Numerical prediction experiment over the United Arab Emirates by using JMA-NHM

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1. Introduction

In 2015, the United Arab Emirates (UAE) Research Program (UAEREP) for Rain Enhancement Science was launched in order to promote scientific advancement and development of new technology. Three projects among many proposed projects were awarded the UAEREP prize. The authors are involved in one of these three projects, "Advanced Study on Precipitation Enhancement in Arid and Semi-Arid Regions," which has four subprojects; (1) data analysis for identifying areas suitable for cloud seeding, (2) laboratory experiments for characterization of seeding material, (3) ground-based observation for evaluating the occurrence frequency of seedable clouds and an airborne seeding experiment for investigating seeding effects in clouds, and (4) numerical modeling for realistic simulation of cloud seeding and the seasonal evaluation of seeding effect. As a collaborative work among subprojects, daily numerical weather prediction over the UAE began in late 2016 to support safe and effective experiments of airborne cloud seeding and to evaluate model performance. This article presents a description of the prediction system and its preliminary results.

2. Numerical prediction system

The numerical prediction system was established based on the Japan Meteorological Agency's Non-Hydrostatic Model (JMA-NHM, Saito *et al.*, 2006) with several modifications, mainly land surface configuration, as described in Hashimoto et al. (2017).

The numerical prediction is conducted twice per day. In each prediction cycle, the simulation with a 5-km horizontal resolution (5km-NHM) is performed first, followed by that with a 1-km horizontal resolution (1km-NHM). Figure 1 shows the computational domain. The 5km-NHM widely, but not completely, covers the Middle East including arid and semi-arid regions in the UAE. The 1km-NHM is embedded in the domain of 5km-NHM. The standard latitude and longitude are at 20.00 ºN and 55.00 ºE, respectively, in the Lambert conformal conic projection. The center of the domain is located at (24.00 ºN, 54.00 ºE) for the 5km-NHM, and at (24.25 ºN, 54.15 ºE) for the 1km-NHM. In the vertical direction, the two simulations are configured identically as follows. The top height of the model domain is 22 km. The vertical grid spacing stretches from 40 m at the surface to 886 m at the top of the domain. Fifty vertical layers are employed in a terrain-following coordinate system.

The initial time of the 5km-NHM forecast is 0400 or 1600 Gulf Standard Time (GST=UTC+4), which corresponds to the forecast time FT = 6 h of the JMA's Global Spectral Model (GSM) forecast with initial times of 2200 or 1000 GST, respectively. The initial time of the 1km-NHM forecast is shifted 12 h later from that of the 5km-NHM forecast. Boundary conditions are provided by the JMA's GSM forecast every 6 h. The 1km-NHM is driven by the hourly meteorological field of the 5km-NHM forecast in the one-way nesting manner. Figure 2 shows the schedule and data flow in the numerical prediction system with the initial time of 0400 GST, for instance. The integration time and time step are 48 h and 12 s for the 5km-NHM, and 27 h and 8 sec for the 1km-NHM, respectively. Hourly output is obtained from each simulation.

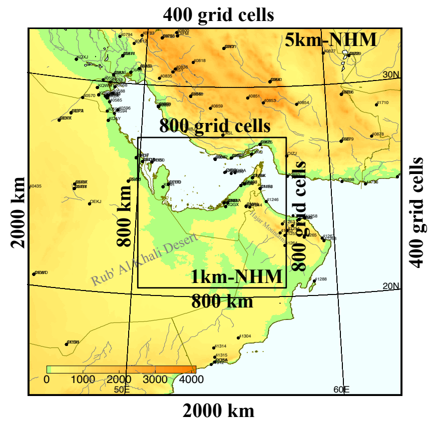

Fig. 1. Computational domain for the numerical prediction.

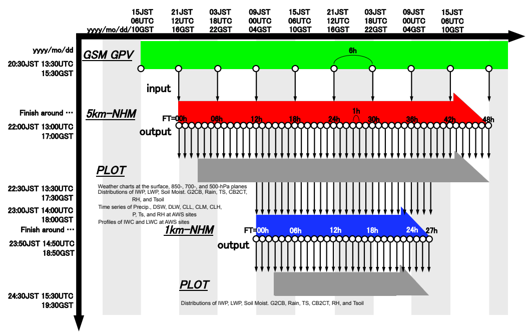

Fig. 2. Schedule for the weather prediction with the initial time of 0400 GST. Fine black arrows indicate the data flow.

3. Computational cost

Computations are conducted on the FUJITSU Supercomputer PRIMEHPC FX100 at the Meteorological Research Institute (MRI) of the JMA. Each job runs with 128 Multi Processor Interface (MPI, 8 MPI x 16 nodes) for the 5km-NHM simulation twice per day, which finishes in about one and a half hours. This costs 17,520 node-hours for year-round simulations (16 nodes x 1.5 h x 2 runs x 365 days). Maximum memory usage is about 10 GB/node. For the 1km-NHM simulation, each job runs with 288 MPI (8 MPI x 36 nodes) twice per day, which also finishes in about one and a half hours. This costs 39,420 node-hours for year-round simulations (36 nodes x 1.5 h x 2 runs x 365 days). Maximum memory usage is about 25 GB/node.

A single run of 5km-NHM requires 20.3 GB of free disk space

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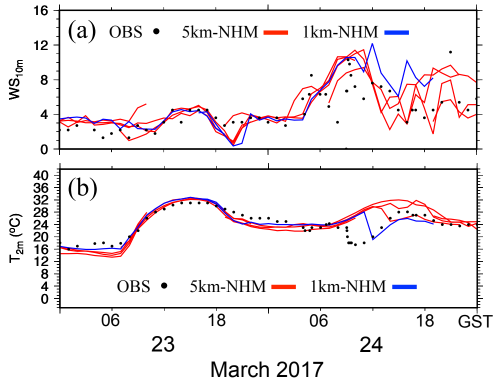

Fig. 3 Observed and predicted results for (a) surface wind speed and (b) surface air temperature at Al Ain International Airport. Black dot indicates the observation. Red and blue lines indicate the 5km- and 1km-NHM predictions, respectively.

for input/output operation. We are archiving two-dimensional data, vertical profiles above observation sites, and plotted graphs for each simulation. The size of the archived data is 1.5 GB/run. This needs the storage space of 949 GB/year. For the 1km-NHM, 84.4 GB/run and 1,678 GB/year are required for running a job and archiving the data, respectively.

4. Result

Figure 3 shows the observed and predicted results for surface wind speed and surface air temperature on 23 and 24 March 2017 at Al Ain International Airport, which will be the base of our airborne cloud seeding experiments planned in the summer of 2017. The 5km- and 1km-NHM predicted well the variation of surface wind speed and air temperature on 23 March. In the morning on 24 March, when a synoptic scale disturbance accompanied with precipitation passed over the observation site, a temperature drop of 6 ºC was observed. This temperature drop was predicted within a delay of a few hours by the 1km-NHM simulation with an initial time of 1200 UTC on 23 March as compared to the actual event. For the 5km-NHM, we have three forecast results available for this temperature drop event with different initial times; 0000, 1200 and 2400 UTC on 23 March. The best result was obtained from the forecast with an initial time of 0000 UTC on 23 March, although the forecast shows a larger delay time and a smaller magnitude of temperature drop than the observation and the 1km-NHM forecast. Figures 4a and 4b show time-height cross-sections of air temperature at Al Ain International Airport observed by multi-wavelength microwave radiometer (MP-3000, Radiometrics) and predicted by the 1km-NHM, respectively. Air temperature below a height of 2-km began to decrease several hours earlier (Fig. 4a) than the surface air temperature drop (Fig. 3b). The predicted temperature decrease at the lower layer preceding the surface air temperature drop (Fig. 4b) was much weaker than the observed decrease (Fig. 4a). K-band Doppler radar (MRR-2, METEK), which was deployed at the same site, detected precipitation during the preceding decrease in low-level air temperature (Fig. 4c), while, in the prediction, the precipitation does not appear until just before the temperature drop (Fig. 4d). This indicates that the cooling of low-level air due to evaporation of precipitation particles was not represented very well in the prediction. To improve the prediction accuracy, it is necessary to consider the predictability of synoptic scale disturbances as well as thermo-dynamical formulations of the prediction system.

5. Summary

A numerical prediction system was established based on the JMA-NHM to support airborne cloud seeding experiments and to evaluate model performance. The procedure of the numerical prediction was described including the computational resources required for performing numerical simulations and for archiving the simulation results. Preliminary results of a comparison between ground-based observation and numerical prediction were presented with respect to the event of surface air temperature drop on 24 March 2017 at Al Ain International Airport. More validation and improvement of the model will be the subject of future study.

Acknowledgement

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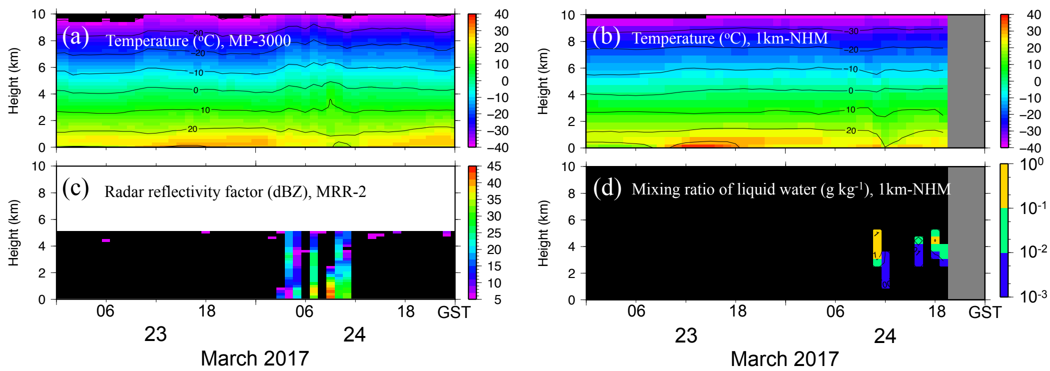

Fig. 4 Time-height cross sections of temperature (a) observed by multi-wavelength microwave radiometer and (b) predicted by the 1km-NHM, (c) reflectivity factor observed by micro-rain radar and (d) mixing ratio of liquid water predicted by the 1km-NHM.