Atmospheric Emitted Radiance Interferometer: Status and Water Vapor Continuum Results

H. E. Revercomb, R. O. Knuteson, W. L. Smith, F. A. Best, and R. G. Dedecker
University of Wisconsin
Madison, Wisconsin

H. B. Howell
National Oceanic and Atmospheric Administration
Systems Design and Applications Branch
Madison, Wisconsin

Introduction

Accurate and spectrally detailed observations of the thermal emission from radiatively important atmospheric gases, aerosols, and clouds are now being provided to the Atmospheric Radiation Measurement (ARM) data base by the Atmospheric Emitted Radiance Interferometer (AERI) prototype at the Southern Great Plains Cloud and Radiation Testbed (CART) site. Spectra over the range from 520 to 3000 cm^{-1} (3 to 19 microns) with a resolution of 0.5 cm^{-1} are collected every 10 minutes. The observed spectra will be used for many diverse functions, including

- identifying and eliminating absolute errors in calculated spectra for known atmospheric states
- evaluating and improving cloud radiation calculations
- characterizing the distribution and evolution of effective cloud radiative properties
- studying the state parameter changes associated with the formation, evolution, and dissipation of clouds.

Further very detailed spectral information (up to 0.003 cm^{-1}) is also being collected at CART from the Solar Radiance Transmission Interferometer (SORTI) prototype on clear days. The emission observations of the AERI and the absorption observations of the SORTI will be combined to enhance the spectroscopic and gas profiling information from each. The SORTI is discussed in the Murcray 1994 Science Team paper (this document).

This paper deals exclusively with the AERI and includes a brief description of the instrument deployment status and a recent spectroscopic result making use of AERI data. The general nature of the AERI spectra and the instrument design have been discussed in the 1993 ARM Science Team paper and in several conference publications (Revercomb et al. 1993, 1994; Smith et al. 1993).

Recent Field Experience

The AERI prototype has been at the CART site since March 1993. Before the optical trailer was ready for use, AERI was operated in a non-standard configuration in order to get early data and operational test experience. The instrument was rolled outside on the deck of the staging trailer during normal working hours and for some special extended periods. AERI was operated in this mode for several blocks of days, including 16-24 March, 8-16 and 19-22 April, and 9-25 June (an ARM intensive operation period). The data from these periods are good, but continuous operation in the humid outside environment caused problems for the liquid nitrogen autofill system used for detector cooling. Also, outside operation in this configuration during the summer posed problems with electronics overheating.

The AERI was moved to the optical trailer when the sky-viewing hatch for precipitation protection was ready in mid-August. New problems were encountered with the liquid nitrogen autofill system because of the extremely long distance from the storage tank location to the AERI (exacerbated by the 104°F outside temperature). After reviewing the options for cooling and the limitations on liquid nitrogen use at the site, we decided to operate with manual liquid nitrogen fills until a Stirling cooler is procured to eliminate the need for liquid nitrogen. Operation in this mode resumed on 8 December 1993, and good data have been collected for 8 to 16 hours per working day since that time. Also, extended operation was accomplished during the Single-Column Model IOP from 21 January to 11 February, thanks to extra efforts by site personnel.

In addition to collecting data from the SGP CART, the operational AERI was successfully field tested in two campaigns, extending from the west coast to the east coast. During three weeks in August and September 1993, the AERI was operated at Point Mugu, California, as part of the VOCAR (Variation of Coastal Atmospheric Refractivity) experiment supported by the Navy. Immediately following VOCAR, AERI was transported to NASA Wallops where it operated as part of the jointly funded Convection and Moisture Experiment (CAMEX) from mid September to early October. Both experiments provided excellent supporting observations, including Raman lidar water vapor. In addition, CAMEX had NASA ER-2 overflights with the High-resolution Interferometer Sounder (HIS).

Water Continuum Results from AERI

The analyses of HIS and AERI data (Revercomb et al. 1989, 1990, 1991; Clough et al. 1992; Knuteson et al. 1993) show the representation of the foreign-broadened water vapor continuum to be one area of spectroscopy which needs refinement. The impact of these refinements is substantial, especially their effect on the top-of-the-atmosphere energy budget and on water vapor remote sensing.

Figure 1 shows data from four observation periods which indicate that the current foreign-broadened continuum in FASCOD3P is too strong by substantial amounts on both sides of the 6.3-micron water vapor band. The required modification on the shortwave side of the band, first proposed by Theriault et al. (1991), is confirmed here. The downlooking and uplooking data provide a reasonably complete, but noisy, definition of the required modification

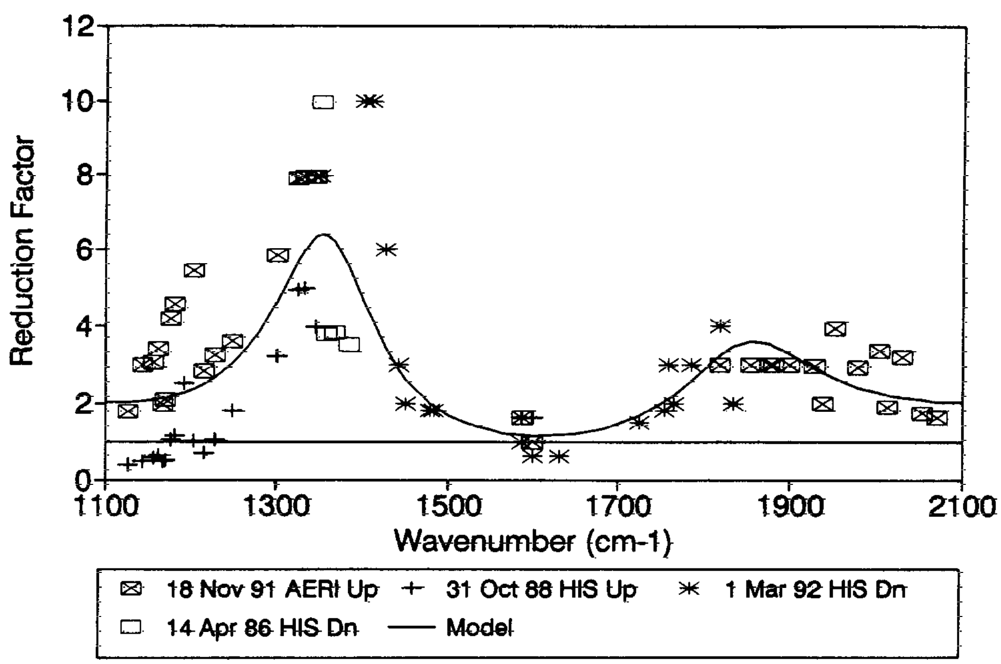

Figure 1. Correction applied to the foreign-broadened continuum contribution currently included in FASCOD3P compared with HIS and AERI data from which the model was derived.

over the spectral region included. The model used to define our change to the current continuum is an analytical function which represents the sense of the data.

The resulting foreign continuum cross-section C_f is compared with the current FASCOD3P C_f (Clough et al. 1986, 1989) in Figure 2. The reduction factor shown in Figure 1 was extended and reduced smoothly to one near the minima of C_f. The data are Burch's laboratory measurements as analyzed by A. Clough (personal communications). For the most part, Burch's data are smaller than the current C_f, but larger than the proposed model based on HIS and AERI.

The FASCOD3P continuum has been modified and tested with AERI data from CAMEX. The complete modification included changing C_f as shown in Figures 1 and 2, eliminating the extra contribution (labelled Fudge in the code) at the suggestion of A. Clough, and also eliminating the FASCODE correction to the self-broadened cross-section. In the longwave window region, the latter change nearly balances the effect of removing Fudge for a moderately moist atmosphere.

The results are shown in Figures 3 and 4 for the regions of the spectrum most affected. Note that the changes are not small, with peaks between 5 and 9 K.

Testing with a much wider range of AERI data is needed to define an optimum modification to the continuum. The model proposed here should be combined in an optimum way with other changes incorporated into LBLRTM, the ARM line-by-line radiative transfer model (Clough 1993).

Future Plans

The AERI prototype will be operated at CART until mid-1994, when it will be replaced with the first operational version. Also during 1994, we expect to start fabricating several AERIs for the boundary sites at the SGP CART. These instruments will be provided with Stirling coolers to eliminate any need for liquid nitrogen. Successful demonstration of operation without the need for liquid nitrogen will enable us to begin serious planning for providing AERIs at both the Tropical Western Pacific and the North Slope of Alaska sites.

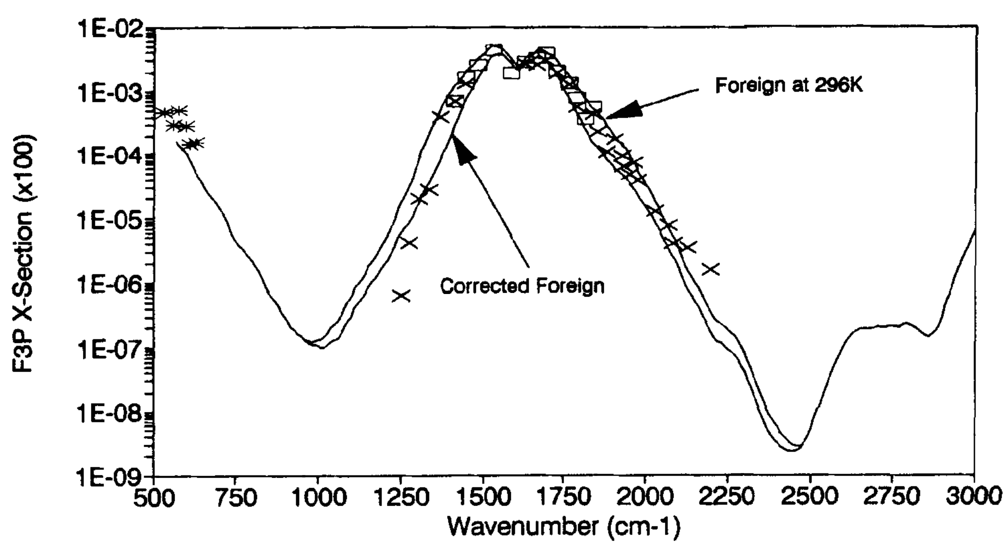

Figure 2. Modified continuum cross-section compared to the original and its basis, Burch laboratory data.

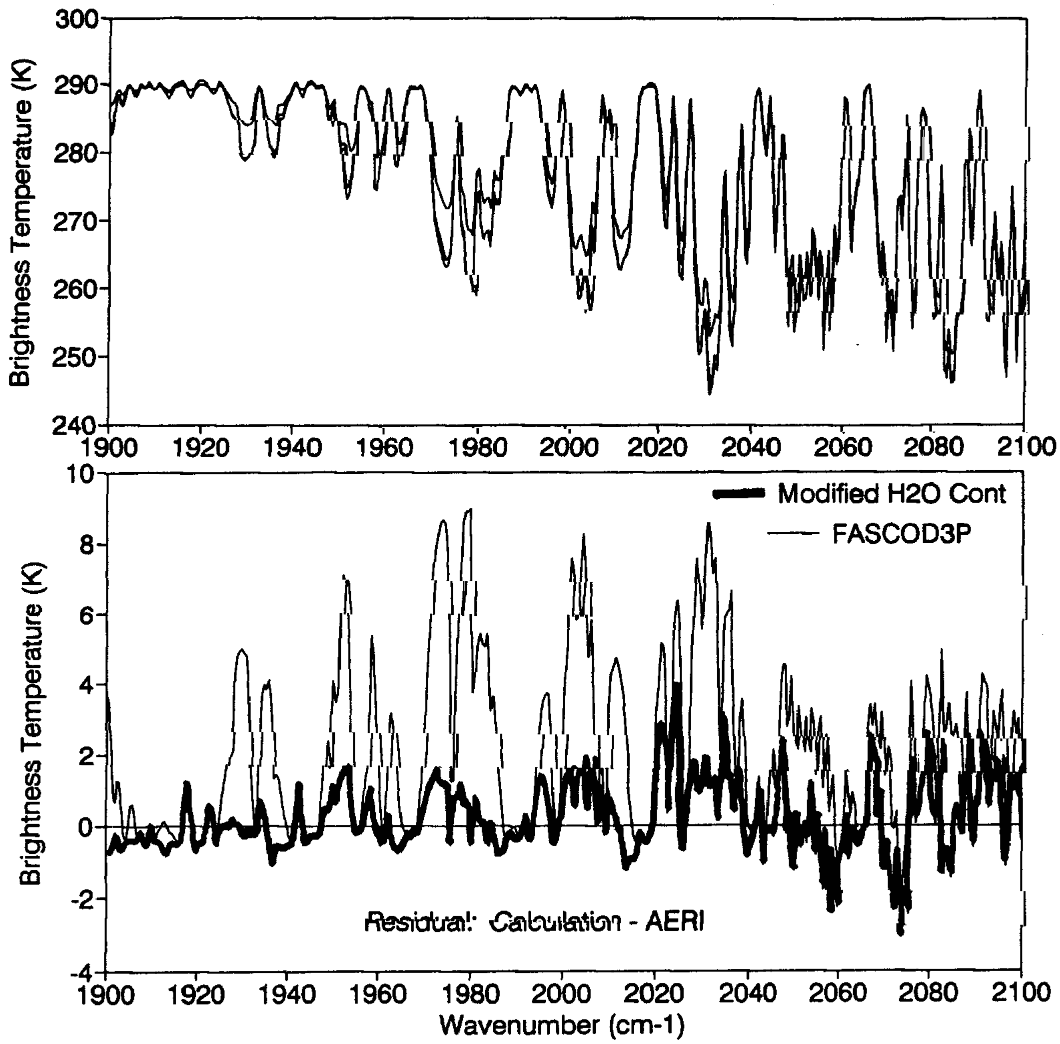

Figure 3. Brightness temperature spectrum from AERI on 29 September 1993 during CAMEX compared with FASCODE calculations. Note the substantially reduced residuals from calculations using the modified water vapor continuum defined here.

Another exciting development for enhancing the spectral data from ARM is the UAV program. We are currently embarking on a two-year effort to develop an AERI for the Perseus UAV and are looking forward to the new dimension provided by both upward and downward observations from several layers inside the atmosphere.

References

Clough, S. A. 1993. Radiative Transfer Model Development in Support of the Atmospheric Radiation Measurement Program. *Proceedings of the Third Atmospheric Radiation Measurement (ARM) Science Team Meeting*. CONF-9303112, U.S. Department of Energy, Washington, D.C.

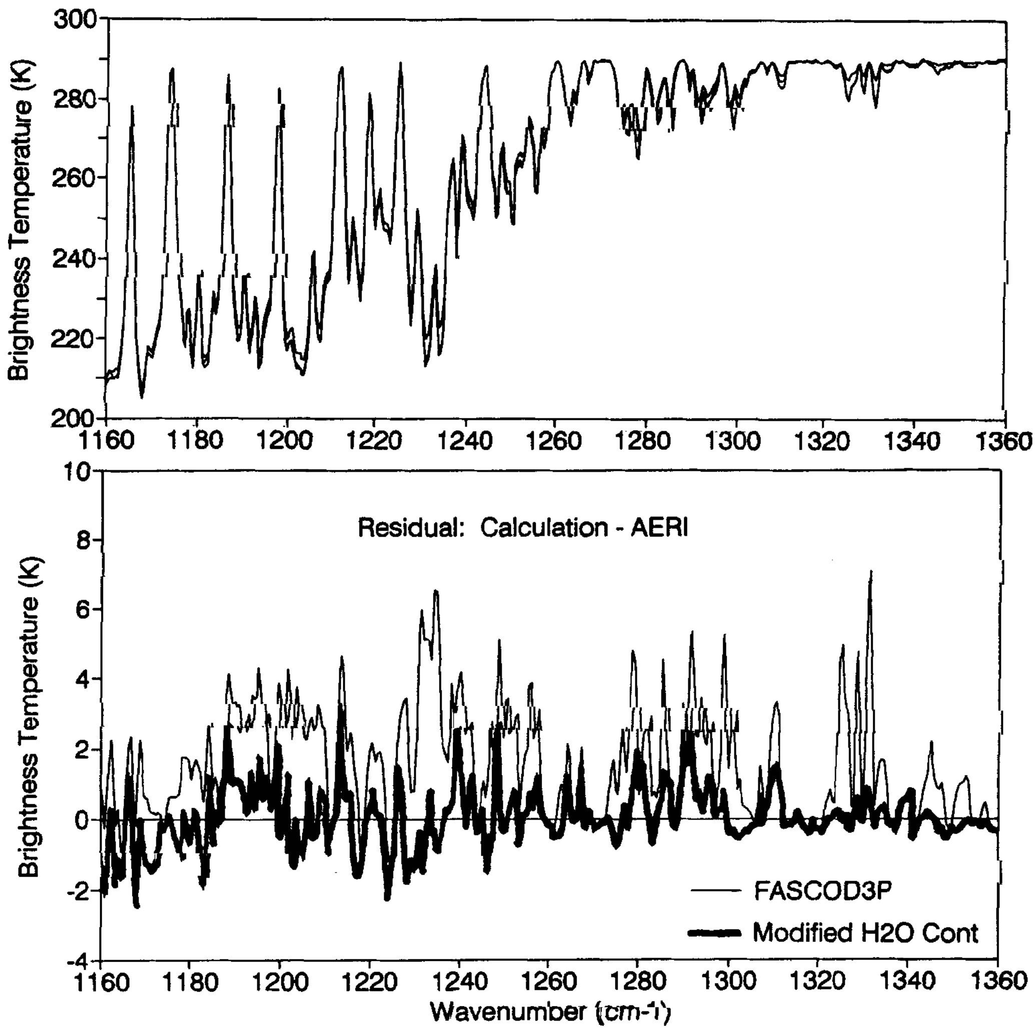

Figure 4. Brightness temperature spectrum from AERI on 29 September 1993 during CAMEX compared with FASCODE calculations.

Clough, S. A., M. J. Iacono, and J-L Moncet. 1992. Line-by-line Calculations of Atmospheric Fluxes and Cooling Rates: Application to Water Vapor. *J. Geophys. Res*. **97**(D14):15, 761-15, 785.

Clough, S. A., F. X. Kneizys, and E. W. Davies. 1989. Line Shape and the Water Vapor Continuum. *J. Atmos. Res.* **23**:229-241.

Clough, S. A., F. X. Kneizys, E. P. Shettle, and G. P. Anderson. 1986. Atmospheric Radiance and Transmittance: FASCOD2. *Sixth Conference on Atmospheric Radiation*, p. 141. American Meteorological Society, Boston, Massachusetts.

Knuteson, R. O., H. E. Revercomb, and W. L. Smith. 1993. Forward Model Comparisons with the High-resolution Interferometer Sounder (HIS). *Proceedings of the Optical Remote Sensing of the Atmosphere Sixth Topical Meeting*, Salt Lake City, Utah, March 8-12, 1993. Optical Society of America, Washington, D.C.

Revercomb, H. E., W. L. Smith, R. O. Knuteson, H. M. Woolf, and H. B. Howell. 1989. Comparisons of FASCODE Spectra with HIS Observations. *Proceeding of the 12th Annual Review Conference on Atmospheric Transmission Models*, 5-7 June, eds. E. P. Shettle, F. X. Kneizys. Optical/Infrared Technology Division, Geophysical Laboratory, Hanscom Air Force Base, Massachusetts.

Revercomb, H. E., R. O. Knuteson, W. L. Smith, H. M. Woolf, and H. B. Howell. 1990. Spectroscopic Inferences from HIS Measurements of Atmospheric Thermal Emission. *Optical Remote Sensing of the Atmosphere*, 1990 Technical Digest Series, Vol 4, from Topical meeting, Incline Village, Nevada, 12-15 February, 1990. Optical Society of America, Washington, D.C.

Revercomb, H. E., R. O. Knuteson, and W. L. Smith. 1991. High-resolution Spectral Measurements of Upwelling and Downwelling Atmospheric Infrared Emission with Michelson Interferometers. Annual Review Conference on Atmospheric Transmission Models, Hanscom, AFB, June 11-12, 1991, eds. L.W. Abru, F.X. Kneizys. Report #PL-TR-92-2059 SR, No. 267., Phillips Laboratory, Hanscom Air Force Base, Massachusetts.

Revercomb, H. E., F. A. Best, R. G. Dedecker, T. P. Dirkx, R. A. Herbsleb, R. O. Knuteson, J. F. Short, and W. L. Smith. 1993. Atmospheric Emitted Radiance Interferometer (AERI) for ARM. Proceedings of the *Fourth Symposium on Global Change Studies*, AMS 73rd Annual Meeting, Anaheim, California, January 17-22, 1993, pp. 46-49. American Meteorological Society, Boston, Massachusetts.

Revercomb, H. E., W. L. Smith, R. O. Knuteson, F. A. Best, R. G. Dedecker, T. P. Dirkx, R.A. Herbsleb, G. M. Buchholtz, J. F. Short, and H. B. Howell. 1994. AERI - Atmospheric Emitted Radiance Interferometer. Proceedings of the *Eighth Conference on Atmospheric Radiation*, Nashville, Tennessee, January 23-28, 1994, pp. 180-182. American Meteorological Society, Boston, Massachusetts.

Smith, W. L., R. O. Knuteson, H.E. Revercomb, F. A. Best, R. G. Dedecker, and H. B. Howell, 1993. GB-HIS: A Measurement System for Continuous Profiling of Boundary Layer Thermodynamic Structure. Proceedings of the *Eighth Symposium on Meteorological Observations and Instrumentation*, AMS 73rd Annual Meeting, Anaheim, California, January 17-22, 1993, pp. J180-J183. American Meteorological Society, Boston, Massachusetts.

Theriault, J.-M., H. E. Revercomb, R. O. Knuteson, and H.-L. Huang. 1991. Intercomparison of FIT and HIS spectral measurements with FASCODE calculations in the 7-11 µm region. *Optical Remote Sensing of the Atmosphere*, Williamsburg, Virginia, November, 1991. Optical Society of America, Washington, D.C.