Improvements of the nested LETKF system

- Impacts of GPS water vapor data and synergistic effects of GPS water vapor data and wind data -

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1. Introduction

The nested Local Ensemble Transform Kalman Filter system has been developed to improve the accuracy of numerical forecast on local heavy rainfalls. To reproduce local heavy rainfalls, their positions and rainfall intensities need to be improved, simultaneously. Mesoscale convergence, in which local heavy rainfalls are generated, was reproduced in this study by the Local Ensemble Transform Kalman Filter (LETKF) with the grid interval of 15 km (Outer LETKF). The convection cells that caused local heavy rainfall were reproduced by the LETKF with the grid interval of 1.875 km (Inner LETKF). The boundary conditions of the Inner LETKF were produced from the outputs of the Outer LETKF, and the results of the Inner LETKF influenced the Outer LETKF every 6 hours. To show the performance of this system, this system was applied to a thunderstorm that caused the local heavy rainfall on the Osaka Plain on 5th September 2008. Convergence of low-level water vapor is indispensable in reproducing local heavy rainfalls. GPS-derived PWV or SWV (slant path water vapor) and horizontal wind or radial wind observed by Doppler radars provide information about low-level convergence of water vapor. A number of data assimilation experiments on radial wind from Doppler radars and PWV using the EnKFs have been reported so far. In this study, the impacts of the SWV and the synergistic effect of simultaneous assimilation of Doppler radar data and GPS water vapor data (PWV or SWV) are investigated, as well as the GPS-PWV data and Doppler radar data.

2. Outlines of the nested LETKF system

This data assimilation system was composed of two NHM-LETKFs (Miyoshi and Aranami, 2006): the Outer and Inner LETKFs. The number of vertical layers was 50 and the depth of the vertical layers was increased from 40 m to 880 m as the height increased. The number of ensemble members was 12.

As for the Outer LETKF system, the grid interval is 15 km and the grid number in the horizontal directions was 80 × 80. The Kain-Fritch parameterization scheme was adopted. The ensemble forecast started at 0900 JST 1st September 2008 and the initial seed of the Outer LETKF was obtained from the JMA mesoscale analysis fields from 29th to 31st August. The boundary condition from 1st to 5th September was also produced from the JMA mesoscale analysis. The data assimilation window was 6 hours and the conventional data, which was used in the JMA mesoscale analysis, were assimilated every hour.

The grid interval of the Inner LETKF was as small as 1.875 km to resolve small convection cells. In the microphysical process, the mixing ratio of cloud, rain, ice crystals, graupel and the number density of ice crystals were predicted. The boundary conditions and first initial seed of the Inner LETKF were produced from the Outer LETKF. The data assimilation window is 1 hour, and three series of 6 cycles were performed from 03 JST 5th. In addition to the conventional data, GPS water vapor data and radar wind data were assimilated every 10 minutes.

To reflect the analysis of the Inner LETKF in the Outer LETKF, the analyzed value of the Outer LETKF was replaced by that of the Inner LETKF every 6 hours at the end of the assimilation windows of the Outer LETKF. To reduce the inconsistencies between the Inner and the Outer LETKFs, the values of the Outer LETKF near the boundary of the Inner LETKF were produced by blending with those of the Outer LETKF.

3. Impacts of GPS water vapor data and the synergistic effects of GPS water vapor data and wind data

a. Impact of GPS water vapor data

In this study, PWV and SWV estimated from the atmospheric delays (Shoji et al. 2004) were used as assimilation data. PWV and SWV are the integrated value of water vapor in the column or along the paths from GPS satellites to GPS receivers. Because LETKF cannot assimilate the non-local data (i.e. integrated value data, such as PWV) directly, water vapor at the points where the paths crossed each layer of LETKFs (intermediary data) was estimated, and then assimilated in the Inner LETKF. In the estimation of this input data, the following two assumptions were used; (1) Differences between input data and first guess are proportional to the spread of water vapor. Due to position errors of rainfall regions and large dispersion of water vapor distributions caused by small ensemble numbers, area-mean water vapor profile and area-maximum spread profiles of water vapor within the areas from 18 km from GPS receivers were used as the first guess and spread profiles of water vapor (Seko et al. 2011). (2) The input data is produced at the layers where the correlation among the ensemble members between water vapor of each layer and PWV exists (Fujita et al. 2011). The assimilation method of SWV was the same as that of PWV, except for the slant paths and the small areas that were used in producing the ensemble mean and maximum spread profiles of water vapor. Because SWV is water vapor between GPS satellites and receivers, SWV provides water vapor values as well as its direction. If large areas were used in producing the ensemble mean and maximum spread profiles, the direction would become ambiguous because large areas dilute this information. To exploit this advantage of SWV, areas used in producing ensemble mean and maximum spread were reduced from 18 km to 3 km.

Figure 1 is the analyzed rainfall distributions at 17 JST reproduced by the Inner LETKF to show the development of the rainfall on the Osaka Plain. In a few ensemble members, the intense rainfall regions on the Osaka Plain extended northwestward. This feature of the analyzed distributions, which was the same as the observed one at 16 JST, indicates that the local heavy rainfall on the Osaka Plain were well reproduced in a few members, though there was a time lag of 1 hour.

Figure 2 shows the rainfall regions at 17 JST that were obtained by assimilation of PWV and SWV data. These data from 9 JST to 15 JST was assimilated in the Inner LETKF. When the PWV data was assimilated, the number of ensemble members in which the rainfall regions were extending northwestward increased. Especially, rainfall became more intense in most of ensemble members. When SWV data was assimilated, the number of ensemble forecasts in which the intense rainfalls were well reproduced was further increased in this study. It is deduced that some paths from GPS receivers to GPS satellites penetrated humid regions that generated the convection cells on the Osaka Plain.

b. The synergistic effect of GPS water vapor data and Radial wind data

As for the Doppler radar data, two kinds of data were assimilated. The first was the horizontal wind obtained by the dual analyses of the radial wind of Kansai and Osaka international airports. The second kind of data is radial wind of Doppler radar. This wind data is expected to be more effective to improve the rainfall forecasts because it provides the information from a wider area.

Figures 3a is the rainfall distributions at 17 JST that were obtained by the assimilation of the horizontal wind. The horizontal and radial winds were assimilated from 14 JST to 15 JST, because the rainfall regions were fewer and smaller before 14 JST. When the horizontal winds were assimilated, the number of ensemble members in which the intense rainfall regions extended northwestward was increased. When the radial winds were assimilated, the number was further increased though the rainfall intensity remained relatively weak (not shown). These results indicate that the wind data, especially radial wind, can improve rainfall forecasts.

Figure 3b is the rainfall distributions that were obtained by the simultaneous assimilation of the horizontal wind and PWV. When this data was assimilated, the rainfall forecasts in the ensemble members #007 and #011, in which the intense rainfall region was not reproduced by the individual assimilation of the PWV and horizontal wind, were improved. The improvements of rainfall forecasts in the ensemble members #002 and #003 became unclear, compared with those in which the PWV or horizontal wind was assimilated separately. However, the rainfall distributions of #002 and #003 remained better than those obtained from the assimilation of conventional data. These results indicate that the simultaneous assimilation is useful for increasing the number of members in which local heavy rainfalls are reproduced.

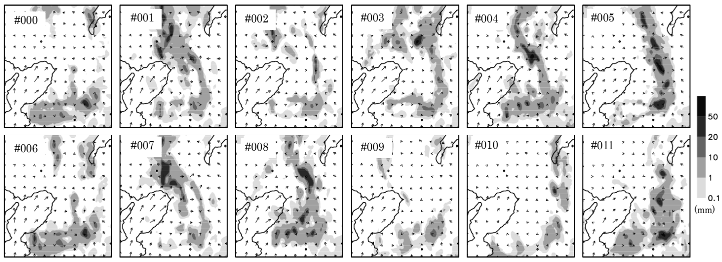

Fig. 1 Horizontal distributions of 1 hour rainfall and horizontal wind at the height of 20 m reproduced with the Inner LETKF by assimilation of conventional data.

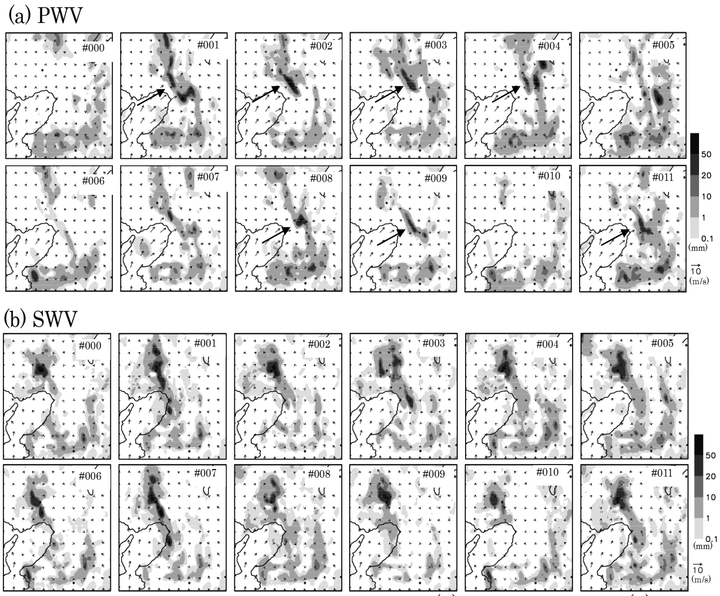

Fig. 2 Same as Fig. 1 except by adding (a) PWV data and (b) SWV data to the assimilation data.

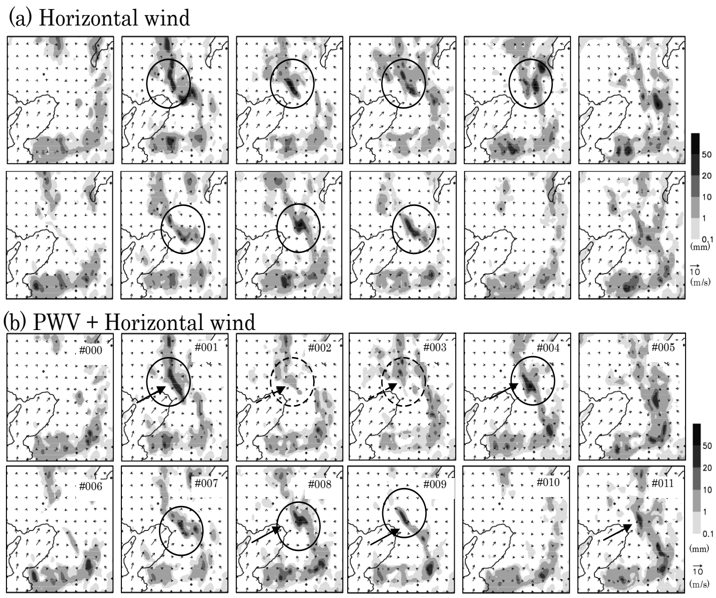

Fig. 3 Same as Fig. 1 except by adding of (a) horizontal wind and (b) horizontal wind and PWV data to the assimilation data.

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Reference

Miyoshi, T. and K. Aranami, 2006: Applying a four-dimensional local ensemble transform Kalman filter (4D-LETKF) to the JMA nonhydrostatic model (NHM). SOLA, 2, 128-131.