LATENT HEATING FROM TRMM AND GPM MEASUREMENT

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ABSTRACT

The Goddard Convective-Stratiform Heating (CSH) algorithm, used to estimate cloud heating in support of the Tropical Rainfall Measuring Mission (TRMM), is upgraded in support of the Global Precipitation Measurement mission (GPM). The algorithm is required to use look-up-tables (LUTs) from cloud-resolving model (CRM) simulations from the Goddard Cumulus Ensemble model (GCE). This paper will present the heating retrievals from the Goddard CSH algorithm in the TRMM and GPM using precipitation products (rainfall, radar reflectivity).

Index Terms— Precipitation, Latent Heating, satellite

1. INTRODUCTION

Rainfall production is a fundamental process within the Earth’s hydrological cycle because it represents both a principal forcing term in surface water budgets, and its energetics corollary, latent heating, is the principal source of atmospheric diabatic heating. Latent heat release itself is a consequence of phase changes between the vapor, liquid, and frozen states of water. The properties of the vertical distribution of latent heat release modulate large-scale meridional and zonal circulations within the Tropics - as well as modify the energetic efficiencies of mid-latitude weather systems. This paper highlights the retrieval of latent heat release from satellite measurements generated by the Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Mission (GPM) satellite observatory, which were launched in November 1997 and February 2014, respectively. Both TRMM and GPM measurements have been providing an accurate four-dimensional account of rainfall over the global Tropics and mid-latitudes: information that can be used to estimate the space-time structure of latent heating.

Two sets of latent heating retrieval algorithm methodologies (CSH, and Japan Spectral Latent Heating or SLH) have been developed to estimate latent heating based on rain rate profile retrievals obtained from TRMM and GPM measurements. Table 1 shows the differences between CSH and SLH algorithm in terms of their respective inputs and products. The table also provides the main references of their algorithms, including the developments, improvements and performances. Table 2 lists the required data and type of heating products for CSH algorithm. Note that one of the major inputs for the standard products is the improved rainfall estimate. Figure 1 shows an example of the LH products generated from the new version of the CSH algorithm (Lang and Tao, 2018).

<table>
<thead>
<tr>
<th>Key References</th>
<th>SLH</th>
<th>CSH</th>
</tr>
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<tbody>
<tr>
<td>Tropics: COARE Winter: 6 events (all over oceans)</td>
<td>Tropics: 9 field campaigns (land and ocean)</td>
<td></td>
</tr>
<tr>
<td>Winter: 6 events (land and ocean)</td>
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<tr>
<td>Inputs</td>
<td>PR/DPR</td>
<td>Combined</td>
</tr>
<tr>
<td>Products</td>
<td>LH, Q1R</td>
<td>Tropics: LH, Qr eddy Winter and high latitudes: LH</td>
</tr>
<tr>
<td>Convective-Stratiform separation</td>
<td>PR/DPR</td>
<td>GCE method (Tao et al. 2003)</td>
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<tr>
<td>Look-up Tables</td>
<td>No horizontal eddy Based on CRM (whole) domain and time averaged Consistent with surface rainfall</td>
<td>Include horizontal and vertical eddy Subset (32 or 64 out of 512 whole domain)</td>
</tr>
<tr>
<td>19 vs 80 vertical layers</td>
<td>Reduced heating</td>
<td>Increase heating</td>
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Table 1 Summary of the five LH algorithms participating. Data inputs, retrieved products, and salient references included. Note the conventional relationship between \( Q_1 \) (apparent heat source), \( LH \), and \( Q_e \) (radiative heating) is expressed by \( Q_1 = LH + EHT \), where the final term represents eddy heat transport by clouds (noting that vertically
integrated EHT is zero, i.e., it provides no explicit influence on surface rainfall. Note that CSH and SLH explicitly use CRM-simulated latent heating profiles in their heating algorithm look up tables.

<table>
<thead>
<tr>
<th>Type</th>
<th>Spatial scale</th>
<th>Temporal scale</th>
<th>Retrieved Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSH-Combined</td>
<td>Gridded</td>
<td>Instantaneous</td>
<td>LH, EHT, Q₂, micro/eddy Q₂</td>
</tr>
<tr>
<td></td>
<td>0.25° x 0.25°</td>
<td>80 layers</td>
<td></td>
</tr>
<tr>
<td>CSH-Combined</td>
<td>Gridded</td>
<td>Monthly</td>
<td>LH, EHT, Q₂, micro/eddy Q₂</td>
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<tr>
<td></td>
<td>0.25° x 0.25°</td>
<td>80 layers</td>
<td></td>
</tr>
<tr>
<td>CSH-Combined Orbital</td>
<td>Pixel</td>
<td>Instantaneous</td>
<td>LH, EHT, Q₂, micro/eddy Q₂</td>
</tr>
<tr>
<td></td>
<td>80 layers</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2  GPM cloud heating and moistening products from the CSH algorithm. The three individual heating components of the total apparent heat source or $Q_1$ (i.e., LH, EHT, and $Q_2$) retrieved separately where LH is latent heating, EHT the eddy heating rate, and $Q_2$ the radiative heating/cooling rate. Likewise, the apparent moistening source or $Q_2$ is separated into its microphysical and eddy components. *Orbital (pixel) heating is available but not a standard GPM product. Note that the CSH will only have LH and QR outside TRMM region.

Fig. 1  LH products (left) from the version 2 CSH algorithm based on V7 rainfall data from the TRMM Combined Algorithm: (bottom) instantaneous pixel scale LH off the southeast coast of Africa 1 January 2001 at a height near 2.5 km from the orbital product, (middle) same but for the 3G31 gridded (0.5° x 0.5°) orbital product, and (top) same but for monthly mean LH from the 3H31 gridded monthly product.

Fig. 2 shows the mean surface rainfall from the Combined algorithm for the 3-month period 1 April – 30 June 2014 for TRMM (i.e., 2B31, bottom panel) and for GPM (i.e., DPRGMI, top panel) over the TRMM domain (i.e., 37 N to 37 S). The rainfall is gridded onto a 0.5° x 0.5° grid for TRMM and a 0.25° x 0.25° grid from GPM, which are the official grid resolutions for TRMM and GPM gridded products, respectively, including gridded CSH heating products. Prominent rainfall features commonly observed within the Tropics in association with the ITCZ, the SPCZ, the Maritime Continent and midlatitude storm tracks over and downwind of the continents are all evident. In terms of the rainfall characteristics, the TRMM rainfall tends to have more moderate values (i.e., 4 to 6 mm/day, shown in green) whereas GPM shows large areas of higher values (i.e., > 10 mm/day). This is partially due to the increased averaging of the coarser TRMM grid, but also because GPM can detect more rain. The TRMM average surface rain rate over the entire domain and 3-month period is 2.8 mm/day, whereas for GPM, it is 3.3 mm/day.

Figures 3 and 4 show the mean diabatic heating rates ($Q_1 - Q_2$) over the TRMM domain during this same 3-month period retrieved from the CSH algorithm at 2 and 7 km, respectively. The lower panels show TRMM CSH-retrieved heating and the top panels show GPM CSH-retrieved heating using the new LUTs binned according to echo top height and low-level reflectivity gradient. Immediately evident is the large increase in shallow heating in both GPM retrievals over TRMM at low levels. At 2 km (Fig.

3. Results
there is both much more intense heating within
the hot spots already apparent in TRMM (e.g., the
ITCZ, SPCZ, and equatorial Indian Ocean) as well
as an intensification and expansion of shallow
heating outside of these regions into the sub-tropics.
This is tied to the increased detection of shallow,
mostly convective rain. Both the composite and the
split echo top versions of the new LUTs show
similar robust heating patterns at the 2-km level. At
upper-levels (Fig. 4), the heating patterns and mean
intensities are fairly similar between the GPM and
TRMM retrievals with strong areas of heating over
equatorial Africa, northern South America, the
Maritime Continent, and within a sharp, well-
defined ITCZ extending across the Central and East
Pacific. Other areas of prominent heating in the
equatorial Atlantic, the SPCZ, and the equatorial
Indian Ocean are also similar in shape and
magnitude when accounting for the coarser TRMM
grid resolution.

The retrieved heating can be vertically integrated
to produce an equivalent surface rain rate, which
can then be compared against the observed (input)
surface rain rate to check for biases (Lang and
Tao, 2018). Figure 5 shows the net difference in
integrated heating minus the observed (input)
surface rain rate from the Combined algorithm
over the global. A consistent pattern emerges for
the retrieval with broad areas of surplus heating
occurring over ocean in the weaker rain rate
regimes poleward of the ITCZ and heating deficits
occurring primarily over ocean at even higher
latitudes along the edges of the midlatitude storm
tracks. These areas are dominated by convective
and stratiform rain, respectively, which is
consistent with the imbalance in heating versus
rainfall for these two regions in convective
systems as some of the condensate generated in
the convective region, which produces heating
there, falls out as precipitation in the stratiform
region. deficit heating such as within the ITCZ,
equatorial Africa, and tropical South America.
The zonal mean differences is less than 0.5 mm d-
1. Also integrated heating is always stronger than
observed in all latitudes and smaller differences is
in sub-tropics.
column-integrated less CSH cloud diabatic heating rates \((Q_f - Q_p)\) for the 3-month period 1 April to 30 June 2014 for GPM with new CSH algorithm. Bottom panel is the zonal mean retrieval and GPM combined rain.

4. CURRENT WORKS

Additional model grid configurations (3D, quasi-3D), domain sizes (1024 or more) and resolutions (200 m – smaller, shallower clouds) for LUTs will be tested. Winter and high latitudes cases (for both oceanic and continental region) is currently adding into LCTs (Tao et al. 2018). In addition, validation (integrated heating vs rainfall at higher latitudes, model self-consistency tests) will be studied. Both CSH and SLH teams are working closely in terms of sharing GCE, WRF and JMA model simulated latent heating structures (improving the look-up tables). The microphysical processes (or schemes) used in the GCE and WRF model are being improved by using GMP ground validation (GV) data sets.

REFERENCES


