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Marine Ecosystem Simulation in the Indonesian Seas

Yoshikazu SASAI[1], Aditya R. KARTADIKARIA[2],
Yasumasa MIYAZAWA[1] and Kazuo NADAOKA[2]

[1]*Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology, Showa-machi, 3173-25, Kanazawa-ku, Yokohama 236-0001, Japan*
[2]*Tokyo Institute of Technology, Ookayama, 2-12-1, Meguro-ku, Tokyo 152-8550, Japan*

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Abstract—An eddy-resolving ocean model incorporating biological processes was applied to the Indonesian Seas to understand the current marine ecosystem and to investigate the influence of river discharges on the marine ecosystem. The model captures surface ocean circulation and relevant energetic eddy activity in the complex topography of the Indonesian archipelago. The simulated surface chlorophyll data reproduced a distribution similar to that of the satellite ocean color data. The model shows high concentrations of surface chlorophyll in the coastal and Indonesian archipelago regions and low concentrations in the subtropical region. The model also shows the large impact of river discharges on the marine ecosystem in the estuary.

Keywords: Indonesian archipelago, marine ecosystem, river discharge, high-resolution ocean model

INTRODUCTION

The Indonesian archipelago is one of the richest marine biodiversity in the world. This region is subject to a number of river discharges from the Indonesian islands and has throughflow pathways with complicated topographies. The Indonesian Throughflow (ITF) between the Indian and Pacific Oceans is important to global thermohaline circulation (Broecker, 1991). The region is characterized by various temporal and spatial oceanic phenomena (e.g., mesoscale eddies, ocean currents, throughflow, coastal upwelling and tidal mixing) (e.g., Kashino *et al.*, 1999; Qiu *et al.*, 1999; Susanto *et al.*, 2000; Masumoto *et al.*, 2001). Furthermore, the Asia-Australian monsoon, El Niño Southern Oscillation (ENSO), and the Indian Ocean Dipole (IOD) also affect this region (e.g., Meyers, 1996; Saji *et al.*, 1999; Susanto *et al.*, 2001; Ashok *et al.*, 2003).

In recent years, the condition of the coastal ecosystem in the Indonesian archipelago has become critical due to the increase in the influence of human-induced loads (e.g., population pressure, coastal overfishing, and water pollution) and the stress of climate change (e.g., global warming and rainfall fluctuation) (e.g., Kaly and Jones, 1998; Abram *et al.*, 2003; Belkin, 2009). In addition to global climate change, mass coral bleaching due to high water temperatures is our major focus. Therefore, it is very important to determine appropriate strategies for the conservation and management of coastal ecosystems.

The goals of our study are to determine clear coastal ecosystem conditions and to predict changes to the coastal ecosystem along with climate change in this region. In this study, we developed a lower trophic marine ecosystem model that represents primary production, which is important to nutrient distribution, in addition to a physical model. We verified the performance of the marine ecosystem model and investigated the influence of river discharges on the coastal ecosystem.

METHOD

In this study, we used an eddy-resolving numerical model called the Japan Coastal Ocean Predictability Experiment (JCOPE2) model, which was developed by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) (Miyazawa *et al.*, 2009). The model is based on the Princeton Ocean Model (POM) with σ-coordinates (Mellor *et al.*, 2002). The ocean model has a two-level nesting structure. The outer model covers most of the Indian and Pacific Oceans (62°N–30°S, 35°E–70°W) with a horizontal resolution of 1/3° and 21 vertical layers (IP1 model). The outer model is necessary to provide the lateral boundary values of the prognostic variables for the higher horizontal resolution model that covers the South East Asian seas and Western Pacific areas (42°N–24°S, 90°E–168°E) (IP2 model) with a horizontal resolution of 1/9° and 47 vertical levels. All of the prognostic variables except for two turbulent properties in the coarse model are linearly interpolated onto the boundary grid points of the fine model. The model is forced by a six hourly NCEP/NCAR reanalysis (Kalnay *et al.*, 1996) from 1993 to 2010 after a seven-year-long (1987–1993) spin-up using the climatological monthly mean NCEP/NCAR. The model includes river discharge data obtained from the Global River Discharge Database produced by the Center for Sustainability and the Global Environment at the University of Wisconsin-Madison (http://www.sage.wisc.edu/riverdata/). The model topography was created using a combination of data from ETOPO2v2 and General Bathymetric Chart of the Oceans (GEBCO).

The marine ecosystem model has eight compartments including phytoplankton, zooplankton, particle organic matter (POM), dissolved organic matter (DOM), and the nutrients nitrate (NO_3), ammonium (NH_4), and phosphate (PO_4), and suspended sediment (SS) (Fig. 1). The model is based on the work of Fasham *et al.* (1990), and it incorporates PO_4 and SS. SS is an important compartment for photosynthesis and the kinematic transfer of PO_4 in the coastal ecosystem. The evolution of any biological tracer concentration in the IP2 model is governed by an advective-diffusive equation with source and sink terms. The source and sink terms represent the biological activities in Fig. 1. The phytoplankton growth rate is a function of phytoplankton concentration, temperature, salinity, nutrient concentrations (NO_3, NH_4, and PO_4), and light intensity (e.g., Guo and Yanagi, 1998). Light intensity is given by the shortwave radiation of the NCEP/

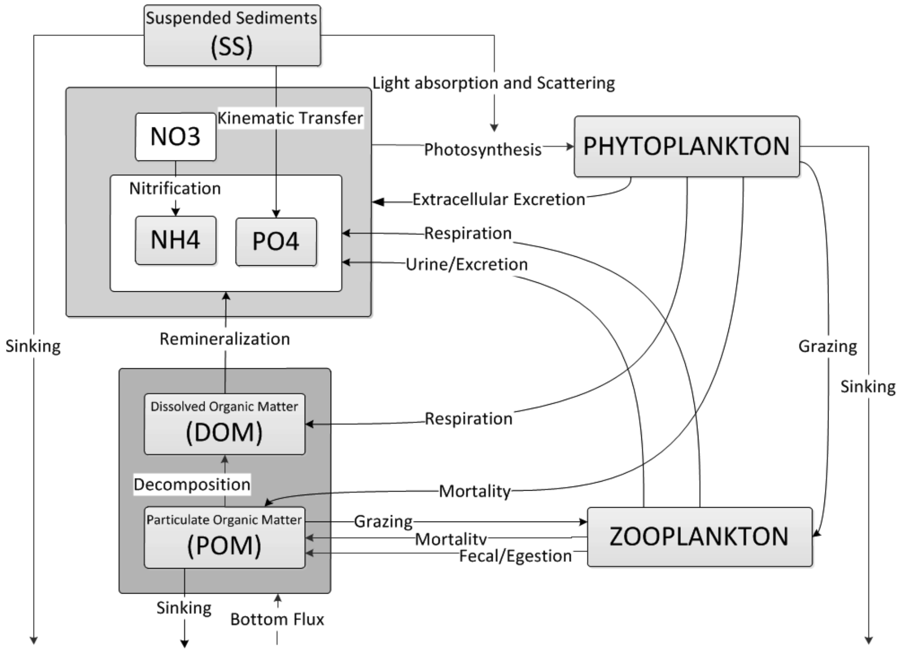

Fig. 1. Schematic diagram of marine ecosystem model. The model has 8 compartment biological tracers. The arrows indicate nitrogen flow among biological tracers.

NCAR reanalysis data. The grazing rate is temperature dependent and is represented by an Ivlev equation with a feeding threshold (Kishi *et al.*, 2007). The other biological activity parameters are found in the work of Guo and Yanagi (1998) and Kishi *et al*. (2007). To investigate the influence of river discharge on the coastal ecosystem, we added discharge data from 37 rivers (5 rivers in China and 32 rivers in South East Asia) to the IP2 ecosystem model. The variability of the biological fields had no feedback on the physical fields. The marine ecosystem model was coupled with the IP2 model at the beginning of 1999, and a simulation of the coupled physical-biological model was conducted from 1999 to 2010.

RESULTS

The simulated ocean circulation performed well in comparison to the observed data. A comparison of the simulated north-south and east-west velocity components with TAO/TRITON data (http://www.pmel.noaa.gov/tao/jsdisplay/) showed high correlation with the observed data. The temporal variability of the surface current velocity was also well reproduced. In addition, the model reproduced the energetic eddy activity in the complex topography of the Indonesian archipelago, especially in the Java Sea, the Banda Sea, and the Celebes Sea. The sea surface temperature given by the model matched the observed seasonal and

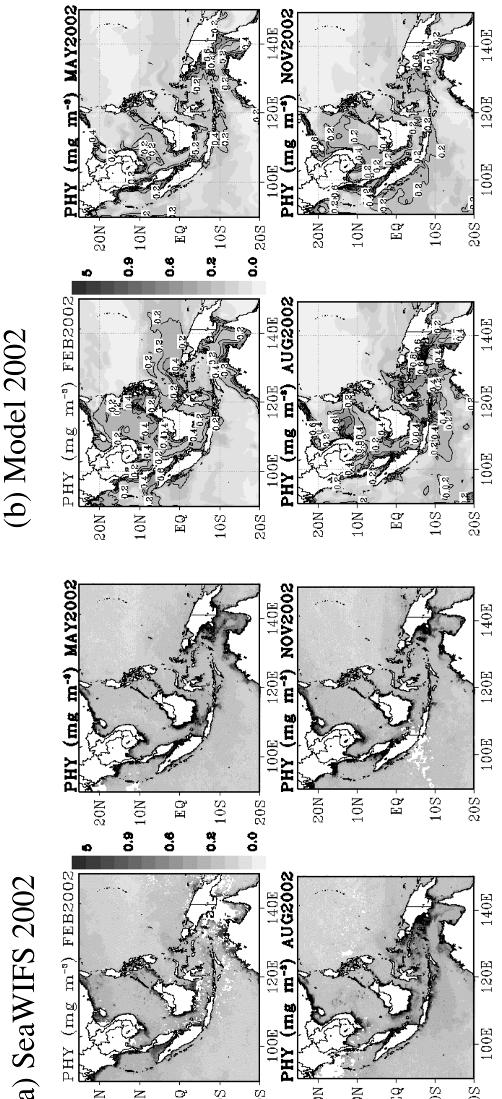

Fig. 2. Monthly mean surface chlorophyll concentration (mg m^{-3}) in 2002 from (a) SeaWiFS and (b) IP2 model.

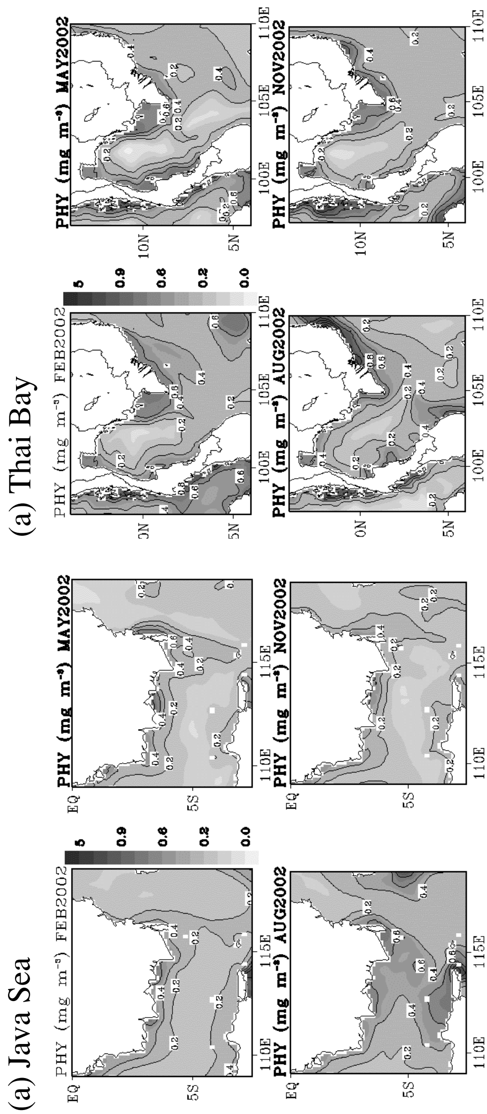

Fig. 3. Monthly mean surface chlorophyll concentration (mg m^{-3}) in 2002 from (a) Java Sea and (b) Thai Bay in IP2 model.

interannual variability.

The simulated surface chlorophyll represents a spatial pattern similar to that shown in the SeaWiFS data. Overall, the seasonal variability of simulated surface chlorophyll is in good qualitative agreement with the SeaWiFS data (Fig. 2). The simulated distribution of surface chlorophyll is influenced by oceanic circulation and mesoscale eddies. The model showed high chlorophyll concentrations in the coastal ocean and Indonesian archipelago, and low concentrations in the subtropical ocean. In May and August (the southeast monsoon season), along the south coast of the Java-Timor islands, high concentrations of chlorophyll were found in both the SeaWiFS data and in the model due to coastal upwelling. In the Banda Sea, high concentrations of chlorophyll were also shown to be associated with upwelling (Gordon and Susanto, 2001; Moore *et al.*, 2003). However, in the South China Sea and the Indian Ocean, the simulated chlorophyll concentration data was generally higher than the SeaWiFS data whole year round. In August, the simulated chlorophyll concentration in the Karimanta Strait and the Java Sea was much higher than the SeaWiFS data. In the Arafura Sea (Westside of New Guinea Island), the simulated chlorophyll concentration was lower than the SeaWiFS data.

The model also shows the large impact of river discharges on the marine ecosystem in the estuary, especially in the south of Kalimantan Island (Java Sea) and Thai Bay (Fig. 3). The outflow of nutrients from the river mouth spreads into the open ocean due to ocean circulation. In August, the surface chlorophyll concentration is the highest in the Java Sea and Thai Bay because of the large volume of river flow. In the Java Sea and the Makasar Strait, the effect of river discharge on the marine ecosystem is limited in the estuary because of the small river discharge volume.

SUMMARY

In this work, we developed coupled ocean general circulation and marine ecosystem models. We verified the precision of the ecosystem model coupled with the Indo-Pacific physical model using satellite ocean color data. The model reproduced the seasonal variability of surface chlorophyll concentration and the difference in chlorophyll concentration between the coastal and the Indonesian archipelago regions and the open ocean. To the south of Java Island, coastal upwelling significantly affected the surface chlorophyll concentration. Along the coastal region of the Indonesian archipelago, however, the surface chlorophyll concentration remained low because the nutrient supply from the river was not sufficient or because the nutrient supply due to tidal mixing was absent. To reproduce a more realistic distribution of the chlorophyll concentration in this region, it is necessary to improve the physical processes of our model.

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Y. Sasai (e-mail: ysasai@jamstec.go.jp)