Application of 1DVAR Technique using Ground-based Microwave Radiometer Data to Estimating Thermodynamic Environments in Winter Convective Clouds

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1. Introduction

In winter, convective clouds sometimes develop and cause local snowfalls and lightning strikes in the Kanto plain in Japan. To understand and forecast these winter convective clouds, temporally high-resolution analysis of environmental conditions is required. Recently, in order to understand temporal variations of thermodynamic conditions of convective clouds, one-dimensional variational (1DVAR; Araki et al., 2015) analysis combined with numerical weather model and microwave radiometer (MWR) data has been applied into the cases of convective clouds causing a tornado in spring (e.g., Araki et al., 2014) and causing local heavy rainfalls in summer (e.g., Araki et al., 2017) in the Kanto plain. In this study, we performed a case study on the winter convective clouds on 26 January 2019, and examined the temporal variation of environmental conditions and features of convective clouds by using Japan Meteorological Agency (JMA) analysis data, dense surface meteorological observation data, Himawari-8 data, JMA operational radar data, disdrometer and MWR data obtained at the Meteorological Research Institute (MRI) in Tsukuba, Ibaraki.

2. Temporal variation of thermodynamic environment of winter convective clouds

In this study, a ground-based multi-channel MWR (MP-3000, Radiometrics) installed at the MRI in Tsukuba (36.05°N, 140.13°E) is used for analysis of atmospheric environments and microphysical properties of convective clouds. The MWR measures the brightness temperatures 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. Vertical profiles of atmospheric temperature and water vapor density were retrieved by the 1DVAR (Araki et al., 2015) technique combining the MWR observation data and the results of the JMA Non-Hydrostatic Model (NHM) simulations. A rain sensor is combined with the MWR, and the MWR data at the time of rain was not used for the retrievals. A numerical experiment was performed using the NHM with a horizontal grid spacing of 1 km and a model domain of 500x500 km covering the Kanto plain, and the 18-hour atmospheric conditions were simulated from 06:00 JST (=UTC+9h) on 26 January 2019. The initial and boundary conditions were taken from the 3-hourly JMA mesoscale analyses, and other setups were the same as those used in Saito et al. (2006). The NHM-derived vertical profiles at Tsukuba were interpolated to MWR observation times and used for the 1DVAR retrievals. In this study, the data of a micro rain radar (MRR, METEK) and a disdrometer (Parsivel, OTT) installed at the MRI were also used for the analysis of cloud microphysical properties of the convective clouds.

On 26 January, the surface pressure pattern was the winter monsoon type and the upper cold vortex moved to the northern Japan. Since the Kanto plain was located on the southeastern side of the cold vortex, synoptic condition was favorable for convection development in the Kanto plain. In respect of the mesoscale environments, the low-level convergence line was formed in the Kanto plain by west-northwesterly and northerly airflows that crossed the mountain areas (Fig. 1). The Himawari-8 infrared images captured the cloud street associated with the convergence line from 13:30 JST, and radar echoes of convective clouds were observed by the JMA Tokyo radar from 14:40 JST. Two convective clouds developed in the convergence line and passed over Tsukuba from about 15:30 to 16:30 JST. The results of the MRR showed the existence of echo at the altitude of 3–5 km 5–10 minutes before the surface precipitation (Fig. 2a). The disdrometer observed precipitations by two convective clouds from 15:34 to 15:44 JST and from 16:03 to 16:32 JST, and liquid water path (LWP) derived by the MWR significantly increased about 20 minutes before the surface precipitation by the first convective cloud.

To investigate the temporal variation of thermodynamic environments, variations of following stability indices calculated from 1DVAR-derived thermodynamic profiles were examined; precipitable water vapor (PWV), lifted condensation level (LCL), level of free convection (LFC), equilibrium level (EL), convective available potential energy (CAPE), Showalter stability index (SSI), lifted index (LI), and K index (KI). The LCL, LFC, EL and CAPE were calculated under the assumption that the air parcel averaged over 0–500 m altitudes was lifted. From the comparison of PWVs derived from 1DVAR, NHM, and the JMA local analyses, it was indicated that the 1DVAR technique overperform the results of the NHM simulations in the water vapor field and that results of 1DVAR would contain errors due to water clouds from 15:00 to 17:00 JST. As the results, EL increased from 09:00 to 15:00 JST significantly, and LCL and LFC showed similar trends (Fig. 3a). The values of CAPE were 100–900 J kg^{-1} before the surface precipitation in Tsukuba (Fig. 3b). Indices of SSI, LI, and KI also showed that thermodynamic environments significantly became unstable before the precipitation in Tsukuba. From the results of temporal variations of retrieved PWVs, low-level and upper temperature fields, it was found that the thermodynamic environments became unstable until 15:00 JST because of the increases of low-level atmospheric temperature and influence of upper cold air flow.

3. Conclusions and remarks

In this case, the thermodynamic environments, which were obtained from the 1DVAR technique combined with the MWR data and numerical simulation data, showed unstable atmospheric conditions favorable for the convective cloud development in the Kanto plain prior to the other observations of cloud and precipitation by satellite and radar. These results suggest that the 1DVAR technique using MWR data would be of benefit in nowcasting winter convective clouds causing local snowfalls and lightning strikes. It is desired that the applicability and effectiveness of the 1DVAR technique in the other winter cases are examined in the future.

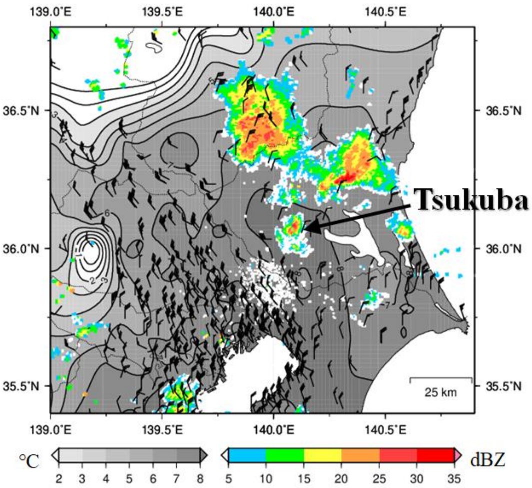

Figure 1. Surface air temperature (gray) and wind (barb) at 15:00 JST derived from the JMA stations and the Atmospheric Environmental Regional Observation System of the Japanese Ministry of the Environment. The PPI reflectivity (color) observed by the Tokyo radar at the elevation angle of 1.1° at 15:32 JST.

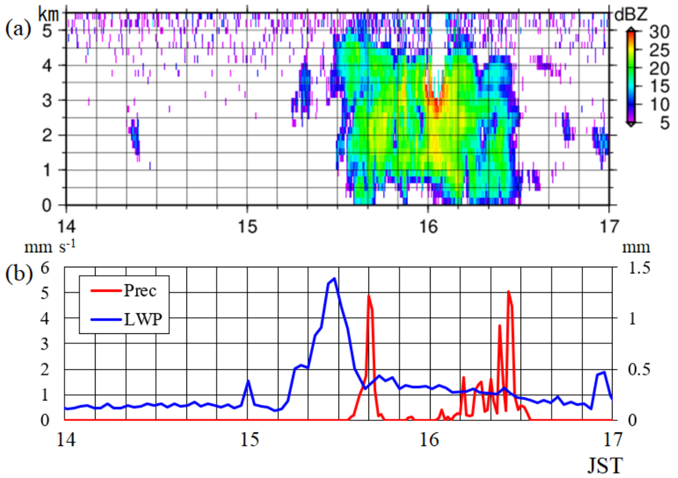

Figure 2. (a) Time-height cross sections of reflectivity derived from MRR and (b) time series of precipitation intensity (mm h^{-1}; red line) derived from the disdrometer and LWP (mm) obtained from the zenith observation by the MWR at the MRI in Tsukuba.

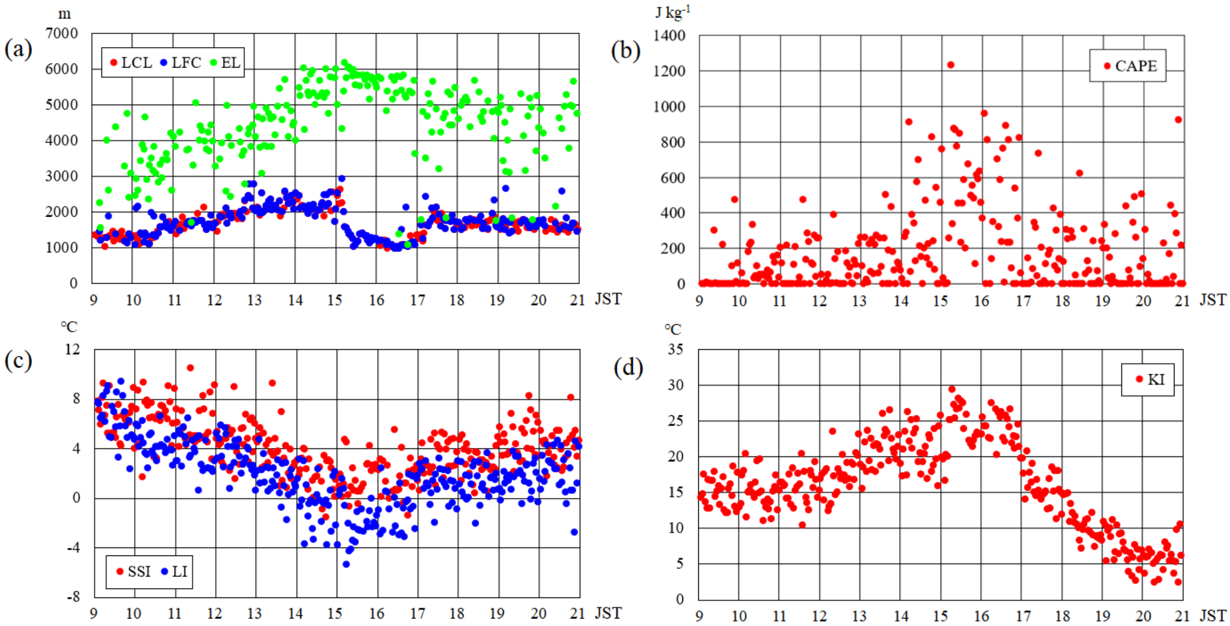

Figure 3. Temporal variations of stability indices of (a) LCL, LFC, EL, (b) CAPE, (c) SSI, LI, and (d) KI calculated by atmospheric thermodynamic profiles derived from the 1DVAR technique.

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