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Wind Wave Effects On Surface Stress In Hydrodynamic Modeling

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ABSTRACT

Wind, wave and current interactions control the boundary fluxes, momentum and energy exchange between the atmosphere and the ocean, and within the water column. The wind wave effect on surface stress is investigated using a three-dimensional time-dependant ocean circulation model. The POM (Princeton Ocean Model) based model is implemented with realistic coastlines in South China Sea and emphasizes the simulation of physical parameters in the water column. Taking account of the wind waves, an increase in air-sea drag coefficient, reflecting an enhanced sea surface roughness due to increased wave heights, is shown to improve the simulated surface current and the sea surface elevation. It is also found that developing waves with smaller peak periods influenced the surface circulation more significantly.

KEY WORDS: Wave-current interaction; surface stress; ocean circulation model; model coupling.

INTRODUCTION

In the ocean environment, the physical processes governing the water column are influenced by atmospheric flow, currents, surface waves, tides and their mutual interactions. A better understanding of the physical process is essential for studying the chemical and biological processes in scientific and practical applications, such as beach erosion, upwelling, storm surges and transport of various materials. Compared to high cost of field measurements, the numerical model for solving time dependent flows is both effective and economical. Extensive and intensive studies of ocean modeling have been undertaken in last a couple of decades. Ocean models have become an important tool for understanding the seasonal ocean circulation and thermal structure, and for establishing a nowcast system for regional seas.

The South China Sea (SCS) has complex bottom topography and open boundaries. The hydrodynamics in the region is very complicated. Metzger and Hurlburt (1996) first applied a layered model to the SCS and compared upper layer currents and sea levels of the model with the observed data. Recently, Cai et al. (2002) developed a coupled single-layer/two-layer model to study the upper circulation. An enhanced understanding of the circulation characteristics has been achieved. Chu and Chang (1997) and Chu et al. (1999) studied the seasonal thermodynamics in the SCS using the POM with limited boundary conditions, monthly mean climatological wind stress data set (Hellerman and Rosenstain, 1983) and bi-monthly variation of mass transport at the open boundaries (Wyrtki, 1961).

Wind wave impact on the ocean circulation is an important aspect of the hydrodynamics. Recent computational studies by Davies and Xing (2000), Xie etc al. (2001) and Moon (2005) bear this point. Their studies show that the wave contributes to local current and sea level changes, and momentum and stratification mixing throughout the whole water column. Moon (2005) also investigated the effects of ocean waves on sea surface temperature simulations. Without considering the wave effect at the surface, the surface stress is a function of wind speed based on the drag coefficient (Large and Pond, 1981). However, the action of wind over the sea induces the exchange of momentum between air and ocean, leading to wave development. Therefore the surface stress would be significantly enhanced by the wind waves. Charnock (1955), Janssen (1989, 1991) and Donelan et al. (1993, 2004) presented various models to calculate surface roughness by taking into account the effects of the surface waves. Most recently, Massel and Brinkman (2001) presented an analytical solution for the wave-induced set-up and flow through simple shoal geometry when water depth is a linear function of distance. The existing empirical knowledge has shown that surface waves enhance the mixing in the upper ocean, which can be applied to the newly derived continuity, momentum and energy equations for more accurate modeling. Mellor (2003) and Qiao et al. (2004) coupled surface wave equations to mixing equations in three-dimensional ocean models. Their result has confirmed a strong wave-induced mixing in both hydrodynamics and temperature. Graig and Banner (1994) and Zhang and Chan (2003) have suggested that surface waves can enhance mixing in the upper ocean. The SCS is monsoon dominated, and surface waves play a significant role in the circulation process.

In the present study, the wind wave effect to the circulation is investigated using a three-dimensional time-dependant POM based model. The model is configured with realistic coastlines and the emphasis is on the simulation of physical parameters in the water column. A third-generation wave model (WAM) is employed to