Lighting simulation using a cloud-resolving model: Comparison with observations

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ABSTRACT: Lightning flashes can be simulated by introducing the charge generation and lightning parameterization scheme to the Cloud Resolving Storm Simulator (CReSS: Tsuboki and Sakakibara, 2002). The lightning simulation includes three processes, (1) charge generation, (2) lightning propagation, and (3) charge neutralization. As the charge generation process, riming electrification occurs between graupel and snow, and between graupel and cloud ice [Takahashi, 1978]. At the lightning propagation and charge neutralization processes, we used the lightning parameterization [MacGorman et al., 2001]. In this scheme, lightning propagates along the maximum gradient of the electric potential. The net electric charge is neutralized along and around the lightning path, because this parameterization does not permit branched propagation. After neutralization, the net electric charge is redistributed into each hydrometeor category. In this study, the lightning simulation calculates two cases of thunderstorms, the line-shaped heavy rainfall system in the Tokai Area of Japan with horizontal grid of 2 km and a winter thunderstorm in the Hokuriku Area of Japan with horizontal grid of 1 km. In both case, thunderstorms are successfully simulated. These results are compared with the observations about the temporal variation of lightning frequency at cloud-to-ground (CG) flashes and ratio between the positive and negative discharges. In the simulation of the line-shaped heavy rainfall system, negative CGs occurred more frequently than the positive CGs, consistent with the observations. In contrast, the positive discharges occurred more than the negative discharges in the simulation of a winter thunderstorm. The temporal variation in numbers of simulated lightning is similar to observed that when we use lightning flashes only with large charge neutralization in the line-shaped heavy rainfall system. Simulated lightning number and ratio of positive to negative is highly dependent on lightning parameters and neutralization scheme. Therefore, optimizing the lightning parameter and understanding the neutralization scheme are essential for quantitative comparing between the simulation and observation.

INTRODUCTION

Constructing lightning simulation is necessary to forecast location and timing of lightning. Cloud Resolving Storm Simulator (CReSS) is a three-dimensional, non-hydrostatic and compressible equations systems with a fine-grid system, which considers water vapor, rain, cloud, ice, snow and graupel using bulk method of cold rain [Tsuboki and Sakakibara, 2002]. In this study, by introducing the lightning parameterization to the CReSS, we simulated lightning flashes, and compared with observations.

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In Japan, discharge characteristic differs between summer and winter. Winter lightning is rare phenomenon all over the world. We will show that winter lightning flashes are successfully simulated in our lightning model.

METHOD

The lightning simulation includes three processes, charge generation, lightning propagation, and charge neutralization.

1) Charge generation

Riming electrification occurs between graupel and snow, and between graupel and cloud ice [Takahashi, 1978].

2) Lightning propagation

We used lightning parameterization by MacGorman et al. [2001] to calculate lightning propagation. In this scheme, a lightning flash occurs initially at a grid, which exceeds the initiation threshold of electric field magnitude. Lightning propagates along the maximum gradient of the electric potential until falls below the stop threshold.

3) Charge neutralization

We used MacGorman et al. [2001] scheme for calculation of charge neutralization. The net electric charge is neutralized along and around the lightning path, because this parameterization does not permit branched propagation. After neutralization, the net electric charge is redistributed into each hydrometeor category according to its relative surface area.

DATASET

In this study, two cases of thunderstorms were calculated by the lightning simulation. The line-shaped heavy rainfall system in the Tokai Area of Japan (Case 1) and a winter thunderstorm in the Hokuriku Area of Japan (Case 2). Experimental design of these cases is summarized in Table1.

In this study, we use two kinds of observation data, JMA-radar and lightning location data. The lightning location data were provided by NTT docomo Inc. The lightning locations were calculated from LF-band signals produced by lightning. Therefore, we used only cloud-to-ground (CG) discharge for comparison.

Table 1 Experimental design of the line-shaped heavy rainfall system (Case 1) and winter thunderstorm (Case 2)

	Case 1	Case 2
domain	x 200, y200, z 15 km	x 250, y250, z 12 km
grid number	x 103, y103, z 53	x 253, y253, z 43
grid size	H 2000 m, V 300 m	H 1000 m, V 300 m
integration time	4 hrs	2 hrs
Initial time	2010/07/15 09UTC	2012/01/25 12UTC

RESULT

Figure 1 shows the locations of observed and simulated flashes and precipitation. Our results show that lightning occurred around the line-shaped heavy rainfall system in Case 1. In Case 2, lightning occurred along the Sea of Japan coast. These results were consistent with observation.

Figure 2 shows the temporal variations in the numbers of lightning flashes in Case1. In integration time between 3600 and 4680, observed lightning flashes occurred more frequently than that in the later time. After the time, the numbers decrease with time. In contrast, the simulation shows nearly-constant frequently of lightning flashes with time. However, the temporal variation in the numbers of lightning flashes with large charge neutralization were similar to the observed that.

In the Case 1 simulation, the negative CGs occurred more frequently than the positive CGs, consistent with the observations. In contrast, the positive discharges occurred more than the negative discharges in Case 2.

SUMMARY

We simulated the line-shaped heavy rainfall system in the Tokai Area of Japan and a winter thunderstorm in the Hokuriku Area of Japan. Our result shows that the temporal variation in the simulated lightning flashes with large charge neutralization is similar to the observed that. The numbers of lightning flashes and ratio of positive to negative are highly dependent on lightning parameters and neutralization scheme. Optimizing lightning parameter and understanding the neutralization scheme are essential for quantitative comparing between the simulation and observation. We will investigate model dependency of lightning parameter and neutralization scheme in our future work.

ACKNOWLEDGMENT

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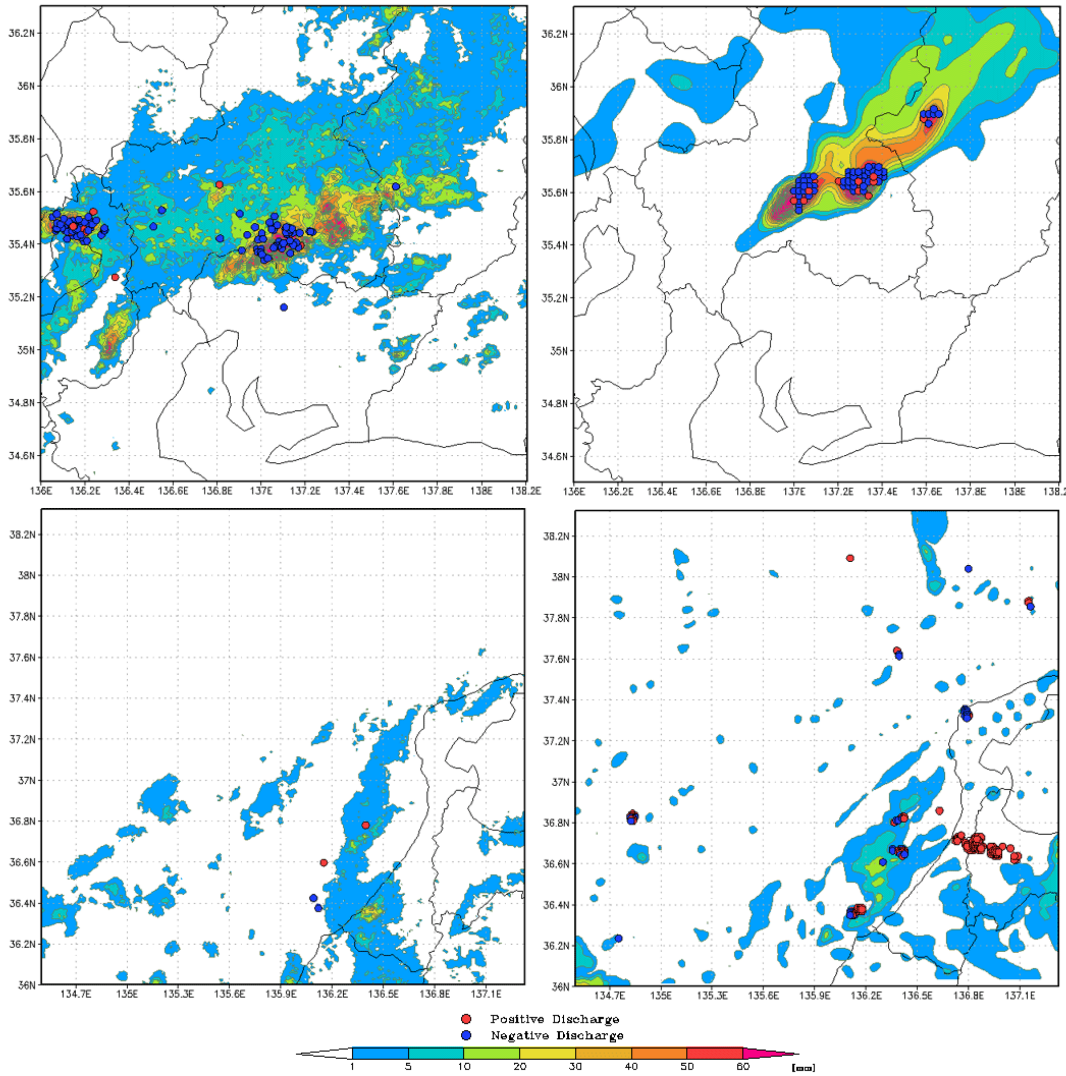

Figure 1. Locations of lightning flashes observed (upper left) and simulated (upper right) in Case 1 at 4800 seconds from the initial time and observed (lower left) and simulated (lower right) in Case 2 at 6000 seconds from the initial time. Color indicates precipitation.

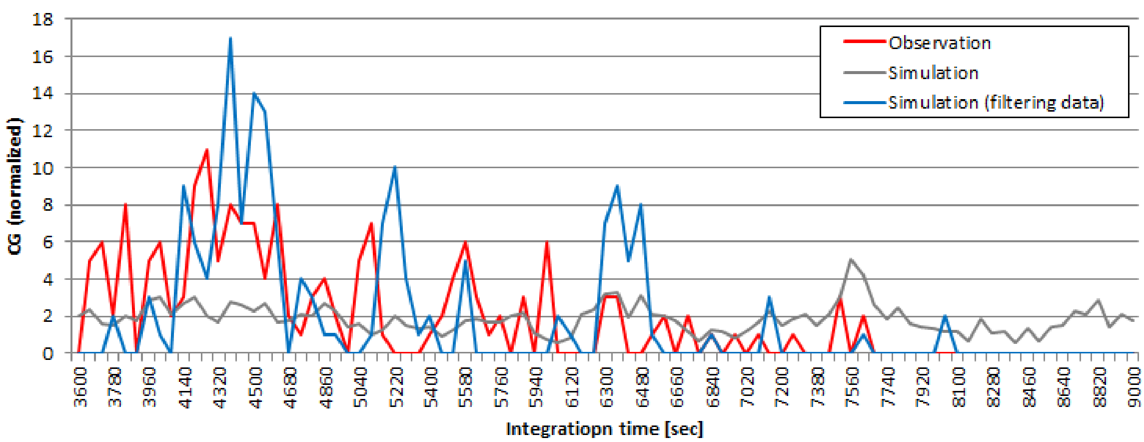

Figure 2. Numbers of the observed and simulated cloud-to-ground lightning flashes as a function of time.