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.

2. TRMM AND GPM LH ALGORITHMS

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>
</thead>
<tbody>
<tr>
<td>Cases</td>
<td>Tropics: COARE, Winter: 6 events (all over oceans)</td>
<td>Tropics: 9 field campaigns (land and ocean), Winter: 6 events (land and ocean)</td>
</tr>
<tr>
<td>PR/DPR</td>
<td>PR/DPR</td>
<td>GTCE method (Tao et al. 2003)</td>
</tr>
<tr>
<td>LH, Q1R</td>
<td>Tropics: LH, Qr eddy, Winter and high latitudes: LH</td>
<td></td>
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<tr>
<td>Convective-Stratiform separation</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>Look-up Tables</td>
<td>Reduced heating</td>
<td>Increase heating</td>
</tr>
</tbody>
</table>

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 $Q_r$ (radiative heating) is expressed by $Q_1 = Q_r = LH + EHT$, 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, Qs, micro/eddy Q2</td>
</tr>
<tr>
<td>Gridded</td>
<td>0.25° x 0.25°</td>
<td>80 layers</td>
<td></td>
</tr>
<tr>
<td>Monthly</td>
<td>0.25° x 0.25°</td>
<td>80 layers</td>
<td>LH, EHT, Qs, micro/eddy Q2</td>
</tr>
<tr>
<td>Orbital*</td>
<td>Pixel</td>
<td>80 layers</td>
<td>LH, EHT, Qs, micro/eddy Q2</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 \( Q_s \)) retrieved separately where LH is latent heating, EHT the eddy heating rate, and \( Q_s \) 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.

3. RESULTS

Figure 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.
3), 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.
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


