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Observations of water temperature and salinity in Ongul Strait, Antarctica, in 1998 and investigations of their intraseasonal, seasonal, and interannual variations

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Abstract: Water temperature and salinity variations were observed below fast ice in Ongul Strait, Antarctica, in 1998. Vertical profiles of temperature and salinity were obtained with a conductivity-temperature-depth profiler, and temperature and salinity were continuously observed with moored sensors. Intraseasonal variations were observed in both fields. Especially, temperature variation of about 0.05°C was apparent on the time scale of about one month near the thermocline depth. Seasonal variations of temperature and salinity were similar to those observed in 1982–1983 and 1990–1991. However, the temporally averaged temperature and salinity for 1998 showed differences from those for previous years; temperature was higher in 1998 than in 1982–1983 and 1990–1991 at middle to deep layers, and salinity was intermediate between 1982 (more saline) and 1990–1991 (fresher) throughout the water column.

1. Introduction

The coastal ocean around Antarctica is one of the regions which can produce dense water for the global oceans. Oceanic variations in this region are linked with variations in other regions and changes in the atmosphere and sea ice. Hence, continuous observations are important in monitoring the Antarctic and global climate.

Lützow-Holm Bay is located at the eastern end of the Weddell Gyre. *In-situ* observations during winter seasons have been conducted several times from the mid-1970s in the framework of Japanese Antarctic Research Expeditions (JARE). Below fast ice in Ongul Strait, east of Syowa Station, oceanographic observations were conducted in 1976 (Wakatsuchi, 1982), in 1982–1983 (the BIOMASS project period; Fukuchi *et al.*, 1985: Watanabe *et al.*, 1986), and in 1990–1991 (the ACR project period; Ushio and Takizawa, 1993: Ohshima and Kawamura, 1994). There are few regions that have been studied so extensively over winter seasons around the Antarctic coast, and thus Ongul Strait is one of the most important sites for monitoring oceanic variations.

From those past observations, oceanic structure and its variations in this region have been investigated, and our understanding of the variations has been significantly increased. Intraseasonal variations were observed in bottom pressure and current velocity fields. Sea level variation at Syowa Station has spectral peaks at periods of about 15 days and 30–40 days (Nagata *et al.*, 1993). Variability of current velocity has a typical time scale of about a week (Ohshima *et al.*, 1993). Connection with variations of wind system and ice edge location is suggested (Ohshima *et al.*, 2000).

Seasonal variation of hydrographic conditions has been investigated extensively. Generally, fresh and cold water accumulates in the upper layer in the austral fall, and then the depth of the layer gradually decreases with appearance of saline and warm water in the middle and deep layers (Ohshima *et al.*, 1993). This seasonal cycle is highly affected by lateral advection (Ohshima *et al.*, 1991, 1993), and it is suggested that the seasonal change is due to the coastal current variation that is caused by the variation in Ekman convergence (Ohshima *et al.*, 1996).

On longer time scales, interannual variation is suggested in the salinity field in the surface layer. The salinity averaged annually in 0–200 m depth was 0.1–0.2 psu higher in 1982–1983 than in 1976 and 1990–1991 (Ohshima *et al.*, 1996).

Although several aspects of the variations have been revealed as noted above, many characteristics of the variations are still unclear. The number of observations is not enough to describe general characteristics of the long-term variations. On the other hand, the characteristics of short-term temperature and salinity variations are not totally understood. If the magnitudes of the intraseasonal variations are large, they can affect results concerning the seasonal variation quantitatively. Thus, observations throughout the year have been keenly needed in Ongul Strait.

In JARE-39, *in-situ* observations were conducted from July to December in 1998. Vertical profiles of temperature and salinity were obtained with a Conductivity-Temperature-Depth (CTD) profiler. Continuous temperature and salinity variations were observed with the sensors attached to mooring cables. In this study, characteristics of their intraseasonal, seasonal, and interannual variations were investigated. The obtained time series of temperature and salinity on time scales shorter than the annual cycle were examined in Section 3.1. In Section 3.2, their vertical profiles and seasonal variations in 1998 were described. In Section 3.3, the observed results were processed for comparison with previous observations of 1982–1991 to study evidence of interannual variations.

2. Observations

In 1998, oceanographic observations were conducted in Ongul Strait (Fig. 1). Ice conditions in Lützow-Holm Bay were fairly unstable. Around the Ongul Islands, open water surface prevailed from January 1998, and growth of fast ice was delayed. South and west of the Ongul Islands, fast ice began to grow from April, but it became detached again in June. Hence, observations were started in late July. An observation point was established at almost the center of the strait (OS 5–68° 59′26″ S, 39° 39′44″). The depth at OS 5 was 549 m. Observations were also conducted at another point (OS 2) on the western slope of the strait.

Vertical profiles of temperature and salinity were obtained with a CTD profiler (Seabird SBE-19). Accuracy in temperature is 0.01°C, and that in conductivity is 0.01 mmho/cm. Observations were conducted approximately once a month from July 22 to December 8 at OS 5 and from July 23 to September 11 at OS 2.

Continuous variations of temperature and salinity were observed at 50 m, 100 m,

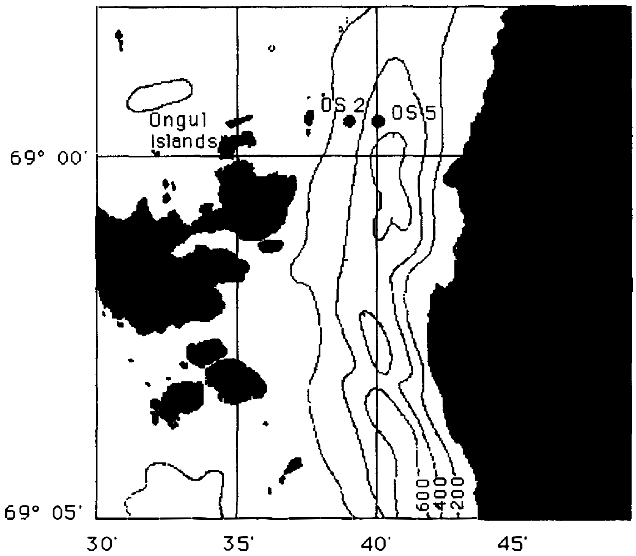

Fig. 1. Locations of the observation points in Ongul Strait. Isobathymetric lines are drawn in meters, edited from Moriwaki and Yoshida (1990).

and 300 m depths with sensors attached to the mooring cables that were suspended below fast ice. Temperature at 100 m depth was observed with the thermistor sensor attached to a recording current meter (AANDERAA Instruments RCM 9). Its accuracy is 0.05°C and its resolution is 0.008°C. Temperature and salinity at 50 and 300 m were observed with different thermistors and conductivity cells (ALEC Electronics Inc. MDS-CT). Accuracy in temperature observation of the MDS-CT is 0.05°C and its resolution is 0.02°C. Accuracy in conductivity is 0.1 mmho/cm. At OS 5, the mooring observation was conducted for about four months, during two periods: from July 21 to October 12 and from October 12 to November 14. Temperature measurements were successfully conducted for all the instruments. Conductivity was successfully measured at 300 m depth, but no data were obtained at 50 m.

Temperature calibration of the ALEC MDS-CT conducted previously in warm water was inadequate for the low temperature range. Thus the temperature data were calibrated several times with *in-situ* simultaneous observations with a thermistor sensor attached to a current meter (ALEC ACM-8). The re-calibrated data were compared with five sets of CTD observations at OS 5. The averaged differences were about 0.02°C and the standard deviations were 0.02–0.03°C at 50 m and 300 m. The same comparison was made with the AANDERAA RCM 9 thermistor sensor at 100 m depth. The averaged difference was about 0.003°C and the standard deviation was about 0.02°C. Salinity accuracy with the ALEC MDS-CT recorder is less than that of the Seabird CTD, so the data were calibrated with CTD observations. Measurements of the MDS-CT sensor had a large offset, so those data were calibrated with the five sets of CTD observations at OS 5. After removing the derived offset, the standard deviation of the difference between the MDS-CT and Seabird SBE-19 was reduced to 0.007 psu.

The mooring data were sampled at 20-min intervals. The obtained data were combined into one-hour intervals to reduce random noise, and then the time series were low-pass filtered with a 2-day tide killer filter (Thompson, 1983).

Continuous mooring observations can be affected by tilt of mooring cables due to oceanic current. The effect of the tilt was approximately corrected using the depth sensor of RCM 9 at 100 m, applying the temperature gradient derived from the CTD observations. The sensor depth variations sometimes amounted to about 15 m. At 100 m, the homogeneous gradient of −0.0026°C/m derived from the observations from July to December was applied. The correction did not change the general characteristics of the time series. No correction was applied to the time series at 50 m and 300 m, because the temperature gradients were generally small at those depths. No correction was applied to the salinity time series at 300 m.

3. Results

Variations from intraseasonal to interannual time scales were analyzed. Time series of temperature and salinity variations at point OS 5 were examined. Continuous mooring data were analyzed and then combined with vertical profile data. The results were compared with past observations to investigate long-term variations.

3.1. Intraseasonal variations

Time series of temperature variations at OS 5 are shown for the three levels 50 m, 100 m, and 300 m (Fig. 2a). Warming trends as part of seasonal variations were prominent at 100 m and 300 m. Besides the trends, variations of higher frequencies from several days to about a month were observed in all the time series. Especially at 100 m, large temperature fluctuations were apparent; temperature variations of about 0.05°C were observed on the time scale of about one month. Power spectral analysis shows a significant peak at 20–30 days, together with a few peaks at the periods from 5 to 10 days (Fig. 3). At 50 m and 300 m, spectral peaks were also observed from 3 to 16 day periods, but the spectral powers at 20–30 day periods were not significant.

Salinity variation is shown for 300 m depth with temperature variation (Fig. 2b). Increase of more than 0.1 psu was detected. Besides the increase, fluctuations of several day periods were observed. For the former half period, the phase of the salinity variation was opposite to that of the temperature variation: a positive saline anomaly corresponded to a cold anomaly. For the latter half period, however, the magnitude of the variation was smaller, and the relationship between salinity and temperature was not clear.

3.2. Seasonal variation

Although the total observation period was only about five months, part of the seasonal variation of vertical temperature profiles was clearly revealed (Fig. 4a). The cold layer beneath the surface gradually thinned with time. The depth of the thermocline changed from about 150 m in July to 50 m in December. The warming of 0.2°C was also detected at 100 m depth with the moored temperature sensor. Since the magnitude of the higher frequency variations is only order of 0.05°C, they do not affect the general characteristics of the seasonal variation. In intermediate and deep layers below the mixed-layer, temperature became gradually warmer.

Salinity profiles also showed significant seasonal variation (Fig. 4b). Thinning of

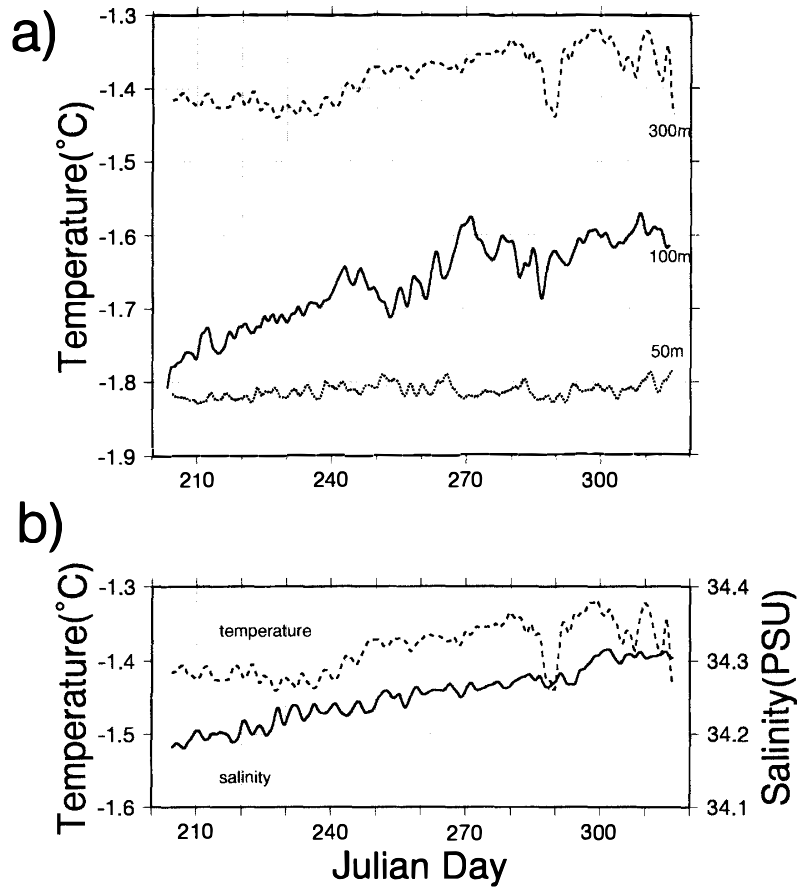

Fig. 2. a) Temperature variations at OS5 at the depths of 50 m (dotted line), 100 m (solid line) and 300 m (broken line), respectively. b) Salinity (solid line) and temperature (broken line) variation at 300 m depth.

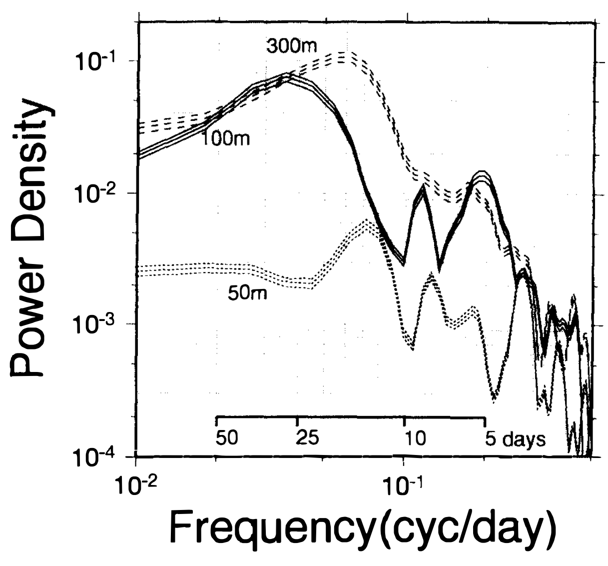

Fig. 3. Power spectra density of temperature variations at OS5 with their 95% confidence levels. Dotted lines denote the spectra and error bars for 50 m, solid lines for 100 m, and broken lines for 300 m.

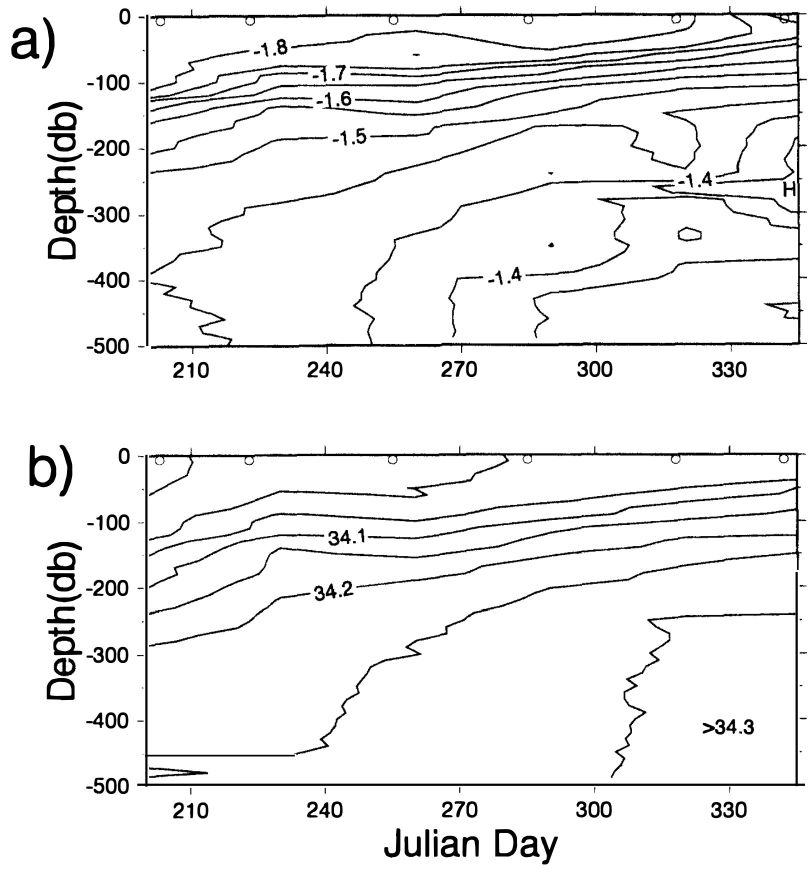

Fig. 4. Seasonal variations in (a) temperature and (b) salinity profiles at OS5. Open circles denote the dates of observations.

the fresh surface layer was detected. Salinity in intermediate and deep layers became more saline from July to December. The salinity increase of about 0.1 psu was also consistent with the result of the mooring conductivity measurement.

3.3. *Interannual variation*

The obtained temperature and salinity profiles were compared with those observed in 1982–1983 and 1990–1991. The data used for each period were taken from the deepest observation point in Ongul Strait. The temperature and salinity variations are shown for the standard depths from 10 m to 400 m for all the years (Fig. 5). In 1998, the general tendency of the seasonal variation was consistent with that in previous years. However, the annually averaged temperature and salinity were different from year to year. Temperature was generally higher in 1998 than in 1982–1983 and 1990–1991 in intermediate and deep layers (200–400 m). Salinity was generally intermediate between 1982 (more saline) and 1990–1991 (fresher) at all the depths (10–400 m), and similar to the variation in 1983.

To show the interannual differences quantitatively, a linear trend and quadratic polynomial were fitted to the time series at all levels, and their averaged values were calculated over the period from July 22 to December 8 for each year. The profiles of the averaged temperature and salinity are shown in Fig. 6; this figure is for the linear

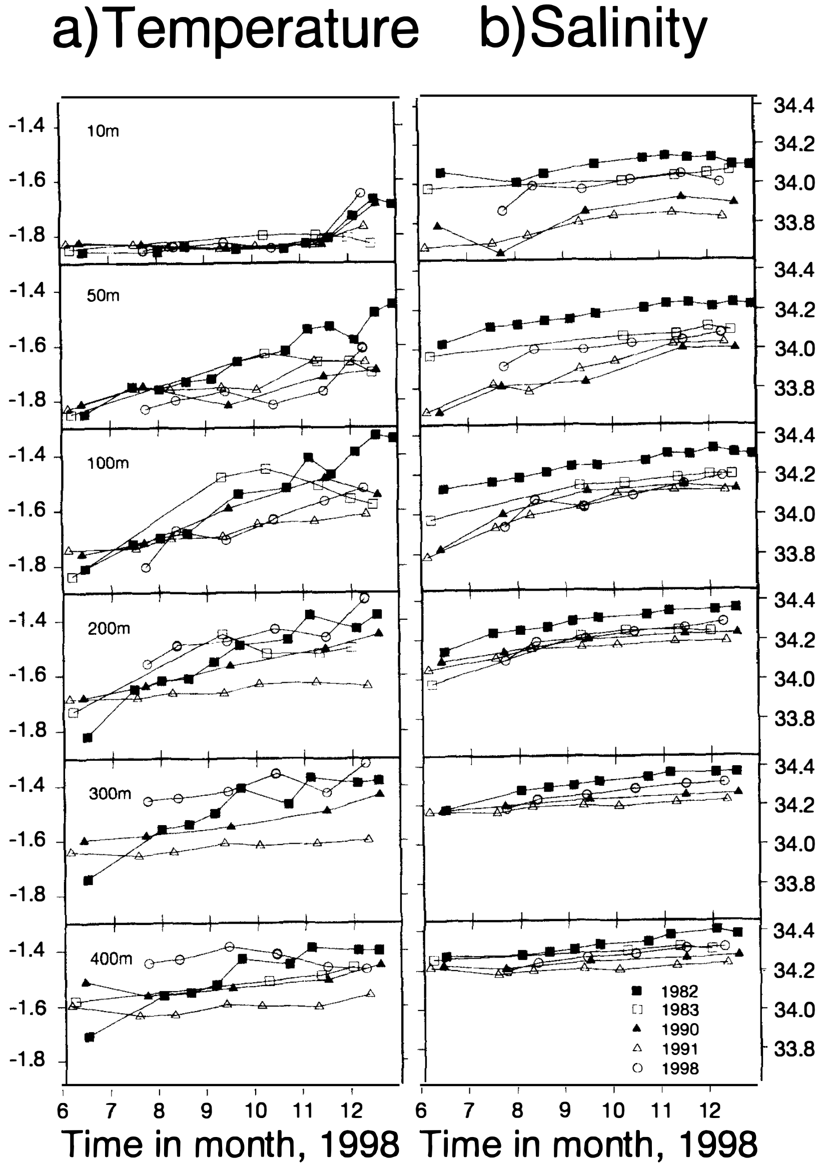

Fig. 5. Seasonal variations in (a) temperature and (b) salinity at the depths of 10, 50, 100, 200, 300, and 400 m, respectively. The squares denote the observations in 1982 (closed) and 1983 (open), the triangles in 1990 (closed) and 1991 (open), and the dots in 1998. The data are taken from the deepest point in Ongul Strait in each observation period.

trend case because the profiles were not so different from those for the quadratic polynomial case. For the depths deeper than 200 m, the temperature was highest in 1998, as also seen in Fig. 5. The difference in temperature increased with depth. Below 300 m, it was higher by about 0.05℃ compared with 1982–1983 and by 0.2℃ with 1990–1991. The salinity difference was large between 1982 and 1990–1991: about 0.3 psu at the surface and about 0.15 psu in the deep depths. The averaged salinity in 1998 was intermediate between them.

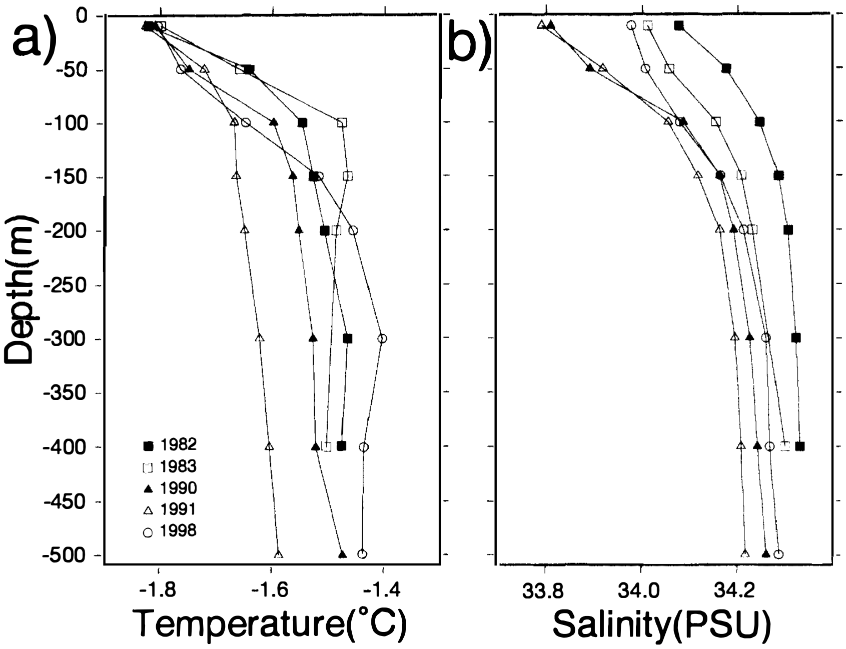

Fig. 6. Averaged (a) temperature and (b) salinity profiles from 1982 to 1998. Symbols are as shown in Fig. 5.

4. Summary and discussion

Oceanographic observations were conducted in Ongul Strait in 1998. Continuous data with the moored sensors were analyzed and then combined with vertical profiling data.

Intraseasonal variations were observed in temperature and salinity fields. Variation of 20–30 day period was detected in the temperature time series near the depth of the thermocline, suggesting the baroclinic nature of the variation. However, the magnitude of the variation may be affected by change in thermocline depth, because the thermocline depth thinned from about 150 m to 50 m and the temperature gradient at the fixed depth changed with its movement. Sea level variation at Syowa Station has shown spectral peaks at similar periods (Nagata *et al.*, 1993). Studies of the relationships with the simultaneous sea level field and velocity fields will be conducted as a next step.

Seasonal variations of temperature and salinity were consistent with those observed in 1982–1983 and 1990–1991. However, each field revealed an interannual difference from the past observations. Especially, the highest temperature was observed in intermediate and deep layers in 1998. Temperature differences from past periods were well above the instrumental error level. The characteristics and reason for the interannual variation are not clear. It may be part of long-term variations such as a decadal or longer time scale (Fahrbach *et al.*, personal communication: Aoki, 1997) or the Antarctic Circumpolar Waves (White and Peterson, 1996), although their existence in the coastal regions is not clear yet. Difference in local sea ice condition may affect the density structure. On the other hand, the possibility of an artificial effect is not completely excluded. Positional changes in the observation point can contaminate the obtained variation. Comparison of the CTD profiles between OS 5 and OS 2 (1.5 km apart and one day later) gave the difference of 0.01–0.02°C at each level. This difference is much smaller than the observed interannual temperature anomaly, but careful treatment is necessary in quantitative arguments. Observations over a broader area are required. As for the accuracy of the interannual difference in salinity, the present observations for 1998 may include some errors. Results of salinity calibration suggested that the CTD indicated values 0.018 psu lower than those measured with bottles, although the values used in the calibration have much more randomness and the availability of the correction is ambiguous. However, the correction of 0.018 psu does not alter the basic results for the interannual variation.

The above results demonstrate the importance of observations in this region. In order to describe the seasonal and interannual variations, observations should be extended to summer. Observations were continued in 1999, and are being extended to 2000. Further observations are needed to monitor long-term oceanic changes.

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