Direct Measurements of Mid-Depth Circulation in the Shikoku Basin by Tracking SOFAR Floats*

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Abstract: Mid-depth circulation of the Shikoku Basin was measured by tracking four SOFAR floats drifting at the 1,500 m layer. Two floats were released on 17 April 1988 at 30°N, 135°59'E and tracked for 433 days. Another two were released on 3 November 1988 at 29°52'N and 133°25'E, and tracked for 234 days. Two floats flowed clockwise around the Shikoku Warm Water Mass with a diameter of 400 km centered at 31°N and 136°E and a mean drift speed of 4.5 cm sec⁻¹. One of the floats showed about ten counterclockwise rotations with a period of about 8 days and a maximum speed of 80 cm sec⁻¹ in the sea area west to the Izu Ridge. In the east to Kyushu, a southward flow was observed under the northward flowing Kuroshio. The southward flow of 4 cm sec⁻¹ drift speed was considered to be a part of the counterclockwise circulation at deep layers along the perimeter of the Shikoku Basin. One float remained for 234 days in a limited area of 100 km by 150 km in the western part of the basin.

1. Introduction

The Kuroshio, the western-boundary current of the subtropical gyre in the North Pacific Ocean, flows through the Shikoku Basin (Fig. 1) entering from the Tokara Strait and going out over the Izu Ridge. Although the water depth of the Tokara Strait and the Izu Ridge is hundreds of meters, the Kuroshio has a deep current structure in the Shikoku Basin (e.g., Worthington and Kawai, 1972; Taft, 1978). The mid-depth circulation of the Shikoku Basin is very different from the surface circulation which has been measured with the GEK and the satellite tracking of drifters.

In the past ten years, direct current measurements with moored current meters have been made in the Shikoku Basin. Taira and Teramoto (1981) showed a northward mean flow of 3 cm sec⁻¹ at 1670 m depth under the northward flowing Kuroshio west of Hachijojima. This measurement was made 100 m above the bottom. A current variation with an amplitude of 20 cm sec⁻¹ and a period of 35 days was predominant during their observation period of 271 days. Nishida and Kuramoto (1982) showed a weak northward deep flow along the western flank of the Izu Ridge. Taira and Teramoto (1985) showed that a northward flow at about 3,000 m depth turned to the southwest along an isobath of the Nankai Trough. Their measurements were made along the northeastern perimeter of the Shikoku Basin. A westward flow was observed under the eastward flowing Kuroshio off Omaezaki (Ishizaki et al., 1983) and off Shionomisaki (Fukasawa et al., 1986). Along the western perimeter of the Shikoku Basin, a southward deep flow was observed to the east of Tanegashima, Okinawa, and Taiwan (Chao et al., personal communication). These measurements suggest a counterclockwise circulation at deep layers along the perimeter of the Shikoku Basin.

Circulations in the Shikoku Basin are subject to cold and warm water masses. South of the
Kuroshio path, a warm water mass is located off Shikoku (e.g., Sugimoto et al., 1986). The center of the warm water mass shifts westward by about 300 km when the large meandering path of the Kuroshio appears. A large cold water mass off the Kii Peninsula appears to the north of the Kuroshio when the Kuroshio path meanders. Taira and Teramoto (1986) showed that the Kuroshio could not flow into Sagami Bay because of the cold water masses which appeared south of the Izu Peninsula in the spring of years 1977, 1978, and 1979.

A Lagrangian measurement of the current, or the tracking of a water parcel at mid-depths, is most required to elucidate the deep circulations in the Shikoku Basin. Tracking of neutral floats over a distance of several hundred kilometers for several hundred days was achieved as one of the core projects of the Priority Area Programme “Dynamics of the Deep Circulation, 1987-1989” represented by Prof. T. Teramoto. Acoustic tracking of the floats was adopted.

A vertical profile of sound speed shows a minimum around 1,000 m depth in tropical and subtropical oceans (e.g., Nakamura, 1986). The sound speed increases at the rate of 4.7 m sec\(^{-1}\) °C\(^{-1}\) with temperature and 0.017 m sec\(^{-1}\) db\(^{-1}\) with pressure increase. High temperature in the upper layer and high pressure in the deeper layer give a larger value of sound speed, resulting in the sound speed being a minimum at mid-depth. A ray path of sound waves is refracted towards the layer of minimum sound speed, and the energy density of the waves is kept high at that layer for a long distance. The sound propagation through the layer was confirmed in the 1940s (Munk, 1983). Shore-based listening stations were monitored for the emergency rescue of aviators who were afloat on the sea and had dropped a signal bomb. The signal could be heard several thousands of kilometers away. The technique is called sound fixing and ranging (SOFA) and the wave guide is called the SOFA channel.

Stommel (1954) proposed tracking the deep circulation by using a neutral float equipped with dozens of SOFA signals which could be ranged from shore listening stations by explosions at a regular time interval. His idea was not activated until the development of electric transducers in
the 1970s (Rossby and Webb, 1971). SOFAR floats were widely used during the MODE Experiment (MODE Group, 1978) and successfully delineated ocean eddies of high energy in a sluggish mean flow (Rossby, 1983). An autonomous listening station for the mooring was developed (Baker, 1981), and operation of SOFAR floats became available in a wide sea area without any shore-based listening stations.

Tracking of a SOFAR float is by quasi-Lagrangian measurements of water movement on an isobaric surface since the float is usually equipped with buoyancy-adjustment gear to keep the pressure constant. The trajectory of a float shows a net displacement of water parcels which are sometimes influenced by a local topographic effect. It is usually very hard to obtain a global flow pattern in a wide area with topographic irregularities from records of moored current meters. We need a large number of current meters moored at many stations. The trajectories of SOFAR floats released in a core of warm and saline water from the Mediterranean Sea showed peculiar loop currents spreading into the North Atlantic (Richardson et al., 1989). This kind of motion is also very hard to detect with current meters. The correlation function of Lagrangian velocity gives an eddy diffusivity and the kinematics of deep circulations can be investigated (e.g., Riser and Rossby, 1982).

Tracking of four SOFAR floats was made at 1,500 m in the Shikoku Basin from April 1988.

Fig. 2. The SOFAR float of 780 Hz acoustic waves contained in glass balls of 43.2 cm in diameter.
to June 1989. Two floats were released in April 1988 and another two in November 1988. Three sets of autonomous listening stations were moored at a spatial separation of about 250 km. Data from the listening stations recovered in November 1988, June 1989, and August 1989 are analyzed in this report.

2. Buoyancy adjustment and tracking observation

We used a SOFAR float with a capability depth of 6,500 m, manufactured by Webb Research Corporation (Fig. 2). Two glass balls are used both for buoyancy and for pressure housings. One glass ball contains a control unit, and the other a battery unit. Outer diameter of the glass ball is 43.2 cm. The float transmits sound waves of 780 Hz for 80 sec twice every day for tracking. The sound source is a piezoelectric bending element with a resonator tube made of aluminum 60 cm long and 25 cm in diameter. The float is deployed at drifting depth after a buoyancy balance in the laboratory (cf. Ollitrault, 1987). When the float is drifting, it has a tendency to sink slowly due to pressure compression of the glass balls. A weight made of zinc is dissolved by an electric current controlled by the pressure sensor signal. A mean vertical motion of SOFAR floats is estimated to be less than several tens of meters (cf. Richardson et al., 1989).

Buoyancy balance of the SOFAR floats was made in a cylindrical tank of 61 cm inner diameter and 170 cm long. The tank was filled with seawater. A SOFAR float was weighed in the air and then was immersed in the seawater tank. Usually, a float had a positive buoyancy of less than 1 kg. Pieces of lead were prepared and were added until the float had a negative buoyancy of less than 100 g. The added lead was weighed after drying. Temperature and salinity of the seawater in the tank were measured with a reversing thermometer and a desk-top salinometer. Density of the seawater was calculated from temperature and salinity by using the equation of state of seawater (Fofonoff and Millard, 1983).

Volume of a SOFAR float under experimental conditions is estimated to be \( V = \frac{W_a}{R_t} \), where \( W_a \) is weight of the float with neutral buoyancy in seawater of density \( R_t \), temperature \( T_t \) and salinity \( S_t \). The volume of a SOFAR float varies with pressure and temperature. The largest variation is caused by the volume change of the two glass balls, and the change is estimated by the following calculation.

Let \( T_i \) be the temperature of seawater at the deployment depth for a SOFAR float, then the temperature difference from the experimental condition is \( dT = T_i - T_t \). The volume change of a glass ball is estimated to be \( dV/V = \beta dT \), where \( \beta = 3.8 \times 10^{-5} \, ^\circ C^{-1} \) is the thermal expansion of glass.

The volume change of a sphere due to pressure variations is estimated from the change in radius \( U \) at distance \( r \) from the spherical center:

\[ U = ar + b/r^2, \]

where

\[ a = \frac{(P_1R_1^3 - P_2R_2^3)}{(R_2^3 - R_1^3)} \left(1 - 2a\right) \]

and

\[ b = R_2^3R_1 \left(P_1 - P_2\right) (1 + a), \]

\( P_1 \) is the inner pressure and \( P_2 \) is the outer pressure. The sphere of inner radius \( R_1 \) and outer radius \( R_2 \) is assumed to be composed of a material having Young modulus \( E \) and Poisson ratio \( \sigma \). For the

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![Fig. 3. Vertical profiles of temperature, salinity, in-situ density and sound speed at 30°N and 135°E for the CTD cast on 6 December 1985 from the R/V Hakuho-Maru.](image-url)
glass ball, \( E = 6.32 \times 10^9 \text{ kg cm}^{-2} \) and \( \varepsilon = 0.2 \) (Benthos Inc., 1987). The radius change was estimated at distance \( r = (R_1+R_2)/2 \), where \( R_1 = 20.2 \text{ cm} \) and \( R_2 = 21.6 \text{ cm} \).

Temperature and salinity at the deployment depth were given by a CTD cast at 29°N and 135°E (R/V Hakuho-Maru, KH-85-5, Ocean Research Institute, University of Tokyo). Figure 3 shows vertical profiles of temperature, salinity, in-situ density, and sound velocity at the station. The sound velocity is a minimum at about 1,000 m, indicating that the SOFAR channel is located there. For a deployment depth of 1,500 m, temperature is 2.528°C and in-situ density is 1.0345 g cm\(^{-3}\).

In the deployment operation from a ship, the SOFAR float was lowered down to the sea surface by rope with a wedge stopper. The wedge was pulled away after the resonator tube was filled with seawater. Two floats were released on 17 April 1988 from the R/V Hakuho-Maru at 1,500 m depth in the Shikoku Basin, and another two on 3 November 1988 from the T/S Keiten-Maru. The release positions and times of signal emission are shown in Table 1.

A SOFAR receiver is composed of a hydrophone array with eight elements, a signal processor and a digital cassette recorder. The hydrophone array of 3.5 m overall length is tuned for sound waves from the horizontal direction and is set in the SOFAR channel, i.e., about 1,000 m depth in the Shikoku Basin. A wavetrain of 780 Hz with unit amplitude is generated in the signal processor and is multiplied by the received signal which is clipped to have an unit amplitude. Output signal of the multiplier has a maximum amplitude when the 80 sec signal from a SOFAR float is received. The largest four amplitudes within every 10 min and their arrival time are recorded on a cassette tape.

Three sets of SOFAR receivers were moored in the Shikoku Basin with a separation of about 250 km (Fig. 1). The first moorings were kept from April 1988 to October 1988, and the second from October 1988 to June 1989 (see Table 2). A typical configuration of the mooring line is shown in Fig. 4.

Binary data on a cassette tape were converted to a computer compatible tape. Each day three signals from each float were recorded with an amplitude exceeding the noise level. Two signals were for tracking, and they were emitted with a time separation of 12 hours. A telemeter signal was emitted after the first tracking signal on each day. Unfortunately, the time modulation logic for signal transmission did not work for the experiment, and the telemeter signal was not used here. Sporadic noise included in the records had forced a tedious data processing.

Records from SOFAR receivers moored at R1 were of low quality. The record in the first mooring was erroneous and only about one-third of the total data could be used. The recorder was stopped 100 days after deployment of the second mooring. A complete dataset for 433 days from 20 April 1988 to 27 June 1989 was

<table>
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<tr>
<th>No.</th>
<th>Emit time</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Water depth</th>
<th>Date of deployment</th>
</tr>
</thead>
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<tr>
<td>F1</td>
<td>0h, 12h</td>
<td>30°00'N</td>
<td>135°59'E</td>
<td>4,410 m</td>
<td>17 April 1988</td>
</tr>
<tr>
<td>F2</td>
<td>6h, 18h</td>
<td>30°00'N</td>
<td>136°00'E</td>
<td>4,390 m</td>
<td>17 April 1988</td>
</tr>
<tr>
<td>F3</td>
<td>3h, 15h</td>
<td>29°52'N</td>
<td>135°25'E</td>
<td>3,521 m</td>
<td>3 November 1988</td>
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<tr>
<td>F3</td>
<td>9h, 21h</td>
<td>29°52'N</td>
<td>135°25'E</td>
<td>3,530 m</td>
<td>3 November 1988</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>St. No.</th>
<th>Latitude</th>
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<th>Depth</th>
<th>Set date</th>
<th>Recovery date</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1 #4</td>
<td>32°30.2'N</td>
<td>136°02.1'E</td>
<td>4,640 m</td>
<td>16 April 1988</td>
<td>27 October 1988</td>
</tr>
<tr>
<td>R2 #6</td>
<td>28°59.4'N</td>
<td>133°50.6'E</td>
<td>3,380 m</td>
<td>18 April 1988</td>
<td>1 November 1988</td>
</tr>
<tr>
<td>R3 #5</td>
<td>28°59.0'N</td>
<td>135°59.8'E</td>
<td>4,430 m</td>
<td>17 April 1988</td>
<td>2 November 1988</td>
</tr>
<tr>
<td>R1 #1</td>
<td>32°30.2'N</td>
<td>136°02.1'E</td>
<td>4,600 m</td>
<td>27 October 1988</td>
<td>27 June 1989</td>
</tr>
<tr>
<td>R2 #2</td>
<td>29°06.5'N</td>
<td>133°29.8'E</td>
<td>3,340 m</td>
<td>1 November 1988</td>
<td>11 August 1989</td>
</tr>
<tr>
<td>R3 #3</td>
<td>29°01.0'N</td>
<td>136°00.2'E</td>
<td>4,250 m</td>
<td>2 November 1988</td>
<td>27 June 1989</td>
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obtained at the listening stations of R2 and R3 for the floats released on 17 April 1988. For the floats released on 3 November 1988, the dataset is 234 days long starting on 6 November 1988.

A maximum tracking range of our float system is about 600 km. For simplicity, a cartesian coordinate system is used for the positioning of the floats. The position \((x, y)\) of a float is determined from the following three quadratic equations:

\[
(x-x_1)^2 + (y-y_1)^2 = (ct_1)^2,
\]

\[
(x-x_2)^2 + (y-y_2)^2 = (ct_2)^2,
\]

\[
(x-x_3)^2 + (y-y_3)^2 = (ct_3)^2,
\]

where \((x_1, y_1), (x_2, y_2), \) and \((x_3, y_3)\) are positions of the listening stations, \(t_1, t_2,\) and \(t_3\) the arrival times at the stations, and \(c\) the mean sound speed.

Float position \((x, y)\) and the mean sound speed \(c\) were determined from three arrival times, \(t_1, t_2,\) and \(t_3\). This gave the coarse trajectory of the float because the arrival time at station \(R_1\) was obtained for a limited period.

For the data set of two arrival times at stations \(R_2\) and \(R_3\), the mean sound speed of 1.48 km sec\(^{-1}\) was used to determine float position \((x, y)\). The mean sound speed was equal to the minimum value of the vertical profile of the sound speed in Fig. 3. Although two sets of \((x, y)\) were obtained by solving the quadratic equations, we selected only one of them by consulting the coarse trajectory obtained from the three arrival times.

3. Trajectories of Sofar Floats

Four floats were deployed at 1,500 m in the Shikoku Basin, two on 17 April 1988 at 30°N and 135°59'E, and two on 3 November 1988 at 29°52'N and 133°25'E (see Table 1). The trajectories of these four floats show that the flows at 1,500 m depth in the Shikoku Basin can be classified into three types: 1) a clockwise circulation in the central part, 2) northward and southward flows along the western perimeter of the basin, and 3) a sluggish flow in the western part of the basin.

3.1. Clockwise circulation in the Shikoku Basin

Figure 5a shows trajectories of floats F1 and F4. Numerals on the trajectories show elapsed days from deployment. Three circles in the figure show the mooring stations of the SOFAR receivers. Two lines in the left portion show the bottom contour of 1,500 m (see Fig. 1). Float F1 drifted eastward for several days after deployment, but turned to the south and then to the west. It turned to the north 220 days after deployment. From day 250 to day 350, it made a cyclonic turn around at 31°30'N and 133°30'E. After the turn, it flowed northeastward. Float F4 deployed on day 196 of float F1, flowed northeastward after a cyclonic turning of about 10 km diameter at 30°30'N and 133°30'E. The float flowed southeastward, and it showed quick cyclonic turnings about ten times at 30°20'E and 138°30'E.

Two trajectories showed a clockwise circulation in the Shikoku Basin. The diameter of the circulation is estimated to be about 400 km. A period of 400 days for one turn gives a mean speed of 4.5 cm sec\(^{-1}\). Drift of F4 from day 50 to day 100 gave a mean speed of 11 cm sec\(^{-1}\). The quick turnings in the eastern portion will be discussed in the next section.
3.2. Northward and southward flows along the western perimeter

Figure 5b shows the trajectory of float F2, which was deployed on the same day and at nearly the same position as float F1. The two trajectories were identical for several days, but float F2 flowed to the west until day 150. It flowed to the north until day 200, and then flowed southward along an isobath of 1,500 m. From day 250 to day 380, it flowed back into the Shikoku Basin and made a clockwise turn of 100 km diameter. It flowed again southward along the western perimeter until the end of tracking. The speed of the southward flow was about 4 cm sec⁻¹. The trajectories are estimated to be in the western area where water depth is less than 1,500 m. Distance from the 1,500 m isobath is about 30 km, and this may indicate a delay of about 20 sec in the clock of the float.

3.3. Sluggish flow in the western part of the basin

Figure 5c shows the trajectory of float F3 which was deployed together with float F4 on 3 November 1988 at 29°52′N and 133°25′E. It

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Fig. 5a. Trajectories of the SOFAR floats F1 and F4. Numbers on the trajectories show elapsed days from 20 April 1988 for F1, and from 6 November 1988 for F4. The lines in the upper left corner show the 1,500 m isobath, approximately.

Fig. 5b. Trajectories of the SOFAR float F2. Numbers on the trajectory show the elapsed days from 20 April 1988.
Fig. 5c. Trajectory of the SOFAR float F3. Numbers on the trajectory show the elapsed days from 6 November 1988.

Fig. 6a. Northward component of the drifting velocity of the SOFAR float F4 from 25 March 1989 to 13 June 1989 (upper panel) and its power spectrum (lower panel).

Fig. 6b. Same as Fig. 6a except for the eastward component.
stayed in an area of 150 km in the north-south direction and 100 km in the east-west direction. The mean drift speed was less than 2 cm sec$^{-1}$. The float made clockwise turnings several times.

4. Discussion

4.1. Cyclonic eddies on the western slope of the Izu Ridge

The trajectory of float F4 (Fig 5a) showed quick cyclonic turnings in an area around 30°20′N and 138°30′E. The area is located on the western slope of the Izu Ridge where the water depth is between 1,500 m and 3,000 m as shown in Fig. 1.

Figure 6a shows the northward component of the drift velocity and its power spectrum for the period from 25 March 1989 to 13 June 1989. A periodic oscillation is dominant with a maximum amplitude of 80 cm sec$^{-1}$. The power spectrum shows a peak at 4/32 cycle per day, or a period of 8 days. Figure 6b shows the eastward component of velocity and its power spectrum for the same period. The oscillation has a maximum amplitude of 40 cm sec$^{-1}$. The spectrum shows the peak at 4/32 cycle per day.

The energetic oscillation is related to the cyclonic turnings of an elliptic shape. The trajectory gives axes of the eddies to be 80 km in the north-northwest and 25 km in the east-northeast direction. The cyclonic turnings were observed on the western slope of the Izu Ridge. The topographic effect of the Izu Ridge may play an important role for the generation of the cyclonic eddy.

The oscillation was observed from March through June. Taira and Teramoto (1986) observed that the Kuroshio in Sagami Bay was weakened for about 20 days in July 1977, May 1978, and April 1979. The Kuroshio current is unstable in the spring season in the sea area near the Izu Ridge. The energetic oscillation observed on the western slope of the ridge may have a close relation to the instability of the Kuroshio in the spring season.

The cyclonic turnings were observed for the first time by the present study. A cold eddy is suggested to be related to the cyclonic motions, and evidence of the thermal structure is required for further investigation.

4.2. Southward flow under the Kuroshio

Figure 7 shows isotherms at 200 m depth observed from 20 October to 1 November 1988 (Prompt Report of Sea Conditions, Hydrographic Department, Maritime Safety Agency). The Shikoku Warm Water Mass, described by the 19°C isotherm in the figure, is located southeast of Shikoku. Floats F1 and F4 flowed around the water mass. This shows that the anticyclonic circulation around the water mass extended to the depth of 1,500 m.

The path of the Kuroshio is indicated by the
15°C isotherm at 200 m (Kawai, 1969). The Kuroshio path during the period had no large meanders. The isotherm curved northeastward from Tanegashima, where float F2 flowed southward. The float revealed the countercurrent under the Kuroshio.

Moored current meters deployed along the perimeter of the Shikoku Basin showed a counterclockwise circulation at the deep layers (Taira and Teramoto, 1981; Nishida and Kuramoto, 1982; Ishizaki et al., 1983; Taira and Teramoto, 1985; Fukasawa et al., 1986; Chazen et al., personal communication). Shimamura (1989) showed that sediment particles were transported from east to west in the deep channel of the Nankai Trough. The southward flow detected by the SOFAR float east of Kyushu may be a part of the counterclockwise circulation along the perimeter of the Shikoku Basin, although the vertical and horizontal extents of the circulation are not yet fully described.

5. Summary

Circulation at 1,500 m depth in the Shikoku Basin was measured from April 1988 to June 1989 with tracking SOFAR floats. Two SOFAR floats were released on 17 April 1988 at 30°N, 135°59'E, and tracked for 433 days. Another two were released on 3 November 1988 at 29°52'N and 133°25'E, and tracked for 234 days. Three flow characteristics of the mid-depth circulation in the Shikoku Basin were delineated by the trajectories of the SOFAR floats: 1) a clockwise circulation around the Shikoku Warm Water Mass centered around 31°N and 136°E. Two floats made a clockwise turning around the water mass with a diameter of about 400 km at a mean drifting speed of 4.5 cm sec⁻¹. 2) a southward flow under the northward flowing Kuroshio in the east to Kyushu. One float revealed the southward flow of 4 cm sec⁻¹ speed. The float first flowed northward, and then went out to the center of the Shikoku Basin in the middle of the southward drift. Although the southward flow was not steady, it was suggested to be one part of a counterclockwise circulation at deep layers along the perimeter of the basin, which had been shown by the records of moored current meters. 3) a sluggish flow in the western part of the basin. One float deployed at 29°52'N and 133°25'E remained in a limited area about 150 km in the north-south direction and 100 km in the east-west direction for 234 days. The trajectory of the float, however, crossed several times the trajectories of the floats drifting around the Shikoku Warm Water Mass and of the float flowing under the Kuroshio.

The trajectories of the floats showed several cyclonic and anticyclonic eddies in the Shikoku Basin. Among them, the cyclonic eddy observed on the western slope of the Izu Ridge was the most remarkable. The shape of the turnings was elliptic about 80 km long in the north-northwest and 25 km long in the east-northeast direction, and the period was about 8 days. The quick turnings were observed for about 80 days from March to June 1988. Generation of the eddy may be related to topography of the Izu Ridge, and to instability of the Kuroshio in the spring season.

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References


ソーファーフロート追跡による四国海盆の中深層循環の評価

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要旨: 海水とともに流動する 4 台の中立ソーファーフロートを声響信号を用いて追跡して、四国海盆の 1,500 m 層の循環を調べた。1988 年 4 月 17 日に 30°N, 135°59′E で 2 台、1988 年 11 月 3 日に 29°52′N, 133°25′E で 2 台を

放流して、1989年6月27日までにそれぞれ433日と234日までの追跡を行った。2台のフロートは31°N, 136°Eを中心にとする直径約 400 km の軌跡で四国沖暖水の発生を示し時計回りに流れ、平均の流速は約 4.5 cm sec⁻¹ であった。その中の 1 台は伊豆半島の西方で周期 8 日で

最大流速 80 cm sec⁻¹ で反時計回りに約10回転した。1 台のフロートは九州の東方で南向きの折りの下層を南向きに流れ、南向きの流速は 4 cm sec⁻¹ であり、四国海盆の南に沿う反時計回りの深層循環の一環であると考えられる。四国海盆の西部に投下した 1 台のフロートは

南北 100 km, 東西 150 km の範囲で 234 日間留まった。

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