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Numerical ship navigation based on weather and ocean simulation ☆

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ABSTRACT

Sea states, such as waves, tidal currents, and wind are important factors for safe and economic ship navigation. In previous papers of Xia et al. (2006a, 2006b) single factor generated by low pressure was studied independently. The objective of this paper is to study how ship navigation is affected by the combined effects of these factors. For clarification, simulations of two representative typhoons were conducted, and the results were compared. Numerical simulations of tidal currents, waves, and wind were applied to provide high-resolution information, which was then used to simulate ship navigation. Estimation of ship position was found effectively by comparing the results from these two cases and using the proposed numerical navigation simulation method.

1. Introduction

With the increasing influence of global warming, typhoons are becoming bigger and stronger, leading to more high-wave areas in the ocean. Therefore, the navigation of vessels will involve a higher risk. Besides weather routing for oceangoing ships (Motte, 1972; Bowditch, 1995) and the ensemble prediction system (EPS) run at ECMWF (Hoffschildt et al., 1999), those navigating in coastal areas also need exact weather and ocean forecasts because of more complex topography and higher ship density.

A busy shipping area, Osaka Bay in Japan is often attacked by strong typhoons coming from different directions. Therefore, the need for high-resolution information on wind, waves, and currents has been brought to the attention of scientists and engineers. Shiotani, S. studied about the influence of tidal current on a sailing ship (Shiotani, 2002), making the initial step of numerical ship navigation. Several numerical navigation experiments in the Japan coastal area were also carried out (Xia et al., 2006a, 2006b), verifying the possibility to estimate ship position, however, the high-resolution weather and ocean data was not utilized to improve the accuracy of ship simulation. In their research, the ship simulation model known as MMG was effectively verified to calculate the ship response to the ocean currents and waves, which has been studied in the 1980s (Yoshimura, 1986).

Recently, the combined effects of tidal current, wave and wind on a ship was analyzed in the Ise Bay of Japan (Shiotani et al., 2012), indicating a good agreement between simulation and observation of the weather and ocean data.

Other researchers have also studied about the influence of weather and ocean on a sailing ship in coastal area (Soda et al., 2012), however, their simulation was conducted using a small vessel "Fukae Maru" only in one low pressure case without experiment verifying data, which is substituted by using a normal container ship model "SR108" in two symmetrical typhoon cases in this paper to further confirm the correctness of the proposed ship simulation method, while the next step is to implement a real navigation experiment based on the present feasibility confirmation.

Therefore, to find different effects on ship navigation as well as conduct the first step for constructing a numerical weather routing system, two representative typhoons were analyzed to make a ship navigation simulation with consideration of the tidal current, waves, and wind in Osaka Bay.

First, the mesoscale meteorological model of WRF-ARW version 3.4 (Weather Research and Forecasting Model) (Skamarock et al., 2005) was used to generate high-resolution wind data, which was then put into SWAN (Simulating Waves Nearshore) (Booji et al., 1999; The SWAN Team, 2009) and POM (Princeton Ocean Model) (Blumberg and Mellor, 1987; Mellor, 1998) to get wave and tidal current data. Second, the numerical simulation data of wind, waves, and currents were applied to the navigational simulation of an oceangoing ship in Osaka Bay.

The accurate estimation of a given ship's position is very important for ship safety as well as economics. Such estimations

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can be obtained when the hydrodynamic model MMG, which is widely used for describing a ship's maneuvering motion, is adopted to estimate a ship's position.

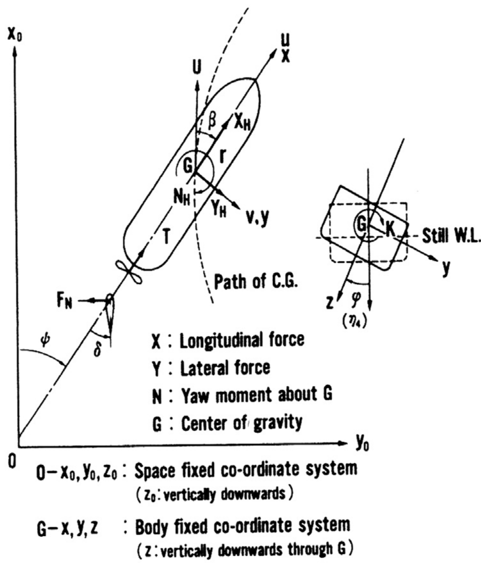

Fig. 1. Coordinate system of MMG.

2. Model description

2.1. Weather research and forecasting model

he large gradients in wind velocity and the rapidly varying wind directions of the typhoon vortex can generate very complex ocean wave fields. In this paper, the simulation of wind was carried out by WRF-ARW, which has been widely used for operational forecasts as well as for realistic and idealized research experiments. It can predict three-dimensional wind momentum components, surface pressure, dew point, precipitation, surface-sensible and latent heat fluxes, relative humidity, and air temperature on a sigma-pressure vertical coordinate grid. The equation set for WRF-ARW is fully compressible, Eulerian, and non-hydrostatic, with a run-time hydrostatic option. The time integration scheme in the model uses the third-order Runge-Kutta scheme, and the spatial discretization employs 2nd to 6th order schemes.

As boundary data, GFS-FNL data were used (Mase et al., 2006). The GFS (Global Forecast System) is operationally run four times a day in near-real time at NCEP. GFS-FNL (Final) Operational Global Analysis data are on 1.0 × 1.0-degree grids every 6 h.

2.2. Princeton ocean model

The Princeton Ocean Model was used to simulate the tidal current affected by these two typhoons. As a three-dimensional,

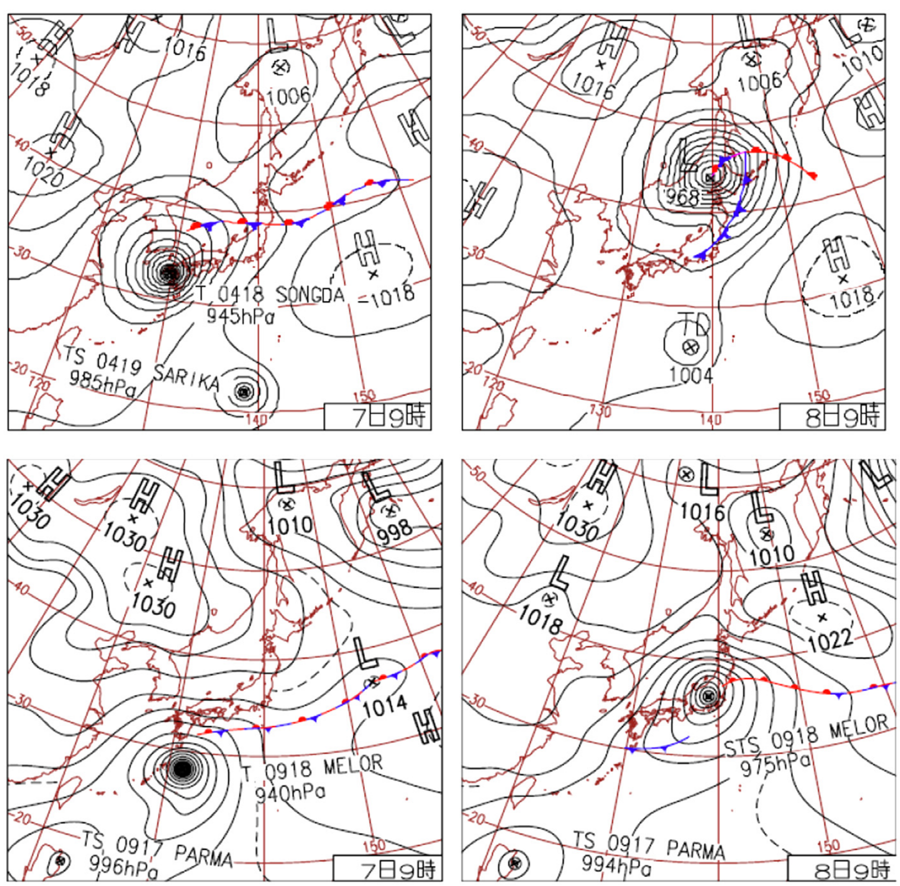

Fig. 2. Weather charts of simulated typhoons.