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# TOLEX-ADCP monitoring

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***Abstract.*** Since February 1991, the Physical Oceanography Group, Tohoku University has conducted a program to monitor the oceanic current field across the Kuroshio over the Izu Ridge, south of Japan, using the Acoustic Doppler Current Profiler (ADCP) system installed on the ferry Ogasawara Maru. This ferry shuttles 58 times in a usual year between Tokyo and Chichijima in the Ogasawara (Bonin) Islands. This ADCP monitoring is regarded as one component of the Tokyo-Ogasawara Line Experiment (TOLEX). In this paper, we will briefly describe our ADCP system and data processing procedures, and will present several aspects of the current fields using the data obtained through January 1996. During the period, the Kuroshio took the bimodal paths of 34°N and 32°30'N as mean positions on the ship course. In the sea south of the Kuroshio, many cyclonic and anticyclonic eddies with a scale of 200-400 km in diameter were observed with passing time of two-four months.

## Introduction

It has been widely recognized that the shipmounted Acoustic Doppler Current Profiler (ADCP) system is a very powerful tool to measure the surface and subsurface current velocities along a ship track. Therefore, at the present, most research vessels are equipped with a system and a huge amount of current data is archived (e.g., Caldwell, 1995). When this system is installed in regular-line vessels, velocity data along an almost uniform ship course and at a quasi-regular sampling interval can be obtained. This is a very desirable situation for monitoring the flow field of western boundary currents such as the Kuroshio and the Gulf Stream.

During the course of a project named "Ocean Mixed Layer Experiment" (OMLET, 1987-1991: Chairperson Prof. Y. Toba, Tohoku University), which was one of the Japanese WCRP activities, the Physical Oceanography Group, Tohoku University, had considered the possibility of monitoring the Kuroshio Current System south of Japan. Finally, we decided to install an ADCP system on the ferry Ogasawara Maru, which regularly shuttles between Tokyo and Chichijima in the Ogasawara (Bonin) Islands. By using part of the obtained ADCP data, Ebuchi and Hanawa (1995) already have compared surface velocities perpendicular to the ship course estimated by the TOPEX altimeter and examined the performance of the TOPEX altimetry. They concluded that the TOPEX altimeter reliably observes variations of surface currents including fluctuations of the Kuroshio axis.

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In this paper, we will briefly describe our ADCP system and data processing procedures, and will present several aspects of the current fields using the data obtained from February 1991 through January 1996.

## TOLEX-ADCP monitoring

The goal of the "Tokyo-Ogasawara Line Experiment (TOLEX)", a subprogram of OMLET operated by the Physical Oceanography Group, Tohoku University, is to monitor the Kuroshio Current System over the Izu Ridge south of Japan, by using the ferry "Ogasawara Maru" (Ogasawara Kaiun Co., 110 m long, 3553 tons), which regularly shuttles 58 times in a usual year between Tokyo and Chichijima in the Ogasawara (Bonin) Islands. The ship runs between the two ports in 29 hours. Figure 1 shows an example of the ship track with the three typical Kuroshio paths presented by Kawabe (1985).

Since August 1988, XBT measurements as TOLEX-XBT monitoring have been conducted to monitor the upper thermal structure along the ship course (Hanawa and Yoshikawa, 1993: Yoshikawa et al., 1996). In addition to this monitoring, since February 1991, TOLEX-ADCP monitoring has begun. Although the ADCP system was originally installed in February 1990 on the ferry, meaningful data were not obtained until January 1991, because of instrument troubles. After re-installation in late January 1991, good quality data became available for scientific use.

Since this ferry regularly shuttles 58 times a year, 116 cross sections are obtained in a year, and therefore the approximate sampling interval at some given point is three days in time. This is good enough for detection of synoptic-scale oceanic variations.

## ADCP system

A 150-kHz ADCP (RD Instruments, U.S.A.) was installed with a data acquisition system (DAS) and a personal computer (PC) as a recording facility. In addition, a Global Positioning System (GPS) receiver (GP-500, Furuno Electric Co., Japan), with another PC for recording, and a gyro compass (GM-21, TOKIMEC Co., Japan) were also installed.

Along the ship track, the ADCP system can update water velocities relative to the moving vessel. Our sample averaging interval is five minutes. The ADCP transducer can transmit an acoustic signal approximately every second, and the five-minute value is obtained as an ensemble average of about 300 soundings. The cruising speed of this ferry is about 20 knots in the open ocean, so the five-minute sampling interval approximately corresponds to a 3-km resolution.

The vertical bin length is set at 16 m. This type of ADCP can usually measure the velocities from the surface to approximately 400 m (26 bins) or more, but the sounding depths are frequently less than that, because of the bubbles, which cause increased noise and/or attenuation of the acoustic pulse in bad weather conditions and the resulting severe sea state. Although the %good lies within 50 to 80 in the usual sea state, in the

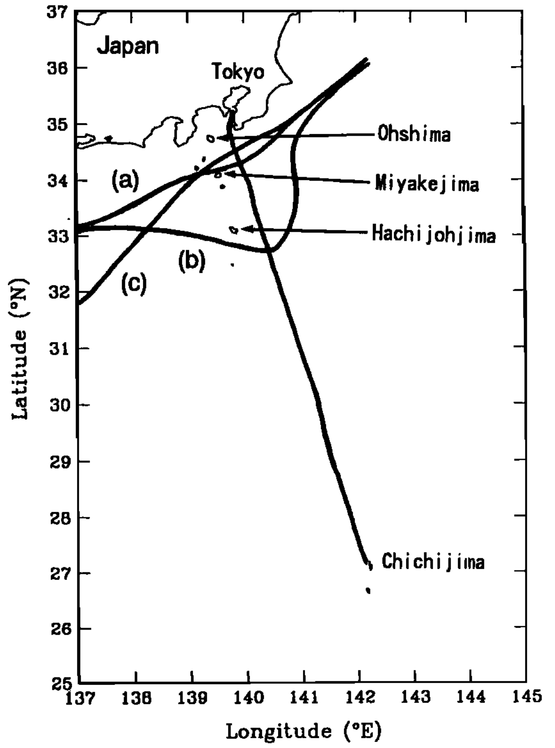


**Fig. 1.** Example of ship track of the ferry Ogasawara Maru and three typical Kuroshio paths (corresponding to 15°C isotherms at 200 m). The three typical Kuroshio paths are cited from Kawabe (1985): (a) the nearshore non-large-meander path, (b) the offshore non-large-meander path and (c) the typical large meander path. The paths shown here are smoothed compared with those originally presented.

severe sea state it decreases to much lower values. In our analysis, the %good threshold was set as 5. Although this value is relatively low, we found the data are sometimes available as long as the data are obtained as the four-beam solution.

Positions of the ferry by GPS are also archived in the PC every 24 seconds. From these data, ship's velocity is carefully calculated. Finally using both the data sets of water velocity relative to the moving ship and the ship's velocity, current velocity relative to the solid earth is computed.

## Data processing procedures

In this section, we will give a brief description of the ADCP data processing procedures, since the detailed, complete description is to be made elsewhere (Yoshikawa and Hanawa, manuscript, 1996).

***"Angle correction":*** In the open ocean, this ferry cruises keeping a predetermined heading direction (see Fig. 1) and an almost constant engine rotation rate, which means that the ferry goes forward with an almost steady speed. These are desirable and favorable conditions for ADCP measurement. Nevertheless, the original five-minute average data inevitably include erroneous data, because of various reasons such as bubble conditions, fluctuation of ship heading, pitching and rolling of the ship, and positioning error of GPS, as pointed out by Joyce (1989), Pollard and Read (1989) and Kaneko et al. (1990).

One of the most severe error sources for the updated ADCP data is a mismatch of true ship heading and the ADCP coordinate system used in the DAS for computation of absolute water velocities. This mismatch occurs from two causes: misalignment of the ADCP transducer from the true ship heading, and mis-indication of the gyro compass (Joyce, 1989). As mentioned before, since the cruising speed of the ferry is about 20 knots in the open ocean, a mismatch of 1 degree between true ship heading and the ADCP coordinates causes a velocity error of about 18 cm/s (0.15 cm/s) in the direction perpendicular (parallel) to the ship heading. Therefore, this error must be carefully and exactly corrected and thus this correction can be called an "angle correction".

In order to find the angle correction, we performed the following analysis. Since this ferry shuttles almost every week (i.e. approximate sampling interval of three days) and the ship tracks are almost identical, we can assume that the transports crossing the vertical section are almost the same between any two consecutive cruises in time. Under this assumption, we can estimate the magnitude of angle to be corrected so as to minimize the difference between all pairs of transports. As a result, we found that the angles to be rotated are fairly stable in time, i.e., have an almost constant value. After February 1992, we set the value of the angle corrections at 3.03°. The individual values for the angle correction scatter with a standard deviation of about 0.25°. We can regard this value of 3.03° as the angle of misalignment between the ADCP transducer and the true ship heading. Please note that this methodology becomes available because the ferry used is a regular-line vessel.

***Filtering procedure in space:*** After this angle correction, we applied a spatial filter to the data using the following procedure. A Gaussian filter with e-folding scale of 10 minutes in latitude was used to smooth and obtain regularly gridded data. These gridded data were obtained every ten minutes in latitude from 35°N to 27°10'N along the ship track, i.e., 48 grid points. These procedures give good quality data for each cross section. We did no filtering in the vertical.

***Filtering procedure in time:*** The ADCP data are an almost instantaneous field, a so-called "snapshot", including ageostrophic velocities such as tidal currents, inertial oscillations, internal waves, wind-driven surface drift currents and so on. Therefore, in order to obtain a qualified geostrophic velocity field, we adopted further filtering and smoothing processes in time. A Gaussian filter with e-folding scale of 15 days was used. The resulting data were taken approximately every two weeks in time: the 1st and 16th of each month. Therefore, approximately ten cross sections (ten cruises) were used to obtain the temporally-averaged data set. It can be expected that in these data, small scale variations in space and time are filtered

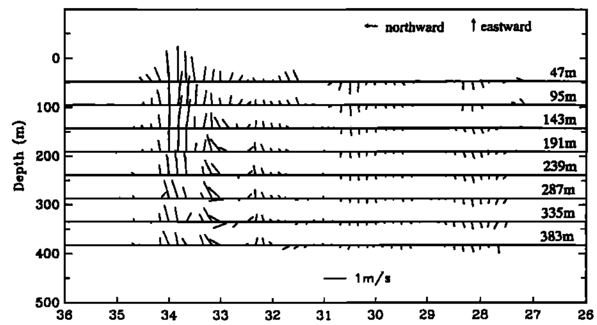


**Fig. 2.** Example of current field. Vectors are shown on only eight layers (bins). The data were taken on 28-29 July 1995 on the course from Chichijima to Tokyo.

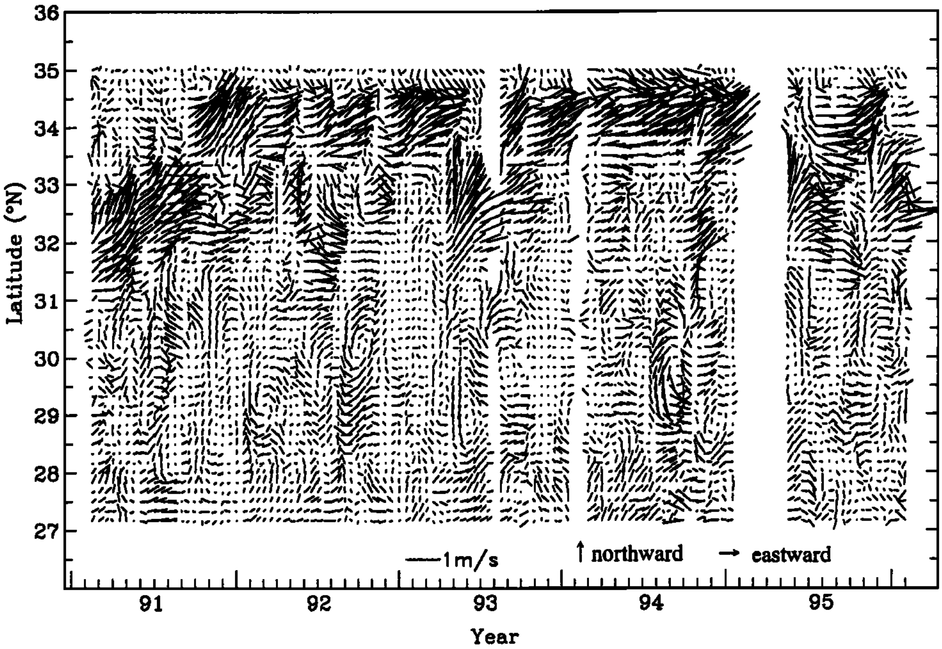


**Fig. 3.** Velocity vectors at about 47 m depth (3rd bin) from February 1991 through January 1996.

out and the current field obtained is regarded as being close to geostrophically balanced.

## Description of obtained current field

Figure 2 shows a typical current field obtained on 28-29 July, 1995 on the course from Chichijima to Tokyo. The Kuroshio is clearly seen flowing eastward with the velocity greater than 1 m/s around 34°N and the existence of an anticyclonic eddy centered on 31°N, south of the Kuroshio. At the northern frontal region of the Kuroshio, the currents show relatively strong vertical shear around 300m in depth. In the southern region of the Kuroshio, the current field shows an almost barotropic form.

Figure 3 shows the velocity vectors at about 47 m depth (the 3rd bin) from February 1991 through January 1996. The position of the Kuroshio can be clearly recognized as the eastward or northeastward flow within the latitudes from 35°N to 32°N. It is also seen that in the area south of the Kuroshio, many cyclonic and anticyclonic eddies frequently pass across the ship course. By the lag-correlation analysis in space and time, approximate diameter of eddies and passing time were estimated as 200-400 km and two-four months, respectively.

Figure 4 shows a map of *Stability* which is defined as the ratio of vector-averaged current speed to scalar-averaged current speed. This parameter can be represented as the variability of current direction: if the current flows in only one direction for a certain time, then *Stability* equals 1, and if the current direction rotates, it decreases towards zero. As expected from Fig. 3, *Stability* is high around the Kuroshio (around 34°N and from 32°50'N to 31°40'N), while it is very low in the other regions, especially south of 31°N. This reflects frequent passing of cyclonic and anticyclonic eddies in the southern regions as mentioned above. This present distribution of *Stability* is very similar to the *Stability* map shown in Marine Environmental Atlas (JODC, 1979).

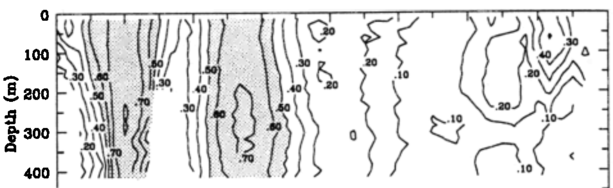


**Fig. 4.** *Stability* (ratio of vector-averaging current speed to scalar-averaging current speed) of the current field. Layers with *Stability* greater than 0.5 are shaded.

Figure 5(a) shows time series of the positions of the Kuroshio axis detected for individual cross sections. The position of the Kuroshio axis is defined as that having the maximum value of velocity averaged for three consecutive points in space (56 km). It is found that the Kuroshio vigorously and quickly changes its position over the ship course. Figure 5(b) shows the frequency distribution of positions of the Kuroshio axis for 10' meridional interval. There are two peaks: one is around 34°N and the other is around 32°30'N. These latitudes correspond to the positions between Ohshima and Miyakejima and south of Hachijyohjima, and also coincide with the positions of the typical Kuroshio paths (see Fig.1; Kawabe, 1985). This result confirms the findings of previous authors, that is, the Kuroshio tends to take the bimodal paths of around 34°N and around 32°40'N over the Izu Ridge (e.g., Hanawa and Hoshino, 1988).

## Conclusion

In this preliminary report, we have briefly described TOLEX-ADCP monitoring, the ADCP system used and the data processing procedures. In addition, several aspects of the current fields obtained from February 1991 through January 1996 were presented. During the period, the Kuroshio took the bimodal paths of 34°N and 32°30'N as mean positions over the Izu Ridge. In the sea south of the Kuroshio, many cyclonic and anticyclonic eddies with a scale of 200-400 km in diameter were observed with passing time of two-four months. The *Stability* of the current field was high around the Kuroshio, while it was very low in the other regions, due to frequent passing of cyclonic and anticyclonic eddies.

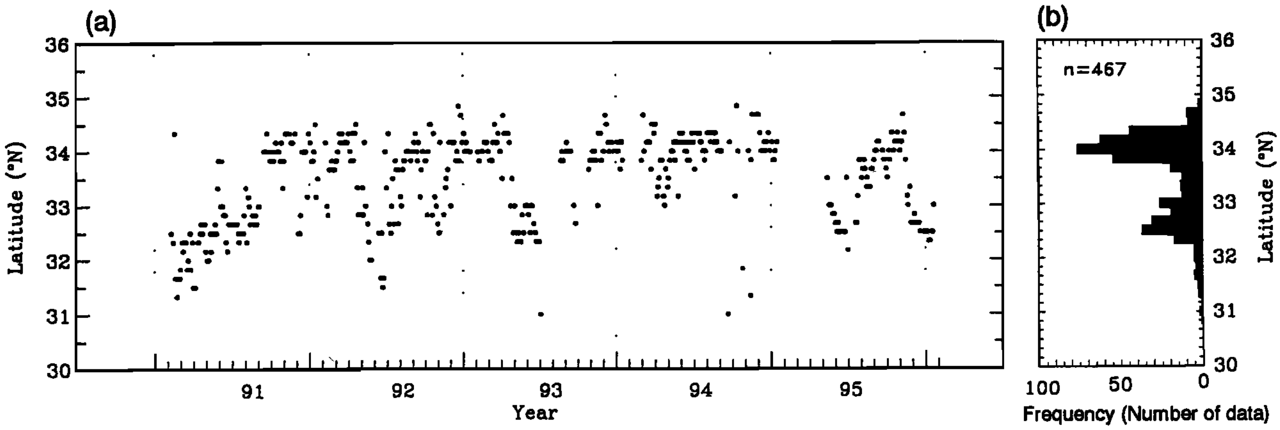


**Fig. 5.** (a) Time series of positions of the Kuroshio axis for individual cross sections. During the period treated here, 467 cross sections were obtained. See text for the definition of the Kuroshio axis. (b) Frequency distribution (number of data) of positions of the Kuroshio axis for 10' meridional interval.

A comprehensive analysis of the present ADCP data is to be made in the near future and we expect to be able to extract much useful information from it. Finally, we would like to say that our ADCP data are promptly used in the "Prompt Report of Oceanic Condition (*Kaiyo Sokuho*)" issued every two weeks by the Hydrographic Department of the Japan Maritime Safety Agency.

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