

## Impact of sea level rise on current and wave in Van Uc coastal area

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### Abstract

This paper presents the results of analysis, comparison of some characteristics of current, wave at Van Uc estuary area when being affected by sea level rise due to climate change based on Delft3D model. Scenario groups are established: The current scenario and the scenarios simulating effect of sea level rise 0.5 m and 1.0 m. The results of calculation and simulation show that the velocity values change locally when sea level rises: Rise in the northern and southern areas (0.2–5 cm/s); decrease in the navigation channel (0.6–30 cm/s). Sea level rise causes the increase of wave height in the coastal area (13.5–43.8% in the dry season and 20–40% in the rainy season) and fewer changes in the outer area.

**Keywords:** Hydrodynamics, sea level rise, Van Uc river.

## INTRODUCTION

Van Uc River is one of the three largest mouths of Red-Thai Binh river system [1], located in Southwest of Do Son peninsula at latitude of 20.5–20.9° North and longitude of 106.5–107.1° East (fig. 1). The bathymetry of Van Uc coastal area is shallow and slightly sloping. Tide of this area is diurnal type with high amplitude (about 3.5 m). Moreover, it is in tropical climate area, so the role of tide and flow of river varies with season strongly [2]. This is evident in the coastal area of Van Uc

river when the bathymetry always fluctuates strongly with influence of dynamic factors such as wave, tidal current and river flow. There are studies related to current and wave such as Dinh Van Uu [3], Vu Duy Vinh [4]. However, until now, no research has evaluated the impact of sea level rise on current and wave in this area. Hence, the results of this study will give supplemental knowledges about the influence of sea level rise (SLR) on flow and wave condition in Van Uc coastal area in particular and Hai Phong in general.

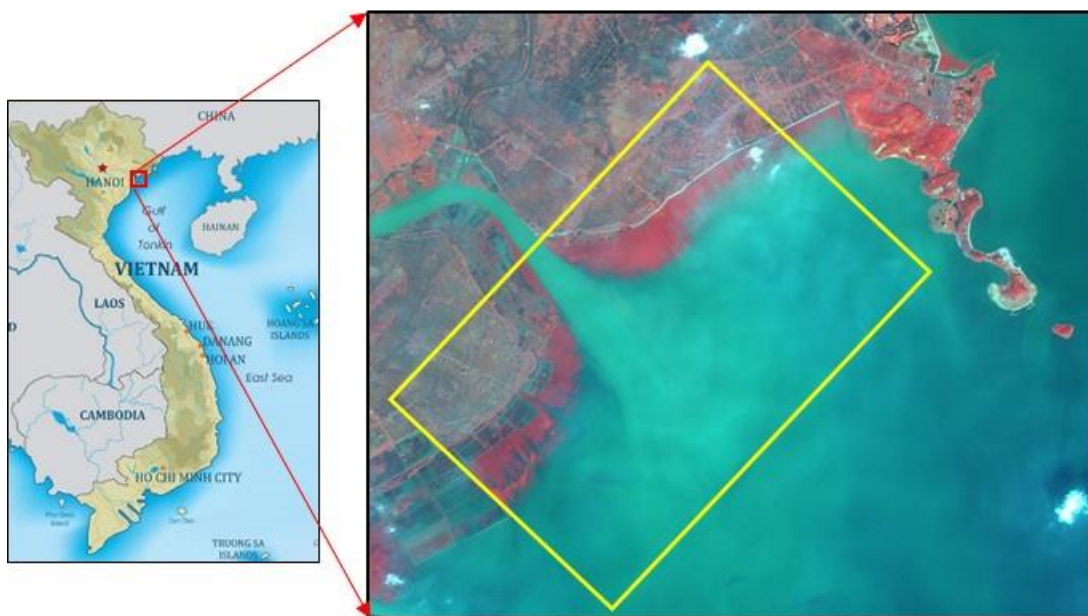


Fig. 1. The coastal area of Van Uc river

## DATA AND METHOD

### Data

In this paper, these data have been collected from results of the different researches related to subject and handled to be input for model, including:

Bathymetry and coastline in the Van Uc coastal area were digitized from topography maps in VN2000 coordinates (national coordinate system of Vietnam corresponding to UTM projection with WGS84 reference ellipsoid and specified local parameters) with scales 1:50,000 in the coastal zone and 1:25,000 in the estuary. Bathymetry offshore was extracted from GEMCO-1/8 with 30 arc-second interval grid [5, 6].

Wind data measured for many years at Hon Dau station with interval of 6 hours are processed as input for the model. In addition, this study also referred to wind data at the website <https://rda.ucar.edu> in 3 months of the dry season and rainy season.

Sea level elevation measured at Hon Dau station in 2016 was used for model calibration and validation. Moreover, the water level data near the coast was analyzed to determine the harmonic constants of 8 tidal components ( $M_2$ ,  $S_2$ ,  $K_2$ ,  $N_2$ ,  $O_1$ ,  $K_1$ ,  $P_1$ ,  $Q_1$ ) to be imposed at sea boundaries in the refined grid. The tidal harmonic constants at the offshore area were extracted from FES2014 [7, 8].

Current velocities measured in the framework of the project “Research and building arguments to set up plan for the mud and sand dumps by dredging in Hai Phong area” in 2016 (January and July) were used to calibrate and validate model. Temperature and salinity data were extracted from WOA13 [9] with a resolution of 0.25 degrees to be imposed at sea boundaries of the external model.

Water discharges at the hydrographic stations (Cua Cam in Cam river and Trung Trang in Van Uc river) that were measured by the National Meteorological and Hydrological Center were collected. On the other hand, the discharges of rivers such as Chanh, Rut, Bach Dang, Thai Binh and Tra Ly rivers were taken on average monthly according to Vu Duy Vinh

research [10]. These data were used as river boundaries.

### Method

The Delft3D model was used in this study to simulate hydrodynamic condition in Van Uc coastal area. The computational model used orthogonal curvilinear grid. The model frame includes all the coastal zones of the north of Ha Long bay to the south of Tra Ly estuary. The region had a size of about 106 km in the northeast - southwest and 64 km in the northwest - southeast. The horizontal grid of model was divided into  $272 \times 293$  points with grid size between 8.3 m and 340 m. Along the vertical grid, it was sigma coordinate with 5 layers (20% of the depth for each layer).

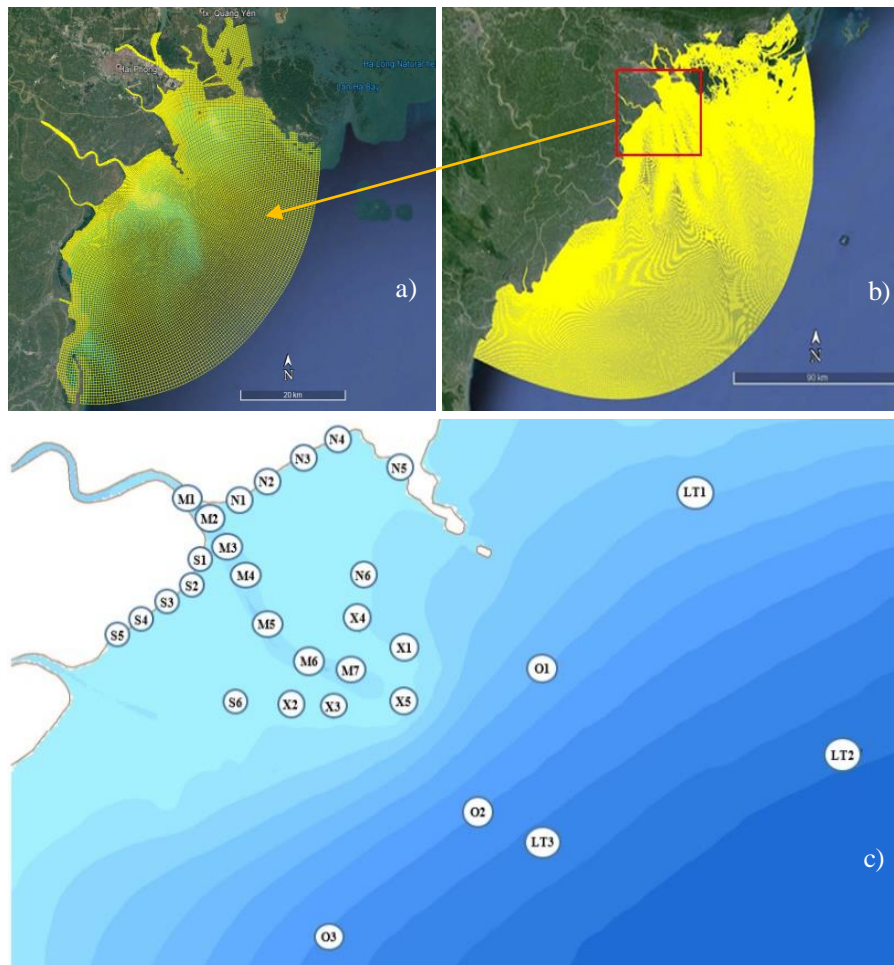


Fig. 2. The grid of the detailed model (a), overall model (b) and location of the points to calibrate and extract the results of the model (c)

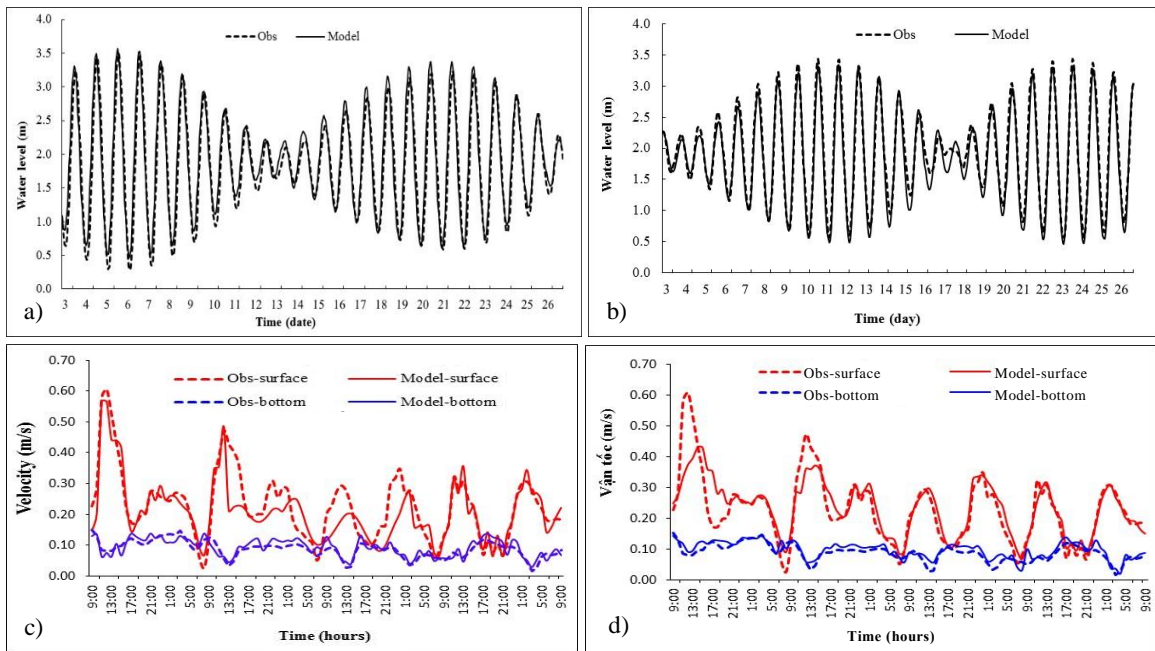


Fig. 3. Comparison of water level: (a: 3–26/7/2016; b: 3–26/1/2016) and current (c: 22–26/7/2016; d: 15–19/1/2016)

The model was established with different scenario groups during the 3 months of dry season (January, February and March) and 3 months of rainy season (July, August, September): Present scenario, sea level rise 0.5 m and sea level rise 1.0 m scenarios.

The discrepancy between results and measurements was quantified for each simulation, using the Nash-Sutcliffe efficiency (NSE) number [11], calculated as follows:

$$NSE = 1 - \frac{\sum (obs - calc)^2}{\sum (obs - mean)^2} \quad (1)$$

In which the sum of the squared differences between the predicted and observed values is normalized by the variance of the observed values during the period under investigation. *NSE* varies from 1.0 (perfect fit) to  $-\infty$ , a negative value indicating that the mean value of the observed time series would have been a better predictor than the model [12].

The results of present scenario are compared with observation data of water level at Hon Dau station and current of the measured points of the Hai Phong project. In this paper,

*NSE* is used to define the coefficients of the model. For the water elevation, the comparison shows that there is a good match in both the phase and the amplitude between measurement and model results with *NSE* coefficients in the range 0.917–0.937 (fig. 3).

Current velocity measured in surface and bottom layers (LT3 station) was compared with model result. The results showed that there is the relative fit between model and measurement with *NSE* coefficients between 0.646 and 0.825.

## RESULTS AND DISCUSSION

### Characteristics of current at Van Uc coastal area

The currents at Van Uc coastal area vary strongly with tidal oscillation. During flood tide in the dry season, the current field has direction from the offshore area to upstream area of the river. In the coastal area, they are mainly from southeast to northwest. The mouth area is affected by water discharges, so the current direction is downstream. The current velocity in this tidal phase changes in the range of 0.2–0.5 m/s. At some regions in the river, the current can reach the highest velocity about 0.8–1.0 m/s.

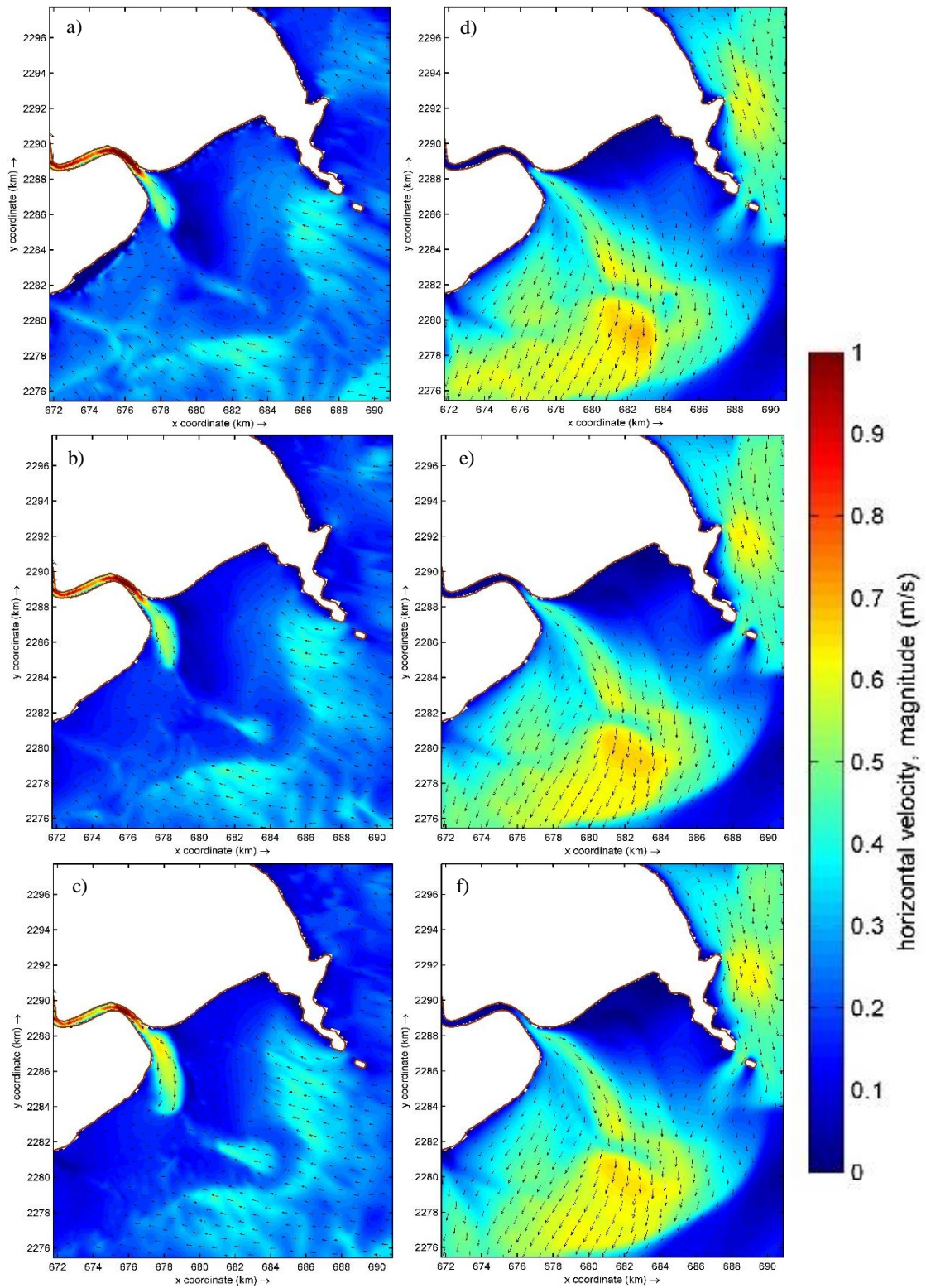


Fig. 4. Current field at Van Uc area, surface layer-dry season (flood tide: a- 2016, b- SLR0.5 m, c-SLR 1.0 m; ebb tide: d- 2016, e- SLR 0.5 m, f- SLR 1.0 m)

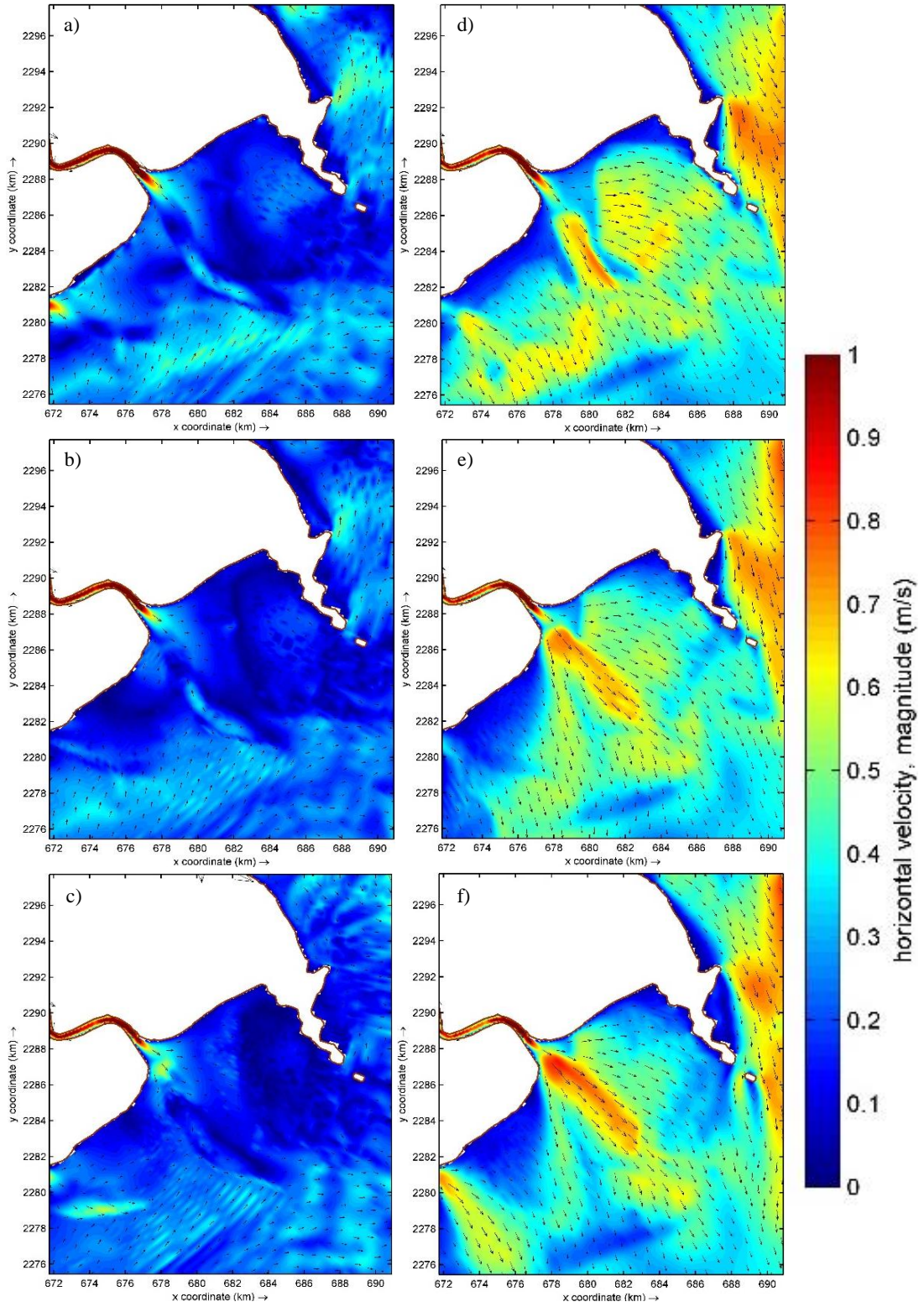


Fig. 5. Current field at Van Uc area, surface layer- rainy season (flood tide: a- 2016, b- SLR 0.5 m, c- SLR 1.0 m; ebb tide: d- 2016, e- SLR 0.5 m, f- SLR 1.0 m)

During ebb tide, because of the combination between tidal current and river seaward current, the total current velocity is almost higher than during flood tide (especially in surface layer). It changes from 0.3 m/s to 0.7 m/s. The direction of current is mainly from northwest to southeast (fig. 4a).

In the rainy season, due to the higher water discharge than in the dry season, therefore, current velocities during flood tide are lower than in the dry season, with value from 0.2 m/s to 0.5 m/s. The combination of river and tidal current is clear during the ebb tide, so current velocity in this tidal phase is higher than in other tidal phases. The current direction is oriented seaward, and mainly in the southeast and south. Current velocity changes between 0.3 m/s and 1.0 m/s. In the surface layer, it can reach over 1.0 m/s inside river (fig. 5a).

The previous studies on integrated current in the Red river coastal area also reported the role of tidal current and river discharge on the current field [2, 10], especially the strengthening of velocity during the ebb tide in the rainy season [4, 10]. These results are similar to the results in this study.

#### **Impact of sea level rise on the current**

The modelling results show that the spatial distribution of current velocities also differs between calculated scenarios (present, SLR 0.5 m and SLR 1.0 m). In the dry season, during the flood tide, the current velocities increase in nearshore area and the navigation channel area of the Van Uc estuary (fig. 4b, 4c). However, they are likely to decrease in offshore area. During the ebb tide, there is a slight decrease of the current velocities in the North, the Southeast and the navigation channel area of the Van Uc estuary due to SLR (fig. 4e, 4f).

In the rainy season, in the North area and the navigation channel of Van Uc estuary, current velocities would increase due to SLR. Meanwhile, they would decrease in the South coastal area and neighboring navigation channel (fig. 5b, 5c, 5e, 5f).

The impact of SLR on the average velocity differs at all the monitoring points in the study

area. During the dry season, in the south area (S1–S4) and north area (N1–N4), the average velocities are likely to increase when sea level rises (more than 0.5–3 cm/s and 0.6–5 cm/s corresponding to the north and the south areas). At the navigation channel points (M1–M5), the average velocities are likely to decrease, less than 0.6–6 cm/s and 1–8 cm/s corresponding to SLR 0.5 m and SLR 1.0 m scenarios. At the points far from the shore, there is a difference of the average velocity between two regions. At the points in the north of navigation channel (X1, X4), average velocity is likely to increase slightly (0.2–1 cm/s). In contrast, in the Southern points (X2, X3), it decreases softly (0.2–3 cm/s). The average velocity at offshore points (O1–O3) is quite similar to the present scenario and the SLR scenarios (fig. 6a).

In the rainy season, the average velocity at the points of the northern (N1–N4) and southern regions (S1–S4) has the same tendency and is likely to increase when sea level rises (0.2–3 cm/s and 0.3–5 cm/s corresponding to SLR 0.5 m and SLR 1.0 m scenarios). At the points in the navigation channel (M1–M5), average velocity in SLR scenarios is much lower than the present scenario (less than 5–16 cm/s and 10–30 cm/s corresponding to SLR 0.5 m and SLR 1.0 m scenarios). The average velocity of offshore points (O1–O3) is not significantly different between scenarios (fig. 6b).

Impact of SLR on hydrodynamic conditions was reported in the previous studies. These results showed that SLR affected current speed [13, 14]. One of typical studies is in Kuala Pahang estuary that simulated effect of SLR on the hydrodynamics and suspended sediment concentration based on Mike 21HD model. The results showed that SLR would increase 10% of the current speed in the year 2060 based on the 2014 model [15]. Other study of French [16] said that increase of 0.30 m in SLR in the year 2050 would cause increase of 20% in tidal current and 28% in discharge in a meso-tidal estuary.

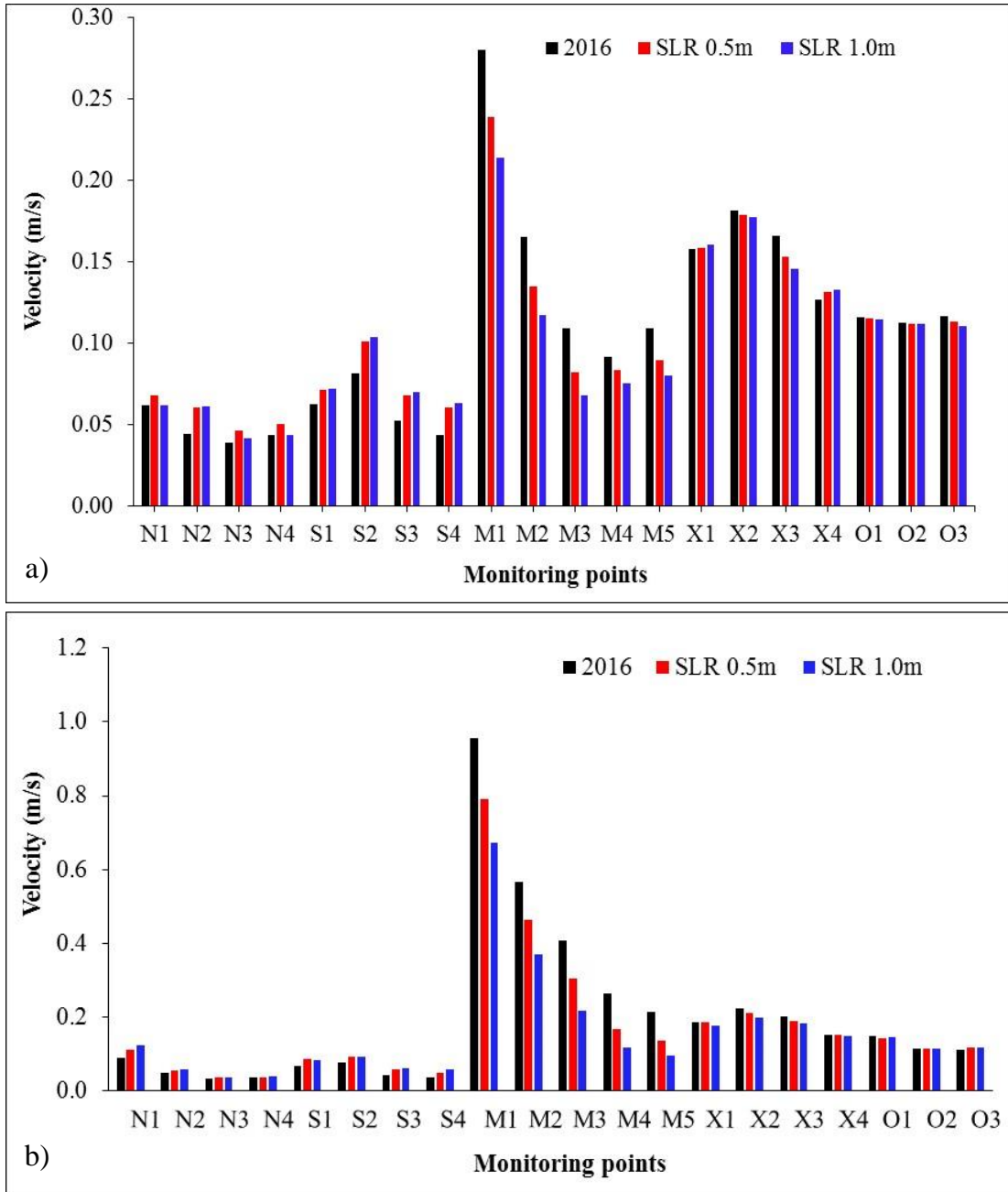


Fig. 6. Average velocity at monitoring points (a-dry season, b-rainy season)

**Wave characteristics in the study area**

The study area has a complex of morphological structure due to sandbars and tidal channels. When wave transmits from the offshore area to the shore, its characteristics (propagation speed, height, period, length, direction) are modified due to bottom friction.

In the dry season, the wave in the study area has the prevailing direction of E, NE and S. Wave height varies from 0.2 m to 1.2 m, in which the wave height of NE is higher than the other waves (fig. 7a). In the rainy season, main directions of wave are E, S, SE, SW. The wave height changes between 0.2 m and 1.3 m (fig. 8a).



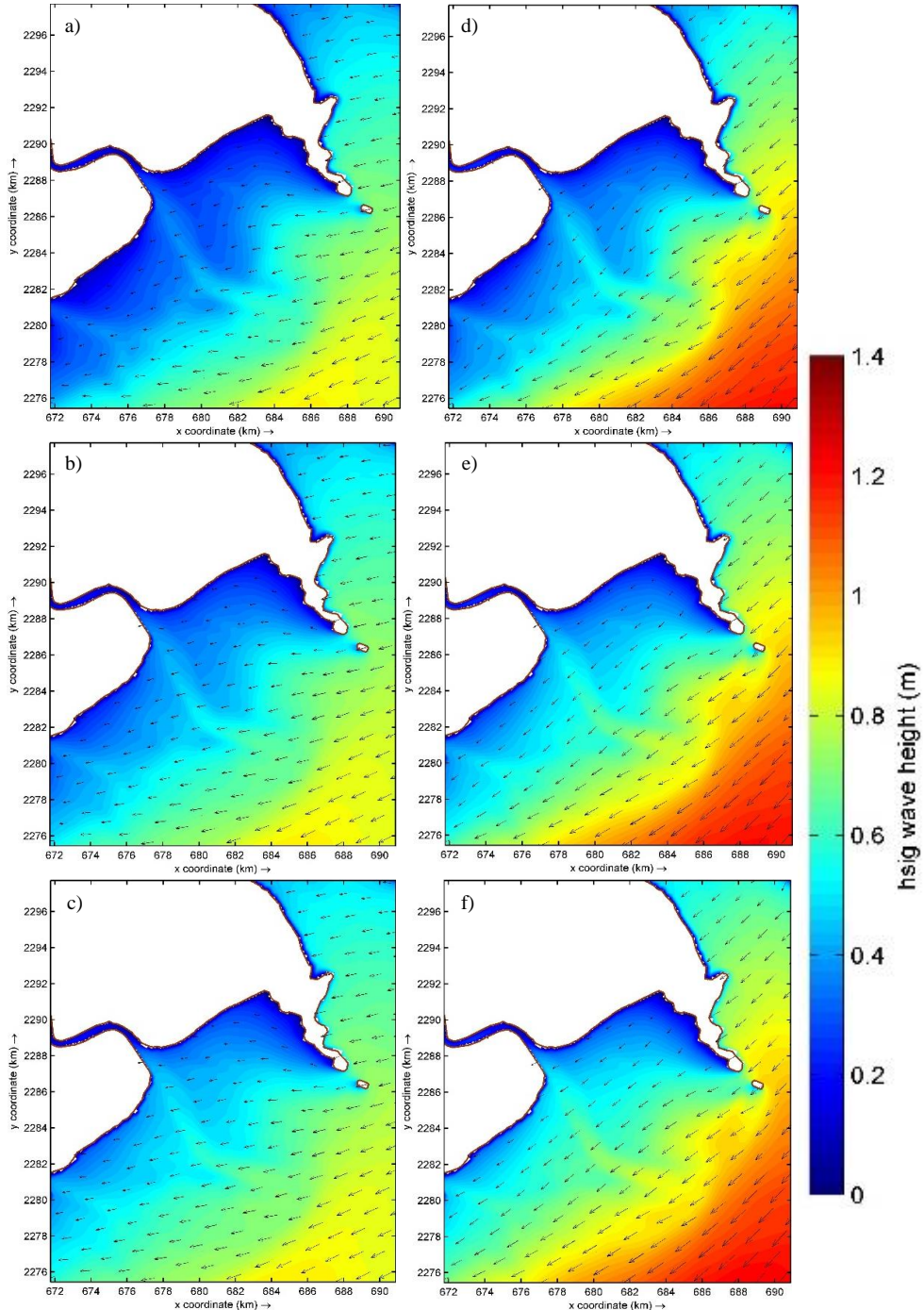


Fig. 7. Wave field at Van Uc area, dry season (E direction: a- 2016, b- SLR 0.5 m, c- SLR 1.0 m, SE direction: d- 2016, e- SLR 0.5 m, f- SLR 1.0 m)

**Impact of sea level rise on wave**

There are differences in spatial distribution of the field wave height between the present scenario and the SLR scenarios,

especially in the coastal area. Wave height is likely to increase in the coastal area and changes insignificantly in the offshore area when sea level rises. In the coastal area, the

wave height varies from 0.25 m to 0.7 m for the SLR 0.5 m scenario (increasing 13.5% in the dry season and 20% in the rainy season). For SLR 0.1 m scenario, it changes between

0.3 m and 0.8 m (increasing 43.8% and 40% corresponding to dry season and rainy season) (fig. 7 b, 7c; fig. 8b, 8c).

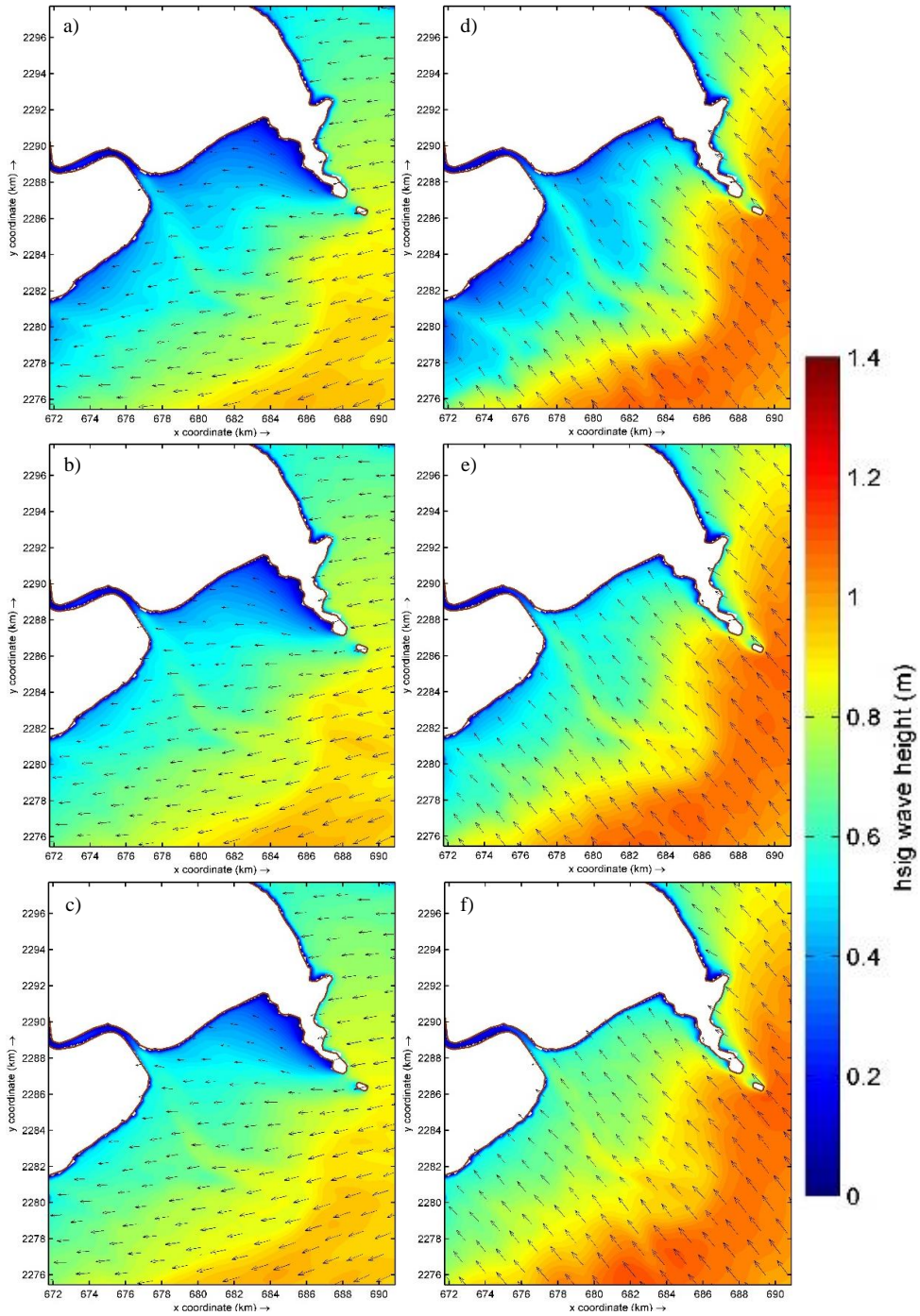


Fig. 8. Wave field at Van Uc area, rainy season (E direction: a- 2016, b- SLR 0.5 m, c- SLR 1.0 m, SE direction: d- 2016, e- SLR 0.5 m, f- SLR 1.0 m)

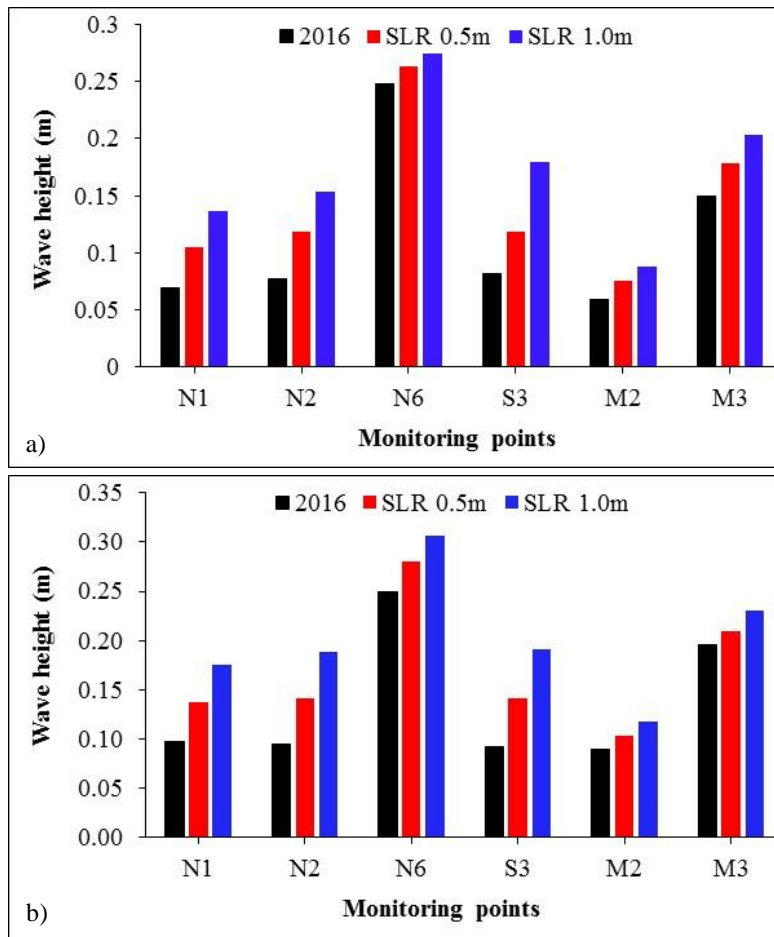


Fig. 9. Average wave height at monitoring points (a- dry season, b- rainy season)

In both seasons, the average wave height has the same trend. It is likely to increase due to influence of sea level rise. In the rainy season, it increases about 6.2–54% and 10–119% corresponding to SLR 0.5 m and SLR 1.0 m scenarios. In the dry season, it rises about 6.9–47% and 17.1–94% corresponding to SLR 0.5 m and SLR 1.0 m scenarios (fig. 9a, 9b). Some previous studies reported that SLR will cause an increase of shallow water depth, and the nearshore waves can enhance. Young and Ribal [17] based on the data during 1985–2018, found that wave height increases around the globe about 5%. With 0.36 m sea level rise in the north coast area of the United States, significant wave height near coast increased between 0.2 m and 0.24 m [18].

Although increases of wave height might not seem like much, a combination of SLR and

human activities will continue to carry the foreshore sand to the coastal area, exacerbating the shoreline landward migration efforts; sea level rise is through the enhancement of wave force that causes beach erosion. According to the principle of wave dynamics in shallow water, the wave energy is proportional to the square of wave height, the wave energy transmission speed is proportional to the square root of the water depth, and the wave intensity can be increased to 5.6 times when the water depth is increased by 1 time, as Cornity et al. [19] had predicted.

## CONCLUSION

Sea level rise does not alter the current regime, characteristics of spatial distribution and temporal variation of the current field at the Van Uc estuary coastal. However, the

current velocity value is likely to change locally when the water level rises. In the north and south coastal areas, the velocity increases about 0.2–5 cm/s. In the navigation channel, the average velocity gradually decreases under the influence of sea level rise (0.6–8 cm/s and 5–30 cm/s corresponding to the dry season and rainy season). At the offshore points (O1–O3), the average velocity differs insignificantly between calculated scenarios (increase less than 1 cm/s or decrease less than 3 cm/s).

When sea level rises, the wave height is likely to increase about 0.05 m to 0.1 m in the coastal area and changes insignificantly in the offshore area during the rainy and dry seasons. The height of waves increases as the water level rises. In the coastal area, in the dry season, the wave height increases about 13.5% and 43.8%, corresponding to SLR 0.5 m and SLR 1.0 m scenarios compared to the present scenario. In the rainy season, these values are 20% and 40% respectively.

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