An Evaluation of MWR Retrievals of Liquid Water Path and Precipitable Water Vapor

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Introduction

This paper offers some observations on the quality of Microwave Radiometer (MWR) retrievals of precipitable water vapor (PWV) and liquid water path (LWP). The paper shows case study comparisons between the standard "statistical" approach and those obtained using an iterative solution of the microwave radiative transfer equations.

These examples show how improvements in the retrieval of LWP can be obtained by using an iterative approach, but that possible improvements are limited by the accuracy of the forward model absorption coefficients and errors in the brightness temperature measurements. Each of these effects limits the accuracy of the LWP from about 5 to 15 g/m^2.

The errors in the forward model absorption coefficients may well produce a bias in the retrieval results. These errors become apparent when comparing clear-sky measurements and calculations of the brightness temperature at 31 GHz.

The PWV accuracy appears to be quite good for clear-sky cases (a few percent), but was degraded in the cloudy-sky case presented here to about 5 percent.

Cloudy-Sky Example

On March 3, 2000, the Atmospheric Radiation Measurement (ARM) site was covered by a single- (or at most two-) layer stratus cloud from about 17.6 to nearly 22 Universal Time Coordinates (UTC), as shown in Figure 1. The white x's show the cloud base as determined from ground-based Lidar.

Figure 2 shows a plot of the associated MWR-retrieved water vapor (WV) from (1) an iterative or minimization approach based on a single nearby (in time) radiosonde profile and using the Liebe 87 absorption model, (2) the standard ARM statistical retrieval (data straight from the archive), and (3) the MWR profile (PROF) value-added procedure. The MWR PROF retrieval (one of the ARM standard value-added procedures) combines Radio Acoustic Sounding System (RASS) and Lidar data to "estimate" an atmospheric profile upon which to perform an iterative retrieval, but is run only once per hour.

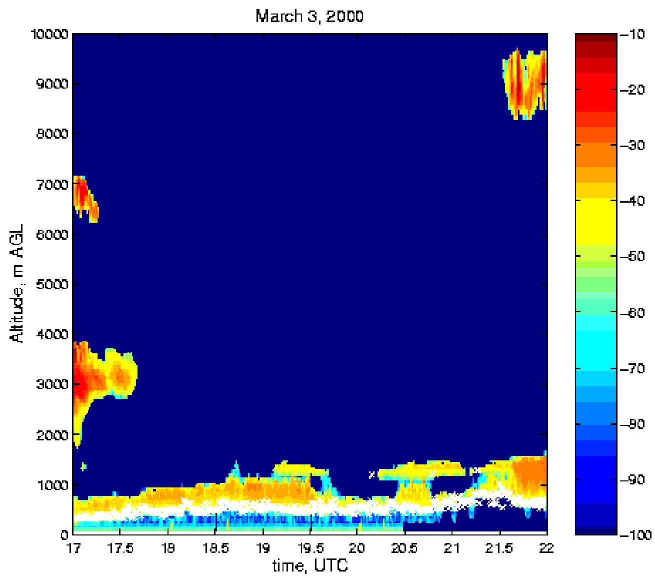

Figure 1. Millimeter cloud radar data for March 3, 2000.

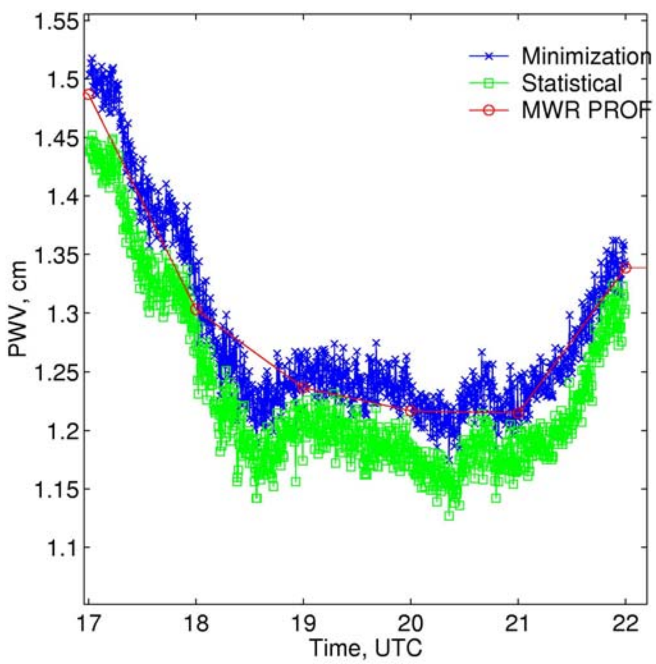

Figure 2. Retrieved PWV for March 3, 2000.

Both the minimization and the MWR PROF techniques show that the PWV is actually higher than that obtained by the statistical approach. The difference between the minimization and MWR PROF is due to the difference between the MWR PROF estimate of the atmospheric profile and that measured by the radiosonde.

What role do uncertainties in the microwave radiative transfer model or errors in the measurements themselves play? Figure 3 shows the relative difference between the statistical approach and the minimization approach for three conditions. The blue curve is the difference between the minimization using the Liebe 87 absorption model and the statistical approach. The upper red curve is the difference between the statistical approach and the minimization approach, but using the Rosenkranz 98 absorption model, and the lower black curve is the same as the blue curve, but, the brightness temperatures in both channels have been shifted by their root mean square (rms) uncertainty (as claimed in the ARM data file) to obtain the maximum possible reduction in the PWV.

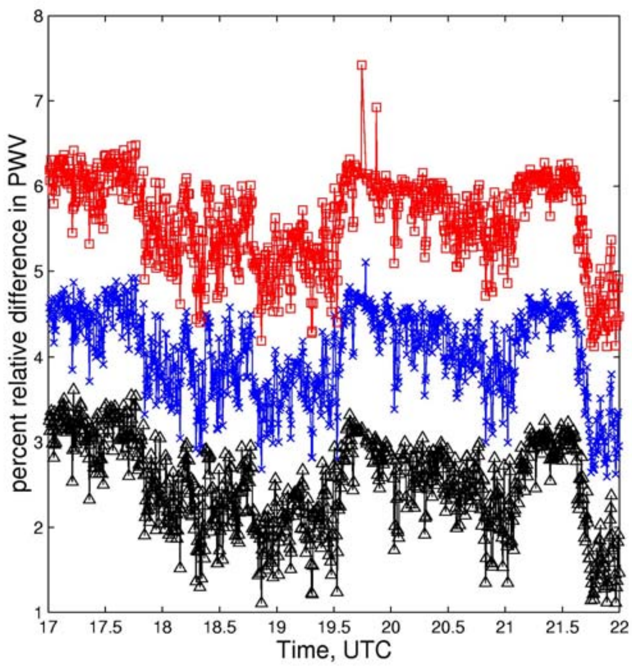

Figure 3. This figure shows the relative difference between the statistical approach and the minimization approach for three conditions (see text).

As can be observed, the effect of the uncertainty in the measurement (i.e., the difference between the blue and black curves) is small, about 1 to 2 percent. This is about the same as the uncertainty due to the model (i.e., the difference between the blue and red curves). The statistical approach has underestimated the PWV by 4 to 6 percent (depending on which absorption model you select (blue curve or red curve).

Turning our attention to the cloud liquid water, Figure 4 shows a plot of the MWR-retrieved LWP from (1) the iterative or minimization approach based on a single nearby (in time) radiosonde profile and using the Liebe 87 absorption model, (2) the standard ARM statistical retrieval (data straight from the archive), and (3) the MWR PROF value-added procedure. (The MWR PROF retrieval combines RASS and Lidar data to “estimate” an atmospheric profile upon which to perform an iterative retrieval, but is run only once per hour.) Figure 4 is the same as Figure 2, except that Figure 4 shows the cloud liquid water instead of the atmospheric WV.

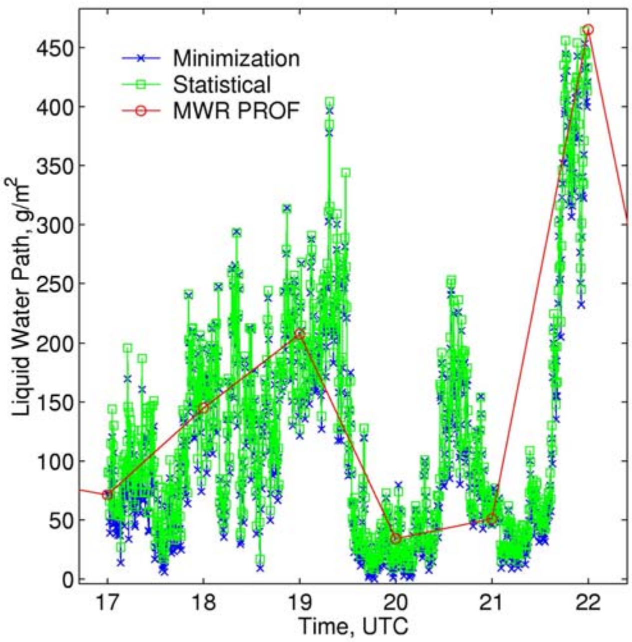

Figure 4. MWR-retrieved LWP for March 3, 2000.

The statistical and minimization approaches track each other well, but the minimization approach is producing smaller water amounts than the statistical approach.

Figure 5 shows the difference between the statistical retrieval of LWP and the minimization approach for three cases. As in Figure 3, the blue symbols use Liebe 87 (blue x's), the red symbols use the Rosenkranz 98 (red squares), with rms error representing measurement uncertainty applied to both channels (black triangles). This figure shows that:

1. The Liebe 87 model produces LWP that are lower than the statistical of about 10 g/m^2 (excluding the region before 17.6 UTC during which a mid-level or upper-level cloud was present).

2. Using the Rosenkranz 98 model produces even smaller LWP by an additional 10 to 15 g/m^2 over Liebe 87.

3. The difference between the choice of the Liebe 87 or the Rosenkranz 98 model makes as large or larger difference that the uncertainty in the brightness temperature measurements!

Clear-Sky Example

All available data, including radar and Lidar data, show that March 20, 2000, was a clear-sky day. Surface measurements and estimated clear-sky values (calculated via Chuck Long's technique) for the total and diffuse surface shortwave flux are shown in Figure 6. There was a very light haze in the early morning, which was also visible in TSI imagery) and cirrus clouds arrived just before sunset.

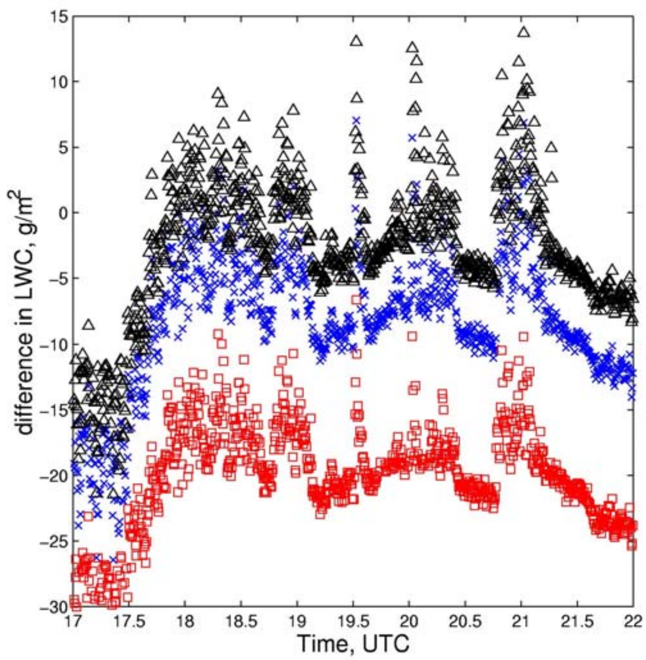

Figure 5. Difference plot of the statistical retrieval of LWP and the minimization approach for three cases (see text, same cases as Figure 3).

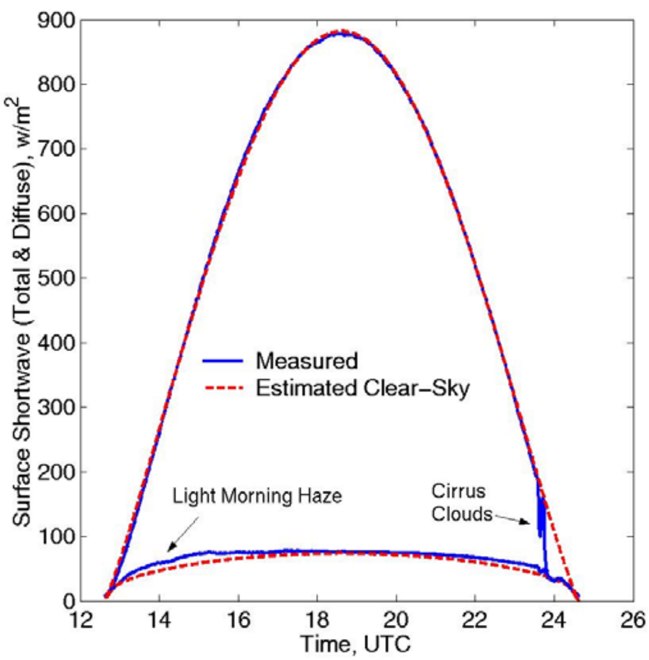

Figure 6. Measurements and estimated clear-sky values (calculated via Chuck Long's technique) for the total and diffuse surface shortwave flux on March 20, 2000.

Figure 7 shows the relative difference between the statistical approach and the minimization for this clear-sky case. The blue curve is the difference between the minimization using the Liebe 87 absorption model and the statistical approach. The upper red curve is the difference between the statistical approach and the minimization approach, but using the Rosenkranz 98 absorption model. As is true in the cloudy-sky case, the choice of model makes a 1 to 2 percent difference in the retrieved PWV. In this case and in all clear-sky cases examined, the difference between the statistical and minimization approaches is small.

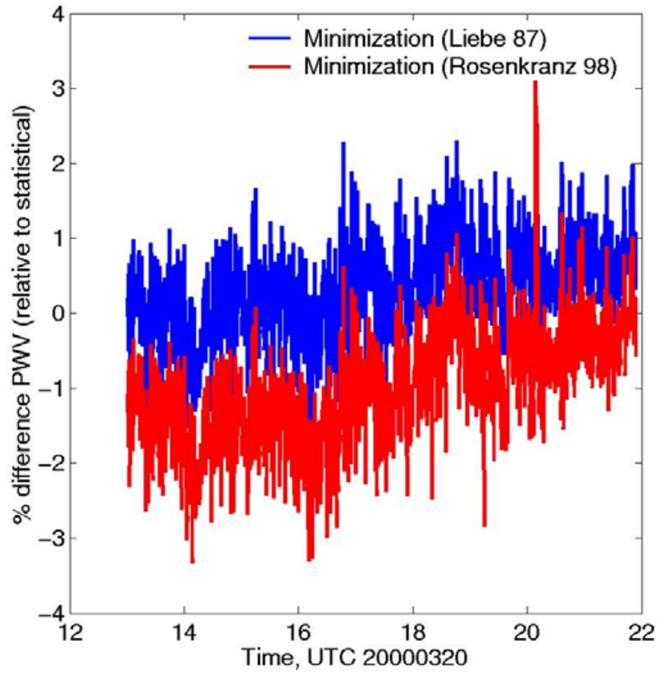

Figure 7. Relative difference between the statistical approach and the minimization approach using the Liebe 87 (blue line) and Rosenkranz 98 (red line) for March 20, 2000.

Whenever the statistical retrieval yields negative values, the minimization approach (for both absorption models) yields no water. In Figure 8 the blue line is hidden by the red line, except for a brief period near 20 UTC. During clear skies, the MWR statistical retrieval tends to produce estimates of the LWP that are slightly negative. The minimization approach cannot return a value less than zero.

When the statistical ARM retrieval produces a small but POSITIVE LWP, it is also possible for the minimization approach to find some LWP. One such case occurred on February 7, 1998 (Figure 9). On this day, the radar and Lidar both detected a cloud for the first half-hour or so and then again near the end of the day. Examination of the hemispherical total and diffuse measurements also suggests that the skies were clear from 14 UTC to almost 23 UTC.

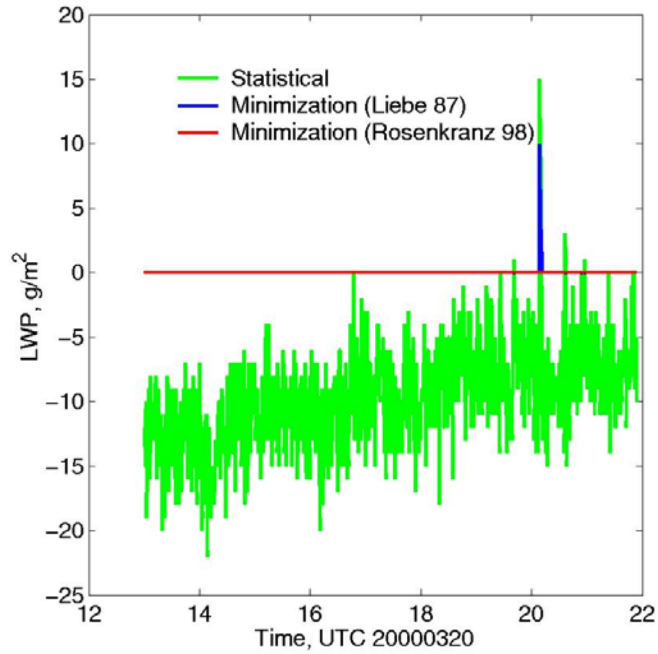

Figure 8. Retrieved LWP for March 20, 2000.

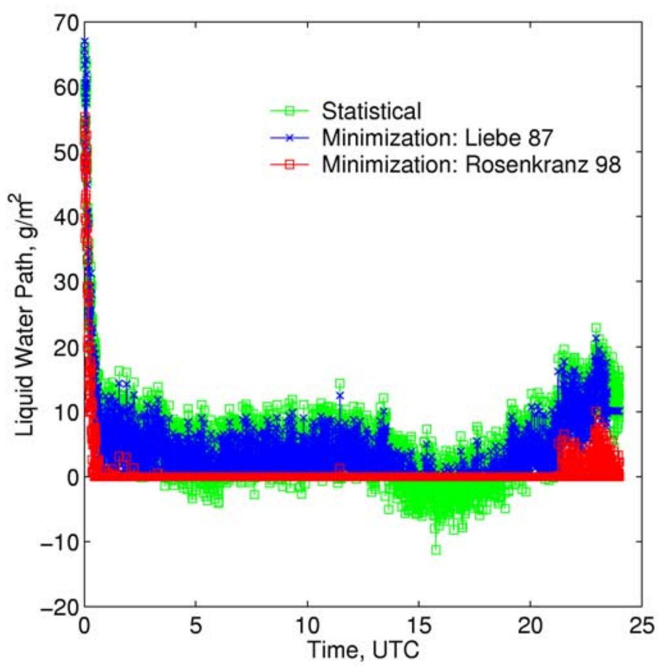

Figure 9. Retrieved LWP for February 7, 1998.

In the cloudy-sky case, it is possible to find a solution using the iterative technique to an arbitrarily good fit (for purposes of this study it was set to 0.001 degree K) in both measured channels. In the clear-sky case, however, once the liquid water is zero the brightness temperatures in the 31 GHz channel cannot be forced lower without lowering the WV and, hence, the model may not be able fit to match both measurements. March 20, 2000, was a typical case, as shown in Figure 10.

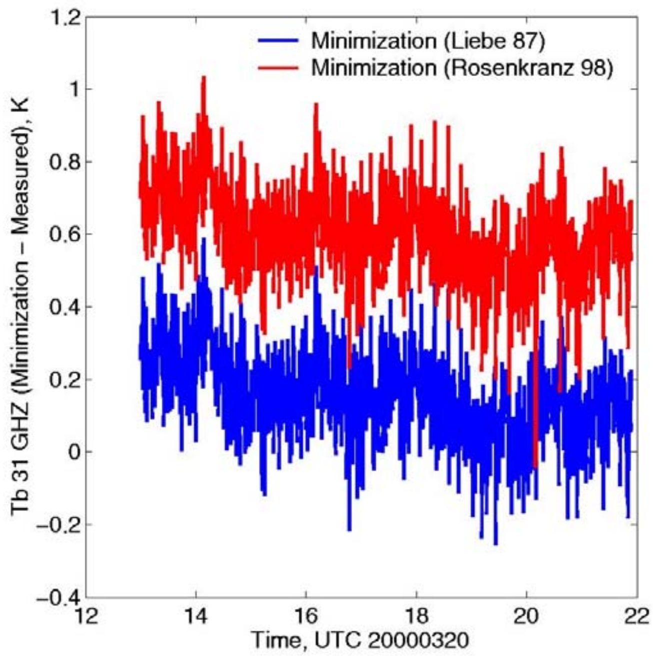

Figure 10. Difference between model and measured brightness temperatures at 31 GHz for March 20, 2000, a clear day.

Discussion

Retrievals of LWP, which are more accurate than those obtained via the ARM statistical approach, are needed. ARM has the necessary auxiliary data (radiosonde pressure, temperature, and relative humidity profiles, surface pressure, radar and Lidar cloud boundaries, etc.) to run retrievals that are more accurate. However, the accuracy of these retrievals is limited by the accuracy of the following:

- the brightness temperature measurements
- the ancillary data
- the forward model absorption coefficients.

At present, the uncertainty in the forward model (as represented by the two absorption models) is significant. In his paper Rosenkranz [1998] finds that his model overestimates brightness temperature measurements at 90 GHz by 2 K. He states that he observes the same problem at 31.65 GHz, but unfortunately doesn’t show this data. Since Rosenkranz finds no dependence in the overestimate with PWV, he puts forth the supposition that this is a problem with the dry atmosphere contribution. In any event, it seems clear that there is some problem with the absorption coefficients as a whole.

The overestimate in clear-sky brightness temperatures at 31.4 GHz suggests that the retrievals of liquid water could well be biased. If retrievals with an accuracy of better than ~10 to 15 g/m^2 are sought, a re-evaluation of the forward model absorption coefficients is required.

Finally, not discussed in this report is the temperature dependence of the liquid water dielectric constant. A recent analysis by Westwater and Han indicates that this could be the source of another 20 percent uncertainty in the liquid water, at least for liquid water temperatures less than -5°C.

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References

Han, Y., and Westerwater, E., 2000: "Analysis and improvement of tipping calibrations from ground-based Microwave Radiometers. *IEEE Transactions on Geosciences and Remote Sensing*, **38**(3), 1260-1276.

Rosenkranz, P. W., 1998: Water vapor microwave continuum absorption: A comparison of measurements and models. *Radio Science*, **33**(4), 919-28.