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GEOGRAPHY

Investigation of Specific Features of Rhythmodynamics of Interannual Variability of Hydrometerological and Hydrological Processes in Coastal Zones

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Any large water basin with a surrounding coastal zone and relevant atmosphere and electromagnetic fields can be considered a complex hierarchic nonlinear dynamic system. The study of such systems [4, 7, 8, 11, and others] shows a complex, largely undulating mode of both temporal and spatial variations in their internal processes. The mutually balanced interaction between system (subsystem) components makes up combinations of its natural frequencies, at which a maximum response to various external and internal perturbations is recorded [6].

The search and study of such natural frequency combinations should begin by defining a common group of stable rhythms in dynamics of all the subsystems. Previously, such periodicity groups were defined in the form of temporal series for some processes using the method of intraspectral analysis (ISA) [2, 5]. It is used for the search and analysis of regularities in dynamics of basic characteristics of dominant temporal and spatial fluctuations in various processes.

In so doing, a series of measurements is subdivided into equal but not overlapping temporal sets, and each of them is subjected to the complete Fourier transform. The temporal series of amplitude variability is plotted for each of the harmonics of the spectra series. These series, in turn, are analyzed using the Fourier transform. The presence of dominant harmonics in the obtained secondary spectrum suggests basic regularities in temporal amplitude variations of corresponding harmonics of the initial spectrum. Such a procedure can be repeated several times to obtain the tertiary and subsequent spectra if the length and discreteness of initial observation series are sufficient.

This method was used to analyze long-term series of daily mean, monthly mean, and annual mean values of individual parameters for several different physical processes. The data from free Internet centers (WDC, NCDC, NODC, NGDC, PSMSL, DECVAR, SPIDR, and others) were used for this purpose. These data include Wolf numbers, geomagnetic indices (A_p, K_p) and parameters of the magnetic field for some stations, air temperature, precipitation, atmospheric pressure and humidity, sea level and water temperature for individual observation sites in coastal zones, fields of the atmospheric pressure, river runoff (for the former Soviet Union), and known indices of oceanic and atmospheric variability (PDO, NAO, SOI, NP, and others). Series of paleomagnetic data for large periods were taken from published sources [7–9]. In total, over 300 temporal series from different observation sites in coastal zones of the Northern (largely Europe and the former Soviet Union) and Southern hemispheres over a period of at least 45 yr were analyzed.

First, we used the daily mean series. They were divided into annual subseries, which were subjected to successive ISA procedures. Figure 1 presents examples of variability fields obtained for amplitudes of primary spectra harmonics. For better presentation of the essential features of field structures, they were subjected to low smoothing using the Surfer program. Processing of data for 45 yr (1943–1987) or a similar period (with shift of ±1–3 yr) showed that all the secondary spectra contain three groups of dominant harmonics with periods close to 2–3, 4–6, 9–12, 15, and 22 yr (Fig. 2). As was assumed, most of the harmonics in these periodicity groups are common for all the obtained spectra.

Similar structures of variation fields were obtained also for all other examined processes. The applied method made it possible to define several additional features in their rhythmical dynamics. Due to the filter-

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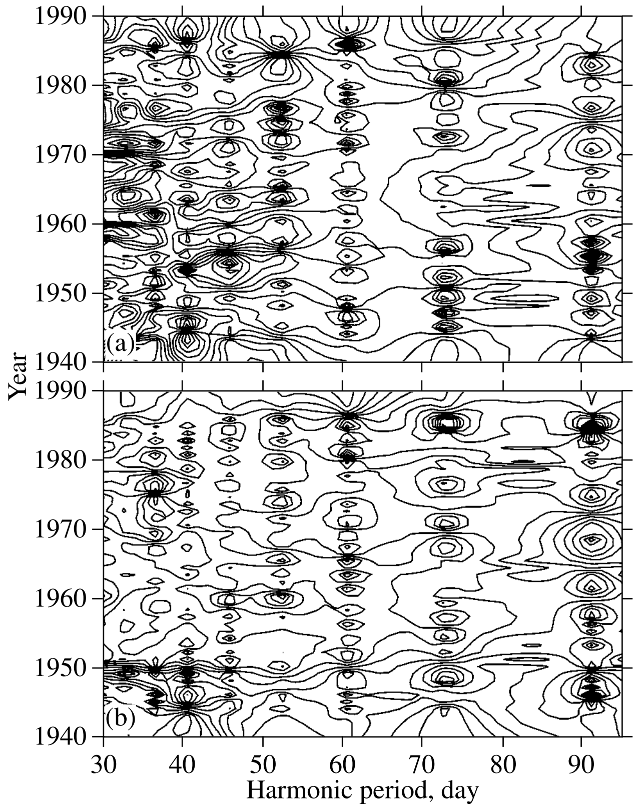

Fig. 1. Amplitude variability fields of primary spectra harmonics depending on their period and year for the air (t_a) and water (t_w) temperature series in (a) Dikson and (b) Yalta, respectively.

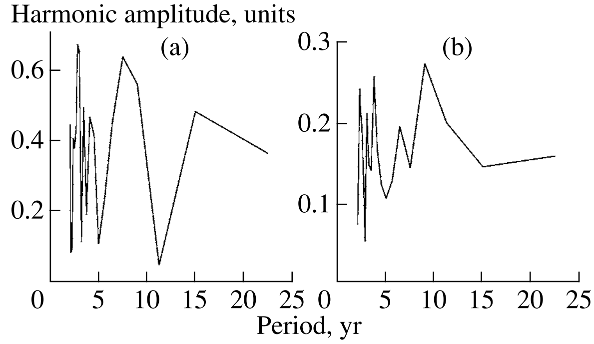

Fig. 2. Secondary spectra of the 1st harmonic dynamics (365 days) in the air (t_a) and water (t_w) temperature series in (a) Dikson and (b) Yalta, respectively.

ing effect of some oscillations and their groups in this case, both similarity and dissimilarity are better manifested in temporal variations of individual harmonics in obtained spectra. For example, amplitudes of harmonics with periods of 365 to 30 days (in primary spectra) are characterized by similar, mainly one-phase variability at middle and high frequencies of their dynamics despite differences at low frequencies (LF). For harmonics with periods of 30 to 2 days, this situation is distorted, resulting in a disordered field of their temporal variability. However, order in these fields is restored after the liberation of harmonics with particular periods that are inconsistent with LF harmonic periods according to the octave principle [2].

This is probably related to the possible resonance interaction between harmonics, because quasi-periodic fluctuations are present in variations of their amplitudes along the frequency axis in spectra of each temporal subseries. Close properties are also typical of similar fields obtained for harmonics of secondary spectra. Therefore, the discovered phenomenon cannot adequately be described as usual amplitude modulation or reduced to principles of the harmonic analysis theory or to other known model concepts [1, 10]. Therefore, it is called an autonomous intraspectral variability (ISV).

The change in position of the point or area corresponding to the current spatial state of the system or process is usually called a functional trajectory. The thorough analysis of obtained results with account for synthetic transformation of views on fractality, fractional multitude, self-similarity, cyclicity, and hierarchy of natural systems [3, 6, 11] suggests that a circle consisting of smaller similar circles can represent such a trajectory for natural processes with periodic or quasi-periodic wave properties.

It means that when the spectral transformation of a natural measurement series results in periodic or quasi-periodic amplitude harmonics (i.e., they form a certain rhythm or group of dominant rhythms), the same will be repeated at all the subsequent levels of smaller (or larger) circles forming a system of self-similar or superimposed structures (according to terminology in [3]). For practical purposes, only two of all the possible superimposed levels are presented in this communication. Presence of such properties in any process indicates in fact the fractal-undulating structure of its variability (FUSV). This term is related to the following feature. According to B.B. Mandelbrot, the fractal, which is characterized by self-similarity, consists of geometrical fragments of different sizes and orientations but of similar shapes and has fractional dimensionality; i.e., it can be described by the theory of fractional (p-adic) multitudes [3].

To test this assumption, we applied the ISA method of analysis of the monthly mean and annual mean values of used series. As in previous works, the series were subdivided into equal (but not overlapping) 1-yr, 10-yr, and longer subseries depending on the total duration of the series and its discreteness. Figure 3 demonstrates some of the obtained results. Compared with Fig. 1, fields in Fig. 3 are less detailed, because a number of harmonics in spectra of corresponding series are an order of magnitude lower due to coarse discreteness. However, the variability structure remains the same or similar at all levels. Figures 1 and 3 support the last assumption. This is also confirmed by the results of ISV analysis of physical processes in coastal zones of both

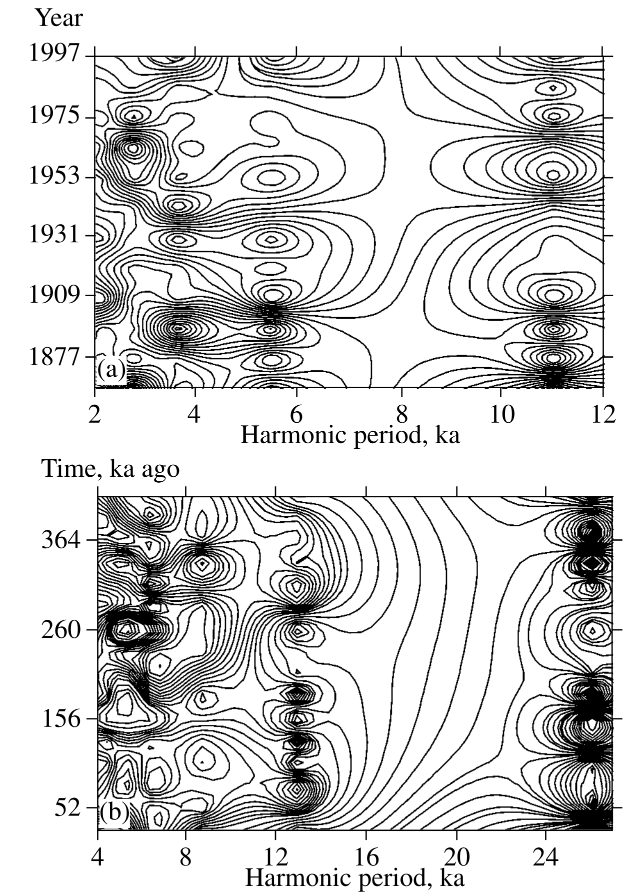

Fig. 3. Amplitude variability fields of primary spectra harmonics depending on their period and year for (a) the NAO index series and (b) reconstruction of air temperature (t_a) based on deuterium concentration in ice cores from Antarctica.

intracontinental (Black, Azov, and Caspian) and marginal (White, Baltic, and Japan) seas [2, 5].

The general rhythmical–dynamic approach and methods applied in this communication allow us to unite descriptions of various processes functioning in marine systems using the previously proposed nontraditional model, namely the hierarchical system of multiperiodic oscillators that possess common properties of a multilevel self-similar (superimposed) amplitude modulation and resonance interaction between the major tones and overtones functioning in the oscillation system [5]. Returning to ISV properties briefly described at the beginning of this communication, such a concept provides grounds for their preliminary explanation.

It can be assumed that the quasi-periodic structure of ISV fields is related to the superposition of two orthogonal (relative to coordinate axes) undulating processes. Each oscillation of the totality of a process behaves functionally as the whole process, resulting in spotty patterns of the field, i.e., in the formation of specific areas. Due to the superimposed amplitude modulation of the dominant oscillations at relatively constant phase interrelations, the amplitudes in such areas will be temporarily close to values of their nondominant counterparts and relevant overtones, resulting in the common noise-type appearance of a signal. Such areas are observed in Figs. 1 and 3. In HF harmonic regions of ISV fields, this mechanism functions permanently because of a small difference between their amplitudes. Alternating areas of rhythms and noise-type temporal variability in natural processes were noted long ago [10, 11]. They served as a basis for substantiating notions of periodically and almost periodically correlated random processes. In the considered case, this provides no obstacles for the search of structure and system-forming characteristics for the set of stable dominant oscillations.

Deficiency of primary data, their irregular distribution over the earth's surface, different durations of observation series, and their partial asynchronous patterns do not allow us to make any definite inferences. At first approximation, the used data and results of the analysis, however, are sufficient for some preliminary conclusions:

(1) Annual variability of processes in marine ecosystems during the last 50–100 yr is quasi-periodic at least for 60–70% of their energy field. They are characterized by stable rhythms with periods of approximately 2–3, 4–6, 9–12, 15, and 22 yr.

(2) Variability of the processes is characterized by the fractal-undulating structure of rhythmical dynamics and, consequently, intraspectral variations in dominant harmonics.

(3) Regional features in the totality of all natural undulating properties of marine systems are largely manifested in different amplitudes and, partly, in phases of individual oscillations typical for particular observation areas and sites. This difference is responsible for the formation of spatial heterogeneity of variation fields of regional parameters.

For a detailed description of such heterogeneities and a search of possible mechanisms responsible for their formation, further studies based on direct measurements over a smaller-scale grid and satellite data are needed.

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