Some regularities in the formation of extremely low-ice winter seasons in the Okhotsk Sea

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Introduction

Ice conditions are formed as a result of complex mechanisms taking place between the atmosphere and ocean. Research needs to continue in order to reveal the interdependencies between the atmosphere and ice, and to explore their causal relationships in order to make predictions. The evolution of ice cover in the Okhotsk Sea for the period of observations determined in this paper is divided into relatively low-ice and extreme ice periods. There is a certain cyclic recurrence in the distribution of interannual variability estimations of ice conditions. However, these regularities have a generalized character.

The prevalence of cold winter conditions in the Okhotsk Sea was noted until the mid-1980s. Later, a radical change occurred in the course of average annual ice conditions values. The prevalence of low-ice winter seasons was noted since 1984 (Muktepavel, 2001). In certain situations, low ice-cover distributions at separated years, or even at separated periods, has an untypical character and can interrupt the long-term averages. So, extremely low-ice winters in the Okhotsk Sea were noted in 1991, 1996, 1997 and 2006.

The baric fields above the central part of the Northern Hemisphere at 30°–70°N, 120°–160°E were analyzed to reveal the mechanism for the ice formation phenomena. It is shown in this paper that such ice condition extremes are formed as a result of anomalous 500 hPa geopotential growth above the Okhotsk Sea. The anomalous atmospheric circulation promotes the carrying of warm air masses to offshore water. These masses are localized above the central part of the Okhotsk Sea, where the temperature anomalies are about +8°.

In this paper we identify a mechanism for the formation the regularities of extremely low-ice winters in the Okhotsk Sea with a provision for large-scale processes above the second natural synoptical region in the North Hemisphere.

Data and Methods

The complete database of averaged 10-day ice cover in the Okhotsk Sea was obtained from satellite imagery. The anomalies of ice cover in February for extreme ice years in the Okhotsk Sea were chosen:

$L_M - Lcp > 1/2\ A$ for extremely high ice years,
$L_M - Lcp < 1/2\ A$ for extremely low ice years

where L_M is the monthly mean ice cover in February, Lcp is the mean annual ice cover in February, and A is the amplitude in the change of parameter.

Data of aerologic stations from 1950–2006 were used from the Far Eastern Regional Hydro-meteorological Research Institute’s archives. The archives of average monthly data on H500 geopotential were obtained from the CD-ROM “NCER/NCAR reanalysis of monthly mean CD-ROM 1948–1998” and the average monthly data on above-earth pressure was taken from http://dss.ucar.edu/datasets/ds.010.1/data for 1948–2003.

Results and Discussion

Figure 1 shows the long-term distribution of average annual deviations of ice cover in the Okhotsk Sea on a background of ice cover anomaly distributions.

It demonstrates the presence and length of short and long cycles of the anomalous increase and decrease in ice cover from 1957 to 2007. Starting from 1984, there is an accumulation of negative anomalies that represent low-ice years. Years of extremely low-ice conditions in Okhotsk Sea, in which ice cover was more than 20% less than the annual mean average, were determined for 1984, 1991, 1996, 1997, and 2006.

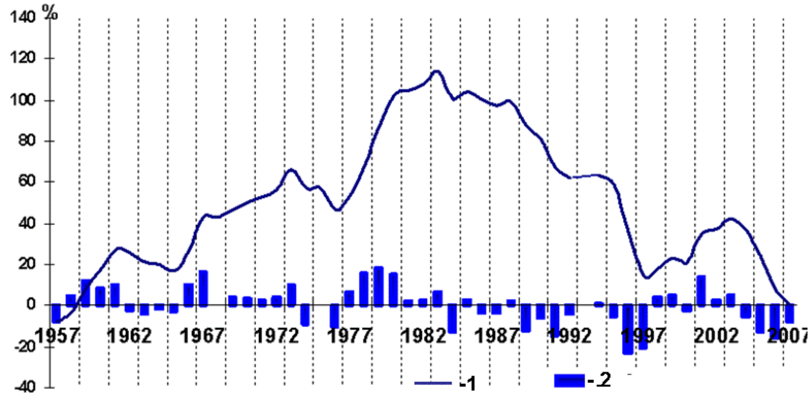

Fig. 1 (1) Long-term distribution of average annual deviation of ice cover in the Okhotsk Sea on (2) background of ice cover anomaly distributions.

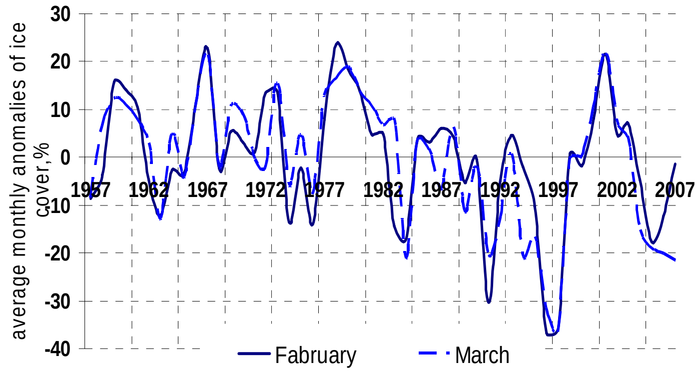

Fig. 2 Long-term distribution of ice cover anomaly in February (—) and in March (- -).

Figure 2 shows the long-term distribution of anomaly ice cover during months of maximum development of the ice area in the Okhotsk Sea. The anomalous low-ice years of 1984, 1991, 1996, 1997, 2006 were determined when ice cover was more than 20% less than the annual mean average.

Figure 3 shows the mean annual ice positions of the ice edges during extremely low-ice years. During these years, there is a characteristic absence of ice in the central part of the Okhotsk Sea and to northeast of the Sakhalin shelf. For comparison, the positions of the ice edge for the extremely high ice year (2001) is also shown.

The significant changes in the baric fields at AT 500 over the Asia-Pacific region existed during the 1990s (Shatilina, 1998). First, to explain the mechanism of extremely low ice formation, we analyzed the local atmospheric processes over the Okhotsk Sea using observed data of aerological stations, located on perimeter of the Okhotsk Sea.

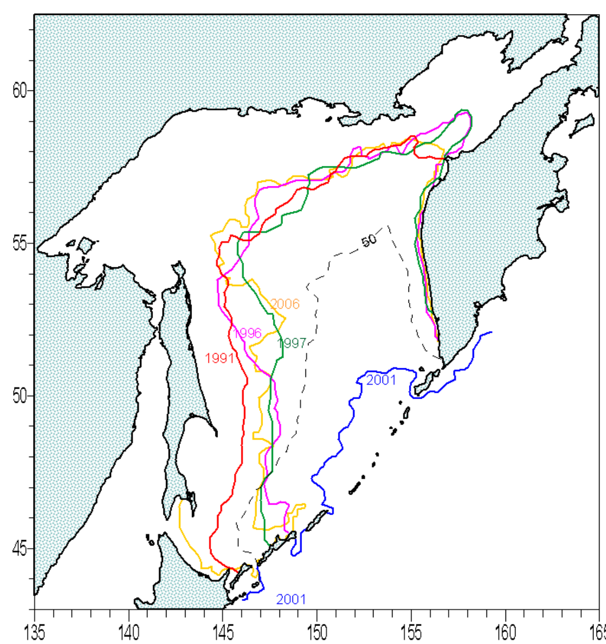

Fig. 3 The location of the ice edge in February of extreme ice years in the Okhotsk Sea (by remote sensing).

In Figure 4 we see the general regular pattern of atmospheric processes for extremely low-ice years. There is a high pressure system over Okhotsk Sea that causes a growing geopotential here. In 1984, the area of the low heights at a level of AT500 was displaced into the region of the south Kuril Islands while high-altitude Pacific atmospheric ridge intruded into the Okhotsk Sea (Fig. 4a). Anomalies of geopotential reached 6–9 dam over the sea (Fig. 4 b). In January 1996 the Okhotsk Sea was also under the influence of a high-altitude Pacific tropospheric ridge. The tropospheric whirl was displaced on continental regions adjacent to the northwestern part of the Okhotsk Sea (Fig. 4 d).

In 2006 there was the same regularity over the Okhotsk Sea as in 1984, 1996, 1997. We found a general regularity in the structure of the atmospheric baric field over the Okhotsk Sea in extremely low-ice years. Figure 5 shows the anomalous increasing geopotential heights over the sea.

Figure 6 shows the difference of the high-altitude baric field in extreme high-ice years in comparison with extreme low-ice years in the Okhotsk Sea. For example, in February of 1979 and 2001 historical maximum ice cover was situated in the area of the Okhotsk Sea having a very low pressure at a level of AT500 (502–504 hPa) (Fig. 6a and c). Its anomalies in the eastern part of the sea ranged from –10 to –16 dam (Fig. 6b and d).

The regularities in the change of atmospheric circulation forming extreme ice cover are a response to the large-scale processes existing in the North Pacific and near Arctic. Figure 7 presents such a large-scale process with the average annual of baric field at AT500. The position of the main climatic hollow (isobar 516 hPa) on the eastern side of the Okhotsk Sea can be seen. South of it is the High Altitude Frontal Zone of the Northern Hemisphere. The cold climatic hollow is located over the Okhotsk Sea.

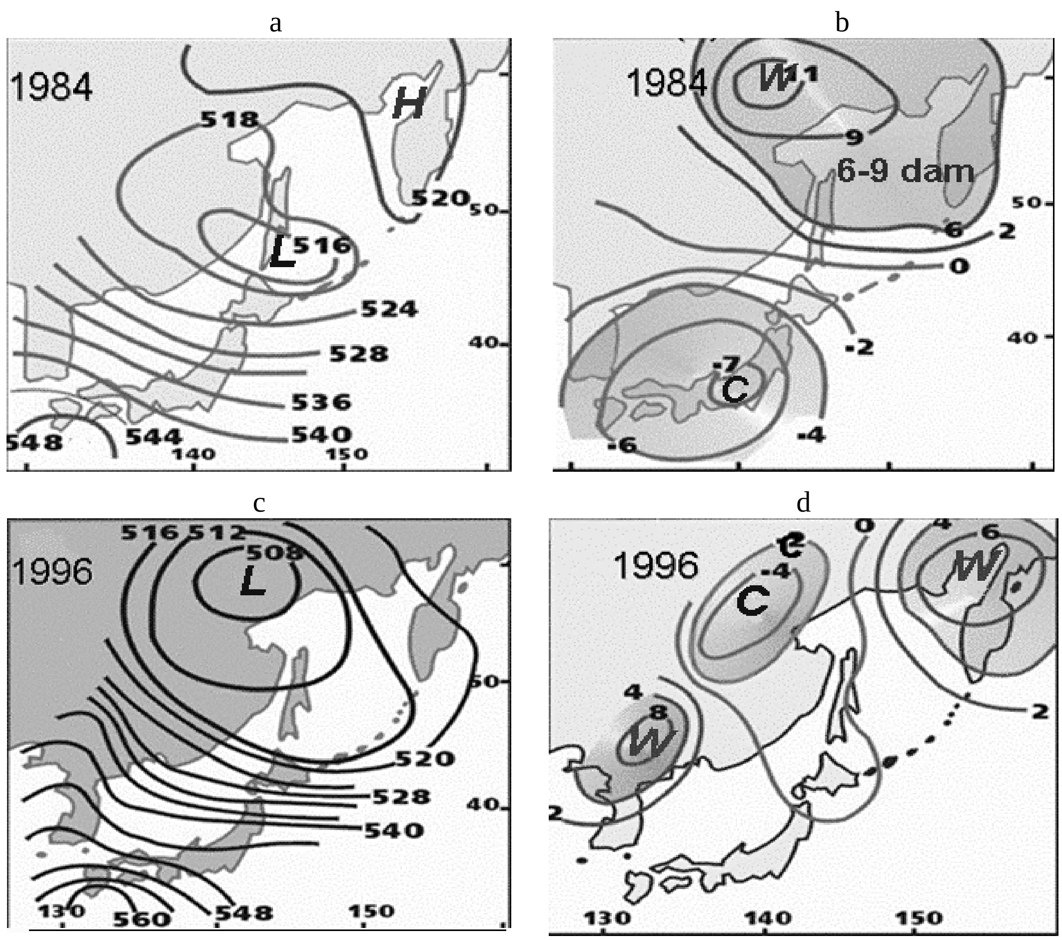

Fig. 4 Structure of high-altitude fields during the extremely low-ice period of January 1984 and 1996 (a and c) AT500 field; (b and d) anomalies of 500 hPa geopotential (data from aerologic stations).

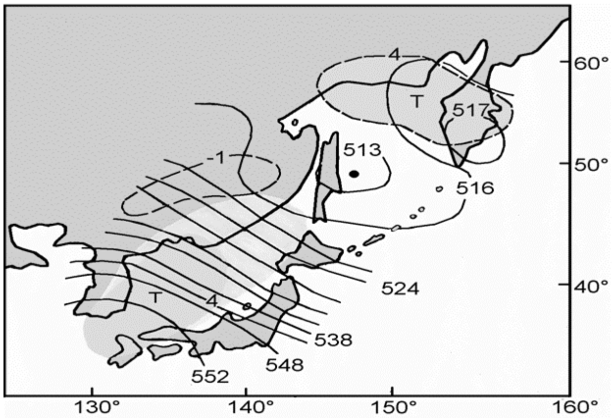

Fig. 5 Structure of the high-altitude (AT500) baric field during extremely low ice over the Okhotsk Sea, in January 2006.

Figure 8 shows the large-scale field AT500 in January 1991 and 1997 when extreme H500 values were registered over the Okhotsk Sea. These anomalies were shown by the position of a tropospheric hollow, which was practically absent in extreme warm winters (Shatilina, 1998). The Okhotsk tropospheric cyclone occupied the southern position over the north Kuril Islands. The hollow is not noted in extreme warm winters.

The increase of high-altitude pressure in January and February means a weakening of the high-altitude climatic hollow and Okhotsk minimum (the secondary arctic curl). This means a decrease in the intensity of incoming arctic cool air on the surface of the Okhotsk Sea.

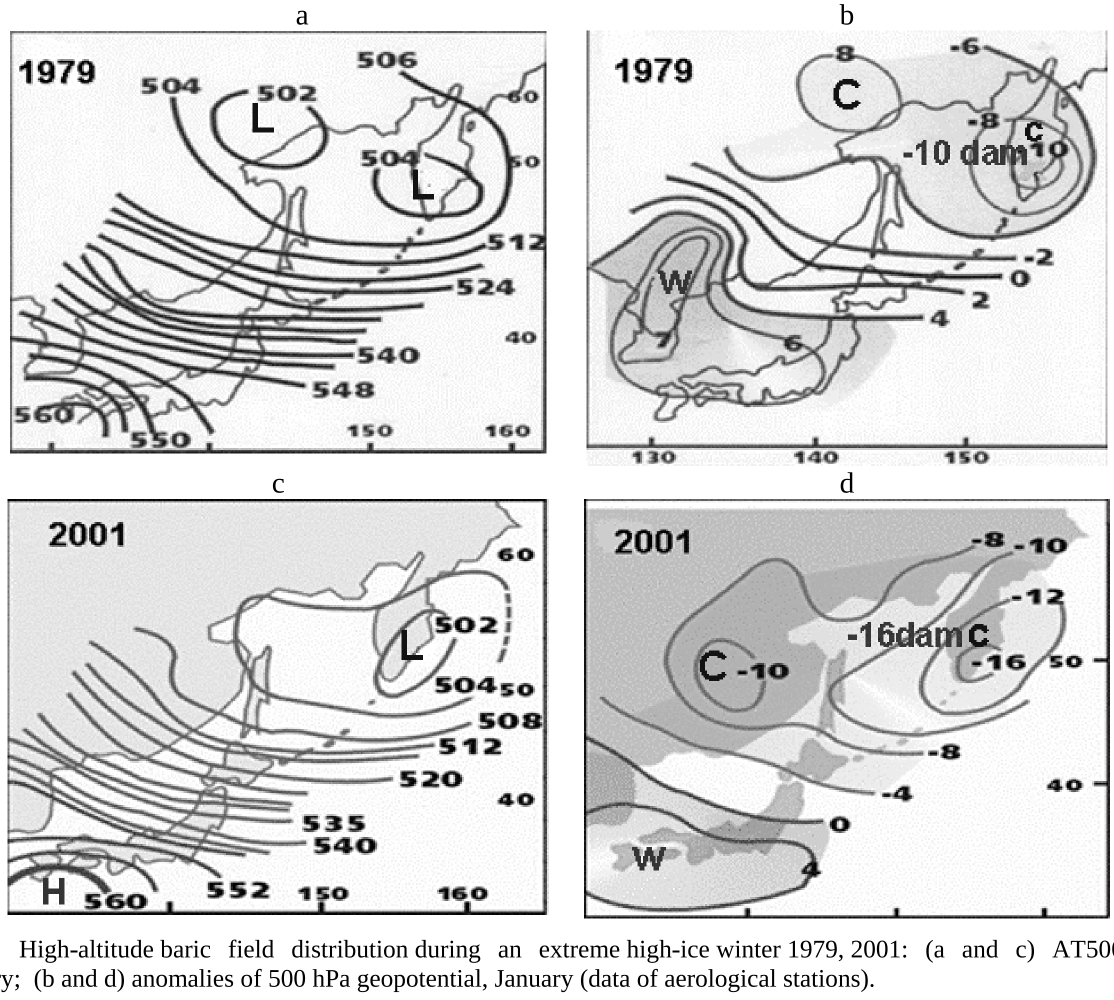

Fig. 6 High-altitude baric field distribution during an extreme high-ice winter 1979, 2001: (a and c) AT500 field, January; (b and d) anomalies of 500 hPa geopotential, January (data of aerological stations).

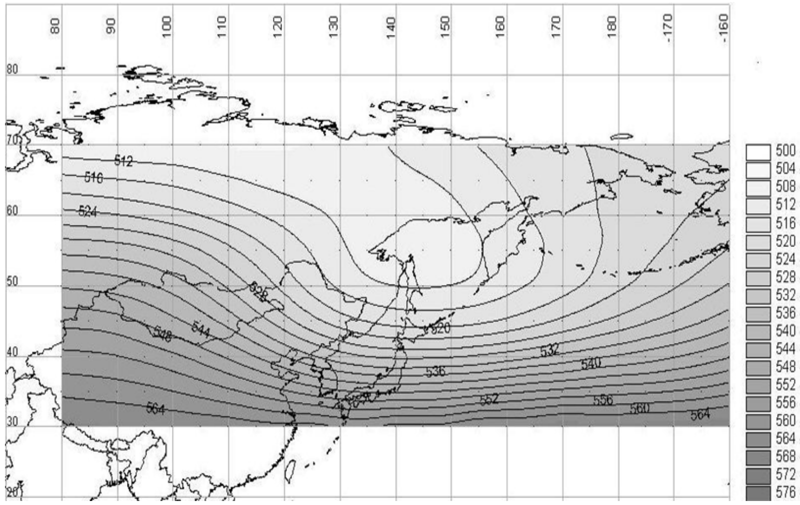

Fig. 7 Average annual of baric field at a level of AT500 in January (data from Reanalysis MONTHLY Mean CD-ROM 1948–1998).

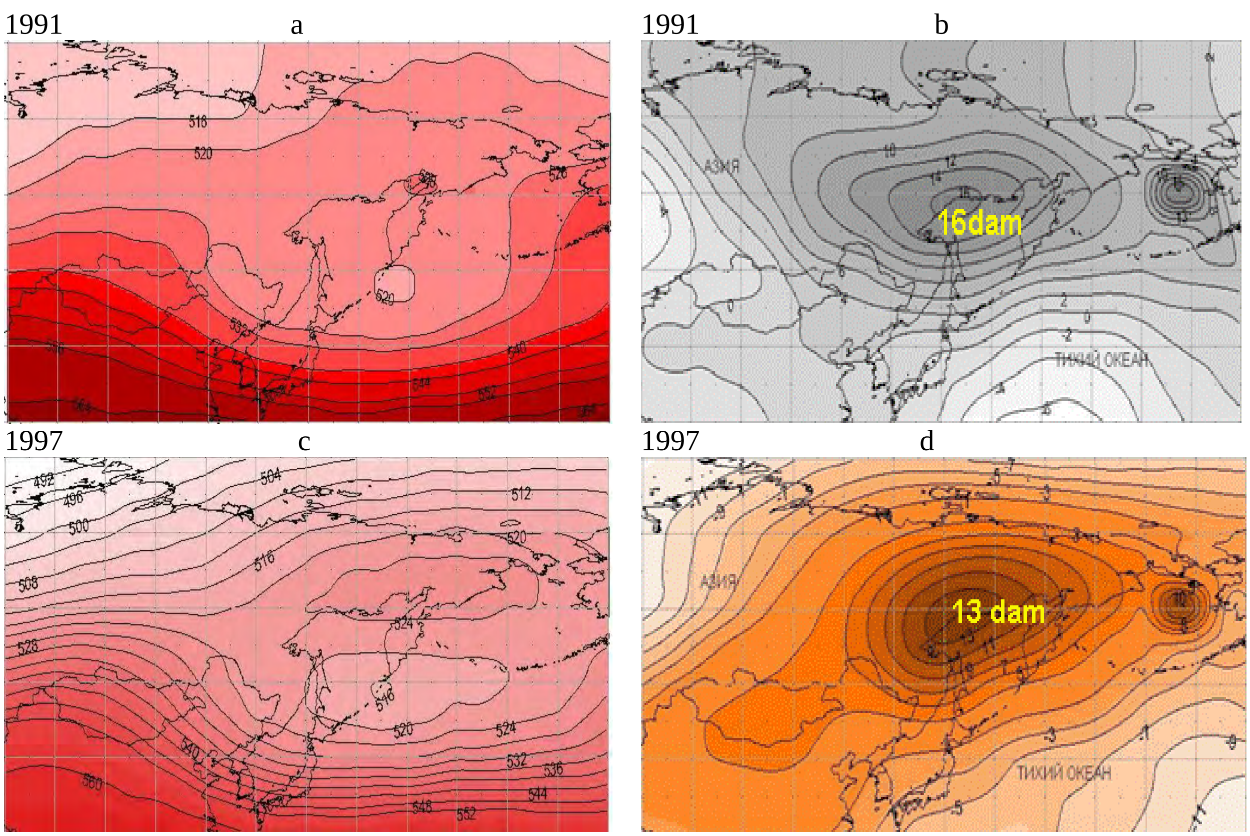

Fig. 8 (a and c) Spatial distribution large-scale baric fields at a level of AT500 and (b and d) distribution anomalies of 500 hPa geopotential for January 1991, and 1997 (Shatilina and Matyushenko, 2006).

In January 1996 (Fig. 9a and b) the northeastern part of the Okhotsk Sea was under the influence of a Pacific high-altitude ridge which means that there was an intensive intrusion of warm air over the Okhotsk Sea water (a high-altitude ridge is formed over the warm water of the Pacific Ocean).

The anomalous circulation in the troposphere prompted a change in the trajectory of surface cyclones forming a cyclogenesis over the Okhotsk Sea. The trailing part of the cyclones displaced over the Okhotsk Sea caused the transportation of warm air and increased warm ocean water advection through the Kuril Straits (Fig. 9) (Pavlichev and Muktepavel, 2000).

For comparison of the position of the climatic hollow and of the Okhotsk tropospheric cyclone, Figure 10 shows large-scale processes in January 1978 which was an extreme high-ice year. The position of large anomaly centers (marked with “Cold” and “C”) in the H500 field can be seen, one of which lies over the northwestern part of the Okhotsk Sea. The results show that large-scale processes for extremely low-ice conditions in the Okhotsk Sea were due to a localization of warm air over the central part of the sea. Positive anomalies of the air temperature along 55°N were about 8°C (Fig. 11). Increased advection of warm ocean water inside the Okhotsk Sea through Bussol Strait is seen in Figure 12 for the noted years

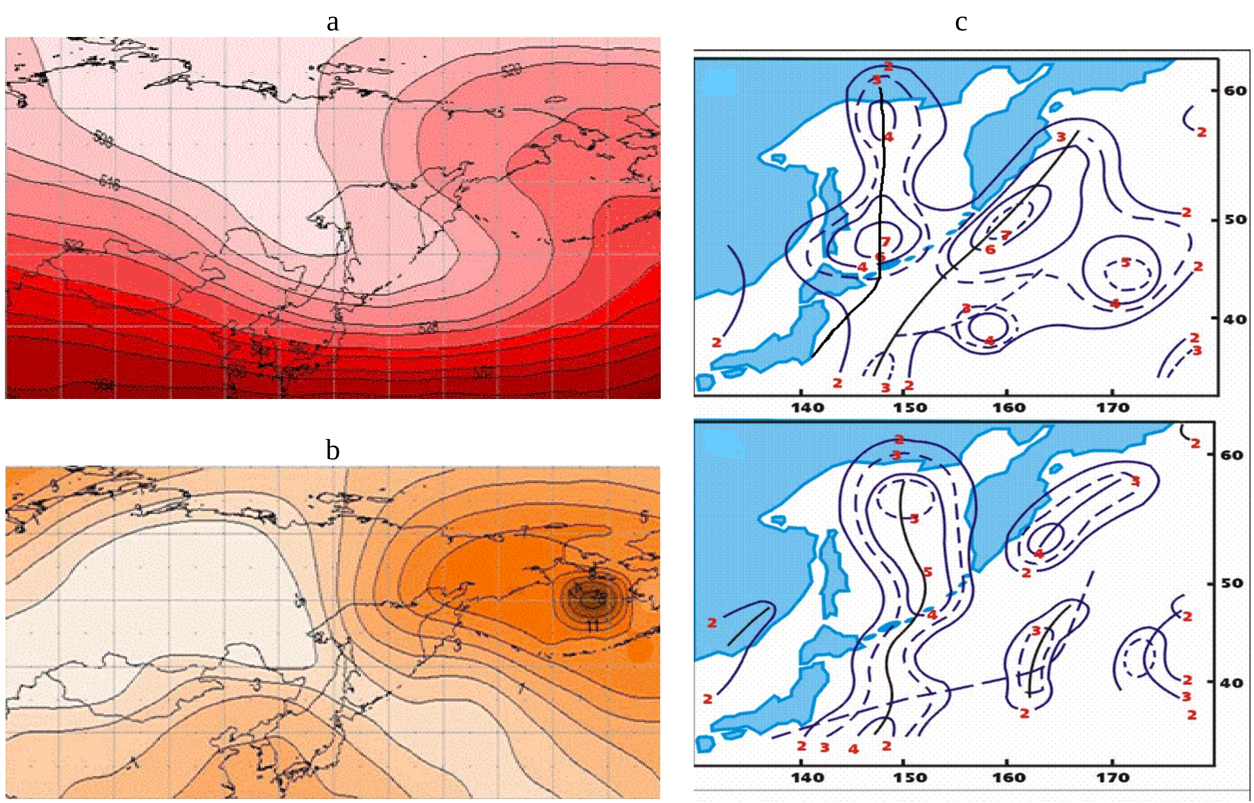

Fig. 9 (a) Spatial distribution of the baric field at a level of AT500; anomalies of 500 hPa geopotential (b) in January 1996. Paths and frequency of occurrence (days) of surface cyclones in (a) January and (b) February 1996, (c) Pavlychev and Muktepavel (2000).

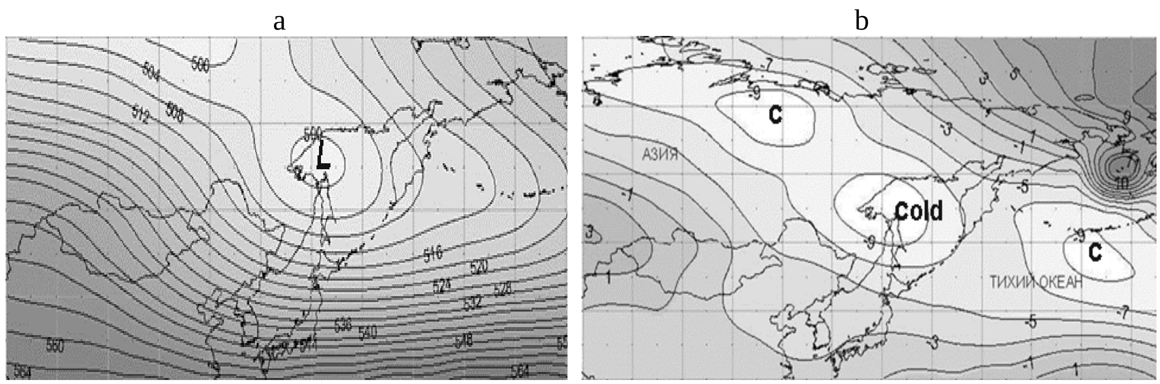

Fig. 10 (a) Spatial distribution baric field at a level of AT500 and (b) anomalies of 500 hPa geopotential, in January 1978.

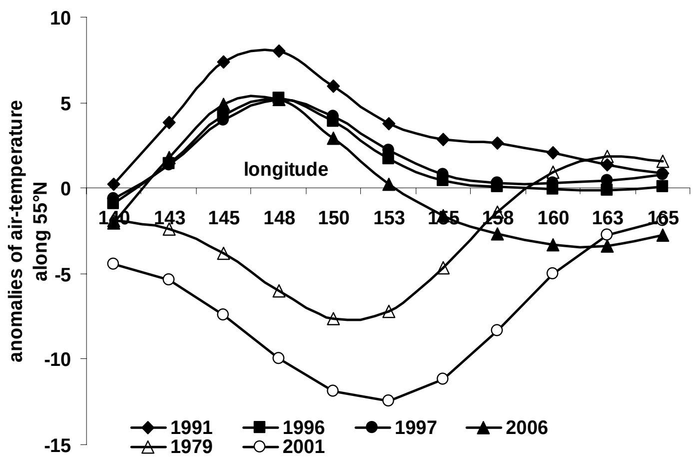

Fig. 11 Distribution anomalies of air temperature over the Okhotsk Sea along 55°N in February.

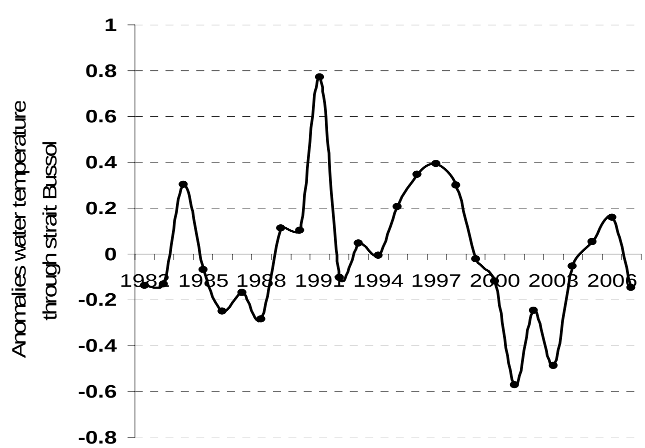

Fig. 12 Intra-annual run of water temperature anomalies in Bussol Strait in January–March from 1982 to 2007.

Conclusions

Figure 13 presents a general scheme of large-scale processes responsible for the formation of extreme low-ice in the Okhotsk Sea.

We conclude that:

- An Okhotsk Sea tropospheric cyclone (in January, February) weakens and is displaced on continental regions under extremely low-ice conditions;
- A cold centre in the troposphere over the Okhotsk Sea had large positive anomalies of 500 hPa geopotential (centres of the heat);
- Such a situation formed as a result of frequent intrusions of a Pacific tropospheric ridge over most areas of the Okhotsk Sea;
- The anomalous circulation in the troposphere of the research region prompted a change in the trajectory of surface cyclones forming a cyclogenesis over the Okhotsk Sea;
- The trailing part of the cyclones, displaced over the Okhotsk Sea, caused the transportation of warm air and increased the advection of relatively warm ocean water through the Kuril Straits;
- Localization of the warm air is observed above a central part of the Okhotsk Sea.

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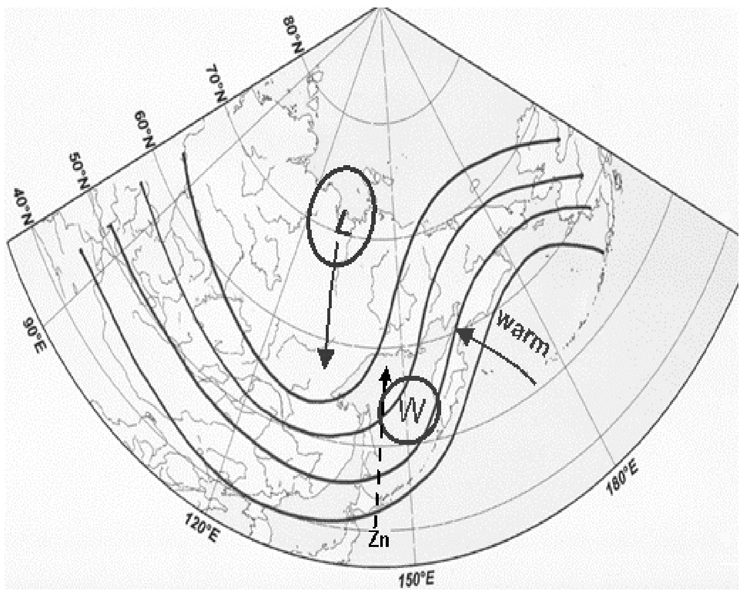

Fig. 13 Scheme of large-scale processes forcing the formation of extreme low-ice in the Okhotsk Sea.

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