Comparisons of Brightness Temperature Measurements and Calculations Obtained During the Spectral Radiance Experiment

Y. Han, J. B. Snider, and E. R. Westwater
National Oceanic and Atmospheric Administration
Environmental Research Laboratories/Environmental Technology Laboratory
Boulder, Colorado

S. H. Melfi
National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland

R. A. Ferrare
Hughes STX Corporation
Lanham, Maryland

Introduction

In radiometric remote sensing of the atmosphere, the ability to calculate radiances from underlying state variables is fundamental. To infer temperature and water vapor profiles from satellite- or ground-based radiometers, one must determine cloud-free regions and then calculate clear-sky radiance emerging from the top of the earth's atmosphere from the underlying profiles of temperature and water vapor. Equally important is the validation of the radiometric retrievals. Usually such validation is made by comparing retrievals with profiles derived from other sensors. Traditionally, such "forward model" calculations and validations have coupled radiosonde observations of the state variables with detailed absorption and radiative transfer models. However, for a variety of reasons, radiosonde moisture measurements are not always satisfactory, especially during low humidity conditions or when there are large horizontal or temporal gradients in the humidity structure.

A recent alternative to radiosonde moisture measurements is Raman lidar. The Raman lidar provides humidity measurements with temporal and spatial resolution far superior to radiosonde measurements.

In November-December 1991, a substantial number of remote sensor and in-situ instruments were operated together in Coffeyville, Kansas, during the First ISCCP[a] Regional Experiment (FIRE) II. Included in the suite of instruments were 1) the Environmental Technology Laboratory's (ETL) three-channel microwave radiometer, 2) the NASA/Goddard Space Flight Center's (GSFC) Raman lidar, 3) ETL's radio acoustic sounding system (RASS), and 4) frequent research-quality radiosondes. The Raman lidar operated only at night, and this portion of the experiment focused on cloud-free conditions. In this presentation, we present results of simultaneous microwave radiometer measurements with collocated Raman lidar measurements of water vapor over 10 nights during the experiments. Information on temperature profiles was also obtained from composite data from radiosondes and RASS.

Microwave Radiometer and Raman Lidar

The NOAA/ETL transportable microwave radiometer is a three-frequency system whose primary products are the column abundances of liquid water in clouds and water vapor in the atmosphere. The system contains three independent microwave radiometers with frequencies at

(a) International Satellite Cloud Climatology Project.

20.6, 31.65, and 90.0 GHz, respectively. The brightness temperatures of the three channels were calibrated by the so-called "tipping curve" calibration procedure, a technique which is completely independent of either radiosondes or Raman lidar. The data sets used had 2-minute temporal resolution.

The NASA/GSFC Raman lidar measures profiles of water vapor mixing ratio. The random error associated with the lidar water vapor mixing ratio profiles increases with altitude. For a 1-minute profile, the random error is less than 10% for altitudes below 7.5 to 8.5 km. This maximum altitude depends on averaging time, vertical resolution, ambient water vapor amounts, background skylight, and aerosol attenuation. For this experiment, Raman lidar profiles with 2-minute averaging time and 75-m vertical resolution were used.

Comparison of Brightness Temperature Measurements and Calculations

Recently, both Liebe's water vapor and oxygen absorption models have been updated. In these recent models, the values of parameters describing the 22.235 GHz water vapor line, the 60 GHz oxygen band, and the water vapor continuum have been changed from those reported by Liebe and Layton (1987) and by Liebe (1989). Here we compare measurements of brightness temperature with calculations based on Waters (1976) and both the previous (1987) and the more recent absorption models of Liebe. For convenience we will refer to the models as: RTE76 (Waters [1976] for H_2O, Rosenkranz [1988] for O_2); RTE87 (Liebe and Layton [1987] for H_2O, Rosenkranz [1988] for O_2) and RTE93 (Liebe et al. [1993] for H_2O, Liebe et al. [1992] for O_2). We use water vapor profiles provided by the Raman lidar and temperature profiles provided by RASS merged with radiosondes as model inputs.

We present in Table 1 a summary of our statistical analysis carried out over the entire data set of clear and quality-controlled measurements. These statistical results show that the 20.6 GHz results are better with RTE76, the 31.65 GHz results are better with RTE93, and the 90 GHz results show no improvement using the RTE87 over the RTE93 model. The latter results are consistent with those of Westwater et al. (1990), which show poor agreement with Waters' equations at 90.0 GHz.

Comparison of Column Water Vapor Retrievals and Raman Lidar Measurements

The radiometric retrieval algorithm we used was the linear statistical method, conditioned on clear sky conditions; all three channels were used in the retrievals. In addition, using rawinsonde data as ground-truth profile data, we removed radiometric-RTE model offsets by adjusting the radiometer brightness temperature data to be consistent with the RTE93 calculations. Our method of deriving column water vapor differs slightly from the usual ETL methods. Rather than using a climatological value for the mean radiating temperature T_{mr}, we estimated it for each 2-minute data point from surface temperature measurements. Rather than use only the diagonal elements of the covariance matrix of experimental errors (in T_b), we used all elements of the covariance matrix.

We compared radiometric measurements of column water vapor with those from Raman lidar, as well as those from radiosondes. On short time scales, the Raman and microwave data show excellent correlation and, because of the radiometric offset adjustments, only a very small bias. There is also good agreement with the radiosonde measurements, the best agreement being with the CLASS radiosondes. The rms difference between the column water vapor derived from the microwave radiometer and that from the Raman lidar is 0.03 cm, which should be compared with the values of 0.17 cm reported by Hogg et al. (1983) and the more recent value of 0.11 cm of Martner et al. (1993).

Conclusions

The use of Raman lidar data for the detailed studies of tropospheric water vapor absorption and emission has significant potential. The vertical resolution of 75 m and the temporal resolution of 1 min have significant advantages

Table 1. Comparison of measured and calculated brightness temperature at 20.6, 31.7, and 90.0 GHz. Sample size = 2506

	rms diff. (k)	bias (k) (meas.-cal.)	slope	intercept (k)
RTE76(20.6GHz)	0.40	0.27	0.99	-0.10
RTE87(20.6GHz)	1.48	1.41	0.90	0.28
RTE93(20.6GHz)	0.63	0.53	0.94	0.46
RTE76(31.7GHz)	1.30	1.27	0.88	0.53
RTE87(31.7GHz)	1.96	1.93	0.83	0.70
RTE93(31.7GHz)	0.76	0.73	0.94	0.23
RTE76(90.0GHz)	7.66	-7.38	1.27	-2.36
RTE87(90.0GHz)	1.95	1.77	1.00	-1.75
RTE93(90.0GHz)	1.48	-0.04	1.18	-6.42

over radiosondes. Using Raman lidar water vapor profiles, as well as temperature profiles obtained from RASS and radiosondes, we have examined three absorption models here. At the lower frequencies of 20.6 and 31.65 GHz, the calculations based on RTE76 and RTE93 produced similar results, with rms differences between measurements and calculations of about 0.5 K. However, the results at 90 GHz using RTE93 are not substantially better than the earlier RTE87, and may be worse. The excellent temporal correlations between the Raman lidar's and the microwave radiometer's determination of column water vapor confirms the ability of both of the instruments to follow rapid changes in moisture.

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