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

Progress Report

DOE Grant #
DE-FG02-90ER61057

Henry E. Revercomb, PI

Space Science and Engineering Center
University of Wisconsin - Madison
1225 W. Dayton St., Madison, WI 53706
(608-263-6758)

Co-I: David G. Murcray (University of Denver)
Co-I: Frank J. Murcray (University of Denver)
Co-I: Robert O. Knuteson (University of Wisconsin - Madison)

1 August 1997

I. 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 subgrant to the University of Denver (Co-Is: David and Frank Murcray). We are in the first year of a three year continuation of our grant for ARM high spectral resolution studies. This year has been especially busy, and we will not have any unexpended funds at the end of this budget period.

II. Summary of Activities

This year, we have made considerable progress in the areas of instrument performance evaluation and refinements, spectroscopic analyses, and water vapor determination. Highlights include evaluation and presentation of results from the water vapor IOP, contributions toward extending and refining the AERI/LBLRTM Quality Measurement Experiment, continued support for the first operational AERI (continuously operating since December 1995), semi-operational data collection from the high resolution AERI-X, new AERI calibration modeling and documentation (culminating in a presentation to NIST in April), and refined analyses of AERI observations in the tropics from the Combined Sensor Program (CSP) cruise on the Discoverer. Many of these accomplishments were also presented at the ARM Science Team Meeting in March and at other ARM related meetings. The following sections review the progress in each of these areas.

A. Instrument Performance Evaluation and Refinements

AERI Foreoptics Refinements

In late 1996 an important enhancement of the AERI system design was made to help maintain the integrity of the radiance observations under adverse environmental conditions. The AERI-01 system encountered a calibration problem associated with Oklahoma dust settling on the system scene viewing mirror. It was determined that this mirror contamination was leading to a scattered component of radiation from around the ceiling hatch opening which was not being subtracted in the calibration process. A three pronged approach was applied to the solution to this problem. First a warning light was added to the site operator display to indicate when the system scene mirror requires cleaning. A clean mirror avoids any possible scattering contribution. The second approach was to match the field of view for scattered radiation to the blackbodies to that of the sky. This was accomplished by installing a "sky view aperture" at the same distance (and of the same diameter) as that of the calibration reference blackbodies. Matching the scattering fields of view means that any scattered component of radiation will be subtracted in the calibration process. Lastly, the previously exposed scene viewing mirror was almost completely enclosed by modifying the blackbody support structure to eliminate all openings except the one required for vertical sky viewing and to include a filtered fan to provide positive pressure in the front end optics enclosure. This last modification will help prevent dust, sea spray, or ice crystals from settling on the scene viewing mirror. These approaches have been demonstrated at the Oklahoma central facility and will be a part of all of the future AERI systems for ARM. This immunity to environmental conditions is important since many of the ARM sites are even more remote than the one at Lamont, Oklahoma.

AERI-X

During this period the higher spectral resolution emission system for the ARM program (referred to as AERI-X) was deployed to the ARM southern great plains central facility on a semi-operational basis. The AERI-X is a joint effort between the University of Denver (DU) and the University of Wisconsin (UW). The primary responsibility for the interferometer hardware implementation and data acquisition software is at the University of Denver. The primary responsibility for the calibration hardware and software lies with the University of Wisconsin. The AERI-X system was set up next to the operational AERI (AERI-01) in the central facility optical trailer in September 1996 for the first water vapor intensive operating period. The system has operated nearly continuously (with periodic maintenance down periods) on an experimental basis from September 1996 through the present. It had a few problems, which were difficult to repair due to high humidity in the trailer. After the site staff put together a plastic tent and a small dehumidifier, we were able to carry out the repairs safely. A purge gas system providing dry, CO_2 free air was connected to the AERI-X, improving the calibration near atmospheric CO_2 emission lines which will be used for temperature sounding.

Software for the AERI-X has been written which makes it very much like the other AERI systems in terms of display and data handling. In addition, a singular value decomposition algorithm has been used to improve the signal-to-noise on a set of 5 days data during the SITAC IOP in June. This test of the new agorithm was very successful and warrants the early implementation for routine AERI-X data.

The evaluation of data from this higher resolution instrument is presently underway and involves comparison to the lower spectral resolution AERI-01 system as well as radiative transfer model calculations based on coincident atmospheric profiles. The AERI-01 comparisons to verify calibration accuracy have shown very good agreement. We are now performing more refined comparisons with LBLRTM calculations, with special emphasis on water vapor line parameter validation and on spectral regions where AERI shows unidentified differences.

SORTI

The operational SORTI was installed in the fall of 1996, but was not ready for routine use until early spring. We now have a significant amount of data archived in Denver. Because SORTI observes the transmission along the slant path to the sun, comparisons with the AERI and AERI-X data have to be done via two LBLRTM calculations. The high spectral resolution of SORTI has limited this to a few cases so far.

TWP and Arctic AERIs

The remaining AERI instruments in a series under construction at the University of Wisconsin for the DOE ARM program include two instruments for the Tropical Western Pacific "ARCS" sites at Nauru and Christmas Island, an instrument for the North Slope of Alaska in Barrow, an instrument for participation in the interagency SHEBA experiment on the ice pack north of Alaska, and one instrument for each of the four boundary facilities of the ARM Southern Great Plains site. The new tropical and polar sites provide some new design challenges which have been partially addressed under this grant. For the TWP, the primary issues were (1) avoiding direct sunlight on the detectors, and (2) defining useful low data rate, health and status information for remote monitoring. A sun sensor mounted near the sky viewing aperture was added to trigger stowing the mirror in the downlooking direction before the sun enters the field-of-view. For SHEBA and the NSA, the challenges were posed by the (1) low responsivity of the extended range detector leading to EMI issues, and (2) enclosure design, working with Connor Flynn. Regarding the EMI issue, extensive efforts were made to explore a wide range of grounding configurations and active filtering designs, that recently led to finding a configuration immune to Stirling cooler generated interference. The extended range AERI is now able use an MCT detector cooled to 68 K to give spectral coverage out to at least 24 microns.

AERI-01 / AERI Prototype Intercomparison

The September 1996 water vapor intensive operating period (WVIOP96) provided an opportunity to collect data intercomparing two AERI instruments collocated at the ARM Southern Great Plains central facility. The two AERIs were the operational instrument at the central facility (AERI-01) and the AERI prototype installed in a mobile vehicle (the "AERIbago"). Extensive analyses of these observations were performed during the current grant year. Each instrument obtains a calibrated radiance spectrum of the downwelling atmospheric infrared emission in a zenith view at approximately ten minute intervals. The excellent agreement (< 1 mW/(m^2 sr cm^{-1})) between these instruments provides confidence in the reproducibility of the measurements obtained by the AERI systems. In particular, the radiance difference between the two AERIs is an indication of the size of the measurement uncertainty of the AERI-01 which is relevant to the interpretation of the AERI/LBLRTM Quality Measurement Experiment (QME).

AERI Calibration Refinements

(1) AERI Blackbody Calibration - NIST Presentations

Both the AERI instrument design and the AERI blackbody design, calibration methodology, and typical calibration results were presented at the Council for Optical Radiation Measurements (CORM) 1997 Annual Meeting, held at the National Institute of Standards and Technology (NIST), in Gaithersburg, Maryland. Discussions were held with NIST representatives with the hope of conducting radiance comparison tests between NIST and AERI blackbodies. It was the opinion of the NIST representatives that their existing radiance standards would not be significantly more accurate than the AERI blackbodies, and comparison tests should wait until a new NIST radiance standard is completed, hopefully within the next year. This new radiance standard is being developed, in part, with funding from NASA's Mission to Planet Earth Program. We will monitor the progress of this new standard and schedule AERI blackbody tests as soon as practical.

(2) AERI 01 Blackbody Calibration Stability

In June of 1997 the AERI-01 hot and ambient blackbodies were replaced with new units and the originally installed blackbodies were re-calibrated using the dedicated AERI facilities at the University of Wisconsin. Figure A illustrates that over the 30 month period from initial blackbody calibration (12/94) to the (6/97) re-calibration, there was less than 0.05 °C drift in the cavity temperature sensing thermistors. At the time of blackbody change-out, additional testing was performed on the AERI-01 instrument that showed the thermistor resistance readout electronics drift (when converted to equivalent temperature) was on the order of ± 0.005 °C. The June testing provided us the first demonstration of the excellent long term stability of the AERI blackbody thermistors and readout electronics. We will continue to monitor the blackbody temperature measurement stability of all the AERI blackbodies in order to better characterize long term behavior. An important goal for monitoring blackbody stability is to define the maximum allowable time between calibrations; this period is now estimated to be on the order of 30 months.

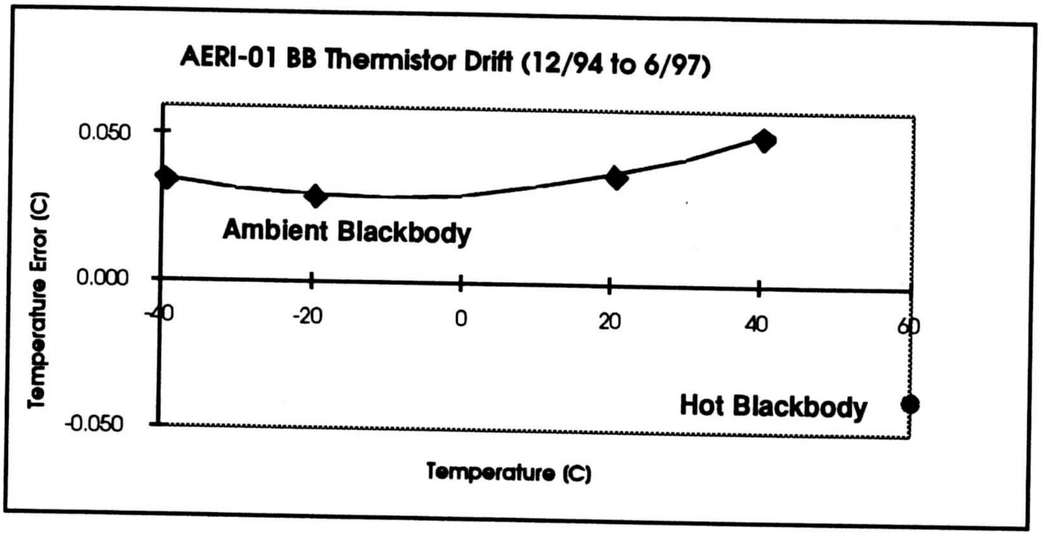

Figure A. AERI-01 blackbody thermistor drift over the 30 month period from 12/94 to 6/97. Over the temperature the ambient blackbody operating range of (-40 to +40 °C) and at the hot blackbody operating temperature of +60 °C, the drift was less than 0.05 °C. The thermistor resistance readout electronics drift converted to equivalent temperature error was measured to be an order of magnitude smaller than the thermistor drift shown above.

B. Spectroscopic Analysis

The focus of our current effort in radiative transfer model validation has been characterization of the spectroscopic issues related to water vapor in the infrared. A key goal is the validation of the water vapor "continuum" absorption under a wide range of conditions. The ongoing work being performed at the SGP ARM site is summarized in the quality measurement experiment (QME) known as the AERI/LBLRTM QME. Another important milestone was obtained with the observations of an AERI system in the Tropical Western Pacific during the CSP cruise under conditions of high absolute water amount. These conditions are key to accurate testing of the self-broadening continuum contribution in the longwave window region. The AERI/LBLRTM QME status and CSP cruise results are described in the following sections.

AERI/LBLRTM QME

The ARM program's primary tool for the validation of radiative transfer modeling in the infrared region has been the AERI/LBLRTM QME. This QME has been in place since April 1994 using first the AERI prototype instrument and then the operational AERI-01 unit to compare observed infrared radiance spectra to calculated spectra. Until recently the QME depended entirely on the central facility balloon soundings for characterization of the atmospheric state (atmospheric pressure, temperature, and water vapor versus height). The ARM Instantaneous Radiative Flux working group concluded at the beginning of 1996 that the ability of this QME to test the validity of the line-by-line radiative transfer model was limited by that absolute accuracy and statistical fluctuations of the Vaisala radiosonde system (BBSS) used at the SGP central facility to perform the balloon soundings. Using the AERI as a reference standard and the LBLRTM model as a transfer standard, the AERI/LBLRTM QME has shown that sonde-to-sonde peak variations can be as much as 30% of absolute water amount and the sonde batch-to-batch calibration can change by as much as 10% of absolute water amount. The desired accuracy for validation of the LBLRTM model is more like 3-5% of absolute water amount (at the SGP site). This sonde "problem" has brought to the forefront the need for a water vapor reference standard that can be applied to the sonde profiles (or the Raman water profiles) to correct for sonde calibration errors. The September 1996 Water Vapor IOP at the SGP site was focused (in part) on the evaluation of candidates for this reference standard which included the microwave radiometer, chilled mirror sensors on a tethered balloon, and calibrated sensors on the 60 meter tower. There is a dramatic reduction in the QME residual (AERI minus LBLRTM) when the MWR is used as a water vapor reference standard. It appears that use of the MWR to scale the balloon sondes will meet the previously stated requirements. The AERI/LBLRTM QME will be reprocessed to reflect this change.

CSP Cruise

Data from the AERI prototype on the ARM-sponsored Combined Sensor Cruise to the Tropical Western Pacific in March-April 1996 was further analyzed during the current year. For the CSP, AERI prototype was reconfigured to allow both vertical observation of the atmosphere (and clouds) as well as angle scanning of the atmosphere and the ocean surface. This measurement technique was used to obtain a highly accurate measurement of the ocean surface radiative "skin" temperature on an "around-the-clock" basis for the duration of the 30 day cruise. Measurements were made from American Samoa to Manus Island along the equator and back again to Hawaii. These measurements are being used for the validation of algorithms for the measurement of sea surface temperature from satellite data, as well as for spectroscopic applications. Initial comparisons with line-by-line calculations indicate consistency with the limited ARM measurements from the TOGA-COARE experiment in 1993 and imply the existence of an "enhanced" emission due to water vapor in the 8-12 micron region which is not easily explained. AERI measurements from the ARM tropical sites will be used to further characterize this "anomalous" behavior.

C. Water Vapor Determination

Water Vapor IOP

The first Intensive Operating Period to improve ARM capabilities for accurate water vapor profiles was successfully conducted near the beginning of the current grant year. This year, we performed extensive analyses on the data collected during the IOP and performed detailed calibration of the chilled mirror electronics interfaces and tethersonde temperature sensors. General results and conclusions were presented at the GVAP Workshop in Geneva during early December, at a WVIOP Workshop coordinated with the IRF Meeting in January, at the Bob White review of ARM, and at the ARM Science Team Meeting.

Sonde Reprocessing

One of the activities carried out at the WVIOP96 deserves special mention. A detailed study of the balloon borne sounding system (BBSS) performed by Barbara Whitney of the University of Wisconsin, in coordination with the BBSS instrument mentor, indicated that the automated processing of the radiosonde data included some significant artifacts that made comparison of the sonde data to the 30m and 60m tower sensors problematic. The sonde time of launch as determined by the automated BBSS software using the pressure sensor was frequently in error. This "time of launch" error often translates into a height error of 5-10 meters. This level of uncertainty would probably be acceptable if the automatic software did not also replace the measured sonde temperature and humidity values with "interpolated" values often putting grossly incorrect data into the final data product. The solution to this problem was to determine a time of launch from the "raw" sonde data and to simply substitute the "raw" data values in the sonde profile in the first 100 meters in place of the values produced by the automatic software. Dr. Whitney performed this "reprocessing" for all the sondes launched during the 1996 Water Vapor IOP. These reprocessed sonde files should be used by any investigations that need an accurate temperature and humidity profile in the first 100 meters, such as sonde/tower comparisons. These reprocessed sondes are available as part of the WVIOP96 dataset from the ARM archive.

III. Upcoming Year-One Activities

The remainder of the current funding year will include participation in the September 1997 intensive operating period (the "mega-IOP") at the southern great plains

ARM site. A second water vapor IOP will be conducted during this time for which H. Revercomb will be chief scientist. The objective of this IOP is to extend the assessment of the accuracy of water vapor measurements above the 0-1 km range which was the focus of the first WVIOP in Sept. 1996. In addition, it is expected that aerosol and remote sensing studies will benefit from the planned coordination with PI instruments on site at that time, such as the Goddard Scanning Raman Lidar.