Estimate of 3D convective latent heating (SLH) from space-borne radar measurements and its assimilation with the JMA Local Forecast Model

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Roles of Diabatic Heating: $Q = Q_R + Q_C$

Convective Latent Heating

In Climate:
Latent heating takes 1/7 part of the atmospheric warming in the global average energy budget.

In Weather Systems:
Generation of Potential Vorticity (PV)
in mesoscale circulations  

(Houze et al. 1989)

$$\frac{Dq}{Dt} = -g(f + \zeta) \frac{\partial}{\partial p} Q$$  
$q$ : PV,  $Q$ : diabatic heating

Generation of PV results in Explosive Intensification of Mid-lat storms

(Boettcher and Wernli, 2011)
Estimate LH in 3D Utilizing Space-Borne Radar Data

Yanai et al. 1973

\[ LH = L_v(c-e) + L_f(f-m) + L_s(s-sv) \]

\[ Q_1 = Q + \frac{\partial s}{\partial t} + \nabla \cdot s \nabla + \frac{\partial \tilde{\omega}}{\partial p} \]

\[ Q_2 = -L \left( \frac{\partial q}{\partial t} + \nabla \cdot q \nabla + \frac{\partial q \tilde{\omega}}{\partial p} \right) = L(c-e) + \frac{\partial}{\partial p} \left( c_p T + gz \right) \]

Q1: apparent heat source, Q2: apparent moisture sink, QR: radiative H.

TRMM / GPM Precip Radar

Cloud Resolving Models: Simulation

Spectral LUT

Q1-QR, Q2

1997.11.28 launch

2014.4 overlap 2015.3

17 years

2014.2.2 8 launch current
Spectral Latent Heating (SLH) in the Tropics and Mid-lat.

Monthly Climatological Precipitation Regime Maps

Module selections are based on the monthly regime classification using TRMM/GPM data.

**Mid-latitude Module**
(orange, yellow, purple)
LUTs based on JMA LFM simulations
e.g. Takayabu et al. 2019

**Tropical Module**
LUTs based on GCEM simulations
Shige et al. (2004, 2007⋯)

Tropics: TRMM/PR and GPM/KuPR (35S-35N)
Mid-lat: GPM/KuPR and JRA-55 (65-35S, 35-65N)
Tropical Module: TRMM Spectral Latent Heating (SLH)  

\[ \text{Goddard CEM: TOGA-COARE simulation} \rightarrow \text{Rain-LH tables} = \text{Estimate LH Data} \]

Rain Type
- PTH
- Melt-Lvl Precip.
- Sfc Precip.

Rain Top Height
- Convective
- Deep Stratiform
- Shallow Stratiform
- Melting-L Precip Rate

Spectral Rain-LH tables
Mid-latitude Spectral Latent Heating with GPM DPR

8 Extratropical Cyclone cases Simulated with JMA LFM

The JMA’s 2km resolution forecast model (LFM) is employed. 3hr and 4hr forecast data for 8 extratropical cyclone cases with GPM overpasses are utilized to construct the LUTs.

Input GPM KuPR-precip.

SLH Look Up Tables
Precip→LH

Radar Reflectivity 2ADPR_NS 04A

Retrieval of LH,Q1R,Q2

Output LH, Q1-QR, Q2
### Precipitation Classifications for SLH

<table>
<thead>
<tr>
<th>Tropical region</th>
<th>Middle-latitude region</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Convective</td>
<td>110: Convective</td>
</tr>
<tr>
<td>2: Shallow stratiform</td>
<td>121: Shallow stratiform</td>
</tr>
<tr>
<td>3: Deep stratiform</td>
<td>122: Deep stratiform, downward decreasing</td>
</tr>
<tr>
<td>4: Deep stratiform with low melting level</td>
<td>122: Deep stratiform, downward increasing</td>
</tr>
<tr>
<td>5: Intermediary</td>
<td>124: Deep stratiform, subzero</td>
</tr>
<tr>
<td>6: Other</td>
<td>160: Other</td>
</tr>
</tbody>
</table>

We use precip radar data.

Various relationships between the stratiform cloud base height and the freezing level in midlatitude.
Mid-lat Spectral LUTs for LH produced from the LFM simulations

Convective LUT (color: LH)

Spectral LUTs for LH produced from the LFM simulations

Stratiform DD  Stratiform DI  Stratiform Sub0  Others

Precipitation Top Height (km)

Max Precip (mm/h)

Altitudes (km)

Max Precip (mm/h)
GPM-Retrieved SLH Latent Heating:
16Apr2016 An Extratropical Cyclone
Sometimes LH images give us even clearer idea for precipitation characteristics than observed reflectivity.
Q1-QR : TRMM_V8 vs GPM_V06X AMJ2014

7 km

Q1R@7km (TRMM_V8)

Q1R@7km (GPM_V06A_SLP20191104)

2 km

Q1R@2km (TRMM_V8)

Q1R@2km (GPM_V06A_SLP20191104)
Zonal mean Q1-QR

Comparison of Q1R between TRMMV7, GPMV4A and GPMV6X (Zonal 3-month mean vertical profile)
Latent Heating Nudging with Kalman Gain

Addition of the **nudging term** to temperature tendency in the physics process.

\[
\frac{dT}{dt} = \left. \frac{dT}{dt} \right|_{mp} + C_n(t) \cdot K \cdot \left[ y_{SLH} - H \left( \left. \frac{dT}{dt} \right|_{mp} \right) \right]
\]

\( C_n(t) \): **Nudging coefficient**

Relaxation time \( \tau \) (≈180 sec)

Processes of cloud microphysics related to latent heating
- Evaporation / Condensation
- Sublimation / Deposition
- Melting
- Freezing

\[
K = BH^T (R + HBH^T)^{-1}
\]

\[
B = \langle \delta x, \delta x^T \rangle 
\]

\[
R = \langle \delta y, \delta y^T \rangle
\]

By Y. Ikuta (JMA)
Correction to Temperature Tendency

Initial Time of LFM: 1100 UTC 5 July 2018

Temperature tendency is corrected by LH nudging during time integration.

1-hour forecast after 3D-Var

Forecast range: 2018070510UTC to 2018070511UTC

Local Analysis

1st Guess (t=-3h) from MSM

3D-Var(t=-3h) + 1-hour Forecast (t=-3h to -2h)

3D-Var(t=-2h) + 1-hour Forecast (t=-2h to -1h)

3D-Var(t=-1h) + 1-hour Forecast (t=-1h to 0h)

3D-Var (t=0h)

LH Nudging

LFM (t=0h to 10h)

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Precipitation Forecast

Lead Time: 1-hour

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Precipitation Forecast

Lead Time: 3-hour

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Precipitation Forecast

CONTROL

TEST

OBSERVATION

Lead Time: 6-hour

By Y. Ikuta (JMA)
Summary

Latent Heating Estimates using TRMM/GPM Precipitation Radar data

• GPM Spectral Latent Heating algorithm is extended to mid-lat, 65N-65S, utilizing JMA’s high resolution model (LFM) simulations.
• Estimated variables are LH, Q1-QR, Q2, in Level2 (instantaneous 3D orbital), and in Level3 (monthly 3D gridded).
• GPM SLH data are released as a JAXA/NASA standard product. Ver.5 on 11 July, 2017, currently Ver.6 since 2018, will be revised as SLH ver.6X by May 2020.

Assimilation Experiment with JMA LFM

• New nudging method with Kalman Gain for LH assimilation in 3D-Var data assimilation system has been developed to test its impact in JMA Local NWP system.
• Forecast skill for precipitation is improved in very-short range (1hr, 3hr) precipitation forecast.
• However, convection cell became active and heavy rain is increased in the experiment; left for future works.
Thank you!