# Radiative Heating Profiles for Tropical Cloud Regimes

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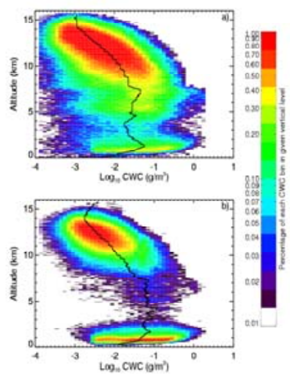
### 1. Introduction

Vertical profiles of radiative heating rates are important for cloud evolution and for driving vertical motions that play a role in atmospheric circulations on a wide range of temporal and spatial scales.

Atmospheric Radiation Measurement (ARM) program Millimeter Cloud Radar (MMCR) observations can be used to derive cloud property profiles that in turn can be applied to calculating radiative heating profiles (Mather et al., 2007).

We have segregated the heating profiles according to vertical cloud structure and examine the radiative heating profiles associated with the most prevalent cloud forms.

These cloud and heating structures can be used for model validation as well for refining satellite-based retrievals of these structures.




### 2. Cloud Distributions at Manus and Nauru

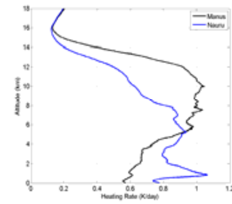
The frequency distributions of condensed water for Manus (top left) and Nauru (bottom left) were derived from MMCR observations (Feb-Jul 2000 for Manus and 1999 for Nauru).

The cloud distributions for the two sites are similar – both with cirrus and boundary layer features.

However the frequency of these features differs between the two sites and Nauru is missing the mid-level feature observed at Manus.

A fundamental question we will examine is whether there is a significant difference in the clouds at the two sites or only in the frequency with which certain cloud classes occur.

### 3. Radiative Heating Profiles




Shown above are the average shortwave radiative heating profiles for Manus and Nauru. The two profiles are significantly different with more upper level heating at Manus and low level heating at Nauru.

### 4. Cloud Classes

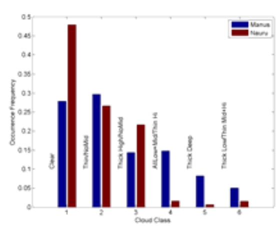
For each time step in the Manus and Nauru observations, we have assigned a cloud class based on the optical thickness in three vertical layers. This scheme is very similar to that used by the satellite-based ISCCP product.

***Vertical Layers***: Instantaneous cloud profiles observed by the MMCR are sorted according to the cloud optical depth in three vertical layers:

Low cloud: 0-3 km
Middle cloud: 3-7 km
High cloud: 7-16 km

***Optical Thickness***: Within each of these layers, clouds are binned into ranges of optical depth:

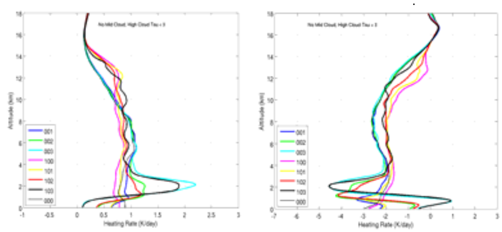
Tau = 0 - 0.001 (clear)
Tau = 0.001 – 3
Tau = 3 – 20
Tau = 20 – 1000




Four optical depth ranges in three vertical levels results in sixty-four possible cloud layer combinations. The chart above sorts these sixty-four classes into six groups:

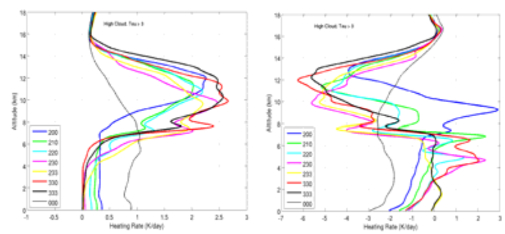
1. Clear
2. No mid-level cloud; tau < 3 for high clouds
3. Tau < 3 for low clouds; tau > 3 for high clouds
4. Mid-cloud present; tau < 3 for high clouds;
5. Tau > 3 for low and high clouds
6. Tau > 3 for low clouds; tau < 3 for high clouds

### 5. Radiative Heating by Class

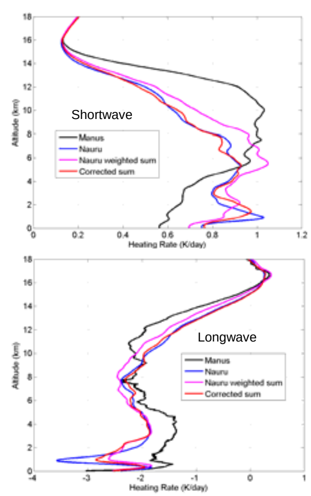



Shortwave (left) and longwave (right) heating profiles for cloud classes at Manus with no mid-level cloud and optical depths for high level cloud less than 3.

The 3-digit code in the legend indicates the optical depth range for the high- middle-low layers (eg: 102 => thin high cloud, no mid cloud, moderate low cloud)




Shortwave (left) and longwave (right) heating profiles for cloud classes at Manus with optical depths of high clouds greater than 3.




### 6. Comparison of Cloud Classes At Manus and Nauru

The composite heating profile for the study period is shown for Manus (black) and Nauru (blue). For each, the heating profile is calculated as a weighted sum of the individual classes for that site.

The magenta curve was calculated again with a weighted sum – but using the individual cloud class profiles from Manus but with the weights for Nauru.

The red curve was also calculated using Manus profiles and Nauru weights, but the profile was corrected by the difference between the Manus and Nauru clear sky profiles. This correction effectively compensates for the different average water vapor profiles at the two sites.

The corrected weighted sum closely matches the actual average heating profile for Nauru.

### 7. Conclusions

The tri-modal distribution of clouds in the tropical Pacific leads to distinct vertical heating patterns. In the shortwave, clouds lead to heating in cloud and cooling below. Longwave profiles are more complex: optically thin clouds are heated throughout the layer (relative to clear sky) while optically thick clouds tend to heat below and cool above.

The fact that we are able to reproduce the average Nauru heating profile using a composite of Manus cloud class profiles strongly suggests that the cloud properties at Manus and Nauru are very similar. The difference between the two sites is the frequency with which individual cloud classes occur.

This similarity in heating profile characteristics between these sites suggests that cloud observations at the tropical sites can be broadly applied throughout the region.