DEEP FLOW FIELD IN THE JAPAN SEA DEDUCED FROM DIRECT CURRENT MEASUREMENTS

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Introduction

The deep water in the Japan Sea (the Japan Sea Proper Water) is characterized by the extreme homogeneity in temperature and salinity. This character makes a difficulty to deduce the deep flow field from the dynamical calculation. Therefore, the flow field in the abyssal Japan Sea has been mainly deduced from water property distributions (*e.g.* Gamo *et al.*, 1986; Senjyu & Sudo, 1993 and 1994).

On the other hand, direct current measurements with moored current mater have been carried out in the Japan Sea, and long-term moorings in the Japan Sea Proper Water were frequently made in the last ten years. For example, Takematsu *et al.* (1999a, b) performed the direct current measurement at seven stations in the Japan Basin in the CREAMS program and revealed a vertically coherent structure of the flow field in the Japan Sea Proper Water. Nowadays the number of direct observational data on deep currents is increasing rapidly. In this study, we collected all the available direct current measurements made by Japanese organizations, and try to deduce the deep flow field in the Japan Sea.

Data

In total 41 moorings data were used in the study. These moorings were made by the Japanese Maritime Safety Agency (the Japanese Coast Guard), the Japan Sea National Fisheries Research Institute, the Hokkaido Fisheries Experimental Station, and the Hokkaido University as well as our CREAMS and Kakuyo-Maru observations. Fig. 1 shows the location of mooring sites; they were distributed in the wide area of the Japan Sea. Most of the current measurements were carried out under the main thermocline of deeper than 500 m and made in the period from 1986 to 1999.

Mean Flow Field in the Japan Sea Proper Water

To see the mean flow field in the Japan Sea Proper Water, average velocities through the observation period were calculated for each current meter and they were regarded as the long-term mean value, though the duration of some current meters is shorter than one year. Further, we averaged the long-term mean values for each mooring line and looked upon it as the representative velocity at each mooring site, because almost all currents indicated the vertically coherent structure as pointed out by Takematsu *et al.* (1999a, b).

Fig. 2 shows the mean flow vectors obtained by the operation. Relatively strong currents of more than 2.0 cm/s are found on the slope of basin peripheries: the eastern and the western boundary of the Japan Basin, around the Yamato Rise, and the southern boundary of the Yamato Basin. These strong currents are in the direction of the isobath seeing the shallow region on its right-hand side; this implies the earth rotation effects. On the contrary, mean flows in the interior region of each basin are very small; for example, slow currents of less than 1.0 cm/s are seen in the center of the Japan Basin and the Yamato Basin. However, it should be noted that flows accompanied by the eddy motion are not small even in the interior region (Takematsu *et al.*, 1999b).

Deep Flow Field Estimated by the Variational Method

In order to estimate the deep flow field in the entire Japan Sea area, the variational method was applied to the observed current field shown in Fig. 2. The variational method used in this study is the Nagashima model developed by Imasato *et al.* (1993). This is the method to obtain the best flow field satisfying the physical constrains of the mass conservation and the vorticity conservation as the Sverdrup relation on the basis of a given sparse flow data.

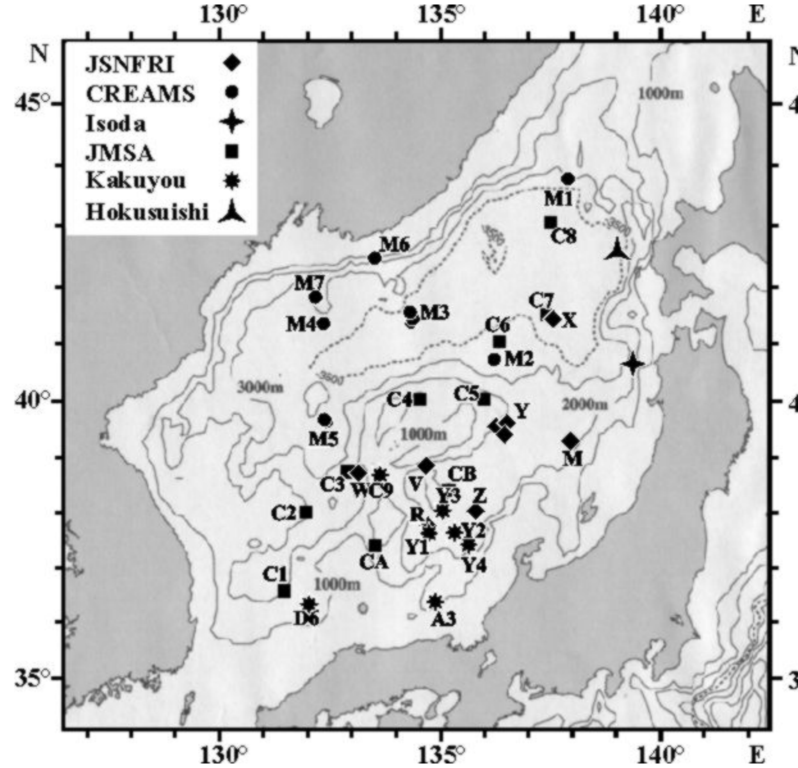

Fig. 1. Positions of mooring stations in the Japan Sea

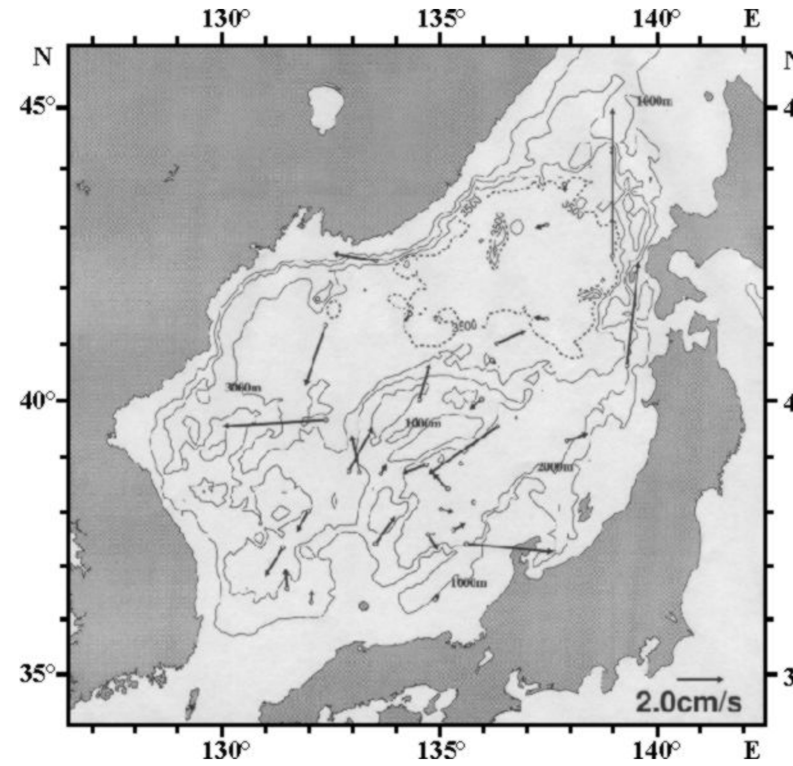

Fig. 2. Averaged direction of deep currents in the Japan Sea

We applied the Nagashima model to the area deeper than 1500 m in the Japan Sea and set the horizontal resolution 1/3 degrees in latitude and longitude, respectively.

The deep flow field estimated by the Nagashima model is shown in Fig. 3. The flow configuration is characterized by the cyclonic circulation along the basin periphery and the weak currents in the interior region. Relatively strong currents exist in the eastern and western parts of the Japan Basin, around the Yamato Rise, and the southern part of the Yamato Basin. This circulation pattern is consistent with the deep flow field deduced from the water property distributions (*e.g.* Gamo *et al.*, 1986; Senjyu & Sudo, 1993 and 1994).

Unacceptable strong currents are seen to the west of the Yamato Rise. These strong westward currents are evidently the influence from the strong current observed at St. M5 (see Figs. 1, 2). This fact indicates that the applied method depends strongly on the initial current field, that is the observed flow field, and in turn, that we have to investigate the observed current data in detail and select the data carefully.

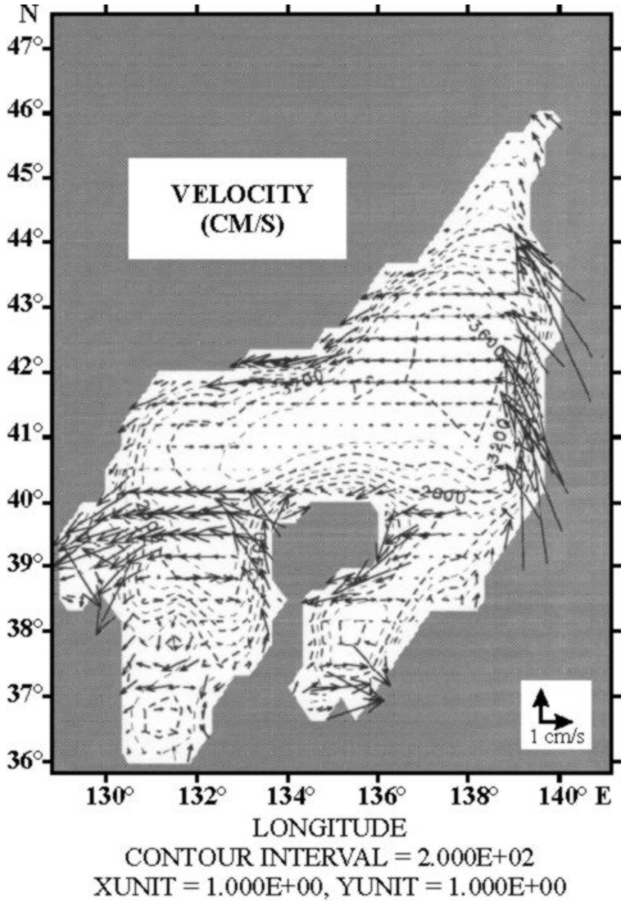

Fig. 3. Calculated deep currents of the Japan Sea by Nagashima model

Seasonal Variation of the Deep Flow Field

Seasonal variation in the deep flow field was examined using the monthly flow field estimated from the monthly mean current data. As the typical example, flow fields in February and August are shown in Fig. 4.

The basic flow pattern is the same in both seasons, though the westward currents to the west of the Yamato Rise is weaker in August than those in February; this is because the observed current at St. M5 becomes weak in summer (Takematsu *et al.*, 1999a). The cyclonic subarctic circulation in the Japan Basin to the north of 40°N is intensified in February compared to that in August; in particular the southwestward currents along the Russian coast are strengthened. This winter spin-up of the subarctic gyre is found in the numerical model made by Kim & Yoon (1999), and they attributed it to the positive wind stress curl associated with the winter monsoon blowing from the Asian Continent.

Remark

In this study, we could image the flow configuration in the Japan Sea Proper Water from the direct current measurements, which is characterized by the cyclonic circulation along the basin periphery and weak currents in the interior region. At the next step, studies on the time variation in the deep flow field are desired.

We confirmed that the variational method is a powerful tool to estimate the deep flow field in the Japan Sea, if the number of direct current observations is increased in the future. However, in the same time, we realized that the improvement of some defects of this method, such as the strong dependency on the observed field and on the assumed parameters, is necessary to obtain the reasonable flow field.

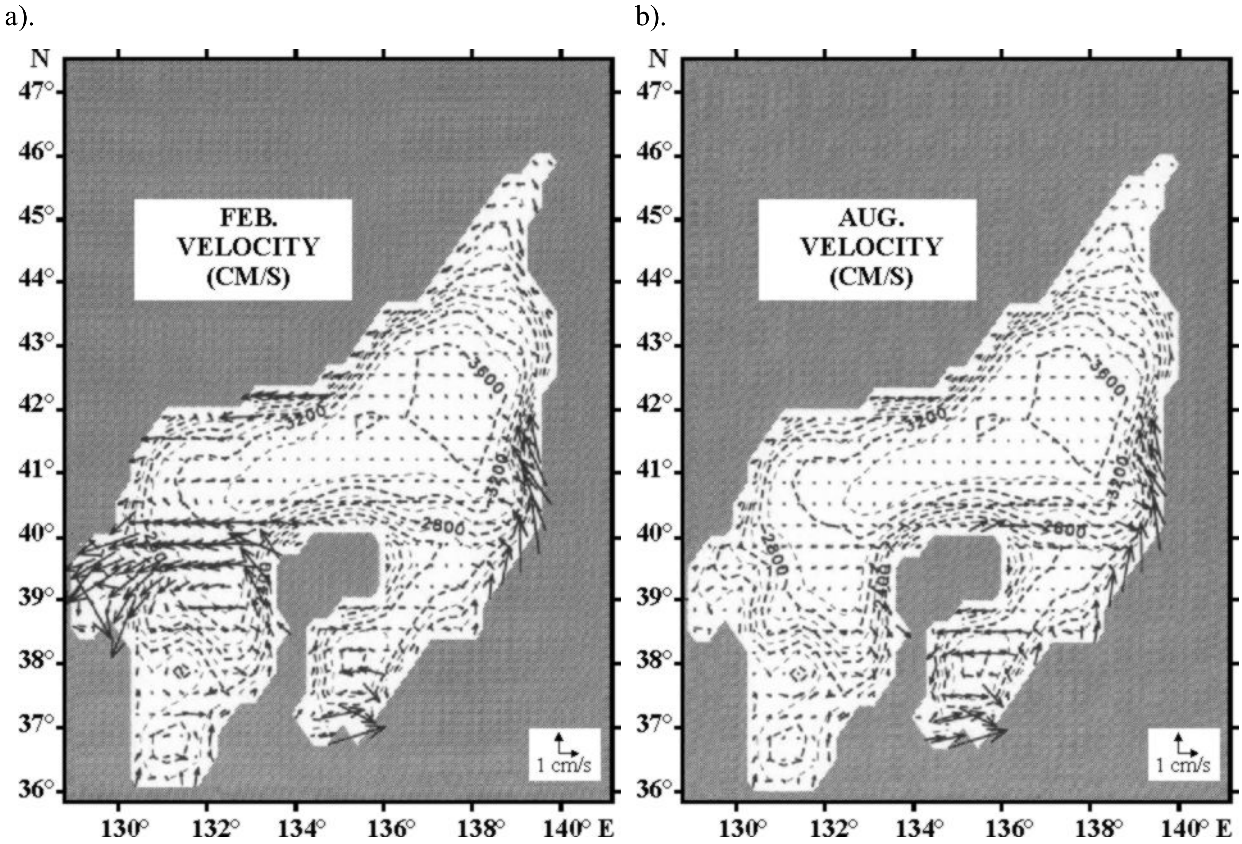

Fig. 4. Monthly flow field estimated from the monthly mean current data, February (a) and August (b)

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