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Modelling suspended sediment dynamics on the subaqueous delta of the Mekong River

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ABSTRACT

Fluvial sediment is the major source for the formation and development of the Mekong Delta. This paper aims to analyse the dynamics of suspended sediment and to investigate the roles of different processes in order to explore flux pattern changes. We applied modelling on two scales, comprising a large-scale model (the whole delta) to consider the upstream characteristics, particularly the Tonle Sap Lake's flood regulation, and a smaller-scale model (tidal rivers and shelf) to understand the sediment processes on the subaqueous delta. A comprehensive comparison to in-situ measurements and remote sensing data demonstrated that the model is capable of qualitatively simulating sediment dynamics on the subaqueous delta. It estimates that the Mekong River supplied an amount of 41.5 mil tons from April 2014 to April 2015. A substantial amount of sediment delivered by the Mekong River is deposited in front of the river mouths in the high flow season and resuspended in the low flow season. A sensitivity analysis shows that waves, baroclinic effects and bed composition strongly influence suspended sediment distribution and transport on the shelf. Waves in particular play an essential role in sediment resuspension. The development of this model is an important step towards an operational model for scientific and engineering applications, since the model is capable of predicting tidal propagation and discharge distribution through the main branches, and in predicting the seasonal SSC and erosion/deposition patterns on the shelf, while it is forced by readily available inputs: discharge at Kratie (Cambodia), GFS winds, ERA40 reanalysis waves, and TPXO 8v1 HR tidal forcing.

1. Introduction

Deltas are low-lying plains with both riverine and marine influences (Nguyen Anh Duc, 2008). In these coastal environments, saline and fresh water, and riverine and marine sediments mix. As such, deltas are nutrient-rich, and very productive ecological areas with high biodiversity. Deltas have socio-economic importance, as they support up to ~500 million people (Syvitski et al., 2009). Consequently, deltas are heavily impacted by human activities such as land-use changes, port development, land reclamation, diking, damming of channels, dredging and sand mining. These anthropogenic factors add to natural fluctuations and lead to modifications of hydrodynamics (Marineau and Wright, 2014), sediment discharge (Manh et al., 2015; Renaud et al., 2013), and morphology (Dissanayake and Wurpts, 2013). Rivers have been used as a fresh water resource for agricultural irrigation and hydropower dams, leading to changes in river morphology and hydrodynamics (Anthony et al., 2015). In addition, deltas are highly vulnerable to climate change, including sea level rise and other natural hazards (Renaud et al., 2013; Wong et al., 2014). According to recent assessments, 40 deltas in the world are projected to be at risk in terms of coastal erosion due to a decrease of sediment supply and due to sea level rise in combination with subsidence (Wong et al., 2014). Among these, the Mekong Delta is one of the deltas that are extremely vulnerable to predicted sea level rise by the year 2050 (Tri et al., 2013). The main reason for this vulnerability is that deltas are highly dynamic areas that can be significantly impacted by changing environmental conditions. They are low-lying areas (about 26,000 km^2 in the world lying below local mean sea level), which makes them vulnerable to sea level rise (Overeem and Syvitski, 2009). Understanding systematic sediment dynamics of a delta is vital to assess impacts of the mentioned factors.

In this study we focus on the Vietnamese Mekong Delta (VMD,

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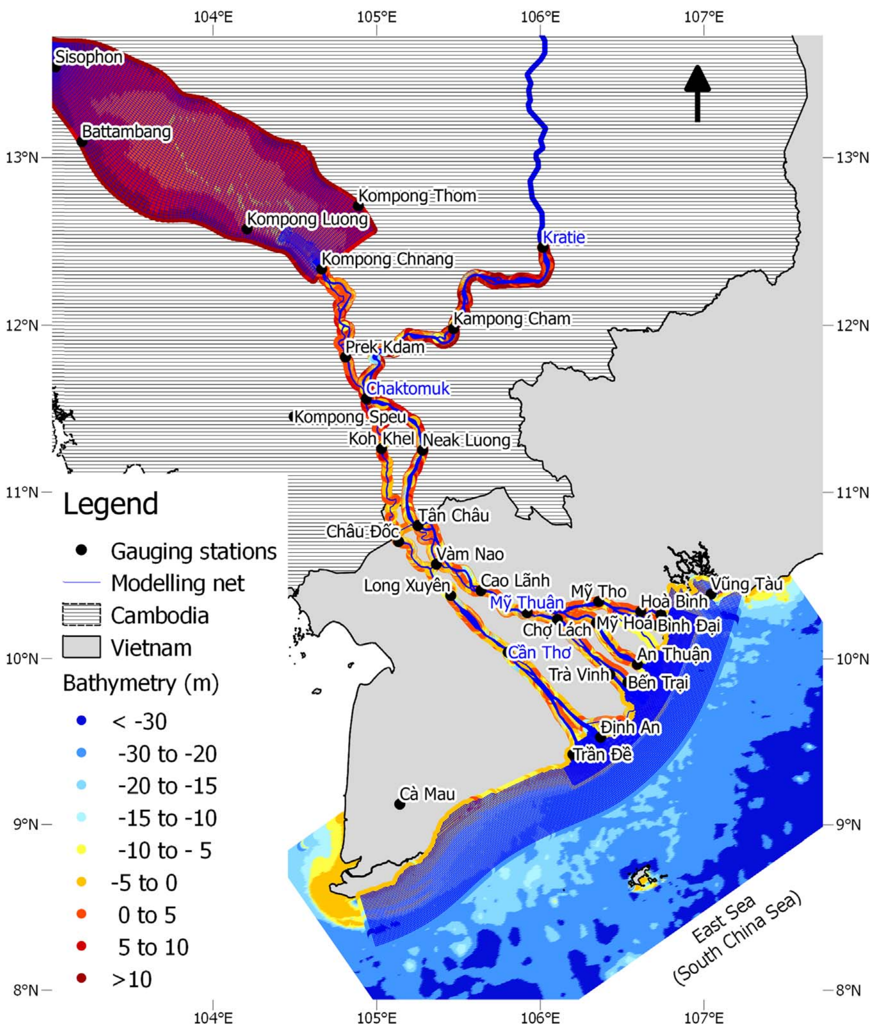

Fig. 1. River bathymetry from cross-section interpolation and shelf bathymetry from GEBCO (Weatherall et al., 2015) of the Mekong Delta, model network, and measurement stations.

Fig. 1). It is home to 17 million people and has been extremely modified by human interventions, such as hydropower dams and sand mining (Anthony et al., 2015; Brunier et al., 2014; Cosslett and Cosslett, 2014). Different approaches have been applied to understand sediment dynamics in the VMD, including field data analyses (e.g. Hung et al., 2014a; Nowacki et al., 2015; Wolanski et al., 1996), processing of satellite images (e.g. Heege et al., 2014; Loisel et al., 2014) and numerical modelling (e.g. Xue et al., 2012; Manh et al., 2015; Vinh et al., 2016). Among these approaches, modelling is a powerful tool for understanding sediment dynamics in a complex system like the VMD, while the others could be used for validating modelling work. Furthermore, modelling is not only helpful in explaining sediment dynamics, but also in predicting bed composition changes under changing forcing and boundary conditions.

A number of modelling studies have been carried out in order to understand hydrodynamics and sediment transport in the Mekong Delta. For modelling on the scale of the whole delta, Wassmann et al. (2004) conducted a study to assess impacts of sea level rise on rice production by using a 1D numerical model (VRSAP). Results show that inundation in the VMD would shift significantly landward due to the projected sea level rise. It can be concluded that the tide plays a significant role in the flood drainage in the VMD. A similar inundated pattern was found by Van et al. (2012). They also applied a 1D hydrodynamic model (ISIS) which was used by the MRC (Mekong River Commission) to study changes of flood characteristics under upstream development and sea level rise. As a result, flooding caused by tides would be stronger due to sea level rise impacts, and may lead to changes in sediment convergence near the river mouths. Manh et al. (2014) estimated the spatial sediment distribution in the Mekong Delta by using a MIKE11 model to simulate rivers (1D) and floodplains (quasi-2D). The study indicated that more than half (53%) of the sediment is transported to the VMD's coastal areas via the Can Tho and My Thuan distributaries, but the sediment dynamics in these areas have not been investigated yet. Xing et al. (2017) investigated sand dynamics of the Song Hau branch and morphological changes. Their model suggests that the ratio between seaward and landward velocity will increase and morphology would be highly affected in the context of relative sea level rise and delta plain subsidence. For the marine realm, Xue et al. (2012) modelled the sediment budget for the Mekong Delta shelf by applying the COAWST system (Warner et al., 2010). It was found that ~90% of total sediment derived from the Mekong River is concentrated in the delta front zone. Although their study considered interactions of wave, tides, and currents, the dynamical role of river mouths that are the connections of river and ocean were not considered. Regarding the modelling of connections of river and ocean, Vinh et al. (2016) modelled the variation of suspended sediment concentration (SSC) as a function of the time-varying wave climate by using a numerical model (Delft3D). Their domain covered the Mekong River from Cần Thơ (on the Song Hau) and Mỹ Thuận (on the Song Tien) to the sea. Noticeably, the increase of wave height would enhance sediment resuspension and expand the sediment plume seaward along the delta front. The study is attractive in that it systematically explores the sediment concentration and transport patterns as a function of the river discharge and wind/wave conditions. However, since their study