Data Assimilation Experiments of Ground-based Microwave Radiometer and small UAV by using Meso-NAPEX

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1. Introduction

The heavy rainfalls caused by quasi-stationary line-shaped rainfall systems bring about floods or landslides in Japan almost every year. The low-level warm and humid inflow supplied to heavy rainfalls is one of the crucial factors that affect the rainfall amount. To improve the forecast accuracy of quasi-stationary line-shaped rainfall systems, a ground-based microwave radiometer (MWR) network, which observes the precipitable water vapor (PWV), vertical profiles of temperature and humidity, was constructed in western Japan by the Japan Meteorological Agency (JMA) in 2022. Vertical profiles of temperature, humidity, and horizontal wind in the lower atmosphere were observed by a small UAV (unmanned aerial vehicle) aboard a JMA's vessel on the East China Sea (ECS), the upstream side of heavy rainfall, as the part of the intensive observation from June to October 2022 conducted by the Meteorological Research Institute.

These data on low-level inflows to heavy rainfalls are expected to improve the accuracy of numerical forecasts of heavy rainfalls. To show the impact of MWR and small UAV on heavy rainfalls, data assimilation experiments of these observation data were conducted using an experimental system (Meso-NAPEX) based on the operational mesoscale analysis of JMA (Ikuta et al 2021). The results of data assimilation experiments including the observation data of the MWR and small UAV, and their impacts on rainfall forecasts are reported in this paper.

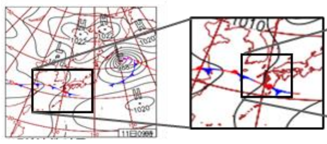
2. Assimilation of ground-based MWR

The 14-channel brightness temperatures are obtained by the ground-based MWR every minute. The hourly data of PWV, vertical profiles of temperature and humidity were estimated from the brightness temperatures using the 2-channel method and 1d-var method, respectively (Araki et al 2015). To show their impacts on rainfall forecasts, these data were assimilated in addition to the operationally assimilated data of JMA.

In the assimilation experiments, the MWR data on 11 August 2021 obtained at Fukue in Goto Islands, west of Kyushu, under the second period of the Strategic Innovation Program (SIP2) were used. On that day, a stationary front over Kyushu was moving northward (Fig. 1). During the period of the assimilation window (0 to 3JST 11 August), the observed PWV increased from 45 mm to 55 mm with approaching the front, and the observed PWV was larger than that of first guess by 2-7 mm.

Figure 2 shows 3hour rainfall and the differences in PWVs and wind velocities obtained with and without assimilating the PWV data (wPWV, CTL). By assimilating the PWV data observed by the MWR, the PWV and wind velocity in the ECS, south-western side of Fukue, increased from the first guess at the initial time of forecasts. These increased regions moved northeastward, and then enhanced the rainfall at FT (forecast time) = 3 hours.

As for the vertical profiles obtained by the 1d-var method, the first guess was used in the estimation of vertical profiles and in the assimilation with the Meso-NAPEX. Although it is undesirable using the first guess twice, the 1d-var profiles were assimilated because the information on the vertical profiles is expected to be effective for improving the rainfall forecast. The vertical profiles obtained by the 1d-var show that the low-level inflow below 0.8 km height was more humid and the temperature above 6 km height was colder than those of the first guess (not shown). When the temperature and humidity profiles were assimilated, the amount of water vapor supplied to the rainfall region increased and the atmosphere became more unstable, and then rainfall on the western side of northern Kyushu intensified (wTRH, Fig. 3). When only humidity profiles were assimilated, the rainfalls were weaker than that of TRH (wRH, Fig. 3). This result indicates that the temperature profiles were crucial to increase the accuracy of rainfall amount forecast in this case.



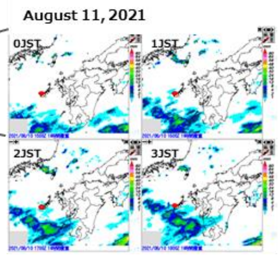


Fig. 1 (left) Weather map at 9JST August 11. 2021. (right) Rainfall distributions from 0JST to 3JST on August 11. The position of Fukue is indicated by red circles.

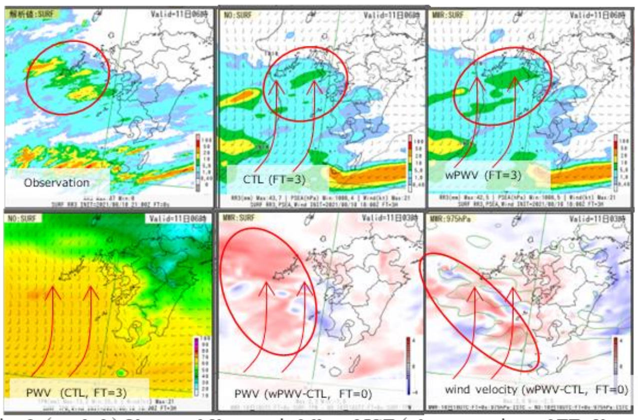


Fig. 2 (top left) Observed 3hour rainfall at 6JST (the same time of FT=3hours). (top center) 3hour rainfall obtained by using only operationally assimilated data of JMA (CTL). (top right) obtained by adding PWV data of MWR to the operationally assimilated data (wPWV). (bottom left) PWV of CTL at FT=3hours. Differences of (bottom center) PWV and (bottom right) wind velocity at FT=0 between wPWV and CTL.

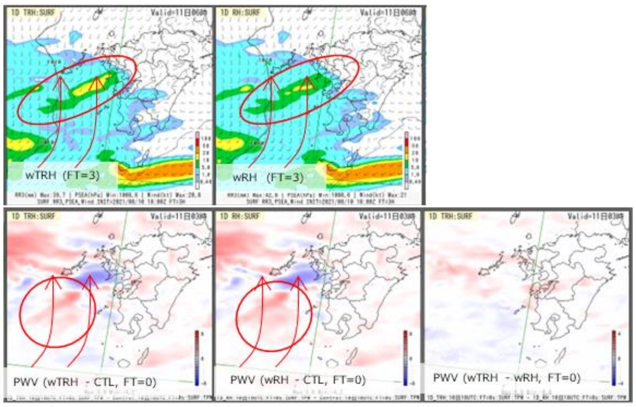


Fig. 3 (top left) 3hour rainfall at FT=3hours obtained by using vertical profiles of temperature and humidity (wTRH). (top center), the same as (top left) but by using vertical profiles of humidity (wRH). Difference of PWV distributions at FT=0 (bottom left) between wTRH and CTL. (bottom center) between wRH and CTL. and (bottom right) between wTRH and wRH.

3. Small UAV observation and assimilation result

On 18 July 2022, a heavy rainfall occurred by the stationary front over northern Kyushu (right panel of Fig. 4). From 10 to 12 JST 18 July, the vertical profiles of temperature, humidity, and horizontal wind upstream side of the northern Kyushu in the ECS were obtained by the small UAV aboard the JMA research vessel Ryofu Maru. The maximum heights of observation were 150~300 m because of the strong wind over the sea. The small UAV ascended and descended at the 3 m/s and 2 m/s, respectively. Because the temperature and humidity sensors cannot catch up with the temporal change during the ascent and descent, the observed values were corrected as follows:

$$T_{tru} = T_c + (T_{c+\Delta t} - T_{c-\Delta t})e^{-\frac{2\Delta t}{\tau}} \quad ,$$

where Tc is the observed temperature, $Ttru$ is the value after correction, Δt is 30 seconds. As for temperature, τ was set to 40 seconds.

The vertical profiles were plotted in Fig. 4. Before the correction, temperatures at the same heights were different between the ascent and descent (top panels of Fig. 5a, blue lines) because the sensor cannot catch up with the temporal change. After the correction, temperature profiles during the ascent and descent were almost the same (orange lines). This result indicates that the correction was successful. Thus, these corrected profiles of temperature were used in the experiments. As for the humidity, the profiles during the ascent and descent differed after the correction, so the averages of the ascent and descent data were used. The horizontal winds during the ascent above 50 m height were used because the anemometer was attached to the upper side of the UAV where less turbulence was expected during the ascent, and the small UAV moved before the ascent to the position where the vessel was expected to be moved while the observation.

Compared with the first guess, the observed temperature was slightly higher, the humidity was larger below 250 m height, and the southerly and westerly winds were more intense during the observation periods. To show the impact of the small UAV data on the forecast more clearly, the one-cycle data of assimilation (10-12 JST 18 July) were added to the operationally assimilated data of JMA in this report. It is expected that the rainfall becomes more intense when these data are assimilated.

When the observation data of the small UAV at the heights of every 50 m from 50 m height were assimilated, PWV and wind speeds increased in the western side of southern Kyushu. Moreover, the area of rainfall over 20 mm increased and be closer to that of the observed rainfall distribution (wUAV, Fig.6). It is found that the small UAV observation can improve rainfall forecasts through data assimilation if it observes the upstream side of the low-level inflow.

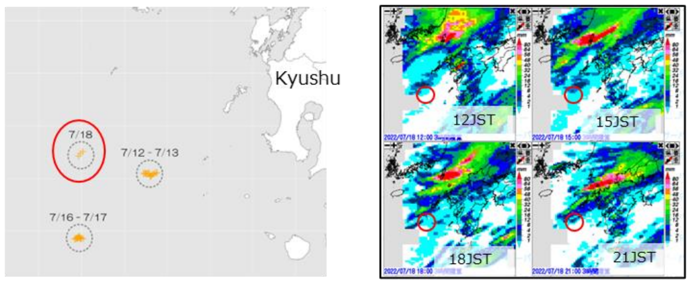


Fig. 4 (left) Positions of small UAV. (right) Rainfall distributions from 12JST to 21JST 18 July 2022. The position of JMA's vessel is indicated by red circles.

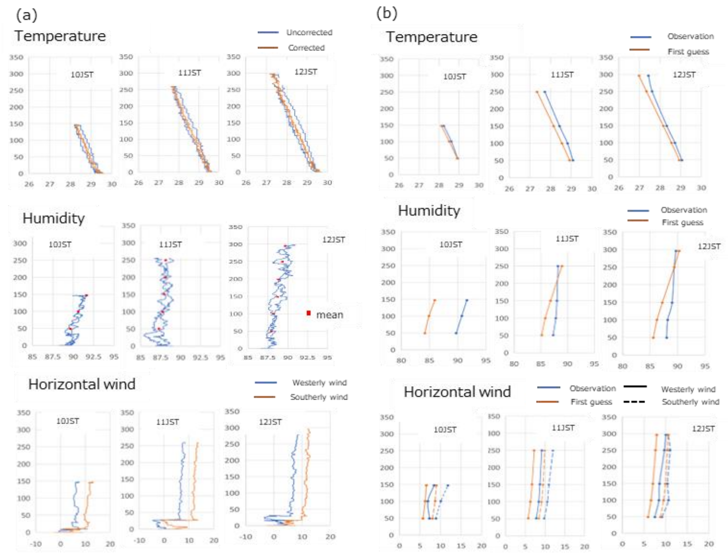


Fig. 5 (a) (upper) Observed vertical profiles of temperature before and after correction. Observed vertical profiles of (middle) humidity and (bottom) horizontal wind.
(b) Observed vertical profiles used in the assimilation and first guess vertical profiles of (upper) temperature, (middle) humidity, and (bottom) horizontal wind.

4. Summary

Assimilation experiments of PWV, vertical profiles of temperature and humidity observed by MWR and temperature, humidity, and horizontal winds in the lower atmosphere observed by small UAV were conducted using Meso-NAPEX. It is found that rainfall forecasts were improved even if the observation data at one point were assimilated, although the impact was weak. To obtain a more conclusive result, it is necessary to increase the number of assimilation data of MWR and small UAV, to assimilate more frequently, and to use brightness temperatures of MWR that include information on the vertical distribution of the temperature and humidity.

Acknowledgement:

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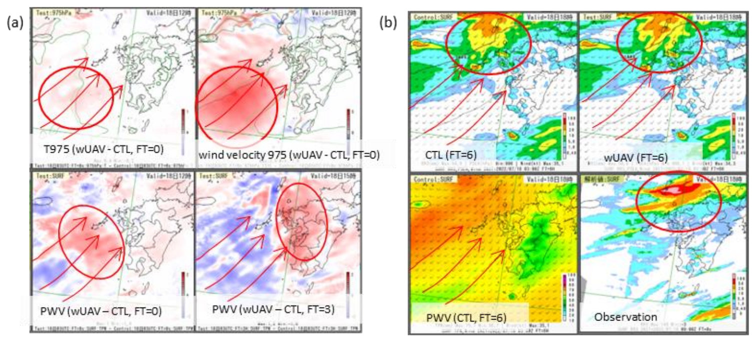

Fig. 6 (a) Differences of (upper left) temperature and (upper right) wind speed of 975 hPa height at FT=0 obtained with small UAV data (wUAV) and without small UAV data (CTL). Differences of PWV between wUAV and CTL at (bottom left) FT=0 and at (bottom right) FT=3hours. (b) 3hour precipitations of (upper left) CTL and (upper right) wUAV. (bottom left) PWV distribution of CTL at FT=6hours, and (bottom right) observed rainfall region at18JST (the same time of FT=6hours).

Reference

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