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Observed sub-inertial current variability and volume transport over the continental shelf in the northern South China Sea

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ABSTRACT

Sub-inertial currents (SICs) over the continental shelf of the northern South China Sea (NSCS) are investigated using the in-situ current observations of acoustic Doppler current profiler (ADCP) mooring arrays off the Pearl River Estuary in 2006 and 2007. The survey was carried out in four separate time periods: summer, winter, spring (before the onset of the southwesterly monsoon), and fall (after the establishment of the northeasterly monsoon). The observations showed that the current directions were generally along the shelf, consistent with the directions of monsoonal winds. The currents were also affected by a few of mesoscale eddy events. In summer 2006, the volume transport was northeastward with a mean magnitude of 1.4 Sv through a cross-shelf section from the site of the depth of 135 m to the coast; in winter 2006/2007, spring 2007 and fall 2007, the volume transports were all southwestward with magnitudes of 2.0, 2.1, and 0.9 Sv, respectively, through a cross-shelf section from the site of the depth of 290 m to the coast. The standard deviations of the SICs were generally smaller than the velocities of the mean currents, and the variability of SICs showed significant correlation with the local sea surface winds. No persistent counter-wind currents were observed in the study area during the fall and winter observational periods.

1. Introduction

The northern South China Sea (NSCS) (Fig. 1) has a broad continental shelf (shallower than 200 m) and a large deep basin (with the maximum depth greater than 4000 m). It is connected to the western Pacific Ocean to the east through the Luzon Strait where the Kuroshio intrudes. The monsoonal winds dominate over the NSCS, with the northeasterly in winter and the southwesterly in summer. The oceanic circulation over the continental shelf in the NSCS is under the influence of wind forcing, the Kuroshio intrusion, and the mesoscale processes (e.g., Guo et al., 1985; Qu, 2000; Yang et al., 2002; Metzger, 2003; Centurioni et al., 2004; Chapman et al., 2004; Qu et al., 2004; Caruso et al., 2006). The influence of monsoonal winds on the ocean circulation over the continental shelf in the NSCS is evident: wind-forced upper layer currents primarily flow in the along-shelf direction, that is, mainly northeastward in summer and southwestward in winter. Guan (1978) proposed, however, that a counter-wind current flowing to the northeast existed in winter in the NSCS, and called it the South China Sea Warm Current (SCSWC) (see also Hu et al., 2000; Guan and Fang, 2006). Qiu et al. (1984) and Guo et al. (1985) proposed that the effect of the Kuroshio intrusion on the NSCS circulation is important and there is a southwestward current known as the SCS Branch of the Kuroshio (SCSBK) existing near the shelf break. It has been suggested in the following studies that the Kuroshio intrusion into the NSCS varies on seasonal timescales. In particular, the greatest strength of the intrusion occurs in winter, and can split into several components after entering the South China Sea. Some studies (e.g. Shaw, 1991; Xue et al., 2004; Wang et al., 2010) suggested that the SCSBK provides a source for the SCSWC. Chao et al. (1995) proposed that the SCSWC could appear only when the northeasterly winds are

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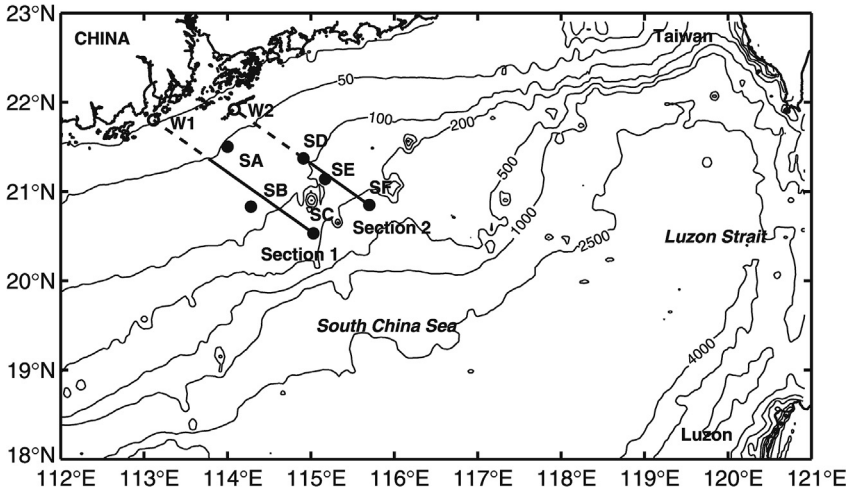

Fig. 1. Map of the northern South China Sea. Locations of ADCP moorings are denoted by solid dots. Measurement was carried out in summer at stations SA, SB, and SC, and in winter, spring and fall at stations SD, SE, and SF. Two parallel lines indicate the cross-shelf sections for estimating volume transports; W1 and W2 indicate the crosspoints of these sections with the islands near the mainland coast (see text of Section 4.4 for details).

relaxed. Fang et al. (1998) believed that, in term of mean state, the SCSWC could not exist in the western part of the NSCS but might exist in the eastern part of the NSCS shelf. Zheng et al. (2006) and Fang et al. (2009) further speculated that the SCSWC is normally only present in the north-easternmost area of the NSCS. Therefore, the existence of the SCSWC in wintertime on the NSCS shelf is still an unsolved issue.

There have been many studies on current variability based on mooring observations over the continental shelf/slope in the NSCS (e.g. Fang et al., 2000, 2005; Liang et al., 2005; Guo et al., 2012; Lee et al., 2012), which contribute to a better understanding of the physical processes on the NSCS continental shelf/slope regime. Observed near-inertial oscillations and their relation to passing typhoons or tropical storms were also reported in a number of studies (e.g. Chu et al., 2000; Sun et al., 2011; Liu et al., 2011). However, these investigations were focused on the near-inertial, internal tidal processes, and were mostly based on individual mooring observations. Our knowledge of the NSCS circulation is mainly based on numerical modeling (e.g. Shaw and Chao, 1994; Metzger and Hurlburt, 1996; Fang et al., 1996; Hsueh and Zhong, 2004; Xue et al., 2004; Wang et al., 2010), calculations of geostrophic current from water density, and individual (or short-term) direct current observations (e.g. Guan, 1978: Qiu et al., 1984; Guo et al., 1985). As compared to the other shelf areas such as the Taiwan Strait and the Korean Strait (Teague et al., 2002, 2003), reports on the low-frequency currents in the NSCS are rare, mainly due to the lack of long-term mooring observations. In particular, no observation-based estimates of volume transport along the shelf have been reported so far. To estimate the magnitudes of volume transport in various seasons, and to understand longer-term current structure and temporal variability over the continental shelf in the NSCS, in-situ observations were conducted in four seasons of 2006 and 2007 by an array of bottom mounted acoustic Doppler current profiler (ADCP) moorings. Based on these observations we are able to provide estimates of the along-shelf volume transport, and to reveal the current variability, as well as to examine the existence of the SCSWC in the area. Our study may contribute to the community for better understanding the current variability in the NSCS and particularly for model validation and development.

This paper is organized as follows. Section 2 describes the data and analysis methods. Section 3 presents sea surface winds during the measurement periods. Section 4 shows the SIC variability and estimated volume transport. Section 5 discusses the effect of mesoscale processes on the current variability. Section 6 provides a discussion and a summary.

2. Data and methods

The current moorings were deployed southeast of the Pearl River Estuary, roughly in the middle of the NSCS shelf (see Fig. 1). Observations were conducted by the South China Sea Branch of the State Oceanic Administration of China in four periods: summer 2006, winter 2006/2007, spring 2007, and fall 2007. During each time period, an array consisting of three bottom-mounted RDI ADCPs was deployed across the shelf on the sea floor from southeast to northwest. In summer 2006, the depths of mooring sites (SA, SB, and SC in Fig. 1) were from 55 to 135 m. In the other three seasons the depths of mooring sites (SD, SE, and SF in Fig. 1) varied from 95 to 290 m. The horizontal distances of SA-SB and SB-SC were about 80 and 85 km, respectively, and those of SD–SE and SE-SF were about 37 and 64 km, respectively.

Current profiles were recorded by ADCPs at 10-min time interval over nearly the full water column. The shortest continuous observational period, during which three ADCPs worked simultaneously, was 33 days (in summer), and the longest was 59 days (in winter). The ADCPs worked well and provided high quality current data. The mooring site depths, observational periods, and instrument configurations of the ADCPs are given in Table 1.

The obtained current records were nearly complete and very little corrections were required. Few unrealistic extreme values in the raw data were first rejected and replaced by linearly interpolated values. The tidal analyses had been performed and the results have been reported in another paper by Guo et al. (2012). Since this work is aimed at studying the current variability with time scales longer than a few days, the high frequency currents, such as tidal and inertial currents, were removed from the current records by applying a fourth-order Butterworth low-pass filter. With the range of inertial frequencies at mooring sites (from 0.70 to 0.74 cpd) considered, the cutoff frequency of the filter was selected as 0.60 cpd, corresponding to the period of 40 h. The filtered currents are called sub-inertial currents (SICs).

To reveal the scatter characteristics of observed current vectors, a principal axes of variance (PAV) analysis can be used, which