Numerical Simulation of Potential Impact of Aerosols on Heavy Rainfall Event Associated with Typhoon Hagibis (2019)

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1. Introduction

Typhoon Hagibis (2019) caused heavy rainfall in eastern and northern areas in Japan on 11-13 October 2019. The operational mesoscale model of Japan Meteorological Agency (JMA) successfully forecasted the occurrence of the heavy rainfall events, but a quantitative forecast of rainfall amount remains challenges. It is considered that the supply of a large amount of water vapor associated with Hagibis (2019), the front formed on the north side of the typhoon, and the precipitation enhancement due to the orography were important factors for this heavy rainfall (Araki 2020). Aerosols play a key role in not only the earth climate, but also 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. In this study, we investigated the potential impacts of aerosol indirect effects by CCNs and INs on the forecast for the heavy rainfall event associated with typhoon Hagibis (2019).

2. Model settings of sensitivity experiments

Numerical simulations were performed by the JMA Non-Hydrostatic Model (NHM) with a domain of 2,500 x 2,500 km covering Japan and a horizontal grid spacing of 5 km. The initial and boundary conditions were provided from the 3-hourly JMA mesoscale analysis data and the models were run from 09 JST (JST=UTC+9h) on 11 to 15 JST on 13 October 2019. 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. 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). 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).

3. Potential effect of CCNs and INs on a heavy rainfall associated with Hagibis (2019)

Typhoon Hagibis (2019) moved northward over the south of Japan on 11 October, landed in Japan around 19 JST on 12, and moved toward the northeast. Heavy rainfall in eastern and northern areas in Japan began on 11 October and got significant on the north side of the center of the typhoon. Moreover, the precipitation amount particularly increased in the mountainous areas.

Time series of the Regional Specialized Meteorological Center (RSMC) Tokyo best track (BT) central pressure and simulated central pressures are shown in Fig. 1a. The central pressure of each experiment was lower than that of the best track, but the temporal variations were similar. Comparing the central pressures of the sensitivity experiments and the central pressure of CNTL, the absolute values of the differences were more than 1 hPa for CN01 and CIN01 after 12 JST on 12, but both were less than 2.5 hPa (Fig. 1b). In each experiment, the courses of the typhoon were almost the same as the best track while the typhoon passed over land (Fig. 2), and the landing in Japan was delayed by 2 hours.

The radar analysis (RA), results of simulated precipitation in CNTL, and the differences from CNTL for each experiment are shown in Fig. 3. From the comparison with radar analysis, the CNTL successfully reproduced heavy rainfall associated with the typhoon. In the sensitivity experiments, there were the differences of rainfall areas with precipitation amount over 100 mm from CNTL because of the differences of the representations for the location of precipitating clouds including spiral bands associated with typhoon. From the results of sensitivity study on orography in Araki (2020), in addition to the sustained precipitation associated with the front formed in the north side of the typhoon center, orographic precipitation enhancement through the Seeder-Feeder mechanism was suggested to have been important for the heavy rainfall. Although it was expected that the precipitation would also change as the process of precipitation enhancement through the Seeder-Feeder mechanism was modulated in mountainous areas in sensitivity experiments, the present experimental results suggest that the indirect effect of aerosols may affect the overall precipitation associated with both of the typhoon and front. Table 1 shows the summary of central pressures of typhoon at the longitude of 138.7°E and precipitation amounts for RSMC Tokyo best track (radar analysis) and each experiment. Precipitation amounts averaged in all domain were almost the same for each experiment. A comparison of precipitation amounts in the domain A with a particularly large amount of precipitation shows that the averaged precipitation amount in CNTL is almost the same as in RA, and those of the other experiments are almost the same, albeit a few percent different from the CNTL. On the other hand, maximum precipitation in domain A was less in CNTL than in RA, with absolute differences of more than 10% between CN01, IN01, CIN01 and CIN10 compared to the maximum precipitation amount in CNTL.

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

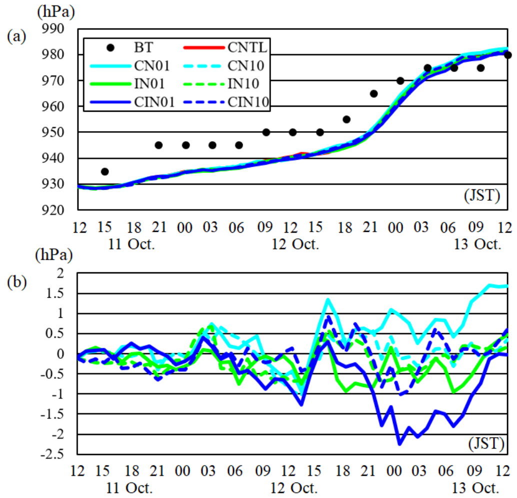

Figure 1. Time series of (a) RMSC Tokyo BT central pressure and simulated central pressures, and (b) differences of central pressure in the sensitivity experiments from that in CNTL.

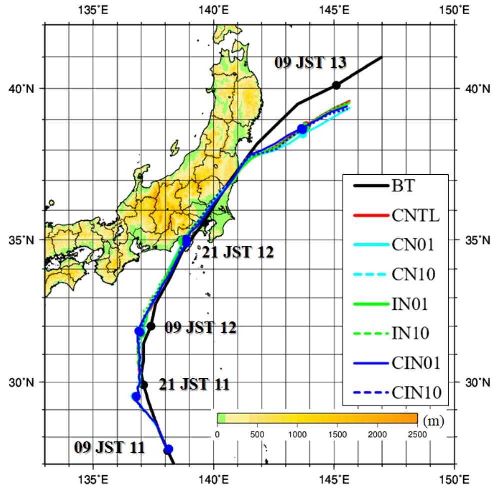

Figure 2. RMSC Tokyo BT and simulated tracks from 09 JST on 11 October to 12 JST on 13 October.

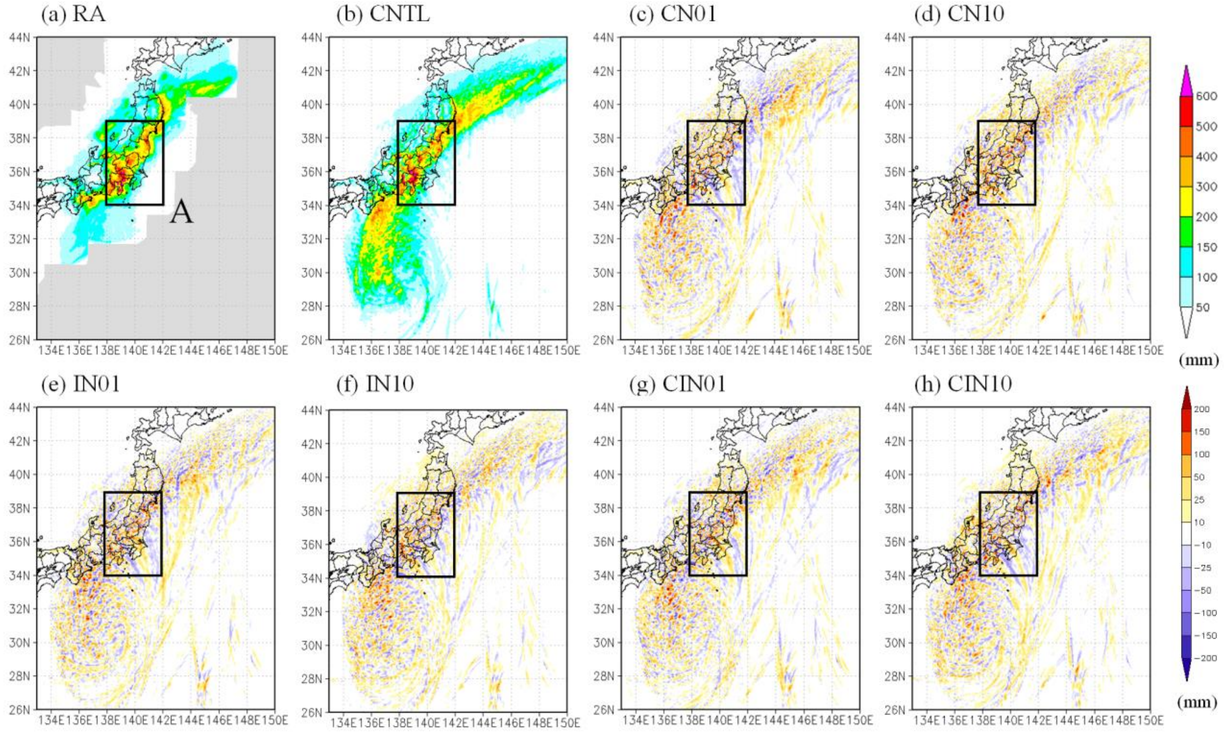

Figure 3. Horizontal distribution of precipitation amounts from 09 JST on 11 to 12 JST on 13 October 2019 in (a) radar analysis (RA), (b) CNTL, and (c)-(h) the differences from CNTL for each experiment.

Table 1. Summary of central pressures at the longitude of 138.7˚E and precipitation amounts. The values under the precipitation amounts from 09 JST on 11 to 12 JST on 13 October of each sensitivity experiment indicate the changes (%) from the precipitation amount of CNTL.

	BT / RA	CNTL	CN01	CN10	IN01	IN10	CIN01	CIN10
Central pressure at longitude 138.7°E (hPa)	955	949.6	951.2	950.1	949.2	950.4	948.3	949.2
Averaged precipitation amount in all domain (mm)	-	29.6	29.8	29.6	29.6	29.8	29.8	29.8
			0.4 %	-0.1 %	0.0 %	0.4 %	0.4 %	0.4 %
Averaged precipitation amount in domain A (mm)	163.8	161.3	158.8	164.3	161.0	159.9	163.0	157.6
			-1.5 %	1.8 %	-0.1 %	-0.9 %	1.1 %	-2.3 %
Maximum precipitation amount in domain A (mm)	1346.1	788.5	705.6	735.4	876.6	797.7	700.4	709.7
			-10.5 %	-6.7 %	11.2 %	1.2 %	-11.2 %	-10.0 %

References:

Araki, K., 2020: Numerical simulation of heavy rainfall event associated with typhoon Hagibis (2019) with different horizontal resolutions. *Research Activities in Earth System Modelling, Working Group on Numerical Experimentation,* **50**, *WMO,Geneva,* p.3.03–3.04.