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Structure and Vorticity of the Current Observed Across the Western Channel of the Korea Strait in September of 1987-1989

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Abstract: With sectional data obtained in September of 1987, 1988 and 1989 by quadrireciprocal ADCP measurement and CTD cast, the current structure, volume transport and vorticity in the Western Channel of the Korea Strait were studied. The characteristics of Tsushima Current water persisted throughout the summer especially in the homogeneous water of temperature 14-16°C located at the depth of 50-100 m below seasonal thermocline. Thickness and velocity of the homogeneous layer are about 10-70 m and 20-60 cm/s, and the relative vorticity for this layer is shown to be nearly constant and it is smaller than the planetary vorticity. Potential vorticity of $2.70\text{-}7.10 \times 10^{-6}\ m^{-1}s^{-1}$ is found to be dependent mainly on planetary rather than on the relative vorticities. The Tsushima Current water represented by the homogeneous layer of 14-16°C may keep the potential vorticity at the area of strong current in the Strait. The ADCP current structure is similar to geostrophic current and the core of the current with the speed of 30-50 cm/s is situated in the middle layer over the deep trough. With large tidal fluctuation the volume transport has mean value of 1.17 sv which was about 40% larger than that of geostrophic calculation.

Key words: Tsushima Current, Potential vorticity, Relative vorticity, Velocity structure, Volume transport.

1. Introduction

The Korea Strait connects the East Sea (Sea of Japan) with the southern sea of Korea and it is divided by Tsushima island into two parts of Western and Eastern Channels. In the Western Channel there is a deep trough with the maximum depth of 227 m. The Tsushima Current is known to bring the warm and saline water into the East Sea throughout the year. The surface water shows the seasonal variation of salinity, i.e., low in summer and high in winter. In the Western Channel the cold water originating from the East Sea exists near the bottom and the lowest temperature appears in summer season.

The exact description of the current structure and water transport through the Korea Strait has been one of the prime concerns of oceanographers studying water circulation of the East Sea and the southern sea of Korea. Traditionally the volume transport was calculated indirectly either by geostrophic method from the density distribution (Yi 1966; Byun and Seung 1984) or by sea level difference between two sides of the Strait (Yi 1970; Kawabe 1982). On the other hand, in spite of the vandalism of deployed currentmeters caused by strong fishing activity, the current in the Korea Strait was also measured directly by using currentmeter and the data have been accumulated to provide the sectional structure. Nishida (1927) initiated the direct measurement of current done in the Western Channel of the Korea Strait during 1923-1926 at 6 stations located along the southeastern coast of Korea from Geojae island to Ulki. Despite the short period of measurements for 1 day at 3 layers (upper, middle and bottom), his results could show the northeastward mean current with the semidiurnal and diurnal tidal fluctuations. From the current measurements performed during 1924-1974 by Japanese Maritime Safety Agency the annual mean volume transport through the Korea Strait was estimated to be 2.7 sv ($=10^6$ m^3/s) with the deviation of 1.7 sv (Tawara *et al.* 1984). Lee (1974) showed the sectional structure of current from the mean current speeds measured for 25 hours during 1968-1973 at 4 or 5 layers of 8 different stations in the Western Channel.

Since 1981, current data with the period longer than 1 day were begun to be collected by deploying self-recording currentmeter in the Western Channel (Byun and Chang 1984; Byun and Seung 1984). From the long term measurement of current at the deep trough of the Western Channel during 1991-1995, it was found that the surface and middle waters flow northeastwards and the deep cold water moves southwestwards for whole year (Shinozaki *et al.* 1995).

Acoustic Doppler Current Profiler (ADCP) has been used in the Korea Strait since 1987, and the results provide the sectional profile of current from the transectional survey (Kaneko *et al.* 1991a, 1991b; Isobe *et al.* 1991; Ro *et al.* 1995; Nam *et al.* 1999) and also the time variation of vertical current profile from the mooring survey (Lee *et al.* 1998; Park *et al.* 1999). The volume transport measured by ADCP was reported to have large variation in magnitude among the observers. Egawa *et al.* (1993) showed, by using ADCP data obtained in the Korea Strait during 1987-1990 by the patrol ships of Japanese Maritime Safety Agency, that the seasonal variation of the Tsushima Current was considerably small and the northeast current demonstrated maximum speed during November-December. Katoh (1993) estimated the summer transport through the Eastern Channel to be between 0.59 sv and 1.30 sv with large year-to-year fluctuation and he showed the maximum current existing above 20 m depth from the sea surface. Isobe *et al.* (1994) collected the sectional current data crossing the Korea Strait about every two months from 1990 to 1991 and demonstrated the large variation in volume transport ranging from 5.6 sv in September to 1.0 sv in April. Recently Takikawa *et al.* (1999), having analyzed the current data from ship-mounted ADCP installed on a ferry boat of Pusan (Korea) - Hakada (Japan) during 1.5 years from February, 1997, showed the mean transport of 2.6 sv in the Korea Strait (1.5 sv in the Western Channel) with large seasonal variation.

In this study it was aimed to provide the detailed sectional structure of current and water transport and also to describe the vorticity in the Western Channel of the Korea Strait in September when the transport is known to reach its maximum in a year.

2. Data Measurement and Methods

In September of 1987, 1988 and 1989 the measurements of transectional current and hydrography were performed in the Western Channel of Korea Strait (Fig. 1). The current observations were carried out by towing a fish-mounted Acoustic Doppler Current Profiler (ADCP, RD Instruments, 150 kHz) as described by Kaneko and Koterayama (1988). The temperature and salinity data were collected by CTD at 5 stations.

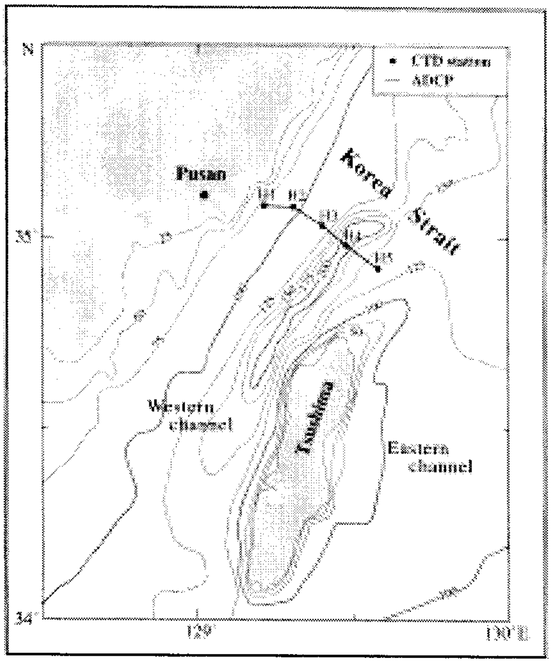

Fig. 1. Location map for CTD and ADCP measurements in September of 1987, 1988 and 1989.

The observing time of ADCP passing at each hydrographic station is listed in Table 1. In 1987 only one time measurement of ADCP was done. But in 1988 ADCP measurements were repeated four times (4 round trips) at intervals of about 6 hours. By using the so-called quadrireciprocal method (Katoh 1988), i.e., the calculation of mean current by summing 4 sets of 6-hour interval data which were repeatedly collected at the same position in the transverse section, we tried to eliminate the semidiurnal and diurnal components and therefore to obtain the mean current. In 1989 the traversing survey was carried out 7 consecutive times (3 and a half round trips) on the section of stations 1-5 and the observed data were resulted in good quality only 4 times (2nd, 3rd, 4th and 6th cruises). Assuming that the time variation of tidal currents are symmetrical on both sides of the maximum current of flood or ebb, we utilized the data of the 3rd cruise for the place of the 8th one which was not observed.

Table 1. Time table of ADCP measurement (in local standard time).

	Cruise number	Station 1	Station 2	Station 3	Station 4	Station 5
14 September 1987	1st	13:05	14:31	15:40	16:40	17:58
8-9 September 1988	1st	08:00	08:40	09:17	09:51	10:24
	2nd	14:00	14:36	15:11	15:43	16:17
	3rd	20:20	21:00	21:40	22:20	23:00
	4th	02:10	02:40	03:15	03:49	04:28
18-19 September 1989	2nd	19:30	20:20	21:20	22:20	22:50
	3rd	01:35	00:56	00:10	23:20	22:50
	4th	01:40	02:20	03:17	04:20	04:56
	6th	07:45	08:25	09:21	10:25	11:05

ADCP data were sampled every 1 minute (10 minutes in 1988) at bin depth interval of 8 m. Because the water was shallower than the ADCP range (about 480 m), the velocity obtained in the instrument coordinates could be auto-

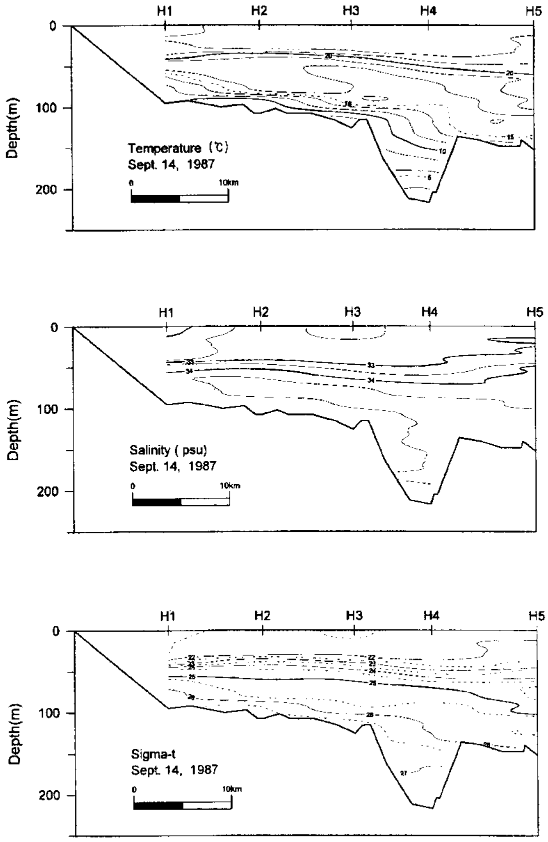

Fig. 2. Sectional profile of temperature, salinity and density observed on September 14, 1987.

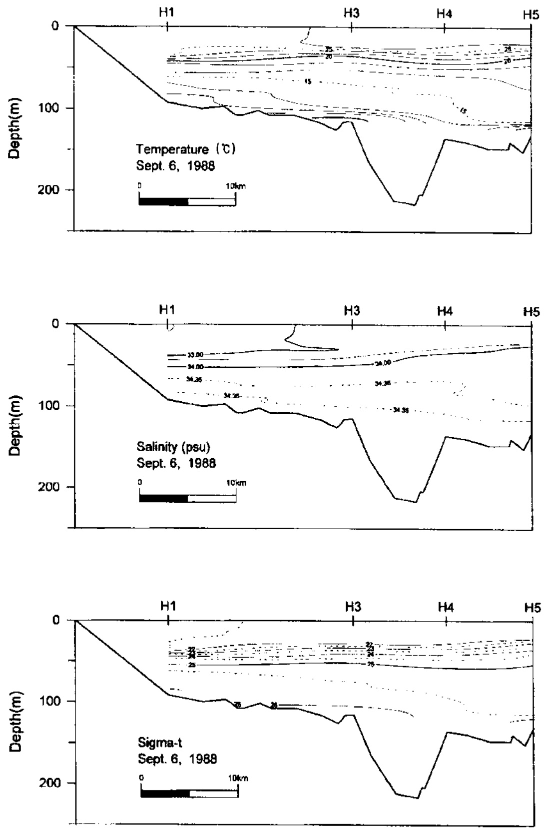

Fig. 3. Sectional profile of temperature, salinity and density observed on September 6, 1988.

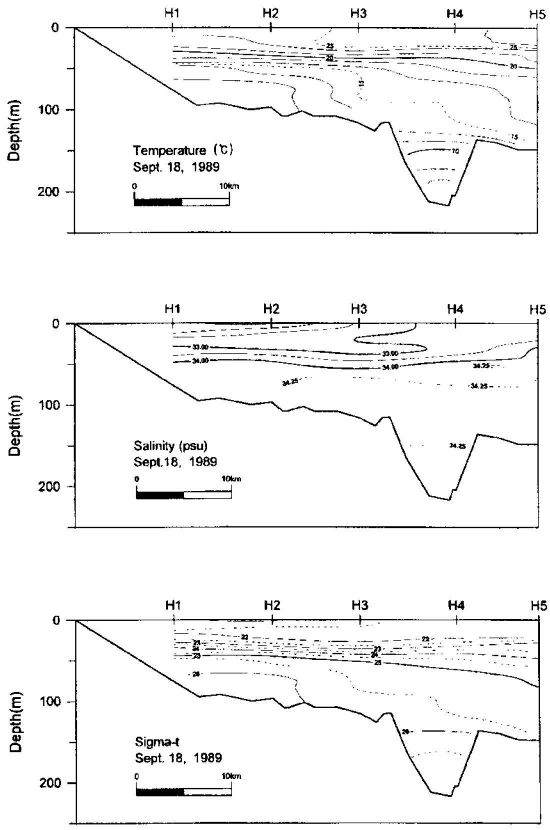

Fig. 4. Sectional profile of temperature, salinity and density observed on September 18, 1989.

matically transformed to that of earth coordinates by using bottom-tracking bins. High frequency disturbances in the collected raw data were eliminated by using a rectangular window filter of 10 minute x 16 m as done by Kaneko *et al.* (1991a).

3. Current Structure in the Section

The sectional profiles of temperature, salinity and density obtained in September of 1987, 1988 and 1989 are shown in Figs. 2, 3 and 4 respectively. The general hydrogaphic feature is similar to each other. Temperature and salinity are low near Korean coast (station 1) compared to offshore area (station 5). There are 3 layers divided by seasonal and permanent thermoclines which may be represented by the isotherms of 20°C and 10°C. The surface layer has a water of high temperature and low salinity. The middle layer is mostly occupied by the homogeneous water of temperature 14-16°C and salinity higher than 34.25 psu, and the bottom layer shows the cold water in the trough.

Fig. 5 shows the sectional velocity profile obtained on September 14, 1987 by one time ADCP measurement. There is the horizontal and vertical variations in sectional distribution. We can find that the water is generally flowing northeastwards as the Tsushima Current and its core of the speed more than 70 cm/s appears above the trough. The strong vertical shear is seen at the depths of about 50 m

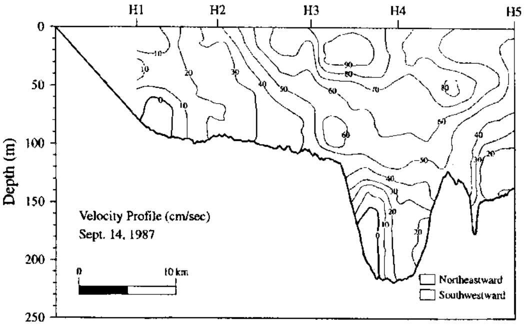

Fig. 5. Sectional current profile observed on September 14, 1987.

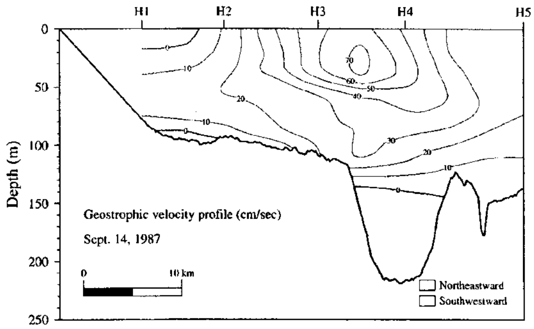

Fig. 8. Sectional geostrophic current profile observed on September 14, 1987.

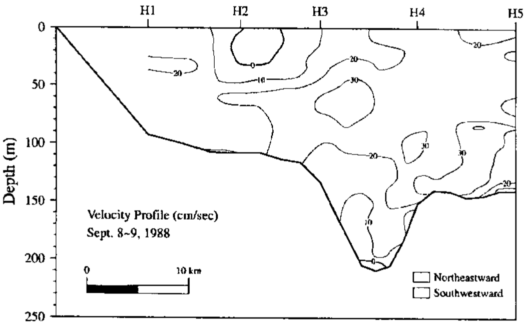

Fig. 6. Sectional mean current profile observed during September 8-9, 1988.

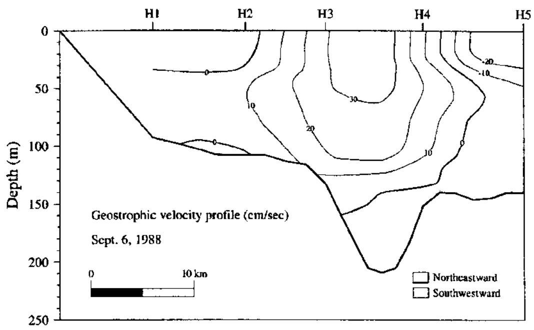

Fig. 9. Sectional geostrophic current profile observed on September 6, 1988.

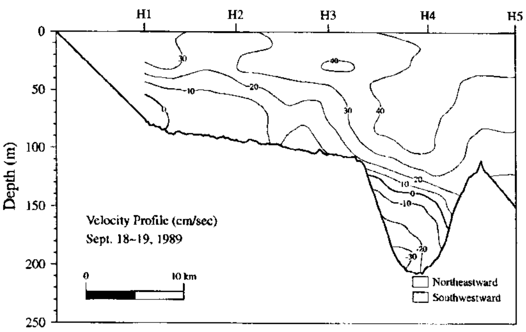

Fig. 7. Sectional mean current profile observed during September 18-19, 1989.

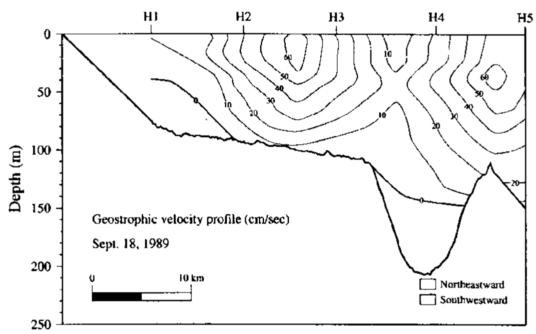

Fig. 10. Sectional geostrophic current profile observed on September 18, 1989.

and 150 m where the thermoclines are located. In the trough southwestward flow is found on the Korean side flank of bottom as a bottom current.

In the Western Channel of the Korea Strait, the semidiurnal and diurnal tidal currents are known to be comparable with the mean current (Park *et al.* 1999) and therefore the elimination of the tidal currents from the raw data is necessary in order to have the mean current. Using the quadrireciprocal method, the average of observed current data at 6 hours interval was considered to provide the

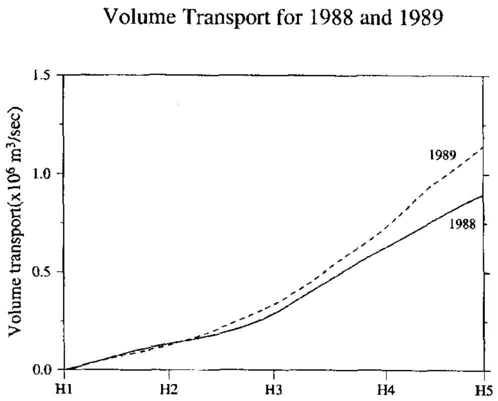

Fig. 11. Mean volume trransport in September of 1988 and 1989.

mean current and the difference obtained by subtracting the mean current from the observed current was considered to be the tidal current at the observing time. The results showed that the tidal currents were barotropic with the isotaches of the velocity running vertically (not shown here). The sectional profile of the mean current for September 8-9, 1988 is given in Fig. 6. Generally the sectional speed of current is lower than 40 cm/s. The core of Tsushima Current showing the speed higher than 30 cm/s is seen at the depth deeper than 50 m to the east of station 3. The core is found at deeper depths toward offshore direction and it is located near the bottom to the east of the trough. The southwestward flow is seen in the surface layer, as well as in the trough, between stations 2 and 3 where a front of temperature and salinity is situated as seen in Fig. 3.

Fig. 7 shows the mean current profile observed during September 18-19, 1989. The speed of the Tsushima Current is generally decreasing with depth from the sea surface and the southwestward bottom current appears near the bottom of the trough. The core of the Tsushima Current with speed higher than 40 cm/s is found above 100 m depth over the trough. In 1989, a boundary between the northeastward Tsushima Current and the southwestward bottom current was clearly seen at about 120-170 m depth where the density is 26.0-26.5 as shown in Fig. 4. The southwestward bottom current has the maximum speed higher than 30 cm/s near the bottom of trough, which is strong compared with those in 1987 and 1988.

The sectional profiles of the geostrophic current for 1987, 1988 and 1989 obtained with reference level at the density surface of 26.0 or at the bottom where the density is lower than 26.0 are shown in Figs. 8, 9 and 10 respectively. The general pattern of geostrophic current is similar to ADCP profiles depicted in Figs. 5, 6 and 7. The water is flowing northeastwards above the density surface of 26.0 in the Channel and the southwestward flow is seen particularly in the trough. In 1987 and 1988 the magnitude of geostrophic current is smaller than that of ADCP measurement. But in 1989 the geostrophic current was stronger than that of the ADCP measurement and there exist two cores of geostrophic current separated at stations 3 and 4 which was not seen in ADCP measurement. This discrepancy between the current from ADCP and the geostrophic current indicates that there may be the other forces acting on the current, i.e., tide and wind which were not considered here.

4. Volume Transport in September

The sectional volume transport in the Western Channel of the Korea Strait from ADCP survey in September 1988 and 1989 is shown in Fig. 11 and the volume transports for each cruise are summarized in Table 2. The transport has the mean value of 1.17 sv (0.98 sv in 1988 and 1.14 sv in 1989) and it varies from 2.35 sv (northeastwards) to -0.03 sv (southwestwards). Each cruise shows an alternation of high and low values of transport over about 12 hours and it seems to be due to the predominant semidiurnal tidal current. The tidal transport has the same magnitude as the mean transport. In 1989 the difference of 2.38 sv between maximum and minimum transports is almost 2 times larger than the mean of 1.17 sv. The gradient of transport is high at the location between stations 3 and 5

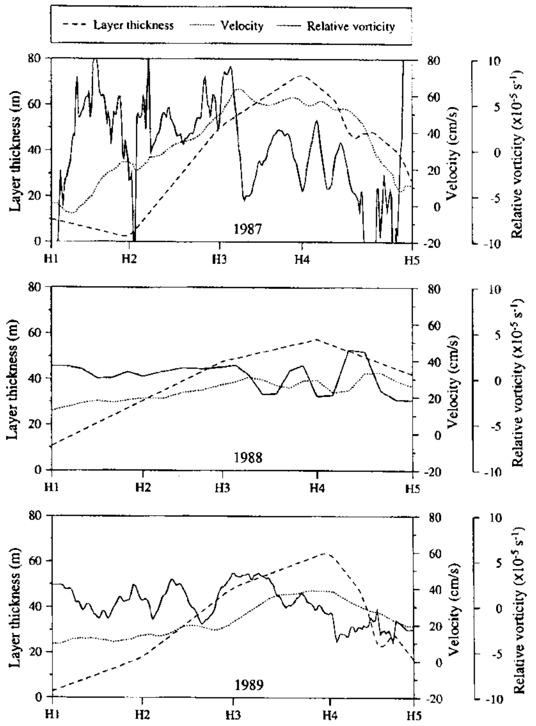

Fig. 12. Thickness, speed and relative vorticity of the 14-16°C layer in September of 1987, 1988 and 1989.

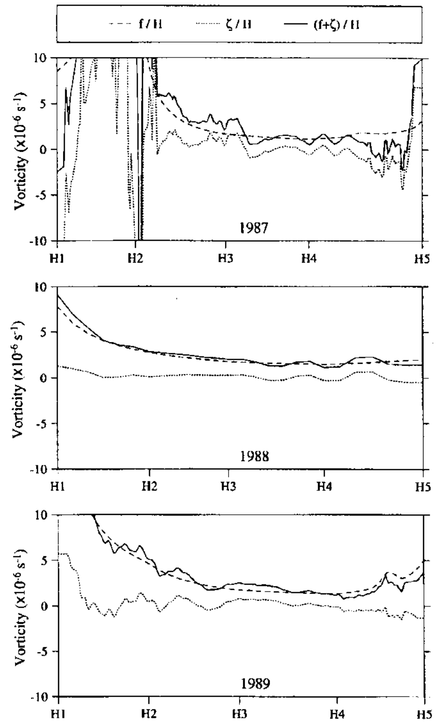

Fig. 13. Planetary, relative and absolute vorticities divided by the thickness of 14-16℃ layer in September of 1987, 1988 and 1989.

and the location of high gradient coincides with the locations of the Tsushima Current axis and the trough. The volume transport measured from ADCP is larger than the geostrophic transports which are calculated to be 1.24 sv, 0.32 sv and 1.01 sv for 1987, 1988 and 1989 respectively.

Table 2. Volume transport for each cruise.

	Time	Voulume transport ($\times 10^6 m^3/sec$)	
		ADCP meas.	Geostrophic cal.
1987	1st cruise (Sept. 14)	2.26	1.24
1988	Mean	0.98	0.32
	1st cruise (Sept. 8)	1.55	
	2nd cruise (Sept. 8)	0.09	
	3rd cruise (Sept. 8)	1.44	
	4th cruise (Sept. 9)	0.57	
1989	Mean	1.14	1.01
	2nd cruise (Sept. 18)	0.55	
	3rd cruise (Sept. 18-19)	2.35	
	4th cruise (Sept. 19)	2.19	
	6th cruise (Sept. 19)	-0.03	
	total mean	1.17	0.86

From the data of September of 1987-1989, we have seen similarity in speed and volume transport between ADCP measurement and geostrophic calculation although there is discrepancy in magnitude. Such a result can be noticed in the analysis of data collected in May, 1994 showing that the volume transport of ADCP was an order of magnitude larger than the geostrophic transport (Ro *et al.* 1995). The baroclinicity of the Tsushima Current water seem to contribute mainly to the similarity if we consider that the baroclinic component is related to the geostrophic current. In September, 1990 the volume transport from one time ADCP measurement in the section located a little north than ours was reported to be 5.6 sv for the whole Korea Strait (Isobe *et al.* 1994) which was about 5 times larger than ours. There may be large year-to-year variation of volume transport in September.

5. Vorticity in the Current

In the Korea Strait it is well known that the Tsushima Current water still keeps the homogeneity in temperature and salinity, especially in the middle layer, even though separated farther south from the Kuroshio. In September of 1987, 1988 and 1989, this homogeneity was easily seen in the temperature profile of 14-16°C rather than in salinity higher than 34.25 psu as previously seen in Figs. 2, 3 and 4.

Fig. 12 demonstrates thickness, speed and relative vorticity of the layer between 14°C and 16°C. The thickness and the speed shows similar trend: they increase to the offshore direction and reach the maximum at station 4. At station 1 the thickness is about 10 m with the speed of about 20 cm/s, but at station 4 it increases to 60-70 m with 30-60 cm/s. At station 5 located to the east of the trough there find the thin thickness and the weak speed compared with those at station 3 located to the west of the trough. The relative vorticity fluctuates generally in the range of $\pm 5 \times 10^{-5}\ s^{-1}$ with year-to-year variation.

The potential vorticity is expressed as $(f+\zeta)/H$ where f is the Coriolis parameter, ζ is the relative vorticity and H is the layer depth. Fig. 13 shows the planetary, relative and absolute vorticities divided by the thickness of 14-16°C layer, and Table 3 lists the mean and standard deviation of ζ/H and $(f+\zeta)/H$. For the section between stations 1 and 5,

Table 3. Relative vorticity divided by layer thickness ($\frac{\zeta}{H}$) and potential vorticity($\frac{\zeta}{H}$) (unit in $m^{-1}s^{-1}$).

		1987	1988	1989
$\frac{\zeta}{M}$	Mean	0.99×10^{-6}	0.16×10^{-6}	0.24×10^{-6}
	Standard Deviation	6.60×10^{-6}	0.45×10^{-6}	1.30×10^{-6}
$\frac{f+\zeta}{M}$	Mean	7.10×10^{-6}	2.70×10^{-6}	4.40×10^{-6}
	Standard Deviation	11.00×10^{-6}	1.90×10^{-6}	5.70×10^{-6}
Data Number		266	24	221

f can be considered to be constant of $8.36 \times 10^{-5}\ s^{-1}$. From Fig. 13 it is seen that ζ/H is nearly constant for whole section although there are some fluctuations between stations 1 and 2. ζ/H is smaller than f/H whose magnitude is about $4.27 \times 10^{-6}\ m^{-1}s^{-1}$ in the study area, and therefore the potential vorticity depends mainly on planetary rather than on the relative vorticities. The potential vorticity has the mean of $7.10 \times 10^{-6}\ m^{-1}s^{-1}$, $2.70 \times 10^{-6}\ m^{-1}s^{-1}$ and $4.40 \times 10^{-6}\ m^{-1}s^{-1}$ in 1987, 1988 and 1989 respectively. At the coastal area of stations 1-2, the potential vorticity is changed exponentially and it differs from year to year. But over the trough especially between stations 3 and 4 the potential vorticity is showed to be constant with the value of about $2 \times 10^{-6}\ m^{-1}s^{-1}$ for September of 1987-1989. The Tsushima Current water represented by the homogeneous layer of 14-16°C seems to keep the potential vorticity at the area of strong current in the Strait.

6. Conclusions

The exact description of the current in the Korea Strait is essential for studying the surface circulation in the East Sea as well as in the southern sea of Korea. With the help of sectional data gathered in September of 1987, 1988 and 1989 by quadrireciprocal ADCP measurement and CTD cast, the characteristics of current, water transport and vorticity in the Western Channel of the Korea Strait were studied. The Tsushima Current water keeps its typical characteristics of temperature and salinity in the middle layer despite surface heating and dilution from fresh water discharge in summer season. The homogeneous water of temperature 14-16°C and salinity higher than 34.25 psu was found at the depth of 50-100 m below the seasonal thermocline. The thickness and the cross-sectional velocity of the homogeneous layer are about 10-70 m and 20-60 cm/s respectively, and they reach maximum over the trough. But in this layer, the relative vorticity divided by the layer thickness is shown to be nearly constant and it is smaller than the planetary vorticity in magnitude. In the section the potential vorticity depends mainly on the planetary vorticity rather than on the relative vorticity and it is estimated to be $7.10 \times 10^{-6}\ m^{-1}s^{-1}$, $2.70 \times 10^{-6}\ m^{-1}s^{-1}$ and $4.40 \times 10^{-6}\ m^{-1}s^{-1}$ in 1987, 1988 and 1989 respectively. Except the coastal area the potential vorticity is showed to be constant with the value of about $2 \times 10^{-6}\ m^{-1}s^{-1}$ for September of 1987-1989. It was considered that the Tsushima Current water represented by homogeneous layer of 14-16°C may keep the potential vorticity at the area of strong current in the Strait.

There is a similarity in the general structure between the mean current observed directly by ADCP and the geostrophic current calculated indirectly from CTD data, despite the slight difference in magnitude. The core of the Tsushima Current is seen in the middle layer over the deep trough with the speed of 30-50 cm/s. The volume transport shows a large fluctuation within semidiurnal period. The mean transport of 1.17 sv is almost the same as tidal transport and it is about 40% larger than that of the geostrophic calculation.

The lack of long-term repeated ADCP measurements makes it difficult at present to figure out in detail the current structure in the Korea Strait. In particular, to find the temporal variability of the current, we need to have the accumulation of data which is in progress nowadays. If combined with CTD measurement, high resolution of the vertical ADCP data will enable us to reveal the dynamical characteristics of the Tsushima Current in the Korea Strait.

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References

Byun, S.- K. and S.- d. Chang. 1984. Two branches of Tsushima Warm Current in the Western Channel of the Korea Strait. *J. Oceanol. Soc. Korea*, 19, 200-209.

Byun, S.- K. and Y.- H. Seung. 1984. Description of current structure and coastal upwelling in the south-west Japan Sea -summer 1981 and spring 1982. p.83-93 In *Ocean Hydrodynamics of the Japan and East China Seas*. ed. by T. Ichye. Elsevier, Amsterdam.

Egawa, T., Y. Nagata, and S. Sato. 1993. Seasonal variation of the current in the Tsushima Strait deduced from ADCP data of ship-of-opportunity. *J. Oceanogr.*, 49, 39-50.

Isobe, A., A. Kaneko, S.-K. Byun, S.-d. Chang, and S. Tawara. 1991. On the current structures in the western channel of the Tsushima/Korea Strait -from the result of the ADCP surveys in September 1989. *Engineering Sciences Reports, Kyushu University*, 13, 45-51 (in Japanese).

Isobe, A., S. Tawara, A. Kaneko, and M. Kawano. 1994. Seasonal variability in the Tsushima Warm Current, Tsushima-Korea Strait. *Continental Shelf Research*, 14, 23-35.

Kaneko, A and W. Koterayama. 1988. ADCP measurements from a towed fish. *EOS*, 69, 643-644.

Kaneko, A., S.- K. Byun, S.- d. Chang, and M. Takahashi. 1991a. An observation of sectional velocity structure and transport of the Tsushima Current across the Korea Strait. p.179-195 In *Oceanography of Asian marginal seas*. ed. by T. Takano. Elsevier, Amsterdam.

Kaneko, A., S.- K. Byun, S.- d. Chang, and M. Takahashi. 1991b. On the current structures in the Western Channel of the Tsushima/Korea Strait -from the result of the ADCP surveys in September 1989. *Engineering Sciences Reports, Kyushu Univ.*, 13, 45-51 (in Japanese).

Katoh, O. 1988. Measurement of residual current using the Doppler sonar. *Bull. Seikai Reg. Fish. Res. Lab.*, 66, 59-

67 (in Japanese).

Katoh, O. 1993. Detailed current structure in the Eastern Channel of the Tsushima Strait in summer. *J. Oceanogr.*, 49, 17-30.

Kawabe, M. 1982. Branching of the Tsushima Current in the Japan Sea. Part I. Data analysis. *J. Oceanogr. Soc. Japan*, 38, 95-107.

Lee, C. K. 1974. A study on the currents in the Western Channel of the Korea Strait. *Bull. Fish. Res. Dev. Agency*, 12, 37-105 (in Korean).

Lee, J. C., S.-R. Lee, S.-K. Byun, M.-J. Park, J.-C. Kim, and H.-J. Yoon. 1998. Variability of current and sea level difference in the Western Channel of the Korea Strait in winter 1995-96. *J. Fish. Sci. Tech.*, 1, 276-282.

Nam, S. Y., K.-Y. Chang, M.-S. Suk, D.-Y. Kim, K.-H. Lee, and M.-B. Shim. 1999. On the seasonal variation of volume transport between the straits in the South Sea of Korea. p. 5-1 - 5-3. In *Proceedings of the 10th PAMS/JECSS Workshop*, Kagoshima, Japan.

Nisida, K. 1927. Report of the oceanographical investigation. No. 2. Report of the current observations. The first report - results of the current measurements in the adjacent seas of Tyosen, 1923-1926. Government Fishery Experimental Station, Pusan.

Park, M.-J., S.-R. Lee, J.-C. Lee, and S.-K. Byun. 1999. Tidal and nontidal fluctuations of currents in the Western Channel of the Korea Strait. *J. Korean Soc. Oceanogr.*, 34, 133-143.

Ro, Y. J., M.-J. Park, S.-R. Lee, and J.-C. Lee. 1995. Structures and variability of the T-S field and the current across the Korea Strait. *J. Korean Soc. Oceanogr.*, 30, 237-249.

Shinozaki, T., A. Tashiro, T. Nagahama, H. Ishii, K. Omura, Y. Ouchi, Y. Hashimoto, and K. Kawatate. 1995. Time variation of the current northwest of Tsushima. p.62. In *Proceedings of the 8th PAMS/JECSS Workshop*, Ehime University, Matsuyama, Japan.

Takikawa, T., J.-H. Yoon, H. Hase, and K.-D. Cho. 1999. The monitoring of the Tsushima Current through the ferry line between Hakata and Pusan. p.27-30. In *Proceedings of the CREAMS'99 International Symposium*, Fukuoka, Japan.

Tawara, S., T. Miita, and T. Fujiwara. 1984. The hydrography and variability in the Tsushima Strait. *Bulletin on coastal oceanography*, 22, 50-58 (in Japanese).

Yi, S.- U. 1966. Seasonal and secular variations of the water volume transport across the Korea Strait. *J. Oceanol. Soc. Korea*, 1, 7-13.

Yi, S.- U. 1970. Variation of oceanic condition and mean sea level in the Korea Strait. p.125-141. In *The Kuroshio*. ed. by J. C. Marr. East-West Center Press, Honolulu.

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