THE TIDAL OSCILLATIONS UNDER THE SEA LEVELRISE EFFECTS IN CENTRAL VIETNAM

Nguyen Quoc Trinh[1*], Nguyen Minh Huan[2], Pham Van Tien[3] , Nguyen Quang Vinh[4]
[1]*National Centre for Hydro-Meteorological Forecasting, MONRE. E-mail:* maitrinhvinh@gmail.com;
[2]*Hanoi University of Science-VNU;*
[3]*Vietnam Institute of Meteorology-Hydrology and Climate Change, MONRE;*
[4]*Aero-Meteorological Observatory, MONRE.*

ABSTRACT: Tide is one of the most important phenomena in the oceans. In all over the world as well as in Vietnam, the tide has been studied very early and such great achievements have been recorded.However, under the impact of climate changes and sea level rise, the local-to-regional-scalechanges will cause significant changes in the coastal system. This paper gives some results ofresearch on the tidal changes in the central region of Vietnam by using the hydrodynamic modeland data analysing model. The simulation results of the tide in the central coast of Vietnam showthat the tide can change both in the amplitude and phase distribution of the tidal constituents as M2,S2, K1 and O1. Specifically, the results of the average values of M2 are 0.1 m and 10.20; for S2 are0.12 m and 12.50; for K1 are 0.2 m and 17.20; for O1 are 0.21 m and 20.20. Some results of thisstudy showed that the most important contribution to the change of the tide in the region is thechange of topography and the submerged areas.

Keywords:Vietnam's central sea, tidal change, hydrodynamic models, the sea level rise impact,tidal components.

1. Overview

The tide is one of the most important phenomena in the ocean.In the world as well as in Vietnam, the tide was studied very early and great achievements have been recorded. The estimated current tide at observed stations, which the time is long enough, can be reached centimeter accuracy. However, under the impact of rising sea level due to climate change which has been built the scenarios [1], the processes of local-scale and area-scale, will cause significant changes in coastal systems including tides.

In the world, there are some researches on the change of the tide phenomenon due to sea level rise, however, the quantities are small. The typical studies can mention as researches of Ana Picado et al., (2010) [2], Dias J. M., et al., (2013) [3], Arau´jo et al., (2008) [4], JuWhan Kang et al., (2009) [5], Wei Zhang et al., (2010) [6]…Overall, these studies have confirmed the important role of the change of the depth and the submerged areas led to the change of the tide.

The typical domestic researches may be mentioned as Tran Thuc and Duong Hong Son (2012) [7], which have shown that the rising sea level makes changes to terrain, leads to various changes of the tide in thecoastal of Vietnam; Nguyen Xuan Hien's PhD thesis (2013) [8] pointed out the important changes in the tides of Haiphong'scoastal estuariesdue to the rising sea level.

The main purposes of the paper are aim to study and evaluate the impacts of the phenomenon of rise sea level on the tide of change in the region of Central Vietnam. The study's results also confirm that the most important contribution to the change of the tide in the region is the terrain changes.

2. Research areas

Coastal area in Central Vietnam (Fig. 1) stretches from latitude 10^{o}N to 17.25^{o}N, and their administrative boundary is from Ba RiaVung Tau province to Quang Tri province. Seabed and shoreline topography is complicated. The north is from Quang Tri to Quang Nam which the shoreline with direction of the Northwest - Southeast. The south is from BinhThuan to Ba Ria - Vung Tau which the shoreline with direction of theNortheast – Southwest. The terrain of these two areas changes slowly from shore to sea. Meanwhile, the central area, from Quang Ngai to NinhThuan with steep terrain, changes rapidly from the shore out to the sea, the direction of the shoreline is North - South.

The tides in these areas are complex, there is a substantial change in the feature and the magnitude. According to the studyresultof Nguyen Ngoc Thuy (1995) [9], the tide in the study area was very diverse, from North to South, the feature of tide change from irregular semi-diurnal tide (Cua Tung estuary) to regular semi-diurnal tide(Thuan An estuary), irregular tide (Quy Nhon, Nha Trang), and finally irregular semi-diurnal tide (Vung Tau). The degree of tide decreases from Quang Tri (Cua Tung) to ThuanAn, then increase to Vung Tau.

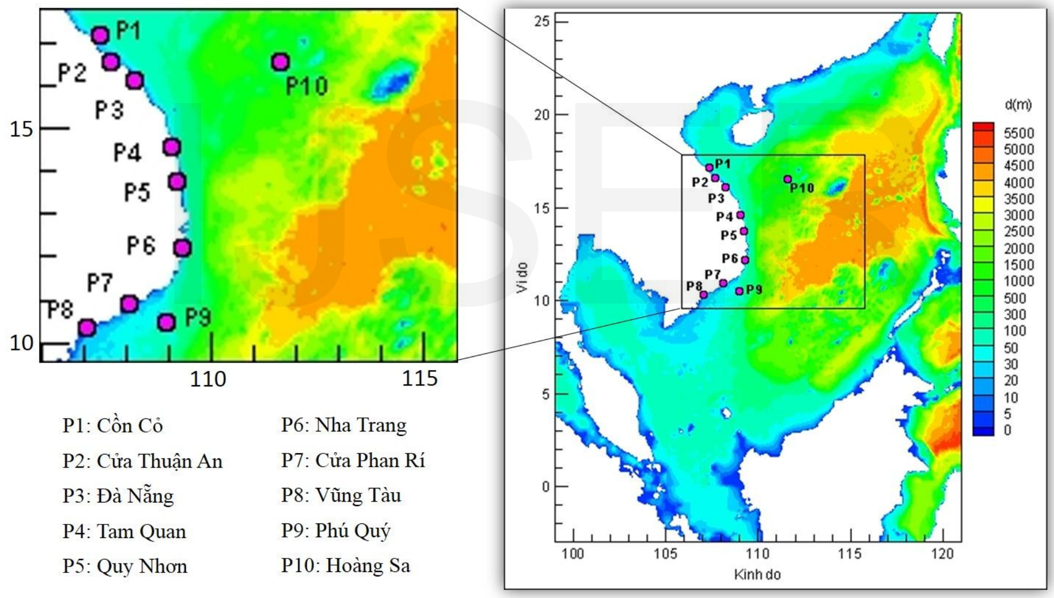


Fig 1. Topography, maps of the study area and locations of the tidal test sites

In this study, we use 10 points (Fig. 1) with water level data to compare and evaluate the variation of the tides under the impact of the rise sea levels. In particular, coastal 8 points distribute relatively evenly over the coastal of the central and 2 points onthe islands of Phu Quy and Hoang Sa.

3. Methods

In the research, we applythe harmonic analytical method and modeling method. The harmonic analytical method is used for the string datas of the observed water leveland 1-year estimated from the hydrodynamic model.

The calculations are made on the basis of hydrodynamic model MIKE 21 for both case ofnormal condition and another with taking into account the effects of sea level rise. The changes of the tide in the region are evaluated by analyzing and comparing the calculated results in the normal conditional scenario toanother with the effects of sea level rise and to the harmonic analytical data which has been observed at 10 coastal oceanographic stations as shown in Fig.1.

The data, which is used in the research, includes NOAA's terrain data TOPO1 and coastal topography from navy maps. The water level data at the edge of liquid is extracted fromNOAA's the global tidal harmonic constants.

3.1. Describe and establish hydrodynamic model

MIKE 21 HD is two-dimension hydrodynamic model, in the package of MIKE modeldevelopedby Danish Hydraulic Institute (DHI). The equations, which are used in the model, include the continuity equation and two momentum equations:

$$\frac{\partial \zeta}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=\frac{\partial d}{\partial t} \quad (1)$$

$$\begin{gathered}\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial x}+\frac{gp\sqrt{p^2+q^2}}{C^2h^2}\\ -\frac{1}{\rho_w}\left[\frac{\partial}{\partial x}\left(h\tau_{xx}\right)+\frac{\partial}{\partial y}\left(h\tau_{xy}\right)\right]-\Omega_q-fVV_x+\frac{h}{\rho_w}\frac{\partial}{\partial xy}\left(p_a\right)=0\end{gathered} \quad (2)$$

$$\begin{gathered}\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial y}+\frac{gp\sqrt{p^2+q^2}}{C^2h^2}\\ -\frac{1}{\rho_w}\left[\frac{\partial}{\partial y}\left(h\tau_{yy}\right)+\frac{\partial}{\partial x}\left(h\tau_{xy}\right)\right]-\Omega_p-fVV_y+\frac{h}{\rho_w}\frac{\partial}{\partial xy}\left(p_a\right)=0\end{gathered} \quad (3)$$

Where $h(x,y,t)$ is the water depth ($=(\zeta,-d)$) (m); $d(x,y,t)$ is water depth which is veriable over time (m); $\zeta(x,y,t)$ is the surface water level (m); $p,q(x,y,t)$ is the traffic density in the x, y directions $(m^3/s/m)=(uh,vh)$; u,v are average speeds in the x, y directions; $C(x,y)$ is friction coefficient,Chezy; g is the gravitational acceleration (m/s^2); $f(V)$ is the wind friction coefficient; $V,V_x,V_y(x,y,t)$ are windspeed and components with the directions of x,y; $\Omega(x,y)$ is Coriolis parameter; $p_a(x,y,t)$ is the atmospheric pressure $(kg/m/s^2)$; ρ_w is the density of water; x,y are distances in coordinate (m); t is time and $\tau_{xx},\tau_{xy},\tau_{yy}$ is the component of sliding stress.

MIKE 21 HD can solve complex problems for shallowing water, especially in intertidal areas, moving border techniques and wetting-drying algorithm is used by considering the depth of grid, continuously for each calculating step and defining the limits of the drying grid and submerged (wetting) grid. The border of calculated domain will be changed in steps of time depending on the drying, wettinggridsin this domain.

The model is established to calculate in two cases: (1) Calculate thescenario of background inthe year of 2010; (2) Calculate the tide in the case of taking into account the phenomenon of sea level rise in the years of 2020, 2050 and 2100 (Table 2).Sea level rise is average value throughout the considering region, value of the region which istaken from the public source of Ministry of Natural Resources and Environment in 2012 (Table 1).

Table 1. Sea level rise under the scenario ofa high emission of greenhouse gas (cm) [1]

Regions	Year		
	2020	2050	2100
Ngang pass -HaiVan pass	9,0	28,0	94,0
HaiVan pass- DaiLanh cape	9,0	29,0	97,0
DaiLanh cape - KeGa cape	9,0	30,0	102,0
KeGa cape - CaMau cape	9,0	30,0	99,0
Average throughoutthe Central coastal area	9,0	29.3	98,0

Table2. The scenarios in calculating

No.	Scenario name	Year	Rising sea water level (cm)	Note
1	MT2010	2010		Background scenario
2	MT2020	2020	9,0	High levelscenario
3	MT2050	2050	29,3	High levelscenario
4	MT2100	2100	98,0	High levelscenario

3.2 Adjusting hydrodynamic model

Hydrodynamic model is adjusted during the 6 days of 4/2014. Adjusted results in Fig.2 shows that the tidal simulating models in the region are quite good, the biggest absolute error is over 17cm.

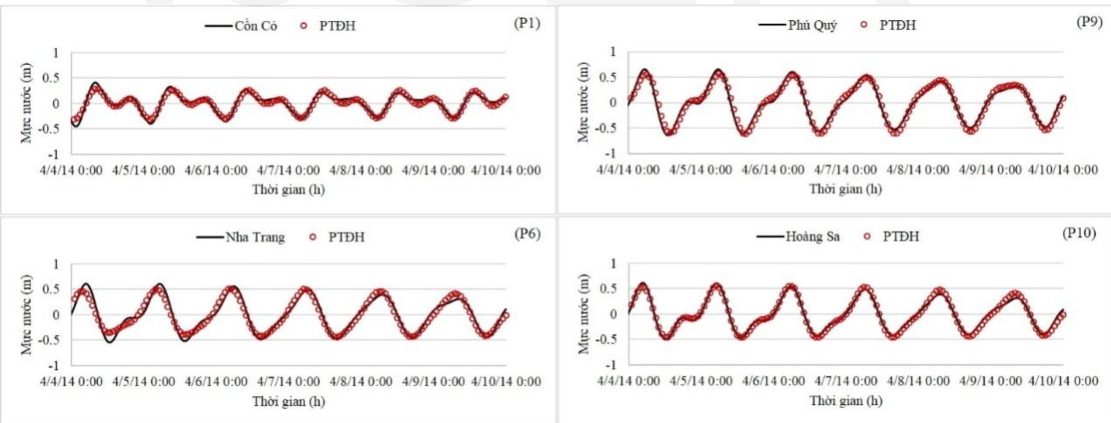


Fig.2. Compare calculating tidal water level (dark black solid line) with harmonic analyticaltidal water level (red brown circle) at some coastal oceanographic stations and offshore areas in Central Vietnam

Based on the results of model adjustment, the parameters of the model obtained after adjusting model will be kept during the calculation for the scenarios in Table 2.

4. Results and discuss

Model calculations implemented under four scenarios, simulating time in each scenario is one year. The results obtained one-year water levelseries at each grid point for each calculated scenario. From the series of these water levels, we do analysis and obtainharmonictidal constants at each grid in each scenario.

Figure 3 shows the calculated water level at 00Z July 15thin the senarios. The results also reflect the distribution law in the South China Sea tide. The largest tides in the northern South China Sea area, China coast (Taiwan Strait area and eastern and westerncoastal region coast of Leizhou Peninsula), two tidal peak areas in Vung Tau, along Vietnam coast and PulauBurungsea, Malaysia is also presented.

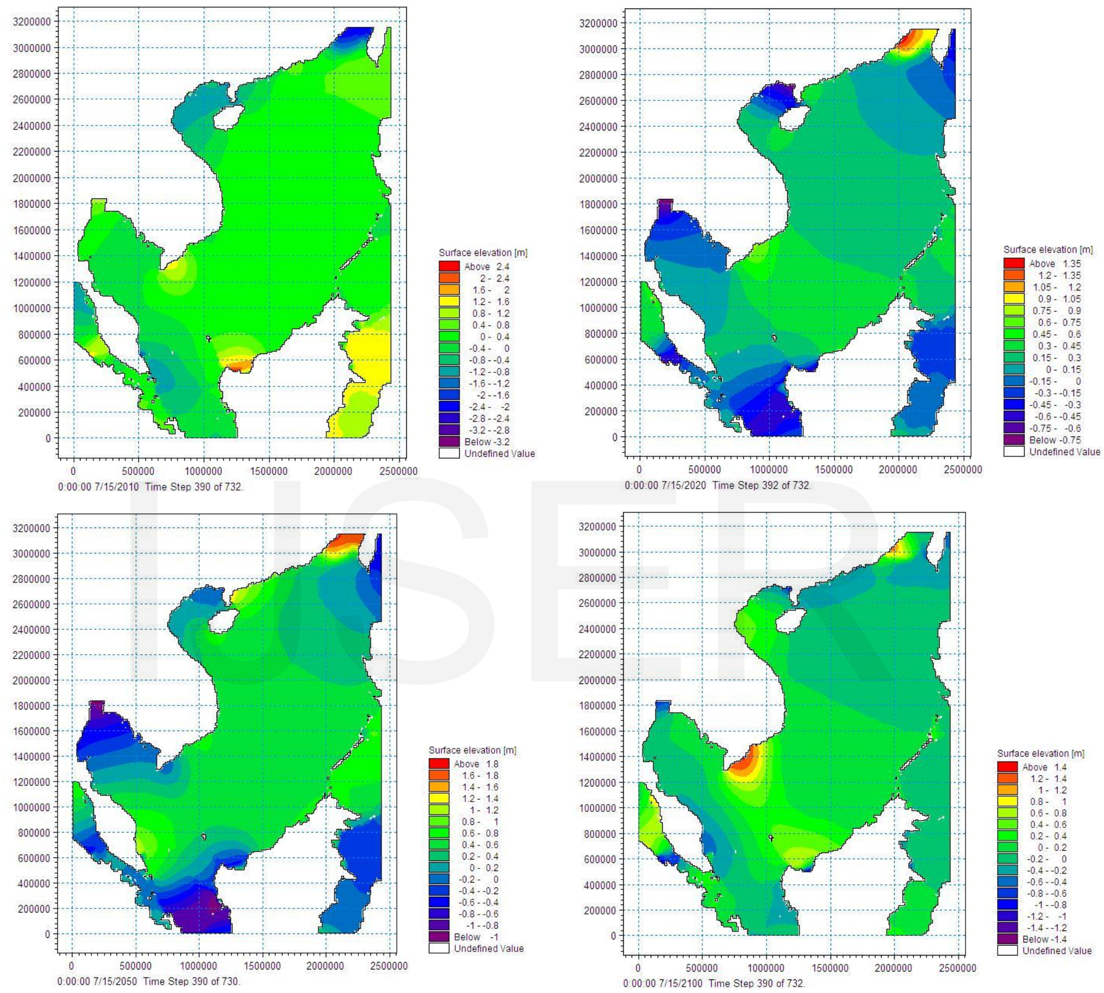


Fig 3. Calculated water level in four scenarios

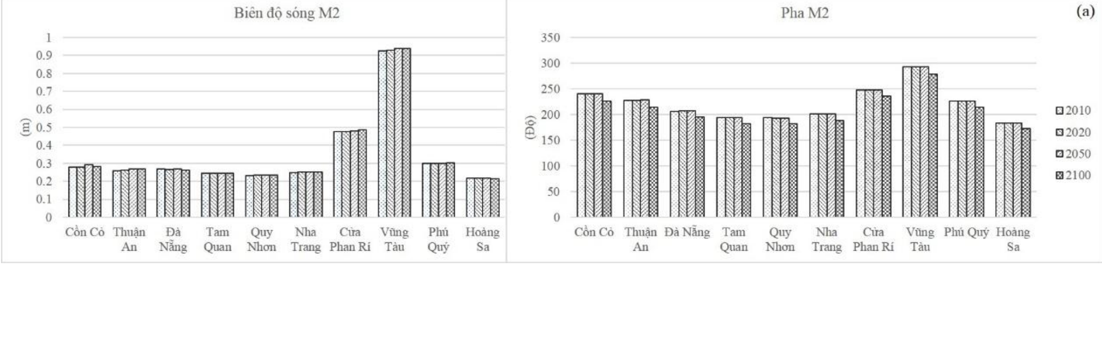
Comparing the harmonic constants of 4 main waves between observed and background scenario shows the high relevance of the amplitude and phase. Largest error between calculation and observation for M2 wave is 17.5cm and S2 wave is 5.1cm in Phan Riestuary, K1 wave is -8.1cm in Vung Tau, O1 wave is 10.5cm at Phu Quy (Table 3).

In the current scenario which takes into account sea level rise shows that, for four main tidal waves at stations do not indicate a unified trend, increase or decrease in amplitude. For example, ConCo station, the M2, S2 wavestend to rise and then decline slightly in amplitude, while the K1, O1 wavestend to increase as sea water level increase gradually (Fig. 4a-h). In MT2020scenario, 0.6% for M2 wave, 3.2% for S2wave, 0.2% for K1 wave and 1.2% for O1 wave. In MT2050scenario, the largest fluctuation on amplitude is5.2% for M2 wave, 2.5% for S2wave, 0.8% for K1 wave and 7.3% for O1 wave. In MT2100scenario, the largest fluctuation on amplitude is2.9% for M2 wave, 4.7% forS2 wave, 17.4% for K1 wave and 16.8% for O1 wave. The fluctuation in phase in the scenarios is very small compared to the background scenario (Fig. 4a-d), particularly for K1 and O1 wave, in MT100 scenario, there islarge fluctuation in phase (Figure 4c, d). Thus, it can be seen that the K1 and O1 waveshave greater fluctuation than M2 and S2 waves, especially when there is a significant change of depth (MT2100 scenario).

Table 3. Harmonic constant of four main waves between observed and background scenario

Wave			**Stations**									
			P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
M2	Amplitude (m)	Observed	0.19	0.18	0.17	0.20	0.18	0.10	0.30	0.79	0.19	0.17
		Calculated	0.28	0.26	0.27	0.24	0.23	0.25	0.47	0.92	0.30	0.22
	Phase (°)	Observed	351.0	322.3	301.0	295.0	303.9	303.5	3.0	35.8	323.5	271.8
		Calculated	239.8	227.0	206.4	193.5	193.5	200.6	247.3	293.0	225.8	183.7
S2	Amplitude (m)	Observed	0.05	0.04	0.06	0.10	0.07	0.04	0.10	0.31	0.08	0.08
		Calculated	0.08	0.08	0.09	0.09	0.08	0.09	0.15	0.27	0.10	0.08
	Phase (°)	Observed	355.8	28.4	340.4	338.0	325.0	340.4	23.0	80.9	6.7	322.9
		Calculated	272.2	254.5	234.6	223.0	222.7	230.5	277.3	332.6	254.0	212.7
K1	Amplitude (m)	Observed	0.06	0.03	0.20	0.30	0.34	0.29	0.40	0.60	0.37	0.27
		Calculated	0.07	0.07	0.20	0.30	0.31	0.32	0.41	0.51	0.36	0.29
	Phase (°)	Observed	65.9	255.3	289.5	300.0	296.2	315.8	287.0	312.2	289.8	290.4
		Calculated	18.4	299.6	279.3	282.9	284.2	285.5	291.6	308.0	289.6	282.5
O1	Amplitude (m)	Observed	0.14	0.02	0.13	0.30	0.28	0.23	0.40	0.45	0.20	0.23
		Calculated	0.15	0.07	0.15	0.26	0.27	0.28	0.35	0.41	0.31	0.25
	Phase (°)	Observed	33.3	5.1	244.1	257.0	273.7	269.7	248.0	262.5	250.0	247.1
		Calculated	358.7	326.5	249.3	246.5	247.6	248.6	252.9	266.6	251.5	247.2

Spatial distribution of the tidal harmonic constants in the calculatedscenariosare presented in Fig. 5. The variation in amplitude of the four main tidal waves in sea level risescenarios which compared to the background scenario are small (Fig. 5a-h), the major difference only found at coastal sites, where depth changes in accordance to the sea level rise scenarios. For the phases of the 4 main tidal wavehave similar trend (Fig. 5i-m, o), particularly for K1 and O1 waves, in MT100 scenario,have very strong fluctuations of phase (Fig. 5n, p), corresponding to the case of sharp fluctuations in the terrain.



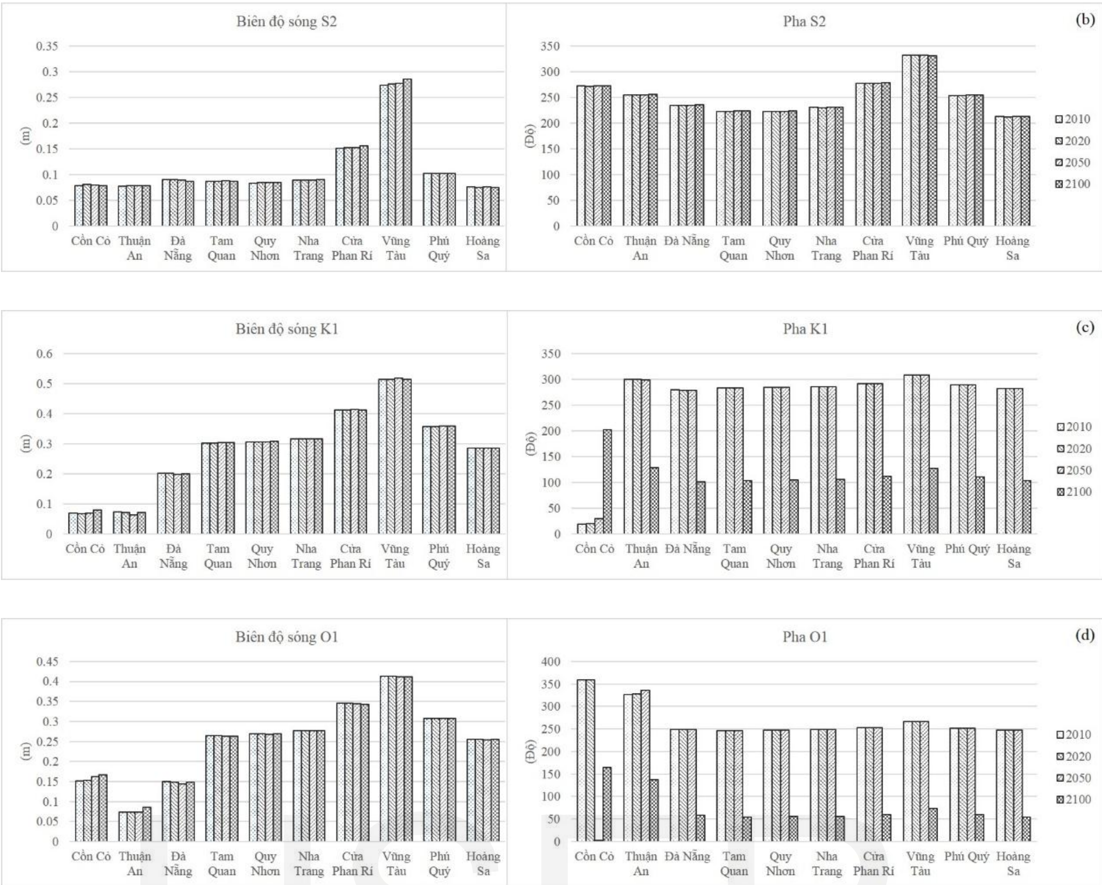


Fig 4. Calculated water level in four scenarios

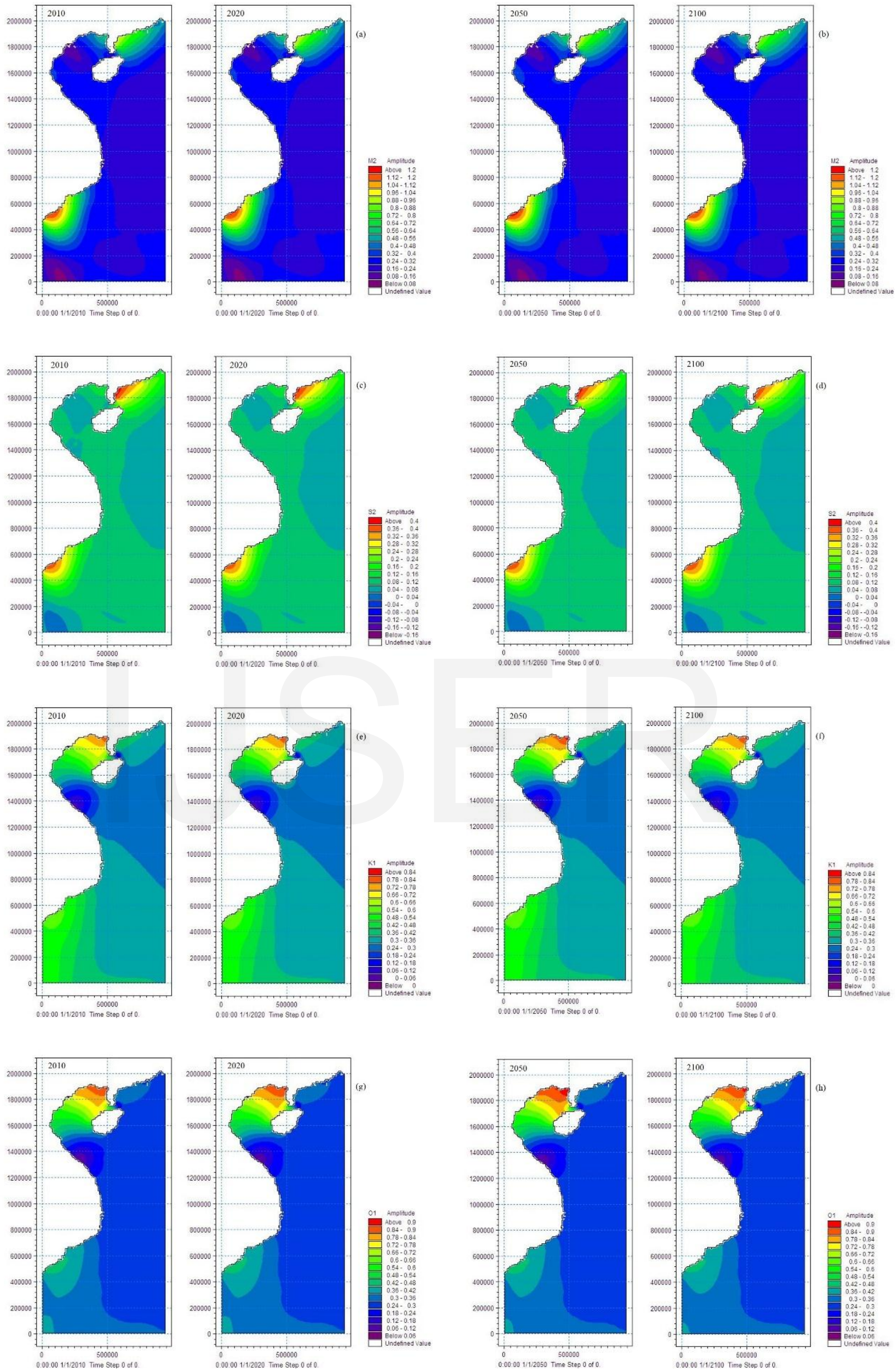
5. Conclusions

The article evaluate the effects of sea level rise on the change of tide in Vietnam Central under the threescenarios in 2020, 2050 and 2100. The results showed that all four main tidal waves M2, S2, K1, O1 have not shown the same trend was uniformly increased or decreased in both amplitude and phase.

The K1 and O1 waves tend to fluctuate more powerful than M2 and S2 waves inboth amplitude and phase. The most differentas there is a significant change in sea depth (MT2100 scenario).

There needs to be studied in more detail for small areas, especially estuaries, coastal terrain has small slope, whereas the impact of sea level rise on the transformation of the watershed area is worth matter.

Acknowledgments: The authors thank QGT Đ.13.09 project were funded to complete this research.


2010
2020
(a)
2050
2100
(b)
M2 Amplitude
2010
2020
(c)
2050
2100
(d)
S2 Amplitude
2010
2020
(e)
2050
2100
(f)
K1 Amplitude
2010
2020
(g)
2050
2100
(h)
O1 Amplitude
Undefined Value

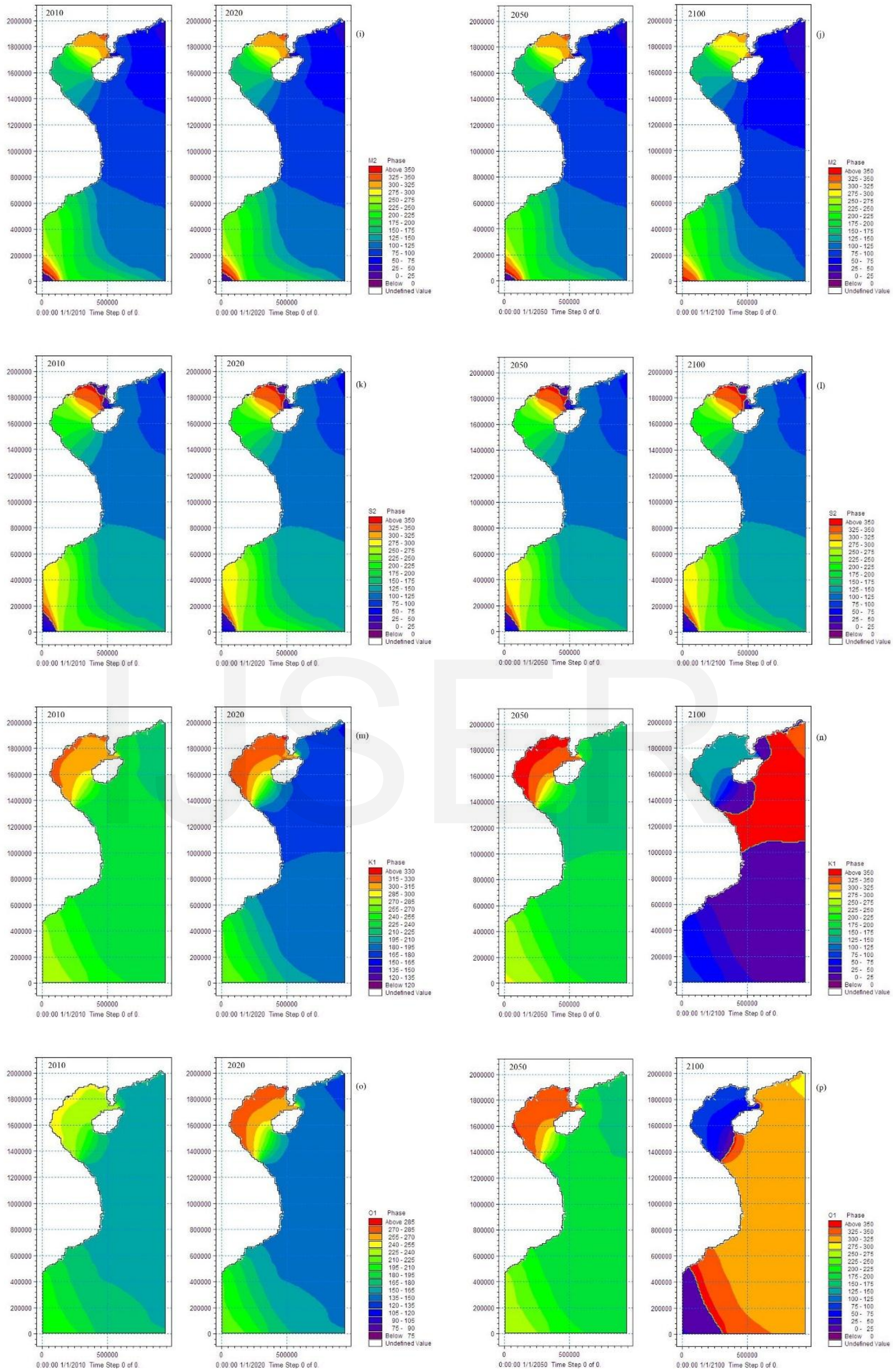


Fig. 5. Maps of harmonic constants of four main waves in the scenarios

References

1. Ministry of Natural Resources and Environment (MONRE) (2012). Scenarios of climate change and sea level rise for Vietnam (In Vietnamese).

2. Nguyen Minh Huan (2010). Determination of spatial distribution of tidal constants in the Tonkin Gulf sea. Journal of Sciences, Vietnam National University, Hanoi. Natural Sciences and Technology, Vol.25 No.3S – 2009, 439-449 (In Vietnamese).

3. Nguyen Xuan Hien - PhD thesis (2013). Research on surging due to typhoons taking into effect of waves and apply to coastal areas of Haiphong (In Vietnamese).

4. Tran Thuc and Duong Hong Son (2012). The impact of sea level rise on the tide along the coast of Vietnam. Journal of Marine Science and Technology Vol.12 (2012). No.1. 10-16 (In Vietnamese).

5. Ana Picado, Joao M. Dias và Andre´ B. Fortunato (2010). Tidal changes in estuarine systems induced by local geomorphologic modifications. Continental Shelf Research 30 (2010) 1854–1864.

6. Arau´jo, I.G.B., Dias, J.M., Pugh, D.T., (2008). Model simulations of tidal changes in a coastal lagoon, the Ria de Aveiro (Portugal). Continental Shelf Research 28, 1010–1025.

7. Dias JM, Valentim JM, Sousa MC (2013) A Numerical Study of Local Variations in Tidal Regime of Tagus Estuary, Portugal. PLoS ONE 8(12): e80450. doi:10.1371/journal.pone.0080450.

8. JuWhan Kang, Seong-Rok Moon, Seon-Jung Park, Khil-Ha Lee (2009). Analyzing sea level rise and tide characteristics change driven by coastal construction at Mokpo Coastal Zone in Korea. Ocean EngineeringVolume 36, Issues 6–7, May 2009, Pages 415–425.

9. Wei Zhang, XiaohongRuan, Jinhai Zheng, Yuliang Zhu, Hongxu Wu (2010). Long-term change in tidal dynamics and its cause in the Pearl River Delta, China. GeomorphologyVolume 120, Issues 3–4, 15 August 2010, Pages 209–223.