The Impact of Ground-Based Microwave Radiometer Data to Estimation of Thermodynamic Profiles in Low-Level Troposphere

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1. Introduction

In order to forecast and nowcast severe storms, temporally and spatially high-resolution estimation of thermodynamic and dynamic environments is highly required. A ground-based microwave radiometer profiler (MWR) has been used to retrieve vertical profiles of atmospheric temperature, water vapor, and liquid water content at time intervals within a few minutes. As retrieval methods, various inversion methods such as neural networks (NNs) and variational techniques (e.g., Araki et al. 2014; Ishimoto 2015) have been proposed. Recently, variational approaches have been known to outperform other methods in retrieving vertical profiles of atmospheric temperature and water vapor, especially in lower troposphere. These approaches are based on the data assimilation of 1-dimensional variational (1DVAR) techniques which combine radiometric observations with the outputs from numerical weather prediction model. The purpose of this study is to investigate the effectiveness of a new 1DVAR method using zenith and off-zenith observations. Using the MWR observation data collected at Tsukuba, Japan, NN- and 1DVAR-derived thermodynamic profiles are compared with radiosonde observations.

2. Accuracy of 1DVAR-derived thermodynamic profiles

In this study, we used the ground-based multi-channel MWR (model: MP-3000A, Radiometrics) installed at the Meteorological Research Institute of Japan Meteorological Agency (JMA) in Tateno, at 36.05°N, 140.13°E. The MWR observes the brightness temperatures (TBs) of 21 K-band (22–30 GHz) and 14 V-band (51–59 GHz) microwave channels with the band width of 300 MHz in zenith direction and at an elevation angle of 15° in north and south azimuth directions, the radiation temperature of one zenith-looking infrared (9.6–11.5 μm wavelength) channel, and the in situ surface atmospheric temperature, relative humidity, and pressure. A rain sensor is also combined with the MWR. The MWR observations were sccessfully conducted from 25 April to 27 June 2012, and the radiosonde observations at the JMA station in Tateno during this period were used for verification of retrieved vertical profiles of temperature and water vapor density. The vertical resolutions of NN-derived profiles are 50 m from the surface to 500 m, 100 m to 2 km, and 250 m to 10 km.

The 1DVAR technique used in this study is based on Ishimoto (2015). In this method, retrieval variables $\mathbf{x}$ represents profiles of atmospheric temperature and water vapor density. The iterative solution that minimizes the cost function is given by

$$\mathbf{x}_{\mathbf{i+1}} = \mathbf{x}_{\mathbf{i}} + (\mathbf{B}^{-1} + \mathbf{H}_{\mathrm{i}}{}^{T}\mathbf{R}^{-1}\mathbf{H}_{\mathrm{i}})^{-1}[\mathbf{H}_{\mathrm{i}}{}^{T}\mathbf{R}^{-1}(\mathbf{y} - \mathbf{F}(\mathbf{x}_{\mathbf{i}})) - \mathbf{B}^{-1}(\mathbf{x}_{\mathbf{i}} - \mathbf{x}_{\mathbf{b}})]$$

where $\mathbf{x}_{\mathbf{i}}$ and $\mathbf{x}_{\mathbf{b}}$ are current and background state vectors, respectively; $\mathbf{H}_{\mathbf{i}}$ is the Jacobian matrix of the observation vector with respect to the state vector; $\mathbf{B}$ and $\mathbf{R}$ are the error-covariance matrices of $\mathbf{x}_{\mathbf{b}}$ and of the observation vector $\mathbf{y}$, respectively; and $\mathbf{F}(\mathbf{x}_{\mathbf{i}})$ is the forward model operator. Note that the zenith and off-zenith observations are separately used as the observation vectors in this study. By using the off-zenith observations as the observational vectors, the sensitivities to water vapor and atmospheric temperature increase in all altitudes and in low-level troposphere, respectively (not shown).

The numerical model used in this study is the JMA non-hydrostatic model (NHM; Saito et al. 2006). Numerical experiments with a horizontal grid spacing of 5 km and a domain covering Japan were performed. The 24-hour atmospheric conditions were simulated from 24 hours before each radiosonde observation. The initial and boundary conditions were provided from 3-hourly JMA mesoscale analyses and the 1-hourly forecasts of the JMA operational global spectrum model, respectively. The time step of the simulation was 20 seconds, and the results were output at 10-minute intervals. Other setups were the same as those used in Saito et al. (2006). Vertical profiles averaged over 25 × 25 km squares centered at Tateno were interpolated to MWR observation times and used for the 1DVAR retrievals. The vertical profiles derived from Sonde, NHM, and 1DVAR were interpolated according to the NN altitude resolution. In this study, NN-, NHM-, and 1DVAR-derived profiles averaged for 30 minutes before each radiosonde observation were compared with Sonde-derived profiles.

Figure 1 shows the vertical profiles of mean difference (MD), standard deviation (STD) and root-mean-square (RMS) error of NN-, 1DVAR-, and NHM-derived atmospheric temperature with respect to Sonde-derived profiles for cases where a rain sensor didn't observe rain 1 hour before and after the radiosonde observations between 25 April and 27 June 2012 (87 cases). The inferiors of Z, S, and N in NN and 1DVAR respectively indicate the retrievals using zenith, off-zenith observations in southern and northern azimuth directions. Figure 2 is same as Fig. 1 but for water vapor density.

NHM- and 1DVAR-derived temperature profiles showed good agreement; the absolute MD was less than 1 K in any altitudes (Fig. 1). The STD and RMS error for 1DVAR-derived temperature were about 1 K in any altitudes, but those of NHM-derived one reached 1.5 K below 0.5 km. The absolute MD for NHM- and 1DVAR-derived water vapor densities was less than 0.5 g m^{-3} in any altitudes, and the values of 1DVAR-derived one were less than that of NHM-derived one (Fig. 2). The STD and RMS error for 1DVAR-derived vapor density were less than 1.5 g m^{-3} in any altitudes, although those of NHM-derived one reached 2 g m^{-3} at around 1 km. The result shows 1DVAR technique successfully improves the thermodynamic profiles especially in low troposphere as compared to the other methods. Cimini et al. (2011) investigated the accuracy of vertical profiles obtained by a different 1DVAR technique using off-zenith observations as observational vectors and the 1-hourly analyses provided by the NOAA Local Analysis and Prediction System as the first guesses, and showed that their 1DVAR technique outperformed the analyses. Although their study used the MWR observation data during a winter season when there was less water vapor, our results showed that the 1DVAR technique also significantly improved the accuracy of water vapor profiles in comparison with NHM simulation results even in a warm season when water vapor concentrations are much higher than winter season.

3. Conclusions and remarks

A new 1DVAR technique using MWR observations was applied and the accuracy of retrieved thermodynamic profiles was statistically investigated. The comparisons with radiosonde observations showed that the 1DVAR technique successfully improved the vertical profiles of temperature and water vapor density, especially in low troposphere as compared to retrievals by neural networks and numerical simulation results. This result suggests that the 1DVAR technique is helpful in nowcasting the severe storms. It's also desired that the impact of MWR data used in cloud-resolving four-dimensional variational data assimilation system on the accuracy of severe storm forecast will be investigated.

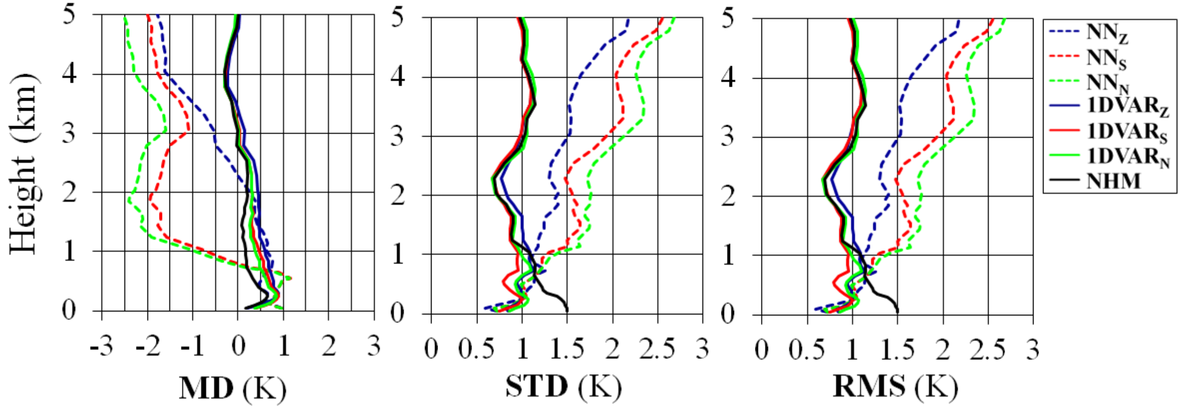

Figure 1. Mean difference (MD), standard deviation (STD) and root-mean-square (RMS) error of NN-, 1DVAR-, and NHM-derived atmospheric temperature with respect to radiosonde soundings.

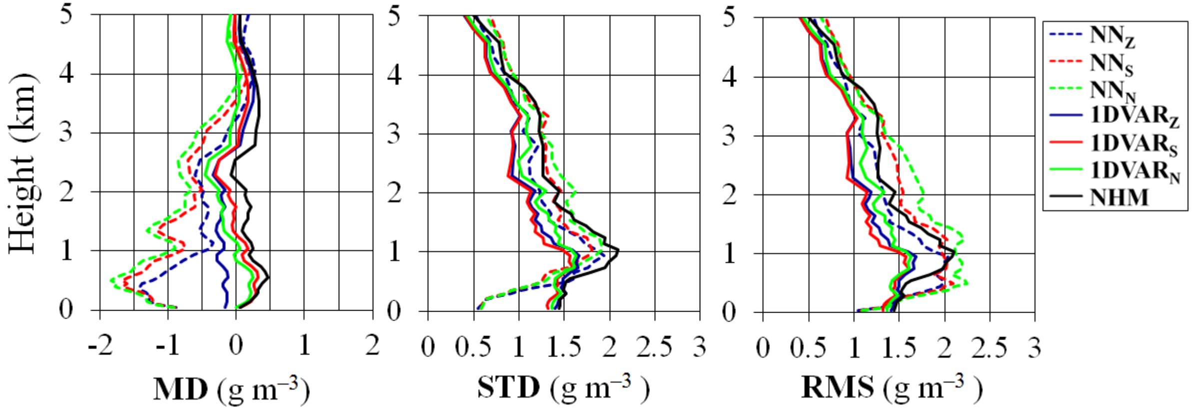

Figure 2. Same as Fig. 1, but for water vapor density.

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