Long-term changes of atmospheric centers and climate regime of the Okhotsk Sea in the last three decades

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Abstract

The thermal regime of the Okhotsk Sea is determined by the Aleutian Low and Siberian High interaction in winter but depends on the interaction of the Far Eastern Low and Hawaiian High in spring and summer. These large-scale cyclones and anticyclones are referred to as "centers of atmosphere action". In the last three decades (1974–2007), both winter centers shifted gradually southwestward and weakened. As a result, the quantity of the "cold" and "moderate–cold" types of atmospheric processes decreased, the duration of the local winter monsoon over the Okhotsk Sea shortened, and its activity lessened. Hence, the thermal regime of the Okhotsk Sea changed towards a decrease in ice cover and an increase in sea surface temperature in spring. The position of the summer centers also changed. The Far Eastern Low shifted southwestward, farther from the sea shore, and the Hawaiian High moved northwestward, moving nearer to the Okhotsk Sea. In particular, the intensity of both atmospheric centers has increased recently. These changes have caused a decrease in local summer monsoon activity, but its influence has been prolonged which means that autumn processes begin later. As the result, sea surface temperature in the Okhotsk Sea in summer is increasing. We conclude that the long-term reorganization of the barometric regime which occurred during the last several decades has caused a warming of the Okhotsk Sea climate.

Introduction

The Okhotsk Sea has unique hydro-meteorological conditions favorable for many commercial species. Therefore, these conditions should be revealed for the future estimation of Okhotsk Sea bio-productivity.

Thermal conditions in the Okhotsk Sea are closely connected with large-scale atmospheric processes, formed by the atmospheric actions centers (AAC), such as the Aleutian Low and Siberian High in winter and the Far Eastern Low and Hawaiian High in summer.

Data and Methods

The position of the AAC was determined by analysis of sea surface atmospheric pressure charts of 10-day averaging for the period 1974–2007. A total of 1188 averaged charts were prepared (36 charts per a year). Latitude, longitude and intensity of the seasonal AACs were determined and the atmospheric processes over the Okhotsk Sea were classified. The position and intensity of the AAC, in particular the Aleutian Low, and the direction of wind over the Okhotsk Sea were used as the main criteria for the definition of the synoptic types. A total of seven characteristic synoptic situations or types have been determined for the Okhotsk Sea (Glebova, 2004); Katz's meridional indices of atmospheric circulation (as the quantitative parameter of intensity and direction of local wind transfer over the Okhotsk Sea) (Katz, 1954) were calculated as a number of isobars crossing latitudes inside and on the boundaries of the area 40–60°N, 130–160°E (including the Okhotsk Sea), taking into account their orientation. Using the formula $Im = Is – In/N$, where Is is the number of isobars orientated from south to north, In is their number orientated from north to south, N is the number of the crossed latitudes, and $Im > 0$ characterizes southern wind (summer monsoon) while $Im < 0$ characterizes northern wind (winter monsoon).

Monsoon changes occur over the Okhotsk Sea in spring and autumn. (In spring northern winds usually cease by the third 10-day period of April, and in autumn they begin in the third 10-day period of September; in terms of real synoptic situations, a change of monsoon can occur earlier or later than these "average" terms.)

The values of all parameters were averaged for the cold season (October–March) and warm season (April–September) of each year. Thermal conditions of the Okhotsk Sea were characterized by ice cover and sea surface temperature in spring and summer (obtained from http://goos.kishou.go.jp/rrtdb/usr/pub/JMA/cobesst/). To determine long-term tendencies, and for the best comparability of results, all meteorological and oceanologic parameters were averaged using 5-year periods.

Results and Discussion

It is known that in winter the climatic regime and character of wind transfer in the Okhotsk Sea depend on the Aleutian Low and Siberian High. Their interaction usually forms the northern circulation over the entire region of the Okhotsk Sea.

The analysis of long-term changes in parameters of both atmospheric centers has shown that during the last three decades their condition has gradually varied. As can be seen, the Aleutian Low and Siberian High have constantly shifted to the south and west (Fig. 1A–D). In addition, pressure in the Aleutian Low has heightened (Fig. 1E) and the pressure in the Siberian High has slightly lowered (Fig. 1F).

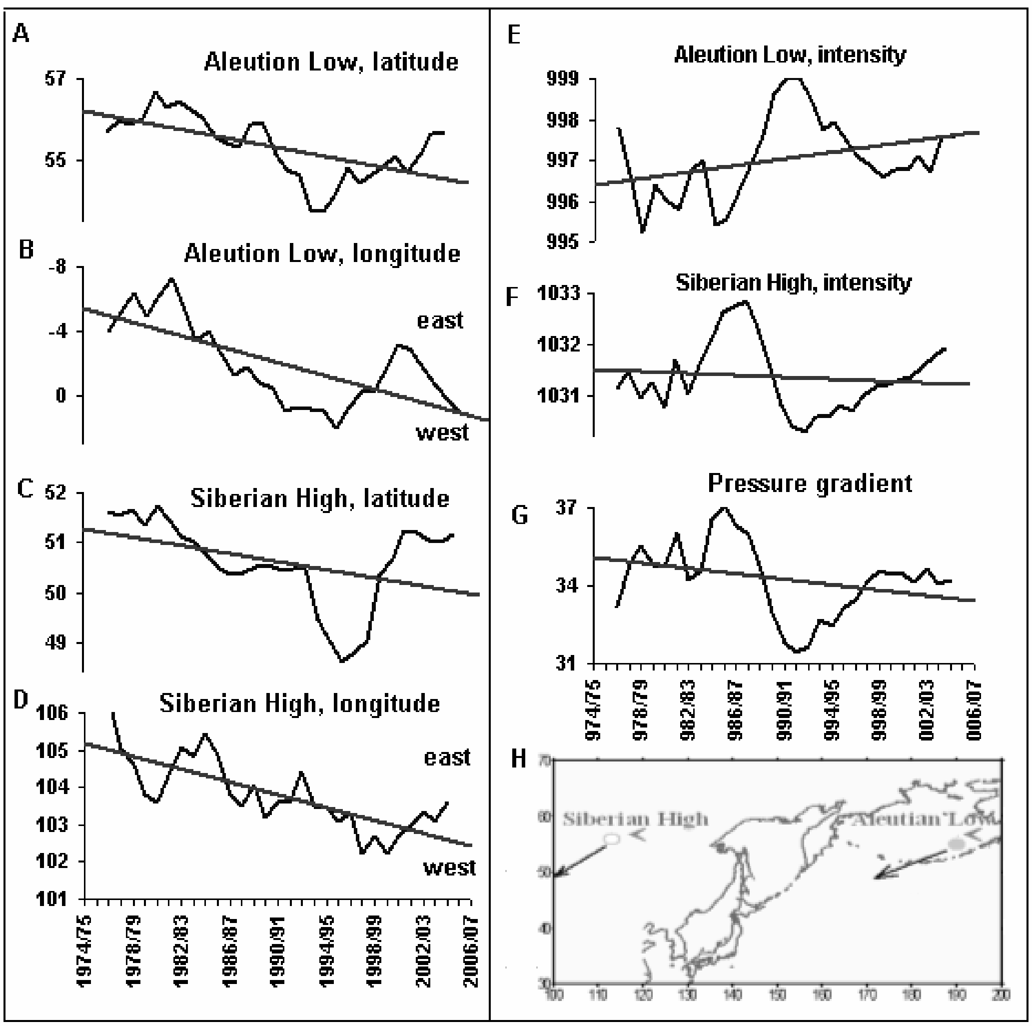

Fig. 1 Long-term changes in the parameters of the winter (October–March) atmosphere action centers (AACs) from 1974 to 2007. Pressure is in mbars.

The pressure gradient between these centers has also decreased (Fig. 1G). It is a parameter of general northern circulation over the region, and its weakening means that the intensity of cold air invading the sea area has decreased.

As a result of the southwestward shift (Fig. 1H), a wedge of the Siberian High has been removed from the Okhotsk Sea while a trough of the Aleutian Low, on the contrary, has moved closer to the sea where its influence has amplified in comparison with the Siberian High. Therefore, atmospheric processes directly over the Okhotsk Sea have also varied: the repeatability of "warm" and "moderate–warm" synoptic types with excessive cyclonic activity over the Kuriles and over the Okhotsk Sea has begun to increase (Fig. 2A). This implies that warm oceanic air masses have entered the Okhotsk Sea with cyclonic activity and that the quantity of the "cold" and "moderate-cold" atmospheric types with intensive northern wind transfer and intrusion of Arctic cold air masses have been reduced (Fig. 2B). The changes in the atmosphere are reflected in the thermal regime of the sea. The ice cover has been generally reduced in the last three decades (Fig. 2C). Although there have been interdecadal fluctuations, the last "wave" of heightened ice cover in the early 2000s was much lower than the previous one in the early 1980s when the quantity of the "cold" and "moderate–cold" types was maximal.

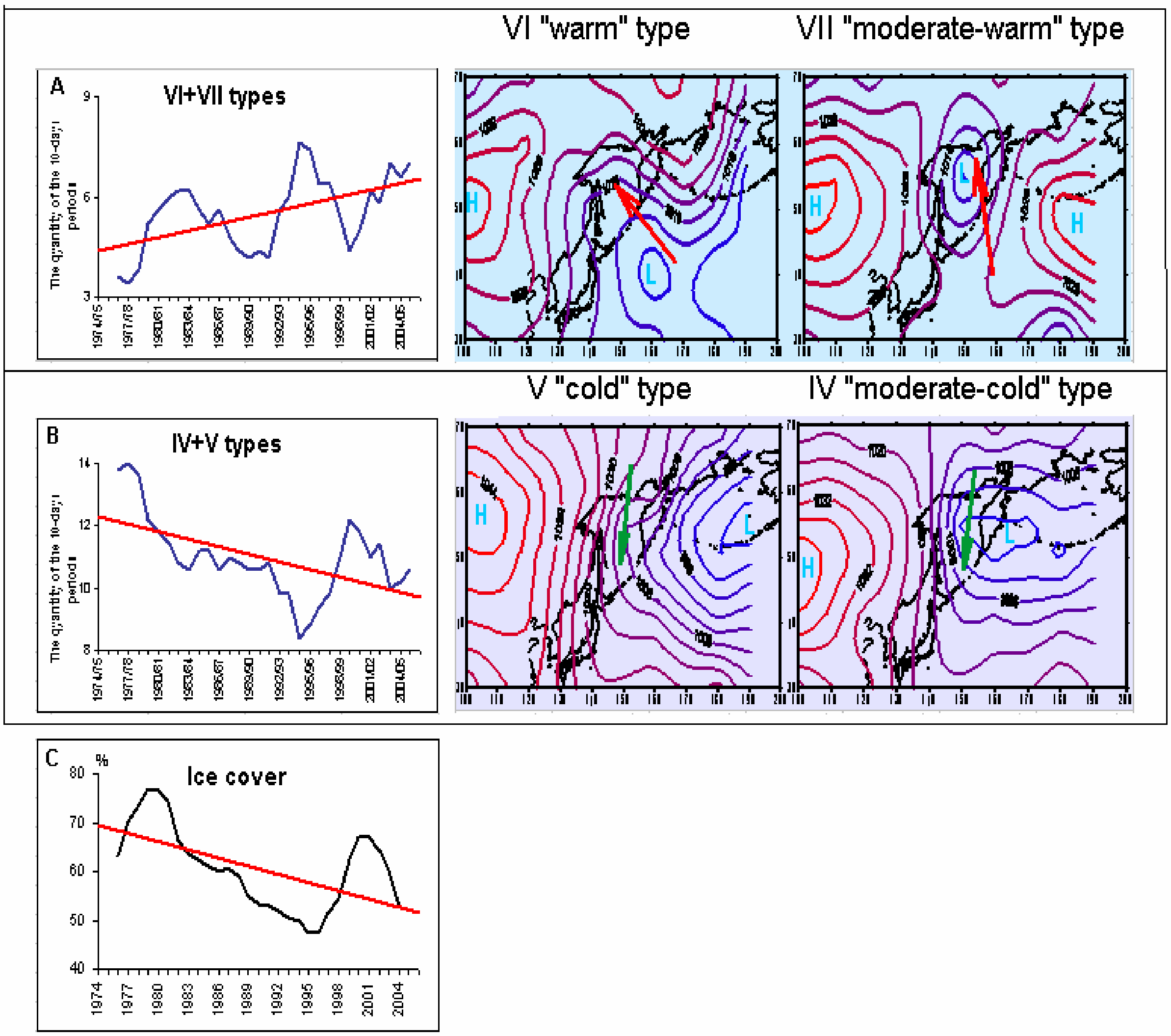

Fig. 2 Long-term trends in the change in repeatability of atmospheric processes over the Okhotsk Sea and ice cover in the cold season (October–March) from 1974 to 2007.

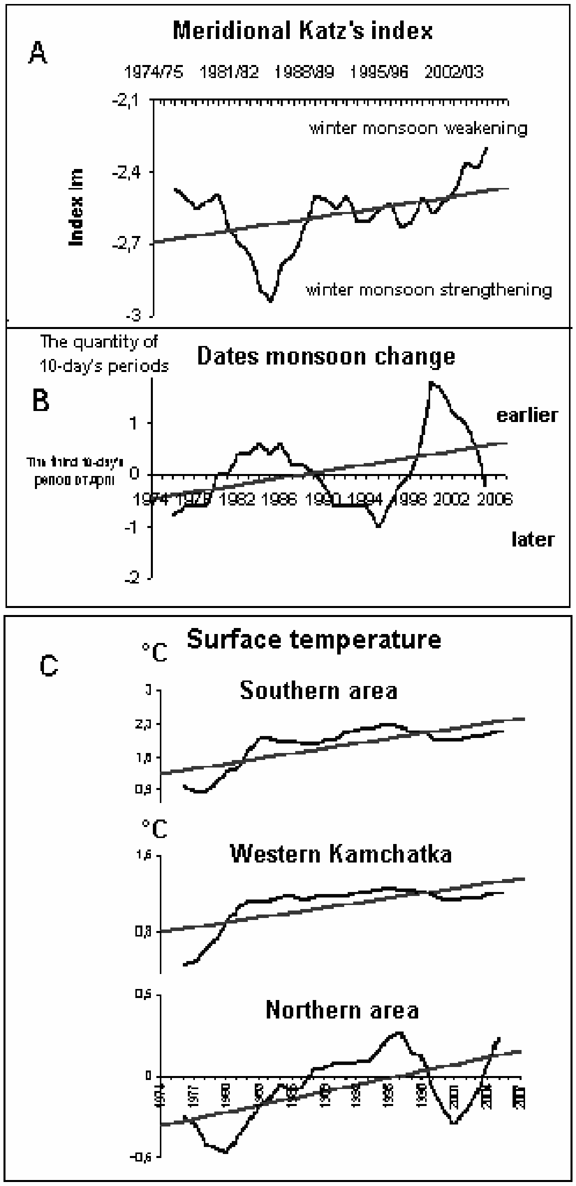

Fig. 3 Trends in variability of (A, B) winter monsoon parameters and (C) sea surface temperature in the Okhotsk Sea in spring.

Climate change in the Okhotsk Sea is also revealed in the character of wind transfer. As shown in Figure 1G, during last 30 years a relaxation of the general circulation (pressure gradient) has occurred over Pacific region in winter. Undoubtedly, this event should be reflected in the character of the local wind transfer in the Okhotsk Sea. The intensity of the northern wind (a winter monsoon) in the Okhotsk Sea has begun to decrease too, and in recent years it has happened especially quickly (Fig. 3A). It is curious that the duration of the winter monsoon has also varied, namely, the termination date of northern transfer (and beginning of formation of southern transfer) has gradually moved to earlier times (Fig. 3B). In other words, the duration of the northern monsoon has been reduced and the spring processes have started earlier in the Okhotsk Sea. It is quite possible that exactly these factors — the lessening of the winter monsoon activity and its shortened duration — have been the cause of the increase in sea surface temperature in spring in various areas of the Okhotsk Sea (Fig. 3C). The atmospheric regime during the warm seasons has also undergone considerable changes. As a general rule, the southern overall circulation is observed in spring and summer as a result of the interaction between the Far Eastern Low and Hawaiian High.

As can be seen in Fig. 4E–F, the intensity of both AACs have increased gradually (the pressure in the Far Eastern Low has lowered and the pressure in the Hawaiian High has heightened). Recently, the intensity of both centers has reached their highest values yet. The pressure gradient between them has also increased (Fig. 4G) so that the southern general circulation over the Pacific region has become more active. Both atmospheric centers have shifted westward (Fig. 4A and C) and simultaneously, the Far Eastern Low has also moved towards the south (Fig. 4D) and the Hawaiian High has moved toward the north (Fig. 4B), *i.e.*, the Far Eastern Low has moved from the coast deeper into the continent, and its influence on the Okhotsk Sea has lessened (Fig. 4H). However, the Hawaiian High has steadily come nearer to the Okhotsk Sea, and it has had important consequences. On the one hand, the field of high pressure, prevailing over the Okhotsk Sea, is responsible for a considerable weakening of the local southern wind transfer (summer monsoon) (Fig. 5A). On the other hand, it is accompanied by more frequent sunny days and, accordingly, increasing radiation warming. As a result, an increase in the sea surface temperature has been observed in different areas of the Okhotsk Sea (Fig. 5B).

One more important feature of a summer monsoon is noted — the gradual change of its end date to a later time (Fig. 6A) which means a delay in the formation of autumn processes in the Okhotsk Sea. As discussed above, the termination date of the northern transfer has shifted to an earlier time (Fig. 3B), *i.e.*, in general, the duration of the warm season in the Okhotsk Sea has become longer, and the cold season has shortened (Fig. 6B).

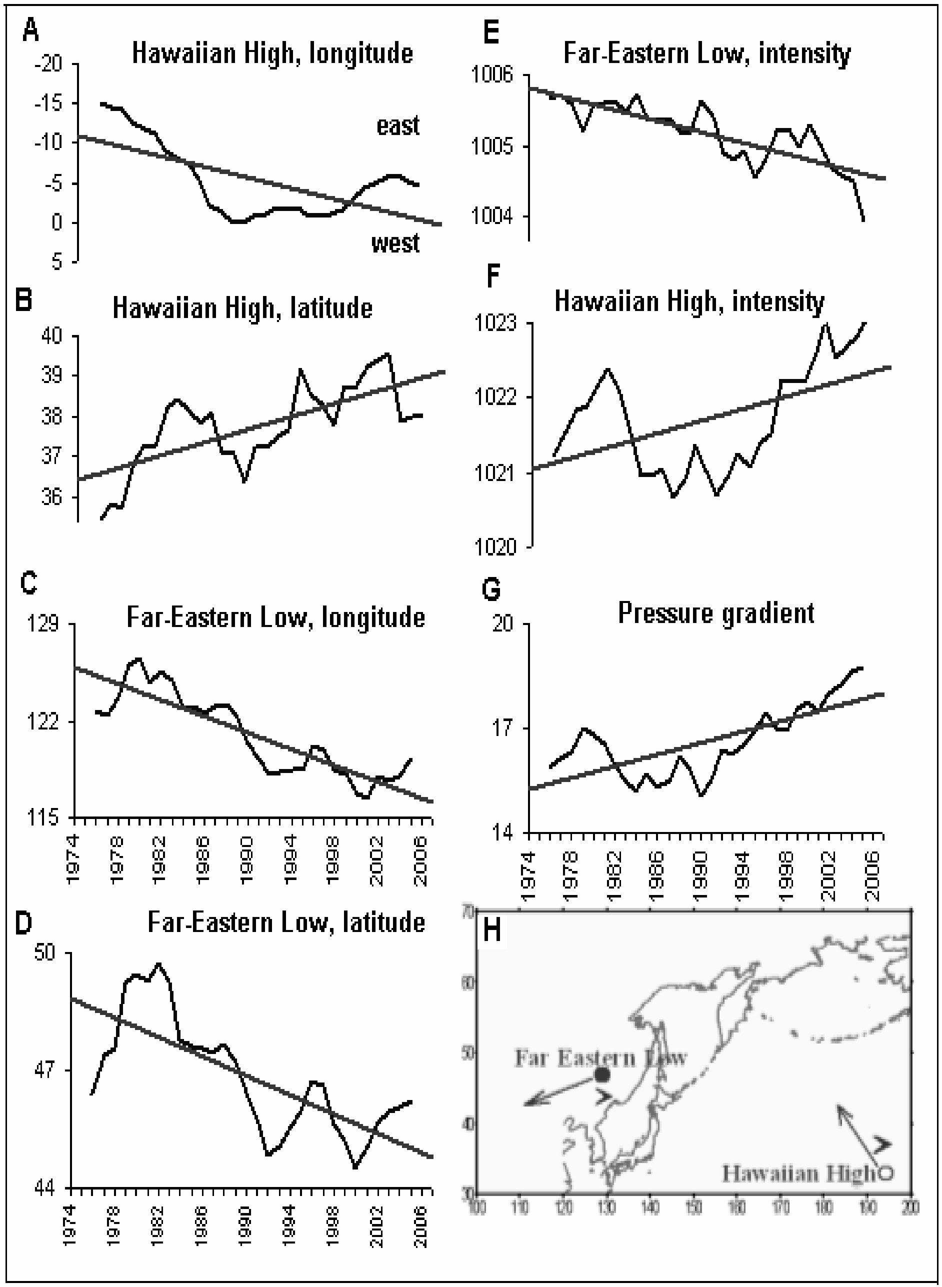

Fig. 4 Long-term changes in parameters of the summer atmosphere action centers (April–September).

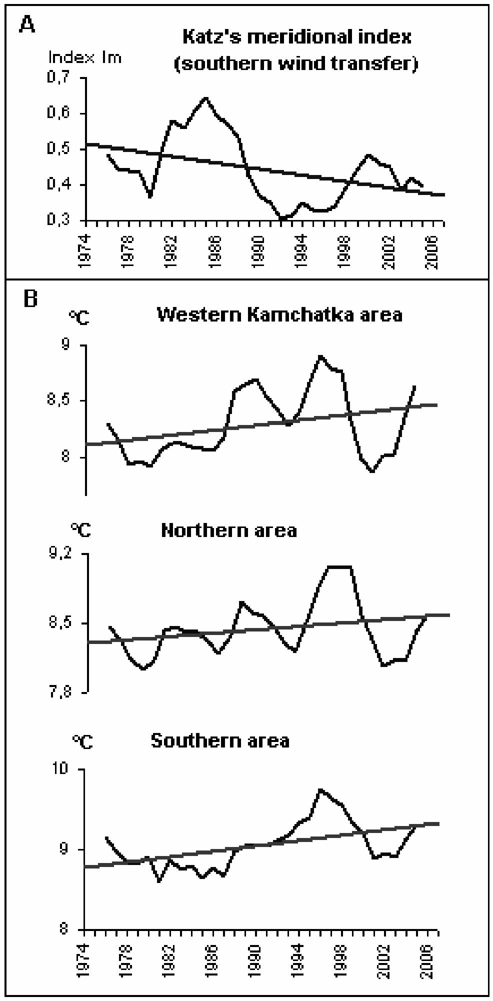

Fig. 5 Variability in intensity of local southern wind transfer (monsoon) and sea surface temperatures in the Okhotsk Sea in summer.

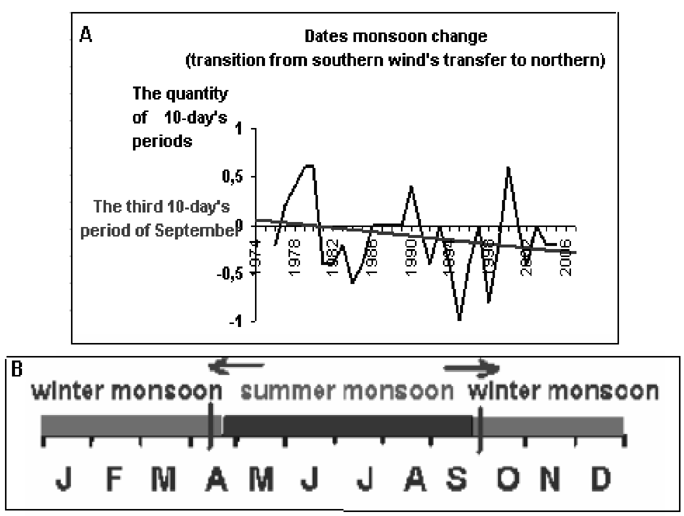

Fig. 6 Dates showing local monsoon changes in (A) autumn and (B) the period of formation of the winter and summer monsoon in the Okhotsk Sea.

Summary

Thus, the most important changes in the atmospheric regime have been during the last three decades in the Okhotsk Sea and adjacent regions.
In winter there has been:

- A relaxation and southwestward shift of the Aleutian Low and Siberian High;
- A weakening of the prevailing northern circulation over the Pacific region;
- A reduction of the "cold" and "moderate-cold" synoptic situations with an intrusion of Arctic air masses and more frequent "warm" and "moderate-warm" atmospheric processes with cyclonic activity, causing warm oceanic air masses to enter the Okhotsk Sea;
- A lessening in the intensity and duration of local winter monsoons;
- A reduction of ice cover and sea surface warming in spring.

In summer there has been:

- An activization of the Far Eastern Low and Hawaiian High, especially in recent years;
- A strengthening of the prevailing southern circulation over the Pacific region;
- A southwestward shift of the Far Eastern Low and a northwestward shift of the Hawaiian High;
- A weakening of the local summer monsoon over the Okhotsk Sea, but with an increased duration;
- An increase in radiation warming in the Okhotsk Sea as the result of the Hawaiian High's influence;
- An increase in sea surface temperature in the Okhotsk Sea in summer.

All the facts discussed above indicate a gradual warming of the Okhotsk Sea climate, which has occurred during last 3 decades on the background of large-scale changes of atmospheric circulation over the whole Pacific region.

References

Glebova, S.Yu. 2004. Influence of the atmospheric processes over the Okhotsk Sea on variability of its ice cover. Proceeding of the 19th International Symposium on Okhotsk Sea and Sea Ice, Mombetsu, Hokkaido, Japan. pp. 169–172.

Katz, A.L. 1954. On studying and estimation of the general circulation of atmosphere. *Meteorol. Hydrol.* **6**: 11–29.