Retrieval of Latent Heating Profiles from TRMM Radar Data

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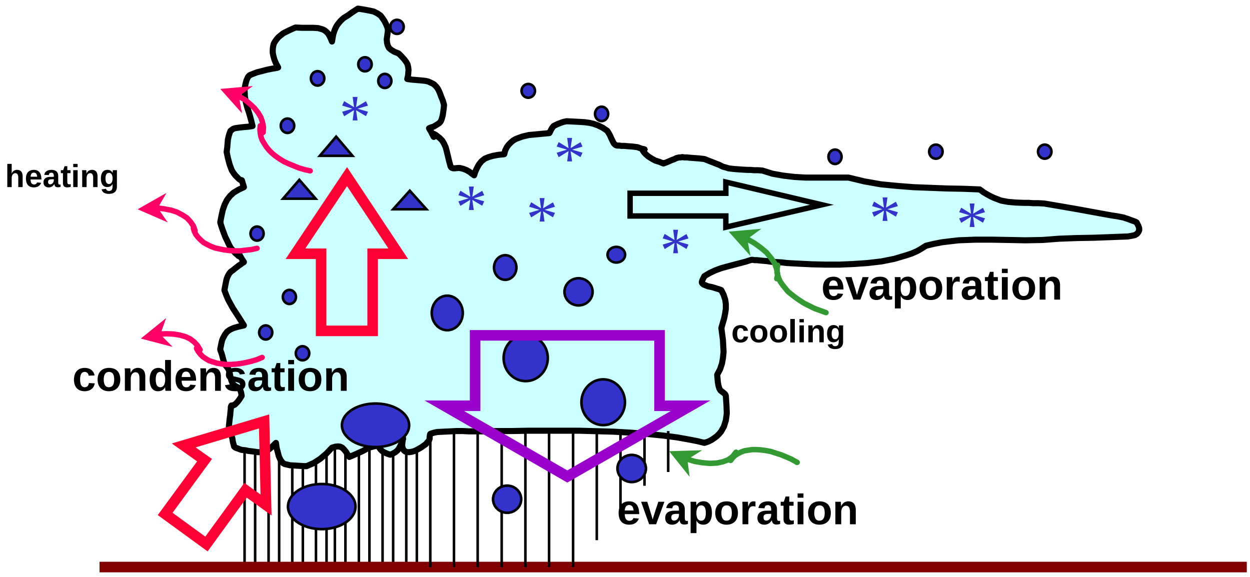


Objectives:

- to propose a new latent heating algorithm using TRMM PR data
- to display the application of the algorithm to TRMM observation cases

Importance:

- the major energy source driving global-, meso-, and cloud-scale circulation
- TRMM data assimilation for numerical prediction models

Introduction

(1) Previous works

$$LH = \frac{Lv}{C_P}(c-e) + \frac{Lf}{C_P}(f-m) + \frac{Ls}{C_P}(d-s)$$

Tao(1993), Olson (1999)

$$\int_0^{ZTOP} \rho \ LH \ dz \approx \frac{Lv}{C_P} R / 3600$$

Yanai (1973), Tao(1993)

- GPROF algorithm (2A12) by Kummerow (1996), Olson(1996)
  → Bayesian technique
- Hydrometeor/Heating algorithm by Tao (1990)
  → Hydrometeor profiles estimation from TMI data
- Convective-Stratiform Heating Algorithm by Tao (1993, 2000)
  → Stratiform amount, surface rainfall, look-up table

(Cloud Resolving Model is the basic of every algorithm)

(2) The significance of the PR heating algorithm

<u>NOT depend on numerical model results</u>

Advantage of PR data

- fine resolution (ΔX=4.2 km, ΔZ=0.25 km)
- uniform quality everywhere (over ocean, land, ice/snow surface)

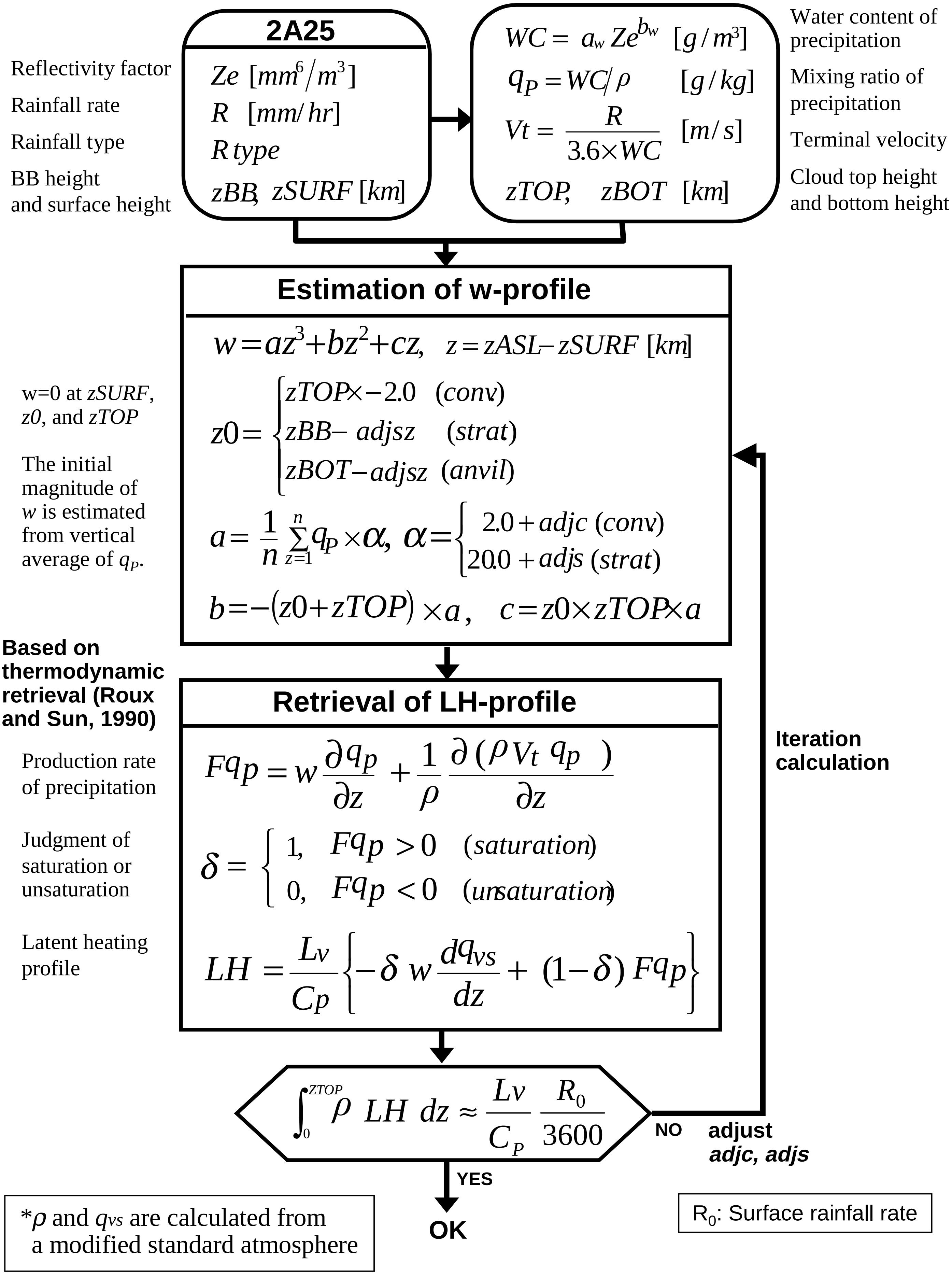
Limitation of PR data

- difficult to classify various hydrometeor (rain, snow, graupel/hail)
- impossible to detect cloud, drizzle, weak precipitation (R<0.5mm/h)

⇩

- Validation/Improvement of the TMI heating algorithm
- Application to over-land data in high-latitude (GPM)

PR Heating Algorithm



2A25

Reflectivity factor: $Ze\ [mm^6/m^3]$

Rainfall rate: $R\ [mm/hr]$

Rainfall type: $R\,type$

BB height and surface height: $zBB,\ zSURF\ [km]$

Water content of precipitation: $WC = a_w\, Ze^{b_w}\ [g/m^3]$

Mixing ratio of precipitation: $q_P = WC/\rho\ [g/kg]$

Terminal velocity: $Vt = \dfrac{R}{3.6 \times WC}\ [m/s]$

Cloud top height and bottom height: $zTOP,\ zBOT\ [km]$

Estimation of w-profile

$$w = az^3 + bz^2 + cz, \quad z = zASL - zSURF\ [km]$$

w=0 at *zSURF*, *z0*, and *zTOP*

$$z0 = \begin{cases} zTOP \times -2.0 & (conv) \\ zBB - adjsz & (strat) \\ zBOT - adjsz & (anvil) \end{cases}$$

The initial magnitude of *w* is estimated from vertical average of q_P.

$$a = \frac{1}{n} \sum_{z=1}^{n} q_P \times \alpha, \quad \alpha = \begin{cases} 2.0 + adjc\ (conv) \\ 20.0 + adjs\ (strat) \end{cases}$$

$$b = -(z0 + zTOP) \times a, \quad c = z0 \times zTOP \times a$$

Based on thermodynamic retrieval (Roux and Sun, 1990)

Retrieval of LH-profile

Production rate of precipitation

$$Fqp = w \frac{\partial q_p}{\partial z} + \frac{1}{\rho} \frac{\partial (\rho\, Vt\ q_p)}{\partial z}$$

Judgment of saturation or unsaturation

$$\delta = \begin{cases} 1, & Fqp > 0 \quad (saturation) \\ 0, & Fqp < 0 \quad (unsaturation) \end{cases}$$

Latent heating profile

$$LH = \frac{Lv}{Cp} \left\{ -\delta\, w \frac{dq_{vs}}{dz} + (1 - \delta)\, Fqp \right\}$$

$$\int_0^{ZTOP} \rho\ LH\ dz \approx \frac{Lv}{C_P} \frac{R_0}{3600}$$

NO **adjust *adjc, adjs***

Iteration calculation

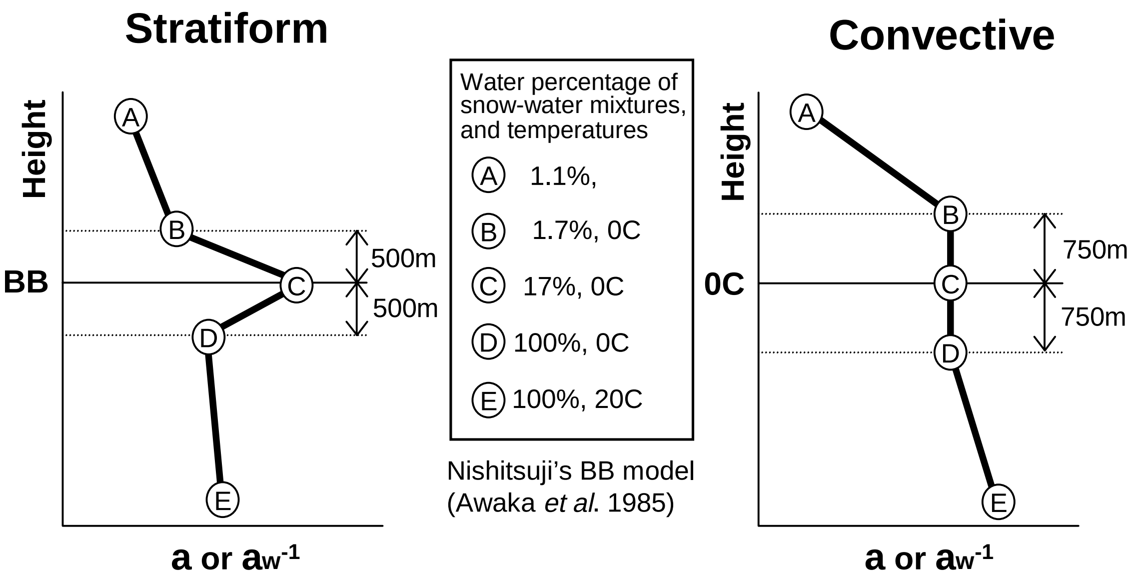
YES

OK

*ρ and q_{vs} are calculated from a modified standard atmosphere

R_0: Surface rainfall rate

Z_e-R and WC-Z_e relations in 2A25 (Iguchi, 2000)


Stratiform

Convective

Nishitsuji's BB model (Awaka *et al*. 1985)

The initial Z_e-R and WC-Z_e parameters for stratiform ($Z_e = a R^{b}$, WC = $a_w Z_e^{b_w}$)

	a	*b*	$a_w \times 10^3$	b_w
A	250.8	1.294	3.836	0.713
B	304.6	1.308	3.250	0.705
C	1649.3	1.372	0.743	0.666
D	283.9	1.446	1.998	0.613
E	275.7	1.487	2.238	0.597

The initial Z_e-R and WC-Z_e parameters for convective ($Z_e = a R^{b}$, WC = $a_w Z_e^{b_w}$)

	a	*b*	$a_w \times 10^3$	b_w
A	174.1	1.323	6.209	0.689
B	159.5	1.511	3.918	0.579
C	159.5	1.511	3.918	0.579
D	159.5	1.511	3.918	0.579
E	147.5	1.554	4.444	0.562

The basic DSD is assumed to the Gamma distribution: $N(D) = N_0 D^{\mu} \exp(-\Lambda D)$

	stratiform		convective	
version 4	$\mu = 1$	$N_0 = 10600$	$\mu = 1$	$N_0 = 37500$
version 5	$\mu = 3$	$N_0 = 3175\Lambda^{1.54}$	$\mu = 3$	$N_0 = 2724\Lambda^{2.25}$

The terminal velocity is expressed by Gunn-Kinzer (rain): $v(D) = 4.854D \exp(-0.195D)$

Magono-Nakamura (snow): $v(\rho_s) = 330 (\rho_s - \rho_a)^{0.25}$

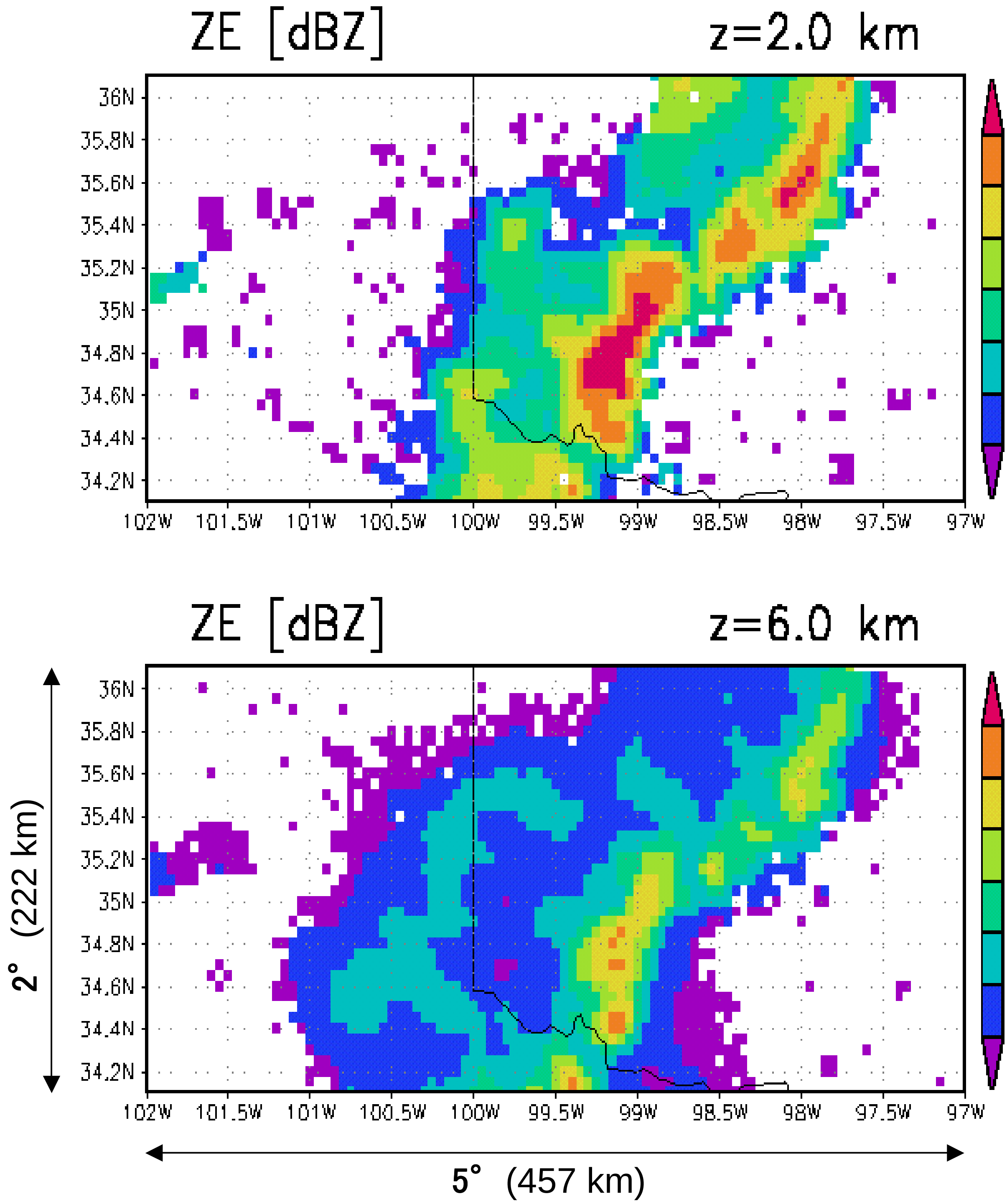
Determination and adjustment of Z_e-R parameters in 2A25 (Iguchi *et al*, 2000)

(1) Using the two basic DSD model (Kozu *et al*. 1999) determined from world-wide Z-R collections,
(a) the rainfall rate (*R*): $R = \int(\pi/6)N(D)\, D^3\, v(D)\, dD \times (\rho_{a0}/\rho_a)^{0.4}$
(b) the equivalent reflectivity factor (Z_e) at 13.8 GHz from Mie-scattering formula
(c) the specific attenuation (*k*)
are calculated for different temperatures and different phase states.

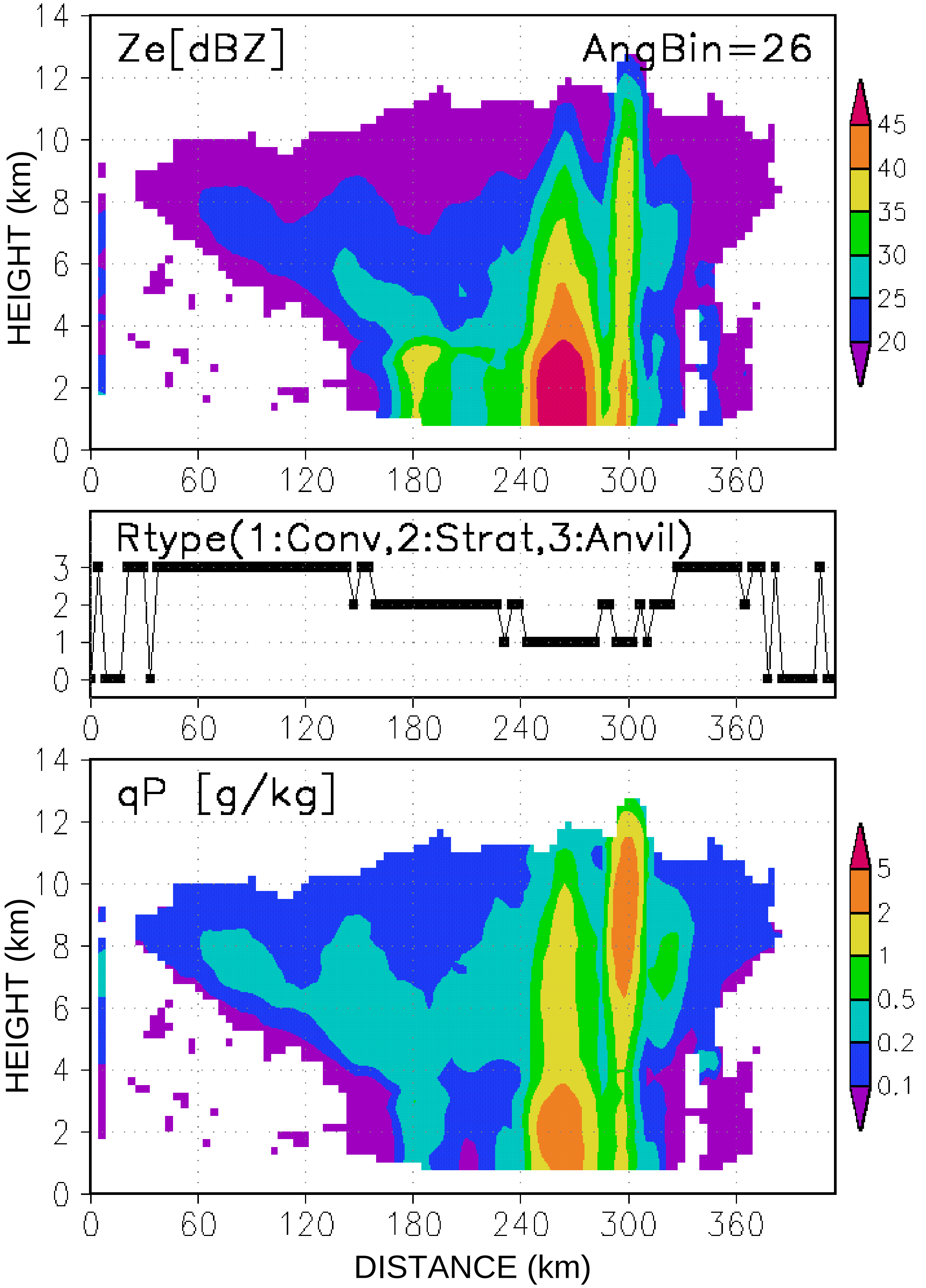
(2) From the pairs (k, Z_e), (Z_e, R), the regression coefficients of k-Z_e, Z_e-R relations are calculated for different temperatures and different phase states.

(3) The initial k-Z_e, Z_e-R parameters are adjusted through the attenuation correction process.

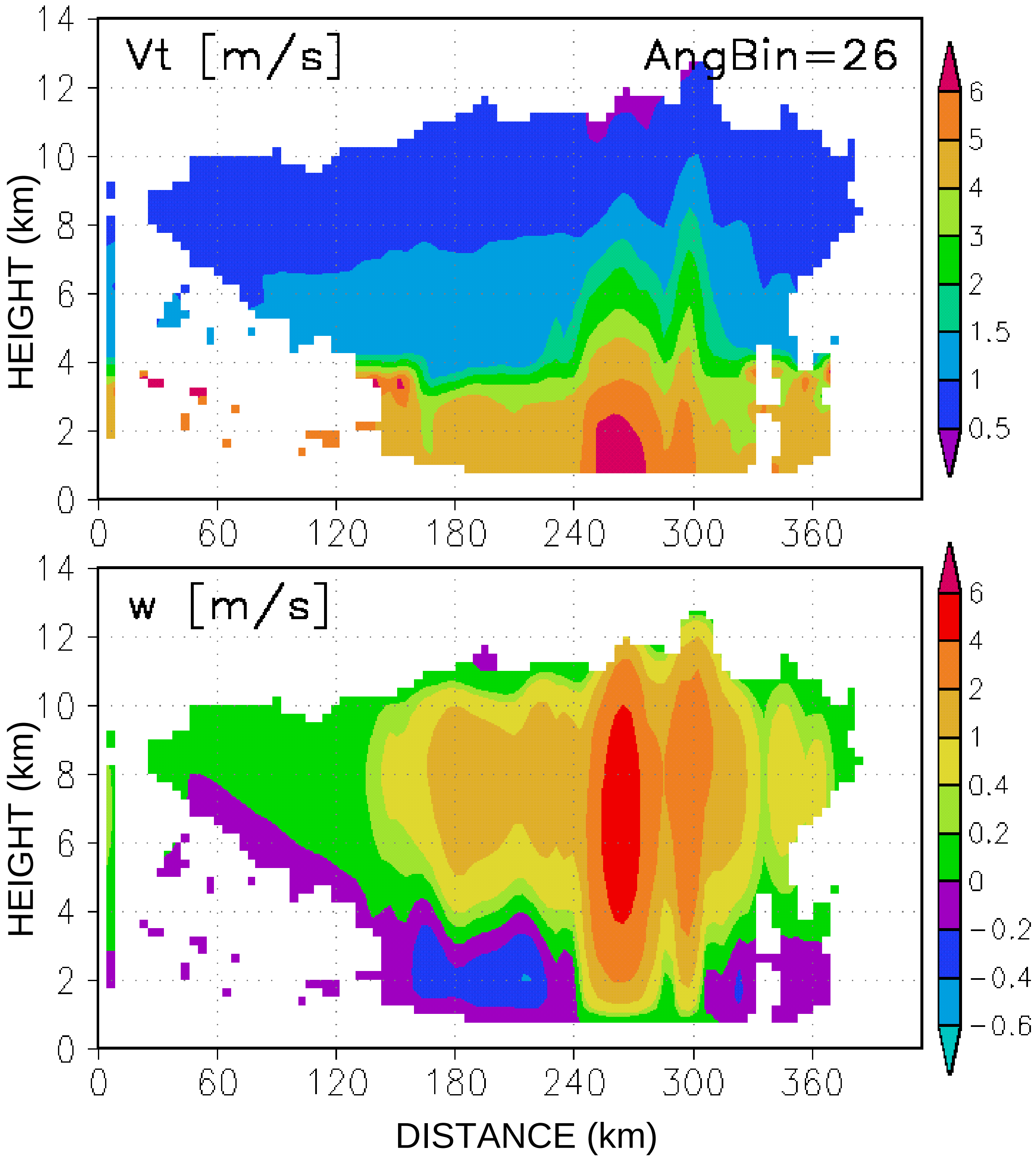
A squall line observed by TRMM over Oklahoma on 0137Z, May 10, 1999 (orbit no. 8329)



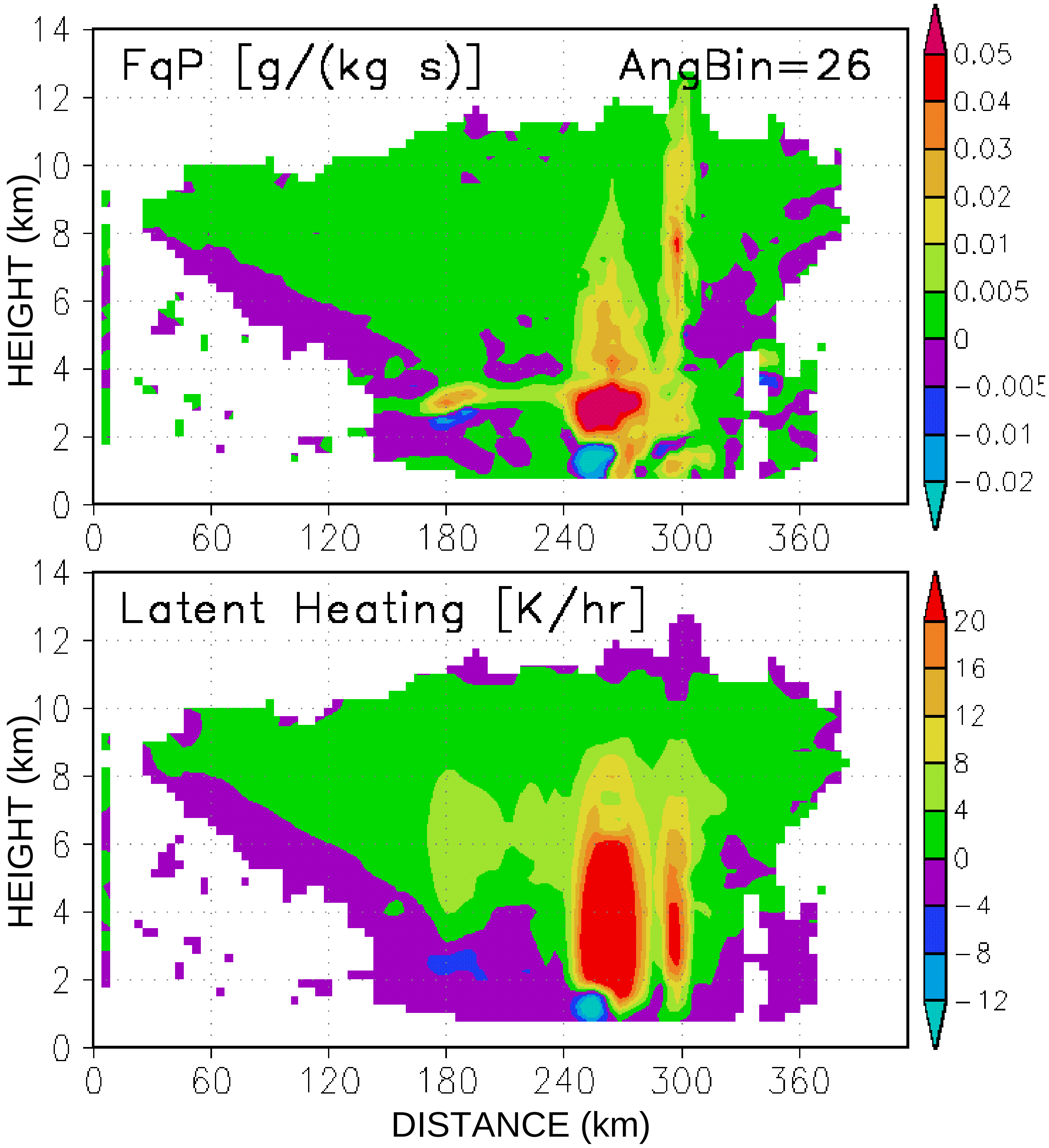
Input data (2A25) for the heating algorithm



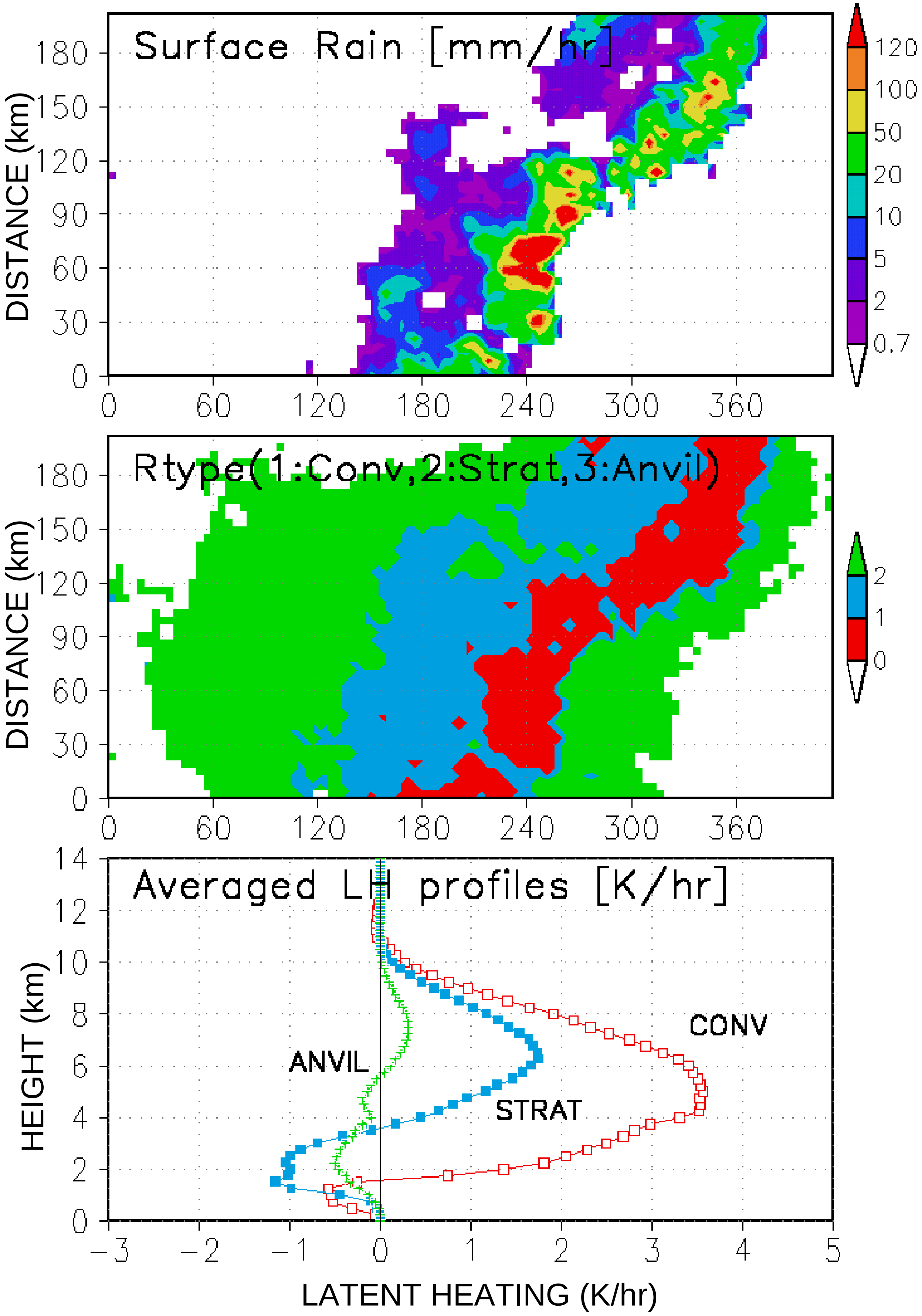
Vertical distributions of terminal velocity (Vt) and estimated vertical velocity (w)



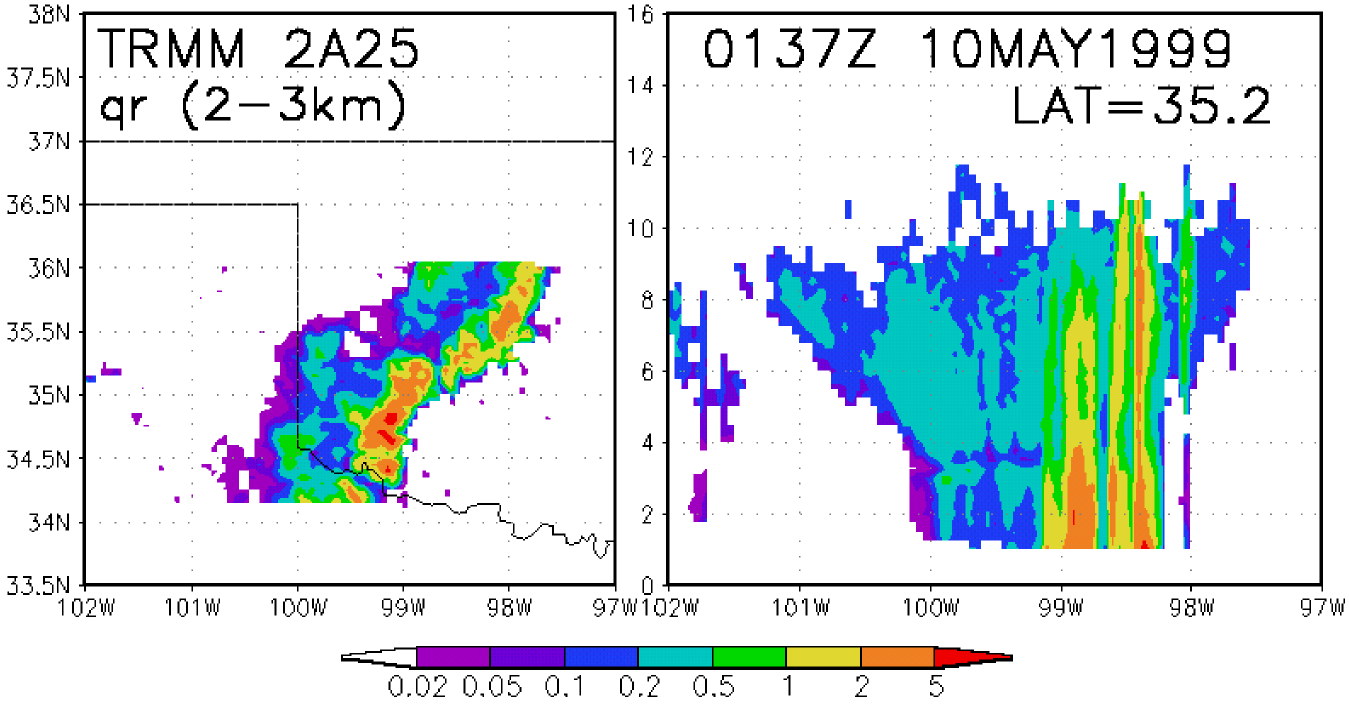
Vertical distributions of production rate of precipitation (Fq_P) and latent heating (LH)

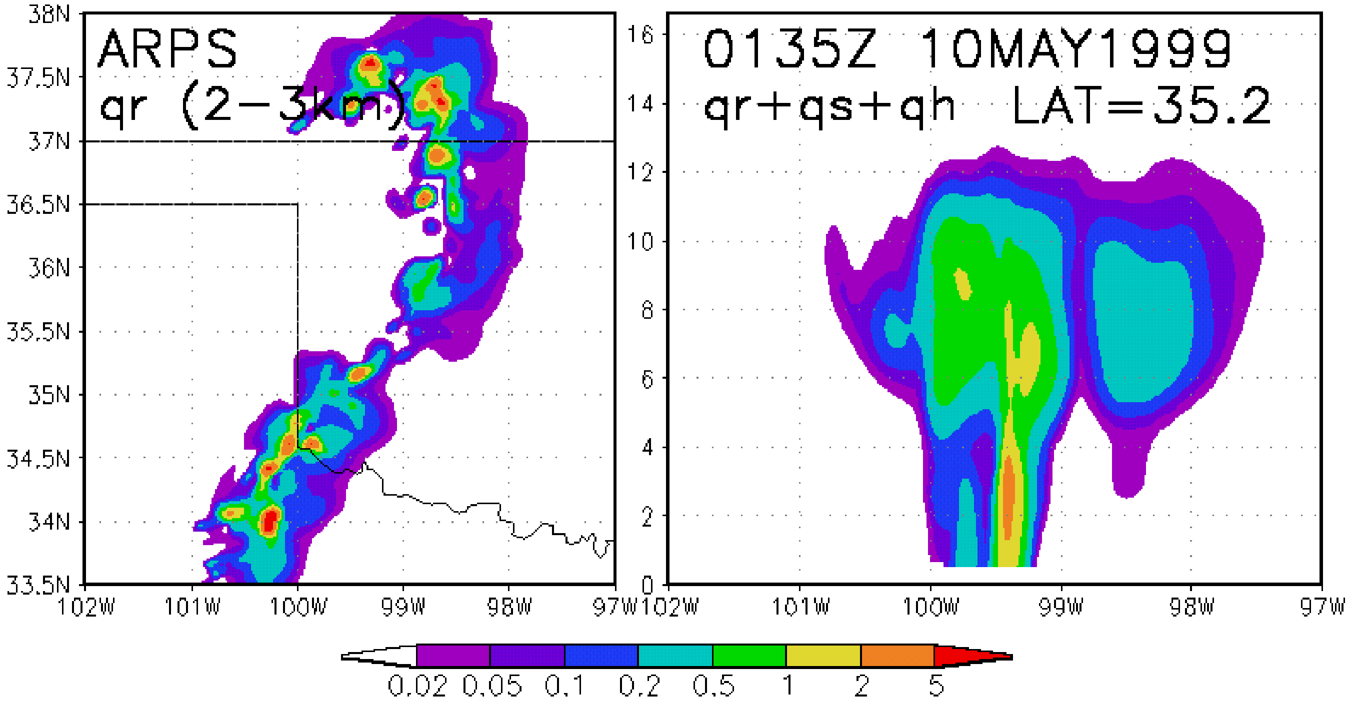


Latent heating profiles averaged in convective, stratiform, and anvil regions

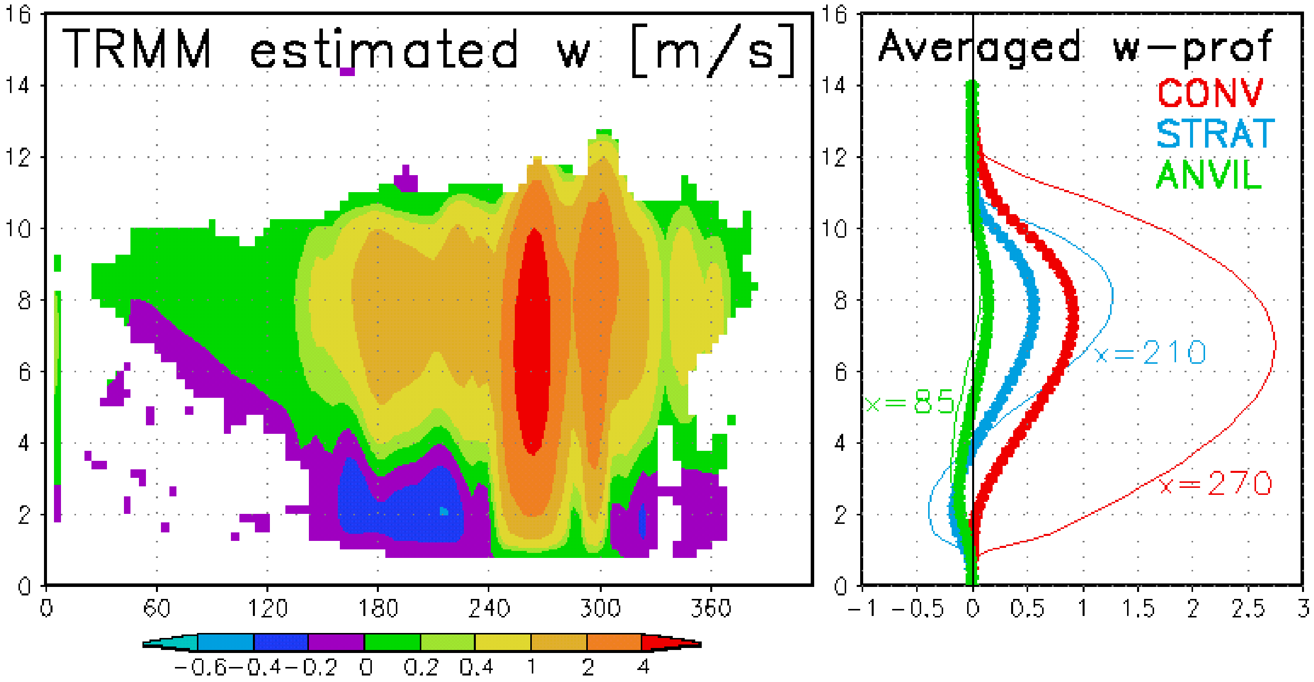


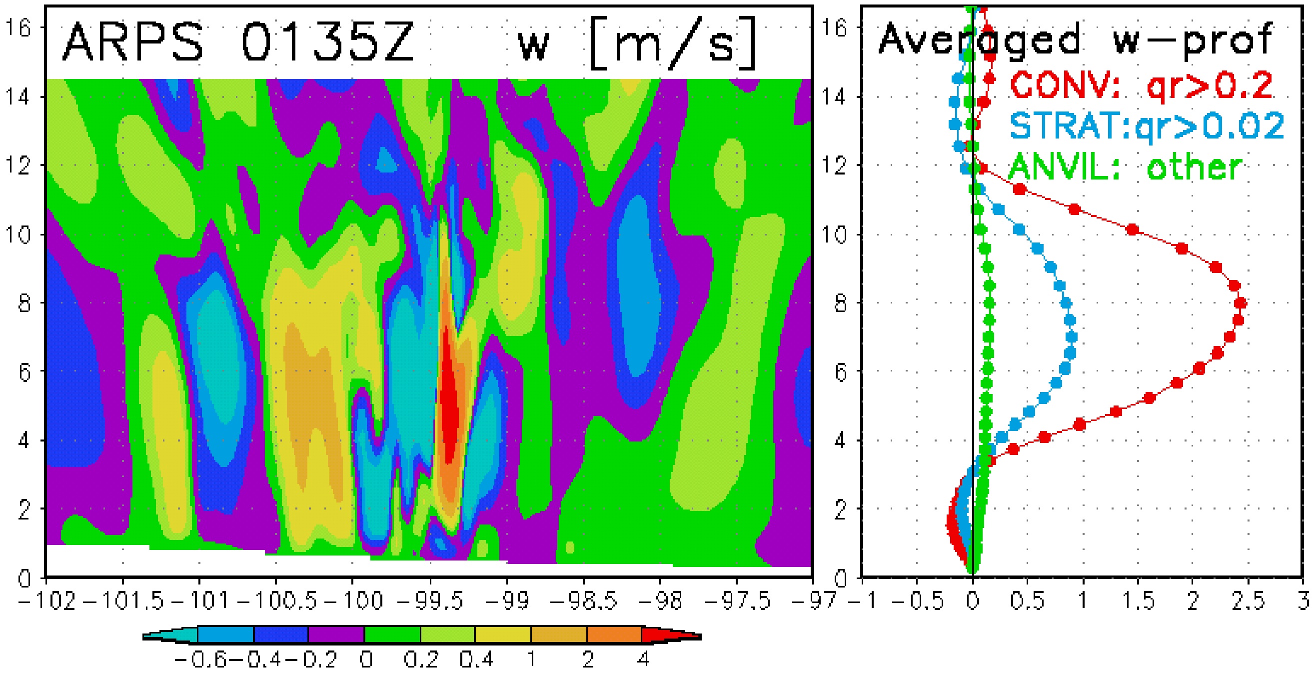
Comparison between TRMM qp and simulated qp by ARPS model



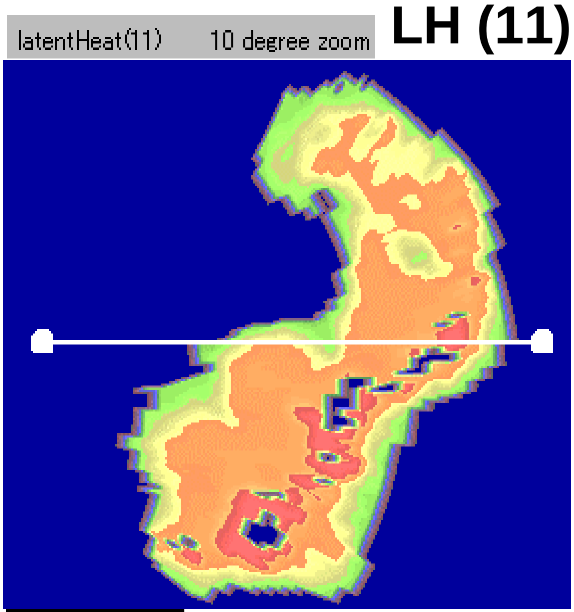


Comparison between estimated w profiles and simulated w profiles by ARPS model

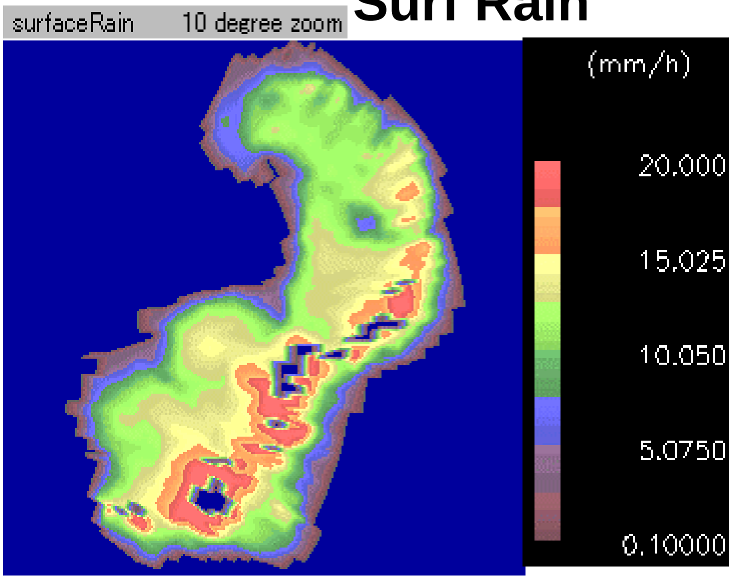


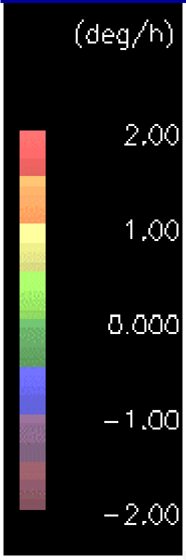


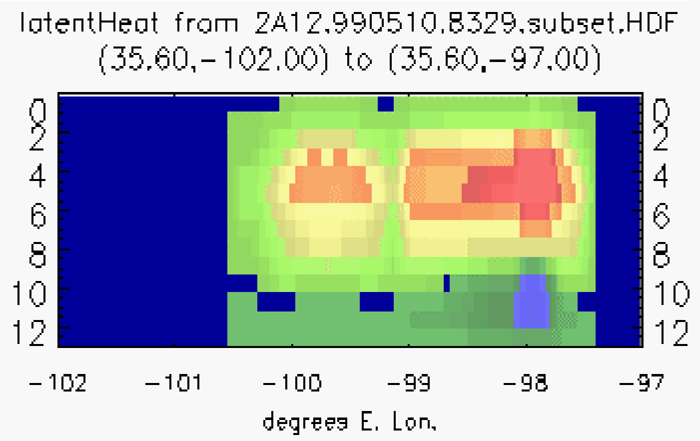
LH (11)



Surf Rain



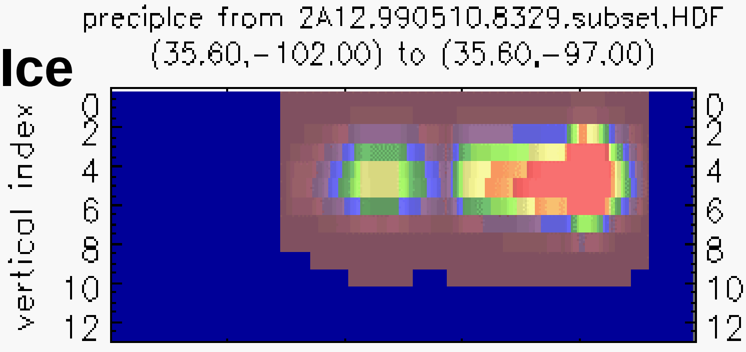




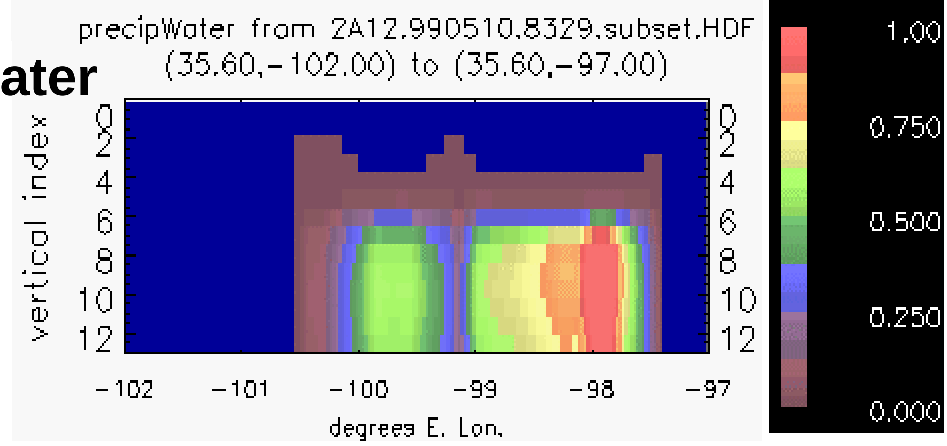
35.6000 degrees N Lat.

2A12 Latent Heating

Prec.Ice

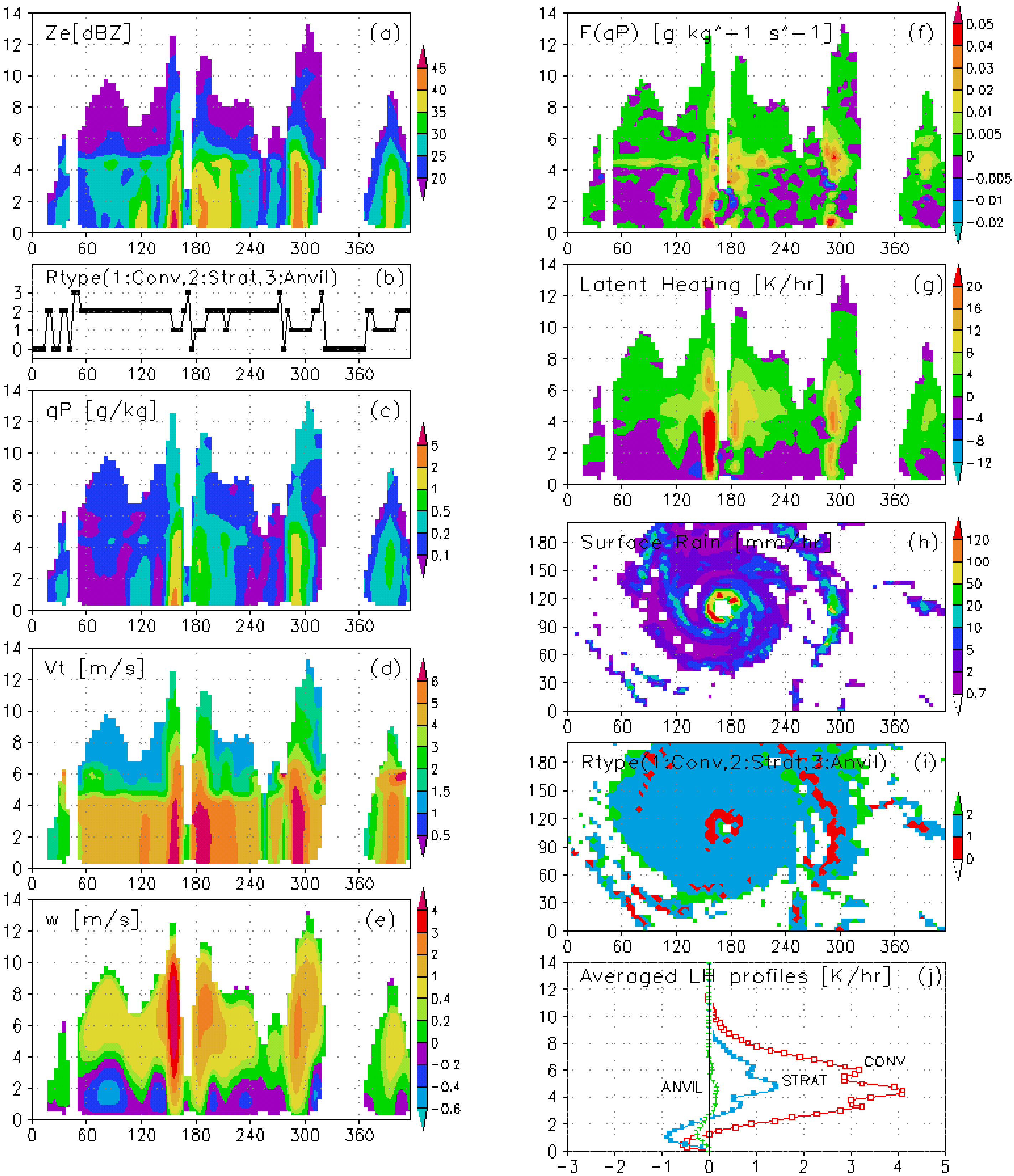


Prec.Water



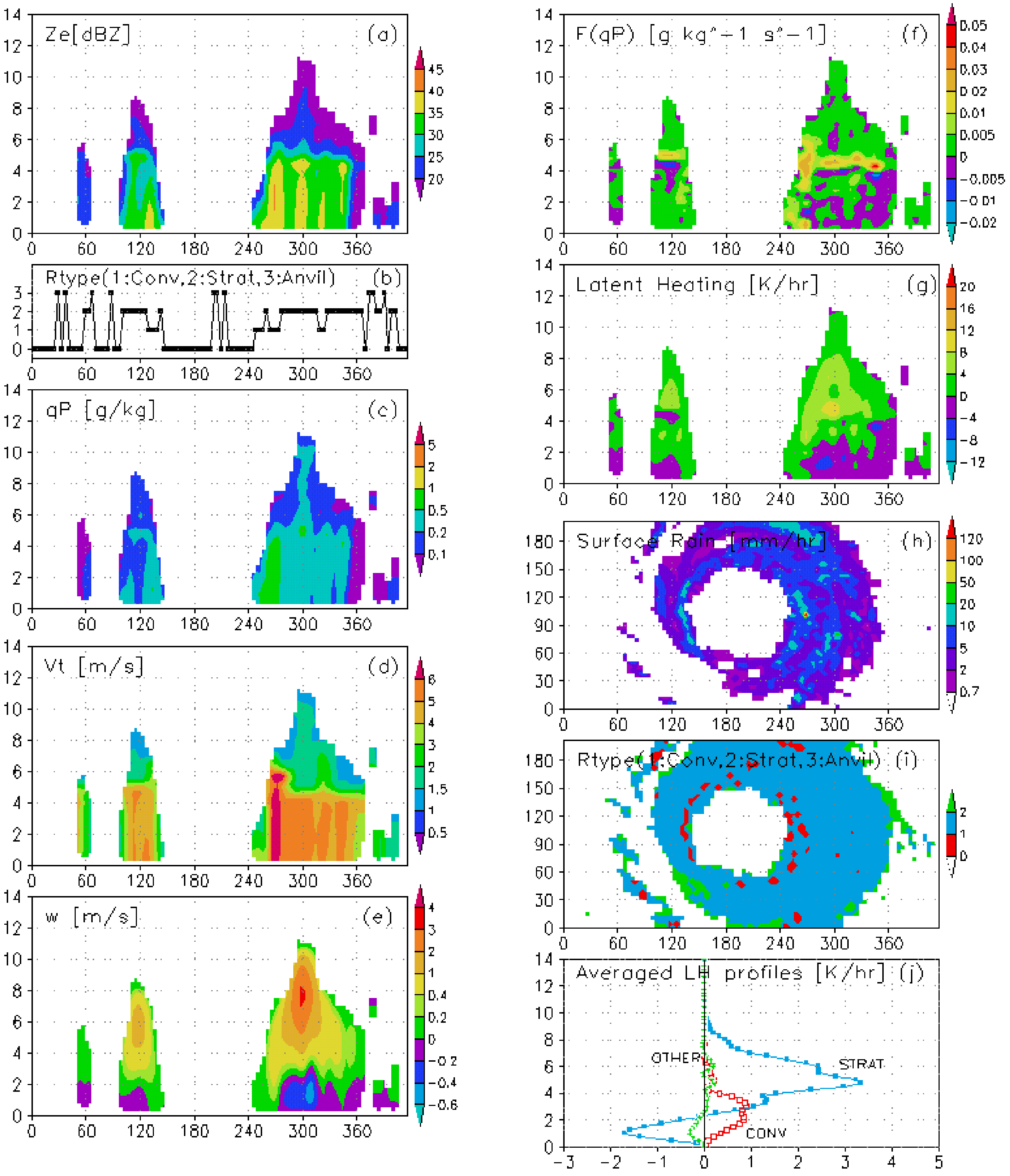
A developing typhoon observed on Aug 2, 2000

(no. 15432)



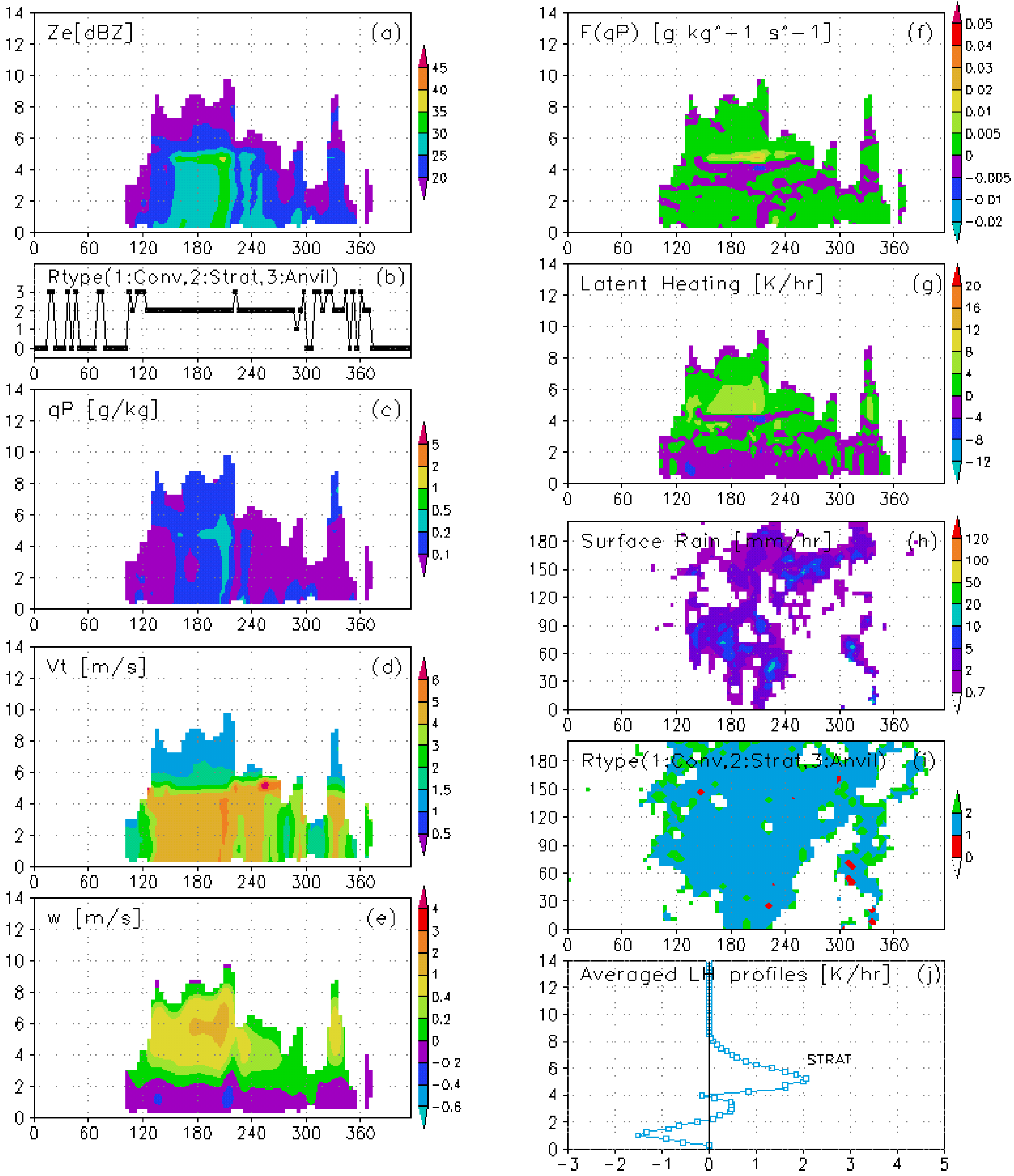
A decaying typhoon observed on Aug 8, 2000

(no. 15526)



Baiu-frontal precipitation observed on May 26, 1998

(no. 2826)



Conclusions

(1) The latent heating retrieval algorithm using TRMM PR data (2A25) is proposed. The application of the algorithm to actual observation data (squall line, typhoons) provides realistic heating profiles averaged in both convective and stratiform regions.

(2) Although the estimated w-profile distribution by a cubic function appears to unreal, it may be suitable in a time-space averaging sense.

(3) The accuracy of the retrieved heating seems to depend on the surface rainfall estimation in 2A25. The rainfall type classification in 2A23 also affects the retrieved heating profiles. The influence of the cloud top estimation and the assumption of a simple temperature profile (to estimate q_{vs}/dz) is small.

(4) In future works, we have to apply the algorithm to various cloud systems over various regions with validation data. Also, we should evaluate the accuracy of the heating profiles is adequate for statistical climate studies or data assimilation studies.

Acknowledgments

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