Relation of Dec. 2005 heavy snowfall and cloud-top heights around the Japan-Sea side of the Japan Islands, estimated from objective analyses and forecasts of cloud-resolving model

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Cloud-top heights of cumulonimbi are almost estimated from the level of neutral buoyancy (LNB). A low-level humid air is lifted adiabatically from the originating level to the lifting condensation level along the dry adiabat, and it is lifted further along the moist adiabat. The upper point at which the moist adiabat crosses the profile of temperature is the LNB. The higher equivalent potential temperature makes the LNB higher. Over the Sea of Japan in winter, a near-surface air gets sensible and latent heat from relatively warm sea surface. This air-mass transformation becomes larger when the fetch becomes longer and the temperature distance between sea surface and cold air-mass becomes larger. Therefore, the low-level equivalent potential temperature becomes higher around the Japan-Sea side of the Japan Islands, and consequently cloud-top heights become higher there. It should be noted that the Japan Islands are located on the downstream side of the Sea of Japan for the winter monsoon (i.e., northwesterly winds).

The LNB around the Japan-Sea side of the Japan Islands is statistically examined using 6-hourly Regional Objective Analysis Data (RANAL, horizontal resolution: 20 km) of the Japan Meteorological Agency (JMA). The statistical period is December and January in 2001-2005 winter seasons. The relation between Dec. 2005 heavy snowfall and cloud-top heights is comparatively examined from the horizontal distributions of averaged LNB in Dec. 2005 and the other years. The averaged LNB in 2005 is higher than 700 hPa, and it becomes exceeding 50 hPa higher than that in the other years. The appearance rate of LNB in 2005 is also 20-30 % higher. Therefore, heavy snowfall in Dec. 2005 was caused by the environmental condition under which cumulonimbi not only easily form, but also develop higher.

The consistency between cloud-top heights and the above-mentioned LNB is examined using the simulated results of a cloud-resolving model (JMA nonhydrostatic model (Saito et al 2006) with the horizontal resolution of 1 km, 1km-CRM). The initial and boundary conditions of 1km-CRM are produced from the 12-hour forecasts of JMA nonhydrostatic model with the horizontal resolution of 5 km (5km-NHM). The initial and boundary conditions of 5km-NHM are produced from the RANAL. The precipitation in 1km-CRM is calculated using a bulk-type microphysics scheme in which the mixing ratios of cloud and ice cloud, rain, snow and graupel are predicted. In 5km-NHM, the Kain-Fritsch convective parameterization scheme is used conjunctionally with a microphysics scheme. 9-hour forecasts are performed 4 times a day by the 1km-CRM, and 3-9 hour predicted data are used in this statistical study. The rainfall distribution predicted by the 1km-CRM (Fig. 4a) well reproduced that of JMA Radar-Raingauge analyzed precipitation (R-A, not shown), although the rainfall amount is overestimated. This overestimation could be brought from the underestimation of R-A.

Figure 1a shows the horizontal distribution of averaged cloud-top heights in Dec. 2005 simulated by the 1km-CRM. Higher cloud-top heights are found over plain areas (about 680 hPa). Meanwhile, cloud-top heights are relatively lower over mountainous areas, because clouds formed by updrafts on the slope are included. The vertical profiles of appearance rate of predicted cloud-top heights (Fig. 2a) show that the LNB over a 600-hPa level in Dec. 2005 appears exceeding two times more frequently than in Jan. 2006, and the vertical level with the maximum frequency is exceeding 50 hPa higher. In other words, the higher development of snow clouds caused the heavy snowfall in Dec. 2005.

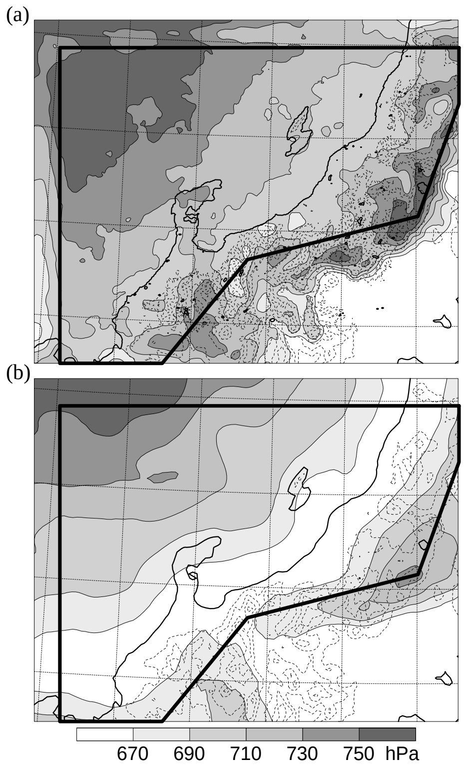

Fig. 1 Horizontal distribution of averaged cloud-top heights in Dec. 2005 predicted by (a) the 1km-CRM and (b) 5km-NHM. Cloud-top heights are determined by the threshold value of hydrometeor mixing ration 0.1 g kg^{-1}. Broken lines denote the topography with intervals of 500 m.

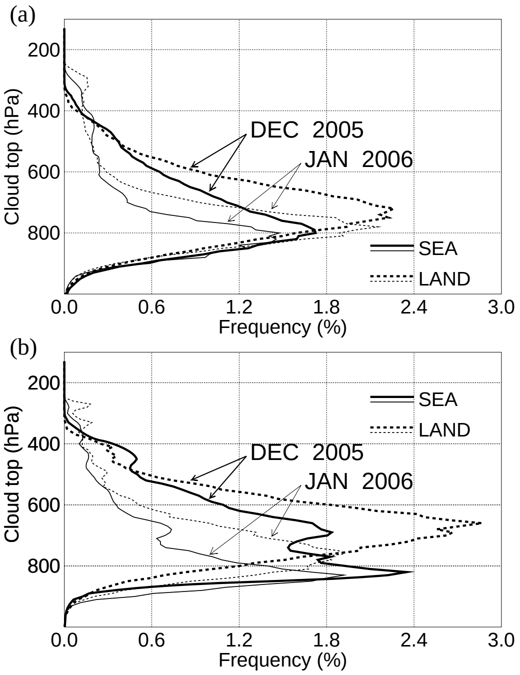

Fig. 2 Vertical profiles of appearance rate of cloud-top heights, found over grids points with updrafts, predicted by (a) 1km-CRM and (b) 5km-NHM. Each rate is calculated by dividing the heights into 100 vertical levels with an interval of 1 hPa

The vertical profiles of appearance rate of LNB (Fig. 3a), estimated from the results of CRM, well correspond with those from the RANAL. In the profile of Dec. 2005 over the sea, the appearance rate of LNB over a 600-hPa level is remarkably higher than that of Jan. 2006. The comparison of heights between cloud tops and LNB shows that cloud-top heights appear with about an half frequency of LNB, and the vertical profiles of appearance rates of LNB over the sea are very similar to those of cloud-top heights on the land. This indicates that snow clouds forming over the sea develop on the land.

For the averaged cloud-top heights in Dec. 2005, the results of 5km-NHM (Fig. 1b) are higher about 50 hPa than those of 1km-CRM (Fig. 1a). Meanwhile, such differences are never found for the averaged LNB (not shown). These indicate that cloud-top heights are differently simulated for the horizontal resolution and the treatment of moist convection. The above-mentioned features are ascertained from the relation of appearance rate distributions between cloud-top heights (Fig. 2) and LNB (Fig. 3). Rainfall amount over plain areas and near the coast is less simulated by the 5km-NHM than the 1km-CRM, and the rainfall of 5km-NHM is concentrated over mountainous regions. Meanwhile, the rainfall distribution of 1km-NHM is well similar to the R-A (not shown).

In comparison with the results of 1km-CRM, the 5km-NHM overestimates cloud-top heights (Fig. 2), and it underestimates rainfall amount over the plain and near the coast (Fig. 4) although the appearance rate of cloud-top heights overestimates there (Fig. 3). This cause will be examined from the distribution of simulated hydrometeors and diabatic heating. Further, for our future works, the relation of predicted cloud-top heights by the 1km-CRM to those observed by meteorological radars should be examined.

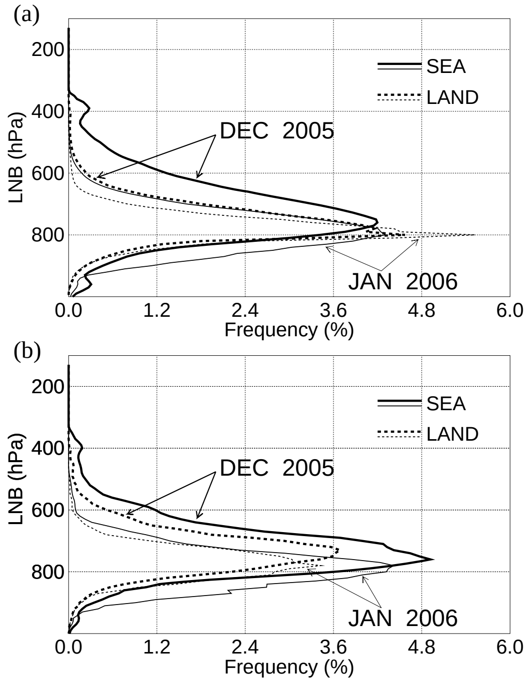

Fig. 3 Same as Fig. 2, but for the LNB that is estimated by lifting an air around a 20-km height.

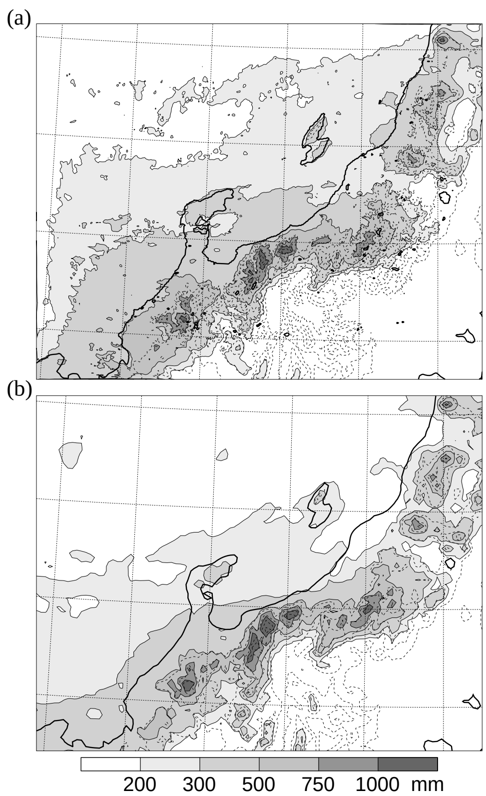

Fig. 4 Same as Fig. 1, but for the monthly accumulated rainfall.