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

\[ LH = \frac{L_v}{C_p}(c - e) + \frac{L_f}{C_p}(f - m) + \frac{L_s}{C_p}(d - s) \]

\[ \int_0^{Z_{TOP}} \rho L_H dz \approx \frac{L_v}{C_p} \frac{R}{3600} \]

Tao (1993), Olson (1999)

• 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

NOT depend on numerical model results

Advantage of PR data
  • fine resolution (\( \Delta X = 4.2 \text{ km}, \Delta Z = 0.25 \text{ km} \))
  • 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 (\( R < 0.5 \text{ mm/h} \))

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

**Estimation of w-profile**

\[ w = az^3 + bz^2 + cz, \quad z = z_{ASL} - z_{SURF} [\text{km}] \]

\[ z_{TOP} \times -2.0 \quad \text{(conv)} \]

\[ z_0 = z_{BB} - \text{adj}sz \quad \text{(strat)} \]

\[ z_{BOT} - \text{adj}sz \quad \text{(anvil)} \]

\[ a = \frac{1}{n} \sum_{i=1}^{n} q_p \times \alpha, \quad \alpha = \begin{cases} 2.0 + \text{adj}c \quad \text{(conv)} \\ 200 + \text{adj}z \quad \text{(strat)} \end{cases} \]

\[ b = -(z_0 + z_{TOP}) \times a, \quad c = z_0 \times z_{TOP} \times a \]

**Retrieval of LH-profile**

\[ Fq_p = w \frac{\partial q_p}{\partial z} + \frac{1}{\rho} \frac{\partial}{\partial z} (\rho V_t q_p) \]

\[ \delta = \begin{cases} 1, \quad Fq_p > 0 \quad \text{(saturation)} \\ 0, \quad Fq_p < 0 \quad \text{(unsaturation)} \end{cases} \]

\[ LH = \frac{L_v}{C_p} \left\{ -\delta w \frac{dq_{vs}}{dz} + (1-\delta) Fq_p \right\} \]

**Integration**

\[ \int_{z_0}^{z_{TOP}} \rho \ LH \ dz \approx \frac{L_v}{C_p} \frac{R_0}{3600} \]

\*\( \rho \) and \( q_{vs} \) are calculated from a modified standard atmosphere

**Algorithm Flowchart**

- **Input Parameters:**
  - Reflectivity factor
  - Rainfall rate
  - Rainfall type
  - BB height and surface height

- **Output Parameters:**
  - Water content of precipitation
  - Mixing ratio of precipitation
  - Terminal velocity
  - Cloud top height and bottom height

**Algorithm Steps:**

1. Estimation of w-profile
2. Retrieval of LH-profile
3. Iteration calculation

**Mathematical Formulations:**

- **Production rate of precipitation**
- **Judgment of saturation or unsaturation**
- **Latent heating profile**

**Notes:**

- \( w = 0 \) at \( z_{SURF}, z_0, \) and \( z_{TOP} \)
- The initial magnitude of \( w \) is estimated from the vertical average of \( q_p \).

**References:**

Based on thermodynamic retrieval (Roux and Sun, 1990)

- **R** 0: Surface rainfall rate

- \( * \rho \) and \( q_{vs} \) are calculated from a modified standard atmosphere
Ze-R and WC-Ze relations in 2A25 (Iguchi, 2000)

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

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
<th>( a_w \times 10^3 )</th>
<th>( b_w )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>250.8</td>
<td>1.294</td>
<td>3.836</td>
<td>0.713</td>
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<td>B</td>
<td>304.6</td>
<td>1.308</td>
<td>3.250</td>
<td>0.705</td>
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<tr>
<td>C</td>
<td>1649.3</td>
<td>1.372</td>
<td>0.743</td>
<td>0.666</td>
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<tr>
<td>D</td>
<td>283.9</td>
<td>1.446</td>
<td>1.998</td>
<td>0.613</td>
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<tr>
<td>E</td>
<td>275.7</td>
<td>1.487</td>
<td>2.238</td>
<td>0.597</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
<th>( a_w \times 10^3 )</th>
<th>( b_w )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>174.1</td>
<td>1.323</td>
<td>6.209</td>
<td>0.689</td>
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<tr>
<td>B</td>
<td>159.5</td>
<td>1.511</td>
<td>3.918</td>
<td>0.579</td>
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<tr>
<td>C</td>
<td>159.5</td>
<td>1.511</td>
<td>3.918</td>
<td>0.579</td>
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<tr>
<td>D</td>
<td>159.5</td>
<td>1.511</td>
<td>3.918</td>
<td>0.579</td>
</tr>
<tr>
<td>E</td>
<td>147.5</td>
<td>1.554</td>
<td>4.444</td>
<td>0.562</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>stratiform</th>
<th>convective</th>
</tr>
</thead>
<tbody>
<tr>
<td>version 4</td>
<td>( \mu = 1 )</td>
<td>( \mu = 1 )</td>
</tr>
<tr>
<td></td>
<td>( N_0 = 10600 )</td>
<td>( N_0 = 37500 )</td>
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<tr>
<td>version 5</td>
<td>( \mu = 3 )</td>
<td>( \mu = 3 )</td>
</tr>
<tr>
<td></td>
<td>( N_0 = 3175\lambda^{1.54} )</td>
<td>( N_0 = 2724\lambda^{2.25} )</td>
</tr>
</tbody>
</table>

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 Ze-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 \( (R) = (\pi/6)N(D)D^3 v(D) dD \times (\rho_a/\rho_s)^{0.4} \)
(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)

ZE [dBZ]  z=2.0 km

ZE [dBZ]  z=6.0 km
Input data (2A25) for the heating algorithm

Ze[dBZ]  \[\text{AngBin} = 26\]

Rtype(1:Conv, 2:Strat, 3:Anvil)

\[q_P \text{ [g/kg]}\]
Vertical distributions of terminal velocity (Vt) and estimated vertical velocity (w)
Vertical distributions of production rate of precipitation (Fq_p) and latent heating (LH)

FqP \([\text{g/(kg s)}]\)  \quad \text{AngBin=26}

Latent Heating \([\text{K/hr}]\)
Latent heating profiles averaged in convective, stratiform, and anvil regions

![Surface Rain [mm/hr]](image1)

![Rtype(1:Conv, 2:Strat, 3:Anvil)](image2)

![Averaged LH profiles [K/hr]](image3)
Comparison between TRMM qp and simulated qp by ARPS model

TRMM 2A25
qr (2–3km)

0137Z 10MAY1999
LAT=35.2

ARPS
qr (2–3km)

0135Z 10MAY1999
qr+qs+qh LAT=35.2
Comparison between estimated w profiles and simulated w profiles by ARPS model
A developing typhoon observed on Aug 2, 2000
(no. 15432)
A decaying typhoon observed on Aug 8, 2000 (no. 15526)
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

Dr. T. Kozu provided their calculation of Z-WC relation.
Drs. S. Weygant, G. Bassett, K. Droegemeier allow us to use the ARPS model of CAPS, Univ. of Oklahoma.
This research was supported by NASDA.
An Oklahoma squall line observed on May 10, 1999

(no. 8329)