Numerical simulations of the cloud and precipitation processes during the heavy rainfall events of early July 2017 and 2018 in Japan

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1. Introduction

From July 5 to 6, 2017, stationary convective systems brought heavy rainfall to northern Kyushu, where a total rainfall amount of more than 300 mm was recorded at several observation sites, with 586 mm being recorded at Asakura in Fukuoka Prefecture. This rainfall event caused river floods and landslides, leading to serious damage to houses, transportation networks, and public utilities such as electricity and water. In addition, there were 40 deaths and 2 people went missing (Cabinet Office Japan, 2018). A year later, from late June to early July 2018, a wide area of western Japan was struck by record heavy rainfall. The total rainfall recorded during the period June 28 to July 8 was more than 500 mm in many places: in particular, 1852 mm was recorded at Yanase in Kochi Prefecture. This event also caused enormous damage, as well as 237 deaths and more than 400 injuries. Eight persons were recorded as missing (Cabinet Office Japan, 2019).

These heavy rainfall events were investigated from a synoptic-scale to mesoscale perspective by several studies. Based on the results of numerical simulations, this report presents preliminary results on the microphysical characteristics of these two events.

2. Numerical simulations

A numerical simulation system was established based on the Japan Meteorological Agency's nonhydrostatic model (JMA-NHM, Saito *et al*., 2006) using the option of a double-moment bulk cloud microphysics scheme to predict both the mixing ratio and concentration of particles for all hydrometeor classes (i.e., cloud water, rain, cloud ice, snow, and graupel).

The numerical simulations were successively conducted once a day, shifting the initial time in 24-hour steps from July 3 to 6, 2017 and from July 4 to 7, 2018. Each simulation was first performed at a horizontal resolution of 5 km (5km-NHM) over a 2750 km × 3000 km wide domain as shown in Fig. 1. Following this, simulations with a 1-km horizontal resolution were performed and were named 1km-NHM-KYS and 1km-NHM-CGK for the 2017 and 2018 events, respectively (Fig. 1).

In the case of 5km-NHM, the top height of the model domain was 22 km. The vertical grid spacing ranged from 40 m at the surface to 723 m at the top of the domain. Sixty vertical layers in a terrain-following coordinate system were employed. The integration time was 45 hours, with a time-step of 15 s. Computations of the radiative processes were performed every 15 minutes at a horizontal grid spacing of 10 km. The initial and boundary conditions were obtained from the JMA's mesoscale analysis data (MANAL). The initial time was set to 1500 JST (UTC + 9) for each day. Boundary conditions were provided with steps of every 3 hours.

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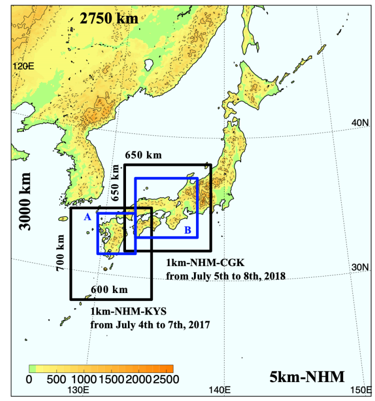

Fig. 1. Computational domains for the numerical simulations: 5km-NHM, 1km-NHM-KYS, and 1km-NHM-CGK.

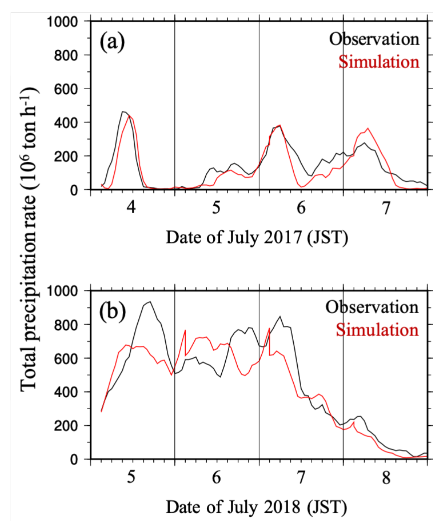

Fig. 2. Time-series of the total precipitation rate for the heavy rainfall events in (a) 2017 and (b) 2018, which were evaluated for the areas within the blue boxes A and B, respectively, shown in Fig. 1. The black and red lines denote the observations and simulations, respectively.

The vertical grid arrangement in the 1km-NHM-KYS was the same as in the 5km-NHM, and the domain size was 600 km × 700 km (Fig. 1). The integration time used was 30 hours with a timestep of 4 s. Computations of the radiative process were performed every 15 minutes at a horizontal grid spacing of 2 km, and the initial and boundary conditions were obtained from the 5km-NHM simulation. The same configuration was adopted for the 1km-NHM-CGK, except that the domain size was 550 km × 600 km and the simulation was centered on Chugoku district (Fig. 1). The initial time for the 1km-NHM-KYS and CGK simulations was 12 hours later than that of the 5km-NHM.

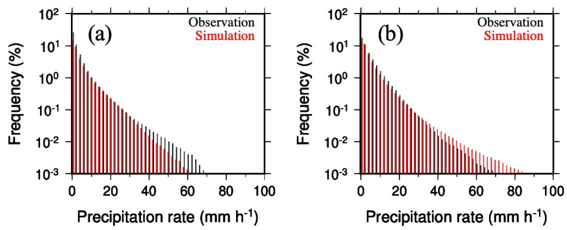

Fig. 3. Appearance frequency for the total precipitation rate for the heavy rainfall events in (a) 2017 and (b) 2018, as evaluated for the areas within the blue boxes A and B, respectively, shown in Fig. 1. The black and red bars denote the observations and simulations, respectively.

3. Results

To validate the results of simulation, we first compared the simulated precipitation intensity with the observations**;** the Radar/Raingauge-Analyzed Precipitation product provided by the JMA. Figure 2a shows the time-series of the total precipitation rate evaluated for area A in Fig. 1 for the heavy rainfall event in 2017. The rainfall in July 4 was that associated with the typhoon Nanmadol. A disastrous rainfall event occurred in Fukuoka Prefecture occurred on July 5 and 6. The simulated total precipitation rate was in good agreement with the observations throughout the period of the simulation. For the 2018 event as shown in Fig. 2b, the simulation slightly underestimated the precipitation rate. Figure 3 shows the appearance frequency for the total precipitation rate. Rainfall with an intensity of about 20 mm h^{-1} was well represented by the simulation of the 2017 event, whereas lighter and heavier rainfall was underestimated. In the case of the 2018 event, the appearance frequency of the rainfall with an intensity of less than 25 mm h^{-1} was underestimated, whereas rainfall with an intensity greater than this was overestimated by the simulations.

Hamada and Takayabu (2018) stated that the extreme rainfall events in midsummer in Japan are not necessarily accompanied by extreme convection or lightning activity. Figure 4 shows a time-series of the flash rate observed by the Lightning Detection Network system (LIDEN) of the JMA. The flash rate during the 2018 event was one or two orders of magnitude lower than during the 2017 event. This is notable considering that the total precipitation rate (Fig. 2) recorded during the 2018 event was larger than in the 2017 event throughout most of the simulation period. The simulated updraft velocity was larger and the peak height was higher during the 2017 event than in the 2018 event. Figure 5 shows the appearance frequency of the mixing ratios of hydrometeors. In the 2017 event, supercooled liquid water and graupel were found to prevail throughout the troposphere to a much greater extent than in the 2018 event. Generally speaking, lightning activity is closely related to the existence of graupel in a cloud. The simulated results indicate that the difference in flash rate between the two events was produced by the microphysical differences shown in Fig. 5.

Figure 4 also shows the simulated graupel-dominated volume (the sum of all the grid volumes in which the mixing ratio for graupel is the largest among the modeled hydrometeors). In both events, the temporal changes in the simulated graupel-dominated volume roughly correspond to the changes in the observed flash rate, which indicates the potential of constructing a regional weather prediction model that can be used to make dynamical predictions of the flash rate.

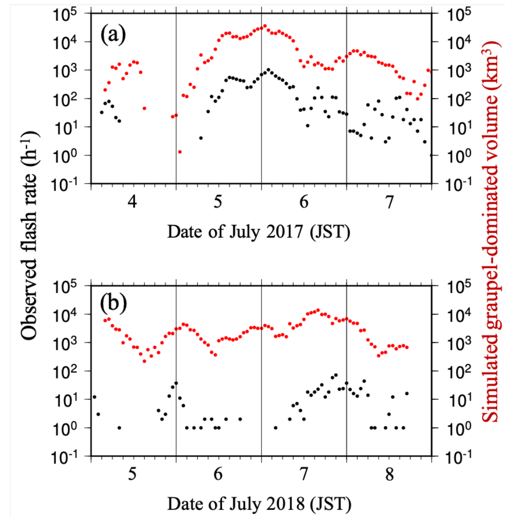

Fig. 4. Simulated graupel-dominated volume (red dots) and observed flash rate (the number of cloud-to-ground lightning strikes per hour: black dots) for the heavy rainfall events in (a) 2017 and (b) 2018, as evaluated for the areas within the blue boxes A and B, respectively, shown in Fig. 1.

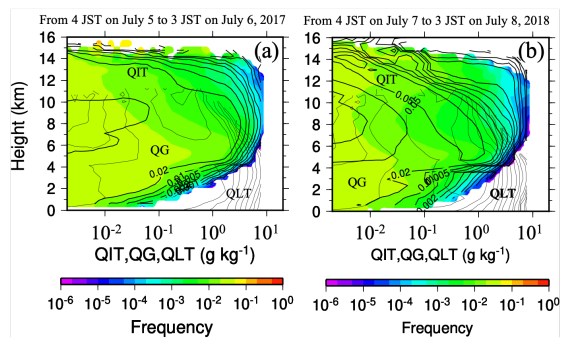

Fig. 5. Appearance frequency for the mixing ratio of total solid water (QIT: black contours), graupel (QG: color shading), and total liquid water (QLT: gray contours) for the (a) 2017 and (b) 2018 events.

Acknowledgements

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References

Cabinet Office Japan, 2018: *White paper on disaster management in Japan 2018.* 129pp. (http://www.bousai.go.jp/kaigirep/hakusho/pdf/H30_hakusho_english.pdf, accessed 28 April 2020)

Cabinet Office Japan, 2019: *White paper on disaster management in Japan 2019.* 140pp. (http://www.bousai.go.jp/kaigirep/hakusho/pdf/R1_hakusho_english.pdf, accessed 28 April 2020)

Hamada, A. and Y. Takayabu, 2018: Large-Scale Environmental Conditions Related to Midsummer Extreme Rainfall Events around Japan in the TRMM Region. *J. Climate*, 31, 6933-6945, doi:10.1175/JCLI-D-17-0632.1.

Saito, K., T. Fujita, Y. Yamada, J. Ishida, Y. Kumagai, K. Aranami, S. Ohmori, R. Nagasawa, S. Kumagai, C. Muroi, T. Kato, H. Eito, and Y. Yamazaki, 2006: The operational JMA nonhydrostatic mesoscale model. *Mon. Wea. Rev.*, **134**, 1266–1298.