



Modeling transport and deposition of the Mekong River sediment

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ABSTRACT

A Coupled Wave–Ocean–Sediment Transport Model was used to hindcast coastal circulation and fine sediment transport on the Mekong shelf in southeastern Asian in 2005. Comparisons with limited observations showed that the model simulation captured the regional patterns and temporal variability of surface wave, sea level, and suspended sediment concentration reasonably well. Significant seasonality in sediment transport was revealed. In summer, a large amount of fluvial sediments was delivered and deposited near the Mekong River mouth. In the following winter, strong ocean mixing, and coastal current lead to resuspension and southwestward dispersal of a small fraction of previously deposited sediments. Model sensitivity experiments (with reduced physics) were performed to investigate the impact of tides, waves, and remotely forced ambient currents on the transport and dispersal of the fluvial sediment. Strong wave mixing and downwelling-favorable coastal current associated with the more energetic northeast monsoon in the winter season are the main factors controlling the southwestward along-shelf transport.

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1. Introduction

The majority of the world's modern deltaic systems began their formations between 7400 and 9500 cal yr BP as a result of decelerating sea-level rise (Stanley and Warne, 1994). Today, approximate half a billion people are living on or near these deltas. Ever increasing human activities, such as extensive damming have reduced sediment flux to the coastal zones. These, along with a rising sea-level have made deltas regions more vulnerable to storm surges and beach erosion problems. Indeed, 85% of the 33 major deltas of the world have experienced severe flooding in the past decade (Syvitski et al., 2005, 2009). Improved understanding of sediment transport dynamics in deltaic systems is therefore much needed for better coastal resource planning and management.

In southeastern Asia, the Mekong River Delta (MRD hereafter) has an area of 49,500 km² (Le et al., 2007). Trailing the Amazon and the Ganges-Brahmaputra Deltas, it is the third largest delta plain in the world (Coleman and Roberts, 1989). The Mekong River itself is the largest river in Southeast Asia. It originates in the Tibetan Plateau, running through China, Myanmar, Thailand, Lao PDR, Cambodia, and eventually to the South China Sea (SCS hereafter) in southern Vietnam (Fig. 1a). The river has a length of ~4750 km and a drainage area of 832,000 km² (Xue et al., 2010a). Its annual

freshwater discharge is $\sim 470 \times 10^9$ m³ and the estimated annual sediment flux is ~ 160 million tons (Milliman and Syvitski, 1992). The weather systems in the lower Mekong region are dominated by the Southeast Asian monsoon. Approximately 80% of the annual rainfall happens during the rainy season between May and October (Debenay and Luan, 2006). Because of this, river discharge in the lower Mekong reaches a maximum in September and a minimum in April (see averaged water discharge at Pakse station during 1960–2005 in Fig. 2a). The resulting MRD is bounded by the SCS to the east and the Gulf of Thailand (GOT hereafter, Fig. 1a) to the west. Borehole studies showed that this delta plain began its progradation in 8000 cal yr BP as a result of decelerating sea-level rise (Tamura et al., 2009). Over the past 5500 yrs, tremendous amount of Mekong River sediment input has allowed the MRD to prograde more than 250-km to the southeast (Nguyen et al., 2000). Recent observations on sediment grain size variations along boreholes further suggested the MRD evolution during this period experienced a phase shift from “tide-dominated” to “tide-and-wave-dominated” condition around 3000 BP (Ta et al., 2002a, 2002b). Today, with ~200 new dams to be added to the river basin in the next couple of decades, more significant changes are expected in MRD hydrological regime, coastal circulation, and delta dynamics (Xue et al., 2010a).

Research progresses on quantifying the physical processes in MRD have been hindered by lacking of observations. As a result, the computer modeling approach has been widely used. Earlier circulation modeling studies have shown that the monsoonal wind produces a basin-wide cyclonic gyre in winter and double

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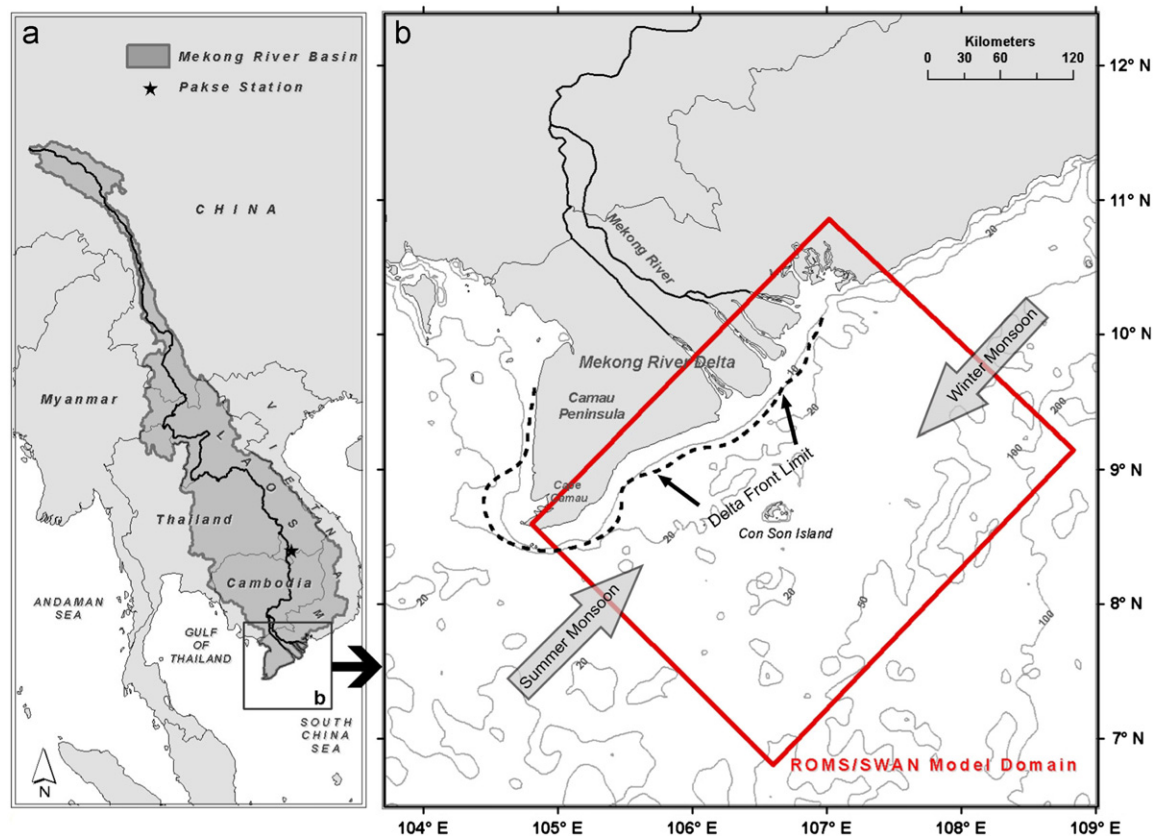


Fig. 1. A map of the Mekong River Delta and the ROMS/SWAN model domain. (a) Mekong River basin with the location of the study area shown by a black box. (b) The ROMS/SWAN model domain used in this study. The positions of delta front limit are from Xue et al. (2010b).

gyres in summer with a cyclonic flow in the north and an anticyclonic flow in the south (Shaw et al., 1999; Liu et al., 2001; Gan et al., 2006; Wang et al., 2006). SW monsoon season runs from May to October and NE monsoon season from November to April (Fig. 3a and b). A recent modeling study by Kubicki (2008) showed the coastal current northwest of the Mekong River mouth has similar directional shifting from NE in winter to SW in summer. Tides are another important circulation process. The amplitude of the dominant semi-diurnal tide M2 (diurnal tide K1) decreases (increases) after the tidal waves propagate from the western Pacific into the SCS through the Luzon Strait (Zu et al., 2008). Both M2 and K1 tidal amplitude are more than 0.9 m seaward of the Mekong River mouth (Fig. 3c and d). Hordoir et al. (2006) simulated the Mekong River plume, indicating that: (1) the large amount of fresh water discharged by the Mekong River forms a baroclinic coastal current flowing in the propagation direction of Kelvin wave; (2) the Mekong River plume is mostly geostrophic and exhibits a strong seasonal variability related to the monsoon wind.

Sedimentary studies of the Mekong Shelf are limited by the scarce of observations as well. Earlier geological studies have focused on MRD long-term (millennium to a couple of thousands years) evolution. A recent acoustic profiling investigation started to reveal some spatial details of the subaqueous deltaic system. For instance, an up to 20-m thick subaqueous delta was identified at the front of the deltaic system (Liu et al., 2009; Xue et al., 2010b). This subaqueous delta accounted for ~80% of the fluvial sediment input over the past 3000 yrs. On a relative shorter time scale; however, significant erosion with a rate of 1.1 km²/yr, has been documented along the eastern part of the MRD (SCS side) since 1885 (Saito, 2000). While there is a general consensus that the MRD formation is a result of along-shelf sediment transport (Gagliano and McIntire, 1968; Nguyen et al., 2000; Xue et al., 2010b), the

Mekong sediment transport dynamics has not been fully quantified. Xue et al. (2010b) based on acoustic profiling and coring data proposed the following seasonal sediment transport/dispersal mechanism: during the high flow season (May–October), a considerable part of riverine sediment was delivered to the Mekong River mouth and temporally deposited there; then during the low flow season (November–April), previously deposited sediment was resuspended by strong mixings associated with the strong northeast monsoon and subsequently transported southwest along-shelf by coastal circulation.

It is worth noting that significant progress in understanding general river sediment transport and dispersal dynamics has been made through the combination of in situ observations (e.g. tripod deployment) and three-dimensional prognostic model simulations. Some recent examples in this regard include a series of river sediment studies conducted in the Adriatic Sea (e.g., Traykovski et al., 2007; Harris et al., 2008; Bever et al., 2009). Numerical modeling is in particular useful in testing mechanism and hypothesis deduced from limited observations, and this is the approach we will utilize in this study as well. Our objectives are two-fold: (1) to better understand the seasonal transport and dispersal patterns of Mekong-derived sediments using a newly developed wave–current–sediment coupled ocean model; and (2) to investigate the relative importance of along-shelf current, waves, and tides in transporting and dispersing Mekong-derived sediments.

2. Methods and data

We applied the Coupled Ocean–Atmosphere–Wave–Sediment Transport Modeling system (COAWST, Warner et al., 2010) in this study to simulate the transport and dispersal of Mekong-derived

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