On the Year-to-Year Change in Subarctic Water Characteristics Around the Kuril Islands

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A counterclockwise circulation centered approximately at 50°N 165°E is seen in the western Subarctic Pacific Ocean. The Oyashio makes up the southwestern rim of this circulation, and flows southwestward along the Kuril Islands and the eastern coast of Hokkaido. The water characteristics of the Oyashio show a considerable seasonal change due to the direct influence by the Okhotsk Sea (Kono and Kawasaki, 1997). The seasonal change in subsurface waters beneath the pycnocline is less those above the pycnocline, and we consider only the data taken in the same seasons every year. We confine our attention to the subarctic dichothermal (inter-cooled) water, which shows considerable year-to-year change due to the yearly variations in winter cooling and in global climate conditions. In this study, we analyze the data of subsurface water deeper than pycnocline depth observed around the Kuril Islands, and discuss the yearly change in water characteristics of the subarctic.

Bussol Strait, the sill depth of which is 2200 m, is one of the main straits connecting the North Pacific Ocean with the Okhotsk Sea. The Hokkaido National Fisheries Research Institute (HNFRI) is continuing observations along a line which is passes through Bussol Strait (NU-line) by using the R/V *Hokko-Maru* belonging to HNFRI, every year since 1988. The location of the observational stations are shown in Figure 1. Annual observations are made from late August to early September. Kawasaki and Kono (1994) discussed the characteristics of subarctic waters of the Western North Pacific Ocean and of the Okhotsk Sea and showed that they are distinguished by maxima and minima of water temperature in particular density surfaces. The difference of the water characteristics is discussed here by comparing their potential temperature on isopycnal (isosteric) surfaces. In the subarctic region, salinity is more uniform on isopycnals than potential temperature, as the salinity effect on water density is much larger than temperature.

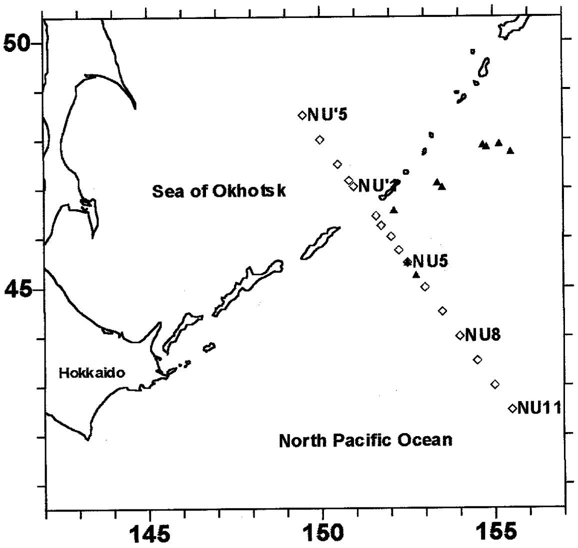

Fig. 1 Location of stations on the NU-line, 1987-1997, *R/V Hokko-maru*. Triangles denote the stations which were used for the East Kamchatka Current water (see text).

The distributions of potential temperature (°C) averaged over 10 cruises (1988-1997) and its standard deviation along the NU-line are shown in Figure 2. The potential density (σ_θ: left axis) and the thermosteric anomaly ($\Delta s\theta$:right axis) are given on the ordinate. The station NU9 corresponds to the Subarctic Front. Water characteristics in the subtropical region (NU10-11) are evidently different from those in the subarctic region (NU8-NU'5). The water in the subarctic region may be divided into the Okhotsk Sea water (NU'2-5), the Kuril water (NU'1-NU2), and the Western Subarctic Pacific water (NU3-8). A dichothermal (inter-cooled) structure is observed both sides of Bussol Strait: 26.5-26.8 σ_θ layer (75-150 m in

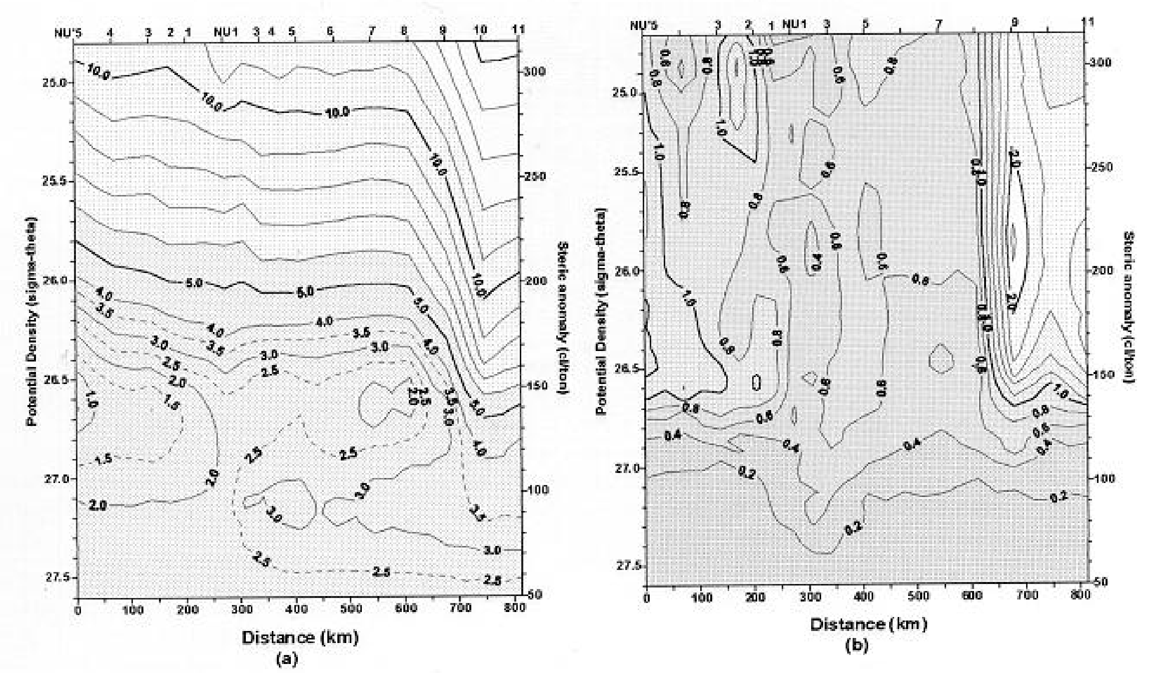

Fig. 2(a) Potential temperature distribution (°C) along NU-line averaged for ten years from 1988 to 1997. The potential density or the steric anomaly is taken in the ordinate. The distance (in km) measured from NU'5 is taken in the abscissa. **Fig. 2(b)** Same as 2(a) except for the averaged standard deviation (°C) of the potential temperature.

water depth) in the Pacific side, and 26.5-27.0 σ_θ layer (50-300 m in water depth) is seen on the Okhotsk side. A methothermal (inter-warmed) structure is observed in 26.9-27.2 σ_θ layer (200-400 m in water depth) in the Pacific side, while a deep warm water in 27.3-27.4 σ_θ layer (900-1100 m in water depth) is seen on the Okhotsk side. High standard deviations (>1.5°C) are found near the Subarctic Front (NU9) in Figure 4b. This high variance seems to be caused by the fluctuation of the position of the front. Other high standard deviation values (>1.0°C) appear in the subsurface layers of the northern stations (NU'3-5). This high variance would be caused by inflow of a very cold water lower than 0°C, which seems to originated from the East Sakhalin Current Water. Beneath the 26.7 σ_θ layer (lower part of dichothermal layer), the standard deviation value decreases monotonically with depth, indicating that yearly temperature variations hardly penetrate into deeper layers. However, relatively high value tends to penetrate into deeper depths around Bussol Strait (see, for example, isopleths of 0.4 and 0.2). This would indicate that active mixing reaches deeper layers near Bussol Strait.

In order to remove the considerable variation of the standard deviation in the cross-section, and in order to exaggerate the temperature variation beneath the pycnocline, the temperature deviations from the mean values (Fig. 2a) for each year were normalized by the mean standard deviation (Fig. 2b). Distributions of this normalized temperature deviation are shown in Figures 3a-c for the years of 1990, 1993, and 1996, respectively. Conspicuous negative deviations are found in the subsurface layers of the Pacific side in 1990 (Fig. 3a) and 1991 (not shown), and in the Okhotsk side in 1993 (Figure 3b). In 1993, many positive and negative deviation domains having small spatial scales appear in complicated ways in the Pacific side. On the other hand, the conspicuous positive deviation appears in almost the whole cross-section in the layer below 26.6 density surface in 1996 (Figure 3c), though the thickness of the positive deviation region on the Okhotsk side

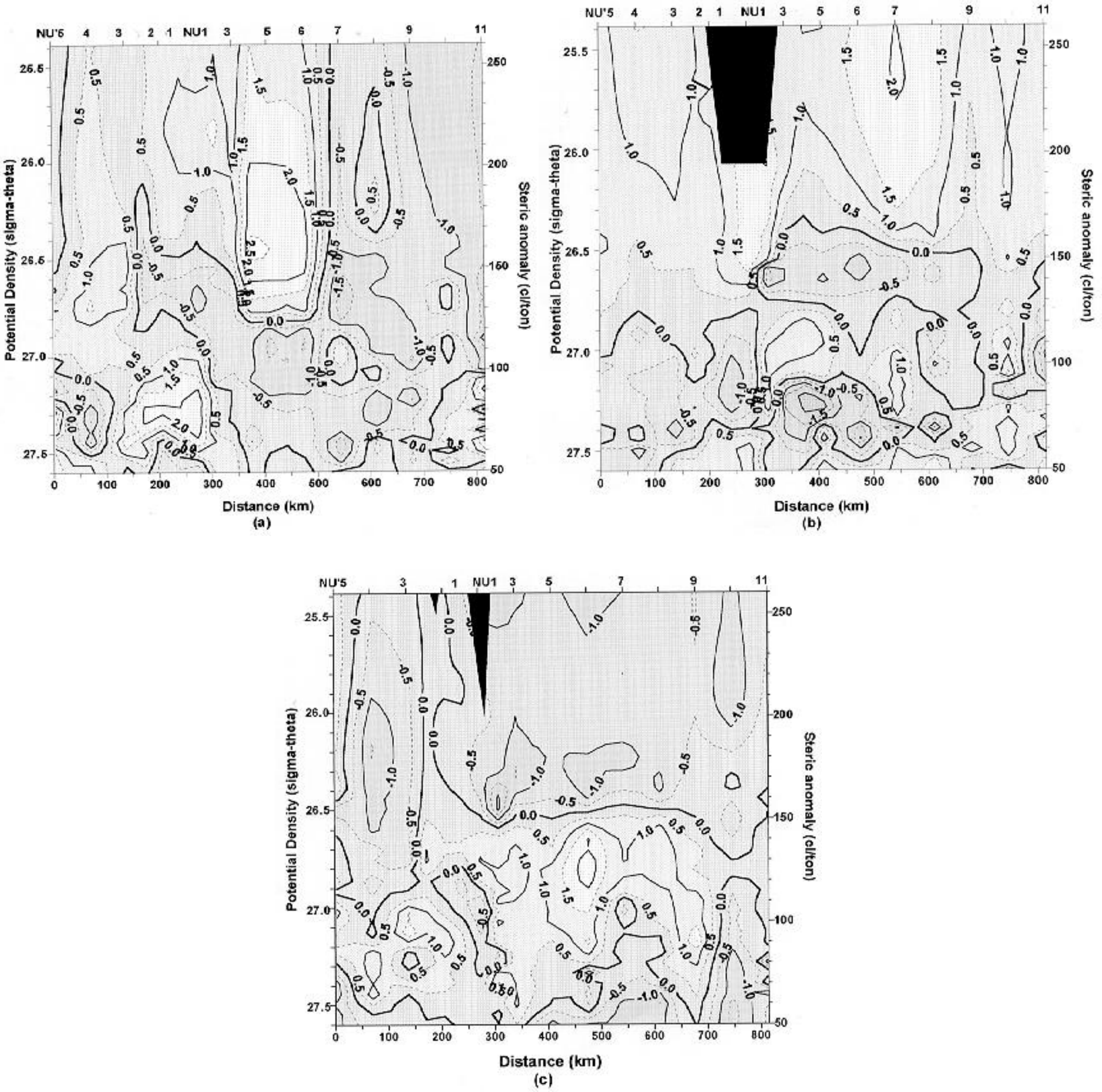

Fig. 3 As in Figure 2a except for the nomalized temperature deviation in (a)1990, (b) 1993 and (c) 1996. See text for the definition of normalized temperature deviation.

(NU'5 and NU'4) is rather limited. A similar distribution is also seen in 1997 and the thickness of the positive region increases considerably in 1997, just as on the Pacific side in 1996. The density range (26.6-27.3), where conspicuous deviations are seen, corresponds to the lower part of the dichothermal layer and the methothermal layer.

Yearly changes of the normalized temperature deviations are shown in Figure 4 for two observation points, NU'4 and NU 8. NU'4 is located at the center of the Kuril Basin in the Okhotsk Sea (48°N 150°E), and NU8 at the center of the Western Subarctic Circulation in the North Pacific (44°N 154°E). Relatively large negative deviations are seen in the layer of 27.3-27.5 density in 1990 at NU'4 (Figure 4a).

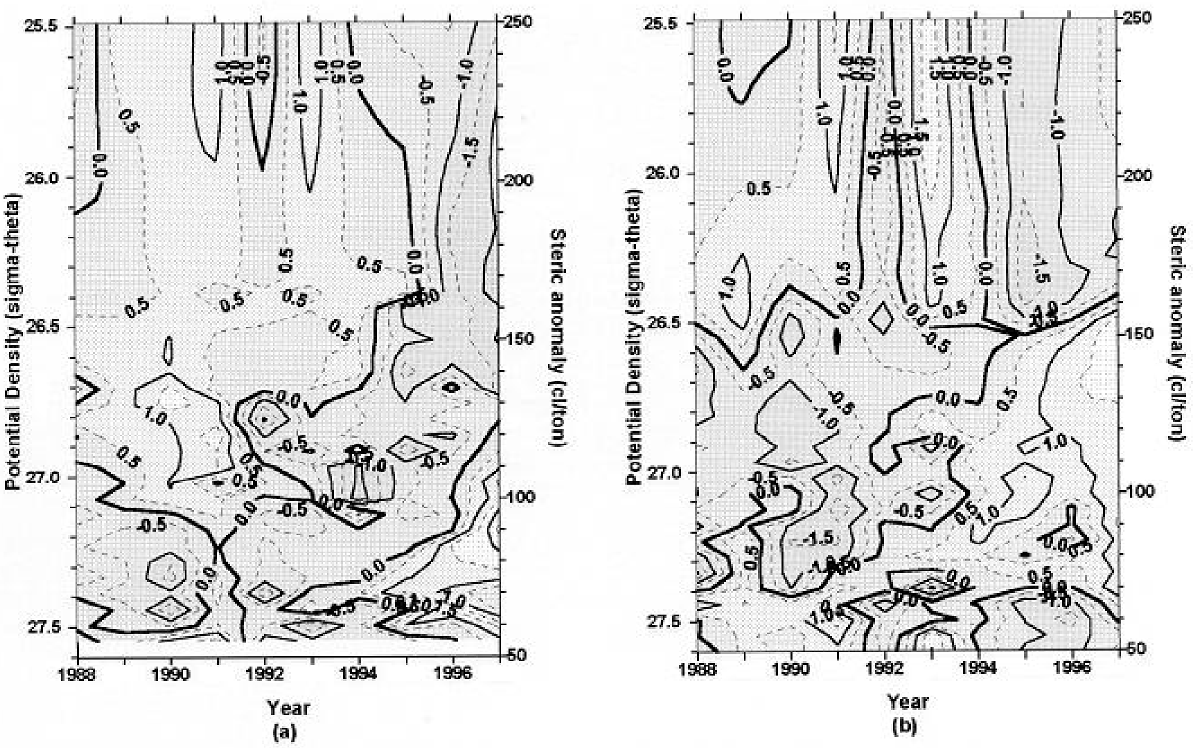

Fig. 4 Temporal change of the normalized temperature deviation: (a) at NU′4 (the center of the Kuril Basin in the Okhotsk Sea) and (b) at NU8 (the center of the western subarctic circulation in the North Pacific Ocean).

This negative domain is seen near the lower left corner in Figure 3a. Though the spatial extent of this domain is very limited in the 1990 cross-section (Figure 3a), its time scale (or persistency) appears to be considerably large: no such domain is seen in 1991, but the similar distribution is also seen in 1992 and 1993. This domain shifts towards lower density ranges during the period from 1993 to 1997. Instead, the positive deviation domain was created in the 27.4-27.5 density layer in 1993, and this positive domain increased its magnitude and its thickness continuously afterward, as seen in the cross-section in 1996 (Fig. 3c).

As we are discussing the temperature deviation from mean value (the average value for all cross-section and for all period would be very small even normalized by standard deviation), the situation at NU8 (the center of the Western Subarctic Circulation) tends to behave just oppositely in general: the positive deviation domain found in the 27.2-27.5 density layer in 1992 or in 1993 shifted towards lower density range, and its thickness tends to increase after 1993. It should be noted that the yearly change of the temperature deviation in the subsurface layer between 26.5 and 27.0 density surfaces is more clearly seen in Figure 4b than Figure 4a. The temperature deviation in Figure 4b before 1992 or 1993 is negative in this layer, and positive after. The subsurface water in the Western Subarctic Circulation region appears to be significantly warmed in recent years.

We selected the observation points which were identified to be in the East Kamchatka Current Region from available spatial distribution of water quantities for the period from 1988 to 1997. The distribution of the selected points are shown with closed triangles in Figure 1. Though the positions are distributed in rather wide area, the data

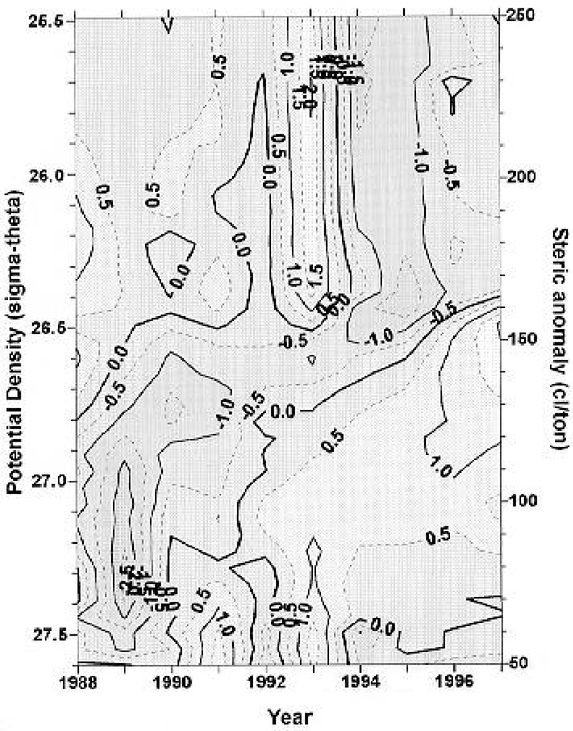

Fig. 5 As in Figure 4 except for East Kamchatka Current Water.

obtained at these points were assumed to be at single point, and the time series data were obtained. The normalized temperature deviations were calculated in a similar manner, and the computed yearly change of the vertical section is shown in Figure 5. The variation in Figure 5 is much simpler than that in Figure 4b, probably the small scale structures seen in Figure 4b are caused by the outflow of the Okhotsk Water brought in the NU-line sporadically. However, the main features seen in Figure 4b discussed above are also reproduced in Figure 5. The high positive anomaly domain, which was created below the 27.3 density surface in the period between 1991 and 1993, shifted towards lower density ranges after 1993, and its thickness tended to increase. The yearly change of the temperature deviation in the subsurface layer between 26.5 and 27.0 density surfaces is negative before 1992, and positive after 1992. This suggests that the cause of the recent warming of the subsurface water should be sought in the East Kamchatka Current Water or in the whole Western Subarctic Circulation area of the North Pacific.

Concluding remarks

The influence of the Okhotsk Water on the Oyashio Water has been discussed by various investigators (e.g. Talley and Nagata, 1995), but little investigation has done of the East Kamchatka Current Water. The result of the present paper indicates that the influence of the East Kamchatka Current Water is essential to understanding the inter-annual variation of the subsurface waters in the Oyashio region.

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References

Kawasaki, Y. and Kono, T. 1994. Distribution and transport of subarctic waters around the middle of Kuril Islands. *Umi to Sora, 70(2),* 71–84.

Kono, T. and Kawasaki, Y. 1997. Results of CTD and mooring observations southeast of Hokkaido. 2. Annual variations of water mass structure and salt flux of the Oyashio. *Bull. Hokkaido Natl. Fish. Res. Inst., 61,* 83–95.

Talley, L.D. and Nagata, Y. (eds.). 1995. The Okhotsk Sea and Oyashio Region. *PICES Scientific Report No. 2,* Sidney, B.C., Canada, 227 pp.