Development of Taiwan's community ocean model

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Abstract

The purpose of this project is to develop a three-dimensional, multi-scale, community ocean model. The scope of the development ranges from tide (wave) models to basin-scale circulation models. The model domains will cover the entire North Pacific Ocean with 1/4° horizontal grid resolution and down to the surrounding seas in the vicinity of Taiwan with 1/128° horizontal resolution. A three-year plan is proposed. The major tasks for the first year are listed in the following. (1) Establishing computing facilities, manpower and observational database; (2) developing the prototypes of 3-D, 1/12°, 51 -layer tide and 1/4°, 26 z-level North Pacific circulation models independently; and (3) conducting the required observations including tidal sea level measurement and drifter observation for the model validations. In the second and following years, the main tasks are (1) performing further model development to improve the accuracy and resolution, and (2) offering the model products online and improving the model dynamic along with the development. The associated drifting trajectory and contaminant dispersion models will be incorporated to the system. It is expected that associated investigators could gain substantial modeling experience through the project. The ultimate goal aims to build a public-released oceanic model for general oceanographic community and enhance Taiwan's ocean nowcasting/forecasting ability.

1. Introduction

Taiwan is located along the southeast Coast of the Asian continent, across the Taiwan Strait from the mainland China. It acts as the pivot on the west edge of the Pacific Ocean. The surrounding seas in the vicinity of Taiwan are strategically important and knowledge of the temperature, salinity and velocity fields is crucial for understanding the physical oceanography. An observation system around Taiwan will be established under the support from the National Applied Research Laboratories (NARL) in the near future. The physical observations system, together with a comprehensive modeling system play an important role in understanding and predicting marine environmental conditions, particularly those during episodic and extreme events.

This project will develop a three-dimensional, multi-scale, community ocean model system. The scope of the system development ranges from tide (wave) models to basin-scale circulation models. The model domains will cover the entire North Pacific Ocean with 1/4° horizontal grid resolution and down to the surrounding seas in the vicinity of Taiwan with 1/128° horizontal resolution. At the current stage, each component of the integrated model system is developed independently. Here we report on the development of a high-resolution tidal model in the vicinity of Taiwan and a coarse-resolution primitive equation North Pacific Ocean circulation model in order to simulate multi-scale dynamics accurately. The tidal model includes very detailed small-scale tidal impacts while the large scale circulation model is used to the general and providing adequate boundary conditions for the tidal model. The current model development will be integrated into an ocean modeling system and can be used in many future applications, e.g. ocean ecosystem, typhoon-included circulation and climate change studies. Eventually, the circulation and tide models will be merged into a single model. The two models are described individually below.

2. Model description

At current stage, the community model development is divided into two parts: the circulation model and the tide model. The basic settings of the two models are described as follows.

2.1 Circulation model

The circulation model is a fourth-order accurate, collocated Arakawa-A grid similar to DieCAST (Dietrich/Center for Air Sea Technology) model described in Dietrich (1997), Dietrich et al (2004a) and Tseng et al. (2005). The control volume equations include fluxes of the conservation properties (momentum, heat and salt) across control volume faces. The model domain covers the entire North Pacific Ocean ranging from 30°S to 60°N and from 100°E to 80°W (Fig. 1) with horizontal resolution 1°/4.

Model bathymetry is established using unfiltered ETOPO2 depth data[1] supplemented with 1-min depth archive in the Asian seas from Taiwan's Ocean Data Bank. The vertical resolution is linear-exponentially stretched by 26 levels. The layer thickness varies from 13.28 m in the top layer to 891.02 in the bottom layer. The vertical mid-points of the layers are at depths 6.46, 20.51, 36.34, 54.35, 75.02, 98.94, 126.82, 159.55, 198.20, 244.07, 298.77, 364.26, 442.91, 537.65, 652.04, 790.43, 958.13, 1161.62, 1408.85, 1709.48, 2075.34, 2520.88, 3063.73, 3725.44, and 4532.33 m. Within each horizontal grid, longitudinal resolution is uniform and latitudinal resolution is specified such that each control

[1]http://www.ngdc.noaa.gov/mgg/global/relief/ETOPO2/ETOPO2v2-2006/ETOPO2v2c/

volume is approximately square (Mercator grid); thus, the model control volumes decrease with increasing latitude as do the typical ocean eddy sizes.

The surface wind forcing is obtained from the interpolated monthly Hellerman and Rosentstein's wind stresses (Hellerman and Rosenstein, 1983). The Levitus'94 climatology (Levitus and Boyer, 1994) is used to initialize the model and determine its surface sources of heat and fresh water (evaporation minus precipitation) using the non-damping approach described in Dietrich et al. (2004b). The northern boundary is closed. The southern boundary condition (30°S) is slowly nudging toward climatology in a sponge layer. The bottom is insulated, with no-slip conditions parameterized by a nonlinear bottom drag. Sub-grid scale vertical mixing is parameterized by eddy diffusivity and viscosity using a modified Richardson number dependent formula (Staneva et al., 2001; Tseng et al., 2005) based on Pacanowski and Philander (1981). Background lateral viscosity (or diffusivity) is 200 m^2/s.

2.2 Tide model

The three-dimensional baroclinic tide model is modified from the Princeton Ocean Model described in Blumberg and Mellor (1987). The nonlinear primitive equation model with Boussinesq and hydrostatic approximations is driven by the barotropic tidal forcing. The vertical axis is transformed to the σ–coordinate by $\sigma=(z-\eta)/(H+\eta)$, where z is positive upward with the origin placed at the mean sea level, η is the sea level fluctuation and H is the mean water depth. The governing equations and essential model settings were delineated in Jan et al. (2007). The model is bounded within 99.25°–135.25°E and 2.25°–43.25°N with 1°/12 horizontal resolution (Fig. 2). There are 51 uneven σ layers in the vertical with σ_k=–(0.002, 0.004, 0.006, 0.008, 0.01, 0.012, 0.014, 0.018, 0.022, 0.026, 0.03, 0.034, 0.037, 0.045, 0.053, 0.061, 0.069, 0.077, 0.085, 0.1, 0.116, 0.132, 0.148, 0.179, 0.211, 0.243, 0.274, 0.306, 0.337, 0.369, 0.4, 0.432, 0.464, 0.495, 0.527, 0.558, 0.59, 0.621, 0.653, 0.684, 0.716, 0.748, 0.779, 0.811, 0.842, 0.874, 0.905, 0.937, 0.968, 1), from k=1 (surface) to 51 (bottom). The bottom topography was established using the revised ETOPO2.

The motionless ocean is subsequently driven by the tidal potential and prescribed tidal sea levels on all open-ocean boundaries through a forced radiation condition similar to that used by Blumberg and Kantha (1985). The tidal sea levels on the open boundaries are computed using harmonic constants compiled in a database (hereafter NAO.99) described in Matsumoto et al. (2000). The depth-averaged tidal current velocity normal to the open boundaries is determined by

$$\mathbf{u}_{nB}=\mathbf{u}_{2D}+C\,(\eta_B-\eta_{pre})\,/H \qquad (1)$$

where u2D is calculated from a fine-tuned, two-dimensional tide model of Jan et al. [2004], C ($=\sqrt{gH}$) is the phase speed of a shallow water gravity wave, η_B is sea level calculated by the three-dimensional tidal model, and η_{pre} is prescribed tidal sea level on open boundaries. A flow relaxation scheme described by Engedahl (1995) is applied to the internal mode velocity and temperature in a 1° wide strip adjacent to open boundaries to eliminate artificial reflections.

3. Preliminary results

Fig. 3 shows the circulation model simulated instantaneous North Pacific Ocean current speeds at the first day of year 54. Early results show realistic: Kuroshio intrusion and retreat through Luzon Strait and over southern East China Sea; formation of a warm core eddy in northern South China Sea in winter; seasonal variation of circulation in Taiwan Strait; and big Kuroshio meander over Izu Ridge southeast of Japan. Of special interest are: Kuroshio intrusions into Luzon Strait and possible instability; Kuroshio response to typhoons and meso-scale eddies; and variability of circulation in the South and East China Seas and Taiwan surrounding seas. These are also contemporary interests not only in Taiwan but also in the world's oceanographic communities.

The harmonic constant derived from model results are validating with observations and NAO.99. Fig. 4 shows the model-simulated co-tidal charts for the O1, K1, M2 and S2 constituents in the Luzon Strait (LS) as an example. The averaged sea level root-mean-square discrepancies, which considers both amplitude and phase differences, are 2.2, 2.9, 2.5 and 1.0 cm respectively for O1, K1, M2 and S2 as compared with the sea level calculated from NAO.99 at depths greater than 200 m in 115-127°E and 18-23°N. The associated goodness of fit relative to the sea level calculated from NAO.99 is 95.4, 93.7, 98.7 and 98.8% for O1, K1, M2, and S2, respectively, suggesting that barotropic tides are reasonably reproduced in the model. Fig. 5 shows the model-simulated depth-averaged tidal current ellipses of the O1, K1, M2 and S2 constituents in the LS. Briefly, the current amplitudes are of similar magnitude ~0.2 m/s for the O1, K1 and M2 and relatively small, 0.1 m/s, for the S2 in the LS. The barotropic tidal currents are much weaker, <0.1 m/s, in the deep Pacific Ocean and the deep northern South China Sea (SCS). The intensification of the barotropic tidal currents in the LS is mainly due to the narrowing and shoaling topographic effects when tidal waves propagate westward from the deep western Pacific into the SCS through the two submarine ridges in the LS. The characteristic of diurnal tides, which are quasi-resonant, partial-standing waves in the SCS with a meridional nodal band roughly across the LS, also contributes to the barotropic tidal current strengthening.

4. Summary

The development of the Taiwan Community Modeling System is now underway. The ultimate goal aims to build a public-released oceanic model for general oceanographic community and enhance Taiwan's ocean nowcasting/forecasting ability. The tidal model has been used in some operational rescue plan. The circulation model has been used in some studies of the ocean responses to typhoons. The integrated modeling system will be accomplished in the near future.

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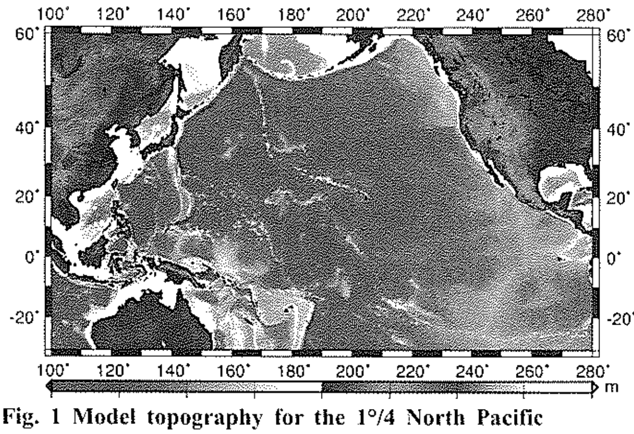

Fig. 1 Model topography for the 1°/4 North Pacific Ocean circulation model.

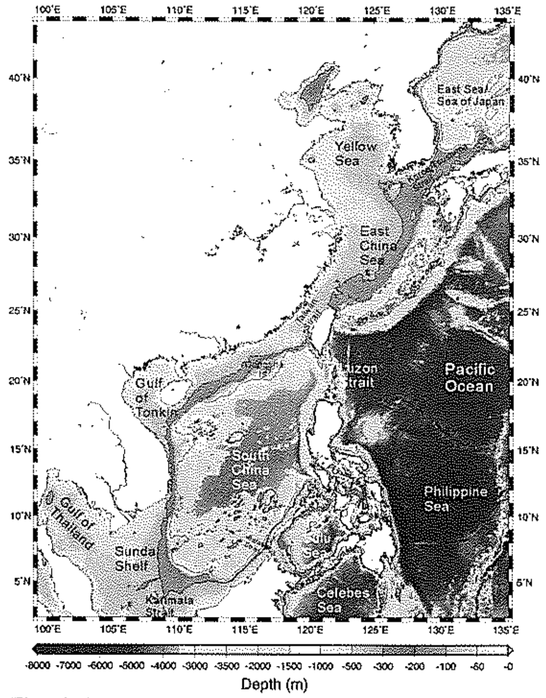

Fig. 2 Bathymetry of the three-dimensional model domain, including the East Asian seas and northwest Pacific Ocean.

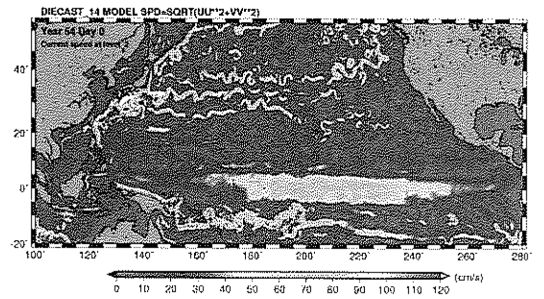

Fig. 3 Circulation model simulated instantaneous North Pacific Ocean current speeds at the first day of year 54.

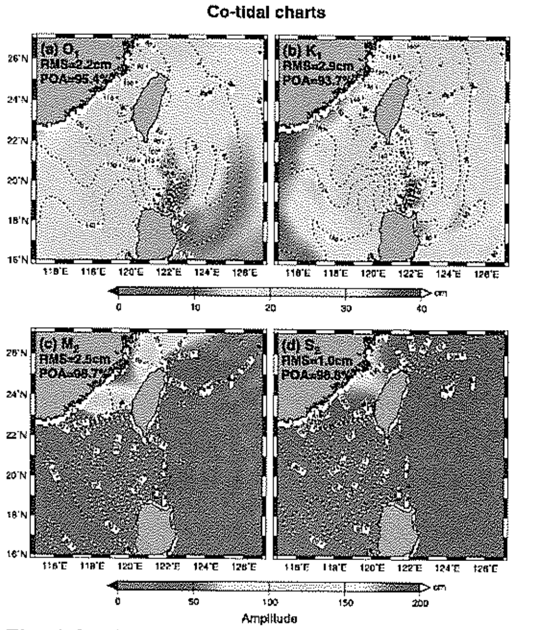

Fig. 4 Co-tidal charts for simulated (a) O1, (b) K1, (c) M2 and (d) S2 constituents.

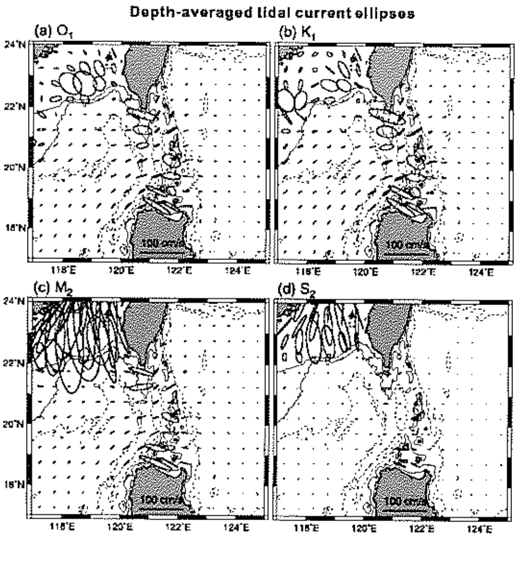

Fig. 5 Depth-averaged tidal current ellipses for simulated (a) O1, (b) K1, (c) M2 and (d) S2 constituents.