CHARACTERISTIC FEATURES OF THE KUROSHIO WITH AND WITHOUT THE COLD WATER MASS SOUTH OF ENSHUNADA

Rikiishi, Kunio
Research Institute for Applied Mechanics, Kyushu University : Associate Professor

Umatani, Shin-ichiro
Research Institute for Applied Mechanics, Kyushu University : Research Associate

https://doi.org/10.5109/6610209

出版情報：Reports of Research Institute for Applied Mechanics. 25 (79), pp.79-101, 1977-12. 九州大学応用力学研究所
バージョン：
権利関係：

Reports of Research Institute for Applied Mechanics
Vol. XXV, No. 79, 1977

CHARACTERISTIC FEATURES OF THE KUROSHIO WITH AND WITHOUT THE COLD WATER MASS SOUTH OF ENSHUNADA

Kunio RIKIISHI* and Shin-ichiro UMATANI**

The data of GEK measurements for these eighteen years and serial observations for these fifty years have been analyzed statistically in order to clarify characteristic features of the Kuroshio with and without the Cold Water Mass south of Enshunada.

The warm eddy south of the Kuroshio between 133° and 138° E has been delineated clearly. The eddy for the period when the Cold Water Mass is absent is larger in scale and more extensive in the fall of isotherms than that for the period when it is present. It has been found that a remarkable difference in the path of the Kuroshio east of Honshu is seen in a statistical sense between the two modes of the Kuroshio meander: when the Cold Water Mass is absent the path of the Kuroshio broadens and fluctuates to the north and south, while the path is confined in a narrow zone when it is present. The volume transport of the Kuroshio is about $50\times10^6\,m^3/sec$ at the region south or southeast of Shikoku, irrespective of whether the Cold Water Mass is present or absent. While the transport decreases gradually toward the east from $50\times10^6\,m^3/sec$ to $30\times10^6\,m^3/sec$ when the Cold Water Mass is present, the transport keeps roughly a constant value of $50\times10^6 m^3/sec$ when it is absent.

Geographical examination of detailed features of the Kuroshio meander and the Cold Water Mass south of Enshunada suggests a close dynamical relationship between the kuroshio and the bottom topography. Vertical structures of temperature fields have been presented in Appendix.

1. Introduction

The displacement of the current path of the Kuroshio to the south of Honshu between 136° and 140° E, associated with the Cold Water Mass of radius about 100 km, is one of the most outstanding features of the Kuroshio having no counterpart in the Gulf Stream. During these fifty years, the displacement or meander of the Kuroshio has occurred four times: 1934 to 1944, 1953 to 1955, 1959 to 1963, and from 1975 up to present (October, 1977). Exclusive of those periods, the Kuroshio current flowed eastward in the region south of Honshu between 133° and 140° E.

* Associate Professor, Research Institute for Applied Mechanics, Kyushu University.
** Research Associate, Research Institute for Applied Mechanics, Kyushu University.

This bimodal behavior of the Kuroshio path has been a most interesting and challenging subject to be explained, and a number of authors have proposed various hypotheses in their attempts to give a plausible physical explanation (Uda[1] 1949, Nan'niti[2] 1958, Fukuoka[3] 1960, Ichie[4] 1960, Robinson and Taft[5] 1971, Nitani[6] 1975, White and McCreary[7] 1976, and others). Despite those attempts, it may be fair to say that none of them is considered to be conclusive as yet.

In order to have an insight into the physical mechanism of the Kuroshio meander, the need for direct observation of the vertical structure and volume transport of the Kuroshio current should be emphasized. At the same time, it is also important to study the statistics of the Kuroshio based on a vast number of the surface current measurements and serial observation data. Indeed detailed knowledge on overall features and time variations of the Kusoshio is indispensable for the further comprehensive study of the Kuroshio system.

A statistical study of the Kuroshio was made first by Winterfeld and Stommel[8] (1972), and also by the Japan Oceanographic Data Center[9] (1975) in a more detailed manner. Although they succeeded in showing gross features of the Kuroshio, the results contained some ambiguities arisen from the fact that all observations for these fifty years were averaged regardless of whether the meander was present or absent.

The object of the present study is therefore to delineate separately averaged features of the Kuroshio with and without the Cold Water Mass in order to find possible differences in the Kuroshio system between the two modes. Statistical analysis of the variation of the Kuroshio will be appear in other papers*.

2. Data and data analysis

Observational data of the surface currents and oceanographic elements of the adjacent seas of Japan have been collected by the Japan Oceanographic Data Center (JODC), established in 1965, from both domestic and foreign institutions. The original data files on magnetic tapes of the JODC cover the area of 0°-48°N and 100°-170°E. The total number of surface current measurements by GEK during the period from 1953 to 1970 amounts roughly to 80000, and that of serial observations by Nansen bottle during the period from the beginning of the twentieth century to 1972 amounts to 110000.

Of all those data, the observations for the area bounded by 20°N, 40°N, 120° E, and 150° E, excluding the Japan Sea, have been analyzed in the present study. In the statistical analysis of oceanographic elements such as temperature, salinity, dissolved oxygen, sigma-t and dynamic depth

* A preliminary study of the time variation of the Kuroshio has been made elsewhere (Rikiishi[10], 1976).

anomaly, only the values interpolated from observations to standard depths (0m, 50m, 100m, 150m, 200m, 250m, 300m, 400m, 500m, 600m, 800m, 1000 m) have been utilized. For detailed information on the number of serial observations at those depths, the reader should refer to the Marine Environmental Atlas[9] published by the JODC in 1975.

Those observational data have been processed as follows. First, all data have been divided into two groups according to the absence or presence of the Kuroshio meander in view of the historical position of the Kuroshio axis south off Daiozaki (Shoji[11], 1972). Specific chronological divisions of the period for the two modes are:

a) GEK measurements
   meander absent; 1956-1958 and 1964-1970.
   meander present; August 1953-1955 and July 1959-1962.
b) Serial observations
   meander absent; 1923-1933, 1944-1952, 1956-1958, and 1964-1972.
   meander present; May 1934-1942, August 1953-1954, and July 1959-1961.

Note that we have omitted some observations corresponding to the periods when the path of the Kuroshio was considered to be in a transient state between the two modes.

Second, the data have been sorted geographically by one-degree square. The one-degree square is defined so that every intersection of meridians and parallels of latitudes of integral degrees is centered at the square, considering the fact that Japanese observations of the Kuroshio were often conducted along fixed meridans or parallels of latitudes of integral degrees.

Finally the data for one-degree square have been averaged and the standard deviations have been also computed. It is noted here that, while all serial observations have been used for the computation of the scalar average, the highest 3/4 of the total GEK measurements have been used for both the scalar and vector averaging. Some results of analysis are presented below.

3. Surface currents of the Kuroshio

The vector averages of the GEK measurements by one-degree square have been shown in Figs. 1 (a) and 1 (b) for the periods when the meander was absent and present, respectively. To make up for some ambiguities seen in these figures, the dynamic depth anomalies, referred to 1000 db, at the sea surface have been also shown in Figs. 2 (a) and 2 (b). Characteristic features of the surface currents for the Kuroshio with and without the Cold Water Mass are now clear. These figures may tell us much about the nature of the Kuroshio.

Anti-cyclonic eddies can be seen clearly to the south of the Kuroshio bet-

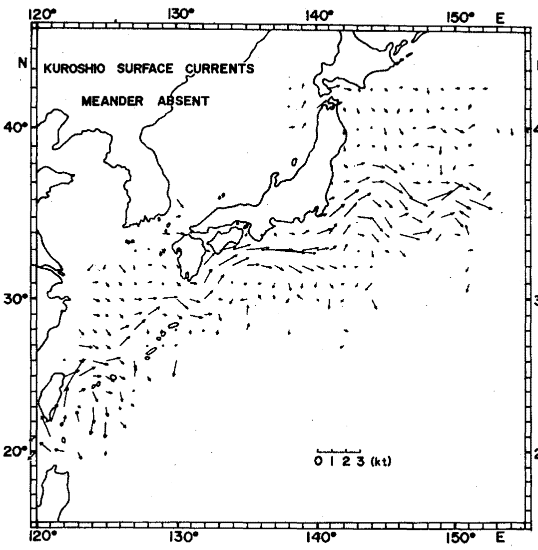

Fig. 1(a). Surface currents of the Kuroshio for the period when the meander was absent. Some one-degree squares with number of observations less than 5 are ignored.

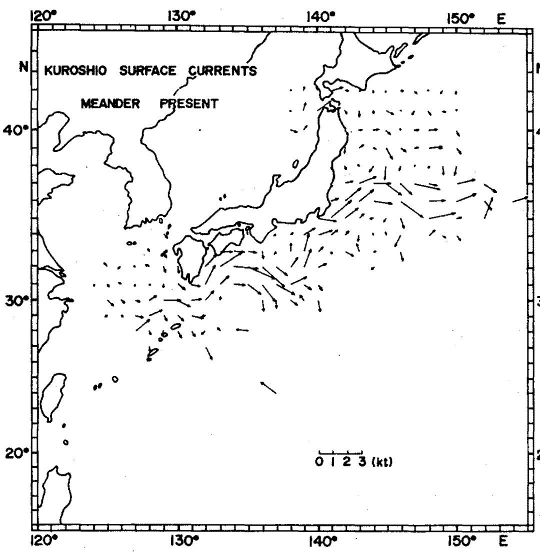

Fig. 1(b). Surface currents of the Kuroshio for the period when the meander was present. Some one-degree squares with number of observations less than 5 are ignored.

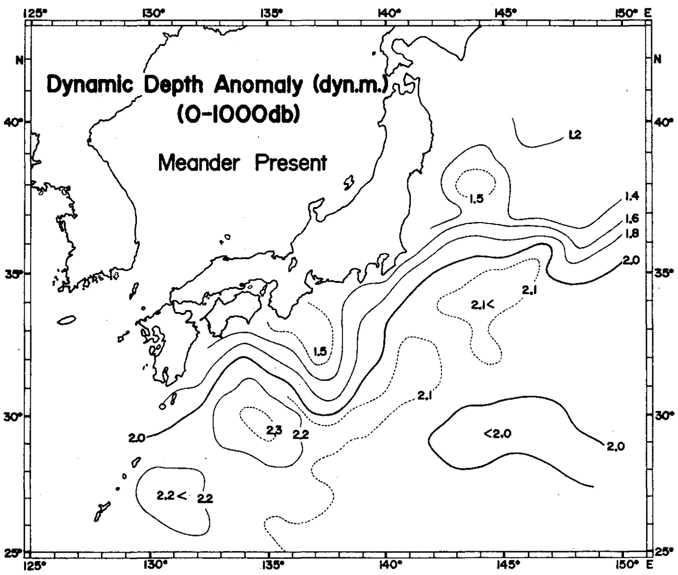

Fig. 2(a). Dynamic depth anomaly for the period when the meander was absent (0-1000db).

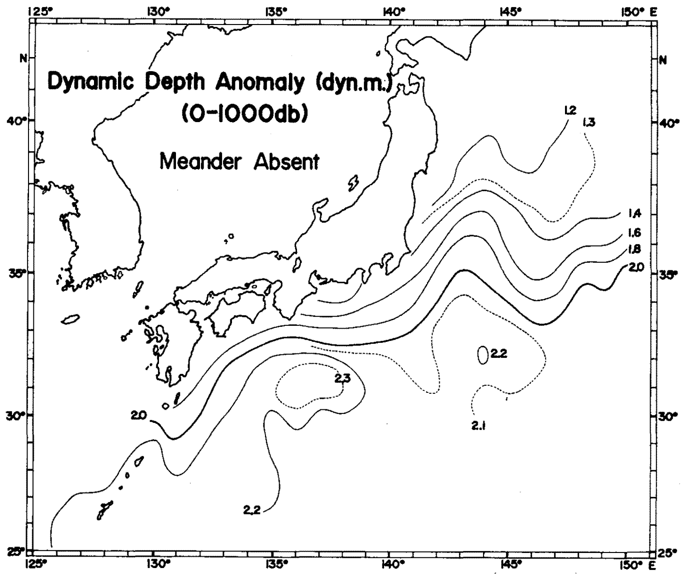

Fig. 2(b). Dynamic depth anomaly for the period when the meander was present (0-1000db).

ween 134° and 139° E (when the meander was absent*) or between 132°30′ and 136°30′ E (when it was present). These eddies will be referred again in some detail in Section 6.

East of 140°E, the path of the Kuroshio broadened and fluctuated to the north and south in a statistical sense when the meander was absent, while the current flowed roughly eastward in a narrow zone between 35°30′ N when it was present. This is a remarkable difference in current path between the two modes of the Kuroshio. This narrow zonal path of the Kuroshio can be also inferred from Fig. 57 of Kawai [12] (1972) representing the northernmost position of the Kuroshio between 142° and 146°E in chronological order. The gentle slope of dynamic topography in Fig. 2(a) may not suggest that the width of the Kuroshio widened abruptly in the eastern region, but probably that the axis of the Kuroshio stream moved to the north and south from time to time. Indeed the figure of Kawai [12] (1972) seems to indicate the existence of long-term variations in the Kuroshio axis east of Honshu when the meander was absent.

In Figs. 1 (b) and 2 (b) a clockwise cut-off eddy is seen to the north of the Kuroshio between 142° and 145°E. The figures may suggest that eddies formed in this region and stayed there for relatively long time. In fact, Kimura (1975, unpublished manuscript) reported that clockwise eddies appeared in the region and moved slowly toward the north. In his report, however, the eddies formed generally twice a year whether the meander was present or absent, while the eddy is seen in our figures only when the meander was present. This may reflect the fact that the area of eddy formation was geographically fixed when the meander was present, while it moved to the north and south when the meander was absent. (It is noted additionally that an eddy is also seen in Figs. 1 and 2 to the south of the Kuroshio between 142° and 146°E.)

Apart from the Kuroshio south and east of Honshu, one of the most remarkable results shown in Fig. 1 (a) is that most of velocity vectors for the East China Sea indicate eastward surface currents. One cannot recognize in the figure the existence of the Tsushima Current which is expected to flow northward towards the Japan Sea. Although this is quite different from what was long believed in the past, the result seems plausible because the average current vectors show a quite good continuation in current direction, and because Nishida and Hori (1975, unpublished manuscript) demonstrated that GEK measurements in the East China Sea agreed well with the direct current observations. Long-term observation of the subsurface current as well as the surface current is needed in order to obtain a decisive conclusion.

* Because the Cold Water Mass is always accompanied by the meander of the Kuroshio, the expression "the Cold Water Mass was absent (present)" will be often replaced in this paper by "the meander was absent (present)".

4. Volume transport of the Kuroshio

In his study of the volume transport of the Kuroshio, Nitani[13] (1972) pointed out that the transport of the Kuroshio varied from time to time showing smaller values when the meander was present. On the basis of this fact, Nitani[6] (1975) and White and McCreary[7] (1976) have proposed theories by which the smaller transport of the Kuroshio was related to the beginning of the Kuroshio meander. On the other hand, other authors including Hayami[14] (1955), Robinson and Taft[5] (1972), Ishii and Toba[15] (1976), and Matsukawa[16] (1977) assumed that the depth to which the Kuroshio extended was a key factor in the meandering phenomena.

Anyway it is clear that direct measurement of the transport and vertical structure of the Kuroshio current is primarily important for the dynamical study of the Kuroshio. However, we have not succeeded as yet in the direct observation of the Kuroshio by current meters. In order to obtain some information on the transport and vertical structure of the Kuroshio, therefore, we must resort to the dynamic calculation of the geostrophic flow assuming a level of no motion.

Three meridional zones have been selected for the study of the transport of the Kuroshio for each of the two periods: 135°-136° E, 137°-138° E, and 143°-144°E when the meander was absent; 133°30′-134°30′E, 137°-138°E, and 143°-144°E when it was present. Along these zones the average dynamic depth anomalies have been computed for every 30′ (north-south) × 60′ (east-west) square. Then eastward geostrophic flow has been computed. Finally the results have been smoothed with hanning's weights (0.25, 0.50, 0.25).

An example of the vertical profile of geostrophic flow has been shown in Fig. 3 for the meridional zone of 137°-138°E. It can be seen from the figure that when the meander was absent the transport was larger, the current speed was higher, and the width of the Kuroshio was narrower as compared with those for the period when the meander was present. The volume transport of the counter current south of the Kuroshio (when the meander was absent) amounted to 15.8×10^6 m^3/sec, while the transport of the counter current north of the Kuroshio (when the meander was present) amounted to 6.8×10^6 m^3/sec.

As for the question whether or not the Kuroshio extended deeper in the period when the meander was present than in the period when it was absent, no conclusion can be drawn from the figure.

The volume transports at the three meridional zones have been given in Table 1 for each of the two periods. It is noteworthy that no significant difference in the transport of the Kuroshio south of Shikoku is seen between the two modes. When the meander was present the transport decreased towards the east, from 52×10^6 m^3/sec to 31×10^6 m^3/sec. This decrease in the transport towards the east seems to be explained by the existence of the clockwise eddy between 132° and 136°E and the cyclonic eddy between

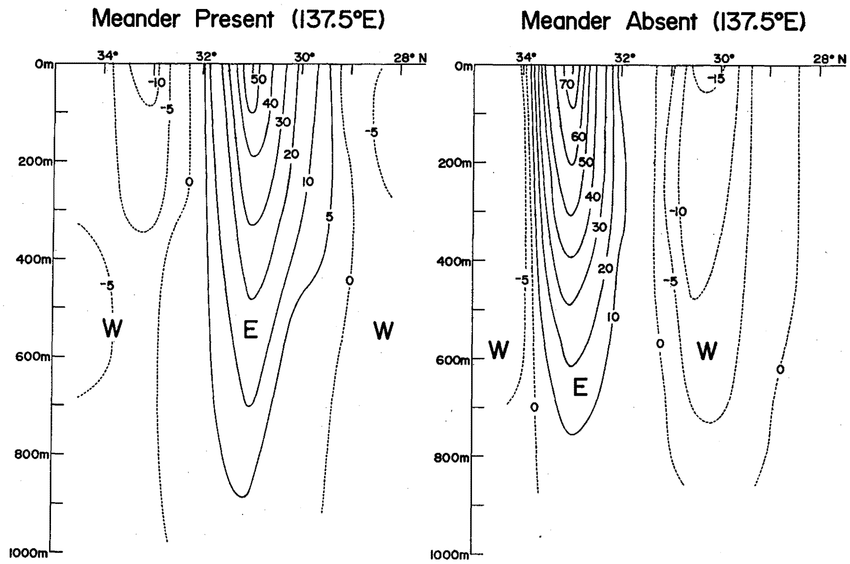

Fig. 3. Vertical structure of geostrophic flow for the meridional zone of 137°-138°E (unit in cm/sec).

Table 1. Eastward volume transport of the Kuroshio at three zones.

Meander Absent	(135°—136°E)	(137°—138°E)	(143$_o$—144°E)
	51.4	53.3	50.0
Meander Present	(133°30′—134°30′E)	(137°—138°E)	(143°—144°E)
	52.1	38.1	31.0

(unit in $10^6 m^3/sec$)

136° and 139°E. When the meander was absent, on the other hand, it kept roughly a constant value of 50×10^6 m^3/sec along the path of the Kuroshio. Considering the westward transport by the Kuroshio Countercurrent[17] (30°-31°N, 134°-139°E), however, it is likely that the transport of some 15×10^6 m^3/sec was added to the Kuroshio from the north and/or south in the region east of Honshu.

5. The Kuroshio meander and the Cold Water Mass

So far we have described characteristics of the bimodal behavior of the Kuroshio. Now it may be appropriate to see detailed features of the Kuroshio meander and the Cold Water Mass by reproducing some results of Rikiishi[18] (1974).

The 30-minute square averages of the surface currents of the Kuroshio meander have been shown in Fig. 4 for the years 1960 to 1962. The figure delineates well the mean feature of the meander and the cyclonic eddy rotating slowly anticlockwise. In Fig. 5 the distribution of index K defin-

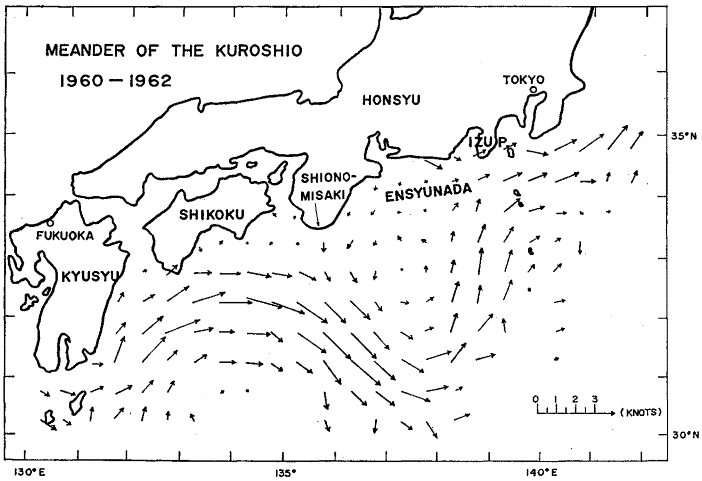

Fig. 4. Surface currents of the Kuroshio meander for the years 1960 to 1962. Some 30-minute squares with the number of observations less than 5 are ignored.

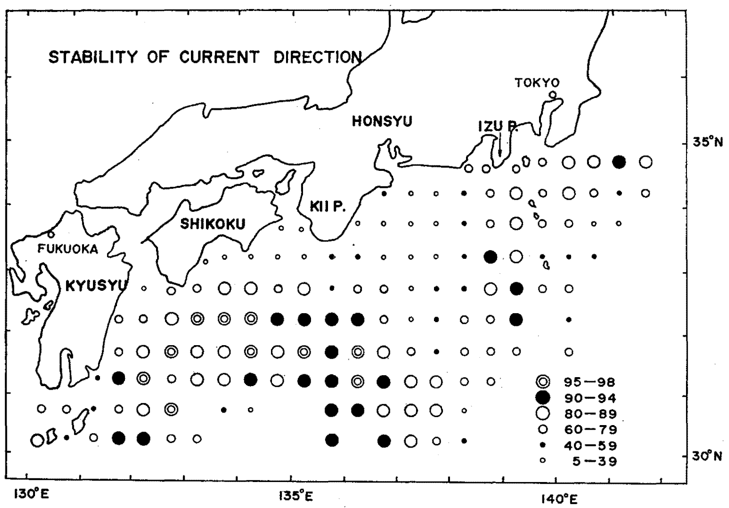

Fig. 5. Stability index K for the Kuroshio meander. Some 30-minute squares with the number of observations less than 5 are ignored.

ed by $K=[|\overline{\mathbf{U}}|/\overline{|\mathbf{U}|}]\times 100$, where $|\overline{\mathbf{U}}|$ denotes the speed of vector averaged velocity and $\overline{|\mathbf{U}|}$ the average of current speeds, has been presented.

On inspecting these figures, one may find that characteristics of the meander in the west side of 138°E are different in several respects from those in the east side. First, the speed of vector averaged velocity amounts to about 2.0 knots in the west side, and 1.3 knots at most in the east side. Taft[19] (1972) also pointed out the abrupt decrease in current speed along the path of the meander between 137° and 138°E. Second, the stability index K is larger in the west side and smaller in the east side. It is noteworthy that the meander shows remarkably high stabilities in current direction (about 95) in the west side despite of the extensive displacement of the stream axis. The K decreases rather abruptly to its minimum (about 70) in the region between 138° and 139°E, and increases again to 80–90 along the northward path of the meander in the western flank of the Izu Ridge.

To see the relation between the Kuroshio meander and the bottom configuration, the sea-floor topography south of Honshu has been shown in Fig. 6. The mean region of the Cold Water Mass estimated from Fig. 4 has been also indicated in the figure by the hatched area. It is impressive that the region of the Cold Water Mass is confined in an area bounded by

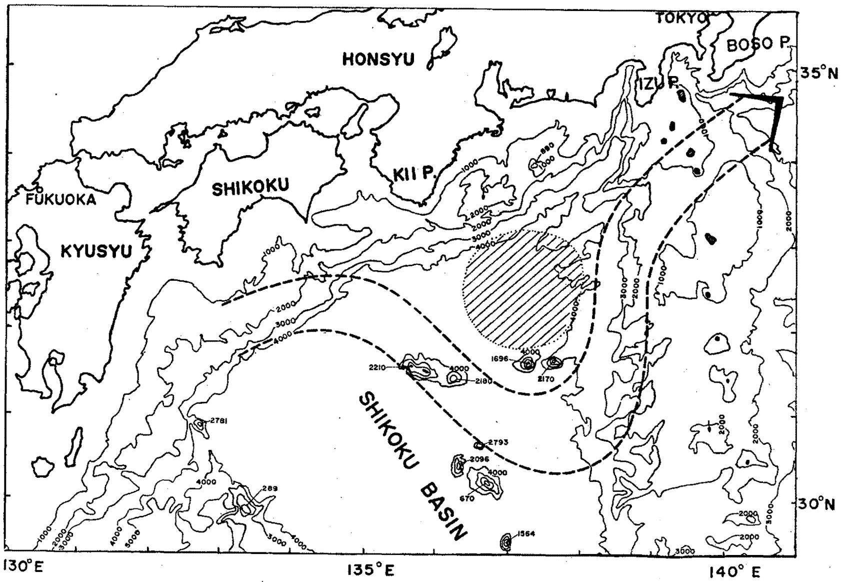

Fig. 6. Bathymetric chart south of Honshu. The regions of the Cold Water Mass and the path of the Kuroshio meander estimated from Fig. 4 are also shown.

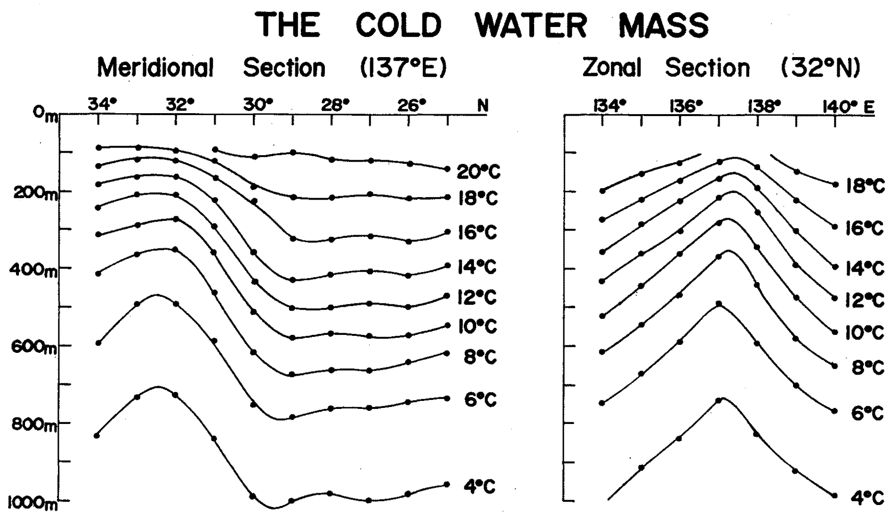

Fig. 7. Meridional and zonal sections of the temperature field of the Cold Water Mass.

the continental slope on the north, the Izu Ridge on the east, and four sea mounts on the south. This may suggest that the cold eddy extended to a depth greater than 3000 m. It is important to note that the northward flow between 138° and 139°E was situated over the steep slope in the western flank of the Izu Ridge.

These figures are highly suggestive of a close dynamical relationship between the Kuroshio and the bottom topography. Indeed we can cite a number of authors who supposed that a possible influence of the Izu Ridge on the Kuroshio was essential to the meandering phenomena (Uda[1]) 1949, Hayami[14]) 1955, Nan'niti[2]) 1958, Ichie[4]) 1960, Ishii and Toba[15]) 1976, Matsukawa[16]) 1977).

For the present, we have no observational information on the vertical structure of the meander current. It may be, therefore, of some interest to see the vertical structures of temperature fields. In Fig. 7 both the meridional and zonal sections of temperature field of the Cold Water Mass have been shown in terms of isotherm. (Figures of temperature fields at several standard depths have been presented in Appendix *A*.) In this figure it is very interesting that there is a distinct north-south asymmetry in isotherm at layers upper than the depth of 500 m, which corresponds roughly to the average depth of the Izu Ridge. This means that the behavior of the cyclonic eddy of the upper layer differs from that of the lower layer, suggesting a possible influence of the Izu Ridge on the eddy motion.

A weak east-west asymmetry seen in the figure, on the other hand, may

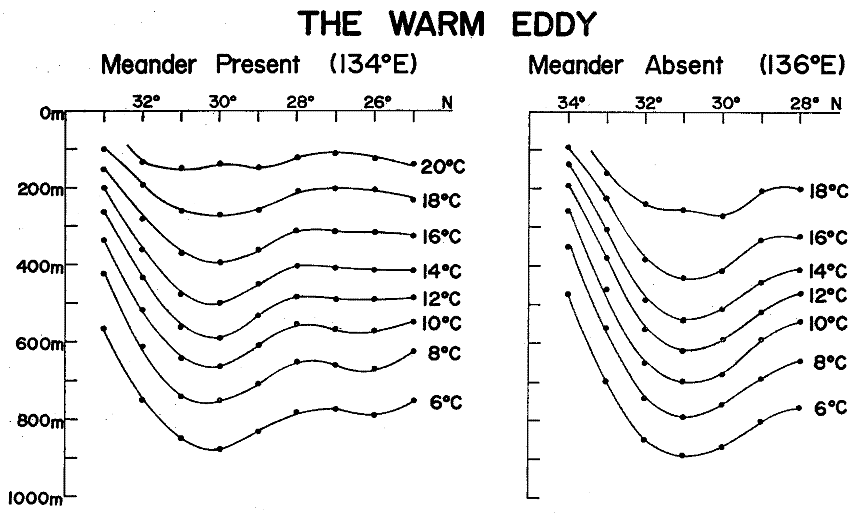

Fig. 8. Meridional sections of the temperature field of the warm eddy for the periods when the meander was present and absent.

simply reflect the fact that the line of 32°N crosses the Kuroshio stream at an oblique angle in the west side. The rise of isotherm from the mean level outside the Kuroshio amounts to roughly 300 m at the center of the cold eddy. This eddy seemed to extend to as far as a depth of 3000 m (Nishida[20], 1977).

6. The warm eddy

There are several clockwise eddies along the right-hand side of the Kuroshio. One of the most noticeable eddies is the warm eddy* lying to the right of the Kuroshio between 134° and 140°E (when the meander was absent) or between 132°30′ and 136° E (when it was present) [see Figs. 2 (a) and 2 (b)]. This eddy can be also seen clearly in Figs. A4(a) and A4(b).

In order to see the difference in vertical structure of the warm eddy between the two periods when the meander is absent and present, meridional sections of the eddy have been shown in Fig. 8 for each period. One may find that fall of isotherm is more extensive when the meander is absent.

The role of this eddy in the dynamics of the Kuroshio meander is uncertain as yet. White and McCreary[7] (1976) have simulated this kind of eddies in their numberical study of the formation of the Kuroshio meander,

* Another example is the eddy in the Luzon Strait (see Fig. 1(a)). The existence of this cyclonic eddy was pointed out long ago by Shigematsu[21] (1932) and Koeauma[22] (1936), and described in detail recently by Nitani[6] (1972).

and explained the increase in transport between the regions south of Kyushu and south of Shikoku by the existence of the warm eddy.

7. Concluding remarks

Characteristic features of the Kusoshio with and without the Cold Water Mass has been delineated in detail by the statiatical analysis of the past observations of surface current and hydrographic survey. One of the notable results is that the path of the Kuroshio between 142° and 148° E is confined in a narrow zone when the Cold Water Mass was present. This seems to suggest a possibility that the behavior of the Kuroshio south of Honshu plays an important role in the meandering phenomena of the Kuroshio. Another result to be noted is that the average transport of the Kuroshio south or southeast of Shikoku is unchanged whether the meander was present or not. Since the possible variation in the transport of the Kuroshio has been of great interest from a theoretical point of view[6)7)], further and detailed examination shoud be made on the subject.

Acknowledgments

All observational data used in this study have been collected from the master magnetic tapes "Current Data (GEK) Geo-File I" and "Oceanographic Station Data File I-73-Geographic" of the Japan Oceanographic Data Center. The authors are much indebted to the members of the JODC who kindly provided them the data. Acknowlegments are also extended to Miss K. Kojo for typing the manuscript and drawing the figures. Numerical computations were carried out on the FACOM 230-48 of the Research Institute for Applied Mechanics, Kyushu University.

References

1) Uda, M.: *On the correlated fluctuation of the Kuroshio Current and the cold water mass*, Oceanogr. Mag. **1** (1949) 1.
2) Nan'niti, T.: *A theory of the mechanism of the generation of the cold water region in the offing of Enshunada*, Pap. Met. Geophys. 8 (1958) 317.
3) Fukuoka, J.: *An analysis on the mechanism of the cold water mass appearance in the Enshu-nada*, Oceanogr. Mag. **11** (1960) 127.
4) Ichie, T.: *On the deep water in the western North Pacific*, Oceanogr. Mag. **11** (1960) 99.
5) Robinson, A.R. and Taft, B.: *A numerical experiment for the path of the Kuroshio*, J. Marine Research **30** (1972) 65.
6) Nitani, H.: *Variation of the Kuroshio south of Japan*, J. Oceanogr. Soc. Japan **31** (1975) 154.
7) White, W.B. and McCreary, J.P.: *On the formation of the Kuroshio meander and its relationship to the large-scale ocean circulation*, Deep-Sea Research **23** (1976) 33.

8) Winterfeld, T. and Stommel, H. : *Distribution of stations, and properties at standard depths in the Kuroshio area,* In: Kuroshio, physical aspects of the Japan Current (Univ. Tokyo Press, 1972) 81.
9) Japan Oceanographic Data Center: *Marine Environmental Atlas-Northwestern Pacific Ocean-,* (Japan Hydrographic Association, 1975).
10) Rikiishi, K. : *Time variation of the Kuroshio south off Shionomisaki,* Ocean Science 8 (1976) 234 (in Japanese).
11) Shoji, D. : *Time variation of the Kuroshio south of Japan,* In: Kuroshio, physical aspects of the Japan Current (Univ. Tokyo Press, 1972) 217.
12) Kawai, H. : *Hydrography of the Kuroshio Extension,* In: Kuroshio, physical asspects of the Japan Current (Univ. Tokyo Press, 1972) 235.
13) Nitani, H. : *Beginning of the Kuroshio,* In: Kuroshio, physical aspects of the Japan Current (Univ. Tokyo Press, 1972) 129.
14) Hayami, S. : *On the dynamics of Kuroshio off the southern coast of Japan,* Proc. UNESCO Symp. Phys. Oceanogr. (1955) 139.
15) Ishii, H. and Toba, Y. : *Structure of water masses in Kuroshio-Cold Eddy region down to the deep layer: a working hypothesis on the Kuroshio meander,* Ocean Science **9** (1977) 193 (in Japanese).
16) Matsukawa, Y. : *Long-term variation of wind system over the North Pacific and Kuroshio meander,* Ocean Science **9** (1977) 496 (in Japanese).
17) Rikiishi, K. : *On the Kuroshio Countercurrent south of Honshu,* Rec. Oceanogr. Wks. Japan **12** (1974) 31.
18) Rikiishi, K. : *Note on the Kuroshio meander,* J. Oceanogr. Soc. Japan **30** (1974) 42.
19) Taft, B. A. : *Characteristics of the flow of the Kuroshio south of Japan,* In: Kuroshio, physical aspects of the Japan Current (Univ. Tokyo Press, 1972) 165.
20) Nishida, H. : *The deep structure of the Cold Eddy and Kuroshio south of Japan,* Ocean Science **9** (1977) 181 (in Japanese).
21) Shigematsu, R. : *Some oceanographical investigation of the results of oceanographic survey carried out by H. I. J. M. S.* Manshu from April *1925* to March *1928*, Rec. Oceanogr. Wks. Japan **4** (1932) 151.
22) Koenuma, K. : *On the hydrography of the southwestern part of the North Pacific and the Kuroshio. Part 2: Characteristic water masses which are related to this region, and their mixtures, especially the water of the Kuroshio,* Imper. Marine Observ. Memoirs **6** (1938) 349.

(Received October 11, 1977)

Appendix A. Vertical structure of temperature field

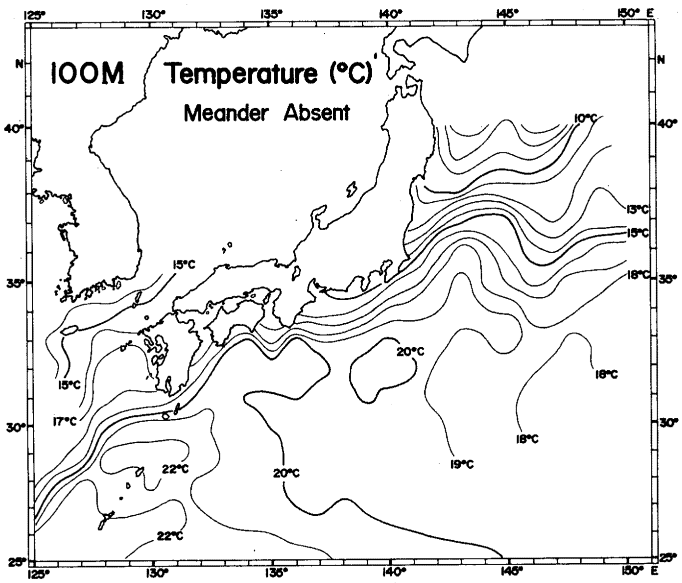

Fig. A1(a). Temperature (°C) at 100 meters for the period when the meander was absent.

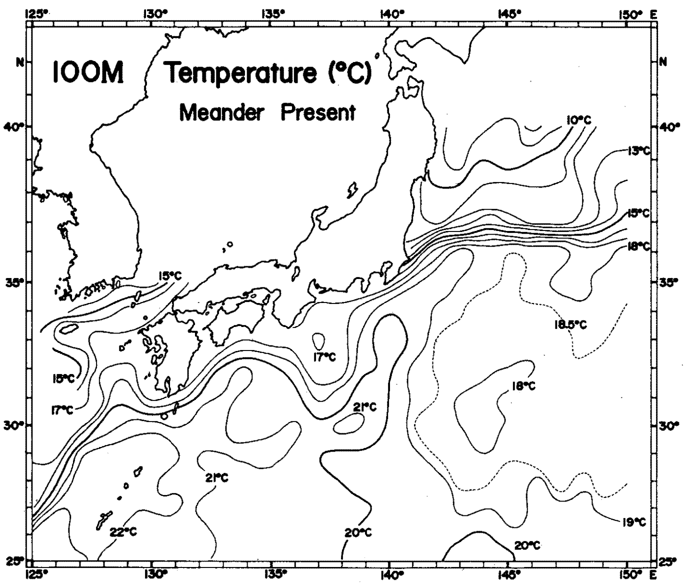

Fig. A1(b). Temperature (°C) at 100 meters for the period when the meander was present.

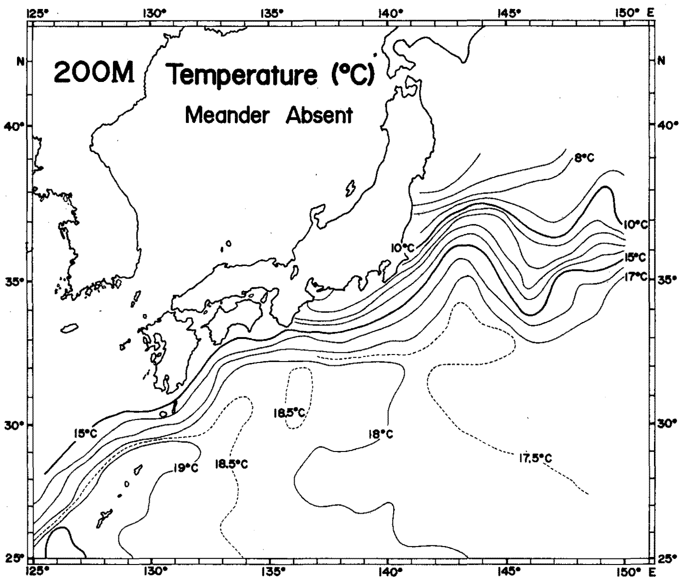

Fig. A2(a). Temperature (°C) at 200 meters for the period when the meander was absent.

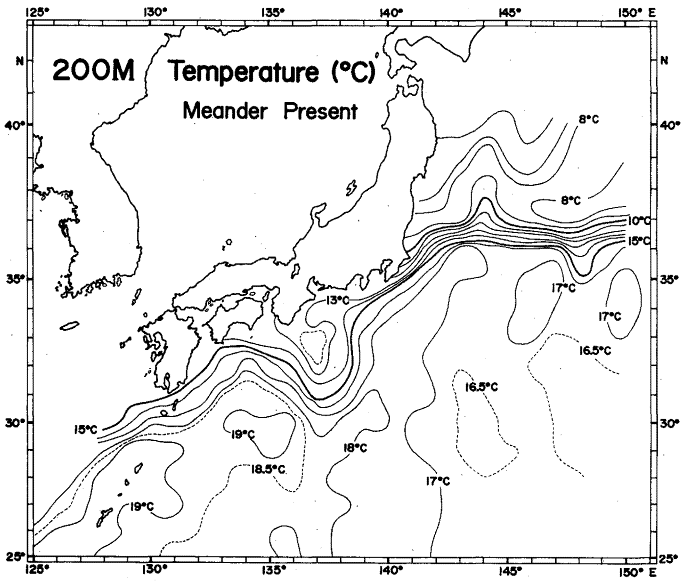

Fig. A2(b). Temperature (°C) at 200 meters for the period when the meander was present.

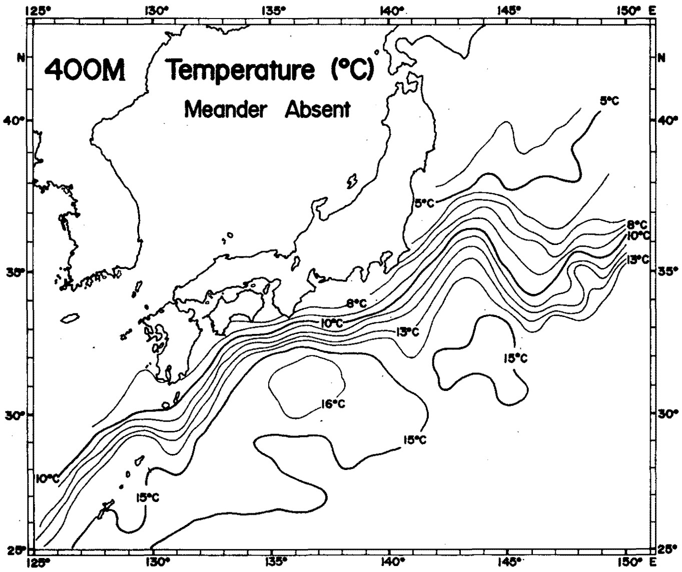

Fig. A3(a). Temperature (°C) at 400 meters for the period when the meander was absent.

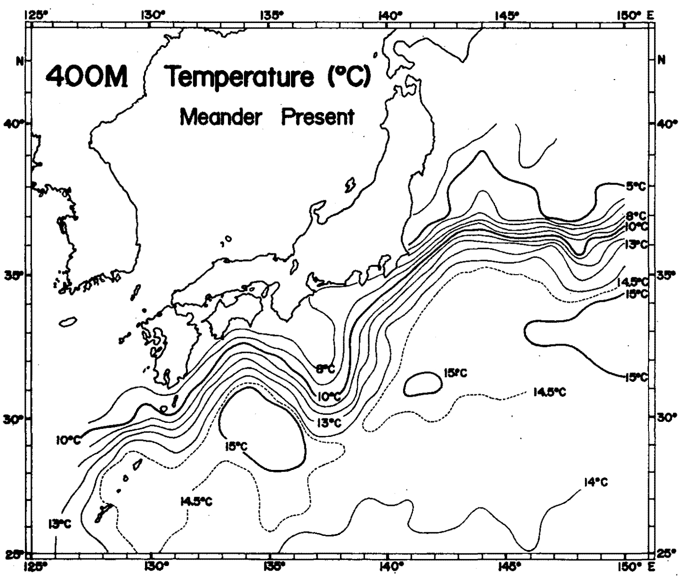

Fig. A3(b). Temperature (°C) at 400 meters for the period when the meander was present.

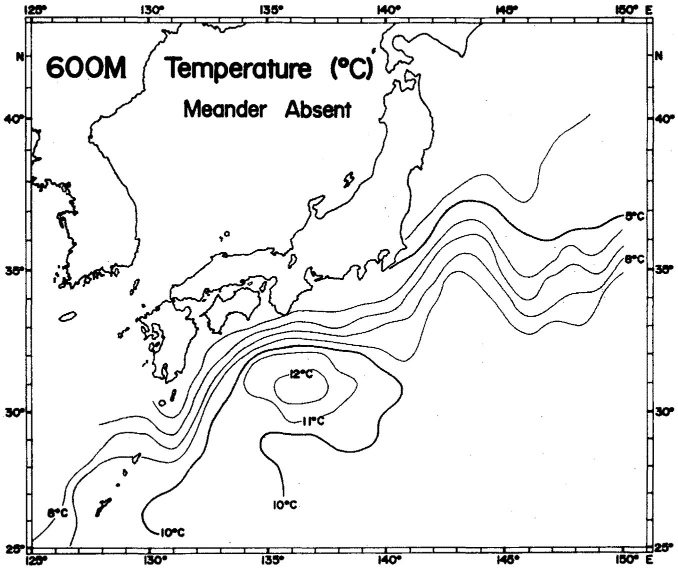

Fig. A4(a). Temperature (°C) at 600 meters for the period when the meander was absent.

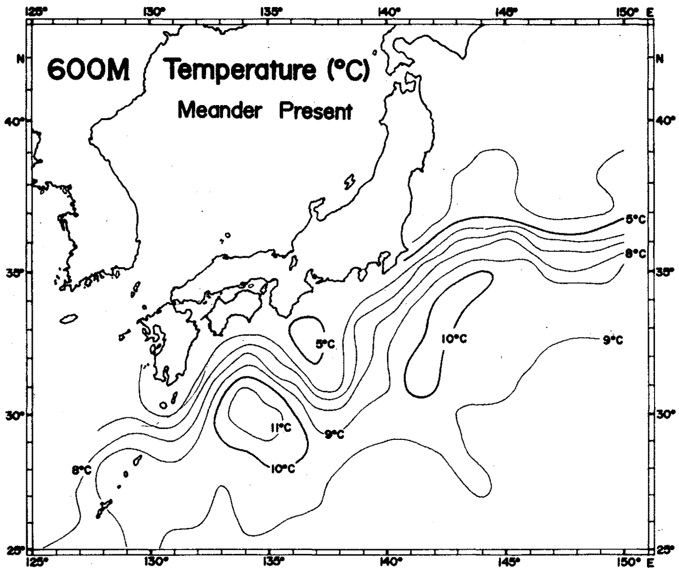

Fig. A4(b). Temperature (°C) at 600 meters for the period when the meander was present.

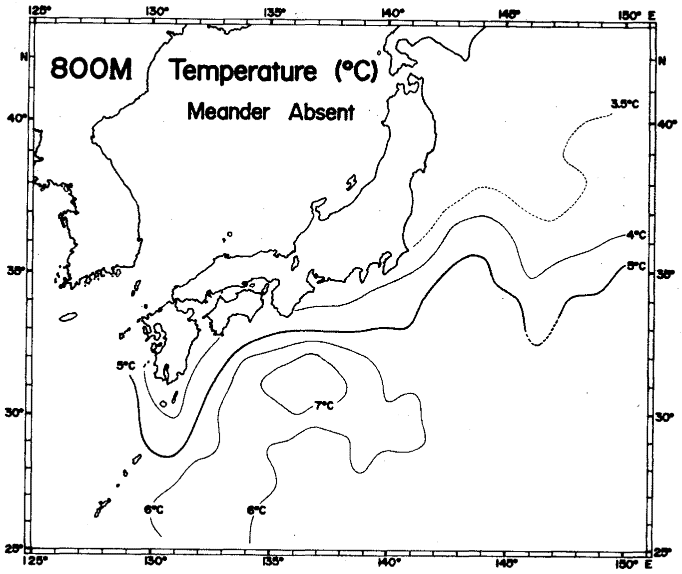

Fig. A5(a). Temperature (°C) at 800 meters for the period when the meander was absent.

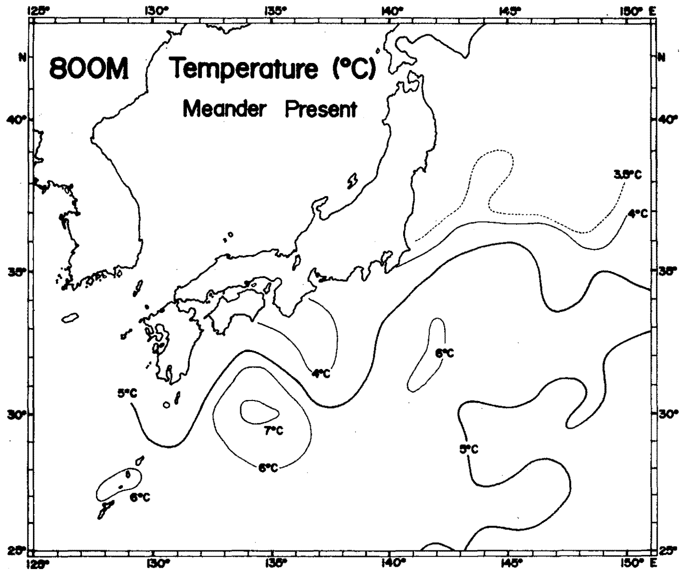

Fig. A5(b). Temperature (°C) at 800 meters for the period when the meander was present.

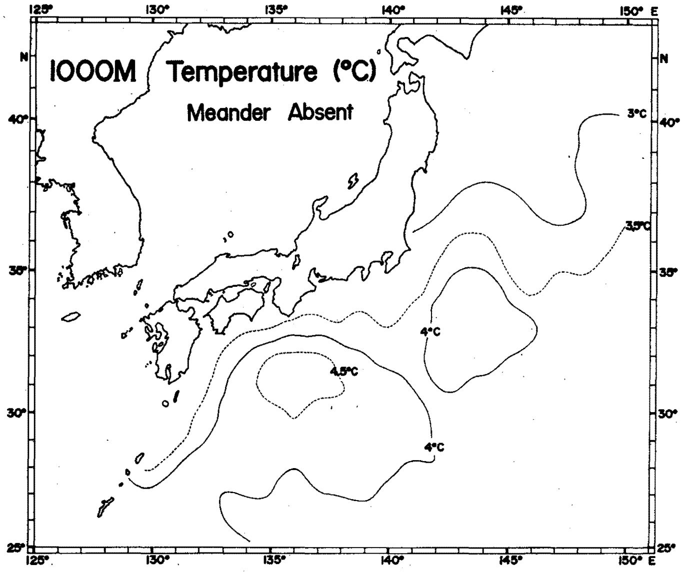

Fig. A6(a). Temperature (°C) at 1000 meters for the period when the meander was absent.

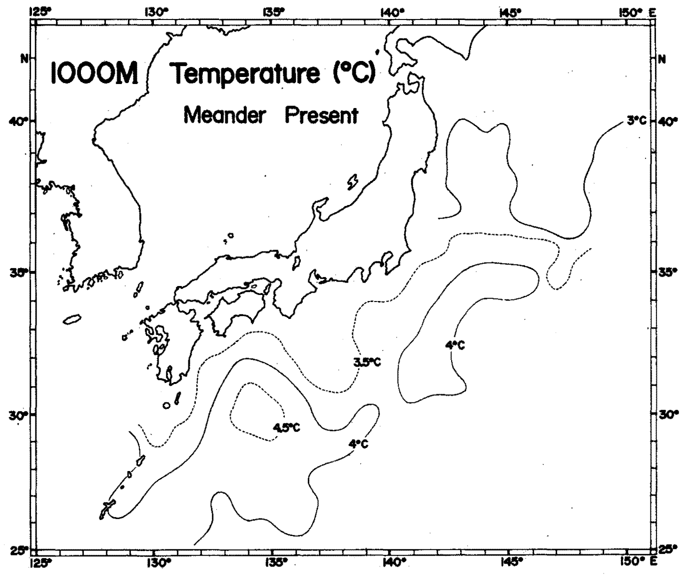

Fig. A6(b). Temperature (°C) at 1000 meters for the period when the meander was present.

Appendix B. Sea-water properties at 200 meters

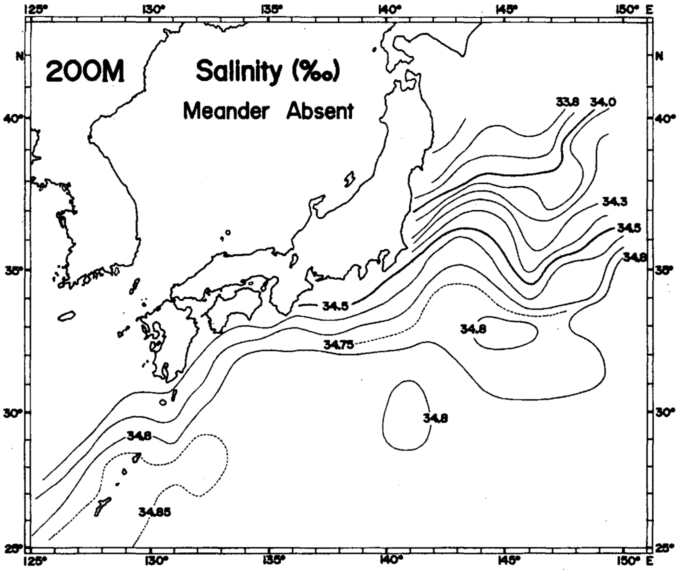

Fig. B1(a). Salinity (‰) at 200 meters for the period when the meander was absent.

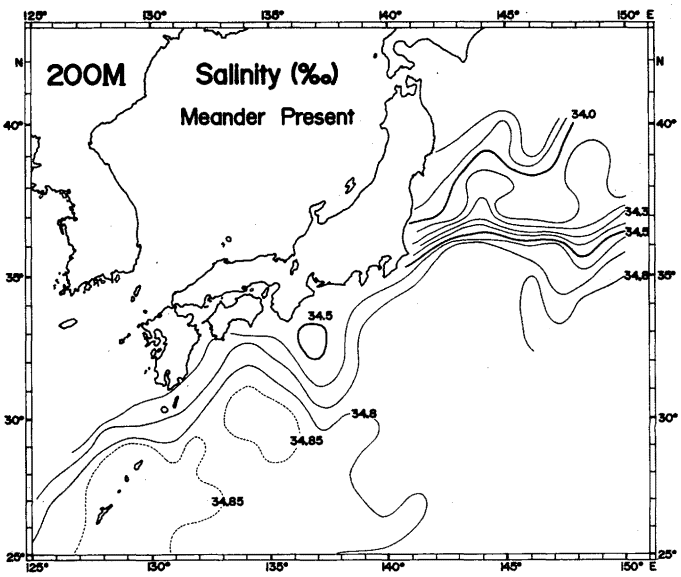

Fig. B1(b). Salinity (‰) at 200 meters for the period when the meander was present.

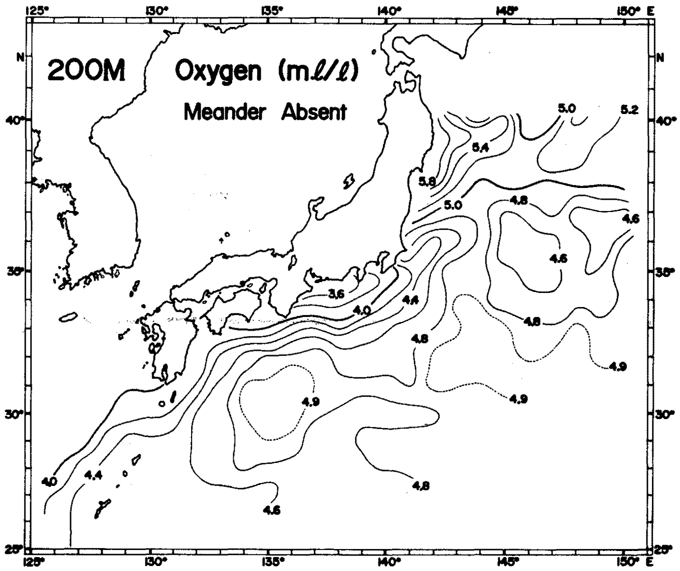

Fig. B2(a). Dissolved oxygen (*ml/l*) at 200 meters for the period when the meander was absent.

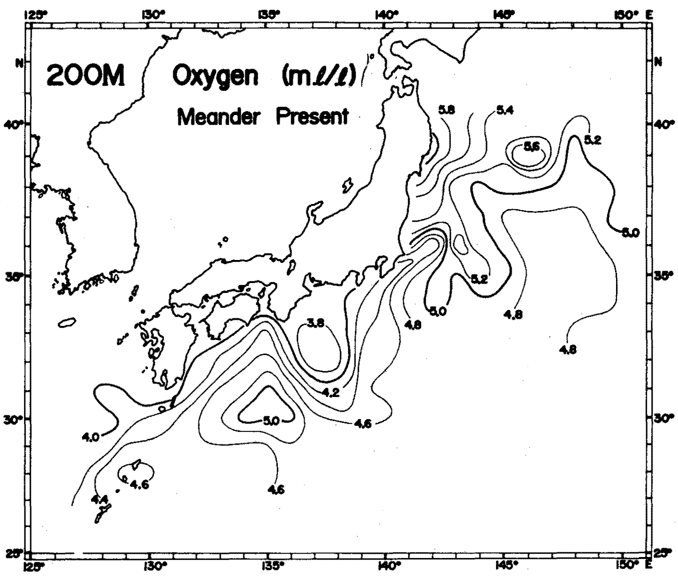

Fig. B2(b). Dissolved oxygen (*ml/l*) at 200 meters for the period when the meander was present.

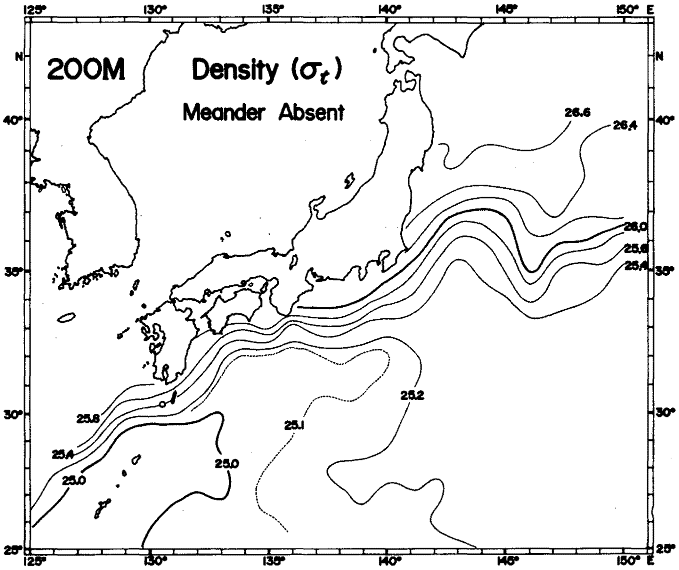

Fig. B3(a). Density (Sigmaa-t) at 200 meters for the period when the meander was absent.

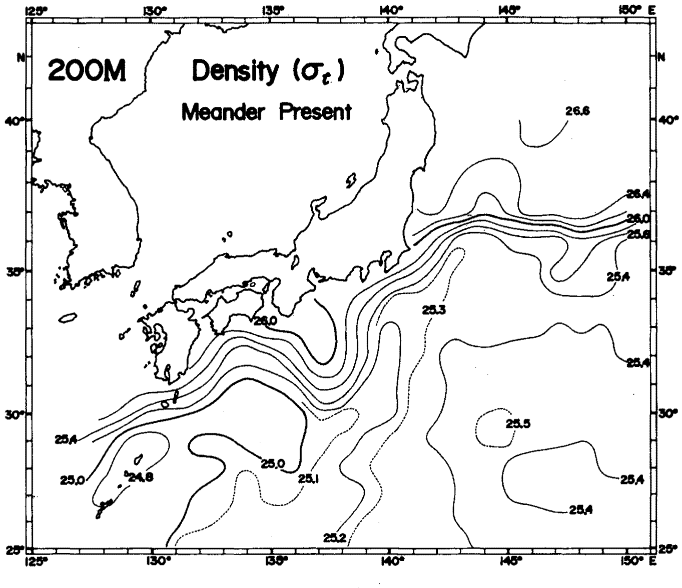

Fig. B3(b). Density (Sigma-t) at 200 meters for the period when the meander was present.