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Research papers

Observations of cohesive sediment behaviors in the muddy area of the northern Taiwan Strait, China

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A B S T R A C T

To study cohesive sediment behaviors and their time-variability in the near-bottom layer in the muddy area of the northern Taiwan Strait (TS), a short-term bottom-mounted tripod, which was equipped with an acoustic Doppler velocimeter (ADV), an upward acoustic Doppler current profiler (ADCP) and a CTD with a Seapoint turbidity sensor, was deployed at the northern TS over seven days between July 22 and 29, 2012. The near-bed current velocity, wave orbital velocity, bottom shear stress induced by wave and current, near-bed suspended sediment concentration (SSC) and variations in the bed elevation were resolved. The observation results indicate that the most important semidiurnal constituent at the northwest TS is M_2 and that the near-bed (0.7 mab) current speed showed spring-neap cyclic characteristics, with a maximum value of 0.453 m/s. Additionally, the water flowed in acounter-clockwise rotary current pattern. The weather was fair during the observation, and the significant wave height ranged from 0.60 m to 1.81 m, which generated an extremely low wave orbital velocity (the maximum value was 0.128 m/s). The near-bed SSC estimated from the signal-noise ratio recorded by the ADV ranged from 1.48 mg/L to 74.95 mg/L. The relation between the bottom shear stress and the SSC suggested that the local sediment resuspension is primarily controlled by a tidal current and that the wave action was practically negligible during the observation. The resulting net near-bed horizontal transport flux was 1387.59 kg/m^2 during the observations, dominated by the along-shelf flux (approximately 3.74 times than cross-shelf flux) and directed toward the NNE. The bed elevation revealed that the mean value of the erosion and deposition depth during a tidal cycle could reach 14.8 mm in an intermediate tide, with a maximum value of 17.9 mm; the net effect during the observation was erosion, with a depth of 0.4 mm.

1. Introduction

In the context of biogeochemical cycling, particularly organic carbon, there has been special recent interest in the ocean margin. Uncertainties in exchanges in the ocean margin are comparable with uncertainties in global budgets. To resolve these uncertainties, as well as to determine whether the continental shelf and slope act as a "sink", the following near-bed conditions are examined: advective fluxes, transport, settling and resuspension (Huthnance et al., 2002; Couceiro et al., 2013). The dynamic process of the near-bottom sediment is important for determining the transport and fate of terrestrial particulate matter discharged into the coastal seas. Previous studies have indicated that there are three distinct mud deposits in the East China Sea (ECS) due to the amount of terrestrial materials discharged by the Yellow River, the Changjiang River and other small mountainous rivers distributed along the Zhejiang-Fujian coast (Milliman et al., 1985; Hu and Yang, 2001; Liu et al., 2006; Xu et al., 2012). Although terrestrial sediment enters the coastal area, the fate of this bulk sediment is largely controlled by shelf circulation, mass movement, the coastal current, upwelling and by some extreme weather events. The relation between near-bottom sediment dynamic processes and the sediment record is unclear, and this relation remains a scientific problem to be solved in the future (Gao, 2010). Moreover, the near-bottom sediment dynamic processes and associated mechanisms are complex and are controlled by processes of different time and space scales (Sternberg and Nowell, 1999). Thus, observations of sediment behaviors are required to understand the evolution of the inner-shelf mud center.

The Taiwan Strait (TS) is located between the East China Sea (ECS) and the South China Sea (SCS) and forms part of China's continental shelf. The deposited sediment at the northern TS is cohesive sediment, which originates from the Changjiang River, small mountainous rivers along the Zhejiang-Fujian coast, and

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from Taiwanese river discharges (Liu et al., 2008; Xu et al., 2009; Huh et al., 2011; Horng and Huh, 2011; Xu et al., 2013). However, most previous studies focus on the sediment source and depositional sequence, and the near-bottom hydrodynamics associated with sediment dynamic processes in the northern TS have hardly been measured. Additionally, no research in the northern TS has focused on the near-bed suspended sediment transport, mud deposit and bed erosion processes at a microscopic scale or on associated controlled mechanisms. However, near-bottom hydrodynamics and sediment transport observations have been performed on many continental shelves in the world (Sternberg et al., 1985; McPhee et al., 1998; Vangriesheim et al., 2001; Martin et al., 2008; Yuan et al., 2008).

This paper reports the results of an investigation of the near-bottom current and bottom sediment transport in northern TS and discusses the variation in cohesive sediment behaviors associated with hydrodynamic processes.

2. Methodology

2.1. Site description

The Taiwan Strait (TS) is located between the East China Sea (ECS) and the South China Sea (SCS) and forms part of China's continental shelf (Fig. 1). The strait is generally shallower than 60 m, except over the deep Penghu Channel in the southeastern corner. The TS plays an important role in the water exchange between the ECS and the SCS, and the net mean volume transport from the TS to the ECS is approximately 1.8×10^6 m^3/s and 1.0×10^6 m^3/s based on the shipboard ADCP data and numerical modeling, respectively (Wang et al., 2003; Wu et al., 2007). The circulation in the TS and its temporal and spatial variations are modulated by strong monsoon forcing and by complex topography. The entire TS is dominated by northeastward currents in summer, and controlled by three currents (Zhe-Min coastal current, the Kuroshio intrusion and the extension of the SCS Warm Current) in winter (Jan et al., 2002). There are four main upwelling areas in the TS. The first two are wind-driven, with topographic forcing upwelling areas near Dongshan and Nanao in the southwestern TS and near Pingtan in the northwestern TS, where upwelling occurs during the summer monsoon; the other two are the topographically induced upwelling areas near the Taiwan Bank and around the Penghu Islands (Chen et al., 1982; Hu et al., 2003). Upwelling is a predominant feature in the TS and shows dynamic short-term, seasonal and interannual variations (Hong et al., 2011). Apart from the circulation of the water mass at greater spatial and temporal scales in the TS, the tidal current also plays an important role in the hydrodynamics and in the sedimentation dynamics in estuarine, coastal and shelf environments, and the semidiurnal M_2 tide is by far the most predominant one (Wang et al., 2003). The surface sediment of the northern TS is primarily composed of silt and clay (Xu et al., 2013).

2.2. Field data collection

A bottom boundary layer (BBL) tripod was deployed in the northern Taiwan Strait at a 40 m depth (Fig. 1). The measurements started at 16:00 h on 22 July 2012 and ended at 15:00 h on 29 July 2012, covering a spring-neap tide cycle. The instruments mounted in the tripod included two acoustic Doppler velocimeters (ADVs, produced by Nortek, 6 MHz Nortek Vector) and a CTD (SBE 19+, produced by Seabird, equipped with a Seapoint turbidity sensor). Because the ADVs can measure flow velocities without a calibration and disturbance before the transducer (approximately 0.15 m), one was placed at 0.85 m above the bottom (mab) to measure the velocity at 0.7 mab, and another was mounted at 0.4 mab to measure the velocity at 0.25 mab and seabed variations. The SBE19+, equipped with a Seapoint turbidity sensor (optical backscatter sensor), was mounted at 0.7 mab to measure near-bed water turbidity. Additionally, an upward-looking acoustic Doppler current profiler (ADCP, produced by R & D Instruments, 600 kHz workhouses) is located at 1.8 mab. These instruments were programmed to sample every hour. According to the particle size analysis of the surface sediment collected during the observation, the sand, silt and clay contents were 9%, 75% and 16%, respectively, with a median grain size of 11.8 μm.

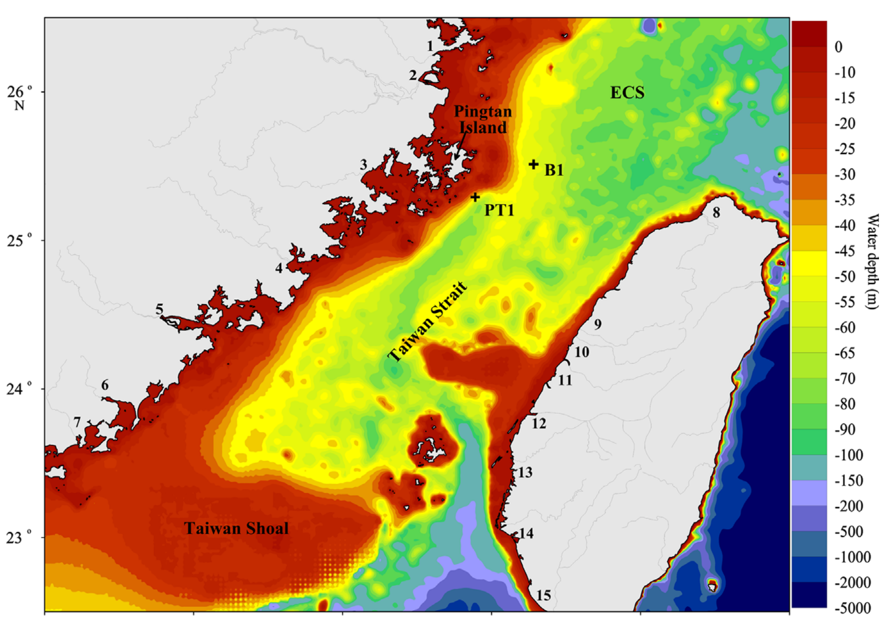

Fig. 1. Map showing the observation site, the bathymetry of the Taiwan Strait, and rivers on both sides of the strait. Rivers near the Taiwan Strait are: (1) Aojiang, (2) Minjiang, (3) Mulan, (4) Jinjiang, (5) Jiulongjiang, (6) Zhangjiang, (7) Hanjiang, (8) Tanshui, (9) Taan, (10) Tachia, (11) Wu, (12) Choshui, (13) Peikang, (14) Tsengwen, and (15) Gaoping.