La mer 34: 163–171, 1996
Société franco-japonaise d'océanographie, Tokyo

Time variations of the current northwest of Tsushima

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Abstract: We measured current and temperature northwest of Tsushima. On the basis of records obtained from July 1991 to March 1995 we confirmed that in shallow and middle depth, all year round, the current goes northeast and the temperature is higher than 10℃; in deep depth, in spring, summer, and autumn, the current goes southwest and the temperature is about 5℃, in winter, however, the current northeast and the temperature higher than 10℃.

1. Introduction

It has drawn attentions of researchers in ocean that bottom water intrudes from north to south at a basin northwest of Tsushima.

NISHIDA (1927) reported, in northwest of Tsushima, existence of southward flowing phenomenon of the Japan Sea bottom cold water. CHANG and UDA (1968) also wrote about intrusion of the Japan Sea cold bottom water into the Strait of Korea. LIM and CHANG (1969) discussed water mass structure and proposed 10 ℃ as an index number of the cold water. MIITA (1976) made Eulerian measurements of the current for about ten days. OGAWA (1983) analyzed observation data along a line between Kawajiri and Ulsan. He pointed out that it is difficult to recognize the cold water clearly in winter. NAGATA (1985) wrote about forming of the cold water mass region along the Korean and the Japan shore lines. ISOBE (1993) discussed a relation between the cold water and the Tsushima current.

On the basis of these pioneering works, we made a plan to measure the current northwest of Tsushima and carried it out. Until now we showed data obtained in summer of 1991 (OMURA and KAWATATE, 1994).

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2. Method

We have used three kinds of lines: 173, 40, and 25 m long. We show them schematically in Fig. 1, where a signal buoy, current meters (denoted by CM), floats, and an acoustic releaser (denoted by AR), a sinker, and an anchor are illustrated. The line of 173 m long is equipped with two current meters. We have used an iron sinker of 240 kgf in air. Each of the shorter two lines has one current meter and a sinker of 120 kgf.

We set mooring lines in a circle of a point 5 nautical miles (nm) radius with a center at 340 degrees (°) from north and 9.5 nm away from Mitsushima lighthouse, the northern extreme of Tsushima. Depth is about 220 m there. We show measuring stations in Fig. 2. We deployed eight lines, among which we retrieved five lines and lost three shown by solid circles.

We show items of lines used in Table 1, which includes mooring terms, measure interval, and positions. In 1991 the line was recovered safely. In 1992 we lost one short line with one current meter. A cluster of top floats was recovered in January 1993 at Murakami city on the coast of the Japan Sea, Niigata, Japan. In 1993 we lost one long line with two current meters. We had no news of this line until now. In 1994 we put two short lines. In February 1995 we found that one line was lost. In June we went the site to retrieve the remaining line. During three months and half, from February to June, the line was disappeared. We lost all

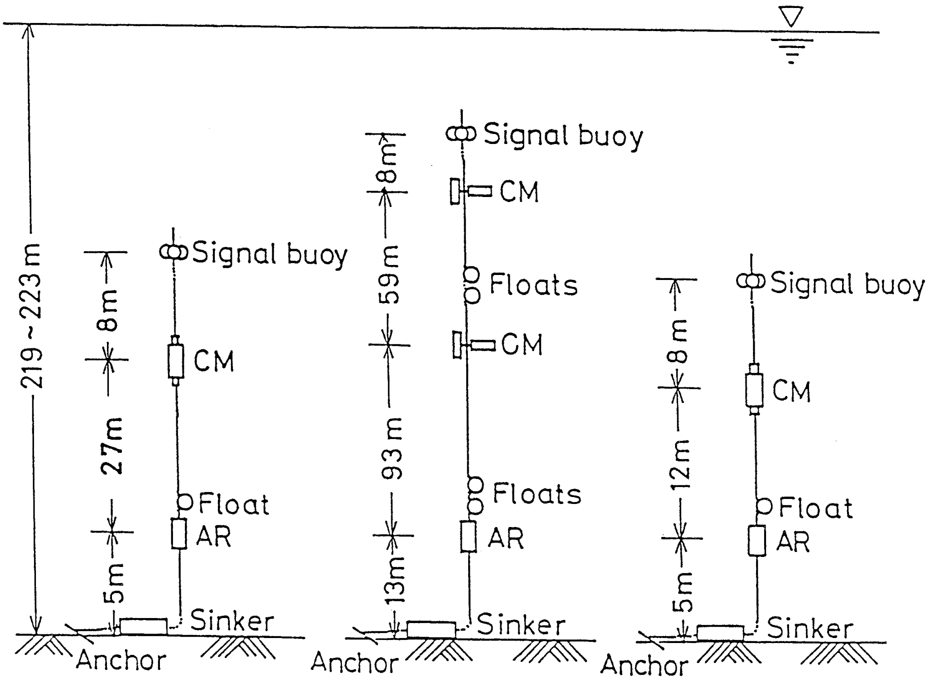

Fig. 1. Schematic mooring lines used northwest of Tsushima.

two lines at the measuring station. In May, however, a fisherman caught one line at Okinoshima in the Japan Sea, Shimane, Japan with one current meter, data of which will be shown later. As for the other one line we had no news until now.

In total we deployed eight lines. We lost three lines with four corrent meters. We retrieved five lines with six current meters.

3. Results

We show the current vector after taking 24 hours running average in Fig. 3 with an interval of 3 hours. Data obtained from six current meters are presented. We outline results in the following. In summer of 1991 at deep depth the current goes southwest. In summer of 1992 at shallow and middle depth the current goes northeast. In deep depth from the middle of May to the end of December 1993 the current goes southwest. From January to April 1994 the current goes northeast. From May to December 1994, it goes southwest again. Exceptionally we see northeastward currents in September and October 1994, which seem to be caused by passing of typhoons. From January to March 1995 the current goes northeast as in 1994.

Temperature records are shown in Fig. 4. In summer, in deep depth the temperature is low, 5℃ or less; in middle and shallow depth the temperature is higher than 10℃. Turning to deep depth, we see as follows. From June to December the temperature is low, about 5℃. From January to April it is 10℃ or higher. In May and June it is about 8℃. From July to January it is about 5℃. In February and March the temperature becomes higher.

Hereafter we examine the current and the temperature at deep depth. We calculated velocity components of northeast-southwest (NE-SE) and southeast-northwest (SE-NW). We show temporal variations of velocity (NE-SW) component and temperature from May 1993 to March 1995 with 1 hour interval in Fig. 5. Manners of both variations are different from each other. The velocity change is fast and the temperature slow. Examining data of May and June 1993, for example, we see that the current went southwest and the temperature was still higher than 10℃ (more specific 13.6℃) at the end of May, for about 3 weeks the temperature decreased, then the temperature became the

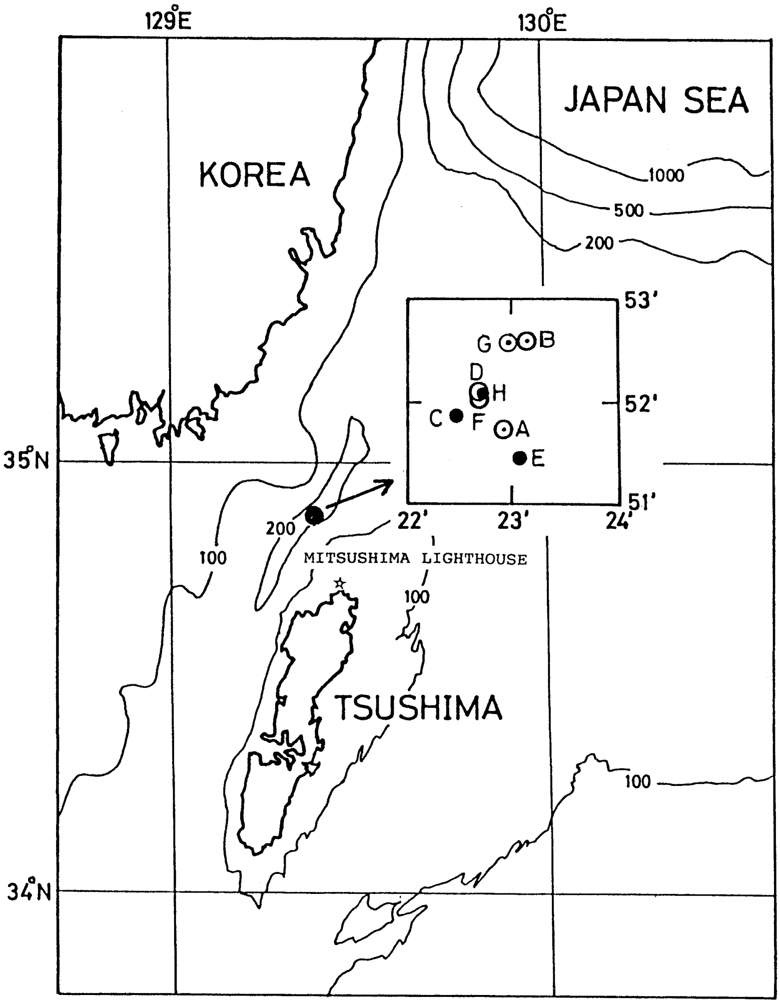

Fig. 2. Observation stations, solid circles demotes station where current meters were lost.

Table 1. Items of lines used northwest of Tsushima.

No.	From	To	Terms (day)	Bottom Depth (m)	Line Length (m)	Current Meters Number	Measure Interval (minute)	Site	
								Latitude (° ′ N)	Longitude (° ′ E)
A	11 Jul 1991	03 Oct 1991	85	221	40	1	30	34°51.73′	129°22.93′
B	07 Jul 1992	13 Nov 1992	130	219	173	2	20	34°52.604′	129°23.159′
C	07 Jul 1992	Lost		222	40	1		34°51.870′	129°22.460′
D	19 May 1993	05 Aug 1993	79	222	25	1	30	34°52.086′	129°22.687′
E	05 Aug 1993	Lost		220	173	2		34°52.434′	129°23.091′
F	05 Aug 1993	08 Jun 1994	308	223	25	1	60	34°52.034′	129°22.681′
G	08 Jun 1994	31 Mar 1995	297	219	25	1	60	34°52.568′	129°22.965′
H	08 Jun 1994	Los		222	25	1		34°52.097′	129°22.744′

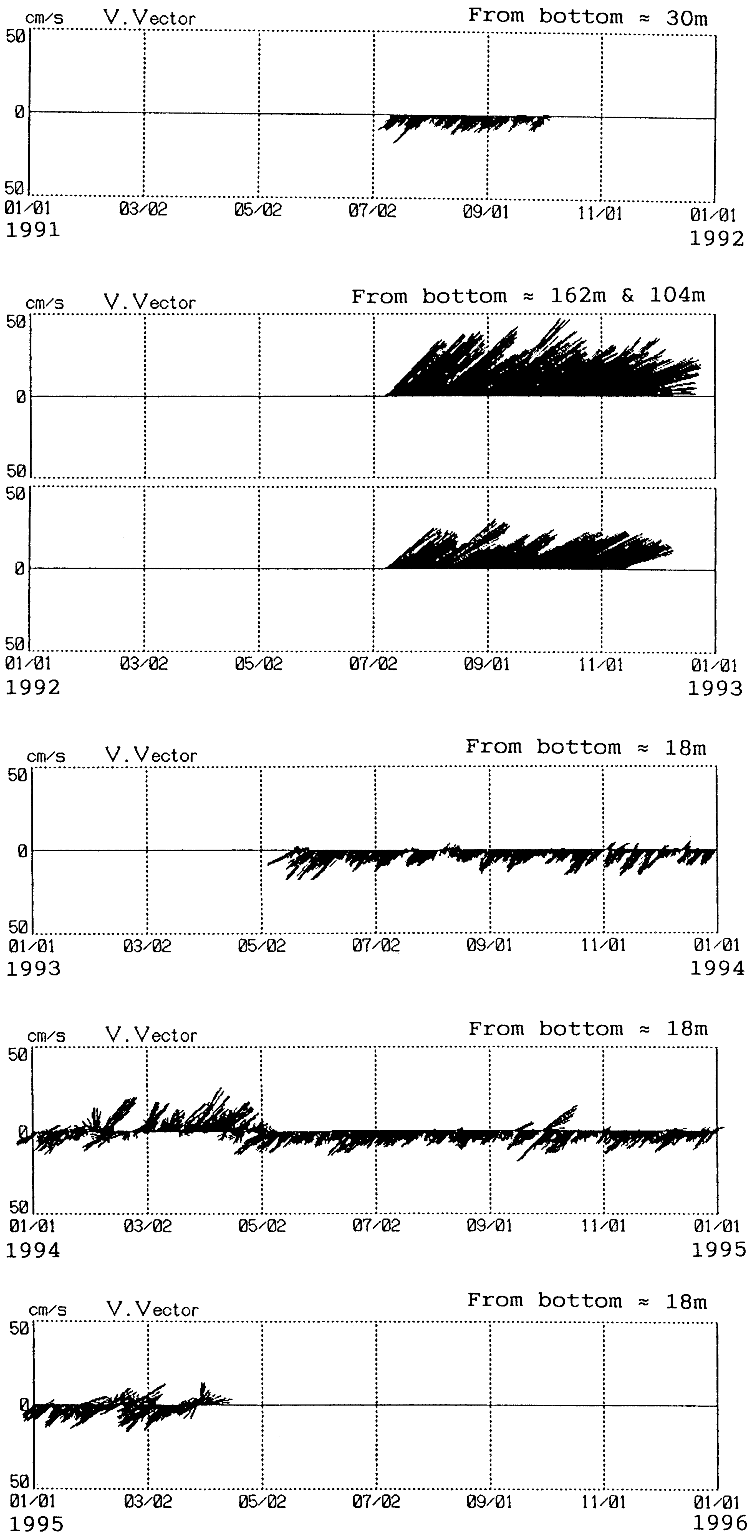

Fig. 3. Current vector, from July 1991 to March 1995.

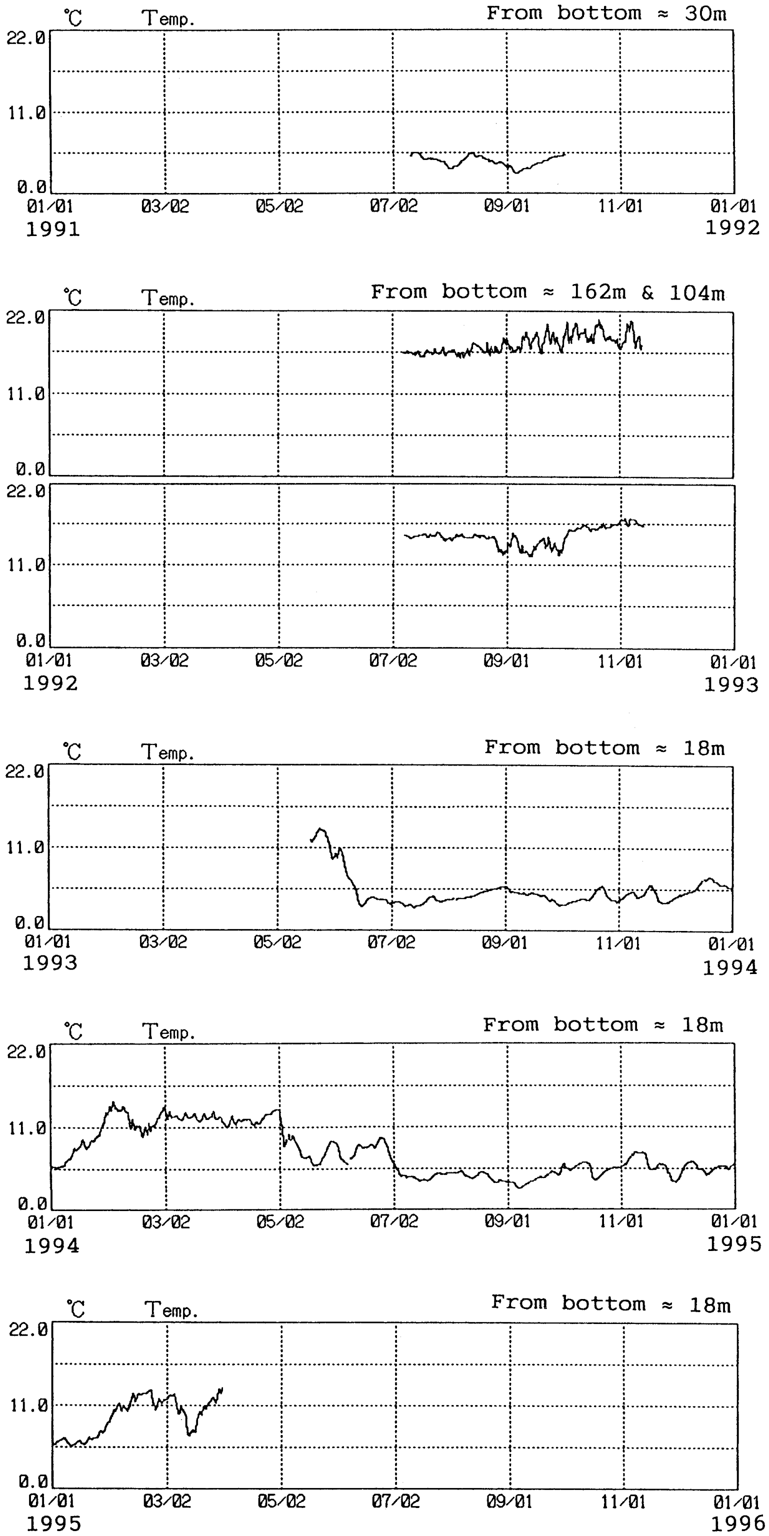

Fig. 4. Temperature, from July 1991 to March 1995.

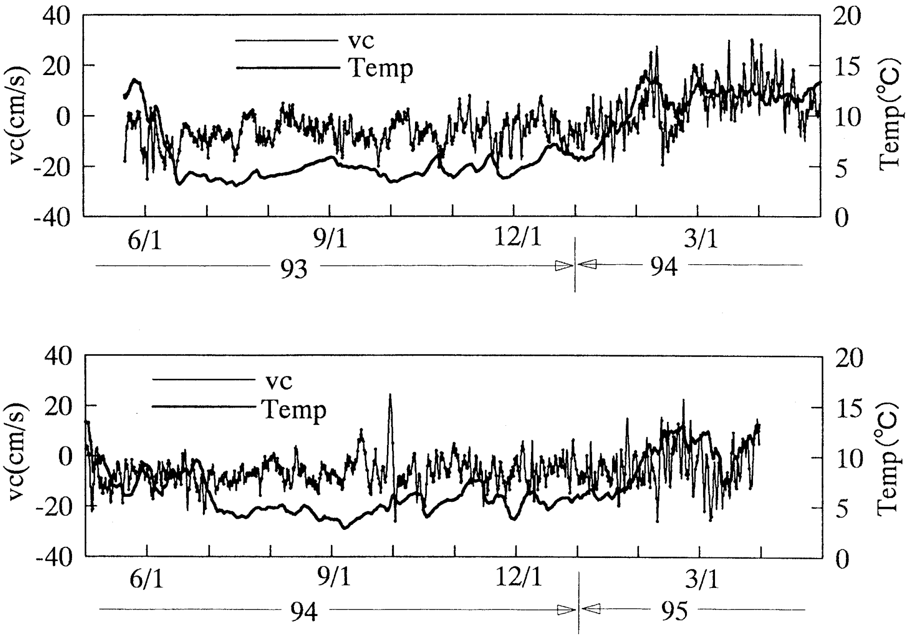

Fig. 5. Velocity component (NE-SW) and temperature, from May 1993 to March 1995.

minimum less than 5℃ (3.2℃) in the middle of June. To explain the above, we use a primitive conjecture. Characteristics of current must reflect the properties of upstream. At steady state a property of downstream is the same as that of the upstream. At an instance when the current direction changes, the downstream turns to a new upstream, of which property remains as before. It needs time for the new upstream to get a new property. To confirm the conjecture or determine an extent of current source, such as area, depth, and duration, we need measurements in wider range and longer terms. It also attracts our attention to seek what is a mechanism of changing the current direction.

We took monthly averages of velocity components of NE-SW with SE-NW and temperature. Values of SE-NW components were at maximum 1/3 or less of NE-SW components. We show changes of the velocity of NE-SW components and the temperature of 1991, 1993. 1994, and 1995 in Fig. 6. From the upper drawing we know that the both average values change from year to year. The yearly differences are large from February to June and they are small from July to December and January. From the lower drawing we see as follows. When the current goes northeast, the temperature is higher than 10℃, the warm water; when the current goes southwest, the temperature becomes less than 10℃, the cold water. Three exceptions are pointed out: 1) in May 1993, the SW current velocity was 7.4 cm/s, the temperature was still 12.3℃, indicating the cold water intrusion delayed; 2) in February 1995, the SW current 1.9 cm/s, already the temperature 11.5 ℃; and 3) in March 1995, the SW current 4.5 cm/s, already the temperature 10.6℃, showing that supply of the cold water already stopped. The exceptions are related to problems of transition process: from warm to cold and vice versa. To explain the first exception we used the primitive conjecture before. To cope with the second and third exceptions we perhaps need another conjecture, in which we assume an extent of source and an influence of surrounding environments. To polish and prove the conjecture we again need another measurements.

We made spectral analysis, by use of the fast Fourier transform (FFT) method and the auto-regression (AR) method. Both methods were applied under conditions: number of data

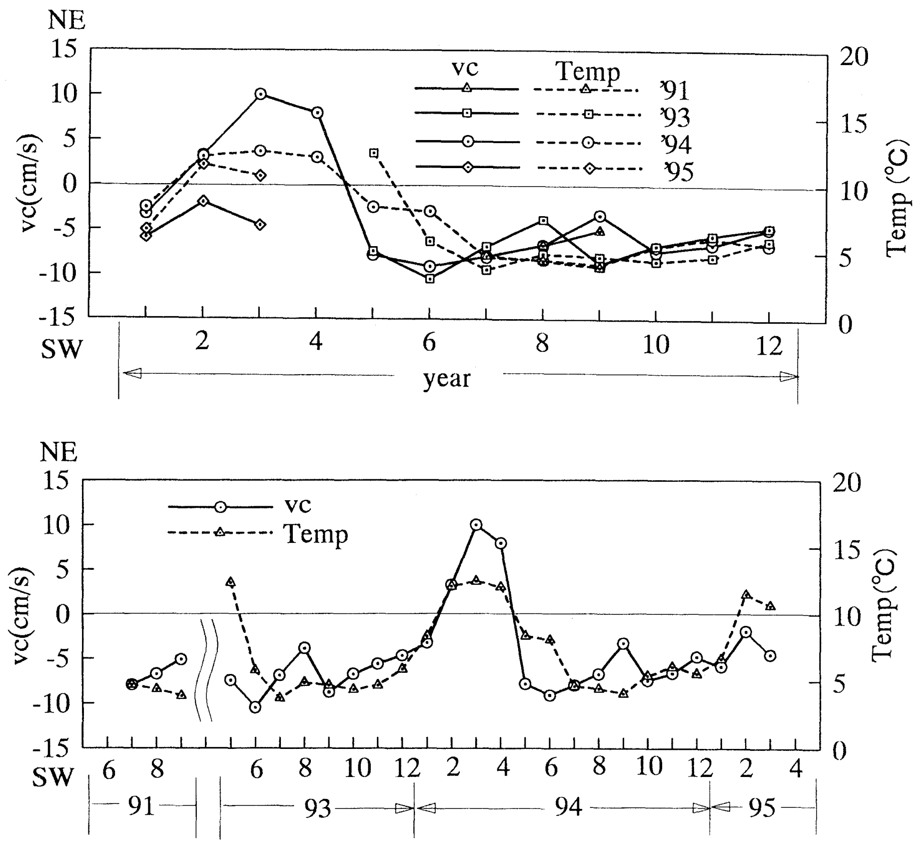

Fig. 6. Average values of velocity component (NE-SW) and temperature, in 1991, 1993, 1994, and 1995.

N is 1,024 and sampling interval $\triangle T$ is 1 hour. Thus, a fundamental frequency $f_0 = 1/(N\triangle T) =$ 0.000977 cycles per hour (1/h) and the Nyquist limit $f_{N/2} = 1/(2\triangle T) = 0.5/h$. We sought linear trends for data by use of the least square method, subtracted them from the original data, and obtained series of data for analysis. On applying the AR method, we express a datum by a linear combination of the past M and the future M data. We choose M that makes Akaike's final prediction error $\{(N+2M)/(N-2M)\}^2 \times P$ minimum, where P is an auto-correlation of difference between the original and the auto-regressed data. We took data from 00: 00 on 6 August 1993 to 15: 00 on 17 September 1993. Both FFT and AR methods give similar results on the whole. Power spectrum becomes almost zero as the frequency goes high. We present results from 0 to 0.1/h in Fig. 7, where values obtained by the FFT method are shown by thin lines and those of the AR method by bold lines. On applying the AR method we used M=60 for the velocity (NE-SW) component and M=30 for the temperature. The maximum appears in each spectrum at 0.000977/h (period 1,024 hours, which coincides with the length of data). It has no physical significance, probably being brought by a leakage effect of data truncation other than multiple of the period. For the velocity, we see local peaks at 0.0127/h (3.28 days), 0.0244/h (1.71 days), 0.0420/h (23.8 h), 0.061/h (16.5 h), and 0.0830/h (12.0 h). Shape of spectrum is round except around 0.0830/h. Through a visual inspection of Fig. 5, we may predict existence of the peak at a period of about 3 days. Most energy is recognized in low frequency range. For the temperature, we see no appreciable peaks. Shape of spectrum is almost monotonous. These may also be expected by examining Fig. 5. Energy is contained in lower frequency range.

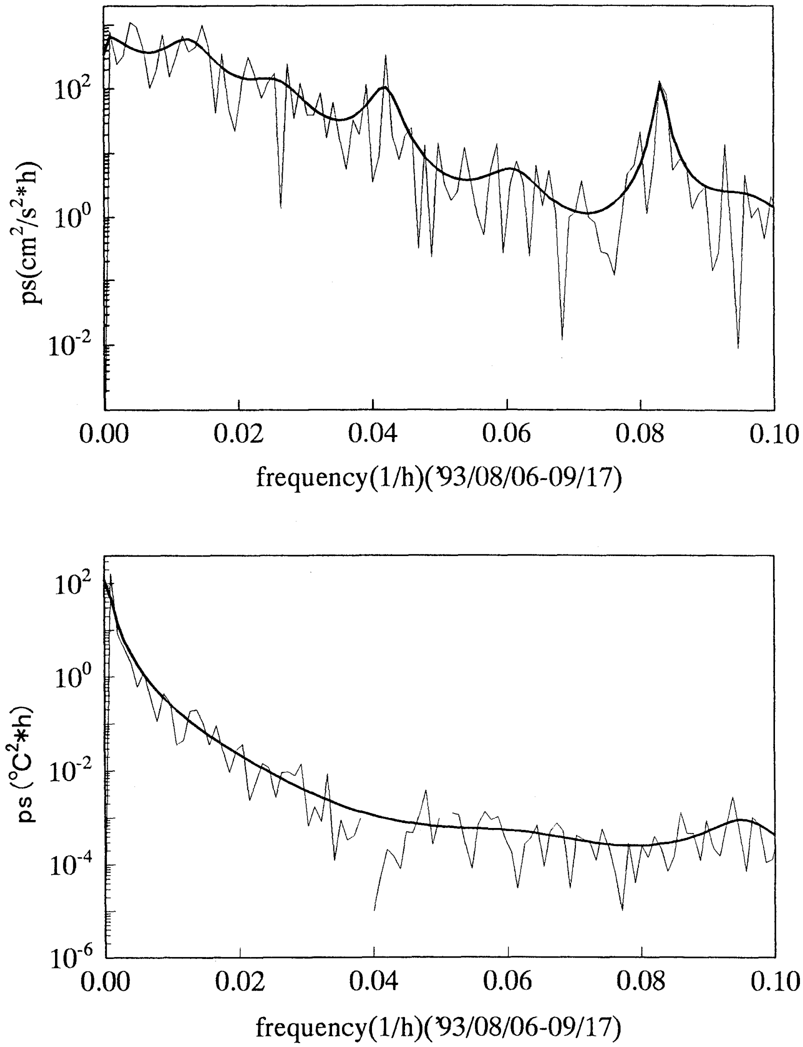

Fig. 7. Power spectrum of velocity component (NE-SW) and temperature, from 6 August 1993 to 17 September 1993

4. Conclusion

We have surveyed time variations of the currents northwest of Tsushima, in particular, relating to intrusion of the cold water. As seen in the above we learn that times for beginning, continuation, and stopping of the intrusion of the cold water change year by year.

After examining data obtained we have confirmed the following in outline. Where the depth is shallow or middle, all year round, the current goes northeast and the temperature is higher than 10℃. Where the depth is deep, in spring, summer, and autumn, the current goes southwest and the temperature is about 5℃; in winter, however, the current northeast and the temperature about 10℃.

Acknowledgments

We express our sincere gratitude to Tsunehiko MIITA, the former director of Fukuoka Fisheries and Marine Technology Research Center, who proposed and promoted long term measurements at the basin northwest of Tsushima. Our thanks also go to Captain Shigemi YOSHIMURA of the Research Vessel Genkai and his crew for skills and patients which they show in deploying and retrieving the lines. We are grateful to Dr. Hong-Ryeol SHIN, Korea Ocean Research and Development Institute, for his pointing out and reminding us of passing of Typhoons in September and October 1994. We are deeply thankful to Mr. Kiyoshi MAEKAWA, Okinoshima Ama Fishermen's Cooperative Society, for his kindness that he caught our line with one current meter and sent them back to us. The current meter contained data from June 1994 to March 1995.

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Received December 24, 1995
Accepted March 18, 1996