The Application of POM to the Operational Tidal Forecast for the Sea around Taiwan

Shan-Pei YEH[1] Hwa CHIEN[2] Sen JAN[3] and Chia Chuen KAO[4]

[1] *Coastal Ocean Monitoring Center, National Cheng Kung University, Tainan , Chinese Taipei,*
Email: n8689123@ccmail.ncku.edu.tw
[2] *Department of Hydraulics & Ocean Engineering, National Cheng Kung University, Tainan, Chinese Taipei,*
Email:n8885105@sparc2.cc.ncku.edu.tw
[3] *Department of Physical Oceanography, National Sun Yat-sen University, Kaohsiung, Chinese Taipei*
Email:senjan@mail.nsysu.edu.tw
[4] *Department of Hydraulics & Ocean Engineering, National Cheng Kung University, Tainan, Chinese Taipe*
Email:kaoshih@mail.ncku.edu.tw

Abstract

With the economic progress over the past decades in Taiwan, the demand of tidal forecast is urgently requested concerning the increasing near-shore activities and coastal disaster rescues. It is the goal to establish the high resolution tidal model that forecast the water elevation and tidal current around Taiwan operationally. In present study, Princeton Ocean Model (POM) is adopted to simulate the tidal phenomenon around Taiwan. To satisfy the stable, accurate and computation time-saving requirements of operation model, it is the purpose to verify, validate and improve the model so as to meet the needs in the local environments.

To obtain the water elevation and tidal current on the open boundaries of the focused area, nested system that combines three meshes is applied. The proposed nestled system consists of three sub models. Computational results from the gross mesh model are used as inputs to the finer mesh regional models so as to get high resolution tidal data around Taiwan as well as to keep in the balance with the computation time in the viewpoint of routine forecast operation.

Referring to Wang (1999), tidal current speed larger than 5 m/s is used as criterion indicating the divergence during the computation. The factors that might influence the computation stability are then tested accordingly. It is found from the results of series testing that radiative boundary condition setting gives more stable model computation. Manning formula, which reflects the average current speed in varies water depths, is more representative than the original POM friction formula, which only consider the bottom velocity variation in these cases.

The model is then validated by the field data that measured by 12 tidal stations around Taiwan. It is found that the model prediction is close to the field data in the western coastal of Taiwan. The overall RMS error is 11 cm. Regarding to the validation of proposed model with respect to the field data measured in the eastern coast of Taiwan, 30 cm difference of M2 tide and 10 cm of K1 tide are revealed. Generally, proposed Taiwan water tide model features better performance in the western part than eastern part of Taiwan island.

Keywords: POM, Operational Tide Model, Nested Grid

1. INTRODUCTION

Ocean covers 70% of the earth surface. It offers tremendous either biological or mineral resources as well as the possibilities for the navigation and resort for human beings. It is of great importance to develop and utilize the ocean resources with the concepts of sustainable development. In order to improve the sustainable development of ocean resources, the well understanding and acknowledgment of oceanographic and meteorological phenomena should be emphasized and carried out. Among those phenomena, tide is one of the most dominated factors, which bring direct impacts to the coastal zones. Besides the observation of tidal elevation and currents, numerical simulation is the frequent applied alternative to realize the tide. It is also the kernel of the establishment of ocean/coastal disaster alert system, which gives regular forecast that contribute to the ocean pollution control, ocean structure design and disasters rescue. It is the purpose of present study to establish a tide forecast model, which could be further implemented in the ocean/coastal disaster alert system in Taiwan.

To meet the demands of ocean/coastal disaster alert system, the numerical model has to be operational. Considering the facts that the public domain POM (Princeton Ocean Model) has been utilized as regional operational model in certain cases, POM is selected and adopted in present study. Furthermore, since accuracy, computational stable and time-saving are the fundamental requirements of operational numerical model, investigation and tuning of the POM with respect to the environments of Taiwan water are carried out based on the three requirements.

2. POM MODEL AND THE GRID SYSTEM

POM, which was proposed by George L. Mellor & Alan Blumberg in 1977, is a fully three dimensional ocean circulation model. The computational scheme of splitting mode is applied in POM to integrate the barotropic (external mode) and baroclinic (internal mode) equations at their respective time steps so as to reduce the computation time. Based on the assumptions of static equilibrium and Boussinesq approximation, the simplified governing equations in the Cartesian coordinate can be expressed as Eqn. (1) and Eqn. (2):

The equation of continuity:

$$\nabla \cdot \vec{V} + \frac{\partial W}{\partial z} = 0 \qquad (1)$$

The equation of momentum:

$$\frac{\partial U}{\partial t} + \vec{V} \cdot \nabla U + W\frac{\partial u}{\partial z} - fU = -\frac{1}{r_0}\frac{\partial p}{\partial x} + \frac{\partial}{\partial z}\left(K_M \frac{\partial U}{\partial z}\right) + F_u \qquad (2)$$

$$\frac{\partial V}{\partial t} + \overline{V} \cdot \nabla V + W\frac{\partial V}{\partial z} + fV = -\frac{1}{r_0}\frac{\partial p}{\partial y} + \frac{\partial}{\partial z}\left(K_M \frac{\partial V}{\partial z}\right) + F_v$$

$$rg = -\frac{\partial p}{\partial z}$$

Nested grids system is utilized in present study to obtain the water elevation data for the boundary conditions at the open boundary of focused Taiwan water area. The nested grids contain three different scale meshes, i.e. the global mesh, Mesh of Asian Continental shelf and the Mesh of regional Taiwan water. In the global system, a nonlinear barotropic dynamic model that developed by Lakshmi H. Kantha in 1995 is used to simulate the ocean circulation. This model was proved to be capable of accurately simulating the semi-diurnal tidal, diurnal tidal and low frequency tide. In the mesh of Asian Continental shelf and regional Taiwan water, POM is adopted. Fig. (1) illustrates the layout of the grid systems.

In the following, the tuning of POM is made considering the computational stability, output accuracy and time-saving requirement in sequence. To obtain the better computational stability, setting of the model parameters and boundary conditions is investigated according to the criterion that the maximum current speed ever calculated should be less than 5 m/sec. Comparisons of the measured tidal elevation to the model output is then carried out. The major model parameters and boundary condition setting are (1) Topographical effect, (2) Setting of time steps, (3) Setting of boundary conditions at the open boundary and (4) Setting of boundary conditions at the bottom.

3. MODEL TUNING

It is the first step to investigate the computational stability of POM in the meshes system of Asian continental shelf and Taiwan water. It is found during the computations that the instability occurs mostly on the grid points around E 130^{o} N 5^{o}, where lays in the midpoint between Minda Nao and Palua islands. Eastern to the point is the Philippines Gulf of 9000m water depth. The rapid change of topography will reflect the incident tidal wave. And the rather complicated propagation behavior may induce the computational instability. To clarify the topographic effects, the original water depth data and two modified topographies i.e. replacement of the Philippines Gulf by averaged water depth and removal of the Minda Noa Island are used as inputs to the model. The results show very little difference regarding to the computational stability. In all the tests, the model begins to diverge on the 2.33 days. Therefore, it can be concluded that the rapid change of bottom topography does not account for the computational instability in our case.

Setting of Time step

Splitting mode is used in POM to integrate the internal mode and external mode. The external mode, which is Barotropic, calculates the two dimensional surface dispersive waves, which propagation in high celerity. Thus the explicit numerical scheme is adopted to reduce the computation time. The internal mode, which is Baroclinic, calculates fully three dimensional gravity waves. The implicit scheme is adopted in internal mode to gain higher spatial resolution and avoid the computational divergence.

To setting of time steps in both the internal and external modes is one of the critical parts of tuning the POM. The time steps should obey the limitation:

$$\Delta t_E \le \frac{1}{C_t}\left(\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2}\right)^{-1/2} \qquad (3)$$

$$\Delta t_I \le \frac{1}{C_t}\left(\frac{1}{\Delta x^2} + \frac{1}{\Delta y^2}\right)^{-1/2} \qquad (4)$$

Various settings of the time steps are tested in present study. 8 Field measured water elevations around Taiwan are then used to validate the results. Table (1) is the setting time step in both the internal and external models. It should be reminded that the shorter the time step, the longer the computation time. Considering the accuracy and time consuming factors, the optimal time setting is chosen as 8 sec for external mode while 480 sec for internal mode.

Setting of the boundary condition at the open boundary

The given of the open boundary conditions and the satisfaction at the close boundary are essential of solving the governing equation of tidal wave motion. In the cases if the information of water elevation at the open boundary condition can not be offered, the boundary conditions are often set as symmetric boundary. However, the computational error hence could not be transfer to the outside of the domain and leads to the instability of the computation. In the opposite way, the radiative boundary condition allows the energy that coming from the perturbation in the computation domain to transfer to the outside. According to the characteristics of progressing wave in deep water, the tidal current and elevation at the boundary could be obtained:

$$\vec{U} \cdot \vec{n} = \sqrt{g/hx} \tag{5}$$

Both the symmetric and radiative boundary conditions are tested in present study. The results show that the symmetric boundary condition setting is the major reason of causing computational instability at the boundary. The model is stable and could be spun up and continuously processing for months if the setting of radiative boundary condition and other previous mentioned setting are made.

Bottom friction condition setting

Originally, the law of second order friction was adopted in POM to estimate the bottom friction of the tidal current at the sea bed. The logarithm distribution of current profile is assumed. Once the coefficient of friction near the bottom C_d is given, the velocity profile can be gained as:

$$C_z = MAX\left[\frac{k^2}{\left[\ln\{(1+s_{kb-1})H/z_0\}\right]^2}, 0.025\right] \tag{6}$$

Another expression of bottom friction Manning formula, which is often used in the hydraulic engineering aspects, is tested in present study. The Manning formula is expressed as:

$$C = \frac{1}{n}h^{1/6} \tag{7}$$

$$C_z = \frac{g}{C^2}$$

From the expressions, it can be seen that the coefficient of friction is depend on the average current speed. It implies that Manning formula is more appropriate to describe the bottom friction when it is dominating. The original and Manning expression of bottom frictions are tested in present study through the simulations of K1 tide. The results are list in Table (2). The error between the field observations and the outputs of the model is smaller when Manning formula is utilized. To improve the performance of POM is estimating the tidal current and elevation around Taiwan, the Manning formula is used to describe the bottom friction.

4. VALIDATION OF THE MODEL

It is the first step to validate the Kantha's global model. From the comparison of the field observation in Guan in the year 2000 to the output of the model, it is obvious that the model prediction agrees with the observation very well. As indicated in Table (3), the amplitude difference of M2 tide, which features the largest error, ranges up to only 1 cm. The phase difference of J1 tide is 13.19 degree. They output of the global model is validated to be appropriate to used as boundary input to the Asian Continental Shelf POM model.

The validation of Asian Continental Shelf POM model is done by comparing the output to previous studies, i.e. Fang (1999) and Kang (1998). Field observation from 8 tidal stations that marked in previous studies and 2 stations around Taiwan Island are utilized. The harmonic coefficients of model output and the field observations are list in Table (4). The Root Mean Square Error of this area is 9.3 cm of K1 tide and 13,2cm of M2 tide respectively. The results demonstrate the reasonable prediction results of the model. These data are then used as the input to the focused Taiwan Water POM model. Nine tidal observation on the western coast and three on the eastern coast are used to as reference as list in Table (5). The model performs better for the tidal behavior in the western coast of Taiwan than Eastern coast.

5. SUMMARY

(1) The POM model is applied and modified to simulate the tidal wave in Asian Continental Shelf area and Taiwan water area based on the nested grid system. It is shown from the results that the long-term, stable and accurate simulation can be yielded. It can be used as an operational ocean circulation model to give tide forecast of Taiwan water.

(2) The investigation of optimal model parameters setting can be concluded as:

    I. The radiative boundary condition is more appropriate and should be adopted in the model to simulate the tide in Taiwan water.

    II. The optimal time step setting for the Asian Continental Shelf model is 8 sec for external mode, 480 sec for internal mode. At the meanwhile, it is suggested that 6 sec for the external mode and 240 for the internal mode for the Taiwan water model.

III. Manning formula is better than the original term in the POM model of describing the bottom friction in present computation domain.

(3) The validation of the Taiwan water model by field observed tidal elevation data shows that:

I. The Root Mean Square Error of the model output of K1 and M2 tides is smaller than 8 cm except in the narrower part of Taiwan Strait where the tidal range is larger.

II. The Root Mean Square Error of M2 in eastern coast goes up to 30 cm. In general , the present model performs better to predict the tide in the western coast of Taiwan than in the eastern coast.

REFERENCES

Blumberg, A. F., and G. L. Mellor 1987 "A description of a three-dimensional coastal ocean circulation model", Three-Dimensional Coastal Ocean Models, Vol. 4, pp. 1-16

Jan, S., Y. –H. Wang, S. –Y. Chao and D. –P Wang 2001, Development of a nowcast system for the Taiwan Strait(TSNOW). Ocean and Polar Research, 23, 2, 195-203

Kang, S. K., S. R. Lee and H. J.Lie 1998, "Fine grid tidal modeling of the Yellow and East China Seas", Continental Shelf Research, Vol. 18, pp. 739-772

Kantha, L. H. 1995, "Barotropic tides in the global ocean from a nonlinear tidal model assimilating altimetric tide, part I model description and results" , Http://www.cast.msstate.edu/Tide2D

Lefevre, F., C. Le Provost, and F. H. Lyard, "How can we improve a global ocean tide model at a regional scale? A test on the Yellow Sea and the East China Sea", Journal of Geophysical Research, Vol. 105, No.C4, pp. 8707-8725

Y. Y. Kuo 2001, Coastal Engineering.

FIGURES & TABLES

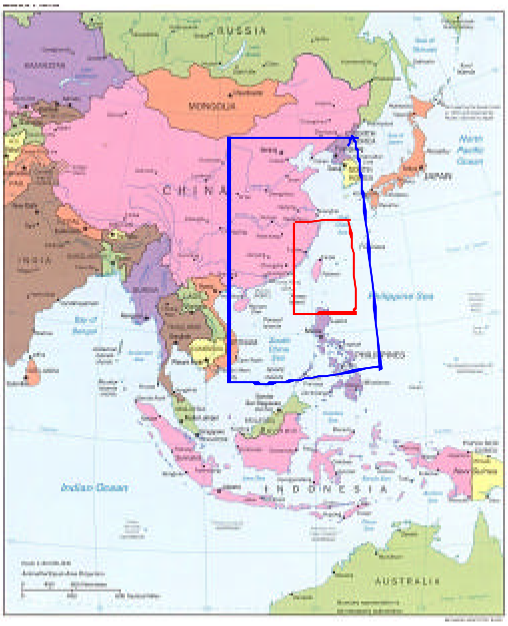

Figure 1 The Layout of the grid system

Table 1 Setting time steps in both the internal and external models

	external mode time step(sec)	internal mode time step(sec)	Calculated day (day)
Test 1	1	20	4.67
Test 2	1	80	3.3
Test 3	2	80	2.3
Test 4	2	120	2.3
Test 5	2	160	2.33
Test 6	5	100	2.3
Test 7	5	200	2.33
Test 8	5	300	2.33
Test 9	5	400	3.04
Test 10	8	160	3.33
Test 11	8	480	4.625
Test 12	8	640	4.625
Test 13	8	800	3.625
Test 14	10	400	2.29

Table 2 The original and Manning expression of bottom frictions are tested through the simulations of K1 tide

Station No.		1	2	9	12	root mean square error
Location	longitude（degree)	121.86	121.18	128.9	123.46	
	latitude（degree)	24.58	22.78	32.7	25.73	
Time step	external mode（sec)	8	8	8	8	
	internal mode(sec)	480	480	480	480	
Boundary condition		Radiation condition	Radiation condition	Radiation condition	Radiation condition	
Amplitude of K1	observations (m)	0.188	0.164	0.25	0.17	
	the law of second order friction was adopted in POM (m)	0.16	0.1856	0.2273	0.15	0.023
	Manning formula (m)	0.1698	0.18	0.24	0.1504	0.017

Table 3 Comparison of the field observation in Guan in the year 2000 to the output of the model

	observations		kantha		difference	
	Amplitude (cm)	phase (°)	Amplitude (cm)	phase (°)	Amplitude (cm)	phase (°)
Q1	2.57	34.6	2.79	47.49	0.22	12.89
O1	10.95	43.67	10.51	44.86	-0.44	1.19
K1	16.08	68.86	15.88	62.3	-0.2	-6.56
J1	1.02	80.39	1.36	67.2	0.34	-13.19
OO1	0.61	88.4	1.13	75.53	0.52	-12.87
N2	4.46	278.87	4.30	273.83	-0.16	-5.04
M2	21.18	289.77	19.27	288.05	-1.91	-1.72
L2	0.74	308.4	0.43	304.89	-0.31	-3.51
S2	5.69	313.92	5.11	321.97	-0.58	8.05

Table 4 The harmonic coefficients of model output and the field observations

Station No.	Location		Amplitude of K1		Amplitude of M2	
	Longitude (°)	Latitude (°)	Observation (m)	Prediction (m)	Observation (m)	Prediction (m)
1	121.86	24.58	0.188	0.160	0.4087	0.42
2	121.18	22.78	0.164	0.180	0.4232	0.44
3	123.46	25.73	0.170	0.150	0.46	0.47
4	115.35	22.75	0.330	0.440	0.28	0.31
5	111.82	21.58	0.420	0.580	0.68	0.8
6	108.62	19.10	0.540	0.510	0.18	0.14
7	109.22	13.75	0.340	0.460	0.18	0.18
8	107.07	10.33	0.610	0.780	0.79	0.67
9	128.90	32.70	0.250	0.240	0.85	0.67
10	121.08	27.45	0.290	0.230	1.67	1.34
RMS(m)			0.093		0.132	

Table 5 Nine tidal observation on the western coast and three on the eastern coast

			M2		K1	
	Longitude (°)	Latitude (°)	Observation (m)	Prediction (m)	Observation (m)	Prediction (m)
Danshui	121.42	25.17	1.03	1.08	0.20	0.17
Zhuwei	121.23	25.12	1.19	1.19	0.21	0.178
Hsinchu	120.9	24.85	1.65	1.47	0.22	0.14
Boziliao	120.13	23.62	0.97	0.97	0.22	0.08
Penghu	119.57	23.55	0.91	1.10	0.24	0.06
liuqiuyu	120.37	22.35	0.05	0.06	0.05	0.03
Jiangjun	120.1	23.22	0.44	0.50	0.17	0.04
Mazu	119.95	26.17	2.10	1.98	0.31	0.23
Taichung	120.55	24.3	1.73	1.60	0.24	0.12

			M2		K1	
	Longitude (°)	Latitude (°)	Observation (m)	Prediction (m)	Observation (m)	Prediction (m)
Suao	121.87	24.58	0.41	0.12	0.19	0.10
Hualien	121.62	23.97	0.38	0.08	0.14	0.07
Lanyu	121.48	22.05	0.16	0.04	0.05	0.30