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A three-band semi-analytical model for deriving total suspended sediment concentration from HJ-1A/CCD data in turbid coastal waters

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ABSTRACT

The accurate assessment of total suspended sediment (TSM) concentration in coastal waters by means of remote sensing is quite challenging, due to the optical complexity and significant variability of these waters. In this study, three-band semi-analytical TSM retrieval (TSTM) model with HJ-1A/CCD spectral bands was developed for the retrieval of TSM concentration from turbid coastal waters. This model was calibrated and validated by means of one calibration dataset and three independent validation datasets obtained from three different turbid waters. It was found that the TSTM model may be used to retrieve accurate TSM concentration data from highly turbid waters without the spectral slope of the model requiring further optimization. Finally, the TSM concentration data were quantified from the HJ-1A/CCD images after atmospheric correction using the dark-object subtraction technique. Upon comparing the model-derived and field-measured TSM concentration data, it was observed that the TSTM model produced <29% uncertainty in deriving TSM concentration from the HJ-1A/CCD data. These findings imply that the TSTM model may be used for the quantitative monitoring of TSM concentration in coastal waters, provided that the atmospheric correction scheme for the HJ-1A/CCD imagery is available.

1. Introduction

Total suspended sediment matter (TSM) in coastal waters plays an important role in biogeochemical cycles in estuarine ecology, due to the fact that the fine-grained particles are an important carrier of various chemical compounds (Turner and Millward, 2002). TSM concentrations in estuaries are strongly affected by a combination of hydrodynamic physico-chemical and biological processes. Understanding the spatial and temporal dynamics of TSM in estuarine environments can allow for the estimation of the transport of terrestrial and anthropogenic materials to pelagic oceans. In addition to these, the interaction between TSM and seawater may strongly modify the nutrient concentration in estuarine systems (Chen et al., 2012a). These processes can rapidly alter the optical properties of coastal waters and their impacts can be clearly observed by water color. However, coastal regions are ecosystems with quickly hydrodynamics where events and processes operate over short time and small space scales, usually causing conventional station samples to be insufficient for the purpose of mapping patterns, thus new observational methods with the capability to rapidly sample at high resolution are needed. Fortunately, the recent advances in optical sensor technology have allowed scientists to utilize ocean color satellite images to synoptically investigate large-scale TSM concentration in coastal zones (Chen et al., 2013e).

Numerous works have demonstrated that remotely sensed data can be used to retrieve TSM concentration from turbid coastal waters (Miller and Mckee, 2004; Nechad et al., 2010; Ouillon et al., 2008). Many TSM models based on empirical methods have been used in operational satellite remote sensing systems. These models were developed on the basis of statistical relationships between TSM concentrations and single-channel or multi-channel reflectance (Aguirre-Gomez, 2000; Tassan, 1997). For example, the single waveband reflectance in the green–red regions has been proposed in the Delaware Bay (Stumpf and Pennock, 1989), Biscay Bay (Aguirre-Gomez, 2000), Hangzhou Bay (Wang et al., 2008), and Irish Sea (Bowers et al., 1998), with varying degrees of success. However, the exact form of the relationship between TSM and reflectance also depends on the mineralogy, color, and particle

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scattering properties (incorporating particle size distribution and refractive indices) (Bing et al., 2005; Bowers and Binding, 2006). These factors can be highly variable in natural aquatic environments, and therefore the applicability of an empirical model is generally assumed to the setting in which the data were collected (Long and Pavelsky, 2013). More recently, the ratio of the red to NIR bands might be effectively applied to retrieve TSM concentration from satellite images (Doxaran et al., 2002; Doxaran et al., 2009; Min et al., 2012). It was suggested in these studies that the variability in reflectance resulting from changes in particle characteristics could be avoided by using the band ratio model (Bing et al., 2005; Doxaran et al., 2002; Moore et al., 1999).

Although these empirical models may be effectively applied to satellite images concurrent with the calibration dataset, their accuracy may be reduced outside the conditions of the calibration dataset because of the empirical basis (Nechad et al., 2010). Fortunately, a semi-analytical model which combines physical methods with statistical methods can overcome these limitations of empirical models, and thus may become a promising technique for TSM concentration retrieval (Chen et al., 2013a; Long and Pavelsky, 2013; Ouillon et al., 2008). Over the past several years, semi-analytical models have been established by many authors based on the relationship between the absorption or scattering properties and TSM concentration (Aguirre-Gomez, 2000; Chen et al., 2013a; Onderka and Pekarova, 2008; Ondrusek et al., 2012). Due to the fact that radiance scattered from particulate particles is generally the first-order determinant for variability in reflectance in coastal waters, the backscattering coefficients can be used to estimate the TSM concentration (Bowers and Binding, 2006; Volpe et al., 2011; Zawada et al., 2007). In addition, if the absorption coefficient of particles can be isolated from the apparent optical properties using an analytical model, it can then be used to quantify the TSM concentration (Binding et al., 2008; Bowers and Binding, 2006; Neukemans et al., 2009; Tassan and Ferrari, 2003). However, although these models may be effectively applied to satellite images concurrent with calibration datasets, some problems are encountered when they are applied to the turbid coastal waters of China. For example, when the TSM models proposed by Doxaran et al. (2009), Miller and Mckee (2004), and Fettweis et al. (2007) were applied to process satellite data in the Oujiang River Estuary, the values of the retrieved TSM concentrations were all less than 40 mg/l. Therefore, due to the optical complex in the coastal waters of China such as the Ouijang River Estuary, Changjiang River Estuary, and Bohai Sea, an innovative regional semi-analytical model is required, and such a model is still under development.

In this study, a three-band semi-analytical TSM retrievals model (TSTM) was developed for deriving TSM concentration from HJ-1A/CCD data in turbid coastal waters. The specific goals of the study are as follows: (a) to evaluate the accuracy of four existing models for accurately estimating TSM concentrations in turbid coastal waters; (b) to improve the performance of four exiting models by a proposed TSTM model with the spectral bands of HJ-1A/CCD sensor; and (c) to compare the accuracy of three existing models and TSTM model in estimating TSM from highly turbid and productive coastal waters in China.

2. Study area

The Oujiang River Estuary (Fig. 1) is located between longitudes 120°48′E and 121°32′E, and latitudes 27°36′N and 28°12′N, near the center of Wenzhou City, Zhejiang Province, a location which is well known in China for its rapid economic development over the past two decades. The optical properties of coastal waters such as the Oujiang River Estuary are vital to local human activities and needs, and play a critical role in the regional ecosystem, which may also impact climate changes. Due to the rapid economic development and population growth in this region, enormous quantities of nutrients and other pollutants have been transported from land

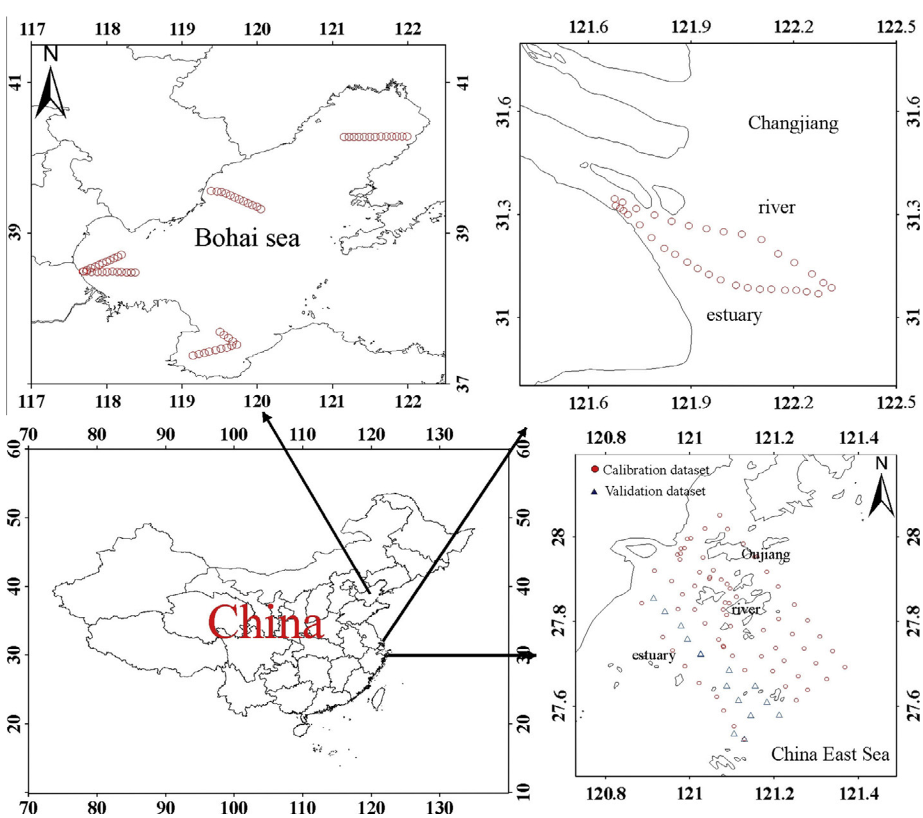

Fig. 1. Study areas.