The Impact of 3-Dimensional Data Assimilation using Dense Surface Observations on a Local Heavy Rainfall Event

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1. Introduction

Local heavy rainfalls (LHRs), which often cause disasters with loss of human life, are known to be caused by mesoscale convective systems (MCSs) composed of small-scale convective cells without synoptic forcing in warm seasons. In spite of recent progresses in numerical modeling and data assimilation, accurate prediction of such small-scale convective cells and LHRs remains challenges. To improve the forecasts of LHRs, it's required to understand the processes of convection initiation (CI) and preconvective environments where and when deep convective cells and MCSs develop.

On 9 August 2009, in the situation without synoptic forcing, a LHR event occurred in the Chiba city on the Kanto Plain in Japan and 3-hour accumulated rainfall by 1800 Japan Standard Time (JST; JST = UTC + 9 h) reached 150 mm (Fig. 3). The operational mesoscale model of the Japan Meteorological Agency (JMA) failed to predict the LHR. We performed a case study on mesoscale data assimilation using a surface network of JMA's Automated Meteorological Data Acquisition System (AMeDAS) with horizontal resolution of about 21 km and another dense surface observation network of the Atmospheric Environmental Regional Observation System (AEROS; Nishi et al. 2015) of the Japanese Ministry of Environment (Fig. 1). The AEROS ('Soramame' in Japanese) observes surface relative humidity in addition to air temperature and wind with a horizontal resolution of about 4–5 km in urban areas. The dense surface observation network revealed that a triple point (TP) was formed near the Chiba city (east of Tokyo) about 1.5 hours before the CI and triggered the CI at 1320 JST. Since convective cells initiated on the TP moved northeastward, where cold and moist northeasterly flow was observed at the surface, the TP was not likely affected by cold outflows from convective cells. As the result, the TP was maintained and caused the formation of a MCS and the LHR in the Chiba city.

2. Design of data assimilation

We performed numerical experiments by the JMA non-hydrostatic model (NHM; Saito et al. 2006). In the experiments, triply nested one-way grids (horizontal grid spacing of 20 km; 20km-NHM, 5 km; 5km-NHM and 2 km; NODA) were used. The initial and boundary conditions in 20km-NHM were provided by the JMA global analysis and results of JMA global spectrum model, respectively. Setups of the model were almost the same as in Saito et al. (2006), except that the Kain-Fritsch convective parameterization scheme was switched off in NODA.

In order to reproduce the preconvective environments in the initial field, the 3-dimensional variational assimilation system (JNoVA0; Miyoshi 2003) was also used in this study. The dense surface observations, which captured the TP triggering the CI, would be of benefit in predicting the CI and the LHR. The forecast of 5km-NHM from 1200 JST on the day was used as the first guess, and the initial fields were produced by assimilating surface observation data within a domain of 138–142°E and 34–37°N at 1200 JST; wind and temperature observed by AMeDAS, and wind, temperature, and relative humidity observed by AEROS. The horizontal resolution of the analysis was 5 km, and the observational error was set same as one of AMeDAS in JMA mesoscale analysis. Experiments with horizontal grid spacing of 2 km were performed by using the initial conditions provided by the JNoVA0 analyses using only AMeDAS data (AME) and AEROS and AMeDAS data (SORA). In SORA, relative humidity data only within the plain

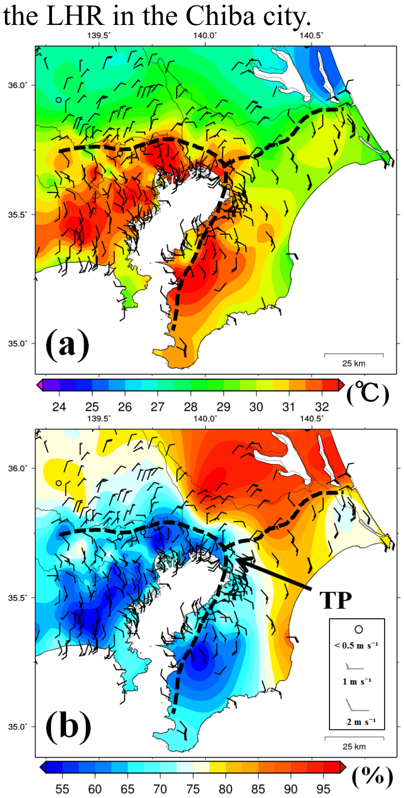

Figure 1. (a) Surface temperature and (b) relative humidity observed by the dense surface observation network at 1200 JST on 9 August 2009. A Barb indicates horizontal wind. Broken lines denote convergence lines.

regions of 139.5–141.2°E and 34.7–36.5°N were used, because the use of the relative humidity data in mountainous region tended to overestimate the water vapor in analysis.

3. Impact of data assimilation using dense surface observations

Figure 2 shows initial fields in NODA, AME, and SORA. Although the initial field in NODA reproduced a part of low-level convergence lines in the Kanto Plain, northeasterly flow in the north of the Chiba city was absent. On the other hand, the northeasterly flow was successfully analyzed in the initial fields in AME and SORA, and the convergence line in the west of the Chiba city was well produced in SORA. This result suggests that dense surface wind observations are necessary to analyze the detailed convergence structure in the lower troposphere. Although the surface temperature in urban areas in NODA was 3–4 °C lower than observations, the initial field in AME improved the horizontal distribution of temperature. The initial field in SORA also resolved the detailed temperature structures in urban areas. The initial field in SORA successfully analyzed high relative humidity in the north of the Chiba city, while NODA and AME did not reproduce the distribution.

As the result of NODA, the intense rainfalls were not reproduced at all (Fig. 3). In the experiments with initial field analyzed by using only wind of AMeDAS and Soramame, short-lived convective cells were appeared but observed MCS were not reproduced (not shown). On the other hand, the MCS was reproduced in the experiments with initial field analyzed by using temperature and wind such as AME, because the structure of temperature in urban areas maintained the convergence lines in the Kanto Plain. As the result of SORA, an LHR with 3-hour accumulated rainfall of 250 mm was reproduced in the Chiba city, and another LHR in the west of the Chiba city was also reproduced. This result indicates that data assimilation of low-level water vapor is important in predicting accurate location and amount of precipitation in LHR events.

In this study, dense surface observations including wind, temperature, and relative humidity were used for the data assimilation and the effect on reproducibility of a LHR event was investigated. The result showed that dense surface observations capturing the detailed preconvective environment of low-level convergence, temperature, water vapor fields, which were necessary for the CI and formation of the MCS, had an advantage in predicting an LHR event.

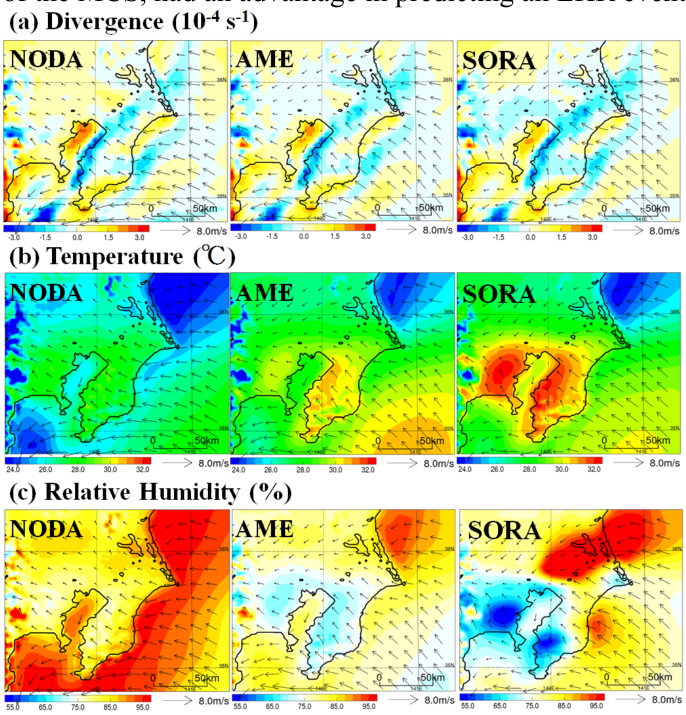

Figure 2. Initial fields of (a) horizontal divergence, (b) temperature, and (c) relative humidity of 20 m above the surface in each experiment. Vectors indicate horizontal wind at the same height.

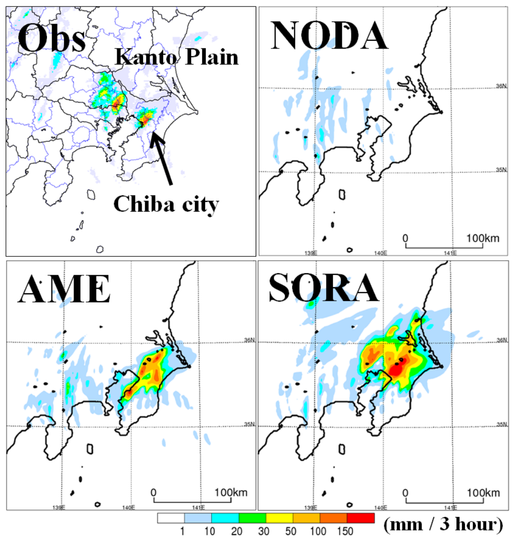

Figure 3. Observed and simulated 3-hour accumulated rainfalls by 1800 JST.

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