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RETRIEVAL OF LATENT HEATING PROFILES FROM TRMM RADAR DATA

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1. INTRODUCTION

The latent heating profiles in cloud systems have an important role in not only global circulation but also meso- and cloud-scale circulation. The latent heating retrieval is one of the goals of Tropical Rainfall Measuring Mission (TRMM), and some algorithms have been proposed (Tao *et al.*, 1990; Tao *et al.*, 1993; Olson *et al.*, 1999). Since most of the algorithms use TRMM microwave imager (TMI) data, however, they have limitations on the application of over-land data, and on the horizontal and vertical resolution. On the other hand, the TRMM precipitation radar (PR) is a superior instrument to observe the three-dimensional fine structure of precipitation over both ocean and land. However, it is difficult to retrieve the latent heating profile from the PR data directly, because a distinction between various hydrometeors cannot be measured, and it is impossible for TRMM PR to detect weak snowfall, drizzle, cloud droplets and so on. Since the latent heating is a result of the phase change of water, it is possible to retrieve the latent hating profile if both microphysical and dynamic structures are obtained. In this study, a new algorithm to retrieve the latent heating profile from TRMM PR data is proposed. Moreover, the algorithm is applied to actual TRMM observation data of a squall line as an example.

2. ALGORITHM

Figure 1 shows a schematic diagram of the procedure for retrieving the latent heating profiles, and all equations used in this algorithm. The main input data is radar reflectivity (Ze) and rainfall rate (*R*) provided by the PR profiling standard algorithm (2A25) described in Iguchi *et al.* (2000). In 2A25, two drop size distribution (DSD) models for convective and stratiform rainfall (Kozu *et al.*, 1999) are assumed. Using the DSD models, the coefficients (a_w, b_w) of the relationship between Ze and water content (*WC*) are determined. The coefficients are variable, and are defined at five nodes, which is similar to the Ze-R coefficients (Iguchi *et al.*, 2000). Mixing ratio (q_P) and terminal velocity (V_t) of precipitation are derived from *WC*, *R*, and air density (ρ), where ρ is calculated from a modified U.S. standard atmosphere. Since the algorithm is based on thermodynamic retrieval technique (Roux and Sun, 1990; Kawashima *et al.*, 1995; Satoh *et al.*, 1996) for dual-Doppler radar observation, a vertical velocity (*w*) profile is required. In this algorithm, the *w*-profile is estimated by a cubic function to obtain realistic profiles for both convective and stratiform clouds. The coefficients of the cubic function depend on a rainfall type (*Rtype*: convective / stratiform / anvil), a cloud top height (*zTOP*), a bright band height (*zBB*), a cloud bottom height (*zBOT*) in anvil regions, and a surface height (*zSURF*). For the cubic form, the vertical average of q_P and arbitrary coefficient α determine on the maximum *w*, and three heights (*zTOP*, *zSURF*, and *z0*) determine on the *w*=0 levels. A latent heating profile (*LH*) is calculated from either a production rate of precipitation (Fq_P) or the product of *w* and

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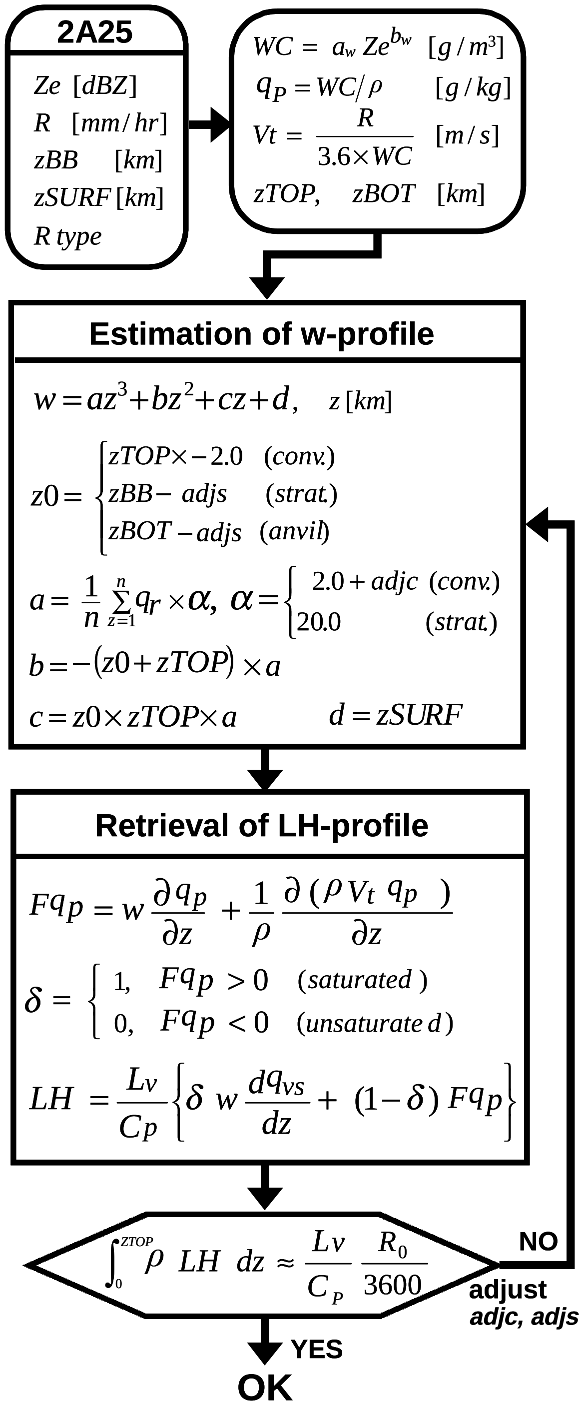

Fig. 1. A schematic diagram and equations for the latent heating retrieval algorithm. Meanings of the variables are described in the article.

a vertical differential of saturation mixing ratio of water vapor (q_{VS}). q_{VS} is calculated from a temperature profile in the modified U.S. standard atmosphere. The first term of the Fq_P equation is vertical advection of q_P, while horizontal advection and time differential terms are ignored in this formulation. The second term is a source/sink term of precipitation water, which is a vertical differential of R (=3.6 ρ q_P V_t). Positive values of Fq_P indicate that rain is produced from cloud in saturated air, while negative values indicate evaporation of rain in unsaturated air. Although the rain evaporation rate (Fq_P <0) means the latent heat absorption (i.e. cooling), the rain production rate (Fq_P >0) is not equal to the latent heat release because cloud droplets, which are the origin of rain, will be remained in saturated air. Unless all cloud droplets change into raindrops measured by radar, the rain production rate (Fq_P >0) cannot apply to latent heating estimation. Remember that the latent heating is released when water vapor changes into cloud droplets, not raindrops. Therefore, in saturated air, the latent heating rate should be calculated from saturation adiabatic change in the first term of the *LH* equation. The above description about rainfall can be applied to snowfall in upper layers except that the latent heat of sublimation (L_s) should be used instead of the latent heat of vaporization (L_v). In the final step, the retrieved latent heating profile is integrated from the ground to the cloud top level. Since Tao *et al.* (1993) suggested the vertical integrated heating profile is related to surface rainfall based on Yanai *et al.* (1973), the both are compared using the last equation in Fig. 1. According to the result of the comparison, some coefficients to estimate the w-profile are adjusted through iterating calculation.

3. APPLICATION TO ACUTUAL SQUALL LINE

A typical squall line was observed by TRMM on 0138 UTC, May 10, 1999 in Oklahoma. Figure 2 and 3 show the same vertical slices of 26th angle bin of the RP data, which include convective, stratiform, and anvil echo regions. Figure 2 shows input observation data in 2A25, derived microphysical values (q_P , V_t) and estimated *w*-profiles. Figure 2 (d) shows very realistic distribution of V_t derived from Ze-*WC* relationship, which means the assumed DSD model in 2A25 is suitable. For example, the contour of 1.5 m/s looks to be the boundary between rain and snow. The estimated *w* distribution (Fig. 2 (e)) seems to be good in both convective and stratiform regions. A large updraft region (*w*>0) appears at dis.=300 km in Fig. 2(e), and it seems to support the large q_P above 7 km in height (Fig. 2(c)). While, there are small downdraft (*w*<0) under the bright band level in stratiform regions. Figure 3 shows the retrieval result of latent heating profiles. In the regions of positive precipitation production rate (Fq_P >0), the latent heating profiles are affected by estimated w-profiles. Although the maximum magnitude of the latent heating is vary large (>15 K/hr) in the convective region, that is the result of heavy surface rainfall (>120 mm/hr) shown in Fig. 4(a). Remember the surface rainfall adjusts the vertical integration of the heating profile. Figure 4(c) shows the horizontal average of the latent heating profile in each rainfall type (Fig. 4(b)). Although there is no validation data for this case study, the three *LH*-profiles in convective, stratiform, and anvil regions seem to be realistic. In convective region, the heating peak appears around 3 km height. In stratiform and anvil regions, the upper layer heating and lower layer cooling are retrieved. However, the reason for the upper layer heating is not so large may be the influence of the detectable limitations of TRMM PR. Although our algorithm does not depend on the radar sensitivity in the saturation region, it is impossible to retrieve the heating profiles within no data regions.

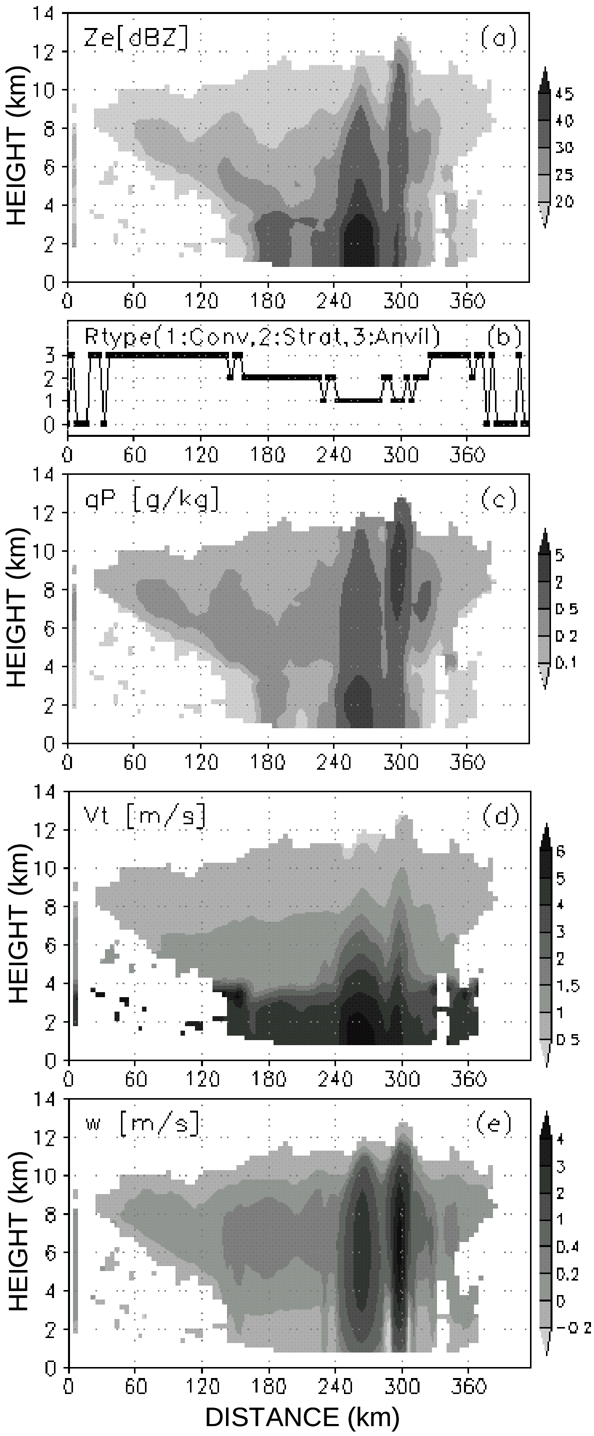

Fig. 2. Vertical cross sections of (a) reflectivity, (b) rainfall type classification, (c) mixing ratio of precipitation, (d) terminal fall velocity of precipitation, and (e) estimated vertical velocity.

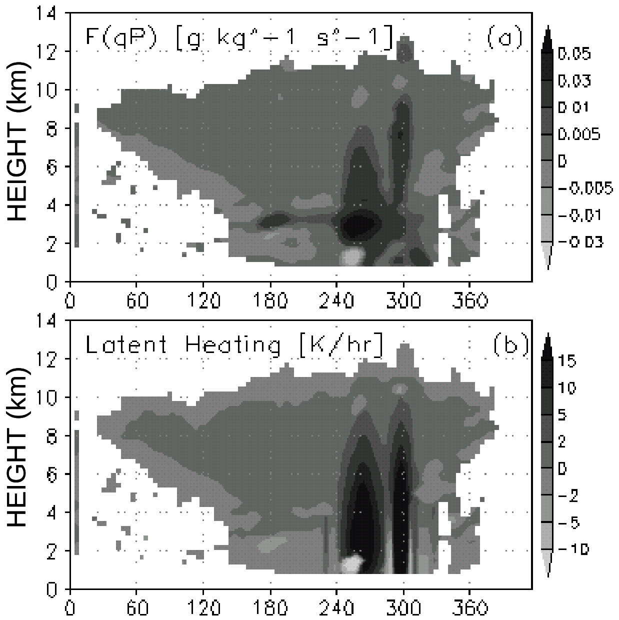

Fig. 3. Vertical cross sections of (a) production rate of precipitation, and (b) latent heating profiles.

4. CONCLUDING REMARKS

The application of the proposed algorithm to an observed squall line provides suitable results of latent heating structure. Since the retrieval algorithm calculates the latent heating profile from only TRMM PR data, the uniform quality profiles are expecting to obtain all over the ocean, land, and mountains observed by TRMM. However, our algorithm has included several problems as yet. At first, the estimated w-profile using a cubic function is sometimes doubtful. To evaluate the magnitude and shape of the w-profile, a cloud resolving model (ARPS) is used to simulate the observed squall line. Although the simulated *w*-profile on average is similar to the estimated *w*-profile, the model output indicates that the variable *w*-profile in time and space is hard to estimate from only a precipitation profile. In our algorithm, the estimation error of w will lead to unreal heating profiles, because the balance of V_t and w determines saturate or unsaturated condition. A next problem is the estimation of cloud top height. Although the cloud top height at which w=0 is estimated from an echo top height, the difference between cloud and echo top heights must be variable in various cloud systems. The result of comparison between an echo top height and a cloud top height evaluated from the infrared brightness temperature observed by TRMM VIRS (10.8 μm) shows that the difference is not so large. If anything, the evaluation of the cloud top has some problems, which are that the temperature inversion often appears over the cloud top, and it is hard to obtain an ideal sounding data. A third problem is that the unnatural horizontal distribution of latent heating sometimes appears according to the alternate convective and stratiform classification. Finally, we will have to apply the algorithm to various cloud systems over various regions. It should be evaluated that the quantity accuracy of retrieved heating profiles is adequate for statistical climate studies or data assimilation studies for numerical models.

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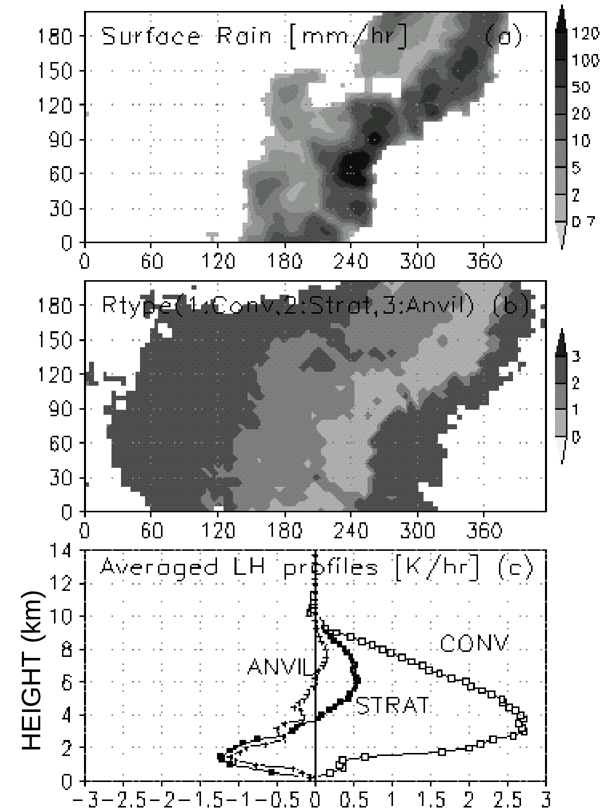

Fig. 4. Horizontal distributions of (a) surface rainfall rate, and (b) rain type classification. (c) Horizontal average of latent heating profiles in convective, stratiform, and anvil regions.

REFERENCES

Iguchi, T., T. Kozu, R. Meneghini, J. Awaka, and K. Okamoto, 2000: Rain-profiling algorithm for the TRMM precipitation radar. *J. Appl. Meteor.*, **39**, 2038-2052.

Kawashima, M, K. Tsuboki, and T. Asai, 1995: Maintenance mechanism and thermodynamic structure of a Baiu frontal rainband retrieved from dual Doppler radar observations. *J. Meteor. Soc. Japan*, **73**, 717-735.

Kozu, T., T. Iguchi, K. Shimizu, and N. Kashiwagi, 1999: Estimation of raindrop size distribution parameters using statistical relations between multi-parameter rainfall remote sensing data. *Proc. of 29th Conf. Radar Meteor., Montreal, AMS*, 689-692.

Olson, W., C. Kummerow, Y. Hong, and W.-K. Tao, 1999: Atmospheric latent heating distributions in the tropics derived from satellite passive microwave radiometer measurements. *J. Appl. Meteor.*, **38**, 633-664.

Roux, F., and J. Sun, 1990: Single-Doppler observations of a West African squall line on 27-28 May 1981 during COPT81: Kinematics, thermodynamics and water budgets. *Mon. Wea. Rev.*, **118**, 1826-1854.

Satoh, S., D. Abe, M. Kawashima, T. Ushiyama, and K. Takeuchi,1996: Retrieved thermodynamic structures of mesoscale convective systems observed in the western tropical Pacific. *Proc. 12th Int. Conf. on Cloud and Precipi., Zurich,* 550-553.

Tao, W.-K., J. Simpson, S. Lang, M. McCumber, R. Adler, and P. Penc, 1990: An algorithm to estimate the heating budget from vertical hydrometeor profiles. *J. Appl. Meteor.*, **29**, 1232-1244.

Tao, W.-K., S. Lang, J. Simpson, and R. Adler, 1993: Retrieval algorithm for estimating the vertical profiles of latent heat release: Their applications for TRMM. *J. Meteor. Soc. Japan*, **71**, 685-700.

Yanai, M., S. Esbensen, and J. Chu, 1973: Determination of average bulk properties of tropical cloud clusters from large-scale heat and moisture budgets. *J. Atmos. Sci.*, **52**, 551-573.