Application of the Improved Vertical Mixing Scheme to the Modeling of the Japan Sea Under Traveling Typhoons

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Application of the Improved Vertical Mixing Scheme to the Modeling of the Japan Sea Under Traveling Typhoons

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Abstract

The surface mixed layer in response to two different mixed layer schemes in the Japan Sea under traveling typhoon is investigated using a high-resolution ocean circulation model. The simulated sea surface temperature in the original Mellor-Yamada (1982) mixed layer scheme model is obviously warmer than observation data. It agrees with the viewpoint of previous studies implying that the intensity of the turbulent mixing is underestimated in the Mellor-Yamada scheme. On the other hand, the improved Mellor-Yamada turbulence closure scheme, which proposed by Nakanishi and Niino (2009), provides improved sea surface temperature. Furthermore, the correlation between the model vertical temperature profile and the Argo Profiling Float data is relatively higher. This study concludes that the improved mixed layer scheme contributes to a certain extent to overcome the shortcomings of the original Mellor-Yamada scheme, namely, insufficient growth of the mixed layer and underestimates of the turbulent kinetic energy, showing a better performance compared with the original Mellor-Yamada scheme in modeling the ocean mixed layer.

Key words: *turbulent mixing, improved mixed layer scheme, sea surface temperature, typhoon, the Japan Sea*

1. Introduction

The vertical turbulent mixing, in the planetary boundary layer and the oceanic surface mixed layer, plays an important role through the momentum and heat transfer across the air-sea interface. The turbulent mixing scheme can regulate the sea surface temperature (SST) and determines the accuracy of the surface mixed layer representation. So far, several kinds of ocean mixed layer schemes have been developed to simulate the upper ocean processes such as SST and mixed layer depth.

The famous second-order turbulence closure mixed layer scheme developed by Mellor and Yamada (1982) (hereafter MY82) has been widely incorporated into numerical models. However, a variety of numerical models demonstrate shortcomings of MY82 such as a slow growth of mixed layer (Sun and Ogura, 1980; Martin, 1985; Kantha and Clayson, 1994). To fix this problem, Nakanishi and Niino (2009) developed an improved mixed layer scheme (hereafter MYNN) by taking into account the effects of buoyancy and stability on the turbulent length scale as well as modifying the empirical constants based on the LES database. The improved mixing scheme has been applied in the atmosphere model successfully, whereas, its performance in oceanic general circulation models (OGCMs) has not been examined.

One of most notable factors in vertical turbulent mixing is the wind-induced mixing. It is well known that typhoon affects the surface ocean raising the cold sub-surface water up to the surface layer and causing the decrease of SST by intense vertical mixing. The typhoon processes generally make the sea surface temperature 1 ℃ to 4 ℃ cooler (Leipper and Volgenau, 1972; Price, 1981; Zedler et al., 2002), which significantly reduces or even reverses the ocean-atmosphere temperature difference regionally. The purpose of this study is to assess the performance of the MYNN to the strong typhoon in an ocean general circulation model as the first step.

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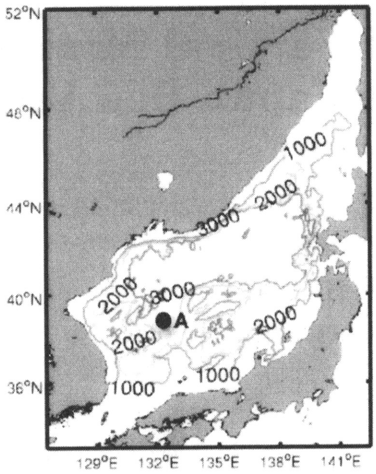

Fig 1. The model domain and topography. A presents the ARGO data.

2. Data and Model

A 3D z-coordinate RIAM Ocean Model (RIAMOM), with 1/12° 1/12° horizontal resolution and 36 vertical levels, is used to investigate the performance of the MYNN. The model covers the domain of the whole Japan Sea (33°N-52°N, 126.5°E-142.5°E) as shown in the Fig 1. The topography is combined from ETOP5 data and the depth data of the Coastal and Ocean Dynamics Studies Laboratory of Sungkyunkwan University (Choi et al., 2002). The experiments are designed in September of 2003, due to a super typhoon named 'Maemi' passed through the Japan Sea. The initial conditions are determined from the daily results of a 1/4° 1/5° Western North Pacific Ocean Model (Hirose, 2011), as well as the boundary thermohaline conditions. The inflow through the Tsushima Straits comes from Takikawa et al. (2005), and the outflow through the Tsugaru Strait and Soya Strait are 65% and 35% of the total inflow, respectively. The 0.125° 0.1° hourly Meso-Scale Model of Japan Meteorological Agency (MSM-JMA) datasets, such as wind stress, humidity and air temperature, are used in the numerical model. The surface momentum flux, precipitation, and long wave radiation are directly given at the top level of the model. The short wave radiation is distributed within the surface and subsurface layers as a result of its penetration. The freshwater flux from Amur is given from the monthly mean data of the Global Runoff Data Center. The sensible and latent heat fluxes are calculated using the bulk method. In order to investigate the response of SST to the turbulent mixing, there are no relaxations for the sea surface temperature and salinity.

3. Results

The model results are reasonably good compared with observations qualitatively, especially for those with the MYNN scheme. Fig 2 illustrates the horizontal distribution of observed SST (Tohoku University) in the Japan Sea after the passage of typhoon, as well as the results from the numerical experiments using two different mixing schemes, MY82 and MYNN. According to observations and model results, the turbulent mixing process is very strong in this area and the SST decreased about 1.5℃ after the passage of typhoon (not shown here). In the experiment with the MY82, the SST in the western Japan Sea is obviously higher than that in the experiment with the MYNN, although a warm SST bias still remains in the MYNN. The area-averaged SST with the MY82 is about 0.36℃ higher than that with the MYNN. This implies that downward transports of the momentum and heat from the upper layer are generally weaker in MY82 compared with that in MYNN. The turbulent mixing intensity is clearly enhanced in the upper layer according to the improved scheme.

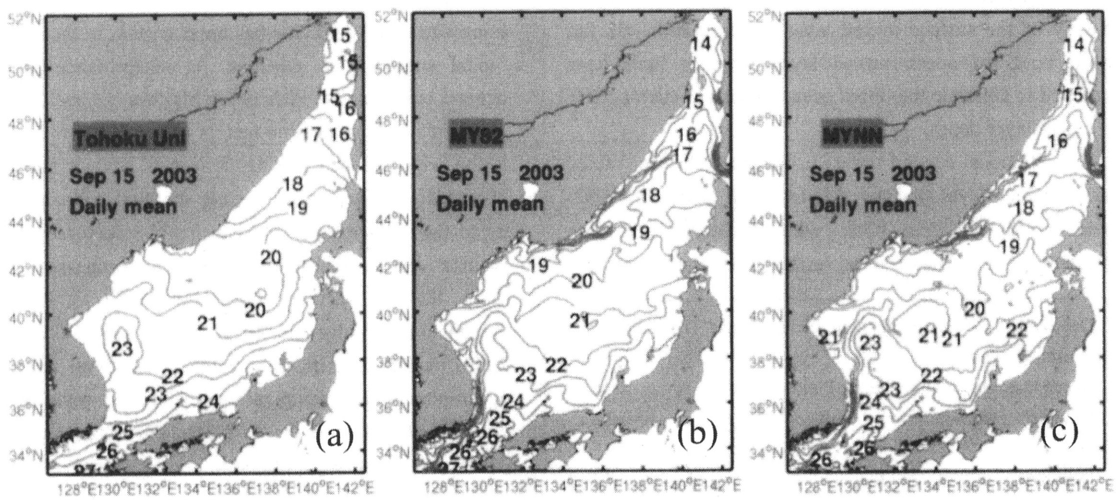

Fig 2. The horizontal SST distributions: a) observations, b) with MY82, c) with MYNN.

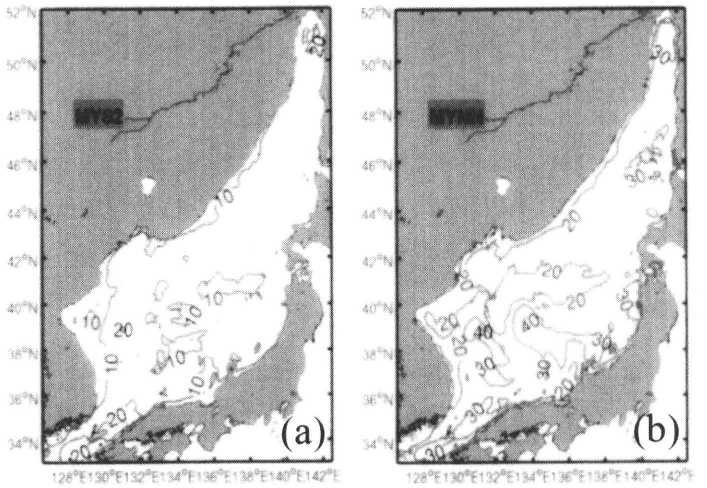

Fig 3. The mixed layer depth in meter: a) with MY82, b) with MYNN.

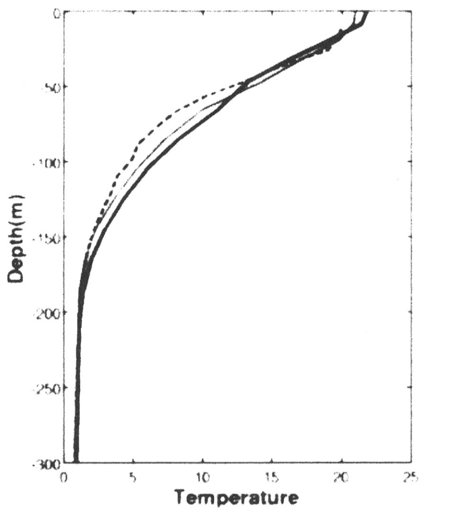

Fig 4. Simulated temperature profiles with MY82 (thick solid line) and MYNN (thin solid line) and ARGO data (dash line) at station A.

The mixed layer depths in the experiments are highly consistent with the horizontal SST distribution mentioned above. The warmer SST implies that the mixed layer depth grows insufficiently in experiment with the original MY82 scheme (Fig 3a). By contrast, the mixed layer develops rapidly in the MYNN (Fig 3b) with the increase of turbulent kinetic energy (not shown here).

Furthermore, the vertical temperature profiles are shown in Fig 4. The model reproduces the vertical structure of temperature profile successfully compared with the distribution of Argo Profiling Float data at station A (38.56°N, 132.43°E, Fig 1). The correlations between observed and simulated temperatures in the MY82 and the MYNN are 0.893 and 0.926, respectively. However, the weaker thermocline compared with ARGO data and the warm SST biases suggest that there is still some room in improving this model. The simulated temperature profiles also imply that, after considering the effects of buoyancy and stability on the turbulent length scale as well as modifying the empirical constants based on the LES database, the turbulent intensity with the improved MYNN scheme is significantly enhanced. The increased downward heat and momentum transformations from upper layer lead to the higher temperature of the water below the surface.

4. Conclusions

The warmer SST in the experiment with the MY82 compared with that using the MYNN implies that downward transports of the momentum and heat from the surface layer are generally weaker in the MY82 compared with that in the MYNN. Further analyses confirm that the mixed layer develops rapidly in the MYNN with the increase of turbulent kinetic energy. In summary, the improved scheme contributes to a certain extent to overcome the shortcomings of MY82, namely, insufficient growth of the mixed layer and underestimates of the turbulent kinetic energy. MYNN scheme shows a better performance compared with the original MY82 model in simulating the ocean mixed layer.

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