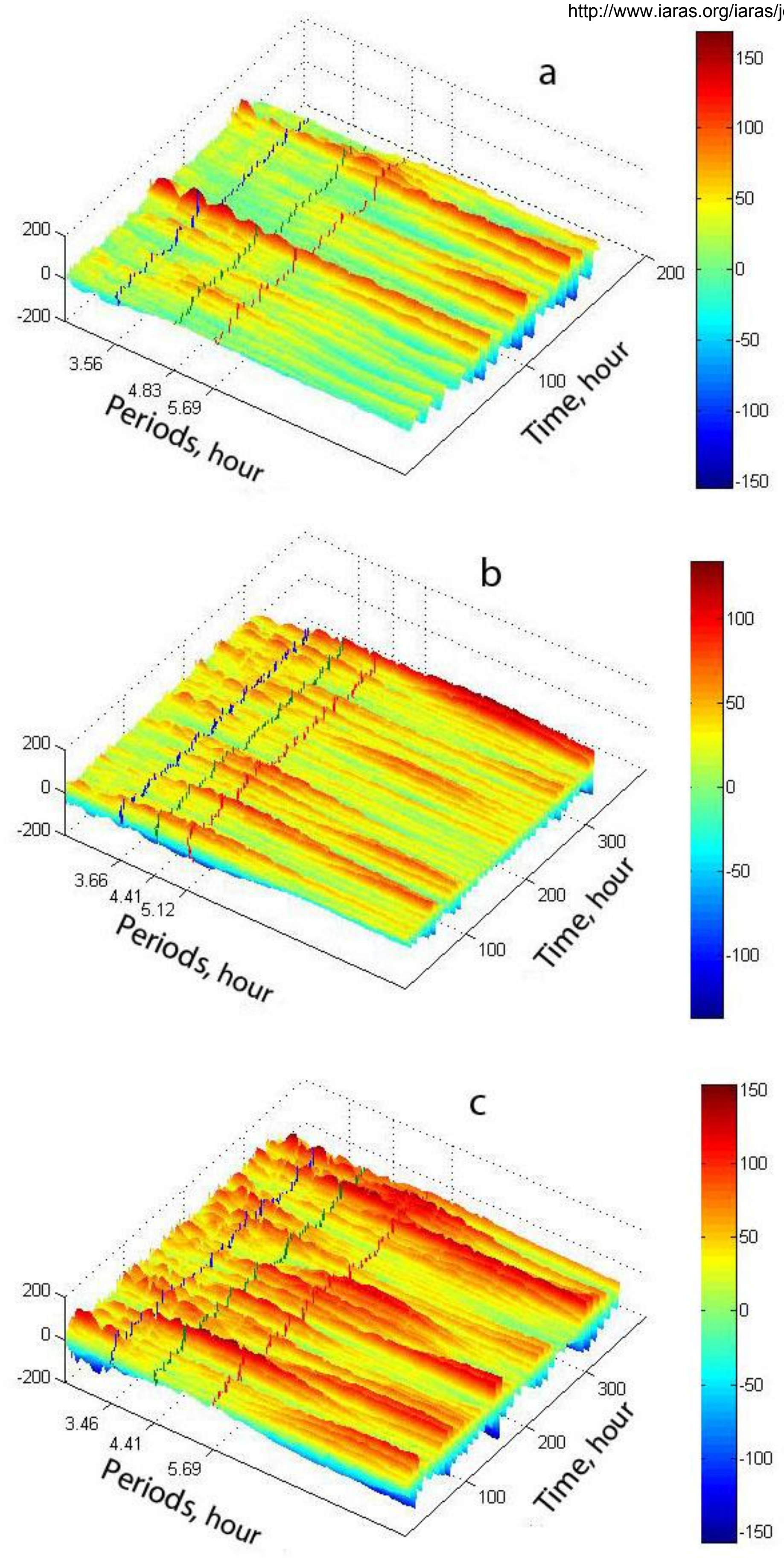

Fig. 5 Waveletograms of volumetric radon activity series recorded in the village of Tsarevichi (a), Solomennoye Town (b) and the City of Pitkäranta (c).

The surface layers of the earth crust at Solomennoye and Tsarevichi consist of Solomennoye breccia. Low uranium, potassium and thorium concentrations in this volcanogenic rock are responsible for background radiation levels of 0.06-0.12 μSv/h, which are not consistent with volumetric radon activity values (Fig.3 a,c,e) exceeding normative 200 Bq/m^3. It seems that radon in the above areas ascends onto the earth surface from deep horizons.

Daily periodicity in seismic noise and geomagnetic variation series reflects the alternation of day and night, variations in the light, geomagnetic and temperature regimes and a production rhythm. Semi-diurnal periodicity is attributed to tidal phenomena and an 8-hour period with the non-linearity of the processes. Attempts to interpret a complete set of the periods revealed by these phenomena alone have failed. Most of them can be attributed to the Earth's natural oscillations (Table 2).

The Earth's natural oscillations are the mechanical oscillations of the Earth's elastic body. They are divided into seismogravitational oscillations in a varying gravity field and torsional vibrations in a constant field. The former type is recorded by gravimeters, the latter type by deformation meters and both types by seismographs. The linear spectra of natural oscillations are used for checking the internal structure models of the Earth and other planets.

The Earth's natural vibrations were initially recorded after strong earthquakes [18]. Their presence in a background seismic process has enabled scientists to obtain a more precise statistical vibration spectrum, to compare the periods obtained by various authors and to confirm the similarity of their results. Periods in the 3.06-6.03 hour range are shown in column A of Table 2 [19].

The harmonics of periods shorter than 3.45 hours are attributed to space rhythms, spherical Earth's vibrations, variations in atmospheric pressure and the oscillations of AE-index [20].

The cyclicity of endogenous activity and geophysical processes is believed to be due to the gravity of celestial bodies in the Earth's model, which was constructed as a system of unbalanced non-spherical shells [21-23]. This model introduces new types of oscillations. The natural oscillation of the gravity centre of the earth core relative to the gravity centre of the mantle has a period of 4.01 hours and the frequency Ω. This oscillation, modulated by the Earth's daily rotation at the frequency ω, generates harmonics with the frequency $\Omega \pm n\omega$ (n is natural numbers) and periods shown in columns C and B of Table 2.

Seismic noise and geomagnetic variation modulation by the Earth's natural vibrations is well-known [24-26]. It is triggered by the high sensitivity of an elastically deformed medium, which makes a spasmodic transition from one metastable condition to another under the influence of external factors. Unstable radon emission is attributed to local geodynamics and atmospheric and man-induced factors [27]. Its connection with the Earth's natural vibrations is not discussed. The similarity of the periods in Table 2 for volumetric radon activity, on the one hand, and the Earth's natural vibrations, seismic noise and geomagnetic variations, on the other, points to its existence.

The modulation of radon exhalation into the atmosphere can be explained using the degassing of the Earth. Heavy radon moves into subsurface ground layers and atmosphere together with hydrogen and methane vesicles [28]. In contrast to methane, which carries radon at sites with trails of hydrocarbon clusters [29], hydrogen is a multi-purpose carrier. The global scope of hydrogen degassing is supported by monitoring of the ozone layer destroyed by hydrogen on leaving the planet [30]. Simultaneous variations, shown on dynamic maps of ozone concentrations in the different parts of the globe, point to a common deep source of hydrogen. The source is assumed to be provided by the earth core, which vibrates, modulating hydrogen degassing and, by means of degassing, the exhalation of radon into the atmosphere. Radon emission could be affected by other factors related to the Earth's vibration such as the opening-closing of fractures and the ground water level.

The existence of the Earth's hydrogen degassing has been proved by direct measurements of endogenous hydrogen flow [31]. Fluid flows can change the stressed state, filtration properties and electrical conductivity of rocks, affect the ionosphere and generate seismic noise and acoustic emission. Degassing is used for modelling plume-tectonics [32] and a seismic process [33].

The data shown in Table 2 are consistent with periods of variations in the Earth's velocity, atmospheric pressure, the geoelectrical parameters of rocks, acoustic emission and degassing [34, 35]. The chronostructure of the Earth's natural vibrations is responsible for the distinctive pattern of auto-oscillation systems and the polyrhythmicity of physico-chemical, meteorological, hydrological and biological processes [36].

It is important for organisms to correlate their cycles with environmental cycles. Let us demonstrate the adjustment of biological rhythms to geophysical rhythms by discussing the Earth's natural deformational vibration with a period of 12.175 days [35] and vibration with a period making up one-third of it, i.e. 4.058 days. These harmonics are present in the dynamics of rapid decreases of atmospheric pressure, the vertical component of the interplanetary magnetic field and variations in the daily concentrations of summer near-surface ozone [36]. They are recognized in biological activity rhythms, glucocorticoid hormone concentration and myotic epithelium activity [36]. Synchronized with an annual cycle, fitting into it 30 and 90 times, they confirm a relationship between biological rhythms and the Earth's natural vibrations.

6. Conclusion

Automated instrumental complexes, monitoring the lithosphere and magnetosphere in Karelia, provide information for the study of geophysical processes. Time series of seismic noise, geomagnetic variations and volumetric radon activity, recorded under low seismic and geomagnetic activity conditions, provide information for analyzing the cyclicity of processes.

The high resolution of the power spectra of these series enables scientists to identify the harmonic constituents of processes and to determine their parameters.

The similarity of the periods of processes analyzed to the Earth's natural vibrations points to the modulating and synchronizing role of the Earth's natural vibrations. The polyrhythmicity of processes may be controlled by combinations of natural vibrations and be dependent on variations in the Earth's diurnal rotation velocity.

The volumetric radon activity modulation mechanism proposed relates the exhalation of radon into the atmosphere to earth core vibrations by means of hydrogen degassing.

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