REPORT OF HYDROGRAPHIC RESEARCHES No. 17, March, 1982

VARIATION OF THE KUROSHIO COLD EDDY
— LARGE MEANDER OF THE KUROSHIO IN 1975-1980 (II) —

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Received 1981 September 19

Abstract

Variations of the internal structure of the Kuroshio cold eddy associated with the large meander of the Kuroshio, and its correlation with the external features of the eddy from 1975 to 1980, are investigated. Vertically averaged values of temperature, salinity and dissolved oxygen content are used to describe the internal structure of the eddy, the position of the center of the cold eddy, and the area of the eddy region was used as parameters of the external features of the eddy.

The investigation revealed the following items. The temperature in the deep layer (1000–2500 m) in the central area of the cold eddy, increased most of the time in the meander period, but showed an intermittent decrease from time to time. This intermittent decrease of temperature may be a cause for long-period staying of the cold eddy and the Kuroshio meander. The temperature in other layers (upper 200–500 m, intermediate, 500–1000 m) has not varied in phase with the temperature of the deep layer. In the decaying and disappearing stage of the Kuroshio meander, a conspicuous increase in temperature is observed in the deep layer. Along with this temperature increase, the water characteristics themselves also changed in the whole area south of Japan (the increase in salinity and dissolved oxygen content).

1. Introduction

It is widely known that a large-scale cold eddy accompanied with the Kuroshio meander appears south of Japan from time to time, and stays at almost fixed region for more than two years. This is one of the most remarkable phenomena of the Kuroshio south of Japan, and called "the Kuroshio cold eddy" or "the Kuroshio large meander" mainly because of its largeness and long-period stationarity. Since the first report by Uda (1937), it has been a matter of great concern for Japanese oceanographers, and recently also for foreign researchers. In spite of many investigaitons to clarify the dynamical mechanism of generation, maintenance and disappearance of the cold eddy and the meander, there is, however, no successful explanation yet.

The cold eddy and the meander occurred three times (1953–1955, 1959–1963, 1975–1980) since the early 1950's when routine observation in the Kuroshio region started in Japan. On the former two cases, the cold eddies have been described on the basis of the time series of external features such as size, shape and position which can be drawn out from the flow pattern of surrounding Kuroshio (for example, Masuzawa 1960, Shoji 1972, Taft 1972 and Nitani 1975). Their descriptions of the cold eddy are rather of qualitative nature except a few works (for example, Nan'niti

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1960). On the other hand, the internal structure down to deep layer in the cold eddy has been studied only temporarilly (for example, Moriyasu 1956). Therefore, the variation of the internal structure throughout the meander period has not been examined yet, mainly because of lack of suitable data.

During the latest period, relatively dense observations in time and space were conducted, as shown in Nishida's (1982) detailed description of the meander, partly under the favour of KER (Kuroshio Exploitation and Utilization Research) project sponsored by Science and Technology Agency since 1977. With the aid of above relatively dense data, in this report, the variation of the internal structure, as well as external features, of the cold eddy during the period from 1975 to 1980 are described. It is possible that the internal changes may lead to the change of the external features through eddy dynamics. Therefore, by examining the relationship between the two kinds of variations, it is expected to obtain some knowledge regarding the mechanisms of maintenance and/or disappearance of the cold eddy.

The external features of the cold eddy are described in section 4. In order to examine the variation of internal structure, temperature, salinity and dissolved oxygen content are taken. They are discussed in section 5. Section 6 deals with the correlation between the external and the internal structure. Further, section 7 deals with the T-S and T-O_2 relationships for deeper waters in the area south of Japan which includes the cold eddy region.

2. Data Sources

Data used for obtaining the averaged values of temperature, salinity and dissolved oxygen content (section 3), are included in the following publications.

Data Report of Hydrographic Observation, Series of Oceanography
(published by Maritime Safety Agency)

The Results of Marine Meteorological and Oceanographical Observations
(published by Japan Meteorological Agency)

Data Report of KER, No. 1–3
(published by Japan Oceanographic Data Center)

The Prompt Report of the Oceanographic Conditions, published semimonthly by Hydrographic Department, M.S.A., are also used for obtaining the parameters of external features of the cold eddy and the Kuroshio meander.

3. Parameters of eddy's variation

Several parameters are selected to describe the time variation of the cold eddy. As the external features, positions of center of the cold eddy and trough of the meandered Kuroshio and area of the cold eddy region are employed.

Temperature, salinity and dissolved oxygen content are used as parameters for description of internal variation. For each element, two kinds of indices which can represent the whole condition of the eddy in each cruise are adopted.

Above parameters or indices are obtained as follow.

3-1 Parameters of external variation

The trough (T) and the two ridges (S and R) are shown in a typical path of the Kuro-

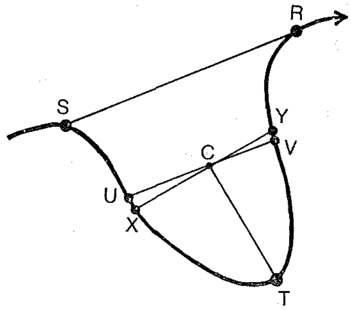

Figure 1 A typical path of the Kuroshio meander. Two ridges (S, R), a trough (T) and U, V, X, Y are in stream axis. C is a center of cold eddy.

shio meander in Figure 1. The positions of trough and ridges are read from the surface current chart in the Prompt Report of the Oceanographic Conditions.

The position of center of the eddy (C in Fgure 1) is defined as the mean of following positions; namely, geometrical center of cyclonic flow pattern at the sea surface, and the positions at which temperature minimum is observed at 200 m and/or 400 m depth.

The area of the eddy region is approximated by the sum of those of a figure XTYCX and a trapezoid SUVR (Figure 1); where U, V, X and Y are on the stream axis. $\overline{UV}$, passing through C, is drawn to be parallel to SR. Further, the area of XTYCX is approximated by that of a half ellipse whose axes are $\overline{CT}$ and $(\overline{CX}+\overline{CY})/2$, where $\overline{CX}$, $\overline{CY}$ are taken to be normal to $\overline{CT}$.

3-2 Parameters and indices of internal variation

From the hydrographic stations occupied in each cruise, three stations which have the lowest, second lowest and third lowest temperature values are selected (Figure 2). The vertically averaged values of temperature, salinity and dissolved oxygen content are respectively calculated in 200–500 m (upper layer), 500–1000 m (intermediate layer) and 1000–2500 m (deeper layer) at those three stations.

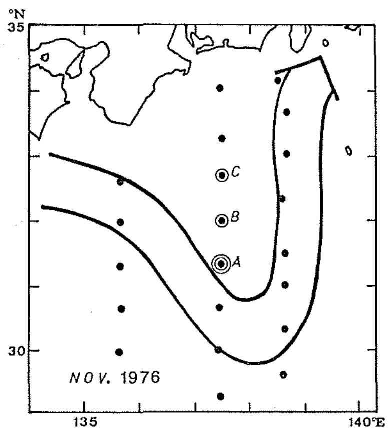

Figure 2 Axis of the Kuroshio. Solid circles show hydrographic stations. A indicates the station at which temperature averaged in 200–500 m, 500–1000 m and 1000–2500 m are the lowest. B and C show the second and third lowest.

The two kinds of indices for each element above are employed to represent adequately the internal condition of he cold eddy at each cruise ; namely, one is the value at the stations where the lowest temperature is observed, the other is the mean value of those at stations where three lowest temperatures are observed. They are used for the description of the time variation of temperature, salinity and dissolved oxygen content in the cold eddy.

In order to check whether above two kinds of indices are representative for whole condition of the eddy region, averaged values over the whole cold eddy region, as reference, is calculated in the following manner. First, geostrophic mass-transport chart in the cold eddy region and the Kuroshio region surrounding the eddy is drawn to circumscribe the cold eddy as shown in Figure 3. Mass-transport charts are drawn in 0–500 m, 500–1000 m (both refered to 1000 db (deci-bar) surface) and 1000–2000 m (refered to 2000 db) for calculation of vertically averaged values of temperature, salinity and dissolved oxygen in upper, intermediate and deeper layers respectively. The reason for employing 2000 db as a reference level instead of 2500 db, is to use as many hydrographic data as possible for more detailed mass-transport chart which bring more adequate circumference. Next, the region inside the circumference which separates the eddy from the outside Kuroshio is divided into several portions. Then, the product of area and averaged values of three elements in each portion are estimated. This is done in upper, intermediate and deeper layers, respectively. Dividing, finally, the sum of above products by the total area inside the circumference gives the average value over the

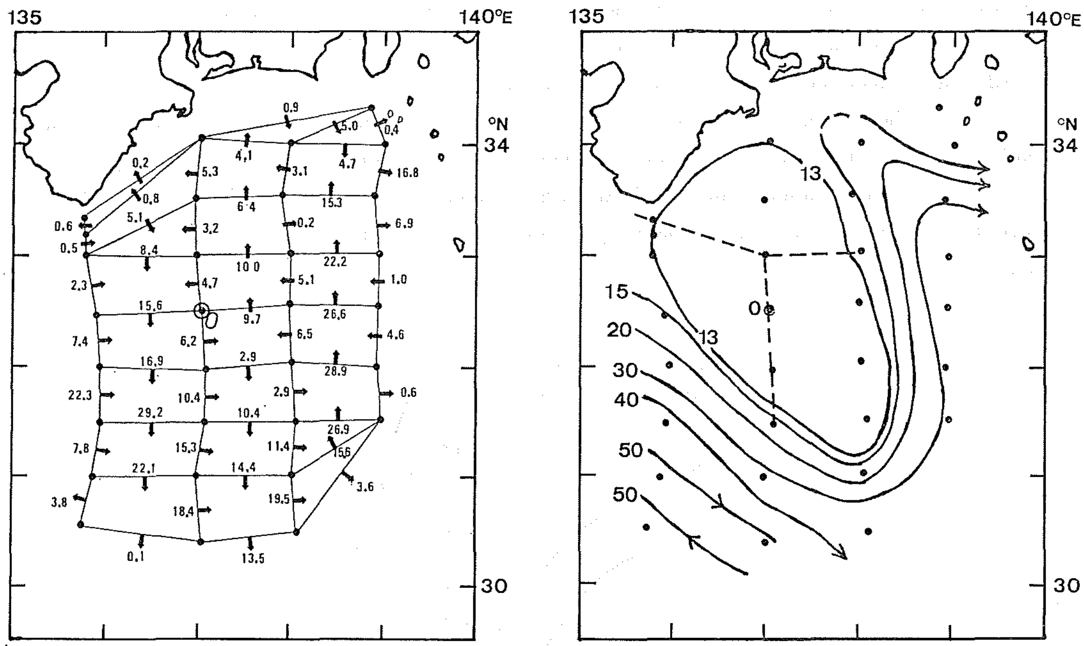

Figure 3 (left) Mass transport (0–500 m) relative to 1000 db surface. Arrows indicate direction of flow, and numeral show mass transport in 10^6 tons/sec.

(right) Mass transport chart (0–500 m) relative to 1000 dB. Circumference is defined as the contour which shows mass transport 13×10^6 ton/sec reffered to the station ⦿. Region inside circumference is divided into three portions by dashed line for calculation of average value over the whole eddy region.

whole eddy region; which is calculated in eleven cases where the determination of circumference in deeper layer is possible.

4. Variation of the external features of the cold eddy

For the description of time variation of external features, the positions of center of the eddy and trough of the meander, the distance between two successive positions of center, and the area of the cold eddy region are taken (Figure 4). The discontinuity in Figure 4 during May to August 1977 corresponds to the period when the separated cold ring was observed (Kamihira *et al.*, 1978; Nishida, 1982). Except the above period, the center and the trough move coherently as tabulated in Table 1. Two of the most southwestern location of the center are shown in May 1977 and March or April 1979 when the cut-offing of cold ring were experienced (Kamihira *et al.*, 1978; Nishida, 1982); the cold ring is originally a part of the cold eddy and separated from the extreme portion of sharply bending meander. It is a noteworthy fact that both cases occurred when the center of the cold eddy reached at near 31°30′N, 136°20′E after its west-southwestward moving, although the mechanisms of cut-offing and westward moving of the eddy are not known.

The coherency between latitude and longitude of the center is attributed to the fact that the eddy's movement is mostly parallel to the continental slope along the southern coast of Japan as shown in Figure 5, where geographical positions of the center and the meander trough are plotted. Figure 5 shows that the cold eddy is mostly located at the corner bounded by the 400 m contour of the Izu-Ogasawara Ridge and of the continental slope, except in the period of the "decaying" or "disappearing" (Nitani, 1982) stage of the Kuroshio meander, when the eddy is located over the Ridge. Above facts suggests that the bottom topography south of Japan strongly affects the long-period staying of the cold eddy.

It is shown in Fiure 5 that the center of the eddy was relatively stationary in 1976 to 1978. Figure 4(c) is the variation of distance which eddy's. center traveled from its previous position. It also indicates that the eddy was stable in the middle of 1976 and latter half of 1978. Those stable state continued for about a half of year. The area of the cold eddy region (Figure 4(d)) became relatively large when the eddy was stable, and its variation is in phase with that of position of center in the period from spring 1976 to summer 1979. Therefore, the area of eddy region shows a tendency to be large when the cold eddy is located on the east in the area south of Japan, except in the generation and decaying stages.

Since April 1979, the cold eddy continued to move generally east-northeast direction and came to the disappearance in August 1980. For the prediction of disappearance of the meander,

Table Correlation coefficients computed from the data smoothed for 1.5 month

	lat. of center	long. of center	lat. of trough	long. of trough
lat. of center		0.90	0.92	0.81
long. of center	0.90		0.89	0.93
lat. of trough	0.92	0.89		0.85
long. of trough	0.81	0.93	0.85	

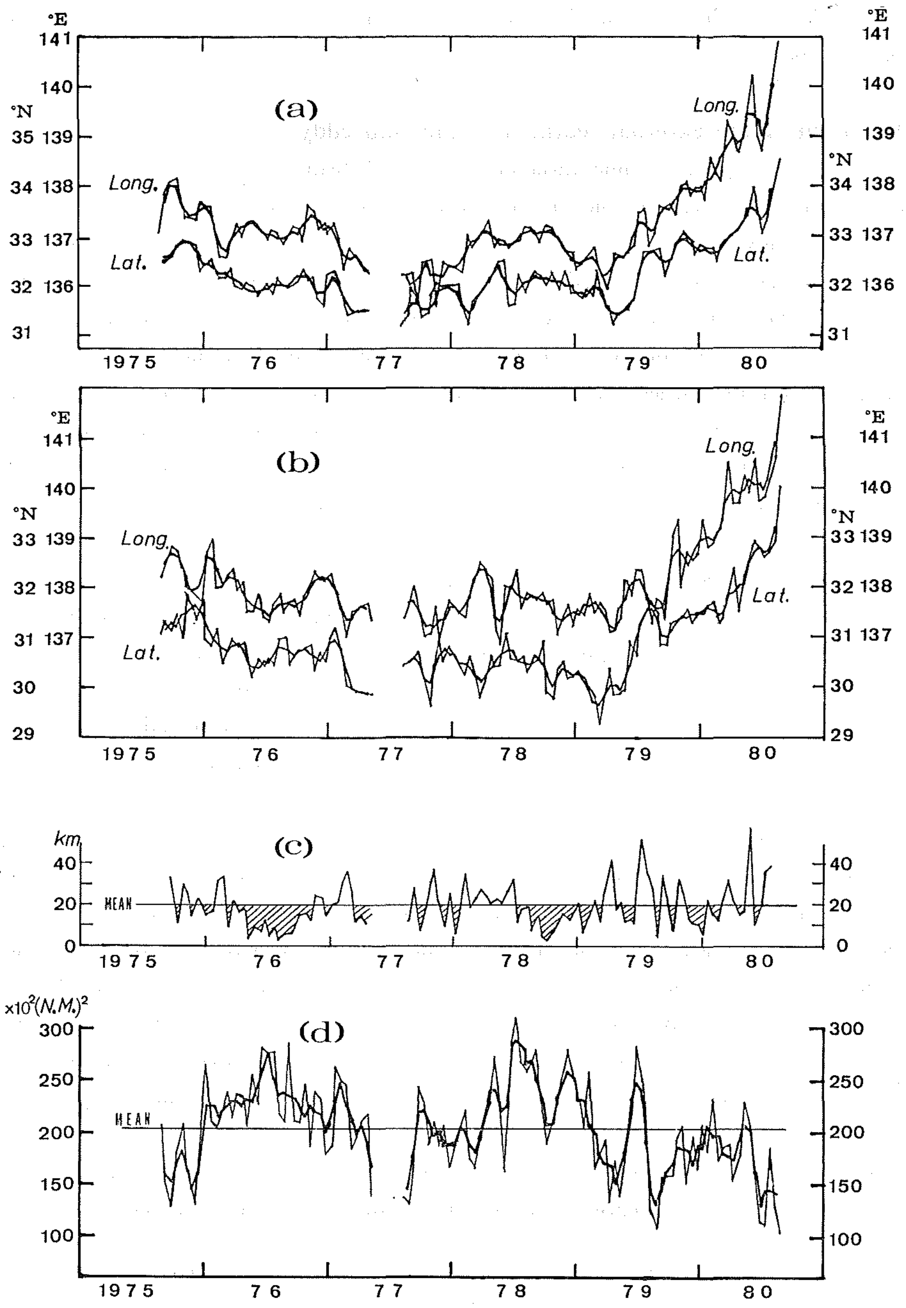

Figure 4 Variation with time of (a) latitude and longitude of center of cold eddy, (b) latitude and longitude of trough of meander, (c) distance between two successive positions of the center of the eddy (d) area of the eddy region in $10^2 \times$ (nautical mile)^2. Thin line in (a), (b) and (d) shows raw data, thick line show averaged data smoothed for 1.5 months. Values in (c) are calculated from smoothed center positions which are indicated as thick line in (a).

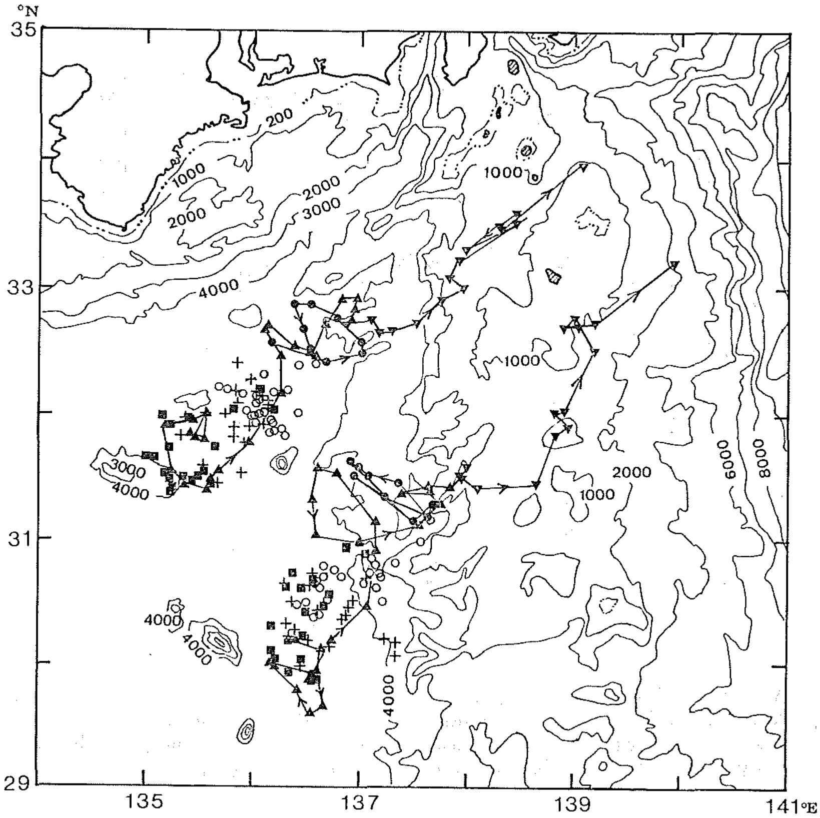

Figure 5 Geographical positions of center of cold eddy (northern) and meander trough (southern). Data which are shown as thick line in Figures 4(a) and 4(b), are plotted. ● in 1975, ○ 1976, ■ 1977, + 1978, ▲ 1979 and ▼ 1980. Directions of displacements are shown in 1975, 1979 and 1980

Nitani (1977) and Nakabayashi (1981) suggested that first sign of the meander disappearance south of Japan might be shown when the most southerly position of meander axis reached near 138°E. The result in Figures 4(a) and 4(b) also suggests that the position of the center or the trough has a certain critical value by which the starting into the decaying stage of the meander and the cold eddy can be predicted.

5. Variation of internal structure of the cold eddy

Variations of averaged temperature, salinity and dissolved oxygen content which are represented by two kinds of indices (section 3-2) are shown in Figures 6, 7 and 8. The values at 1000 m or 1500 m depth, which are mean of those at stations where three lowest temperatures are observed, are also plotted in above Figures to supplement the relatively small number of the data in the deep layer. The left side bar is standard error which is estimated from the difference between index value and regional averaged value (solid triangle in Figures) as a reference as explained in section 3-2. The smallness of standard error relative to the range of variation of each element, implies that both indices can represent the condition of whole eddy region instead of the regional averaged value.

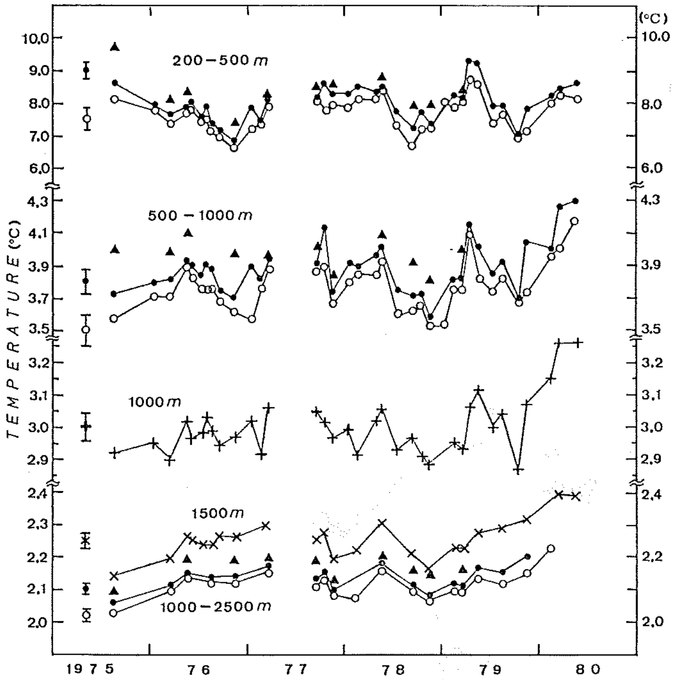

Figure 6 Variation with time of temperature around the cold eddy. Open circle shows the lowest value in each cruise. Solid circle, + and × are mean of the lowest, second lowest and third lower. Solid triangle shows averaged value over the whole cold eddy region. Left side bar indicates a standard error (explantion is in text)

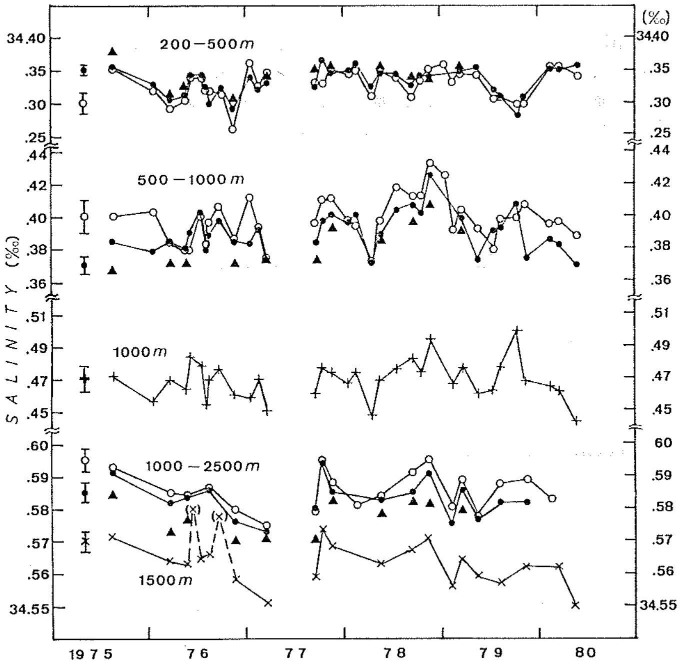

Figure 7 Variation with time of salinity in the cold eddy. Open circle shows value at the station where the lowest temperature is observed in each cruise. Solid circle, + and × are mean value of those at station where three lowest temperature are observed. Other symbols are same as in Figure 6.

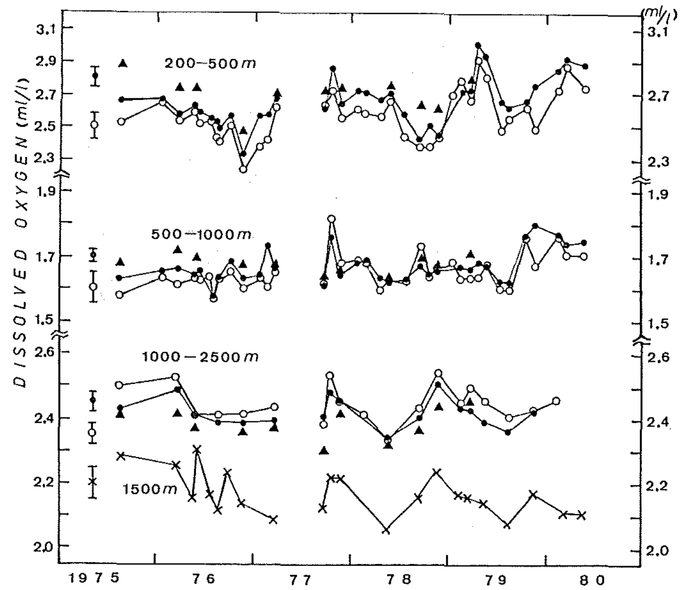

Figure 8 Variation with time of dissolved oxygen content in the cold eddy. Symbols are same as in Figure 7

The variations of three elements in the upper layer are not always in phase with those in the deep layer. In temperature variation, for instance, negative correlation between upper-layer and deep-layer is found in two periods ; namely, from the eddy generation to November 1976 and from March to October 1979. Positive correlation is found in the rest of the period. Temperature variation in the intermediate layer is relatively similar to that in the deep layer.

Salinity and dissolved oxygen content vary with time as is roughly expected from T-S or T-O_2 relation respectively. In the central region of the eddy, a salinity minimum is observed at 400 m or 500 m depth, then salinity has negative correlation with temperature in the intermediate and deeper layer, and has positive one in the upper layer but not so clear. Dissolved oxygen content, whose minimum appears at near 800 m as shown by relatively small fluctuation in the intermediate layer, changes a sign of correlation with temperature in upper and deep layers.

Although three elements vary expectedly as mentioned above, unexpected variations of salinity or dissolved oxygen from T-S, T-O_2 relationship are also seen. For example, since August 1979 decreases of salinity and dissolved oxygen in the deep layer are not conspicuous against increase of temperature. It suggests the change of water characteristics in the deep layer as will be discussed later in section 7.

The temperature variation is clearly reflected in that of the isotherm depth (Figure 9), where selected isotherm depth is decided as an average of the depths at which the three lowest temperature are found. According to Yoshida (1972), it has generally been believed that upwelling of cold water from the intermediate layer is associated with the cold eddy. However, if the ascent of isotherm with time as shown in Figure 9 is caused by upwelling, it must occur at even 2000 m layer depth. This may agree with a fact that the cold eddy keeps its own structure at least until 3000 m depth (Nishida, 1982). Furthermore, the intermittent ascent of the isotherm over the

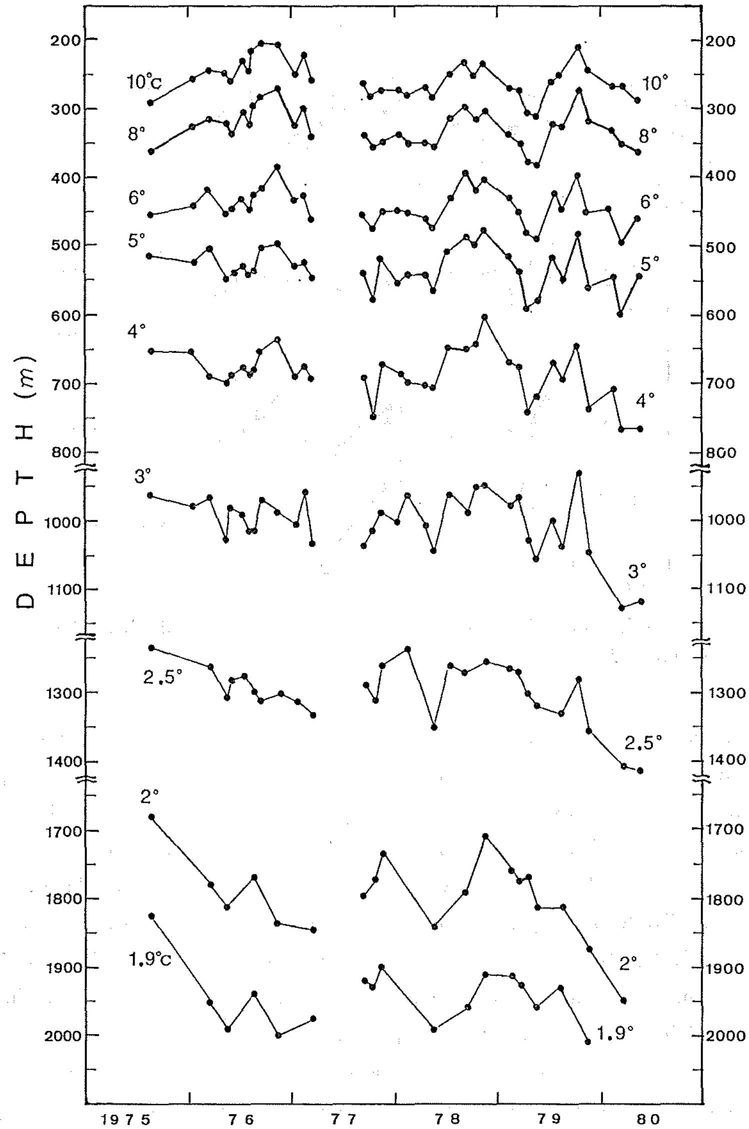

Figure 9 Variation in the depth of selected isotherms around the center of the cold eddy.

most layers as observed during the time from May to November 1978 is in contrast to the generally monotonical descent of isotherms observed in the cold ring in the Sargasso Sea (Cheney and Richardson, 1976). It also suggests the occurrence of replenishment of the Kuroshio cold eddy by upwelling of cold water, although such replenishment may act only in the upper or intermediate layer as it did in the periods of middle 1976 and middle 1979.

6. Comparison of external and internal variations

In order to find some relationshps between the external and the internal variation, comparison between the time changes of several parameters or indices obtained in the previous sctions are made. Temperature is mainly attentioned in respect to the internal variation because it can be sufficiently representative.

A good correlation exists between the area of the cold eddy region and the temperature in the upper layer during the most of period when the eddy presented ; that is, larger area coincides with lower temperature. This fact agrees with Nitani's (1977) result that the increase of cold water area coincides with the decrease of the minimum temperature value at 200 m depth in the eddy, being attributed to the upwelling ; although studied period was limited in from August 1975 to November 1976. Considering a good coherency between temperature and isotherm depth as mentioned in preceding section, it seems to be confirmed that upwelling has important effect on the variation of area. Further, the east-west movement of the eddy, which is related to the size of eddy as shown in section 4, has a correlation with upper-layer temperature except in generation and decaying stage, although the reason for it is not clear.

It is noteworthy that temperature in the deep layer is generally increasing in the periods from the generation of the eddy to March 1977 and from November 1978 to May 1980. In 1980, the data is not suitable to calculate vertically averaged value because the eddy was located mostly on the Ridge. However, temperautre in the deep layer is infered to be high from that at 1000 m or 1500 m depth. The increase of deep-layer temperature occurred in the period which amounts to about 80% of the total period shown in Figure 6. This fact suggests that temperature in the deep layer of the cold eddy monotonically increase if intermittent upwelling does not happen. The first cut-offing of the cold ring occurred in May 1977 after the succesive increase of the deep-layer temperature, which was, however, not so high in March or April 1979 when the second cut-offing occurred. Therefore, it is speculated that cut-off phenomenon is independent of the increase of temperature in the deep layer.

In the variation of deep-layer temperature in the cold eddy, the highest value appeared in the decaying stage after the successive increase prior to that in intermediate or upper layer. Therefore, the deeper-layer temperature might be a index for the disappearance of the eddy. Salinity or dissolved oxygen content is not so adequate to predict the disappearance, because they seemed to be out of expected T-S or T-O_2 relation in the decaying stage.

7. T-S and T-O_2 relaitonships in deep waters

As is stated in section 5, salinity and dissolved oxygen content in the deep layer of the cold eddy are not so large in the decaying stage, as is expected from the general T-S or T-O_2 relationships. This indicates the change of the water characteristics itself. In this section, the variations of T-S and T-O_2 relationships in the deep layer of the cold eddy and their correlation with that of external features are described.

The T-S relations of the stations which have the lowest temperature value in each cruise are shown in Figure 10, where vertically averaged temperature and salinity values in the deep layer (1000–2500 m) are used to represent the characteristic condition in each cruise. It is felt that some measure on the plotting error should be given because the range of the change which is dealt here is very small (0.2°C in temperature, 0.03% in salinity). There are two kinds of errors in above plotting values. One is the error which comes from the field observation, and the other is the error which comes from the fact that the selected stations may not represent the whole cold eddy because

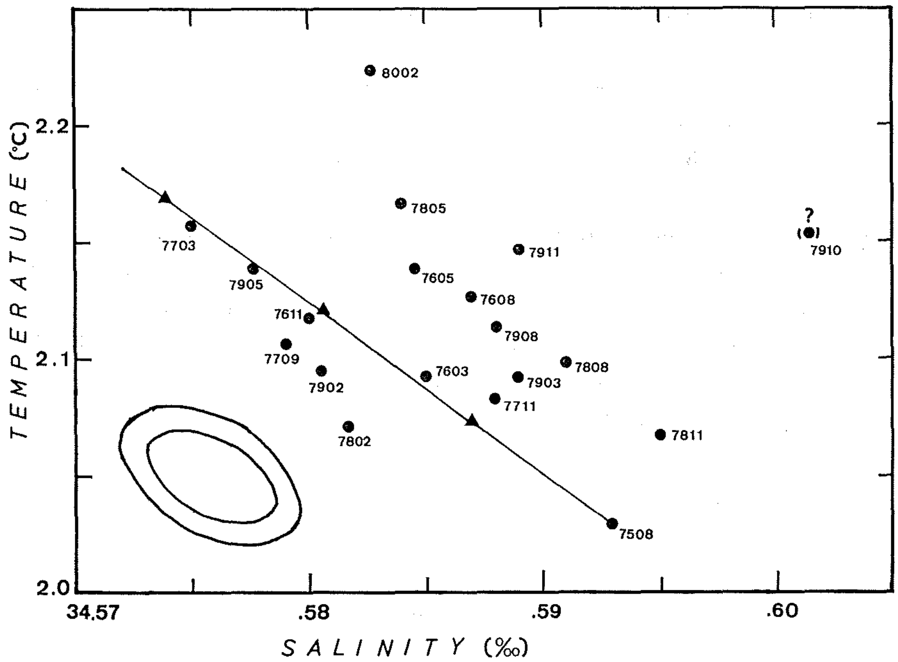

Figure 10 T-S diagram for deeper water whose temperature is the lowest in the cold eddy at each cruise. Numerals show year and month of cruise. For example, 7508 indicates August 1975. Explanation for figures and line are in the text.

of the sparsity of station distribution. The error in field observation is estimated as follows. The error in temperature measurement is assumed to be ±0.03°C, and the error in salinity measurement is assumed to be 0.003‰. The number of layers which are used to compute the average value in the deep layer (1000–2500 m) is five or six. Assuming the independency of each measurement, the standard error is estimated

for temperature as ; $\sigma_T = 0.03/\sqrt{5} = 01013(°C)$

and for salinity as ; $\sigma_S = 0.003/\sqrt{5} = 0.0013(‰)$

The error which comes from the sparsity of station distribuiton is estimated as follows. The average values over the whole cold eddy region (section 3-2) are adopted as references. The differences between the lowest temperature (highest salinity) values and the above references are calculated whenever the reference values can be obtained. The standard deviations of those differences is adopted as the measure of the error. Because there is a correlation between the differences of temperature and salinity, the coordinate is rotated for temperature and salinity to become independent each other. The standard deviations on the rotated axes make a ellipse of error which is shown on lower left corner in Figure 10. The total error is less than the sum of above two kinds of errors, which is shown as a larger figure in Figure 10.

The change of T-S plots is greater than the error estimated in the above way, and it seems to be significant. The change of the T-S relation is analyzed in the following way. Let us assume that the water, which is observed at the time of establishment of the cold eddy, makes a vertical movement retaining its T-S characteristics. The shift of a T-S plot caused by above vertical move-

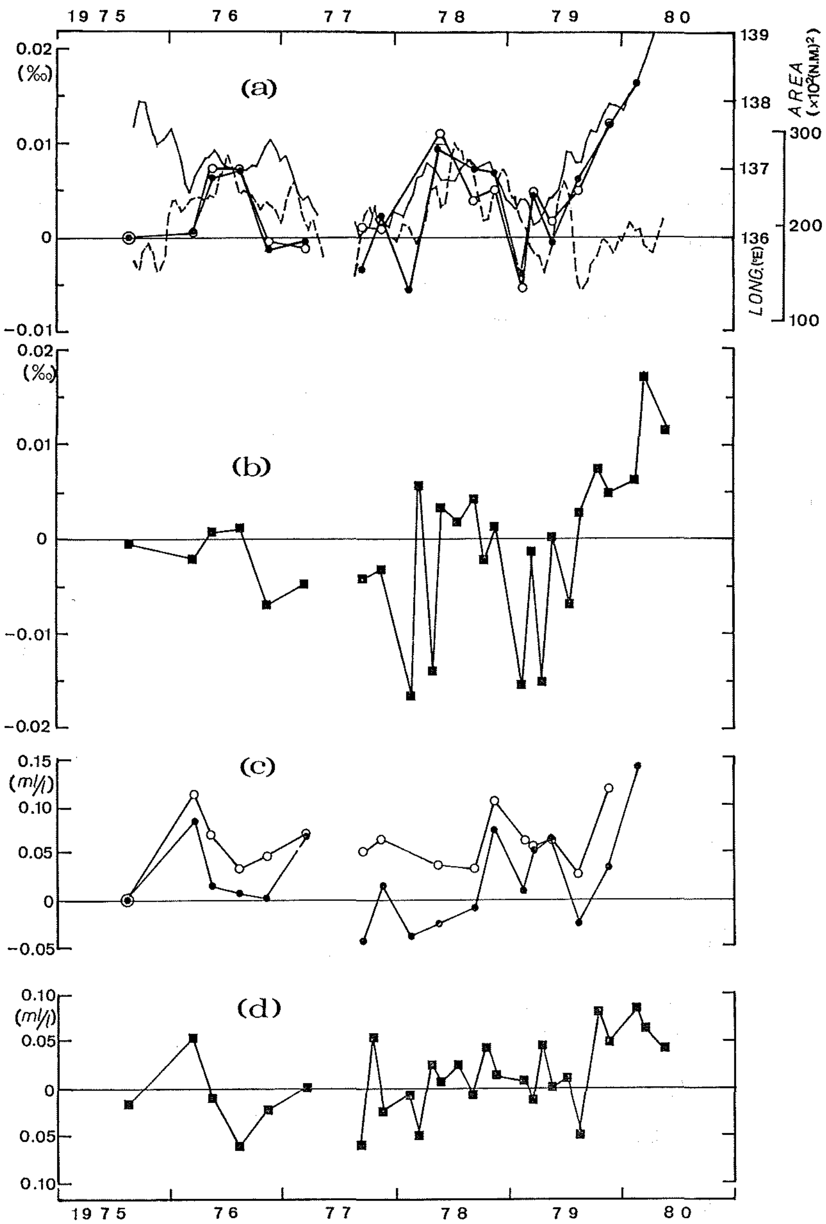

Figure 11 Variation with time of (a) salinity displacement in deep-layer water in the cold eddy (thick lines), longitude of the center of the cold eddy (thin line) and area of the cold eddy region (dashed line), (b) salinity displacement of the deeper waters outside the cold eddy, (c) displacement of dissolved oxygen content for deep-layer water in the cold eddy, (d) displacement of dissolved oxygen content for deeper waters outside the cold eddy

ment is shown by the solid line in Figure 10, where the solid triangles represent the points when the water moves down by the amount of 50 m, 100 m and 150 m, respectively. The displacement of each T-S plot from the assumed line indicates the change of the water characteristics itself or the exchange of some cold eddy water with surrounding waters which have different T-S characteristics. The displacement of the salinity for each cruise, namely the horizontal distance between the line and each T-S plot, is shown as solid circle in Figure 11(a). An open circle in the same graph shows the salinity displacement which is obtained using the three lowest temperature (three highest salinity) values instead of the lowest (highest) one. They have similar tendencies. In the same graph, the area of the cold eddy and the longitude of center of eddy are also shown for comparison. There is a good correlation between the variaiton of the salinity displacement and the area of the eddy, except in the period of the decaying stage of the Kuroshio meander. There is also a good correlation between the variation of the salinity displacement and the longitude of the center except in 1975 and in November 1976. Especially in 1980, the large value of salinity displacement is found. This increase in the displacement, along with the temperature increase in the deep layers, may be one of the important factors which characterize the decay of the cold eddy and the Kuroshio meander.

One possible explanation to interprete the relatively high correlation between the salinity displacement and the east-west movement of the cold eddy is the following. When the position of cold eddy moves, the water consisting the cold eddy does not move, but rather is replaced by a water which occupied the area originally. For this explanation to be correct, the geographical distribution of the salinity should have higher values on the east and lower values on the west in the area south of Japan. In order to check this possibility the mean T-S distribution south of Japan is looked over. The data are taken from the area consisting of 12 blocks as shown in Figure 12. Figure 13 shows the plots of vertically averaged temperature and salinity in 1000–2500 m which are

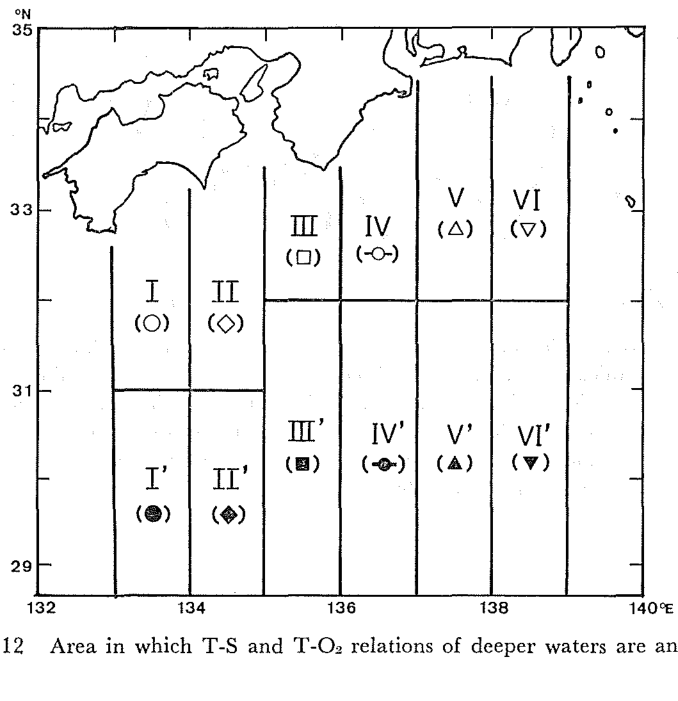

Figure 12 Area in which T-S and T-O_2 relations of deeper waters are analyzed

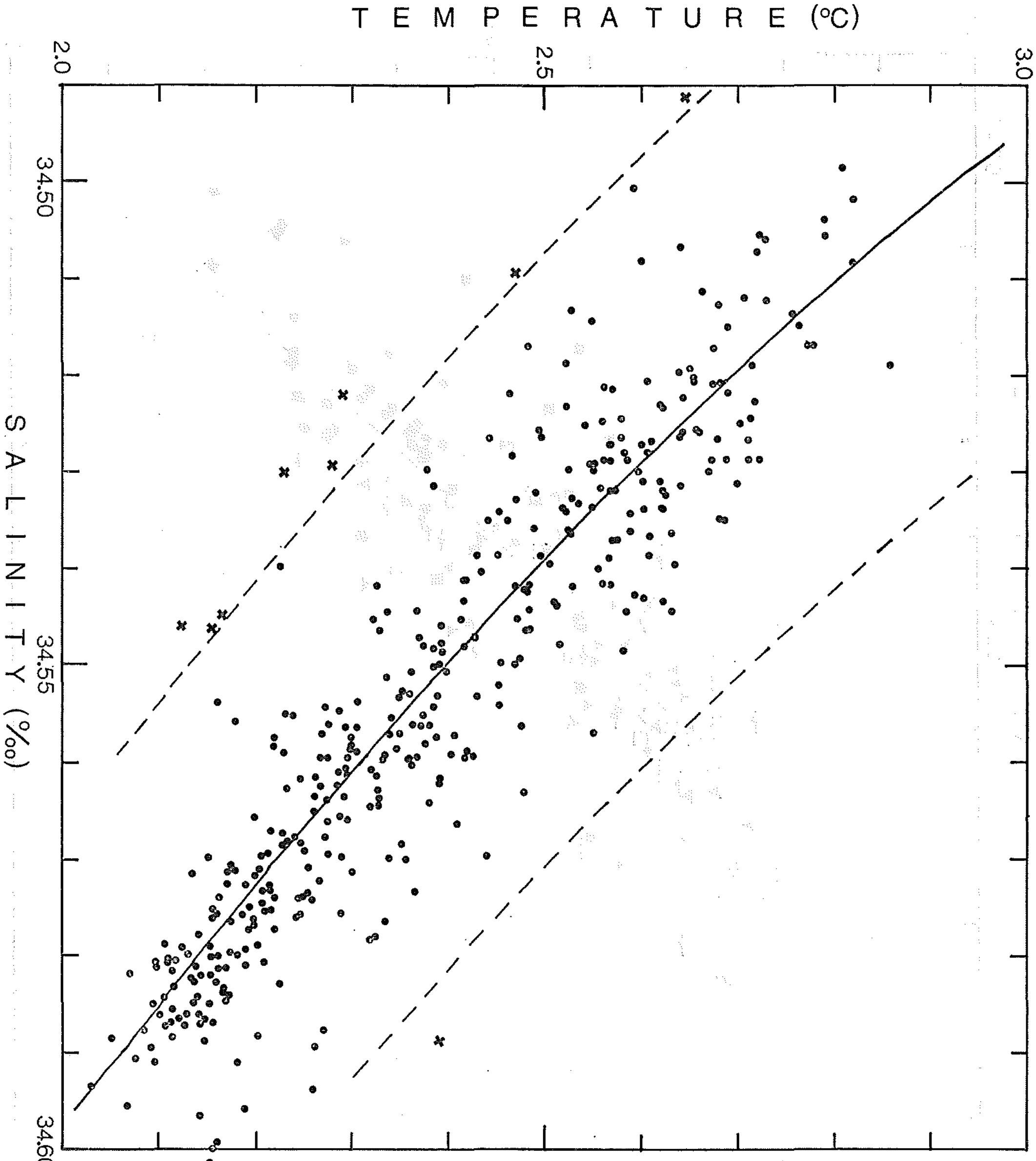

Figure 13 T-S diagrams for deeper waters observed in south of Japan shown as twelve blocks in Figure 12 during the period from August 1975 to May 1980. Solid curve show regression and dashed curve show three times of standard deviation of salinity displacement from regression.

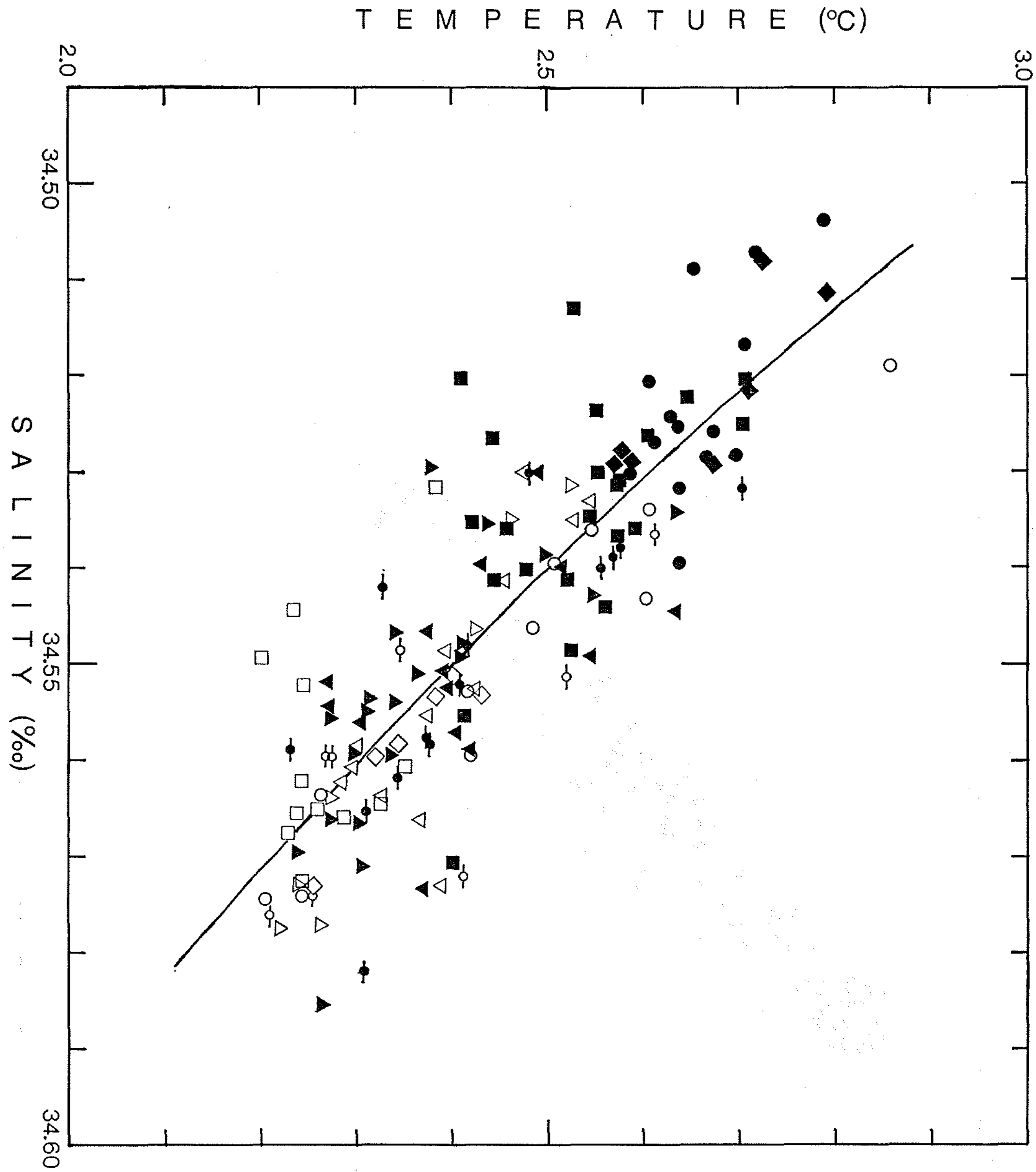

Figure 14 T-S diagrams for cruise-meaned values of deeper waters in twelve blocks in Figure 12.

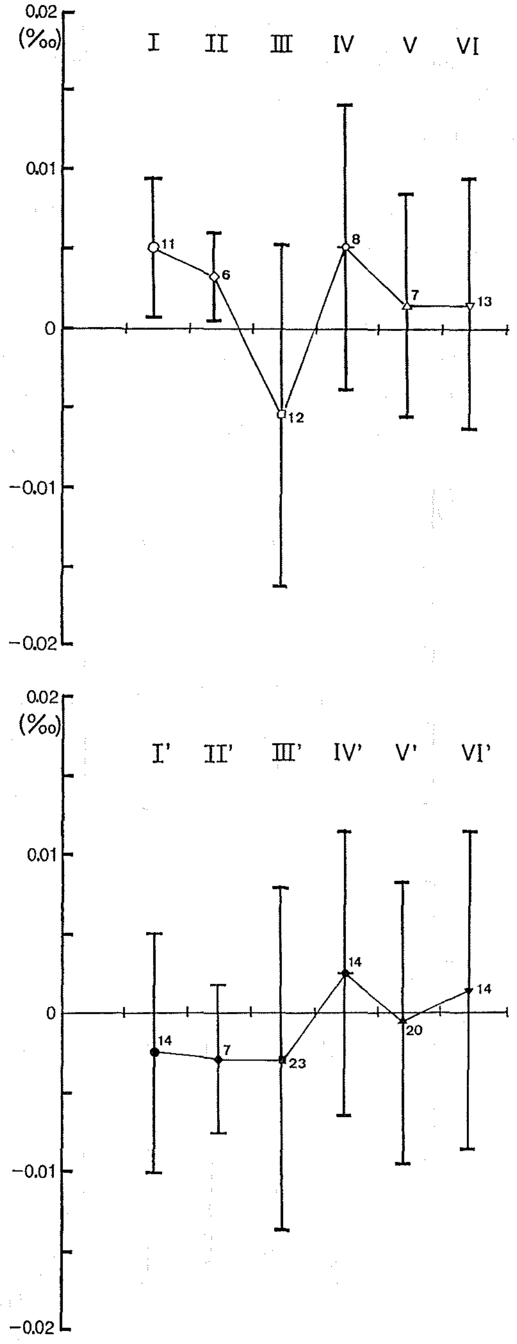

Figure 15 Mean and standard deviation of salinity displacements in each block in Figure 12. Numeral show number of cruise

obtained during the period from August 1975 to May 1980. The regression is shown as a solid curve, and three times as much as the standard deviation in salinity displacements from the regression is shown as a dashed curve in Figure 13. The plots outside the dashed curve are not used in the following analysis. The T-S values are grouped into 12 blocks (Figure 12) and shown by different symbols in Figure 14, where the values are averaged for each cruise and the data in the cold eddy region are excluded. The mean displacement of salinity from the regression curve in Figure 14 and its standard deviation are plotted in Figure 15. As shown in Figure 15, there is no tendency that the salinity values is higher on the east in the northern six blocks, but in the southern blocks the salinity is slightly higher on the east although it does not seem to be significant. This means that the above hypothesis should be rejected.

In order to look for another explanation, the time variation of the salinity displacement for the deep waters outside the cold eddy is plotted in the Figure 11(b). Very good correlation is found between the values inside and outside the cold eddy. This implies that the variation of T-S

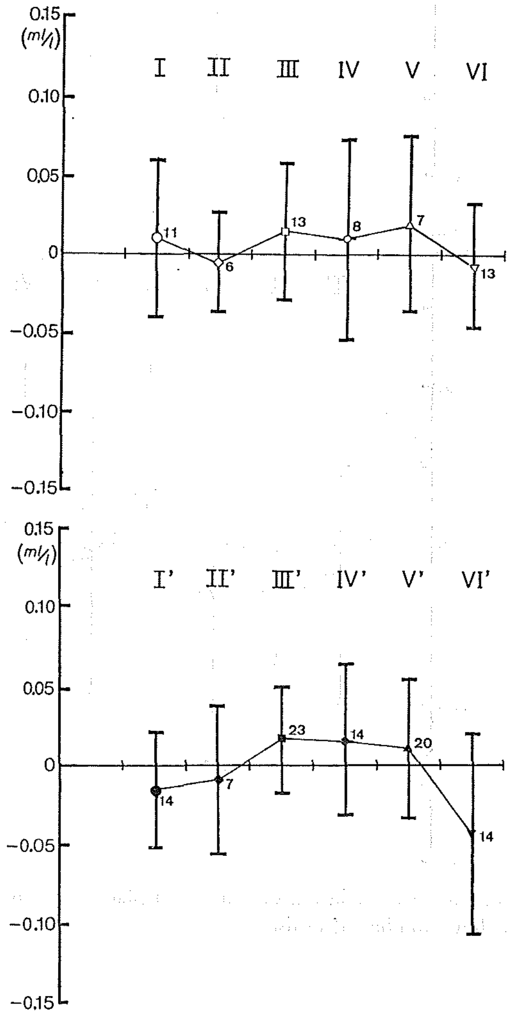

Figure 16 Mean and standard deviation of displacement of dissolved oxygen content for deeper waters in twelve blocks in Figure 12. Numeral show number of cruise

characteristic occurs not only in the cold eddy region, but also over the whole area south of Japan.

A similar method is applied to T-O_2 relation for the deeper waters. The displacement of dissolved oxygen content inside and outside the cold eddy are shown in Figure 11(c) and 11(d) respectively. There is no good correlation between the values of displacement in salinity and dissolved oxygen content. However, in the decaying stage, the increase in the displacement of dissolved oxygen content is found. As is shown in Figure 16, the geographical distribution of oxygen content south of Japan has lower values on the east. It is in contradiciton with the increase of displacement of dissolved oxygen content when the cold eddy is located near the Ridge. Above changes of salinity and dissolved oxygen content indicate that the water characteristics of the deeper waters south of Japan have changed in the decaying stage. The reason for explaining this changes is not clear, but it seems to be a noticeable fact.

8. Summary

The variations of the Kuroshio cold eddy in 1975 to 1980 is investigated, mainly attentioning on the internal structure and its relationship with the external features of the cold eddy. In the course of analysis, the following results are obtained.

1) A stable state of the cold eddy continued for about half a year, and there were two periods of satble state during the five years. In above periods, the area of the cold eddy region was relatively large.

2) The variations of temperature, salinity and dissolved oxygen content in the upper layer (200–500 m) are not always in phase with those in the deep layer (1000–2500 m).

3) The vertical movement of the isotherm in the central area of the cold eddy is a good indicator of the temperature change in the eddy. The variation of area of the cold eddy region has a significant correlation with that of temperature in the upper layer, and it might be explained by upwelling which is indicated by the vertical movement of the isotherm.

4) The temperature in the deeper layer is increasing in eighty percent of the whole period except in May to August 1977. This increase may be similar to the one found in the cold ring in the Sargasso Sea. However, they are different in that the Kuroshio cold eddy has intermittent temperature decrease from time to time. This indicates that the Kuroshio cold eddy is replenished by intermittent upwelling. The mechanism to produce this upwelling is important to explain the long life of the Kuroshio cold eddy and the Kuroshio meander.

5) Temperature increase in the decaying stage of the cold eddy is conspicuous in the deeper layer, but not so conspicuous in the upper and intermediate layers. This may indicates that the first sign of the decay of the cold eddy and the Kuroshio meander appears in the deep layer.

6) The variation of T-S relation for the deeper waters in the cold eddy cannot be explained by the simple vertical movement of the cold eddy water retaining its T-S characteristics. The variation of the displacement of salinity from the values assumed by the simple vertical movement of the cold eddy water, has a relatively good correlation with those of position and area of the cold eddy. The increase in the displacement of salinity and dissolved oxygen content in the decaying stage is observed in the whole region south of Japan, and may be related to the decay of the cold eddy and the meander themselves.

The author is greatly indebted to the members of the Oceanographic Div. for their various field works, valuable discussions and comments. A part of the serial observation data used in this study were taken through "Kuroshio Exploitation and Utilization Research" project (KER) sponsored by Science and Technology Agency.

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