LONG-TERM FLUCTUATIONS OF THERMODYNAMIC CONDITIONS IN SURFACE LAYER OF THE JAPAN SEA AS RESPONSE TO CLIMATIC CHANGES IN ATMOSPHERE

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Introduction

The global changes of climate are connected with long-term variations of main parameters of atmosphere in a wide range of frequencies from 2 to 70-80 years. One of the most important climatic parameter in which the similar variations are clearly shown is the atmospheric circulation. Other important parameters are position and intensity of centres of action in atmosphere (CA). Large-scale fluctuations in atmosphere definitely influence underlying surface of oceans and adjacent seas forming water exchange fluctuations and changing a number of oceanological characteristics such as sea level and thermal mode. Now this fact does not cause doubts and proves to be true by numerous researches. In particular in the Bering Sea thermal conditions, sea level regime (Girs, 1974; Luchin *et al*., 1998; Luchin & Saveliev, 1999), water exchange with the adjacent areas (Roach *et al*., 1995) are closely connected with long-term variability of Aleutian Low (position and size) and air fluxes direction. As shown in some publications (Beamish & Bouillon, 1993; Klyashtorin & Sidorenkov, 1996; Shuntov, 1986) the changes in water structure induce respective alterations in biological productivity and number of fishes.

Present work examines long-term variations of thermodynamic conditions in the Japan Sea surface waters and its possible mechanisms. Similar researches were undertaken earlier for long-term variability of a thermal mode (Miita & Tawara, 1984; Klimov, 1986; Pokudov & Vlasov, 1980; Sigimoto, 1990; Watanabe *et al*., 1985), sea level of the Japan Sea (Lubitskiy, 1987; Pang & Oh, 1994; Firsov, 1989), ice conditions. However, these works were executed only with any one parameter and were limited of data. There was no attempt to connect the obtained results with large-scale fluctuations in the atmosphere.

Taking into account that the marine environment is a part of atmosphere-ocean system it is necessary to estimate its change by means of the complex approach with the analysis simultaneously of several hydrometeorological characteristics. Such work is carried out at first in the Japan Sea.

Data and Methods

The monthly mean data of a sea level, surface water layer (t_w) and air (t_a) temperature, ice cover duration (T_{ice}), collected from coastal stations of Russia, Japan, Korea (Fig. 1, Table 1) were used. The ice cover duration is the number of days from the moment of steady ice cover in autumn up to the moment of ice-clear water in spring. The sources of the information were Marine hydrological monthly journals and yearly books for the Japan Sea and Climatic directories of the USSR (Russia).

To analyse the connection between long-term evolution of examined hydrometeorological characteristics and atmospheric large-scale processes following climatic parameters were applied:

- monthly mean values of latitude, longitude and pressure in the centre of Honolulu High for the period 1947-1994. The information is received from the published sources (Smolyankina, 1999; Synoptical bulletin, 1995);
- atmospheric circulation indexes of Vangengeim-Girs for the Northern Hemisphere.

The climatic features of atmospheric and oceanological processes, its long-term variations are generated by stationary thermobaric waves in the troposphere and low stratosphere (Girs, 1971). These waves in many respects drive circulation of air masses, determine geographical position of jet currents, position and intensity of the CA, *etc*. Vangengeim (1938 and 1961) assimilated all forms of atmosphere circulation in 3 basic types-western (*W*), eastern (*E*) and meridional (*C*). It is necessary to notice that though Vangengeim established types of large-scale processes for the Atlantic-European sector, however these types of circulation are described quite well all Northern Hemisphere. Indexes of atmospheric circulation (IAC) are determined as repeatability (days) of type of atmospheric circulation. In this work the IAC records for the period 1900-1997 were taken from Girs (1971) and kindly presented by

Primorsky Hydrometeorological Service and Pacific Oceanological Institute (Far Eastern Branch Academy of Science, Vladivostok).

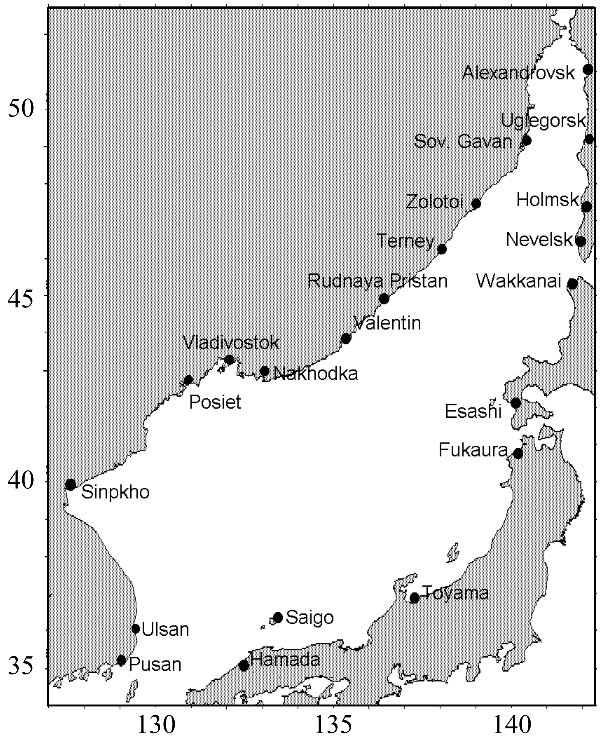

Fig. 1. Position of coastal stations in study area

Table 1

The observation spans (years) at coastal stations in the Japan Sea.
t_a – air temperature; t_w – water temperature; T_{ice} – ice cover duration

Stations	Parameters			
	Sea level	t_a	t_w	T_{ice}
1. Pusan	-	1966-1995	1966-1995	-
2. Ulsan	-	-	1953-1995	-
3. Sinpkho	1966-1990	-	-	-
4. Posiet	1951-1997	1931-1997	1932-1997	1934-1997
5. Vladivostok	1926-1997	1917-1994	1928-1997	1925-1997
6. Nakhodka	1948-1991	1932-1997	1933-1997	1936-1997
7. Valentin	1942-1963	-	-	-
8. Rudnaya Pristan	1940-1996	1933-1997	1934-1997	1935-1997
9. Terney	1948-1965	1940-1995	1940-1975	-
10. Zolotoy	-	1940-1997	1938-1997	-
11. Sov. Gavan	1948-1980	1929-1990	1939-1957, 1966-1994	1967-1996
12. Alexandrovsk	-	1951-1989	1939-1994	1951-1996
13. Uglegorsk	1964-1992	1951-1989	1947-1994	1951-1996
14. Holmsk	1947-1992	1951-1989	1947-1994	-
15. Nevelsk	1955-1992	-	-	-
16. Wakkanai	1975-1994	1938-1998	-	-
17. Esashi	-	1941-1998	-	-
18. Fukaura	-	1940-1998	-	-
19. Toyama	1967-1994	-	-	-
20. Saigo	1965-1994	-	-	-
21. Hamada	1900-1924	-	-	-

It is necessary to note that the W-type characterises zone processes in an atmosphere when waves of small amplitude in troposphere displacing from west to east are observed. The processes *E*, *C* are characterised by the meridional air transport with the large amplitude tropospheric waves (Girs, 1948 and 1971). Therefore in this work indexes (*E*+*C*) is accepted as the characteristic of meridional air transport. We used the anomalies of indexes relative to their long-term averaged values (monthly or annual).

Data analysis was carried out by standard statistical techniques (filtering, smoothing, correlation-spectral analysis).

The power spectral function was carried out under the formula (Bruks & Krausers, 1963; Kazakevitch, 1971):

$$S_i(\omega) = R_i(0) + 2\sum_{i=1}^{N} R_i \ (\tau)\cos\omega\tau \ , \qquad (1)$$

where $R_i(\tau)$ – unnormed means of autocorrelation function of time series at different time shifts;

$R_i(0)$ – the value of autocorrelation function without shift);

τ – shift of autocorrelation function;

$\omega = 2\pi / T$ (T – period).

The smoothing of spectra was made by Parsen filter. The confidential intervals of spectra were calculated at 80% level of significance. The long-term tendencies were determined by exponential smoothing (Brown technique).

Results and Discussion

The spectral analysis of hydrometeorological parameters time series has allowed to reveal prevalence of three-modal structure of power spectral functions with maximums near the frequencies of 9-12 years (in some case 7-8 years), 3-5 and 2-2.5 years (Table. 2).

Table 2

The spectral analysis results of hydrometeorological data obtained at coastal stations of the Japan Sea

Station's name	Parameters			
	Sea level	t_a	t_w	T_{ice}
	Periods (years)	Periods (years)	Periods (years)	Periods (years)
1.Pusan	-	9.5 3.7 2.2	13.3 3.4 2.2	-
2. Ulsan	-	-	12.5 3.2 -	-
3. Sinpkho	11.3 4.0 2.4	-	-	-
4. Posiet	11.5 3.1 2.2	8.8 4.4 2.4	10.0 4.5 2.7	12.5 3.2 2.4
5. Vladivostok	10.5 3.4 2.7	9.7 4.3 2.4	10.0 5.0 2.3	11.8 4.6 -
6. Nakhodka	7.8 3.8 2.5	8.8 4.0 2.6	9.5 4.5 2.5	11.1 3.2 2.7
7. Valentin	7.3 3.7 2.6	-	-	-
8. Rudnaya Pristan	10.5 4.8 2.5	10.5 4.4 2.4	10.5 4.8 2.5	9.5 3.0 -
9. Terney	9.1 4.9 2.5	10.6 4.3 2.3	9.2 4.8 2.8	-
10.Zolotoy	-	10.1 4.8 2.7	10.0 5.0 2.3	-
11. Sov. Gavan	10.0 4.0 2.3	10.0 4.4 2.5	- 5.5 2.3	- 5.1 2.2
12. Alexandrovsk	-	9.8 4.1 2.4	10.1 5.5 2.4	8.7 - 2.7
13. Uglegorsk	10.8 3.9 2.4	10.9 4.3 2.6	9.5 3.2 2.3	9.5 - 2.8
14. Holmsk	7.7 4.1 2.5	8.7 4.2 2.5	8.3 3.3 2.3	-
15.Nevelsk	8.5 3.7 2.4	-	-	-
16. Wakkanai	10.1 4.5 2.5	10.0 4.0 2.4	-	-
17. Esashi	-	10.1 4.4 2.4	-	-
18. Fukaura	-	12.5 4.7 2.5	-	-
19. Toyama	9.5 3.9 2.2	-	-	-
20. Saigo	9.1 3.9 2.5	-	-	-
21. Hamada	10.5 4.5 2.4	-	-	-

The low-frequency variability (9-12-years) were found out earlier in interannual variability of water temperature along the coast of Japan (Watanabe *et al.*, 1985), of an active layer of Oyashio and Kuroshio current system (Faxiu & Shenyu, 1989), of Kuroshio meandering (Cort, 1970; Ichiye, 1955) *etc.* They are closed (and at some stations practically coincide) with well-known 11-year solar activity cycle that gives the basis to believe in their astronomical origin. Fukuoka (1955) has the similar opinion.

The cycles 7-8 year occurring mainly in sea level spectra at some stations also are shown in many natural phenomena of East Asian and Pacific region: in intensity and meandering of Kuroshio, heat content of waters in barocline layer of the ocean, riverine discharge, intensity and repeatability of typhoons, ice cover of seas. Maximov (1970) as shown such occurrence of fluctuations at ocean and atmosphere is connected to effect so-called "pole tide".

The cycle 3-5 year are connected to the well known phenomenon El-Niño-Southern Oscillation which frequency is the same (Faxiu & Shenyu, 1989; Mason *et al.,* 1996; Tenberth, 1976). More detailed analysis of El-Niño influence on a variation of surface water temperature and other characteristics of the Japan Sea is executed by the author in separate article (Saveliev, 1999). The results of work prove existence of connection between processes in the atmosphere of a tropical zone and processes occurring in surface water layer of the Japan Sea.

The 2-2.5 year fluctuations correspond to so-called quasi-two-year cycling which is found out in evolution of a number of processes in the atmosphere and in the ocean (Fukuoka, 1955; Klimov, 1986; Luchin *et al.*, 1998; Luchin & Saveliev, 1999; Maximov & Karklin, 1970; Sigimoto, 1990). The majority of researchers suggest that such fluctuations are determined by variations of a geographical position and intensity CA and the change of their mutual position each other as well (Sleptsov-Shevlevitch, 1968; Sleptsov-Shevlevitch & Gordienko, 1977; Ugrumov, 1968). The similar conclusion was received in present work by results of the spectral analysis of geographical coordinates and pressure at the centre of Honolulu High (Fig. 2). The most clearly quasi-two-year fluctuations are shown in the latitude and intensity of Honolulu High.

The considered above waves in hydrosphere of the Japan Sea and in the atmosphere occur on a background of low-frequency fluctuations (Fig. 3-4). The curves represented in Figures are treated with 15-year smoothing of initial time series that has allowed excluding the higher frequencies fluctuations.

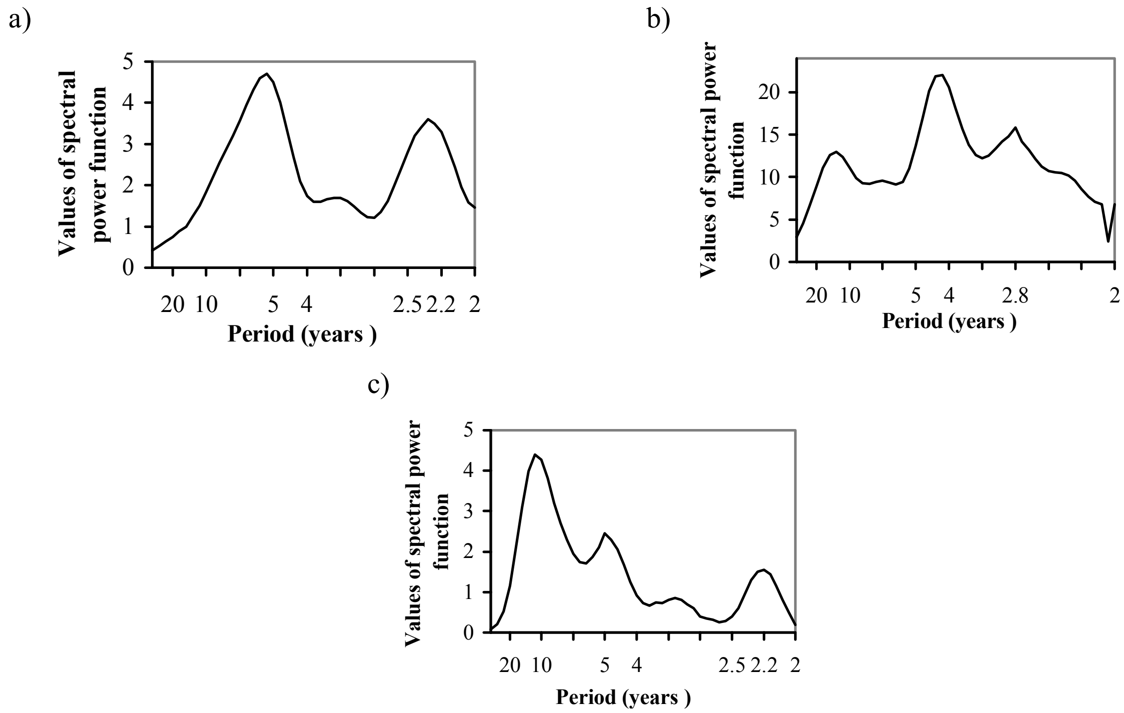

Fig. 2. Spectral power functions for latitude (a), longitude (b) and sea level pressure (c) in Honolulu High

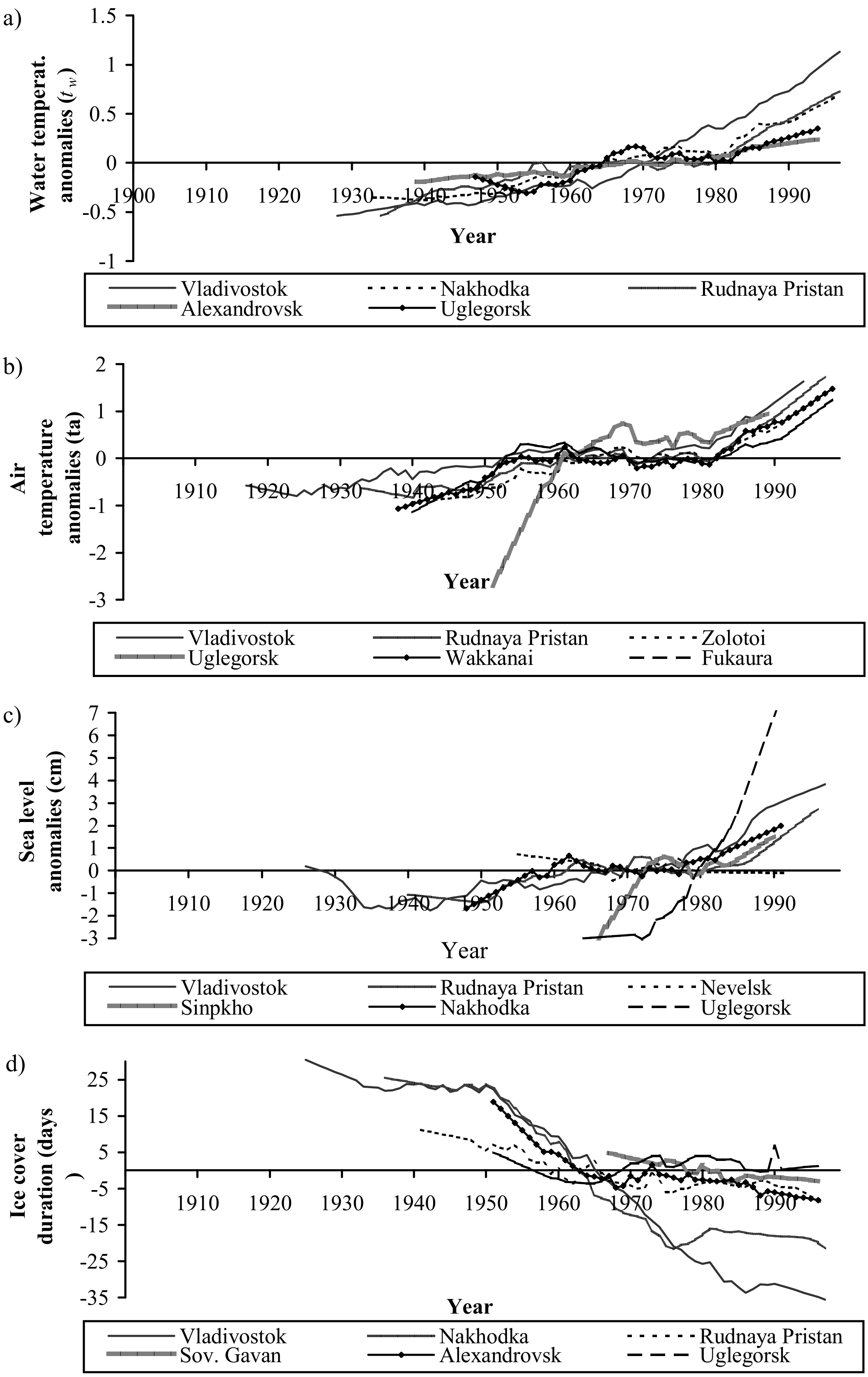

Fig. 3. Long-term tendencies of time series of anomalies of water (a), air (b) temperature, sea level (c) and duration of ice cover (d) in the cold season

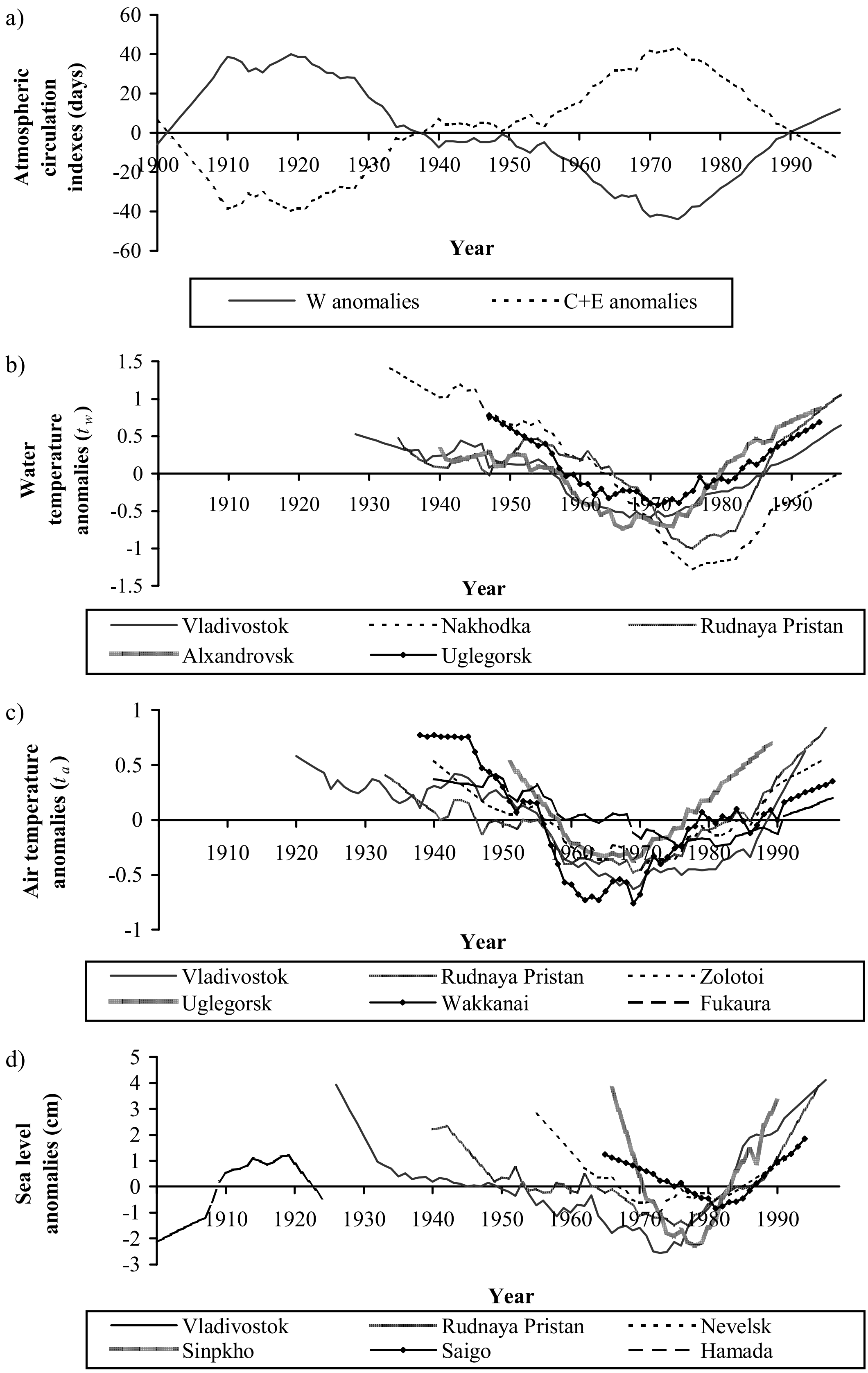

Fig. 4. Long-term tendencies of time series of annual anomalies of atmospheric circulation indexes (a), water (b) and air (c) temperature, sea level (d) in the warm season

The long-term tendencies of t_a, t_w and sea level anomalies have clearly expressed seasonal differences. Therefore in this work we examined the tendencies of hydrometeorological parameters averaged for the warm and cold seasons separately. The warm season is limited to a time range June - September, cold-December-April when tendencies were identical.

It is necessary to pay attention that in several stations long-term tendencies of some parameters had no seasonal differences.

The results testify that in the cold season the long-term trend of t_a, t_w, T_{ice} and sea level is the same and positive (for duration of ice cover-negative) and agree with global warming of the Earth. In time span from the 1920-30^s to the 1990^s the background warming of an atmosphere above the sea was about 2 °C, surface water-about 1 °C; sea level was increased up to 4-5 cm and sea-ice cover duration was decreased down to 20-30 days.

On the contrary, the warm season is characterised by tendencies of t_a, t_w and sea level like long-term climatic waves with smooth downturn of examined parameters from 1920-30^s to 1960-70^s when their minimal values were observed (Fig. 4). Last two decades differed by steady warming of air and surface water layer and increase of the level of the Japan Sea. The amplitudes of these waves are about 2 °C for temperature anomalies and 6 cm for sea-level anomalies.

The law-governed natures of long-term fluctuations of the Japan Sea oceanological parameters find their conformation in other publications. Watanabe *et al.* (1985) investigating long-term variations of water temperature along the eastern coast of the Japan Sea have found out sudden cooling in the beginning of 1960^s years which proceeded down to 1975-76. This cooling was fixed at all researched stations. The average decrease of t_w was 0.7-0.8 °C in comparison with the previous 20-year's period. The sharp downturn of water temperature in 1960^s on the area from southern Honshu up to the Eastern-Chinese Sea is marked by other authors (Iida *et al.*, 1975; Wear *et al.*, 1976). The large-scale variations with the period 50-70 years in long-term variability t_a, t_w, sea-level pressure in the North Pacific and Northern America are found out by Minobe (1997).

The comparison of our results and references allows to propose the possible mechanism of long-term variability of thermodynamic conditions of the Japan Sea waters. It is possible to assume that in warm period the wavy tendencies in hydrosphere of the Japan Sea are formed under the influence of global changes in atmosphere circulation. According to Fig. 4a, during last century in an atmosphere of the Northern Hemisphere the complete climatic cycle reflected in wavy variations of the prevailing types of circulation was observed. In Asian-Pacific region such variations can be result of spatial displacement and changes of intensity of the basic climatic CA: Siberian and Honolulu Highs, Aleutian and Asian Lows.

The existence of long-term variability of parameters of these CA, executed in (Dashko & Varlamov, 2000), has shown presence of similar wave tendencies. For example, since 1940^s up to middle 1970^s the growth of winter and summer large-scale baric gradients were marked. The gradients were determined as a pressure difference at the centres referred to unit of distance between them (for winter gradients was calculated between the Siberian High and Aleutian Low, for summer-between Honolulu High and Asian Low). The increase in large-scale gradients induced strengthening of meridional air transport above study area for this period.

An opposite situation is marked from the end of 1970^s till the present time: reduction of summer and winter large-scale gradients. Accordingly, the climatic easing of meridional circulating processes and strengthening of zone transport in an atmosphere is observed.

Discovered by us in warm period the wavy tendencies of hydrometeorological parameters are in good conformity with the tendencies of atmospheric circulation indexes (see Fig. 4). The prevalence of meridional processes (E+C indexes in 1960-70^s) results in strengthening of monsoon activity. Thus the prevailing southern and south-eastern winds favour to advection of cooler sea air over the Japan Sea that resulted by the lowered temperature background in an atmosphere and appropriate downturn of t_w and sea level. On the contrary, reduce of meridional processes in an atmosphere (1980-90^s) results in reduce of summer monsoon activity. In this period main role in atmospheric circulation begin to play zone processes (W-type). Intensification of western air transport favours to input of warm continental air from Mongolia and China toward the Japan Sea. Warm air advection results in background warming of atmosphere above the sea and accordingly in increase of surface water temperature and sea level. So long as period of large-scale waves in an atmosphere has a time interval about 1970-80^s (Fig. 4a), it is possible to assume that the appropriate fluctuations of the examined characteristics in the Japan Sea have the same periodicity.

In the cold period the long-term changes of atmospheric circulation types don't cause similar variations of thermodynamic parameters of the Japan Sea. The reason of it is following. When meridional processes dominate in an atmosphere above the Japan Sea winter monsoon is made active and the cold continental air masses from northern areas of East Siberia come to this region. The reducing of meridional processes and strengthening of zone one favours to cold continental air transport from Mongolia and China. The temperature contrasts between indicated air masses are insignificant and practically are not shown in long-term tendencies of t_a, t_w, T_{ice} on a background climatic warming.

Conclusions

The fluctuations with the periods 9-12, 3-5 and 2-2.5 years are found out in long-term variability of air and water temperature, ice cover duration and sea level of the Japan Sea. The first one coincides with the frequency of well-known 11-year solar cycle. Second corresponds to periodicity of the El-Niño-Southern Oscillation phenomenon. Third is caused by quasi-2-year cycle of atmospheric processes. These fluctuations occur on a background of the low-frequency tendencies, which have seasonal differences.

In cold season the monotonous tendency to increase of t_a, t_w, T_{ice} is marked. In warm season the variability of thermodynamic parameters has a character of long-range climatic waves with downturn from 1930^s to the 1960-70^s and steady increase during last two decades. Such variations in hydrosphere of the Japan Sea in warm season are caused by large-scale variations of atmospheric circulation in the Northern Hemisphere occurring with periodicity about 70-80 years. Abnormal development of meridional air mass transport causes strengthening of summer monsoon activity and of relatively cold sea air advection over the Japan Sea. That results in cooling of surface water layer and decrease sea level. The abnormal development of zone processes induces intensification of heating continental air mass transport from Mongolia and China into the Japan Sea. The consequences are the occurrence of positive anomalies of air and water temperature, increase of sea level.

References

1. Beamish R.J. & Bouillon D.R. 1993. Pacific salmon production trends in relation to climate. Canadian // J. Fish. and Aquatic Scien. Vol. 50. N 5. P. 1002-1016.
2. Bruks K. & Krausers H. 1963. Application of statistical methods in meteorology / Leningrad: Gidrometeoizdat. 250 pp.
3. Cort V.G. 1970. About large-scale interaction of ocean and atmosphere (on an example of Northern Part of Pacific Ocean) // J. Oceanology. Vol. X. N 2. P. 222-239.
4. Dashko N.A. & Varlamov S.M. 2000. Estimation of changes of the Centres of action of an atmosphere characteristics in Asian-Pacific region within 20 century and their influence on circulation above the Japan Sea // FERHRI Special issue. N 3. P. 10-25.
5. Faxiu Z. & Shenyu Y. 1989. The low frequency oscillations of the sea surface temperature in the Equatorial Eastern Pacific and El-Nino formation // Acta Oceanologica Sinca. Vol. 8. N 4. P. 521-533.
6. Firsov P.B. 1989. To a question on variability of nonperiodical oscillations of level at the Japan Sea coast // FERHRI Works. Vol. 39. P. 86-97.
7. Fukuoka J. 1955. The variation of the polar front in the sea adjacent to Japan // Oceanogr. Mag. Vol. 6. N 4. P. 82-87.
8. Girs A.A. 1948. To a question of study of the basic forms of atmospheric circulation // J. Meteorology and Hydrology. N 3. P. 34-40.
9. Girs A.A. 1971. Long-term fluctuations of atmospheric circulation and long-term hydrometeorological forecasts / Leningrad: Gidrometeoizdat. 280 pp.
10. Girs A.A. 1974. Many-yearly variations of the atmospheric circulation and long-term trends in the change of hydrometeorological condition in the Bering Sea aria // Proc. Oceanography of the Bering Sea Intern. Symp. Ch. 25. P. 475-482.
11. Ichiye T. 1955. On the variations of oceanic circulation in the adjacent seas of Japan // Oceanogr. Mag. Vol. 6. N 4. P. 41-66.
12. Iida H., Katagiri K., Maeda I & Kamihara E. 1975. On the normals of monthly sea surface temperatures from 1956 to 1970 for 5-degree squares in the western North Pacific Ocean // Oceanogr. Mag. Vol. 26. P. 73-89.
13. Kazakevitch D.I. 1971. Principles of the theory of stochastic functions and its application in hydrometeorology / Leningrad: Gidrometeoizdat. 267 pp.
14. Klimov S.M. 1986. Estimation of large-scale variability of temperature of a surface layer in a zone of Tsushima current // FERHRI Works. Vol. 25. P. 3-10.

15. Klyashtorin L.B. & Sidorenkov N.S. 1996. Long-term climatic changes and fluctuations of number of pelagic fishes of Pacific Ocean // News of Pacific Fishering and Oceanogr. Inst. Vol. 119. P. 33-54.
16. Lubitskiy Y.V. 1987. Long-range fluctuations of a sea level on Sakhalin shelf // FERHRI Works. Vol. 129. P. 64-74.
17. Luchin V.A. & Saveliev A.V. 1999. Interannual and long-term variability of waters in western part of the Bering Sea // J. Meteorology and Hydrology. N 5. P. 91-99.
18. Luchin V.A., Saveliev A.V. & Radchenko V.I. 1998. Long-term climatic waves in ecosystem of western part of the Bering Sea // Proc. Arctic Region Centre (Vladivostok). Vol. 1. Climatic and interannual variability in atmosphere-land-sea system in the American-Asian sector of the Arctic Region. P. 31-42.
19. Mason O.K., Salmon D.K. & Ludwig S.L. 1996. The periodicity of storm surges in the Bering Sea from 1898 to 1993 based on newspaper accounts // Climatic Change. Vol. 34. P. 109-123.
20. Maximov I.V. & Karklin V.P. 1970. Seasonal and long-term changes of pressure and geographical position of Aleutian Low for the period from 1899 to 1951 years // News of Russian Geograph. Soc. Vol. 102. N 5. P. 422-431.
21. Maximov I.V. 1970. Geophysical forces and waters of Ocean / Leningrad: Gidrometeoizdat. 447 pp.
22. Miita T. & Tawara S. 1984. Seasonal and secular variations of water temperature in the East Tsushima Strait // J. Oceanography Society. Japan. Vol. 40. P. 91-97.
23. Minobe S. 1997. A 50-70 years climatic oscillation over the North Pacific and North America // Geophysical Research. Lett. Vol. 24. P. 683-686.
24. Pang I. Ch. & Oh I. S. 1994. Long-period sea level variations around Korea, Japan and Russia // Bull. Korean Fish. Soc. Vol. 27. N 6. P. 733-753.
25. Pokudov V.V. & Vlasov N.A. 1980. Temperature regime of Primorye and Sakhalin shore waters on the base of coastal stations data // FERHRI Works. Vol. 86. P. 109-118.
26. Roach A.T., Aagard K., *et al*. 1995. Direct measurements of transport and water properties through the Bering Strait // J. Geophysical Research. Vol. 100. N 9. P. 443-457.
27. Saveliev A.V. 1999. Japan Sea response to EL-Niño // FERHRI Special issue. N 2. P. 54-70.
28. Shuntov V.P. 1986. A status of study of long-term cyclic changes of number of fishes in the Far Eastern Seas // Biology of the Sea. N 3. P. 3-14.
29. Sigimoto T. 1990. A review of recent physical investigations on the straits around the Japanese Islands / The physical oceanography of the sea straits. Ed. Pratt L. Kluver Academic Press. P. 191-209.
30. Sleptsov-Shevlevitch B.A. & Gordienko A.I. 1977. To a question on variability of morphometric characteristics of some Centres of action of an atmosphere // FERHRI Works. Vol. 61. P. 4-11.
31. Sleptsov-Shevlevitch B.A. 1968. To study of two-years variability of atmospheric circulation in Northern Hemisphere of the Earth // Problem of Arctic and Antarctic Region. V. 29. P. 36-44.
32. Smolyankina T.V. 1999. Features of half-year changes of intensity and geographical positions of the Centres of action of an atmosphere in the Northern Hemisphere / Dep. VNIIGMI-MCD. N 1212-gm99. 14 pp.
33. Synoptical bulletin. Northern Hemisphere. The daily data. 1995 / Ed. Chuchkalova B.S. Moscow: Gidrometeocenter of the USSR. Obninsk. Data Centre. 346 pp.
34. Tenberth K.E. 1976. Spatial and temporal variation of the Southern Oscillation. Quart // J. Roy. Meteorolog. Soc. Vol. 102. P. 639-653.
35. Ugrumov A.I. 1968. Two-years cycles in troposphere of moderate latitudes of the Northern Hemisphere // J. Meteorology and Hydrology. N 12. P. 24-31.
36. Vangengeim G.Ya. 1938. To a question of typicality and schematisation of synoptic processes // J. Meteorology and Hydrology. N 3b. P. 57-65.
37. Vangengeim G.Ya. 1961. About a degree of uniformity of atmospheric circulation of various parts of Northern Hemisphere at the basic forms W, C, E // Proc. Arctic and Antarctic Research Inst. Vol. 240. P. 10-19.
38. Watanabe T., Hanawa K. & Toba Y. 1985. Analysis of year-to-year variation of water temperature along the coast of the Japan Sea // J. Progress in Oceanography. Vol. 17. P. 337-357.
39. Wear B.C., Navato A.R. & Newell R.E. 1976. Empirical orthogonal analysis of Pacific Sea surface temperature // J. Physical Oceanography. Vol. 6. P. 671-678.