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Remotely sensed variability of the suspended sediment concentration and its response to decreased river discharge in the Yangtze estuary and adjacent coast

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ABSTRACT

Satellite observation is an excellent tool for exploring the variability of the suspended sediment concentration (SSC) of turbid estuarine and coastal waters. We used a recently developed semi-empirical radiative transfer model combined with a multi-wavelength switching algorithm for the SSC retrieval from MEdium Resolution Imaging Spectrometer (MERIS) satellite data. This method can successfully retrieve SSC from satellite data in turbid estuarine and coastal waters with a wide range of sediment concentrations (20–2500 mg l^{-1}) and is robust for quantifying realistic patterns of the surface sediment dynamics. The seasonal and annual variability of the MERIS-derived SSC from 2003 to 2010 were analysed in this work. Five regions-of-interest (ROIs) in the Yangtze estuary and coast are included in the analysis: the upper estuary, the lower estuary, the outer estuary, the Hangzhou Bay and the Qidong shore. The results reveal that the SSC of the upper estuary has significant seasonal and annual variations in response to seasonal cycling and annual fluctuation of the river discharge. A long-term continuing decrease of river discharge may cause an overall decline of the SSC in the entire estuary and adjacent areas. The existence of horizontal exchanges of the sediments between the Yangtze estuary and the Jiangsu coast implies that the decreased fluvial sediment loads of the estuary may partially be compensated by supplementing contributions from other origins.

1. Introduction

River discharge and sediment loads play an important role in deltas, estuaries and coasts. Analyses for 33 global deltas (Vermaat and Eleveld, 2013) showed that river discharge decrease and storm surge, rather than sea level rise, may be the main reasons of land loss and flooding risk in coastal areas. The Yangtze River is the longest river in Asia and one of the largest in the world due to its enormous runoff and sediment loads. However, the sediment delivery into the Yangtze estuary (Fig. 1) has been dramatically reduced since the last decade. The annual average sediment delivery was approximately 400 million tons yr^{-1} from the 1950s to 2000. After 2000, the sediment delivery decreased to less than 200 million tons yr^{-1} and to less than 100 million tons yr^{-1} during the extreme 2006 drought, according to statistical data (the Sediment Bulletin of the Yangtze Water Resources Commission) (Fig. 2).

A decrease in river discharge over a long period would change sediment fate and budgets in the estuary and coastal waters, leading to variation in deposition and erosion processes. Li et al. (2007) reported that the sedimentation rate of the Yangtze coastal delta has begun to decrease and that −10 m isobaths in the delta have begun to undergo scouring. Consequently, the maintenance of estuarine and coastal facilities, such as the Yangtze estuarine reservoirs, the tunnel that links Chongming Island to Shanghai and deep-water navigation channels, may be affected.

The recently increasing research interest in this area has been inspired by a need to assess the impact of the Three Gorges Dam (TGD) on the estuarine system. The TGD has induced a decrease in sediment loads, accounting for approximately 25% of the overall sediment decrease (Yang et al., 2007). However, the variability of the suspended sediment concentration (SSC), which is closely associated with the reduced river discharge, on a spatially large and temporally long scale, has been poorly quantified. Historically, this variability has not been confidently estimated because of the cost of conventional ship-point samplings, technical limitations and adverse environmental conditions.

Satellite ocean colour sensors facilitate the approximately daily observation of the concentration and distribution of suspended sediment over a large area and in the long term, which is not possible with other data sources. Satellite ocean colour sensors such as the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), the MODerate-resolution Imaging Spectroradiometer (MODIS) and the MEdium Resolution Imaging Spectrometer (MERIS) have shown the ability to quantify water components and their concentrations

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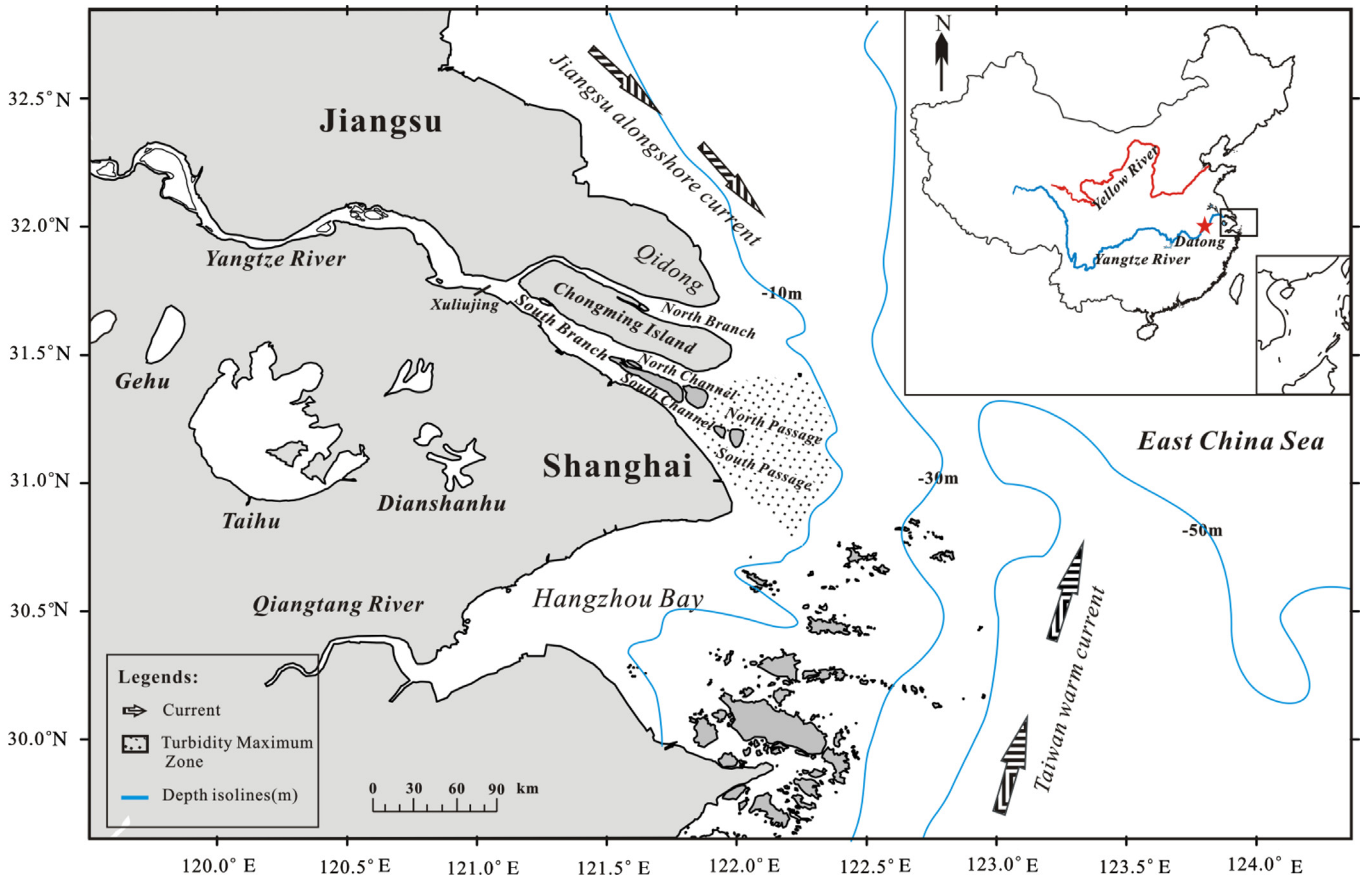

Fig. 1. A geographic map of the study area. A three-order bifurcation in the Yangtze estuary forms the South and North Branches, the South and North Channels and the South and North Passages. The Xuliujing site is situated in the estuary head. The grey area denotes land. The empty area indicates water.

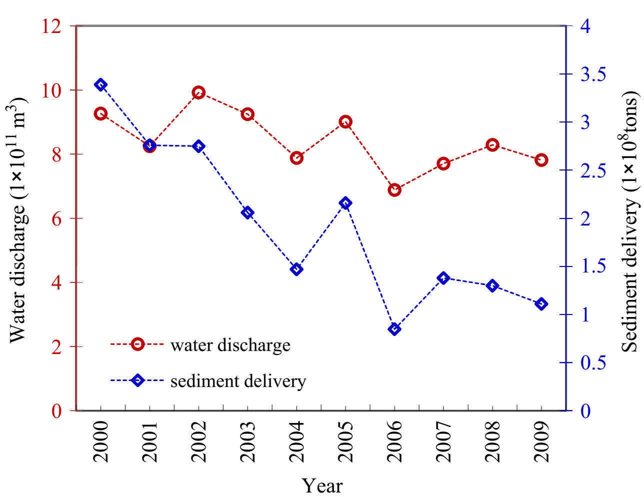

Fig. 2. Averaged fresh waters discharge (in m^3) per year and sediment delivery (in tons) per year recorded by the Datong hydrological station (the closest station to the Yangtze Estuary) from 2000 to 2009.

in estuarine and coastal waters (Doxaran et al., 2002; Kratzer et al., 2008; Menon et al., 2006; Shen et al., 2010; Salama and Shen, 2010; Warrick et al., 2004). However, current standard algorithms of SSC retrieval have a limited applicability to highly turbid waters, such as the Yangtze estuarine waters. Recently, we proposed a novel algorithm for SSC retrieval over turbid waters using MERIS satellite data (Shen et al., 2010). This algorithm is based on a semi-empirical radiative transfer (SERT) model combined with multi-wavelength switching for high-sensitivity reflectance to determine the SSC variation with a wide range, between 20 and 2500 mg l^{-1}.

The spatio-temporal distribution of the SSC exhibits high variability in estuaries that are situated in a dynamic interface between terrestrial and oceanic environments. The low frequency of polar-orbiting satellite revisits and the high frequency of cloud cover in coastal areas only allow us to explore the seasonal variability of the SSC. The objective of this work is to quantify and analyse the seasonal and annual variability of SSC through MERIS satellite observations from 2003 to 2010 and to determine how the SSC magnitude and distribution have changed in the last decade in response to the decrease of river discharge in the Yangtze estuary. The results will contribute to a better understanding of the sediment fate and dynamics in the Yangtze estuary and coastal waters and will help in predicting the evolution of the Yangtze estuarine and coastal system.

2. Materials and methods

2.1. In situ data

There is a three-order bifurcation in the Yangtze estuary that consists of the South and North Branches, the South and North Channels and the South and North Passages (Fig. 1). The estuary has four outlets. The Xuliujing site is located in the estuary head. The South Branch is situated in the upper estuary and the South Passage in the lower estuary. We organised seven ship-based surveys in the Yangtze estuary and neighbouring Hangzhou Bay during February 2003, February and September 2004, June to August 2005, February and March 2006, February and September