Numerical simulation of shallow cloud formation in the United Arab Emirates

Akihiro Hashimoto[1], Narihiro Orikasa[1], Takuya Tajiri[1], Yuji Zaizen[1], and Masataka Murakami[2,1]

[1]*Meteorological Research Institute, Japan Meteorological Agency, Tsukuba, Japan*
[2]*Institute for Space-Earth Environmental Research, Nagoya University, Nagoya, Japan*

1. Introduction

We conducted ground-based observations to evaluate the frequency of occurrence of seedable clouds (Hashimoto *et al*., 2017a), and airborne seeding experiments to investigate the effects of seeding in clouds (Orikasa *et al*., 2019). This work was undertaken as part of the research project “Advanced Study on Precipitation Enhancement in Arid and Semi-Arid Regions”, funded by the United Arab Emirates (UAE) Research Program (UAEREP) for Rain Enhancement Science. Numerical simulations were performed using a numerical weather prediction model; the objective was to predict the observed clouds for the purposes of model performance evaluation. This report presents preliminary results of the numerical simulations.

2. Numerical simulation

Numerical simulations were performed using the Japan Meteorological Agency Non-Hydrostatic Model (JMA-NHM, Saito *et al*., 2006) with modifications, mainly related to land-surface configuration, as described by Hashimoto *et al*. (2017b). Initial simulations used a 5-km horizontal resolution (5km-NHM); these were followed by simulations with a 1-km horizontal resolution (1km-NHM), as described by Hashimoto *et al*. (2017a). Additional simulations were performed with a 200-m horizontal resolution (200m-NHM) to reproduce fine-scale cloud convection in the area targeted for seeding experiments.

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

3. Results

The calculated air temperature time series (1km-NHM) were compared to an observed air temperature time series collected at Al Ain international airport (Fig. 2a,b). Diurnal air temperature variations were observed that extended from the surface of the

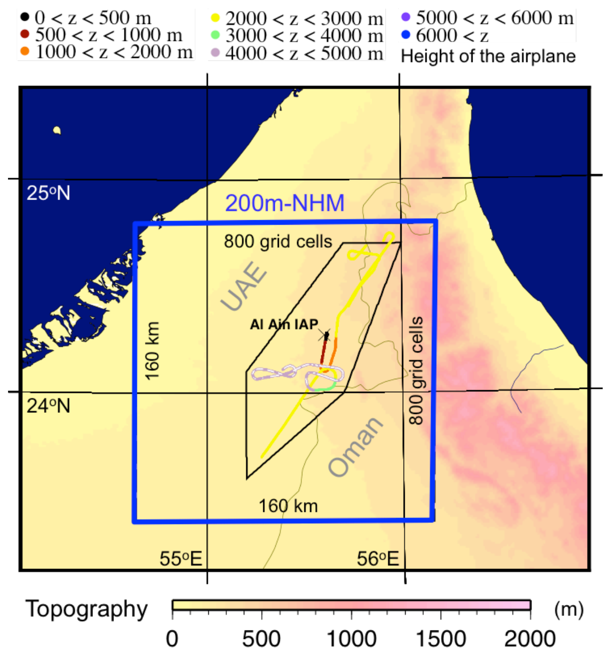

Fig. 1. Computational domain for the 200m-NHM (blue line). Colored dots show the flight path and the height of airplanes.

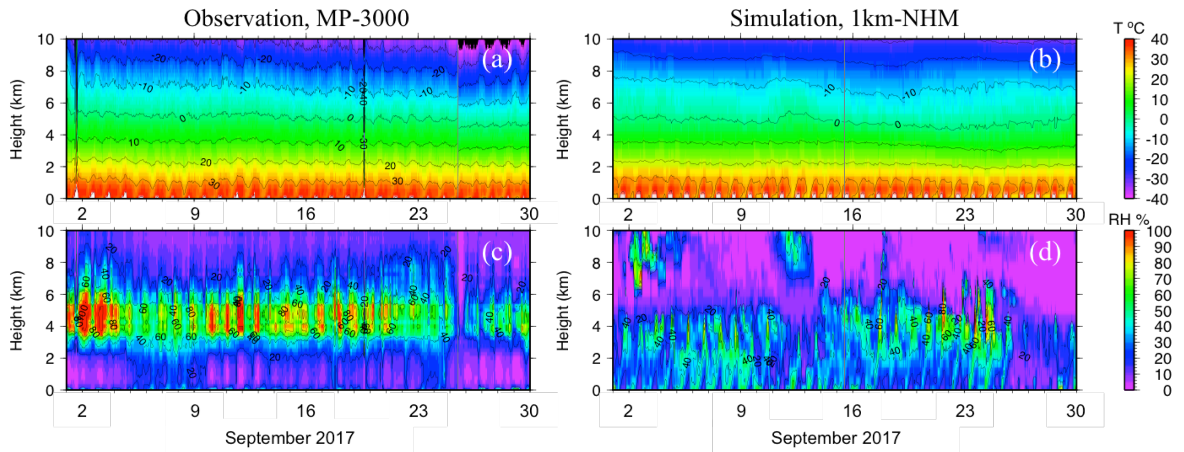

Fig. 2. Time series vertical profiles for September 2017. (a) observed air temperature; (b) simulated air temperature; (c) observed relative humidity; (d) simulated relative humidity. Observations were performed using a multi-wavelength microwave radiometer (MP-3000, Radiometrics) at Al Ain international airport. Simulation results are from the 1km-NHM.

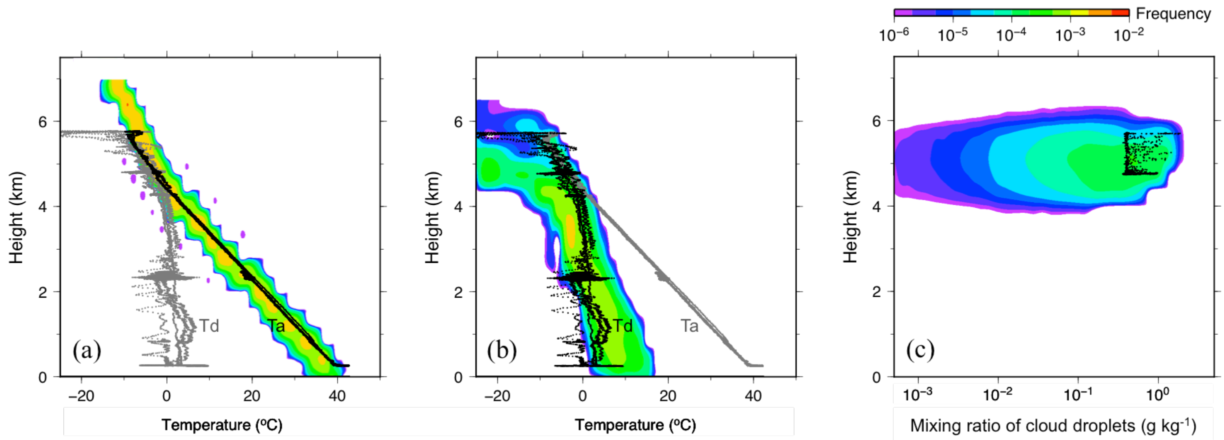

Fig. 3 Frequency of occurrence of simulated: (a) air temperature (Ta); (b) dew point temperature (Td); and (c) mixing ratio of cloud droplets on 21 September 2017. Color indicates the frequency of occurrence. The results were evaluated within the area enclosed by the solid black line in Fig. 1. Black or grey dots show the observed data. Simulation results are from the 200m-NHM.

Earth to 5 or 6 km height. The calculated and observed amplitudes of diurnal air temperature variations matched well at heights of less than 2 km above the Earth's surface, but the calculated amplitude was smaller than the observed amplitude for the middle troposphere. The relative humidity was overestimated in the lower layers of the simulations (Fig. 2c,d). The observed relative humidity was highest at heights between 3 and 6-km height throughout the period of observation. This feature is not clearly seen in the simulations, which is taken to indicate that the thermodynamically-driven circulation in the boundary layer, or turbulent fluxes of heat and moisture at the surface, are not reproduced well by the model. Despite these issues, the maximum predicted relative humidity between the 17th and 22nd September 2017 at around 3-km height agrees well with the observed humidity. A seeding experiment was performed on the 17th, 18th, 20th and 21st September, so it is possible to use predictions on these dates to test the numerical simulations of cloud seeding. We performed control simulations (no-seeding) for these four dates using the 200m-NHM embedded in the 1km-NHM. Preliminary results for the 21st September are presented below.

The observed air temperature, dew point temperature and mixing ratio of cloud droplets were compared to the results of the 200m-NHM simulation (Fig. 3). Black dots show the observed air temperature profile along the airplane flight path shown by colored dots in Fig. 1 (Fig. 3a); the color indicates the frequency of occurrence of simulated air temperature in the area enclosed by the black line in Fig. 1. There is good agreement between the observation and simulation (Fig. 3a). A similar approach was taken for simulation of dew point temperature (Fig. 3b). The simulations successfully predict the observed dry layers below 4.5 km height, and the water vapor saturated layers above 4.5 km height. The highest concentrations of cloud water in the water vapor saturated layer are observed to be of the order of 1 g kg^{-1} (Fig. 3c). The model reproduces this feature successfully. In future work, we will compare the concentration of cloud droplets and other microphysical features in the simulations to the observations (Orikasa *et al*., 2019), and improve the results by adjusting microphysical parameters in the model.

Acknowledgements

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