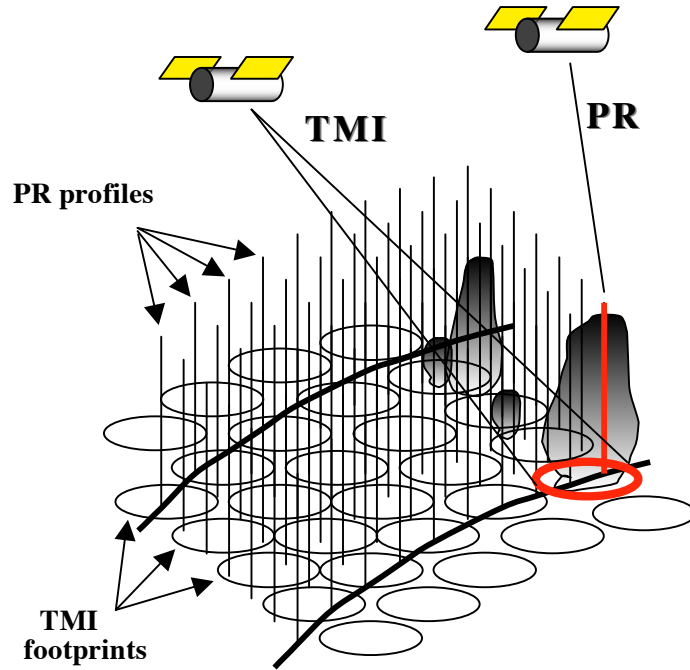


# Estimation of Precipitation and Latent Heating Distributions in Tropical Convection from a Combined Analysis of Passive Microwave and Spaceborne Radar Observations

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An improved method for evaluating consistent precipitation and latent heating distributions based upon satellite passive microwave radiometer observations is presented. The method is “trained” using coincident passive microwave radiometer and spaceborne radar observations- a variational procedure is used to optimize the intercept,  $N_o^*$ , of the normalized precipitation size distribution, as well as the mean density,  $\rho_{ice}$ , of ice-phase precipitation in each retrieved vertical profile. These parameters are optimized to obtain simultaneous consistency between the solution profile’s path integrated attenuation and radiance normalized polarizations and those drawn from PR surface backscatter and TMI radiance observations, respectively. The optimization is accomplished by minimizing the functional,  $F$ , at right.



$$F = \frac{1}{2} \left[ \mathbf{PIA}_{\text{obs}} - \mathbf{PIA}(Z_{\text{obs}}, N_o^*, \rho_{ice}) \right]^T \mathbf{W}_{\text{PIA}}^{-1} \left[ \mathbf{PIA}_{\text{obs}} - \mathbf{PIA}(Z_{\text{obs}}, N_o^*, \rho_{ice}) \right] \\ + \frac{1}{2} \left[ \mathbf{NP}_{\text{obs}} - \int_{\Omega} \mathbf{G}(A) \mathbf{NP}(A, Z_{\text{obs}}, N_o^*, \rho_{ice}) dA \right]^T \mathbf{W}_{\text{NP}}^{-1} \\ \times \left[ \mathbf{NP}_{\text{obs}} - \int_{\Omega} \mathbf{G}(A) \mathbf{NP}(A, Z_{\text{obs}}, N_o^*, \rho_{ice}) dA \right] \\ + C$$

Using the procedure outlined above, vertical profiles of cloud and precipitation are estimated at every PR footprint location at roughly the horizontal and vertical resolution of the PR data (4.3 km / 0.25 km). This procedure has been applied to all PR/TMI swaths in one-month periods to obtain a very general sampling of precipitation structures in the tropics and subtropics. A training set based upon one month of these data may contain ~1 million precipitation profiles.

Next, latent heating rates are assigned to each cloud/precipitation profile with the aid of tabulated, cloud model simulated profiles of precipitation/latent heating to complete the training set. The assignment of latent heating profiles is based upon a method similar to that of Shige et al. (2004). In this method, cloud-resolving model simulations are used to generate lookup tables of vertical heating structures, indexed by precipitation profile depth. The tables for convective and stratiform heating profiles are illustrated graphically, below. The mean heating profile associated with each “cloud top height” (actually the radar echo top) in the cloud-resolving model simulations is entered into the

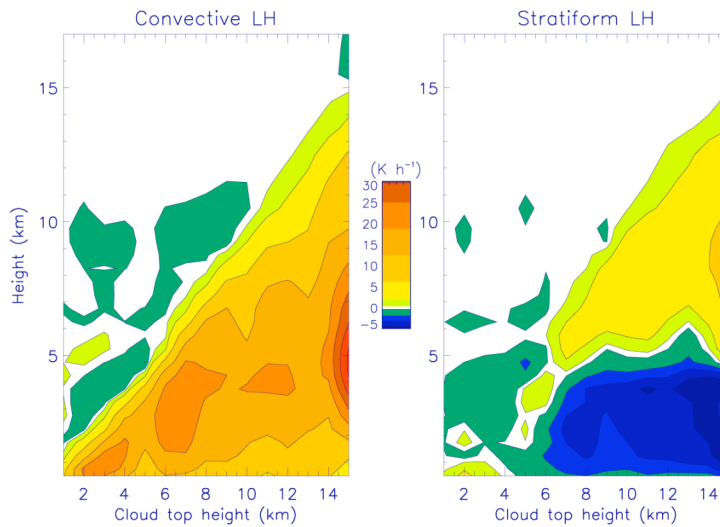
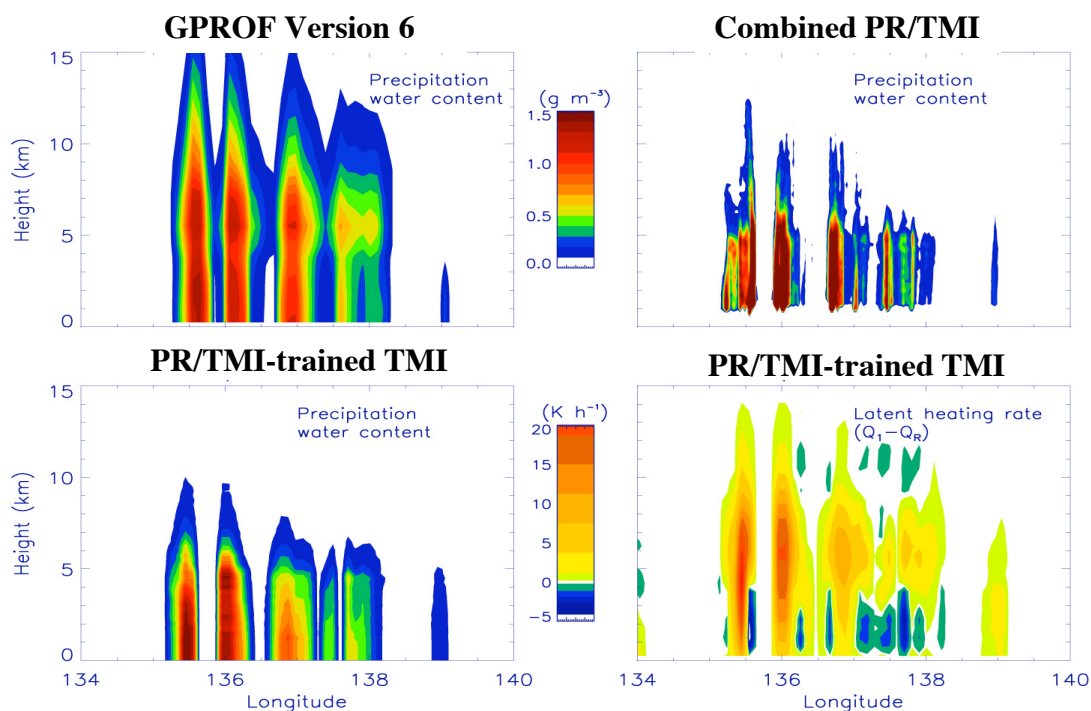


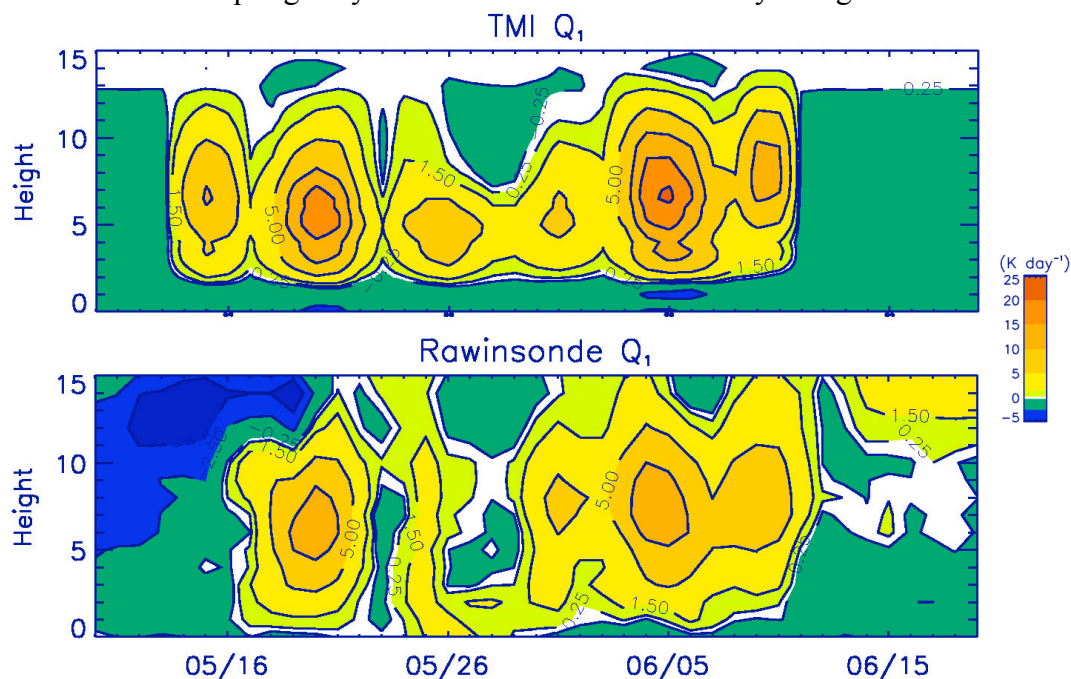
table. For a given vertical precipitation profile in the training set, the tabulated heating profile with the same cloud top height is extracted from the table and renormalized by the surface precipitation flux (convective) or the surface and freezing level precipitation fluxes (stratiform) to obtain a consistent heating profile.

Upwelling microwave radiances associated with the precipitation/latent heating training profiles are simulated using radiative transfer calculations, such that the relationships between precipitation/latent heating and observed radiances applicable to any satellite microwave radiometer (e.g., TRMM Microwave Imager; Special Sensor Microwave/Imager, Advanced Microwave Scanning Radiometer-EOS) can be established. Given a set of observed radiances, the large set of training data is quickly searched and radiatively compatible profiles are composited to obtain best estimates of precipitation/latent heating.

An application of the improved microwave precipitation/latent heating estimation method to TMI observations of Supertyphoon Paka (1997) is presented in the figure below. For reference, the top-left panel is a vertical cross-section of estimated precipitation from an earlier algorithm (GPROF Version 6), which was trained using only cloud-resolving model simulations. In contrast, the Combined PR/TMI estimates (top-right panel), which are representative of training data for the improved algorithm, yield vertical precipitation structures that are not as deep as the GPROF estimates. As expected, the TMI estimation method that is trained using Combined PR/TMI data from July 2000 yields precipitation distributions with similar structure (bottom-left panel). Latent heating ( $Q_I - Q_R$ , or the apparent heat source less radiative heating) estimates from the same method are shown in the bottom-right panel. The latent heating distribution reveals deep, intense heating in the eyewall region (135.0-136.5 °E), while upper-level heating and low-level cooling characterize the predominantly stratiform region (137.0-138.0 °E).



Below is an application of the improved microwave radiometer method to TMI observations of the South China Sea Monsoon Experiment's Northern Enhanced Sounding Array during the period May 10 - June 19, 1998. Time series of TMI-retrieved and rawinsonde-derived vertical latent heating structure are shown. The rawinsonde  $Q_I$  is derived from an analysis by Johnson and Ciesielski (2002). A climatological estimate of radiative heating is added to the TMI estimates of  $Q_I - Q_R$  to obtain  $Q_I$ . Note that the discrepancies at 05/15 and 05/26 are largely the result of deficient temporal sampling by TMI. Deficient sampling may be overcome in the future by using data from multiple



radiometers.

A notable deficiency in the current latent heating estimation method is the apparent lack of low-level heating ( $< 2$  km altitude), as seen in the TMI  $Q_l$  time series. This deficiency can be overcome by including a better representation of shallow convection in the latent heating table look-up procedure.

One intended application of these satellite microwave radiometer estimates of precipitation and latent heating is to produce, in combination with other observations, a more consistent picture of the Earth's energy and water cycles. In this regard, an advantage of the radiometer-based estimation technique relative to spaceborne radar methods is the potential for greater temporal sampling of precipitation systems globally, given that several satellite microwave instruments are currently operating, and additional radiometer missions are planned.

### *References*

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