Proc. NIPR Symp. Polar Meteorol. Glaciol., 4, 74–80, 1991

A NOTE ON WATER EXCHANGE UNDER FAST ICE IN LÜTZOW-HOLM BAY, ANTARCTICA

Kay I. OHSHIMA, Nobuo ONO, Takatoshi TAKIZAWA and Shuki USHIO

Institute of Low Temperature Science, Hokkaido University, Kita-19, Nishi-8, Kita-ku, Sapporo 060

Abstract: Under coastal fast ice in the Ongul Strait near Syowa Station, Antarctica, warmer, more saline, and oxygen-poorer water appears in mid-depth and deep layers from winter to spring every year. This water is explained as a result of mixing between Circumpolar Deep Water (CDW) and Winter Water (WW). This water becomes more like CDW and more homogenized with time from winter to spring, and in December a mixing ratio of 1 : 3–1 : 4 for CDW to WW is required to explain the properties of the homogenized water. It is inferred that the CDW comes along the glacial troughs. Transport of CDW results in a significant amount of heat supply into the water under fast ice.

1. Introduction

The Antarctic Climate Research (ACR) project is being undertaken in 1987–1991. Geophysical investigation of sea ice is one of the main subjects of this project, since sea ice is believed to have a great impact on regional and global climate. In general, growing or melting of sea ice is closely related to the oceanic structure there. Growth of sea ice results in haline convection into the ocean through salt exclusion (FOSTER, 1972). On the other hand, heat flux from the ocean reduces sea ice growth or melts the ice (ALLISON, 1981).

So far scant observations have been made in fast ice-covered regions because of its difficulties. The only site which is intensively observed is near Mawson Station, where ALLISON *et al.* (1985) investigated the annual salt and energy budget beneath a fast ice cover. Lützow-Holm Bay is a typical fast ice-covered region facing an open Antarctic sea. Thus, water exchange, accordingly exchange of heat and salt, occurs with the open ocean. On the other hand, several glaciers (Shirase Gl., Kaya Gl. *etc.*) flow into this region from the Antarctic Continent, and glacial ablation occurs there. The glaciers are ultimately melted by the oceanic heat, resulting in a fresh water flux into the ocean. Therefore, both the open ocean and the glaciers affect the heat and salt budget processes in this region.

The purpose of this paper is to derive a plausible picture of oceanic processes in Lützow-Holm Bay on the basis of past oceanographic observations.

2. Water Mass Analysis

Syowa Station is located on East Ongul Island in the eastern part of Lützow-Holm Bay (Fig. 1). In Ongul Strait near Syowa Station, there have been four sets of year-round oceanographic observations. The first one was made by WAKATSUCHI (1982) on the 17th Japanese Antarctic Research Expedition (JARE-17). The second and most intensive one was made by a marine biology group on JARE-23 (FUKUCHI *et al.*, 1985a, b, c), and the third and fourth ones were subsequently made by the same group on JARE-24 and JARE-25.

Figure 2 shows the seasonal variations in temperature, salinity and dissolved-oxygen which are averaged over the 200, 400 and 600 m depths in these observations. Common features are: relatively warm, saline and oxygen-poor water appears in mid and deep-depth layers from winter to spring, although there are some interannual variabilities. It is unlikely that such deep water is heated directly from the atmosphere in this season. So this water is interpreted as advected water from somewhere or mixed water with warmer, more saline, and oxygen-poorer water.

Figure 3 shows the vertical profiles of temperature, salinity and dissolved-oxygen for typical water in Ongul Strait and the open ocean off Lützow-Holm Bay. In general, in the open ocean around Antarctica, Circumpolar Deep Water (hereafter CDW), which is identified as relatively warm, saline, and oxygen-poor water, lies under Winter Water (hereafter WW), which is identified as cold, fresh, and oxygen-rich water. As shown in Fig. 3, WW occupies the upper 300–400 m off Lützow-Holm Bay. In Ongul Strait, well homogenized water occupies the full depth to bottom except for the surface layer. This homogenized water shows intermediate properties between CDW and WW for all quantities.

Figure 4 shows temperature versus dissolved-oxygen (a) and salinity versus dissolved-oxygen (b) diagrams with respect to water at Ongul Strait and the open ocean off Lützow-Holm Bay. The open ocean data were taken in different years at dif-

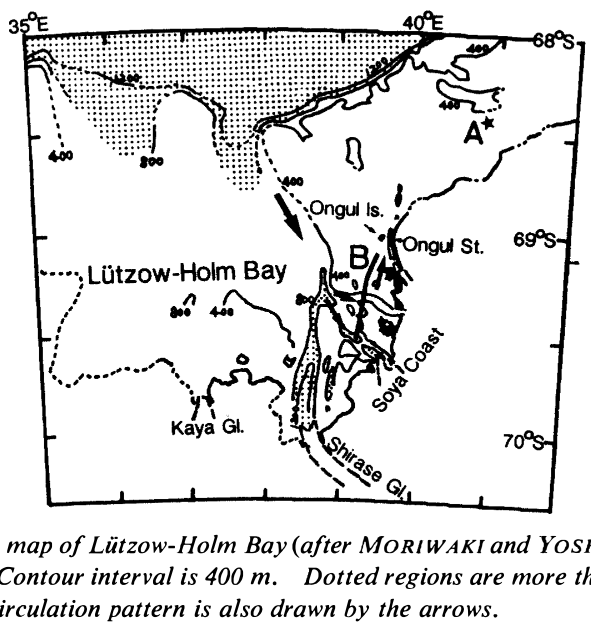

Fig. 1. Bathymetric map of Lützow-Holm Bay (after MORIWAKI and YOSHIDA, 1983) and station locations. Contour interval is 400 m. Dotted regions are more than 800 m in depth. A speculated circulation pattern is also drawn by the arrows.

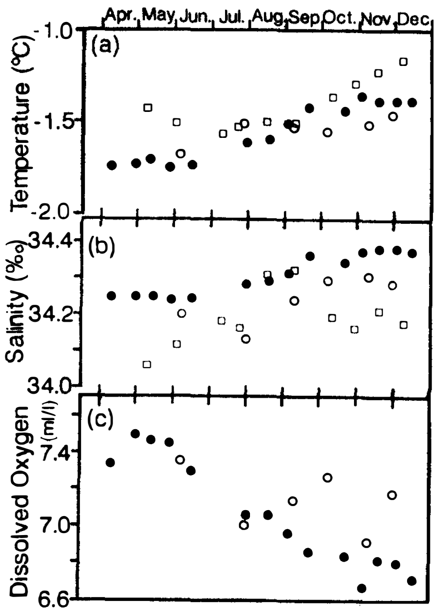

Fig. 2. Seasonal variations in temperature (a), salinity (b), and dissolved oxygen (c) of the sea water in Ongul Strait. Each value is an average of water at 200, 400 and 600 m depths. □: *1976 (by WAKATSUCHI, 1982),* ●: *1982 (by FUKUCHI et al., 1985a),* ○: *1983 (by WATANABE et al., 1986).*

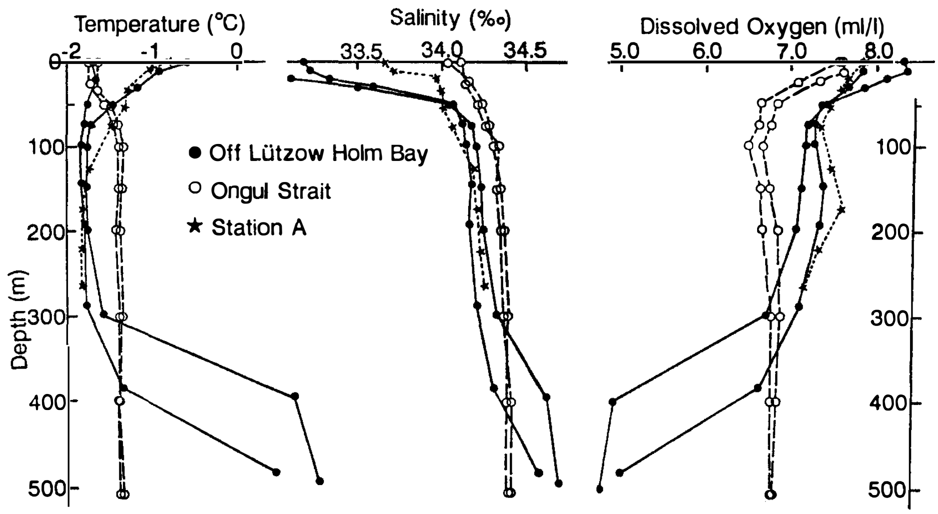

Fig. 3. Vertical profiles of temperature (left panel), salinity (middle) and dissolved oxygen (right) for the typical water of Ongul Strait and open ocean. The data sources are as follows: ●: *Feb. 13, 1967 (WATANABE et al., 1968) and Feb. 2, 1966 (HORI et al., 1966),* ○: *Dec. 3 and 16, 1982 (FUKUCHI et al., 1985a),* ★: *Jan. 19, 1966 (HORI et al., 1966).*

ferent stations; water mass properties show little difference among them. The open ocean water is clearly separated into two water masses: CDW in deep and WW in surface layers. The linear mixing lines between CDW and WW are also indicated in Fig. 4. All the water at Ongul Strait, except for the surface layer, is located near these lines on both diagrams. WEISS *et al.* (1979) showed that oxygen content is negligibly altered by consumption or production during sub-surface circulation and mixing in the Weddell Sea. If this is valid also in this region, the diagrams suggest a possibility that the homogenized water at Ongul Strait is formed by mixing between WW and CDW with the ratio of 3: 1–4: 1, although local surface water, whose properties are close to WW, may contribute to the water formation to some extent. The ratio is determined by the position of the homogenized water on the linear mixing lines.

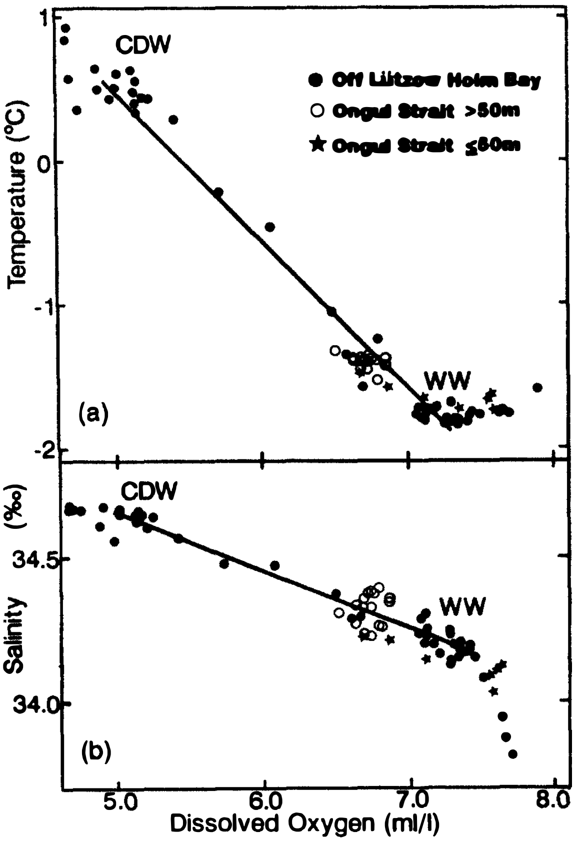

Fig. 4. Temperature versus oxygen content (a) and salinity versus oxygen content (b). CDW and WW represent Circumpolar Deep Water and Winter Water, respectively. The linear mixing lines between CDW and WW are also indicated. The data sources are: Feb. 1, 1966 (HORI et al., 1966), Feb. 25, 1976 (SHIBAYAMA and OHNIWA, 1977), Feb. 20, 1986 (IWANAGA and TOHJU, 1987), in addition to those used in Fig. 3.

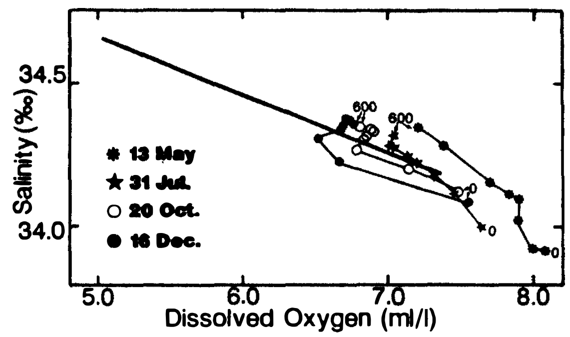

Fig. 5. Seasonal variations in water masses at Ongul Strait on salinity versus oxygen content relationship in 1982. From data by FUKUCHI et al. (1985a). The linear mixing line between CDW and WW is also indicated.

In Fig. 4, the data of Ongul Strait were taken mostly in December. As shown in Fig. 2, water properties show some seasonal variations. We next show the seasonal variations in water mass using a salinity versus dissolved-oxygen diagram (Fig. 5). According to Fig. 5, the water properties shift from those of WW toward those of CDW with time from fall to spring. Also, the water is more homogenized with time. These features are more clearly shown in Figs. 2 and 3 of FUKUCHI *et al.* (1985a).

The results of water mass analysis are summarized as follows: appearance of warm, saline, and oxygen-poor water in mid-depth and deep layers near Syowa Station is explained as a result of mixing between the CDW and WW or local surface water. The water becomes more like CDW and more homogenized with time.

3. Discussion

Influence of CDW on the water in Ongul Strait implies that CDW is advected from somewhere. Then where does CDW come from? In Fig. 3, vertical profiles to near the bottom at Station A, which is located north of Syowa Station (see Fig. 1), are also shown. We cannot find any water which is influenced by CDW at this station. On the other hand, Fig. 6 (adapted from WAKATSUCHI, 1982) shows the results of oceanographic observations along the Soya Coast (denoted by the line-B in Fig. 1). We can find the water whose properties are close to those of CDW in the southern deep layer. As shown in Fig. 1, several glacial troughs exist in the westward and southward region around the Ongul Islands. These troughs are probably connected with the open ocean (although enough soundings have not been made to say that exactly). Thus, CDW possibly intrudes into the trough regions. It is inferred that CDW comes to Ongul Strait along these troughs, as schematically shown in Fig. 1. This inference is consistent with the fact that northward flow is dominant at Ongul

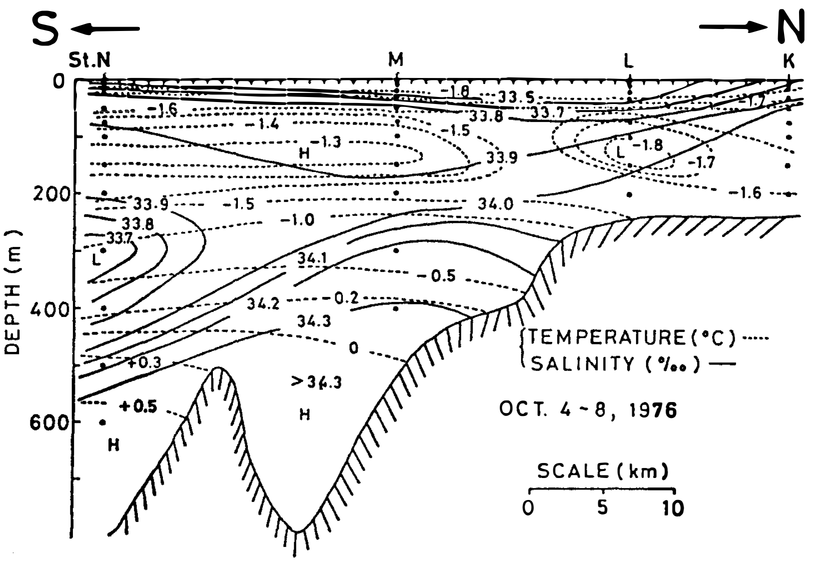

Fig. 6. Temperature and salinity distributions in a cross section off the Soya Coast line-B in October, 1976 (adapted from WAKATSUCHI, 1982). The line-B is denoted in Fig. 1. St. N is the southern end of line-B.

Strait from winter to spring (FUKUCHI *et al.*, 1985b).

In order to mix CDW with WW and to form the homogenized water, vertical mixing is indispensable. Thus, we next consider the mixing process. The homogenized water is only in mid-depth and deep layers, hence local convection from the surface, caused by the wind stirring, cooling and salt exclusion, does not seem to cause the mixing. One candidate for the mixing between CDW and WW is tidal mixing. As shown in Fig. 1, the bottom topography along the Soya Coast has much undulation (see MORIWAKI and YOSHIDA, 1983 in detail); thus tidal currents are expected to be relatively strong in this region. Actually, FUKUCHI *et al.* (1985b) observed tidal currents of 10–20 cm/s in Ongul Strait.

When CDW, which is 2–3 degrees higher than the freezing point, is transported from the open ocean to the fast ice-covered ocean, a significant amount of heat is transported simultaneously. This heat should be transported to the upper layer, which results in increase of oceanic heat flux into fast ice, especially in spring, when the water is more influenced by CDW. This may explain the fact that the thickness of fast ice near Syowa Station does not increase after October despite atmospheric cooling (WAKATSUCHI, 1982). It is noted here that also in other fast ice-covered regions the oceanic heat flux into the fast ice is increased from winter to spring (ALLISON, 1981). Is it common for CDW to affect the water in a fast ice-covered region more in spring? The thickness of first-year ice in the eastern part of Lützow-Holm Bay decreases toward the Soya Coast (*e.g.*, YOSHIDA and MORIWAKI, 1990). Is this related to the ocean structure or oceanic heat flux there? Understanding of such problems must await future observations.

Acknowledgments

We are much indebted to Prof. M. WAKATSUCHI for his valuable comments and suggestions. Thanks are extended to Ms. Rika KANO for typing the manuscript.

References

ALLISON, I. (1981): Antarctic sea ice growth and oceanic heat flux. International Association of Hydrological Sciences Publication 131 (Symposium at Canberra 1979—Sea Level, Ice and Climatic Change), 161–170.

ALLISON, I., TIRENDALE, C. M. and COPSON, G. R. (1985): Annual salt and energy budget beneath an Antarctic fast ice cover. Ann. Glaciol., **6**, 182–186.

FOSTER, T. D. (1972): Haline convection in polynyas and leads. J. Phys. Oceanogr., **2**, 462–469.

FUKUCHI, M., TANIMURA, A., OHTSUKA, H. and HOSHIAI, T. (1985a): Marine biological data of BIOMASS program at Syowa Station in the 1982 winter (JARE-23). JARE Data Rep., **98** (Mar. Biol. 6).

FUKUCHI, M., TANIMURA, A., OHTSUKA, H. and HOSHIAI, T. (1985b): Tidal current data in the Ongul Strait, Antarctica, from April to December 1982 (JARE-23). JARE Data Rep., **102** (Oceanogr. 5).

FUKUCHI, M., TANIMURA, A. and OHTSUKA, H. (1985c): Marine biological and oceanographical investigations in Lützow-Holm Bay, Antarctica. Antarctic Nutrient Cycles and Food Webs. Berlin, Springer, 52–59.

HORI, S., SHIOZAKI, M. and AKIYAMA, T. (1966): Oceanographic observations of the 7th Japanese Antarctic Research Expedition 1965–1966. Nankyoku Shiryô (Antarct. Rec.), **27**, 18–44.

IWANAGA, Y. and TOHJU, H. (1987): Oceanographic data of the 27th Japanese Antarctic Research Expedition from November 1985 to April 1986. JARE Data Rep., **127** (Oceanogr. 8).

MORIWAKI, K. and YOSHIDA, Y. (1983): Submarine topography of Lützow-Holm Bay, Antarctica. Mem. Natl Inst. Polar Res., Spec. Issue, **28**, 247–258.

SHIBAYAMA, N. and OHNIWA, Y. (1977): Oceanographic data of the 17th Japanese Antarctic Research Expedition 1975–1976. Nankyoku Shiryô (Antarct. Rec.), **60**, 100–131.

WAKATSUCHI, M. (1982): Seasonal variations in water structure under fast ice near Syowa Station, Antarctica, in 1976. Nankyoku Shiryô (Antarct. Rec.), **74**, 85–108.

WATANABE, K., SATOH, H., KANDA, H. and TAKAHASHI, E. (1986): Oceanographic and marine biological data from routine observations near Syowa Station between February 1983 and January 1984 (JARE-24). JARE Data Rep., **114** (Mar. Biol. 9).

WATANABE, R., SHIOZAKI, M. and SUGIMURA, Y. (1968): Oceanographic data tables of the 8th Japanese Antarctic Research Expedition 1966–1967. Nankyoku Shiryô (Antarct. Rec.), **31**, 33–65.

WEISS, R. F., ÖSTLUND, H. G. and CRAIG, H. (1979): Geochemical studies of the Weddell Sea. Deep-Sea Res., **26**, 1093–1120.

YOSHIDA, Y. and MORIWAKI, K. (1990): Some observations of sea ice in the vicinity of Lützow-Holm Bay, Antarctica. Nankyoku Shiryô (Antarct, Rec.), **100**, 8–14.

(Received January 18, 1990; Revised manuscript received June 4, 1990)