

ESTIMATION OF CLOUD PROPERTIES OVER OCEANS USING VIRS AND
TMI MEASUREMENTS ON THE TRMM SATELLITE

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1.0 INTRODUCTION

Clouds are very important regulators of the hydrological cycle and the energy balance of the earth. Liquid water path (LWP) is one of the most important macro-physical cloud properties and can only be determined globally using satellite remote sensing. Cloud vertical structure, including cloud top and base heights, cloud layer thickness, and cloud overlapping, also affects the short- and longwave radiation budget as well as the vertical distributions of latent heat release. Thus, the accuracy of global LWP retrievals and the knowledge of the temporal and spatial distributions of multi-layered clouds are very critical to understand the hydrological cycle and the energy balance of the earth.

Because surface observations of LWP are usually limited to a few specific sites, the global validation of LWP is very difficult. Currently, LWP can be derived directly from microwave (MW) data only over oceans. It can also be estimated over land and ocean from optical depths and effective particle sizes retrieved using infrared (IR) and visible (VIS) data. The VIS-IR methods, however, have not been adequately tested. Ideally, they should provide values that are consistent with those derived with MW data over ocean. In multilayer clouds, the VIS-IR radiances are primarily sensitive to the upper cloud layer so that it is not possible to distinguish lower-level water clouds from high-level overcast, thick ice/water clouds. Over oceans, it is possible to combine both techniques to determine the presence of water clouds below the ice clouds, the temperature of

The objectives of this study are twofold. The MVI (MW, VIS, and IR) method of Lin et al. (1998) is adapted and applied to collocated data from the TRMM Microwave Imager (TMI) and the Visible and Infrared Scanner (VIRS) on the Tropical Rainfall Measuring Mission (TRMM) satellite to estimate the frequency of overcast non-precipitating, multi-layered clouds. For non-overlapped clouds, the LWP values retrieved from TMI data using the microwave retrieval method are compared to the corresponding results derived from VIRS retrievals of optical depth and effective particle size. This consistency check between the VIRS and TMI LWP values constitutes a form of validation and should lend confidence to the LWP values determined over land surfaces.

2. DATA and METHODOLOGY

Launched in the summer of 1997, TRMM is in a 350-km circular orbit with a 35° inclination angle (Kummerow et al., 1998). This precessing orbit produces a sequence of Equatorial crossing times that covers the full diurnal cycle in about 46 days. Thus, measurements can be taken over the full range of solar zenith angles over a given region twice in a season. The TRMM data used here were taken between January 1 and July 31, 1998.

VIRS is a five-channel imaging spectro-radiometer that measures radiances at 0.65, 1.64, 3.75, 10.8, and 12.0 μm . The VIRS 2-km radiance data were used to retrieve cloud fraction, phase, optical depth, effective particle size, and water path (WP) as well as sea surface temperature SST and cloud-top temperature T_c and height for the Clouds and Earth's Radiant Energy System (CERES) project (Minnis, et al. 1999). The VIRS scan allows coverage between 38°N and 38°S. The pixel-level data were matched with the TMI footprints.

TMI is a nine-channel, passive radiometer measuring radiance at the frequencies of 10.7, 19.35, 21.3, 37.0 and 85.5 GHz. All channels have both the vertical (V) and horizontal (H) polarization measurements except 21.3 GHz which is a vertical polarization channel. TMI makes conical scans with an incident angle of 52.8° at the earth surface. The scanned sector yields a swath width of 758.5 km. The 85.5- and 37-GHz footprints are 6.9 km (down-track direction) by 4.6 km (cross-track direction) and 9.7 km by 16 km, respectively.

Since TMI has larger footprints than VIRS, the VIRS cloud products were convolved with the TMI point spread functions to produce equivalent TMI footprints that are spatially matched to the actual TMI fields of view. Because TMI and VIRS are on the same platform, the temporal and spatial mismatches of VIRS cloud products and TMI footprints are negligible. The time difference between the mismatches of VIRS pixels and the TMI footprints is less than 0.04 seconds. The TMI-VIRS results were averaged into a 1° latitude-longitude grid to reduce the scatter due to noise in the MW retrievals (~0.04 mm). The result is an uncertainty of ~0.01 mm in the 1° TMI LWP.

A plane-parallel MW Radiation Transfer Model (MWRM; Lin et al. 1998) was used to simulate the brightness temperatures (T_b) for all TMI channels. The subscripts for T_b of each channel denote the frequency in GHz and the polarization, H for horizontal and V for vertical. A lookup table (LUT)

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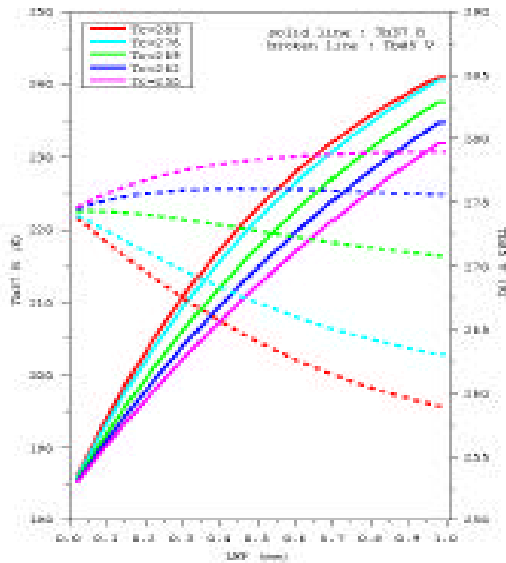


Fig 1. Microwave radiative transfer simulation of Tb_{37H} and Tb_{85V} for liquid-water clouds.

was built for various atmospheric conditions including a range of cloud temperatures, LWP , and atmospheric water vapor. Because Tb_{37} , especially Tb_{37H} , has a stronger dependence on LWP and less sensitivity to CWV than other channels, Tb_{37H} is most frequently used to estimate LWP . Due to the liquid-water absorption coefficient increasing with decreasing cloud water temperature (T_w), Tb_{37H} increases with cloud height. Conversely, the cloud transmittance at 85 GHz is small, so that the variation of Tb_{85} with LWP depends on the competition between cloud temperature and upwelling microwave radiation at cloud base. The near-surface wind speed (WS), column water vapor (CWV), and SST can be retrieved from TMI measurements. To use the MW LUT to retrieve LWP and T_w , the bias between the simulated and TMI-observed values of Tb must be determined first using clear footprints. Clear-sky conditions for each TMI footprint are determined from the convolved VIRS products. The retrieved SST , WS , and CWV for these pixels are put into MWRTM to simulate the clear-sky Tb , which is then used to compute the bias relative to the observations. For each cloudy pixel, LWP and T_w are retrieved from the LUT simultaneously (Fig. 1) using the SST , WS , CWV , and bias-corrected values of Tb_{37H} and Tb_{85V} .

3. RESULTS

The LWP values retrieved from VIRS, LWP_V , are compared with those from TMI, LWP_T . To differentiate between ice-free and ice-contaminated footprints, the comparisons use two categories: warm ($T_c > 273.15K$) and cold, non-precipitating, overcast clouds. The cloud is defined as precipita-

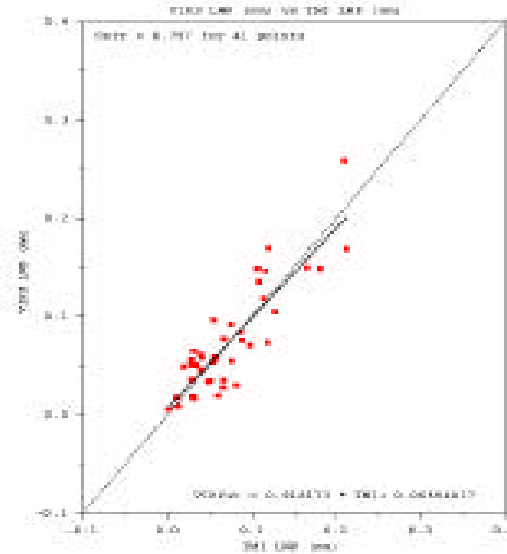


Fig. 2. Comparison of LWP_T and LWP_V for $1^\circ \times 1^\circ$ grid boxes between $25^\circ N$ and $38^\circ N$ and $15^\circ W$ and $30^\circ W$ for warm overcast, clouds, July 1998.

ting if $Tb_{37H} - Tb_{37V} > 37$ K. Figure 2 shows an example of coincident LWP_T and LWP_V for warm clouds over an area in the North Atlantic ($25^\circ N$ - $38^\circ N$; $15^\circ W$ - $30^\circ W$) dominated by stratus and stratocumulus clouds with no indication of contaminating cirrus clouds. The results are well correlated with a mean difference $LWP_V - LWP_T$ of 0.005 mm with a standard deviation of 0.004 mm. Similar results are found globally as shown in Fig. 3 which compares the 1° values of LWP_V and LWP_T for all warm overcast non-precipitating clouds observed by VIRS during July 1998. The correlation coefficient is 0.305 for the 4500 points. The root mean square difference between these data is 0.0189 mm and the mean difference is 0.0063 or 10%.

The larger value from VIRS may be due to an overestimation of the effective radius or optical depth or to contamination by cirrus clouds. The effective radius inferred with the VIRS method is generally more representative of the cloud top although the droplet radius profile in a stratus cloud typically increases from base to top. Thus, the derived value should exceed the mean for the entire cloud. Cloud optical depth also may be overestimated at high solar zenith angles because of three-dimensional effects that occur in nature but are not taken into account in the plane-parallel retrieval model. And finally, a mean value of $T_c > 273$ K does not completely ensure that ice clouds were not present. A few cirrus pixels in a warm cloud scene may not be enough to reduce T_c below the freezing point, but are sufficient to raise the mean effective radius value.

The mean zonal results for July 1998 in Fig. 4 show good agreement between the results for more

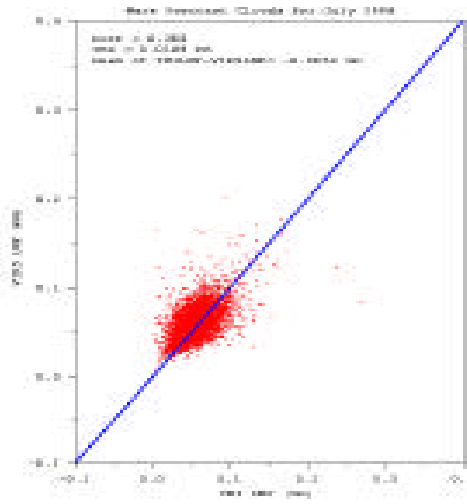


Fig 3. Scatter plot of LWP_T and LWP_V for all warm, overcast 1° regions during July 1998.

than half the globe. VIRS underestimates LWP over the Inter-Tropical Convergence Zone (ITCZ) relative to the TMI. LWP_T decreases north of 25° while LWP_V increases. A smaller zone of divergence is evident south of 30°S . The July 1998 results are summarized in Table 1 for the entire domain (Global, $37^\circ\text{S} - 37^\circ\text{N}$), the Tropics (20°S to 20°N), and the southern ($20^\circ\text{S} - 37^\circ\text{S}$) and northern ($20^\circ\text{N} - 37^\circ\text{N}$) mid-latitudes. The global mean overestimate from VIRS is primarily due to the mean difference of 0.016 in the northern mid-latitudes. This more than compensates for the 0.003 overestimate in the Tropics. The reasons for these zonal variations in the LWP differences are not immediately apparent but may partially result from the previously mentioned error sources. Additionally, there may be some water-vapor-dependent biases that result from uncertainties in the absorption coefficients used in the MWRM. The sampling pattern of the VIRS may also play a role because the daytime samples in the northern or southern mid-latitudes may be skewed to early morning and late afternoon resulting in a preponderance of samples at high solar zenith angles in one of those zones. A closer examination of the results is needed to better understand the differences. Nevertheless, the mean difference between the results varies with month. For

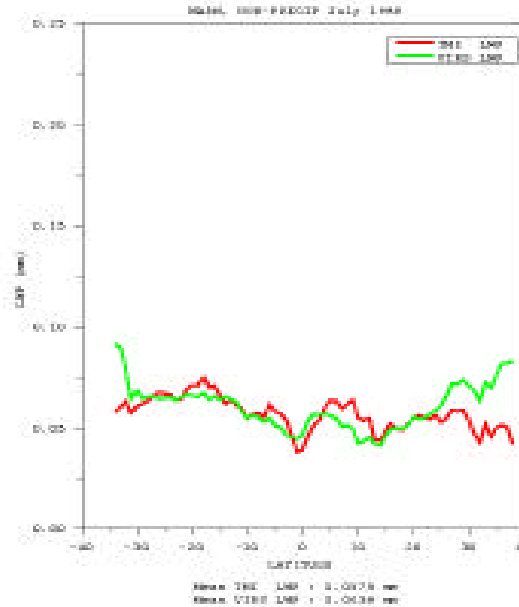


Fig 4. Zonal mean July 1998 LWP from VIRS and TMI for warm overcast, non-precipitating clouds.

example, global mean LWP_T for April 1998 is 0.0553 mm compared to 0.0541 mm for LWP_V .

The bottom rows of Table 1 provide a summary of the values of LWP_T and WP_V for cold ($T_c < 273\text{ K}$) overcast, non-precipitating clouds. In all cases, the VIRS water path, which is often mostly ice water path IWP , is about 0.1 mm greater than LWP_T . Almost 25% of the derived water path from VIRS in these cases is actually from liquid water beneath the upper layer clouds. Thus, the assumption, that the cloud is entirely ice, used to compute IWP is incorrect for the cases having liquid water in the lower layers. However, the error may not be too significant on average since the error affects only a quarter of the signal.

It clear from the results in Table 2 that some information about the vertical structure of the cloud fields can be derived from the combined VIRS and TMI datasets. A set of thresholds was established to determine the occurrence of multilayer clouds and the relative height differences between the layers.

		Global	Tropics	Northern Mid-latitudes	Southern Mid-latitudes
Warm Non-precipitating	TMI	0.0575 \pm 0.0609	0.0578 \pm 0.0664	0.0519 \pm 0.0593	0.0635 \pm 0.0517
	VIRS	0.0638 \pm 0.0522	0.055 \pm 0.0521	0.0678 \pm 0.0522	0.0692 \pm 0.0511
Cold Non-precipitating	TMI	0.0392 \pm 0.0551	0.0392 \pm 0.0557	0.029 \pm 0.0478	0.0482 \pm 0.0566
	VIRS	0.1391 \pm 0.2199	0.1304 \pm 0.2120	0.1220 \pm 0.2109	0.1671 \pm 0.2342

Table 1. Mean and standard deviation of TMI and VIRS WP for July 1998

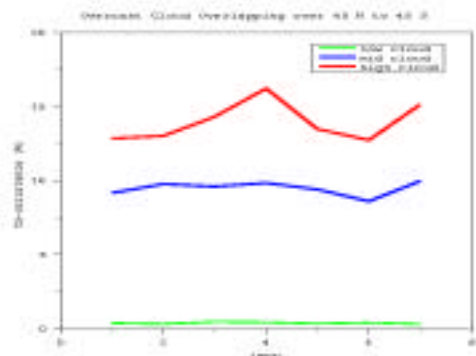


Fig 5. Occurrence of overcast overlapping low, middle and high clouds for January - July 1998.

Because of the instantaneous uncertainties only scenes with $LWP_T > 0.04$ mm were used. The value of T_c corresponds closely to cloud-top while T_w is more representative of the cloud center. To account for the instantaneous uncertainties in T_w and the finite thickness of the clouds, it is assumed that clouds with $T_w - T_c < 8$ K are not overlapped. The water cloud is assumed to be overlapped by a low-level or mid-level cloud if $8K \leq T_w - T_c < 10$ K or $10K \leq T_w - T_c < 15$ K, respectively. The upper layer cloud is assumed to be a high cloud if $T_w - T_c \geq 15$ K. The global (38°N to 38°S) occurrence of cloud overlapping for high, middle and low clouds are shown in Fig 5. The percentages in this figure refer to the portion of the overcast cold non-precipitating clouds that were

SUMMARY and CONCLUSIONS

The overall 10% difference between early VIRS and TMI liquid water path values are at odds with the initial comparisons of LWP derived from surface MW radiometers and VIRS over Oklahoma in the northern mid-latitudes. Dong et al. (1999) found that LWP_V was 10% less than the surface-based LWP for 17 matched cases between January and July 1998 due to differences in the effective radii and optical depths. The results presented here and by Dong et al. (1999) rely on preliminary retrievals from the CERES cloud algorithms. Several changes have been introduced in the CERES algorithms since the current analyses were performed. The new CERES results, including additional months, will be compared to the TMI data as soon as they become available. The reasons for the differences between the two retrievals must also be closely examined to determine if some correction can be applied to

either one of the datasets. Cloud conditions that these two methods will be disagreed are excluded. For warm non-precipitating overcast clouds, the zonal means of TMI LWP agree well to those of VIRS LWP for different climatological regions and different latitudes. The global mean of TMI

By combining cloud top temperature, cloud fraction, cloud optical depth retrieved from VIRS VIS and IR measurements, and cloud LWP and T_w retrieved from TMI measurements, the vertical cloud layering information for overcast non-precipitating clouds can be derived. The global frequencies of the occurrence of water clouds below thick (optical depth > 6) water/ice clouds are about 13 to 18 % for high clouds, 10 % for middle clouds and 1 % for low clouds for the first seven months of 1998.

References

- Dong, X., P. Minnis, S. Sun-Mack, G. G. Mace, E. E. Clothiaux, and C. N. Long, Validation of CERES/VIRS cloud property retrievals using ground-based measurements obtained at the DOE ARM sites. *Proc. AMS 10th Conf. Atmos. Rad.*, Madison, WI, June 28 – July 2, 29-32.
- Kummerow, C., W. Barnes, T. Kozu, J. Shiue, and J. Simpson, 1998: The tropical rainfall measuring mission (TRMM) sensor package. *J. Atmos. Oceanic Tech.*, **15**, 809-817.
- Lin, B., B. Wielicki, P. Minnis, and W. Rossow, 1998: Estimation of water cloud properties from satellite microwave, infrared and visible measurements in oceanic environments, I : microwave brightness temperature simulations, *J. Geophys. Res.*, **103**, 3873-3886.
- Minnis, P., D. F. Young, B. A. Wielicki, P. W. Heck, S. Sun-Mack, and T. D. Murray, 1999: Cloud properties derived from VIRS for CERES. *Proc. AMS 10th Conf. Atmos. Rad.*, Madison, WI, June 28 – July 2, 21-24.