Improvement of multi-limit mixed-layer entrainment parameterization from the results in an ocean global circulation model

Akiyoshi Wada[1*], Hiroshi Niino[2], Hideyuki Nakano[1]

1) Meteorological Research Institute, Tsukuba, Ibaraki, 305-0052, Japan
2) Ocean Research Institute, the Univercity of Tokyo, Nakano, Tokyo, 164-8639, Japan
*E-mail:awada@mri-jma.go.jp

1. Purpose

The purpose of this investigation is to improve a multi-limit mixed-layer entrainment parameterization (Deardorff, 1983) to improve the reproduction or prediction of oceanic impact on tropical cyclones. Even though the original parameterization, installed in a slab mixed-layer ocean model (hereafter SOM), was useful for the reproduction of sea surface cooling (SSC) by the passage of Typhoon Rex (1998) (Wada, 2005), the processes of SSC production, occurred within a mixed layer, could not be investigated by using the SOM. First, we clarify the processes of SSC production within a mixed layer from the result of numerical simulation performed using an oceanic global circulation model. Then we attempt to modify the multi-limit mixed-layer entrainment parameterization using the result of the numerical simulation.

2. Methods

Meteorological Research Institute Community Ocean Model (MRI.COM, Ishikawa et al, 2005) was used to perform the numerical simulation in the case of the ocean response to Rex. The MRI.COM has a horizontal resolution of a quarter degrees and 54 vertical layers. The runs consist of three parts: spin up procedure, numerical simulation in the North pacific and numerical simulation over the regional domain (120-160ºE, 10-50°N). The time step in MRI.COM was 10 minutes. The result of numerical simulation over the regional domain was used to investigate the processes of SSC production and to modify the entrainment parameterization (Deardorff, 1983) used in SOM.

The National Centre for Environmental Prediction (NCEP) Department of Energy Atmospheric Model Intercomparison Project reanalysis (hereafter, NCEP R-2) data was used as atmospheric forcing. However, wind stress was replaced with the objective analysis data in Japan Meteorological Agency merged with an artificial Rankin vortex based on Regional Specialized Meteorological Center (RSMC) tropical cyclone best-track data.

The detail of modification of the entrainment parameterization from the original Deardorff's scheme is in the followings:

a. Introduction of turbulent kinetic energy (TKE) production by wave breaking to turbulent transport term (add $5u_*^3$ where u_* is the frictional velocity).

b. Relative contribution of an interfacial (gradient) Richardson number R_{iv} to an initial guess of turbulence Richardson number R_{iq} is reduced.

c. Proportional coefficient of third power of TKE (q_i^3) in the turbulent dissipation term in the entrainment zone is changed from 0.07 to 1.0.

3. Results

3-1. Validity of simulated ocean response to Rex

Figure 1 illustrates the horizontal distribution of simulated sea temperature at a depth of 0.5 m (hereafter, SST in MRI.COM) and oceanic currents in case of the developing (Fig. 1a) and mature (Fig. 1b) stages with center positions of Rex denoted as typhoon symbols and observational points by R/V Keifu-Maru denoted as triangles. During the developing stage, moving speeds of Rex were relatively fast. In a fast translation, local SSC was significantly produced on the rightward of the moving direction.

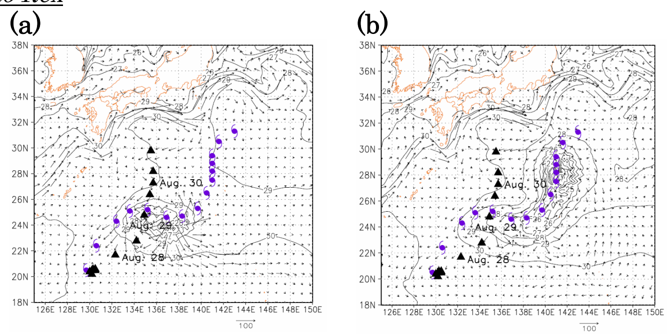
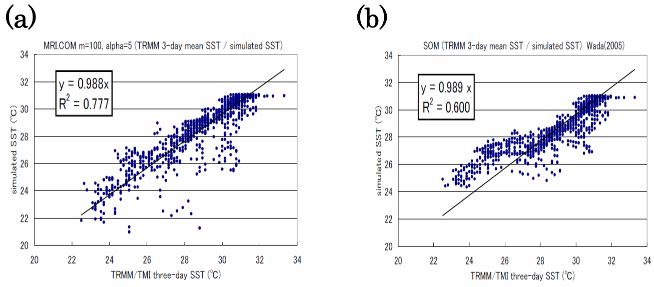


Fig.1 Horizontal distribution of simulated sea temperature at a depth of 0.5 m (contours), oceanic currents (vectors), center position of Rex (typhoon symbols), and observational points by R/V Keifu-Maru.

In contrast, local SSC was significantly produced around the center of Rex in a slow translation. Around the center, divergence was produced by Rex-induced currents. This reveals that upwelling was dominant around the area. The upwelling causes the increase in local SSC by Rex.

3-2. Relationship between TRMM/TMI three-day-mean SST and simulated SSTs

From the result of numerical simulation in MRI.COM, the relationship between TRMM/TMI three-day mean SST and simulated SSTs at the area with a 6.25° square centered at the Rex's center position (Fig. 2a) was investigated. The regression coefficient was nearly 0.99 and correlation coefficient was nearly 0.68. The high coefficients indicated that MRI.COM could properly reproduce SST. Figure 2b depicts the relationship between TRMM/TMI three-day mean SST and simulated SSTs in SOM at the same area. The positive bias of simulated SST was more obvious than the result in Fig. 2a. Figure 2c depicts the relationship between TRMM/TMI three-day mean SST and simulated SSTs in SOM with modified entrainment scheme (MSOM) at the same area. Both regression and correlation coefficients in MSOM were higher than those in SOM.



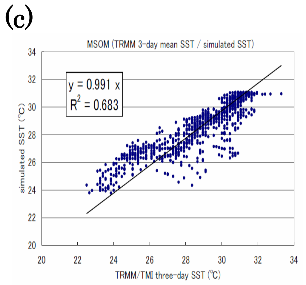


Fig.2 Relationship between TRMM/TMI three-day mean SST and simulated SSTs, (a) in MRI.COM, (b) in SOM with the original entrainment scheme, (c) in SOM with the modified entrainment scheme (MSOM).

3-3. Simulations of rapid SST decrease observed by R/V Keifu-Maru

Figure 3 depicts the time series of observed SST by R/V Keifu-Maru and simulated SSTs in each of ocean models: MRI.COM (Fig. 3a), SOM (Fig. 3a and 3b), and MSOM (Fig. 3b). Rapid decrease in SST, observed by R/V Keifu-Maru, was successfully simulated in MRI.COM, while the amplitude of decrease in SST in SOM was smaller than observational decrease in SST about 3℃, which was in contrast to the result of Wada (2005). The relatively low amplitude of SST decrease was partly because atmospheric forcing used in the present investigation was different from that in Wada (2005). The MSOM could successfully simulate the rapid decrease in SST.

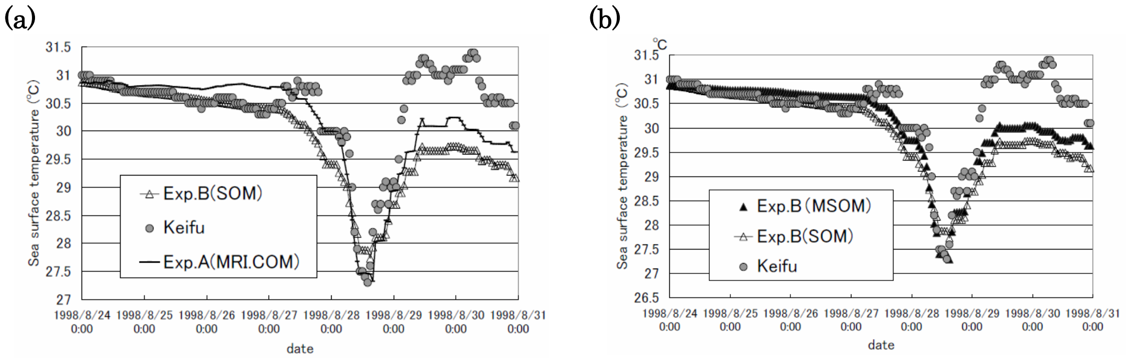


Fig.3 Time series of SST observed by R/V Keifu-Maru and simulated SST at the same locations. (a) Observed SST and simulated SSTs in MRI.COM and SOM with the original entrainment scheme. (b) Observed SST and simulated SSTs in SOM and MSOM.

References

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