Numerical Simulation of Potential Impact of Aerosols on Heavy Snowfall Events Associated with Japan-Sea Polar-Airmass Convergence Zone

Kentaro Araki[1]

1: Meteorological Research Institute, Tsukuba, Ibaraki, Japan

e-mail: araki@mri-jma.go.jp

1. Introduction

Aerosols play a key role not only in the earth climate, but also in short-term precipitation phenomena, working as cloud condensation nuclei (CCNs) and ice nuclei (INs). Although recent studies have suggested aerosol indirect effects on convective clouds and mesoscale convective systems such as invigoration process by CCNs, uncertainties still remain especially in the aerosol properties of INs and their effects on cloud and precipitation systems (Araki and Sato, 2018). For the heavy snowfall events in the Pacific regions in Japan, it is indicated that the aerosol indirect effect by INs considerably affected snowfall amounts and distribution (Araki and Murakami, 2015; Araki, 2016). On the other hand, it is known that the Japan-sea Polar-airmass Convergence Zone (JPCZ) sometimes brings extreme heavy snowfall in the areas on the Japan Sea side compared with the areas in the Pacific side in winter. In this study, we investigated the potential impacts of aerosol indirect effects by CCNs and INs on the forecast for the heavy snowfall events in the areas in the Japan Sea side associated with the JPCZ.

2. Model settings of sensitivity experiments

Numerical simulations were performed by the Japan Meteorological Agency (JMA) Non-Hydrostatic Model (NHM) with a domain of 2,400x2,000 km covering Japan and a horizontal grid spacing of 2 km. The initial and boundary conditions were provided from the 6-hourly JRA-55 reanalysis data and the models were run from 00 UTC on 3 to 00 UTC on 8 February 2018. A convection parameterization scheme was not used and a bulk cloud microphysics scheme with 2-moment cloud water, cloud ice, snow, and graupel was used in a control run (CNTL). As sensitivity experiments on CCNs, experiments with changing a coefficient of number concentration of cloud droplets in the formula of cloud condensation nucleation by factors of 0.1 (CN01) and 10 (CN10) were performed. Focusing on the aerosol indirect effect by INs, we also performed experiments with changing coefficients in the formulas of deposition/condensation-freezing-mode ice nucleation (Meyers, 1992) and immersion-freezing-mode ice nucleation (Bigg, 1955) by factors of 0.1 (IN01) and 10 (IN10). In addition, combining these settings, we conducted two sensitivity experiments assuming clean (CIN01) and dirty (CIN10) environments. The other setups in each experiment were the same as those used in Saito et al. (2006).

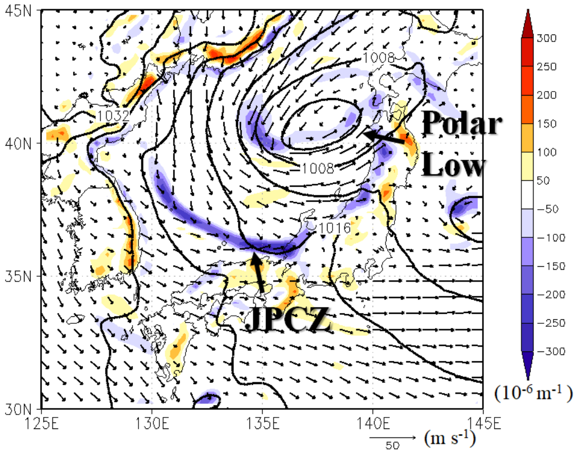

Figure 1. Environmental conditions at 00 UTC on 7 February 2018 obtained from the JMA global analysis. Horizontal distributions of horizontal divergence at 950 hPa (shaded) and sea level pressure (contour).

3. Potential effect of CCNs and INs on a heavy snowfall event associated with the JPCZ

From 3 to 7 February 2018, a polar low had maintained over the Japan Sea under the unstable atmospheric conditions with upper cold air flow (Fig. 1). The JPCZ clearly formed on 4, and had been sustained until 7 February. Convective clouds associated with the JPCZ brought heavy snowfall in the areas in the Japan Sea side, the total snowfall and precipitation amounts in Fukui respectively reached 143 cm and 169.5 mm from 00 UTC on 3 to 00 UTC on 8 February.

The radar analysis, results of simulated precipitation in CNTL, and the differences from CNTL for each experiment are shown in Fig. 2. From the comparison with radar analysis, the CNTL successfully reproduced heavy snowfall associated with the JPCZ in the land areas including Fukui. In the sensitivity experiments, there were the differences of snowfall areas with precipitation amount of 10–20 mm from CNTL because of the differences of the representations for the location of convective clouds. Although the CN01 and CN10 had the similar difference from the CNTL, there were significant differences with respect to the precipitation amounts (intensity) in the other experiments. From the results that the differences of precipitation amount over the Japan Sea from the CNTL for IN01, IN10, CIN01, and CIN10 were larger than those for CN01 and CN10, it was suggested that the INs were highly sensitive to the formation and development of convective clouds associated with the JPCZ. Table 1 shows the maximum, minimum, and averaged differences of precipitation amounts from the CNTL for each experiment in the heavy snowfall areas including Fukui. The absolute values of maximum and minimum differences for IN01, IN10, CIN01, and CIN10 were about 1.5 to 2 times those for CN01 and CN10. It was also found that precipitation amount increased in the heavy snowfall areas including Fukui in IN10 and CIN10 compared with the CNTL, and opposite features were found in IN01 and CIN01. There were the same characteristics of precipitation amount for all domains of the simulation.

From these results, it is indicated that the quantitative forecast of precipitation amount is sensitive to the aerosol effect by CCNs and INs, and that the effect of INs would be more significant than that of CCNs in this case. It is desired that the parameterization of CCNs and INs in mesoscale models for the short-term forecast should be improved in the future.

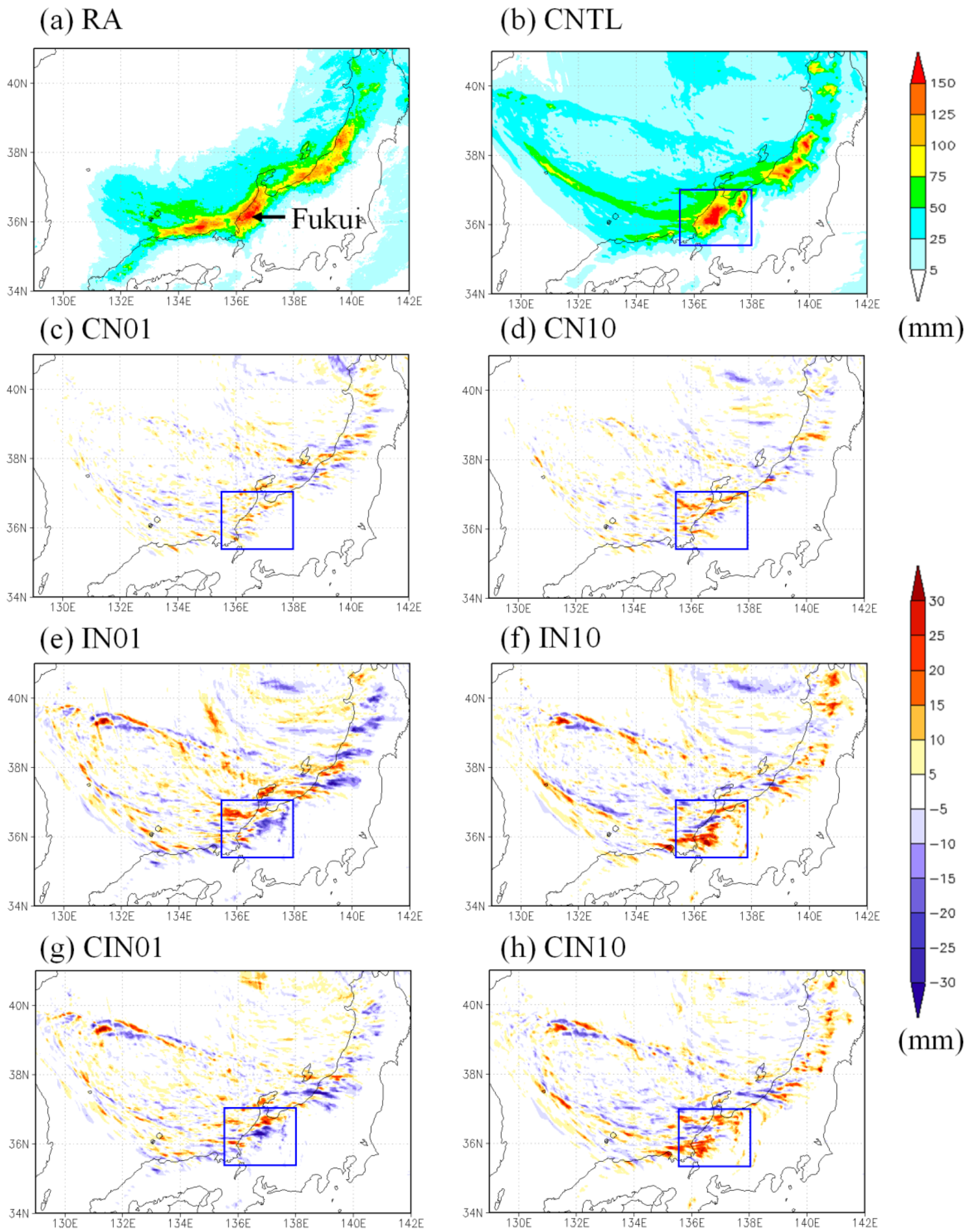

Figure 2. Horizontal distribution of precipitation amounts from 00 UTC on 3 to 00 UTC on 8 February 2018 in (a) radar analysis (RA), (b) CNTL, and (c)-(h) the differences from CNTL for each experiment.

Table 1. Differences of simulated precipitation amounts from 00 UTC on 3 to 00 UTC on 8 February 2018 in each experiment from CNTL. Maximum, minimum, and averaged values (mm) in the area of blue rectangular in Fig. 2 (b)-(h) are shown.

(mm)	CN01	CN10	IN01	IN10	CIN01	CIN10
Max	20.59	26.67	30.50	44.29	33.52	33.40
Min	-20.17	-21.23	-40.09	-32.48	-49.62	-26.40
Ave	0.59	1.68	-1.65	3.01	-1.24	2.81

References:

Araki, K., 2016: Influence of cloud microphysics scheme and ice nuclei on forecasting a heavy snowfall event in Japan associated with the "South-Coast Cyclones". *CAS/JSC WGNE Research Activities in Atmospheric and Oceanic Modelling*, **46**, 4.03–4.04.

Araki, K., and M. Murakami, 2015: Numerical simulation of heavy snowfall and the potential role of ice nuclei in cloud formation and precipitation development. *CAS/JSC WGNE Research Activities in Atmospheric and Oceanic Modelling*, **45**, 4.03–4.04.

Araki, K., and Y. Sato, 2018: Review of numerical simulation studies of aerosol impacts on clouds and precipitation. *Earozoru Kenkyu*, **33**, 152-161.