The Enhancement of Condensation in Melting Layer Simulated by Cloud Resolving Non-hydrostatic Model

Akihiro HASHIMOTO[1], Masataka MURAKAMI[2], Chiashi MUROI[2], Sachie KANADA[1], Yasutaka WAKAZUKI[1], Kazuaki YASUNAGA[1], Teruyuki KATO[2], Kazuo KURIHARA[2], Masanori YOSHIZAKI[2]

[1]*Advanced Earth Science and Technology Organization, Tokyo*
[2]*Meteorological Research Institute / Japan Meteorological Agency, Tsukuba*

1. Introduction

In order to examine the change of precipitation intensity around Japan under the situation of global warming and to contribute IPCC, we have conducted numerical simulations with the regional climate model with 5-km horizontal resolution which has been developed on the basis of JMA-NHM (Japan Meteorological Agency Non-Hydrostatic Model; Saito et al., 2001). In those numerical simulations, the condensation growth of cloud droplets was found to be enhanced in melting layer so that the heating by condensation exceeded the cooling due to the melting of snow particles in the layer. We are investigating how this enhancement of condensation occurred in the numerical experiments in order to ascertain whether this phenomenon can be realized in nature or not. A sensitivity test was done for this purpose and its result is reported here.

2. Numerical experiments

The microphysical processes in JMA-NHM are formulated with a bulk parameterization composed of three solid (ice, snow, graupel) and two liquid (cloud, rain) water categories. All of the categories are represented by a two-moment parameterization which has two prognostic variables, mixing ratio and number concentration in each category. The condensation growth of cloud droplets is formulated with saturation adjustment method. For the melting rate of snow and graupel particles, the heat budget relevant to melting and evaporation is considered.

When we conducted the simulations to contribute to IPCC, the model domain was set to cover the area of 4000x3000 km^2 over East Asia with 5-km horizontal resolution. However, we set the smaller domain with the area of 1500x1500 km^2 centered at west Japan shown in Fig. 1 to save a computational resource, when we conduct a sensitivity test in order to investigate the processes which cause the enhancement of condensation in melting layer. Vertically, 48 layers with variable intervals of 40 m to 960 m were employed. The model top is located at about 22 km. Integrated time interval is 12 s. The integration is conducted up to 24 hours. We referred the result of the global warming simulation with global climate model along the IPCC's A1B scenario as the initial and boundary conditions. For the sensitivity test, we conducted two simulations; one considered the cooling resulted by melting of snow and graupel particles (EXP1) and another neglected (EXP2).

*Corresponding author address: Akihiro Hashimoto, Meteorological Research Institute, 1-1 Nagamine, Tsukuba, Ibaraki 305-0052 Japan: e-mail: ahashimo@mri-jma.go.jp

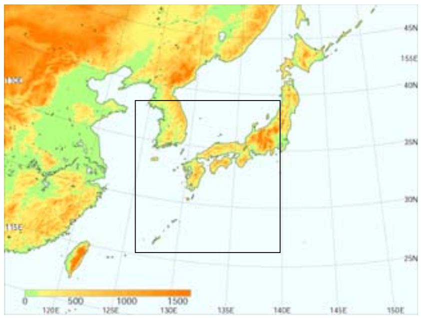

Fig. 1 The simulation domain with the area of 4000x3000 km^2 for the IPCC contribution. The inside rectangle corresponds to the domain with the area of 1500x1500 km^2 adopted in the sensitivity test.

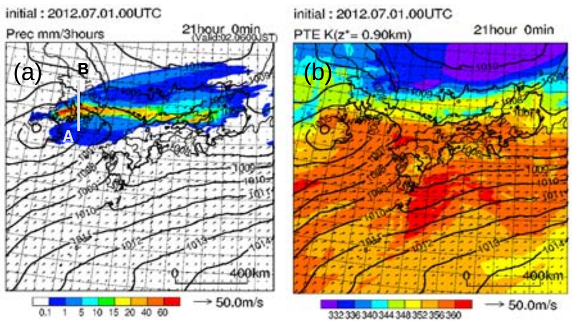

Fig. 2 (a) Precipitation (color) and wind (vector) at the surface. (b) Equivalent potential temperature (color) and wind (vector) at 900 m. Contour indicates sea level pressure.

3. Simulation results

Figure 2a shows the precipitation distribution for the particular case simulated under the global warming situation. An intense precipitation band extends from Korean peninsula to the coast of west Japan. The difference of equivalent potential temperature θ_e is more than 20 K for 200-km distance crossing the precipitation band (Fig. 2b), which indicates that the air with high θ_e from south comes upon the air with low θ_e and is lifted so as to generate convective system.

Figure 3 shows the diabatic moistening rate in the vertical cross section along the line A-B in Fig. 2a. In the EXP1, the region of large negative value of diabatic moistening rate distributes horizontally just under the freezing level, while, in the EXP2, this feature is not found. The negative value of diabatic moistening rate means condensation of water vapor onto cloud droplets. In Fig. 4, the diabatic heating rate in EXP1 which includes both heating and cooling effects due to condensation and melting shows large positive value in the region corresponding to that of large negative value of diabatic moistening rate in Fig. 3a. Figs. 3 and 4 indicate that condensation growth of cloud droplets is enhanced in the melting layer by the effect of the cooling due to the melting of snow and graupel particles so that, however, the heating due to condensation dose not just offset the cooling due to melting, but exceeds it. This means that, in the numerical simulation, the other mechanism than the cooling due to melting should exist to enhance the condensation in melting layer.

4. Discussion and summary

When water saturation has been achieved, the cooling of air due to any processes immediately produces super-saturation to result in condensation. Sub-grid eddy diffusion process also can produce super-saturation, because this process tends to modify the temperature and water vapor profiles to be linear ones while saturated water vapor amount is a non-linear function of temperature. Fig. 5a shows that turbulent kinetic energy (TKE) is distributed where corresponds to the region of the enhancement of condensation. This means that the sub-grid eddy diffusion is effective in the melting layer.

The stability of the air has an important role to produce and maintain the TKE in melting layer. The air tends to become unstable between the cooled layer due to melting and the layer below it. Fig. 5b shows the value of buoyancy term in TKE equation. There is a thin layer which indicates small positive buoyancy or neutral state at about 5-km height in cloud system. In this layer, TKE is enhanced by shear and maintained by the non-negative buoyancy.

Above discussion reveals that the sub-grid eddy diffusion as well as the cooling due to the melting of snow and graupel particles plays a main role to enhance the condensation growth of cloud droplets in the melting layer in our numerical simulation. The simulation result is supposed to be dependant to the grid size and the mixing length in the formulation of sub-grid eddy diffusion, because we applied the parameterization of Klemp and Wilehelmson (1978) and Deardorff (1980). We plan for the further investigation into the sensitivities to grid size and mixing length.

Acknowledgements

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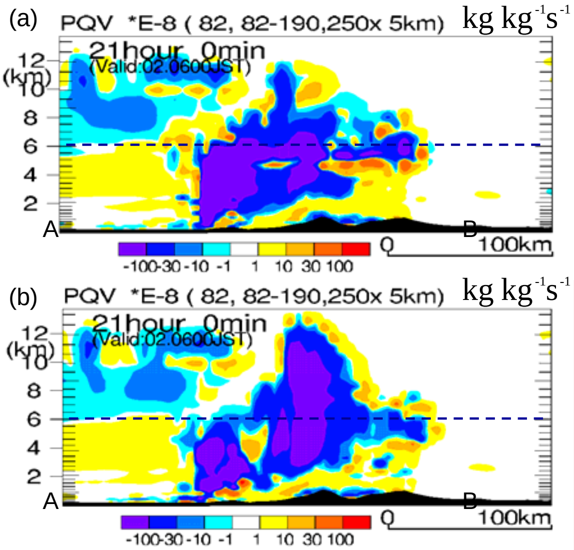

Fig. 3 Diabatic moistening rate in the vertical cross section along the line A-B in Fig. 2a. (a) and (b) correspond to EXP1 and EXP2, respectively. Broken line in each panel indicates the freezing level.

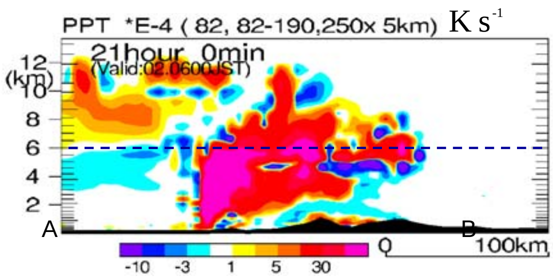

Fig. 4 Same as Fig. 3, but for diabatic heating rate in EXP1.

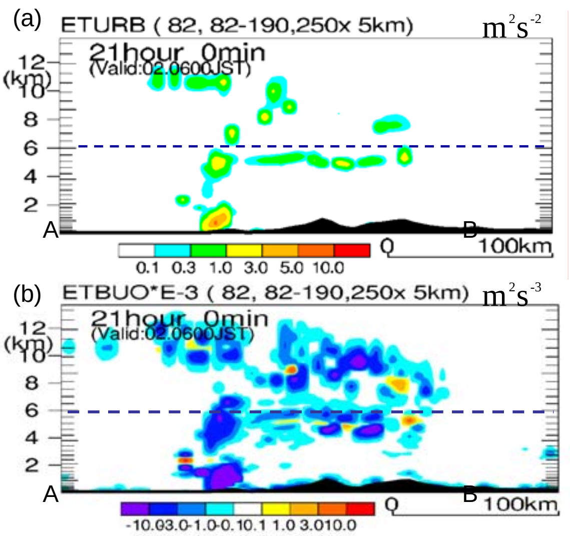

Fig. 5 Same as Fig. 3, but for (a) turbulent kinetic energy (TKE) and (b) buoyancy term in TKE equation in EXP1.