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Effects of wave and current on near-bottom turbulence and acoustic backscatter intensity measured by an ADCP and ADV

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Abstract

Current, wave and acoustic backscatter intensity data were collected by a bottom-mounted Acoustic Doppler Current Profiler (ADCP) and Acoustic Doppler Velocimeter (ADV) in a small tidal river and in estuarine waters off southwestern Taiwan. Three distinctively different environmental conditions were encountered, i.e., torrential rain, current-dominated and wave-dominated cases. Our results show that the ADV and ADCP echo intensity (EI) correlate well with the wave height and turbidity for the case of higher sea state under strong winds. On the other hand, the ADCP EI varies consistently with the current magnitude for all vertical bins for the case of strong flows. In the extreme event of torrential rain and associated swift downstream flows in a small tidal river, a sharp increase of OBS turbidity, ADCP EI, current magnitude and vertical velocity was observed simultaneously for the full water depth, and the bed stress and roughness length, as derived from the logarithmic profile, well exceed the threshold values of sediment suspension.

Keywords: ADCP echo intensity, wave height, turbidity, current speed, bottom shear stress, ADV

1. INTRODUCTION

The ADCP has been widely used during the past several decades to measure vertical profiles of current speed and direction in the river, estuary, coastal and deep oceans based on the Doppler shift of frequencies of acoustic pulses by the particles within the water. More recently, another acoustic instrument, the ADV, has also been used to measure the 3D fluctuating velocities, but only for a single point. Besides measuring currents and turbulence, the ADCP and ADV can also be employed to infer suspended material from acoustic backscatter echo intensity (EI) data. However, the converting process from the acoustic backscatter EI to suspended sediment concentration (SSC) is not straightforward, and careful calibration of the ADCP and ADV for the measurements of suspended particles is usually made either by taking in-situ water samples or by optical measurements simultaneously in order to determine quantitatively the SSC. Examples of such investigations on the spatial and temporal distributions of SSC in the coastal and estuarine waters can be found in Holdaway et al. (1999), Gartner (2004), Hoitink (2004) and Chanson et al. (2008). Qualitative relationship between events of high near-bottom ADCP EI and sediment re-mobilization due to near-bottom orbital movements generated by surface waves was investigated by Klein (2003). As indicated by Deines (1999), combining the EI data with the simultaneous ADCP current profiles can lead to more informed and insightful interpretation of the distribution patterns of the suspended sediments. However, studies on this aspect were scarce, and more in-situ data are necessary.

In this paper we focus on the unusual event of heavy rainfall with fast stream flow and their influence on the bottom shear stress, turbidity and ADCP EI data in a small tidal river. We have also acquired ADCP and ADV data in the estuarine waters under current-dominated and wave-dominated cases. Comparisons between these results will help to clarify the dependence of acoustic backscatter EI with the hydrodynamic properties and its applications to the estimation of SSC.

2. MATERIALS AND METHODS

2.1 Field investigation and sampling site

The field study was conducted at two sites, i.e., the Love Creek, a small tidal river in the city of Kaohsiung, and an estuary off Howan, both are situated at the southwestern Taiwan coast. Love Creek is a relatively small and narrow river with the river mouth about 130 m wide and 5-6 m deep mid-stream. This river flows south-southwestward into the Kaohsiung Harbor which is the biggest port of Taiwan. Field experiments were conducted between 7th and 27th of June 2005, at approximately 2 km upstream of the Love Creek estuary (designated as LC). The water depth and river width at this site are 4.8 m and 100 m, respectively. Harmonic analysis of the water level indicates that the tides are mixed and predominantly diurnal, and the tidal range is about 1-2 m. The amplitude of the four major tidal constituents (M2, S2, K1 and O1) at this site is 17.45, 7.02, 16.26 and 15.10 cm, respectively. Heavy rainfall occurred for a short period of time during the observational period (Fig. 1d).

The estuary off Howan is a coastal zone formed by a small river flows into the ocean off the southwestern Taiwan. Three experiments were conducted at this site, i.e., from November 30th to December 20th 2005 (designated as HW1), from July 1st to August 14th 2006 (designated as HW2), and from 1st to 10th of April 2011 (designated as HW3). The water depth of this site is about 15 m. The tides are mixed and predominantly diurnal.

2.2 Instrumentation

Instruments were mounted on a steel frame which was deployed on the bottom of the experimental sites. In the Love Creek experiment the velocity profiles were obtained with a 1200 KHz ADCP (Teledyne-RDI workhorse) looking upward. Bin size and sampling period were 25 cm and 5 min, respectively. With the settings of 150 pings per ensemble, the standard deviation of the current speed was 1.2 cm/s. Besides currents, the backscatter EI of each of four beams for every cycle and bin were also recorded. Averages of the EI from the four beams for every bin were taken and used in this study. Current speed, direction and turbidity at 50 cmab were obtained every 5 min with a 2 MHz RCM-9 current meter (Aanderaa). Near-bottom water temperature and pressure were recorded by using a T/P logger with a sampling interval of 5 min.

In the Howan experiments a bottom-mounted 1200 KHz ADCP with the wave-measuring capability was also used in HW1 and HW2 experiments. Bin size and sampling period of the ADCP were 1 m and 10 min, respectively. In HW3 experiment an ADV (Nortek Vector) and a OBS were bottom mounted in a tripod and looking downward. The sampling rate and measuring point of the ADV were 32 Hz and 15 cmab, respectively.

3. RESULTS AND DISCUSSIONS

3.1 Love Creek Experiment

The horizontal velocities were decomposed into the along-channel (u) and cross-channel (v) components. The downstream flow is defined as the positive direction. Plotted in Fig. 1(a)(b)(c) are the time series distribution of along-channel velocity, ADCP EI and vertical velocity of all bins during the observational period for the Love Creek experiment. It can be clearly seen that the Love Creek normally flows slowly. The horizontal tidal current is rather weak, but the ADCP EI and vertical velocity can still show tidal signals, especially for the upper layer of about 2-m thick. On June 12th when the torrential rain event occurred with a precipitation rate over 200 mm (Fig. 1d), the downstream flow of the Love Creek intensified dramatically throughout the full water depth with a maximum speed of over 100 cm/s (Fig. 1a). The vertical velocity, which is an index of turbulence intensity in the bottom boundary layer, shows a noticeable peak speed of greater than 5 cm/s over the full water depth and it varies consistently with the along-channel velocity (Fig. 1c). The averaged ADCP EI of four beams also show a strong signal corresponding to this event; the EI increased drastically with maximum values occurred near the bottom and gradually decreased upward (Fig. 1b). As mentioned earlier (Deines, 1999), EI depends not only on the concentration of scatters in the water, such as suspended sediment, zooplankton and bubbles, but also on sound absorption in seawater and beam spreading. Therefore, Fig. 1b indicates that during the torrential rain event the SSC is highest in the BBL possibly due to the stirring of bottom-induced shear stress and the SSC diffuses in the upward direction.

Correlation coefficient between ADCP EI and near-bottom turbidity for each bin is calculated and plotted in Fig. 2. Near the bottom the ADCP EI has a very high correlation coefficient with the turbidity, close to 0.96. This layer of high correlation coefficient (> 0.8) extends to about 3.5 m thick, i.e., bin 1 through bin 9. Also plotted in Fig. 2 are correlation coefficients between EI and the horizontal current magnitude as well as the vertical velocity. From bin 1 to bin 9, the horizontal current magnitude has a higher correlation coefficient (>0.6) with EI, and the correlation drops markedly from bin 10 and upward. On the other hand, the correlation coefficient between w and EI is much lower (~0.6) near the bottom (from bin 1 to bin 4), and it decreases more rapidly further away. In summary, Fig. 2 indicates that the acoustic backscatter echo intensity is a good index of turbidity and suspended sediment concentration in the extreme event of torrential rain in shallow rivers, and the sediment suspension is obviously caused by the strong flow-induced bottom shear stress. The vertical velocity is also another index of bottom turbulence, but is significant only for the near bottom layer.

Within the turbulent BBL, the horizontal velocity varies with the distance from the bed in a semi-logarithmic profile (Thorpe, 2007). Following Lueck and Lu (1997), we analyzed the consecutive vertical profiles of along-channel velocity in every 5 min interval by fitting the lowest three data points to the log law. If the error between the fitted velocity and the original velocity for all points are less than 1 %, one more data point is added, and the procedure is repeated, and so on. Although the first bin of our upward-looking ADCP observation (1.32 mab) is substantially higher than other reported down-looking ADCP observations, a significant portion of all vertical profiles of along-channel velocity in the present study shows reasonable agreement with the semi-logarithmic distribution, as shown by the profiles of stronger flows in June 12 (Fig. 3). Friction velocity u_* and roughness length z_o can be derived from least-square fitting. Profiles with the z_o values greater than 0.1 m are deleted. It is found that (not shown here) the shear stresses during the torrential rain period were substantially greater than the threshold of sediment remobilization.

3.2 Howan Estuary Experiments

Shown in Fig. 4 is the variations of significant wave height, ADCP EI and horizontal current magnitude of bin 3 versus time for the HW1 experiment. The $H_{1/3}$ was mostly less than 1 m while the current speed could reach 60 cm/s from Fig. 4. Therefore, the HW1 can be representative of a weak-wave, strong-current condition. The correlation coefficient between the ADCP EI and the horizontal current is rather high (~0.8) for the bottom layer (Fig. 5). The correlation between EI and w is also fairly good for the near-bottom layer, but the correlation between EI and $H_{1/3}$ is quite small.

Shown in Fig. 6 is the variations of significant wave height, ADCP EI and horizontal current magnitude of bin 3 versus time for the HW2 experiment. During this period the waves are significantly higher due to the prevalent southwestern monsoon and the passage of two typhoons. In the normal days the $H_{1/3}$ is over 1 m and the current speed is about 20 cm/s. During the typhoon passage the maximum $H_{1/3}$ can reach 4.5 m and the current speed also increase consistently. Therefore, HW2 can be representative of the weak-current high-wave condition. The correlation between EI and $H_{1/3}$ is high (~0.7) for the full water depth, but the current speed turns out to be poorly correlated with EI.

In the HW3 experiment an ADV and OBS were used. The acoustic backscatter intensity can be derived from the amplitude signal of ADV (Chanson et al. 2008). Plotted in Fig. 8 is the ADV EI and turbidity variations with the time. It is clearly seen that they display a similar trend of variations, which implies a close correlation between the acoustic and optical measures of SSC. Note that the peak at the day of 94.8 is induced by a maximum wave height of about 90 cm.

4. CONCLUSIONS

Our field observations provide a valuable dataset of velocity profiles, acoustic backscatter EI and near-bottom turbidity in a tidal stream and estuary during the event of torrential rain, wave-dominated and current-dominated cases. The results indicate that the acoustic backscatter EI can serve as a good proxy for SSC. In shallow rivers, the swift flow induced by the torrential rain can generate energetic turbulence in the BBL and the ADCP EI shows excellent correlations with the turbidity, u and w current speeds for the full water depth. In the estuarine zone, the EI shows good correlations with either the $H_{1/3}$ or current speed in the wave-dominated or current-dominated cases. Further studies will be focused on the calibration of ADCP or ADV to quantify the SSC variations.

5. ACKNOWLEGEMENTS

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6. REFERENCES

Chanson, H., M., Trevathan and S.-I. Aoki (2008). Acoustic Doppler Velocimetry (ADV) in a small estuary: Field experience and signal post-processing, *Flow Measurement and Instrumentation*, 19, 307-313.

Deines, K. L. (1999). Backscatter estimation using broadband acoustic Doppler current profilers, *Proceedings IEEE 6th Working Conference on Current Measurements*, 249-253.

Gartner J. W.(2004). Estimating suspended solids concentrations form backscatter intensity measured by acoustic Doppler current profiler in San Francisco Bay, California, *Marine Geology*, 211, 169-187.

Hoitink A.J.F.(2004). Tidally-induced clouds of suspended sediment connected to shallow-water coral reefs, *Marine Geology,* 208, 13-31.

Holdaway, G. P., Thorne P. D., David Flatt, Jones S. E., David Prandle (1999). Comparison between ADCP and transmissometer measurements of suspended sediment concentration, *Continental Shelf Research*, 19, 421-441.

Klein, H. (2003). Investigating sediment re-mobilisation due to wave action by means of ADCP echo intensity data: Field data from the Tromper Wiek, western Baltic Sea. *Estuarine, Coastal and Shelf Science*, 58, 467-474.

Lueck, R. G. and Y. Lu (1997). The logarithmic layer in a tidal channel, *Continental Shelf Research*, 17, 1785-1801.

Thorpe, S. A. (2007). *An Introduction to Ocean Turbulence*, Cambridge University Press, 240 pp.

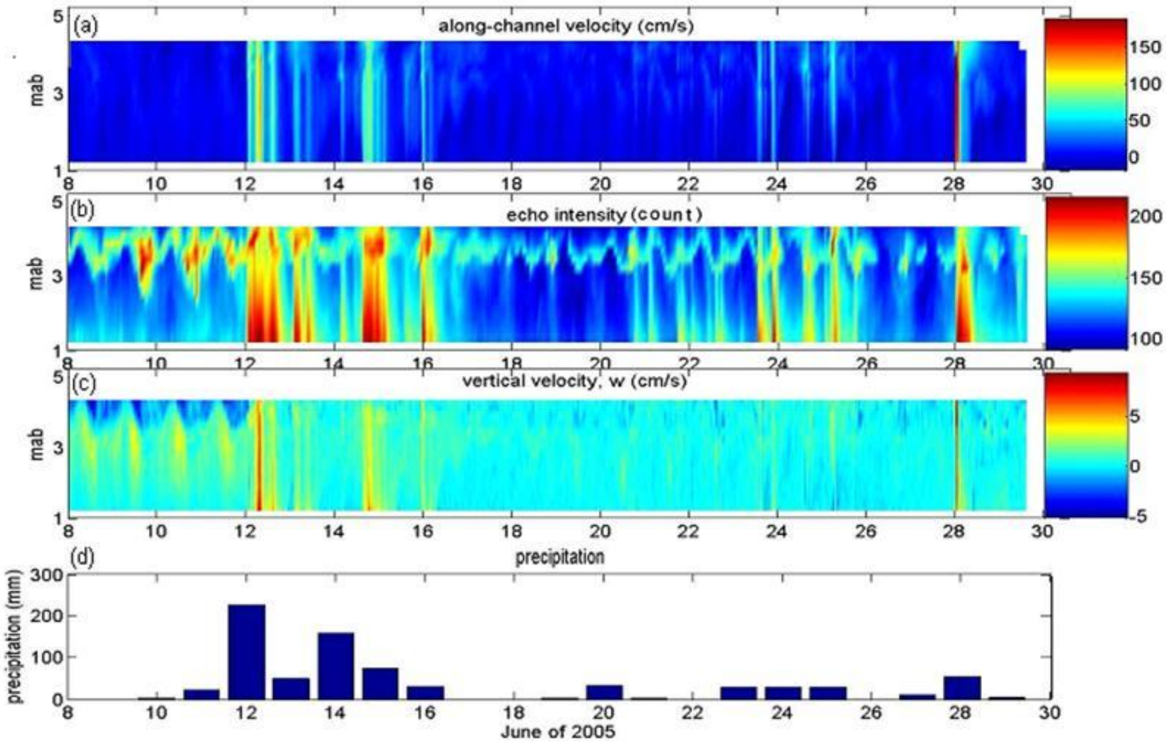

Fig. 1 Bottom-mounted ADCP measurements of (a) along-channel velocity, (b) echo-intensity and (c) vertical velocity as a function of vertical distance and time for the LC esperiment. Daily rainfall of Kaohsiung during the experimental period is shown in (d).

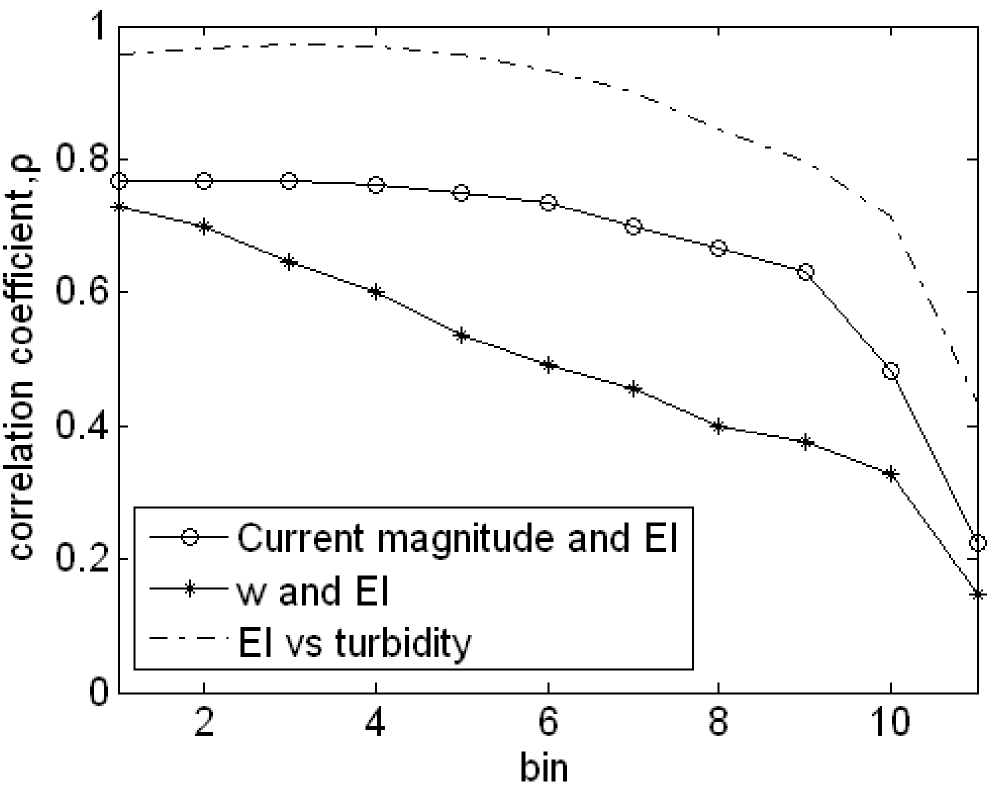

Fig. 2 Correlation coefficients between EI and current magnitude, vertical velocity and near-bottom turbidity, respectively as a function of ADCP bin numbers for the LC experiment.

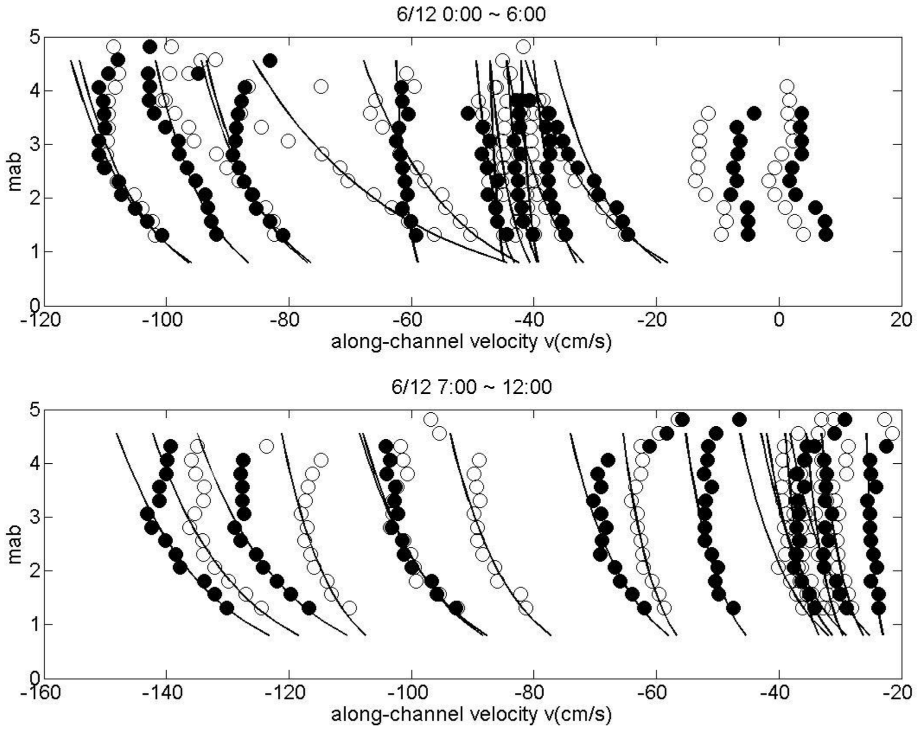

Fig. 3 Consecutive velocity profiles on June 12 2005 and the best-fitted semi-logarithmic curves for the LC experiment. Solid and empty circles are used interchangeably for better viewing effect.

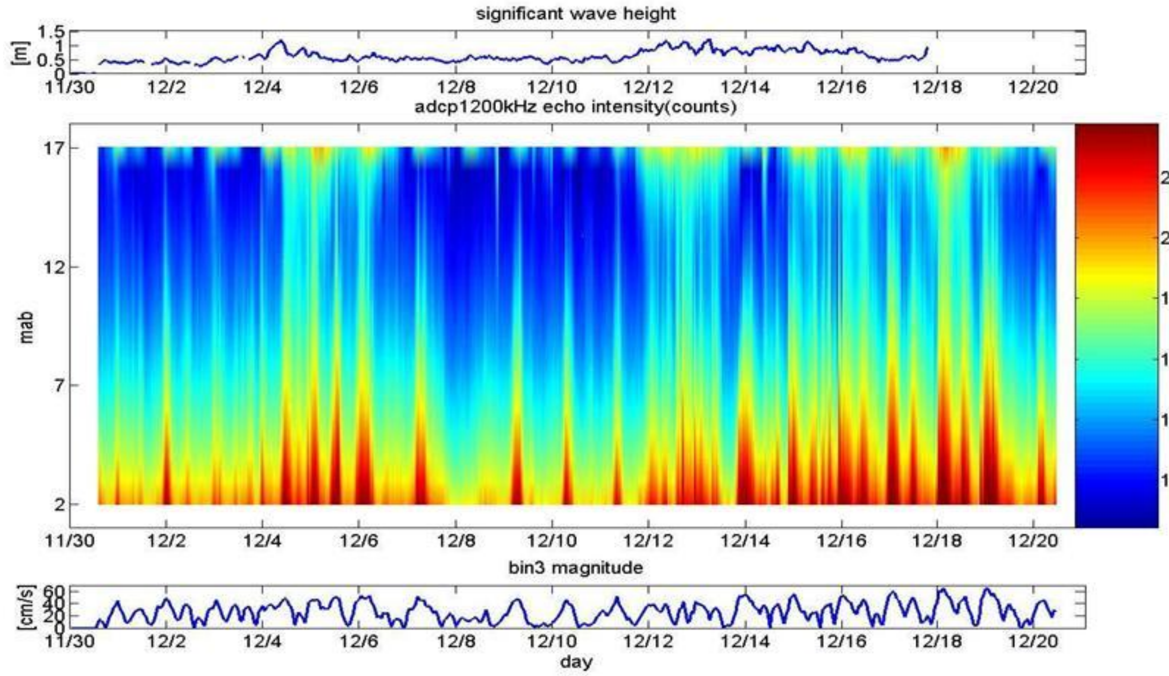

Fig. 4 Time series distribution of (a) significant wave height, (b) ADCP EI and (c) horizontal current magnitude of bin 3 for the HW1 experiment.

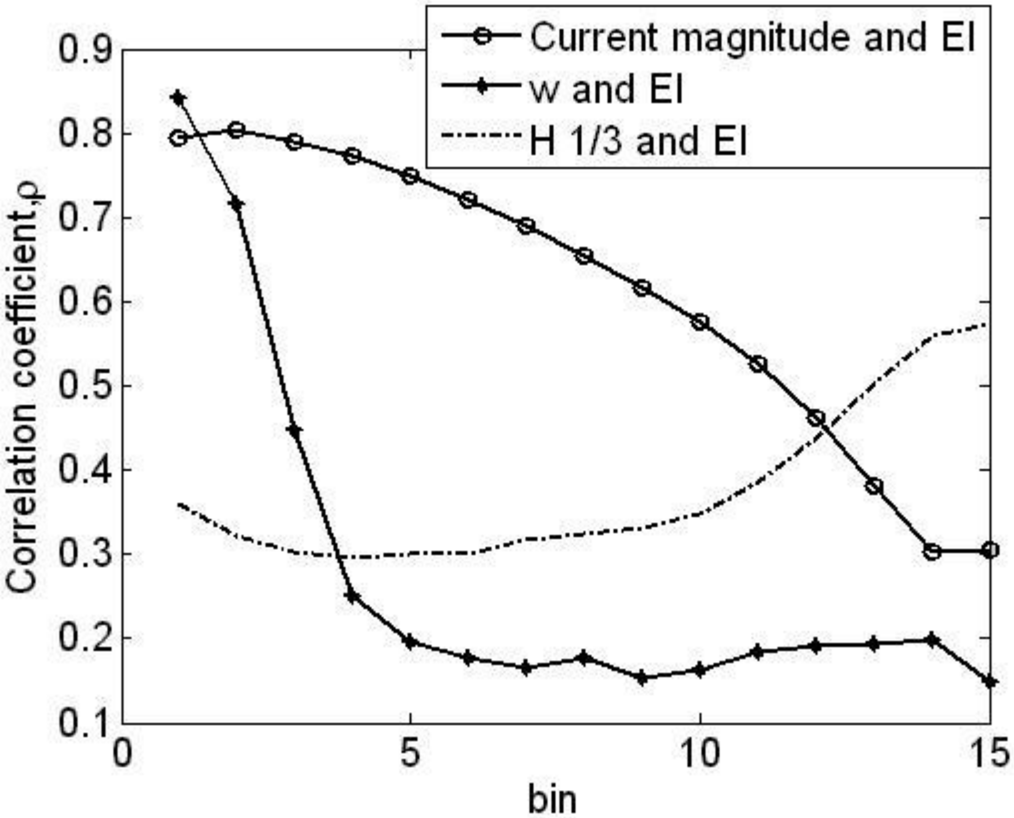

Fig. 5 Correlation coefficients between the ADCP EI and current magnitude, w and significant wave height for the HW1 experiment.

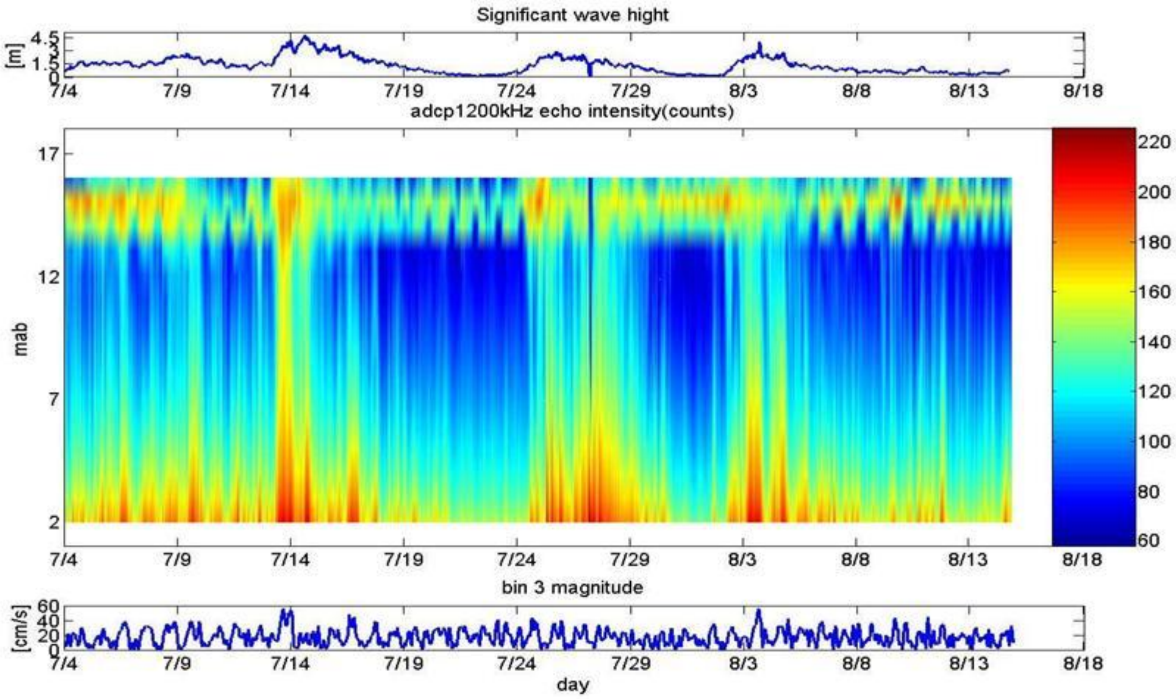

Fig. 6 Time series distribution of (a) significant wave height, (b) ADCP EI and (c) horizontal current magnitude of bin 3 for the HW2 experiment.

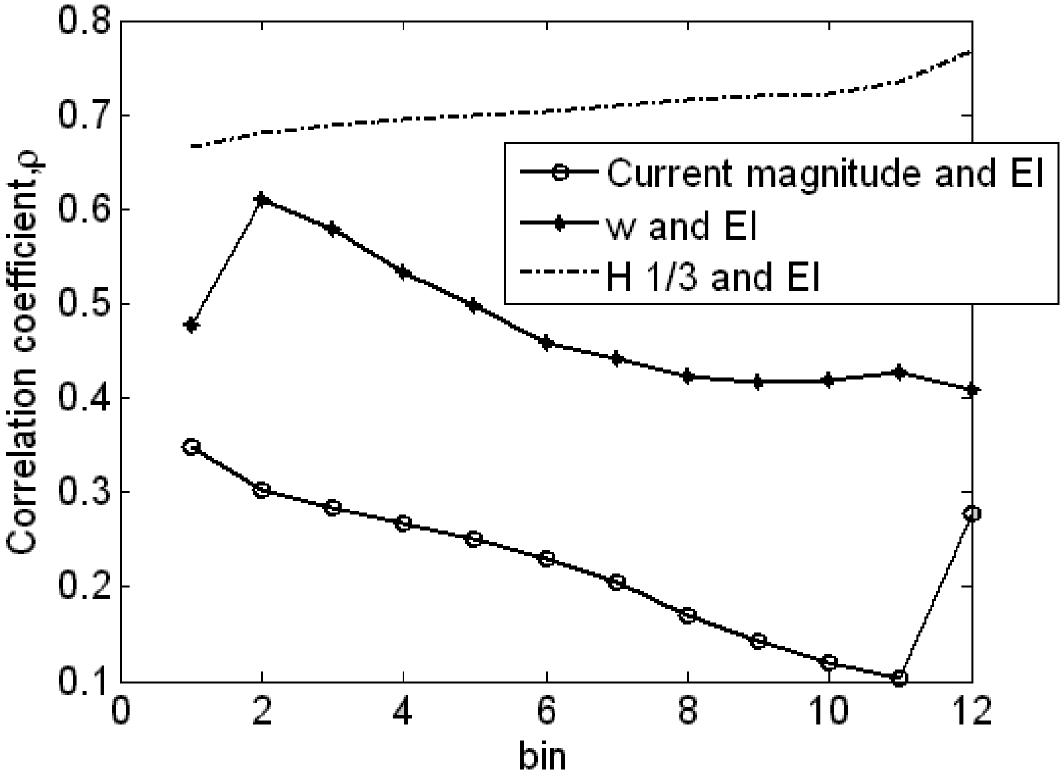

Fig. 7 Correlation coefficients between the ADCP EI and current magnitude, w and significant wave height for the HW2 experiment.

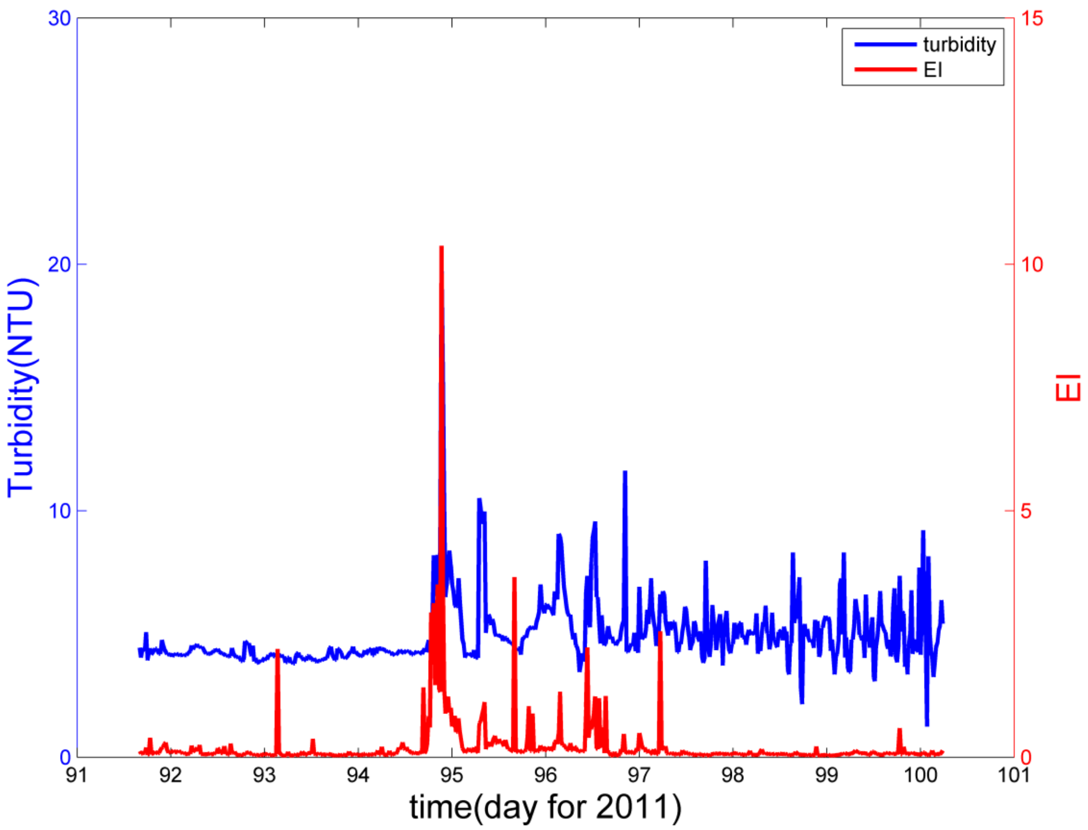

Fig. 8 Variations of ADV acoustic backscatter EI and OBS turbidity for the HW3 experiment.