Validation of Vertical Thermodynamic Profiles by Cloud Base Temperature Obtained from a Ground-Based Infrared Radiometer in a Mountain Region of Central Japan during Warm Seasons

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1. Introduction

Accurate estimation of thermodynamic profiles is required for nowcasting severe storms and diagnosing their environmental conditions. Forecasters have traditionally diagnosed convective cloud development in the Central Mountain regions in Japan in warm seasons by using 12-hourly operational radiosonde observations at Tateno (36.05°N, 140.13°E) in the plain region. However, vertical structure of thermodynamic environments for such convective cloud development and their diurnal variations have not been well understood. In general, mesoscale numerical weather models often fail to reproduce diurnal variations of atmospheric conditions in the boundary layer (e.g., Hanna and Yang 2001). Some studies also reported that the errors of forecasts for atmospheric fields in the boundary layer increase in complex terrains (e.g., Zhang et al. 2013).

Recently, the one dimensional variational (1DVAR; Araki et al. 2015) technique combining a ground-based microwave radiometer (MWR) data with results of numerical model simulations has been known to outperform other methods in estimating thermodynamic profiles in the low-level troposphere. Araki et al. (2016) statistically investigated the diurnal variation of the thermodynamic environment for convective cloud development in the Central Mountain regions using 1DVAR-retrieved vertical thermodynamic profiles based on the MWR observations at Ogouchi (35.79°N, 139.05°E) in the mountain region. They reported that the lifted condensation level (LCL) derived from 1DVAR-retrieved profiles increased during daytime, although the diurnal variation of LCL derived from the Japan Meteorological Agency Non-Hydrostatic Model (NHM; Saito et al. 2006) was unclear. The purpose of this study is to validate the NHM-simulated and 1DVAR-retrieved thermodynamic profiles using cloud base temperature obtained from ground-based infrared radiometer data.

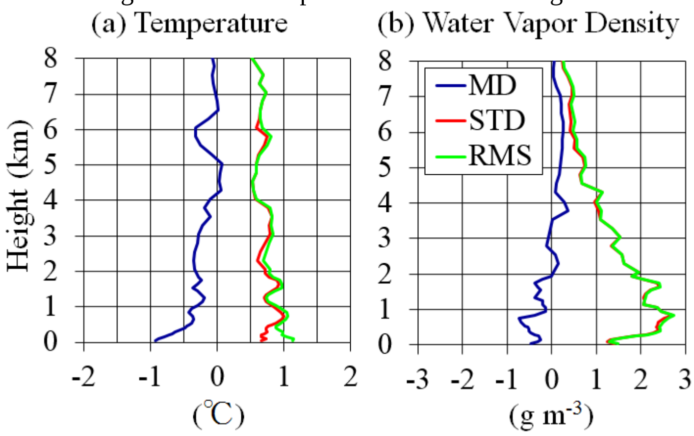

Figure 1. Comparisons between NHM-simulated and observed vertical profiles for (a) temperature (°C) and (b) water vapor density (g m^{-3}) at Tateno. Blue, red, and green lines respectively indicate the MD, STD, and RMS difference of NHM-simulated profiles with respect to observations.

Table 1. MDs, STDs, and RMS differences of NHM-simulated (a) surface temperature (°C) and (b) water vapor mixing ratio (g kg^{-1}) with respect to surface observations at Tateno and Ogouchi at 09 and 12 JST.

(a) Temperature (°C)

	MD	STD	RMS
Tateno 09	-1.20	0.93	1.52
Tateno 12	-0.66	0.88	1.10
Ogouchi 09	-0.14	1.50	1.21
Ogouchi 12	-2.07	1.11	2.18

(b) Mixing ratio of water vapor (g kg^{-1})

	MD	STD	RMS
Tateno 09	-0.2	1.23	1.25
Tateno 12	-2.33	1.59	2.83
Ogouchi 09	-3.21	1.26	3.45
Ogouchi 12	-2.65	1.29	2.94

2. Verification of the NHM-simulated and 1DVAR-retrieved thermodynamic profiles

In this study, the 1DVAR technique developed by Araki et al. (2015) was applied to retrieve atmospheric temperature and water vapor profiles at Ogouchi, where the NHM-simulated temperature and humidity profiles (first guesses) are adjusted by assimilating the MWR (MP-3000A, Radiometrics) data of the brightness temperatures (TBs) at 22–30 and 51–59 GHz. The details of the 1DVAR and model settings are given in Araki et al. (2016). The infrared radiometer is attached to the MWR and observes the infrared TB (wavelength of 9.6–11.5 μm) in zenith-looking mode, which provides cloud base information. Vertical thermodynamic profiles derived from 1DVAR and NHM were validated for 29 summertime fair-weather days from 2011 to 2013 selected by Araki et al. (2016).

In order to evaluate the accuracy of NHM-simulated vertical profiles of atmospheric temperature and water vapor, results of the simulations were compared with operational radiosonde observations at Tateno at 09 JST (JST=UTC+9h) for all cases (Fig. 1). Absolute mean differences (MDs) of NHM-simulated temperature and water vapor density with respect to radiosonde observations were respectively 0.5–1.0 °C and 0.2–1.0 g m^{-3} at altitudes less than 2 km, and absolute MDs, standard deviations (STDs), and root-mean-square (RMS) differences were large in low-level troposphere for both temperature and water vapor density. On the other hand, errors of temperature and water vapor density were relatively small at altitudes above 2 km. Table 1 shows the MDs, STDs, and RMS differences of NHM-simulated surface temperature and water vapor mixing ratio with respect to surface observations at Tateno and Ogouchi at 09 and 12 JST. The absolute MDs, STDs, RMS differences of NHM-simulated surface temperature were 0.6–1.0 °C at both 09 and 12 JST (Table 1a). Although these values for Ogouchi at 09 JST were similar to those for Tateno, the absolute MD and RMS difference of surface temperature reached 2 °C at 12 JST. With respect to waetr vapor mixing ratio, the absolute MD and RMS difference became larger at Tateno from 09 to 12 JST. At Ogouchi, the absolute MD and RMS difference at both 09 and 12 JST were similar to those at Tateno at 12 JST. These results suggested that the NHM-simulated thermodynamic environments had significant errors near the surface and in low-level troposphere, and that the errors in the plain region increased during daytime but the errors in the mountain region were large all through the day. Since the 1DVAR technique especially improves low-level thermodynamic profiles (Araki et al. 2015), it’s promising that the 1DVAR-retrieved thermodynamic profiles at Ogouchi would be reliable.

To verify the 1DVAR- and NHM-derived thermodynamic profiles, precipitable water vapors (PWVs) obtained from each water vapor profile were firstly compared with PWVs retrieved from MWR neural network (NN) technique (Fig. 2), which was confirmed to be accurate as same as GPS-derived PWV (Araki et al. 2014). The MD and RMS difference of 1DVAR-derived PWVs were respectively –1.1 and 1.8 mm, although those of NHM-derived PWVs were –3.1 and 4.0 mm. Secondly, cloud base temperature (same as TB) observed by infrared radiometer and temperature at the LCL derived from 1DVAR and NHM were compared (Fig. 3). In this comparison, assuming shallow cumulus formation before the convective cloud development in the afternoon, 10-minute maximum TBs higher than 10 °C, which were measured with the infrared radiometer from 09 to 12 JST, were used in the comparison. The MD and RMS difference of 1DVAR-derived LCL temperature were 0.0 and 1.6 K, although those of NHM-derived LCL temperature were –2.4 and 3.2 K. The difference of NHM-derived LCL temperature increased during the time period from 11 to 12 JST. These results show that the 1DVAR technique successfully outperformed the NHM simulation in estimating vertical thermodynamic profiles.

3. Conclusions and remarks

Vertical thermodynamic profiles derived from 1DVAR and NHM simulations at Ogouchi during warm seasons were verified by using MWR and infrared radiometer data. It’s confirmed that the 1DVAR technique successfully provided reliable temperature and water vapor profiles, and that vertical structures of thermodynamic profiles and their diurnal variations can be discussed by using 1DVAR-derived profiles in Araki et al. (2016). For numerical model developments, it’s desired that the physical processes of the boundary layer, radiation, and land-surface condition would be improved.

References:

Araki, K., H. Ishimoto, M. Murakami, and T. Tajiri, 2014: Temporal variation of close-proximity soundings within a tornadic supercell environment. *SOLA*, **10**, 57–61.

Araki, K., M. Murakami, H. Ishimoto, and T. Tajiri, 2015: Ground-based microwave radiometer variational analysis during no-rain and rain conditions. *SOLA*, **11**, 108–112.

Araki, K., M. Murakami, T. Kato, and T. Tajiri, 2016: Diurnal variation of thermodynamic environments for convective cloud development around the Central Mountains in Japan during warm seasons. *CAS/JSC WGNE Research Activities in Atmospheric and Oceanic Modelling*, **46**.

Saito, K., T. Fujita, Y. Yamada, J. Ishida, Y. Kumagai, K. Aranami, S. Ohmori, R. Nagasawa, S. Kumagai, C. Muroi, T. Kato, H. Eito, and Y. Yamazaki, 2006: The operational JMA nonhydrostatic mesoscale model. *Mon. Wea. Rev.*, **134**, 1266–1298.

Hanna, S. R., and R. Yang, 2001: Evaluations of mesoscale models' simulations of near-surface winds, temperature gradients, and mixing depths. *J. Appl. Meteor.*, **40**, 1095–1104.

Zhang, H., Z. Pu, and X. Zhang, 2013: Examination of errors in near-surface temperature and wind from WRF numerical simulations in regions of complex terrain. *Wea. Forecasting*, **28**, 893–914.

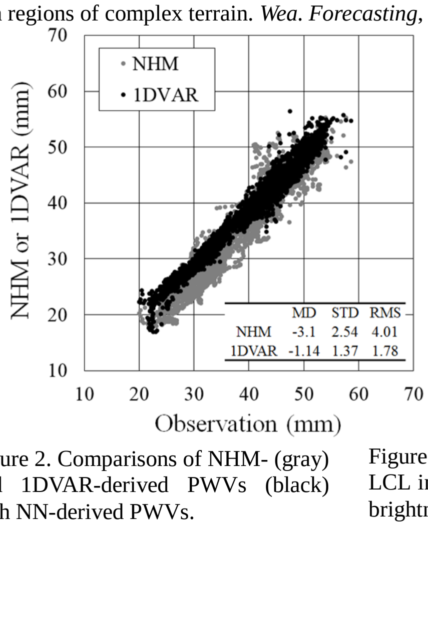

Figure 2. Comparisons of NHM- (gray) and 1DVAR-derived PWVs (black) with NN-derived PWVs.

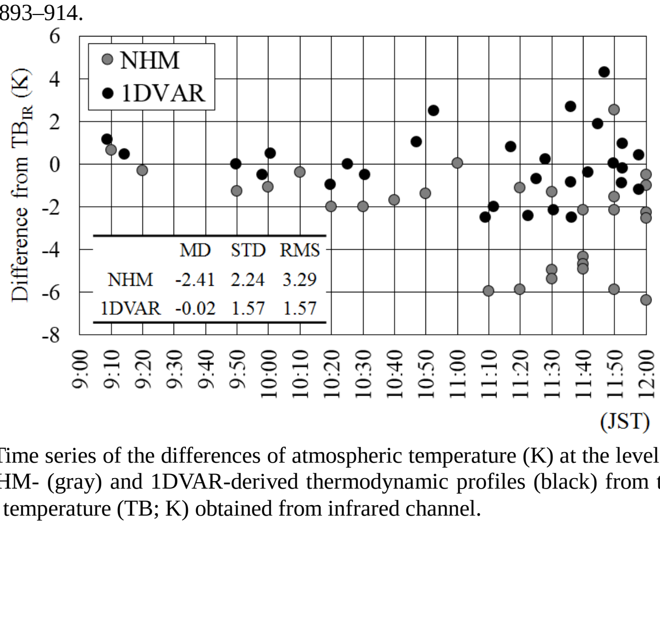

Figure 3. Time series of the differences of atmospheric temperature (K) at the level of LCL in NHM- (gray) and 1DVAR-derived thermodynamic profiles (black) from the brightness temperature (TB; K) obtained from infrared channel.