Sensitivity of Cloud Microphysics Scheme and Ice Nuclei on Forecasting a Heavy Snowfall Event in Japan associated with the "South-Coast Cyclones"

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1. Introduction

In winter seasons, extratropical cyclones moving along the south coast of Japan, so-called "South-Coast Cyclones (SCCs)" in Japan, sometimes bring heavy snowfall in the Kanto plain. Numerical models sometimes fail to forecast the track and intensity of the SCCs, and associated heavy snowfall. Araki and Murakami (2015) investigated an extreme heavy snowfall case on 14–15 February 2014 by numerical simulations, focusing on the aerosol indirect effect by ice nuclei, and noted that the concentration of ice nuclei considerably affect snowfall amounts and distribution. In this study, we investigated the sensitivities of cloud microphysics schemes and aerosol indirect effect by ice nuclei on the development of the SCC and snowfall amounts in the Kanto plain in the heavy snowfall case on 8–9 February 2014.

2. Model settings of sensitivity experiments

Numerical simulations were performed by the Japan Meteorological Agency Non- Hydrostatic Model (NHM; Saito et al. 2006) with a horizontal grid spacing of 5 km and a domain of 3,000×2,750 km covering Japan. The initial and boundary conditions were provided from the 3-hourly JMA mesoscale analysis and the model was run for 72 hours from 21 Japan Standard Time (JST=UTC+9h) on 6 February 2014. In a control run (CNTL), only a bulk cloud microphysics scheme with 2-moment cloud ice, snow, and graupel is used. The other setups were the same as those used in the JMA operational mesoscale model. To estimate the sensitivities of different cloud microphysics schemes, we performed two numerical experiments; one is a bulk cloud microphysics scheme with 2-moment cloud ice and 1-moment snow and graupel (Ice-2m), and the other is that with 1-moment cloud ice, snow, graupel (Ice-1m). Numerical experiment with the same cloud microphysics scheme as CNTL, but additionally using the Kain-Fritsch convection parameterization (KF), was also performed. To examine the aerosol indirect effect by ice nuclei, two sensitivity 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) were performed. To compare magnitudes in sensitivities between initial/boundary conditions and cloud microphysics schemes, we performed numerical experiments with initial and boundary conditions derived from the 6-hourly JMA global analysis (GA) and JRA-55 reanalysis (JRA-55; Kobayashi et al. 2015).

3. Sensitivity on the SCC and accumulated snowfall

Firstly, cyclone tracks from 09 JST on 8 to 21 JST on 9 (integration time from 36 to 72 hours) simulated by each experiments and analyzed by the JMA were compared (Fig. 1). At 09 JST on 8, the centers of the SCC in CNTL and KF were positioned near the center of the analysis. Differences of simulated cyclone tracks from the JMA analysis increased in the east of about 140E (after 15 JST on 8), and the SCC in all experiments traveled south of the analyzed track. The differences of cyclone tracks between each experiment were smaller than those between simulated and analyzed tracks after 15 JST on 8. The temporal variations of sea level pressure (SLP) in the center of the SSC in each experiment were similar to those of the JMA analysis (Fig. 2a). The differences of SLPs in the center of the SCCs in IN01, KF, GA, and JRA-55 from that in CNTL exceeded 2 hPa (Fig. 2b). These results show that some cloud microphysics schemes, convection parameterization, and initial and boundary conditions have comparable uncertainties of the forecasts for the developments of the SCCs.

Secondly, horizontal distributions of precipitation amounts by snow from 21 JST on 7 to 06 JST on 9 in each experiment were compared (Fig. 3). Simulated distribution in CNTL was similar to that of observations by surface stations (Fig. 3a). Compared with CNTL, both Ice-2m and Ice-1m had the following similar difference; accumulated precipitation amounts by snow were generally underestimated except in some areas of the Kanto plain (Fig. 3b, c). This differences were caused by the treatment of number concentration of snow, resulting in less surface snowfall amounts in the schemes with 1-moment snow. The positive difference in KF was found especially on the windward (southern) side of mountainous regions (Fig. 3d), and the similar tendency has been reported in heavy rainfall cases. The results of IN01 and IN10 were similar features of the differences of snowfall from CNTL especially in heavy snow inland areas (Fig. 3e, f). Since the results of IN01 and IN10 were reported to be opposite features in snowfall in another case (Araki and Murakami 2015), it's suggested that the aerosol indirect effect by ice nuclei would be depend on atmospheric conditions such as water vapor supply or temperature even in heavy snowfall cases associated with SCCs. GA and JRA-55 had similar features that were negative and positive differences respectively found in mountainous and plain areas (Fig. 3g, h). In addition, the maximum differences exceeded 20 mm in each experiments.

As the results, it's indicated that cloud microphysics schemes, aerosols indirect effect by ice nuclei, and initial/boundary conditions have similar magnitude of sensitivity on the development of SCCs and associated snowfall in this case. Improvements of not only initial/boundary conditions but also cloud microphysics scheme including the parameterization of ice nuclei are required.

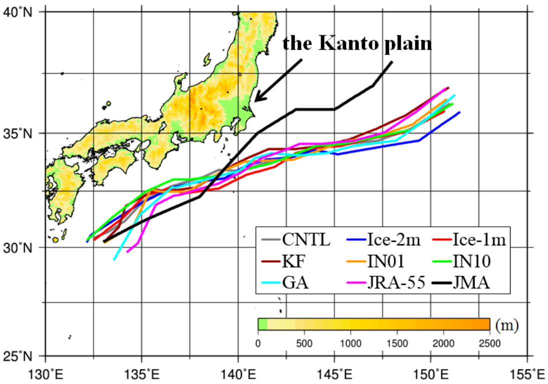

Figure 1. Cyclone tracks in each experiment and the JMA analysis from 09 JST on 8 to 21 JST on 9 February 2014.

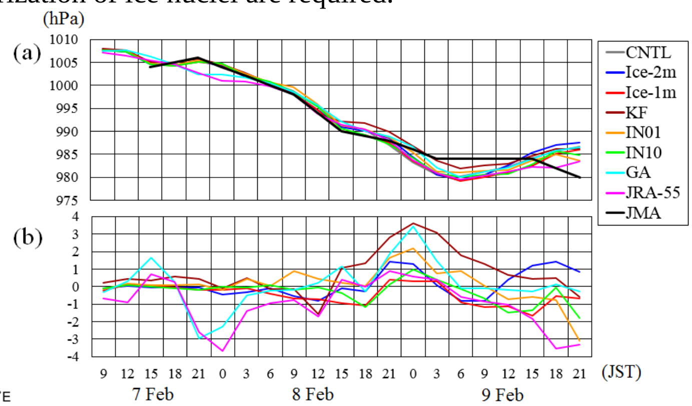

Figure 2. Time series of (a) SLPs in the center of the SCCs and (b) their differences from CNTL.

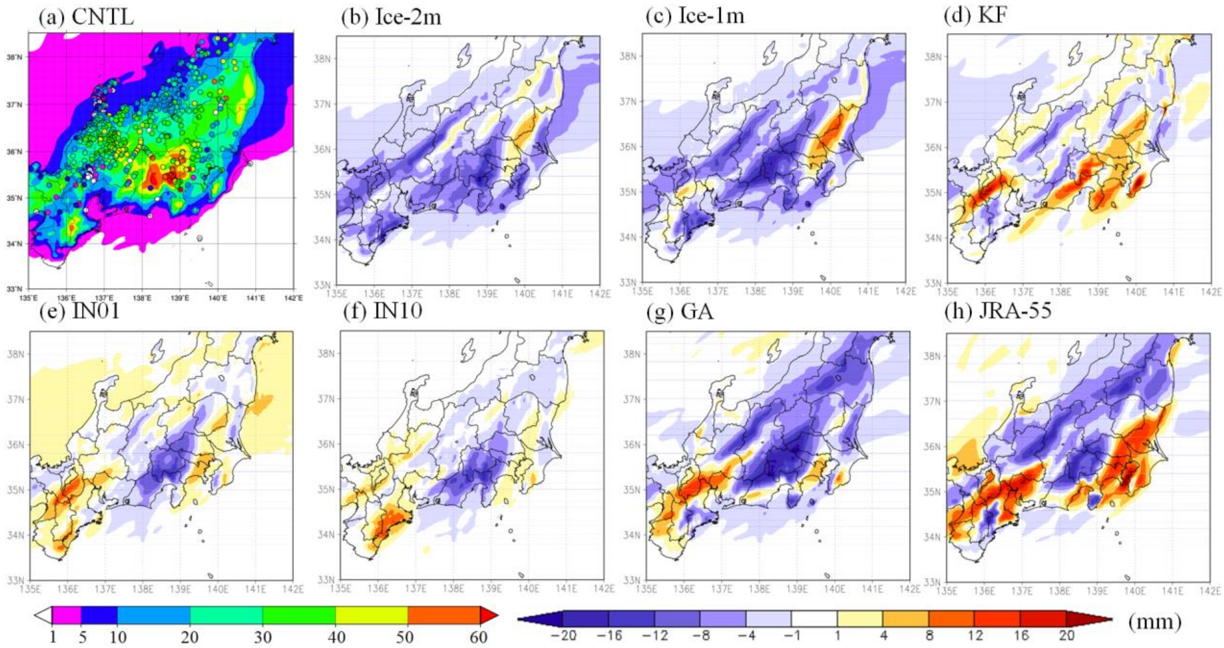

Figure 3. (a) Horizontal distribution of precipitation amounts by snow from 21 JST on 7 to 06 JST on 9 in CNTL, and the differences from CNTL for each experiments. Circles in (a) denote snowfall observations (cm).

References:

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