Intermediate cold layer and ice cover in the Sea of Okhotsk

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Introduction

The ice cover of the seas is a product of the interaction of atmosphere and hydrosphere. The reason for the appearance of ice is a decrease of temperature of air. Air temperature is also the basic influence for the formation of ice cover in shallow seas. In deep-water seas (the Okhotsk Sea) the influence of hydrological conditions in a number of cases can prevail above meteorological ones. The experience of the FERHRI forecasts shows that the correspondence between ice cover of the Okhotsk Sea and air temperature data is observed only in 2/3 cases and success of the forecasts based only on meteorological factors does not exceed 70–80 %. This allows us to assume that ice cover is affected by other factors, in particular, hydrological conditions. This is confirmed by numerical experiments (Petrov and Frolov, 1980).

In the present paper we analyze the relationship between the characteristics of ice cover in the Sea of Okhotsk and meteorological and hydrological conditions.

Variations in the extent of ice cover by size and meteorological conditions

For the variability in the extent of ice cover, the diagram of the extent for 1962–1986 is constructed (Fig. 1). All range of variability is divided so that to the maximal size there corresponds to 100 (standardization on the maximal size in %), minimal to 0. Such division allows us to estimate better the conformity between size of ice cover of the sea and meteorological characteristics (Fig. 2).

For the effects of meteorological conditions we calculated the sums of average ten-day temperatures of air from November through March for the period from 1962 through 1986 for 18 meteorological stations located evenly along a perimeter of the Okhotsk Sea. The resulting values characterize a temperature background of the winter season. The analysis of the diagrams shows that the size of the ice cover and temperature background coincide in general. The most interesting features are winters with extreme (minimal and maximal) values of the extent of ice cover and air temperature. Let us consider the diagrams more in detail. Here it is possible to classify the following winters according to Table 1.

There are however, the winters in which an essential discrepancy (20 and more %) between the size of an ice cover and meteorological conditions is found. The most significant of them are summarized at Tables 2 and 3 and presented in Figure 3.

Variations in winters and hydrological conditions

To relate winters and hydrological conditions data on the distribution of the characteristics of the cold intermediate layer (ICL) in the previous warm period of year were used. This layer of negative water temperatures in its core is the basic feature of the Okhotsk Sea. It is formed as a result of thermodynamic destruction of a winter homogeneous

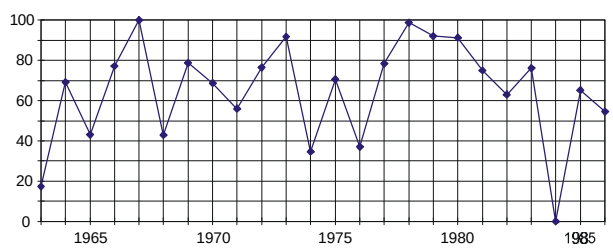

Fig. 1 Variability of an ice cover size (in %) in the Okhotsk Sea.

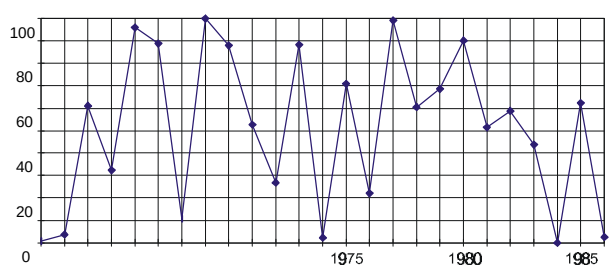

Fig. 2 Variability of air temperature (in %) over the Okhotsk Sea.

Table 1 Winters according to ice cover and air temperature.

with extremely small ice extent	with extremely large ice extent	with extremely low air temperature	with extremely high air temperature
1962–1963	1966–1967	1965–1966	1962–1963
(1973–1974)*	1972–1973	1966–1967	1967–1968
(1975–1976)	1977–1978	1968–1969	1973–1974
1983–1984	1978–1979	1969–1970	1983–1984
–	1979–1980	1972–1973	1985–1986
–	(1965–1966)	1976–1977	–
–	(1968–1969)	1979–1980	–
–	(1971–1972)	–	–
–	(1976–1977)	–	–
–	(1980–1981)	–	–
–	(1982–1983)	–	–

*The years in brackets are close to extreme.

Table 2 Size of an ice cover much below expected on meteorological conditions:

Year	1968–1969	1969–1970	1976–1977	1983–1984	1984–1985
%	+21	+20	+21	+32	+29

Table 3 Size of an ice cover much above expected on meteorological conditions:

Year	1967–1968	1967–1968	1973–1974	1977–1978	1978–1979	1980–1981	1982–1983	1985–1986
%	–32	–49	–32	–38	–23	–23	–32	–24

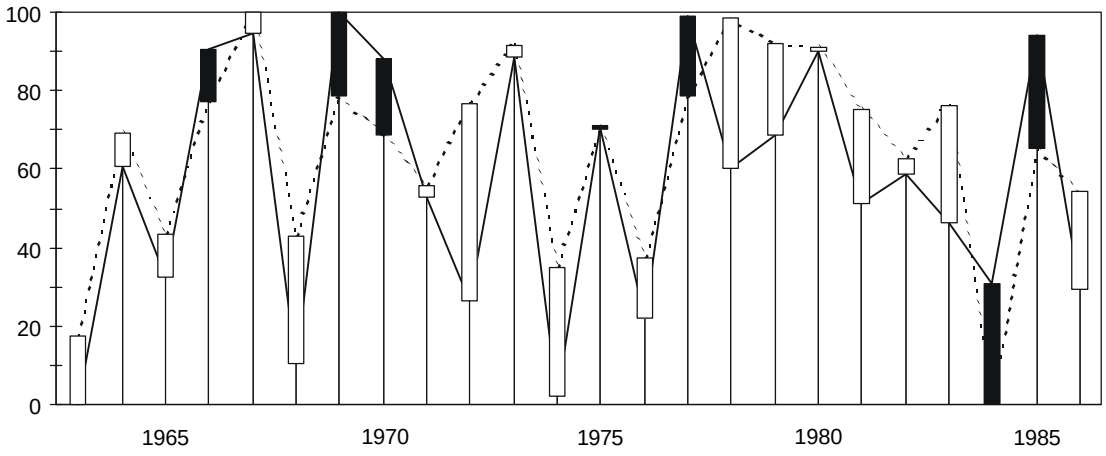

Fig. 3 Joint diagram of sea ice variability and meteorological conditions in the Okhotsk Sea (in %). Black bars refer to mean excess of real ice cover above the expected ice cover. White bars refer to the mean real ice cover below the expected on the meteorological conditions.

layer, which is formed as a result of winter convection. The more ice is formed in the sea, the thicker the water layers cooled down to negative temperatures and the more area it occupies.

ICL actively influences all thermodynamic processes in the sea. Among them it is possible to examine the influence of the ICL on an ice cover. The more extensive ICL is developed, the less the thermal content of the top active layer, and the more ice is formed with other conditions being equal. This given assumption used as a working hypothesis, which was confirmed by this work.

As the most significant influence of the hydrological conditions on the ice cover, we examined ICL parameters in the central part of the Okhotsk Sea to the east of Sakhalin Island.

First we constructed average long-term maps of the ICL characteristics based on all available historical data for months, which had being chosen as an original definition of thermal conditions prior to each winter of the studied period. These are maps of the top and bottom borders of the layer with negative temperatures and its thickness. Maps for the period 1962–1986 were also constructed for July, August and September. From further analysis it was supposed that the hydrological conditions are characterized by the presence of the ICL, namely, when the ICL is increased strongly, the hydrological conditions are assumed to be extremely cold, and in the opposite case – extremely warm (Fig. 4).

Joint analysis of the characteristics of winters on the extent of ice cover, meteorological, and hydrological conditions

We carried out a joint analysis of the extent of an ice cover, meteorological and hydrological conditions. The results of the analysis are presented in Tables 4–6.

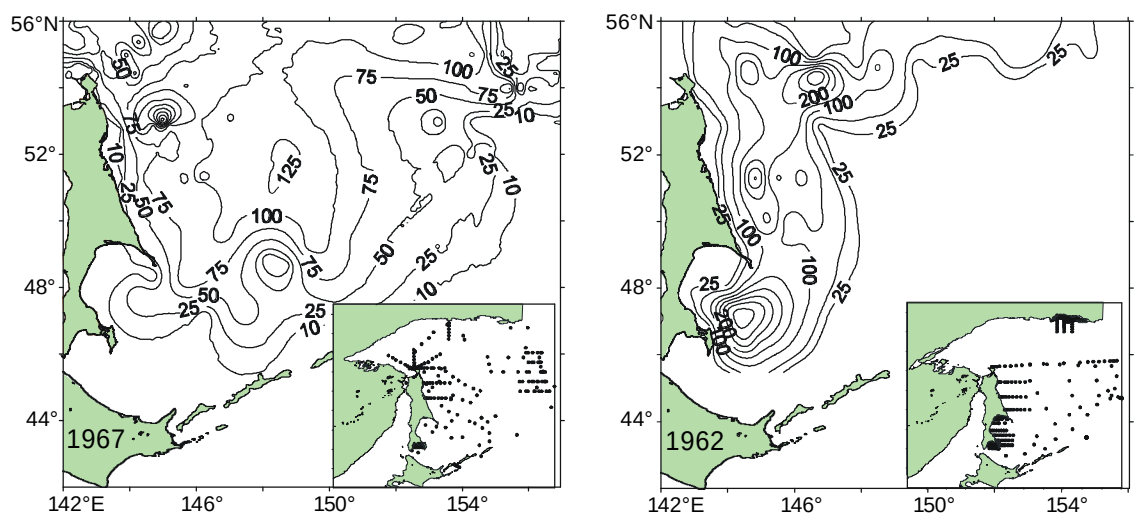

Fig. 4 Example of the classification of a cold (1967) and a warm (1962) year from hydrological conditions in summer. Contours of the thickness of the intermediate cold layer (ICL) are shown.

Table 4 The characteristic of winters with extreme values of an ice cover.

Winter with extremely small size of an ice cover		
Year	Meteorological conditions	Hydrological conditions
1962–1963	Extremely warm	Extremely warm
1983–1984	Extremely warm	Extremely warm
(1973–1974)	Extremely warm	Extremely cold

Table 4 Continued.

Winter with the extremely large sizes of an ice cover		
1966–1967	Extremely cold	Extremely cold
1972–1973	Extremely cold	Extremely cold
1977–1978	Warm	Warm
1978–1979	Warm	Extremely cold
1979–1980	Extremely cold	Extremely cold
(1976–1977)	Extremely cold	Warm

Table 5 The characteristic of winters with extreme values of air temperature.

Winters with extremely low temperatures of air		
Year	Size of an ice cover	Hydrological conditions
1965–1966	Close to the extremely high	No date
1968–1969	Close to the extremely high	No date
1969–1970	Is higher than the average	No date

Winters with extremely high temperature of air		
1967–1968	Close to average	Cold
1985–1986	Average	Cold

Table 6 The characteristic of winters, in which the mutual discrepancy between an ice cover and air temperatures is observed.

Winters with size of an ice cover much below expected on meteorological conditions			
Year	Size ice ñover	Meteorological condition	Hydrological condition
1968–1969	Above the average	Extremely cold	No data
1969–1970	Above the average	Extremely cold	No data
1976–1977	Above the average	Extremely cold	Warm
1983–1984	Extremely small	Close to average	Extremely warm

Winter with size of an ice cover much above expected on to meteorological conditions			
1967–1968	Close to average	Extremely warm	Cold
1971–1972	Is higher average	Below average	Warm
1973–1974	Close to average	Extremely warm	Extremely cold
1977–1978	Extremely high	Warm	Warm
1978–1979	Extremely high	Close to average	Cold
1980–1981	Above average	Average	Warm
1982–1983	Above average	Below average	No data
1985–1986	Average	Extremely warm	Cold

Conclusions

It is necessary to note that the qualitative analysis of conditions of the cold intermediate layer (in view of the lack of reliable and representative initial data) does not allow us to characterize the thermal condition of an active layer of the sea objectively and fully enough. However, from the obtained results, in the absolute majority of cases the extent of an ice cover is completely defined only by appropriate combinations of meteorological and hydrological factors. At strongly advanced ICL, the ice cover of the next winter is frequently observed to be greater than that expected from meteorological conditions, and at a weaker state of the ICL, the ice extent is lower even under colder meteorological conditions. This conclusion is important for using the characteristics of the cold intermediate layer for forecasting, and for research in connecting ice cover with meteorological parameters. Frequently, when using the data on only ice extent, one might calculate various periodicities caused by atmospheric circulation parameters (and by other factors) to try to explain their physical meaning. Taking into account hydrological factors can help researchers make more accurate statements regarding research problems, both for the ice cover studies directly and for other questions concerning atmospheric circulation, and the climate as a whole.

References

Petrov, A.G. and Frolov, I.E. 1980. The numerical model of ice conditions during the pre-winter period. *Trudy DVNIGMI (Proc. FERHRI), 80*, 3–12. (in Russian)