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INTERANNUAL VARIABILITY OF SEA ICE CONDITIONS IN SYOWA STATION SECTOR DEDUCED FROM DMSP SSM/I DATA

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Abstract: This paper focuses on the interannual variability of sea-ice conditions in spring and summer in the vicinity of Syowa Station. Sea ice extent and concentration are discussed using DMSP SSM/I satellite passive microwave data. Persistent high ice concentration was observed in December in 1989 and 1993. In those years, sea ice was formed earlier in the autumn (April–May) and expanded rapidly in this initial stage. The sea ice concentrations were higher throughout the winter season in these years. Cold and calm weather conditions in autumn seem to be important in determining the following winter ice condition.

1. Introduction

Sea ice extent in the Antarctic has been monitored by satellite observations, and the fluctuations and related atmospheric conditions have been investigated by several researchers (*e.g.*, PARKINSON and CAVALIERI, 1982). Most works uses the area of sea ice extent or ice concentration as an indicator of sea ice variability. However, there are many components to describe sea ice characteristics, not only areal extent or ice concentration but duration of ice cover and ice thickness. Microwave data are useful since they are available in all weather, daily with global coverage. These data have been archived for more than 20 years (GLOERSON *et al.*, 1992; ZWALLY *et al.*, 1983; PARKINSON *et al.*, 1987). The ice concentration data have been improved by several researchers (STEFFEN *et al.*, 1992). However, ice thickness is still difficult to estimate. Only a few experiments have been done to estimate ice thickness (CAVALIERI, 1994; STEFFEN, 1991; WENSNAHAN *et al.*, 1993; ENOMOTO, 1996).

KUSUNOKI (1981) showed interannual fluctuations of ice edge position in the Syowa Station sector and compared them with the records of icebreaker operations. He found that icebreaker movement is easier when the annual temperature is high. Expanded ice edge positions have not always correlated with difficulty of icebreaker movement, but thick or converging ice can be a problem. Therefore, information on ice thickness is required to study sea ice variability.

This study investigates the ice concentration in the inner pack ice zone and discusses on observations of ice conditions such as thick or packed ice distribution and ice convergence.

2. Data

This study uses passive microwave data of the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager (SSM/I). Daily data since December of 1987 were available. These data are distributed by the National Snow and Ice Data Center (NSIDC) at the University of Colorado. There are some algorithms to estimate sea ice concentrations but there are no algorithms to estimate ice thickness globally. This study uses the sea ice concentration data from NSIDC and also uses the microwave brightness temperature to discuss ice conditions related to ice thickness. These microwave data have spatial resolution of 25×25 km, thus it is very difficult to observe the Otone Lead. Accordingly, visible images with 50 m spatial resolution obtained by the Japanese Marine Observation Satellite (MOS)-1 were used to observe the opening of Otone Lead in 1993. Flight observations of sea ice were performed using an infrared thermometer and a video camera in 1993 by the 34th Japanese Antarctic Research Expedition (JARE-34) over sea ice around Syowa Station. These data were used to study fluctuations of Otone Lead. Meteorological data at Syowa Station were provided by the Japanese Meteorological Agency.

3. Ice Concentration in Spring

Distributions of sea ice in the Antarctic show three sectors with high concentration and longer duration of sea ice cover (Fig. 1). They are the Syowa Station sector, Weddell Sea and Amundsen Sea. This study focuses on one of those regions, the Syowa Station (39°E) sector, where highly concentrated or thick pack-ice can be observed even in summer.

Figure 2 shows the distributions of brightness temperature in the beginning and middle of December for each year. Areas of high brightness temperature appeared in 1989 and 1993. Such core region of high brightness temperature implies a concentrated sea ice area (ZWALLY *et al.*, 1983). Figure 1 shows the case in 1989. Sea ice concentra-

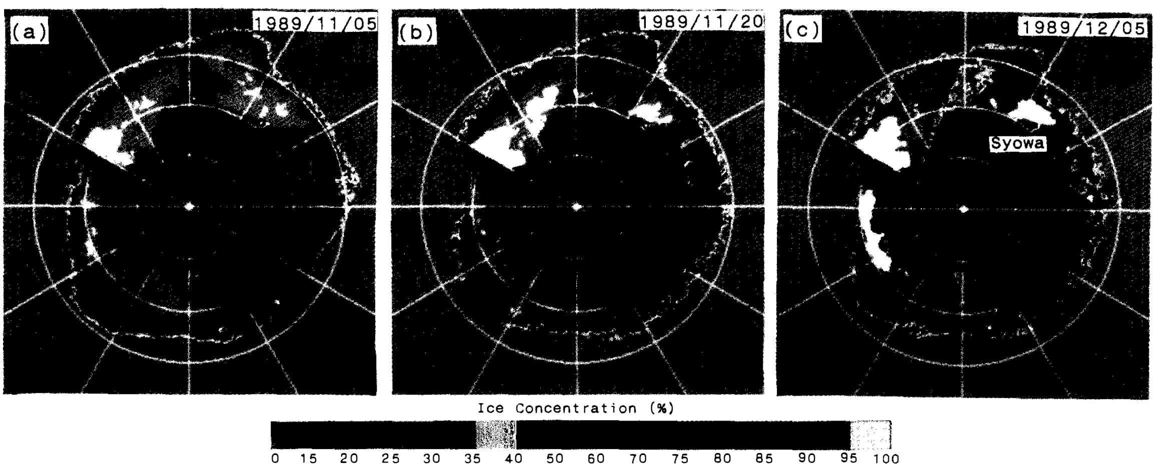

Fig. 1. Sea-ice distribution in the Antarctic. A bright area indicates a sea-ice area with high concentration. (a) 1989/11/05, (b) 11/20, (c) 12/05.

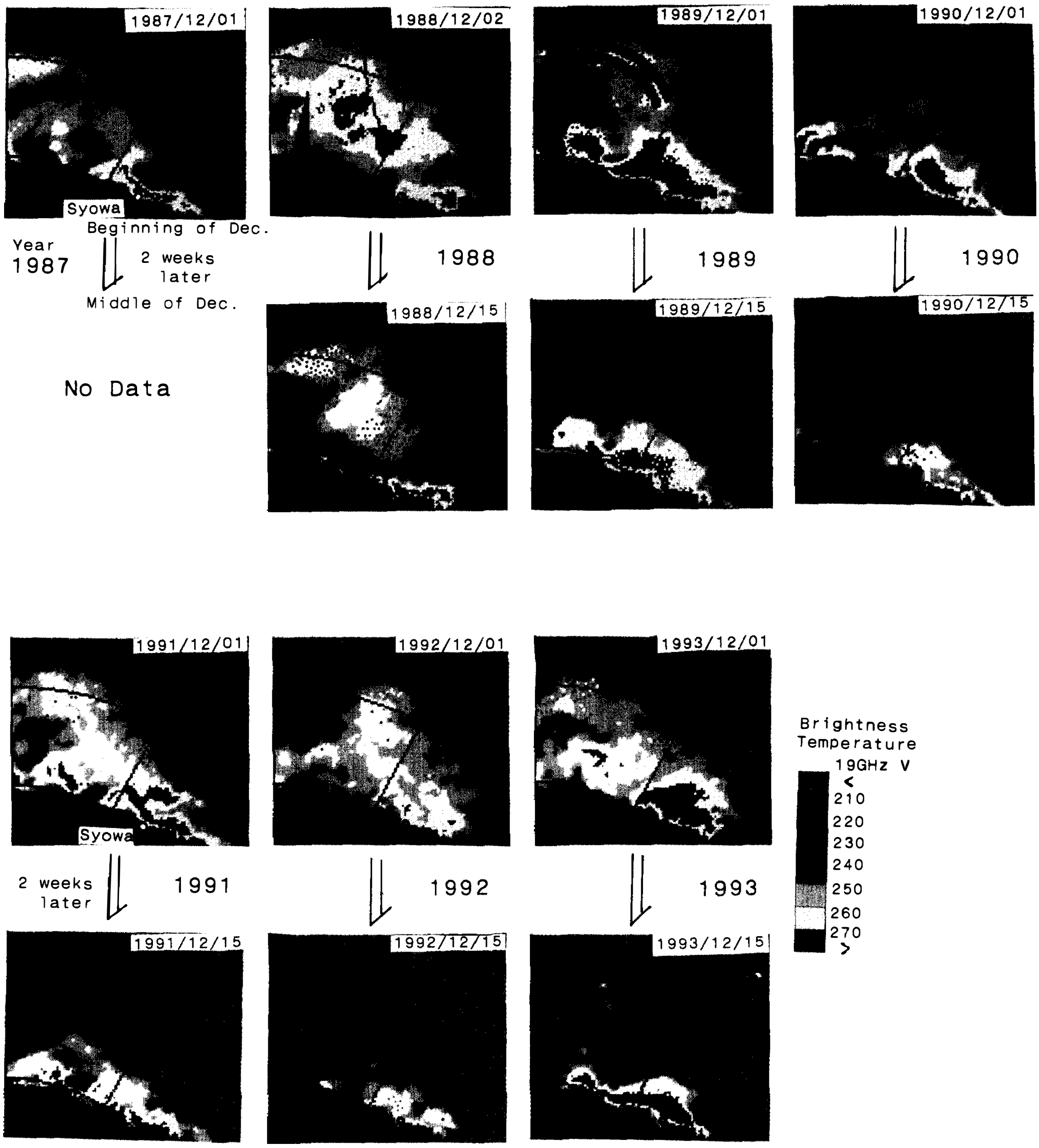

Fig. 2. Microwave brightness temperature TB (SSM/I 19 GHz V) in the vicinity of Syowa Station (69°S, 39°E). Comparisons of distributions from 1987 to 1993. Core region with high TB in sea-ice area are marked.

tion in the inner pack-ice zone increased from spring to summer in 1989. In the outer pack-ice zone, on the other hand, sea ice concentration decreased from spring to summer (Figs. 1b and 1c), thus strong contrast of concentrations was appeared between inner and outer pack-ice zones. Although microwave brightness temperature decreases due to sparse ice distribution in spring and summer, brightness temperature increased in the inner zone in such cases.

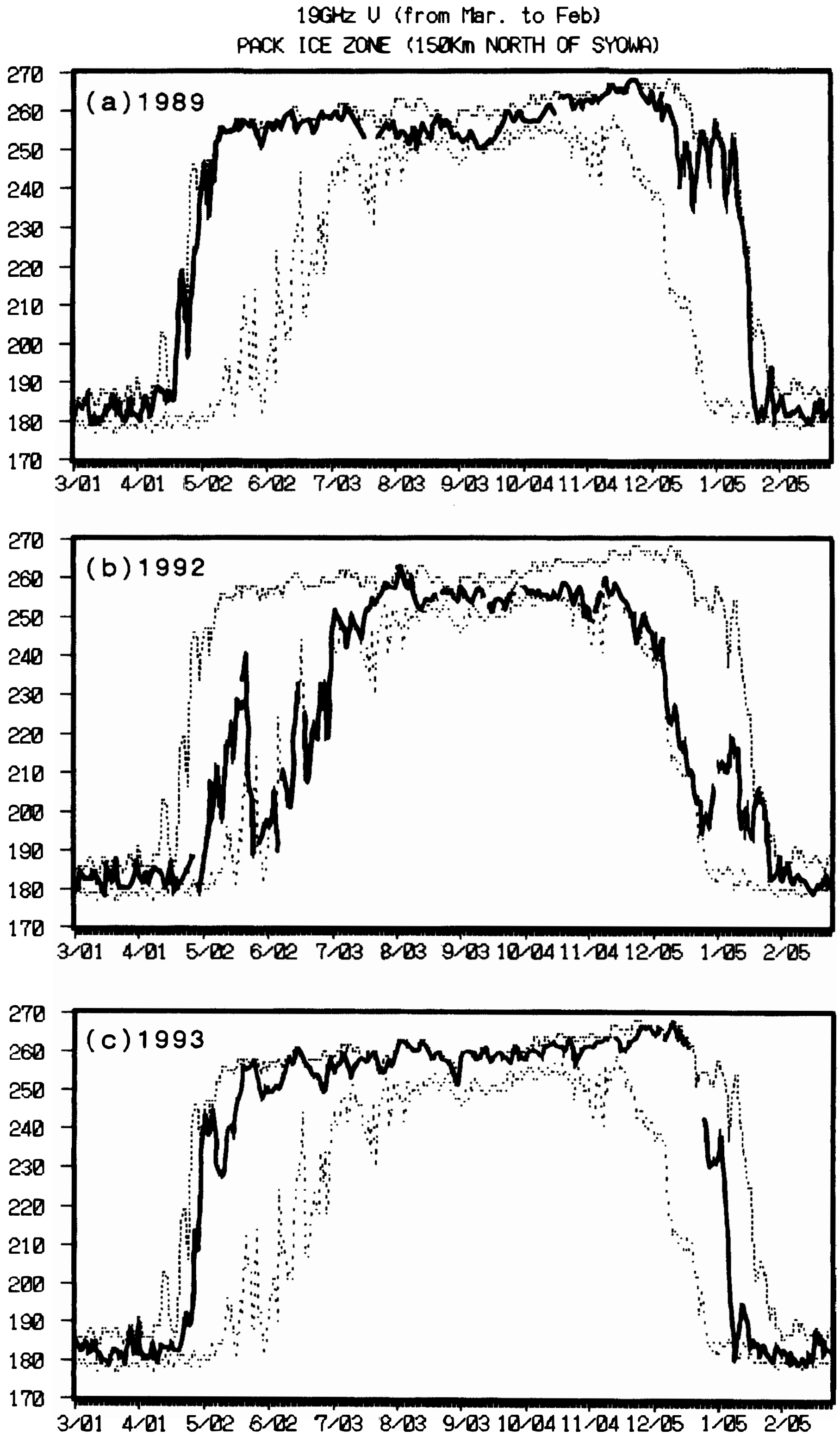

Fig. 3. Annual changes of brightness temperature (SSM/I 19 GHz V) for the pack ice zone 150 km north of Syowa Station. Solid line indicates the data for (a) 1989, (b) 1992 and (c) 1993. Dashed lines indicate maximum and minimum value between 1988 and 1993.

4. Initial Stage of Sea-Ice Growth

The area with high brightness temperature became significant, north of Syowa Station, in December 1989 and 1993 as shown in Fig. 2. In these cases, higher brightness temperature were already appeared in the preceding autumn (May). Figure 3 shows the time series of brightness temperature of 19 GHz observed at a fixed point in a pack ice zone 150 km north of Syowa Station. This point is almost the center of the high brightness temperature as observed in Fig. 2. Growth of sea ice began earlier in autumn in 1989 and 1993 and remained high during the winter.

Severe ice conditions such as ridging, recurring convergence/divergence of pack-ice and heavy snow cover were observed in December 1993 when the icebreaker SHIRASE with the JARE-35 approached Syowa Station. The largest value of brightness temperature in all of Antarctica was observed near Syowa Station in this period. Such high brightness temperature was observed also throughout the year in 1993. However, the areal extent of ice was not large in 1993. The opposite condition occurred in 1992. That is, widespread but sparse ice condition occurred in December 1992. The signs of these seasonal changes appeared in the microwave brightness temperature in May (Fig. 3). This implies that sea-ice was formed earlier in 1989 and 1993, and the ice cover was stable with high concentration in winter in such cases. The annual ice conditions could already be determined in autumn. This characteristic is significant not for ice concentration but ice growth and ice persistence in the inner pack ice zone.

5. Discussion

5.1. Meteorological conditions

Seasonal changes in air temperature and wind speed at Syowa Station are shown in Figs. 4a and 4b, respectively. The dotted areas indicate the ranges of air temperature and wind speed observed since 1987. The data of 1989, 1992 and 1993 are shown in these figures. It can be seen that wind was weak in 1989 and 1993, and temperature was relatively low in the first half of 1989 and 1993 (Fig. 4). Large differences can be seen in May. It was windy and warm in 1992. This can be seen before May, however it became significant in May.

5.2. Estimation of ice thickness

The cumulative daily mean temperature, in degree days, was calculated when the daily mean temperature was below 0°C.

$$I = A\sqrt{\Sigma T},$$

I is ice thickness (cm), T is air temperature (°C) and A is a constant. NARUSE *et al.* (1971) obtained the value of A between 2.0–2.4 near Syowa Station. This study uses 2.4 as A. The estimated ice thickness well indicates the interannual differences of sea ice growth (Fig. 5). The interannual differences of ice growth rate became apparent in autumn. A cold autumn seems to be an early indicator of large growth of sea ice in the corresponding year.

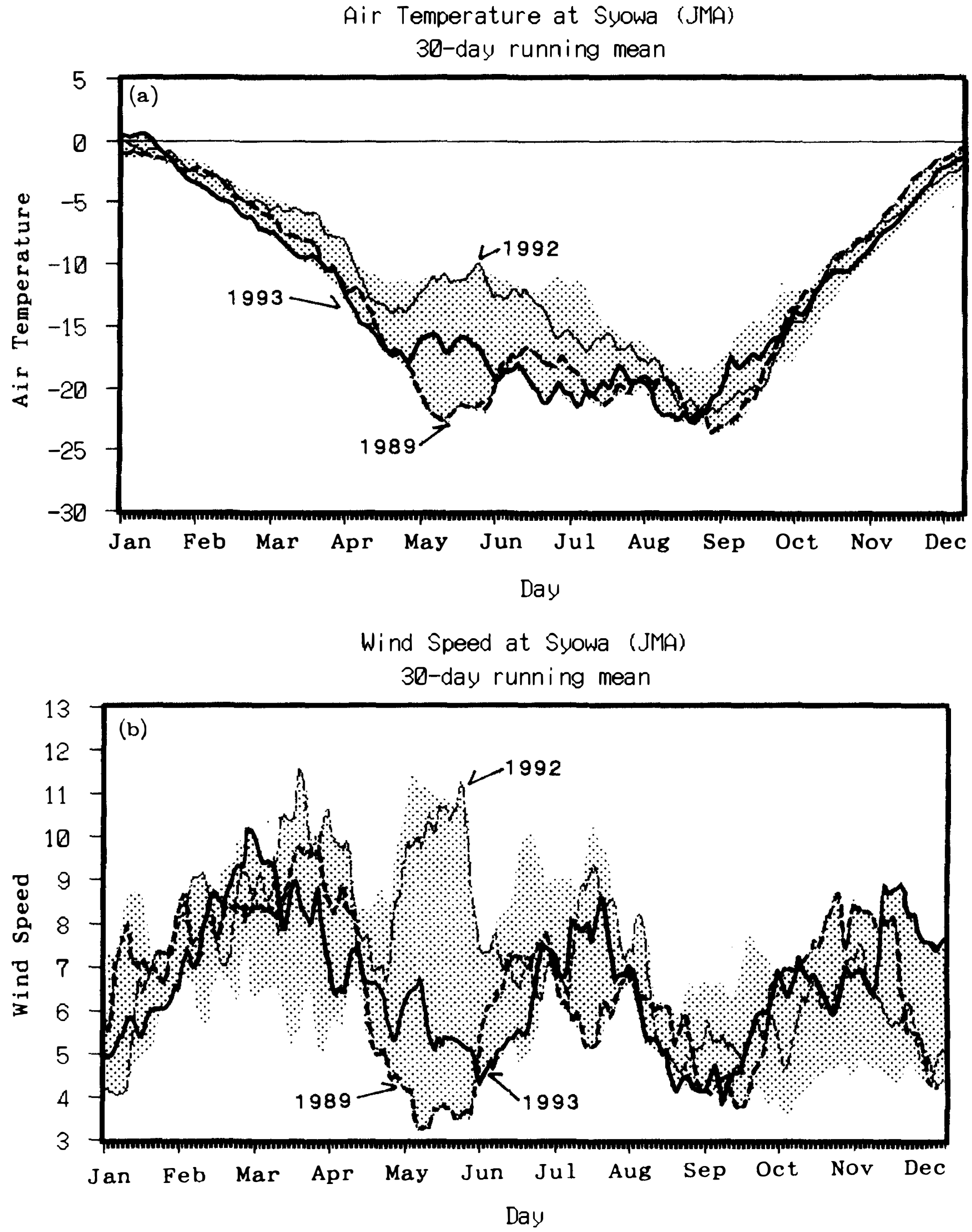

Fig. 4. (a) Air temperature and (b) wind speed at Syowa Station (30-days running mean). Dashed line, thin solid line and heavy solid line indicate the data for 1989, 1992 and 1993, respectively. The range of observed values from 1988 to 1993 is hatched.

Although this calculation well estimates the growth of the first year ice, there are limits for its application as the surface is assumed to be snow free. The range of interannual variations of ice thickness was calculated as small as 10 cm (Fig. 5) although the value of A was chosen to be the largest (2.4) obtained in NARUSE *et al* (1971). However, there are larger variations as reported by KAWAMURA *et al.* (1993).

On December 30, 1993, continuous snow cover was observed from an airplane near the Otone Lead, and thick snow cover was observed from SHIRASE near the edge of fast ice. Therefore, evaluation of snow cover is required to estimate ice thickness and to

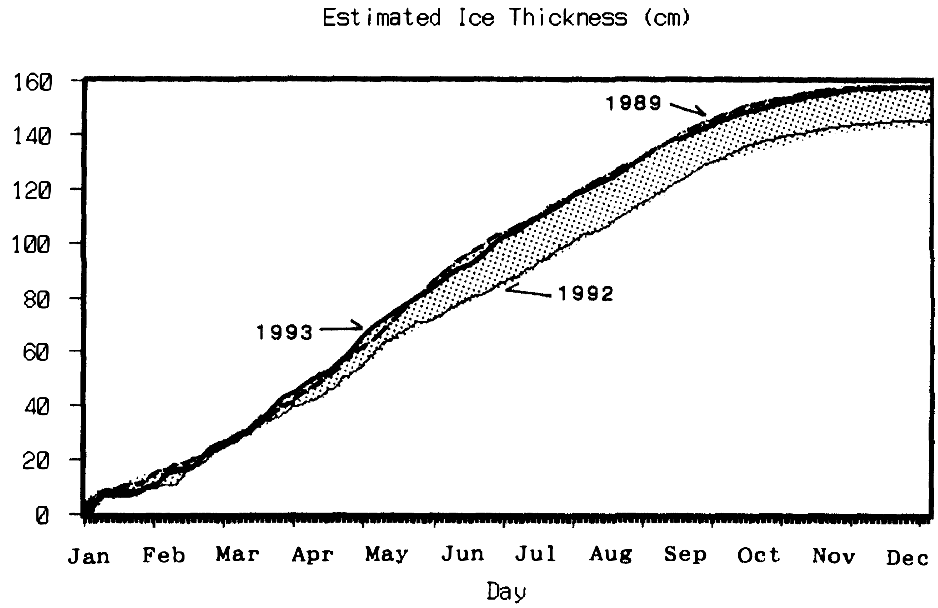

Fig. 5. Sea ice thickness (I) estimated from degree days. $I(cm) = A\sqrt{\Sigma T}$, $A=2.4$, T: daily mean temperature (°C) Dashed line, thin solid line and heavy solid line indicate the data for 1989, 1992 and 1993, respectively. The range of estimates from 1988 to 1993 is hatched.

interpret changes in the brightness temperature.

5.3. Autumn conditions

Seasonal marches of sea ice growth and decay seem to be influenced greatly by atmospheric or oceanic conditions in autumn before May. The circumpolar trough begins to shift northward in May, and it produces changes in the wind field (ENOMOTO and OHMURA, 1990; OSHIYAMA *et al*, 1993) and also the current (OHSHIMA *et al*, 1993). These atmospheric and oceanic changes are remarkable; however, relationships between these phenomena and air temperature are not known. The autumn seems to be, at least, a key season for sea ice growth and extent. Accordingly, air temperature seems to have a persistence tendency in a seasonal scale. In order to understand formation processes of sea ice, the long term tendency of the atmosphere should be investigated. In addition stable ice cover in autumn may affect the air temperature to cool in the following months. However, this is considered to occur on a regional scale.

6. Concluding Remarks

Interannual variability of sea ice was investigated using the DMSP SSM/I data. Weather conditions in autumn seems to affect the sea ice conditions in the following winter. Cold and calm weather may contribute to large growth of sea ice. In such cases, a core region with high microwave brightness temperature was formed in the inner pack ice zone. This high brightness area seems to indicate not only high ice concentration but also thick ice conditions such as rafting, ridging or heavy snow cover.

The ice thickness estimation using degree-days corresponds well to the interannual variability of ice conditions estimated by the changes in microwave brightness temperature. However, estimations of thickness in the snow covered ice were difficult. Bare ice and snow cover will have to distinguished in future research.

Acknowledgments

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