On the spectra of long-period oscillations of geophysical parameters

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ABSTRACT

Computations were made of 21 time series spectra of long-period oscillations of meteorological elements and some geophysical parameters (annual thicknesses of glacial and clastic lake varves, evaporite varves, tree-ring indices). Jackson-Poussin-Vallée kernel was used as a filter. In all the computed spectra, 11- and 22-year energetic components are absent, hence there is no relation with solar activity parameters. The time spectra in the long-period region are approximately similar. An attempt is made to construct a universal curve that describes time spectra of very far-distant geological eras—from Paleozoic (Permian and Carbonic periods) and Cenozoic time (Tertiary-Pleistocene and Quaternary periods) till Recent time.

Modelling of climates of the past epochs is one of the possible lines in the use of ever developing numerical experiments on the general circulation of the atmosphere and the ocean. No quantitative theory of climate can be constructed if there is no clear-cut idea of the character of long-period (intra- and inter-centennial) and year-to-year oscillations of meteorological fields which can be gained from the studies of time spectra in this scale region [1].

Year-to-year time spectra of meteorological fields have been studied inadequately. In spite of this, an actually unfounded assertion of the existence in the "earth" spectra of 5.5-, 11- and 22-year periodic components interpreted as a direct manifistation of the influence of solar activity is frequently encountered in meteorological literature.

The present paper presents systematic consideration of different aspects of the studies of long-period oscillations. It opens with a discussion of the available published materials. A brief analysis of the methods used for data processing is followed by a description of the materials processed, and in conclusion some results of the work are presented and their generalization is made.

1. Available literature

An analysis of the literature dealing with quantitative estimates of periodic components shows that assertion of a direct effect of solar activity is inadequately justified. In fact, as one can see from Table 1 [2–16], an 11-year cycle shows up in spectra comparatively seldom.

Data contained in Table 1 do not corroborate the results given in [17, 18] where estimates of the share of "the sun-dependent bends of integral curves of different meteorological elements" exceed 40%. In our opinion, this can be accounted for by a certain subjectiveness of the integral curve method.

2. Methodological notes

Table 1 results were obtained by different data processing methods and need to be examined critically. First of all, let us consider the running filtrering method used in paper [10] the results of which have often been referred to (for instance [19, 20]) as confirmation of the existence of 3-, 6-, 11-, 38- and 80-year "sun-dependent" cycles. The spectral analysis of the original data [10] made by Anderson & Koopmans [11] did not reveal these components.

The average interval of approximately II years between two abnormally thin varves infered by Richter-Bernburg [13] from the studies of thin evaporites Zechstein (Z-2) is interpreted as an evidence of solar activity effects. It should be noted that the notion of "abnormally thin varve" is used very arbitrarily in constructing histograms since annual thicknesses of evaporite varves change gradually. The initial data

Table 1.

Reference	No. of series	Duration of series	Methods of data processing[a] RF	P	C	A	S	Results presented by the authors
Air temperature								
Landsberg [2]	1	87					+	5.5-, 11- and 22-year components are lacking. Maximum of the curve is between 1.8 and 2.7 years
Druzhinin [3]	73				+			A 10- or 11-year component is found in 7 % of the stations
Kolesnikova & Monin [4]	2	130				+		Curve maximum is about 5.5 years
		198				+	+	Curve maximum is about 3 years
Rubinstein & Polozova [5]	80	80	+					In 20 % of the cases, the curves of 5-year running average temperatures reveal 11-year oscillations in some
	80	80	+					months. Out of the whole number of the stations and months studied (80 × 13 = 1 040) an 11-year cyclic recurrence was found in somewhat mor
	6	80		+				than 2 % of the cases
		156						Mean monthly temperature was studied for 5 or 6 months of mainly the
		161						cold season. In 4 cases, two months have an 11-year cycle, and in 3 cases one month has an 11-year cycle
	2	213			+			No 11-year cycle is found
		133						No 11-year cycle is found
	11							An 11-year cycle is found in 3 cases
					+			An 11-year cycle is found in 2 cases
Atmospheric precipitation								
Landsberg et al.	1	87					+	5.5-, 11- and 22-year components are lacking
Brier [6]	8	100–160						5.5-, 11- and 22-year components are lacking
Druzhinin [3]	70				+			An 11-year cycle is found in 6 % of the stations
Atmospheric pressure								
Druzhinin [3]	29				+			An 11-year cycle is found in 3 % of the stations
River discharge[b]								
Druzhinin [3]	37				+			An 11-year cycle is found in 5 % of the stations
Rozhdestvensky [7]	54		+					An 11-year cycle is found in 15 % of the stations
Nonglacial clastic lake varves								
Shostakovich [10]	7	to 4 096	+					2.8-, 5.9-, 11.6-year cycles
Anderson & Koopmans [11] 6 series from data	7						+	2.8-, 5.9- and 11.6-year components are lacking
of [10]	6	105 4 096					+	
Clastic marine varves								
Anderson [12]	1	471					+	An appreciable peak in 22nd year periods
	1	480					+	A peak on the S-curve corresponding to 100-year periods
Anderson & Koopmans [11]	1	126					+	Peaks on the S-curve in the vicinity of 25- and 12-year periods

Table 1 cont.

Referend	No. of series	Duration of series	Methods of data processing[a] RF	P	C	A	S	Results presented by the authors
Glacial varves								
Anderson & Koopmans [11]	6	100–525					+	An average spectrum indicates a slight increase of S in 5 year periods
Evaporites								
Anderson [12]	2	~100					+	S-curve maximum is about 5 years
Richter–Bernburg [13]		>40 000						An 11-year cycle
Anderson & Kirkland [14]	1	1 592					+	A general decrease of S with frequency growth 180- and 85-year components
Tree-ring varves								
Douglas [15]				+				Periodic components (10, 12 to 14 and 23 years)
Bryson & Dutton [16]	12	to 3 180					+	11- and 22-year components are lacking

[a] RF = runnig filtration, P = periodogram, C = correlogram, A = analyzer, S = spectral density computation.
[b] Jevdjevich [8] (cited from [9]) shows that river discharge oscillations are not essentially cyclic.

of [13] as well as of the well-known paper by Douglas [15] have not been published which makes it difficult to verify the results by a spectral analysis. Note that no distinct manifestation of the 22-year component [12] was found later for other sediment series as mentioned in [11].

The revelation of periodic components by constructing a periodogram [5, 15] or by analyzing correlation function [3, 5] entails certain difficulties. As is well-known, the periodogram cannot be used for a statistically reliable estimate of spectral density [22] because the dispersion of the former does not approach zero as the length of a time series grows infinitely. Irregularity of the periodogram is apparent even with the use of a considerable number of data [11].

The analysis of a correlogram corresponds in essence to the correlation method of detecting repeated signals against a noise background. It is known [23] that if a signal and noise are incoherent the correlation function will detect a periodic component. The effect of noise diminishes and the accuracy of detecting the periodic component grows as the time-delay argument increases (in this case the period of change of the correlation function coincides with the period of the revealed component). Errors in computing the correlation function increase sharply as the argument grows, and the computations to τ arguments exceeding 0.1 T (T is the recording length) result in errors of more than 20%. The periodic component is revealed [3] based on the well-known feature of the correlation function. In other words, the highest absolute negative values of the correlation function are believed to correspond to the time-delay argument of about semi-period. The fact that the restricted recording length leads to a fictitious decrease of the correlation scale of the process under study is neglected. As a result, the position of the extreme is displaced. The use of such inaccurate methods as periodograms and correlograms yields in a number of cases (to 27%), as the authors of [5] point out, discrepant results concerning the presence of periodic components.

It is necessary to emphasize that the computations of spectra should be made by thoroughly selected methods. For instance, the spectra of Bryson & Dutton [16] were obtained at a very low resolution of the filter, i.e. they are extremely smoothed (see details in [11]). The revelation of 22-year components by spectral analysis of short series ($N < 200$; this is particularly true of Landsberg's [2] paper containing the analysis of a 87-year series) entails especially large uncertainties for longer periods.

Table 2.

		Duration of series	Period
Air temperature[a]			
1	Leningrad	215	1752–1966
2	Stockholm	204	1756–1959
3	Stockholm (winter)	204	1756–1959
4	Vilnius	184	1781–1964
5	Basel	205	1753–1957
6	Berlin	192	1769–1960
7	Berlin (summer)	192	1769–1960
8	Trondheim	203	1761–1963
Number of days free from ice[a]			
9	Neva	224	1741–1964
10	Angara	232	1725–1956
11	Severnaya Dvina	226	1734–1959
Evaporite varves			
12	Upper Kama deposit [22]	936	Upper Permian time
Nonglacial clastic lake varves			
13	Saki Lake [10]	4 168	2 300 B.C.–A.D. 1867
Glacial varves			
14	Leningrad region [23]	304	Late Quaternary
15	Leningrad region [23]	198	Late Quaternary
16	Scandinavia [24]	560	Late Quaternary
17	Canada [24]	700	Late Quaternary
18	Canada [25]	630	Pleistocene
19	Canada [25]	510	Pleistocene
Tree rings			
20		524	
21	Tree-ring varves	396	

[a] Data were made available through the kindness of A. V. Shnitnikov.

3. Original data

Let us consider the original data contained in Table 2. The most extended series of meteorological elements do not exceed 200 or 250 years. Therefore when dealing with meteorological information we can study oscillations of about 20-year periods. It is reasonable to use the materials on annual thicknesses (or varves) of layered sedimentary rocks. In the present paper, consideration is being given to halogen rock series whose cross-sections give clear-cut evidence of seasonal changes manifested in a rhythmical alternation of interlayers of different mineral composition and structure. The whole section of Upper Kama deposit[1] was formed [24] in about 20 thousand years. However, since the formation of evaporate varves was influenced both by climatic factors and by the voluminous supply of fresh water which may be due to water displacement under tectonic movements over large areas rather than to climatic changes, we made use of the lower portion of the cross-section (from underlying rock-salt to the Red III^b sylvinite layer) consisting of 936 annual layers [25]. This mass of salts was not subject to intensive movements and hence recrystallization, therefore an ideal banded structure of the salts is close to that peculiar for the sedimentation period.

Clastic lake varves were chosen as an object of studies [26–28] due to the distinctly pro-

[1] Evaporate varves of Upper Kama deposit in their composition and time of formation (Upper Permian) are close to German Zechstein [13].

nounced seasonal layering. The latter fact enables varved clay to be used [27] for compiling detailed regional chronological schemes of late-glacial time.

Besides, we made use of dendrochronological series proceeding from the fact that it is climate [29] that can be considered the basic factor determining the growth of trees in a semiarid zone at the boundary of woods. Since the widths of tree rings are determined by the age of a tree as well, tree-ring indices were initial in the computations. Standardization procedure (corrections for the age of a tree) was accomplished by N. V. Lovelius (Botanical Institute of the USSR Academy of Sciences).

4. Methods for computing spectra

The analysis of the initial series [30, 31] shows that the latter are rather homogeneous. The annual oscillations were excluded because only annual averages were used.

Proceeding from the original data, a structural function[1] was computed

$$D(\tau) = \overline{[\xi(t) - \xi(t+\tau)]^2} \quad (1)$$

which is known to be determined with smaller errors than correlation function $R(\tau)$, since $D(\tau)$ is less affected by long-period components of the initial series.

The analysis of correlation functions computed with the aid of equation

$$R(\tau) = \sigma^2 - \frac{D(\tau)}{2} \quad (2)$$

revealed no "trend" in the original data. Fig. 1 represents correlation functions of tree-ring varves and evaporites [25]. Correlation functions can be approximated by the expression $e^{-\alpha\tau}\cos\beta\tau$. Thus the spectra should have periodic components. The determinations of spectral density were based on the results of the theory of stationary random functions [32, 33]. The spectral density $S(f)$ was determined as Fourier-cosine integral of the correlation function

$$S(f) = 4\int_0^\infty R(\tau)\cos 2\pi f\tau d\tau \quad (3)$$

[1] The line on top stands for averaging in time.

For statistically reliable estimators of spectral density use was made of Bartlett's [34, 35] method of a filtered correlation function which imples that $R(\tau)$ values are taken with weights decreasing from 1 (at the origin of coordinates) to zero at certain values of the time-delay argument. In this case the problem will consist essentially in optimal approximation of the function with only first n Fourier coefficients preassigned. The filter is an even function concentrating at the origin of coordinates. By its properties it is a Fejér type kernel of the integral operator. The present paper deals with the Jackson–Poussin–Vallée [36, 37] type kernel of the form (Fig. 1)

$$\begin{array}{ll} 1-6\left(\frac{j}{n}\right)^2\left(1-\frac{d}{n}\right) & j \leq \frac{n}{2} \\ 2\left(1-\frac{j}{n}\right)^2 & \frac{n}{2} \leq j \leq n \\ 0 & j > n \end{array}$$

Dispersion of the smoothed estimator of spectral density is inversely proportional to the rate at which the filter concentrates at the origin of coordinates. The dispersion value depends greatly on the choice of the filter. If density $S(f)$ in the region of spectral weight function is a smooth function one can easily show [31] that var $\{S_n(f)\}$ decreases as the length of a time series grows. For filter (4) the following equation is approximately valid:

$$\frac{var\{\tilde{S}_n(f)\}}{S^2(f)} \approx \frac{n}{2N}$$

where N is the series length.

It will be recalled that weighted estimator $\tilde{S}_n(f)$ is biased. Decrease of asymptotic bias through the increase of n will naturally result in dispersion growth. Filter (4) has a smaller variation coefficient than the filters of Hanning–Tukey [38], Bartlett [34, 35] or Lanczos [37]. Relationship

$$\frac{var\{\hat{S}_n(f)\}}{S^2(f)} \approx \frac{3n}{4N}$$

is valid for a widely used filter [38]. Let us note that filter (4), unlike the filters of Hanning and Lanczos, has no negative interval. Fig. 2 gives spectral density S/σ^2 of evaporites ($n/N = 0.2$). All the spectra were computed at the relation-

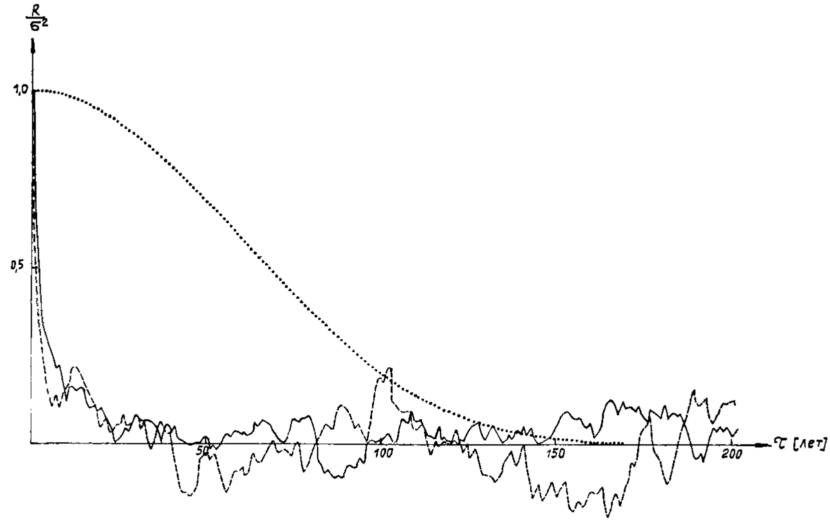

Fig. 1. Correlation function of tree-ring widths and evaporites varves: ....., Filter (4); ---, normalized correlation function of tree-ring indices ($N = 524$); ——, normalized correlation function of evaporites [25] ($N = 936$).

ships between parameters $n/N = 0.1$, 0.2, 0.3, 0.4. The obtained regularities were found to be very stable. The spectrum of nonglacial clastic varves from the Saki Lake (data of [10], series $N = 4\ 168$, unlike [11] in which this series was divided into 20 series with 200 years in each) was computed by L. N. Klukvin by Tukey's methods [38].

The analysis of spectral density of the series [10] has not revealed periodic components with 90 to 80-, 20- or 11-year periods. The spectral density of evaporites and clastic lake varves decreases with the growth of frequency.

It should be noted here that the opinion about the presence of periodic components is often based on the presence of extremes on spectral density curves $S = S(f)$ or energetic spectra curves $Sf = \varphi(\ln f)$ (Fig. 3). Though these curves are connected uniquely (and in both cases the area under the curve determines energy $E = \int S df \equiv \int Sf d(\ln f)$ it should be emphasized that the extremes on the curves do not coincide. In fact, it follows from equation

$$\frac{d(Sf)}{d\ln f} = Sf\left(I + \frac{d\ln S}{d\ln f}\right)$$

that at $dS/df < 0$ spectral extremum $dSf/d \ln f = 0$ corresponds to condition $(d \ln S)/(d \ln f) = -1$, i.e. montone decrease of spectral density. And

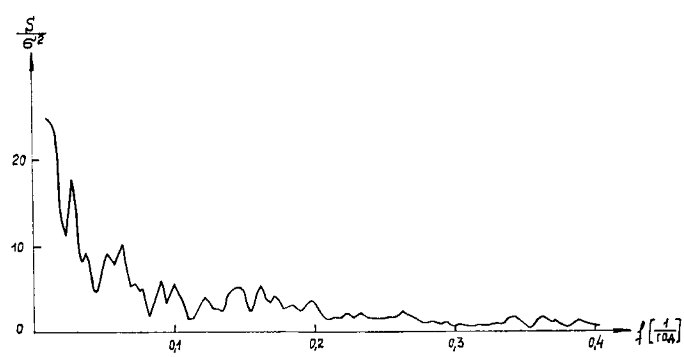

Fig. 2. Spectral density S/σ^2 of evaporites from Upper Kama deposit [25] computed at $n/N = 0.2$.

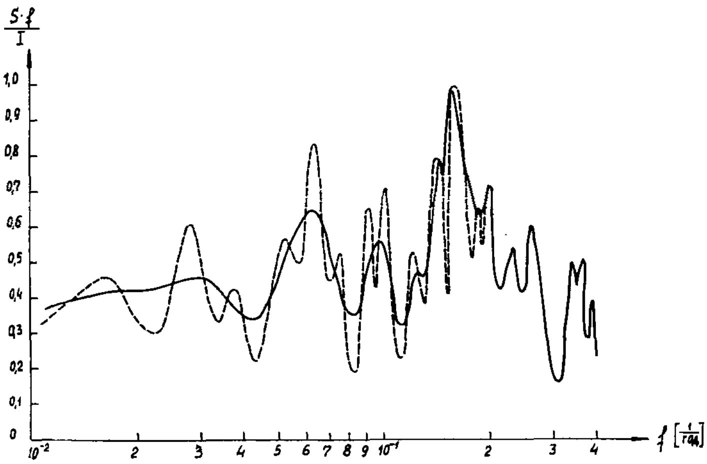

Fig. 3. Normalized energetic spectrum Sf/I of evaporites from Upper Kama deposit [25]. ——, Computed at $n/N = 0.1$; ---, computed at $n/N = 0.2$.

vice versa, equality $(d \ln S)/(d \ln f) = 1$ corresponds to the spectral density extremes. Only in cases of very prominent peaks do the extremes practically coincide.

Energetic spectra are evidently more representative in finding universal laws. Transition to the energetic spectrum $Sf = \varphi(\ln f)$ made possible to establish some general regularities of the curves. The latter were found to be approximately similar in the region of 20- to 3-year periods. It seems natural to take I, i.e. energy falling to some frequency interval common for all the spectra ($I = \int_{f_1}^{f_2} S(f)\,df$, $f_1 = I/18$ I/year, $f_2 = I/2.5$ I/year), rather than dispersion σ^2 as a normalization factor (since the lengths of series differ essentially). Some spectra normalized in this way are represented in Fig. 4. The introduction of coordinates of the form $Sf/(Sf)_m$ and $\ln (f/f_m)$ (where $(Sf)_m$ and f_m correspond to the energetic maximum lying within 3.5- and 7-year periods) makes possible to construct a universal curve. For comparison, Fig. 5 gives two spectra computed in paper [13] for varved clay series.

5. Conclusions

Based on the analysis of time spectra computed from 21 series, the following conclusions are derived.

1. Spectral density differs from zero in the whole range of the periods studied (to 400 years).

2. Spectral density of evaporite and clastic

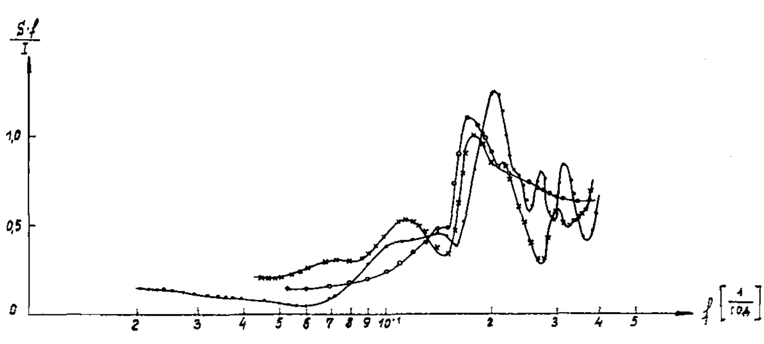

Fig. 4. Normalized energetic spectra. —●—, Glacial lake varves ($N = 510$ [28]); —○—, temperature (Berlin, $N = 192$); —×—, number of days free from ice (Neva, $N = 224$).

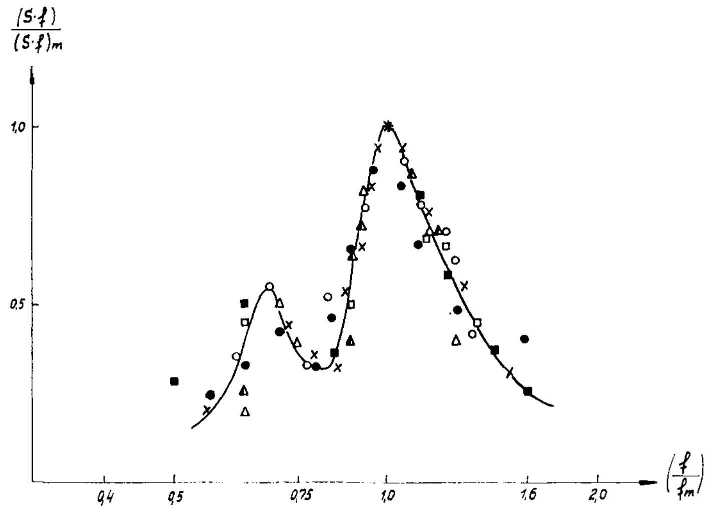

Fig. 5. Universal spectrum of geophysical parameters. □, Nonglacial lake varves ($N = 4\ 168$ [10]); ○, evaporites (Permian, $N = 936$ [25]); ●, glacial lake varves (Pleistocene, $N = 510$ [28]); △, glacial lake varves (Pleistocene, $N = 121$ [28]—from computations of [11]); ▲, glacial lake varves (Carbon, $N = 525$ [39], computations of [11]); ×, temperature spectrum average of 6 stations; ■, number of days free from ice (Neva, $N = 224$).

lake varves decreases monotonously with frequency growth.

3. No components with 11- and 22-year periods and rarely 5.5-year period were found in all the spectra considered.[1]

4. An approximate similarity was found between the spectra of meteorological elements and geophysical parameters. This kind of the universal regularity corresponding to the previously advanced assumptions [4] is interesting because it is valid for time spectra of rather faraway geological eras from Paleozoic (Permian and Carbon) and Cenozoic (Tertiary-Pleistocene and Quaternary time) to Recent time.

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[1] The 5-year component was recorded in 2 out of 21 cases.

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О СПЕКТРАХ ДОЛГОПЕРИОДНЫХ КОЛЕБАНИЙ ГЕОФИЗИЧЕСКИХ ХАРАКТЕРИСТИК

Резюме

Рассчитан 21 временной спектр долгопериодных колебаний метеорологических элементов и некоторых геофизических параметров (годовые мощности отложений ледниковых и озерных ленточных глин, калийных солей, индексы древесных колец). В качестве фильтра использовалось ядро Джексона–Пуссена–Валле. Во всех рассчитанных спектрах отсутствуют 11 и 22-летние энергетические составляющие и, следовательно, отсутствует связь с солнечной активностью. В долгопериодной области временные спектры приближенно подобны. Удается построить универсальную кривую, описывающую временные спектры, относящиеся к весьма отдаленным геологическим эрам — от палеозоя (пермь и карбон) и кайнозоя (третичный — плейстоцен и четвертичный периоды) до современного периода.