Improved PWV and LWP Retrievals from the Microwave Radiometer for ARM

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Introduction

Two important variables for climate, cloud, radiative, and process studies are precipitable water vapor (PWV) and cloud liquid water path (LWP). The ARM program has fielded several 2-channel microwave radiometers manufactured by Radiometrics Incorporated at its Climate Research Facilities. These sensitive radiometers make observations at 23.8 GHz, which is near the pressure insensitive point (i.e., near the hinge point) of the 22.2 GHz water vapor absorption line, and at 31.4 GHz, which is an atmospheric window. PWV and LWP can be retrieved from observations at these two frequencies. An automated algorithm maintains the calibration of these observations to better than 0.3 K RMS (Liljegren 2000).

The ARM program provides estimates of PWV and LWP, along with the observed brightness temperatures, as part of the raw microwave radiometer (MWR) datastream. The PWV / LWP are retrieved from the observed brightness temperatures using a statistical retrieval algorithm which resides on the instrument computer. This retrieval algorithm uses a database of retrieval coefficients to invert the observed brightness temperature observations. These retrieval coefficients are monthly averaged values derived from an absorption model with inputs from a historical database of radiosonde observations in the general location of the MWR; i.e., the retrieval coefficients are site specific. The absorption model used in these “quasi-statistical” retrievals is a combination of the Liebe and Layton model (1987, henceforth “L87”) for dry air and water vapor absorption and the liquid water absorption model of Grant et al. (1957, henceforth “G57”).

The ARM program has continually worked to validate and improve radiative transfer models, and absorption models in the microwave spectral region are no exception. Recent studies by the ARM program have shown that other absorption model combinations [namely the Rosenkranz (1998, henceforth "R98")] absorption model for dry air and water vapor and Liebe et al. (1991, henceforth "L91") for liquid water absorption) improve the LWP retrievals relative to in situ observations (Westwater et al. 2001). ARM has also supported the development of a new radiative transfer model called monoRTM, which is an extension of the line-by-line radiative transfer model LBLRTM (Clough et al. 1992), which is applicable to the microwave spectral region. Marchand et al. (2003) have evaluated a variety of microwave absorption models for a small set of carefully selected case studies, and concluded that significant differences exist between the various models, and that the uncertainty in the retrieved LWP is approximately 25 g/m^2. Both the monoRTM and the R98/L91 models are considered to be more accurate than the L87/G57 model currently used by the ARM program.

A New Value-Added Procedure

In addition to improvements in microwave absorption models, the uncertainties in the retrieved PWV and LWP can be reduced by using more information in the retrieval algorithm. Liljegren et al. (2001) have developed a "variable coefficient" retrieval algorithm where the retrieval coefficients are "predicted" from a regression of surface meteorology observations. This method allows for changes in atmospheric pressure, which influences the dry air absorption, and the mean radiating temperature, which is well correlated with surface temperature and humidity, to be accounted for. The coefficients for this method are derived from the R98/L91 model using radiosondes from the Tropical Western Pacific (TWP), Southern Great Plains (SGP), North Slope of Alaska (NSA), and other locations, thus making the retrieval site-independent. This method also uses the millimeter wave cloud radar (MMCR) reflectivity data from the active remote sensing cloud layer (ARSCL) value-added procedure (VAP) (Clothiaux et al. 2000) along with the nearest radiosonde profile to estimate the temperature of the liquid water; this greatly reduces the uncertainty in the retrieved LWP.

A second retrieval algorithm, a physical-iterative approach, directly accounts for the vertical distribution of the water vapor and temperature in the retrieval (Marchand et al. 2003). This physical-iterative retrieval, which uses an optimal estimation approach (Rodgers 2000), also accounts for the temperature of the liquid water like the variable-coefficient method. The absorption model used in the physical retrieval is monoRTM.

A new Value-Added Procedure (VAP) has been developed to provide improved estimates of PWV and LWP for the ARM program. This algorithm has multiple purposes. The first is to provide additional quality control for the observed brightness temperatures. For example, spikes occasionally occur in either of the two channels that are associated with a communication error between the instrument and the instrument's computer (Figure 1). Second, both the physical retrieval and the variable-coefficient retrieval algorithms have been implemented in the VAP. This allows both the retrieval methodologies to be evaluated as well as the absorption model differences.

This algorithm is still under development; however, the year 2000 from the SGP was processed as part of the broadband heating rate profile (BBHRP) effort (Mlawer et al. 2004). Figure 2 shows an example of the retrieved PWV and LWP, along with 1-sigma uncertainties from the physical retrieval, for an

8-day period. As part of this analysis, we investigated the sensitivity to the retrieved PWV and LWP to changes in the width of the 22.2 GHz water vapor line; the width used in R98 (Liebe and Dillon 1969) is about 5% larger than the width specified in the HITRAN2000 database (which is used by the monoRTM). Using the HITRAN line width (H-width) results in about 3% less PWV than using the Rosenkranz width (R-width) in the variable coefficient retrieval. Comparisons of calculations and observations made by the Radiometrics 12 channel MWR, which observes downwelling radiance at several frequencies on the 22.2 GHz line, have shown that the HITRAN linewidth is more consistent with the 12 channel observations than the Rosenkranz linewidth.

Comparison of PWV retrieved using the original, variable-coefficient (with the HITRAN linewidth), and physical retrieval algorithms for this year-long dataset are given in table 1. The differences, though small over the range of this dataset (0.5 to 4.0 cm), are important at both low and high PWV amounts that are under investigation. However, the differences among these three retrieval algorithms are small (< 1% in terms of sensitivity) and thus the general conclusions of the water vapor intensive operational periods (IOPs) (Revercomb et al. 2003) and the quality measurement experiment (QME) atmospheric emitted radiance interferometer (AERI) Line-By-Line Radiative Transfer Model (LBLRTM) (Turner et al. 2004), both of which are based upon clear-sky PWV retrievals using the original retrieval algorithm, are still valid.

A comparison of the variable-coefficient and physically retrieved LWP for the year-long dataset show very similar sensitivities between the two algorithms (Figure 3). This agreement was expected because the liquid water absorption model in the monoRTM is very similar to the L91 model. However, there are some outliers in the intercomparison that are not understood and under investigation. Furthermore, there are important differences between the two retrieval algorithms for low LWPs (LWPs < 100 g/m^2) that are associated with other differences in the forward models (e.g., the dry air absorption model).

The retrieved LWP in clear-sky conditions are useful in evaluating the uncertainties in microwave absorption models (Marchand et al. 2003). Statistics on the clear sky LWP distributions per month for both the variable coefficient and physical retrieval algorithms for year 2000 demonstrate that the mean clear sky bias changes for both retrieval algorithms, with LWP biases changing from approximately -5 g/m^2 in March to about -15 g/m^2 during August (Figure 3). The changing LWP clear sky bias may be associated with the seasonal changes in PWV or may be related to instrument calibration. We are currently processing data from other time periods, including a period where two MWRs were operating side-by-side simultaneously, to understand these biases.

Summary

A new VAP is being developed to provide improved estimates of PWV and LWP from the ARM MWRs. Two different retrieval algorithms and an improved quality control on the observed brightness temperatures form the core of this VAP. Analysis of one year of data from SGP processed with this algorithm highlight some of challenges that remain to be resolved.

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Table 1. Statistics comparing PWV from the variable coefficient (R98/L91 with HITRAN linewidth) and original retrievals (L87/G57) against the physical retrieval (monoRTM). The dataset contained 94,547 points from Feb 2000 – Feb 2001.

	Variable coefficient	Original Estimate
Mean bias [cm]	-0.036	-0.013
RMS Difference [cm]	0.064	0.051
Slope [ ]	1.018	1.007
Offset [cm]	-0.0014	-0.0014
Correlation [ ]	0.999	0.999

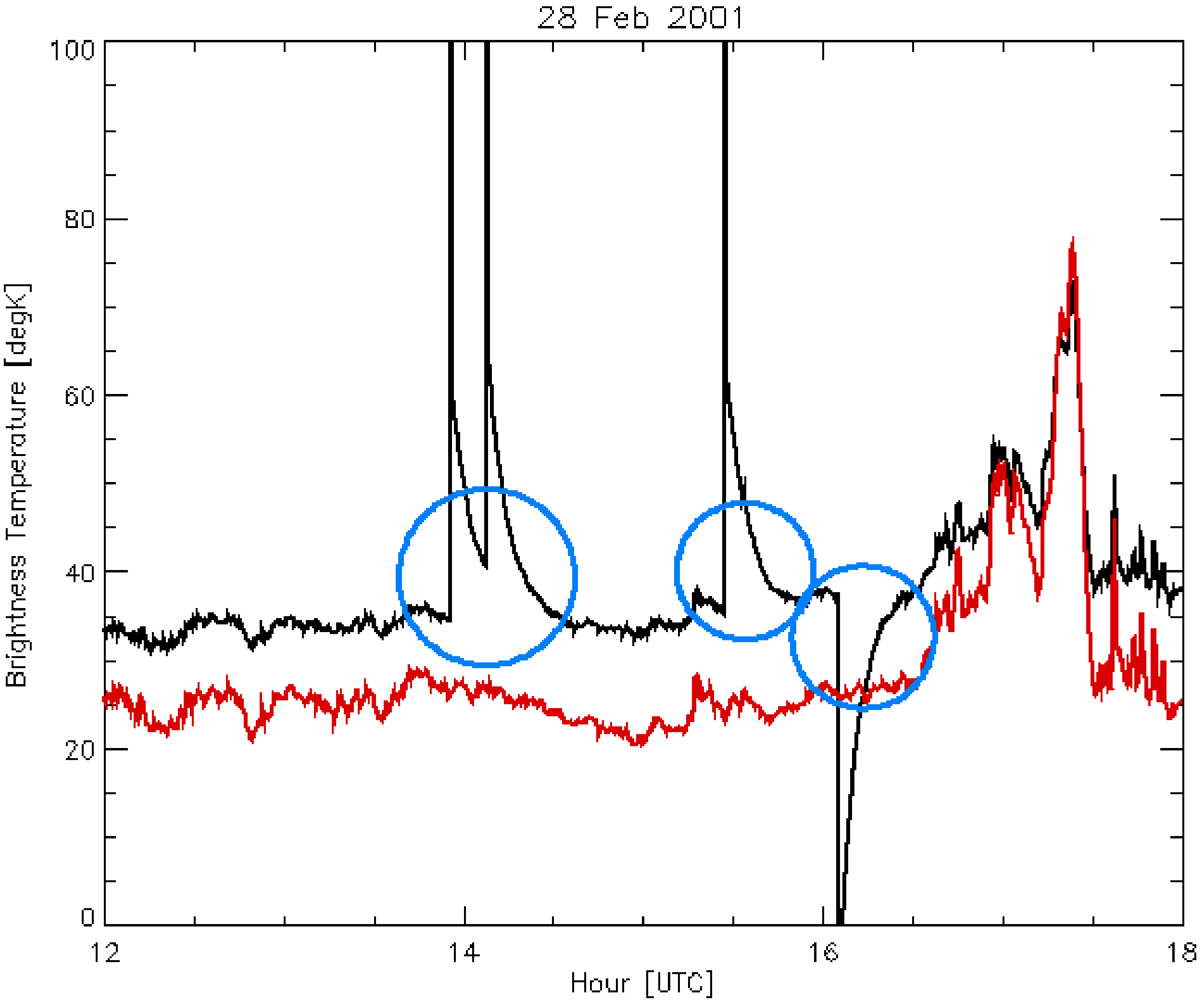

Figure 1. An example of the spikes seen in the MWR's observed brightness temperatures. These spikes (circled in blue) are the result of communication errors between the instrument and its computer. The spikes are found in both the 23.8 GHz signal (black) and in the 31.4 GHz signal (red). These spikes will be identified and flagged as part of the quality control routine in the new VAP.

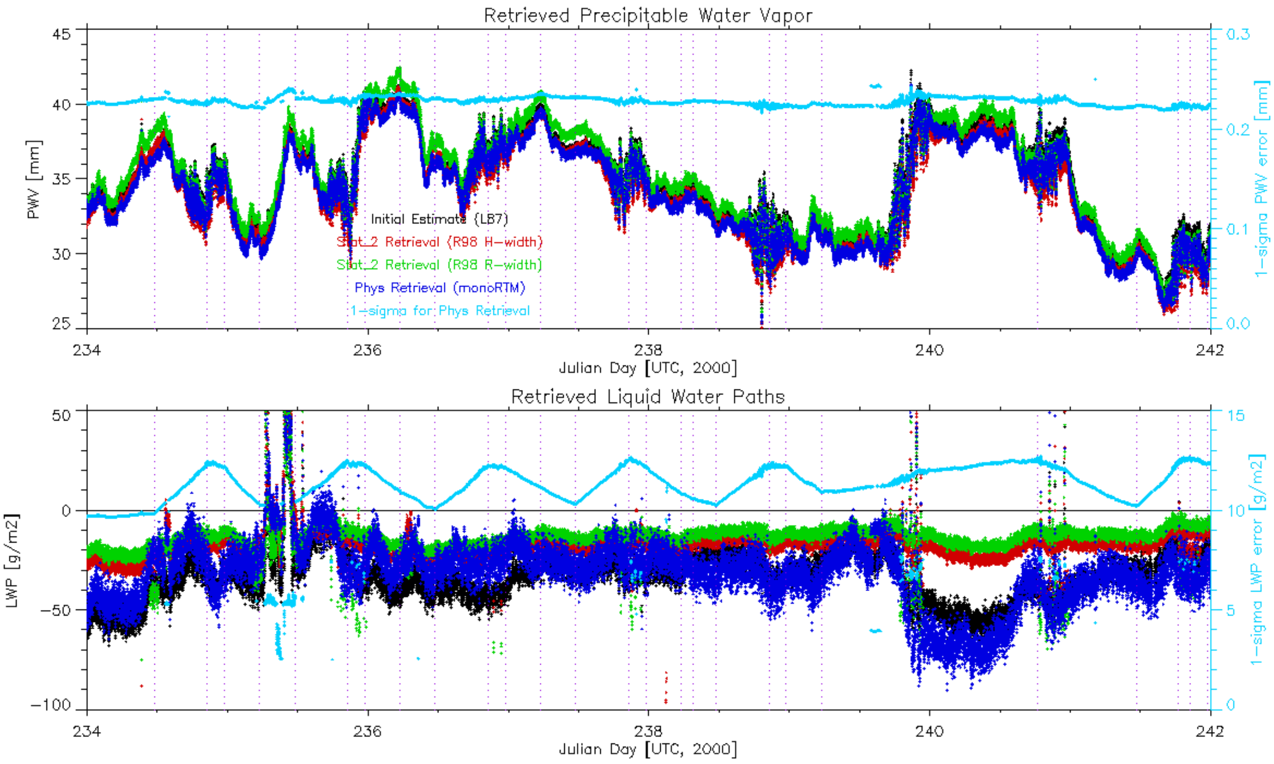

Figure 2. An 8-day time-series of PWV and LWP during a mostly clear sky period. The original statistical “initial estimate” (L87/G57), variable-coefficient “stat_2” (R98/L91), and physical (monoRTM) results are shown. Two results are shown for the variable coefficient retrieval: one with the HITRAN 22.2 GHz linewidth (H-width, in red) and one with the R98 linewidth (R-width, in green). The cyan lines denote the 1-sigma uncertainties that are reported as part of the optimal estimation technique used in the physical retrieval. The vertical dotted lines denote the launch times for the radiosondes which provide the vertical structure of the atmosphere for the physical retrieval.

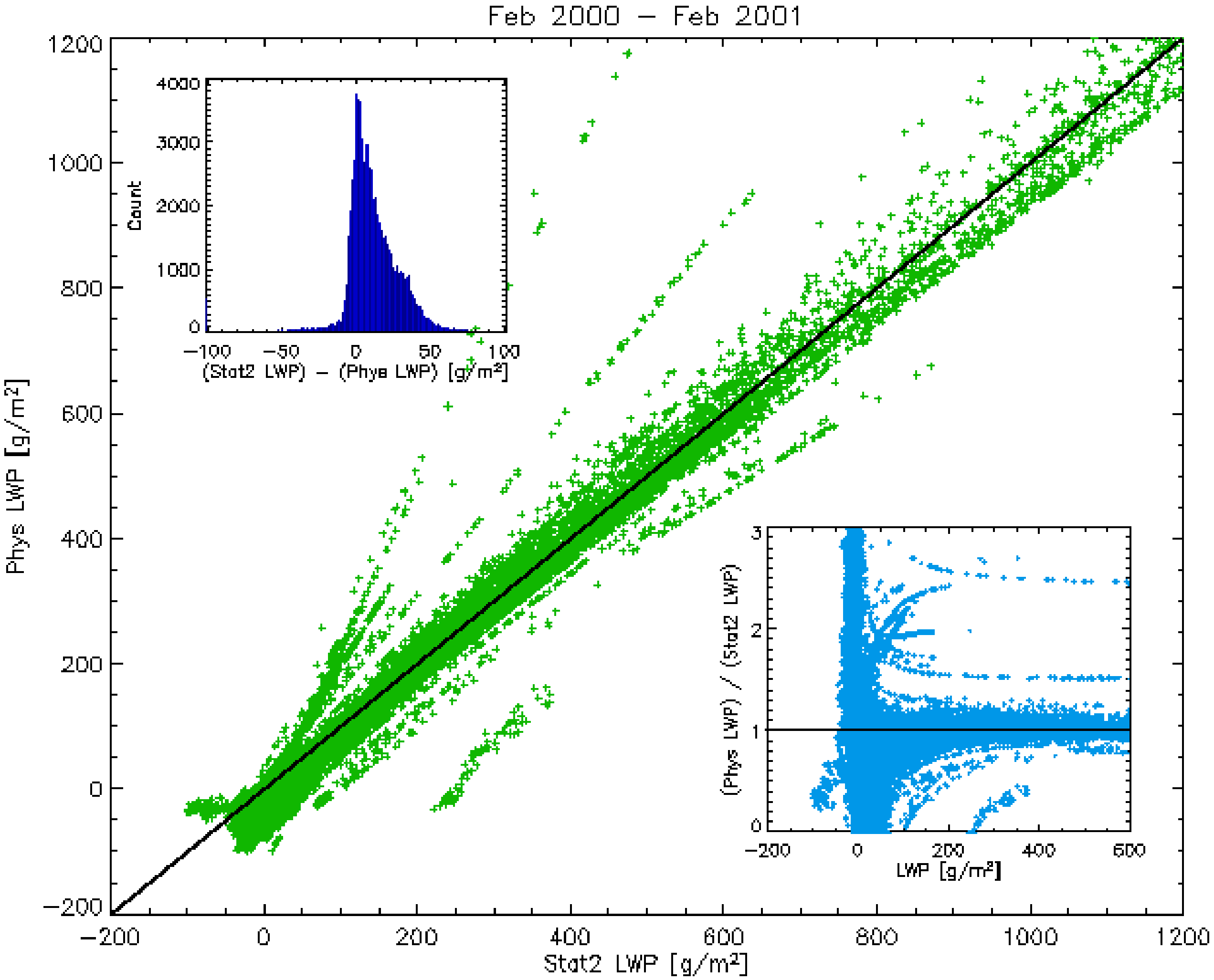

Figure 3. Comparison of LWP from the variable-coefficient ("stat2", using R98/L91 with HITRAN linewidth) and physical retrieval (monoRTM) algorithms for data collected at the SGP from Feb 2000 to Feb 2001. The outliers in the scatterplot, as well as the skewness in the distribution of the residuals, are under investigation.

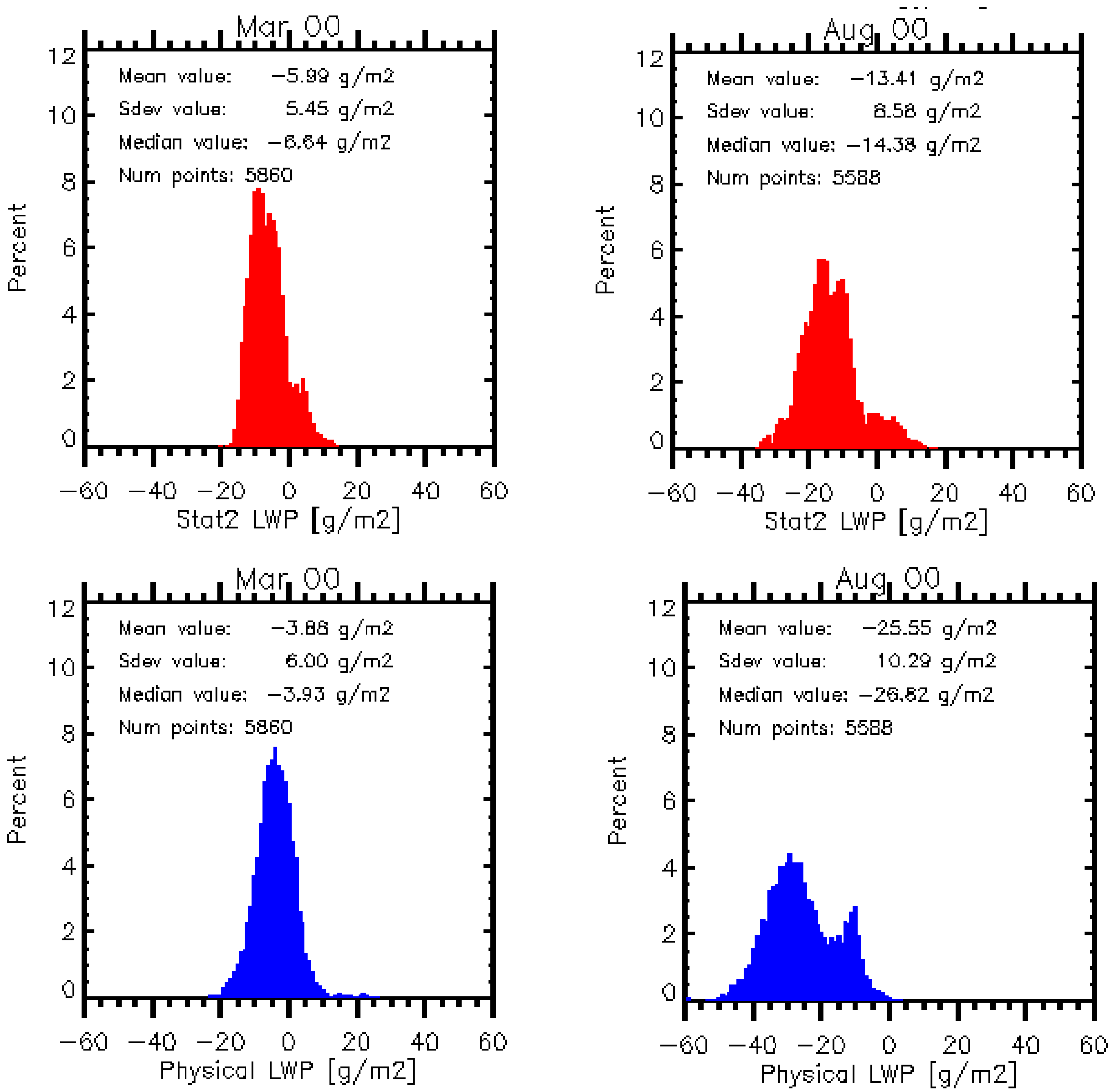

Figure 4. Monthly distributions of the LWP retrieved using both the variable coefficient retrieval (red) and the physical retrieval (blue) in clear sky scenes (as determined from ARSCL data) for data from SGP in March and August 2000.