Improvement of wind induced mixing and entrainment in MRI mixed layer model

Akiyoshi WADA
Meteorological Research Institute, Tsukuba, Ibaraki, Japan

1. Introduction

The interface between the atmosphere and the ocean is known as an active boundary where surface heat fluxes and wind stresses are exchanged. The atmospheric forcing is also responsible for complicated dynamics and thermodynamics in an oceanic mixed layer. These dynamics and thermodynamics are associated with variations of sea surface temperature (SST). On the other hand, SST plays a key role in atmospheric phenomena because turbulent heat fluxes like sensible and latent heat flux are closely related to SST. To develop an atmosphere-ocean coupled model for a short-term forecast such as predictions of tropical cyclones, a mixed layer model, which is an oceanic part of typhoon-ocean coupled model, has been developed at the Meteorological Research Institute (MRI) in Japan Meteorological Agency (JMA). According to Wada (2002), the mixed layer model has turbulent mixing processes such as stabilizing buoyancy fluxes, wind-induced mixing, and vertical shear mixing near the surface in imitation of Price et al. (1986) and entrainment at the bottom of the mixed layer by parameterization of Deardorff (1983). In the present work, both the near-surface process and entrainment parameterization are modified. Observed SSTs by R/V Keifu-Maru are used to validate simulated SSTs by mixed layer model. It is noted that atmospheric forcing to the ocean (wind stresses and heat fluxes) used in the present work are estimated by empirical formulas such as Kondo (1975), Reed (1977), and so on.

2. Modification of MRI mixed later model

Two turbulent mixing processes are modified from previous MRI mixed layer model (Wada 2002). One modification is to reconstruct vertical mixing near the surface. Because Stokes drift is dominant near the surface, vertical shear mixing near the surface can be neglected. In contrast, the process of wind-induced mixing is re-programmed over in order that seawater near the surface may be stirred well even under the moderate wind velocity. On the occasion of this modification, SST depth is defined of 1m instead of 2.5m employed by Wada (2002). The other revision is relevant to a part of entrainment processes at the bottom of the mixed layer. According to Deardorff (1983), entrainment rates are determined by combination of the Richardson number of frictional velocity, buoyancy fluxes, and vertical shear. The vertical shear is estimated by equations of motion in MRI mixed layer model. Here, the criterion of the Richardson number related to vertical shear at the bottom of the mixed layer (we call it the gradient Richardson number) is excluded and background Richardson number at the regions where there is extremely small vertical shear at the bottom of the mixed layer is assumed to be 2.5.

3. Experiments and results

By doing these modifications, computed SSTs under less than 5m/s at 3° N,137° E on November 1994 and nearly 10m/s wind velocity at 20° N, 130° E on August 1998 is simulated better than those of previous model. Fig.1 represents the observed SSTs and computed SSTs at 3° N,137° E on November 1994 under the assumption that the gradient Richardson number is uniformly set to 0.83 during the integration. Maritime observed SSTs, sea temperatures below the surface and salinity throughout layers by conductivity, temperature, and depth measurements (CTD) are used as the oceanic initial condition. In this case, observed SSTs by CTD are almost the same as maritime SSTs. The variance and amplitude of diurnal cycling of observed SSTs are properly simulated in computed SSTs under less than 5m/s wind velocity. Solar radiation in the daytime and entrainment at the bottom of the mixed layer at night is significant for SST variations. Fig.2 represents the result of numerical experiment at 20° N,130° E on November 1994. The setting of oceanic initial condition is similar to the preceding procedure although observed SSTs by CTD are nearly 0.4℃ lower than maritime SSTs. However the gradient Richardson number is determined from data of ocean currents every 24 hours by acoustic current meter (ACM)

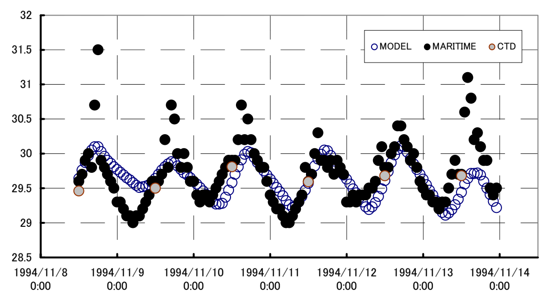

Fig.1 SST variations around 137° E and 3° N under less than 5m/s wind velocity on November, 1994. Close circle represents observed SSTs (●), open circle computed SSTs(○),and gray circle SSTs by conductivity, temperature, and depth measurements (CTD).

*Corresponding author address: Akiyoshi Wada, Meteorological Research Institute, 1-1 Nagamine, Tsukuba, Ibaraki 305-0052 Japan: email: awada@mri-jma.go.jp

equipped with R/V Keifu-Maru. The processes of wind-induced mixing and entrainment are effective for SST variations at night and suppressing the amplitude of diurnal cycling in the daytime

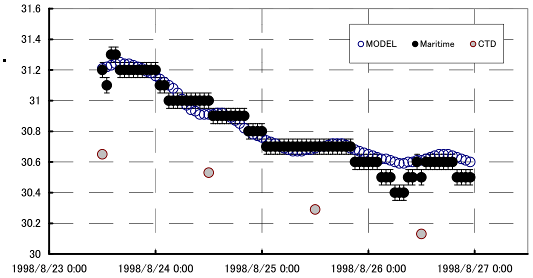

Fig.2 SST variations around 130° E and 20° N under less than 5m/s wind velocity on November, 1994. Close circle represents observed SSTs (●), open circle computed SSTs(○),and gray circle SSTs by conductivity, temperature, and depth measurements (CTD).

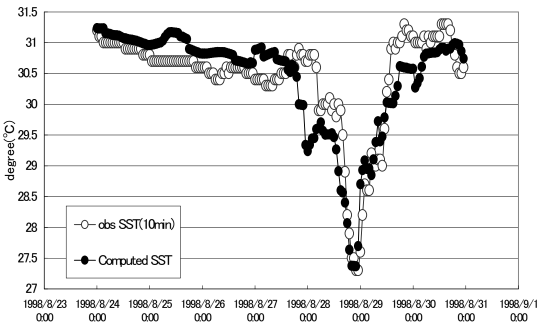

Fig. 3 Time series of maritime observed SSTs (○:open circle) and computed SSTs by upgraded mixed layer model (■:Close square) during August 24, 1998 to August 31, 1998

Observed SST cooling after the passage of Typhoon REX, which is nearly 3℃ decrease at 22JST in August 28 1998, is well simulated in comparison with the result of the previous report by Wada (2002) (Fig.3). The numerical experiments are conducted with global analysis data every 6 hours in JMA and Rankin vortex based on JMA best track maximum wind velocity corresponded to 10-minute average, not on Joint Typhoon Warning Center best track maximum wind velocity corresponded to 1-minute average. TRMM/TMI SSTs and climatological sea temperatures below the surface and salinity throughout layers are used as the oceanic initial condition. The result shown in Fig.3 suggests that maximum wind velocity averaged in 10-minute is appropriate for simulating SST variations. Even in this case, entrainment by the gradient Richardson number is crucial for SST simulation. At that time, the gradient Richardson number by vertical shear at the bottom of the mixed layer is mainly determined from near-inertial currents after the passage of typhoons.

4. Discussion

Under the situation not only strong wind such as typhoons but also moderate or weak wind, we successfully simulate observed SST variations. Through the numerical simulations for SST variations under various wind conditions, we confirm that entrainment by the gradient Richardson number is commonly crucial for SST variations. Two approaches are attempted in setting the gradient Richardson number. As the first approach, SST variations shown in Fig.1 are simulated with the assumption that the gradient Richardson number is assumed to be uniformly 0.83. In contrast, as the second approach, SST variations shown in Fig.3 are simulated using the gradient Richardson number determined by 3-dimensional mixed layer model. Both approaches cannot help but be skeptical about the accuracy of the gradient Richardson number. In fact, the gradient Richardson number by vertical current shear includes near-inertial and geostrophic components. In the region around 137° E and 3° N, Equatorial Counter current may be dominant for vertical shear at the bottom of the mixed layer because in the first experiment, wind-induced currents are considered to be weak under less than 5m/s wind velocity. In contrast, wind-induced near-inertial currents are dominant after the passage of Typhoon REX. Under the situation that stationary currents are weak, the atmospheric forcing is important not only for near-inertial currents near the surface but also for vertical shear at the bottom of the mixed layer. If we need the SST variation more accurately, we will need a high-resolution 3-dimensional ocean model to estimate the vertical shear at the bottom of the mixed layer more accurate. Nevertheless this mixed layer model is able to endure in SST simulations over a period of a week.

References

Deardorff, J. W. (1983): A multi-limit layer entrainment formulation. *J. Phys. Oceanogr.,* **13,** 988-1002.

Kondo, J (1975): Air-sea bulk transfer coefficients in diabetic conditions. *Boundary Layer Meteorol.*, **9,** 91-112.

Price, J. F., Weller, R. A., and R. Pinkel (1986): Diurnal cycling: observations and models of the upper ocean response to diurnal heating, cooling, and wind mixing. *J. Geophys. Res.,* **91,** 8411-8427.

Reed, R. K. (1977): On estimating insolation over the ocean. *J. Phys. Oceanogr.,* **7,** 482-485.

Wada, A. (2002): Improvement of SST prediction by diurnal cycling algorithm in the MRI mixed layer ocean model. *CAS/JSC WGNE Research Activities in Atmospheric and Oceanic Modelling.* 08-29