Storm surge predictions for Vietnam coast by Delft3D model using results from RAMS model

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Abstracts: Storm surges are dangerous phenomena to the Vietnam coast, so they are taken in account by number of researchers. Rapid and accurate prediction of storm surges makes contribution in protection and mitigation of natural damages in coastal areas. Storm surges are considered as a complicated processes under action of air pressure, wind field, tide etc. and they may be well predicted using mathematical models. It is the basic branch of the state scientific project named KHCN-08-05" Technological building for associated predictions of typhoons, storm surges and waves in Vietnam using numerical models for 3-days forecast". This paper describes the preliminary results in storm surge prediction by Delft3D-FLOW model using the meteorological outputs of RAMS model.

Key words: storm surge, tide, South China Sea, numerical method, RAMS, Delft3D-FLOW, prediction.

1. Introduction

Wind-setup is the rise of sea level relatively to the normal still water level in great lakes or seas when wind is blowing to the shore. Wind-setdown is the falling of sea level when wind is blowing from the shore. In the sea affected by tides, wind setup or storm surge is the rise of water level above the tidal level due to storms. Tide, topography, earth's rotation, wind speed, radius of maximum wind, storm movement velocity, atmospherical pressure, precipitation, river flows influence to wind-setup/setdown, but the most important factors are air pressure and wind patterns. Wind-setup/setdown is of short term period, but the propagation is the long wave.

When wind speed exceeds 74 mph (during storms, hurricanes) the rise of water level is very significant and it is called storm surge. This is the short term response of water body to the pressure and wind fields over the sea [2]. If the storm surge is coincident with the high water during spring tide it gives rise of strong damages on humanity and properties in the storm attack region and vicinity. During the setdown, the high cross-shore velocity may give rise of shore erosion. Storm surge/setdown is very dangerous in natural hazards, but one pays much attention to the surge because it affects on the hydrostructures [8].

In Vietnam, because of the natural hazards of this phenomena the storm surge problems have been taken in account since 1970s by Le Phuoc Trinh (1970), Do Ngoc Quynh (1982), Le Trong Dao (1989) etc. Most of them are in the frameworks of the doctorate thesises. The systematical researches on storm surges began in 1984 up to now under state programs. The 48.06.15 and 48B.02.02 (Pham Van Ninh) set the regime nature of storm surges, the locations and the time hiding the Vietnam coast of maximal surges, the relationship between surges and tidal phases etc. in order to give contribution in economical planning for the coastal zones of Vietnam. The project KT.03.06 (Do Ngoc Quynh) researched surges for the certain typhoons. In 2000, the Marine Hydrometeorological Center in collaboration with Delft Hydraulics makes the storm surge prediction for the Vietnam coast using Delft3D model.

In the framework of the state scientific project named KHCN-08-05 "*Technological building for associated predictions of typhoons, storm surges and waves in Vietnam using*

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numerical models for 3-days forecast" there is a branch on storm surges by Delft3D-FLOW model using meteorological predictions from RAMS model, in order to build a prediction associated procedure contributing in protection and mitigation of natural hazards.

To study storm surges in Vietnam one must know the storms in South China Sea. The Disaster Management Unit (UNDP VIE/97/002) in Vietnam in association with the other global meteorological institutions informs that: tropical storms occurring from June in the north part of South China Sea move to the south part up to December, their number also decreases from the North to the South [9]. In fact DMU is not a research agency, it only gives the information, warnings and recommendations for damage mitigations.
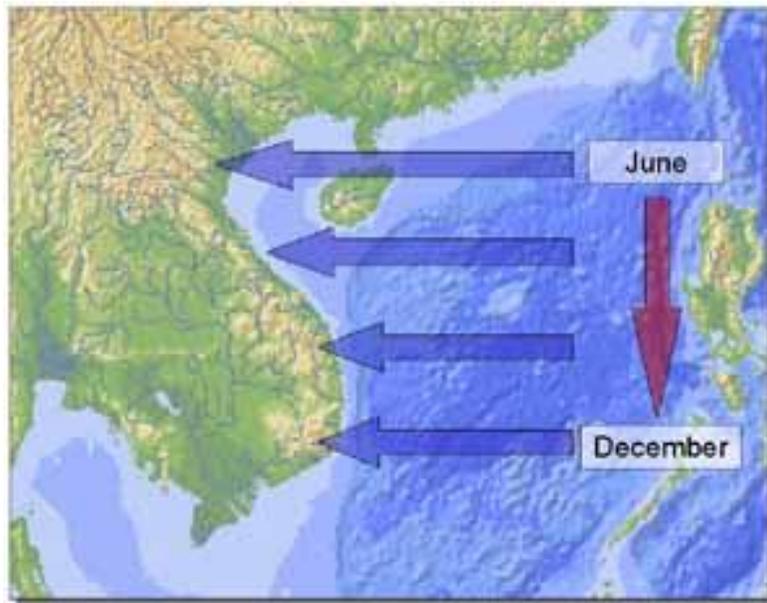

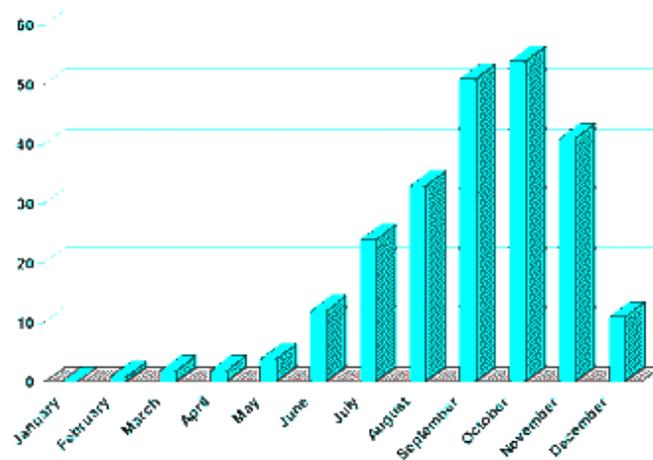Figure 1. Storm distribution in South China Sea (UNDP Project VIE/97/002)

Figure 2. Storm numbers monthly attacking Vietnam coast during period
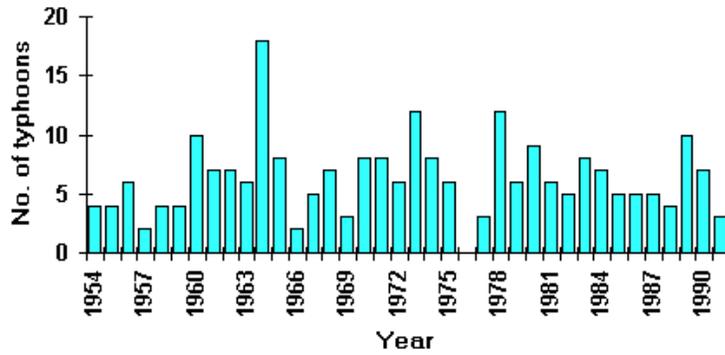of 1945-1998 (UNDP Project VIE/97/002)

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Figure 3. Number of storms attacking Vietnam coast (UNDP Project VIE/97/002)

The research project of Marine Mechanics Sub-institute under Institute of Mechanics evaluated the probabilities and maximum values of storm surges along the Vietnam coast (1954-1993) as follows:

Table 1. Storms and surges along Vietnam coast

Latitude (N)	Number of storms	P%	Annual average number	Observed maximum surge (m)	Expected maximum surge (m)
21-22 North Cửa Ông	29	12.04	0.74	2.2	2.6
20-21 Cửa Ông - Cửa Đáy	39	16.19	1.00	2.2	3.0
19-20 Cửa Đáy - Cửa Vạn	34	14.11	0.87	3.0	4.0
18-19 Cửa Vạn - Đèo Ngang	29	12.04	0.74	3.4	4.0
17-18 Đèo Ngang - Cửa Tùng	16	6.64	0.41	2.2	
16-17 Cửa Tùng - Đà Nẵng	9	3.73	0.23	2.6	
15-16 Đà Nẵng - Quảng Ngãi	23	9.54	0.59	1.4	1.6
14-15 Quảng Ngãi - Bình Định	23	9.54	0.59	1.0	1.2
13-14 Bình Định - Phú Yên	11	4.56	0.28	0.8	1.0
12-13 Phú Yên - Khánh Hoà	9	3.73	0.23	0.8	1.0
11-12 Ninh Thuận -Bình Thuận	10	4.15	0.26	1.0	1.2
10-11 Bình Thuận - Bến Tre	4	1.66	0.10	1.8	2.0
9-10 Bến Tre - Bạc Liêu	3	1.24	0.08	2.0	2.4
8-9 Bạc Liêu - Cà Mau	2	0.83	0.06	2.0	2.4
Total	241	100	6.18		

2. Study methods

2.1. Using an empirical formula

In this manner, the storm surge magnitude over the still water level is calculated with the wind speed according to some design criteria as follows [5, 6, 7]:

$$\Delta S = k \frac{W^2 X \cos \varphi}{gh} \tag{1}$$

where ΔS(m)- storm surge value, k - empirical coefficient, W(m/s) - wind speed, X(m) - fetch length, φ - angle between the wind direction and the normal to the shoreline, h(m) - depth. If the wind speed is about 20m/s, fetch is 100km in length, wind direction is normal to the shoreline, depth is 20m, then ΔS is about 0.4m. In the same wind condition, storm surge is higher in the location where the depth is smaller.

The above formula gives the highest value of storm surges because it is considered in steady condition, so this formula is often used in designing.

2.2. Using mathematical models

In general, the nearshore total currents are affected by:

- tide

- setup/setdown by wind, atmospherical pressures

- seismic fluctuations, tsunami

- river discharges

- season and annual disturbances like El Nino, La Nina.

In the previous periods, these actions were considered separately according to the different reasons. In the present, storm surge is considered as an interaction of simultaneous phenomena such as wind, atmospherical pressure, tide and river discharges.

RAMS (Regional Atmospherical Models System) is the state-of-the-art model used for regional predictions of meteorological factors. The outputs of RAMS may be used as inputs for the other predictions like circulations, waves and storm surges. In the sequence, the Delft3D-FLOW (Delft WL│Delft Hydraulics, The Netherlands) is applied for prediction of storm surges along the Vietnam coast in South China Sea. According to the mathematical base, Delft3D-FLOW is fit for our purpose. In this problem, the total flow is considered as simultaneously impacts of wind,
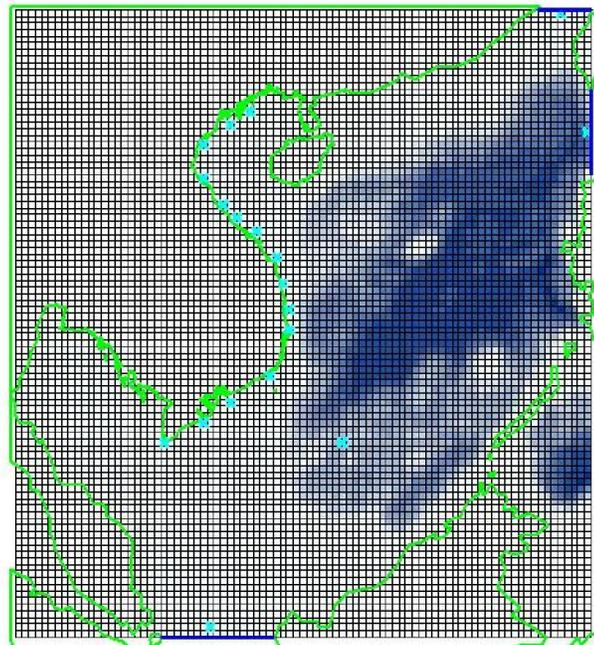

Figure 4. Calculation domain and mesh

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atmospherical pressure and tide [1, 2, 3, 5, 8], it means that storm surge occurs in associating with tidal levels.

3. Applications for vietnam coast

3.1. Data required

- Topography from ETOPO2 added by marine maps.

- Time and space varying atmospherical and wind fields during the storms resulted from RAMS model.

- Tidal harmonics of the 4 main constituents (O1, K1, M2, S2) at the open boundaries.
- River discharges.

3.2. The calculation characteristics

- Domain:

Calculation domain is fixed in the range of $\varphi = 1^o$ - 25^oN, $\lambda = 99^o$ - 121^oE with the resolutions of 0.25^O. The mesh is of 89 x 97 cells (Figure 4).

- Parameters:

Water density is taken constantly as $1025kg/m^3$, temperature as 25^OC, salinity as $31^o/_{oo}$, Manning coefficient n = 0.026, drag coefficient of wind: $C_D = 0.00063$ with wind speed of W = 1m/s and $C_D = 0.00723$ with wind speed of W = 100m/s. The duration of simulation is 72 hours (3 days).

- Boundary and initial conditions:

At the closed boundaries, there are zero normal velocity components. At the open boundaries there are several types to use: water levels or current velocities, river flows. On the surface, the time and space varying wind and preassure fields are forcing factors.

There are 3 open boundaries to use in South China Sea: Taiwan, Bashi and Mallaca. Tidal variations at these straits are very significant so they must be considered. Tidal harmonic constants are given for the 4 main constituents (M_2, S_2, K_1, O_1) at the 3 boundaries. The river discharges are negligible in present calculation, but they can be included at any time. The below table shows the boundary conditions of tide.

Table 2. Tidal harmonic constants at the open boundaries

| Loca-tion	Name	A₀ (cm)	M2		S2		K1		O1	
			H(cm)	g(°)	H(cm)	g(°)	H(cm)	g(°)	H(cm)	g(°)
Left	Taiwan-A	300	200	328	50	22	30	251	20	230
Right	Taiwan-B		163	294	50	336	20	239	17	199
Low	Bashi-A	24	19	167	7	187	12	276	13	234
Up	Bashi-B	78	26	159	11	184	23	247	18	210
Left	Malacca-A	160	80	298	33	351	30	101	28	50
Right	Malacca-B	60	26	96	5	169	14	51	16	356

Water levels and velocities are "0" at initial moment.

3.3. Model calibration

Parameterization for the model is based on the available data of water levels. In the present calculation, the calculated water levels are compared with ones from several station published by Vietnam Hydro meteorological Center in 2001. Figure 5 shows the comparisons. In general the calculated water levels are acceptable. The differences of tidal levels, may be, result from number of constituents chosen. In the future calculations number of harmonics may increase to 11 or more.
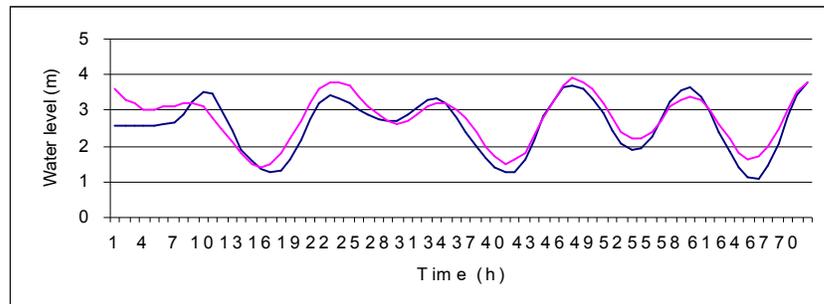
(a) Hòn Dáu
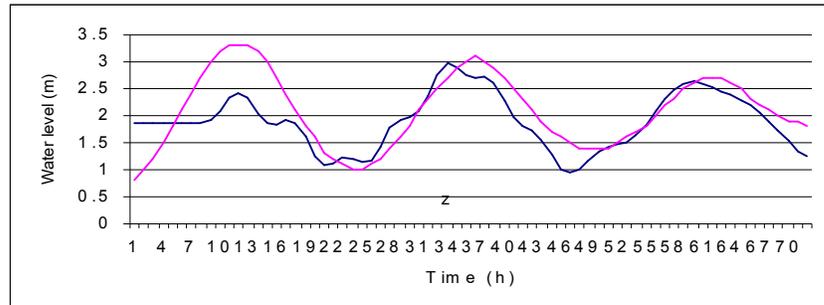
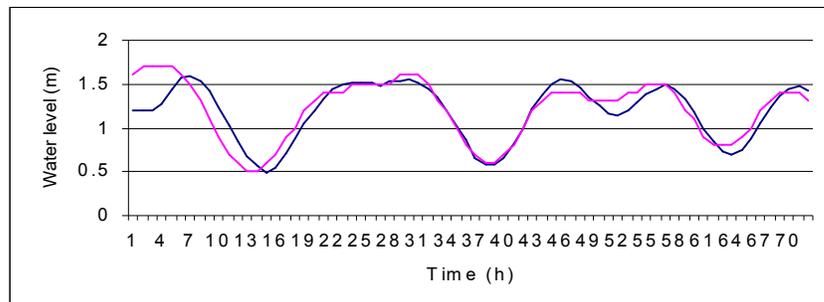(b) Quy Nhơn
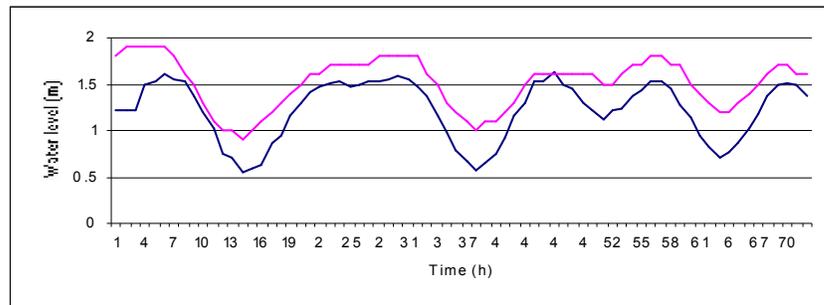
(c) Vũng Tàu

(d) Trường Sa

Figure 5. Comparisons of tidal levels calculated with Delft3D-FLOW and Tidal Table

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3.4. Storm surge calculation using RAMS outputs

Storm LING LING (10/11/2001 to 13/11/2001) is chosen for calculation. This storm generated in the western part of Pacific Ocean, passed Philippins and travelled accross South China Sea towards Vietnam coast (Binh Dinh and Phu Yen provinces). From RAMS model, the minimum atmospherical pressure is 100119 Pa in the eye, the maximum wind speed reaches to 25m/s. Figure 6 shows the air pressure and wind fields at 0h the 12th November in 2001. Unfortunately, in the end of calculation, the storm was still far from Vietnam coast so one could not get the maximum value of surge.
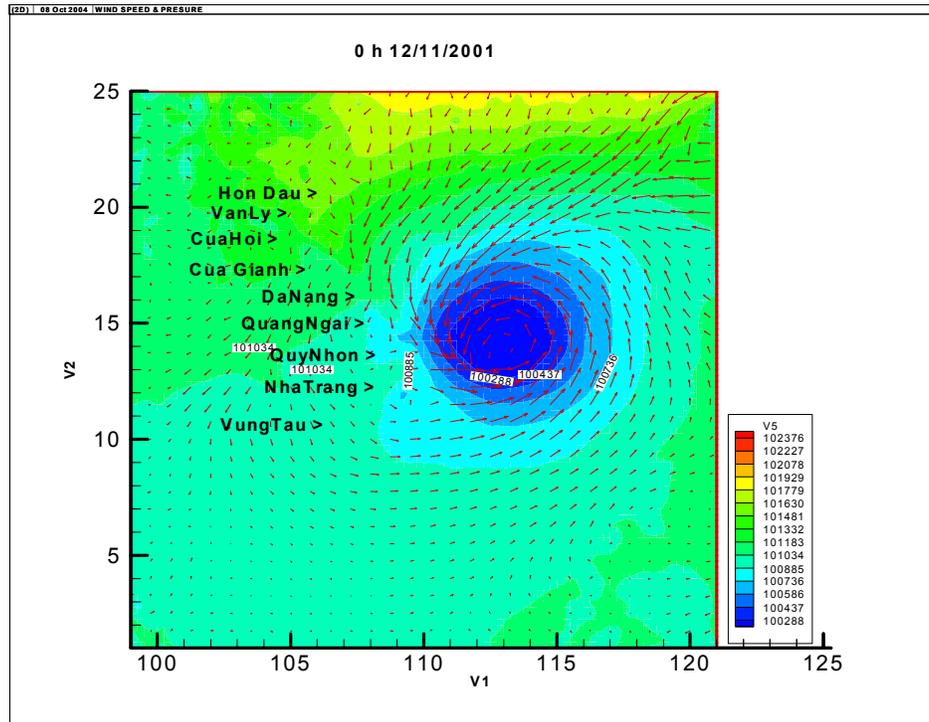

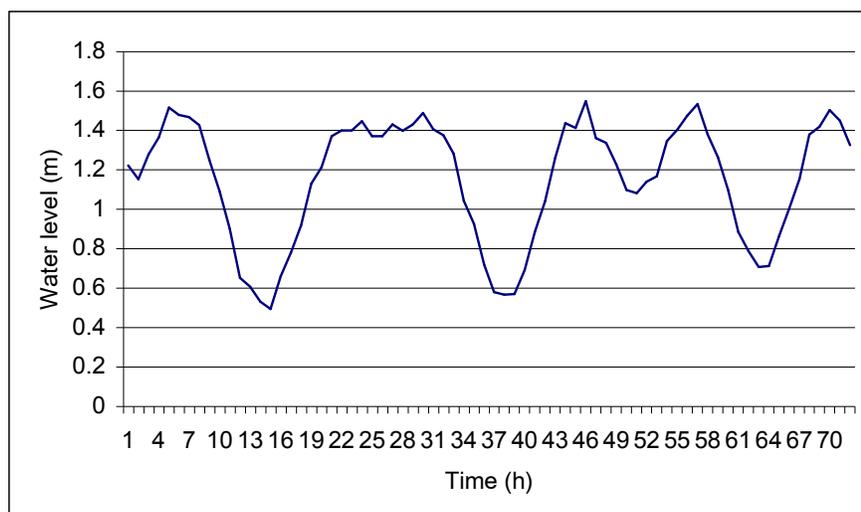Figure 6. Air pressure and wind fields calculated from RAMS model

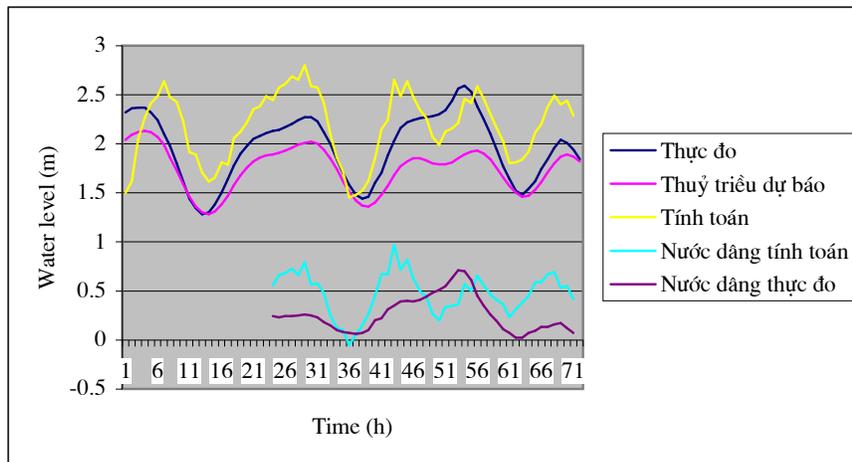Figure 7. Water level calculated by Delft3D-FLOW at Quy Nhơn

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Figure 8. Water level and current pattern at 0 h of 12/11/2001

Observed water levels (Nha Trang Oceanology Institute) are compared with the calculated ones at Hòn Dấu, Sơn Trà, Quy Nhơn and Nha Trang stations. Quy Nhon station is chosen as an example. In Figure 9 there are water levels observed, published in Tidal Table, calculated by Delft3D-FLOW, respectively. The lower part there are observed and calculated surges, they equal water levels minus tidal levels. In general the differences are between 20-30cm at Hòn Dấu, Sơn Trà (Đà Nẵng) and Quy Nhơn.

The simulation is done for 3-days period, the stability of model is 1 day. For the computer of: Pentium IV 2.4 GHz, RAM 512 Mb it took 2 h (CPU time) for 3-days prediction. The CPU time may decrease with computer of higher configurations. On other hand the grid of finer resolutions (1/12 degree with 289 x 265 cells) may get better results.

The below table shows the storm surge values calculated by Vietnam Institute of Mechanics for storm Ling Ling 2001.

Location	Observed (m)	Calculated (Institute of Mechanics)	Calculated (in this paper)
Sơn Trà	0.30	0.30	0.72
Quy Nhơn	0.86	1.00	1.00

In fact, the storm surge calculation may be improved by considering radiation stresses and by using adaptive grids. It needs to consider in future researches.

Figure 9. Water levels calculated by Delft3D-FLOW at Quy Nhơn

4. Conclusions

The above results are preliminary and it requires more careful study. By combining outputs from RAMS model one can build an associated procedure for prediction of storm surges using Delft3D-FLOW model. Both meteorological and hydrodynamical models are suitable for storm prediction.

The results may have better accuracy by using the grid of higher resolution. On other hand, the prediction results for storm surge depend on prediction of air pressure and wind fields of RAMS model. That's why and it requires not only study the Delft3D-FLOW model but also the RAMS model.

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