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# Alongshore and cross-shore circulations and their response to winter monsoon in the western East China Sea

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ABSTRACT

An array of four bottom-mounted acoustic Doppler current profilers (ADCPs) were deployed during the winter of 2008 (28 December 2008 to 12 March 2009) along a cross-shelf section in the western East China Sea to investigate the winter circulation and its response to wind. During the observation period, the observed subtidal currents exhibit coherent spatial structure and temporal variation in terms of their mean (seasonal), trend (intra-seasonal), and synoptic variability. The subtidal currents are polarized roughly in the alongshore direction parallel to local isobaths, and the weak cross-shore current is closely linked to the alongshore component. The temporal variation of the currents follows the rhythm of wind stress, sea level, and sea level difference at the synoptic scale.

The mean currents are basically composed of two anti-parallel currents in the alongshore direction: the East China Sea coastal current (ECSCC) flows southwestward along the inner shelf and the Taiwan warm current (TWC) flows in the opposite direction along the outer-shelf. The strongest current occurs over the mid-shelf as a coastal jet. The intra-seasonal currents exhibit an expansion and intensification of the ECSCC along with shrinking and weakening the alongshore component of the TWC. There is a significant increase in onshore current particularly over the mid-shelf.

The fluctuations of synoptic currents show a significant positive correlation with wind stress, and the fluctuations are negatively correlated with sea level and sea level difference. The coherent spatial structure of the currents indicates that the depth-independent column motion is related to the sea level difference through a barotropic pressure gradient. The vertical shear of currents is related to the density-related baroclinic pressure gradient in the whole water column and to the friction within the surface and bottom boundary layers.



## 1. Introduction

Circulations in coastal seas have been widely studied, in particular, the wind-driven currents on the continental shelf. Much of this work has been summarized in the review articles by Winant (1979, 1980), Allen (1980), Mysak (1980a, 1980b), Allen et al. (1983), Huyer (1990), Brink (1987, 1998, 2005), and Liu and Weisberg (2012) as well as in a textbook by Csanady (1982).

Some features of the circulations have been successfully described by observational data, explained by analytical models, and simulated by numerical models. In spite of strong regional differences in geographic configuration and wind patterns, there are important similarities in the characteristics of the currents over most continental shelves (Huyer, 1990). In all continental shelf regions, the currents fluctuate with periods ranging from 3 to 15 days. These low-frequency synoptic fluctuations tend to have a preferred orientation, to be in approximate geostrophic balance, to be nearly independent of depth at least over the shelf, to decay with distance offshore, to propagate along the coast, and to be coherent over large alongshore distances. These fluctuations at most locations are also correlated with winds and coastal sea level. The dynamics of fluctuating currents is often explained by coastal trapped waves.

Historically, the studies of coastal sea circulations have often concentrated on the alongshore component but less on the cross-shore component, although the latter plays a fundamental role in material transport across the shelf and is the focus in many multidisciplinary studies. The cross-shelf current may be less studied due to the following factors. (1) The alongshore component alone is often considered sufficiently representative for most studies because the currents in the coastal sea are usually

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dominant in the alongshore direction. (2) The characteristics of cross-shore component are much more difficult to extract because it is weak and often masked by noise. (3) The correlated scale of the cross-shore component is much smaller than that of the alongshore component, although its mechanism is often explained by Ekman dynamics.

Over the continental shelf of western East China Sea, the circulation consists primarily of the East China Sea coastal current (ECSCC) along the inner shelf and the Taiwan warm current (TWC) along the outer-shelf. Both the ECSCC and the TWC have seasonal variability in terms of their magnitude and direction. The ECSCC is also called the Zhe-Min coastal current as it flows in the coastal area of Zhejiang (shortened to Zhe) and Fujian (shortened to Min)

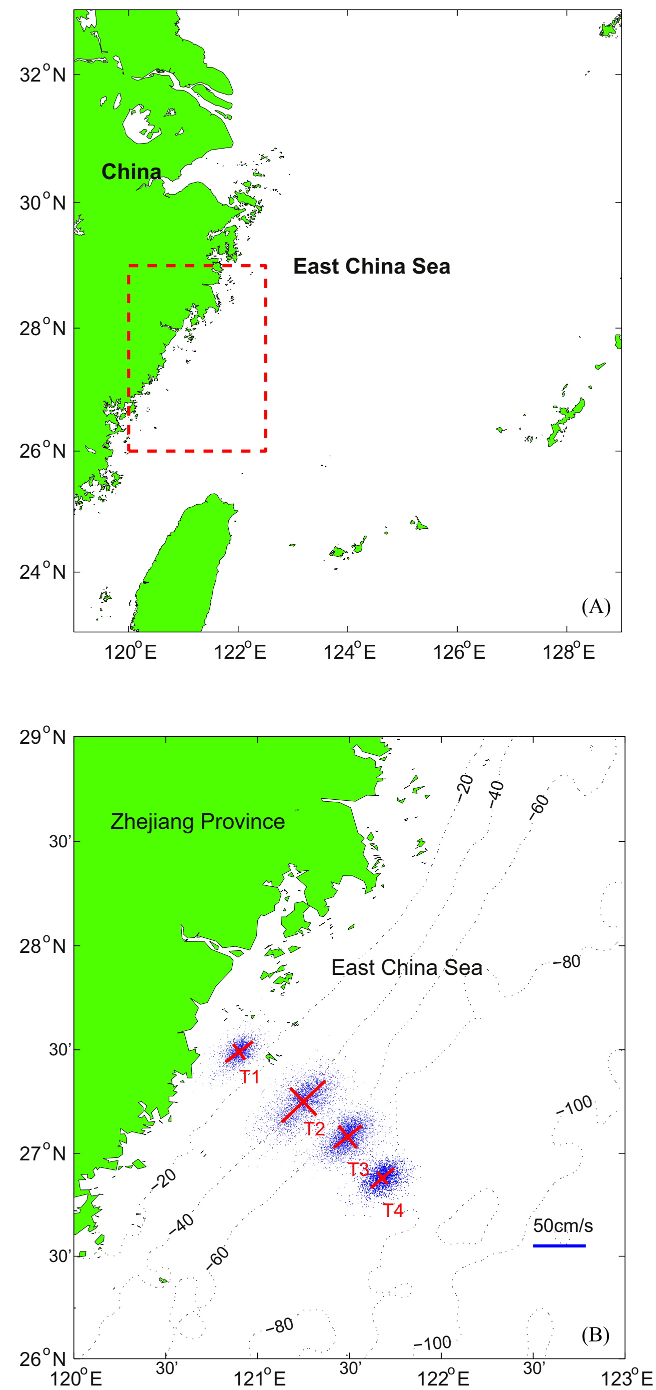


**Fig. 1.** Study area and four observation stations superimposed with the scatter plot of synoptic scale currents.

provinces of China. The ECSCC changes its direction following the reversal of monsoon wind which flows parallel to coastlines in the NE direction in winter and in the SW direction during summer (Su, 1998). The TWC has a persistent NE direction following 50–100 m isobaths throughout the year, although its magnitude varies seasonally (Su and Pan, 1987). There is also a seasonal migration of the TWC in the cross-shore direction with a more shoreward position, narrower width, and weaker speed in winter than in summer (Guan and Mao, 1982). In winter, the vertical averaged speed of the TWC is approximately 0.13 m/s with its maximum current occurring in subsurface layers (Guan and Fang, 2006). The seasonal variation of the TWC is caused by the reversal of the monsoon wind over the area (Cui et al., 2004).

The synoptic variations of the ECSCC and the TWC and their relations with wind stress were investigated by Zeng et al. (2012). They analyzed the alongshore and cross-shelf components separately. Their results indicate that both the ECSCC and the TWC are significantly correlated with the local wind stress. The high correlation between the alongshore current component and the wind stress demonstrates that the synoptic fluctuations of the ECSCC and the TWC are mainly forced by the oscillations of the northerly wind.

The current on the shelf of the western East China Sea is dominated by its alongshore component and is primarily along local isobaths with the constraint of bottom bathymetry. In contrast, the cross-shelf current is rather weak and less is known regarding its spatial and temporal variations. However, it plays a fundamental role in material transport across the shelf and it is a focus in many multidisciplinary studies.

However, the alongshore and cross-shore components at a specific region are often linked by intrinsic constraints. Therefore, it is more reasonable from a physics perspective to first analyze the currents as a whole, and then decompose the obtained results into alongshore and cross-shore components for further exploration. In this way, knowledge of weak cross-shore circulations can be better obtained and understood.

In this paper, we use observational data of the current, sea level, and bottom temperature to explore the coherent spatial structure and temporal variation of subtidal currents in terms of mean (seasonal scale), trend (intra-seasonal scale), and synoptic variability. The variation mechanisms of currents are also investigated.

## 2. Data and methods

### 2.1. Field observation data and sea wind data

In this paper, in addition to the same current and wind datasets used by Zeng et al. (2012), the sea level and bottom temperature datasets are used to explore the coherent spatial pattern and temporal variation of subtidal currents as well as their mechanisms.

The current data used in this study were measured by the bottom-mounted acoustic Doppler current profilers (ADCPs) at four stations along a cross-shelf section on the shelf of the western East China Sea during the winter period from 28 December 2008 to 12 March 2009. The locations of the four stations are shown in Fig. 1. The four stations are named T1, T2, T3, and T4 corresponding to their distances from the coast. The observation information and measured parameters at the four stations are shown in Table 1. The bottom temperature and pressure were also measured during the period, with the exception of pressure at station T4. The temperature and salinity profiles at four stations were also measured immediately after the deployment of ADCPs.