NOTES AND CORRESPONDENCE

The Abrupt Decrease of the Sea Ice over the Southern Part of the Sea of Okhotsk in 1989 and Its Relation to the Recent Weakening of the Aleutian Low

By **Yoshihiro Tachibana**

Research Institute of Civilization, Tokai University, Hiratsuka, 259-12, Japan

Meiji Honda and Kensuke Takeuchi

Institute of Low Temperature Science, Hokkaido University, Sapporo 060, Japan

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Abstract

We investigated the interannual variation of the sea ice over the Sea of Okhotsk by using radar observation data and gridded ice-coverage data for the years 1969–1994. It became evident that the abrupt decrease of sea ice over the southern part of the Sea of Okhotsk occurred in 1989, and that this reduced-ice condition has continued since then. In addition, the winter time Aleutian low has abruptly weakened since 1989. According to the lag-correlation analysis, this weakening has brought about the reduction in extent of the ice-coverage.

1. Introduction

Although many fishermen have reported a decrease in the amount of sea ice around the Okhotsk coast of Hokkaido, nobody has investigated statistically whether the fishermen's claims are correct. Based on sea ice data sets derived from satellite images and radar observations, the authors of this paper have confirmed the fishermen's belief that the extent of the sea ice has indeed decreased. In particular, there has been a reduction in sea ice since 1989. A likely cause for this is a change in ocean conditions in the Sea of Okhotsk, and another possible cause is a change in atmospheric conditions around the Sea of Okhotsk. At this point only the latter possibility has been investigated. Although the causes of the retreat of the ice have not been completely clarified, it is clear to the authors that an abrupt change over the Pacific started at the end of the 1980's and this led to an abrupt retreat of the sea ice. The purpose of this study is to report on: 1), The abrupt decrease in sea ice at the end of the 1980's, 2), The change in global atmospheric circulation at the end of the 1980's and 3), The relationships between the ice reduction and the global atmospheric change. The effects of ocean conditions, the change of meso-scale atmospheric conditions and interactions amongst them are beyond the scope of this short report and will be addressed in future work.

Kashiwabara (1988) pointed out that the intensity of the wintertime Aleutian low has increased since 1977. Nitta and Yamada (1989), Trenberth (1990) and Trenberth and Hurrell (1994) analyzed that this change over the North Pacific is a result of the interdecadal variation of the equatorial Pacific Ocean. Nitta and Yamada (1989) also pointed out that the El Niño phenomena have occurred more often since the middle of the 1970s than during former years, and that the El Niño affects the mid-latitude atmospheric circulations. Figure 6 in Trenberth and Hurrell (1994) showed that the intensified phase of the Aleutian low stopped at the end of the 1980s. The period of their analysis, however, ends in 1992. We prolong the period of the analysis toward 1994 and confirm that the intensified phase stopped at the end of the 1980s, and its weakening dates from

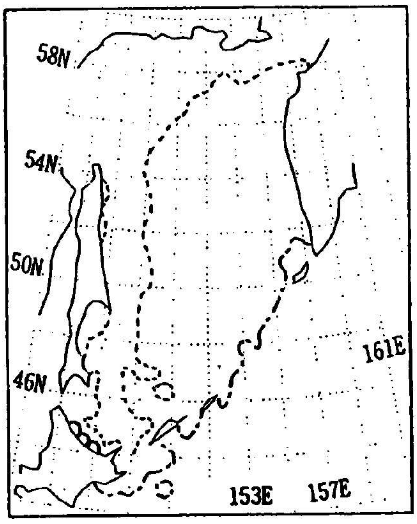

Fig. 1. A map showing the study area. The broken and dash-dot lines respectively show the minimum and maximum ice edges in the middle of March (Kano *et al.*, 1989). The small circles along the Okhotsk coast of Hokkaido indicate the radar ranges.

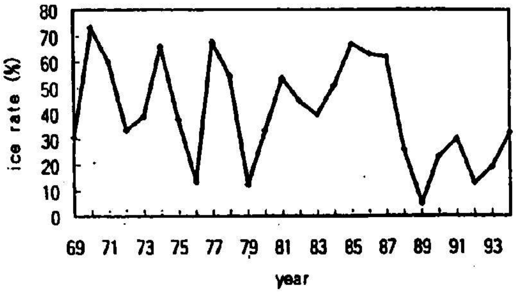

Fig. 2. Interannual variation of the ice concentration as tracked by ice radar and averaged between the beginning of January and the end of February.

then. This change in global atmospheric circulation has, as a result, brought about a reduction in the extent of the ice coverage in the Sea of Okhotsk.

The data used in this study are as follows: 1) Sea ice concentration data around the Okhotsk coast of Hokkaido, as observed by Hokkaido University's Institute of Low Temperature Science's sea ice radar, 2) Ice extent data based on the GMS satellite images provided by JMA (Japan Meteorological Agency), and 3) the objective analysis from National Center for Environmental Prediction (NCEP, previously known as NMC).

2. Abrupt reduction of the sea ice

The Institute of Low Temperature Science of Hokkaido University has maintained an ice-floe monitoring radar network on the coast of Hokkaido, facing the Sea of Okhotsk, since 1969 (Fig. 1). This network consists of three land-based radar stations which allow continuous monitoring of the sea ice field along a 250 km coastline and to 50 km seaward (Aota and Ishikawa 1993). The network enables daily ice concentrations within the radar area to be calculated from the beginning of January to the end of May. The definition of the ice concentration is the extent of the ice area measured within radar range. The ice concentration therefore indicates the ice condition in the narrow area near Hokkaido Island. The normal ice concentration within the radar area increases toward the end of February, and reduction starts at the beginning of March (Aota and Ishikawa 1993). Because our interest is in the variation of the growing and matured stages of the ice, the analysis period is restricted to between the beginning of January and the end of February. Figure 2 shows the interannual variation of the ice concentration averaged between the beginning of January and the end of February for the years 1969–1994. For example, 100 would mean that the whole area is covered by ice every day throughout the period. The figure clearly shows an abrupt reduction in sea ice occurred in 1988, and that this reduced-ice condition has continued since then.

Kano *et al.* (1989) compiled gridded ice data over the Sea of Okhotsk every five days from 1971 onwards, based on ESSA, NOAA and GMS images. The longitudinal and meridional resolutions are the same: 0.25 degrees. Information regarding the presence or not of ice in each block is available for all periods. The normal ice extent in the southern part of the Sea of Okhotsk increases toward the middle of February, after that the large ice extent maintains for about one month, and the retreat of the sea ice starts in the middle of March (Kano *et al.*, 1989). To exclude the melting stage from the analysis, the period is restricted toward the middle of March. By using these data, we calculated the average extent of ice between the beginning of December and March 14 in the southern part of the Sea of Okhotsk as well as the extent of ice in all the Sea of Okhotsk. The southern part is here defined as the area below 50 degrees north within the Sea of Okhotsk (See Fig. 1) . The bold line in Fig. 3 represents the interannual variation of sea ice in the southern part. This line clearly shows that an abrupt reduction in sea ice occurred in 1989. The ice area in 1989 drops to the half of that in 1988. In 1991, moreover, the ice area drops extremely. Apart from Fig. 2, Fig. 3 shows that an increase in sea ice occurred around 1977, a year of climatic change around the Pacific (Kashiwabara 1988; Nitta and Yamada 1989; Trenberth 1990). Another point of the difference is the year the abrupt decrease started, *i.e.*, 1988 in the radar area and 1989 in the southern part of the sea. This

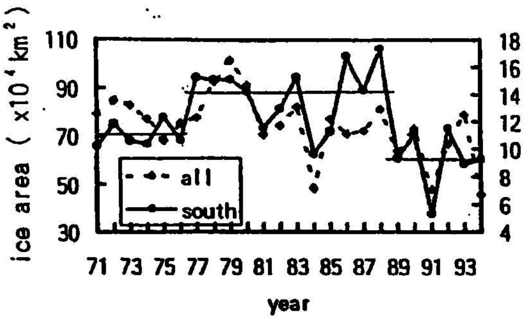

Fig. 3. Interannual variations of the extent of ice-coverage averaged between the beginning of December and March 14 over the southern part of the Sea of Okhotsk (bold line) and over all the Sea of Okhotsk (broken line). The definition of the southern part is the area below 50 degrees north within the Sea of Okhotsk. The left vertical axis indicates the broken line and the right one indicates the bold line. Means for 1973–1976, 1977–1988 and 1989–1994 of the bold line are drawn. The differences between the means of the neighboring periods exceed the 95 percent confident level.

divergence suggests that the cause of the variation of the ice near the coast of Hokkaido was somewhat different from that around the southern part of the Sea of Okhotsk. Very localized phenomena, *e.g.*, the variation of the Soya Current, may affect small-scale variation of sea ice. Another reason for this difference may be the accuracy of the ice data. In particular, data in earlier years are less accurate due to the absence of GMS satellite images at that time. As a rough estimate, however, agreement of an abrupt ice reduction at the end of the 1980s, established by radar observation over a narrow area, and an abrupt reduction over the wider area, as recorded by satellite images, convinces us that the ice reduction really occurred and that these reduced levels of the late 1980s continue. By contrast, the decrease as shown in the southern part did not occur over all the Sea of Okhotsk (the broken line in Fig. 3). Although, in some years, the variation pattern looks the same as in southern part, the values for the 1980s are quite different.

3. An abrupt change in atmospheric circulation

The abrupt reduction of sea ice suggests that environmental conditions determining the ice areas changed sharply at the end of the 1980s. To examine which environmental conditions changed, we compared the mean atmospheric fields after 1989 with those before that date, using the NCEP objective analysis. Figure 4 shows the differences in mean atmospheric fields in January and February between 1989 and 1994 compared to those between 1977 and 1988. Because the common dates analyzed in Fig. 2 and Fig. 3 cover the period from January to February, we investigated the atmospheric field in January and February. Because many studies have pointed out that decadal climatic change occurred in the middle of the 1970s (*e.g.*, Nitta and Yamada, 1989 and Trenberth, 1990), we did not include the data before 1977 in this analysis. Figures 4a, 4b, 4c and 4d show respectively the differences in sea level pressure, 500 hPa geopotential height, 200 hPa geopotential height, and 500 hPa temperature. The sea level pressure in the Pacific Ocean increased and the 500 hPa height level rose there. This change may reflect that the Aleutian low has weakened recently. Although many reports have pointed out that the recent intensification of the Aleutian low started in the middle of the 1970s (*e.g.*, Kashiwabara, 1988 and Nitta and Yamada 1989), our result, by contrast, suggests that the climatic pattern of the Aleutian low changed at the end of the 1980s when it weakened. This result corresponds with that of Trenberth and Hurrell (1994). Due to the weakening of Aleutian low, shown by our results to have been in existence for only six years, it is still too early to consider this weakening as a decadal or interdecadal climatic change. On the other hand, over the Siberian continent, the sea level pressure dropped. These results mean that the wintertime monsoon blowing from the Siberia to the Pacific has weakened.

The temperature at the 500 hPa field around the eastern part of the Pacific also rose. This change also can be understood as a reflection of the weakening of the Aleutian low. In particular, one center where there was a rise in the temperature over Japan. This warming around Japan ought to prevent the formation of sea ice over the Sea of Okhotsk, because, in particular, the southern part of the Sea of Okhotsk is the southernmost sea where sea ice forms, and we can expect sea ice formation to be very sensitive to changes in atmospheric conditions. In addition to the effect of the warming around Japan, the southward component of the surface wind may weaken because of the weakening of the Aleutian low. The weak southward wind stress brings about the decrease in the amount of the ice movement from the northern part of the Sea of Okhotsk to the southern part.

On the other hand, looking at the north Atlantic ocean, the Icelandic low has intensified, and this change has occurred consistently from the surface toward the upper troposphere. Moreover, the change in the 200 hPa height tells us that the polar vortex has intensified during the latter period. This intensification is in agreement with the results of the recent intensification of the vorticity in the Arctic (Tanaka *et al.*, 1995 and Walish *et al.*, 1996).

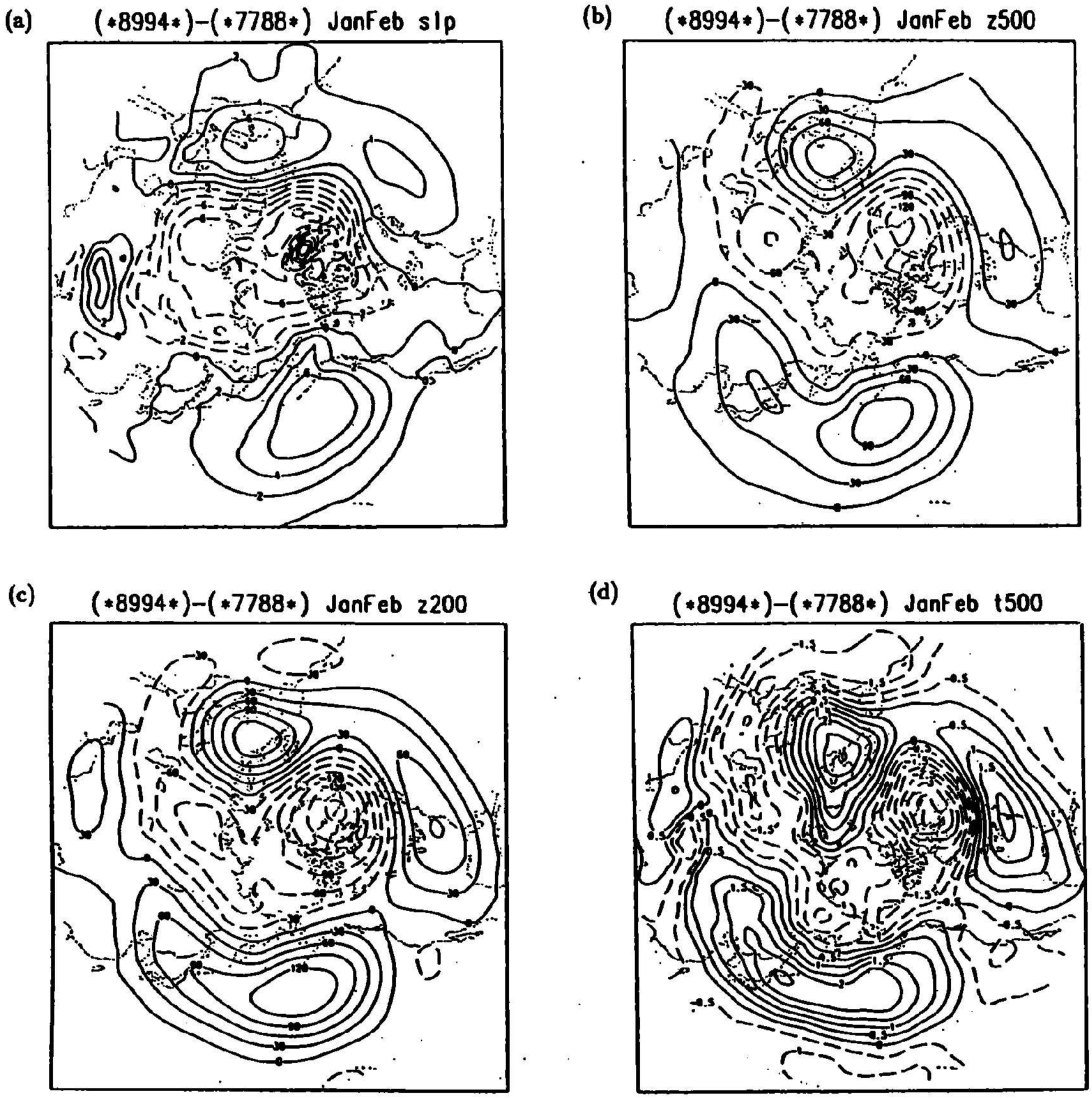

Fig. 4. Changes in mean atmospheric fields in January and February between earlier and more recent years. Earlier years are defined as being between 1977 and 1988; recent years are between 1989 and 1994, (a) is sea level pressure, (b) is 500 hPa geopotential height, (c) is 200 hPa geopotential height, and (d) is 500 hPa temperature. The units for the pressure, geopotential and temperature are, respectively, hPa, m and °C.

This figure also suggests that the climatic change occurred not only around the Pacific region but also all around the northern hemisphere. Figure 5 shows the interannual variations of the 200 hPa height over the Bering Ocean and over Greenland. The values plotted in this figure are area-averaged values in the block between 160E and 170W and between 50N and 60N. Over Greenland, the values are averaged between 20W and 60W and between 60N and 80N. Time sequences of geopotentials clearly indicate that the abrupt climatic change occurred at the end of the 1980s.

To clarify the relationship between the ice and atmosphere, we calculated the correlation coefficients between them. Because the ice and the atmosphere interact with each other, the simultaneous correlation may contain both the cause and the effect. To show only the effect of the atmosphere on the ice, we therefore, calculated the lag correlation. Figure 6 shows that the correlation coefficients between the monthly mean sea level pressure in February and the monthly mean ice area in southern part of the Sea of Okhotsk in March. This correlation map shows that when the sea level pressure over the Pacific is high, the ice area becomes narrow. Correlation coefficients over the Sea of Okhotsk, on the other hand, are smaller than those over the Pacific. Therefore, the variation in the pressure field over the Pacific, including the area where the Aleutian low often develops, is closely related to the ice extent over the

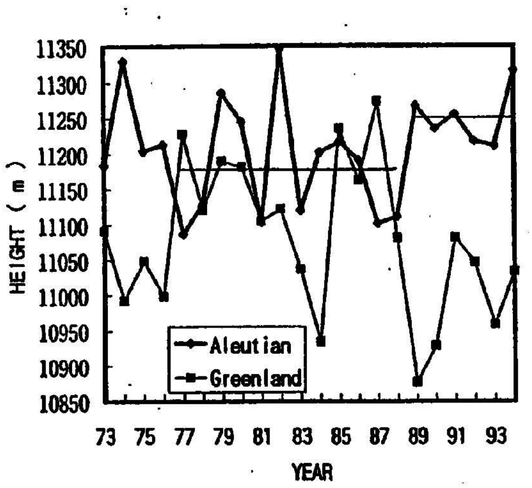

Fig. 5. Interannual variation of mean geopotential height in January and February in the Aleutian area and Greenland area. The Aleutian area is the block bounded by 50N and 60N and longitude 160E and 170W. The Greenland area is the block bounded by latitude 60N and 80N and longitude 20W and 60W. Means for 1977–1988 and 1989–1994 in the Aleutian area are drawn. The difference between the means exceeds the 95 percent confident level.

Fig. 6. Correlation coefficients between the monthly mean sea level pressure in February and the mean ice extent in the southern part of the Sea of Okhotsk in March for 1971 to 1994. The hatched areas are where correlation coefficients exceed the 95 percent confident level, and the dense hatching indicates that correlation coefficients exceed the 99 percent confident level.

Sea of Okhotsk. This relationship between Aleutian low and the sea ice agrees well with the previous studies (Parkinson 1990).

4. Concluding remarks

We found that the abrupt decrease of sea ice over the southern part of the Sea of Okhotsk occurred at the end of the 1980s owing to an abrupt change in global atmospheric circulation. In particular, the weakening of the Aleutian low is a prime cause of the reduction of the ice, as well as the weakening of the Siberian high and the rise of the temperature around Japan. Therefore, this ice reduction can be regarded not as a response to local environments but as a response to a global atmospheric change. Although this study regards sea ice as a passive indicator of climatic change, sea ice can drive the climate actively. We should therefore study the impact of the anomalous spread of sea ice over the Sea of Okhotsk on the hemispheric scale atmosphere.

Acknowledgments

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