Prediction of Localized Heavy Rainfall using a Cloud-resolving Nonhydrostatic model and its Problems

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During the Baiu season, localized heavy rainfall is often observed over the Baiu frontal zone. On 13 and 18 July 2004, heavy rainfalls causing serious floods occurred in Niigata and Fukui areas, Japan-Sea side of Japan Islands, respectively. For both events, band-shaped precipitation systems with the length larger than 100 km stagnated for about 12 hours, and they caused over 200mm accumulated precipitation (see Fig. 1 for Niigata event). These heavy rainfalls were brought by the enhancement of convective instability over the Baiu front that was resulted from the inflows of low-level humid air and middle-level dry air (Figs. 2a and 2c). The humid air had moved over the sea around the edge of Pacific high pressure zone, while the origin of the dry air was downdraft air over the Chinese continent. Therefore, the dry air was considerably warmer, not colder than the surrounding atmosphere (Fig. 2b).

Numerical simulations in an attempt to reproduce these heavy rainfall events were carried out using a cloud resolving model with a horizontal grid of 1.5 km and 5 km, Japan Meteorological Agency (JMA) nonhydrostatic model (1.5km-NHM and 5km-NHM). The initial conditions of 5km-NHM were produced from the JMA mesoscale analysis with a four-dimensional variational assimilation technique. 1.5km-NHM was nested within the forecasts of 5km-NHM. In both NHMs, microphysics with the ice phase are used as precipitation processes, and the Kain-Fritsch convective parameterization scheme is also used conjunctionally in the 5km-NHM.

For Niigata event, Mesoscale model of JMA with a horizontal grid of 10 km (MSM) predicted some rainfall areas around Niigata area, but they were not band-shaped (Fig. 1b). Prediction with a 5km-NHM (Fig. 1c) was not enough to reproduce the band-shaped structure. However, 1.5km-NHM successfully predicted a band- shaped rainfall area (Fig. 1d), although the predicted precipitation intensity was weaker than the observation. This success could result from the 1.5km-NHM being able to reproduce a life cycle of cumulonimbus with a one-hour lifetime.

Even when 1.5km-NHM was applied to Fukui event, any heavy rainfall area was not predicted. This indicates that a cloud-resolving model can not reproduce this event, when a coarse resolution model (e.g., MSM) predicts little precipitation around the area where heavy rainfall was observed. The reason of this failure may be resulted from the uncertain analysis over the sea due to no upper sounding observation. The heavy rainfall, observed over the area marked by a bold circle in Fig. 3b, was caused by the inflow of low-level humid air. This low-level humid air was traced back to the area marked by a dashed cycle in Fig. 3a before 12 hours. The humid air with specific humidity exceeding 16 g kg^{-1}, enough to bring heavy rainfall, did not reach the Fukui area in the MSM prediction (Fig. 4). Therefore, the 1.5km-NHM failed to predict the heavy rainfall due to an inaccurate analysis of the low-level wind field over the sea that determined the movement of the humid air inducing the heavy rainfall.

The paths of the low-level humid air and middle-level dry air bringing heavy rainfall are examined. Since the Japan Islands are surrounded by the sea, these air flows must pass over the sea before reaching the islands. However, since upper-air sounding is seldom operated over the sea, it is difficult to make a highly accurate analysis of atmospheric conditions there. Kato et al. (2003) pointed out that the analysis of water vapor is most difficult because it is independent from the other observed variables. Furthermore, such a slight mistake in the analyzed wind field, as found in the Fukui case, may cause false prediction of heavy rainfall. It is noted that an analysis over areas where no observation is available is mainly made from the uncertain forecasts using the previous initial conditions. Therefore, this study suggested that new systems are required to accurately observe the atmospheric conditions over the sea.

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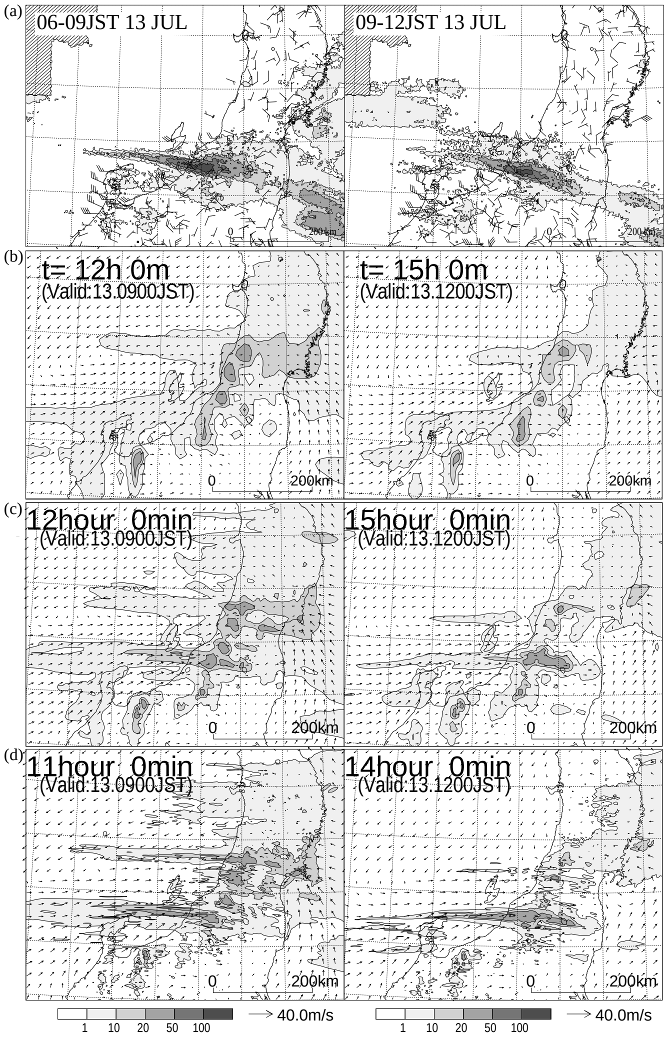

Fig. 1 (a) Observed 3 hourly accumulated rainfall chart on 13 July 2004. Arrows show the observed surface winds. Same as (a), but (b) MSM, (c) 5km-NHM, (d) 1.5km-NHM prediction.

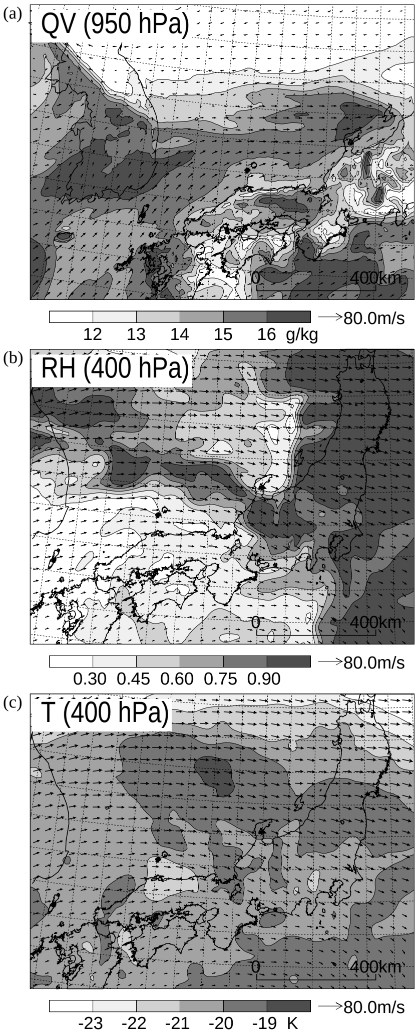

Fig. 2 (a) 950hPa-level specific humidity, 400hPa-level (b) temperature, and (c) relative humidity field at 09 JST on 13 July 2004. Vectors show the same level horizontal winds.

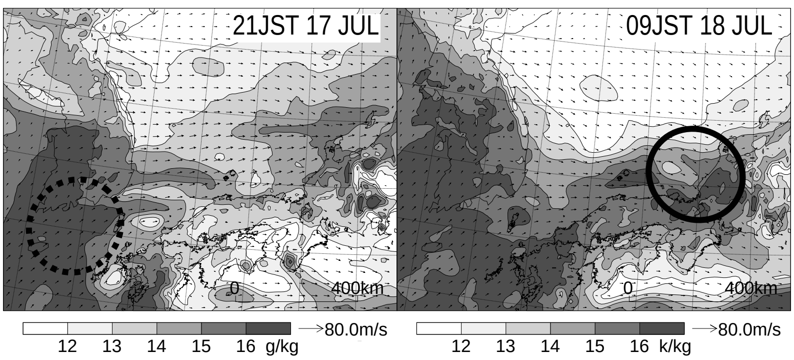

Fig. 3 950hPa-level specific humidity fields of JMA mesoscale analyses at 21 JST 17 July and 09 JST 18 July 2004. Vectors show the same level horizontal winds.

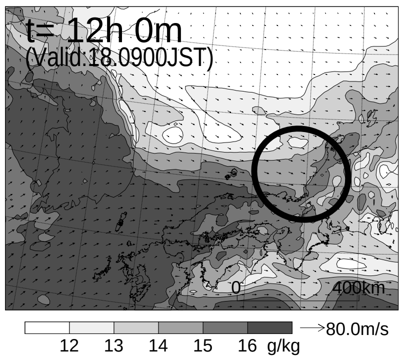

Fig. 4 Same as right panel of Fig. 3, but prediction of MSM.

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