OVERCAST CLOUDS DETERMINED BY TRMM MEASUREMENTS

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Abstract
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ABSTRACT

Using the Tropical Rainfall Measuring Mission (TRMM) Visible and Infra-Red Scanner (VIRS) and TRMM Microwave Radiometer (TMI) measurements, this study retrieves cloud optical depth (τ), liquid water path (LWP), and the frequency of co-occurrence of ice and water clouds based on radiative transfer models. Results show that LWP values for warm non-precipitating clouds are ~0.06mm and cold clouds have large ice water amount (~0.1mm). The cloud systems with significant amounts of water below ice occur about 10 ~ 20% of the time.

1. INTRODUCTION

Clouds are important meteorological phenomena that influence the Earth's weather and climate. They strongly affect shortwave and longwave radiation and fresh water transportation. Over the tropical western Pacific warm pool, warm sea surface water and convergent winds generate strong atmospheric convection, which heats the upper troposphere and regulates sea surface temperature over the region. For large spatial (> 1000 km) and long time (> 1 month) scales, the only effective means to monitor clouds over oceans is with satellites. The U.S. and Japan joint Tropical Rainfall Measuring Mission (TRMM) is the only single space platform so far that provides well-calibrated measurements covering the spectrum from visible (VIS), infrared (IR), to microwave (MW) wavelengths. Previous studies (Lin et al. 1998a & b) found that the combination of satellite VIS/IR/MW observations could be used to retrieve cloud physical properties. Even for cloud systems with cirrus on top and stratiform clouds below, this combination would provide much better cloud information than VIS/IR measurements alone.

Since the particle size of cirrus clouds is generally much less than MW wavelengths, and ice has minimal absorption in the MW spectrum, the radiation measured by the MW radiometer mainly depends on cloud water, water vapor, oxygen, and surface properties. The VIS/IR measurements, on the other hand, are sensitive to micro/macro-physics of both water and ice clouds. Thus, cloud properties, such as cloud cover, LWP, τ, effective particle size (r_e), cloud top and water temperature, and the frequency of multilayered clouds, can be estimated from the combined VIR/IR/MW satellite data (Lin et al. 1998a & b).

2. DATA AND METHODS

The TRMM satellite has a low (350km) altitude, circular orbit with a 35° inclination angle. The data used in this study were obtained during January through July 1998. The VIRS is a 5-channel imaging spectroradiometer with bands in the wavelength range from 0.6 to 12μm. The spatial resolution is ~2.1 km at nadir view and ~3.0 km at 45° scan angle. TMI is a 9-channel, passive thermal microwave radiometer. It measures radiances at frequencies of 10.65, 19.35, 21.3, 37.0, and 85.5 GHz (hereafter referred to as 10, 19, 21, 37 and 85 GHz for short). The vertically (v) and horizontally (h) polarized measurements are taken at all frequencies, except at 21 GHz where TMI, like SSM/I (Special Sensor Microwave Imager), only has a vertically polarized channel. The TMI scan mode is conical which results in an incident angle 52.8° at the Earth's surface. The beam effective field of view (BEFOV) varies from about 5×7 km^2 at 85 GHz to 37×63 km^2 at 10 GHz. The details of the instruments are given by Kummerow et al. (1998). The results of deep space maneuvers and microwave radiative transfer simulations are used in the calibration of Tb values.

The retrievals of the current study are all from rain-free conditions. The rain/no rain decision is made using the TMI 37GHz polarization difference with a threshold of 37K, which is the same as that used by Lin and Rossow (1994). The algorithm developed to estimate LWP and cloud water temperature (Tw) using TMI data is based on the method for SSM/I measurements (Lin et al. 1998a). Since Tb_{85} has significantly different Tw characteristics from Tb_{37},

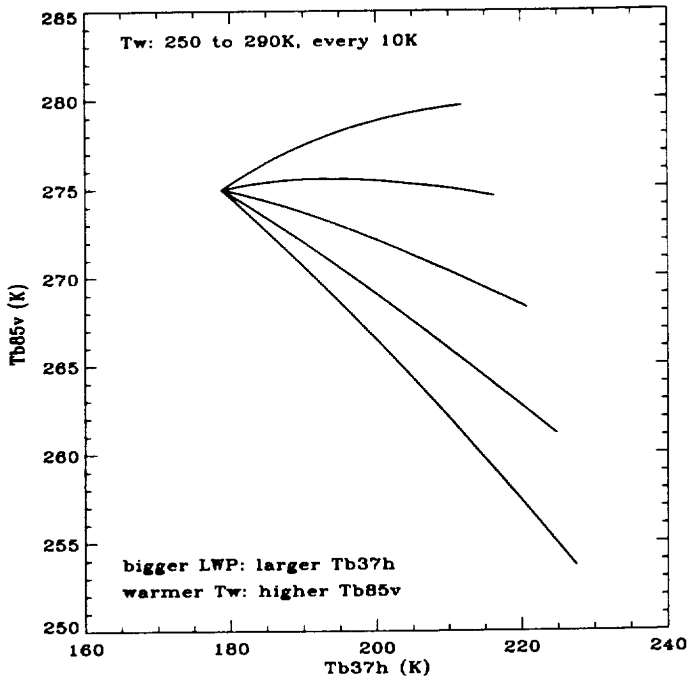

Figure 1: Microwave radiative transfer simulated Tb values.

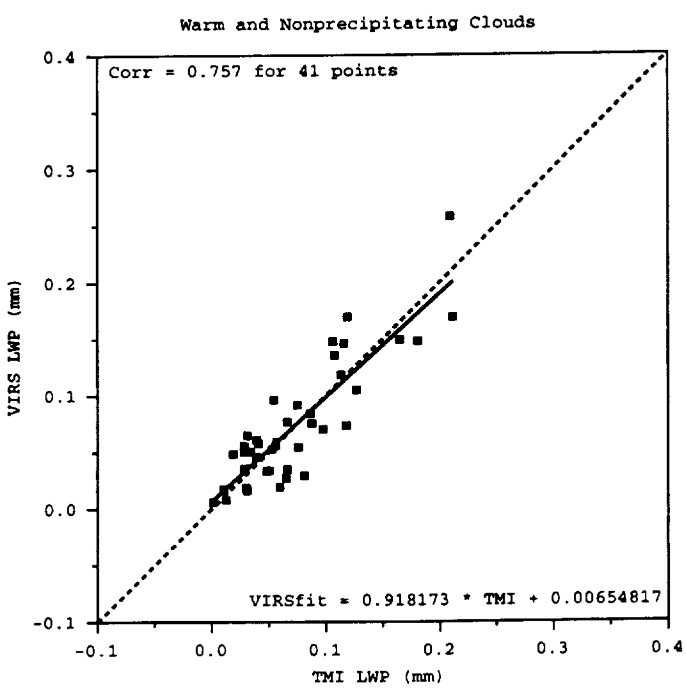

Figure 2: Scattering plot of VIRS and TMI LWP estimates.

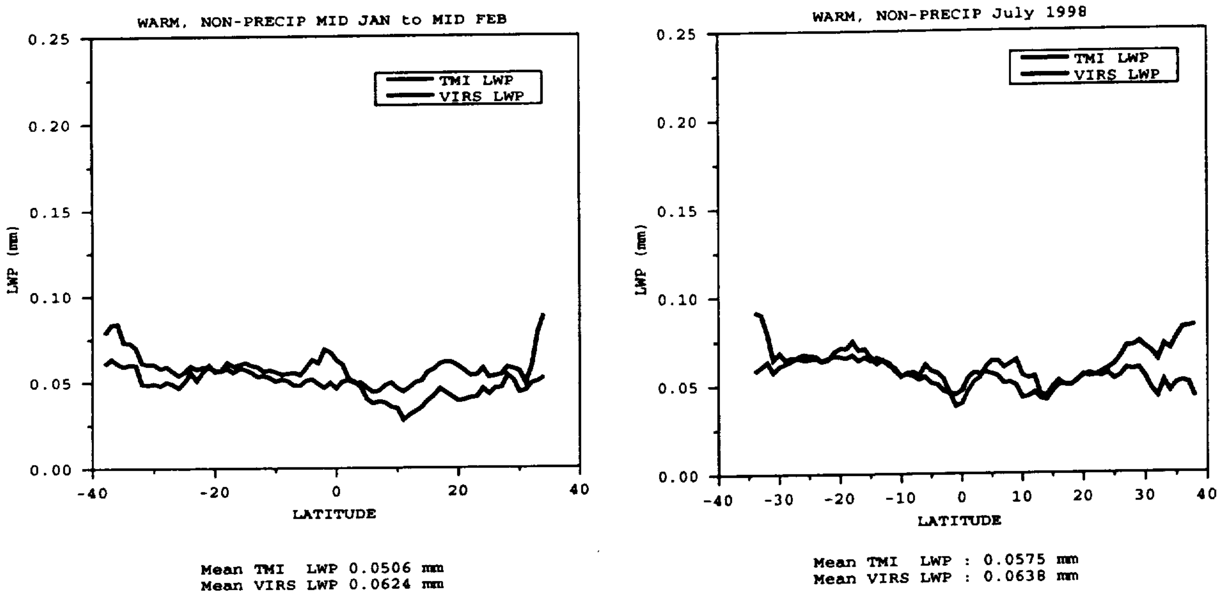

Figure 3: Zonal mean LWP values for warm clouds.

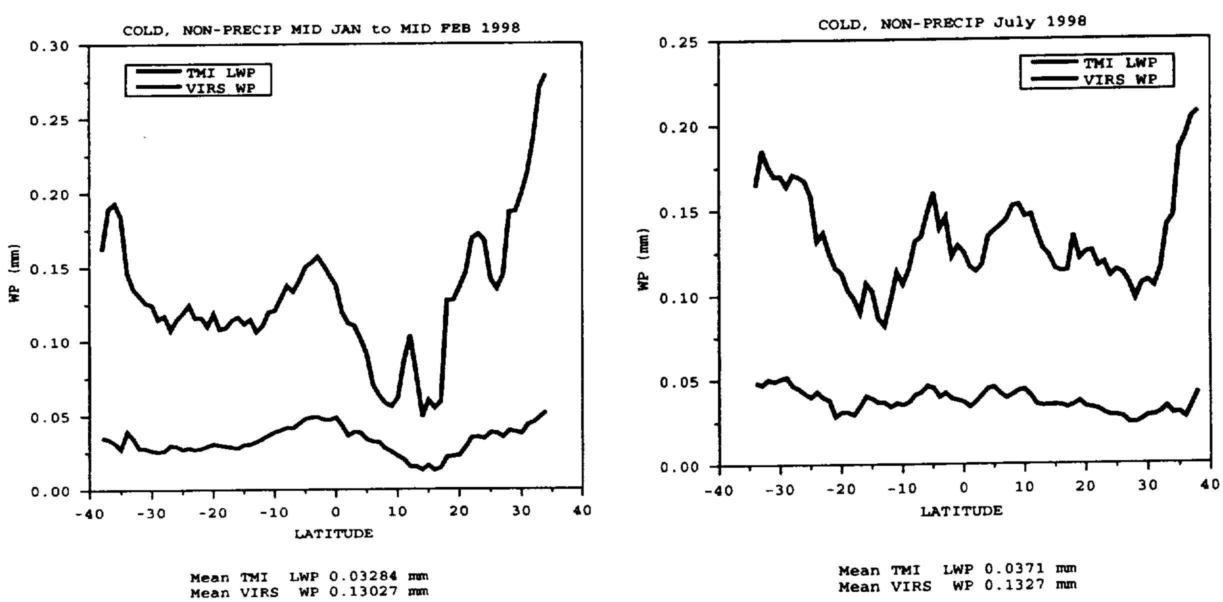

Figure 4: Zonal mean WP retrievals for cold clouds.

combining the observations of the 37 and 85 GHz channels, we can estimate LWP and Tw values simultaneously. Figure 1 shows Tb relationships at 37 and 85 GHz. Within each curve, Tb_{37} increases with LWP; the curves with high Tb_{85} values are for warmer clouds. The cloud top temperature (Tc) and optical depth are retrieved from VIRS (Minnis et al., 2000). Particle size for water clouds is estimated using the following equation:

$$r_e = 1.5LWP/(\rho_w \tau), \qquad (1),$$

where ρ_w is water density.

3. RESULTS

The matched data sets for VIRS and TMI pixels show that the frequency of overcast clouds varies in all FOV scales of TMI channels. At the scale of the FOV of TMI 37 GHz channels (~16 km), about 53% of the overcast cases are warm clouds (Tc > 273.15K), and the others are cold. For these overcast clouds and at larger spatial scales (~63km; or FOV of 10GHz channels), very few cases are detected as multi-layered by VIRS, indicating the overcast clouds (or the top layers of the clouds if they are multi-layered) have horizontal scale length ≥ 60km. Vertically, the retrievals of τ, Tc, LWP and Tw show that these overcast clouds have very complicated structures. The cloud systems with significant amounts of water below ice occur about 10 ~ 20% of the time.

Figure 2 plots the relationship between VIRS and TMI estimated LWP values for warm non-precipitating overcast clouds. The agreement between the two techniques is very good. Statistics also shows that the means and standard deviations for the two kinds of observations are similar. Comparing VIRS and TMI LWP retrievals (Fig. 3), this study finds that warm clouds generally have much more column liquid water than cold clouds (~0.03mm). The total water amounts for cold clouds (~0.13mm) are larger than those of warm clouds (Fig. 4). Ice water contributes significantly to the totals. The distribution of Tw determined by TMI is similar to that of VIRS Tc for warm overcast clouds except it is warmer and broader due to deep penetration of microwave radiation into clouds and multi-layered cases. The uncertainties in Tw retrievals also contribute to some of the broadening (Lin et al. 1998a).

4. DISCUSSION

This study discusses the micro/macro-properties of overcast clouds using TRMM data. This study, along with previous results for SSM/I data, shows that the combination of visible, infrared, and microwave satellite measurements gives us a great potential for monitoring the multi-layered cloud systems with ice on the top of water over large spatial and long time scales, especially over tropical oceans.

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