P2.1

A UNIFIED PARAMETERIZATION SCHEME OF MOIST PROCESS IN THE ATMOSPHERIC BOUNDARY LAYER

Akira NODA* and Toshiki IWASAKI
Graduate School of Science, Tohoku University

1 INTRODUCTION

A shallow cloud occurred in subtropics and the atmospheric boundary layer is known to play an important role in the earth's radiation budget. Smallness of the horizontal scale would continue to prevent from an explicit treatment even with the aid of the remarkable progress of the computer resources. Though some studies attempted to parameterize a subgrid-scale condensation using a probability density function (PDF, e.g., Xu and Randall, 1996; Bony and Emanuel, 2001), those seemed to focus on mainly deep convections.

In order to parameterize the shallow cloud adequately, it is indispensable to evaluate not only the production of a subgrid-scale cloud water amount, but stratification which results from a subgrid-scale turbulent mixing

In this study, we develop the shallow cloud parameterization based on a cloud resolving simulation of a low-level cloud in Yamase. Yamase is a local wind taken place in the northern part of Japan, accompanies a north-eastern cold wind with a low-level cloud, and sometimes brings a cold damage.

2 CASE STUDIED

Yamase on 1 July 2003 is one of the typical one. Figure 1 shows a visible image near the northern part of Japan. One can see that the northern to eastern part of Japan is covered with clouds. A near-infrared image at the same time doesnot indicate apparent signal of the presence of the clouds (not shown), yielding that these clouds develop in a low layer. In the northern part of Japan, a cold air blows southwestward from high pressure over the Sea of Okhotsk. This air receives a heat flux from relatively the warm sea surface with capped by an inversion layer accompanied with the high pressure, resulting in developing the low-level cloud.

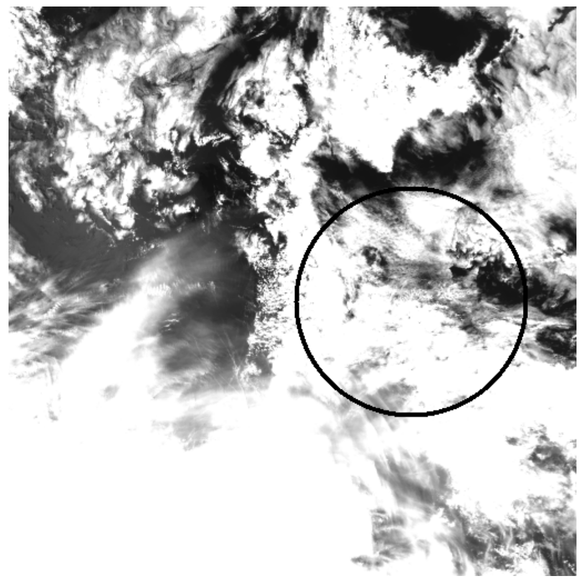

Figure 1: A visible image near the northern part of Japan on 1 July 2003 (courtesy of the Japan Image Database (JAIDAS; http://asiadb.cneas.tohoku.ac.jp/jaidas/)). The shallow cloud accompanied with Yamase is circled.

3 NUMERICAL MODEL

In order to obtain reference data to develop the parameterization of non-uniformity of the low-level cloud, we perform a cloud resolving simulation of a shallow cloud in Yamase under an idealized condition. The 3-dimensional model used in the present study is MRI/NPD-NHM developed by Japan Me-

* *Corresponding author address*:
Akira NODA, Department of Geophysics, Graduate School of Science, Tohoku University, Aramaki, Aoba, Miyagi 980-8578, Japan.
e-mail: noda@wind.geophys.tohoku.ac.jp

teorological Agency (JMA). The vertical resolution varies from 40 m near the sea surface to 100 m near the cloud layer. The horizontal resolution is 100 m for a cloud resolving simulation and 10 km for a low resolution simulation. The calculation domain is 3 km × 3 km horizontally, and 3.6 km vertically. A cyclic condition is used for lateral boundaries. A Rayleigh-type sponge layer with the e-folding time of 60 s is placed above 2.8 km altitude for avoiding the reflection of gravity waves. A Kessler-type warm rain process is considered. A meso-scale objective analysis data provided by JMA is used for initializing the simulation domain. A vertical sounding at 146 longitude and 42 latitude on 12 UTC of 1 July 2003, which corresponds to the windward of the Yamase event, is given for the basic field. The sea surface temperature of 284.3 K is given. The Coriolis force is not included. The atmospheric radiation process is calculated by the broad-band method (Sugi et al., 1990). Only the long wave radiation is taken into consideration, since we shall focus on the low-level cloud in the nighttime. The time integration is performed for 10 hours, and data are stored in the hard disk at every 1 hour for analysis.

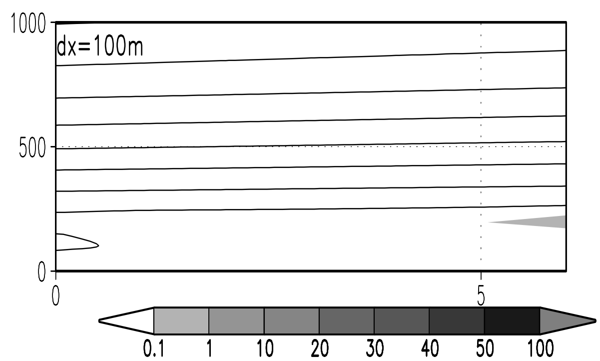

Figure 2: The time-evolution of horizontal-mean potential temperature (contour) and cloud water (shade; g m^{-2}) for the cloud resolving simulation.

4 CLOUD RESOLVING SIMULATION

Figure 2 shows the time-evolution of the potential temperature and cloud water. In the mixing layer, a heat flux causes convections at a horizontal scale of about 500 m, resulting in the evolution of the mixed layer. After 5 hours, the generation of the cloud water begins near the level of 1 km around locally-saturated regions due to penetrative convections. Once the cloud develops, the radiative cooling at the cloud top destabilizes the stratification, which enhancing the condensation.

5 LOW RESOLUTION SIMULATION

In this study, we choose the grid size of 10 km for the low resolution simulation, since it is widely used for operational numerical models. Figure 3 shows the result of the low resolution simulation which performed under the same condition except for the grid size. Comparing with result of the cloud resolving simulation (solid), one can find the delay of the evolution of the mixed layer few production of the cloud water in the low resolution simulation (dashed). These occur because the vertical transports of momentum and heat are not expressed explicitly in the low resolution simulation. We conclude that it is necessary to introduce the parameterization for the subgrid-scale inhomogeneity of the momentum and heat transports and production of the cloud water.

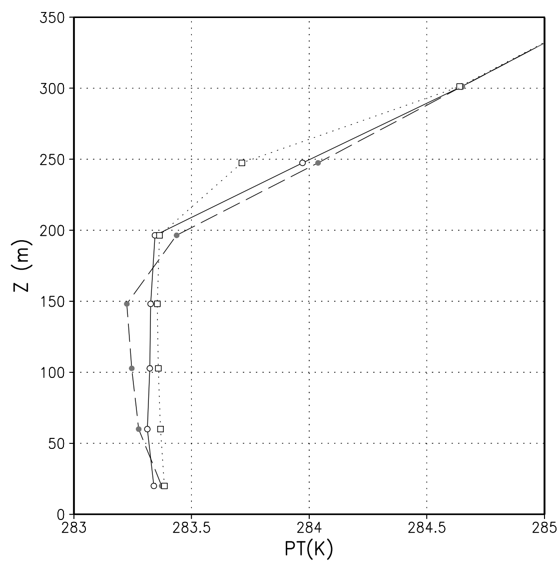

Figure 3: Horizontal-mean potential temperature (contour) and cloud water (shade; g/m^{-2}) at t=3h for (solid) the cloud resolving simulation, (dashed) the low resolution simulation without parameterization, and (dotted) the low resolution simulation with the non-local turbulent mixing length scheme.

5.1 INTRODUCTION OF A NON-LOCAL BOUNDARY LAYER SCHEME

The low resolution simulation cannot express explicitly the vertical transports due to the subgrid-scale plume convections. Some non-local schemes for the boundary layer process have been developed in past studies (e.g., Deardorff, 1970; Nieuwstadt and Tennekes, 1981). We use a modified mixing length scheme described in Kumagai et al. (2003). This scheme determines the top of the mixed layer at which the virtual potential temperature is the same at the lowest grid. The mixing length in the vertical direction is determined using the formulation by Sun and Chang (1986) with the top of the estimated mixed layer. As shown in Fig. 3 (dotted), the non-local mixing length scheme improves the delay of the mixed layer, and succeeds to reproduce the evolution of the stratification as the one appeared in the cloud resolving simulation.

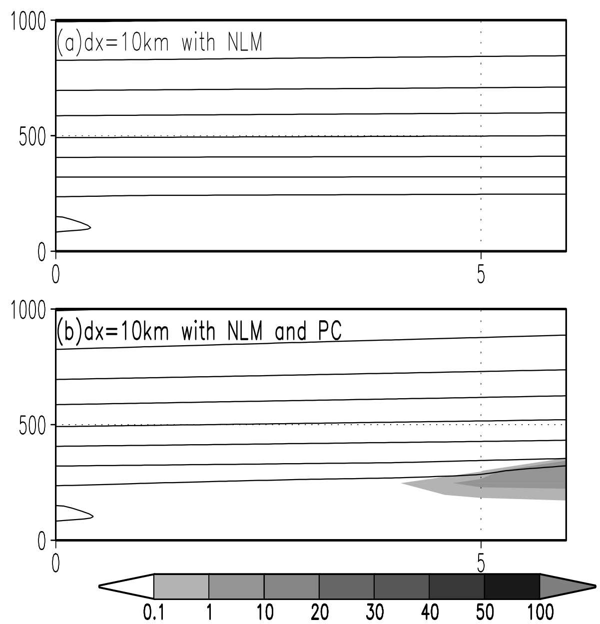

Figure 4: As in Fig. 2, except for the low resolution simulation (a) without and (b) with the partial condensation scheme.

5.2 INTRODUCTION OF A PARTIAL CONDENSATION SCHEME BASED ON A PROBABILITY DENSITY FUNCTION

With development of a convective motion in the subgrid-scale, the cloud water would be generated even if relative humidity at a grid pint is less than unity. We succeed to reproduce the thermodynamic structure by taking the subgrid-scale convection into consideration. In order to reproduce the development of the cloud water, however, we also need to consider inhomogeneity of the moisture. As one of approaches to express inhomogeneity, a PDF is used for the subgrid-scale condensation in past studies (e.g., Sommeria and Deardorff, 1976; Bony and Emanuel, 2001). If neglecting inhomogeneity of q_{vs} for simplicity, one can write the subgrid-scale cloud water amount in the low resolution simulation as:

$$q_c = q_{vs} \int_1^{\infty} (r-1) P(r) dr, \qquad (1)$$

where q_c, q_{vs} and r denote the cloud water mixing ratio, saturation water vapor mixing ratio and humidity $(=(q_c + q_v)/q_{vs})$, respectively.

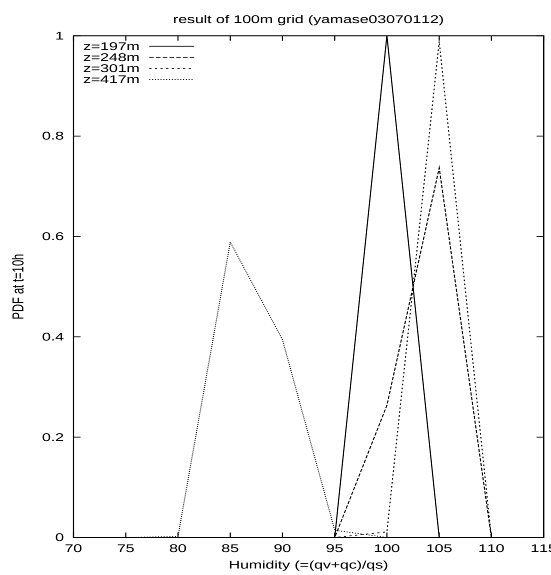

Figure 5: PDFs calculated at various levels in the cloud resolving simulation at t=10h.

Figure 5 shows a PDF drawn for four altitudes after 10 hours. The figure indicates that a triangular-shaped PDF seems to be a good approximation in this case. Figure 6 presents a relation between r and a standard deviation (STD) of r (times $\sqrt{6}$, which is a ratio of the STD to the base of the triangle) for the cloud resolving simulation. The figure shows that the $\sqrt{6}$ STD of about 0.05

% seems to be suitable in this situation. Figure 4(b) presents the result of the low resolution simulation with the partial condensation scheme based on the above analysis. Comparing with the result without the partial condensation scheme (Fig. 4a), the scheme improve the generation process of the cloud water, and results in beginning the condensation after 5 hours, which is nearly the same in the cloud resolving simulation (Fig. 2).

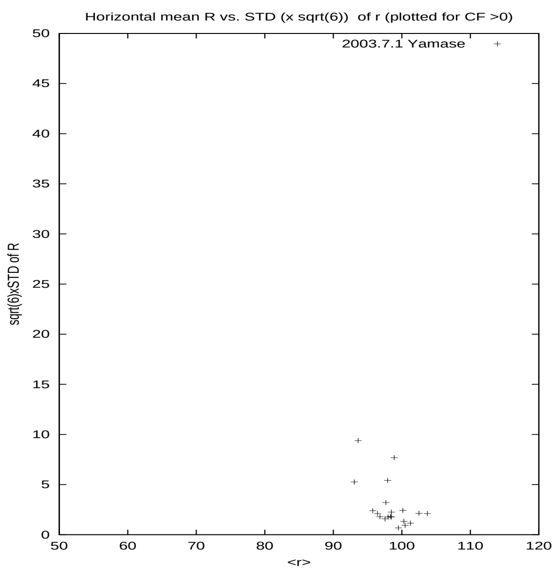

Figure 6: A scatter diagram of $\sqrt{6}\times$ STD of r vs. horizontal mean r in the cloud resolving simulation. A point indicates the one calculated in a horizontal section at every time and height. Only the altitudes at which cloud water is greater than zero are drawn.

6 SUMMARY AND CONCLUSIONS

We have been developing a shallow cloud parameterization scheme based on a cloud resolving simulation. In order to parameterize the shallow cloud, the two processes are necessary to parameterize: One is the vertical transport of momentum and heat, and the other is a partial condensation for inhomogeneity in the subgrid-scale. Though the parameterization scheme seems to work well in the low resolution simulation, further improvement is needed. For example, the shape of the PDF and its STD would be carefully determined with variation of atmospheric states such as stability and so on.

We have also been carrying out a low-resolved numerical experiment the Yamase event using the real atmosphere. Further verification of the parameterization scheme will be shown in the future.

ACKNOWLEDGEMENT

The present study was performed through Research Revolution 2002 (PR2002) of Project for Sustainable Coexistence of Human, Nature and the Earth (FY2002) of the MEXT of the Japanese Government.

REFERENCES

Bony, S., and K. A. Emanuel, 2001: A parameterization of the cloudiness associated with cumulus convection; Evaluation using TOGA COARE data. *J. Atmos. Sci.*, **58**, 3158–3183.

Deardorff, J. W., 1966: The counter-gradient heat flux in the lower atmosphere and in the laboratory. *J. Atmos. Sci.*, **23**, 503–506.

Emanuel, K., 1991: A scheme for representing cumulus convection in large-scale models. *J. Atmos. Sci.*, **48**, 2313–2335.

Kumagai, Y., K. Saito, M. Yoshida, and H. Niino, 2003: Improvement of the land surface processes of the non-hydrostatic model at JMA, Fifth International SRNWP-Workshop on Non-Hydrostatic Modeling, Bad Orb, Germany, 27–29 October 2003.

Nieuwstadt, F. T., and Tennekes, H., 1981: A rate equation for the nocturnal boundary-layer height. *J. Atmos. Sci.*, **38**, 1418–1429.

Sommeria, G., and J. W. Deardorff, 1976: Subgrid-scale condensation in models of nonprecipitating clouds. *J. Atmos. Sci.*, **34**, 344–355.

Sugi, M., K. Kuma, K. Tada, K. Tamiya, N. Hasegawa, T. Iwasaki, S. Yamada, and T. Kitade, 1990: Description and performance of the JMA operational global spectral model (JMA-GSM88). Geophys.Mag., **43**, 105–130.

Sun, W. -Y., and C. -Z. Chang, 1986: Diffusion model for a convective layer. Part I: Numerical simulation of convective boundary layer. *J. Climate Appl. Meteor.*, **25**, 1445–1453.

Xu, K., -M., and D. A. Randall, 1996: Evaluation of statistically based cloudiness parameterizations used in climate models. *J. Atmos. Sci.*, **53**, 3103–3119.