GPM (CSH) Latent Heating Retrieval
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Improvements of the Goddard CSH Algorithm for GPM - Tropics

Development of the Goddard Heating Algorithm for GPM - high latitude and winter season (Extra Tropics)

CSH: Convective and Stratiform Heating


**CRM Simulated $Q_1$ Budget**

$$Q_1 - Q_R = \bar{\pi} \left[ - \frac{1}{\rho} \frac{\partial \bar{w}' \theta'}{\partial z} - \bar{V}' \cdot \nabla \theta' \right] + \frac{L_v}{C} (c - e) + \frac{L_f}{C} (f - m) + \frac{L_s}{C} (d - s)$$

$Q_1R = Q_1 - Q_R$  
Eddy Transport

$$\frac{1}{g} \int_{Lx} \int_{P_{\text{base}}}^P (Q_1 - Q_R) \Delta p \Delta x = LP_o + S_o$$

Rainfall + Sensible heat fluxes

**Sounding Estimated $Q_1$ Budget**  
(Yanai et al. 1973)

$$Q_1 = \bar{\pi} \left[ \frac{\partial \theta}{\partial t} + \bar{V} \cdot \nabla \bar{\theta} + \bar{w} \frac{\partial \bar{\theta}}{\partial z} \right]$$

- Role of convection in tropical intraseasonal variability and quasi-stationary circulation/ITCZ/MJO
- Improvement/Validation of Cumulus parameterization in GCMs/Climate Models

LH: Latent Heat - phase change of water
Improved CSH look-up tables for Tropics

• 4ICE (cloud ice, snow, graupel and hail) scheme

• Large domain and 1 km resolution (better for MCS simulations: Tompkins, 2000; Patch and Gray, 2001; Johnson et al. 2002; Ooyama, 2001)

• Additional Cases (MC3E, DYNAMO, GoAmazon)

• Additional categories based on
  Echo tops
  Low-level dBZ gradient
CSH V6: New Conv-Strat Separation

GCE method
- model resolution
- Churchill & Houze method applied to sfc rain
- rain rate (20 mm/h)
- W (> 3 m/s)
- Cloud (> 0.5, 1.0 g/kg)

2A23-like method
- 4 km resolution
- Steiner method applied to composite dBZs from below melting level
- convective = core + adjacent
- Bright Band (vertical gradient test, -1 dBZ/km, horizontal continuity)

H+V method
- Cores = convective
- Adjacent + BB = stratiform
- Adjacent + no BB = convective
NASA Unified WRF
NU-WRF

Two nesting domains
9 and 3 km

NCEP Re-analyse

Goddard 4ICE Scheme
(Lang et al. 2014; Tao et al. 2016)

Goddard Long- and Short-wave Radiation
(Chou and Suarez 1999, 2001; Matsui and Jacob 2014)

East Coast Synoptic Winter storms

CalWater 2015
Fig. 4  Horizontal distributions of 12-hour accumulated rainfall amounts from (a, d) 1200-2400 UTC 6 February 2015, (b, e) 1200-2400 UTC 19 February 2015, and (c, f) 1200-2400 UTC 15 March 2015, derived from (a–c) the multi-satellite precipitation estimates with gauge calibration in GPM IMERG version 5B and (d–f) the NU-WRF model simulations.
The convective region is associated with very high surface precipitation rates, which only cover a very small area. The stratiform region covers nearly the entire surface precipitation area. These results differ from organized MCSs and tropical convection.
Schematic diagram showing the production of the new cold LUT from NU-WRF simulations and a self-consistency check

NU-WRF

Precipitation rate
Max dBZ height
Echo top height
Freezing level height
2-d max dBZ

Look-up table

Retrieved LH

Original LH

GPM 2BCMB(DPR+GMI) Product

Precipitation rate
Max dBZ height
Echo top height
Freezing level height
2-d max dBZ

Look-up table

Mid-latitude CSH Product

Self-consistency check
Max composite dBZs are linked to higher precipitation rates while lower freezing level heights are linked with lower Max dBZ heights.  

Strong LH occurs with high echo tops, but high echo tops do not always imply strong LH.
Key parameters used for the new cold season LH look-up table (LUT)

The LUT is built from NU-WRF simulated LH profiles from six weather events.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Bin ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface rainfall rate (mm h(^{-1}))</td>
<td>0., 0.178, 1., 1.78, 3.16, 5.62, 7.5, 10., 13.3, 17.8, 22.4, 27.0, 31.6, 44.0, 56.2, 70.0, 100., 9999.</td>
</tr>
<tr>
<td>Max dBZ height (m)</td>
<td>0., 500., 1000., 1500., 2000., 3000., 4000., 5000., 99999.</td>
</tr>
<tr>
<td>Echo top height (m)</td>
<td>0., 1000., 2000., 3000., 4000., 5000., 6000., 7000., 8000., 9000., 10000., 99999.</td>
</tr>
<tr>
<td>Max dBZ intensity</td>
<td>10, 12, 14, ...76, 78, 80 (from 10 to 80 with an interval of 2)</td>
</tr>
<tr>
<td>Vertical levels (80 levels; m)</td>
<td>0, 250, ..., 21750, 22000 (0 to 22000 with an interval of 250)</td>
</tr>
</tbody>
</table>
Convective

Stratiform

Middle-Level

Shallow Cloud

Different Surface precipitation rate,
Composite radar reflectivity
Echo-top height, Freezing level
Maximum radar reflectivity height,
→ LH profilers
Self-consistency check

Vertical cross sections of LH rates and air temperature (contour lines)

**Top panel**
NU-WRF simulated “Truth” LH

**Middle panel**
Retrieved LH using new LUT produced at the same time

**Bottom panel**
Retrieved LH using new LUT built over 36 hours

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## Major Characteristics of CSH and SLH Algorithm

<table>
<thead>
<tr>
<th></th>
<th>SLH</th>
<th>CSH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lang and Tao (2018)</td>
</tr>
<tr>
<td><strong>Cases</strong></td>
<td>Tropics: TOGA COARE</td>
<td>Tropics: 9 field campaigns (land and ocean)</td>
</tr>
<tr>
<td></td>
<td>Winter: 6 oceanic events</td>
<td>Winter: 6 events (land and ocean)</td>
</tr>
<tr>
<td><strong>Input</strong></td>
<td>PR/DPR</td>
<td>Combined GMI/DPR</td>
</tr>
<tr>
<td><strong>Products</strong></td>
<td>LH, Q1R, Q2</td>
<td>Tropics: LH, QR, Q2 and Eddy Heating and Moistening</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High latitudes: LH only</td>
</tr>
<tr>
<td><strong>Look-up Tables</strong></td>
<td>No horizontal eddy</td>
<td>Combined horizontal and vertical eddy</td>
</tr>
<tr>
<td></td>
<td>Based on CRM domain and <strong>time (5min)</strong> averaged (no subset):</td>
<td>Samples 32 (64) km model subdomains for GPM (TRMM) 0.25° x 0.25° (0.5° x 0.5°) gridded products</td>
</tr>
<tr>
<td></td>
<td>Consistent with surface rainfall</td>
<td></td>
</tr>
</tbody>
</table>
\[ \frac{1}{\sigma} \int \int_{P_{\text{base}}} (Q_1 - Q_R) \Delta p \Delta x = LP_0 + S_0 \]
**Action Items**

- Test additional model grid configurations (3D), domain sizes (1024 or more) and resolutions (200 m – smaller, shallower clouds) for LUTs
- Refinement of CSH algorithm
- Convective-Stratiform Classifications (R. Houze)
- Validation (integrated heating vs rainfall at higher latitudes, model self consistency tests)
- Collaboration between CSH and SLH algorithm team (share cases – look-up) – will meet this afternoon
- Collaboration with precipitation feature team
- Radiation profiles as part of Q1 (strong request from users)
1 month
Zonal Mean
Latent Heating

CSH
(July)

\[
\frac{1}{g} \int_{L} \int_{P_{\text{base}}}^{P_{\text{top}}} (Q_1 - \dot{Q}_1)
\]

Red: New July
Blue: V5
Current and future improvements/works

Close collaboration between CSH and Japan SLH team by sharing the same cases and comparing the LH structures.

For example, (1) the SLH team just received all of the data from the GCE simulated cases used to build the new warm season/tropical CSH LUTs, and (2) the CSH team will conduct simulations for a few cases over the Japan Sea--cases that are used for the SLH LUTs for winter systems.

The CSH and SLH derived orbital LH will be compared and their similarities and differences identified.

CSH is now using two different sets of LUTs with differing metrics, one for the Tropics and warm season (Lang and Tao 2018) and one for the cold season / high latitude / winter events.

4ICE: Cloud ice, snow, graupel, and hail

New 4ICE

GCE & NU-WRF simulations

Evaluate with Observations

Validated GCE Simulations

Validated NU-WRF Simulations

Consistency Checks

NEW, IMPROVED, & EXPANDED CSH Algorithm

Warm season, convective LUTs

Cold season, synoptic LUTs

CSH and SLH team will use the same cases for GPM!
Max composite dBZs are linked to higher precipitation rates while lower freezing level heights are linked with lower Max dBZ heights.

A close relationship between dBZ and heating occurs beneath the freezing level

Large surface precipitation rates have high composite dBZs; Strong LH occurs with high echo tops, but high echo tops do not always imply strong LH
Surface Precipitation Changes (V05 vs ITE607)

Combined (V05)
Total Surface Precip
99.8 mm/hr *(Conv)*

Combined (ITE607)
Total Surface Precip
99.4 mm/hr *(Strat)*