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Numerical simulation of sediment transport and morphology changes at the Bach Dang estuary

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Abstract. Morphology change at tidal influent estuary is controlled by the net sediment transport rate of river and tidal transport, and variations in features (bathymetry, structures, etc.) where scour and shoaling take place. To examine river and tidal exchange sediment transport in a systematic way, we investigated sediment transportation at the Bach Dang estuary with a coupled tide, wave and sediment transport-morphology change numerical modeling system. Five simulations consisting of tide forcing, wave forcing (fair-weather and storm), and combined tide and wave forcing were conducted.

1. Introduction

Morphology change at tidal influent estuary is controlled by the net sediment transport rate of river and tidal transport, variations in features (bathymetry, structures, etc.) where local scour and shoaling take place. Common morphologic responses to wave and tide forcing are: deposition and migration of the inlet channel thalweg, development of shoals, beach erosion in the area. Bach Dang estuary in Hai Phong province is an example where all of these responses have been observed. Therefore, we investigate sedimentation transport at the BachDang estuary with a coupled tide, wave, and sediment transport-morphology change numerical modeling system.

Transport paths and morphology change were calculated for combined tide and wave forcing with different return period by application of coupled circulation, wave, and sediment transport-morphology change models. The circulation model DHI Mike21 Flow model [1] has been coupled to the steady spectral parabolic wave NSW model through the Mike Zero System. This coupling provides a method for representing multiple scales of motion, a situation prevalent in coastal dynamics owing to the presences of the tide, waves, and interaction of these processes including wave transformation and breaking [2]. Radiation stress gradients from the wave model are mapped to the circulation model for calculation

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of the wave-induced current [3]. Mud transport is calculated through the Mud transport modul MT as one of several mud-transport formula options [4]. This coupled system calculates tidal propagation; the current driven by the tide, waves, and wind; sediment transport; and bottom morphology change.

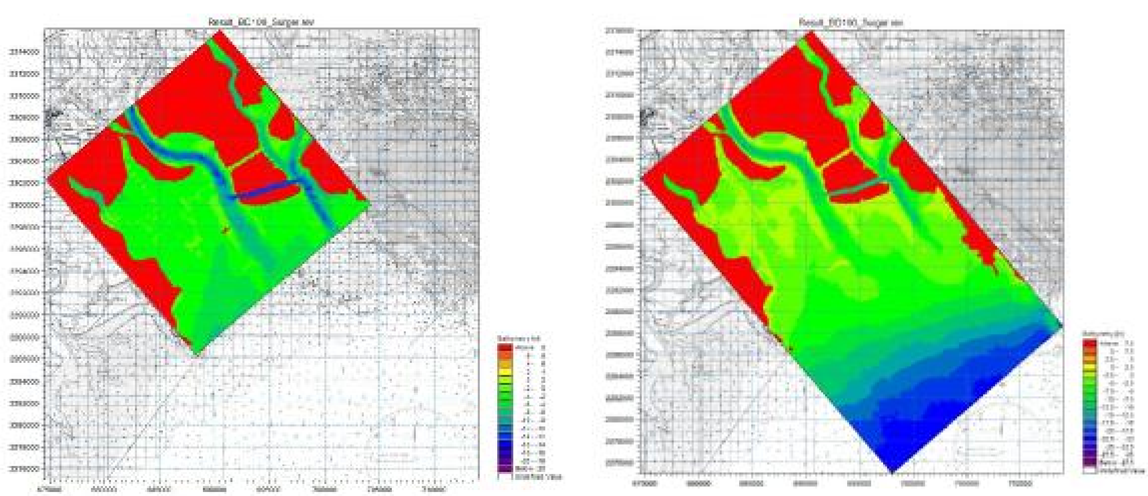
2. Simulation specifications

Two grids were developed base in marine chart of the Bachdang estuary at scal 1:100 000, published in 2005 by the Vietnam's Navy, the first grid with 210 x 210 cells, cell side is 100m for circulation model and another one with 620 x 420 cells, calculation cells were specified to be 50 m on each side for the wave model giving fine resolution for the breaking waves (Fig. 1). (both grids are rotated approximately 320 degrees clockwise from North). The Manning roughness coefficient, specified in the circulation model, varied between 28 $m^{1/3}/s$ in the offshore region to 44 $m^{1/3}/s$ in the estuary and surf zone.

Five simulations were conducted in which combinations of tide and wave forcing with different return period were applied (Table 1). For all cases with both wave and tide forcing.

Table 1. Simulation Properties

Case Number & Description	Tide Range, [m]	Wave Height, [m]	Wave Period, [s]	Wave Direction, [deg]
1. Tide 50% and Fair-weather wave	1.90	0.7	4	135
2. Tide 1% and storm wave 9B	2.55	2.93	7	135
3. Tide 10% and storm wave 9B	2.30	2.93	7	135
4. Tide 1% and storm wave 12B	2.55	5.60	8	135
5. Tide 10% and storm wave 12B	2.30	5.60	8	135



a. Grid bathymetry for circulation model *b.Grid bathymetry for wave model*

Fig. 1. Bachdang estuary grid bathymetry.

Tide forcing for the circulation model was time series of Hon Dau tide station of return period of 2 years (50%), 10 years (10%) and 100 years (1%) (Table 2 and figure 2). Wave height and period were representative of fair-weather and storm conditions 9B and 12B, and a narrow spectrum was specified. A time step of 1 s was applied for all circulation model simulations and model forcing was spun up for duration of 2 day with a ramp function. Simulation duration was 126 hr.

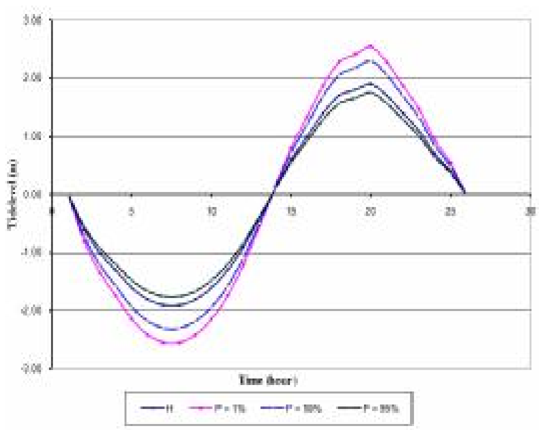


Fig. 2. HonDau Tidal level of 1%, 5%, 10% and 95% of ocurrence.

Table 2 Tide level of return periods

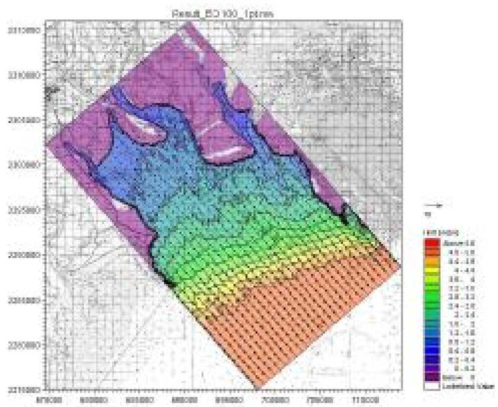
	Return periods (year)			
T(hour)	100 (1%)	20 (5%)	10 (10%)	2 (50%)
1	0.00	0.00	0.00	0.00
2	-0.81	-0.76	-0.73	-0.60
3	-1.34	-1.26	-1.21	-1.00
4	-1.74	-1.64	-1.57	-1.30
5	-2.15	-1.98	-1.94	-1.60
6	-2.42	-2.30	-2.18	-1.80
7	-2.55	-2.40	-2.30	-1.90
8	-2.55	-2.40	-2.30	-1.90
9	-2.42	-2.28	-2.18	-1.80
10	-2.15	-2.03	-1.94	-1.60
11	-1.74	-1.64	-1.57	-1.30
12	-1.21	-1.14	-1.09	-0.90
13	-0.54	-0.50	-0.48	-0.40
14	0.13	0.125	0.12	0.10
15	0.81	0.77	0.73	0.60
16	1.34	1.27	1.21	1.00
17	1.88	1.75	1.69	1.40
18	2.28	2.14	2.06	1.70
19	2.42	2.28	2.18	1.80
20	2.55	2.40	2.30	1.90
21	2.28	2.13	2.06	1.70
22	1.88	1.77	1.69	1.40
23	1.48	1.40	1.33	1.10
24	0.94	0.90	0.85	0.70
25	0.54	0.50	0.48	0.40
26	0.00	0.00	0.00	0.00

3. Hydrodynamic properties

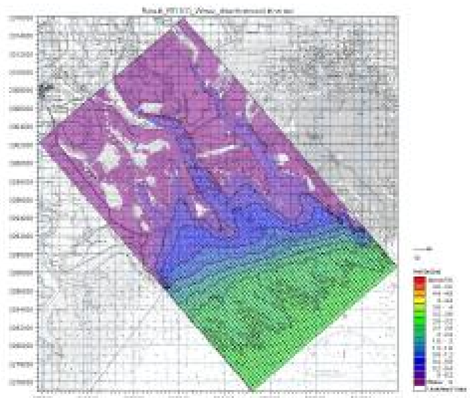
Current and wave fields for the five simulations are presented. Results from simulations with tidal forcing are shown at peak flood (hr 109) and peak ebb (hr 121). Results from mud transport simulations with five hydrodynamics simulations were conducted in which combinations of tide and wave forcing with different return period only show at the end of the simulation (hr 126). Contour scales for the velocity plots vary for each case to best represent the range of speeds calculated.

Wave

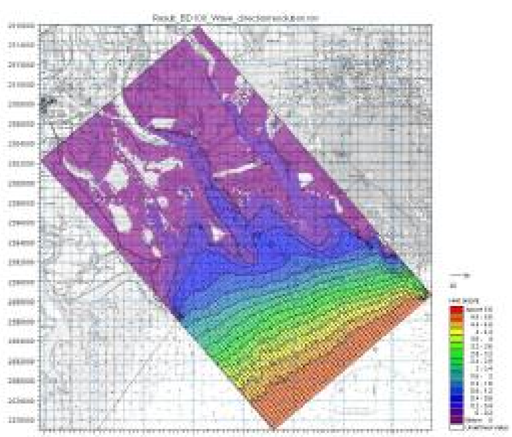
Wave height and direction in the case when supposed storm 12B and 9B hitting the Bachdang estuary from South-East direction are shown in Fig. 3a, 3b, 3c and 3d, respectively. Strong refraction, wave shoaling, and breaking occur at and near the coastal line and inlets. Wave height ranges from 5.60 m at the seaward boundary to 1.08 m, on the canal near by Aval drift signal wave height is 1.47m – 1.49m, on the beach of Văn Phong – Gia Lộc wave height is 1.48m – 1.50m and on the Lạch Huyện inlet wave height is 0.98m – 1.01m.



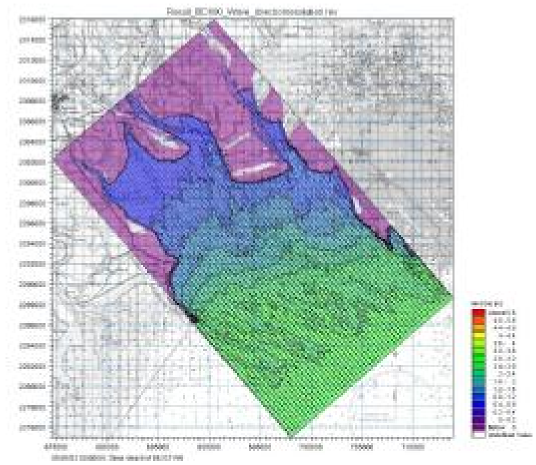
a. case H_{mo}=5.60m; T_p=8s; H_{storm}=2.3m; $H_{tide10\%}$= 2.30m,



b. Case H_{mo} = 2.93m; T_p = 7s; H_{storm} = 2.3m; $H_{tide10\%}$ = 2.30m,



c. Case H_{mo} = 5.60m; T_p = 8s; H_{storm} = 2.3m; $H_{tide1\%}$ = 2.55m,

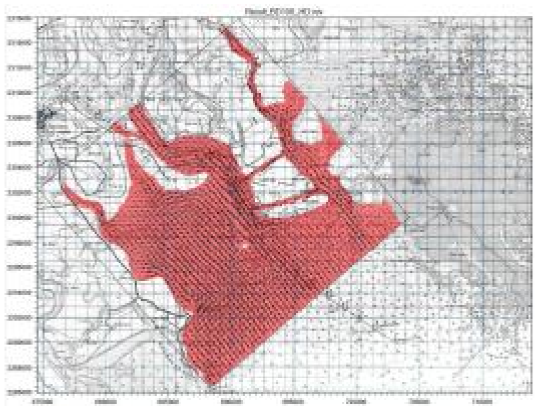


d. Case H_{mo} = 2.93m; T_p = 7s; H_{storm} = 2.3m; $H_{tide1\%}$ = 2.55m,

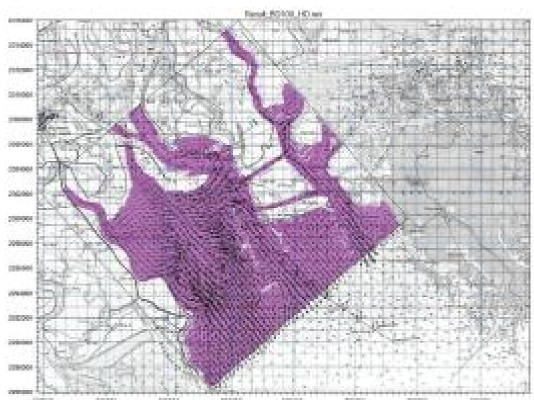
Fig. 3. Wave height and direction.

Current

Current speed and direction for 3 cases of tide 50%, wave H_{mo} = 0,7m; T_p = 4s, direction 135^o ; tide 1%, wave H_{mo} = 2.93m; Tp = 7s, direction 135^o; tide 1%, wave H_{mo} = 5.60m; T_p = 8s, direction 135^o are shown in figures. 4 to 6. In the peak flood time the current velocity reachs maximum of 0.87m/s and 1.05m/s in the peak ebb time in the Nam Trieu and Lach Huyen channels, on the shalow shoals strong south south eastward flow produced, the maximum of flow velocity is 0.97m/s in the shoaling areas of south east Nam Trieu, perimeter Cam and Lach Tray inlets and in the Do Son beach.

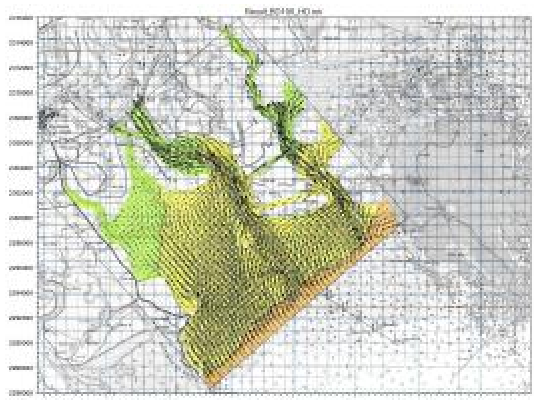


a. Peak flood (hr 109),

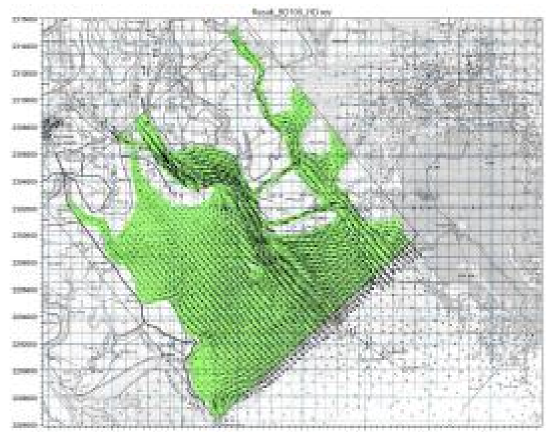


b.Peak ebb (hr 121),

Fig. 4. Current speed and direction, tide 50%, wave H_{mo} = 0.7m; T_p = 4s, direction 135°.



a. Peak flood (hr 109),



b. Peak ebb (hr 121),

Fig. 5. Current speed and direction, tide 1%, wave H_{mo} = 2.93m; T_p = 7s, direction 135°.

4. Sediment transport and morphology change

Sediment transport rate vectors and morphology change are discussed for the five simulations. Contours show change in depth, with yellow/red denoting decreased depth (accretion). Contour scales vary between the plots.

Case 1: Tide 50% and Fair-weather wave

Change in depth and transport vectors for the tide-only simulation are shown in Fig.6 during simulation period of 126h. Maximum change takes place at the Nam Trieu channel area from Nha Mac to Aval Light where 0.006m of accretion occurs. Accretion also takes place at the south of Cong Island, Lach Tray, Lach Bang and Van Phong – Gia Loc beach.

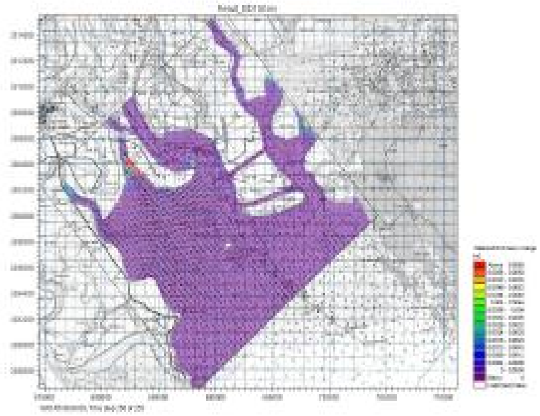


Fig. 6. Change in total bed thickness and transport vectors, tide 50% and fair-weather wave.

Case 2: Tide 1% and storm wave 9B

Transport vectors and change in depth at hr 125 of the tide of 100 years return period and storm wave 9B with height of 2.93m, period 7 sec are shown in Fig.7. Maximum change takes place in the wider areas in comparision to the fair-weather case, it occurs at both the Nam Trieu, Lach Huyen chanels, Cai Trap. Accretion also takes place at the south of Dinh Vu, Lach Tray.

Morphology change on the shoal indicates an overall spreading pattern is southward and south-westward, as the bathymetry moves toward an equilibrium state with the hydrodynamics.

Case 3: Tide 10% and storm wave 9B

Morphology change and transport vectors at hr 125 from the cases of tide 10% and storm wave 9B simulation are shown in Fig. 8.

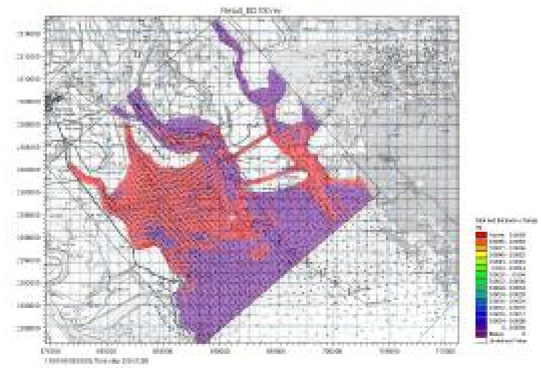


Fig. 7. Change in total bed thickness and transport vectors, tide 1% and storm wave 9B.

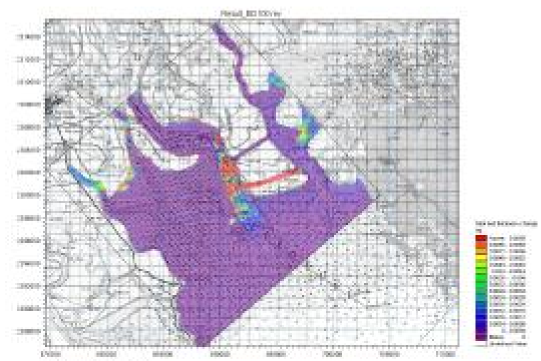


Fig. 8. Change in total bed thickness and transport vectors, tide 10% and storm wave 9B.

Case 4: Tide 1% and storm wave 12B

Morphology change and transport vectors for combined tide 1% and storm wave 12B forcing are shown in Fig.9. Patterns of morphology change are similar to those for the tide 1% and storm wave 9B simulation (Fig. 8), indicating that the waves are the dominant transport mechanism. However, the tidal currents do modify the transport patterns. In the interior of the estuary, transport by tide dominates that of waves.

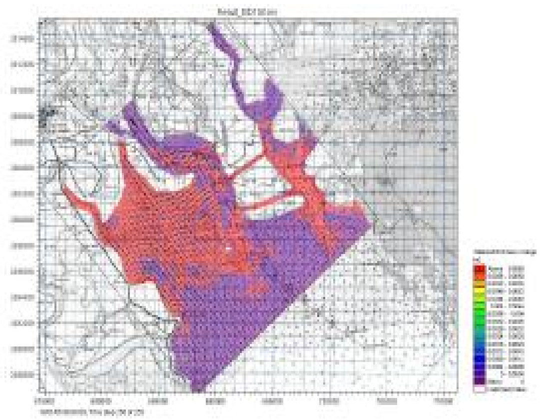


Fig. 9. Change in total bed thickness and transport vectors, tide 1% and storm wave 12B.

Case 5: Tide 10% and Storm Wave 12B

Transport vectors and morphology change for the tide 10% combined with storm waves 12B are shown in Fig.10. Changes in bathymetry for this simulation show little difference from the case with storm waves 9B, indicating the dominance of the waves in sediment transport. The most notable difference between the two simulations (Figs. 9, 10) is that the mud transported southward and south-westward from the river is reduced with the storm intencity.

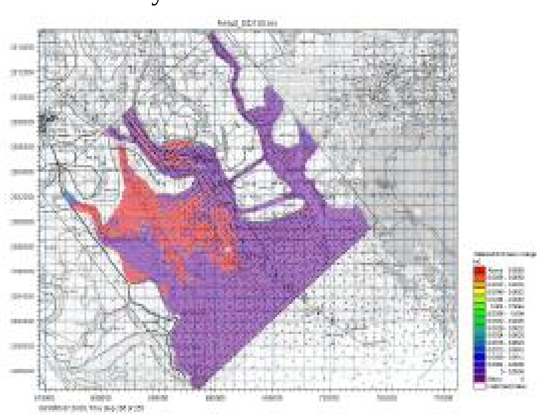


Fig. 10. Change in total bed thickness and transport vectors, tide 10% and storm wave 12B.

5. Conclusions

A coupled wave, circulation, and sediment transport modeling system was applied to the Bachdang estuary to examine the physical response to tide and wave forcing. Five simulations were conducted for combinations of tide, fair-weather waves, and storm waves. Wave direction was specified at 135 degrees from North. Changes in depth from wave forcing were greater than those would be expected over the same duration at a real estuary.

Patterns of response of the current to tide and waves reproduced those that are commonly observed to occur at tidal influent estuary. Wave refraction and breaking on the ebb shoal produced strong and complex currents. For both fair-weather and storm waves, a strong south directed flow was produced on the chanel Nam Trieu and easthern area inlet Lach Huyen.

Calculation of morphology change showed realistic patterns for both wave and tidal forcing. Mud transport by waves impounded material on the canal Nam Trieu even during fair-weather conditions. During storm conditions, mud from the updrift nearshore region was moved to a deltaic formation off the tip of the south shoal. Both storm and fair-weather waves eroded the top of the ebb shoal and deposited material along its north and western perimeter.

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