Improving the observation operator for Phased Array Weather Radar in the SCALE-LETKF system

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The observation operator of Phased Array Weather Radar (PAWR; Ushio et al. 2014; Yoshikawa et al. 2013) in the SCALE-LETKF data assimilation system (Lien et al., 2017) is revisited, and the impact of improving the observation operator on the analysis is examined.

Previous studies (Miyoshi et al., 2016, *IEEE*; Miyoshi et al., 2016, *BAMS*) have shown that the three-dimensional fine-scale structure of radar signals observed by PAWR can be successfully assimilated to produce a high-resolution analysis using a regional model SCALE-RM and the local ensemble transformed Kalman filter (LETKF). Forecasts using a high-resolution regional model from the analysis field has a potential to provide reliable precipitation forecasts for longer period of time than a simple nowcasting technique based on an advection scheme, since the explicit physical processes would allow us to capture the development of new convective cells. However, even with an analysis field incorporating such detailed observational data, accurate forecasting of localized convection systems is generally a challenging issue. In the previous studies mentioned above, there was a known problem that the area of strong radar echo calculated from the forecast field starts to expand unrealistically even within several minutes. Along with systematic model biases and imbalance, the observation operator could be the cause of this misrepresentation. Therefore, the observation operator of PAWR is revisited in this study.

The observation operator calculates equivalent radar reflectivity factor (Z_e [mm6/m3]) from hydrometeor mass density of each particle categories (W [g/m^2]). The cloud microphysics scheme in SCALE-RM (Tomita et al., 2008) is a 1-moment 6-caterogy scheme. They include 3 categories for precipitation particles, namely, rain, snow, and graupel. The relation between Z_e and each of W is obtained by an offline numerical calculation of Mie scattering and approximated in the form of an exponential function.

$Z_e = \alpha_r \exp(\beta_r) + \alpha_s \exp(\beta s) + \alpha_g \exp(\beta_g)$

Previous studies used values from a literature (Xue et al., 2009) for the coefficients. However, the coefficients used for graupel (α_g and β_g) has been originally calculated using assumptions about the particle size distribution different from those in SCALE-RM. In particular, a multiplicative factor of the particle size distribution of graupel in SCALE-RM is much smaller in their calculation ($N_0=3\times10^4$ m^{-4}) than that in SCALE-RM ($N_0=4\times10^6$ m^{-4}). This leads to an underestimation in sensitivity of graupel mass to observed radar reflectivity factor.

The new coefficients for graupel are chosen to be consistent with the SCALE-RM cloud microphysics scheme using the Joint-Simulator developed by Japan Aerospace Exploration Agency (JAXA). The results are $\alpha_g=5.54\times10^3$, $\beta_g=1.70$, where the original values from the literature are $\alpha_g=8.18\times10^4$, $\beta_g=1.50$.

The case study of PAWR assimilation on the localized short-duration heavy rain event on July 13, 2013 is performed again using the new coefficients and compared to previous results (Miyoshi et al., 2016, *IEEE*; Miyoshi et al., 2016, *BAMS*).

The results are shown in Fig. 1. With the new set of coefficients in PAWR observation operator, the evolution for the 30-minute forecast period is closer to the observation than that with the original coefficients. The rapidly-growing unrealistic spread of a large reflectivity area are significantly suppressed. The difference is also clear in the vertical profiles of area-averaged graupel mass. The rapid increase of graupel in the middle troposphere in the conventional forecast experiment implies the recovery from the imbalance by inconsistency between the observation operator and cloud microphysics scheme. The new coefficients lead to improve hte imbalance and provide physically more consistent analysis fields. To further improve PAWR assimilation, this modification to the observation operator allows us to focus on other factors such as a model error treatment as the next step.

Keywords: Data Assimilation, Weather forecasting, Precipitation radar