Assimilation of rainwater estimated by the polarimetric radar for tornado outbreaks on 6 May 2012

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1. Introduction

Three tornadoes were generated almost simultaneously on the Kanto Plain at about 12:30 JST (Japan standard time) on 6 May 2012. Southernmost one (hereafter, Tsukuba-tornado) was one of the strongest tornadoes in Japan (F3 in the F-scale). Northernmost one (hereafter, Moka-tornado) and middle one (hereafter, Chikusei-tornado) were estimated to be F2 and F1, respectively. It is generally not easy to simulate mesoscale vortices associated with such tornadoes because of the lack of observations required to generate realistic initial and boundary conditions for high-resolution numerical weather prediction models. In this case, however, the field associated with the tornadoes was well observed by the dense radar and surface observation network including Meteorological Research Institute Advanced C-band Solid-state Polarimetric Radar (MACS-POL). Therefore, it is expected that assimilation of these data can contribute to reproduce the mesoscale vortices more realistically. In this study, the impact to assimilate rainwater estimated by MACS-POL is discussed.

2. Assimilation experiment using the LETKF system

In this study, the nested-LETKF system (Seko et al. 2013) was used to assimilate dense observations. Figure 1 is the outline of the experiment using the one-way triple-nested system which consists of LETKF-1, 2 and 3. In LETKF-1 (horizontal grid interval: 15000 m), hourly operational observations assimilated in Japan Meteorological Agency (JMA) mesoscale analysis (radar radial wind, surface pressure and upper horizontal wind, temperature and relative humidity) were assimilated every 6 hours from 09 JST on 3 May. In LETKF-2 (horizontal grid interval: 1875 m) nested from the LETKF-1 analysis at 03 JST on 6 May, radar radial wind observed by MACS-POL and JMA operational radars in Kashiwa city and Haneda and Narita airports and surface horizontal wind, temperature and relative humidity every 10 minutes were assimilated every hour. In LETKF-3 (horizontal grid interval: 350 m) nested from the LETKF-2 analysis at 12 JST on 6 May, rainwater estimated by MACS-POL as well as observations assimilated in LETKF-2 were assimilated every 10 minutes. Finally, the downscaling forecast (horizontal grid interval: 50 m) was performed from the LETKF-3 analysis at 12:30 JST on 6 May.

Rainwater assimilated in LETKF-3 was estimated from both reflectivity Z [dBZ] and specific differential phase K_{DP} [deg km^{-1}]. Although K_{DP} is not affected by rain attenuation, a relatively large noise is found in the case of weak rain. Therefore,

$$QR\ [\mathrm{g\,m^{-3}}] = \begin{cases} QR_K & (2 \le QR_K) \\ rQR_K + (1-r)QR_Z & (1 \le QR_K \le 2,\ \ r = QR_K - 1), \\ QR_Z & (QR_K \le 1) \end{cases} \quad (1)$$

$$QR_Z\ [\mathrm{g\,m^{-3}}] = 10^{(Z-43.1)/17.5} \quad \text{(Sun and Crook 1997)}, \quad (2)$$

$$QR_K\ [\mathrm{g\,m^{-3}}] = 3.565\left(\frac{K_{DP}}{f}\right)^{0.77} \quad \text{(Bringi and Chensrasekar 2001)}, \quad (3)$$

where $f = 5.370$ [GHz] is the frequency of MACS-POL, were used to estimate rainwater. In this study, three experiments (KR, ZR and NR) were performed with different methods of the rainwater assimilation. In KR and ZR, QR and QR_Z were assimilated as rainwater observations, respectively. In NR, rainwater was not assimilated.

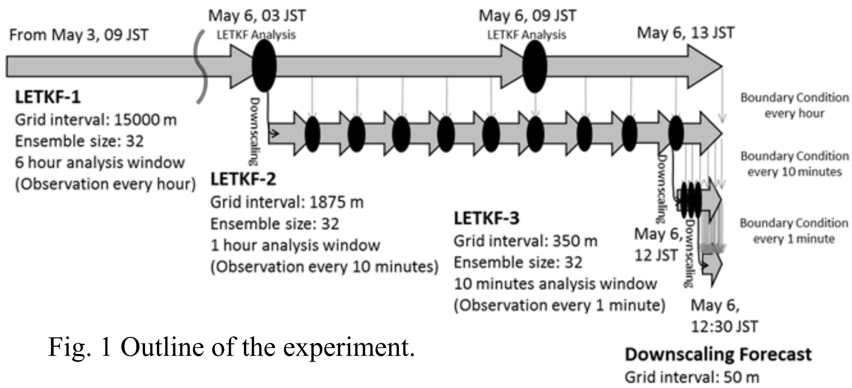

Fig. 1 Outline of the experiment.

3. Impact of the rainwater assimilation

In KR, two points of low-level maximum vertical vorticities were forecasted in south edges of hook-shaped echoes near paths of Tsukuba- and Chikusei-tornadoes at about 12:46 JST (Fig. 2), and both of them were slightly greater than those in ZR and NR. Therefore, rainwater assimilation can affect the predictability of such vortices. It seems to be caused by the modification of low-level water vapor. In fact, the region of large low-level rainwater corresponded to that of large low-level water vapor in the LETKF-3 analysis at 12:30 JST on 6 May (not shown). It means that heavy rain had large correlation with low-level water vapor at that time, and the rainwater assimilation using LETKF affected the distribution of low-level water vapor through the correlation. In this case, smaller rainwater was assimilated in ZR behind heavy rain as seen from MACS-POL than that in KR due to rain attenuation. Therefore, the more humid air was produced by the assimilation of the larger rainwater there in KR, and might affect the vorticities through the difference of the rainfall intensity.

4. Summary

Dense radar and surface observations were assimilated using LETKF in the case of tornado outbreaks, and it was succeeded to forecast two mesoscale vortices associated with tornadoes simultaneously. Rainwater assimilation affected the predictability of such vortices probably through the correction of low-level water vapor. In order to predict such vortices more accurately, clarifying relationship between the predictability and the distribution of low-level water vapor and improvement of how to assimilate rainwater are required.

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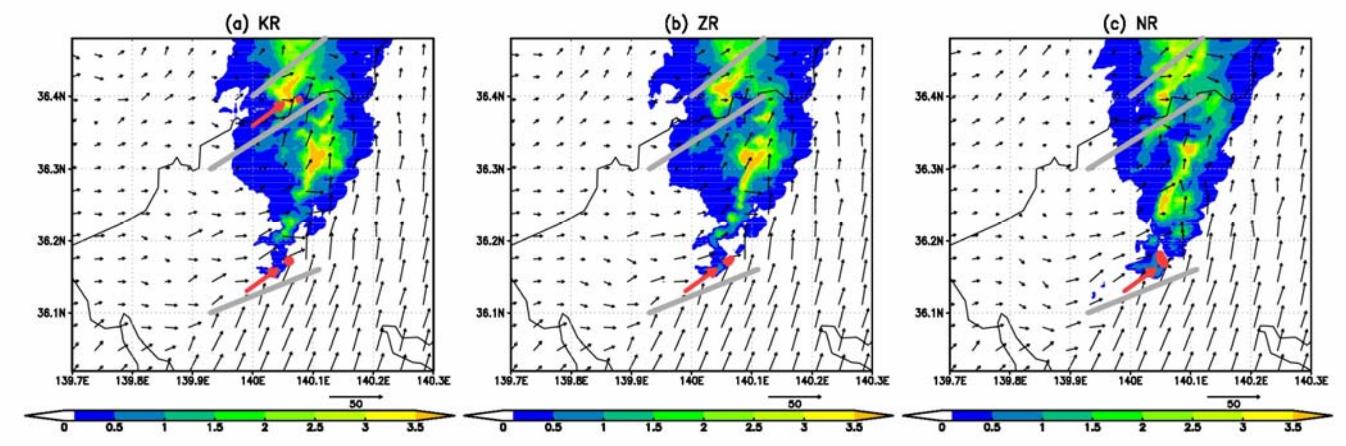

Fig. 2 Mixing ratio of rain greater than 0.1 g kg^{-1} (color, g kg^{-1}), horizontal wind (black arrows, m s^{-1}) and high-vorticity regions greater than 0.04 s^{-1} (calculated in the field coarse-grained in 350 m of the horizontal grid interval, red arrows) at 0.5 km height at 12:46 JST on 6 May in the downscaling forecast (a: KR, b: ZR, c: NR). Gray lines are observed paths of Tsukuba-, Chikusei- and Moka-tornadoes in order from south.