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Numerical analysis of the combined action of littoral current, tide and waves on the suspended mud transport and on turbid plumes around French Guiana mudbanks

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Abstract

Large mudbanks migrate westwards in the nearshore zone from the Cabo Cassipore in the Amapa state (Brazil) to the Waini River in Guiana. These mudbanks are noticeable by their size (about $4\times10^9 m^3$ of sediment) and by the sediment dynamics they induce. Notably, visible remote sensing pictures present high turbid mud plume associated to mudbank erosion. The sediment transport is directly linked to the ambient forcing—littoral current, waves, and tide. In this paper, the turbid plume and the suspended mud transport around Guiana mudbanks are studied through a three-dimensional numerical study, under the three main different forcings. The study aims at describing the plume and the action of various physical processes in the suspended mud transport. The model results qualitatively agree with known observations issued from the literature. It is found that, the erosion—at the back of the bank—and the deposition—in front of the bank—could partly explain the migration process of these mudbanks. Waves are fundamental to create the erosion/deposition process, but littoral current and tide modulate it. Bottom flux and plume

location vary with tide and these oscillations are accentuated during spring tide. In the same way, the wave incidence angle can explain the variability of erosion and deposition rate velocity along the Guiana coast.

Introduction

The Guiana littoral, situated between the Amazon River mouth and the Orinoco River delta, is encompassed in the great intertropical systems of atmospheric and oceanic circulation in the equatorial Atlantic and undergoes direct influence of the Amazon River. Indeed, not only the fresh water coming out from the Amazon River spreads along the French Guiana continental shelf, but also about 22% of the total Amazon mud supply—estimated to about $1.1–1.3\times10^9\,\mathrm{t\,year}^{-1}$ (Meade et al., 1985; Nittrouer and De Master, 1986)—is moving along the Guiana coast to the Orinoco River and the Paria gulf. This mud is conveyed either in suspension—about 13%—or under the form of mudbanks—about 7.5%—(Eisma et al., 1978).

This shore is characterized by a very typical pattern of large and regular mudbanks, close to the coast at isobath less than 20m. As Allisson et al. (2000) show, these banks appear near the Cabo Cassipore in the Amapa state (Brazil) and migrate westwards in the nearshore zone to the Waini River in Guiana. The observation of these mudbanks began before 1875, as archives of the French Hydrographic and Oceanographic Survey (SHOM, 1975) gave evidence and since, many other campaigns were lead, such as the campaign of the commander Yayer (1948) and Lemiere (1953) for the former ones, study of Delft Hydraulics (1962), Nedeco (1968) or Augustinus (1978), which are the first references about mudbanks along Surinam and Guiana, and works of Froidefond, et al. (1988) about mudbanks along French Guiana. These mudbanks are peculiar by their size and their location. Indeed, situated in a well exposed shelf for wave action and micro tidal area (along the classification of Dyer et al., 2000), they could only exist if a large input of sediment nearby—as those of Amazon—offsets the waves erosion (Le Hir et al., 2000). Therefore, only three other regions of mudbanks of the size of those of Guiana coast, situated on open coast can be listed in the world: littoral of Louisiana, Korea and Kerala in India. Close to the most important river of the world, Guiana mudbanks seem to be the highest and the quickest ones.

In 1961, Delft Hydraulics Laboratory (1962) numbered 21 mudbanks during their survey along the Guiana coast. These mudbanks play a fundamental role in the littoral ecology. At the western part of the bank, the coast is in accretion and mangroves overgrow the littoral and the intertidal mudflats. On the opposite, in the erosion area, on the eastern part of the bank, mangroves decay. Moreover, in the context of the anthropization of the littoral, the mud due to its capacity of micro-organisms adsorption, could become a polluting factor, and its hauling around mudbanks could arouse pathogen movement. Also, it is necessary to understand the bank system functioning. However, compared with most other habitats, mudflats and mudbanks are relatively weak-studied. Different studies, mainly based on observations and in situ measurements, have been made, notably during INTRAMUD project, to classify mudflat and to assess influence of external forcing (Dyer et al., 2000; Le Hir et al., 2000). Nonetheless, all the processes acting on them are not completely understood yet.

In situ measurement around Guiana mudbanks operates in quite difficult conditions. Then, to describe and understand the sediment dynamics, studies often couple in situ measurements with modern techniques as visible (Froidefond et al., 2004) and synthetic aperture radar remote sensing (Baghdadi et al., 2004). In order to gain knowledge, it could be interesting to compare the surface turbid plume observation to numerical model results, which describes the suspended sediment transport under the surface. However, numerical experiments of suspended sediment transport above mudbanks are required. When sediment dynamic on mudbanks are investigated, forcings are often dissociated: As, the majority of the mudbanks are dominated by tidal forcing (Dyer et al., 2000), previous modeling studies were carried out by only considering the tide (Friedrichs and Aubrey, 1996; Prichard et al., 2002), whereas Wells et al. (1980) and Rodriguez and Mehta (2000) consider wave action as a significant process. In case of the Guiana mudbanks, Dyer et al. (2000) estimate tide and waves are the main external forcing variables to explain the migration. Some authors as Wells et al. (1980), Roberts et al. (2000) and Rodriguez and Mehta (2000) propose models of global mud transport, but they do not study the suspended matter transport. In this article, we apply a three-dimensional (3D) numerical model taking account of suspended transport, erosion and deposition under the influence of combined effects of current, tide and waves in order to investigate the role of various physical processes in the mud suspended transport around Guiana mudbanks, and on the genesis and fate of resulting turbid plumes in the nearby. This study seems to be one of the first numerical study of mud suspended transport around Guiana mudbanks. The focus is not to present a predictive model for mudbank migration, but to get insight in the understanding of the interplay between the main mechanisms of this transport.

Then, in this paper, first, we describe the mudbank and forces acting on them and we workout a model of suspended mud dynamics in the mudbank system, taking into account the alongshore current, the tide and the swell. Then, we analyze erosion, deposition and suspended mud transport both in time and space in a reference situation. Finally, we consider the evolution of this mud transport under the influence of varying forcings.

Section snippets

The mudbanks and the sediment

The banks are described as regular large oblique extensions in the line of the coast with an average angle of 24° (Nedeco, 1968, Fig. 1). Their “wave length” is about 45 km and areas in erosion—as wide as the bank—separate each bank (Froidefond et al., 1988). They can reach 5 m of height, 20–40 km wide and vanish as far as 20–40 km from the coast at a depth of about 20 m. Their volume is comprised from 2 to $6\times10^9\,m^3$ (Allersma, 1971). The gentle slope of the southeastern flank is generally less than…

Numerical study field

As it was said in introduction, our aim is to understand the role of various physical processes in the suspended sediment transport and not to develop a predictive model, which would require a detailed description of geographical area, hydrodynamics, and full range of sediment occurring in this region. To prevail general purpose of the model and avoid too much local morphology effect, we build a model in an idealized area with a schematic mudbank. This mudbank has the typical scales as those…

Tide and currents

In the reference simulation, the hydrodynamics coastal currents are associated to a mean semi-diurnal tide with a range of 1.15 m at the offshore boundary (northeast boundary) and to the littoral current parallel to the coast. Fig. 4 illustrates the velocity numerically obtained during this experiment. The mean flow, linked to the littoral current, is essentially alongshore and tends to follow the isobaths. Cross-shore, its intensity varies from about $0.05\,m\,s^{-1}$ near the coast to $0.6\,m\,s^{-1}$ offshore. …

Spring-neap cycle

The spring and neap tide modulation effect influences the plume and the mudbank erosion. The five main tidal waves (three semidiurnal waves—M2, S2, N2—and two diurnal ones—K1, O1), deduced from a French Guiana shelf model (Bourret et al., 2005) are introduced in the simulation. At the offshore boundary, their amplitude and phase are presented in Table 2. Fig. 14 presents the bottom concentration and bottom fluxes evolution at points A, C88 and E88.

The bottom flux, the mean concentration and its …

Conclusion

Even if many models of sedimentary dynamics have been developed all over the world, only a few models are used to describe the suspended transport around mudbank and take the combined action of the three forcing wave, current and tide into account. This paper has reported the results of one of the first 3D numerical model of suspended sediment dynamics around Guiana mudbanks taking into account these three main forcings. Using these results, we analyze the combined effects of external…

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…Near estuary mouths, several of which occur between the mouths of the two large rivers, an extensive mudflat can be formed at the updrift side (Lefebvre et al., 2004). The following hydro-meteorological factors have been identified to explain such temporal and spatial variability of the shoreline (Fig. 2): (i) trade-wind wave intensity and direction (Augustinus, 2004; Eisma et al., 1991; Gardel and Gratiot, 2005; Gratiot et al., 2007; Rodriguez and Mehta, 1998), (ii) solitary waves (Wells et al., 1978; Wells and Coleman, 1981a), (iii) the nodal tidal cycle (18.6 yrs) (Gratiot et al., 2008; Wells and Coleman, 1981b), (iv) tidal and coastal currents (Bourret et al., 2008; Chevalier et al., 2008; Gibbs, 1976; Pujos and Froidefond, 1995), (v) the Northern Atlantic Oscillation (Walcker et al., 2015) and (vi) other secondary factors for which correlations have not been clearly demonstrated, e.g., sea-level variation (NEDECO, 1968; Wong et al., 2009) and irregular ENSO variation (Gratiot et al., 2008; Pujos et al., 1996). Mud bank dimensions range from 10 to 30 km wide in the cross-shore direction and from 10 to 50 km long in the longshore direction (Augustinus, 1978; Augustinus et al., 1989; Eisma et al., 1991; Froidefond et al., 1988).…

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…About 20% of this fine-grained sediment is transported either in suspension or in mud bank form and migrates along the coast from the mouth of the Amazon River (Brazil) to the Orinoco Delta (Venezuela) (Eisma et al., 1991). While suspended sediment dynamics in coastal waters are mainly associated with tidal and oceanic currents (Chevalier et al., 2008), mud banks migration occurring in shallow waters (5–20 m depth) and are induced by longshore currents generated by trade-wind waves (Allison and Lee, 2004; Gratiot et al., 2007). Along the Guianas coast, mud banks are estimated to be of about 1060 km length, 2030 km width (cross-shore direction) and up to 5 m thick (Anthony et al., 2013).…

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