

High Spectral Resolution FTIR Observations for the ARM Program: Continued Technique Development, Data Evaluation and Analysis

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Progress Report

DOE Grant #
DE-FG02-90ER61057

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July 13, 1998

1 Introduction

This is the continuation progress report for our DOE Grant # DE-FG02-90ER61057 at the University of Wisconsin-Madison, Space Science and Engineering Center (PI Henry Revercomb, Co-I. Robert Knuteson) with sub-grant to the University of Denver (Co-Is: David and Frank Murcray). We are in the second year of a three year continuation of our grant for ARM high spectral resolution studies. There have been many accomplishments this year, and we will not have any unexpended funds at the end of the budget period.

2 Summary of Activities

Activities for this year are presented in five categories: *Instrument Performance Evaluation and Refinements*, *Spectroscopic Analyses*, *Cloud Radiative Forcing*, *Atmospheric Water Vapor Determinations*, and *AERI-X retrievals*, which are outlined in the following sections.

Highlights include:

- Successful data collection from two extended spectral range AERIs in the Arctic (SHEBA and NSA)
- Significant water vapor continuum improvements derived from AERI observations at the SHEBA ice station
- Coordinated AERI data collection with the High-resolution Interferometer Sounder (HIS) and other aircraft observations during the NASA FIRE Arctic Cloud Experiment
- Cloud Radiative Forcing studies initiated using SHEBA AERI data
- Successful integration of AERI with TWP-Nauru ARCS at Sandia National Laboratory
- Inter-comparison of AERI with National Institute of Standards radiometric reference standards showed excellent agreement (better than 0.05 degrees C)
- Lead scientist for the second ARM water vapor IOP at the Oklahoma CART site
- New analysis of WVIOP chilled mirror and Raman Lidar data suggests absolute calibration adjustments may be needed for microwave and GPS total column water vapor
- Initial results from high resolution AERI-X measurements suggest that higher spectral resolution might extend the altitude range of ground based temperature and water vapor retrievals

2.1 Instrument Performance Evaluation and Refinements

Activities this year include work with new AERIs for the Arctic and the TWP, and important instrument calibration validation observations.

2.1.1 Instrument Status and Evaluation

Under a separate contract with PNNL, the University of Wisconsin built and deployed two AERI instruments to the Arctic for the winter of 1997-8 with extended long wavelength infrared spectral coverage. One of the so called ER-AERI (Extended Range AERI) systems was incorporated in a special shelter provided by PNNL and put aboard the Canadian ice-breaker Des Groiselliers at the beginning of the Arctic SHEBA experiment. The second system was installed at the new ARM North Slope of Alaska (NSA) site in Barrow, AK. An important activity has been the characterization of the performance of these ER-AERI systems both in the lab and under the extremely cold winter conditions. The performance of both systems has been excellent throughout the winter and spring. Good data was also collected coincident with the NASA FIRE-Arctic Cloud Experiment during May-June 1998

which involved the NASA C-130 aircraft and the high altitude ER-2. On board the ER-2, the University of Wisconsin infrared spectrometer HIS instrument was able to obtain the first coincident Arctic up-welling infrared spectra to complement the down-welling spectra obtained by the ARM ER-AERI systems.

With the deployment of AERI systems to the Arctic as well as the delivery of the first TWP AERI system to the ARCS integration site at Sandia, substantial progress was made in the development of remote monitoring capabilities. Using low data rate satellite transmissions the basic performance information and science quality of the SHEBA, NSA, and TWP systems has been constantly relayed to Wisconsin where Health and Status displays are automatically generated using the world wide web. These displays have proven useful for identifying and documenting instrument performance. (For the TWP and SHEBA instruments, these displays can found online at

http://arm1.ssec.wisc.edu/~davet/twp1health/html/hs_calendar.html and

http://arm1.ssec.wisc.edu/~vonw/aeri/sheba/Health_Status/html/hs_calendar.html.)

In a related activity, we assisted the SGP site scientist team in the development of a similar instrument status "metric" for the AERI operating at the CART site in Oklahoma.

2.1.2 AERI / NIST blackbody inter-comparison at the Miami IR Workshop

A milestone in the characterization of the absolute accuracy of AERI observations was accomplished during the Miami IR Workshop (2-4 March 1998) held by Peter Minnett of the University of Miami. A Marine-AERI system was used to view a blackbody reference cavity maintained by the National Institute of Standards and Technology (NIST). The AERI system uses two internal blackbodies designed and built at the University of Wisconsin with calibration traceable to NIST temperature standards. The NIST blackbody uses a temperature controlled water bath to reduce gradients in the cavity. The comparison with the NIST blackbody was performed in a room with ambient temperature of about 30 C at three reference blackbody temperature points; 20 C, 30 C, and 60 C. The lowest temperature point (20 C) was chosen to be above the dewpoint temperature in the uncontrolled laboratory environment. **The agreement between the AERI system and the NIST blackbody reference was excellent at all temperatures and within the combined uncertainty of the AERI and NIST blackbodies.** In the spectral range of AERI between 3.3 and 15 microns (excluding regions effected by the air path in the room) the AERI agreement with NIST was less than 0.02 C at 20 C, less than 0.03 C at 30 C, and less than 0.05 C at 60 C (see Figure 1). The 60 C comparison was performed in order to test the accuracy of the AERI hot blackbody in both knowledge of temperature and emissivity. The excellent agreement of the AERI with the NIST reference is an independent confirmation that the AERI systems for ARM are meeting or exceeding the stated absolute accuracy of 1% of ambient radiance. These tests also indicate that the absolute accuracy of Marine-AERI derived sea surface skin temperatures is better than 0.1 C, an issue important for supporting new satellite climate observations.

For more detailed information on the Miami IR Workshop and the AERI/NIST comparison, please visit the UW IR Workshop web page at

http://arm1.ssec.wisc.edu/~bobk/miami_ir/miami_ir.htm.

2.1.3 SGP CF AERI/AERI Prototype Intercomparison

As part of the 1997 WVIOP, intercomparisons of the SGP CF AERI and the mobile AERI prototype instrument were conducted for several stable clear sky periods to assess the spectral and radiometric integrity of the CF instrument. For all cases and all spectral regions, the agreement between the two instruments was significantly better than 1% of the ambient radiance .

2.2 Spectroscopic Analyses

New results that significantly improve both water vapor continuum and line parameters were derived this year.

2.2.1 ER-AERI at the NSA and SHEBA sites: Far-Infrared measurements of the water vapor continuum

Figure 2 shows a typical clear sky AERI spectrum measured at the SGP CART site compared to a similar spectrum measured at the SHEBA site with the extended longwave sensitivity. Whereas the noise performance limits the spectral range of the standard AERI to about 525 cm^{-1} ($19\ \mu\text{m}$), the AERI-ER has similar performance out to 420 cm^{-1} ($24\ \mu\text{m}$) and is usable with time averaging to beyond 400 cm^{-1} ($25\ \mu\text{m}$). Also shown in the figure is the difference between the measured ER-AERI spectrum and a state-of-the-art calculation performed with LBLRTM. The very large negative differences in the extended longwave region for this and several other carefully selected clear sky cases have been analyzed in detail. Based on these differences, we have derived new water vapor continuum coefficients, which are directly related to the far-wing effects of water vapor absorption, from the data. These new coefficients have been incorporated into a new continuum model (CKDv2.3) through collaborative work with the AER Inc. group of Clough et al. CKDv2.3 has in turn been incorporated into radiation modules in several dynamical models (i.e. CCM2/CCM3) and into other line-by-line radiative transfer codes such as kCARTA, the radiation code for AIRS, an EOS PM-1 high spectral resolution atmospheric sounder. These results are significant to the community in that they directly provide us with a more accurate parameterization of water vapor absorption in the important extended long wave region. Furthermore, they also shed light on past laboratory continuum measurements and the water vapor lineshape and have enabled us to better understand water vapor absorption for all wavelengths.

More details on this study, including the effects of these measurements on the water vapor lineshape and on calculated atmospheric fluxes and cooling rates, are given in an article submitted to JGR-Atmospheres: *Downwelling Spectral Radiance Observations at the SHEBA Ice Station: Water Vapor Continuum Measurements from 17-26 μm* , which can be found on-line at http://tyler.ssec.wisc.edu/~davet/tex/sheba/html/sheba_color.html.

2.2.2 Water Vapor Spectral Line Parameters

An area of active research this year has been concerned with improving our knowledge of the spectroscopic parameters (line strengths, widths, positions) of the infrared water vapor absorption lines. This is important not only for resolving differences in the AERI/LBLRTM QME but is extremely important for remote sensing of atmospheric water vapor from ground based and satellite platforms. It is also important for accurate definition of land surface temperature from high spectral resolution satellite observations. The ARM suite of instruments at the SGP site, armed with accurate high resolution radiance observations *and* accurate knowledge of the atmospheric state, provides a unique setting for determining these parameters. On-going work involves the use of AERI and AERI-X spectra and WVIOP data sets to evaluate line parameters from the HITRAN database and more recently measured parameters of Toth et al.

2.3 Longwave Cloud Radiative Forcing at the Surface - SHEBA Ice Camp, Winter 1998

Here we use observations from the AERI-ER located at the SHEBA ice camp to determine the cloud radiative forcing at the surface for the months of November and December of 1997 and January 1998. These months were selected because they had a sufficient number of observations to provide adequate statistical average monthly radiances of both clear and cloudy conditions. (More data will become available for 1998 as they are archived off the ice camp.) The brightness temperatures over the spectral region $985\text{--}990\text{ cm}^{-1}$ were used to separate clear from cloudy sky conditions using a brightness temperature cutoff of 165 K. Once the clear and cloudy subsets of data were determined for each day, monthly averages of clear-sky, cloudy-sky, and all-sky conditions were calculated. These are shown in Figure 3 for the various months. The monthly averages were used to determine the radiance difference between average conditions of clear and cloudy skies, as well as the longwave cloud radiative forcing at the surface. The outgoing longwave radiance from the surface was estimated, assuming the air

temperature near the interferometer was the surface temperature and that the surface emissivity was unity. The air temperature near the instrument was determined as the mean brightness temperature over the spectral interval 675–680 cm^{-1} , near the center of the 667 cm^{-1} CO_2 band. Figure 4 shows the average window radiances as a function of time for the 3 months, plus the clear-minus-cloudy radiance difference and the longwave cloud radiative forcing at the surface.

For more detailed information on this study, please visit our web page at http://arm1.ssec.wisc.edu/~vonw/aeri/sheba/clouds/aeri_crf.html.

2.4 Water Vapor Determination

We are still making good progress toward learning how to make the highly accurate water vapor observations required for accurate climate studies.

2.4.1 1997 WVIOP

The second Water Vapor Intensive Operations Period to improve ARM capabilities for accurate water vapor profiles was successfully conducted near the beginning of the current grant year at the ARM SGP CART site. This year, we performed extensive analyses of the data collected during the IOP. General results and conclusions were presented at a WVIOP Workshop coordinated with the IRF Meeting in January and at the ARM Science Team Meeting.

A summary statement from the WVIOP group and plans for future IOP's is enclosed.

2.4.2 Analysis of WVIOP'97 data : in search of an absolute standard

In an effort to resolve questions regarding measurements of *absolute* water vapor, several groups have analyzed the IOP data in search the consistencies, and inconsistencies, between the various measurement systems. Here we present one such analysis in which we have incorporated the highly accurate in-situ tower measurements into the picture.

The basic premise of this analysis is that the in-situ tower sensors at 60 meters are highly accurate and that the GSFC Scanning Raman LIDAR profiles can be used to transfer these measurements to all other altitudes. This approach is valid in the sense that the *shape* of the Raman profiles are thought to be highly accurate and need only a single known point (with altitude) for calibration. Therefore, in theory, this approach allows us to compare the tower sensor measurements to measurements at all other altitudes, including total column measurements, using the Raman LIDAR as a transfer standard.

Our confidence in the 60 meter tower sensors is evident in Figure 5. For the entire 1997 WVIOP period and beyond, the agreement between the chilled mirror and Vaisala sensors at 25 and 60 meters was better than 2 percent in water vapor mixing ratio.

For every clear sky GSFC Raman LIDAR profile measured during the IOP, we have calculated the total column water vapor using the 60 meter tower sensors as our calibration point and the Raman profile as our transfer standard. Those calculated precipitable water vapor (pwv) values are compared to the appropriate CART MWR values in Figure 6. This analysis shows very good stability between the tower and MWR values (slope = 1.009) but also clearly shows a constant offset (independent of water vapor amount) between the calculated values and those measured with the microwave radiometer. This discrepancy, which possibly represents true differences between the salt-bath and chilled mirror based measurements and those from the microwave radiometer, is at the root of our search for an absolute standard for atmospheric water vapor. This is an area of ongoing research: possible explanations include: inaccurate Raman LIDAR profiles at the lowest altitudes due to geometrical telescope field of view overlap corrections, offsets in both the 60 meter chilled mirror and Vaisala measurements (unlikely), a calibration problem with the CART microwave radiometer, and/or a systematic bias resulting from inaccurate physics in the microwave forward model such as improper handling of absorption by self broadened water vapor or oxygen. Similar comparisons of the calculated pwv values were also compared to other CART site instruments and these results are summarized in Figure 7. Of particular note is that the GPS derived pwv values were systematically 5 to 2 percent dryer than the tower/Raman calculated values (differences behave as a fractional error, not a pure offset)

depending on what type of GPS processing was used. More information on this analysis procedure and more detailed results are available online at <http://tyler.ssec.wisc.edu/~davet/wviop97/TWRPWV/analysis.html>.

2.5 AERI-X Retrievals

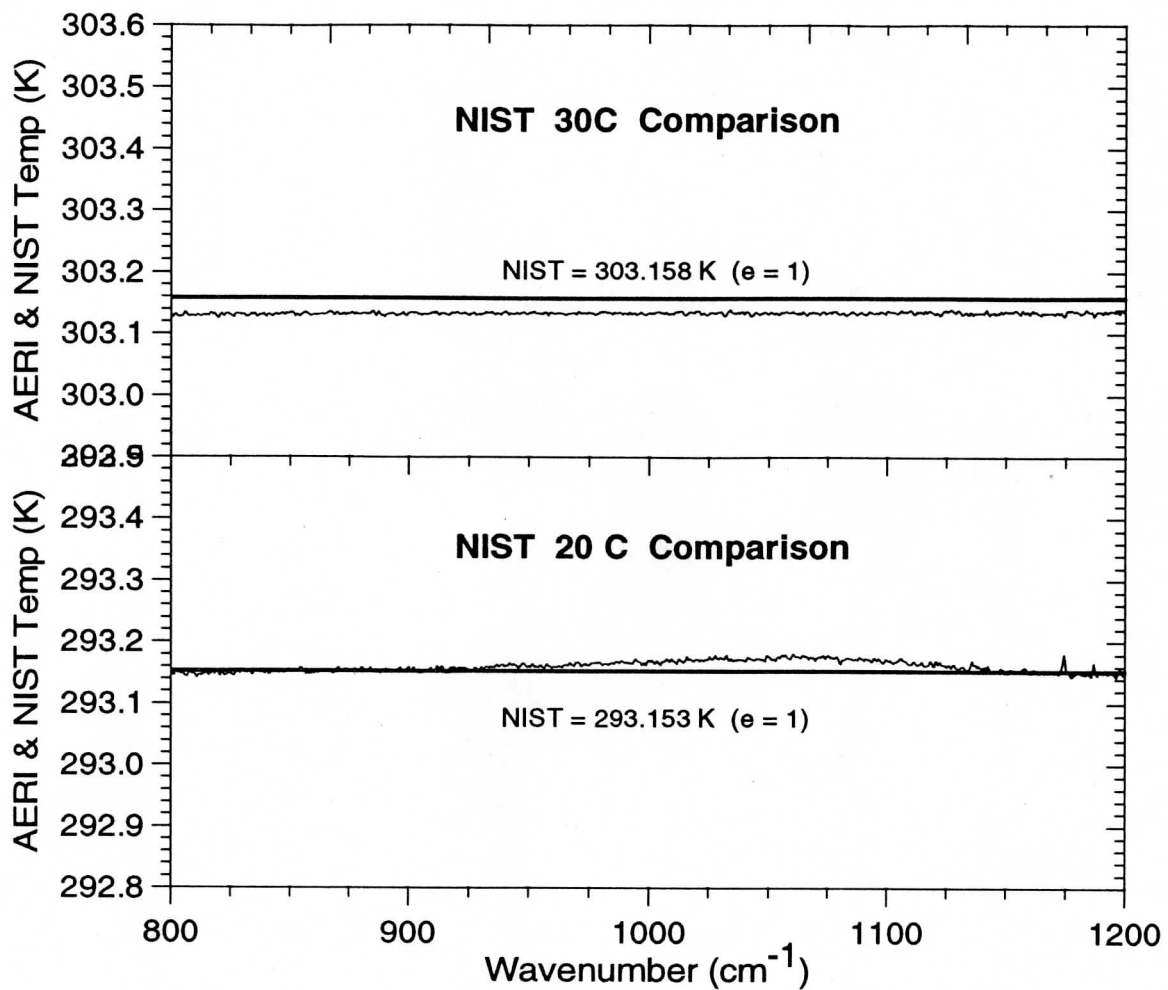
The AERI-X has been operating routinely at the SGP central facility for more than a year. Comparisons between the AERI-X, AERI, and calculated spectra show a small (2-3%) ripple on the AERI-X zero level. This ripple seems to be constant; it is the same for all seasons. We have been unable to determine the cause of the ripple. Corrected AERI-X spectra are being generated by subtracting the ripple. The corrected spectra, degraded in resolution, match simultaneous AERI spectra remarkably well, generally better than 0.5%. [Work on understanding the ripple is continuing. The AERI-X at Eureka, NWT, Canada has similar, but distinctly different zero ripple.]

Detailed comparisons of the corrected AERI-X spectra and LBLRTM calculated spectra showed disagreement with many of the water vapor lines in the window region, and also some disagreement in the edge of the CO₂ band. The CO₂ disagreement was reduced significantly by carrying out a temperature profile retrieval from the spectra. The retrieval made minor adjustments to the profile above 300m, but changed the temperature near the AERI-X by a degree or more. The adjustments are realistic, given the difference in location between the sonde launch and the optical trailer. The disagreement with the water vapor lines was reduced by using a new set of line strengths generated by Toth.

There are still obvious discrepancies, which may be due to errors in other parameter line parameters. [Comparisons between observed and calculated spectra continue to be studied on a nearly line by line basis. A sample comparison is shown in Figure 8. The calculation can also produce very high spectral resolution transmission spectra, which are being compared to SORTI spectra to study the effect of the other line parameters.]

The success of retrieving temperature from the spectra is encouraging, because it implies at least some level of consistency between the observations and the model calculations. [These studies will be continued using the new water vapor continuum formulation.] A sample retrieval is shown in Figure 9.

SORTI spectra have been used to demonstrate water vapor profile retrievals, and for detailed studies of a few water lines.



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Figure 1: Summary of AERI comparison with the NIST blackbody at 20 and 30 degrees C during the Miami IR Workshop.

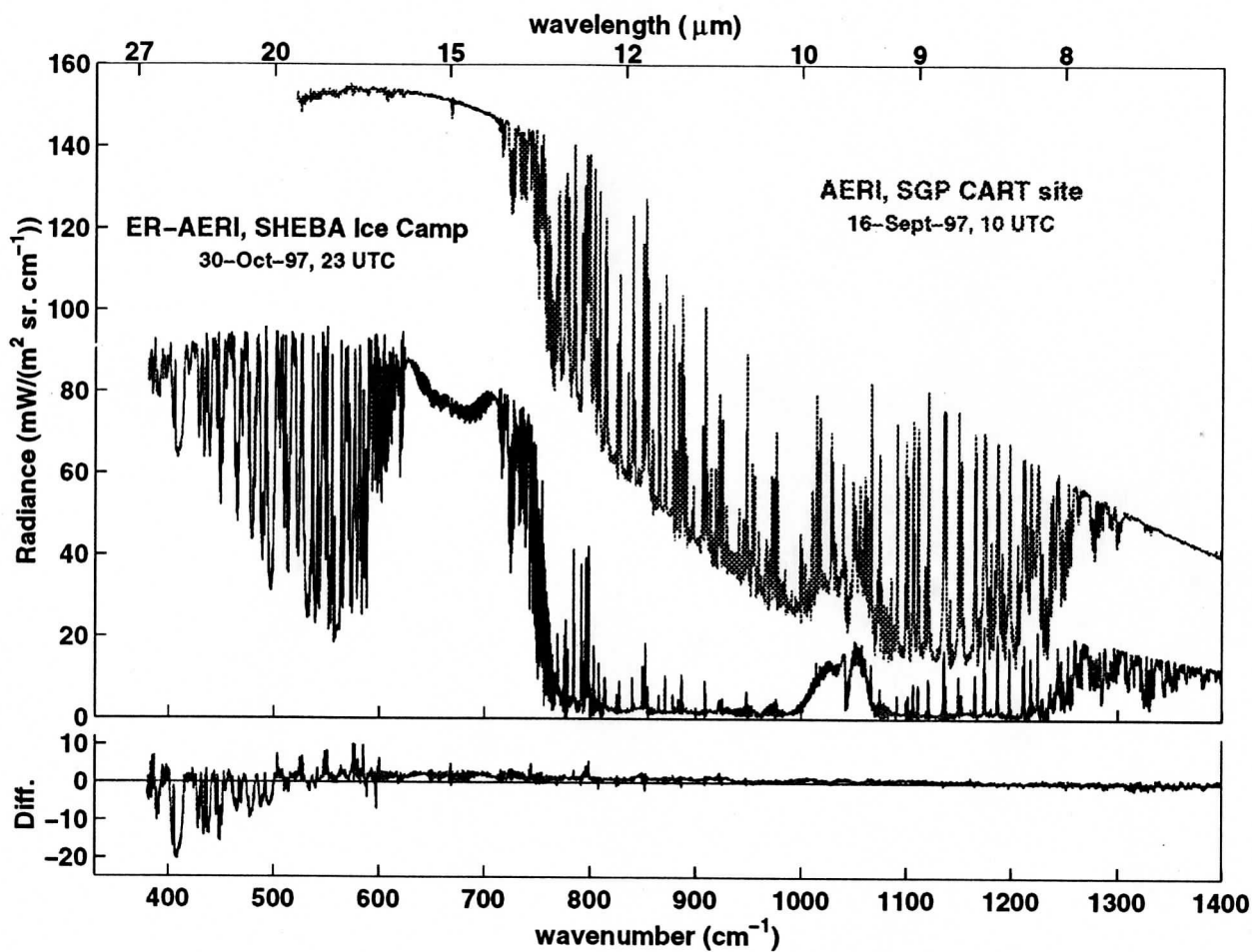


Figure 2: Comparison of clear sky downwelling radiance spectra measured with the AERI system at the SGP CART site near Lamont, Oklahoma ($\sim 300\text{K}$, ~ 4.0 cm pwv) and with the extended range AERI at the SHEBA Ice Station, 300 km north of Barrow, Alaska ($\sim 250\text{K}$, ~ 0.35 cm pwv). The bottom panel shows the radiance difference (observed-calculated) between the SHEBA AERI-ER spectrum and a line-by-line calculation done using the CKDv2.2 water vapor continuum model.

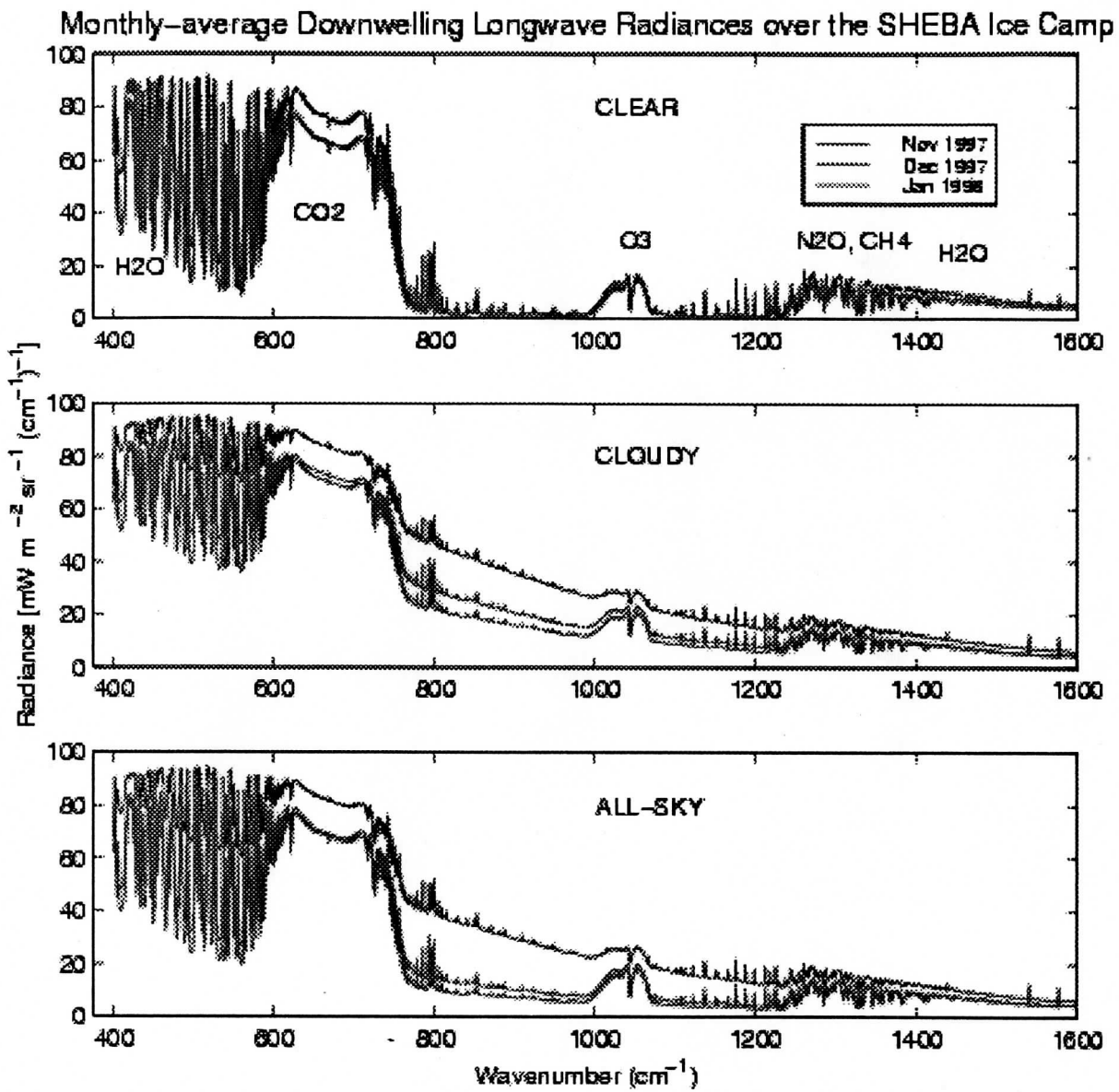


Figure 3: Monthly-average downwelling longwave radiances at the surface of the SHEBA ice camp for clear-sky, cloudy-sky, and all-sky conditions.

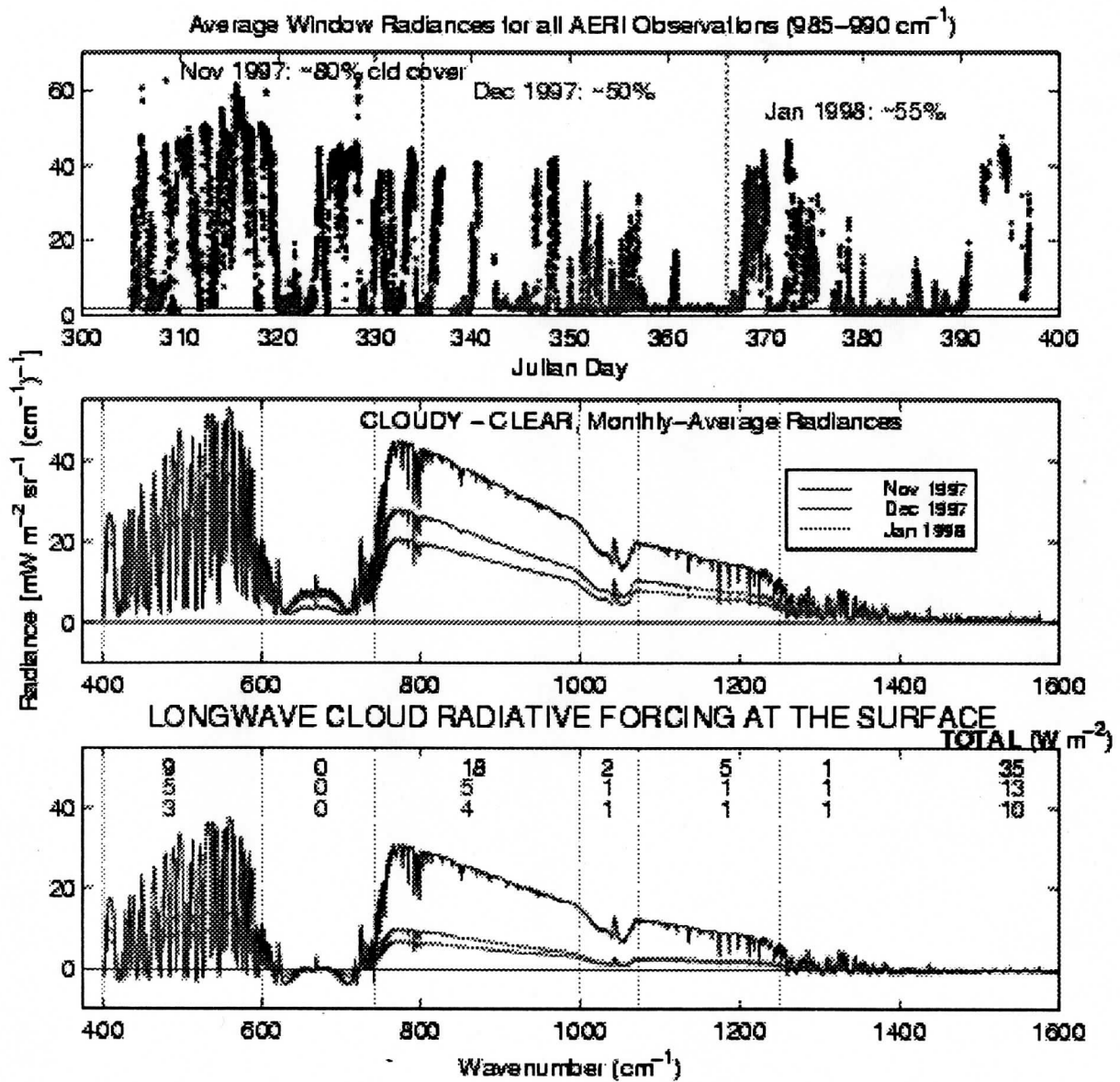


Figure 4: (Upper panel) The average window radiances from 985 to 990 cm^{-1} as a function of time for November 1997, December 1997, and January 1998. (Middle panel) Monthly-average cloudy-sky radiance minus the monthly-average clear-sky radiance. (Lower panel) The longwave cloud radiative forcing at the surface.

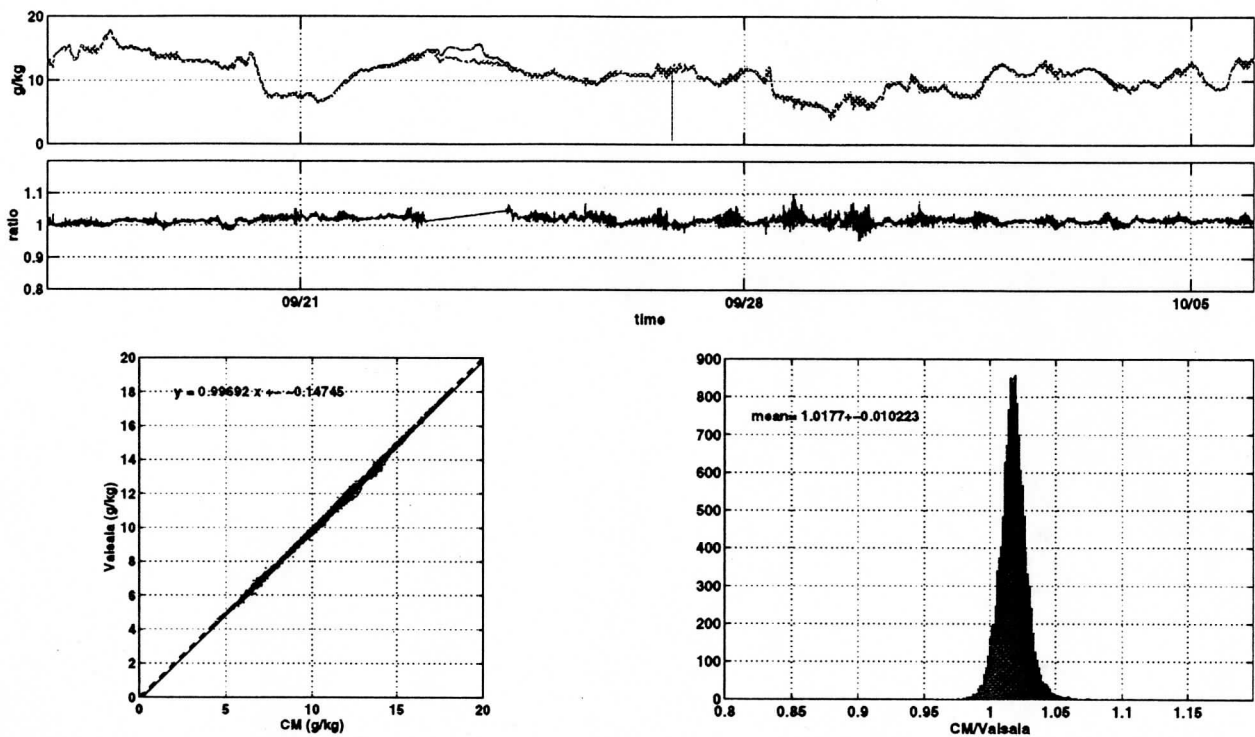


Figure 5: Comparison of chilled mirror and Vaisala sensors at 60 meters. Top panel: Vaisala (red) and chilled mirror (green) water vapor mixing ratios versus time for the WVIOP period; bottom left panel: scatter plot of chilled mirror and Vaisala values; bottom right: histogram of ratios of chilled mirror and Vaisala mixing ratios.

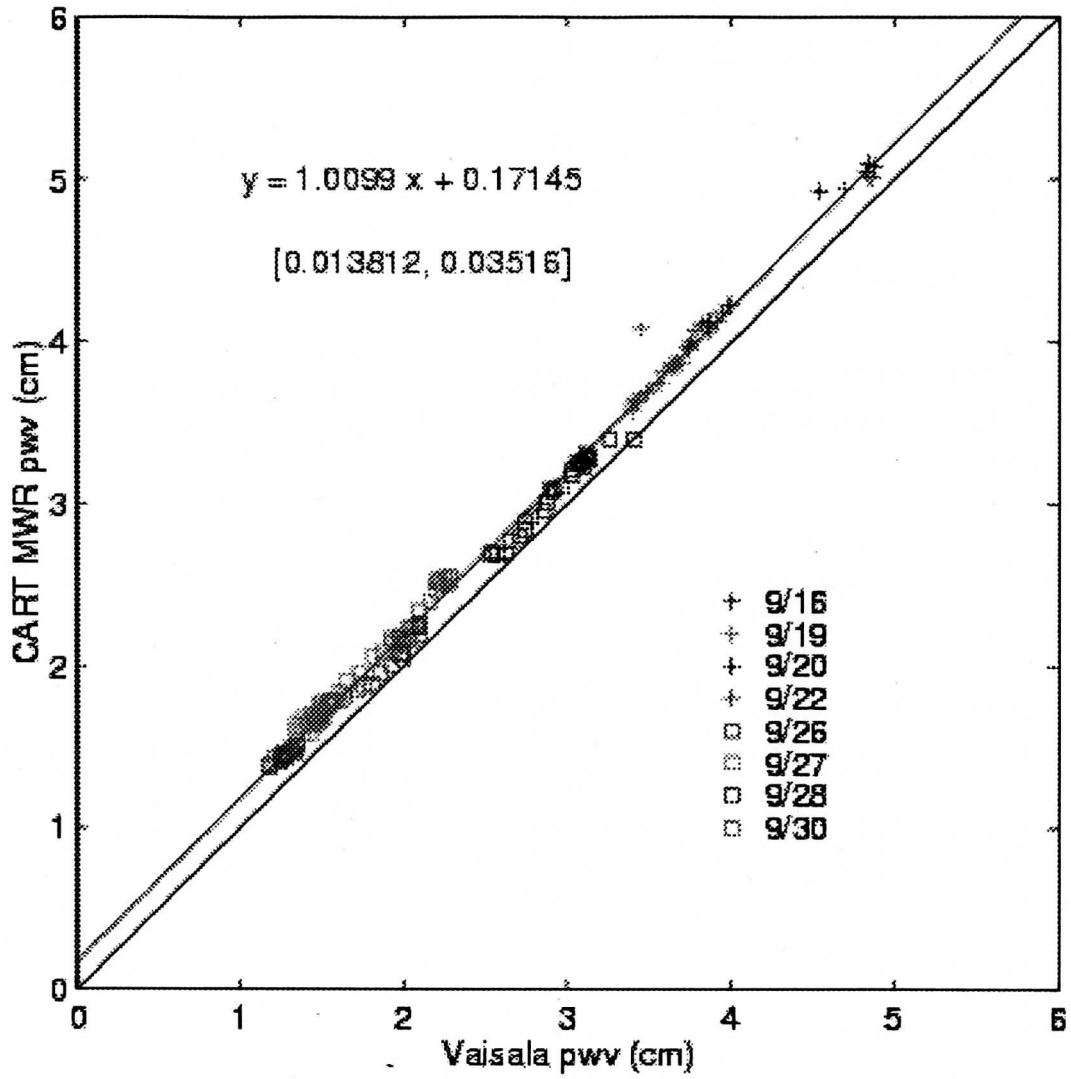
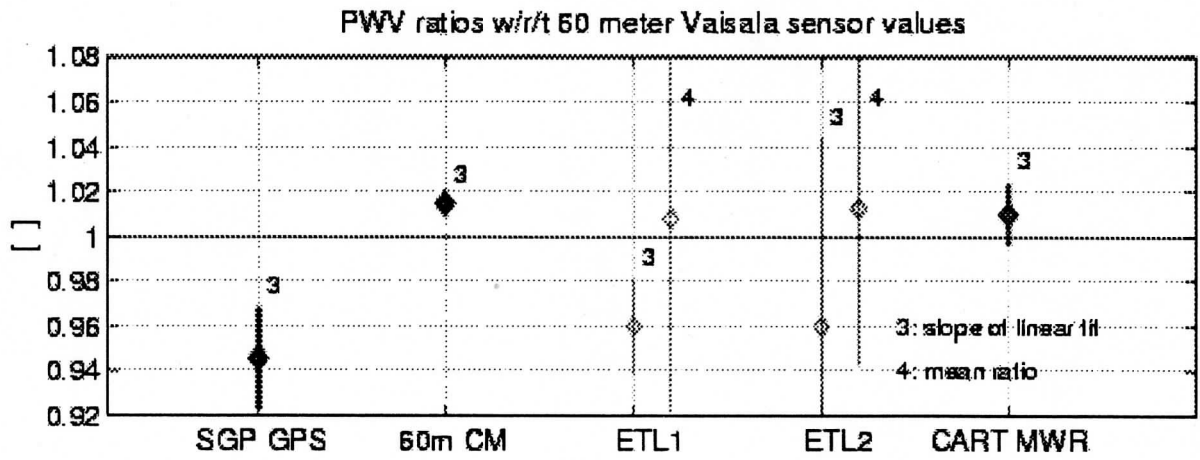
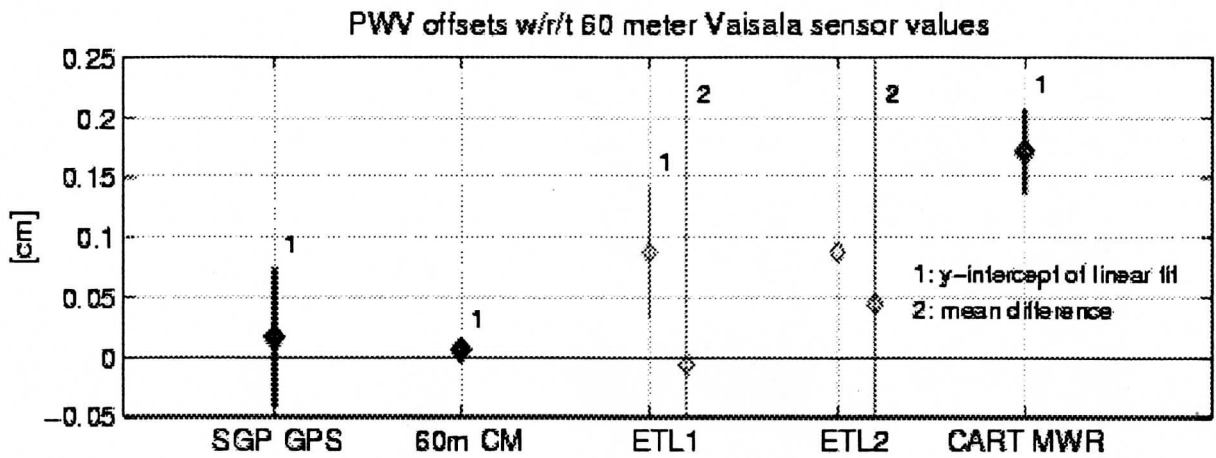


Figure 6: Scatter plot of tower sensor/Raman LIDAR calculated precipitable water vapor and CART MWR values.



(σ sigma uncertainties)

Figure 7: Summary of comparisons of tower/Raman based pwv calculations to other CART instruments. Top panel: pure offset (independent of pwv) and Bottom panel: pure fractional errors (scale linearly with pwv).

Aeri-X: 27 Jun, 14:05 C.U.T.

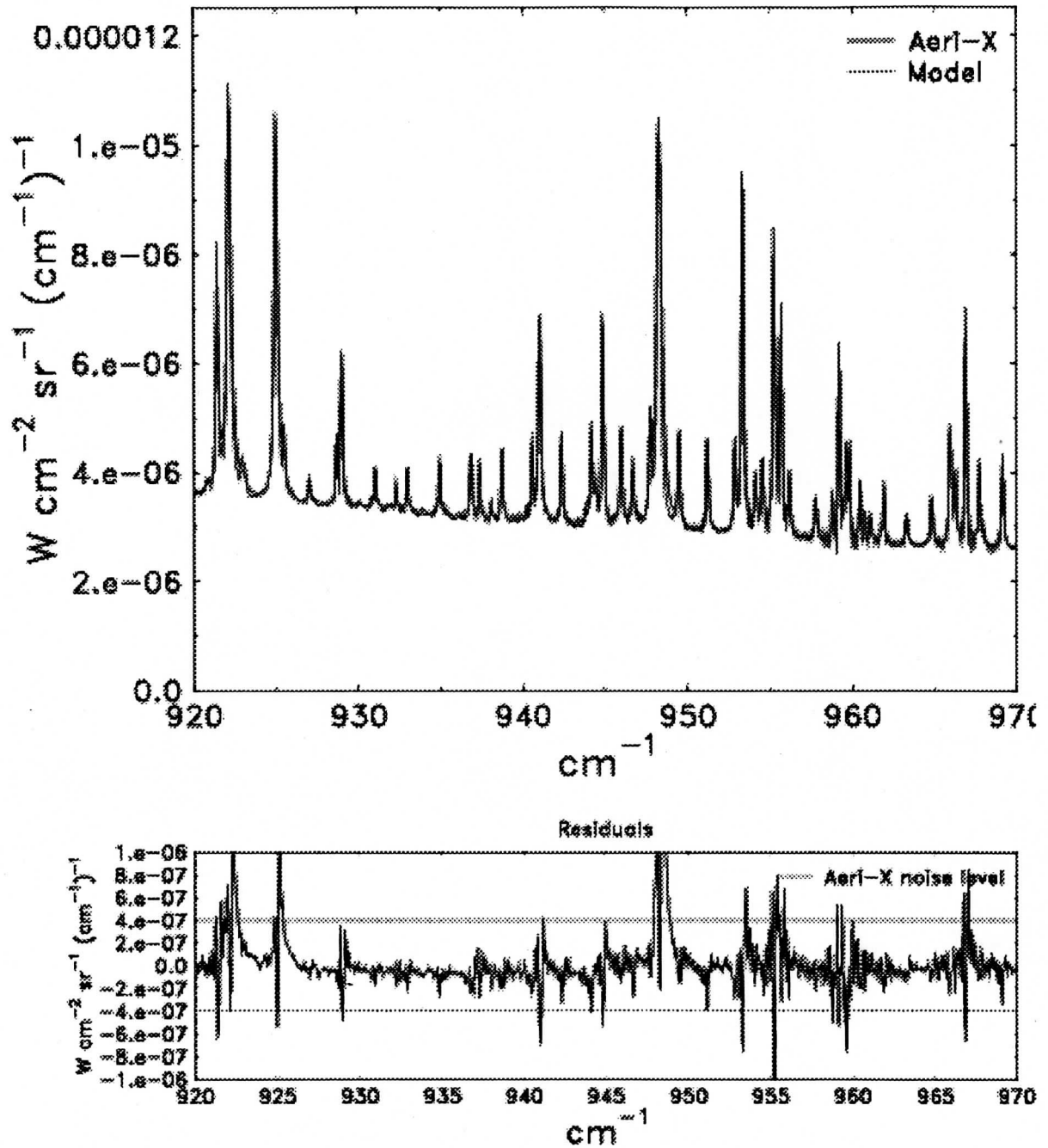


Figure 8: AERI-X spectrum and model calculation.

Retrieved Temperature Profiles 27 Ju

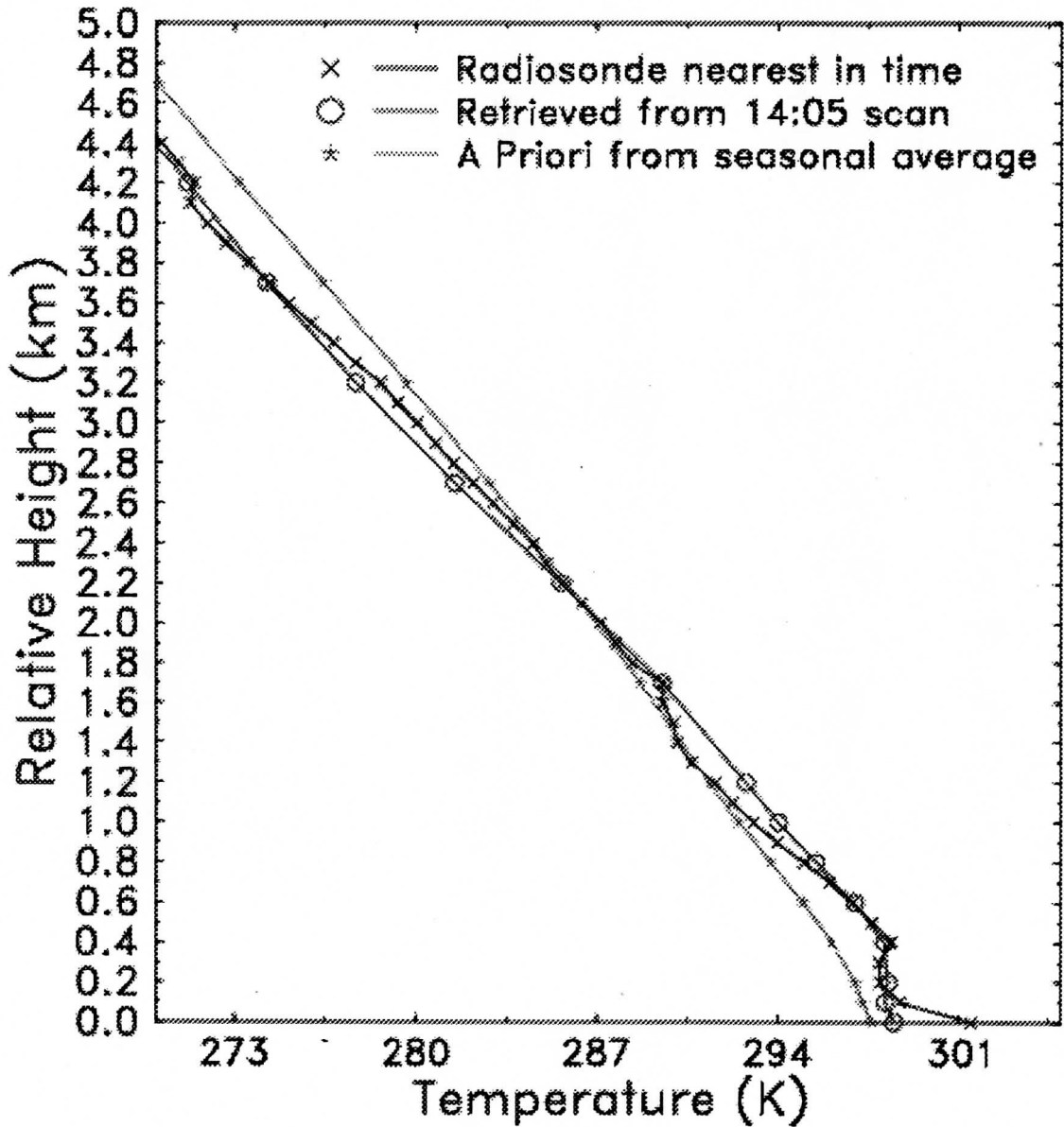


Figure 9: Sample AERI-X temperature retrieval.

3 Recent Publications

3.1 Publications resulting directly from this grant

1. Tobin, D. C., F. A. Best, S. A. Clough, R. G. Dedecker, R. G. Ellingson, R. K. Garcia, H. B. Howell, R. O. Knuteson, E. J. Mlawer, H. E. Revercomb, J. J. Short, P. F. W. van Delst, and V. P. Walden, 1998: Downwelling Spectral Radiance Observations at the SHEBA Ice Station: Water Vapor Continuum Measurements from 17-26 μm . submitted to Journal of Geophysical Research.
2. Knuteson, R. O., F. A. Best, H. E. Revercomb, D. C. Tobin, P. F. W. van Delst, and V. P. Walden, 1998: AERI Instrument Status and Analysis Results. Proceedings of the Eighth ARM Science Team Meeting, Tucson, Az, March 23-27, 1998.
3. Richardson, S. J. and D. C. Tobin, 1998: In Situ Moisture Measurements Using Chilled Mirror Sensors. Proceedings of the Eighth ARM Science Team Meeting, Tucson, Az, March 23-27, 1998.
4. Tobin, D. C., R. O. Knuteson, H. E. Revercomb, V. P. Walden, S. A. Clough, E. J. Mlawer, and R. G. Ellingson, 1998: AERI-ER at the SHEBA Ice Station: Far Infrared Water Vapor Continuum Measurements. Proceedings of the Eighth ARM Science Team Meeting, Tucson, Az, March 23-27, 1998.
5. Mlawer, E. J., S. A. Clough, P. D. Brown, and D. C. Tobin, 1998: A new Formulation of the Water Vapor Continuum. Proceedings of the Eighth ARM Science Team Meeting, Tucson, Az, March 23-27, 1998.
6. Revercomb, H. E., D. C. Tobin, and R. O. Knuteson, 1998: Accomplishments of the Water Vapor IOPs: An Overview. Proceedings of the Eighth ARM Science Team Meeting, Tucson, Az, March 23-27, 1998.
7. Turner, D. D., T. R. Shippert, P. D. Brown, S. A. Clough, R. O. Knuteson, H. E. Revercomb, and W. L. Smith, 1998: Long-term Analyses of Observed and Line-by-line Calculations of Longwave Surface Spectral Radiance and the Effect of Scaling the Water Vapor Profile. Proceedings of the Eighth ARM Science Team Meeting, Tucson, Az, March 23-27, 1998.
8. Richardson, S. J., M. E. Splitt, and D. C. Tobin, 1998: In Situ Moisture Measurements at the SGP ARM CART CF During the First and Second Water Vapor Intensive Observation Periods. Proceedings of the 1998 International Geoscience and Remote Sensing Symposium (IGARSS), Seattle, WA, July 6-10, 1998.
9. van Delst, P. F. W., D. C. Tobin, H. E. Revercomb, and R. O. Knuteson, 1998: AERI Downwelling Infrared Radiance Observations and Calculations: Case Studies from the 1997 DOE ARM CART Water Vapor IOP. Proceedings of the 1998 International Geoscience and Remote Sensing Symposium (IGARSS), Seattle, WA, July 6-10, 1998.
10. Best, F. A., H. E. Revercomb, D. LaPorte, R. O. Knuteson, and W. L. Smith, 1997: Accurately Calibrated Airborne and Ground-based Fourier Transform Spectrometers II: HIS and AERI Calibration Techniques, Traceability, and Testing. Council for Optical Radiation Measurements (CORM) 1997 Annual Meeting, National Institute of Standards and Technology (NIST), April 29, 1997, Gaithersburg, MD.
11. Revercomb, H. E., F. A. Best, D. LaPorte, R. O. Knuteson, W. L. Smith, N. Ciganovich, R. Dedecker, T. Dirkx, R. Garcia, R. Herbsleb, J. Short, 1997: Accurately Calibrated Airborne and Ground-based Fourier Transform Spectrometers I: HIS and AERI Instrument Design, Performance, and Applications for Meteorology and Climate. Council for Optical Radiation Measurements (CORM) 1997 Annual Meeting, National Institute of Standards and Technology (NIST), April 29, 1997, Gaithersburg, MD.

3.2 Related publications

1. Feltz, W. F., W. L. Smith, R. O. Knuteson, H. R. Revercomb, H. B. Howell, Harold H. Woolf, 1998: Temperature and Water Vapor Retrieval Using Groundbased Atmospheric Emitted Radiance Interferometer (AERI) Measurements Part II: Meteorological Applications. Accepted for publication *J. Appl. Meteor.*, October 1998.
2. Smith, W. L., W. F. Feltz, R. O. Knuteson, H. R. Revercomb, H. B. Howell, Harold H. Woolf, 1998: The Retrieval of Planetary Boundary Layer Structure Using Ground Based Infrared Spectral Radiance Measurements. Submitted to *J. Atmos. and Oceanic Tech.*, In Publication 1998.
3. Strow L. L., D. C. Tobin, W. W. McMillan, S. E. Hannon, W. L. Smith, H. E. Revercomb, and R. Knuteson, 1998: Impact of a New Water Vapor Continuum and Line Shape Model on Observed High Resolution Infrared Radiances". *Journal of Quantitative Spectroscopy and Radiative Transfer*, Vol. 59, pp. 303-317, 1998.
4. Tobin, D. C., L. L. Strow, S. E. Hannon, W. J. Lafferty, and W. B. Olson, 1997: Experimental Investigation of the ν_2 Band of Water Vapor. *Proceedings Volume Five Opt. Remote Sensing of the Atmosphere Conference*, Santa Fe, NM, February 9-14, 1997.
5. Knuteson, R. O., F. A. Best, H. B. Howell, P. Minnett, H. E. Revercomb, and W. L. Smith, 1997a: High Spectral Resolution Infrared Observations at the Ocean-Atmosphere Interface in the Tropical Western Pacific using a Marine Atmospheric Emitted Radiance Interferometer (MAERI): Applications to SST Validation and Atmospheric Spectroscopy. *Ninth Conference on Atmospheric Radiation*, American Meteorological Society meeting, 2-7 Feb. 1997, Long Beach, CA.
6. Knuteson, R. O., F. A. Best, T. P. Dirks, H. E. Revercomb, and W. L. Smith, 1997b: Accurate Measurement of Sea Surface Temperature with the Marine - Atmospheric Emitted Radiance Interferometer. *Fall AGU Meeting*, San Francisco, CA, 12 - 16 December, 1997.
7. Feltz, W. F., W. L. Smith, R. O. Knuteson, H. E. Revercomb, H. B. Howell, 1997: Meteorological Dependence on Ground-Based Interferometer Temperature and Water Vapor Retrieval Accuracy. *Proceedings Volume Five Opt. Remote Sensing of the Atmosphere Conference*, Santa Fe, NM, February 9-14, 1997.
8. Feltz, W. F., W. L. Smith, R. O. Knuteson, H. R. Revercomb, and H. B. Howell, 1997: AERI Temperature and Water Vapor Retrievals: SGP CART Seasonal Statistical Analysis, Monthly Climatic Means for Model Integration, and Future GOES/AERI Retrievals. *Proceedings of the Seventh ARM Science Team Meeting*, San Antonio, TX, March 3-7, 1997.
9. Feltz, W. F., W. L. Smith, R. O. Knuteson, H. R. Revercomb, and H. B. Howell, 1997: Continuous Temperature and Moisture Profiling of the Planetary Boundary Layer. *Proceedings of the 12th Symposium on Boundary Layers and Turbulence*, Vancouver, BC, July 28-August 1, 1997.
10. Feltz, W. F., W. L. Smith, S. P. Ho, T. J. Schmit, X. L. Ma, and H. B. Howell, 1998: Combined Surface and Satellite Infrared Measurements of Atmospheric Temperature and Water Vapor Profiles. *Proceedings of the 10th Symposium on Meteorological Observations and Instrumentation*, Phoenix, Arizona, January 11-16, 1998.
11. Smith, W. L., S. A. Ackerman, D. H. DeSlover, W. F. Feltz, S. Ho, R. O. Knuteson, H. E. Revercomb, and S. A. Clough, 1997: ARM Science Applications of AERI Measurements. *Proceedings of the Seventh ARM Science Team Meeting*, San Antonio, TX, March 3-7, 1997.
12. Smith, W. L., W. F. Feltz, D. H. Deslover, and H. B. Howell, 1998: ARM Science Applications of AERI Measurements: 1997 Progress. *Proceedings of the Eighth ARM Science Team Meeting*, Tucson, Az, March 23-27, 1998.