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Application of ROMS-SWAN coupled model to simulate hydrodynamic field in Hai Phong

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ABSTRACT

ROMS and SWAN models have been used quite commonly in studying hydrodynamics. These are open-source models which are suitable for development research. However, using the ROMS-SWAN coupled model has not been studied and applied much in Vietnam. This paper presents the study and use of the ROMS-SWAN coupled model in the COAWST system to calculate the hydrodynamic field in Hai Phong at a primitive level. The calculation gives quite good results when compared with the measured data. The results of this study are the basis for the application of the COAWST model system to calculate sediment transport.

Keywords: Coupled model, ROMS, SWAN, hydrodynamics.

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INTRODUCTION

With the vigorous development of computer science, numerical models are increasingly developed and widely used. There are two models used to compute processes in the seas and oceans: commercial models and open-source models. Commercial models have the advantage of running because they have been calibrated and tested and have an intuitive and easy-to-use interface. Still, the cost of these models is relatively high; users cannot update the results of new research into the model, are

unable to develop applications in their direction, and it is not easy to link with other models. Meanwhile, open-source models are usually free; users can continuously improve them according to their research direction and link to other open-source models. However, these models often make it more difficult for users because they do not have an interface, and users also need a detailed understanding of programming. That leads to which model to use depending on each author's purpose.

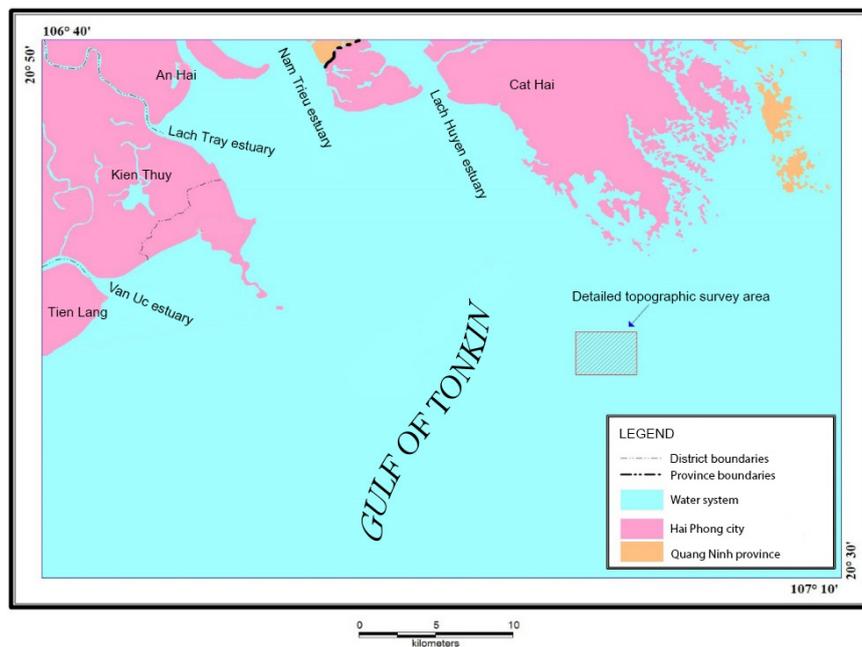


Figure 1. Study area

Understanding the importance of the interactions between the sea and the atmosphere, the USGS has been leading the development of a Coupled Ocean-Atmosphere-Waves-Sediment Transport (COAWST) Modeling System. The COAWST modeling system joins an ocean model, an atmosphere model, a wave model, and a sediment transport model for studies of coastal change. The COAWST Modeling System includes an ocean component—Regional Ocean Modeling System (ROMS) [1]; atmosphere component—Weather Research and Forecast Model (WRF), hydrology component- WRF_Hydro; wave components—Simulating Waves Nearshore

(SWAN) [2], WAVEWATCHIII, and InWave; a sediment component—the USGS Community Sediment Models; and a sea ice model [3–5]. The model system allows calculation and simulation by each model separately or simultaneously many models.

In this study, the ROMS-SWAN coupled model belonging to the COAWST system was studied and used to simulate the hydrodynamic field in Hai Phong. Usually, when using separate models, the results from one model can be used as input to another model; however, these results need to be processed to get the required format of the model. With the COAWST system, users can use multiple

models simultaneously; the models use the results of other models in the system as input without the need for preprocessing steps like when using separate models. The ROMS model provides the SWAN model's water level, bathymetry, and current for. In contrast, the SWAN model provides the ROMS model's wave parameters and radiation stress. Model Coupling Toolkit (MCT [6]) was used to coupled ROMS and SWAN [4].

DATA AND METHODS

Data

Bathymetry: The model can use ETOPO1 terrain data and GEBCO data. These data are freely available to the user community in the world. However, the accuracy of this data source is not good, especially for shallow water, coastal areas, and islands. For the sake of relative detail, the data used in this study is a combination of naval data of 1/25,000 scale, naval data of 1/10,000 scale, and measured data provided by project TNMT.2018.06.15.

Initial condition and boundary condition: These data were obtained from the HYCOM database (<https://www.hycom.org/dataserver>).

HYCOM provides global data with a spatial resolution of 0.125 degrees, 40 layers, and 3 h temporal resolution [7].

In the model system, the forces are obtained from the reanalysis database of the European Centre for Medium-Range Weather Forecasts. This database provides sea surface forcing with a spatial resolution of 0.125 degrees and 3 h temporal resolution. The effects used in the model include wind velocity (U, V) at 10 m above sea level, longwave radiation ($lwrad$), short wave radiation ($sward$), air temperature ($Tair$), sea surface pressure ($Pair$), sea surface precipitation, sea surface air humidity ($Qair$).

Tide data. The liquid boundary condition is given by the harmonic constituents of 14 waves ($M2, S2, K1, O1, N2, P1, K2, Q1, MF, MM, M4, N4, MS4, MN4$) taken from the global tidal model [8].

This study uses the measured water level, wave, and current data provided from the project TNMT.2018.06.15 are used for model calibration and verification. The location and time of the survey are shown in Table 1 and Figure 2.

Table 1. Location and time for measuring water level, waves, current

Time	Water level		Waves, current	
	Longitude	Latitude	Longitude	Latitude
2/8/2019–16/8/2019	106°50'50"E	20°47'54,6"N	106°58'19,37"E	20°34'39,24"N
25/4/2020–9/5/2020	106°50'50"E	20°47'54,6"N	106°58'19,54"E	20°35'30,31"N



Figure 2. Location of measuring stations

Methods

Implementation steps include preparing data, creating a grid, calibrating and validating the model, and calculating according to scenarios.

There are quite a few tools to create grids for ROMS models, such as Gridgen, Easygrid, Gridbuilder, or tools written in Matlab such as `create_roms_xygrid.m`,... in this study, Gridbuilder was used due to its convenience and visualization. Gridbuilder is an addon on Matlab with its convenient interface, which can create mesh files and bathymetry files for the SWAN model [9].

After creating the mesh, using the `editmask.m` program provided with the model tools system to edit the mesh with shoreline data taken from GSHHS <https://www.earthmodels.org/data-and-tools/coastlines/gshhs> [10]. The mesh file for the calculation will be received after updating and smoothing the bathymetry.

For the SWAN model, there are many ways to create a mesh for this model, but the most convenient for the integrated model is to use the same mesh as the ROMS model, with the modeling system providing accompanying tools.

Using the command `“roms2swan(‘grid.nc’)”` on Matlab will create a coordinate file `“swan_coord.grd”` and a bathymetry file `“swan_bathy.bot”` for SWAN model [11].

The data on boundary conditions, initial conditions, impact forces, and tides are obtained from HYCOM, ECMWF, and global tidal models through scripts built on Matlab. In this study, river influence is not considered, and discharge/flow boundary conditions are set to zero.

Calibrate and validate the model to determine the model’s parameters suitable for the research area. Nash coefficient (F^2) and correlation coefficient (R^2) is used to evaluate the calculated results with measured data.

After determining the parameters suitable for the study area, calculations are carried out according to the scenarios of Northeast monsoon season and Southwest monsoon season.

RESULTS

Domains and grids

The calculation domain is shown in Fig. 3. Calculation uses a grid with a resolution of $300\text{ m} \times 300\text{ m}$ corresponding to 545×730 grid cells.

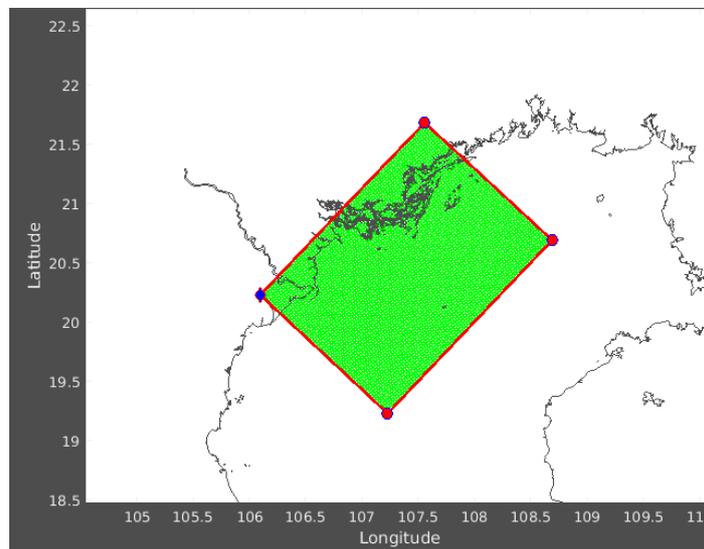


Figure 3. Calculation domain

Calibration and verification

Figure 4 compares the measured water level data and the calculated results from the

model according to the modified parameters. Looking at Figure 4, we can see the similarity in phase and magnitude between the measured

data and the calculated results. Nash coefficient (F^2) is estimated to evaluate the accuracy of the results from the model compared to the measurement, the result $F^2 = 0.93$. The F^2 value is relatively high, greater than 0.8, along with the correlation coefficient $R^2 = 0.969$ (Figure 5) to ensure the exact conditions of the model.

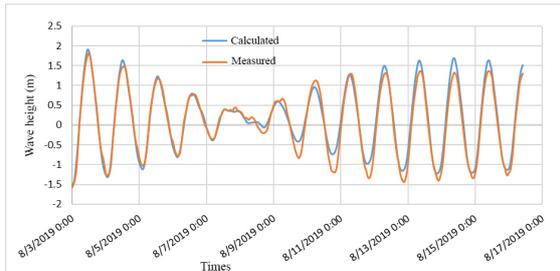


Figure 4. Comparison of measured water level data with calculated results

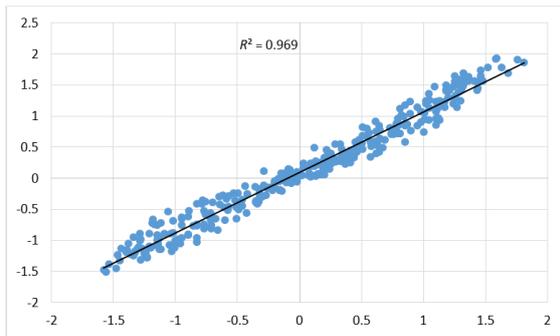


Figure 5. Correlation of measured water level and calculation results

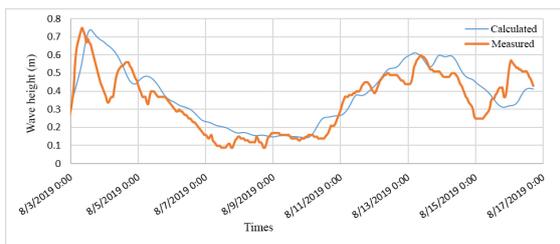


Figure 6. Comparison of wave height data measured and calculated results

A comparison of the measured wave height data and the calculated results from the model according to the changed parameters is presented in Figure 6. Looking at the figure, the correlation between the measured data and the calculated results can be seen; these values

have similarities in phase and magnitude. Nash coefficient is calculated for the value $F^2 = 0.83$, correlation coefficient $R^2 = 0.792$ (Figure 7) to ensure the reliability of the model.

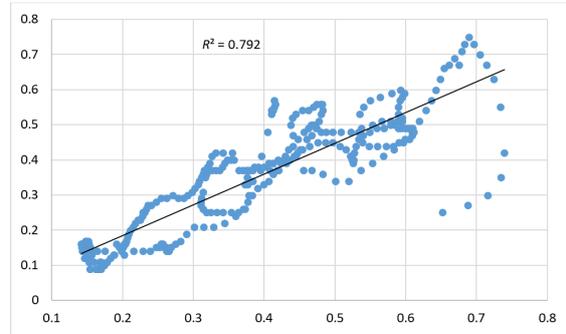


Figure 7. Correlation of measured wave heights and calculated results

The model calibration process gives quite good results, shown in the similarity of phase and magnitude and the value of the Nash coefficient and the correlation coefficient are relatively large. Thus, the model's parameter after calibration is suitable for the study area and this parameter is used to validate the model.

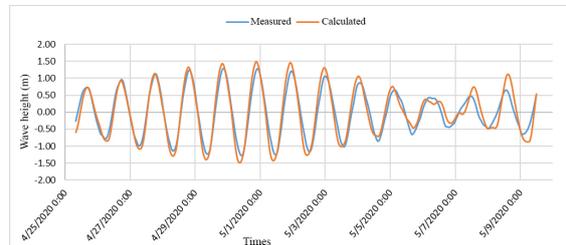


Figure 8. Comparison of measured water level data with calculated results

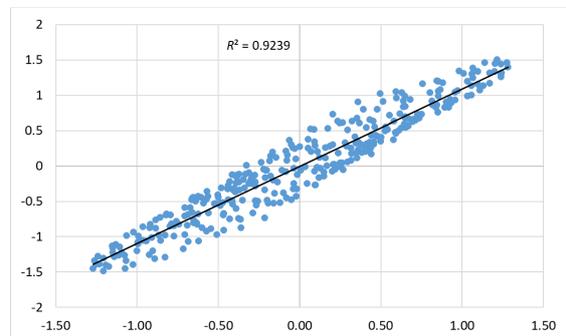


Figure 9. Correlation of measured water level and calculation results

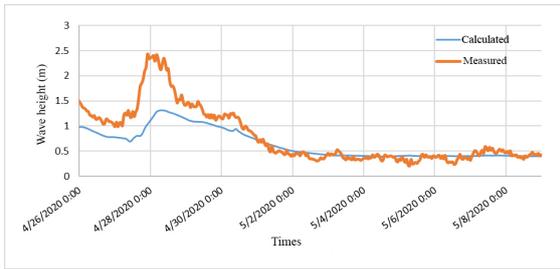


Figure 10. Comparison of wave height data measured and calculated results

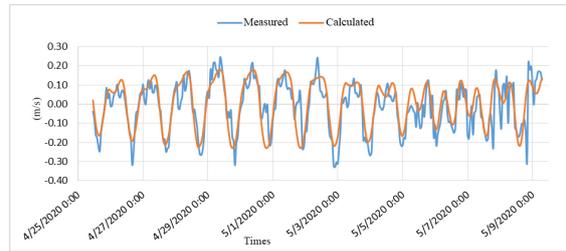


Figure 14. Comparison of V flow velocity components measured and calculated results

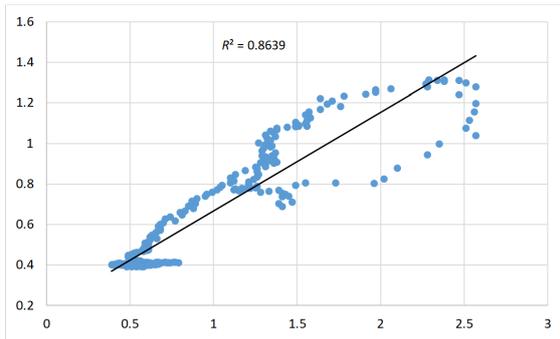


Figure 11. Correlation of measured wave heights and calculated results

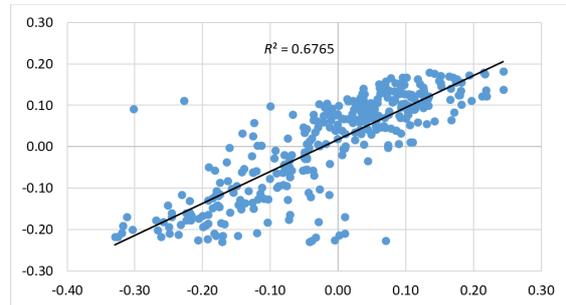


Figure 15. Correlation of V flow velocity components measured and calculated results

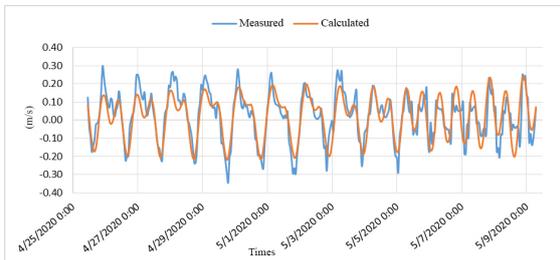


Figure 12. Comparison of U flow velocity components measured and calculated results

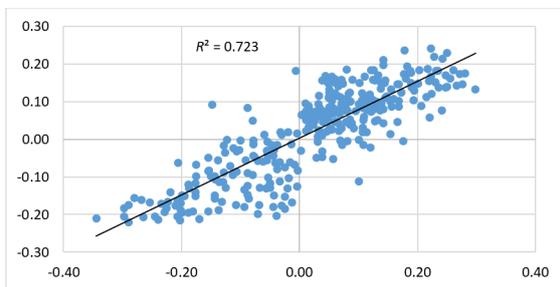


Figure 13. Correlation of U flow velocity components measured and calculated results

Figures 8–15 show the comparison between actual measured water level, wave, and current data with the calculated results from the calibrated model and the correlation between these data. These figures show the similarity in phase and magnitude between these values. The calculated correlation coefficients are all greater than 0.65, so the model parameters defined in the model are suitable for the research area and can be used for other research cases other.

Calculation scenario

In this study, the calculation is carried out according to two regular monsoon seasons, namely the Northeast monsoon season and the Southwest monsoon season. Based on the data collected over the above calculation time, the statistical results of multi-year wave heights (1979–2019) in the directions are shown in Figure 16a for scenario 1 (Northeast monsoon season) and Figure 16b for scenario 2 (Southwest monsoon season).

Statistics of multi-year wave data in the calculated area show that NE and E are the two

dominant direction waves in the Northeast monsoon season (scenario 1), and S and SE are

the two main direction waves in the Southwest monsoon season (scenario 2).

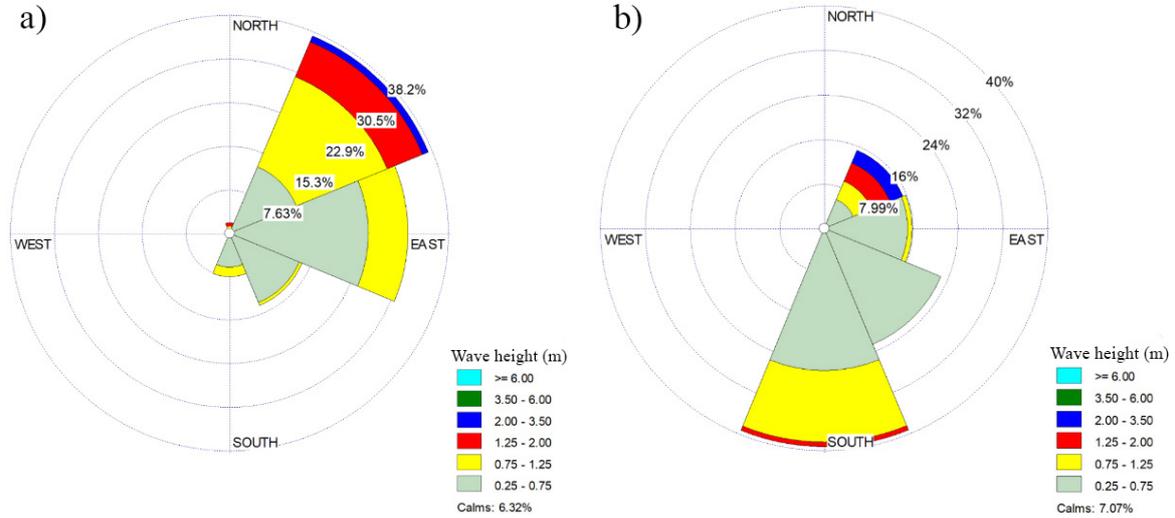


Figure 16. Wave rose: a) Northeast monsoon; b) Southwest monsoon

Result

In the Northeast monsoon period (scenario 1), with the input wave being NE and E direction, the wave field calculation results show that the wave propagating into the coastal area has changed direction due to the barrier island; the wave changes from NE and E direction to E and ESE direction when entering the coastal zone.

During the Southwest monsoon period (scenario 2), because the input wave direction is nearly perpendicular to the shoreline, there is no offshore obstacle terrain, so the wave almost does not change direction when entering the coastal area. Waves propagating from offshore to coastal areas are in S and SE directions. Wave height decreases behind the islands, and wave height in the coastal area is small (Fig. 17).

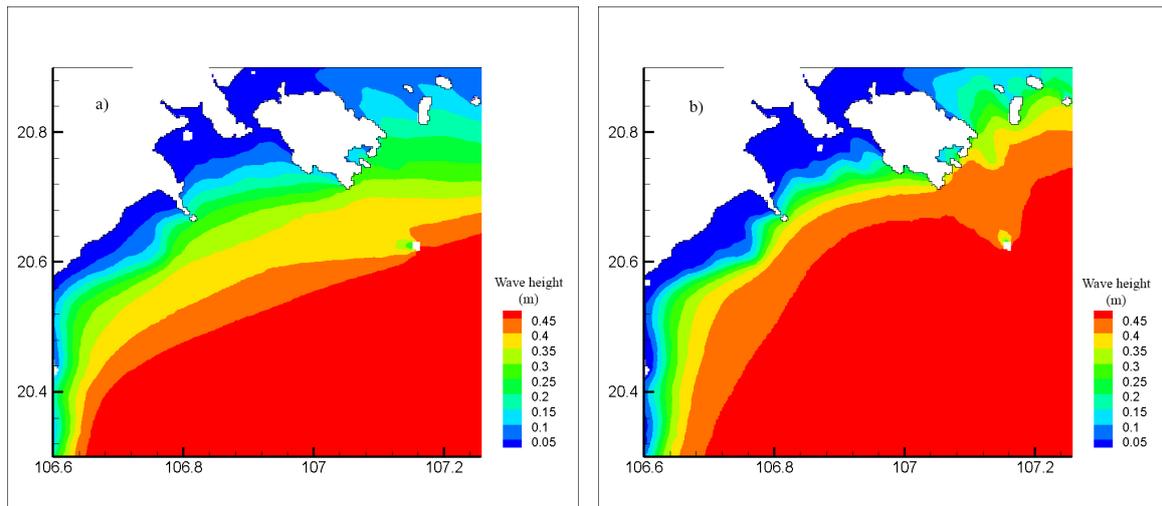


Figure 17. Detailed wave heights in the study area (scenario 1 (a) and scenario 2 (b))

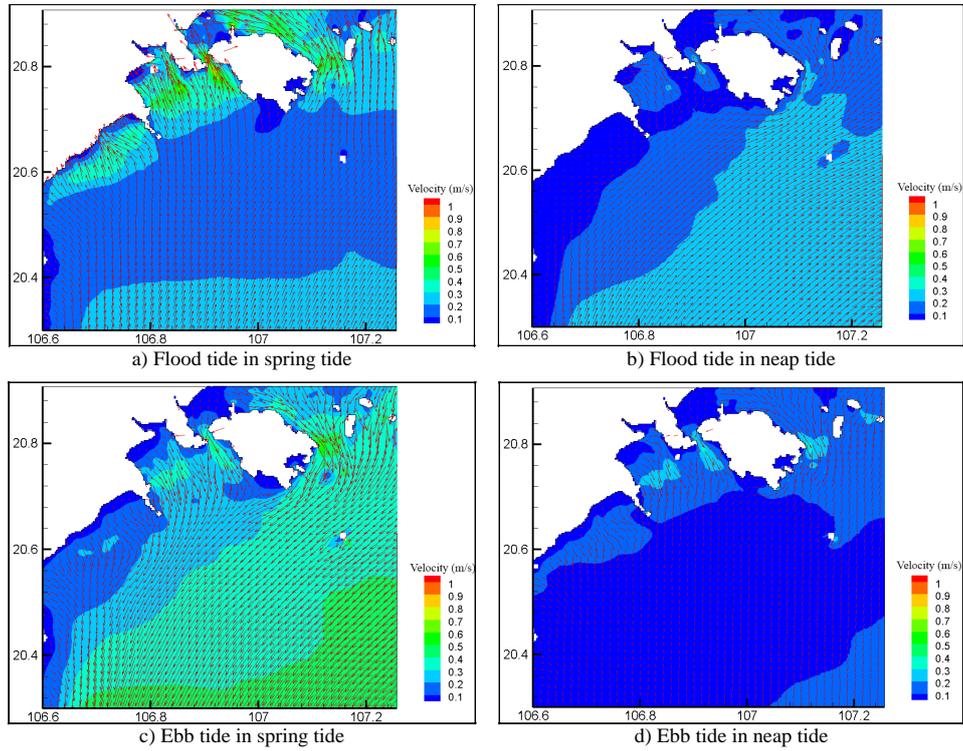


Figure 18. Detailed currents field in the study area under scenario 1

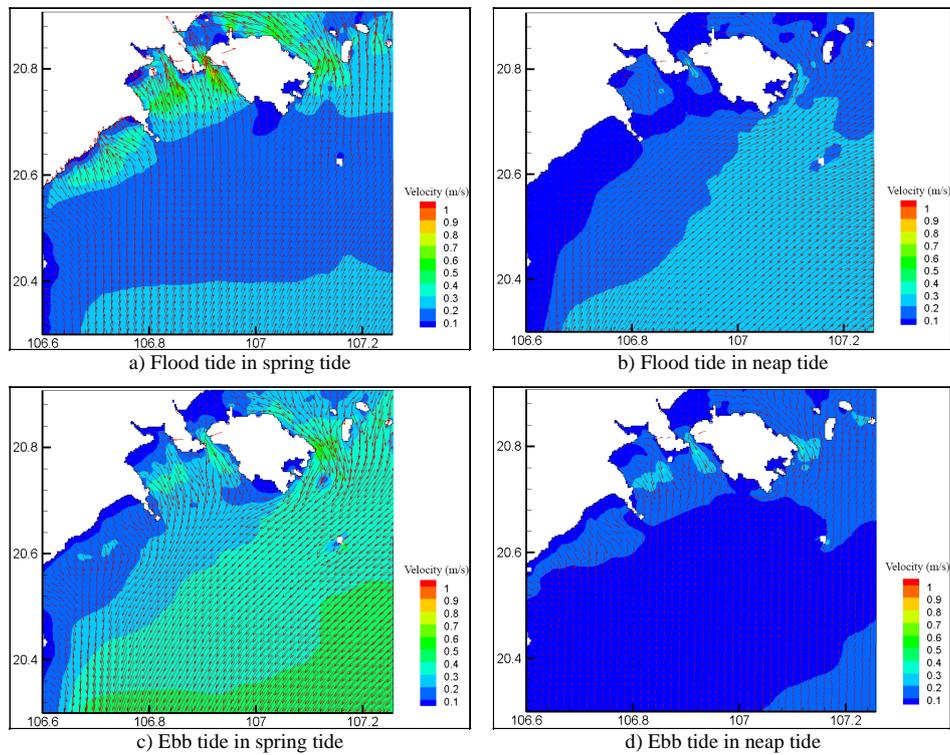


Figure 19. Detailed currents field in the study area under scenario 2

During the Northeast monsoon period, the current regime in this area is quite simple; the current composition is mainly tidal current, currents caused by waves are not large. Figure 18 shows the current picture in the Hai Phong area according to flood tide in spring tide, flood tide in the neap tide, ebb tide in spring tide, and ebb tide in the neap tide. It is easy to see that the current velocities are small during neap tide and larger during spring tide due to the difference in tidal oscillation amplitudes. The flow is northeast in the flood tide and Southwest in the ebb tide in the outer area; in the coastal zone, the current tends to be perpendicular to the flood tide and from the shore to the sea in the ebb tide. Current velocities are typical in the range of 10–50 cm/s and are mainly high in the straits between islands.

Similar to the results in scenario 1, since wave-induced currents are weak, tidal currents are dominant, so the flow direction is identical to scenario 2 (Fig. 19) is identical to scenario 1. The flow is Northeast in the flood tide and Southwest in the ebb tide in the outer area. In the coastal area, the flow tends to be perpendicular to the shore during the flood tide and from the shore to the sea into the ebb tide. The current velocity is small in the neap tide and more extensive in the spring.

CONCLUSIONS AND RECOMMENDATIONS

The study has successfully applied the ROMS-SWAN coupled model of the COAWST model to calculate the hydrodynamic field in Hai Phong. The evaluation with measured data shows that the ROMS-SWAN coupled model system simulates the hydrodynamic field quite well with parallel calculation capabilities. This system can meet the requirements for hydrodynamic simulation in places with dominant tides.

The wave and current field results according to this calculation are relatively simple. The calculation time is in the periods of the Northeast monsoon season and the Southwest monsoon season. However, this sea area is located in the Gulf of Tonkin and is

relatively closed, so the wave height is relatively small, and the sea is quite calm. In the study, the influence of the river has not been taken into the simulation; therefore, tidal flow dominates during the entire calculation period. This report is the first study using the integrated model, so the obtained results are for reference only. It is necessary to have more comparative evaluation studies with each component model, taking into account the effects of the river, combined with the meteorological model to evaluate the ability and effectiveness of this model.

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