Preliminary Analysis of Ground-Based Microwave and Infrared Radiance Observations During the Pilot Radiation OBservation Experiment

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

Introduction

During Phase Two of the Pilot Radiation OBservation Experiment (PROBE) held in Kavieng, Papua New Guinea (Renné et al. 1994), the National Oceanic and Atmospheric Administration's Environmental Technology Laboratory (ETL) operated both microwave and infrared radiometers (Westwater et al. 1994). Phase Two lasted from January 6 to February 28, 1993.

The dramatic differences in the water vapor environment between the tropics and mid-latitudes were illustrated by Westwater et al. (1994) who presented PROBE data as well as additional data that were taken during the 1991 First ISCCP[a] Regional Experiment (FIRE) II experiment in Coffeyville, Kansas. Here, we present an analysis of microwave data and a preliminary analysis of infrared data obtained during PROBE.

Equipment

Microwave Water Substance Radiometer

The basic characteristics of the microwave water substance radiometer (MWSR) used in Kavieng are given by Westwater et al. (1994). The dual-frequency instrument operates at 23.87 and 31.65 GHz and yields precipitable water vapor and integrated cloud liquid with accuracies of 1 mm rms (≈ 5%) and 20%, respectively. During PROBE, 30-sec integration times were used.

(a) International Satellite Cloud Climatology Project.

Fourier Transform Infrared Radiometer

The Fourier transform infrared radiometer (FTIR) developed by ETL is described by Shaw et al. (1991). The FTIR is a compact and rugged Michelson interferometer, operating between roughly 500 and 2000 cm^{-1} (5.0 - 20.0 µm) with 1 cm^{-1} spectral resolution. The instrument views two blackbody calibration targets immediately following each complete atmospheric emission measurement. One calibration target is immersed in LN2; the other is at the ambient temperature within the seatainer containing the instruments. Collection of each spectrum takes about 1 sec, and 100 such spectra are averaged to reduce random noise. With this technique, calibrated atmospheric spectra were collected about once every 6 to 10 min.

Ancillary Measurements

In addition to the radiometric observations, ETL also took surface meteorological observations of temperature, pressure, and relative humidity. Simultaneously, the National Center for Atmospheric Research (NCAR) obtained surface observations, and NCAR-trained weather observers launched Omegasondes four times a day. We note that the humidity sensor on these rawinsondes was HUMICAP. Renné et al. (1994) gives a complete listing of all the instruments used during PROBE.

Observations

The MWSR operated continuously through PROBE and, except for those collected during periods of rain, the data are of high quality. Occasional gaps of about 15-min appear in the data when "tip cals" were performed. During the "tip cal" calibration procedure, elevation scans of the radiometer were made, and calibration constants in our radiometer equation were adjusted so that the linear curve of attenuation versus air mass passes through the origin; clear skies are necessary for "tip cals."

Westwater et al. (1994) show examples of time series of precipitable water vapor (PWV) and integrated cloud liquid (ICL) derived from the calibrated data of the MWSR. These data show the passage of a "dry front" during which the PWV dropped from about 5.5 cm to a minimum of 3.9 cm. The drying is associated with dry air advecting into the region from its origin in Australia.

We also evaluated the statistical characteristics of PWV for the period January 15 through February 28, 1993. For that period, the average PWV was 5.46 cm, its standard deviation was 0.50 cm, and the total range during the experiment was 3.14 cm (3.89 to 7.03 cm). The accuracy of our PWV retrievals, using 181 rawinsondes as ground truth, was 0.31 cm rms. This is at least a factor of 3 higher than our previously attained accuracies, and we are still investigating the possible causes of this discrepancy.

Examples of simultaneous microwave and infrared radiometric data taken during FIRE II and PROBE were also shown by Westwater et al. (1994). The roughly 10-to-1 difference in PWV between Coffeyville and Kavieng is reflected in the infrared spectra, especially in the window region between 750 and 1250 cm^{-1}. We also measured infrared radiance during known (from lidar observations) cirrus conditions. The infrared emission from cirrus clouds, which shows so clearly in the drier Coffeyville environment, is sometimes difficult to identify in the moist tropical atmosphere at Kavieng.

Comparison of Infrared Measurements and Calculations

In the Spectral Radiance Experiment (SPECTRE) data set obtained in Coffeyville, a variety of data, taken under clear conditions, was available to compare measurements and calculations of emission spectra. The increased frequency of clouds and a fewer number of rawinsondes made it much more difficult to obtain matching data during clear conditions in Kavieng. One clear spectrum, in close temporal agreement with a rawinsonde release 34 minutes later, was obtained on January 22, 1993, at 22:25 UTC. Our comparison of measurements and calculated spectra using FASCODE (Clough et al. 1992) is shown in Figure 1. We note that in the 750-1100 cm^{-1} window, the calculations are lower than the measurements.

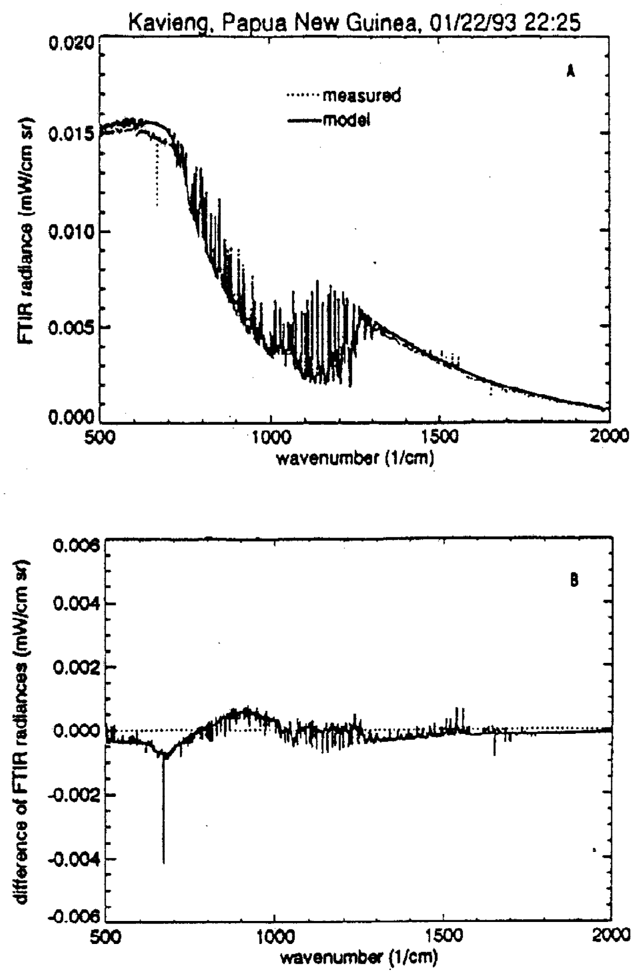

Figure 1. Comparison of measurements and calculations of infrared emission spectra. Kavieng, Papua New Guinea, 2225 UTC 1/22/93. a) Calculated and measured spectra b) Difference of measured versus calculated spectra.

The Use of Water Vapor Retrievals in Emission Calculations

One of the instruments to be deployed at the U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) sites in the Tropical Western Pacific (TWP) is a dual-channel microwave radiometer, which can measure PWV to an accuracy of about 1 mm rms. Since rawinsonde releases in the TWP may be as few as one per day, it is of interest to know how well clear sky infrared radiance, incident on the surface, can be calculated from our remote sensor data. Since the variance of temperature profiles in the troposphere is small (less than 1.0 K^2), the primary component of clear sky fluctuations in infrared radiance is due to water vapor variations. Since the temperature profile can be estimated from surface temperature to an accuracy of about 0.5 K, the unpredictable portion of the radiance will be the portion that is uncorrelated with PWV.

To estimate this residual, we first used FASCODE to calculate radiance from 500 to 2000 cm^{-1} using rawinsonde profiles as input. We used the same data to calculate PWV and estimated temperature profiles. Using these simulated data, we calculated the uncertainty in estimating radiance from PWV measurements of 0.0, 1.0, and 3.0 mm rms errors. The results, shown in Figure 2, indicate that when microwave PWV retrievals of 1 mm rms are used, the radiance can be estimated to an accuracy of better than 5% everywhere in the spectrum.

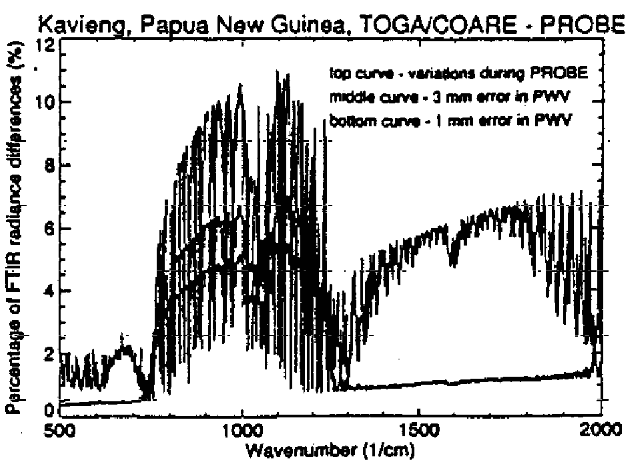

Figure 2. Statistical estimate of the expected accuracy in deriving clear air infrared emission spectra from PWV measurements of the indicated accuracies. There was essentially no difference between perfect accuracy and rms accuracy = 1 mm in estimating the spectra. Spectra and PWV were calculated from 181 rawinsondes taken during PROBE.

Summary and Conclusions

During Phase Two of PROBE, about 6 weeks of continuous measurements of PWV and ICL were obtained. At the same time, about 1700 FTIR spectra were obtained. Initial comparisons of microwave radiometric data with rawinsondes indicate rms agreement of about 6% (0.31 cm rms) in PWV. However, uncertainties exist in the comparisons and are under investigation.

For the only unambiguous clear sounding that we obtained, FASCODE calculations were lower that measurements in the window region, indicating that some adjustments to water vapor continuum calculations are required. Finally, estimation of clear sky narrow-band infrared radiance spectra at the ground can be achieved to an maximum uncertainty of 5% to 7.5% with PWV measurements of 1 to 3 mm rms accuracy.

References

Clough, S. A., and M. J. Iacono. 1994. Line-by-line calculation of atmospheric fluxes and cooling rates: application to water vapor. *J. Geophys. Res.* **97**:15761-15785.

Shaw, J. A., J. H. Churnside, and E. R. Westwater. 1991. An Infrared Spectrometer for Ground-Based Profiling of Atmospheric Temperature and Humidity. *Proc. SPIE Int'l. Symp. on Optical Appl. Sci. and Engineering*, July 21-26, San Diego, California, 1540:681-686.

Renné, D. S., T. A. Ackerman, and W. E. Clements. 1994. PROBE: The pilot radiation observation experiment. *Proc. Eighth Conf. on Atmos.*, January 23-28, 1994, Nashville, Tennessee, pp. 270-271. American Meteorological Society, Boston, Massachusetts.

Westwater, E. R., J. B. Snider, J. H. Churnside, and J. A. Shaw. 1994. Ground-based microwave and infrared radiance observations during PROBE. *Proc. Eighth Conf. on Atmos.*, January 23-28, 1994, Nashville, Tennessee, pp. 272-275. American Meteorological Society, Boston, Massachusetts.