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Numerical Simulation of Heavy Snowfall and the Potential Role of Ice Nuclei in Cloud Formation and Precipitation

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A heavy snowfall event occurred in the Kanto and Koshin regions from 14 to 15 February 2014, when a winter extratropical cyclone rapidly developed along the south coast of Japan. The snow cover exceeded the histrical record in these regions. In order to examine the characteristics of cloud microphysics during the event, we performed a numerical simulation with a horizontal grid spacing 1.5 km and a model domain covering the Kanto and Koshin regions by the JMA Non Hydrostatic Model (JMA-NHM) with bulk-type cloud microphysics. The initial and boundary conditions were provided from 3-hourly JMA mesoscale analyses. The precipitating clouds and atmospheric conditions were simulated for 33 hours from 03 Japan Standard Time (JST) on 14 February 2014.

From the result of high-dense snow cover observations, the total snowfall exceeded 1 m in the areas along the mountains in the Yanamashi, Gunma, and Tochigi prefectures during the event. The numerical simulation successfully reproduced the distribution of total snowfall. By comparing the result of the simulation with the surface observations of automatic weather stations in Tokyo metropolitan, temporal variations of simulated surface atmospheric temperature and relative humidity were consistent. In order to evaluate the reproducibility of cloud microphysics in simulated precipitating clouds, the ground-based microwave radiometer (MWR) operated in the Ome city in Tokyo metropolitan was used in this study. Liquid water path (LWP), which is retrieved from radiometric observations by a statistic inversion method, is compared with simulated LWP during the event. The data including errors due to rain was excluded from the comparison, so that there is large difference between precipitable water vapor (PWV) retrieved by radiometric observations and PWV derived from the global positioning system. As the result, temporal variation of simulated LWP was similar to that of retrieved LWP.

Clouds composed of cloud ice were simulated at the altitude 8-12 and 2-4 km above the Ome city, and the latter cloud was formed on the boundary of a coastal front. Mixing ratio of snow was large below the altitude of 6 km, and number concentration of snow was large at the altitude of 4-10 and 1-3 km. In this case, there were two layers of ice clouds and the heavy snowfall would be increased due to the seeder-feeder effect. Total precipitation by graupel reached 30 mm in some parts of the Kanto region, which was formed by riming process during the passage of the extratropical cyclone in the Kanto plain, where sufficient water vapor flux and super-cooled cloud water existed in low-level troposphere.

In order to investigate the effect of ice nuclei on snowfall, sensitivity experiments were performed by changing coefficients of 0.1 (IN01) and 10 (IN10) times in the formulas of ice nucleation (Meyers 1992) and freezing (Bigg 1955) in JMA-NHM. As the result, there were differences of total precipitation by snow of -5 mm in IN01 and +2-+5 mm in IN10 from the control experiment in the areas with large amount of total snowfall. This difference would be caused by the change of snow due to the change of ice number concentration where there was sufficient water vapor flux below the altitude about 5 km. The total precipitation by rain increased more than 15 mm in IN01, and also decreased less than 20 mm in IN10 in the Kanto plain. On the other hand, total precipitation by graupel decreased about 5 mm in IN01 and increased over 10 mm in IN10 in the areas including the Tokyo metropolitan and Saitama prefecture. Since there were sufficient middle-level snow, low-level water vapor flux, and super-cooled cloud water in the windward side of these regions, snow falling from the upper ice cloud was converted to graupel in the low troposphere in IN10. These results suggest that there are uncertainties related to the aerosol indirect effects in cloud microphysics modeling of bulk method in JMA-NHM.

Keywords: heavy snowfall, numerical simulation, cloud microphysics, ice nuclei