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SEASONAL BEHAVIOUR OF TIDAL INLETS IN A TROPICAL MONSOON AREA

by

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ABSTRACT

Morphodynamics of a tidal inlet system on a micro-tidal coast in a tropical monsoon influenced region is modelled and discussed. Influences of river flow and wave climate on the inlet morphology are investigated with the aid of process-based state-of-the-art numerical models. Seasonal and episodic behaviour of the inlet system under the influence of the forcing processes is then described, modelled and explained.

1. INTRODUCTION

The central coast of Vietnam is located in a tropical monsoon region and characterized as a microtidal, wave-dominated coastal environment. Tidal inlets in such condition are highly dynamic and variable under the influence of wave climate and river flow, which are seasonally varying according to the monsoon regime. Strong episodic influences of river flow discharge and wave action have been mentioned as the cause of seasonal closure of tidal inlets as found on microtidal coasts of India (Bruun 1986), Sri Lanka (Wikramanayake and Pattiarachchi, 1999), Japan (Tanaka *et al.*, 1996), Australia (Gordon 1990; Ranasinghe and Pattiaratchi, 1997, 1998, 1999, 2003), South Africa (Cooper, 1990, 1994; Largier *et al.*, 1992), USA (Elwany *et al.*, 1998), and Brazil (Moller *et al.*, 1996). Many river mouths and tidal inlets along the central coast of Vietnam also have characteristics of seasonal closure. During the flood season, river floods have strong influence on inlet morphology by scouring their channels and cutting through coastal barriers. In the dry season, wave action dominates over the tides and river flows. Wave-induced sediment transport eventually closes some inlets or river mouths. To get further insight into the processes and behaviour of tidal inlets in the central coast of Vietnam, this paper will present a study on morphodynamics of Hue tidal inlets as a specific case study.

1.1 Study area

The Tam Giang-Cau Hai lagoon is located in Thua Thien-Hue province in central Vietnam. This is a system of connected lagoons and two tidal inlets connecting to the South China Sea. The lagoon has a surface area of 220 km² and elongates 70 km in NW-SE direction along the coastline. The lagoon water body is separated from the sea by a system of sandy barriers and island barriers. It receives water from the Huong River Basin which has a catchment area of about 4400 km² and discharges to the sea through two tidal inlets: Thuan An in the north and Tu Hien in the south (**Figure 1**). Under the tropical monsoon climatic conditions, the morphology of the inlets is highly dynamic and variable. The tropical monsoon regime exerts its influence on tidal inlet morphology through the variation of river flow and wave climate into two distinct seasons of the northeast and the southwest monsoon winds. The historical morphological changes of the inlets can be seen in **Figures 2** and **3**.

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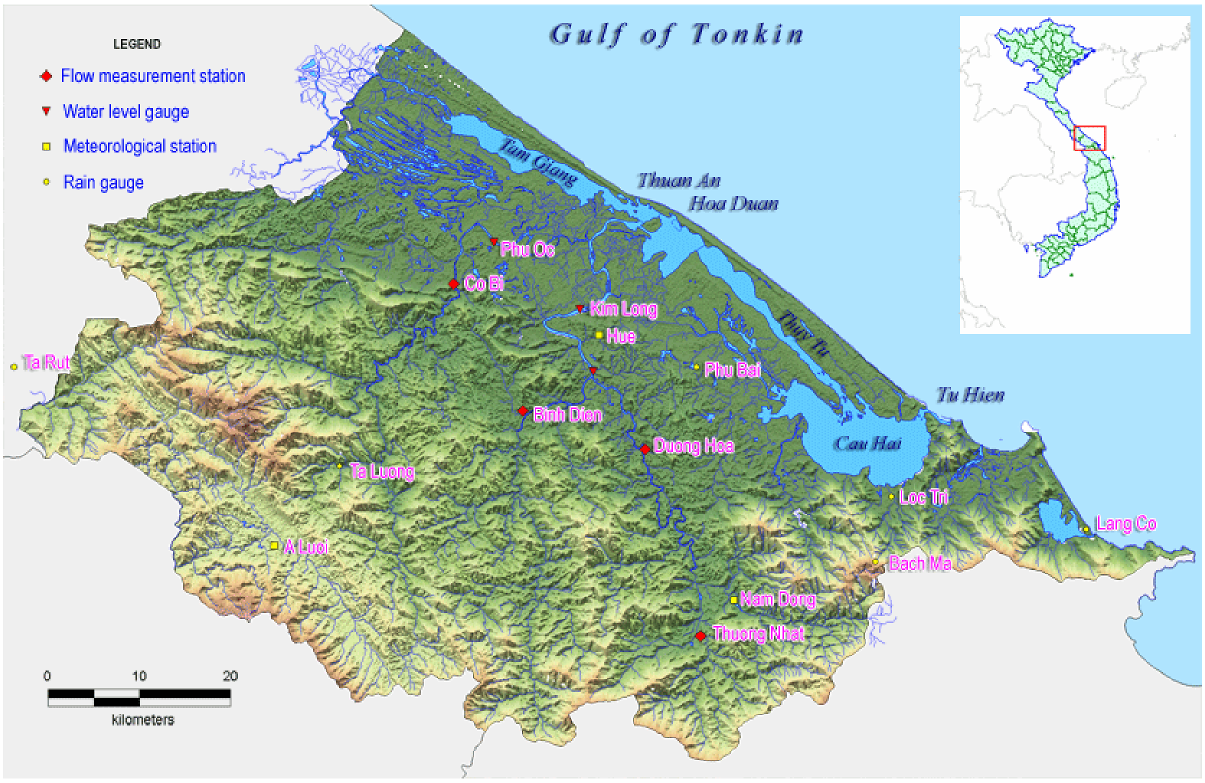


Figure 1: Map of the lagoon and inlet system in Thua Thien-Hue province, Vietnam

1.2 Tidal inlets

2.1.1 Thuan An inlet

In history, the lagoon has discharged to the sea through various arrangements of inlets and breaches. The main inlet nowadays is located at Thuan An. Its creation is dated back to 1404 as a natural breach on the sand barrier. Before that time, the discharge from the lagoon is solely via the Tu Hien inlet in the south. As soon as the Thuan An inlet opened, the Tu Hien inlet started to decline to a small inlet under natural closure processes, and the Thuan An inlet became naturally configured as the main inlet for discharging flood water from the lagoon. Natural seasonal closure and migration due to longshore sediment transport, subsequent storms and flooding, and human interventions make the inlet very dynamic and variable. From 15th to 19th centuries, various attempts have been undertaken to close the breach at this location with structures to maintain the Tu Hien inlet but all failed. Natural or artificial closure of the inlet restricted its ability to discharge the flood waters so this location remained vulnerable to subsequent storms and flooding. The breach was located at different places in different periods. But mostly it was located at the two weakest places of the sand barrier at Thuan An and Hoa Duan.

Under the main influences of river flows and waves, the ebb tidal delta is less developed and a flood tidal delta is almost not present. The ebb channels develop deeply inside the lagoons. **Figure 2** shows the historical changes of the inlet channel. The developement of the inlet channel may be influenced mainly due to high flow velocity of river floods but there is still no explaination on that. The normal width of the inlet is 350m and the depth of the channels is up to 12m. These dimensions of the channels are too large for flood tides of a small tidal range so flood tidal currents become too small to carry sediment to build up flood shoals and to create flood channels. On the ebb delta, terminal lobes are visible but flood channels on the ebb delta are not clearly distinguished.

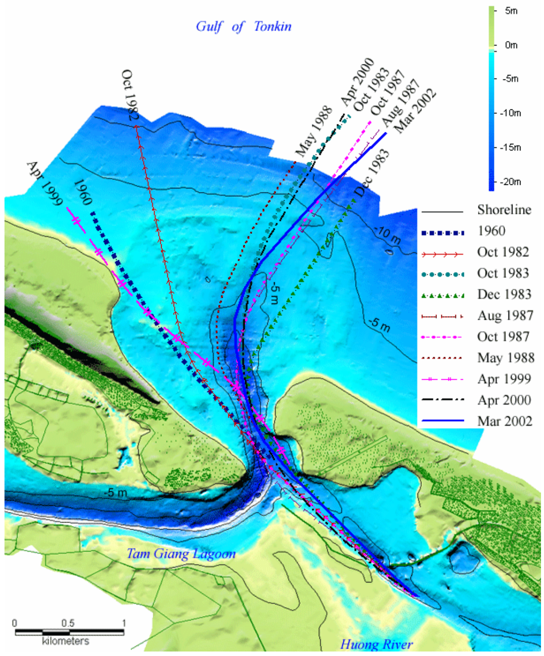


Figure 2: Bathymetry and historical changes of Thuan An channel

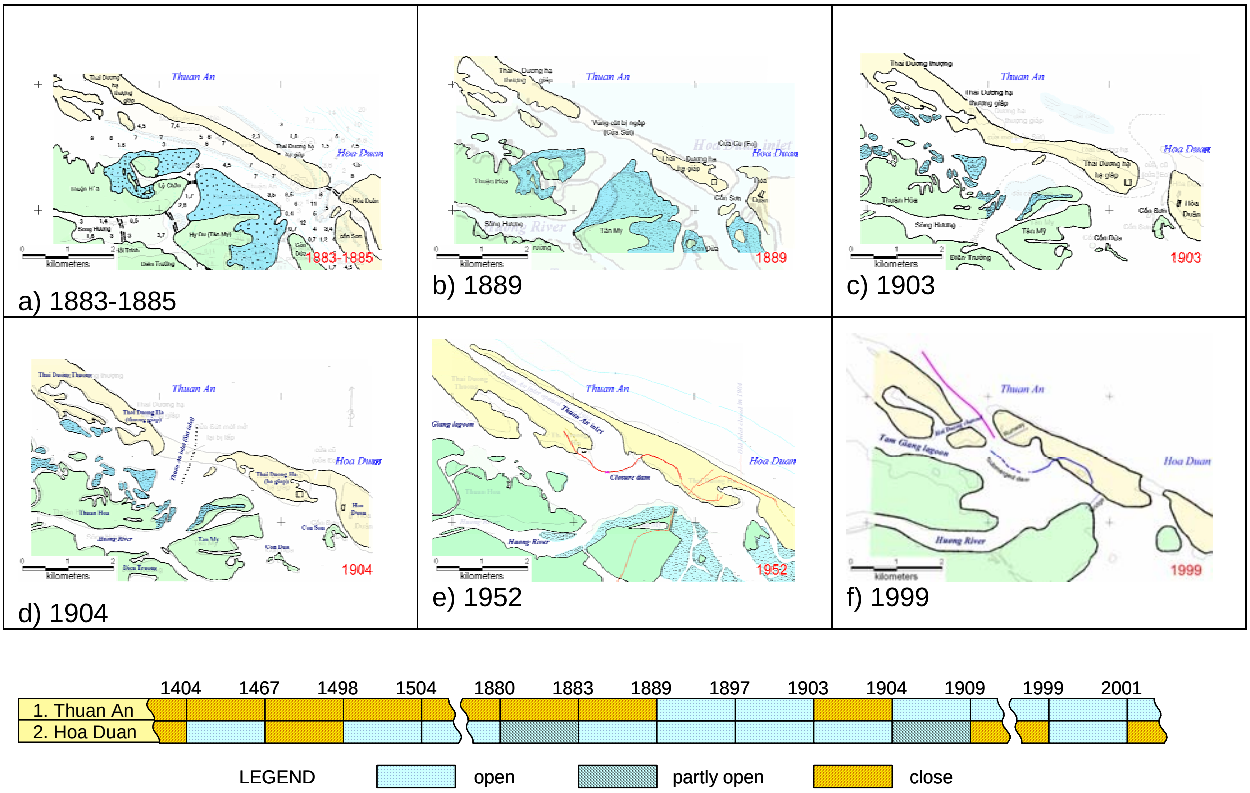


Figure 3: Historical development of Thuan An inlet

During the dry season, the inlet cross-sections become smaller, narrower and shallower. The Thuan An channel tends to migrate northward because the dominant long-shore sediment transport in the inlet area is in the southeast - northwest direction. The southeast sand spit can grow north-westward at a speed of about 15m/year (Hoi *et al.*, 2001). In the period from 1928 to 1953 when a closure dam was present, the tides could not enter the lagoon and the sand spit extended 4km further northwest (**Figure 3**e). River floods seem to be the main reason for the cutting of the sand bars and deepening of the inlet channels. The interruption of sand bypassing in the ebb delta due to floods may also be the cause for coastal erosion which propagates along the shore for several kilometers at both sides of the inlet. During a severe flood in 1999, the inlet became very wide and deep. After that it recovered with longshore sediment entering the channel from both sides. This led to a disturbed pattern of erosion and accretion that caused the northern dune to continue to retreat at a rate of about 10m per year in 2000-2002 with loss of a lighthouse and other properties. After which the retreat has again slowed down.

2.1.2 Tu Hien inlet

For centuries, the system had only one inlet located at Tu Hien. In 1404, one more inlet was opened at Thuan An. After the opening of the Thuan An inlet in 1404, the Tu Hien inlet has carried far less flow discharge and has gradually declined. The northern coast of the inlet is a sandy beach while the southern coast is a rocky shore, constrained and protected by a headland. Therefore the longshore sediment transport due to waves is mainly from the northwest direction.

Under actions of waves, littoral drift and river floods, the Tu Hien inlet is frequently changing and continues to migrate between Vinh Hien and Loc Thuy in a morphological cycle of about 9 years during which it is closed for more than half of the time. The cycle starts with a breakthrough of the sand barrier at Vinh Hien creating a new inlet during an extreme river flood. Due to the dominant wave induced littoral drift south-eastward, the northern sand spit of the inlet is accreting and extending in the southeast direction. When the inlet reaches the rocky headland at Loc Thuy near the cape of Chan May Tay, it declines and then closes to the last stage of its cycle (**Figure 4**).

At the first stage of the morphological cycle, normally the inlet has dimensions of 200 m wide and 3 m deep. But at the last stage of its cycle, it becomes a narrow and shallow channel which is about 4 km long, 50 m wide and 1 m deep.

Unlike the Thuan An inlet, the flood tidal delta of the Tu Hien inlet is well-developed. Flood shoals and marginal ebb channels are distinguished. Channels on the ebb delta are not clearly recognized except the main channel extending from the gorge. On the edge of the ebb tidal delta, a system of bypassing bars is also visible.

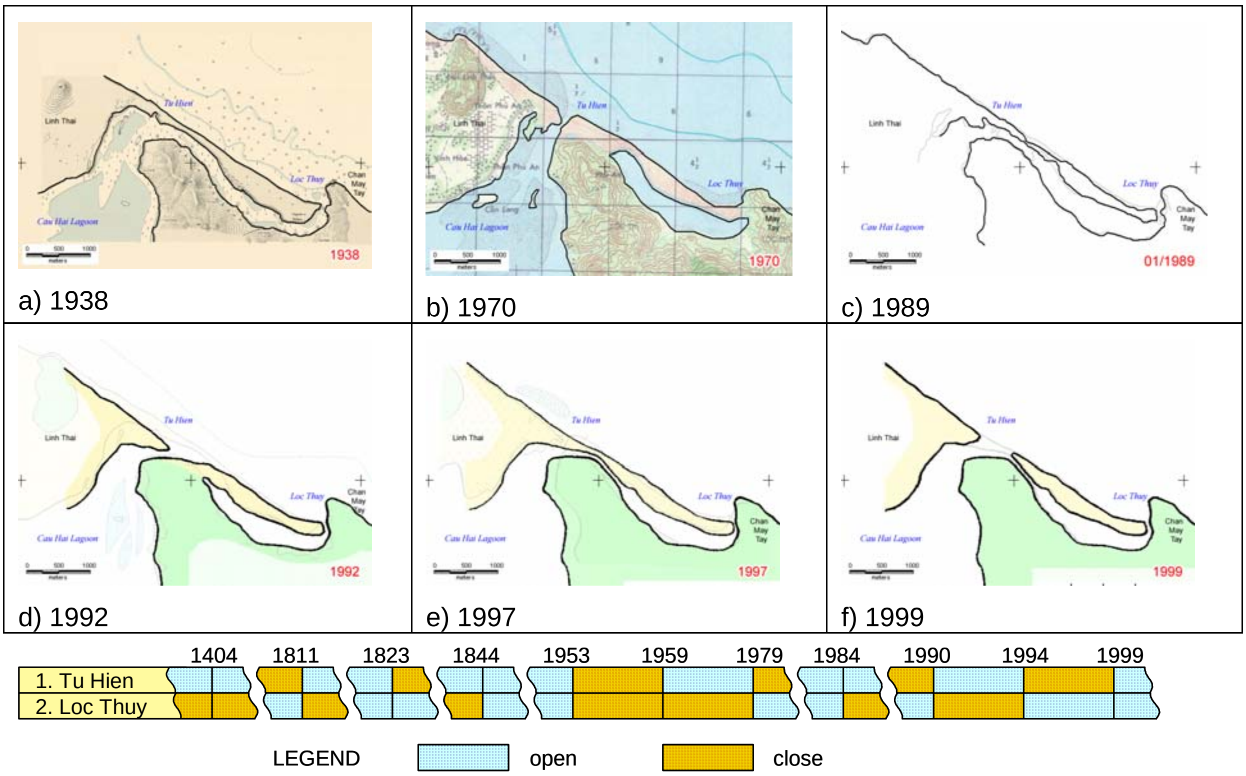


Figure 4: Cyclic evolution of Tu Hien inlet

2. MONSOON SEASONS

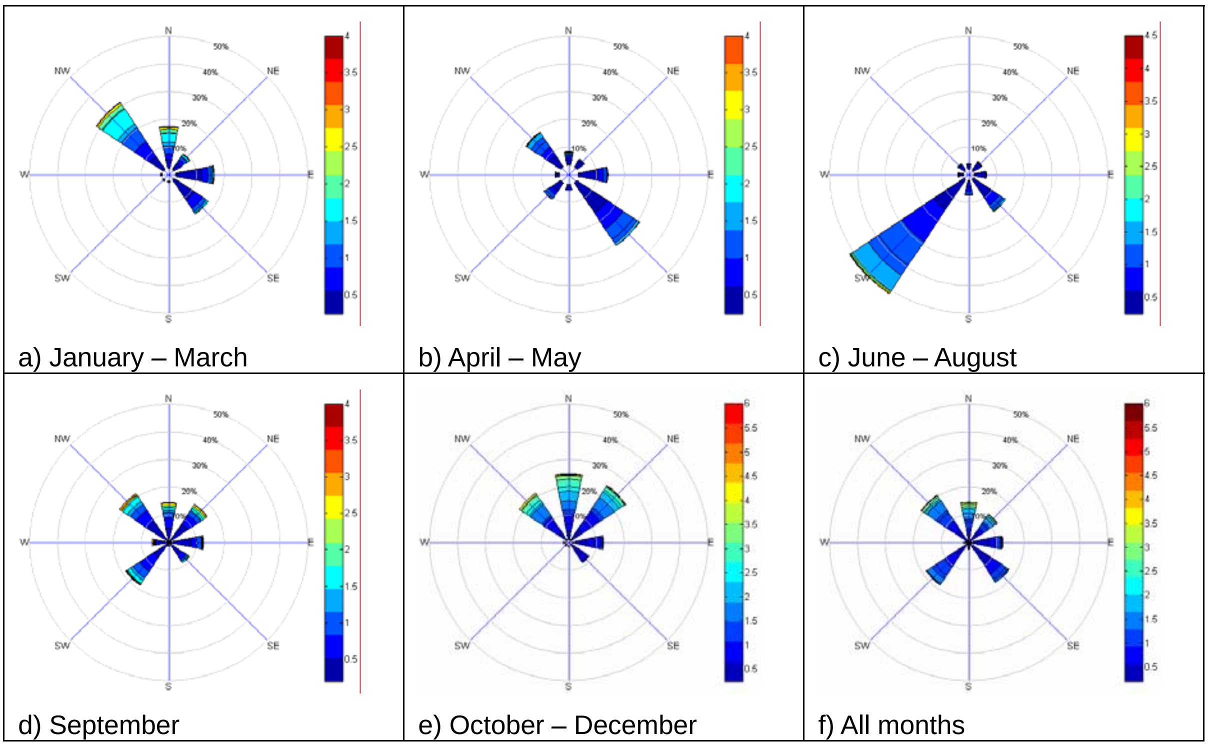
2.1 Northeast monsoon season

The northeast monsoon prolongs from mid-October through February. After crossing the warm and humid South China Sea, it brings abundant precipitation to the coastal mountains of Central Vietnam. During the period from early September through November, typhoons also commonly strike along this coastline. The typhoons drive in from the east and rapidly dissipate into rain-storms when spoiled by the Truong Son Mountain Range on the west. Northeast winds and typhoons create a ‘wet’ or ‘flood’ season lasting from September through December. Although the flood season lasts only four months, it accounts for more than 70% the amount of the basin annual rainfall of 3100 mm. Torrential rainfall on the highly steep topography creates severe floods in the Huong river basin and heavy flooding in the coastal lowland area. During the flood season, the peak discharge of the Huong River may reach 12000 – 14000 m^3/s (Tuan et al. 2001). The floodwater not only flows in the river channels but it also overflows the floodplain with a few meters water depth.

Due to the flood the water level raises rapidly, so that the water level difference at two sides of the inlets may reach about 2 m, creating very high flow velocity in the inlets and causing dramatic changes to the inlet morphology. When flood water level exceeds the crest level of the sand barrier at the critical locations, barrier breaching also may happen at the weakest points to allow additional discharges. These consequences can be seen in a flood that occurred in early November 1999. A tropical depression with a maximum rainfall intensity of 120mm/hour occurred that has produced a serious flood of the central coastal provinces of Vietnam. The flood has enormously scoured tidal inlet channels. The cross-sectional area of the Thuan An inlet has increased from 3250 m^2 to 6200 m^2, and the cross-sectional area of the Tu Hien inlet has been scoured from to 600 m^2 to 1800 m^2. The flood also breached the sand barrier at Hoa Duan to create a new inlet with a cross sectional area of 1750 m^2 (**Figure 3**f).

Flood flow transports sediment from the river basin to the lagoon and inlet areas. A numerical simulation result from SAPROF (JBIC, 2003) yields an sediment amount of 1.48 Mm^3/year transported through the Thuan An inlet to the sea by river floods. Coarse materials may be deposited in the ebb tidal deltas but fine wash-load would be dispersed by wave action and removed from the littoral shoaling zone.

Figure 5 shows the wave climate observed at Con Co Island situated 72 km offshore NNW of the Thuan An inlet. During the northeast monsoon season, northeast winds create a rough sea with dominant waves come from N, NE or NW. Northeast monsoon waves usually cause coastal erosion.



a) January – March
b) April – May
c) June – August
d) September
e) October – December
f) All months

Figure 5: Wave roses at Con Co Island based on 1992-2001 observations

2.2 Southwest monsoon season

During the remaining eight months of the year, river flow significantly diminishes making this period a 'dry' season, especially when the southwest monsoon takes over from May until September. The SW winds after passing the Truong Son Mountain Range have been dried out and become very hot, river flows become lowest. In this season, waves come from SE inducing longshore sediment transport northwestward on the coasts near the Thuan An inlet. Because the tidal range in the area is only 0.41 m (that is smallest along the Vietnamese coast), wave action becomes dominant in the inlet areas.

Characterized as micro-tidal wave dominated, the tidal inlets become unstable with shoals developing and sand spits migrating. Longshore sediment enters the Thuan An inlet and shoals its channel and ebb tidal delta hampering navigation. Prevailing longshore sediment transport from SE causes the inlet to gradually migrate northwestward (**Figure 3**e). In the Tu Hien inlet, because a rocky headland limits the coast just at the southern side of the inlet so the dominant sediment transport entering the inlet is mainly from the northwest direction. The northern sand spit gradually develops and grows southeastward (**Figure 4**). During the next flood seasons, if river flows cannot breach through the sand spit, the spit will continue to develop and pushes the channel to migrate southeastward. At the end of the inlet migration and development process, the entrance is relocated at Loc Thuy nearly 3 km south of the original location Tu Hien, the channel width decreases from 200 m to about 50 m and the depth decreases from 3 - 4 m to less than 1 m. This cyclic development usually takes many years. The last cycle took 9 years starting in 1990 at Tu Hien and relocated at Loc Thuy in the period 1994-1999 until the historical flood of November 1999 happened (**Figure 4**). According to Thanh et al. (2000), the morphologic cycle now becomes shorter.

3. NUMERICAL MODELS

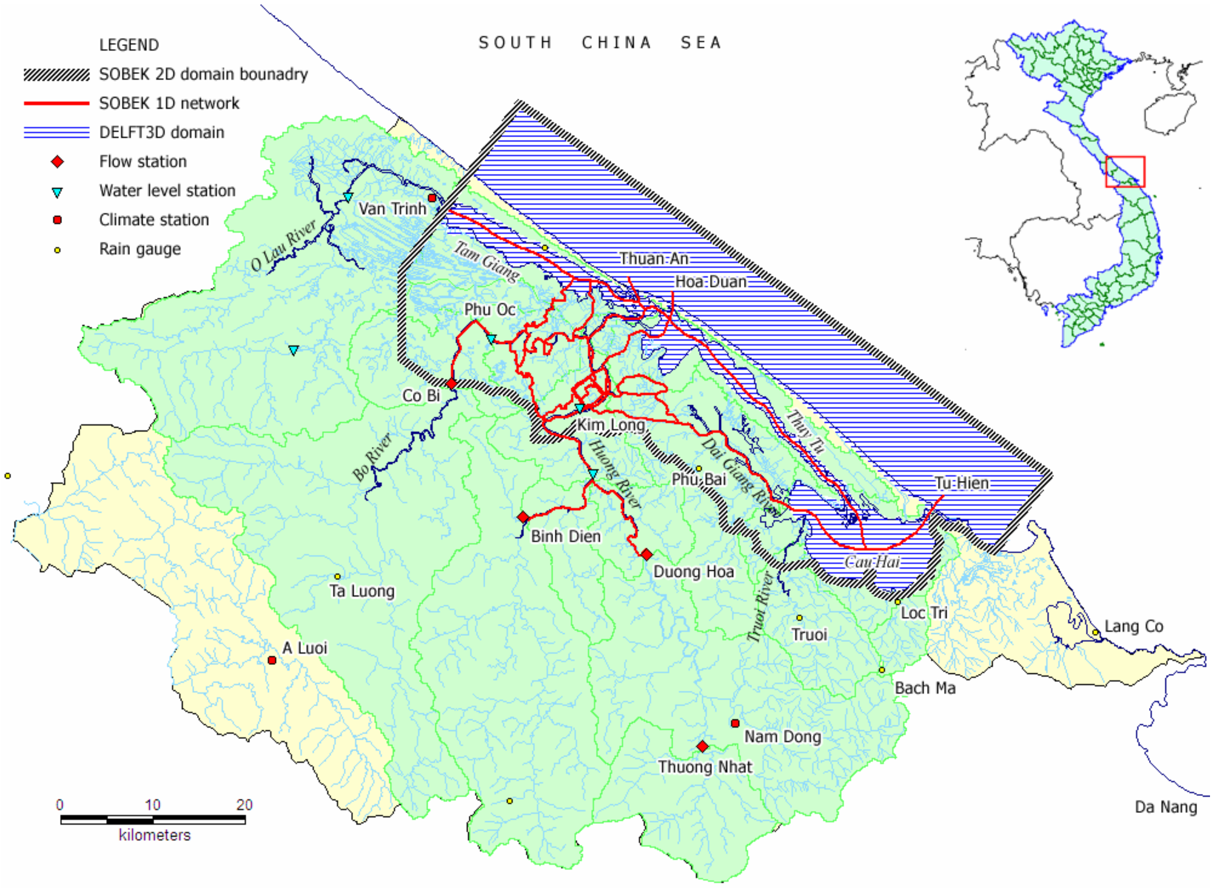


Figure 6: Numerical model domains of Hue coastal waters

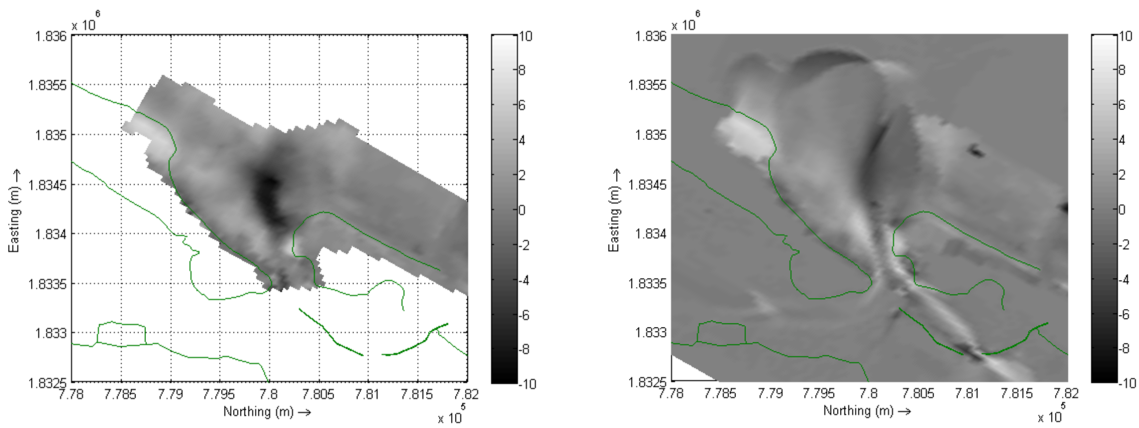
3.1 Hydrodynamic model for river flows

A numerical model of river flow hydrodynamics has been setup based on SOBEK-RURAL (WL | Delft Hydraulics, 2001) with the integration of a 1D module for river channel flow and a 2D module for overland flow on the floodplain (**Figure 6**). The 2D part of the model covers all the areas of the lagoon and the coastal lowland with a DEM of 200 m resolution. The 1D river channel network does not only superpose the DEM but also extends 45 – 65 km upstream to include the flow and water level stations so that the observations at these stations can be used for the upstream boundary conditions as well as for model calibration and verification. Downstream boundary conditions of the model are tidal water levels off the inlets. Upstream boundary conditions of the models are flow discharges at the observation stations. The model has been calibrated and validated for some flood events including the floods of November 1999 and October 1983.

3.2 Ocean dynamic modelling of tides and waves

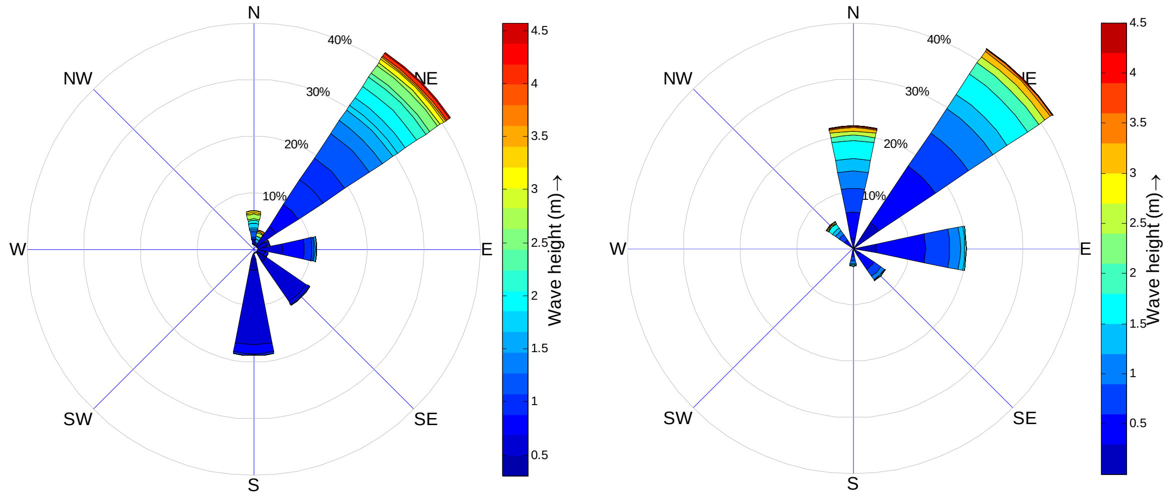
Hydrodynamics of ocean tides and waves and morphodynamics of the inlets are modelled using Delft3D software packages (WL | Delft Hydraulics, 2006). The 2D version of the hydrodynamic and morphological module Delft3D-FLOW integrated with the wave module Delft3D-WAVE of Delft3D has been applied for this case. The simulation model has been setup in Delft3D including in its domain the lagoon and inlets and extended to the continental shelf at a water depth of 30 m (**Figure 6**). The model grid is curvilinear with a minimum grid size at the inlet locations of less than 50 m. The results from the hydrodynamic model for river flow are used as boundary conditions for the model of the lagoon and inlet system. Seaside boundary conditions of the model are ocean tides. The hydrodynamic model of ocean tides has been calibrated and validated based on observation data and boundary conditions from various ocean tide models (Lam, 2006). The result from the morphodynamic model of bottom erosion and accretion at the Thuan An inlet for the river flood in November 1999 shows a similar pattern with the topographic surveys as in **Figure 7**.

In addition to the river flows and tidal forcing, the actions of waves and winds are also taken into account in the model. Information about waves and winds is derived from the observed data at Con Co Island (**Figure 5**). **Figure 8** shows a major similarity in near shore wave climate at the Thuan An inlet computed by the model and field observations from 1 October 1967 to 30 September 1968 (Lee, 1970). The observation data presents a significant occurence of local waves from the S direction generated inside the lagoon during the SW monsoon but this is obmitted in the simulation model.



a) bottom change from 1999 and 2002 surveys b) model simulation

Figure 7: Bottom changes at Thuan An inlet due to a river flood in November 1999



a) observation (Lee, 1970) b) simulation result

Figure 8: Wave roses near Thuan An inlet

3.3 Morphodynamic model for lagoon and inlet system

For the medium-term to long-term morphologic simulations of the system, the “morphological factor” technique (Roelvink, 2006) has been applied. As shown in **Figure 9**, different schematizations of input wave data series have been applied. RUN01 is the “traditional” time sequence of the actual observed wave height and wave direction. RUN02 is the input data of the same wave height series which has been grouped into classes of wave height in the ascending order. Each class has a morphological factor corresponding to the time portion of its occurrence in the whole computational period and the wave direction is sorted increasingly. RUN03 uses the same approach as RUN02 but the schematization is “staged” and applied for each period of different monsoon winds or climatic conditions.

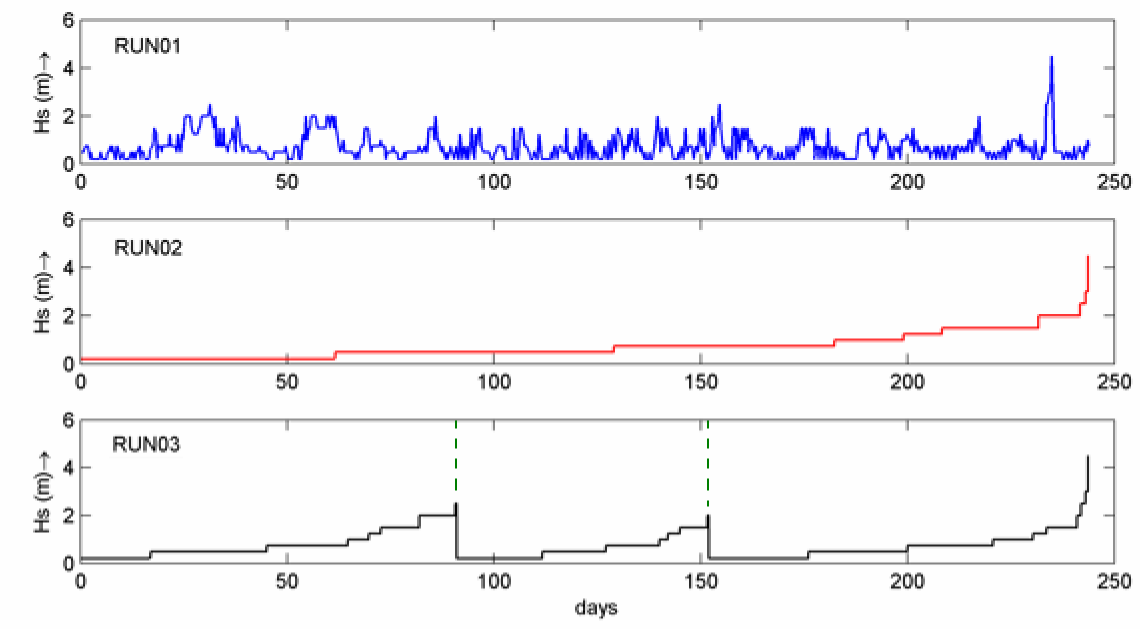


Figure 9: Input wave data for computational schematizations RUN01, RUN02 and RUN03

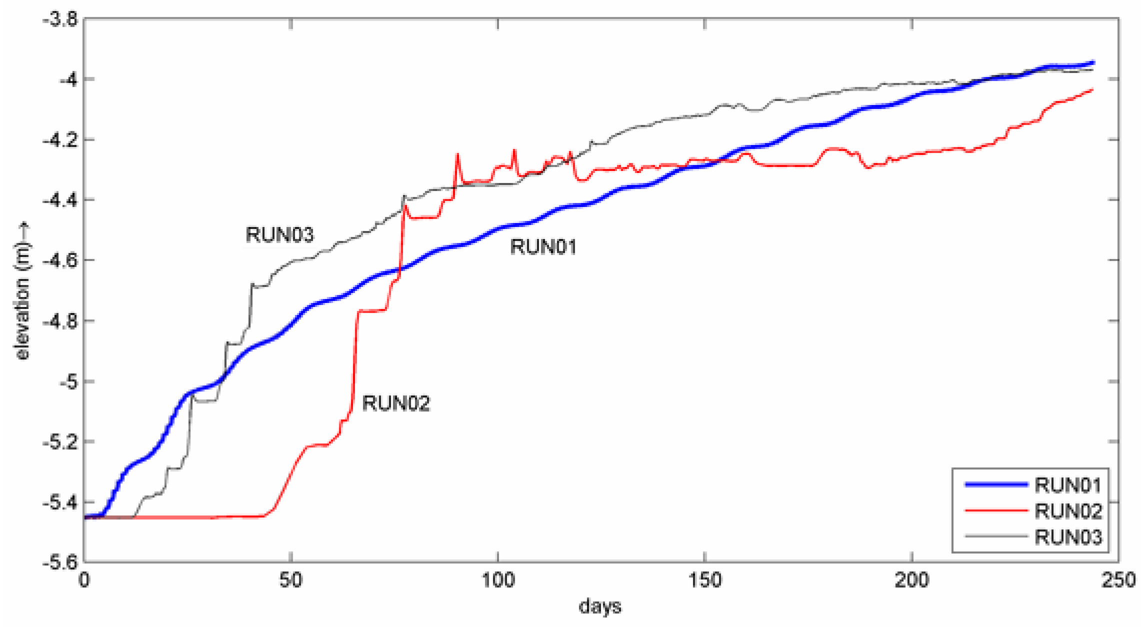


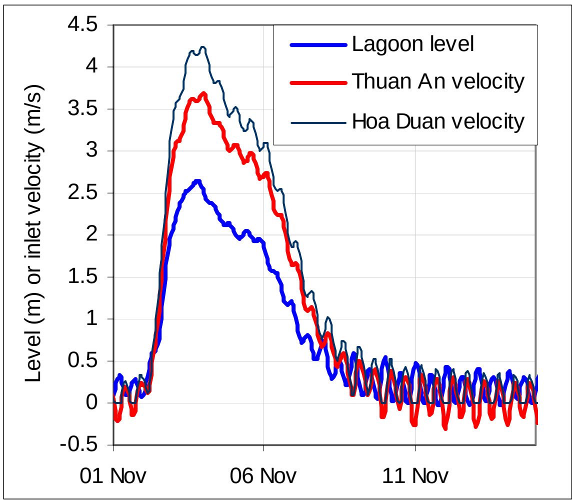
Figure 10: Bottom evolution of the Tu Hien Inlet

Figure 10 plots the deposition process in the Tu Hien inlet according to different wave data schematizations. At the check point in the inlet, inlet bottom is deposited about 1.5 m from -5.5m to -4.0m during 8 months of the dry season. The actual time sequence of wave observed data (RUN01) shows a gradually bottom deposition in the inlet. But this approach requires wave computation carrying out for every observed data that needs a lot of computational effort and time consuming. The schematized wave data of RUN02 and RUN03 produce sudden changes in the deposition process. The changes and the shape of the evolution curves depend on the occurrence of each wave height and wave direction of the schematizations. The sudden changes of bed deposition mostly happen during the northeast monsoon period when longshore sediment transport to the inlet from northwest is strongest. Nevertheless, the final bottom elevations of the inlet at the check point according to different wave schematizations are close to each other. The “staged” schematization of RUN03 has the bottom evolution curve most closely to those of the actual time sequent input RUN01 but it requires more computational effort than RUN02. Therefore the “morphological factor” approach can be used for longer simulations with less computational efforts.

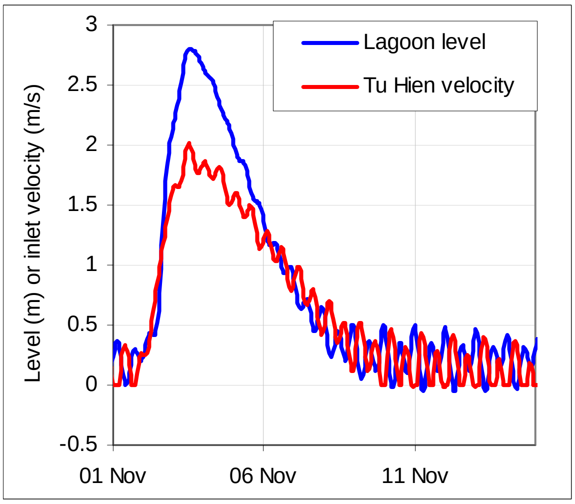
4. RESULTS AND DISCUSSIONS

4.1 River flow influences

During river floods, very strong flow can occur in the inlets. For example, maximum velocity in the Thuan An and Tu Hien inlets during the flood of November 1999 can reach 3.7 m/s and 2.0 m/s, respectively (**Figure 11**). At the inlet, water flows as a strong flow jet which widens and deepens the inlet channel and gorge. Strong currents due to river-flood scour the Thuan An inlet channel and deepen its bottom level from -10 m to -14 m.



a) Thuan An inlet and Hoa Duan breach



b) Tu Hien inlet

Figure 11: Computed lagoon water level and inlet flow velocities at inlets

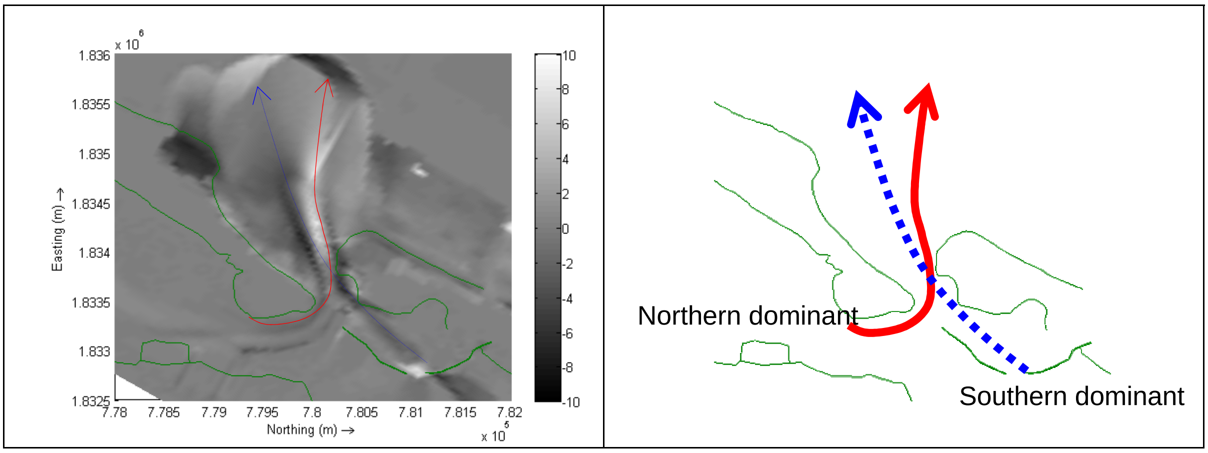


Figure 12: Influence of river floods on Thuan An channel orientation

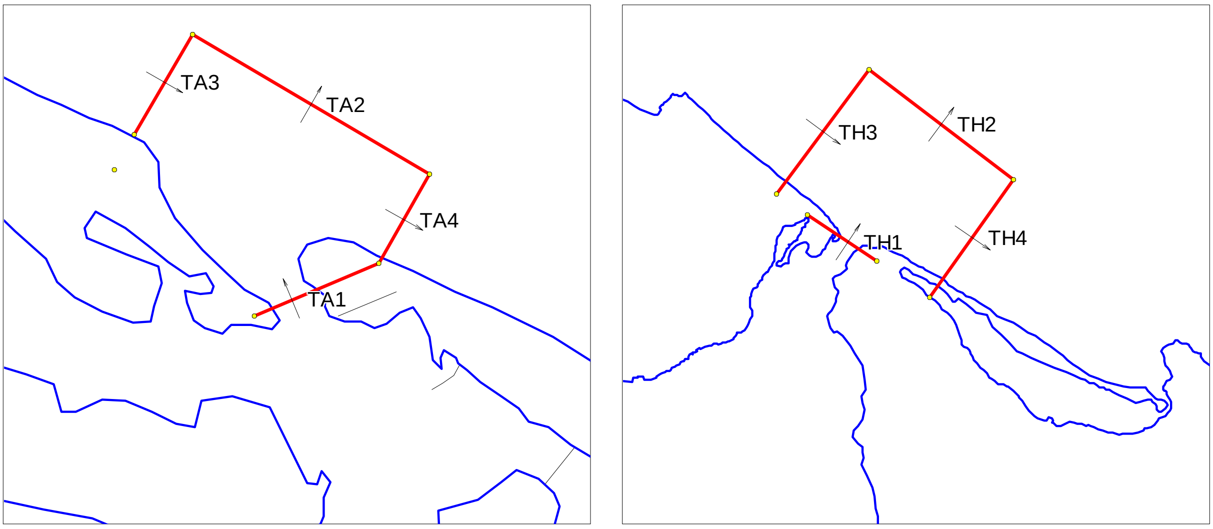
In the Thuan An inlet channel and its ebb tidal delta, the direction of the strong flow current, which depends on the side which the dominant river flood discharge comes from, has an important influence on the reorientation of the inlet channel (**Figure 12**). If the flood water dominantly comes from the southern side of the inlet, i.e. mainly contributed by the rainfall on the Huong River catchment, the jet current will head north or northwest and turn the inlet channel to the same as its direction. If the flood water coming from the northern side is stronger caused by much rainfall happening on the northern catchments of the O Lau and Bo rivers then the jet current will have a tendency to become perpendicular to the coast that turns the inlet channel to the northeast direction. Depending on the direction of the flow jet, the inlet channel is reoriented accordingly. This can explain to the reorientation of the Thuan An inlet channel in **Figure 2**.

Outside the ebb delta, the flow direction changes according to the tidal currents in the sea in the along shore direction. Sediment is mainly removed in the channel and the ebb delta and transported to the terminal lobe of the ebb tidal delta where the flow velocity decreases significantly.

During the non-river flood periods, because the inlet cross-sections were scoured largely, the flow currents in the inlets drop significantly. For instance, the magnitude of flow current in the Thuan An inlet reduces to less than 0.5 m/s just after the flood of November 1999. With this velocity, the inlet is unable to transport out the sediment deposited in the inlets. There is almost no sediment transported from the inlet into the lagoon and the flood tidal delta cannot be built up.

4.2 Seasonal wind wave influences

In the dry season which lasts eight months from January to August, the morphology of the inlets is mainly influenced by the action of waves and tides. The morphological changes in the inlet areas behave correspondently to the seasonal variation of the wave action. The computed longshore sediment transports on both sides of the inlets depending on the monsoon seasons are shown in **Table 1** with the transects and directions used in the computation are shown in **Figure 13**.



a) Thuan An inlet b) Tu Hien inlet

Figure 13: Transects and positive directions for sediment transport computation at inlets

Period	Transport	Thuan An				Tu Hien			
		TA1	TA2	TA3	TA4	TH1	TH2	TH3	TH4
Jan-Mar	(+)	0.098	0.032	0.186	0.193	0.014	0.008	0.208	0.204
	(-)	-0.017	-0.035	-0.147	-0.137	-0.019	-0.004	-0.057	-0.115
	Net	0.081	-0.003	0.038	0.057	-0.005	0.004	0.151	0.089
Apr-May	(+)	0.065	0.027	0.032	0.033	0.013	0.006	0.036	0.035
	(-)	-0.003	-0.075	-0.046	-0.047	-0.017	-0.002	-0.043	-0.047
	Net	0.062	-0.048	-0.014	-0.014	-0.004	0.004	-0.008	-0.012
Jun-Aug	(+)	0.184	0.036	0.005	0.006	0.017	0.008	0.006	0.006
	(-)	-0.004	-0.017	-0.034	-0.034	-0.015	-0.002	-0.031	-0.034
	Net	0.180	0.019	-0.028	-0.028	0.002	0.006	-0.025	-0.028
Sep	(+)	0.523	0.767	0.022	0.024	0.042	0.033	0.027	0.025
	(-)	-0.003	-0.046	-0.043	-0.040	-0.013	-0.001	-0.014	-0.032
	Net	0.520	0.721	-0.021	-0.016	0.029	0.032	0.013	-0.007
Oct-Dec	(+)	0.562	0.635	0.384	0.403	0.078	0.064	0.447	0.429
	(-)	-0.048	-0.075	-0.719	-0.651	-0.036	-0.006	-0.179	-0.517
	Net	0.514	0.560	-0.335	-0.248	0.042	0.058	0.268	-0.088
Yearly	(+)	1.432	1.497	0.629	0.659	0.164	0.119	0.724	0.699
	(-)	-0.075	-0.248	-0.990	-0.909	-0.100	-0.015	-0.324	-0.745
	Net	1.357	1.249	-0.360	-0.249	0.064	0.104	0.400	-0.047

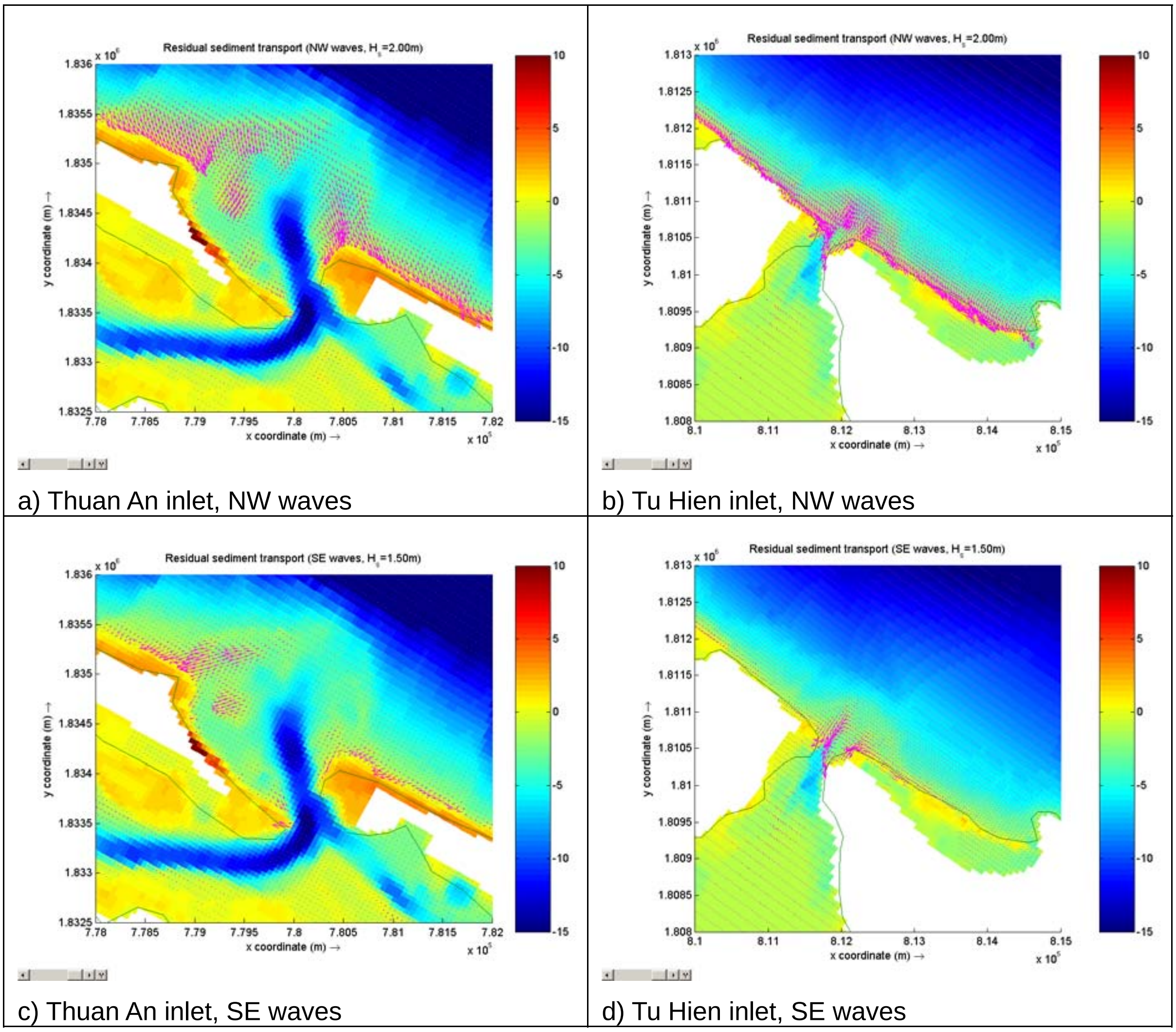
Table 1: Sediment transports through transects (Mm^3/year)

The wave climate observed at Con Co shows that, during the month of September when the southwest monsoon ends and the northeast monsoon starts, the dominant waves may come from NW, NE or SW depending on the domination of which monsoon wind in that period (**Figure 5**d). In the next months from October to December, the northeast monsoon winds become most active and the dominant waves are mainly from N or NE directions (**Figure 5**e). The months from September through December are also the period in which typhoons and tropical cyclones operate most actively. Therefore in these months, the sea is quite rough with wave heights of about 1.5 – 2.5 m. Waves during the typhoons may be as high as 6 m. But these months are also the flood season when the inlets are dominated by the river flows so the influences of sea waves are mainly restricted to the coasts. Although offshore waves are mainly N or NE but near shore waves are NE dominantly and drive the prevailing longshore sediment transport in the SE-NW direction near the Thuan An inlet as can be seen in **Table 1**. The net longshore sediment transports in the vicinity of the Thuan An inlet in this period is about 0.26 – 0.36 Mm^3/year northwestwardly. In the Tu Hien inlet vicinity, the net longshore sediment transport on the north side of the inlet is 0.28 Mm^3/year southeastwardly but the net transport on the south side of the inlet is 0.10 Mm^3/year northwestwardly.

In the end of winter from January through March, the prevailing waves are NW with the significant wave height H_S = 1 – 2 m (**Figure 5**a). Because the alignment of the coastline is in the NW – SE direction, the magnitude of the net longshore sediment transport to the SE direction is largest in these months (**Figure 14**a,b). This value at the Thuan An inlet is 0.04 – 0.06 Mm^3/year. At the Tu Hien inlet, the net transport on its north and south sides are 0.15 and 0.09 Mm^3/year, respectively. In this period, just after the inlet channels have been deepened by the river floods and when the river flow diminishes, the channel cross sections become too large and the tides are too weak to remove the sediment entering the inlet channels. The inlets are hungry for the sediment and become the large sediment sinks. They cause the erosion of the adjacent coasts at both sides of the inlets, especially the updrift coasts on the northern sand barriers of the inlets. The evidence for this can be seen at the coast of Hai Duong commune located on the north side of the Thuan An inlet. Every year, along 3 km of this coast near the Thuan An inlet, the sand dune is eroded for 15 – 20 m during the winter time. The beach is accreted back 10 – 15 m during the summer months resulting in a retreat rate of this beach of approximately 5 m/year (Hoi et al., 2001). Simulation results also show that the southeast monsoon waves in these months gradually move onshore part of the sediment which is transported to the terminal lobe by the river floods to fill in the channel and build up the ebb deltas and the coasts.

In beginning months of summer from April to May, the sea is rather calm with small dominant SE wave of less than 1 m high (**Figure 5**b). The combination of the shoreline direction and the wave direction creates the strongest longshore sediment transport in the northwestward direction by the summer monsoon. Because the southern coast of the Tu Hien inlet is blocked by a rocky headland at Loc Thuy so the longshore sediment transported to the inlet is limited (**Figure 14**c,d). On this coast, the sediment transported by waves is mainly to build up the small sand barrier. During the most active months of the southwest monsoon winds from June to August, the offshore waves at Con Co come dominantly from SW direction (**Figure 5**c). In the nearshore areas the waves which are mainly swell waves, are quite calm and rework the beaches and the ebb deltas.

Small waves and swell in the summer months rework the sediment and transport it onshore. The beaches are restored by onshore sediment transport. The ebb tidal deltas are moved back and become smaller in size. The tidal channels are filled up and the bars in the deltas develop. These developments continue until the system getting the equilibrium state. If the equilibrium is reached then sand by passing in the ebb deltas and the migration of updrift sand spits and sand bars in the ebb deltas will happen. After some severe river floods it may take the Thuan A period of nearly 10 years is needed to regain the equilibrium state (Lam, 2005). When it reaches the equilibrium state, the maximum growing speed of the southern sand spit at the Thuan An inlet can be at the order of about 15m/year according to observations (Hoi et e., 2001). At the Tu Hien inlet, inlet scouring by river floods is much weaker than the Thuan An inlet so the wave reworking and the onshore migrating of offshore sandbars are faster. The landward migration of offshore sandbars may lead to the closure of an inlet as studied by Ranasinghe and Pattiaratchi (2003).



a) Thuan An inlet, NW waves
b) Tu Hien inlet, NW waves
c) Thuan An inlet, SE waves
d) Tu Hien inlet, SE waves

Figure 14: Residual sediment transport in the inlets

Annually, the net longshore sediment transport in the Thuan An inlet area is 0.25 – 0.36 Mm^3/year northwestwardly. On the north coast of the Tu Hien inlet, the net longshore sediment transports is about 0.40 Mm^3/year to the southeast direction. But on the southern side of the inlet, the net longshore sediment transports is only 0.05 Mm^3/year northwestwardly. This indicates that the closure of the Tu Hien inlet is not only contributed by the migration landward of offshore sandbars due to wave reworking but also partly contributed by the growing of its northern sand spit due to longshore sediment transport.

4.3 Conceptual model

Based on the investigation on the numerical models the effects of forcing processes and morphological behaviour of the tidal inlets, the behaviour of the inlets can be summarized as a conceptual model as follows:

1) In the flood season from September to December, river floods create strong flow currents in the inlets that scour inlet channels and flatten the sand bars in the ebb deltas and move sediment further offshore. The layout of the inlet channel is re-oriented by the dominant direction of river floods.

2) During some extreme floods, while inlet scouring is too slow to increase discharge, overflows may create breaches in the sand barriers at the weakest points to create an additional discharge capacity.

3) Due to the river floods, the natural sand by-passing in the ebb delta is interrupted. This causes the lack of sediment supply to the northern sand barrier at the down drift side and causes the beach and sand dune of this barrier eroded. After the river floods, the inlet channels are filled up with the

sediment transported by waves taken from the adjacent coasts while tidal currents are too weak to flush the sediment out. This also causes the erosion of the adjacent coasts more severe, especially the northern sand barrier eroded seriously in the period from January until March when cold fonts sweep in and create strong northeast winds, gusts and rough waves.

4) In the low flow period from January to August when the river flows diminish, the waves rework in the ebb delta. The sand bars are built up and moved landward from offshore.

5) When the rate of sediment transport from the coast to the inlet channels and ebb deltas decreases, the beaches are restore by longshore and onshore sediment transports. After the ebb deltas and inlet channels have been built up, sand by-passing in the ebb delta then continues. These slow processes happen for many months from mid of March to May when SE waves are dominant and from June to August during the activities of SW winds.

5. CONCLUSIONS

More insight into the morphodynamics and behaviour of a double inlet system in a tropical monsoon area has been gained with the help of the numerical models.

The behaviour of the Thuan An and Tu Hien inlets are strongly influenced by of tropical monsoon climatic regime. The episodic influences of river flow and wave climate make the tidal inlet morphology seasonally varying and highly dynamic. The variation of wave climate also determines the change of coastal deposition/erosion pattern.

The inlets are river dominated during the wet season. River flood is the main process to keep the inlets open and reorient the inlet channel. The enlargement and reorientation of the inlet channels are assigned to river influences in the flood season. In the floods, sediment is exported from the river basins through the inlets. The consequences of these influences are also made to the ebb deltas and the adjacent coasts.

During the dry periods, the tidal inlets are wave-dominated and act as sediment sinks. Waves rework the ebb deltas and the adjacent coasts by gradually transporting sand back onshore to build up the sand bars and to restore the beaches.

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