Development of Low-Cost Drifters Array for Nearshore Current Mapping in Coastal Groin Effect Basins

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ABSTRACT

A low-cost disposal Global Navigation Satellite System (GNSS)-tracked surface drifter is developed for nearshore current mapping. Cluster consisted of more than 30 drifters were deployed in the vicinity waters around Wu-Shi fishery harbor in the northeastern coast of Taiwan where exhibited severe coastal erosion. This paper describes the design of the drifter array system and the results from two field campaigns in Nov. 2015 and Feb. 2016.

KEY WORDS: low-cost drifters array; coastal hydrodynamic; groin effect; dispersion coefficient; turbulent kinetic energy

INTRODUCTION

The hydrodynamic is the dominating factor for the coastal processes such as material transport and mixing, sedimentation, coastal accretion and erosion. Considering the coastal water in a control volume from a macro perspective, the dynamic characteristics are controlled by the combined effect of a variety of external forcing on the boundaries of the volume. These forces include the wind shear stress on the surface, the seabed friction at the bottom, the tidal and larger scale current or riverine discharge at the lateral boundaries, the wave radiation stress on the offshore lateral boundary and the pressure gradient induced by the difference of surface level. The actual situation can be more complex with the changing bathymetry, various stratification conditions and various scales of eddy-shedding caused by the cragged coastline or coastal structures. The understanding of the whole picture of the coastal hydrodynamic is always a challenge. The hydrodynamic environment in coastal zone features significant spatial heterogeneity and temporal variability. Therefore the temporal and spatial information of hydrodynamic parameters should be obtained simultaneously with fine enough resolution.

The oceanic observation could be divided into two categories: Eulerian and Lagrangian approaches. Eulerian method could give high temporal resolution data at some fixed locations. The Eulerian method is not satisfactory for coastal hydrodynamic applications because of the rapid increasing cost when deploying a mass number of instruments spread out the domain to obtain the spatial information of hydrodynamic parameters. On the other hand, the Lagrangian method is a sequent tracking observation method and could obtain temporal and spatial features of parameters simultaneously. For the sediment and material transport studies, the Lagrangian method maybe more suitable. In reality, Lagrangian method had been adopted since 1940. The surface drifters were tracked by compass on boat or shore (Shepard et al., 1941; Shepard and Inman, 1950; Sonu, 1972) or by swimmer (Short and Hogan, 1994; Brander and Short, 2000). Besides, the aerial photography technique was employed to track the dye in water continuously (Bowen and Inman, 1974; Rodriguez et al., 1995; Takewaka et al., 2003). In the last decade, the satellite-tracked surface drifters were widely used for water dispersion characteristics analysis (Schmide et al., 2003; Johnson, 2004; Spydell et al., 2015). However, the above-mentioned drifters are not yet widely used in present coastal engineering applications because of the following reasons: (1) the cost of drifters are rather high, and the fee for data transmitting through satellite or GMS network is high; both restrict the mass deployment over the study area to give a valid observation with high spatial resolution; (2) the size of drifters are not small enough to ensure high current following ability for the small scale processes in the coastal zone.

In present paper, we address on the development of small low-cost GNSS-tracked surface drifters. We will also demonstrate the results of field experiments, in which more than 30 drifters were deployed in the vicinity waters around Wu-Shi fishery harbor where severe coastal erosions occurred. We found that the turbulent kinetic energy (TKE) in downstream area of breakwater is relatively stronger and the dispersion coefficient around the coast with severe erosion is also relatively higher.

METHODS and DATA

Drifters Array

The whole system consisted of 3 sub-systems, i.e. 1. the drifter, 2. The coastal relay station sub-system for data transmitting, 3. real-time data display and management sub-system that support the In-situ operation. The spherical drifter (Figure 1), with the diameter of 12 cm, exhibits good surface flow following capacity. The drifters are designed for at least 96 hours deployment as the data transmitted back to the shore station every 10 sec. via digital RF network (Table 1). Each drifter on the sea can communicate with any other elements in the cluster; once the link is established, the data of the array can be downlink to the shore station. A novel data display and manage sub-system was developed for easy deployment and retrieval.
Fig. 1 Drifter element and data transmitting sub-system

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<th>Table 1 Specifications of drifter element</th>
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Field Experiments and Data Processing

In the winter from Nov. 2015 to Feb. 2016, two field experiments were carried out around Wu-Shi fishery harbor in Yi-Lan bay, Taiwan (Figure 2). More than 30 drifters were launched in each experiment, and most drifters experienced a flood and ebb tidal cycle. Some drifters were retrieved and replaced as they ran aground to maintain a high spatial resolution and a large time span of drifter observations.

The QA/QC flow of drifter data is as follows:
(1) Distinguish and remove the data that were collected while the drifter was not in the flow.
(2) Eliminated poor positioning data, i.e., data with low GNSS satellite number and invalid positioning data.
(3) Rationality check: The velocity is calculated via finite differencing of the raw fixes. A velocity greater than four standard deviations from the mean velocity are removed.
(4) Continuity check: The velocity of drifter should change in a linear fashion when the drifter drift freely on sea surface. Velocity difference between adjacent sampling time is calculated via finite differencing of the velocities. A difference fall outside the interval of 95% confidence level should be removed.
(5) Interpolation of fixes. The cubic spline interpolation is applied to the part that data missing within 1 min (the sampling frequency is 0.1 Hz).

Hydrodynamic Parameter: Dispersion Coefficient

Mixing and dispersion are key processes on the interface between riverine outlets and seas especially within the surf zone and coastal waters considering the ability of coastal waters to receive and dilute discharged suspended sediment. The quality controlled data is then used to derive the dispersion behavior of the water body. The dispersion coefficient can be calculated by the following equation:

\[ K_x = \frac{1}{4} \frac{\partial \sigma^2}{\partial t} \]

where \[ \sigma^2 \] is given by

\[ \sigma^2 = \frac{1}{n} \sum_{i=1}^{n} \left( (x_i - \bar{x})^2 + (y_i - \bar{y})^2 \right) \]

where \((x_i - \bar{x})^2\) and \((y_i - \bar{y})^2\) are, respectively, the cross-shore and along-shore squared displacements of the \(i\)th drifter relative to the cluster centroid. For all clusters, the positive cross-shore axis was oriented towards 107° T (e.g. in an ESE direction) and the positive along-shore direction was oriented towards 17° T (e.g. in a NNE direction).

Empirical Orthogonal Function

Empirical Orthogonal Function (EOF) analysis is a statistical method used to decompose a space- and time-distributed dataset into a linear combination of orthogonal functions called modes (Baldacci, et al.; 2001). Most of the variance of the dataset can generally be captured by a small number of modes. The decomposition is useful to reduce the dimensionality of the dataset and to analyze its spatial and temporal variability. In fact only the modes that explain a significant percentage of the total variance of the dataset are considered in the analysis while the remaining percentage of variability due to the noise present in the data is neglected. Therefore, the dataset could be expressed as linear combination of different modes with different weight after EOF decomposition.

The EOF was first published by statistician Pearson in 1902 and was first introduced into meteorological and climate study by Lorenz in 1956. This paper follows Lorenz’s algorithm.

RESULTS and DISCUSSIONS

Potential Influence of Kuroshio Boundary on Yi-Lan Bay

The Yi-Lan bay and Wu-shi harbor are just adjacent to the Kuroshio, which flow along the eastern coast of Taiwan. But due to the blockage
of the Yi-Land ridge, the current pattern in the coastal zone in this area is not clear. Firstly, we investigate the role of Kuroshio in the vicinity waters using hourly data that observed by the coastal High-Frequency (HF) radar. The HF coastal radar systems were installed and operated by Taiwan Ocean Research Institute (TORI) in operational mode. The resolution is about 5 km. It is noted that the Yi-Lan Bay is in the region of the blind zone of the long-range (5 MHz) radar system. Figure 3 shows the result of east-west (u) velocity in Jan. 2016. Figure 3a is the first spatial EOF mode with the contribution up to 65%. The first temporal mode (Figure 3d) and its spectrum (Figure 3c) show the significant signal of M2 tide over the northern coast. The second mode is the modulation of Kuroshio with the tidal wave as shown in Figure 3b and Figure 3e for spatial and temporal modes, respectively. Figure 3b shows a clear frontal boundary in the eastern Yi-Lan bay waters, which indicated the boundary of the main stream of Kuroshio.

The EOF analyses were then repeated for monthly current fields that mapped by HF radar, from Apr. 2015 to Apr. 2016. Figure 4 shows the second spatial modes in summer and winter. It is seen that the location of the frontal boundary of Kuroshio is affected by the seasonal oscillation phenomena. It deviates to the west (closer to the Yi-Lan bay) in winter and moved offshore in summer. This implies that the west boundary of Kuroshio is likely to affect the hydrodynamic in Yi-Lan bay. Hu (1994) found that the main stream of Kuroshio could move away from and approach to Taiwan in Spring/Summer and Autumn/Winter, respectively, based on the trajectories of Argo floats. Lee and Hu (1998) conducted eight CTD surveys from Apr. 1994 to Mar. 1996 around Yi-Lan bay and concluded that the water body in Yi-Lan bay are basically the same as the shelf water in northern Taiwan during Apr. to Oct. They also identified using the T-S diagram that the water body in Yi-Lan bay might similar to Kuroshio water in March. Lee and Hu (1998) suspected that the Kuroshio water is likely to intrude the Yi-Lan ocean ridge (Figure 2) and flow into Yi-Lan bay. However, up to present, there is lack of evidence showing the intrusion of Kuroshio into Yi-Lan bay.

**Current Mapping of Yi-Lan Bay by Drifters Array**

Two field drifter clusters experiments are conducted around Wu-Shi fishery harbor on Nov. 26-27, 2015 (early winter) and Feb. 25, 2016 (late winter), respectively. Both experiments are influenced by strong northeast monsoon and there should be strong southwestward alongshore current. Coupled with the effects of tide, the drifters are likely to float follows the tide and the net movement is southwestward in theory. But things are definitely different. Almost all the drifters flows northeastward whether flood or ebb tide in the early winter experiment (Figure 5a). And almost all the drifters flows southwestward in the late winter experiment (Figure 5b). It means that the west boundary of Kuroshio have intruded into Yi-Lan bay in the early winter and dominated the current field in the bay. In this case, the alongshore and tidal current become secondary impacts. Meanwhile, we found no evidence of the impact of Kuroshio in the late winter. The current field of Yi-Lan bay is dominated by alongshore current and the tide takes the second place.

**Coastal Hydrodynamic: Dispersion Coefficient and TKE**

Figure 6a and b are the distributions of alongshore and cross-shore dispersion coefficient in early winter experiment, respectively. Figure 6c and d are the distributions of alongshore and cross-shore dispersion coefficient in late winter experiment, respectively. By comparison of
Figure 6a,b and Figure 6c,d, the dispersion coefficient of water affected by Kuroshio is relatively larger. In early winter experiment, both the alongshore and cross-shore dispersion coefficients in the coastal area of northern Wu-Shi fishery harbor are larger than surround area. That's probably because the disturbance of the rugged coast there. In late winter experiment (Figure 6c), the strongest alongshore dispersion coefficient appear in the front of Tou-Cheng beach. This can be used to explain the reason why serious erosion occurred here. From Figure 6d, the south area close to Wu-Shi fishery harbor shows negative dispersion coefficient. This can be interpreted as the groin effect of the harbor.

The groin effect is also shown in the distribution of turbulent kinetic energy (TKE) (Figure 7). TKE is often used to describe the strength of turbulent, its formula is shown as the following:

$$TKE = \frac{1}{2} (u'^2 + v'^2)$$

where $u$ and $v$ represent the west-east and south-north velocity, respectively. As can be seen on Figure 7, the downstream area of Wu-Shi fishery harbor shows the higher TKE.

CONCLUSIONS

The small low-cost disposal GNSS-tracked surface drifters array system developed by this study is suitable for coastal hydrodynamic research. After two field experiment around Wu-Shi fishery harbor where severe coastal erosions occurred, we found that the turbulent kinetic energy (TKE) in downstream area of breakwater is relatively stronger and the dispersion coefficient around the coast with severe erosion is also relatively higher.

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