Application of 1DVAR Technique using Ground-Based Microwave Radiometer Data to Estimation of Temporally High-Resolution Thermodynamic Environments in a Tornadic Supercell Event

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1. Introduction

The prediction and nowcast of significant tornadic (SIGTOR) supercells remain challenging because the environments favorable for supercells are not well understood. Although several previous studies have examined proximity soundings within supercell environments, no study has provided information on temporal variations of SIGTOR supercell environments at intervals of a few minutes.

Recently, ground-based microwave radiometer profilers (MWRs) have been used to retrieve vertical profiles of air temperature and water vapor density at time intervals of a few minutes. Araki et al. (2015) showed that 1-dimensional variational (1DVAR, Ishimoto 2015) technique, which combines radiometric observations with outputs from a numerical weather forecast model reduced the error in thermodynamic profiles derived from numerical simulations, especially in low-level troposphere.

The purpose of this study is to investigate the temporal variation, at intervals of a few minutes, of the environment of a supercell which caused a significant tornado (rank F3) in the northern part of the Tsukuba city in Japan on 6 May 2012. MWR observations were successfully conducted at the Meteorological Research Institute (MRI) in Tsukuba at distances less than 20 km from the tornado. We used a 1DVAR technique (Araki et al. 2015) to obtain the thermodynamic profiles and examined the temporal variations of several supercell and tornado forecast parameters by using both 1DVAR-derived thermodynamic profiles and wind profiles obtained from numerical simulations. The details of this study are described in Araki et al. (2014).

2. Temporal variation of tornado forecast parameters

We used the ground-based MWR (MP-3000A, Radiometrics) installed at the MRI in Tateno (in Tsukuba), at 36.05°N, 140.13°E. The MWR observes the brightness temperatures of 21 K-band (22–30 GHz) and 14 V-band (51-59 GHz) microwave channels at zenith direction. The details and accuracy of the 1DVAR technique used in this study are given by Ishimoto (2015) and Araki et al. (2015), respectively. We performed a numerical experiment using the JMA <u>n</u>on-<u>h</u>ydrostatic <u>m</u>odel (NHM; Saito et al. 2006) with a horizontal grid spacing of 1 km and a model domain covering the Kanto Plain, and the result was used for the first guess in the 1DVAR analysis.

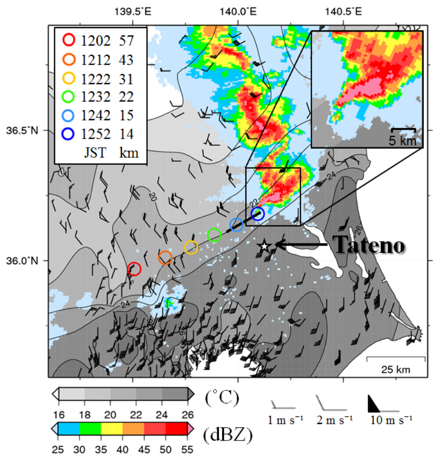

Figure 1. Observed features of the tornadic supercell on 6 May 2012. Surface air temperature (gray), wind (barbs) at 1300 JST, provided by surface networks. PPI reflectivity observed by the Tokyo Doppler radar at an elevation angle of 1.7° at 1252 JST. The white star and the black solid line indicate the location of Tateno and the path of the tornado, respectively. Colored circles indicate the locations of the hook echo observed on the PPIs at the same elevation angle; the observation times and the distances from Tateno are shown in the upper-left corner.

The Tsukuba F3 tornado occurred 13–17 km northwest of Tateno from 1235 to 1251 JST on 6 May 2012 (Fig. 1). A classic supercell with a well-defined hook echo moved east-northeastward along the low-level convergence line formed by warm southwesterly and cold northwesterly flows to the northwest of Tateno. The surface networks observed warm southerly flows and no rainfall at Tateno during the event. These conditions were suitable for the MWR at Tateno to observe the supercell environment.

Time-height cross sections of water vapor density derived from 1DVAR and NHM, and the difference of them between 0900 and 1500 JST are shown in Fig. 2. In the NHM-derived profiles, the thickness of the layer with water vapor density greater than 12 g m^{-3} was about 1 km. From the result of Araki et al. (2015), NHM-derived water vapor density between 500 m and 1 km has a positive bias and error of about 2 g m^{-3}. The 1DVAR-derived profiles successfully reduced the high water vapor density between 500 m and 1 km by more than 1.5 g m^{-3}.

Time series of mean layer (0–1 km) convective available potential energy (MLCAPE), storm relative helicities of 0–1 and 0–3 km (SRH1km, SRH3km), and significant tornado parameter (STP) between 0900 and 1500 JST are shown in Fig. 3. These values were compared with typical values in SIGTOR (F2-F5 tornado damage) supercell environment in the United States reported in Thompson et al. 2003 (hereafter T03). The 1DVAR-derived MLCAPE increased significantly to about 1000 J kg^{-1} 1.5 hours before the occurrence of the tornado, although the value was smaller than the T03 values of 1059–3683 J kg^{-1}. A high MLCAPE before the approach of the supercell indicates the existence of environmental conditions favorable for the supercell. The SRH1km and SRH3km respectively attained maximum values of 170 and 260 m^2 s^{-2} for 1230–1250 JST. These vertical wind shear parameters are comparable to typical values, and indicate that a strong, low-level, vertical wind shear supports the SIGTOR supercell environment. The 1DVAR-derived STP also attained a maximum value of 1.2 at around 1250 JST, which was within the range of typical values, 0.5–6.3.

3. Conclusions and remarks

We used the 1DVAR technique to obtain close-proximity, high-frequency, probable soundings within the Tsukuba F3 tornadic supercell environment. The tornado forecast parameters obtained from 1DVAR-derived thermodynamic profiles indicated that the Tsukuba F3 tornadic event occurred under conditions associated with a SIGTOR supercell category. The results of this study also show that thermodynamic environments became unstable before the approach of the SIGTOR supercell and that low-level vertical wind shear changed locally near the supercell. The combination of high-frequency thermodynamic profiles retrieved from MWR data and wind profiler data would be of benefit in nowcasting severe storms such as SIGTOR supercells.

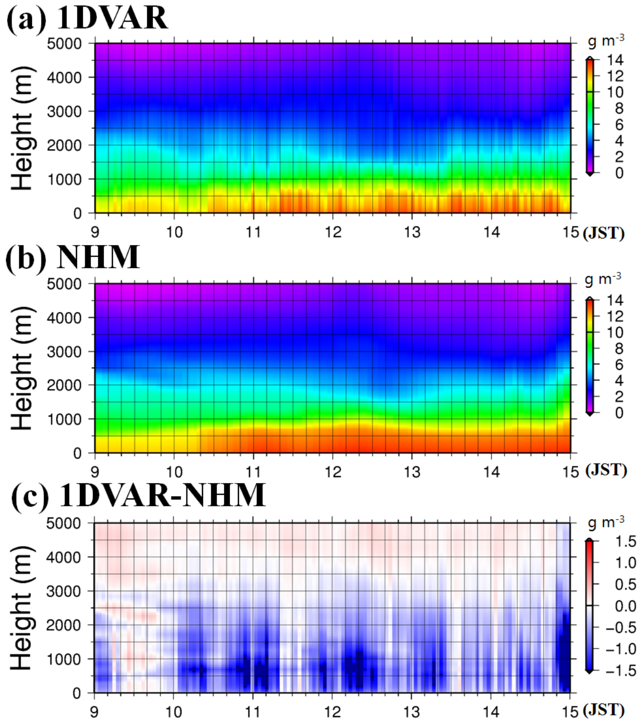

Figure 2. Time-height cross sections of (a) 1DVAR- and (b) NHM-derived water vapor density; and (c) the difference between (a) and (b).

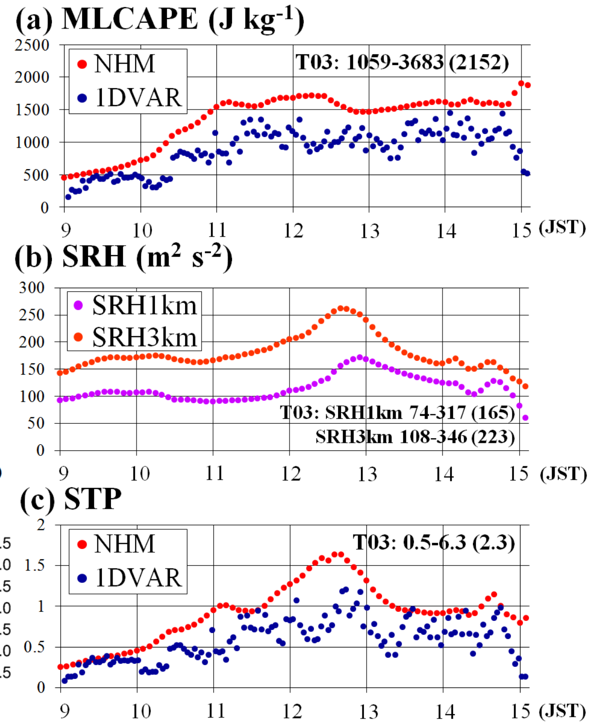

Figure 3. Time series of parameters of (a) MLCAPE (b) SRH1km and SRH3km, and (c) STP. Numbers in each panel indicate the 10th and 90th percentiles, and the median (in parentheses) of each parameter in the SIGTOR supercell category reported by T03.

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