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Reprint of Mechanisms of maintaining high suspended sediment concentration over tide-dominated offshore shoals in the southern Yellow Sea☆

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ABSTRACT

An understanding of the dynamics and behaviors of suspended sediments is vital in analysis of morphological, environmental, and ecological processes occurring in coastal marine environments. To study the mechanisms of maintaining high suspended sediment concentrations (SSCs) on a tide-dominated offshore shoal, we measured water depths, current velocities, SSCs, wave parameters and bottom sediment compositions in the southern Yellow Sea. These data were then used to calculate bottom shear stresses generated by currents (τ_c), waves (τ_w), and wave–current interactions (τ_{cw}). SSCs time series exhibited strong quarter-diurnal peaks during spring tides, in contrast to the semidiurnal signal during neap tides. A Fourier analysis showed that suspended sediment variations within tidal cycles was mainly controlled by resuspension in most stations. There existed relatively stable background SSCs (maintaining high SSCs among tidal cycles) values at all four stations during both windy (wind speed $>$ 9.0 m/s) and normal weather conditions (wind speed $<$ 3.0 m/s). The background SSCs had strong relationship with spring/neap-averaged τ_{cw}, indicating background SSCs were mainly controlled by mean bottom shear stress, with a minimum value of 0.21 N/m^2. On account of the strong tidal currents, background SSCs of spring tides were greater than that of neap tides. In addition, on the base of wavelet, statistics analyses and turbulence dissipation parameter, background SSCs during slack tide in the study area may be maintained by intermittent turbulence events induced by a combined tidal current and wave action.

1. Introduction

An understanding of the behavior of fine sediment suspension is fundamental to biological, chemical, and engineering issues in coastal areas. For instance, as carriers of pollutants and nutrients transported from land sources, marine sediments affect both pollutant diffusion and the ecological preservation in coastal regions (Bass et al., 2002; Wang and Pinardi, 2002). Suspended sediment at the sea surface can strongly hinder sunlight penetration into the water column, thus limiting the growth of pelagic phytoplankton-like organisms in subsurface waters (Vichi et al., 1998). Coastal sediment dynamics involve two physical processes: advection and local processes of erosion and deposition. Advection transports sediments away from input sources, while local processes involve sediment exchange between the seabed and the water column. This vertical sediment flux is governed by sediment settling as well as by turbulence-generated diffusivity in the boundary layer, when shear velocity is stronger than a critical threshold value for resuspension (Wang and Pinardi, 2002; Yu et al., 2012).

Radial sand ridges (RSRs) in the southern Yellow Sea are an important type of continental shelf sand body that occurs in the Jiangsu coastal region (Li et al., 2001; Ni et al., 2014). The RSRs are located between the abandoned Yellow River Delta to the north and the Changjiang Delta to the south, and waters in the area are some of the most turbid in coastal China (Wang et al., 2011; Xing et al., 2012). The

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mechanisms of turbidity maximum (vertical circulation, tidal pumping and resuspension) have been widely researched in estuaries (Yu et al., 2014), while in open coast sea such as Jiangsu coast, the concept of turbidity maximum (also refers to high suspended sediment concentrations (SSCs)) was first mentioned by Wang et al. (2011), and the detailed controls maintaining the high SSCs have not been fully investigated by far in view of deficiency of the observation data. In RSRs region, the M2 tide dominates tidal dynamics (Xing et al., 2012) and the maximum tidal range is 9.3 m (Ding et al., 2014). According to Liu et al. (1998), a radial current field is the major force driving the present-day geomorphology and depositional patterns in the area (Liu et al., 1998). Because of their importance in protecting coastline areas and their influence on navigation, the formation mechanisms and evolutionary processes of RSRs have been widely studied (Zhu, 2000, 2001; Zhu and Chang, 2001; Gao, 2009; Xing et al., 2012). However, the physical processes controlling the distribution and flux of sediments have been relatively less studied; an exception is Song et al. (2006), who revealed that SSCs in the southern Yellow Sea were higher in spring than in autumn. Wang et al. (2011) found that waves played a dominant role (over tides) in controlling sediment transport dynamics in the southern Yellow Sea; when wave effects were not considered, the area averaged surface SSCs was reduced by a factor of four. On the other hand, Xing et al. (2012) demonstrated that the main factor influencing the distribution of SSCs was tides, while the effects of river discharge, wind, and waves were relatively small and localized. During our field work, we found a relatively constant and high background SSCs value, independent of wind speed. As far as we know, considering the difficulty of field work, bottom tripod observations were not reported in RSRs area to measure the near-bed sediment dynamics (e.g. SSCs and velocity). Therefore, in the present study, by conducting *in situ* measurements of current and wave parameters between spring and neap tides, we set out to investigate the mechanisms of high suspended sediment concentrations over an offshore shoal in the southern Yellow Sea (Fig. 1). The paper is organized as follows. Section 2 describes the methods and techniques used for data collection and bottom shear stress calculation. The results are described in section 3. And a discussion of SSCs mechanism and background SSCs is introduced in section 4 with the final conclusion presented in section 5.

2. Methods

2.1. Data collection

From 27 September to 5 October 2014, *in situ* measurements were conducted at four tripod stations (d1, s1, d2, and s2) on an offshore shoal off the southern Jiangsu Coast (Fig. 1b). We collected velocity, SSCs (via acoustic backscatter of ADV), and depth data using tripod-mounted instrumentations. Each tripod was equipped with an Acoustic Doppler velocimeter (ADV) that was configured to capture data on currents and waves, by sampling at 16 Hz for 512 s every 10 min. The quality of the collected data was checked by examining vector correlations, the signal-to-noise ratio (SNR) of ADV and then by proper despiking to exclude outliers. The outliers were replaced by cubic interpolation (Goring and Nikora, 2002. Lu et al., 2012). Using the PUV (P: pressure; U: east-velocity; V: north-velocity) method (Wu, 1994; Sobey and Hughes, 1999; Gordon and Lohrmann, 2001), we extracted wave parameters (significant wave height, peak period and wavenumber) from the water pressure and current velocity data. To measure the bottom SSCs values, we established a calibration dataset between each physically measured SSCs sample (by water samples from the same height with ADV sampling) and averaged SNR values (Fig. 2; Salehi and Strom, 2012; Wei et al., 2013). In addition, sediment and water column data (e.g., bottom sediment samples, water samples) were collected from a ferry moored near the tripod stations. Details of the stations, including latitude/longitude, sensor elevations and deployment time, are listed in Table 1. During the field observations, weather data were collected from a wave buoy near the study area (Fig. 1a). The local wind speed was in the range of 2.8–18.1 m/s (average, 7.8 m/s). The wind direction changed from SE to NE on 29 September, coinciding with an abrupt increase in wind speed (Fig. 3). The grain size parameters of bottom sediments and water samples were analyzed using a Malvern Mastersizer 2000 laser granulometer (requiring sediment samples in the size range of 0.02–2000 μm). Finally, suspended sediment concentrations in water samples were measured by filtering through 0.45 μm filtration membranes (Wang et al., 2012).

2.2. Calculation of bed shear stresses

2.2.1. Current-related shear stress

To determine the shear stress related to currents, we applied a logarithmic velocity profile (LP) law, the Reynolds stress method (RS), and an inertial dissipation method (ID). The classical logarithmic LP law is expressed as follows (Soulsby and Dyer, 1981; Grant and Madsen, 1986; Soulsby and Whitehouse, 1997; Kim et al., 2000; Salehi and Strom, 2012):

$$u(z) = \frac{u_*}{\kappa}\ln\left(\frac{z}{z_0}\right) \tag{1}$$

where u_* is the friction velocity (m/s), κ is von Karman's constant (0.4), and z_0 is the bottom roughness length. Usually, a $u(z)$–$ln(z)$ least squares regression line is fitted to estimate the regression parameter u_*/κ. Because the velocity in the present study was measured at only a single point in the vertical dimension, u_* was determined by an iteration procedure according to Whitehouse et al. (2000), using the mean velocity $\bar{u}$ of the logarithmic velocity profile (LP-mean) or the maximum velocity $u_{\max}$ of the logarithmic velocity profile (LP-max) for each burst at a given point (Whitehouse et al., 2000; Andersen et al., 2007; Salehi and Strom, 2012; Yang et al., 2016a). The bed shear stress due to currents (τ_c) was then calculated based on the definition of the friction velocity (Van Rijn, 1993), according to

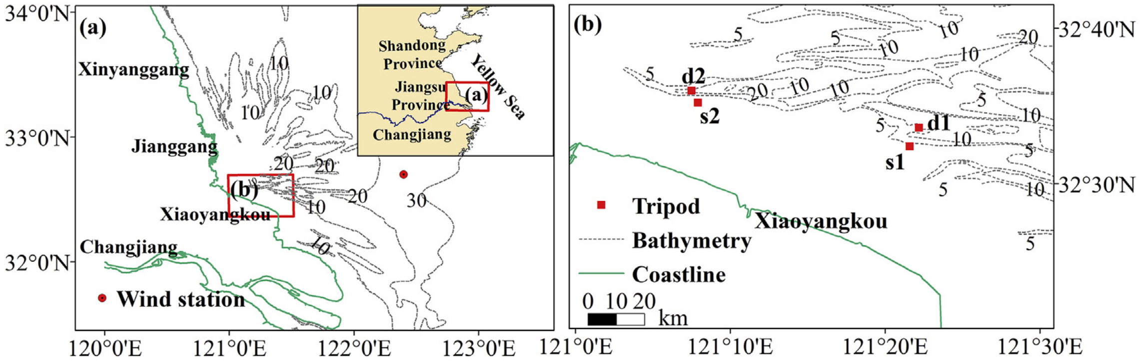

Fig. 1. Maps showing the study area: (a) location of the southern Yellow Sea, and (b) observation stations on the offshore shoal of RSRs.