Diurnal Variation of Thermodynamic Environments for Convective Cloud Development around the Central Mountains in Japan during Warm Seasons

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1. Introduction

Convective clouds often develop in the afternoon of summertime fair-weather days around the Central mountains in Japan. Forecasters have traditionally diagnosed the thermodynamic environments for convective cloud development using operational radiosonde data in the morning, at 09 JST (JST=UTC+9h), of the day, because the forecast of these small-scale convective activity by operational mesoscale models still remain a challenge. Vertical structure of the dynamic and thermodynamic environments for the convective cloud development and their diurnal variation have also not been well understood because of temporally sparse observation data. In this study, diurnal variation of thermodynamic environments for both active and non-active convection cases were statistically investigated using the data from a ground-based microwave radiometer (MWR), surface weather observation system, and radiosonde in July and August from 2012 to 2014.

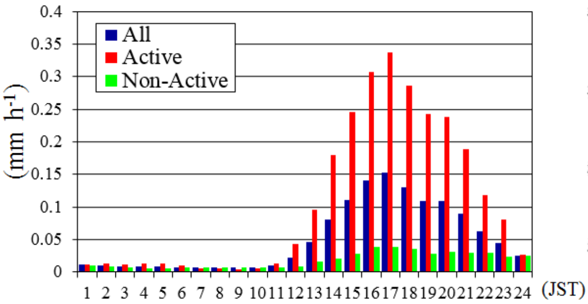

Figure 1. Diurnal variations of hourly RA_{ave} (mm h^{-1}) in (a) the Central Mountain region (137°E–141°E, 34.5°N–38°N) for extracted fair-weather cases. Red, blue, and green bars respectively indicate the average of all (29 samples), active (11 samples), and non-active cases (18 samples).

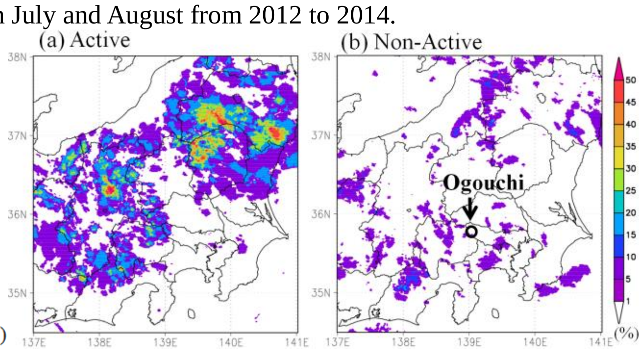

Figure 2. Horizontal distributions of occurrence frequency of rainfall greater than 1 mm h^{-1} at 17 JST for (a) active and (b) non-active cases.

2. Diurnal variation of thermodynamic environments derived from 1DVAR and NHM

Firstly, summertime fair-weather days without precipitation in the morning, which were determined by surface weather map, surface temperature and precipitation observations, were classified into active and non-active convection cases according to the area-averaged rainfall from Radar-AMeDAS Analysis (RA_{ave}). The RA_{ave} was defined as the 1-hour precipitation averaged for the Central Mountain region in Fig. 2. The peak of hourly RA_{ave} was found at 17 JST for all extracted fair-weather cases (Fig. 1). The RA_{ave} of 0.15 mm h^{-1} at 17 JST was used as a criterion between active and non-active convection cases. Active and non-active cases also had peaks of hourly RA_{ave} at 17 JST, and the peak values of RA_{ave} at 17 JST for active and non-active cases were twice greater and smaller than that for all cases, respectively (Fig. 1). Horizontal ditsributions of occurrence frequency of RA larger than 1 mm h^{-1} at 17 JST showed that much precipitation events occurred, especially around high-altitude mountain regions, in active cases (Fig. 2).

Vertical profiles of atmospheric temperature and water vapor were retrieved by a one-dimensional variational (1DVAR; Araki et al. 2014, 2015) technique combining the MWR observation data and the results of the Japan Meteorological Agency Non-Hydrostatic Model (NHM; Saito et al. 2006) simulations. We used the ground-based multi-channel MWR (MP-3000A, Radiometrics) installed at Ogouchi (35.79°N, 139.05°E; Fig. 2) in this study. The MWR observes the brightness temperatures of 35 microwave channels at 22–30 and 51–59 GHz and the radiation temperature of zenith-looking infrared channel (wavelength of 9.6–11.5 μm) at time intervals of a few minutes. A rain sensor is combined with the MWR, and the MWR data up to 10 minutes before rain onset was not used for the retrievals. Numerical experiments were performed using NHM with a horizontal grid spacing of 2 km and a model domain covering the Central Mountain regions, and the 24-hour atmospheric conditions were simulated from 00 JST for all cases. The initial and boundary conditions were taken from 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 Ogouchi were interpolated to MWR observation times and used for the 1DVAR retrievals. It was confirmed that 1DVAR-derived profiles were more reliable than NHM-simulated profiles by comparison with radiosonde data, surface weather data, and cloud base temperature obtained from an infrared radiometer. The detail of the validation of the vertical thermodynamic profiles derived from 1DVAR and NHM is given in Araki et al. (2016).

In order to investigate the diurnal variations of thermodynamic environments for both active and non-active cases, diurnal variations of following stability indices were statistically examined; precipitable water vapor (PWV), lifted condensation level (LCL), level of free convection (LFC), convective available potential energy (CAPE), Showalter stability index (SSI), lifted index (LI), K index (KI), and Total Totals index (TTI). The LCL, LFC and CAPE were calculated under the assumption that air parcel averaged over 0–500 m altitudes is lifted. Diurnal variations of these stability indices calculated from 1DVAR- and NHM-derived profiles for active and non-active cases are shown in Fig. 3. Statistical analysis based on the 1DVAR-derived thermodynamic profiles revealed that the LCL increased and the LFC decreased during daytime for both active and non-active cases, whereas the diurnal variation of NHM-derived LCL was unclear in comparison with 1DVAR-derived LCL. The PWV increased during the time period from around 12 to 18 JST for both active and non-active cases, which was suggested that water vapor in the Central Mountain regions increased due to the horizontal advection of low-level water vapor caused by the thermally-induced local circulation (e.g., Sato and Kimura 2005). Stability indices of CAPE, SSI, LI, KI, and LI had similar diurnal variations for both active and non-active cases, although they showed that atmospheric stratification was more unstable for active cases than for non-active cases. Especially for PWV, SSI, LI, KI and TTI, the differences between active and nonactive cases were significant all through the day. In addition, from the results of surface and wind profiler observations, no significant difference between active and non-active cases was found in vertical structure and diurnal variation of thermally-induced local circulations in terms of ability to trigger the convective clouds (not shown).

3. Conclusions and remarks

Diurnal variation of thermodynamic environments for convective cloud development in the Central Mountain regions in Japan in warm seasons was statistically investigated by using the 1DVAR technique combining the MWR data and numerical model simulations. The 1DVAR technique provided realistic and temporally high-resolution thermodynamic profiles in the mountain region, and revealed the detailed diurnal variations of thermodynamic environment for active and non-active convection cases. It's found that the traditional method based on radiosonde observations at 09 JST is of benefit for the diagnosis of the convective activity in the afternoon of the day around the Central Mountains in Japan, even if considering the effect of diurnal variations of the dynamic and thermodynamic environments.

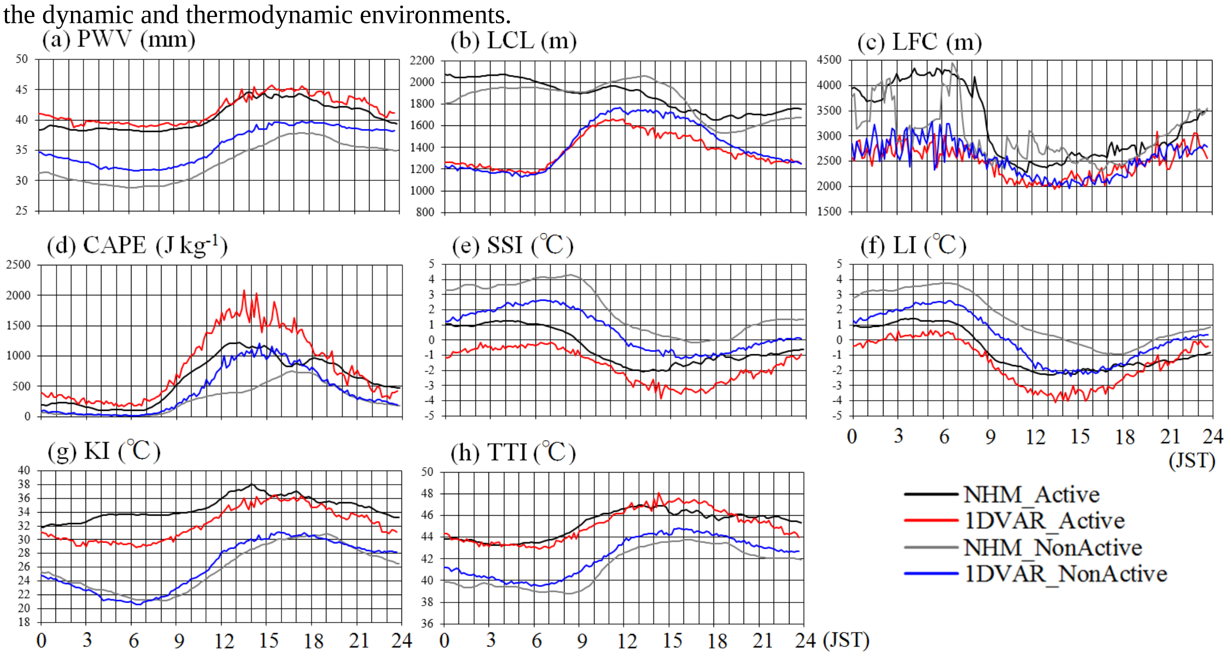

Figure 3. Diurnal variations of stability indices of (a) PWV, (b) LCL, (c) LFC, (d) CAPE, (e) SSI, (f) LI, (g) KI, and (h) TTI calculated by atmospheric thermodynamic profiles derived from NHM-simulation and 1DVAR technique averaged for active and non-active cases.

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