LONG-TERM VARIABILITY OF HYDROMETEOROLOGICAL PARAMETERS IN THE JAPAN, OKHOTSK AND BERING SEAS

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Introduction

The possibility of study of climatic variability depends on the presence of reliable long-time series information. Data on ice cover, air and water temperature from the meteorological stations located at the coast of the Far-Eastern Seas are the longest time series of relatively regular and homogeneous hydrometeorological information.

The purpose of this paper is to investigate the low-frequency variability of the climatically significant parameters in the Far-Eastern Seas and links between the processes in certain regions.

Data and Methods of Analysis

Following characteristics were analyzed: sea ice extent measured by percentage of the ice-covered area of the sea, the position of ice edge in the western part of the Bering Sea and westward from Kamchatka in the Okhotsk Sea, and air and water temperature at the coastal stations.

Air and water temperature data at coastal meteorological stations from the CD "World Weatherdisk", "Meteorological Report", "Monthly Report" and "Annual Report" were used for analysis. The position of the meteorological stations is shown in Fig. 1.

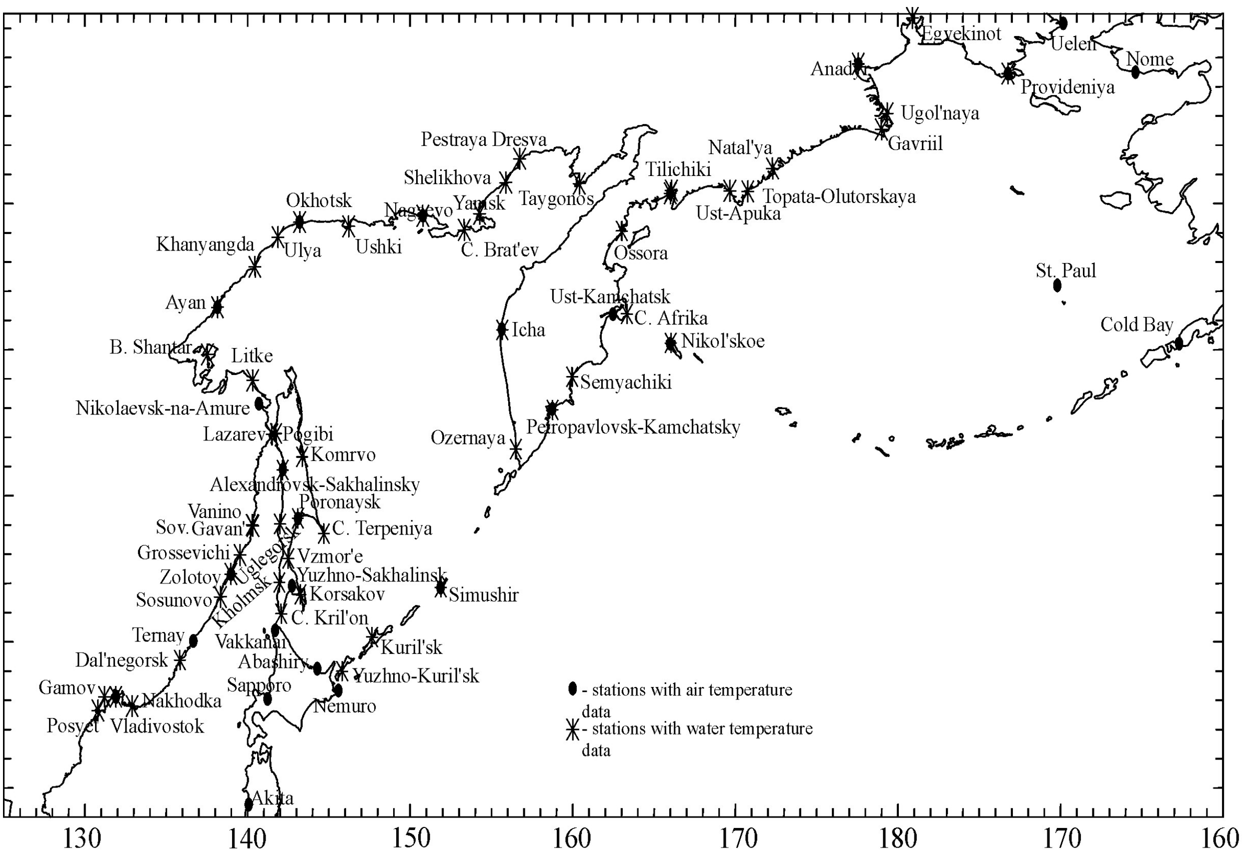

Fig. 1. The position of the meteorological stations

Reliable and homogeneous time series of ice data for the Okhotsk Sea are available since 1957, for the Bering Sea and the Japan Sea (Tatar Strait) since 1960. They are based mainly on regular aircraft observations carried out by Hydrometeorological Service. These observations were finished in 1992. For recent years the ice cover square was determined by Khen (1997) and the authors of this paper on the data of satellite ice charts. We have at our disposal also the data on the largest ice extent in the Okhotsk Sea from 1929 to 1956 published by Kryndin (1964). The initial information on ice was averaged for months and for winter season. Mean winter ice extent was calculated for January – April because ice conditions were the most stable in these months.

Data analysis was made with application of statistical methods (Brillinger, 1980; Davis, 1990; Konyaev, 1981). The spectra were calculated with usage of spectral Parsen's window. Besides, the linear method of periodicity detection grounded on direct calculation of correlation between the data series and a sinusoid of certain period with a lag that gives the maximum correlation coefficient was used for revealing variability periods. Although this method has a problem of reliability of the periods, it allows to reveal the periods comparable with length of data series and to fulfill rough long-range forecasts of time series. The statistical significant level 99% and 95% was used to estimate the trends, spectra, correlation coefficient and coherency.

Results

Changes in coastal sea surface temperature (SST) from month to month were calculated as the measure of rate of seasonal changes, they were averaged for the whole period and shown in Fig. 2, 3, 4. At stations in the Japan Sea the rate of autumn cooling exceeds the rate of spring warming, especially at southern stations (Fig. 2), at stations in the Okhotsk Sea the curve of seasonal changes is almost symmetrical (Fig. 3). At the majority of stations in the Bering Sea the spring warming is faster than autumn cooling (Fig. 4). The maximum rate of seasonal changes in coastal SST is marked in the tip of the Tatar Strait, both during warming and cooling. The most conformed interannual oscillations of autumn cooling rate are marked at the stations of the Japan Sea.

Interannual variability of coastal SST is maximal in summer or autumn. In winter the changes are minimal, naturally, because the temperature is very low and close to a freezing point. These changes are lower at the stations with good water exchange with open sea waters, and higher in relatively closed areas. Interannual variability of air temperature is quite different. It is maximal in winter and minimal in July – September.

Looking for traces of global warming, we have found the positive trends of water temperature in the Japan Sea only in winter and certain months of other seasons.

The well-known cooling of Northwest Pacific in 1984-1986 appeared mostly in the Okhotsk Sea, especially as negative anomalies in 1987. Water warming in late 1980^s – early 90^s was more or less expressed over the whole Far-Eastern coast (Fig. 5, 6, 7). This period was distinguished by increasing rate of spring-summer heating and decreasing autumn cooling, although in the Okhotsk Sea the rate of spring-summer heating was changed only, but the rate of autumn cooling was very stable.

In the Okhotsk Sea the fluctuation of water temperature and ice extent with periods about 7 and 10 years dominate 10-year periodicity was marked at the stations in the Japan Sea, that is well-known from Japanese sources (Watanabe *et. al.*, 1986; Isoda, 1994) and previously was found for air temperature as well.

We fried to find the groups of meteorological stations with similar interannual changes and have calculated a large number of cross-correlation functions between each pair of stations and for every month. Only few groups of coastal stations with the same type of interannual oscillations of water temperature were detected: in the Japan Sea they occupy a part of Primorye coast from Grossevichi to Nakhodka, in the Okhotsk Sea – the western coast from Ulya to Ayan, in the Bering Sea these are the stations Gavriil and Ugol'naya near the Cape of Navarin.

The interannual variability of water temperature at coastal stations is determined in greater degree by local processes than air temperature variability. Quantitatively it is characterised by smaller values of spatial correlation radius for water temperature. Also, correlation between water and air temperature was investigated. The maximum correlation was marked at stations in the Japan Sea in autumn.

The variability of thermal regime in winter was estimated by ice coverage. Since the end of 1980^s the low ice cover was noted in the Far-Eastern Seas until 1997, then the ice cover had increased (Fig. 8).

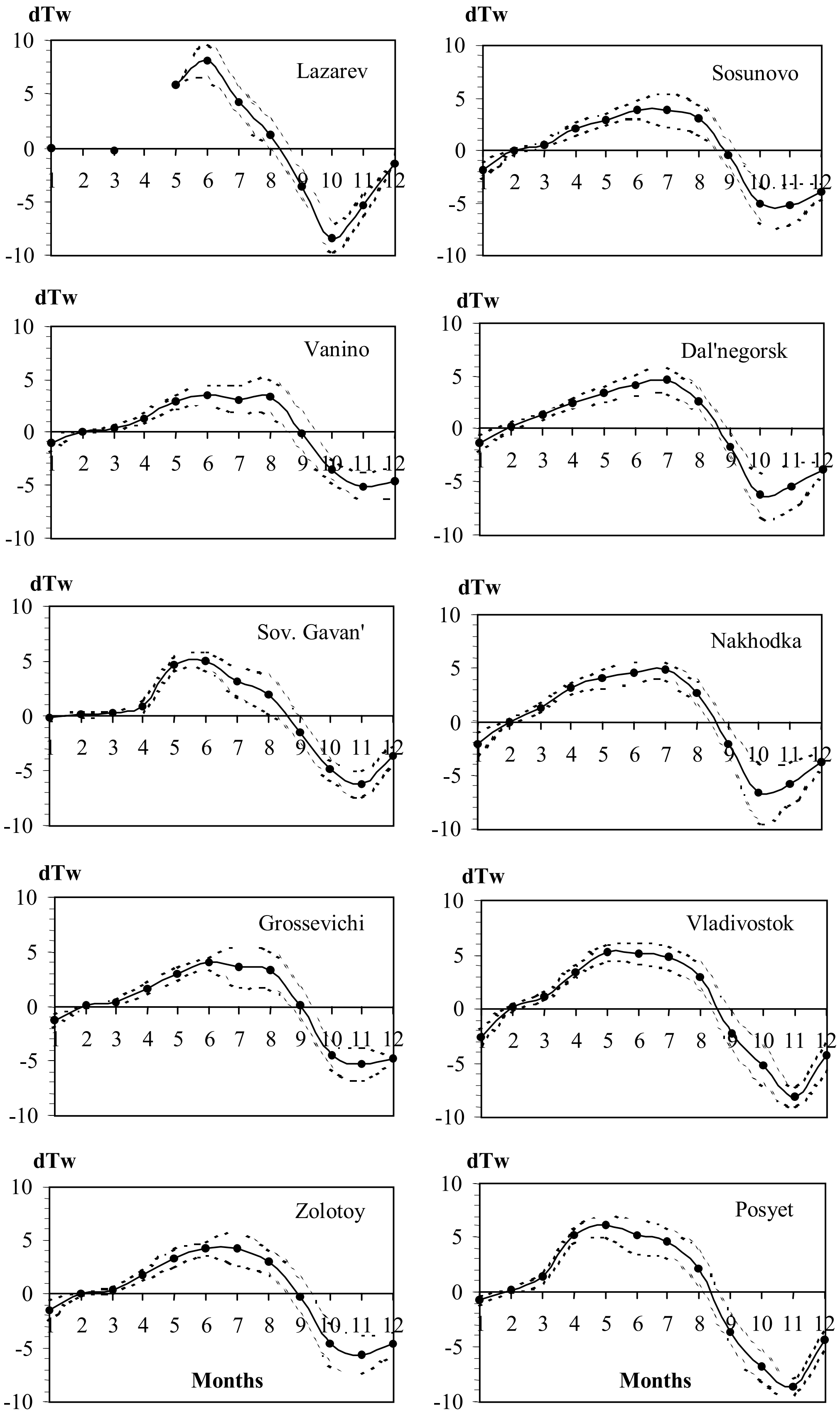

Fig. 2. Climatic changes in SST from month to month and their standard deviations at coastal meteorological stations of the Japan Sea

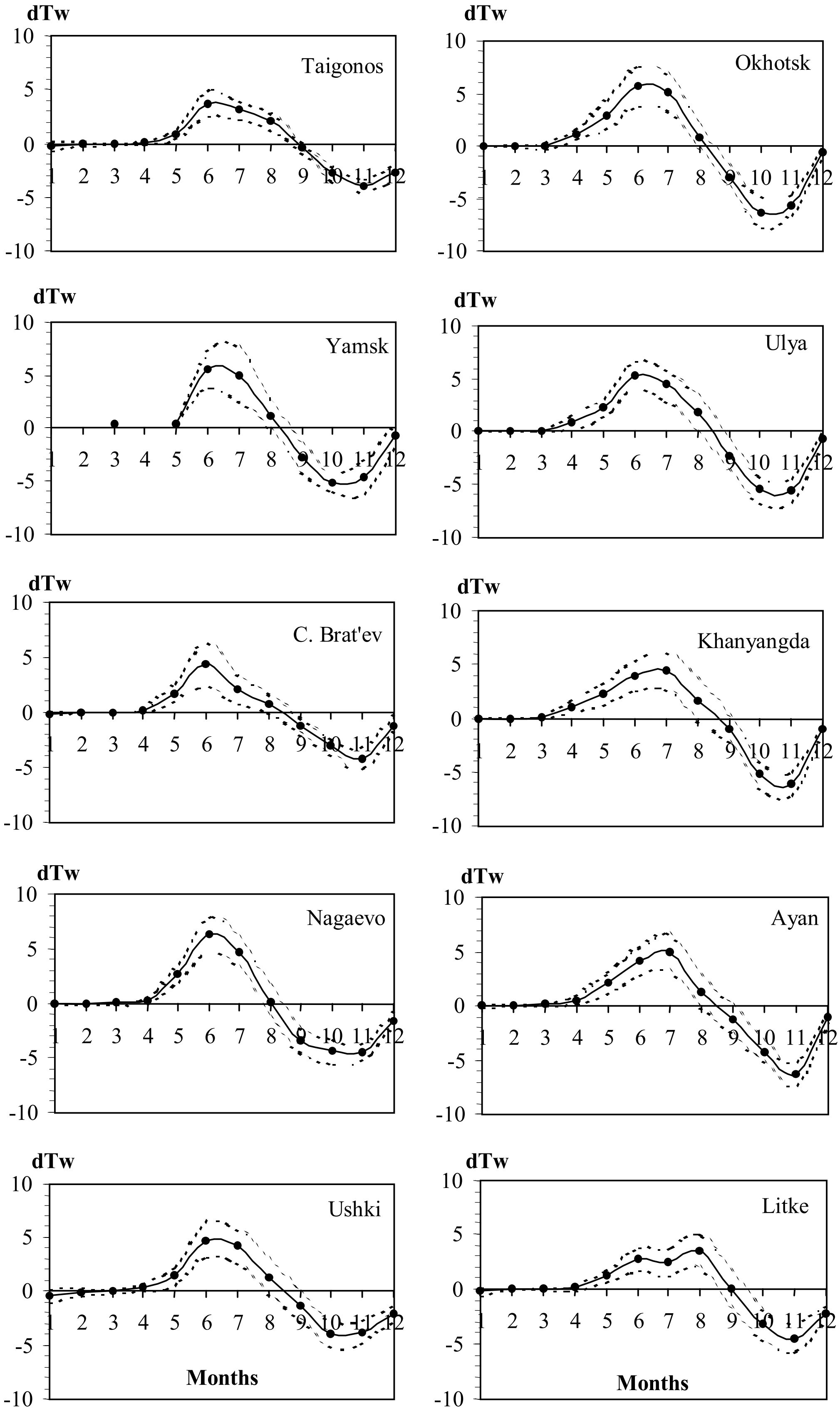

Fig. 3. Climatic changes in SST from month to month and their standard deviations at coastal meteorological stations of the Okhotsk Sea

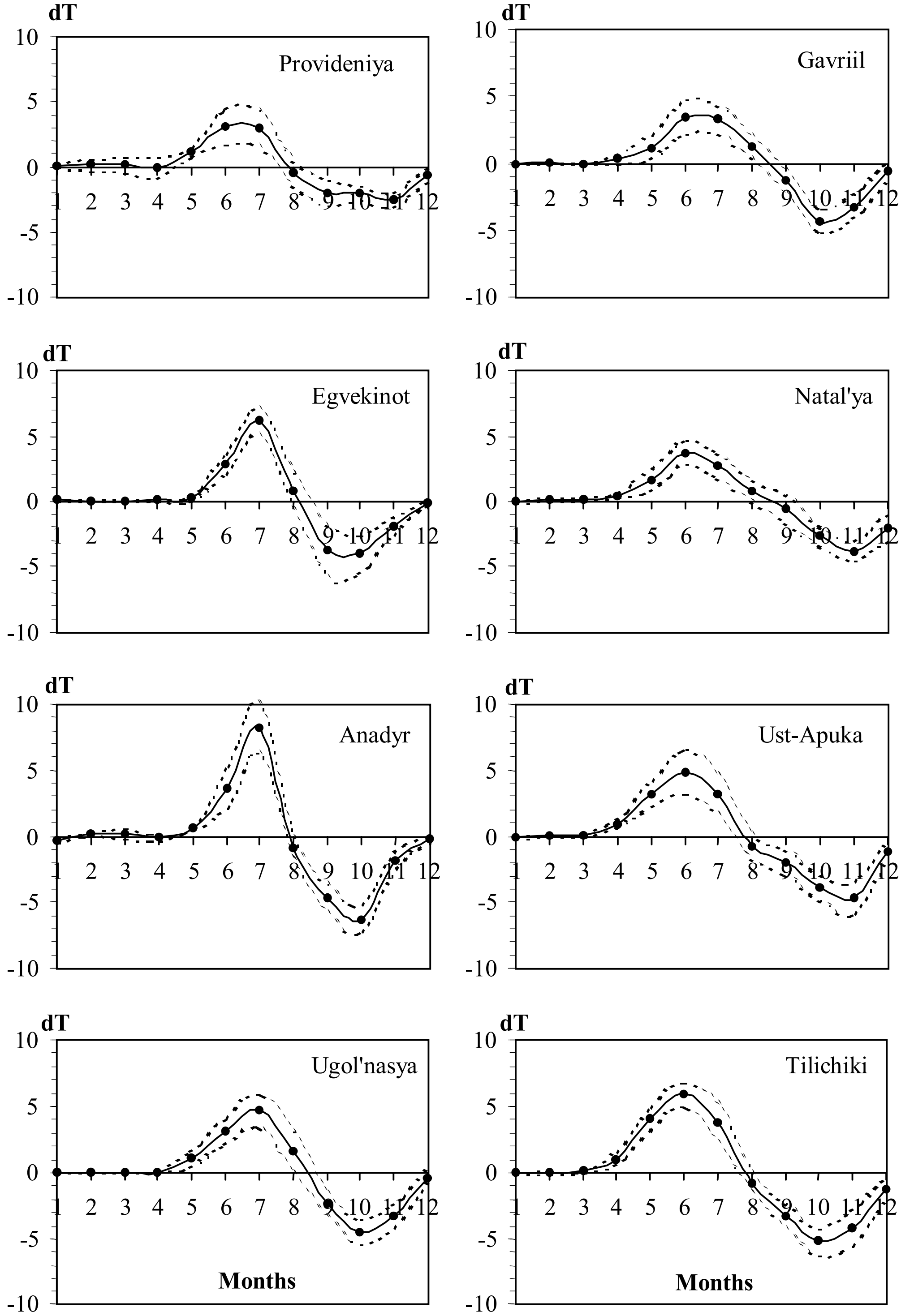

Fig. 4. Climatic changes in SST from month to month and their standard deviations at coastal meteorological stations of the Bering Sea

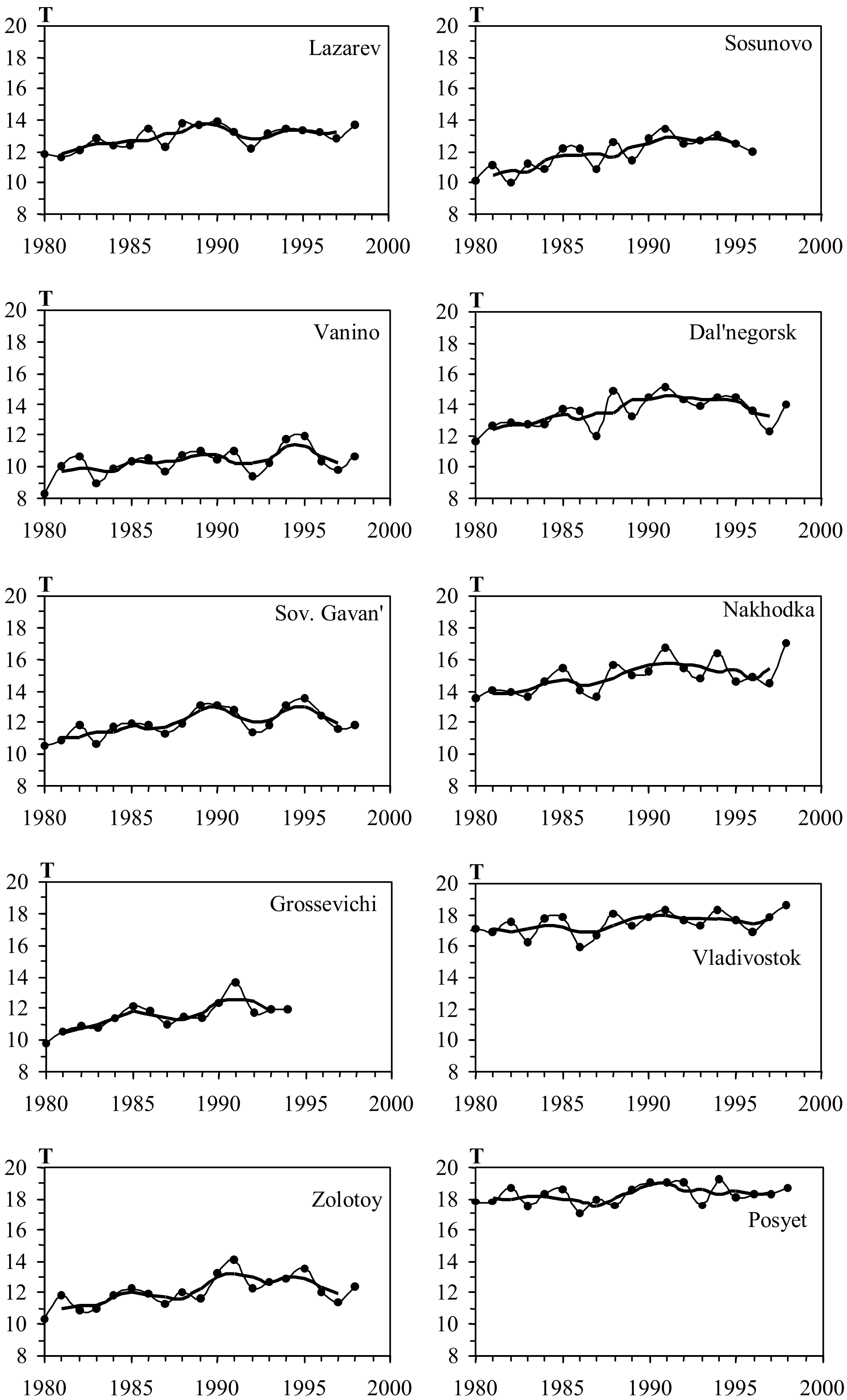

Fig. 5. Coastal sea surface temperature averaged for June – October in the Japan Sea and its 3-year running mean

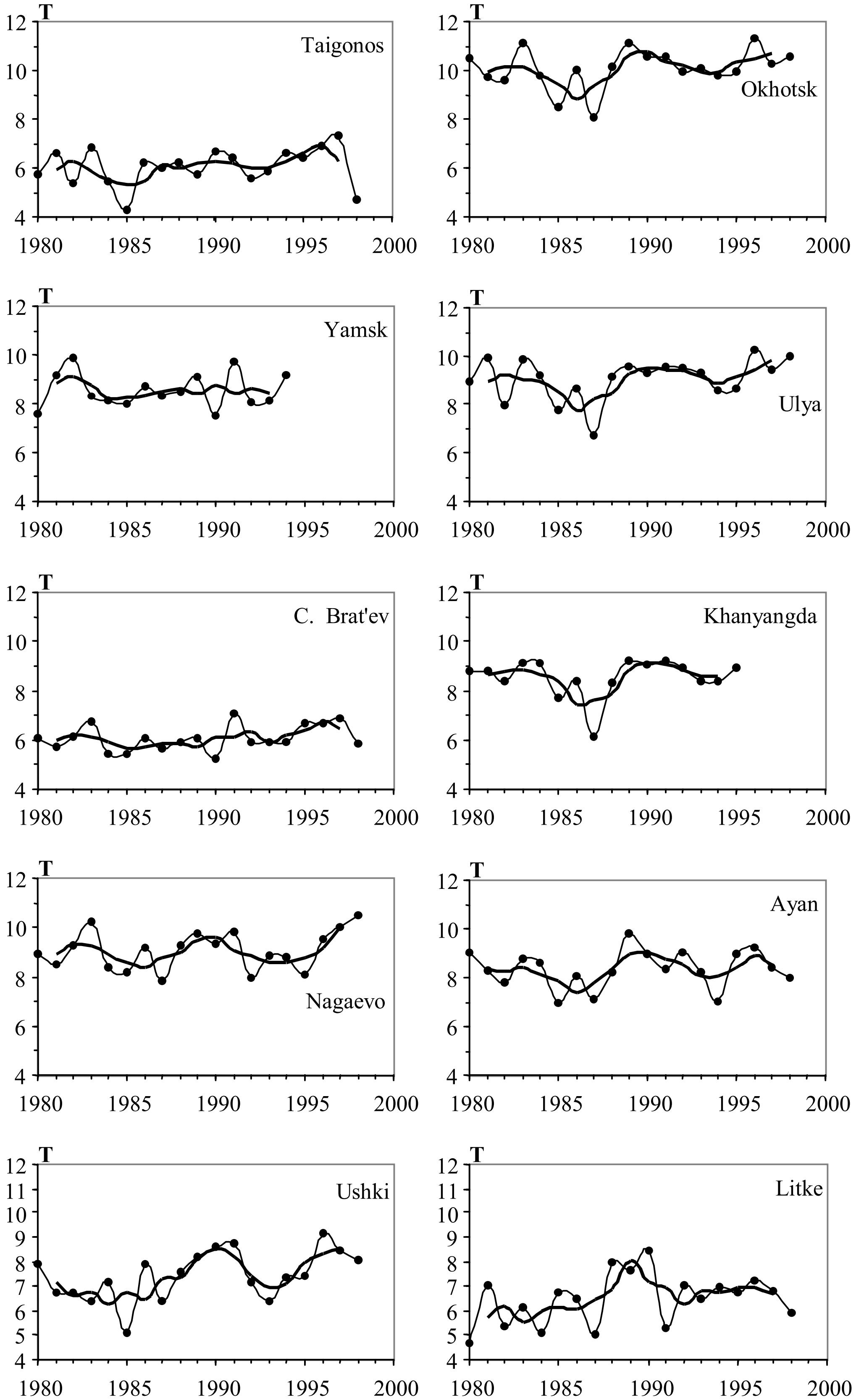

Fig. 6. Coastal sea surface temperature averaged for June – October in the Okhotsk Sea and its 3-year running mean

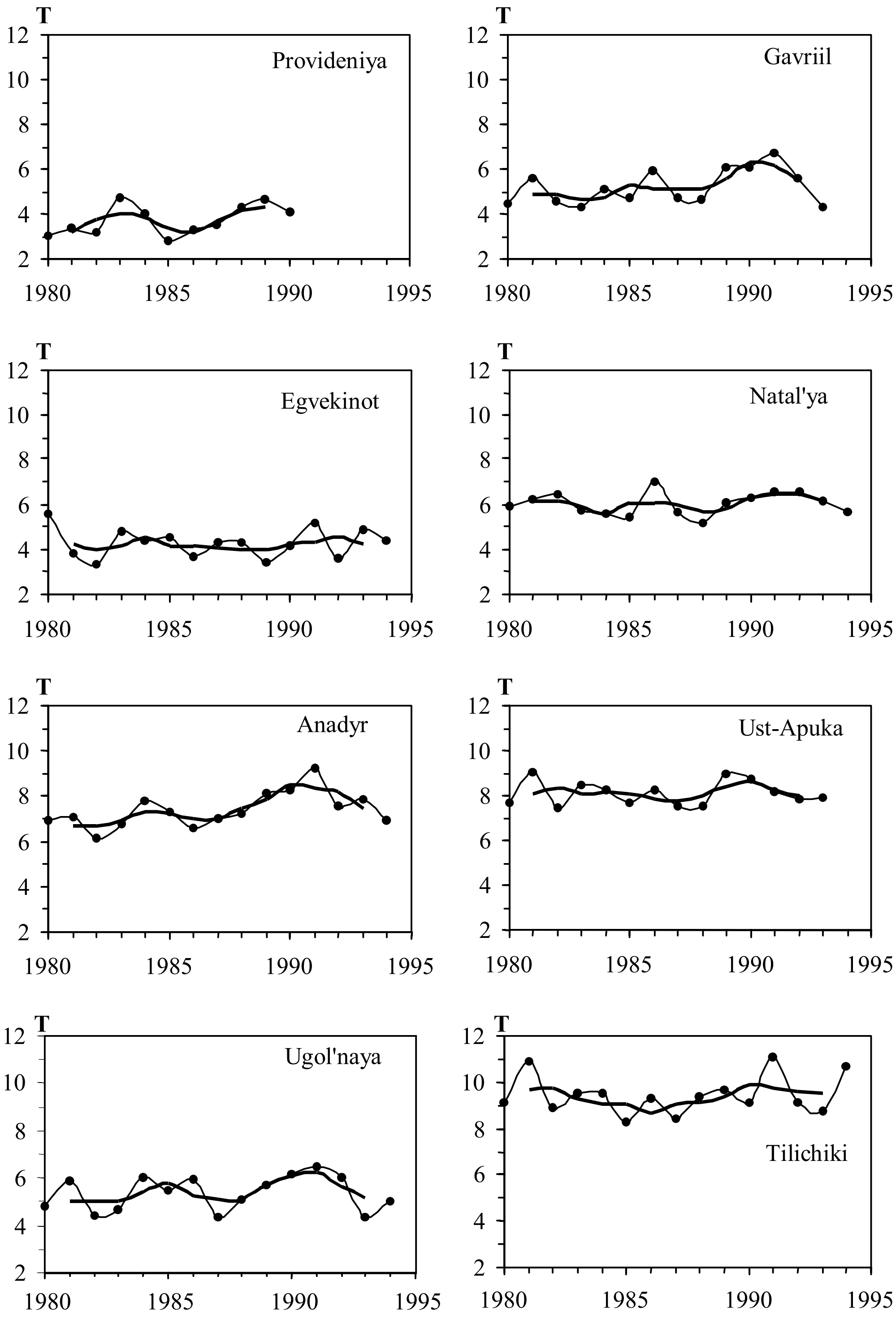

Fig. 7. Coastal sea surface temperature averaged for June – October in the Bering Sea and its 3-year running mean

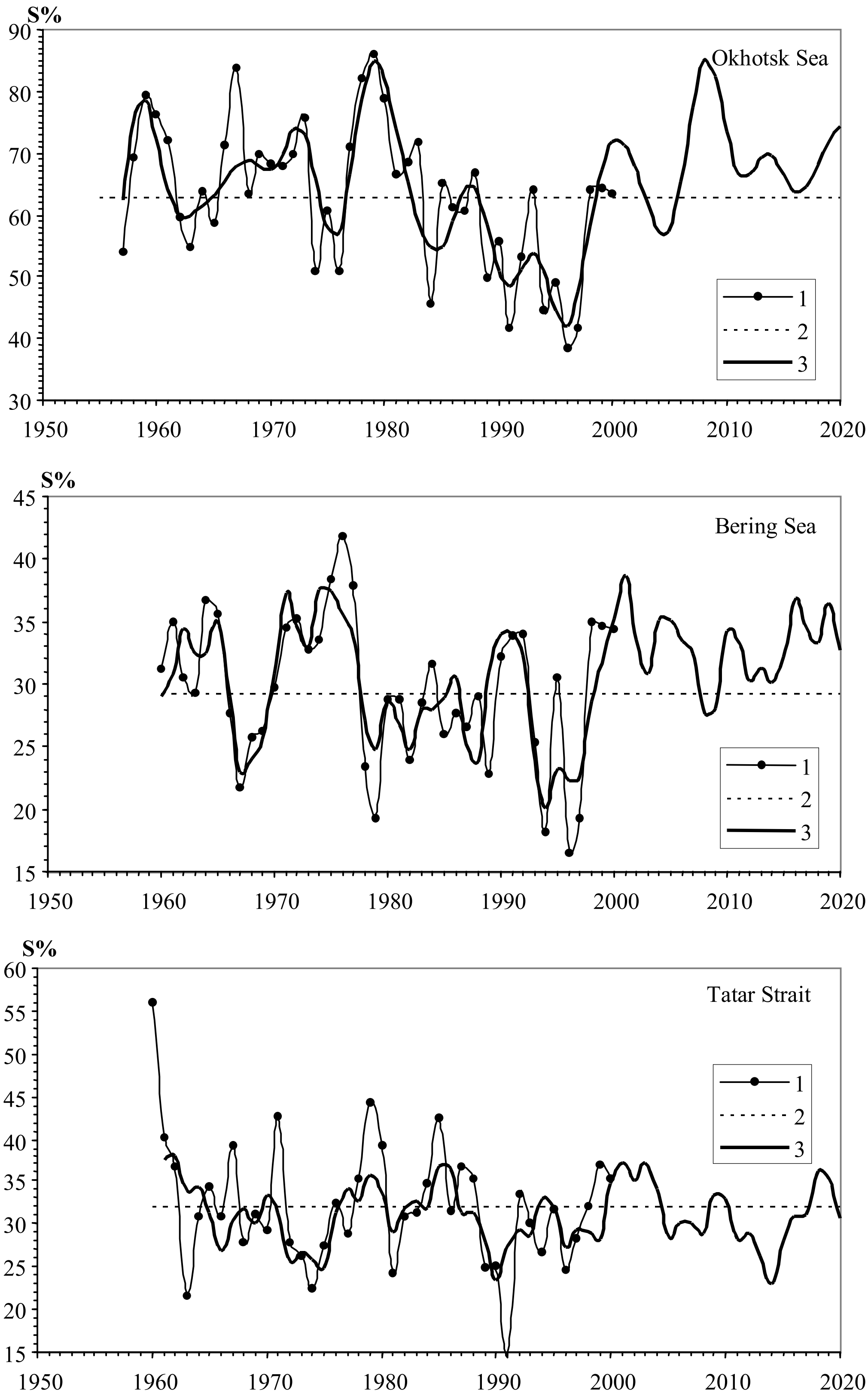

Fig. 8. Mean winter (January - April) ice cover (% to the total square of the Sea) of the Far-Eastern Seas (1), mean multi-year value (2) and approximation of its variations by sum of harmonics (3)

Interannual variability of the ice cover in the Okhotsk Sea has considerable oscillations. In some months the amplitude of year-to-year oscillations achieved 60%. Negative trends were revealed in the ice cover time series in January – May from 1957 to 1999 (Table 1). Usually it means the presence of variability with periods exceeding a length of series of observations. In the Bering Sea the negative trends were not statistically significant. The oscillation periods had less stability. In the Tatar Strait the periodical components are represented weakly.

Table 1

Estimations of linear trends α of monthly mean ice cover in the Okhotsk Sea (1957-1999) and determination coefficient R^2

Month	January	February	March	April	May	December
α, %/year	-0.40	-0.36	-0.43	-0.60	-0.37	-0.10
R^2	0.16	0.13	0.20	0.30	0.25	0.04
Critical R^2 p=99%	0.15	0.15	0.15	0.15	0.15	0.15
Critical R^2 p=95%	0.09	0.09	0.09	0.09	0.09	0.09

Time series of the largest ice cover (in March) in the Okhotsk Sea is very long (72 years) (Fig. 9). So far as there was possible to extract the low frequency periodic components that had looked as trends for shorter series for certain months. Indeed, the spectral analysis of the largest ice extent in the Okhotsk Sea shows that the basic contribution to a variance is formed by oscillations with period about 50 years. This scale was shown by Minobe for North Pacific (Minobe, 1997). Other important contributions are 10-year, 18 and 25-year oscillations (Fig. 10).

On the basis of these periodical components the time series of the largest ice cover in the Okhotsk Sea may be approximated with the correlation coefficient R=0.72 and extrapolated for the next decade (Fig. 9). It is possible to expect an increase in the largest ice cover in the Okhotsk Sea in the next decade.

The spectral analysis of time series for each month shows similar but a bit different cycles. In the Okhotsk Sea the most significant components are with periods 7, 10-11, and more than 20 years. Note that 7-year period was shown before by Dr. Plotnikov (1997). In the Bering Sea were found the periodic components with periods about 4-5 and 10 years. In the Tatar Strait period about 9 years dominates.

These components coupled with 50-year component were used for estimation of the tendencies of mean winter ice extent. Sets of harmonic components correlate with real series with the correlation coefficients 0.86 for the Okhotsk Sea, 0.80 for the Bering Sea and 0.55 for the Tatar Strait.

Contribution of harmonic components to interannual variability is 30% for the Tatar Strait, 74% for the Okhotsk Sea, 64% for the Bering Sea. On the basis of these statistically significant peaks of spectral density of mean winter ice extent, the forecast of general tendency of ice extent as the sum of harmonic components is carried out (Fig. 8). Although this method of forecasting by harmonic components is not highly accurate, it allows us to make quantitative estimation of development of ice processes.

The main difference between air temperature spectra and the spectra of ice cover is that the air temperature variance is contributed mainly quasi-two-year oscillations, while the major part of variance of ice cover is formed by low-frequency oscillations with periods about a decade and more.

For understanding the air – sea interaction, correlation matrices between ice cover and air and water temperature on the coastal meteorological stations were computed for monthly and seasonally averaged data. There were examined the different combinations of characteristics for various transformations of primary data: by exclusion of linear statistically significant trends, by various running averages and by filter of different scale oscillations. Links with air temperature were found only. The most representative (for ice cover) stations were revealed for each sea. For the Bering Sea it is St. Paul, for the Okhotsk Sea it is Icha, for the Tatar Strait it is Alexandrovsk. The maximum correlation and coherency were between ice cover and winter air temperature at station St. Paul. 3-year running smoothing increased the correlation coefficients, and it was noticed for all stations.

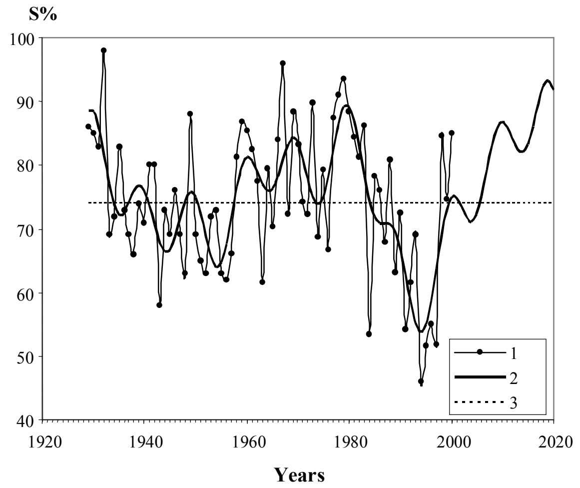

Fig. 9. Ice cover of the Okhotsk Sea (% to the total square of the Sea in March (1), approximation of its variations by sum of harmonics (2) and mean multi-years value (3)

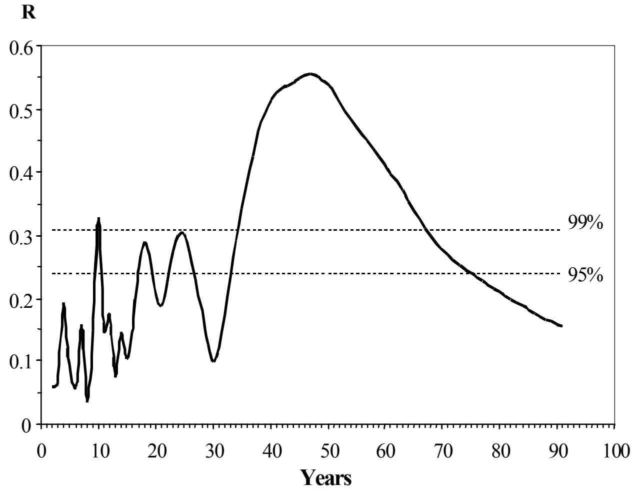

Fig. 10. Periodogram of ice cover of the Okhotsk Sea in March

Conclusions

- Last 20 years unidirectional warming is well expressed only at stations of the Japan Sea in winter season and in separate months of other seasons.
- The groups of coastal stations with the same type of interannual oscillations of water temperature are detected: in the Japan Sea, the Okhotsk Sea and the Bering Sea.
- The basic contribution to a variance of the largest ice cover in the Okhotsk Sea gives oscillations with period about 50 years, 10 years, 18 and 25 years.
- Contribution of harmonic components to interannual variability of ice cover is from 30% for the Tatar Strait to 74% for the Okhotsk Sea.

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