P4.3 METHODS FOR EVALUATING MICROWAVE-DERIVED SATELLITE LIQUID WATER PRODUCTS

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1. INTRODUCTION

Cloud liquid water path (LWP) observed over the oceans by microwave sensors is one of only a handful of physical cloud parameters measured from space. These observations have had some use in, e.g., climate studies (Greenwald et al. 1995, Zuidema and Hartmann 1995), global model verification of cloud LWP (e.g., Lemus et al. 1997), and aircraft icing studies (Tremblay et al. 1996). They also have value in providing key tests for global climate models in terms of the relationships of physical cloud properties to the radiation budget (Stephens and Greenwald 1991); relationships that are the result of cloud-climate feedback processes, which are currently poorly represented in these models (Cess et al. 1990; Cess et al. 1996). In addition, these products may have future application in data assimilation in numerical weather prediction.

Although continuous cloud LWP data over the oceans have been available for nearly 15 years, these data are greatly underutilized. We believe one reason is that little is known about their error characteristics. This study uses previously developed multi-sensor satellite techniques to evaluate and interpret cloud LWP products from the TMI (TRMM Microwave Imager) under different cloud conditions and provides estimates of their accuracy over the global oceans. These methods include cloud clearing TMI LWP products using VIRS (Visible and Infrared Scanner) data and comparing TMI products to similar products derived from VIRS for cloudy scenes. Two different months in 1998 were chosen for analysis.

2. SATELLITE DATA AND METHODS

Because of the variety of instruments on board the TRMM platform (Kummerow et al. 1998), a unique opportunity exists to utilize multisensor data to assess the accuracy of cloud LWP retrievals. This study uses the instantaneous pixel-level cloud LWP products from the TMI derived from the Wentz (1997) algorithm. These products have an effective spatial resolution of 16 km x 9 km. VIRS has channels at 0.62 μm, 1.6 μm, 3.8 μm, 10.8 μm, and 12 μm with an effective spatial resolution of 2.1 km at nadir (Kummerow et al. 1998).

The first step in the procedure is to collocate the TMI products with VIRS measurements by finding the VIRS datum that is located closest to the center of the TMI footprint. Then those VIRS measurements that fit within the TMI footprint are collected. Cloud conditions are determined within the TMI footprint using VIRS data along with a sophisticated cloud detection algorithm (Berendes et al. 1999). Collocations were restricted to daytime to enable greater accuracy in detecting low-lying clouds.

One part of the analysis examines the TMI products in clear-sky conditions only (e.g., Lin and Rossow 1994; Liu and Curry 1993). This serves to identify both systematic and random errors in the background conditions used in the LWP retrievals (i.e., sea surface and atmosphere), which are measures of the minimum retrieval errors.

The next aspect of the analysis directly compares the TMI products with a closely related quantity derived from VIRS measurements. A similar cloud LWP parameter is estimated from VIRS retrievals of visible optical depth and particle effective radius (see, e.g., Greenwald et al. 1997). Comparisons were limited to warm (i.e., 11 μm brightness temperature > 273 K) clouds to ensure a like comparison since microwave observations are sensitive to cloud droplets and not ice particles outside areas of precipitation. Because of the relatively large TMI footprint, the VIRS retrievals were weighted by the TMI antenna pattern when averaged. Data that may have been affected by precipitation were also eliminated using the flags provided in the Wentz TMI datasets. However, this may not have eliminated all occurrences of precipitation, such as drizzle.

3. RESULTS

Results for July and January 1998 (Figure 1) show that the TMI cloud LWP products contain significant clear-sky biases (mainly positive) that vary from region to region and season to season. Biases often exceed the accuracy of 0.025 kgm^{-2} quoted for these products (Wentz 1997). Also, geographic features in the biases appear to follow large-scale weather patterns. For instance, in regions of subsidence off the west coasts of the continents you find low biases. Large, positive biases occur mostly in areas frequented by transient weather systems. Random errors in these products (not shown) are mainly less than 0.02 kgm^{-2}, only occasionally reaching beyond 0.025 kgm^{-2}, indicating that the retrievals have good precision characteristics.

Directly comparing the July 1998 monthly mean cloud LWP derived from the TMI and VIRS for nonpre-

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cipitating warm clouds and overcast scenes reveals that the two fields are highly correlated but the magnitudes of the TMI products are significantly larger than the related VIRS products (see Figure 2). Zonal plots of these two fields for January 1998 and July 1998 show that the differences can be 40-50% (Figure 3). If we subtract the monthly mean clear sky field in Figure 1 for July 1998 from the TMI cloud LWP field in Figure 2, we obtain a new, corrected field that accounts for clear sky biases (see Figure 3). Note this correction is entirely independent of the VIRS measurements. We find the TMI and VIRS estimates of cloud LWP come into excellent agreement, suggesting that positive biases in TMI product are mainly attributed to the clear sky component in the retrievals, possibly caused by biases in water vapor/oxygen absorption and/or biases in sea surface characterization. Remaining differences between the products might be due to other retrieval errors in either method, the occurrence of drizzle (which causes the TMI retrievals to overestimate LWP), or possibly because these quantities are closely related but not precisely the same.

Because satellite microwave sensors have relatively large footprints, their measurements are also susceptible to beam filling – an effect usually associated with rainfall retrievals. Observational studies have demonstrated this effect can be significant for cloud LWP retrievals under broken or scattered cloud fields within the sensor field of view (Miletta and Katsaros 1995; Greenwald et al. 1997). When categorized by cloud fraction within the field of view for warm clouds (Figure 4), the TMI products show a negative bias (relative to overcast scenes) that systematically increases with decreasing cloud amount.

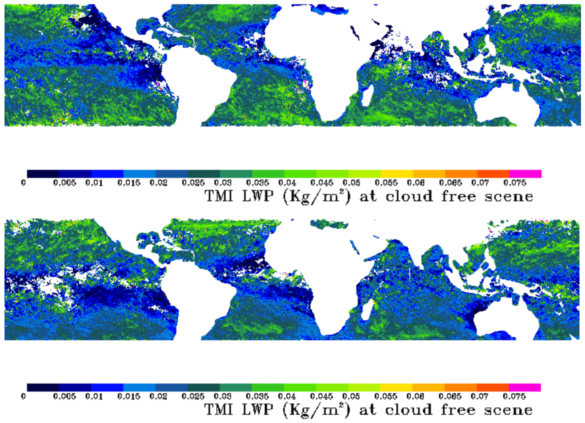

Fig. 1. TMI retrieved cloud LWP for (top) January 1998 and (bottom) July 1998 for daytime cloud free scenes only.

4. CONCLUSIONS

A comprehensive strategy has been presented for interpreting and determining the accuracy of cloud LWP observed by satellite microwave sensors. The methods are simple but require the use of well-collocated visible and infrared data. Coarse collocation methods employed in other studies (e.g. Lin and Rossow 1994; Liu and Curry 1993) are not suitable for extracting detailed information on error characteristics.

The major result is that systematic errors, not random errors, are the single largest source of error in these products. These errors appear to originate mainly from assumptions regarding the clear sky contribution (including the sea surface) in the retrievals. However, these errors may be monitored using the methods developed here. Further research is needed to better understand these errors and hopefully reduce their influence (which may eventually involve incorporating other microwave channels, such as 85 GHz).

Under broken cloud scenes the TMI products were shown to be biased low (i.e., the beam-filling effect), consistent with previous studies (e.g., Greenwald et al. 1997), which demonstrates that in these situations LWP products derived from coarse-resolution microwave measurements are not a true indicator of cloud LWP.

5. ACKNOWLEDGMENTS

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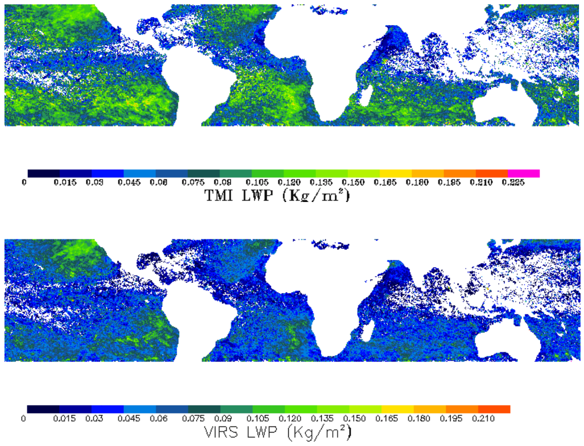

Fig. 2. (top) TMI retrieved cloud LWP and (bottom) VIRS retrieved cloud LWP for July 1998 for daytime overcast scenes with nonprecipitating warm clouds only.

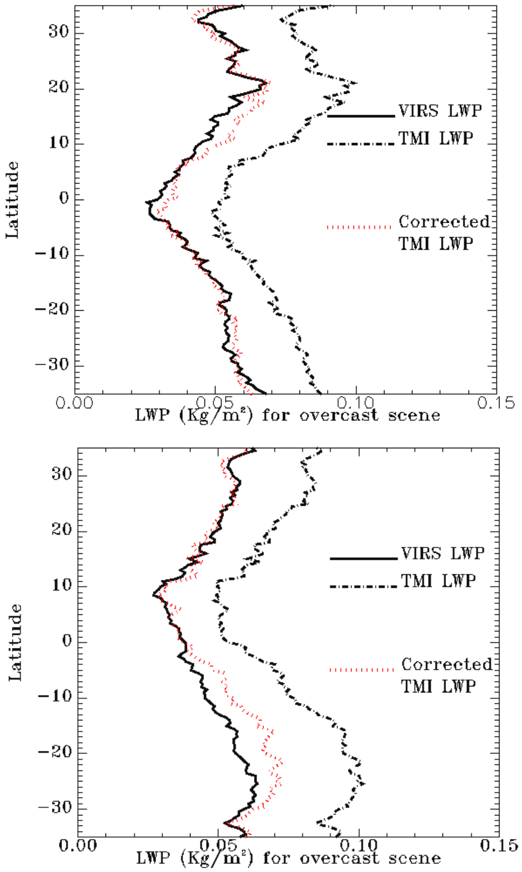

Fig. 3. Zonal average cloud LWP for nonprecipitating overcast warm clouds derived from TMI and VIRS measurements for (top) January 1998 and (bottom) July 1998. Also shown is the TMI cloud LWP after correction for clear-sky biases.

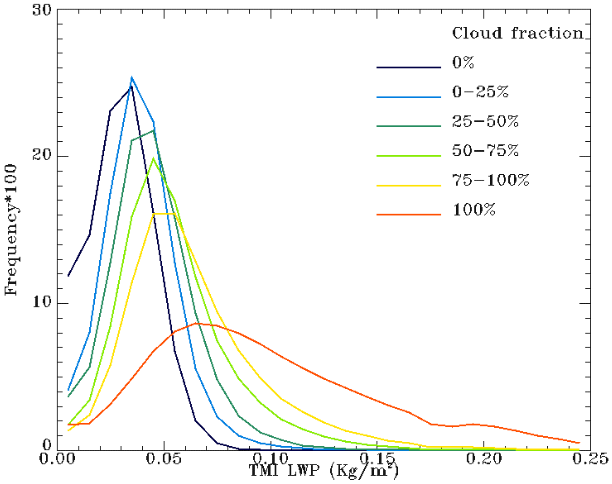

Fig. 4. Illustration of beam-filling errors for nonprecipitating warm clouds in July 1998 using distributions of TMI-derived LWP for different cloud fraction categories.