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Simulating high ebb currents in the North Passage of the Yangtze estuary using a vertical 1-D model

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ABSTRACT

A strong maximum ebb current (>3 m/s) in the upper water column was observed at Station CS3 in the middle of the North Passage of the Yangtze River Estuary during the wet season, which was higher than either its upstream or downstream counterparts. To better understand the mechanisms and factors causing the strong ebb current, a vertical one-dimensional (1-D) model was used to conduct a diagnostic study. The model used time series of observed tidal amplitudes, vertical salinity, and suspended sediment concentration (SSC) profiles to compute the density and turbulence. Two tunable parameters, the tidal amplitude attenuation coefficient (i.e., the phase lag) and the background surface pressure gradient that represents the net pressure gradient induced by the freshwater discharge and baroclinic effect, were used to determine the best match with the observed high velocity amplitudes in addition to the bottom roughness height. Three hypotheses of possible causes are tested: (1) the large freshwater discharge, (2) the bottom stratification effects (which were caused by a possible high near-bed suspended sediment gradient), and (3) the unique location of the CS3 station that was influenced by local geometry. The findings show that neither of the first two factors has much influence on the pronounced ebb velocities. Instead, the energy loss caused by the change of channel geometry and a maximum convex bathymetry in the North Passage of the Yangtze River Estuary are the main reasons behind the extremely high observed ebb current velocity profiles. The high near-bottom SSC and gradient located within 0.5 m above the bed only slightly alters the velocity profiles. This 1-D model is convenient for testing a different hypothesis and for coupling with other selected variables to account for the floc size distributions in future studies.

1. Introduction

The Yangtze River (also known as Changjiang River) in China is one of the largest rivers in the world. The complex dynamics in the Yangtze River Estuary (YRE) are mainly controlled by the interaction of tide and river flow. The YRE is a mesotidal estuary with an annual average runoff of 9×10^{11} m^3 measured upstream at the Datong gauge station (1950–2010), and the mean tidal range measured at the Zhongjun tide-gauge station near the mouth is 2.66 m and the tidal range decreases further upstream (Mao et al., 2001; Shen et al., 2003; Zhu et al., 2016). In the last two decades, the estuary hydrodynamics and sediment transport were significantly influenced by various natural and anthropogenic activities, such as the river slope protection project, Three Gorges Dam and beach reclamation projects, and, especially, the Changjiang River Estuary Deepwater Navigational Channel (CDNC) project (Chu et al., 2013; Wan et al., 2014; Zhu et al., 2016; Dai et al., 2016). The CDNC project was constructed to improve the navigation capacity. It consists of building two along-channel training walls with multiple groins and a dredged deep channel in the North Passage (see Fig. 1(a)). The CDNC starts near the southwest end of Changxing Island, goes through the North Passage, and extends into the East China Sea. The construction of the CDNC took 12 years, from 1998 to 2010, and was divided into three phases (Jiang et al., 2013; Wan et al., 2014). Starting with this project, regular measurements of vertical profiles of salinity, Suspended Sediment Concentration (SSC), and horizontal velocity at selected locations along the

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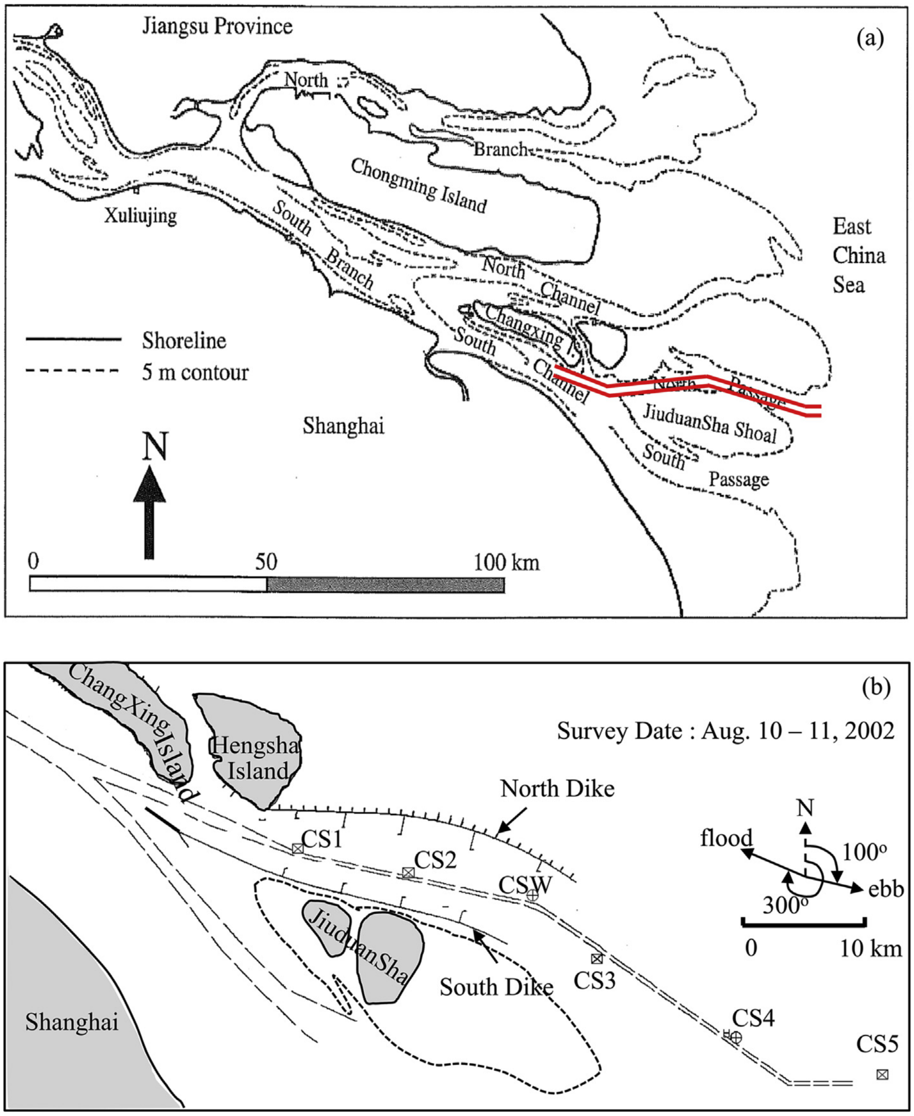

Fig. 1. Location map of (a) the Changjiang Deepwater Navigation Channel (CDNC, marked by the red lines) in North Passage of Changjiang River estuary and (b) measurement stations along the CDNC during the first phase construction period. The minimum channel depth is 8.5 m at this time, and only the constructed channel-parallel dikes are shown. The entire dikes, after completion, will extend to near Station CS5 with a channel parallel alignment. All the measurement stations are outside of the channel, and their depths may be different with that of the channel. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

designed channel in North Passage (Dai et al., 2013) were carried out by the Changjiang River Estuary Investigation Bureau of Hydrology and Water Resources, the Changjiang Water Resources Commission (CWRC) of China (Fig. 1(b)). At the early stage, velocity measurements were conducted by using a propeller-type of current meter at six fixed elevations in the water columns (i.e., 0.5 m below water surface, 0.2 h, 0.4 h, 0.6 h, 0.8 h, and 0.5 m above the bed, where h is the best-estimated local water depth during the survey period). Salinity and SSC were obtained by taking water samples from these six elevations, and measured in the laboratory. The bureau used several vessels for the measurements at different stations along the channel simultaneously. Each vessel has its own measurement of local water depth and the tidal range was estimated between high and low tides. The hourly measurements at each station were conducted for a period of 25 h. Later, the instrument for measuring current velocities was replaced by an ADCP (Acoustic Doppler Current Profiler), and an OBS (Optical Backscatter Sensor) unit was used to measure salinity and SSC. However, the observations were only at the six elevations due to limitation of the scope of the field works.

During the first CDNC construction phase, several field investigations showed that strong maximum ebb current velocities (i.e., >3 m/s) occurred near the upper water column in the vertical current profile during the wet season. To study the causes of the strong ebb velocity, we selected data collected during the spring tide on August 10–11, 2002 to demonstrate the observed high velocity profiles. During this survey period, the first phase of the CDNC project was nearly completed. Part of the north and south dikes (Fig. 1(b)) were constructed, the channel was dredged, and the mean water depth increased from 6 m to 8.5 m. The velocity profiles at the six stations of CS1,CS2, CS3, CSW, CS4, and CS5 along the North Passage (see Fig. 1(b) for relative locations) are available and have shown strong ebb currents, especially at Station CS3 where the maximum ebb current velocity larger than 3 m/s in the upper water column was observed. Strong current velocities will influence the resuspension, erosion, and deposition of suspended sediments. The large vertical gradient and its associated large shear rate will affect the floc size distribution, which is important to