Uncertainties in Atmospheric Diabatic Heating Distributions Derived from TRMM Observations and Reanalysis Datasets

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in collaboration with

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Estimation of Diabatic Heating Distributions

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

- **phase change or “latent heating”**
- **eddy sensible heat flux convergence**
- **radiative heating**

Use satellite data:

- \( Q_1 - Q_R \), in precip from precipitation rate, convective proportion, and depth.
- \( Q_R \) from HERB algorithm; Tristan L’Ecuyer.
- \( Q_1 - Q_R \) in non-precip from an energy balance model, \( Q_R \) from HERB, NCEP env. temp.
1998-2008 Comparison of TRMM and Reanalysis Heating

TRMM

CFS-R

MERRA

ERA Interim

\( Q_1 \)

\( Q_1 - Q_R \)

\( Q_R \)

\( K \text{ day}^{-1} \)

from Jiang, Olson, L’Ecuyer, Grecu (NEWS)
Q: What levels of confidence do we have in TRMM heating, and can the heating fields tell us something about potential biases in reanalysis heating?

- take error modeling approach to estimate total algorithmic uncertainty in TRMM $Q_1 - Q_R$ estimates.

- examine TRMM vs. reanalysis $Q_1 - Q_R$ differences in light of TRMM uncertainties.

**Integration Activities**

- construct stratocumulus topped boundary layer model for understanding sensitivity of water and energy budgets to environmental forcings in lightly- or non-precipitating regimes (Clouds and Radiation working group).

- help complete global water and energy budget publications (from previous NEWS cycles).
Grant Progress

- Developed TRMM version of GPM radar-radiometer precipitation/heating algorithm; 16+ year record.
- Error model for TRMM $Q_1 - Q_R$ estimates being constructed.
- Reanalysis datasets co-gridded at common resolution for 2008-2010 (YOTC period).

Integration Activities

- Stratocumulus topped boundary layer model adapted from Grenier and Bretherton (2001).
- drafts of global water and energy budget publications.
characteristic heating derived for 16 different precipitation “classes”

\[ Q(z) = \hat{Q}(z) P \]

\( Q(z) \) is estimated heating.

\( \hat{Q}(z) \) is “characteristic” normalized heating (from cloud model).

\( P \) is satellite estimated precipitation rate.

\[ \hat{Q}(z) = \left\langle \frac{Q(z)_{\text{model}}}{P_{\text{model}}} \right\rangle \]

\( \left\langle \right\rangle \) is average over large number of model profiles
Error Sources

Q(z) = \hat{Q}(z) P \quad \text{(algorithm)}

total error = bias due to CRM “characteristic” heating of large-scale space/time mean heating estimate
+ bias due to precipitation estimates
+ non-representative CRM heating profile at footprint scale
&
error of precip est. at footprint scale
propagated to large-scale mean
+ error due to temporal undersampling
\[ Q(z) = \hat{Q}(z)P \] (algorithm)

\[ \sigma_{Q(z)}^2 = P^2 \sigma_{\hat{Q}(z)}^2 + \hat{Q}(z)^2 \sigma_P^2 \] (error)

from precipitation algorithm

\[ \sigma_{\hat{Q}(z)}^2 = \frac{\sigma_{\langle Q(z)_{\text{model}} \rangle}^2}{\langle P_{\text{model}} \rangle^2} + \frac{\langle Q(z)_{\text{model}} \rangle^2}{\langle P_{\text{model}} \rangle^4} \sigma_{\langle P_{\text{model}} \rangle}^2 \]

\[ - 2 \frac{\langle Q(z)_{\text{model}} \rangle}{\langle P_{\text{model}} \rangle^3} \text{cov}\{ \varepsilon \langle Q(z)_{\text{model}} \rangle, \varepsilon \langle P_{\text{model}} \rangle \} \]
Footprint-Scale $Q_1 - Q_R$ and Errors at 7 km Altitude

$Q_1 - Q_R$ at 7 km Altitude

$Q_1 - Q_R$ Estimated Error at 7 km Altitude
$Q_1 - Q_R$ Error “Upscaling”

\[ Q(z) = \hat{Q}(z) P \quad \text{(algorithm)} \]

\[ \sigma_{Q(z)}^2 = P^2 \sigma_{\hat{Q}(z)}^2 + \hat{Q}(z)^2 \sigma_P^2 \quad \text{(error)} \]

\[ Q(z) = \frac{1}{N} \sum_{i=1}^{N} Q(z)_i \quad \text{(mean estimate)} \]

\[ \sigma_{\bar{Q}(z)}^2 = \frac{1}{N^2} \sum_{i=1}^{N} \sum_{j=1}^{N} \sigma_{Q(z)_i} \sigma_{Q(z)_j} r \{\varepsilon_i, \varepsilon_j\} \quad \text{(error of mean estimate)} \]

\[ r \{\varepsilon_i, \varepsilon_j\} = \exp \left( -\frac{s_{ij}}{L} \right) \]

where $s_{ij}$ is footprint separation and $L$ is error de-correlation length.
Validation of L using Area-Averaged Rain Estimates

**0.25 degree resolution**

- **Error vs. Surface Rain Rate at 0.25 Degree**
  - slope: 0.3223
  - intercept: 0.0047
  - correlation: 0.9147

**0.50 degree resolution**

- **Error vs. Surface Rain Rate at 0.50 Degree**
  - slope: 0.2177
  - intercept: 0.0046
  - correlation: 0.9289

**error model**

**errors from ground radar comparisons**
Footprint-Scale $Q_1 - Q_R$ and Errors at 7 km Altitude

$Q_1 - Q_R$ at 7 km Altitude

$Q_1 - Q_R$ Estimated Error at 7 km Altitude
0.25 degree $Q_1 - Q_R$ and Errors at 7 km Altitude

$Q_1 - Q_R$ at 7 km Altitude

$Q_1 - Q_R$ Estimated Error at 7 km Altitude
0.50 degree $Q_1 - Q_R$ and Errors at 7 km Altitude

$Q_1 - Q_R$ at 7 km Altitude

$Q_1 - Q_R$ Estimated Error at 7 km Altitude
Rain Rate, $Q_1 - Q_R$ at 7 km and 2 km, and Their Errors (1.0 deg resolution, DJF 2009/2010)
Anticipated for 2014

• “Calibration” of error model using ground radar data and CRM simulations.

• Application of TRMM heating algorithm and error model to 16+ year TRMM record.

• Comparisons to reanalysis datasets over same period.

Integration Activities

• Study quasi-equilibrium response of the stratocumulus model to variations large-scale environmental forcing.

• submit global water and energy budget publications.
Extras
Influence of PR Heating Lookup Table on $Q_1 - Q_R$

**Tropical West Pacific**

![Graph showing $Q_1 - Q_R$ for the Tropical West Pacific.](image)

**Tropical East Pacific**

![Graph showing $Q_1 - Q_R$ for the Tropical East Pacific.](image)
Satellite Estimates vs. Rawinsonde Analyses

**SCSMEX NESA**

- Surface Rain Rates
  - TMI $Q - Q_s$ [K day$^{-1}$]
  - TMI/VIRS $Q_s$ [K day$^{-1}$]
  - Rawinsonde $Q_s$ [K day$^{-1}$]

**MISMO**

- Surface Rain Rates
  - TMI $Q - Q_s$ [K day$^{-1}$]
  - TMI/VIRS $Q_s$ [K day$^{-1}$]
  - Rawinsonde $Q_s$ [K day$^{-1}$]

*rawinsonde $Q_s$ from Johnson and Ciesielski (2002)*

*rawinsonde $Q_s$ from Katsumata et al. (2009), JAMSTEC*