A First Look at Warm Rain Latent Heating from CloudSat

Ethan L. Nelson and Tristan S. L'Ecuyer

University of Wisconsin–Madison

ethan.nelson@aos.wisc.edu

Introduction

- Energy from the surface is transported vertically in the atmosphere and released in the troposphere by latent heating through processes such as condensation.
- Quantifying latent heat release is thus important for understanding the atmospheric energy budget, general circulations, and climatic features (Simpson et al. 1988).
- Studies have shown that light rainfall estimates from some observing platforms are underestimated, yet observations from CloudSat help to fill this gap (Berg et al. 2010).
- Estimates of latent heating likely follow suit, so we attempt to estimate latent heating globally in warm rain systems that precipitate lightly from CloudSat.

Guiding Questions

1. Can we create an algorithm that constrains latent heating in oceanic warm rain systems using characteristics of a W-band reflectivity profile, like one available from CloudSat?
2. Can we estimate other cloud and environmental properties from these profiles?

Algorithm Design

- **Figure 1** illustrates our Bayesian Monte Carlo algorithm pipeline (Nelson et al. 2016).
- The *a priori* database is composed of Regional Atmospheric Modeling System (RAMS) cloud-resolving simulations initialized with Atlantic Trade Wind Experiment observations over the tropical Atlantic Ocean (Saleeby et al., 2014).
- Simulations vary sea surface temperature (SST) and cloud condensation nuclei concentration (CCNC) to represent different stabilities and aerosol environments.
- CloudSat radar observations are associated to the RAMS output with the radar simulator package QuickBeam (Haynes, et al., 2007).
- Characteristics of the reflectivity profile are used as inputs to the algorithm: -30 dBZ height, 0 dBZ height, maximum reflectivity height, path integrated reflectivity, path integrated attenuation, and near-surface bin reflectivity.
- Probabilities are assigned to each database member via:

$$p_i = \frac{exp\{-\frac{1}{2}(\boldsymbol{y_o} - \boldsymbol{y_{s,i}})^T \boldsymbol{C}^{-1}(\boldsymbol{y_o} - \boldsymbol{y_{s,i}})\}}{\sum_{j=1}^{N} exp\{-\frac{1}{2}(\boldsymbol{y_o} - \boldsymbol{y_{s,j}})^T \boldsymbol{C}^{-1}(\boldsymbol{y_o} - \boldsymbol{y_{s,j}})\}}$$

  where $\boldsymbol{y_o}$ is the observed input, $\boldsymbol{y_{s,i}}$ is the database member, and $\boldsymbol{C}$ is the error covariance matrix. The algorithm output is the weighted sum of the database and the uncertainty is the weighted standard deviation.
- Errors (variances) are based on CloudSat data resolutions and accuracies (250 m height, 1 dBZ reflectivity, 2 dB attenuation) while covariances are the Pearson correlation coefficients between variables.

Analysis

- CloudSat observations from 2008-2009 are used and binned on a 1° x 1° grid.
- Mean integrated heating is $\sim$1 K day^{-1} in the strongest regions, with a characteristic of increasing heating zonally from eastern ocean edges westward (**Figure 2**).
- The level of maximum cooling, usually due to strongest entrainment near cloud top, has a similar increasing pattern moving westward (**Figure 3**).
- Average rainfall rates are generally higher in areas of strongest heating, with maxima near 0.08 mm hr^{-1} (**Figure 4**).
- Retrieved sea surface temperature regime highlights regions of upwelling and stabler local thermodynamic stability off western coasts (**Figure 5**).
- Zonal cross sections of latent heating also show the same characteristic of increasing cloud top and instability moving westward (**Figure 6**).

Conclusions and Forthcoming Research

- Our Bayesian algorithm is able to capture the spatial variability of latent heating in oceanic warm rain systems using reflectivity profiles from CloudSat.
- Other model variables, like sea surface temperature and vertical velocity, associated with database profiles can also be retrieved using the algorithm system.
- We plan to look at the incipient stages of the Madden-Julian Oscillation, where crucial low-level heating is underrepresented in products (Jiang, et al., 2011).
- We will also extend the algorithm to other regimes using more RAMS runs and the NASA Earth Observing System Simulator Suite (e.g. Tanelli et al., 2010).

Acknowledgements

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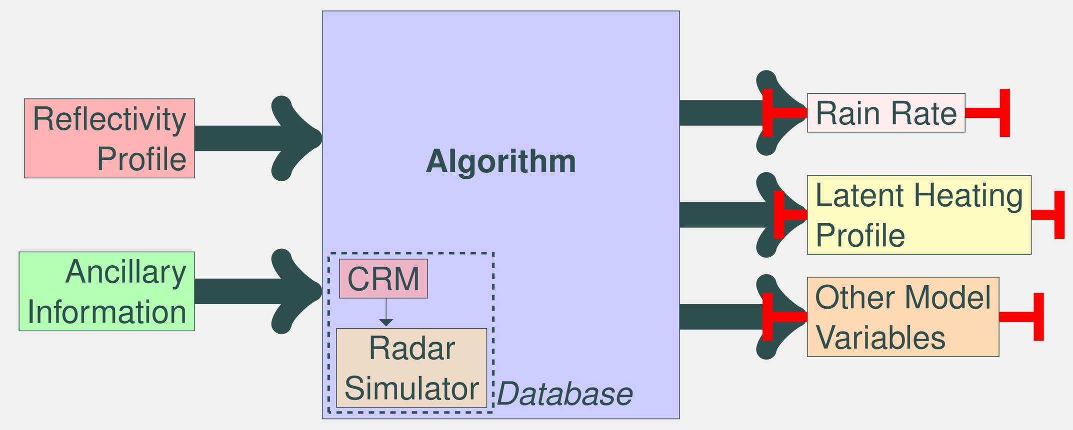
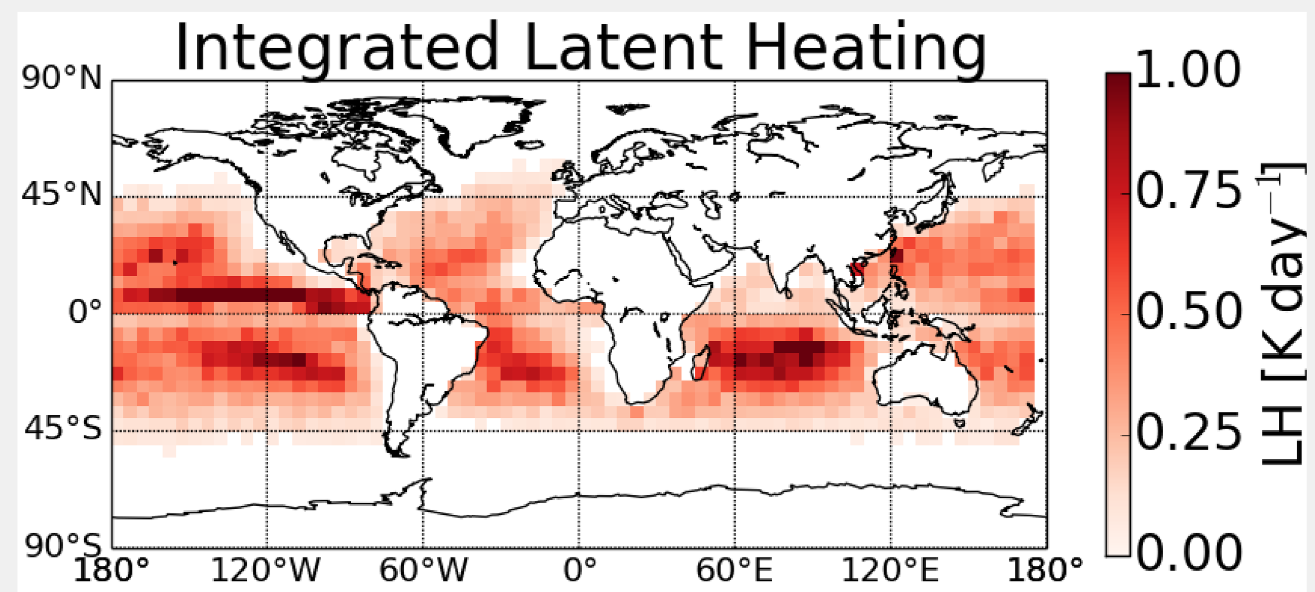
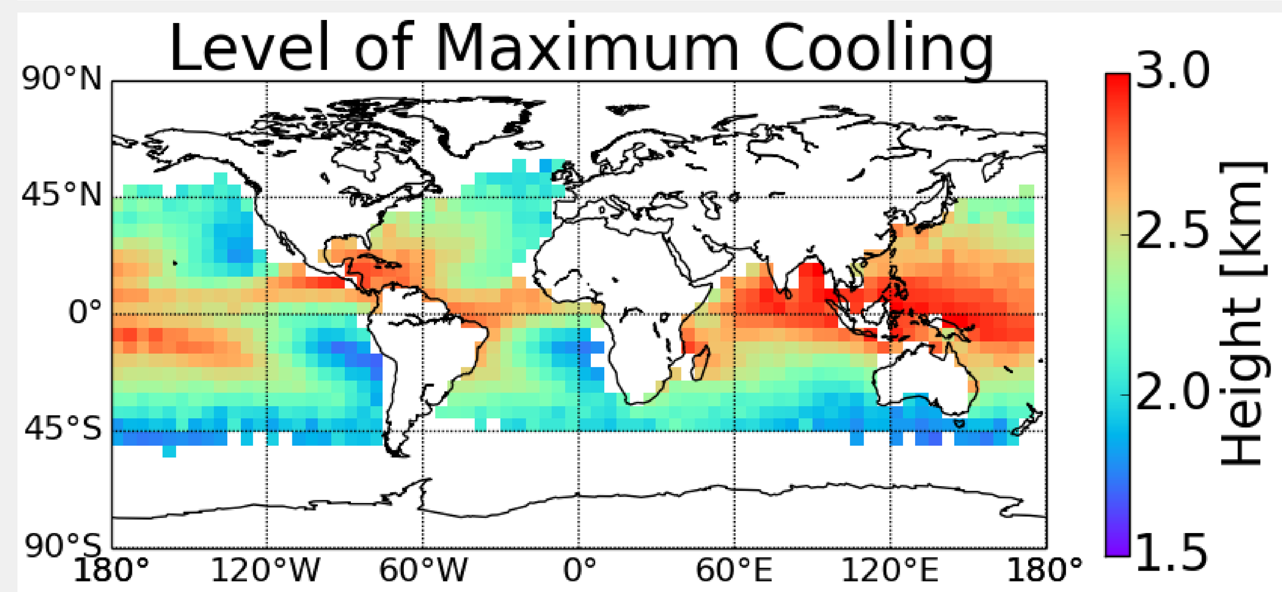


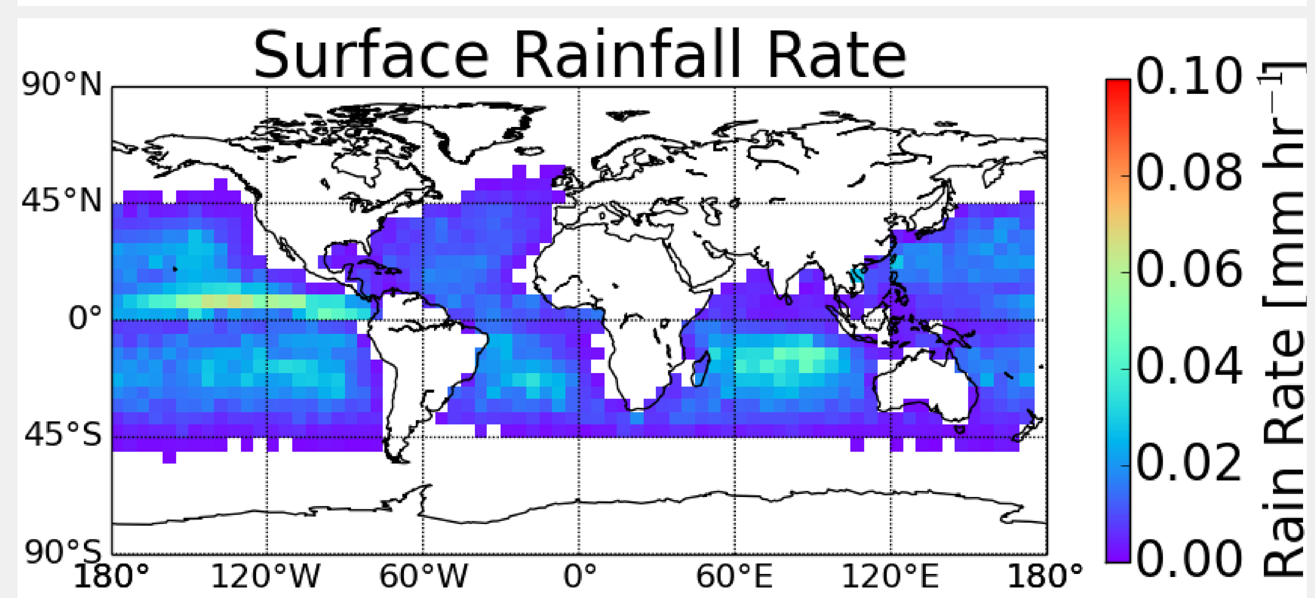
← **Figure 1:** Illustration of the algorithm system.



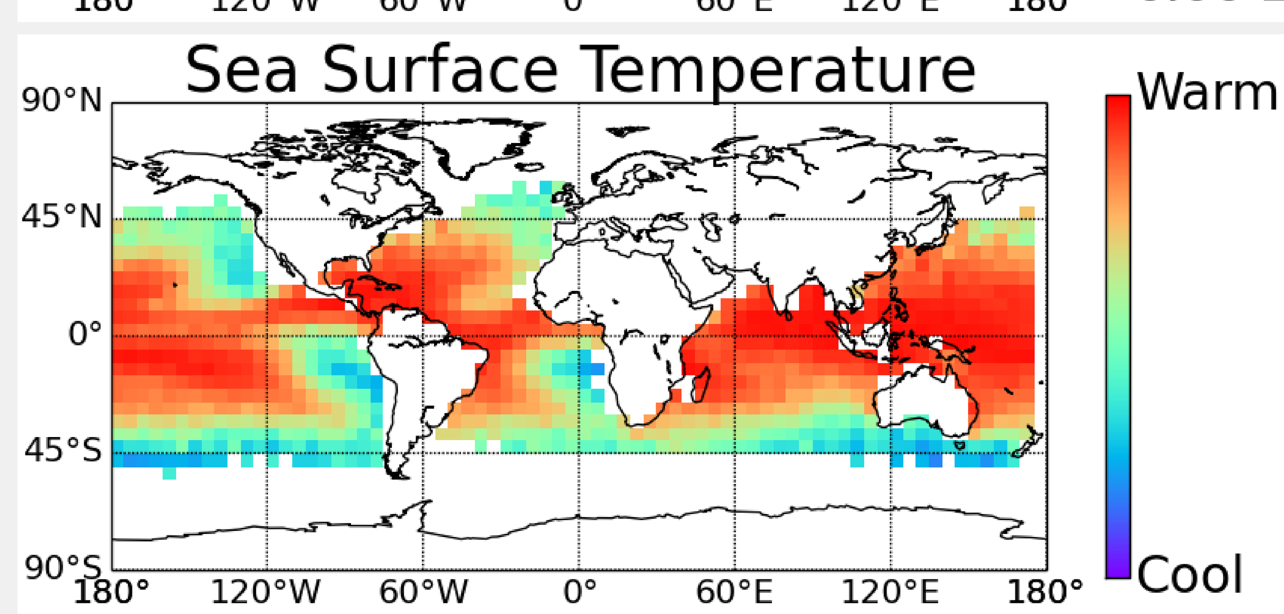
← ***Figure 2:*** *Integrated latent heating in K day^{-1} averaged over the full observational period (2008-2009).*



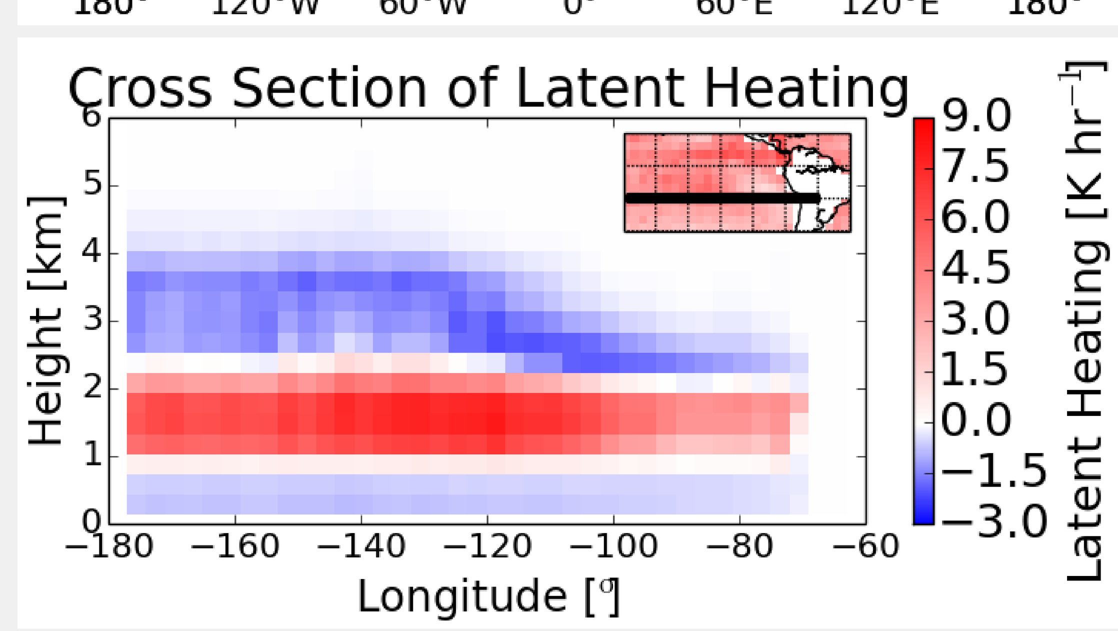
← ***Figure 3:*** *Average retrieved level of maximum latent cooling in km.*



← ***Figure 4:*** *Retrieved rain rate in mm hr^{-1} averaged over the full observational period.*



← ***Figure 5:*** *Average retrieved sea surface temperature regime.*



← ***Figure 6:*** *Example zonal vertical cross section of latent heating centered about the -18° latitude.*

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