Hydrodynamics and Sediment Transport at a Seasonal Inlet and Its Adjacent Beach Cua Dai, Vietnam

Do, Anh T.K.; de Vries, Sierd; Ye, Qinghua; Stive, Marcel J.F.; Nguyen, Trung Viet

DOI
10.1007/978-981-15-2081-5_28

Publication date
2020

Document Version
Final published version

Published in
Estuaries and Coastal Zones in Times of Global Change

Hydrodynamics and Sediment Transport at a Seasonal Inlet and Its Adjacent Beach: Cua Dai, Vietnam

Anh T. K. Do, Sierd de Vries, Qinghua Ye, Marcel J. F. Stive and Trung Viet Nguyen

Abstract Cua Dai inlet is a typical microtidal, mixed energy-wave dominated inlet in a tropical monsoon regime in central Vietnam. Both the river flow regime and coastal processes such as induced by waves and tides influence Cua Dai Inlet and its adjacent coasts. Cua Dai Beach, the northern adjacent coast of Cua Dai inlet, has experienced severe erosion since 1995 due to an apparent non-periodic cyclic process, a decrease of sediment supply from the river, estuary and squeeze by coastal developments (Do et al. in J Coast Res 34(1):6–25, 2018). The inlet channel has shifted from North to South which served as an important controlling mechanism for the creation of a new ebb shoal. However, the role of the ebb-tidal delta in relation to the channel shifting and seasonal varying hydrodynamic conditions (river discharge and wave climate) remains poorly understood. Most studies have only considered the impact of waves and tides on the development of the ebb tidal delta. No study has included the impact of a varying river discharge on ebb shoal development and inlet migration. This chapter investigates the seasonal varying hydrodynamics and sediment transport of the inlet and adjacent coasts due to the seasonal varying river discharge and wave climate. The 2DH process-based morphodynamic numerical model (Delft3D) is applied using schematized wave conditions and river discharge. Six simulations with varying dominant wave conditions for the winter and for the summer are executed in combination with varying river discharge classes that corresponding to the dry, wet and flood seasons. There exists an East North East monsoon with a flood season from September to December, an East North East monsoon with

A. T. K. Do (✉) · S. de Vries · Q. Ye · M. J. F. Stive
Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands
e-mail: dtkanh@dut.udn.vn

A. T. K. Do
Faculty of Water Resource Engineering, The University of Da Nang-University of Science and Technology, Da Nang, Vietnam

Q. Ye
Deltares, Delft, The Netherlands

T. V. Nguyen
Faculty of Civil Engineering, Thuy Loi University, Ha Noi, Vietnam

K. D. Nguyen et al. (eds.), *Estuaries and Coastal Zones in Times of Global Change*, Springer Water,
https://doi.org/10.1007/978-981-15-2081-5_28

a wet season from January to March, and a dry bidirectional South East/East North East monsoon from April to August. We investigate the effect of the seasonal wave climate and seasonal river discharges at Cua Dai inlet by analyzing the effects on the resulting hydrodynamics, sediment transports and potential morphological changes through the inlet and at the adjacent coasts. Primary results indicate that the seasonal variation in the wave climate has a strong influence on the sediment transport patterns in the adjacent coasts. The variation in the river flow dominates the magnitude of sediment transport through the inlet. The results of the simulations show that the inlet generally imports sediment into the estuary except in the case of the flood season. During the flood season the estimated sediment export is significant. Interestingly, the wave direction that varies during summer also influences the magnitude of sediment import into the estuary. Waves coming from the ENE contributes to larger sediment import than waves coming from the SE.

Keywords Seasonal inlet · Seasonal waves · Seasonal river discharge · Hydrodynamics · Sediment transport

1 Introduction

Cua Dai inlet is a typical microtidal, mixed energy- wave dominated inlet in a tropical monsoon regime and is strongly influenced by both river discharge and waves. Cua Dai Beach, the adjacent coast of Cua Dai inlet, located on the north side of Cua Dai Inlet, is experiencing severe erosion since 1995. To aid future management of this system, it is necessary to understand the factors that influence the existing morphology and that cause coastal retreat of the system. Do et al. (2018) reconstructed historical shoreline positions in combination with crude assumptions with respect to longshore sediment transport patterns and associated changes in sediment budgets over recent decades. In the study of Do et al. (2018), it is found that the long-term geomorphological development, and the decrease in sediment supply from the river and the estuary have put Cua Dai Beach under stress by causing the shoreline to erode.

The long-term geomorphological development of Cua Dai inlet appears to reflect a non-periodic cyclic process that takes place over several decades. It appears that the inlet channel shifted from North to South. Welding of the initial ebb shoal to the abandoned ebb-tidal delta and the development of a new ebb shoal were important primary controlling mechanisms. We propose two conceptual theories that represent the geomorphological development of the Cua Dai inlet. The first theory (A; Fig. 1a) is based on Landsat images in 1988 that depict the system in the past. The existing ebb shoal such as present in 1988 suggests that the system was rich in sediment. It is our hypothesis that the river flow was normally directed to the North and provided a large amount of sediment to the inlet gorge and to the ebb tidal delta, depending on the dry or wet season respectively. Hence, the wave driven alongshore sediment transport on the northern beaches, caused by the waves from ENE direction caused

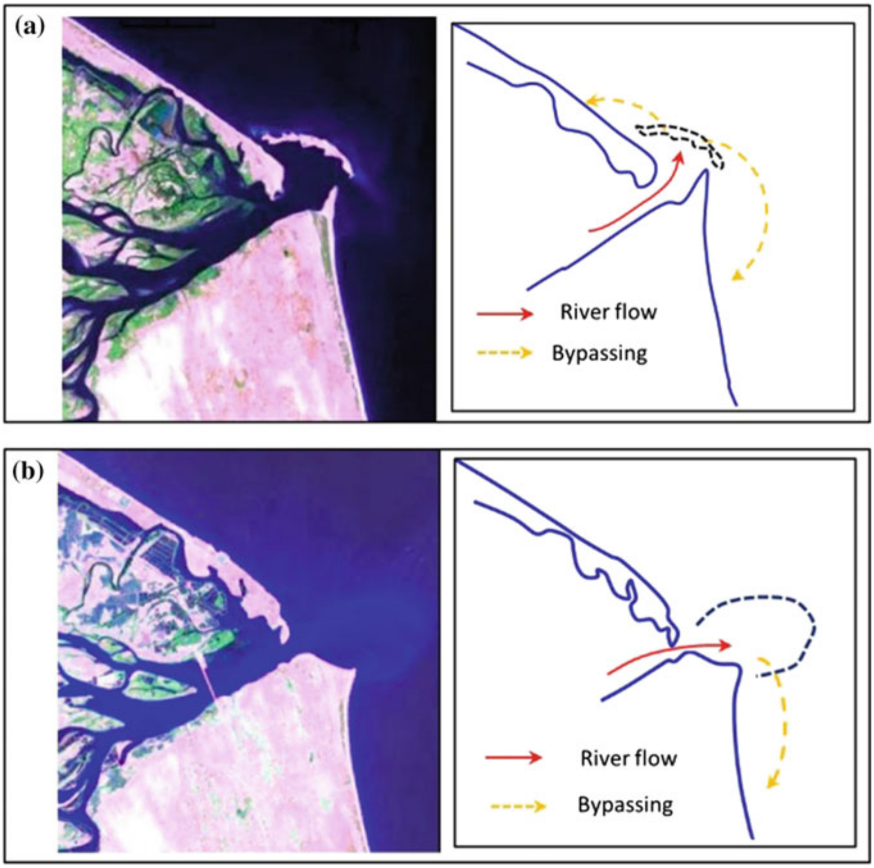

Fig. 1 Conceptual model description for the non-periodic cyclic process of Cua Dai inlet. **a** Scenario in the past, 1989 and **b** scenario at present, 2015

two important mechanisms. It builds a shoal such as present in 1988, preventing erosion of the Cua Dai near inlet shore and it also feds the more northern shore, annihilating the effect of divergence in transport. The second theory (B; Fig. 1b) based on Landsat images in 2015 depicts a more recent image. Due to storm Cecil (1989), the existing ebb shoal in 1988 was abandoned and it migrated landward until it attached to the beach due to bar welding process resulting in accretion at both adjacent coasts during the period 1988–1995 (Do et al. (2018). After the bar welding, a new ebb shoal started to develop further to the south than the previous ebb shoal. This process created a major sediment sink since formation of the new ebb shoal requires sediment to reach equilibrium. The new ebb shoal is also orientated more to the South. The northern beach is now not protected by the shoal and erosion continues due to the local divergence in longshore sediment transport, whereas the southern coast starts to accrete due to sand supply from bypassing.

Understanding the role of the ebb-tidal delta that interacts with the shifting channel and its associated seasonal behavior due to river discharge and wave climate is a remaining challenge. Inlets probably represent the most extreme level of difficulty in evaluating quantities of sediment transport related to the variety of acting physical forces (Komar 1996). The complexity of the interaction of tides, waves, and freshwater discharge, lead to very complex morphodynamic behavior observed in many inlets (Oertel 1972, 1988; Robinson 1975; Hubbard et al. 1979; Sha 1989; Komar 1996; FitzGerald 1984; and FitzGerald et al. 2000).

More recently, numerical modeling has been widely used and has been proved to be useful to study morphological behavior of complex coastal environments, including tidal inlets (e.g. Bertin et al. 2009; Cayocca 2001; Chen et al. 2015; Dissanayake et al. 2009; de Vriend et al. 1993; Herrling and Winter 2014; Nahon et al. 2012; Ridderinkhof et al. 2016; van Leeuwen et al. 2003). Today, medium to long-term coastal behavior can be investigated using process-based morphodynamic models (de Vriend et al. 1993; Roelvink and Reniers 2012; van der Wegen et al. 2010; Winter 2006). Such model simulates the non-linear interaction between currents; sediment transport and bed level changes at real world scales and may therefore overcome limitations of coastline models and flume experiments. Recent advances in numerical morphodynamics models allow simulations over very large spatial and temporal scales (Roelvink 2006; Dissanayake et al. 2009; van der Wegen et al. 2010). In the absence of sufficient observational data, systematic and schematic numerical simulations are assumed to be able to provide insight into medium to long-term coastal evolution (Daly et al. 2011).

Most studies have considered the impact of waves and tides to the development of ebb tidal deltas. Fewer studies have considered the impact of river discharge on the development of ebb shoals and inlet migration. This chapter investigates the seasonal varying hydrodynamics and sediment transport of the inlet and adjacent coasts due to a seasonal varying river discharge and wave climate. This study uses a 2DH process-based morphodynamic numerical model (Delft3D) and schematized wave conditions and river discharge.

2 Methodology

The investigation of the seasonal varying hydrodynamics and sediment transport of the inlet and adjacent coasts due to a seasonal varying river discharge and wave climate requires a comprehensive model. A 2DH process-based numerical morphodynamic model (Delft3D), which consists of Delft3D-WAVE and Delft3D-FLOW, is used to simulate hydrodynamics of river flows, tides, sediment transport at the inlet and its adjacent coasts simultaneously. In this section, the numerical model will first be introduced and then the details of the model setup and hydrodynamic settings will be discussed. An overview of the simulations is finally provided.

2.1 The Numerical Model

The modeling system Delft3D (Deltares 2014) solves the shallow water equations. The systems of equations consist of the equations of horizontal motion, with turbulence models to close the system of mean flow, the continuity equation, and the sediment transport equations. The details of the model have been described in e.g., Lesser et al (2004) and van de Wegen and Roelvink (2008). The spectral wave model SWAN in Delft3D-WAVE (Booij et al. 1999, and Ris et al. 1999) may run in stationary mode to simulate the wave propagation and deformation from offshore to nearshore. The hydrodynamics module (Delft3D-FLOW) is coupled to Delft3d-WAVE through the exchange of relevant parameters. The wave parameters and the forcing terms associated with the wave radiation stresses computed by Delft3D-WAVE module are used as input for the Delft3D-FLOW module to compute wave-driven currents, enhanced turbulence, bed-shear stress and sediment stirring by wave breaking. Then at each interval of one hour has been reached by FLOW, the water level, current velocities and bottom elevation from the Delft3D-FLOW are used as input to computation in Delft3D-WAVE.

The sediment transport formulation of van Rijn (1993) is used. The total sediment transport is calculated as the sum of both bed load and suspended load transport. Suspended sediment transport is treated above a reference height and calculated by a depth-average advection-diffusion equation, whereas the bed load is treated below that reference height.

2.2 Model Setup of Cua Dai Inlet

The computational domain of the model has been developed to represent the Cua Dai inlet which includes the open sea, the inlet and part of the river (Fig. 2). Three nested grids are used that range from a large regional model to Cua Dai inlet with decreasing spatial dimensions and increasing gird resolutions. The largest model with grid cell resolutions of 1500 m covers almost the entire central coast of Vietnam with 125 km in width and 190 km in length. This model was used to generate water level time series at the boundaries of the flow model. The wave model grid extends about 30 km in both northward (up to Son Tra mountain) and southward direction from the Cua Dai inlet to allow the proper development of waves in the domain of interest. The finest flow model extends to Nong Son hydrology station where the observed river discharge is available. Detailed bathymetry at the river area is derived from Vo (2015). Bathymetric data near the coast and inlet areas are collected in 2014 from measurement. The extended bathymetry at the open sea is derived from GEBCO.

The boundary conditions of the regional model are extracted from the global ocean tide model TPXO8.0. Thirteen tidal constituents (M2, S2, N2, K2, K1, O1, P1, Q1, MF, MN, M4, MS4 and MN4) are applied to generate tidal conditions at the boundaries of the regional model. This model is calibrated using the measured tide

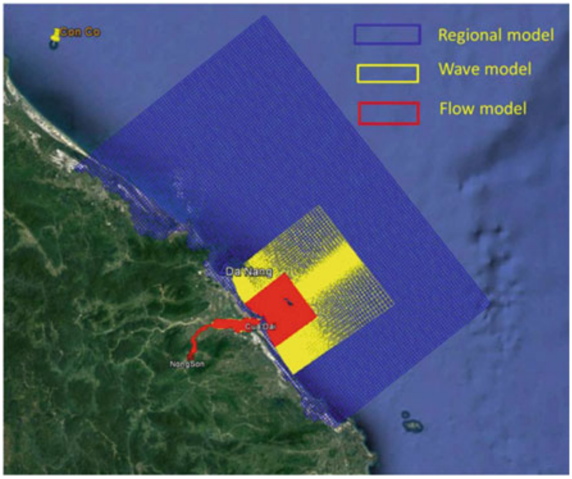

Fig. 2 Model domain including wave model domain and flow model domain

time series measured from the station at Da Nang near to Son Tra mountain. Then the regional model is nested to generate the boundary conditions for the flow model. The results of the flow model are validated with water level and velocity measured at Cua Dai inlet.

Wave forcing at the sea boundary in the wave model was extracted from the National Oceanic and Atmospheric Administration (NOAA) Wave Watch III archives at grid point (16.0°N, 109.0°E) in the period 2005–2013. Fresh water from Thu Bon River that flows into Cua Dai inlet was implemented at the river upstream boundary using the monthly average discharge during period 1977 to 2008. Measured discharge time series were obtained at the Nong Son station.

The sediment transport formulation of van Rijn (1993) is used for computing sediment transport by waves and currents. The simulations were performed with a median sediment diameter (D50) of 0.2 mm, a sediment density of non-cohesive sand of 2650 kg/m^3. A uniform value of 5 m of initial sediment layer thickness at bed is used as default in Delft3D.

2.3 Model Simulations

To test the influence of seasonal waves and seasonal river flow on hydrodynamics and sediment transport at the inlet and its adjacent coasts, this study choose to simulate 6 different conditions that represent winter and summer and one extreme flood event. Details can be found in Table 1. This selection is based on the integrated analysis based on both hydrology and wave climate from Do et al. (2018). For each condition the residual sediment transport patterns were computed and compared. The first five cases are simulated with the same duration of one month and the extreme flood event is simulated in 4 days representing the average time flood in this area.

Table 1 Overview of structure of the morphodynamic simulation considering seasonal waves and seasonal river discharges

Case		River discharge	Wave height	Wave period	Wave direction
		Q (m^3/s)	Hs (m)	Tp (s)	θ (°)
Winter season	Run 1	168	1.25	7.9	60 (ENE)
	Run 2	634	1.25	7.9	60 (ENE)
	Run 3	1037	1.25	7.9	60 (ENE)
Summer season	Run 4	88	0.75	6.42	60 (ENE)
	Run 5	88	0.75	6.4	135 (SE)
Extreme flood event	Run 6	10,600	1.25	7.9	60 (ENE)

3 Results and Discussion

This section firstly presents the results of the hydrodynamics (e.g. water level and velocity at the inlet). Secondly, the results of the alongshore sediment transport at the adjacent coasts are presented and discussed. Thirdly, the results of sediment transport through the mouth are presented and discussed. Fourth, the sediment transport pattern around the ebb tidal delta is presented and discussed. Finally, the morphological feedback around the ebb tidal delta and adjacent coast is presented and discussed.

3.1 Hydrodynamics Results

The regional model is calibrated with measurement of the water level at Da Nang station. Then flow model is also validated with observed data of water level and velocity that was measured in Cua Dai inlet. Figure 3 shows water levels computed by the model and measured data extract from global tides at Da Nang station during a one month period.

Figures 3, 4 and 5 show the comparison of observed and simulated water levels and velocities at Cua Dai inlet. Although the observed velocities are higher than compared to simulated data, the computed water level agrees well with observed data. These plots show that in general the level of agreement between observed and simulated data is quite good. Therefore the model is used to analyze the sediment transport pattern.

3.2 Longshore Sediment at Adjacent Coasts

The longshore sediment transports (LST) computed over one month for each condition during the summer months and the winter months are computed by defining 39

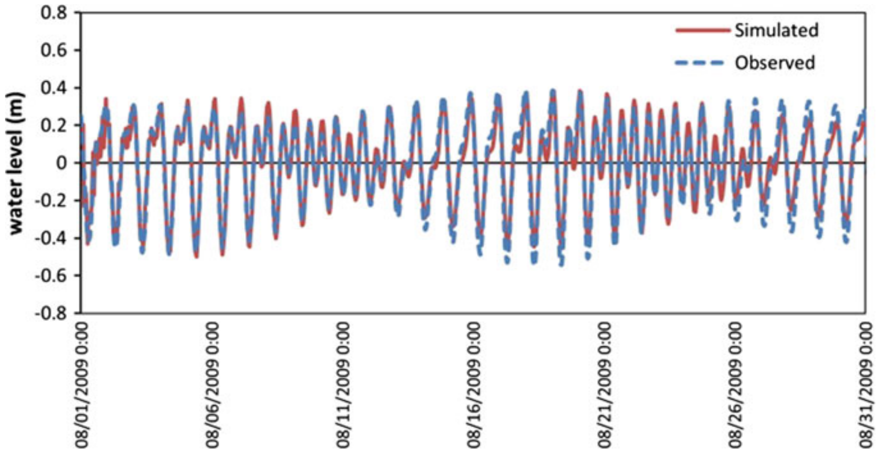

Fig. 3 Observed and simulated water level at Da Nang station

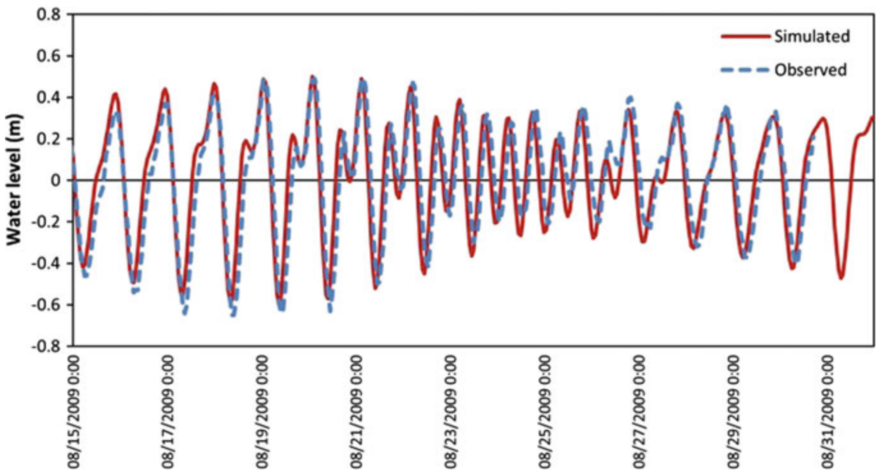

Fig. 4 Observed and simulated water level at Cua Dai inlet

transects in which 20 transects are at the north coast and the other 19 transects are at the south coast. These transects are chosen as the same position that were used to estimate LST induced by wave in Do, de Vries and Stive (2018). Positive values indicate southward transport whereas negative values indicate northward transport. The resulting sediment transports within one month are shown at the cross-sections for the different cases in Figs. 6 and 7.

In the case of ENE waves (60° to north) during the winter (Fig. 6) and the summer (Fig. 7a) the LST at the northern coast, close to the inlet is generally directed to the south, whereas the LST is direct to the north father from the inlet. There is a transport

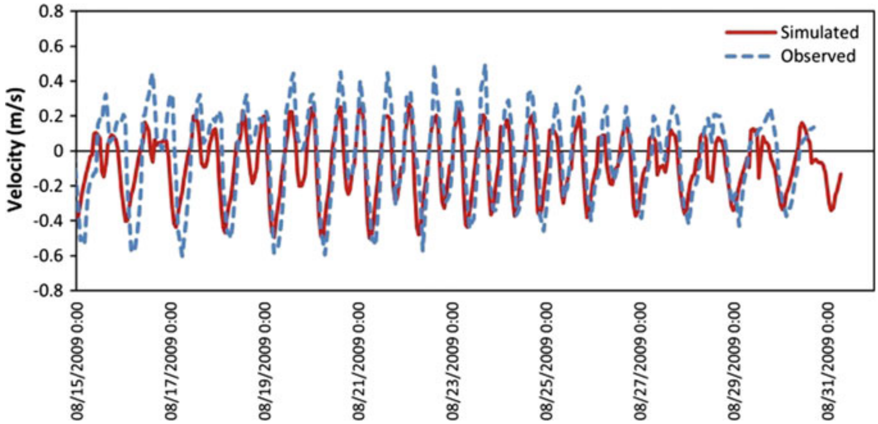

Fig. 5 Observed and simulated depth average velocity at Cua Dai inlet

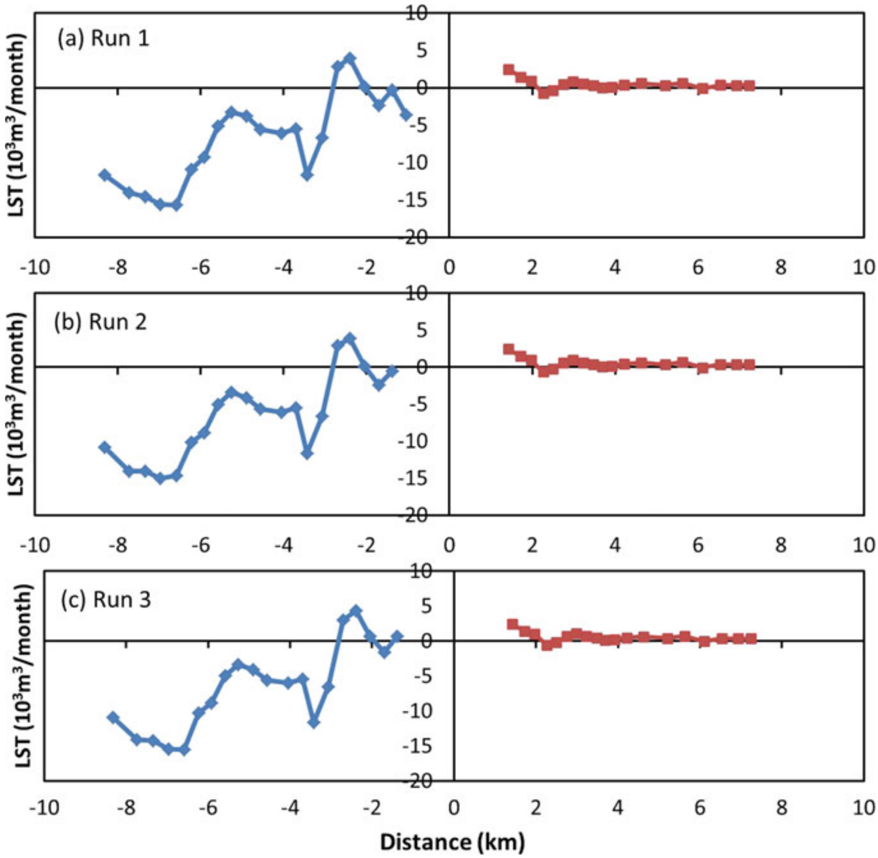

Fig. 6 Longshore sediment transport during the winter with different cases (Run 1, Run 2, and Run 3 as in Table 1)

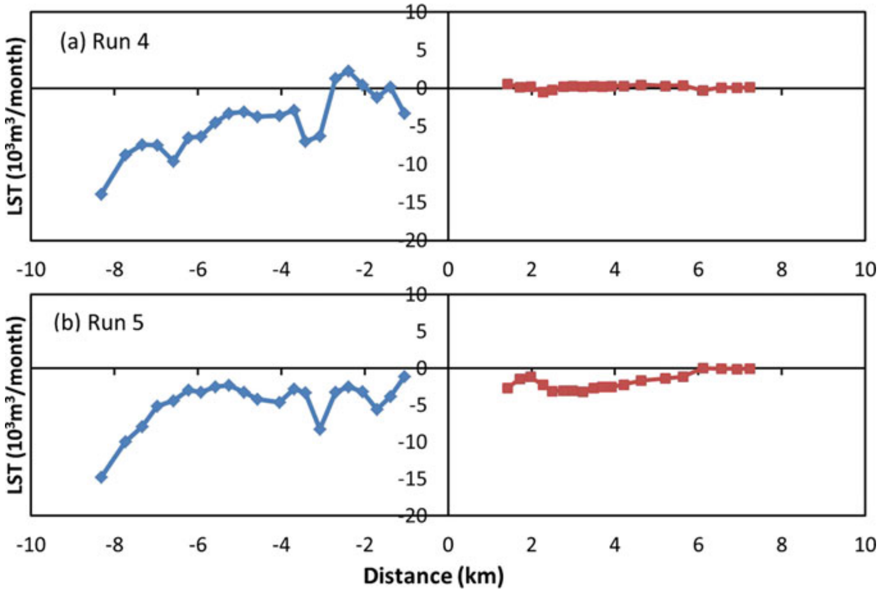

Fig. 7 Longshore sediment transport during the summer with different wave conditions (Run 4 and Run 5 as in Table 1)

diversion point at approximately 3 km to the north. Generally, at the northern coast the LST increase from the inlet to north, whereas at the southern coast the LST decrease from the inlet in the south direction.

For the offshore waves from the SE (135° to the north), the LST is generally towards the northern on both sides of the inlet (Fig. 7b). At the northern coast, the LST slightly increases from the inlet to the north, whereas at the southern coast the LST decreases significantly from the south in direction of the inlet. At around kilometer 6 at the northern coast, the LST significantly increase in the direction to the north. In general, the LST pattern induced by waves, tides and river discharge are similar when compared with the results calculated by Do, de Vries and Stive (2018) LST induced only by wave. The model results show that tides and river discharge do not impact directly on LST at the adjacent coasts.

The extreme flood event has strong impact on the sediment pattern at both southern and northern coast. At the northern coast there is a transport divergent point at approximately 3 km from the inlet to the north as ilustrated in Fig. 8. This phenomenon has found similar results of LST during the winter season when the ENE waves dominate (Do et al. 2018).

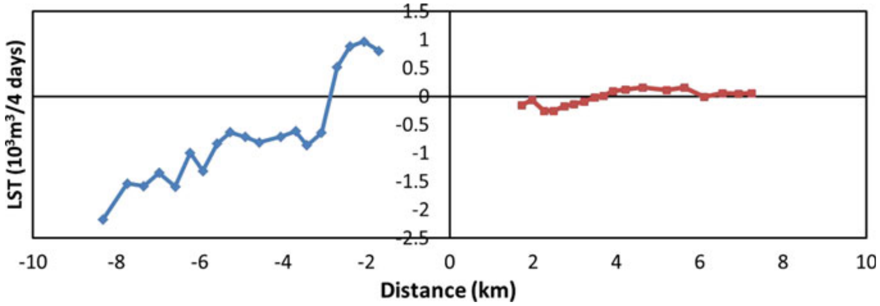

Fig. 8 Longshore sediment transport during the extreme flood event (Run 6 in Table 1)

3.3 *Sediment Transport Through the Mouth*

Sediment transport capacities through the inlet were investigated by comparing the cumulative sediment transport. Figure 9 shows the influence of different waves and river discharges on the sediment transport through the inlet within one month period. Negative values indicate export sediment whereas positive values indicate import sediment. Generally, the inlet experiences sediment import into the estuary, except in the case of the extreme flood event when the river discharge is extremely large. Run 1, 2 and 3 show clearly the impact of river discharge on sediment transport through the inlet. The increasing river discharge lead to less sediment import into estuary. This can be explained wave induced sediment supply to the inlet and the mainly tides and river discharges induced ebb flow capacity to transport the sediment from the

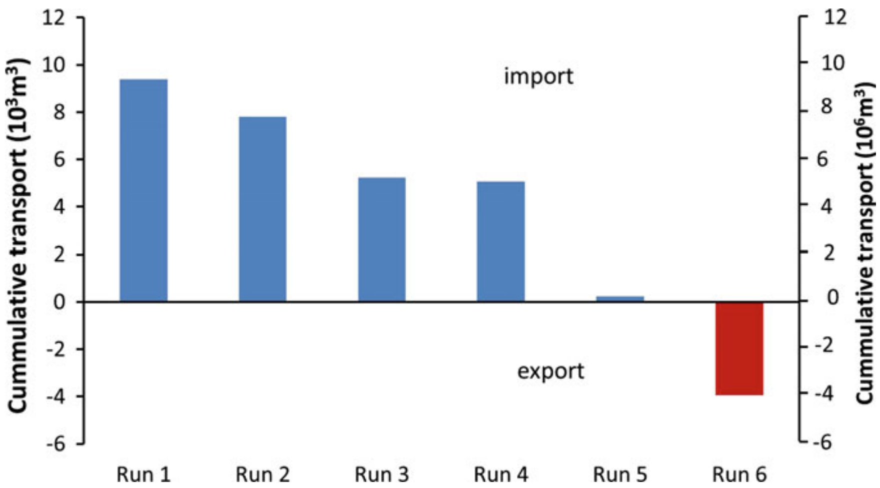

Fig. 9 Cumulative sediment transport through the inlet for varying waves conditions and river discharges

inlet. Therefore when the export sediment induced by tide and river is higher than the import sediment induced by waves the inlet is becoming export sediment.

Figure 9 also shows that waves approaching from both SE and ENE directions cause different magnitudes of sediment import into the estuary. Simulations show that waves coming from the ENE (run 4) contribute to larger sediment import than waves coming from the SE (run 5).

3.4 Sediment Patterns

Sediment transport patterns in the estuary and ebb tidal delta during difference cases in the winter and the summer are shown in Fig. 10. The pattern of sediment transport is quite complex because the flow responds to the combined forcing of tides, river flow, waves, and estuarine circulation. The influence of waves is particularly noticeable in the seaward side of the ebb tidal delta. For the waves coming from the ENE during the winter (Fig. 10a, b, and c), high sediment transport in landward direction can be found around the seaward side of the ebb tidal delta especially at the southward side. At the northward side of ebb tidal delta, the direction of sediment transport toward to the north however, the magnitude depends on the river discharge. The higher sediment transport to the north correspond to the larger river discharge (Fig. 10c) when the case of river discharge of 1037 m^3/s. For the lower river discharge during the summer season (Fig. 10d) the sediment transport is less than compare to other cases. At the landward side of ebb tidal delta there is an interaction between sediment import and sediment export due to river flow, tide and current induced by waves. At the northern side of the coast near the inlet the sediment transport toward to the inlet.

Sediment transport patterns in the estuary and ebb tidal delta during different cases in the summer are shown in Fig. 10d and e. When waves come from the southeast direction (Fig. 10d); sediment transport around ebb tidal delta is tending toward to the North especially at southern side of ebb tidal delta. This results support the results of LST induced by SE waves in the northern direction at the southern coast. Moreover, this result also explains why the sediment import into the estuary induced by SE waves is smaller (or nearly no import) than the import sediment induced by ENE waves. The sediment patterns induced by the ENE waves present the sediment transport in landward direction whereas the SE waves induce sediment in northern direction.

The flush of sediment through the inlet and even ebb shoal is clearly visible in the case of an extreme flood event (Fig. 10f). During the extreme flood event, large amount of sediment flush out from estuary and mainly sediment transport direct to the south. This pattern agrees to our 2nd hypothesis (Fig. 1b), the dominant flow is southwards thus the southern coast is benefiting from sediment bypassing.

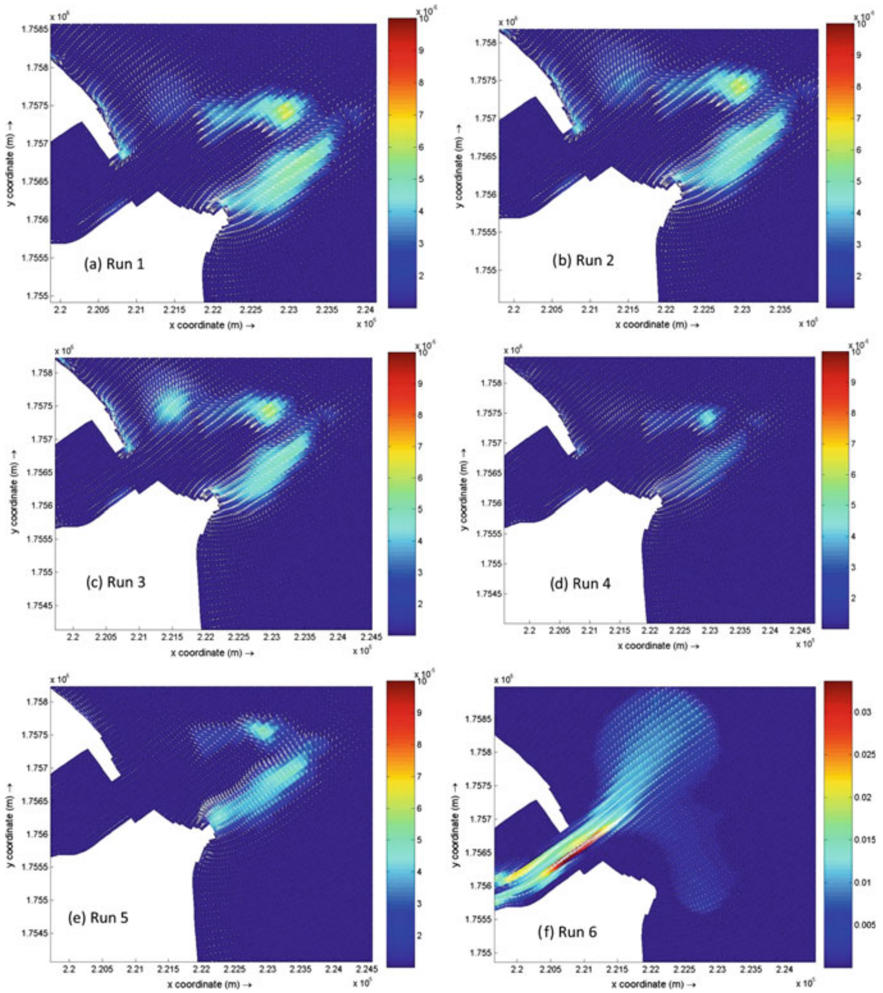

Fig. 10 Mean total sediment transport during one month for all the cases (vectors indicate direction and color map indicate the magnitude, scale on the right)

3.5 Pattern of Erosion and Deposition

Figure 11 shows the erosion/sedimentation pattern for the one month simulation period for the winter/summer cases and 4 days for extreme flood event. The first three cases during the winter exhibit similar erosion/sedimentation patterns. Outside of the ebb tidal delta erosion is shown whereas inside sedimentation is shown. The outside of the ebb tidal delta is affected by wave induced onshore sediment transport. At the inside of the ebb tidal delta, wave induced sediment transport diminishes and consequently erosion appears outside and deposition appear inside the ebb tidal

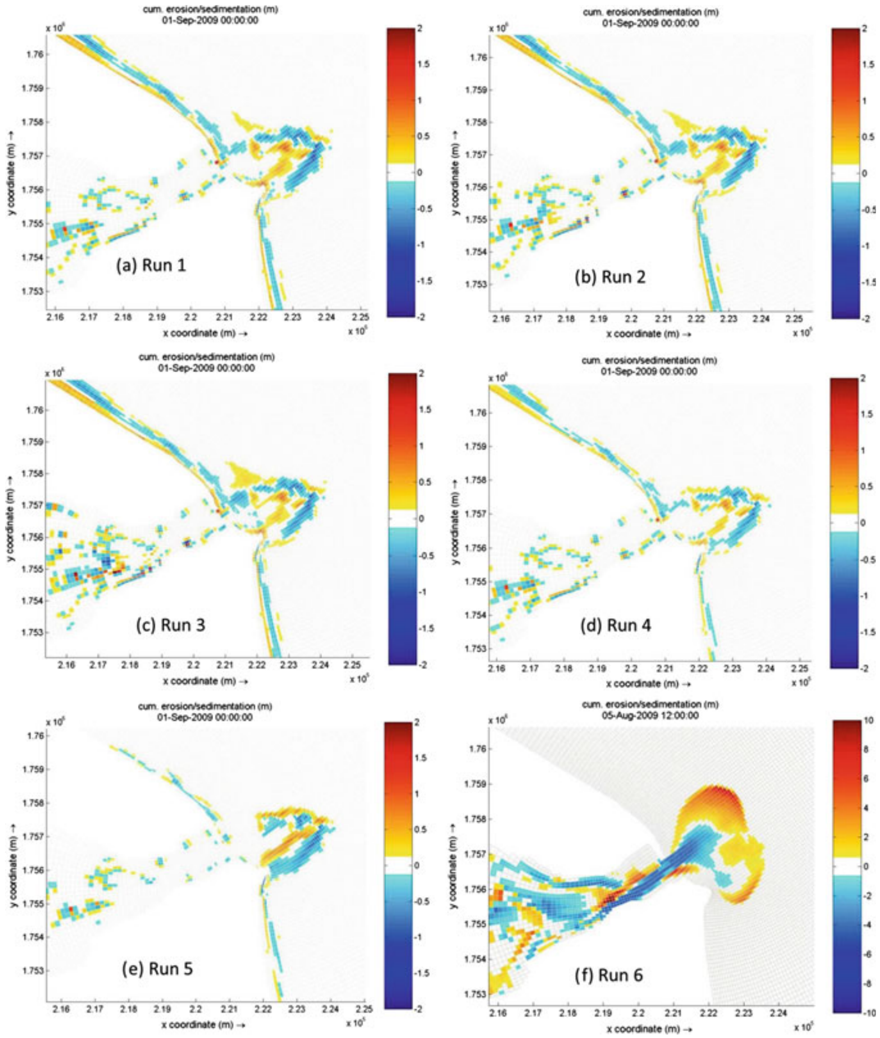

Fig. 11 Modelled erosion/deposition of ebb tidal delta and adjacent coast (negative values indicate erosion and positive values indicate sedimentation)

delta. The sedimentation inside of the ebb tidal delta may originate from the outside of the ebb tidal delta or from river supply. At the north of the ebb tidal delta, sedimentation occurs in all cases considering the winter season. The larger sedimentation corresponds to the larger river flood (Fig. 11c). During the summer, especially when waves are coming from SE and river discharge is very small, this area experiences no sedimentation. The morphology change of the inlet throat is less effected by variability in wave conditions because wave energy is dissipated at the shallow ebb-tidal shoals. There is only large sedimentation at the northern side of the inlet throat. The littoral drift induced by waves and tides along the northern coast supplies sediment to the inlet throat leading to the sedimentation at the northern side to the inlet throat. This can explain the results of sediment import through the inlet in almost all cases in Fig. 9. In the deep part of the channel inlet, the river flow is strong enough to carry out and supply sediment to the ebb tidal delta. The results of the model simulations reveal that the morphological changes mainly occur on the ebb tidal delta during normal conditions in the winter and the summer. Only the extreme flood event has large influences on channel inlet morphology when the river discharge become dominant thus the inlet channel and ebb-tidal delta are scoured and the longshore sediment transport is interrupted.

4 Conclusions

Seasonal variations in river flow and wave climate, and long-term geomorphological developments make Cua Dai inlet a very complex seasonal varying tidal inlet. This study focused on understanding the effect of seasonal variations in wave conditions and seasonal river discharge. The effects of those on the resulting hydrodynamics and sediment transports through the inlet and at the adjacent coasts are investigated. Hydrodynamics and sediment transport at Cua Dai inlet and its adjacent coasts were simulated using Delft3D. Six scenarios with varying dominant wave conditions in the winter and the summer are executed in combination with various river discharge classes that correspond to the dry, wet and flood seasons.

The results from validation in hydrodynamics, e.g. water levels and velocities between simulated and observed indicate the model agree well.

The results from the alongshore sediment transports at adjacent coasts indicate that the seasonal variation in wave climate has a strong influence on the sediment transport pattern. Waves from the SE during the summer time generally induced alongshore sediment transport (LST) to the north, whereas the waves from the ENE create LST to the south. At the northern coast, the LST increase from the inlet to the north. At the southern coast, the LST decrease from the south in the direction of the inlet. The model shows that the patterns of LST are agree well with the LST induced only by waves from Do et al. 2018.

The simulated sediment transports through the mouth show clear variations due to seasonal variability of the river discharge and wave climate. Waves coming from the ENE at the northern coast induce longshore sediment toward the inlet and supply sediment to the inlet. The river flow helps to carry out and supplies sediment to the ebb tidal delta. When the river becomes dominant (extreme flood event) this leads to export of sediment. The results also indicate the influence of wave directions that influence the magnitude of sediment imported into the estuary. Waves coming from the ENE contribute to larger sediment import than waves coming from the SE.

The results from sediment patterns and morphological changes around the ebb tidal delta indicate that the influence of waves are particularly noticeable on the seaward side of the inlet and less in the landward side of the inlet due to the interaction between the tides and river flow. Waves generally induce landward sediment transport. When the river flow is large during the flood season, river process are dominant leading to the system to flush out sediment through the estuary and even ebb tidal delta. Especially during the simulated flood event, sediment fluxes are large at the estuary and inner ebb tidal delta.

In a quantitative sense the simulation results are still insufficient to fully explain the channel shifting from north to south. In a qualitative sense however, the model results of this study show a large impact on the seasonal variation in waves and river discharge on sediment transports at Cua Dai inlet and its adjacent coasts. Especially the extreme flood event creates a large sediment export through the inlet and ebb tidal delta.

Acknowledgements This study is part of the PhD of the first author funded through an Erasmus Mundus Mobility Program with Asia (EMMAsia2014) and supported by Delft University of Technology. The authors gratefully acknowledge their co-author dr Nguyen Trung Viet of Thuy Loi University for providing bathymetry data in 2014 for this study.

References

Bertin, X., Fortunato, A. B., & Oliveira, A. (2009). A modeling-based analysis of processes driving wave-dominated inlets. *Continental Shelf Research, 29,* 819–834.

Booij, N., Ris, R. C., & Holthuijsen, L. H. (1999). A third generation wave model for coastal regions 1. Model description and validation. *Journal of Geophysical Research, 104*(04), 7649–7666.

Cayocca, F. (2001). Long-term morphological modelling of a tidal inlet: The Arcachon Basin, France. *Coastal Engineering, 42,* 115–142.

Chen, J. L., Hsu, T. J., Shi, F., Raubenheimer, B., & Elgar, S. (2015). Hydrodynamic and sediment transport modeling of New River Inlet (NC) under the interaction of tides and waves. *Journal of Geophysical Research: Oceans, 120*(6), 4028–4047.

Daly, C. J., Bryan, K. R., Roelvink, J. A., Klein, A. H. F., Hebbeln, D., & Winter, C. (2011). Morphodynamics of embayed beaches: the role of wave conditions. *Journal of Coastal Research, 64,* 1003–1007.

de Vriend, H. J., Zyserman, J., Nicholson, J., Roelvink, J. A., Pe´chon, P., & Southgate, H. N. (1993). Medium term 2DH coastal area modeling. *Coastal Engineering, 21,* 193–224.

Deltares. (2014). *User manual Deflt3D FLOW*. Online available from: https://oss.deltares.nl/documents/183920/185723/Delft3D-FLOW_User_Manual.pdf.

Dissanayake, D. M. P. K., Roelvink, J. A., & van der Wegen, M. (2009). Modelled channel patterns in a schematized tidal inlet. *Coastal Engineering, 56,* 1069–1083.

Do, T. K. A., de Vries, S., & Stive, M. J. F. (2018). Beach evolution adjacent to a seasonally varying tidal inlet in central Vietnam. *Journal of Coastal Research, 34*(1), 6–25.

FitzGerald, D. M. (1984). Interactions between the ebb-tidal delta and landward shoreline: Price Inlet, South Carolina. *Journal of Sedimentary Research, 54*(4), 1303–1318.

FitzGerald, D. M., Buynevich, I. V., Fenster, M. S., & McKinlay, P. A. (2000). Sand dynamics at the mouth of a rock-bound, tide-dominated estuary. *Sedimentary Geology, 131,* 25–49.

Herrling, G., & Winter, C. (2014). Morphological and sedimentological response of a mixed-energy barrier island tidal inlet to storm and fair-weather conditions. *Earth Surface Dynamics, 2,* 363–382.

Hubbard, D. K., Oertel, G. F., & Nummedal, D. (1979). The role of waves and tidal currents in the development of tidal inlet sedimentary structures and sand body geometry: Examples from North Carolina, South Carolina and Georgia. *Journal of Sedimentary Research, 49*(4), 1073–1092.

Komar, P. D. (1996). Tidal –inlet processes and morphology related to the transport of sediments. *Journal of Coastal Research, 23,* 23–45.

Lesser, G. R., Roelvink, J. A., van Kester, J. A. T. M., & Stelling, G. S. (2004). Development and validation of a three-dimensional morphological model. *Coastal Engineering, 51,* 883–915.

Nahon, A., Bertin, X., Fortunato, A. B., & Oliveira, A. (2012). Process-based 2DH morphodynamic modeling of tidal inlets: A comparison with empirical classifications and theories. *Marine Geology, 291–294,* 1–11.

Oertel, G. F. (1972). Sediment transport on estuary entrance shoals and the formation of swash platforms. *Journal of Sedimentary Petrology, 42*(4), 857–863.

Oertel, G. F. (1988). Processes of sediment exchange between tidal inlets, ebb deltas and barrier islands. In: D. G. Aubrey, L. Weishar (Eds.), *Hydrodynamics and sediment dynamics of tidal inlets*. *Lecture notes on coastal and estuarine studies* (Vol. 29, pp. 297–318). Berlin Heidelberg New York: Springer.

Ridderinkhof, W., de Swart, H. E., van de Wegt, M., & Hoekstra, P. (2016). Modeling the growth and migration of sandy shoals on ebb-tidal deltas. *Journal of Geophysical Research Earth Surface, 121,* 1351–1372.

Ris, R. C., Holthuijsen, L. H., & Booij, N. (1999). A third-generation wave model for coastal regions: 2. Verification. *Journal of Geophysical Research, 104*(C4), 7667–7681.

Roelvink, J. A. (2006). Coastal morphodynamic evolution techniques. *Coastal Engineering, 53,* 277–287.

Roelvink, J. A., & Reniers, A. (2012). A guide to modeling coastal morphology. *Advances in Coastal and Ocean Engineering, 12,* 274.

Robinson, A. H. W. (1975). Cyclical changes in shoreline development at the entrance to Teignmouth Harbour, Devon, England. In J. Hails & A. Carr (Eds.), *Nearshore sediment dynamics and sedimentation* (pp. 181–198). New York: Wiley.

Sha, L. P. (1989). Cyclic morphological changes of the ebb-tidal delta, Texel Inlet, The Netherlands. *Geology Mijnbow, 68,* 35–48.

van de Wegen, M., & Roelvink, J. A. (2008). Long-term morphodynamic evolution of a tidal embayment using a two-dimensional process-based model. *Journal of Geophysical Research: Oceans, 113,* C03016.

van der Wegen, M., Dastgheib, A., & Roelvink, J. A. (2010). Morphodynamic modeling of tidal channel evolution in comparison to empirical PA relationship. *Coastal Engineering, 57*(9), 827–837.

van Leeuwen, S. M., van der Vegt, M., & de Swart, H. E. (2003). Morphodynamics of ebb-tidal deltas: a model approach. *Estuarine Coastal and Shelf Science, 57,* 899–907.

van Rijn, L. C. (1993). *Principles of sediment transport in rivers, estuaries and coastal seas*. The Netherlands: Aqua publications.

Vo, N. D. (2015). *Deterministic hydrological modelling for flood risk assessment and climate change in large catchment. Application to Vu Gia Thu Bon catchment, Vietnam* (Ph.D. thesis), University Nice Sophia Antipolis.

Winter, C. (2006). Meseo-scale morphodynamics of the Eider Estuary: Analysis and numerical modelling. In *Journal of Coastal Research, SI 39 (Proceedings of the 8th International Coastal Symposium)* (pp. 498–503).