SIMULATING THE FORMATION OF TIDAL CHANNELS ALONG AN OPEN-COAST TIDAL FLAT: THE EFFECTS OF INITIAL PERTURBATION

Ying ZHANG[1,2], Zeng ZHOU[1,2,*], Liang GENG[3], Giovanni COCO[4], Jianfeng TAO[2],

Changkuan ZHANG[2]

A state-of-the-art morphodynamic model (Delft3D) was used to explore the effects of bathymetric perturbation on the morphodynamic modeling of tidal channels and flats. Short-term and medium-term modeling results indicate that the two-way interaction of the hydrodynamic forcing and initial perturbation has influence on the evolution of tidal channel ontogeny. There is a critical range of the magnitude of initial perturbation, within which the morphodynamic development tends to be similar. By comparing with the case without initial perturbation, the case with a slight increase in perturbation magnitude can considerably enhance the rate of the morphodynamic development.

Keywords: initial perturbation; parallel tidal channels; numerical modeling

INTRODUCTION

Widely-spread tidal flats and salt marshes are important parts of the intertidal zone (Coco et al. 2013; Zhang et al. 2016), exchanging water and materials between lands and oceans (Mitsch and Gosselink 2000; Zedler and Kercher 2005), providing habitats for coastal biology and potential land resources (Costanza et al. 1997; Barbier et al. 2011; Zhou et al. 2016), and protecting the inland area from extreme situations, such as storm surge and sea level rise (Temmerman et al. 2013; Bouma et al. 2014). Tidal channels developed on tidal marshes are efficient drainage pathways (Fagherazzi et al. 1999; Zhou et al. 2014), promoting tidal flat evolution and the retreat or expansion of adjacent salt marshes.

Affected by coastal hydrodynamic forces and the presence of salt marshes, tidal channel systems morphologically show various planforms: parallel channels, dendritic and elongate dendritic, distributary, braided and interconnected (Eisma 1998). Parallel channels, which are normally seen along the Jiangsu coast, are considered as the study case (Fig. 1). This kind of channel system is similar to the parallel rills with the regular spacing generated in the mountains (Loewenherz 1991; Izumi and Parker 2000), while the latter one is driven by a simpler hydrodynamic condition characterized by unidirectional flow. The formation and medium to long term evolution of tidal channel systems have been extensively studied using simulation models (D'Alpaos et al. 2005; Dastgheib et al. 2008; Belliard et al. 2015; Lanzoni and D'Alpaos 2015).

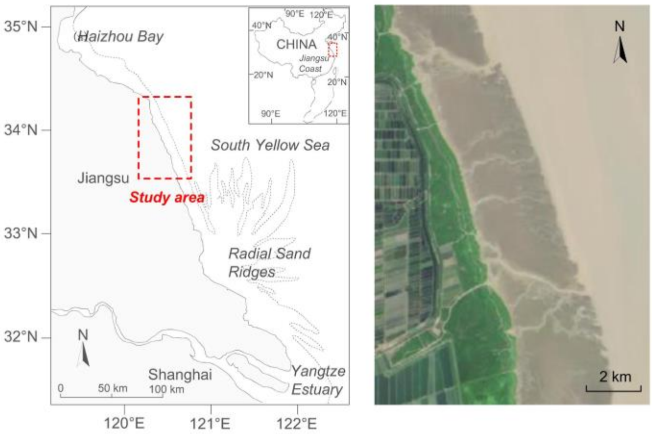

Figure 1. (a) Study site in Dafeng along the Jiangsu coast, China; (b) Satellite image of channels along the Jiangsu coast.

Simulation models, also known as process-based models, have been commonly used to explore long-term coastal morphodynamics (Van der Wegen and Roelvink 2008; Carniello et al. 2011; Gong et

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[1] Jiangsu Key Laboratory of Coast Ocean Resources Development and Environment Security, Hohai University, Nanjing, 210098, China

[2] College of Harbour, Coastal and Offshore Engineering, Hohai University, Nanjing, 210098, China

[3] Department of Civil, Environmental and Architectural Engineering, University of Padua, Padua, 35131, Italy

[4] School of Environment, University of Auckland, Auckland, New Zealand

* Corresponding author: Zeng Zhou, Email: zeng.zhou@hhu.edu.cn

al. 2012; Van Oyen et al. 2014). These models solve the coupled equations describing hydrodynamics, sediment transport, biological activities and morphological changes, covering various spatial and temporal scales. To accelerate the evolution of the geomorphology and make the result authentic, researchers may give topography some initial perturbation (D'Alpaos et al. 2005; Van der Wegen et al. 2008; Iwasaki et al. 2013; Belliard et al. 2015). The importance of initial conditions should be properly investigated. A landscape that experiences a perturbation or a change in process may begin to evolve toward a different equilibrium state, potentially leading to hysteresis or rapid changes in topography (Perron and Fagherazzi 2012). The comparative study of numerical and experimental modeling of tidal networks by Zhou et al. (2014) showed that the initial bottom perturbation plays an important role in determining the morphological development and the final pattern formation. Hancock et al. (2016) also pointed out that complex feedback may occur even in a simple modeled system under the effect of the initial perturbation. However, the effect of initial perturbation remains elusive and the choice of the magnitude of bathymetric perturbation is often arbitrary in simulation models.

The focus of this paper is to evaluate the influence of the initial bathymetric perturbation on the formation of tide channels and explore the effect of different magnitudes of initial perturbation on the morphological evolution of tidal flat-channel systems.

NUMERICAL MODEL AND SETUP

In this study, an open-source morphodynamic model (Delft3D), which is widely used in tidal flat-channel system modeling (Lesser et al. 2004; Marciano et al. 2005; Zhou et al. 2015; Zhou et al. 2016), is applied to explore the effects of specifically designed bathymetric perturbation on short term to medium term modeling of the tidal channels. The nonlinear shallow water equations govern the water flow (i.e., velocities and water level) over the spatial domain. Sediment transport is simulated using Partheniades-Krone formula and van Rijn (1993) formula, respectively for cohesive and non-cohesive sediment. The morphological evolution is governed by the mass balance equation and the elevation of the bed is dynamically updated at every simulation time-step. In order to shorten the computational time, a “morphological accelerating factor” is introduced, which linearly scale-up the bed level changes, and incorporate the morphological developments dynamically into the hydrodynamic flow calculations.

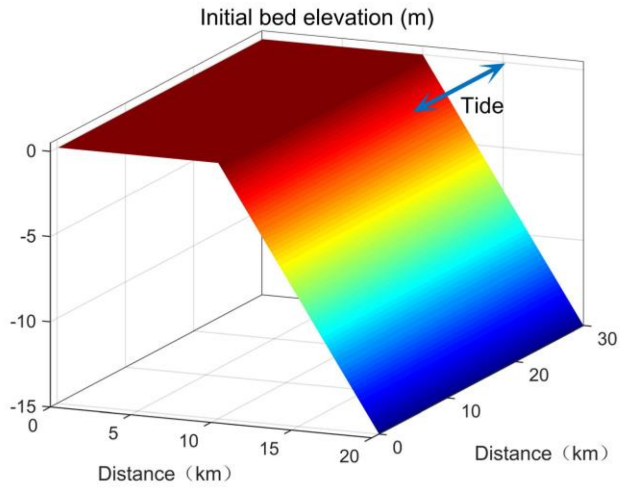

Figure 2. 3-D view of initial bed elevation relative to MSL with no bathymetric perturbation.

A simplified model is set up based on the intertidal mud flat distributed along Jiangsu Coast, China, which is dominated by the along-shore tide (Fig. 2). Using a method for automatic definition of tidal channel networks after the simulation (Geng et al. 2018), the geometric parameters of channels can be acquired.

The model geometry is characterized by a tidal flat consisted of a platform and an initial gentle slope of 0.15%. The simulation domain is a rectangle (20 km×30 km) and the spatial grid resolution is 50 m×50 m. The water depth at the seaside boundary is up to 15.5 m. A harmonic tide with a tidal period of 12 h and an amplitude of 1.7 m, propagates at the along-shore direction. Initially, the tidal flat is covered with a 10 m sediment layer filled with both mud and sand, and the properties of the sediments are provided in Table 1. The boundary mud concentration is assumed to be 0 kg/m^3, while an equilibrium concentration for sand is used. The “morphological accelerating factor” is set as 20.

Varying the magnitude of initial perturbation (from 0 m to 0.5 m), a series of numerical experiments are designed.

Table 1. Parametrizations for this study: Sediment density (ρ_s), sand median grain size (D_{50}^s), mud critical shear stress for erosion (τ_{cr}), mud settling velocity (w_s), initial percentage of mud on the bed (f_{mud}), spring tidal range (TR).

Parameters	ρ_s (kg/m^3)	D_{50}^s (mm)	τ_{cr} (Pa)	w_s (mm/s)	f_{mud} (%)	TR (m)
Value	2650	0.1	0.5	0.3	50	3.4

RESULTS AND DISCUSSION

The morphological evolution under the effect of initial perturbation after 50, 200 and 400 days are shown in Fig. 3 (here we take the initial perturbation of 0.1m for example). The development of tidal channels is quite rapid as the fledgling creeks have appeared after 50 days. Instead of intense headward erosion process, the tidal channel generates from a shallow and wide creek. Subsequently the channels grow deeper and wider, and some of them become branched after 200 days.

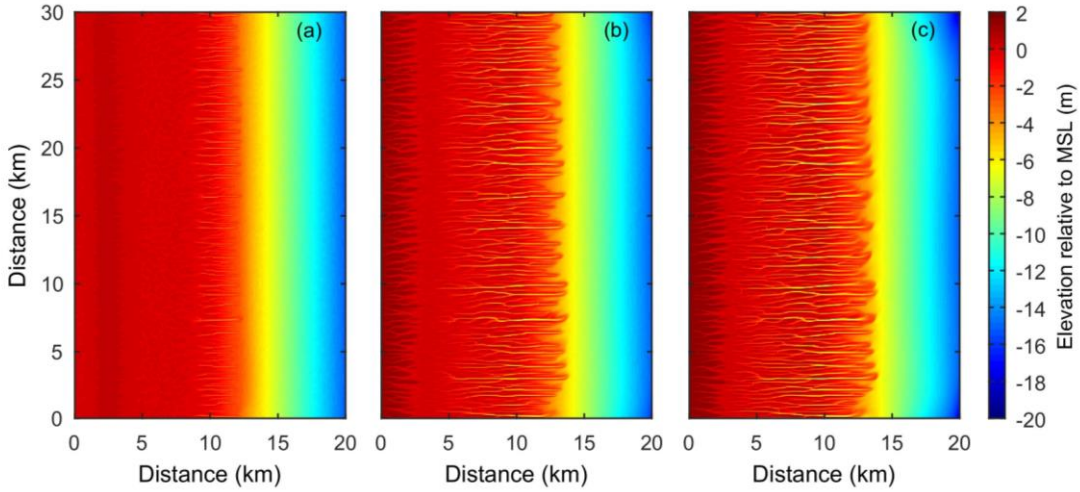

Fig 3. (a)-(c) Morphological pattern after 50, 200 and 400 days simulated by the model under the effect of the initial perturbation of 0.1m.

The morphological patterns of tidal flat-channel systems after one year of cases with different magnitude of initial perturbation are shown in Fig. 4. It can be found that the resultant channel-flat morphology is highly affected by the specified bathymetric perturbation. When there is no initial perturbation, the channels are straight and tidal flat evolves more slightly to some extent. As the magnitude of initial perturbation increases, the generated tidal channels tend to be denser and more curving, and bifurcated channels are also easier to form, because lager magnitude of initial perturbation could make the topography more fluctuant, resulting in a more turbulent flow. The water flow in irregular direction erodes the sea bed, and then tortuous and bifurcated channels generate.

Fig. 5 shows the detailed bed elevation of the profile 5 km away from the land boundary. At the beginning of the evolution (Fig. 5 a), the influence of the initial perturbation is evident. The spatial variation of the bed elevation is dominated by the initial perturbation. However, comparing the generated channels at the same position, the deepest tidal channels are not always generated by the largest initial perturbation after 400 days (e.g. section (ii) in Fig. 5), because the strong flow inside the well-developed tidal channels will not be affected by the initial condition. While the elevation of the tidal flat surface still tends to increase with the increasing initial perturbation, because the flow outside the tidal channels is not so strong to transport sediment outside channels. It is important to point out that even though the initial perturbation has the same spatial distribution in all cases, there are still some differences in the location of tidal channels, resulting from the two-way interaction between the topography and the hydrodynamics.

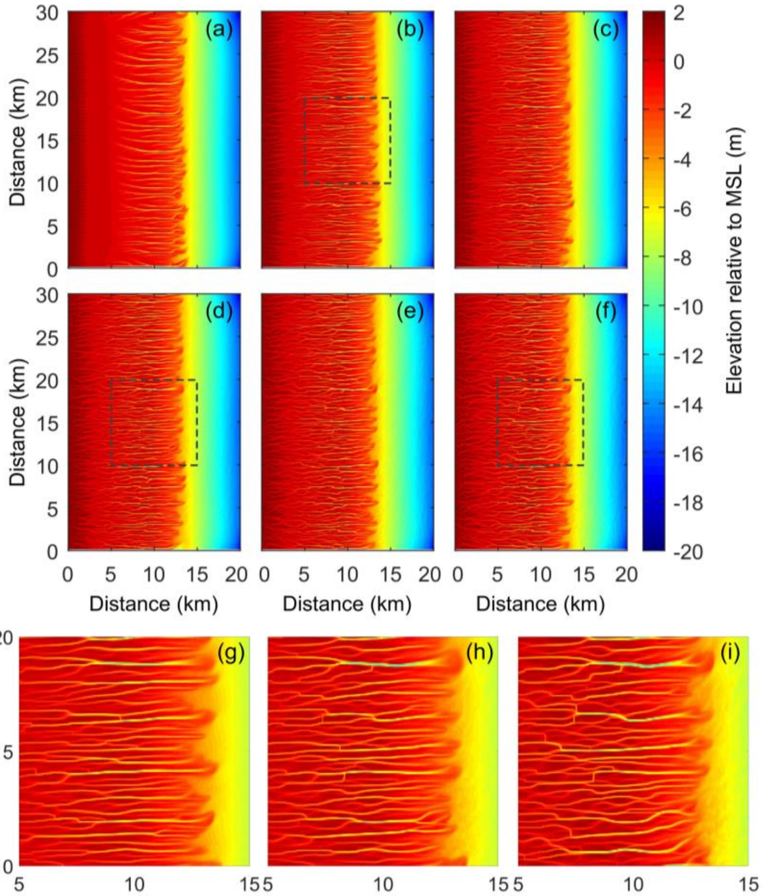

Fig 4. (a)-(f) Simulated bathymetries after 1 year with initial perturbations of respectively 0 m, 0.1 m, 0.2 m, 0.3 m, 0.4 m and 0.5 m; (g)-(i) Partial enlarged views of simulated bathymetries, as shown with black dotted box respectively in (b), (d) and (f).

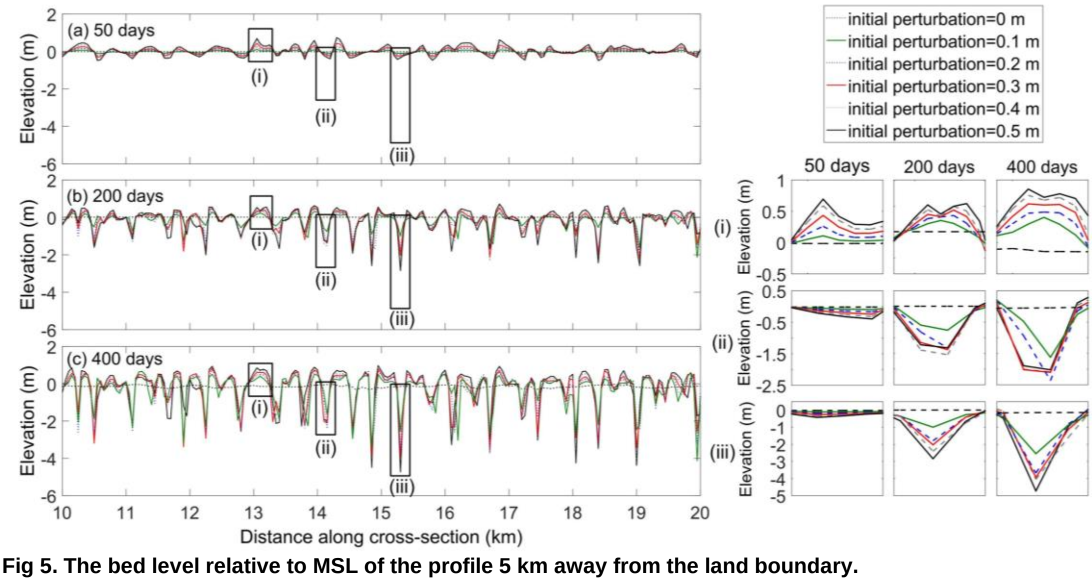

Fig 5. The bed level relative to MSL of the profile 5 km away from the land boundary.

A statistical analysis of tidal channel parameters over time is also conducted. The tidal channel networks are delineated by using the neighboring topography to identify the threshold elevation of each point (Geng et al., 2018). Considering the threshold elevation of all the points, a surface layer of the entire tidal flat is created. As a result, the depth distribution can be calculated according to the differences between the surface elevation and the original bed elevation.

Fig. 6 shows the response of tidal channels geometry parameters to the magnitude of initial perturbation. The initial perturbation can considerably accelerate the channel formation. In the case without initial perturbation, the development of tidal channels is relatively slow compared to the other cases with perturbation. A larger perturbation results in an increase of the channel size, while the increase is relatively smaller for initial perturbation ranging from 0.05 m to 0.30 m (especially for the drainage area, total length and average width of channels). It is worth mentioning that the influences of initial perturbation become more evident with time. The morphodynamic evolution of the tidal channel-flat system is highly affected when the magnitude of perturbation is increased beyond the upper bound of the critical range, resulting in notably distinctive pattern formation.

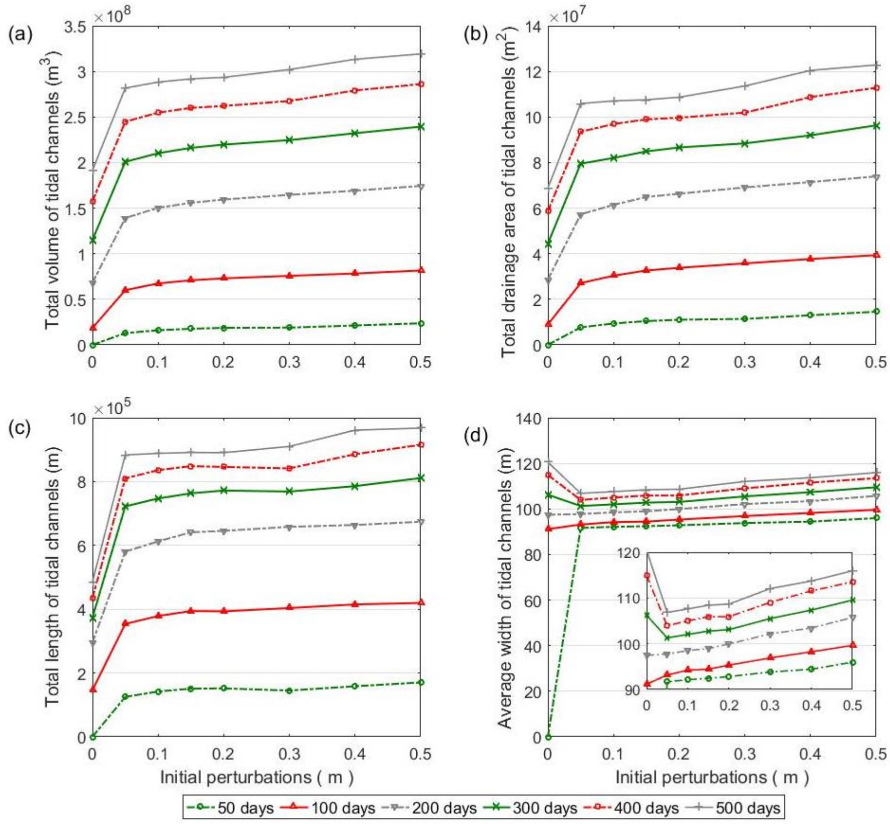

Fig 6. The relationship between channels scale parameters and time. (a)-(d) Total volume, total drainage area, total length and average width of tidal channels respectively.

CONCLUSION

We use numerical model to simulate the generation and evolution of the parallel tide channels under the influence of the initial surface perturbation. The two-way interaction of the hydrodynamic forces and initial perturbation has effects on the evolution of tidal channel ontogeny. The pattern formation of tidal flat-channel system in short-term and medium-term modeling is affected by the initial bathymetric perturbation. Even subtle magnitude of perturbation can accelerate the formation of tidal channels considerably. There exists a critical range of the magnitude of initial perturbation, within which the morphodynamic development tends to be similar. However, perturbation with a magnitude beyond the critical range will lead to a distinctive pattern. Therefore, the magnitude of the initial perturbation should be carefully examined in morphodynamic simulations in morphodynamic modeling, because it may affect the timescale for the ontogeny of morphological units and the final pattern formation.

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