J. Fish. Sci. Tech. 1(2), 276~282, 1998

Variability of Current and Sea Level Difference in the Western Channel of the Korea Strait in Winter 1995~96

Jae Chul Lee*, **Sang-Ryong Lee**[1], **Sang-Kyoung Byun**[2], **Moon-Jin Park**[3],
Jeong-Chang Kim and Hong-Joo Yoon
KIOS, Pukyung National University, Pusan 608-737, Korea
[1]*Department of Oceanography, Pusan National University, Pusan 609-735, Korea*
[2]*Korea Ocean Research & Development Institute, Ansan 425-600, Korea*
[3]*Department of Oceanography, Chungnam National University, Taejon 305-764, Korea*

(Received October 1998, Accepted December 1998)

As a part of the long-term ADCP mooring program to measure the mass flux through the Korea Strait, current velocity data were obtained for 39 days in the deepest point of the strait. Near-surface velocity of this observation was compared with Izuhara-Pusan sea level difference (SLD) to investigate the geostrophic relationship. Principal direction of the Tsushima Current at the mooring station is 44.6 degrees to the north from the east. Variability of the tidal current is greater than the nontidal current by a factor of two. Correlation coefficient of tidal current against SLD is 0.46 but the nontidal current is not correlated. The current velocity (U in cm/s) can be estimated from the demeaned SLD (in cm) by the relation $U=23.63+0.64SLD$ where the maximum range of SLD is 52.9 cm. Current is coherent with SLD at semidiurnal, diurnal and 42.7-hour periods. A dominant nontidal variability with about 5-day period is not coherent with SLD.

Key words: variability, current, sealevel difference, Korea Strait geostrophic

Introduction

The Korea Strait is a unique opening through which the East Sea (Japan Sea) receives heat and salt by the Tsushima Warm Current (TWC). There are three smaller straits but they play a role as the exits for the East Sea waters. Because the TWC is of primary importance for the East Sea circulation, we need to monitor the velocity or volume transport of TWC. It is possible but very difficult to monitor the TWC by direct measurement.

Sea level difference (SLD) across the strait is a convenient alternative for indirect monitoring of current or mass transport. In order to establish a relationship between the current with SLD, we also need time series data of both. Yi (1970) and Lee and Jung (1977) studied the relationship between Izuhara-Pusan SLD and geostrophic current by dynamic method. As Shim et al. (1984) pointed out, dynamic computation has some problems in the shallow strait. Therefore, It is desirable to compare the time series of moored current meter data and SLD.

A year-long current measurement by the ADCP mooring was attempted in the deepest point in the western channel of the strait, but only 39-day record was obtained because we lost an ADCP and other current meters in the subsequent moorings. Although the data is not long enough, this is a very precious record ever made in the Korea Strait. Using this data we investigate the variability of the current and its relation to SLD.

Data and Method

In order to study the vertical structure of the current and its temporal variability, an ADCP (150 kHz, Broad Band model by RD Instruments) was tethered downward from the anchored buoy of 5.2 m in diameter at the deepest point in the western channel of the Korea Strait (Fig. 1). The depth of the transducer heads was 4 m below the surface. The measurement began on 9 December 1995. The time interval of measurement was 20 minutes and vertical resolution was 4 m from about 10 m to 220 m below the surface. It ended on 17 January 1996

---

*To whom correspondence should be addressed.

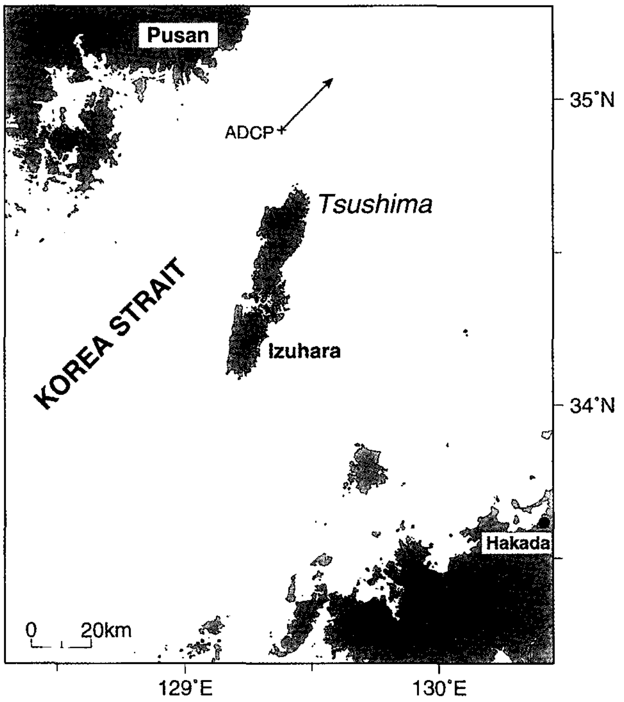

Fig. 1. Location map of the ADCP mooring and tidal stations. Arrow indicates the direction of the principal component of current.

because both of ADCP and buoy were damaged by the unknown accident.

The raw data was subsampled at 1 hour interval after filtering to suppress the high frequency parts shorter than 3-hour period. We did not use the low pass filter to eliminate the tidal components because this method would also remove the shorter nontidal variabilities like the inertial oscillations. Instead, harmonic analysis was carried out to extract the tidal components. Time series of the tidal current was constructed by the harmonic constants, then it was subtracted from the total velocity data to obtain the residual or nontidal velocity. Only the near surface velocity data was used because the purpose of this study is to investigate the SLD-current relation and the surface velocity is most responsible for the sea surface slope in the presence of baroclinicity.

Based on the geostrophic theory, only the along-channel flow must be compared with the cross-channel SLD. Although the along-channel direction can be determined from the local topography, a good alternative is a linear regression in the scatter plot of velocity vectors. The slope of the fitted line can be considered as a direction of the main current. Empirical orthogonal function (EOF) analysis gives a more accurate result. The ratio of the first mode eigenvectors from EOF analysis of u and v components corresponds to the slope of major (principal) axis of current velocity. The EOF method was used for the determination of the respective principal axes for total, tidal and nontidal components of current. The decomposed time series of velocity components along each principal axis (principal components) were derived using the eigenvalues and eigenvectors. Mean value of SLD during the period of observation was subtracted from every hourly data of Izuhara-Pusan difference of sea level and this demeaned data was compared with each principal component of velocities in both of time and frequency domains.

Results and Discussion

Vertical structure of current and its variability is of great interest. Fig. 2 shows the vector time series of nontidal current with three hours interval at some selected depths. The current is mostly to the northeast and is strongest near the surface. The maximum speed is about 71 cm/s. Park et al. (1998) also analysed the same ADCP data and showed that the tidal current was similar to the nontidal one in magnitudes. From surface to about 130 m depth northward currents vary in the same manner but the magnitude decreases considerably. Southward velocity increases from 150 m to 190 m and decreases underneath again due to the bottom friction. It is clearly seen that TWC is baroclinic and the southwestward intrusion of cold bottom water still exists in winter.

The dominant direction of the current becomes more evident in the scatter plot of total, nontidal and tidal current vectors near the surface (Fig. 3). Almost all the nontidal velocity vectors are scattered in the first quadrant whereas the tidal velocities are aligned linearly in the first and third quadrants. The fitted line of tidal velocity can be the principal axis of the current, but the result of fitting for nontidal velocity is questionable.

The result of EOF analysis for the velocity components of current is given in Table 1. For the total velocity, contribution of the first mode is 87.1 % of the total variance with standard deviation of 24.95 cm/s and the direction of the principal axis is 44.6 degrees to the north from the east. This direction is indicated by an arrow in Fig. 1. The principal direction of tidal velocity is exactly northeastward. The principal component of the

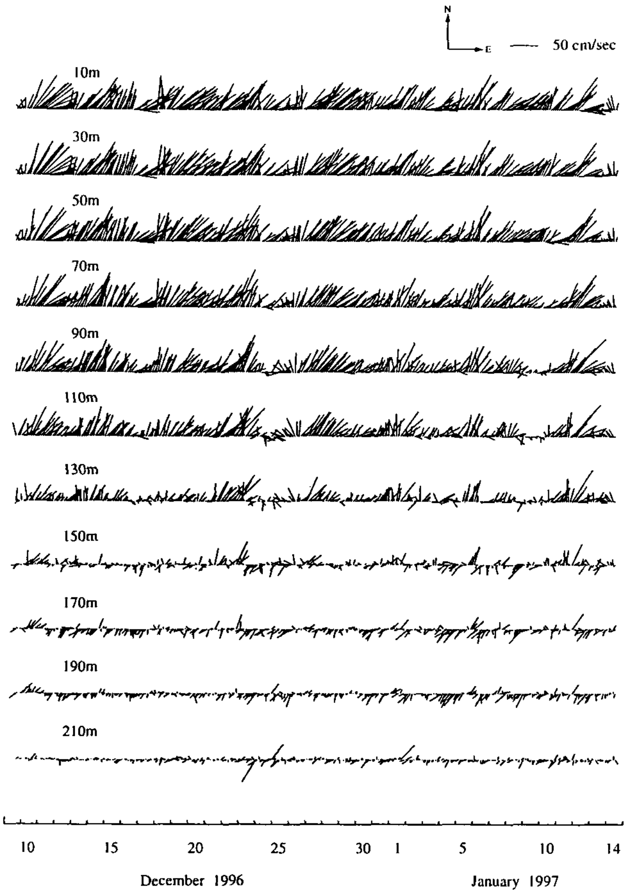

Fig. 2. Stick vector plot of the residual currents.

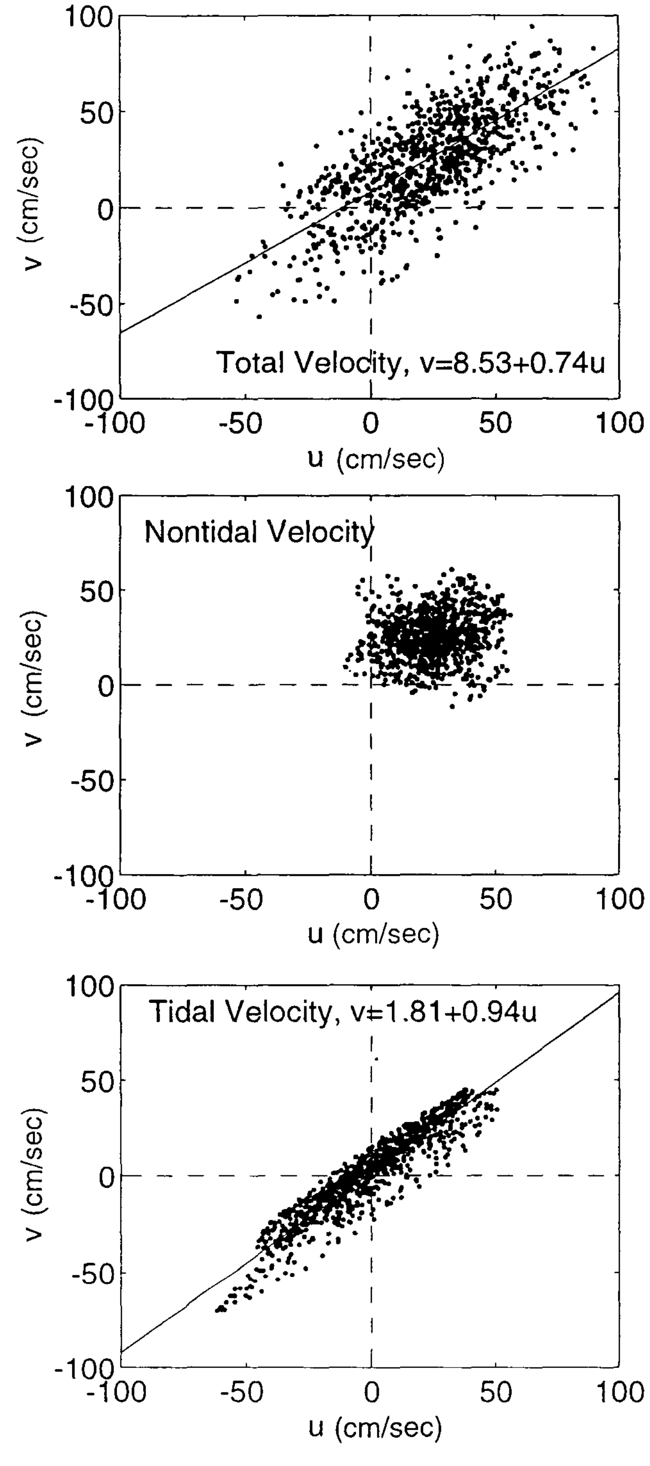

Fig. 3. Scatter plots of the east component (u) versus the north component (v).

tidal current contains about 97% of the total variance that is compared to 87% for total current. The first mode of nontidal current has only 58% of variance and the direction of the principal axis is 33.5 degrees to the north from the east. Therefore the nontidal current has a considerable cross-channel variability while the tidal current is mostly aligned to the northeastward principal axis. Standard deviation of tidal current (22.9 cm/s) is greater than the nontidal current (11.6 cm/s) by a factor of two.

Fig. 4 shows the hourly principal components of current velocities along the respective principal axes and the time series of SLD. Four erratic negative peaks in SLD series were removed and linearly interpolated for further analysis. Maximum range of SLD is 52.9 cm. Nontidal velocity is almost always positive (northeastward) with maximum and average values of 56 cm/s and 25 cm/s respectively. Any visual correlation is not seen between the nontidal current and SLD. Tidal current appears to be correlated with SLD. The peaks and troughs occur at almost the same time although the quantitative relation is not good. It is apparent that relatively good correlation of total current is entirely due to the tidal contribution. It should be noted that about 5-day period of fluctuation is found especially in the first half of the nontidal velocity.

Table 1. Contribution of the first EOF mode (%) to the total variance, the angle (deg.) of the principal axes from the east and standard deviation (SD) for the velocity components of current.

	First Mode (%)	Principal Axis (deg.)	S.D. (cm/sec)
Total Velocity	87.1	44.6	24.95
Nontidal Velocity	57.6	33.5	11.60
Tidal Velocity	96.7	45.0	22.92

The cross correlation of SLD and principal components of velocity is given in Fig. 5. Tidal velocity has greater correlation coefficient of 0.46 than the total velocity (0.43), but both are not significant enough. Low correlation may be due to the fact that the tidal station is located in Izuhara on the east side of the island (Lee et al., 1991). If another tide gauge is installed on the northwestern side of Tsushima island facing the Korean coast, the correlation may be much enhanced. It is rather surprising that nontidal current is not correlated with SLD. The total current (U in cm/s) can be estimated from the SLD in cm by U=23.63+0.64 SLD, but large value of standard deviation (14.2 cm/s) deteriorates the significance of the estimation.

Fig. 6 is the autospectra of the principal velocity

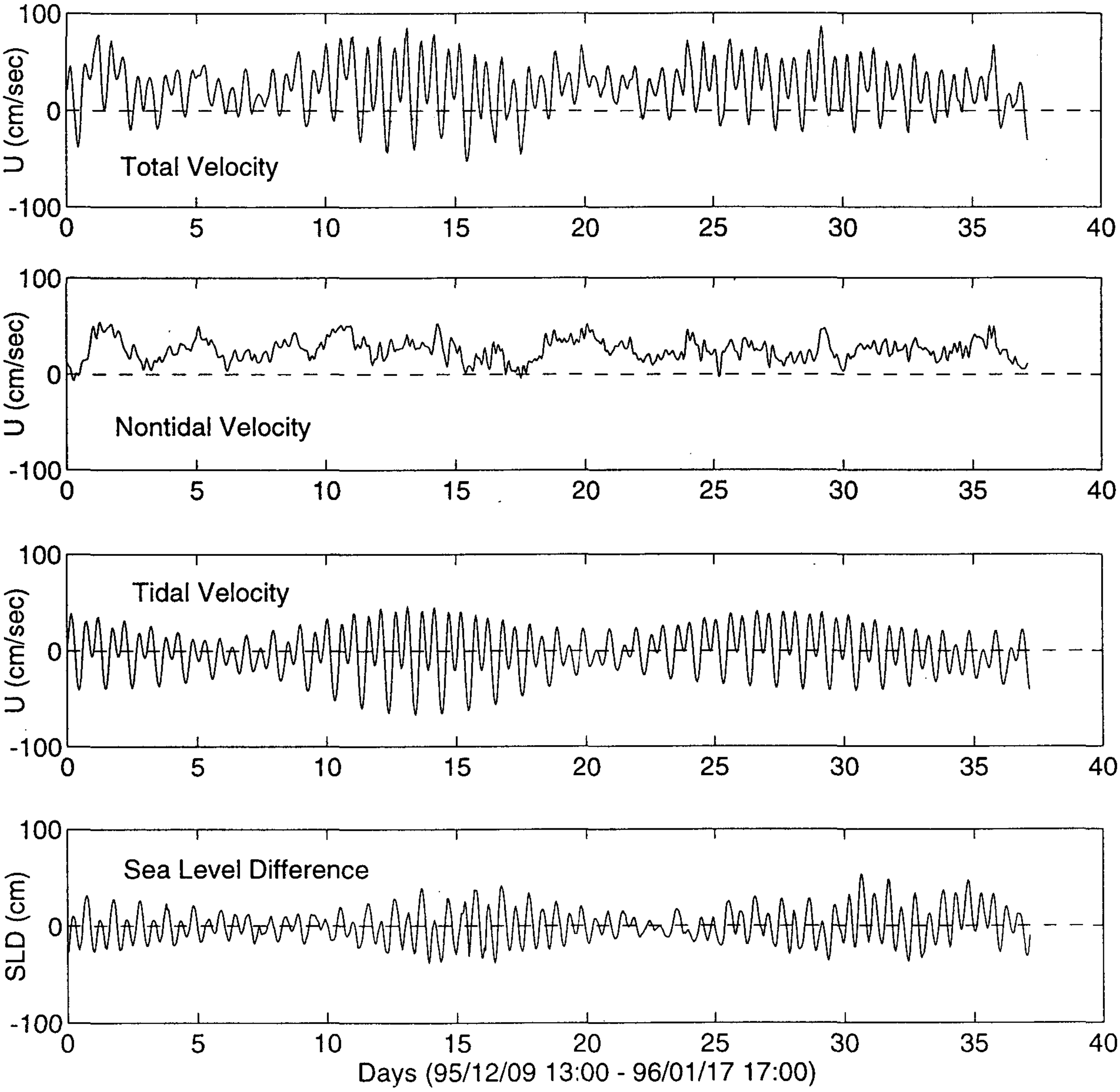

Fig. 4. Time series of velocity components along the respective principal axes and the sea level difference (SLD) between Izuhara and Pusan.

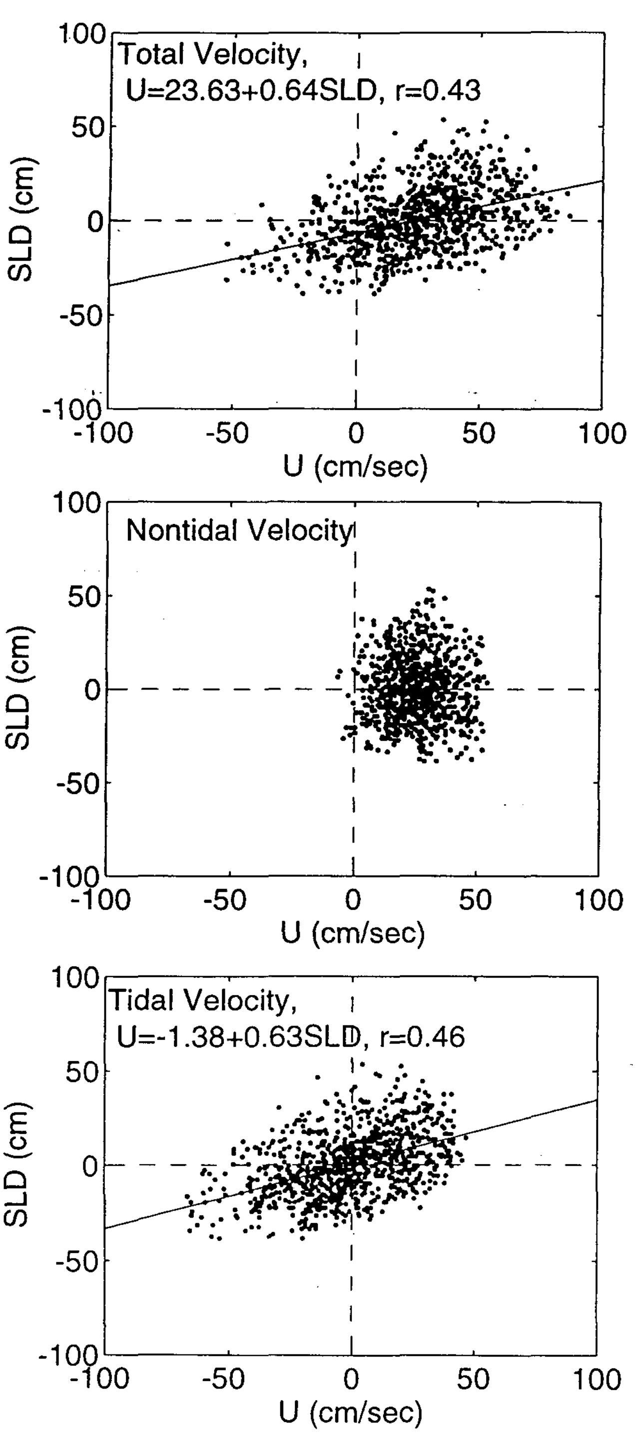

Fig. 5. Correlation between SLD and principal components of velocity.

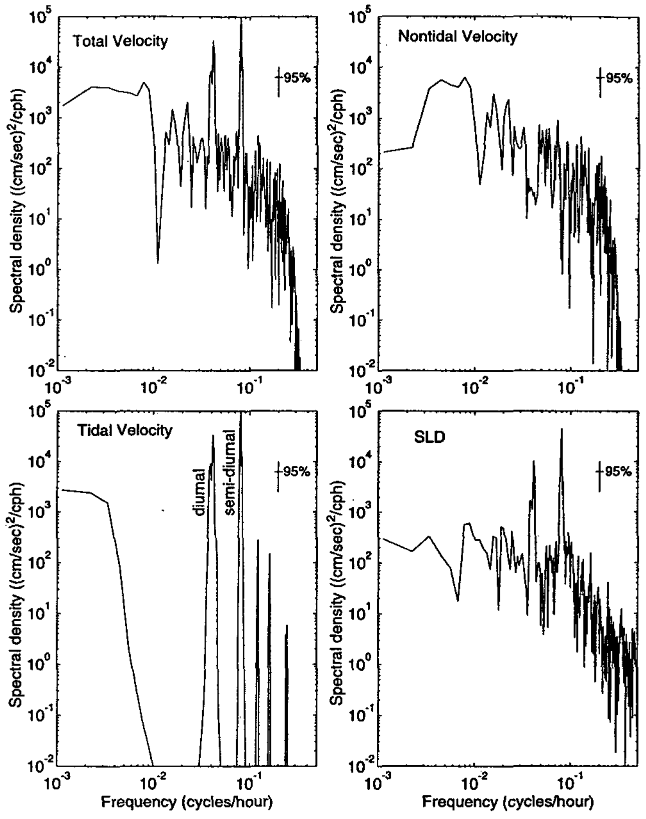

Fig. 6. Autospectra of principal components of velocity and SLD.

components and SLD. Total velocity has two predominant peaks at semidiurnal and diurnal frequencies. The spectrum of tidal current consists of diurnal, semidiurnal and three higher harmonic terms. Two main tidal peaks are also significant for SLD. A dominant peak at 0.008 cph (cycles per hour) for nontidal velocity corresponds to the fluctuation with period of 5 days in Fig. 4. The next two peaks at 0.0157 and 0.0224 cph account for the irregularity superimposed on the 5-day fluctuation. Several peaks at frequencies higher than 0.047 cph are related with the inertial oscillations.

Fig. 7 shows the coherence between SLD and the principal components of velocity in the frequency domain. There are three major peaks in the total velocity. The coherence is close to unity at the diurnal frequency and semidiurnal peak is also very significant. These two peaks are also found for the tidal velocity while the low-frequency coherence is rather low. The upper two graphs show that the coherence is marginally coherent at about 0.02 cph (42.7 hours period) that is of nontidal origin. It is noted that the current is not coherent at periods longer than three days, although the subtidal geostrophic velocity was expected to be important for the SLD-current relation. In particular, a dominant variability of nontidal current with 5-day period in Fig. 4 and Fig. 6 is not coherent with SLD. If this variability is predominantly baroclinic,

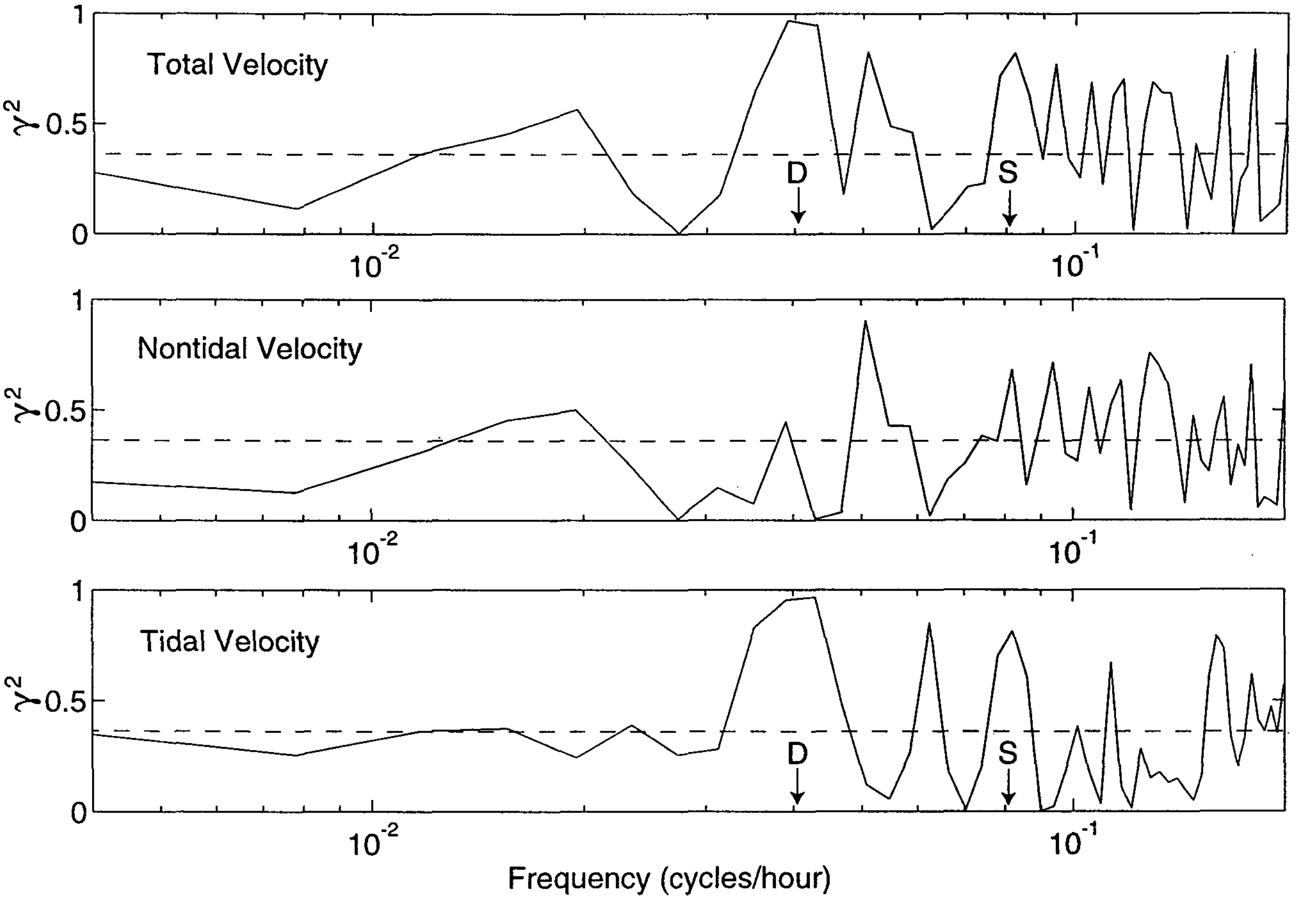

Fig. 7. Coherence between SLD and principal components of velocity. S and D stand for the frequency of semidiurnal and diurnal period respectively.

the current will not be related with SLD because the distance between two tidal stations is much greater than the baroclinic Rossby radius of deformation. However, it is not plausible to conclude from this result that only tidal current satisfies the geostrophic balance in the Korea Strait. We need longer record of current observations to obtain more significant relation at low frequency. For more improved results we will have to install at least another tide gauge on the northwestern side of Tsushima.

Conclusions

A year-long current observation by the ADCP mooring was designed to investigate the vertical structure of current and its variability in the deepest point of the Korea Strait. The observation was not very successful but the data was collected for 39 days in the strait. Principal direction of the near-surface velocity at the mooring station is 44.6 degrees to the north from the east. The current velocity (U in cm/s) can be estimated from the demeaned SLD (in cm) by the relation U=23.63+0.64SLD. SLD is coherent with current at the semidiurnal, diurnal and 42.7 hours periods but the correlation coefficient of 0.46 is lower than expected because the tidal station is located on the east side of the Tsushima islands. Nontidal current has a dominant fluctuation with a period of about 5 days which is not coherent with SLD. For more significant coherence at lower frequency a much longer time series is necessary in the future. We also need additional sea level observation on the northwest side of the Tsushima for better results.

Acknowledgments

This study was supported by the Ministry of Education through the KIOS (Korea Inter-university Institute of Ocean Science) at Pukyong National University. Devoted help of the crew members of R/V Tamyang with current meter mooring is greatly appreciated.

References

Lee, J.C. and C.H. Jung. 1977. An estimation of average current velocity in the western channel of the Korea Strait from mean sea level data. J. Oceanol. Soc. Korea. 12, pp. 67~74.

Lee, J.C., K.D. Cho, S.Y. Kim, H.K Kim and T.B. Shim. 1991. Variability of sea levels associated with the Tsushima Current in the Korea Strait. Bull. Korean Fish. Soc., 24 (6), 437~449.

Park, M.J., S.L. Lee, J.C. Lee and S.K. Byun. 1998. The tidal and non-tidal fluctuations of currents in the western channel of the Korea Strait. J. Korean Soc. of Oceanogr., submitted.

Shim, T., W.J. Weisman Jr., O.K. Huh and W.S. Chuang. 1984. A test of the geostrophic approximation in the western channel of the Korea Strait. Ocean Hydrodynamics of the Japan and East China Seas. 263~272.

Yi, S., 1970. Variations of oceanic condition and mean sea level in the Korea Strait. The Kuroshio. ed. by J. C. Marr. East-West Center Press, Honolulu, pp. 125~141.