Initial Analysis of Water Vapor and Temperature Profiles Retrieved from Integrated Ground-Based Remote Sensors

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Introduction

Defining the state of the atmosphere is an essential task in order for the improvements in radiative and single-column models to become a reality. The Atmospheric Radiation Measurement Program (ARM) currently relies on radiosondes to gather the detailed soundings of temperature, pressure, moisture, and wind because automated remote-sensing methods have been heretofore unable to provide this information. Since radiosondes constitute the single largest expense at the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) (Sisterson et al. 1994), great effort has been directed to the development of automated, remote-sensed sounding techniques in order to lessen our radiosonde burden.

We have implemented a new retrieval algorithm (Han and Westwater 1995) in the ARM Experiment Center as a Value Added Procedure (VAP). This new VAP is run in an automated manner on data from the Central Facility, retrieving profiles of water vapor and temperature at 250 meter resolution hourly. The retrieved profiles are available as a new data platform. Plans are made to run this VAP for the Boundary Facilities in the future also.

Retrieval Method

The retrieval utilizes data from a suite of ground-based instruments. The physical measurements needed for the retrieval are the brightness temperatures from the 2-channel microwave radiometer (MWR); the surface pressure, temperature, and moisture measurements from the surface meteorological observing station (SMOS); the virtual temperature profiles from the radio acoustic sounding system (RASS); and the cloud base height from the Belfort laser ceilometer at the central facility. Currently, only the lack of ceilometers prevent the running of this VAP on data from the boundary facilities.

While the MWR and SMOS data are required for the VAP to run, the use of RASS and ceilometer data improve the retrievals greatly during cloudy conditions. In light of this fact, profiles are retrieved once each hour, since the current sampling strategy of the ARM radar wind profilers is to RASS only for 10 minutes at the top of each hour. Two-minute averages of the MWR and the ceilometer data are used to dampen out any noise.

After the input data have been quality controlled, the Han/Westwater algorithm is invoked. This algorithm is an iterative two-step process. In the first step we apply a physical algorithm to derive precipitable water vapor and integrated cloud liquid from the MWR data. Only climatological average values of medium temperature and absorption coefficients are used in this step. In the second step, a linear statistical inversion procedure is applied to derive water vapor and cloud liquid water profiles from a data vector that is simply related to quantities measured by the MWR, SMOS, RASS, and ceilometer. This inversion is based on cloud-base height stratified statistics obtained from Oklahoma City, OK, radiosondes. From this, a series of iterations are performed, wherein a radiative transfer model (Liebe and Layton 1987) is used to derive approximations of the integrated water vapor and liquid water, from which new water vapor and liquid water profiles are obtained. These new profiles replace the initial ones, and the cycle is repeated. Han and Westwater have concluded that little improvement happens after two iterations, and therefore only two iterations are performed in the VAP. Retrievals are not performed if either the MWR or SMOS data is missing, or if rain is sensed.

Comparison of Retrievals and In-Situ Measurements

Since this retrieval algorithm is new, a quality measurement experiment (QME) was designed to help analyze its output as compared with the radiosonde. For each radiosonde release, comparisons are done with both the prior and next retrieved profiles. Residual profiles are created, and the root mean square error between the two profiles is calculated. Additional information that is captured by the QME include the cloud base height if there were ceilometer data available, whether or not an ice cloud was present, whether or not there was a RASS sample available, and the columnar amounts of water vapor from the retrieval, sonde, and MWR. Examples of the new retrieval method, the "traditional" method (which uses only radiometric and surface observations for its retrievals), and radiosondes are given in Figures 1 and 2. Note the significant improvement of the water vapor retrievals in the cloudy cases in Figure 2.

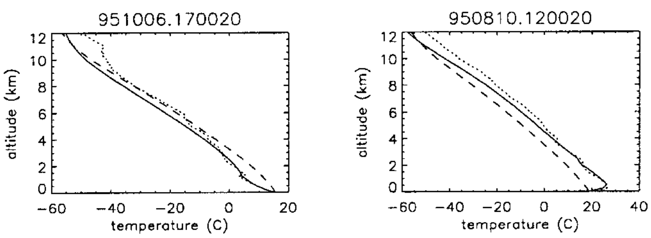

Figure 1. Examples of temperature retrievals. Solid line - new retrieval method, dashed line - traditional method, and dotted line - radiosonde.

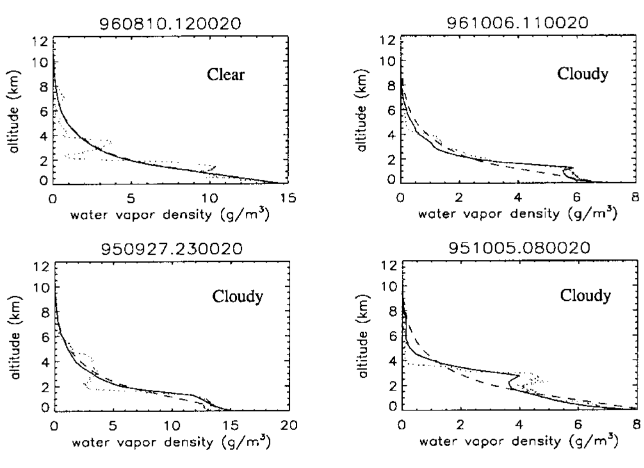

Figure 2. Examples of water vapor retrievals. Solid line - new retrieval method, dashed line - traditional method, and dotted line - radiosonde.

Using this QME, data from the RCS IOP (April 1995), the SEE IOP (June 1995), and the time period leading into and through the ARM Enhanced Shortwave Experiment (ARESE) Intensive Observation Period (IOP) (August through October, 1995) were analyzed. The difference between the water vapor retrievals from the new versus the traditional technique for clear sky cases demonstrated no improvement, which agrees with Han and Westwater's results. However, when we compare the two methods in cloudy conditions, we see that the additional constraint of knowing the temperature at the cloud base helps to improve the water vapor retrievals (Figure 3).

While the improvement between the two methods is on the same order as that shown by Han and Westwater, the water vapor "error" (the root mean square difference between the retrievals and the radiosondes) is about 4 to 6 times greater here. There are many possible sources of error. One is that the retrieval algorithm assumes a single cloud layer; hence the cases where there are multiple cloud layers will have a high error associated with them. There were also several examples where the cloud base height returned by the ceilometer did not match well with that estimated from the radiosonde's relative humidity profile, which could be explained by the drift of the radiosonde away from the field of view of the ceilometer. Another source of error is the discrepancy between the surface thermodynamic values and those measured early during the radiosonde launch. This discrepancy is much higher here than in the results shown by Han and Westwater, and is probably the principal factor that resulted in the increase in error between the two studies.

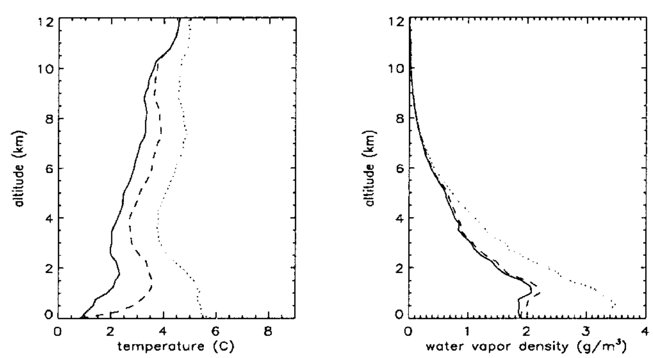

Figure 3. Root mean square differences between retrieved and radiosonde for cloudy conditions. 170 samples. Solid - new retrievals, dashed - traditional retrievals, dotted - standard deviation of 117 radiosondes.

Longwave Radiative Transfer Comparisons

Using retrieved profiles from clear sky periods, the Line-by-Line Radiative Transfer Model (Clough 1993) was run to calculate downwelling longwave radiance, to demonstrate the feasibility of using these remote sensed profiles to drive an intricate model, and to validate these retrievals radiometrically with an atmospheric emitted radiance interferometer (AERI). Two clear sky days were chosen that exhibited little atmospheric variance, as indicated by the standard deviation about the mean radiance during the AERI's skydwell in the 985-990 cm^{-1} window. The model was then driven with the retrieved profiles. Spectral residuals were then calculated using the observed radiance from the AERI. These residuals were then compared to the "normal" observed minus calculated residuals, where radiosonde data was used to drive the Line-By-Line Radiative Transfer Model (LBLRTM). These examples are seen in Figures 4 and 5.

These plots show several things. First, one notices that on 9/13 the retrieved profiles describe the state of the atmosphere better than the radiosondes, using the AERI as the standard. Note the large discrepancy of the total precipitable water vapor in the column as measured by the sondes and calculated by the retrieval algorithm. However, for the 7/12 case, the total column closely agrees between the radiosondes and the retrieved profiles, and the residuals are very similar. In both cases though, the standard deviation was small for the retrieved cases, in fact smaller than that associated with the radiosondes, indicating the consistency and accuracy of the retrievals.

Summary

Remote sensing techniques are highly anticipated by many in the ARM Program, because the expense of the radiosondes prevents the program from sampling the atmosphere as often as desired. This VAP is the first remote-sensing technique to become fully automated in the ARM Program, producing data available in a "real time" manner. It has been shown to be able to retrieve profiles with a fair amount of structure, and that its ability to define the atmosphere during clear sky days is very good. This new VAP will aid the program immensely in defining the state of the atmosphere more continuously above the central facility and, with the future anticipated procurement of ceilometers for the boundary facilities, above them as well.

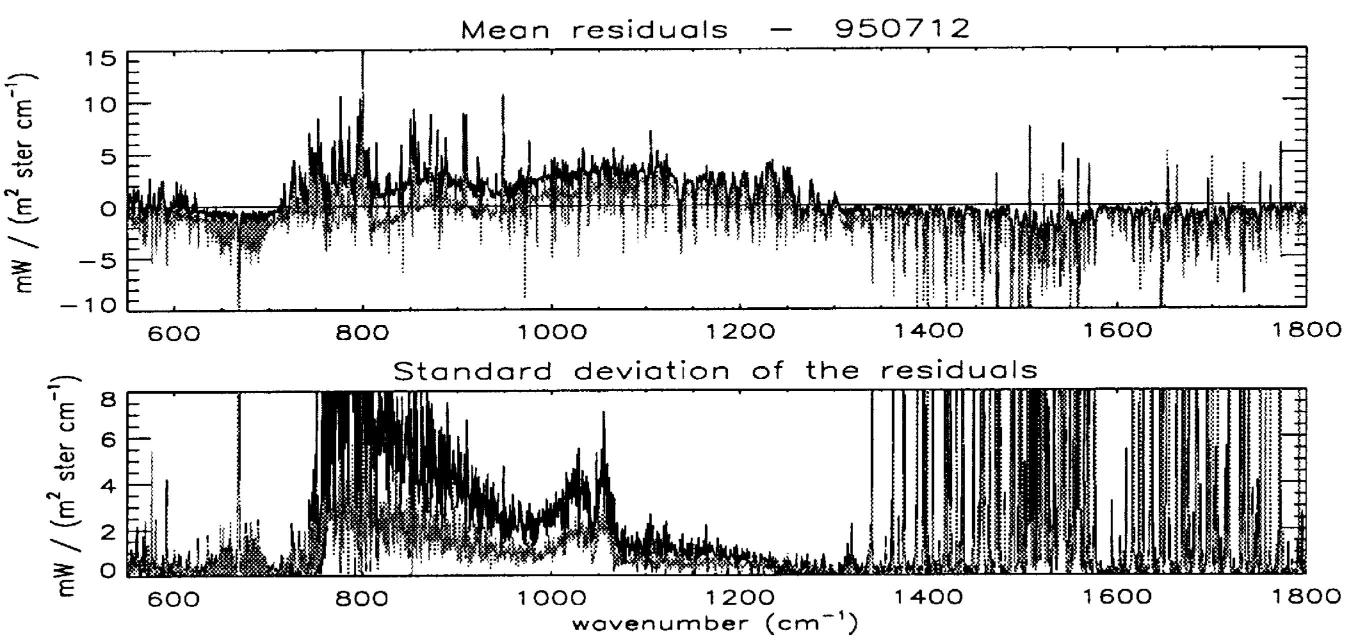

Figure 4. Comparisons of the observed minus calculated downwelling radiance, where the model was driven by the new retrieval method (light) and by the sondes (dark). There were 4 observed minus calculated samples for both, averaged to give these results. The average sonde PWV was 3.16 cm, while the average retrieved column was 3.09 cm. The column from the microwave radiometer was 2.94 cm.

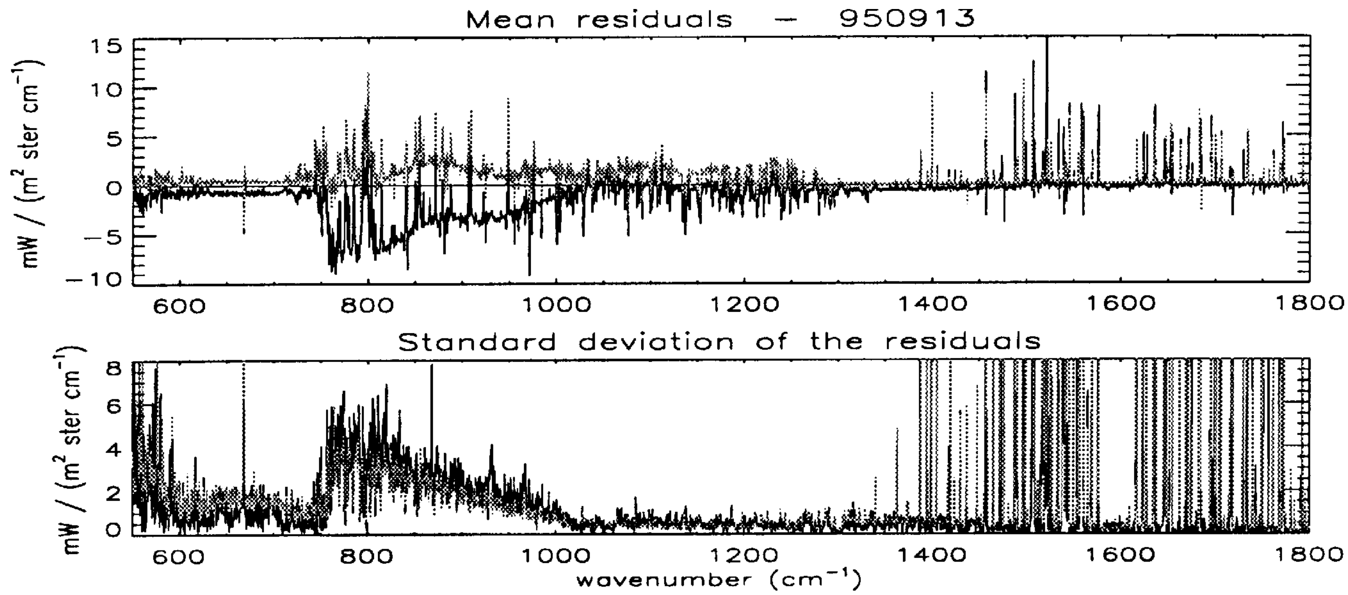

Figure 5. Comparisons of the observed minus calculated downwelling radiance, where the model was driven by the new retrieval method (light) and by the sondes (dark). There were 5 sonde driven model runs, and 11 retrieval driven model runs. The residuals were then averaged to give these results. The average sonde PWV column was 3.15 cm, while the average retrieved column was 2.78 cm. The column from the microwave radiometer was 2.52 cm. Note that the relative humidity sensors on these radiosondes were incorrectly calibrated at the factory- please see paper by Lesht and Liljegren in this volume.

References

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