Changes in the Sea of Okhotsk due to global warming

– Weakening pump function to the North Pacific –

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In recent years, the amount of sea ice in the Arctic Ocean has significantly decreased during the summer months, and several models predict that it will eventually disappear in summer altogether. Recent research has revealed that global warming is also affecting the Sea of Okhotsk, which is also an ice-covered sea.

Southern limit of sea ice in the Northern Hemisphere

Sea ice comes ashore every winter along the Sea of Okhotsk coast of Hokkaido, which is the only place where sizable sea ice can be observed at this latitude. The white areas of Fig. 1 indicate the average distribution of sea ice in February. The figure shows that the Sea of Okhotsk is the southern limit of sea ice in the Northern Hemisphere.

Why does the Sea of Okhotsk represent this limit? Figure 1 shows average February air temperatures using colored isograms. We can see that the cold pole (i.e. the coldest place) in the Northern Hemisphere is located in the upwind region of the Sea of Okhotsk. The biggest factor contributing to this sea's status as the southern limit is the extremely cold air from the cold pole that blows over it from autumn to winter.

Sea of Okhotsk produces the densest water in the North Pacific

When sea ice is formed, most of the salt content is rejected from the ice and thus cold and saline water is released into the ocean below. The colder the seawater or the higher its salt content, the denser it becomes. Since large amounts of sea ice are formed in the Sea of Okhotsk, the densest water in the North Pacific (or to be exact, the densest water on the surface of the North Pacific) is produced there. Large-scale vertical circulation (convection) involving the ocean's deep and intermediate layers is driven by density differences: water sinks in the dense water formation area and then gradually upwells in other areas. Although the dense water that can reach the deep layer is not produced in the North Pacific, the dense water that reaches the intermediate layer (approx. 200 to 800 m deep) can be produced by the sea ice formation in the Sea of Okhotsk. Sinking of this dense water creates the vertical circulation (i.e. convection) down to the intermediate depths in the North Pacific scale. The Sea of Okhotsk thus plays a role as the heart pump of the North Pacific. As such, the cold, dense water produced in the Sea of Okhotsk sinks into the intermediate layer, spreading through the Kuril Straits, then into the whole area of the North Pacific's intermediate layer.

Global warming and the Sea of Okhotsk

Over the last three decades since accurate observation by satellite became possible, sea ice extent in the Sea of Okhotsk has decreased by approximately 150,000 km^2, corresponding to about 10% of the entire area of the Sea of Okhotsk (blue line in Fig. 2). It has been also revealed that yearly variability of sea ice extent in the Sea of Okhotsk is highly correlated with that of surface air temperatures in the upwind region of the Okhotsk (red line in Fig. 2). Of particular note is that this temperature has risen by approximately

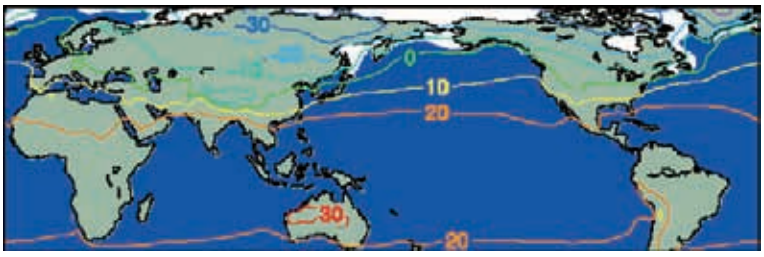

Fig. 1 Climatology of global sea ice distribution (white) and surface air temperatures (isograms) in February.

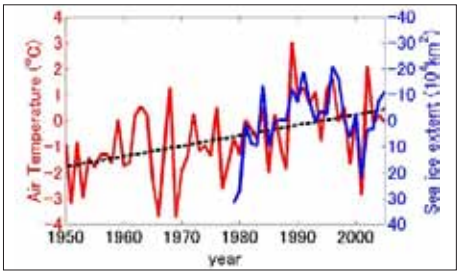

Fig. 2 Time series of sea ice extent anomaly in the Sea of Okhotsk in February (blue line) and surface air temperatures anomaly in the upwind region of the Okhotsk (red line). Note that the scale of the sea ice extent is inverted (the axis on the right). Surface air temperatures are the mean values between October and March.

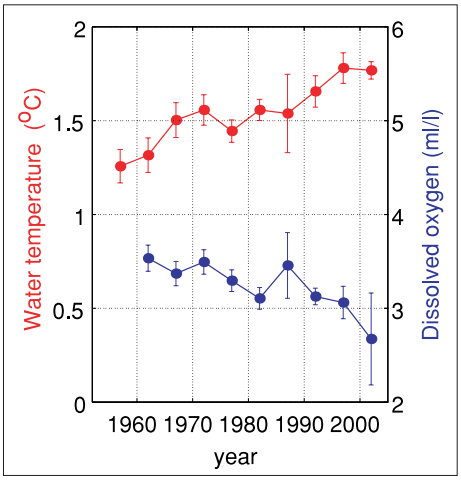

Fig. 3 Time series of temperature (red line) and dissolved oxygen (blue line) of the intermediate water in the Sea of Okhotsk during the past 50 years. Comparison was made at a certain density level, corresponding to approx. 500 m deep.

2.0°C over the past 50 years. This value of 2.0°C far exceeds the rate of average temperature increase worldwide (0.74°C over the past 100 years), thereby clearly indicating that the region is significantly affected by global warming. The correlation between this temperature and the sea ice extent suggests that decreases in the sea ice preceded the beginning of satellite observations.

Sea ice reduction weakens overturning in the North Pacific

If sea ice production decreases, does the level of dense water production also decline? Analysis performed by combining the latest ocean data obtained by Hokkaido University and other institutions with past data pointed to significant changes: the water temperature in the intermediate layer of the Sea of Okhotsk has increased over the past five decades, while the dissolved oxygen concentration has decreased (Fig. 3). This means that the sinking of cold oxygen-rich surface water into the intermediate layer has decreased. That is to say, the decrease of sea ice production causes the decrease in cold, dense water production.

Recent research has also revealed that since the sinking of cold, dense water generated in the Sea of Okhotsk causes the overturning down to the mid-depth of the North Pacific, the influence of changes in the Sea of Okhotsk reaches as far as circulation in the North Pacific. Figure 4 indicates trends in water temperature in the intermediate layer of the North Pacific, including the Sea of Okhotsk, over the past 50 years. The warming trend is the most prominent in the Sea of Okhotsk, and the area of warming signal has spread to the North Pacific along the pathway of the seawater flowing out of the Sea of Okhotsk (green line in Fig. 4). This suggests that the reduction in the amount of water sinking in the Sea of Okhotsk weakens the overturning in the North Pacific.

Further scenarios

In a nutshell, the Sea of Okhotsk is highly sensitive to global warming: over the past 50 years, the level of sea ice production has decreased and the amount of dense water sinking has thus declined, thereby weakening the overturning in the North Pacific. To put it simply, recent global warming has weakened the Sea of Okhotsk's workings as a pump.

The weakened overturning has various implications. Of particular note is iron circulation, which is considered an important factor in determining biological productivity according to recent research. It has been recently revealed that when dense water sinks to the intermediate layer in the Sea of Okhotsk, iron is also brought to this layer. One hypothesis says that this iron is also supplied to the western area of the North Pacific and supports high biological productivity there. If that is the case, it is also possible to suggest that if global warming weakens sea ice production in the Sea of Okhotsk, iron supplies will decrease in the North Pacific as well as in the Sea of Okhotsk, thus reducing levels of biological productivity and fishery resources. Hokkaido University has begun interdisciplinary research programs transcending the fields of physics, chemistry, biology and fisheries with the aim of verifying these hypotheses and scenarios.

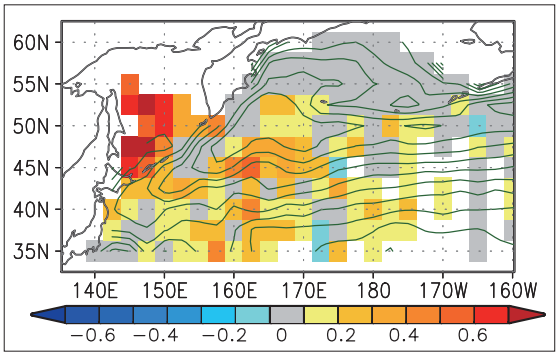

Fig. 4 Trends in temperature of the intermediate water in the North Pacific and the Sea of Okhotsk over the past 50 years. The trends were calculated at a certain density level, corresponding to approx. 300 - 500 m deep.