THE EFFECT OF LOCAL WIND STRESS CURL ON INTERMEDIATE WATER FORMATION

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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 °C/10 years and the dissolved oxygen (DO) has decreased by 5.5 moles/(kg·10 years) in the deep layer of the Japan/East Sea during the second half of this century (Kim *et al.*, 1996, Minami *et al.*, 1997). Riser *et al.* (1999) showed that the deep water formation of the Japan/East Sea has almost stopped at least since 1960s, suggesting the influence of the global climate change. While in the intermediate layer shallower than 1000 m, the DO tends to increase, suggesting the active intermediate water formation which seems to take place mainly off Vladivostok in winter (Senjyu & Sudo, 1996). However the formation process of 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.

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) as surface forcings. The coefficients of horizontal and vertical eddy viscosity are $2.0 \cdot 10^6$ and 1.0 cm^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 (0.35 Sv) 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 0.8 Sv, respectively (Isobe, 1994; Shikama, 1994).

Varlamov *et al.* (1997) have shown that the surface air temperature around the Japan/East Sea has increased by roughly 0.03 °C/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 °C lower than the present one to reproduce the past circulation in the Japan/East Sea. The first 300 years of the integration is considered a spin-up period. Then we integrated it for additional 50 years increasing linearly the air temperature to the present one to reproduce the present state. The model analysis is performed for the last one year and the results after 350 years run are discussed here.

Results

Only the convection down to the intermediate depth (about 900 m) takes place off Vladivostok (132°E-136°E, 41°N-42°N) in the present circulation of the Japan/East Sea. The water below the pycnocline in the Japan/East Sea is very homogeneous (0-1 °C, 33.96-34.14 psu), thus it is called Japan Sea Proper Water (JSPW). The Upper portion of the Japan Sea Proper Water (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) 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. This convergent wind is accompanied by a wind stress vortex pair off Vladivostok. The region with the mixed layer depth over 900 m corresponds to the area of the positive wind stress curl southeast of Vladivostok, suggesting that the UJSPW formation is deeply related to the positive wind stress curl.

There is another formation of remarkable water mass characterized by salinity minimum 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). Since then it had hardly been paid attention to on account of its indistinct character in distributions of volume among potential temperature and chlorinity (Yasui *et al*., 1967; Moriyasu, 1972). 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 & Chung (1984) 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).

The salinity field on the isopycnal surface of 27.13 sigma-theta which corresponds to the SML in our model shows that the cold and fresh water which may originate from the Amur river flows along the Primorsky coast by the Liman Cold Current (LCC), and one branch detours eastward separating from the North Korean coast at around 130 °E. This separating process is due to the cyclonic eddy blocked by isobath between 2000 and 3000 m, which is generated in winter time by the positive wind stress curl and then propagates westward as the Rossby wave. Another branch continues to flow down southward along the Korean coast by the North Korean Cold Current (NKCC) and spreads over eastward 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 27.28 sigma-theta shown by Senjyu (1999).

The vertical section of salinity along 39°N 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.

The formation rate of intermediate water of the Japan/East Sea is investigated through the study of subduction process of the water. The formation rate of intermediate water defined as the volume transport of the mixed layer water transported to the deeper layer during one year is estimated. The detail of method for calculating subduction rate is referred to Yoshikawa *et al*. (1999). The formed intermediate water in the Japan/East Sea mainly ranges from 30.2 to 32.0 sigma-1 with the largest portion 31.7 to 32.0 sigma-1. This result leads to the total formation rate of about 0.477 Sv. Senjyu & Sudo (1996) estimated the formation rate of the UJSPW defined as the potential density between 32.00 and 32.05 sigma-1 to be 0.48 Sv.

Conclusion

In the present circulation in the Japan/East Sea, the UJSPW is formed mainly in the region southeast of Vladivostok which corresponds to the area of positive wind stress curl. There are two mechanisms for the formation of the ESIW. 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 other mechanism is that branch separated from the North Korean coast at around 130°E drives the fresh water along the Primorsky coast into intermediate depth.

The formed intermediate water in the Japan/East Sea mainly ranges from 30.2 to 32.0 sigma-1 with the largest portion 31.7 to 32.0 sigma-1 in our model. Total formation rate of intermediate water all over the Japan/East Sea is about 0.477 Sv which is compared well with the result of Senjyu & Sudo (1996) (0.48 Sv). In our model, the corresponding ventilation time of intermediate water is estimated to be 18.4 years, indicating the intermediate circulation of the Japan/East Sea has the decadal time scale.

The present circulation in our model 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 °C higher compared with the observed one, and the mixed layer depth is too deep. To solve these problems, we are going to adopt the scheme which suppresses the computational diffusion.

References

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