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Distribution and cross-front transport of suspended particulate matter over the inner shelf of the East China Sea

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ABSTRACT

An obvious shear front between the Taiwan Warm Current and the Zhe–Min (Zhejiang–Fujian) Coastal Current exists over the inner shelf of the East China Sea (ECS) in winter. Although the cross-front spread of surface water in the ECS has been reported based on satellite images, the cross-front transport of suspended particulate matter (SPM) has not been well studied. To reveal the detailed characteristics of SPM in vertical direction, in terms of different fractions, and to study its cross-front transport and mechanism, high-vertical resolution profiles of SPM concentrations observed by Laser In-Situ Scattering and Transmissometry (LISST) and derived from water samples at various levels, together with salinity and temperature, were measured in February 2007, from 34 stations in the ECS. Results showed that volume concentration (VC) of SPM finer than 280.07 μm has a good correlation with mass concentration (MC), because coarser factions were thought to be biological components. The VC was then converted to the MC of different fractions at high resolution, by reducing the influence of biological sources. Both temperature and salinity data showed an obvious front along 50 m-isobath in the bottom layer, tilting seaward toward the surface layer. Within 50 m-isobath, the MC was higher than 2 mg/L in the surface layer and 10 mg/L in the bottom layer. The SPM could be transported across the front to the sea in the bottom layer, even to the east of 100 m-isobath, where the MC of SPM was less than 1 mg/L in the surface layer and 2 mg/L in the bottom layer. The SPM across the front was mainly silt fraction with some fraction of clay. An idealized numerical model was established. Numerical experiment results showed that bottom Ekman transport produced by the northerly wind in winter is the key factor controlling cross-front transport, and strong northerly wind is responsible for its expansion. This study helps our understanding of material exchange in the coastal and shelf seas.

1. Introduction

Cross-front material transport and water exchange are important for marine ecology and material recycling (Thomsd et al., 1980; Su, 2005; Dong et al., 2011). In the East China Sea (ECS), the coastal waters off Zhejiang and Fujian (Zhe–Min) provinces in winter (Fig. 1) are controlled by the southward Zhe–Min Coastal Current (ZMCC) and the northward Taiwan Warm Current (TWC), which result in a front characterized by opposite currents and distinct temperature and salinity on the two sides. Moreover, the movement of the northward TWC is accompanied by its significant climbing tendency toward the shore (Su, 2005; Lü et al., 2006; Qiao et al., 2006; Xu et al., 2012). Ocean color and sea surface temperature (SST) data based on the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the Terra satellite illustrate the obvious cross-shelf currents in the surface layer of the YS and the ECS in winter (Yuan et al., 2008; Yuan and Hsueh, 2010). Therefore, the Zhe–Min Coastal Shelf (ZMCS) is recognized as one of the most important channels for transporting coastal material to the open seas in winter. For the mechanism, Yuan and Hsueh (2010) reported that geostrophic current across the ECS continental shelf and slope into the Okinawa Trough, which is produced by the rising sea level caused by the TWC and Kuroshio, is responsible for the cross-shelf transport. Dong et al. (2011) suggested that the cross-front movement of material due to the combination of down-welling and horizontal Ekman transport is caused by the northerly wind in winter. Previous studies have investigated the occurrence of cross-front transport in the surface layer of the ECS, but only few studies have been carried out on material transport in the bottom layer. The lateral transport of suspended particulate matter (SPM) in the ECS has only been reported at two sections, respectively from the Yangtze Estuary to the mid-continental slope area in the northern ECS (Hoshika et

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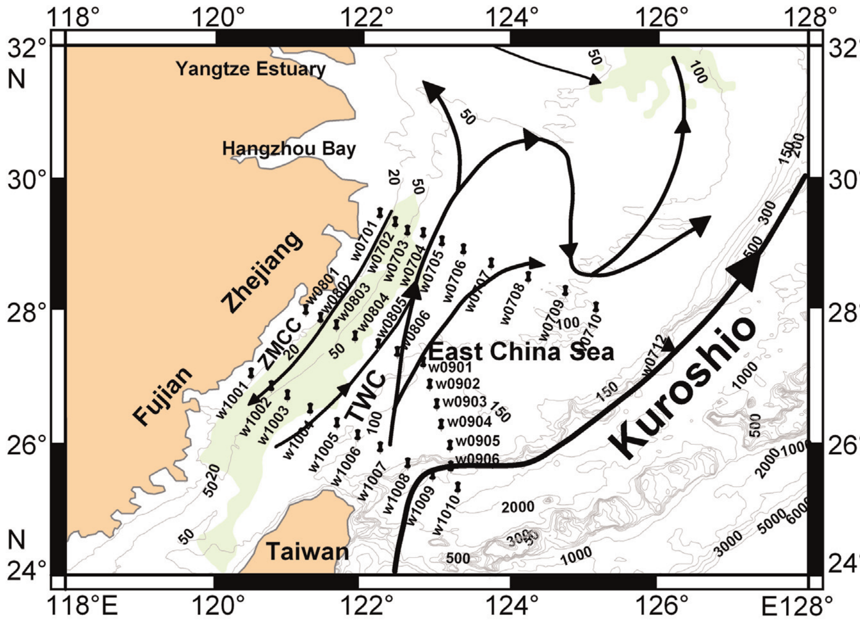

Fig. 1. Observation stations and currents (denoted by black lines with arrows) in the ECS in winter. After Yuan and Hsueh (2010). ZMCC indicates the Zhe–Min Coastal Current, which flows northward in winter carrying cold, low-salinity water. TWC indicates the Taiwan Warm Current, which flows northeastward along the isobaths of 50–100 m (Su and Pan, 1987) with-high temperature, high-salinity water. The Kuroshio has the characteristics of high temperature and high salinity, a branch of which enters the region of water depth between 100 and 200 m, leading to the invasion of upper-layer Kuroshio water into the shelf (Su, 2001; Yuan and Hsueh, 2010). The green shading indicates the inner-shelf mud area in the ECS.

al.,2003), and from the ECS continental margin to the Okinawa Trough in the southern ECS (Yanagi et al., 1996; Hung et al., 1999). However, little is known about the situation in the central ECS. Furthermore, no work has been carried out on its mechanism.

The distribution and deposition of SPM in the ECS are closely related to the formation of the inner-shelf mud area (Fig. 1). Guo et al. (2002) reported that the distribution and transport of the SPM in the ECS are influenced by circulations, storms, tides, and the sediments discharged from the Yangtze River in winter. Based on remote sensing data from 2001 to 2002, Pang et al. (2010) found that the horizontal distributions of suspended sediment in the ECS and the YS in winter are mainly determined by ocean circulations. Based on the Laser In-Situ Scattering and Transmissometry (LISST) data, Yu and Jiang (2011) observed that the volume concentration (VC) of SPM is higher in winter (January) than in summer (July) due to strong winter wind, while the particle size is smaller in winter than in summer. Li et al. (2013b) noted that winter is the key season for particle transportation and deposition, further stated that the bottom turbid layer is the primary channel for sediment transport, and upwelling and oceanic front play important roles in sediment deposition and mud area formation. However, until now, there are few publications on the vertical distribution of the SPM.

In this study, we aim to reveal detailed characteristics of the SPM in different fractions in the vertical direction, and to study the cross-front transport of the SPM in the lateral direction and its mechanism. We use temperature, salinity and SPM concentration data of high vertical resolution measured in February 2007 at 34 stations across the ECS, and an idealized numerical model. The data sources are described in Section 2. Both temperature and salinity are used to analyze front features over the inner shelf of the ECS in Section 3. The VC observed by the LISST is converted to mass concentration (MC) of different fractions at high resolution to describe the vertical and horizontal SPM distributions over the inner shelf of the ECS in Section 4. Numerical simulations are introduced to isolate the mechanism of the cross-front transport in Section 5, and conclusions are given in Section 6.

2. Material and methods

2.1. Data sources

Field data measured in February 2007 at 34 stations along four sections (w07, w08, w09, and w10) from north to south of the study area aboard *R/V Dongfanghong 2* were used in this study (Fig. 1). Sections w07, w08 and w10 were perpendicular to the coastline, cutting across the front and the inner-shelf mud area in the ECS, while Section w09 was located at the shelf edge with the maximum gradient of water depth. Temperature, salinity, MC and VC of SPM were measured. Considering that the duration of the survey was no more than six days, with the absence of strong wind (thus no high waves) and heavy rain (thus small sediment discharge) in the study area during the survey (Yang and Zhou, 2007), the observed results are shown in one contour plot, as done in other studies (Lim et al., 2007; Qiao et al., 2008; J.C. Li et al., 2013; Y.H. Li et al., 2013). Vertical distributions of temperature and salinity were measured by SBE-911 plus CTD (Sea-Bird Electronics Inc., U.S.) at the stations shown in Fig. 1. At every station, the instrument was released at a uniform speed using a winch. The vertical resolution of the data was higher than 0.1 m.

A LISST 100C (Sequoia Scientific Inc., U.S.) particle size analyzer was attached to the CTD in order to obtain in-situ profiles of particle size and VC of SPM at the same depth of temperature and salinity. In this study, the VC is defined as the volume of suspended matter per unit volume. The laser beams of the LISST were scattered, absorbed and reflected by suspended particles of different sizes in the water. Thus, 32 logarithmic distributions of VC of different fractions, from 2.50 to 500 μm, were acquired according to the Mie scattering theory (Agrawal et al., 1991). Volume fractions of all suspended particles in the water column were measured by the LISST, including both mineral- and biological-source