Shipborne Fourier Transform Interferometric Radiometer Measurements of Tropical Atmospheric Spectral Radiance

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Introduction

For one month in 1996, we deployed a mobile Fourier-Transform Interferometric Radiometer (FTIR) emission spectro-radiometer on a ship to study spectral emission from the tropical atmosphere (Han and Churnside 1997). This deployment was part of the Combined Sensor Program (CSP) cruise in the tropical Pacific during March and April 1996. A wide array of active and passive sensors was deployed on the NOAA R/V *Discoverer* as it cruised from Pago Pago, American Samoa, to the vicinity of Manus Island, Papua New Guinea, and returned to Honolulu, Hawaii. A total of 3,702 spectra were collected, at least 15% of which were for clear skies. The columnar water vapor amounts ranged from approximately 3 to 6 cm. We estimate the accuracy of these spectral radiances to be 1% of background radiance, which is supported by comparisons with a University of Wisconsin FTIR system also on board during the cruise.

During the CSP cruise our FTIR measured spectral radiances at $1\,cm^{-1}$ spectral resolution (occasionally $2\,cm^{-1}$) between approximately 500 and 2,000 cm^{-1}, or 20 and 5 µm wavelengths (Shaw et al. 1995). The measurements were made pointing at zenith in a 35-mrad field of view. Calibration was based on measurements of two blackbody targets. A typical measurement sequence was to view the atmosphere between measurements of the hot and warm calibration targets. Each source was viewed for 32 interferometer scans (about three minutes). To limit our need for liquid nitrogen on the CSP cruise, we operated thermo-electric calibration sources at 300 K and 340 K, instead of using 300 K and 77 K sources as we have done previously. Periodically during the cruise, the FTIR was operated with an uncooled pyroelectric detector, which entirely eliminated the need for liquid nitrogen at the expense of lower sensitivity. With averaging times of 30-60 minutes, this detector provided measurements of the warm tropical atmospheric emission, which are comparable to the cooled-detector data averaged over 2-3 minutes. Figure 1 shows a typical clear-sky spectrum measured by the uncooled detector with an averaging time of 30 minutes and a spectral resolution of $2\,cm^{-1}$.

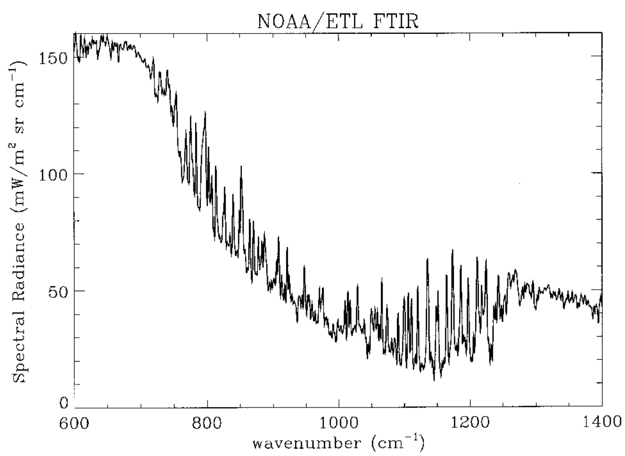

Figure 1. Clear-sky radiance spectrum measured by the NOAA/ETL FTIR, using an uncooled detector and 2 cm^{-1} spectral resolution, aboard the NOAA R/V *Discoverer* in the tropical Pacific.

One important result is that the CSP clear-sky measurements agree well with the recently modified CKD_2.2 water vapor continuum model used in the LBLRTM radiative transfer code (Line-By-Line Radiative Transfer Model: Clough 1995; Clough et al. 1992). Our earlier measurements from the Pilot Radiation Observation Experiment (PROBE) in Kavieng, Papua New Guinea, during January and February 1993 (Westwater et al. 1994; 1995) were 5% to 20% higher in the window region between about 800 and 1200 cm^{-1} than predicted by LBLRTM at that time with the CKD_1 water vapor continuum model. The CKD_2.2 continuum model (Clough 1995), based partly on our PROBE data, provides significantly better agreement with radiances measured during both PROBE and the CSP cruise. This excellent agreement between current radiative transfer models and the CSP measurements validates both the PROBE FTIR measurements and the resulting continuum model, which subsequently has been incorporated in the popular U.S. Air Force Lowtran, Modtran, and Fascode programs.

Figure 2 shows the radiance differences (measurement minus calculation) between a clear-sky measurement and a calculation with the LBLRTM code. Figure 2A is for LBLRTM with the old (CKD_1) water-vapor continuum model, and Figure 2B is for LBLRTM with the modified (CKD_2.2) continuum model. This figure shows the significantly improved agreement between measurements and calculations with the modified continuum model. The radiance residuals shown in Figure 2B are all within 5%, and most less than 4%, well within total measurement uncertainties, particularly those associated with the radiosonde water vapor profile used as input to the radiative transfer model.

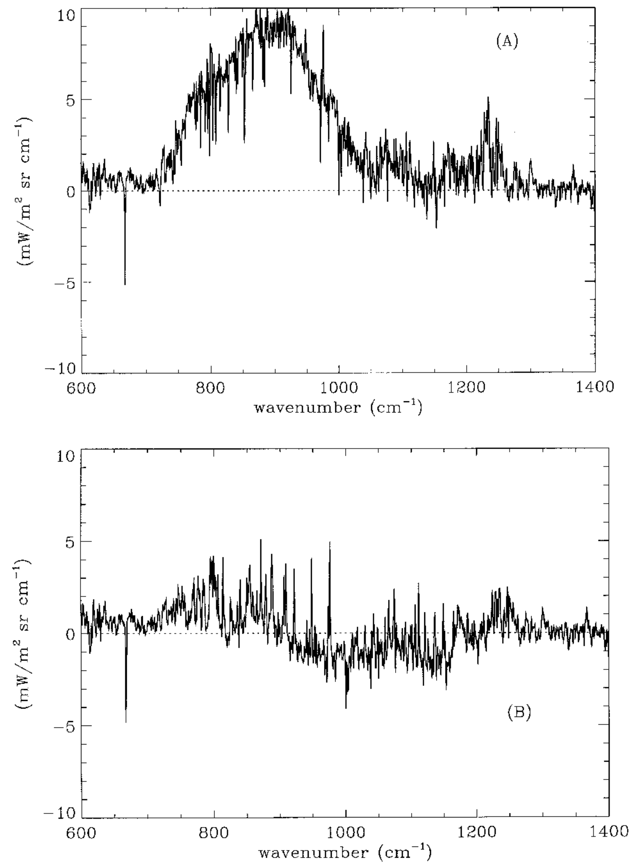

Figure 2. Measurement minus calculations for a clear-sky spectrum. The calculation used LBLRTM with the old CKD_1 (A) and the CKD_2.2 (B) water vapor continuum models. The model water vapor and temperature profiles are from a radiosonde launched from the ship. The measurement was made with a cryogenically cooled detector at cm^{-1} resolution, during the first three minutes of the radiosonde launch.

Acknowledgments

We acknowledge our valuable collaboration with S. A. Clough and P. D. Brown of AER, Inc. and with R. Knuteson of the University of Wisconsin, as well as the support of the officers and crew of the R/V *Discoverer.*

References

Clough S. A., 1995: The Water Vapor Continuum and its Role in Remote Sensing, *Optical Remote Sensing of the Atmosphere*, Vol. 2, OSA Technical Digest Series (Optical Society of America, Washington, D.C.), 76-78.

Clough, S. A., M. J. Iacono, and J.-L. Moncet, 1992: Line-by-Line Calculation of Atmospheric Fluxes and Cooling Rates: Application to Water Vapor, *J. Geophys. Res.,* **97**, 15761-15785.

Han, Y., J. A. Shaw, and J. H. Churnside, 1997: Infrared Spectral Radiance Measurements in the Tropical Pacific Atmosphere, *J. Geophys. Res.* **102(D4)**, 4353-4356.

Shaw, J. A., J. B. Snider, J. H. Churnside, and M. D. Jacobson, 1995: Comparison of Infrared Atmospheric Brightness Temperatures Measured by a Fourier Transform Spectrometer and a Filter Radiometer, *J. Atmos. Ocean Technol.,* **12**, 1124-1128.

Westwater, E. R., J. H. Churnside, J. A. Shaw, and J. B. Snider, 1995: Ground-based Remote Sensor Observations During the PROBE Experiment in the Tropical Western Pacific, *Proceedings of IGARSS '95,* 882-886, Florence, Italy, July 10-14. Geoscience and Remote Sensing Society.

Westwater, E. R., Y. Han, J. H. Churnside, and J. B. Snider, 1994: Preliminary Analysis of Ground-based Microwave and Infrared Radiance Observations During the Pilot Radiation Observation Experiment, *Proceedings of the Fourth Atmospheric Radiation Measurement (ARM) Science Team Meeting,* February 28-March 3, 1994, Charleston, South Carolina, pp. 15-17, CONF-940277, U.S. Department of Energy, Washington, D.C.