The intermediate and deep water formation in the Japan Sea

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The intermediate and deep water formation in the Japan Sea

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The intermediate and deep water formation process are studied by reproducing the past and present circulation numerically. The modeled past circulation shows that the bottom water formation takes place in the eastern Japan Basin, while the present state shows only the formation of intermediate water (the upper portion of the Japan Sea proper water (UJSPW)) which takes place mainly off Vladivostok. Besides the formation of the UJSPW, the formation process of the East Sea Intermediate Water (ESIW) characterized by salinity minimum is reproduced. The low salinity water at the surface advected from the north is subducted into the intermediate layer toward the east forming ESIW after meeting the East Korean Warm Current (EKWC) east of Korean coast of about 40°N.

1. Introduction

Changes in oceanic conditions suggesting the Global Warming have been going on in the deep layer of the Japan/East Sea. The temperature has increased by 0.02℃ /10years and the dissolved oxygen (DO) has decreased by 5.5moles/(kg・10 years) in the deep layer of the Japan/East Sea during the second half of this century (Kim et al., 1996[6], Minami et al., 1997[15]). Riser et al. (1999)[9] showed that the deep water formation in the Japan/East Sea has almost stopped at least since 1960's, suggesting the influence of the global climate change. While in the intermediate layer shallower than 1000m, the DO tends to increase, suggesting the active intermediate water formation which seems to take place mainly off Vladivostok in winter (Senjyu and Sudo, 1996[10]). However the formation process of the intermediate and deep water has not been cleared yet. In this study we try to clarify the intermediate and deep water formation process by reproducing the past and present oceanic state of the Japan/East Sea numerically.

2. Model characteristics

The numerical model used in this study is a multi-level primitive equation model with the grid resolution of 1/6° in both longitude and latitude under the Boussinesq approximation and the hydrostatic assumption using monthly mean wind stress by European Centre for Medium-Range Weather Forecasts (ECMWF) and the long-term monthly mean heat flux calculated from the climatological data by Hirose et al. (1998)[2] as surface forcings. The coefficients of horizontal and vertical eddy viscosity are 2.0×10^6 and $1.0cm^2/s$, respectively. Instead of constant horizontal diffusivity, isopycnal mixing scheme is incorporated and the vertically varying coefficient of vertical diffusivity is used to see the effect of a larger vertical diffusion in the deep layer. We assume a sinusoidal seasonal variation of inflow transport of the amplitude (0.35Sv) through Tsushima Straits with the maximum in September and the minimum in March. The mean volume transport through Tsushima (inflow), Tsugaru and Soya (outflow) Straits are 2.2, 1.4 and 0.8Sv, respectively (Isobe, 1994[1], Shikama, 1994[11]).

Varlamov et al. (1997)[12] have shown that the surface air temperature around the Japan/East Sea has increased by roughly 0.03℃ /year for the last 50 years. So we integrated the model from the initial state for 300 years with the air temperature data which is 2.0℃ lower than the

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present one to reproduce the past circulation in the Japan/East Sea. Then we integrate it for additional 50 years increasing linearly the air temperature to the present one to reproduce the present state.

3. Results

Fig. 1 shows the stream function and the vertical section of the potential density along 137.5°E in February. The homogeneous potential density (about $\sigma_\theta = 27.25$) from the surface to the bottom indicates the active bottom water formation by the winter convection in the eastern part of the Japan Basin. The cyclonic circulation shown in the stream function has two maximum; one is located off Vladivostok and the other the eastern Japan Basin. The latter is generated by the deep winter convection through the effective vertical momentum transfer from the wind stress due to the vertical homogeneity, attaining 10Sv of volume transport which is much larger than 6Sv in the present circulation discussed later. The former is generated by the positive wind stress curl of the winter monsoon southeast of Vladivostok where the winter convection reaches 700m depth. The remarkable difference between the past and present circulation is that the deep water formation down to the bottom does not take place in the present circulation. Only the convection down to the intermediate depth (about 900m) takes place off Vladivostok (132°E ~ 136°E, 41°N ~ 42°N) as shown in **Fig. 2** where the mixed layer depth is defined as the depth at which the potential density differs from the surface value by 0.02. The UJSPW is formed as the result of this convection by subducting the mixed water into the deeper layer through the bottom of convective layer. Kawamura (1998)[4] showed that the winter monsoon from the Eurasian Continent is blocked by coastal mountains and flows through the narrow valley near Vladivostok into the Japan/East Sea as a convergent wind. The convergent wind is accompanied by a wind stress vortex pair off Vladivostok. The region with the mixed layer depth over 800m corresponds to the area of the positive wind stress curl southeast of Vladivostok, suggesting that the UJSPW formation area is deeply related to the positive wind stress curl.

There is another formation of remarkable water mass characterized by salinity minimum

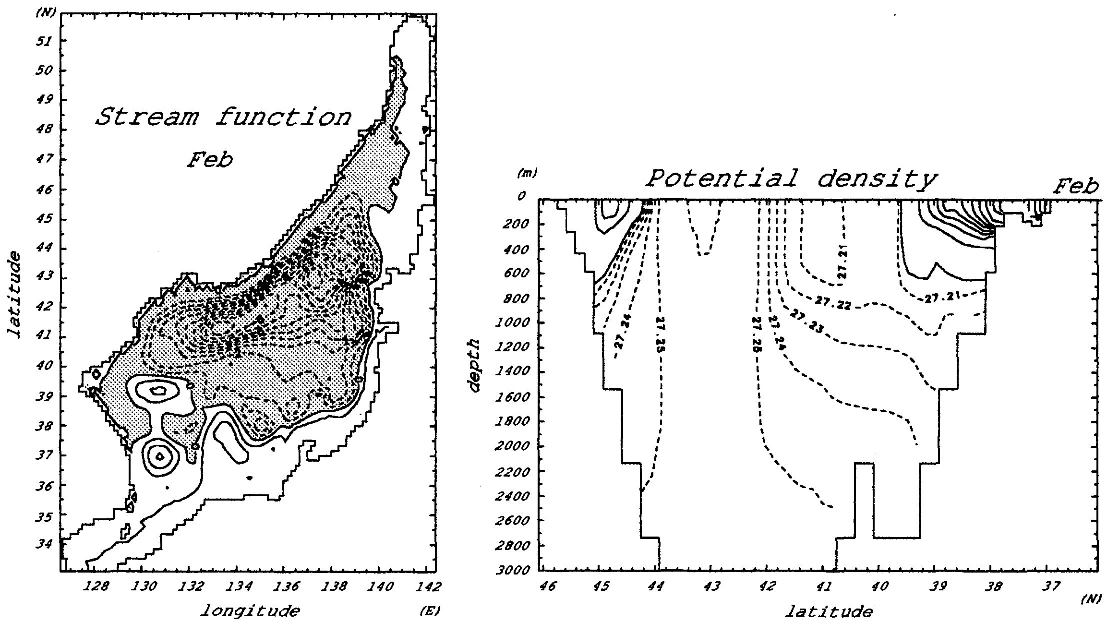

Fig. 1 The stream function (c.i. = 1.0Sv) and the vertical section of the potential density along 137.5°E in February. In the left panel, the hatched area shows less than 0Sv.

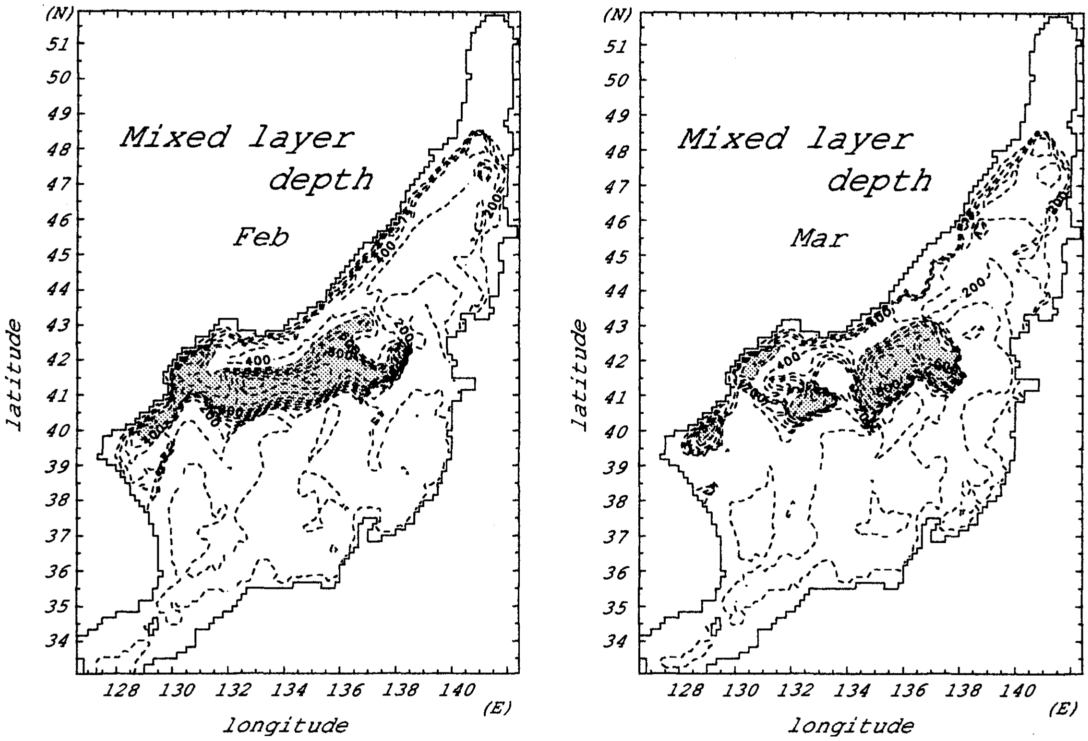

Fig. 2 The mixed layer depth in February and March (c.i. = 100m). The hatched area shows that the mixed layer depth is over 500m.

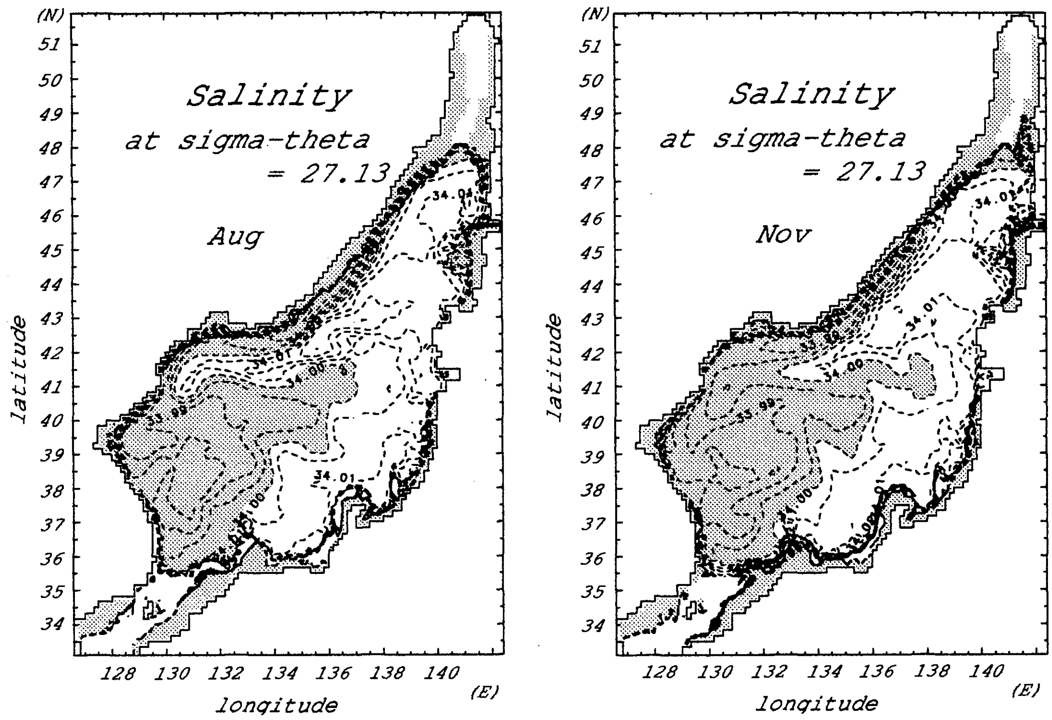

Fig. 3 The salinity field on the isopycnal surface of $\sigma_\theta = 27.13$ in August and November (c.i. = 0.005psu). The hatched area is the low salinity region (less than 34.00psu). In the area where this potential density surface is outcropped or the potential density is less than 27.13 at the bottom, this salinity value is omitted.

in the subsurface, which is called the East Sea Intermediate Water (ESIW). The salinity minimum water in the Japan/East Sea was firstly identified by Miyazaki (1953)[7]. Since then it had hardly been paid attention to on account of its undistinct character in distributions of volume

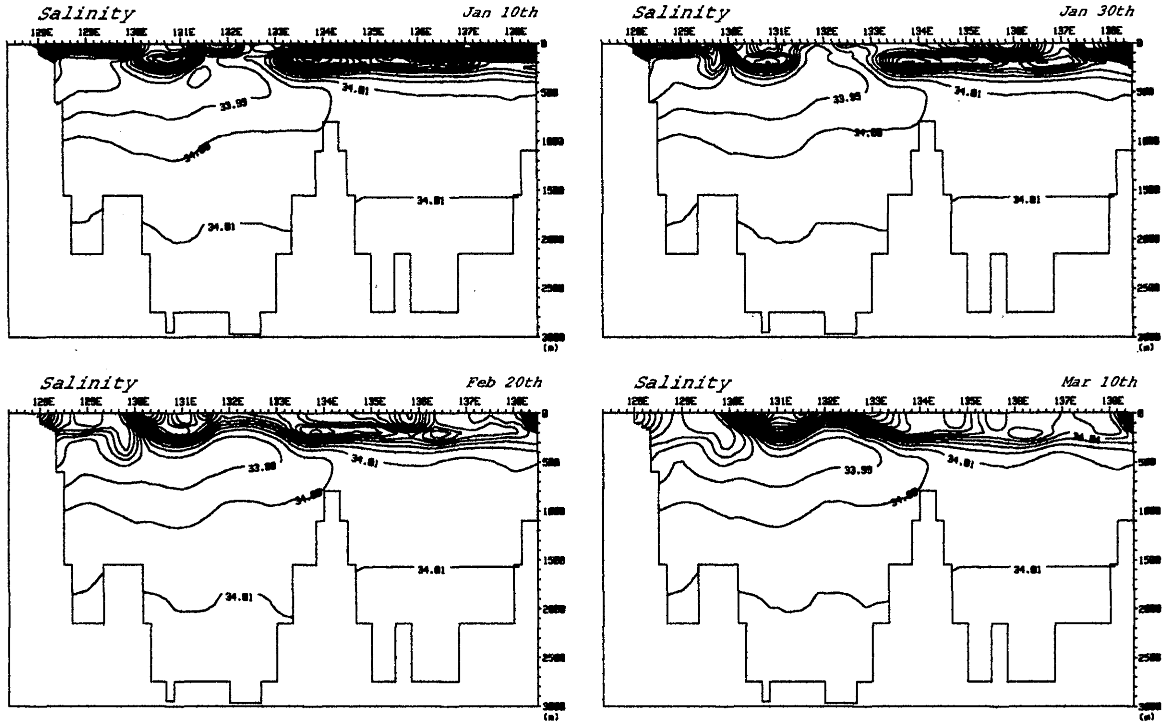

Fig. 4　The vertical section of the salinity along 39°N from January to March (c.i. = 0.01psu).

among potential temperature and chlorinity (Yasui et al., 1967[13], Moriyasu, 1972[8]). However, it is characterized by the salinity-minimum and DO-maximum in vertical profile and plays an important role as a tracer for the circulation in the intermediate layer. Recently, Kim and Chung (1984)[5] found a salinity minimum layer (SML) with a DO-maximum in the southern part of the Ulleung Basin. They named this water the East Sea Intermediate Water (ESIW) because of its distinct similarity to those observed in the central part of the Japan/East Sea (Kajiura, 1958[3]).

Fig. 3 shows the salinity field on the isopycnal surface of $\sigma_\theta = 27.13$ which corresponds to the SML. The cold and fresh water which may originate from the Amur river flows along the Primorski coast and the North Korean coast by Liman Cold Current (LCC) and North Korean Cold Current (NKCC), and spread over northeastward with the tongue structure as the result of advection by the cyclonic circulation north of the polar front. This structure is compared well with the salinity distribution on the isopycnal surface of $\sigma_\theta = 27.28$ by Senjyu (1999)[14].

The vertical section of salinity along 39°N (**Fig. 4**) clearly shows the formation process of ESIW. The low salinity water at the surface is subducted into the intermediate depth toward the east forming ESIW from January after meeting the East Korean Warm Current (EKWC) with high temperature and high salinity.

4. Conclusion

The past circulation in the Japan/East Sea shows the active bottom water formation in the eastern Japan Basin, whereas not in the present circulation. The cyclonic gyre over the Japan Basin associated with the bottom water formation is much stronger than that in the present circulation. In the present circulation in the Japan/East Sea, the UJSPW is formed mainly in the region southeast of Vladivostok. The ESIW is formed by subducting the low salinity water at the surface into the intermediate layer in the region east of Korean coast where the low salinity water from the north meets EKWC with high temperature and high salinity.

The present circulation in our model r reproduces well the real circulation in the Japan/East

Sea, but has some problems. For example, the salinity in the intermediate layer is lower than observational value, and the temperature in the deep layer is about 2.0℃ higher compared with the observed one, and the mixed layer depth is too deep. To solve these problems, we are going to adopt the sheme which suppress the computational diffusion.

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