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Settling fluxes of cohesive sediments measured by sediment traps in a semi-enclosed embayment with strong tidal environments

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ABSTRACT

To understand the variations of vertical settling flux in a spring-neap tidal cycle in strong tidal environments, an anchored vessel with a Hydro-Bios Multi-Sediment Trap and a Nortek Acoustic Doppler Velocimeter (ADV) was deployed in the sub-tidal flat in Luoyuan Bay, a typical semi-enclosed embayment, from January 16 to 31, 2010 (from spring to neap to spring again). The observed results reveal that there is a strong relationship between the Signal-Noise Ratio (SNR) recorded by the ADV and the synchronous suspended sediment concentration (SSC) obtained by the filtrated method. The time-series of SSC and settling velocity were then estimated. The measured results indicated that the maximum tidal range during the observation was 7.03 m, which occurred during the spring tide, and the minimum value during the neap tide was 3.58 m. The near-bottom (1.1 m above the bed) current speed, SSC, bed shear stress, and settling velocity decreased from spring to neap tide, and the maximum values were 0.556 m/s, 53.40 mg/L, 0.806 N/m^2 and 0.26 mm/s, respectively. The horizontal flux varied from 0.04 g/m^2 s to 21.77 g/m^2 s; the horizontal fluxes over a tidal cycle decreased from spring to neap tide, and the net horizontal flux of suspended sediment was 880.66 kg/m^2 with a net transport direction of 292° during the entire observation time. The daily vertical settling fluxes, calculated based on mass balance, varied from 17.03 g/m^2 d to 56.86 g/m^2 d, which were lower than those obtained by the sediment trap (18.50–332.80 g/m^2 d). According to the analyzed results of the hydrodynamic data, when the current speed exceeds 0.20 m/s, the flow can penetrate the whole sediment trap and the bottom quiescent layer no longer exists. The horizontal flux plays an important role in the trap collection efficiency in strong tidal environments, which can lead to overestimation and a maximum value of 585% during the spring tide. A constant settling velocity (mean value during the observation) may underestimate the daily settling fluxes by approximately 22.28–51.80% during the neap tide and overestimate the fluxes by approximately 19.61–30.86% during the spring tide.

1. Introduction

Cohesive sediment can exist in four states of primary interest to engineers, which include erosion, transport, deposition and consolidation. Deposition processes involve sediment settling in a water column onto the seabed (Whitehouse et al., 2000). Knowledge of cohesive sediment settlement dynamics in coastal areas is important for determining the fate of suspended sediment adherent contaminants and rates of biogeochemical cycling (Schoellhamer et al., 2007). However, an accurate representation of cohesive sediment vertical settling fluxes is problematic. Sediment traps have been used extensively in recent years to study the vertical settling fluxes of suspended sediments in different environments, such as the deep ocean, glacial fjords, Antarctic area, submarine canyons, continental shelves, and tidal environments (Baker et al., 1988; Buesseler, 1991; Bale, 1998; Chen et al., 1998; Schloss et al., 1999; Zajaczkowski, 2002; Bonnin et al., 2002; Buesseler et al., 2007; Honjo et al., 2008; Owens et al., 2013), and signatures of storms, terrestrial floods, and tidal effects were identified (Kerfoot et al., 2004; Huh et al., 2009; Liu et al., 2009; Xu et al., 2010). However, sediment traps have several possible sampling biases, such as hydrodynamic issues, swimmer effects and sample solubilization (Buesseler et al., 2007), of which, the hydrodynamic issue is the most important because it is caused by horizontal flow over the mouth of the trap and trap motion that may lead to the under or over sampling of sinking particulate materials (Gardner, 1985; Gust et al., 1996; Buesseler et al., 2007). The role of the horizontal flux is more important in tidal environments (Bale, 1998). Although previous studies demonstrated

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that flow velocity can have an effect on the collection characteristics of sediment traps (Butman, 1986; Hawley, 1988; Gust et al., 1996; Bale, 1998), uncertainty remains regarding how the particle accumulation process in a trap links *with in situ* sediment dynamic processes, such as the flow velocity, suspended sediment concentration (SSC), and particle settling velocity, due to a lack of equipment deployed to measure related sediment dynamic processes synchronously with sediment traps.

Laboratory tests revealed that the settling processes of cohesive sediment are governed by the bottom shear stress, near-bed suspended sediment concentration (SSC) and settling velocity (Krone, 1962; Wolanski et al., 1992). Deposition occurs when the bottom shear stress is less than the critical shear stress for deposition (Krone, 1962) and most of the cohesive sediment settles as flocs (Kranck and Milligan, 1992), which control the settling velocity of the suspended sediments. Because the flocs are very fragile and usually break apart upon sampling and laboratory analysis (Bale and Morris, 1987), *in situ* observations must be undertaken (Voulgaris and Meyers, 2004; Wang et al., 2010). With the advance of acoustic techniques for field applications, Acoustic Doppler Velocimeters (ADVs) can be used to rapidly and synchronously measure the current velocity, SSC and settling velocity (Fugate and Friedrichs, 2002; Voulgaris and Meyers, 2004; Maa and Kwon, 2007).

The purpose of this study was to evaluate the possible biases of a sediment trap used in a semi-enclosed embayment with a strong tidal current and to discuss the importance of horizontal sediment fluxes on the vertical flux measurement based on half-month continuous and synchronous *in situ* data measured by a Multi-Sediment Trap and an ADV.

2. Study area

The Luoyuan Bay, located in the north Fujian coast, is sheltered from the East China Sea by the Luoyuan and Huangqi Peninsulas (Fig. 1). The width of the bay entrance is only 2 km. Rocky, sandy, muddy, mangrove and artificial coasts are distributed extensively in the bay. The total area of the bay is approximately 230 km^2, the area at spring low tidal level is approximately 105 km^2, and the area of intertidal flat is approximately 125 km^2 (Cai and Cai, 1989). A semidiurnal tide dominates this bay, with a mean tide range of 4.98 m. Currents have a mean flood tide period of 6 h 21 min and an ebb tide period of 6 h 4 min (State Oceanic Administration, 1994). According to an *in situ* investigation (Wang et al., 2010), an extensive intertidal flat covered by muddy sediment is located at the southwestern and southern Luoyuan Bay and is >3 km wide, with a low gradient of 0.13%; the sediment is mainly clay silt, and the zonation of geomorphology is not obvious.

3. Materials and methods

3.1. In situ measurements

A field investigation from an anchored vessel (26°23′22.37″N; 119°42′06.87″E) was conducted between January 16–31, 2010 (from spring to neap and to spring tide), on the sub-tidal flat (Fig. 1). A sediment trap with 24 collecting cups, dimensions of 0.8 m × 0.8 m × 1.0 m and a diameter of 16 cm (Advanced Version, a product of HYDRO-BIOS) was deployed at 1 mab (meter above the bed). The sediment trap was programmed to have sampling intervals of 24 h for each cup. A miniature pressure sensor (MkV/D,

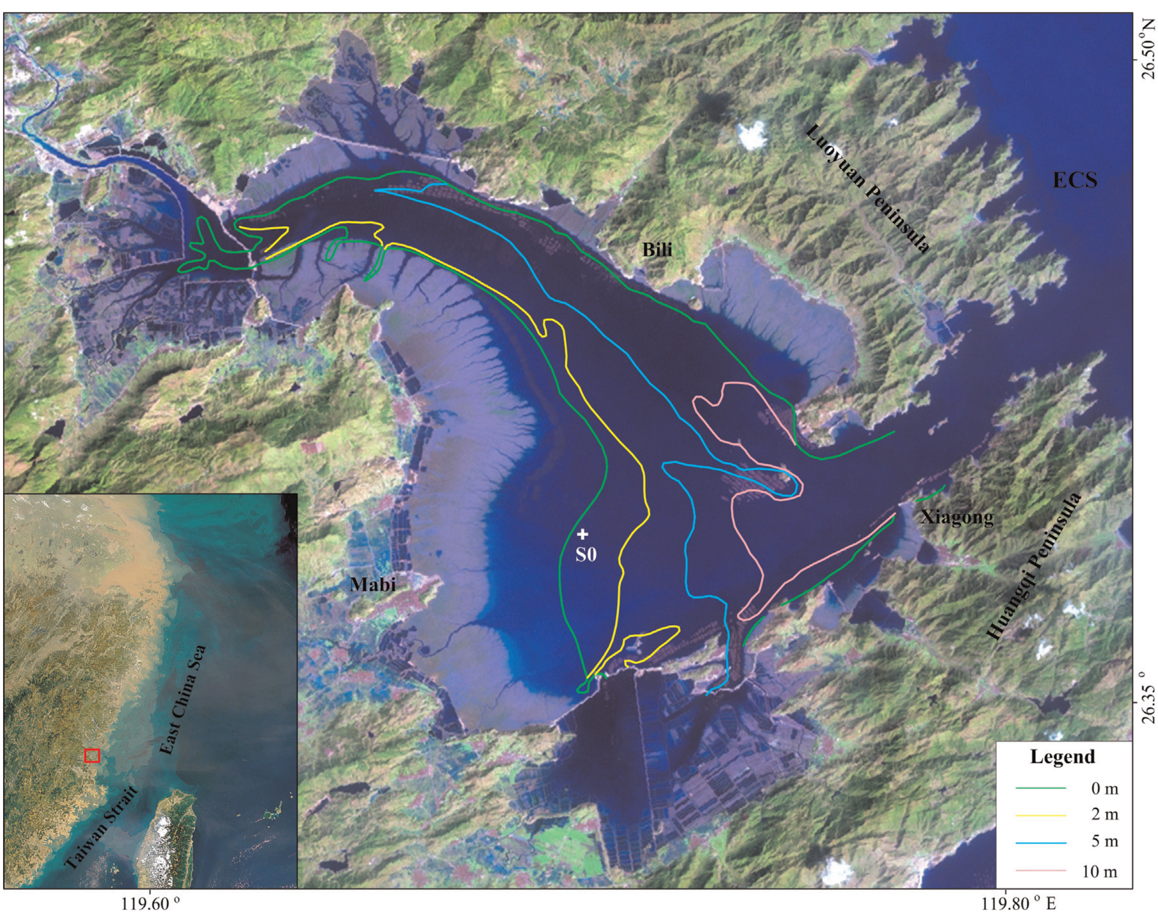

Fig. 1. Sketch map of location and observation site.