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Non-flood season neap tides in the Yangtze estuary offshore: Flow mixing processes and its potential impacts on adjacent wetlands

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ABSTRACT

How flow mixing process influences the wetlands of the Yangtze Estuary is still poorly understood. Hydrological fieldwork was conducted on five vessel-anchored sites (S1-S2; M1-M2-M3) near the major wetlands of the Yangtze Estuary offshore (121°57′-122°30′E, 30°50′-31°23′N) on May 8-11 2004, to examine the dynamics of neap tides in the non-flood season of the Yangtze (~24, 700 m^3s^{-1} at Datong) and their impacts on adjacent wetlands. Based on the measurement of the acoustic Doppler current profiler (aDcp), direct-reading current meter and optical backscattering sensor (OBS-3A), two flow patterns were revealed: 1) well mixing flow pattern caused by the turbulent tidal currents, and 2) weak mixing flow pattern resulted by the estuarine circulation in the North Port of the estuary. The characteristics of such different flow patterns were analyzed and resultant sediment dispersals were discussed in relation to the adjacent wetlands. It is suggested that the estuarine circulation might be the important process to nourish the eastern wetland of the Yangtze Estuary which has been neglected before.

1. Introduction

Wetlands in the estuarine and coastal regions are the semi-enclosed areas at which impoundment of brackish water occurs periodically or permanently. It serves as an important aquatic ecosystem which is abundant in biodiversity for sustainability (Gray, 1997; Worm et al., 2006) and highly efficient in organic carbon storage for global carbon cycling (Fourqurean et al., 2012; Kirwan and Mudd, 2012). By trapping the sediment via the wetland plants (salt marshes, mangroves etc.), it protects the shoreline efficiently against the currents and waves and supplies the valuable land resource for human reclamation, recreation and engineering etc. (Goodwin et al., 2001; Möller et al., 2014; Woodroffe et al., 2016). Meanwhile, wetland environment has also been altered considerably by local and regional human activities in the past decades of years and such changes appear to threaten the future survival of wetlands (Bai et al., 2013; Cui et al., 2016). Therefore, huge needs are required to study the wetland development for better conservation and restoration from the aspects of multi-disciplinary sciences, from the management of sustainable development, and from the interests of socio-economics (cf. Cui et al., 2016).

China has tremendous coastal wetlands (~6×10^4 km^2 in area) along the tens of thousands kilometers long coastline. The Yangtze Estuary (YE), China, is one of largest tidally-influenced river mouth and huge sediment from the catchment nourishes massive wetlands (up to ~ 2500 km^2 in area) annually along the coastline (Tian et al., 2015). The wetlands are usually composed by the intertidal zone and subtidal zone, and practically defined in bathymetry chart as the zone from the surface to isoline of 5 m (Yang et al., 2006). It coincides partially with the delta front region of the YE, which includes: 1) Chongming Eastern shoal, 2) Hengsha Shoal, 3) Jiuduansha shoal, and 4) Nanhui shoal, from the north to the south (Fig. 1; Yang et al., 2006). Since 1980s, these wetlands serve as valuable resources supporting the economic blossom of the megacity, Shanghai. However, like many coastal places facing intensive human interference (Bai et al., 2015; Zhang et al., 2016), these wetland regions are suffering similar survival problems like the pollution, the biodiversity reduction etc. during the rapid economic development (Bai et al., 2013; Cui et al., 2016). Thus, the wetlands of the YE provide a good example to examine how the wetlands could be conserved under the heavy anthropogenic pressures (Cui et al., 2016).

Sediment is the fundamental element to maintain the wetlands

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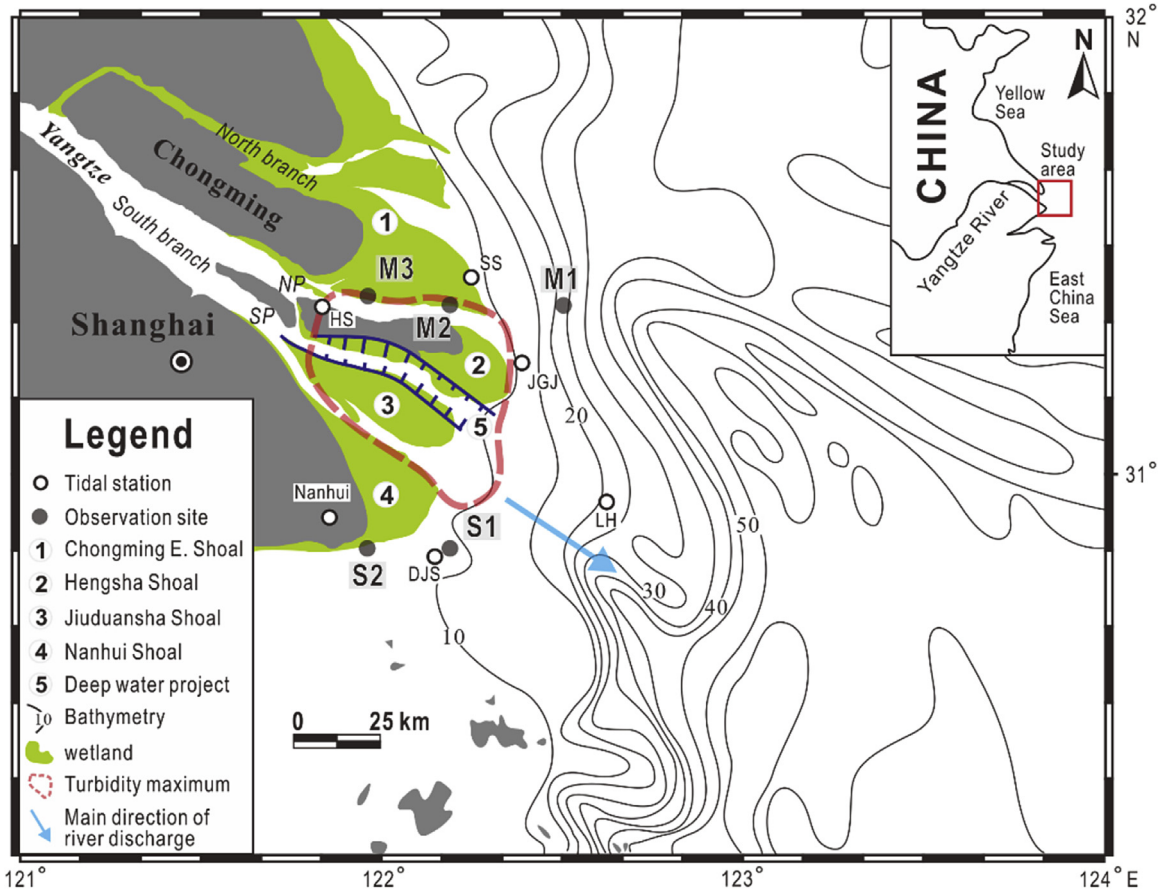

Fig. 1. Bathymetry of the Yangtze estuary and observation sites in the study area. The wetlands are referred to 2004 (Yang et al., 2006). The approximated turbidity maximum is after the works of Shen and Pan (2001).

in the estuarine and coastal regions. Its dispersal is always linked tightly with the flow mixing processes in such environments. (cf. Valle-Levinson, 2010). Stratification is the important index of flow mixing in the estuaries, which occurs due to large density gradient in the vertical (Geyer et al., 2000). When it develops fully, collapse of flow turbulence will occur and cause rapid sediment settling. With the development of the estuarine stratification, an estuarine scale exchange flow, i.e., estuarine circulation, occurs subtidally between the river inlet and the sea side (Geyer and MacCready, 2014). Such circulation is vitally important for the dispersal of sediment and nutrients across the estuary (Geyer et al., 2000; Becherer et al., 2011), for the salt exchange between river and ocean (Geyer and MacCready, 2014) and for the turbidity maximum development etc. (Shen and Pan, 2001). However, how the estuarine circulation is linked with the wetland conservation is not well studied.

Furthermore, intensive human activities (forestation, impoundment etc.) of the Yangtze catchment ongoing for the decade of years have caused the sediment flux into the sea to decrease from ~400 million tons per year in 1980s to <200 million tons per year in 2000s (Yang et al., 2011). In response, the YE has been suffering erosion in its delta front, especially since 2000s (Li, 2012). Interestingly, the wetland region of the YE (<5 m in depth) does not show significant changes during the same periods (Cai and Zhou, 2014; Tian et al., 2015), implying some physical nourishing processes should trigger in and help maintain the wetlands. Hence, related works trying to solve this puzzle have been conducted to examine: 1) sedimentation responses of wetlands to the human activities within the Yangtze catchment (Yang et al., 2006, 2011; Dai et al., 2014), 2) hydro and sediment dynamics caused by the wetland plants (Yang, 1998; Yang et al., 2012), and 3) morphological processes inside the wetland (Fan et al., 2004; Fan, 2013). Considering the extremely large scale of the estuary and the complicated hydro-sediment dynamics, it is still difficult to identify the exact physical process responsible for the wetland development and more works are still required.

This paper presents another systematic deployment of hydrological fieldworks near the major wetlands of the YE (i.e., Chongming Eastern Shoal, Hengsha Shoal and Nanhui shoal; Fig. 1), to examine the dynamics of flow, sediment, salinity and temperature during the neap tides in non-flood season. We have summarized the two patterns of flow dynamics: 1) one is dominated by the well mixing of tidal currents; 2) the other is related to the occurrence of weak mixing process, i.e., the estuarine circulation due to the stratification. We analyze theoretically the mechanism of stratification and the development of estuarine circulation, discuss the sediment dispersal of these mixing flows and its impacts on the wetlands. We finally suggest the estuarine circulation could potentially nourish the adjacent wetlands, which is neglected in the previous studies.

2. Field data collection and processing

Hydrologic survey of neap tides was performed at five vessel-anchored sites in the YE (M1-M3, S1-S2; Fig. 1 and Table 1) on May 8 (05/08) to May 11 (05/11), 2004 when the Yangtze River

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