The Japan Sea Proper Water and Water Circulation in the Japan Sea

by

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Abstract

Water circulation in the Japan Sea is characterized as a formation of the Japan Sea Proper Water from the data observed in 1969 by research vessels belonging to the Japan Meteorological Agency.

Below 500m depth in the Japan Sea, salinity is relatively high in the northern part and low in the southern. This is opposite to the conditions in the surface layer, where the northern part is generally the Cold Current Region and the southern part the Warm Current Region. In the southern part of the eastern Japan Basin of the northern Japan Sea, anticyclonic circulation occurs and sea waters sink towards the bottom. In the western Japan Basin and in the Yamato Basin, sea waters flow upward, in contrast to the southern part of the eastern Japan Basin. Therefore vertical water circulation generates in the deep layer of the Japan Sea, that is, downwelling appears in the southern part of the eastern Japan Basin, and upwelling occurs in the western Japan Basin and in the Yamato Basin.

1. Introduction

The Japan Sea is a basin almost enclosed by coasts with an area of 1,300,000 km² and a mean depth of about 1350m. An 85% of the water volume in the Sea is the Japan Sea Proper Water (JSPW), which is extremely homogeneous, i.e. 0–1.5°C in temperature, 34.04–34.10 in salinity and 220–250 μ mol kg⁻¹ in oxity (Asaoka, 1987). In the upper layer above JSPW is the Polar Front along 40°N latitude line which divides the sea into two characteristic water regions. The Cold Current Region exists to the north of the front and the Warm Current Region to the south of it. The former shows low temperature and low salinity, and the latter high temperature and high salinity. The thickness of these surface layers seldom exceeds 400m. The waters of the latter are the Tsushima Warm Current Water or the modified Tsushima Warm Current Water.

Since Suda (1932) described the mechanism that produces JSPW, many reports have been published, and it has been known that low temperature and high salinity waters are produced when sea waters freeze in winter. Those brined waters must therefore have sunk into the deep layer and formed JSPW (i.e. Oowada and Tanioka, 1971. Nitani, 1971. Nitani, 1972).
Noriki et al. (1988) pointed out from the distribution of tritium and chlorofluorocarbons existing in sea waters that JSPW is produced in the north of the Japan Sea where a rapid vertical water mixing between the surface layer and the deep layer occurs, and that the stagnation time of deep waters is 50~60 years in the deep layer.

Nishiyama et al. (1990) reported from long-term data observed by the Maizuru Marine Observatory in the Japan Sea as follows: warm eddies which have generated with high salinity waters of the upper layer in the Warm Current Region, move into the Cold Current Region, and increase their density cooled by the surrounding cold waters. Consequently, these waters must have sunk into the deep layer and formed JSPW.

Cooperative observation with five research vessels belonging to the Japan Meteorological Agency in 1969 was the first and last plan for the whole of the Japan Sea with latitude~13' and longitude~134'E. Based on these data, Oowada Tanioka (1971) analyzed as follows: there are a cyclonic circulation in the eastern Japan Basin and anticyclonic ones in the western Japan Basin and in the Yamato Basin with a velocity of a few cm s⁻¹, in the deep layer of the Japan Sea. JSPW is produced with brined waters in the far northern area off Primorski Krai (Enkaishu) in winter.

In this paper, the authors reanalyze the data of this cooperative observation, and reconsider the water circulation of the Japan Sea with reference to the formation of JSPW.

2. Temperature distribution of the Japan Sea

Figures 2 show the temperature distributions of the Japan Sea at depths of 100m (2-a), 500m (2-b), 1000m (2-c) and 2000m (2-d), respectively. The isotherm of 4°C at 100m depth (2-a) approaches from 39°N, 131°E, meandering to 41°N, 139°E west of the Tsugaru Strait and then turns to the north. This isotherm indicates the Polar Front. The area of temperatures lower than 4°C to the north of the Front corresponds to the Cold Current Region and the area of higher temperatures that lies to the south of it corresponds to the Warm Current Region. There are two warm eddies with a high temperature core (17°C and 16°C, respectively) whose centers are situated at 38°N, 133°E and at 38.5°N, 135.5°E, respectively.

Temperature distribution at 500m depth (2-b) of the Japan Sea mostly appears lower than 1°C. Higher temperatures than 0.4°C can be seen in the northeast part of the Sea. This is different from the condition at 100m depth where relative by low temperatures appear to the north of the Front. Temperature distributions at depths of 1000m (2-c) and 2000m (2-d) appear to be almost uniform ranging from 0.12°C to 0.26°C.

3. Salinity distribution of the Japan Sea

Figures 3 show the salinity distributions of
Fig. 2  Temperature (°C) distribution in the Japan Sea at the depths of 100m (a), 500m (b), 1000m (c), and 2000m (d). The dotted line shows isobath of each depth.
the Japan Sea at depths of 100m (3—a), 500m (3—b), 1000m (3—c), and 2000m (3—d), respectively. At 100m (3—a) depth, the isohaline of 34.1 corresponds to the isotherm of 4°C in Fig. 2—a which indicates the Polar Front. Salinity is lower than 34.1 to the north and higher to the south of the Front. Centers of the warm eddies which correspond respectively to 17°C and 16°C in Fig. 2—a, show 34.5 in Fig. 3—a. At 500m depth (3—b), the isohaline of 34.06 lies nearly along 40°N latitude line. Relatively, salinity is higher than 34.06 to the north and lower than 34.06 to the south of it, which is opposite to the features at 100m depth, that is, low in the north and high in the south (3—a). There are three high-salinity zonal regions whose centers show 34.07, 34.09, 34.08 respectively at 132°E, 135°E and 138°E along 41°N latitude line in the relatively high salinity area north of 40°N. The warm eddies which appear at 100m depth can not be seen at this depth.

At a depth of 1000m (3—c), the high salinity region over 34.07 is widely seen in the eastern Japan Basin, 40°-42°N, 134°-140°E, and low salinity regions below 34.06 are shown in the western Japan Basin, in the Yamato Basin and in the Tsushima Basin. At a depth of 2000m (3—d), the salinity distribution is similar to that at 1000m depth. The high-salinity region over 34.07 whose center shows 34.09 at 41°N, 136°E, dominates the eastern Japan Basin. Low-salinity regions below 34.07 appear in the western Japan Basin and in the Yamato Basin. These have complex high and low distributions, in comparison with temperature distributions at depths of 1000m (2—c) and 2000m (2—d) of Fig. 2, which show great uniformity.

Figures 4 show the salinity distributions at depths of 100m (4—a), 500m (4—b) and 1000m (4—c) in summer just before the cooperative observation of five research vessels belonging to the Japan Meteorological Agency in fall 1969. Lower salinities than 34.1 at 100m depth (4—a), higher than 34.06 at 500m depth (4—b) and higher than 34.065 at 1000m depth (4—c) can be seen to the north of the Front (Japan Maritime Safety Agency, 1973). But the circular shape of the high-salinity region cannot be clearly seen in the eastern Japan Basin.

4. Salinity section of the Japan Sea

Figure 5—a shows the salinity section along 41°N latitude line which crosses the southern part of the eastern Japan Basin to the east of st. D--9 and the northern part of the western Japan Basin to the west of st. D--10. There are three high-salinity regions whose cores indicate 34.07 at st. D--11, 34.09 at st. D--8 and 34.08 at st. D--5, respectively, at 500m depth. In layers lower than 1000m depth, isohalines of 34.08 and 34.09 rise from the bottom in the center of the eastern Japan Basin like a convex type. Fig. 5—b shows the salinity section in the NW—SE direction in the middle of the Japan Sea which crosses the center of the western Japan Basin in the north of st. F--8. Salinity in its vertical profile monotonously increases with depth except in the surface layer, in comparison with the complex profile of Fig. 5—a, and layers lower than 1000m depth, the isohaline of 34.07 indents towards the bottom, which is opposite to the convex in Fig. 5—a.

5. Dynamic height anomaly of the Japan Sea

Figure 6—a shows the dynamic height anomaly of the sea surface referred to the 50-bar level (near 500m depth). The contour of 0.50 (m² s⁻²) runs from 131°E to 137°E nearly along 40°N latitude line, and then turns to the north through 41°N, 139°E. Anomaly is relatively small to the north of the contour and is large to the south of it. Larger regions than 0.90 correspond to the warm eddies seen in Fig. 2—a and Fig. 3—a. Fig. 6—b shows that of the 50-bar layer referred to the 100-bar level. A wide region (40°-42°N, 132°-140°E) with values less than 0.360 appears, and the eastern Japan Basin except its northern part seems a relatively small anomaly area. On the other hand, the western Japan Basin is occupied by larger anomalies than 0.360 and the Yamato Basin by larger ones than 0.366. Fig. 6—c shows that of the 100-bar layer referred to the 200-bar level, which is similar to Fig. 6—b. Anomalies in the eastern Japan Basin except a part of it are smaller than 0.700. Those in the western part of
Fig. 3  Same as Fig. 2 except salinity.
Fig. 4 Salinity distribution in the Japan Sea at the depths of 100m (a), 500m (b), and 1000m (c) in summer 1969.
the Japan Sea are near 0.706 and those in the Yamato Basin are larger than 0.710.

6. Concluding remarks

In the Japan Sea, the eastern Japan Basin has relatively high salinity and small dynamic height anomaly except in the surface layer from Fig.3 and Fig.6. It seems that the higher in salinity, the smaller in anomaly. This suggests that the dynamic structure of the Japan Sea depends only on salinity distribution in deep layers, because temperature, which is uniformly very low, cannot contribute to the density structure.

Then if the no-motion level is taken in a shallower layer than 500m depth, the small dynamic height anomaly region shows an anticyclonic circulation in a deep layer. But if the no-motion level were taken in a deeper layer than 2000m depth near the bottom, the small anomaly region would show an cyclonic motion in the lower layer (Oowada and Tanioka, 1971). In the Japan Sea, salinity distribution in the deep layer is quite different from that in the surface layer. In a deep layer below 500m depth, it is relatively high in the northern part and low in the southern part, which is opposite to the features of the surface layer (Fig.3). These facts can be seen in the data of the R/V Takuyo belonging to the Japan Maritime Safety Agency (Fig. 4). There must be a boundary layer between the two different ocean structures. We consider that it is proper to take this boundary (no-motion level) between the surface layer and the deep layer from different structures of salinity distribution.

In experiments of rotating fluid dynamics, when relatively heavy water is poured into lighter water in a rotating tank, heavier water sinks towards the bottom and makes an anticyclonic circulation near the bottom, and the boundary between light and heavy water becomes convex in shape from the bottom.
Fig. 6 Dynamic height anomaly (m$^2$ s$^{-2}$) in the Japan Sea at surface referred to 50 bar (about 500m depth) level (a), 50 bar layer referred to 100 bar level (b) and 100 bar layer referred to 200 bar level (c).
From Fig. 5-a, the shape of the isohaline in the eastern Japan Basin is convex from the bottom. This phenomenon means that heavy sea (saline) waters sink into the deep layer and an anticyclonic circulation occurs as in Fig.3 and Fig.6. On the other hand, in the western Japan Basin the isohaline indents towards the bottom as in Fig. 5-b. This feature shows an opposite sense of the eastern Japan Basin. Though this does not necessarily mean that sea waters flow upward, we consider that sea waters may be upwelling there, for the sole reason of the cyclonic circulation in Fig.6. As in the western Japan Basin, the isohaline indents towards the bottom as in Fig. 5-b. This feature shows an opposite sense of the eastern Japan Basin. Though this does not necessarily mean that sea waters flow upwar1, we consider that sea waters may be upwelling there, for the sole reason of the cyclonic circulation in Fig.6. As in the western Japan Basin, sea waters may upwell in the Yamato Basin. Therefore in the deep layers of the Japan Sea, a vertical circulation is generated, in which downwelling occurs in the eastern Japan Basin and upwelling in the western Japan Basin and in the Yamato Basin.

The study of the formation of deep waters is eagerly carried on in the European Polar seas of the Atlantic Ocean, for the Greenland Sea Deep Water contributes to the deep waters of all the oceans of the World (Greenland Sea Project group, 1990). Production rates and turnover times due to deep convection for the Greenland Sea Deep Water are quantitatively studied, based on the distribution of tracers (³H, ³He and chlorofluorocarbons) with a kinematic box model (Heinze et al., 1990). We think the mechanism of producing JSPW to be something like the following. Warm eddies, whose surface water is high-salinity water produced south of the Polar Front, invade north of the Front and, being cooled by the surrounding cold waters, sink to the bottom. In this way, cold saline waters are successively supplied to the deep layers in the eastern Japan Basin. Then the waters supplied sink towards the bottom. Simultaneously, sinking waters generate an anticyclonic circulation in the southern part of the eastern Japan Basin. In this process, JSPW is produced qualitatively. But this is not quantitative.

Fortunately the R/V Seifu-Maru III of the Maizuru Marine Observatory was completed in January 1993. And the joint research program between the Meteorological Research Institute and the Maizuru Marine Observatory called “Research for Water Circulation Structure in the Northern Japan Sea” began in 1992. It is expected that this problem will be made clear on the basis of new and accurate data.

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日本海固有水の生成と日本海の海水循環

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1969年に行われた気象庁の5船共同観測の資料を基に日本海固有水の生成に関連した、日本海の深層の鉱直循環について考察した。

日本海の表層は、極前線を境に北側を寒流域、南側を暖流域と呼ばれ、この表層水は400m深より深くなることはない。これより深層では表層とは逆に、北側が高塩分で、南側が低塩分となっていて、日本海北部の日本海盆東部では高気圧性循環がみられ、海水は沈降し日本海固有水の形成に関与している。そして、日本海盆西部や大和海盆では浅昇している。

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