FINAL REPORT FOR GRANT DE-FG02-92ER61365: CONTINUATION OF DATA ANALYSIS SOFTWARE DEVELOPMENT FOR THE ATMOSPHERIC EMITTED RADIANCE INTERFEROMETER (AERI)

I. INTRODUCTION

This is the final report for DOE grant DE-FG02-92ER61365 to the University of Wisconsin Space Science and Engineering Center with Principal Investigator Robert Knuteson and co-Investigators Wayne Feltz and Shepard Clough.

II. ACCOMPLISHMENTS UNDER THIS GRANT

A. Background

Data from the Atmospheric Emitted Radiance Interferometer (AERI) has been analyzed under the ARM Fourier Transform Data Analysis Tools science team project. A portion of the effort was accomplished through a subcontract to S. A. Clough of Atmospheric Environmental Research (AER), Inc. This section of the proposal highlights a few important accomplishments obtained during the past grant period. Specific accomplishments include:

1) The AERIplus temperature and moisture retrieval algorithm (Feltz et al. 2003, 2005) has now implemented a new fast model based upon LBLRTM. The fast model provides a doubling of vertical resolution within the first 100 hPa of atmosphere (surface to 900 hPa) from 10 hPa spacing to 5 hPa. This algorithm has been implemented at Pacific Northwest National Laboratories to upgrade previous AERI retrieval software. A peer reviewed paper has been published with regard to this work along with Value Added Product (VAP) technical document available through ARM web site.

2) Developed an objective methodology to detect planetary boundary layer (PBL) height using the AERI derived potential temperature field. AERI temperature and moisture data are also used to correlate the perturbation temperature and moisture in time within the planetary boundary layer (PBL) to view the structure of PBL turbulence and convection.

3) The temporal resolution of the DOE ARM AERI systems is now being increased to less than 20 seconds (currently ~ 8 minutes depending on system). The University of Wisconsin mobile AERI system was deployed three times (Texas 2002 at SGP, CRYSTAL-FACE in southern Florida, and AWEX 2003 at SGP) collecting data at 40 second temporal resolution. The DOE ARM science team has requested that all DOE ARM AERI systems be upgraded to run in rapid sampling mode (including the ARM Mobile Facility AERI) to provide improved sampling of changing cloud characteristics using high spectral resolution

infrared data. This grant has facilitated in the demonstration of improved science when the AERI systems on operated in this higher temporal resolution mode.

B. Improvements in Deriving AERI Atmospheric Thermodynamic Retrievals

Previous DOE ARM program support has allowed rapid improvement in the ability to retrieve temperature and moisture profiles within the planetary boundary layer from high spectral resolution infrared radiances (Feltz et al. 2003; Smith et al. 1999). Extensive validation of the water vapor profiles as compared to Raman lidar and microwave scaled radiosondes indicate an absolute rms mixing ratio difference of 5% (Turner et al. 2000). AERI derived temperature profiles indicate RMS differences of less than 1 degree Kelvin as compared to radiosondes in the PBL (Feltz et al. 2003). The These retrievals are used for a variety of purposes such as to improve model parameterizations, to provide thermodynamic state for SCM/CRM model runs, and validate other remote sensing instrument collocated with the systems. Several examples exist indicating the value the retrievals provide to other ARM related research groups:

- **Preliminary studies have been conducted to drive SCM/CRM calculations with AERIplus retrievals and collocated wind profiler data including mass flux water vapor divergence and advection (Xie and Cedarwall).** A grid of five AERI systems within the SGP CART site domain were deployed for a five year period (December 1998 – December 2003) and collocated with operational wind profilers. Preliminary studies have been initiated to test SCM runs with remotely sensed temperature, moisture, and winds and initial results look encouraging (Xie et al. 2000).

- **AERIplus retrievals using the North Slope of Alaska (NSA) and Surface Heat Energy Budget of the Arctic (SHEBA) Extended Range AERI systems have been performed to provide input for Large Eddy Simulation (LES) parameterizations (Curry and Stamnes).** Several NSA and SHEBA ER-AERI data sets have been processed to validate and develop boundary layer Large Eddy Simulation (LES) models (in collaboration with Dr. J. Curry University of Colorado and Dr. K. Stamnes University of Alaska Fairbanks) in the arctic climate.

- **AERIplus retrievals using the Tropical Western Pacific (TWP) AERI and Marine AERI instruments have been performed for Nauru 99 (Minnett and Westwater).** Preliminary Nauru Island TWP AERI retrievals have been calculated and compared to ship-based M-AERI retrievals. The research results indicate a Nauru heat island effect of 1.5 degrees Celsius (in collaboration with Dr. P. Minnett University of Miami and Dr. Ed Westwater NOAA ETL). Similar heat island effect temperature values have been determined with RASS (W. Brown, NOAA ATD).

- **AERIplus retrievals have been incorporated in best estimate of atmospheric state value added products which combine Raman Lidar water vapor and AERIplus temperature to provide ten minute resolution best estimate thermodynamic state profiles (Ferrare and Turner).** Turner, Ferrare and Feltz have developed a value added product to provide the ARM community and near continuous best estimate of atmospheric state over the ARM SGP central facility.

- **New AERIplus retrieval applications have been implemented including objective detection of boundary layer height and turbulent moisture plumes.** A combined Raman Lidar/AERI algorithm is being developed to provide a concensus PBL height determination (in collaboration with Dr. Rich Ferrare of NASA/LaRC) for the SGP central facility at Lamont, OK. AERI temperature and moisture retrievals should provide a new source of data for LES studies. A peer reviewed paper has been submitted to the Journal of Geophysical Research presenting preliminary boundary layer roll detection using AERI and Raman lidar profiles.

- **DOE ARM funded AERI retrieval improvement has also benefited other research programs such as validation of AIRS spectroscopy and atmosphere state (in conjunction with Dr. David Tobin SSEC UW-Madison).** NOAA and NASA Satellite validation funding has provided additional resources to use the best available DOE ARM data sets to reduce satellite derived product uncertainties (Hawkinson, 2004; Schmit, 2002)

AERIplus vertical resolution and temporal resolution has been improved to provide better data sets towards the research contributions above.

C. AERIPLUS Retrieval Vertical Resolution Improvement

Under this grant, the AERIplus temperature and moisture retrieval algorithm has now implemented a new fast model based upon LBLRTM using Hitran 2000. The previous 50-level fast model was developed using FASCODE and a Hitran 1992 data base. The new fast model provides a doubling of vertical resolution within the first 100 hPa of atmosphere (surface to 900 hPa) from 10 hPa spacing to 5 hPa (now 60 levels). The Hitran 2000 line parameter update has dramatically reduced the water vapor line residuals between AERI and calculation. This new 60 level LBLRTM fast model based on Hitran 2000 provides:

1) a consistent line-by-line model based upon ARM research (LBLRTM) which is important when comparing AERI LBL QME results with AERIplus retrieval residuals.

2) improves the AERIplus retrieval vertical resolution within the first kilometer of atmosphere where the fastmodel based upon FASCODE in currently under sampling the AERI radiance vertical resolution; this is a primary concern for several LES studies being conducted using AERIplus retrievals at NSA/SHEBA/ and SGP.

3) indicates that the spectral bias used to stabilize the AERI radiance inversion to profiles will be dramatically reduced, leading to a more direct inversion of atmospheric state

Figure one shows an AERI observation compared to three fast model calculations from a radiosonde launched for the ARM SGP central facility on 06 October 1999 at 0530 UTC (Figure 1). The improved vertical resolution and use of updated line parameters has significantly improved agreement between calculation and AERI observation when strong gradients of temperature and water vapor are present just above the AERI instrument. The increased layering improves the agreement in regions of strong absorption by CO2 used for low level temperature inversions (Figure 2). The new line parameters improve water vapor channel agreement, especially at the longer wavelength channels used for water vapor retrieval. As a result of the fast model improvement, the AERI retrieval algorithm will have reduced dependence on using a spectral bias to account for fast model errors. Since the water vapor lines have become better understood spectroscopically, the vertical range and accuracy of retrieved profiles will improve by selecting well-known weakly absorbing lines with in the 8 - 12 mm region. Figure 3 shows the average improvement comparing three simultaneous AERI observations vs radiosonde calculations using the fast model based on FASCODE with Hitran 1992 and LBLRTM with Hitran 2000. The vertical layering in the LBLRTM fast model in the first 100 hPa is twice that of the FASCODE fast model. Significant improvement is evident between observation and calculation in nearly all spectral regions between 500 - 1000 cm^{-1}.

An example of the temperature retrieval improvement is shown in figure 4 from the IHOP field program on 02 June 2002 from Lamont, Oklahoma. An AERI derived temperature profile from the 50-level algorithm and 60-level algorithm is compared to a radiosonde (black) at 1130 UTC indicating that the 60-level algorithm can better resolve multiple temperature inversions, thereby producing a better match to the radiosonde profile. The IHOP AERI data sets (six instruments) have been reprocessed for the IHOP experiment duration.

This improved AERI thermodynamic retrieval algorithm has been implemented a Pacific Northwest National Laboratories under the direction of Dr. David Turner.

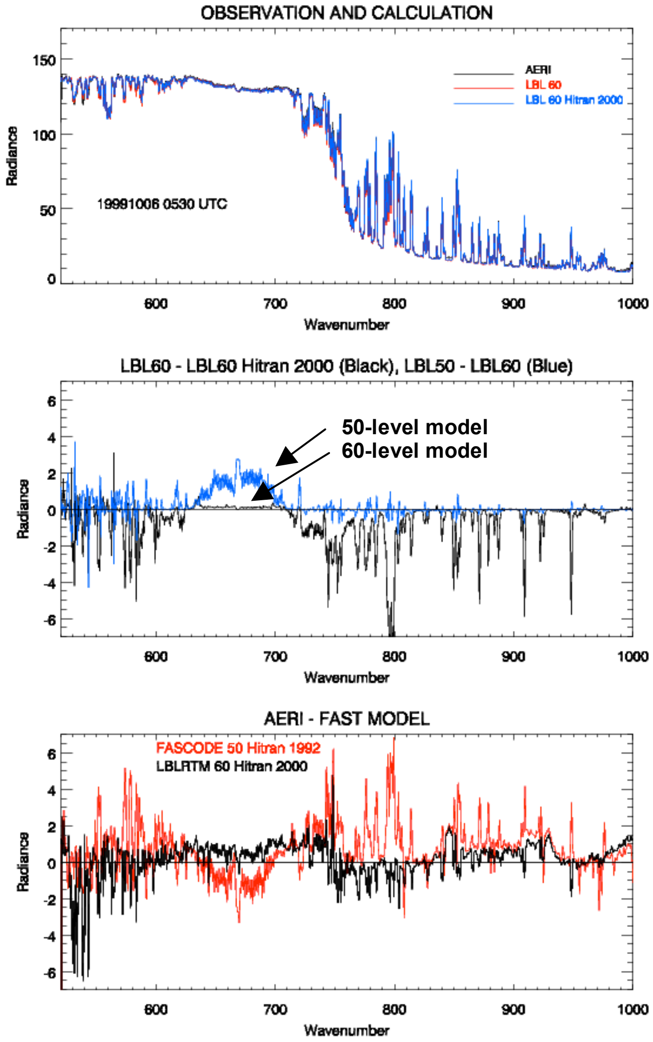

Figure 1: Observed and calculated AERI spectra (top left); calculation differences (middle left), and AERI observation/calculation differences (bottom left). The calculations were performed using the radiosonde shown in figure 2.

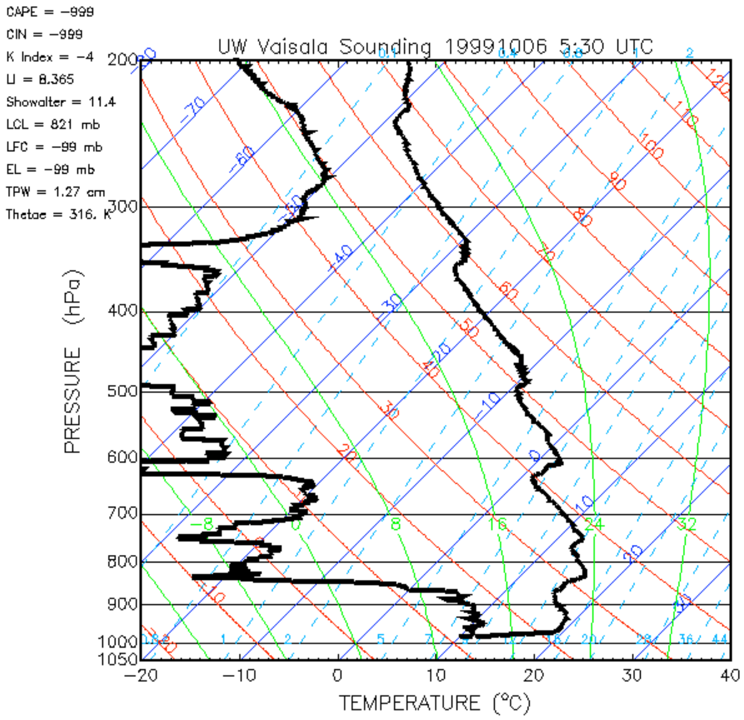

Figure 2: A SKEWT diagram of a radiosonde launched at 0530 UTC on 06 October 1999. This radiosonde was selected due to high confidence of atmospheric state based upon microwave radiometer. Calculations shown on figure 1 were performed with this radiosonde profile. Notice the strong surface temperature inversion is spectrally resolved within Figure 1 using the 60-level LBLTRM fast model.

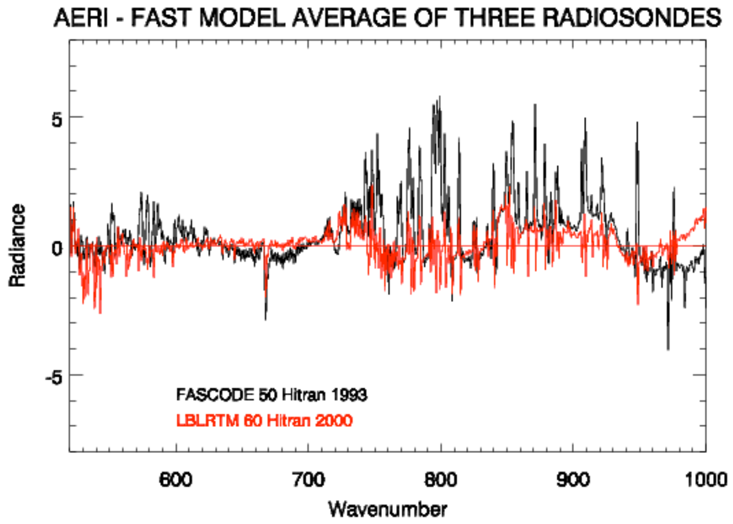

Figure 3: Average spectral differences of three radiosonde calculations and simultaneous AERI observations. The calculations were performed with the outdated FASCODE 50-level fast model, which used HITRAN 1993 transmittance coefficients, and the latest LBLRTM 60-level fast model with HITRAN 2000 coefficients. Notice that the spectral differences within most regions have been significantly reduced due to improvement in spectroscopy and vertical levels.

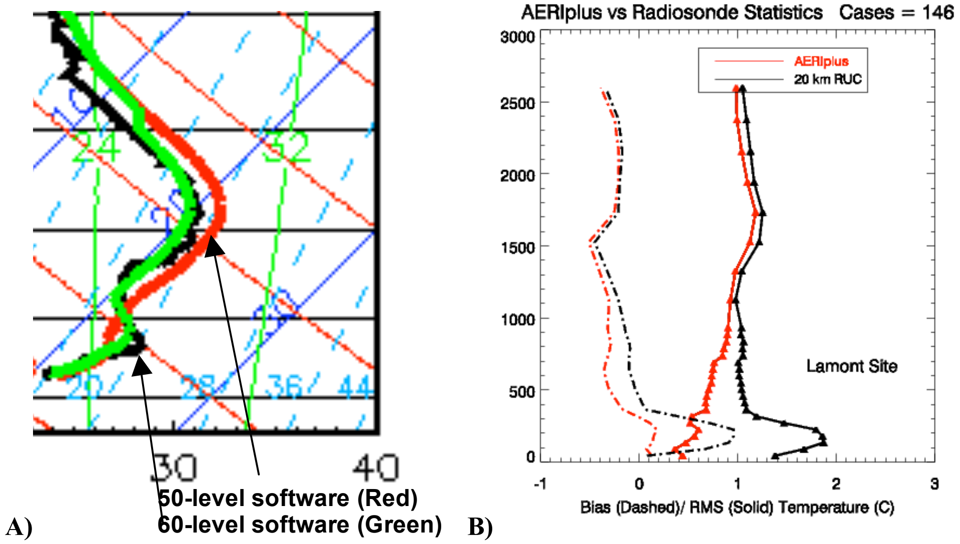

Figure 4: The top figure (A) shows an example of the updated AERIplus temperature retrieval improvement during the IHOP field experiment. One profile was calculated with the 50-level FASCODE fastmodel while the other profile uses the new 60-level LBLRTM based fast model with improved vertical resolution and spectroscopy as compared to radiosonde (thick black line). The bottom figure (B) indicates the improvement in root mean square (solid lines) and mean bias (dashed line) the AERI radiances make to collocated Rapid Update Cycle (RUC) analysis profiles as compared to 146 radiosondes during the IHOP program at Lamont, Oklahoma.

The retrieval algorithm is very robust and is demonstrated in figure 5 where four AERI systems have derived water vapor from 13 May – 25 June 2004 during the International H2O Program experiment in the southern great plains of the United States. This location was selected during IHOP due to the suite of ARM instrumentation available to complement IHOP resources.

D. Gridded AERI Moisture Flux/Advection Measurements

The DOE ARM program has provided an opportunity to rapidly develop robust AERI technology and subsequent thermodynamic/cloud retrieval algorithms. Due to the ARM program the AERI systems have become a proven technology which is now being deployed worldwide for atmospheric state retrievals and satellite validation. The grid of five AERI systems at the ARM SGP has provided another unique opportunity. The quantification of moisture advection/convergence at relatively high temporal resolution between the SGP AERI sites was possible with the AERI/wind profiler grid in place. A methodology to automate moisture flux/advection calculation between the grid of five AERI/wind profiler systems has been funded under this grant which will provide an opportunity to validate CRM/SCM moisture flux calculations and the possibility of improving quantitative precipitation forecasting.

Combined AERI/Wind Profiler data provide continuous monitoring of low-level moisture convergence processes responsible for increasing convective instability and providing sufficient moisture to support convection. A Matlab application has been developed to automate this process. These moisture flux data sets will be provided in near real time on the internet for SCM/CRM validation. An example of moisture flux divergence calculations between Morris, Lamont, and Purcell for 3 August 2002 using AERI and wind profiler measurements is shown Figure 6. These measurement provide a direct way to intercompare the large scale field within a GCM to a grid of groundbased remote sensing instrumentation. These measurements indicate that observing high-resolution moisture gradients is critical to understanding the convective initiation problem and parameterization of convective triggers for numerical weather prediction models. Area-averaged moisture advection and convergence between SGP CART site locations would provide another validation product for comparison to SCM/CRM model output and the means to drive CRM/SCM's between IOP period

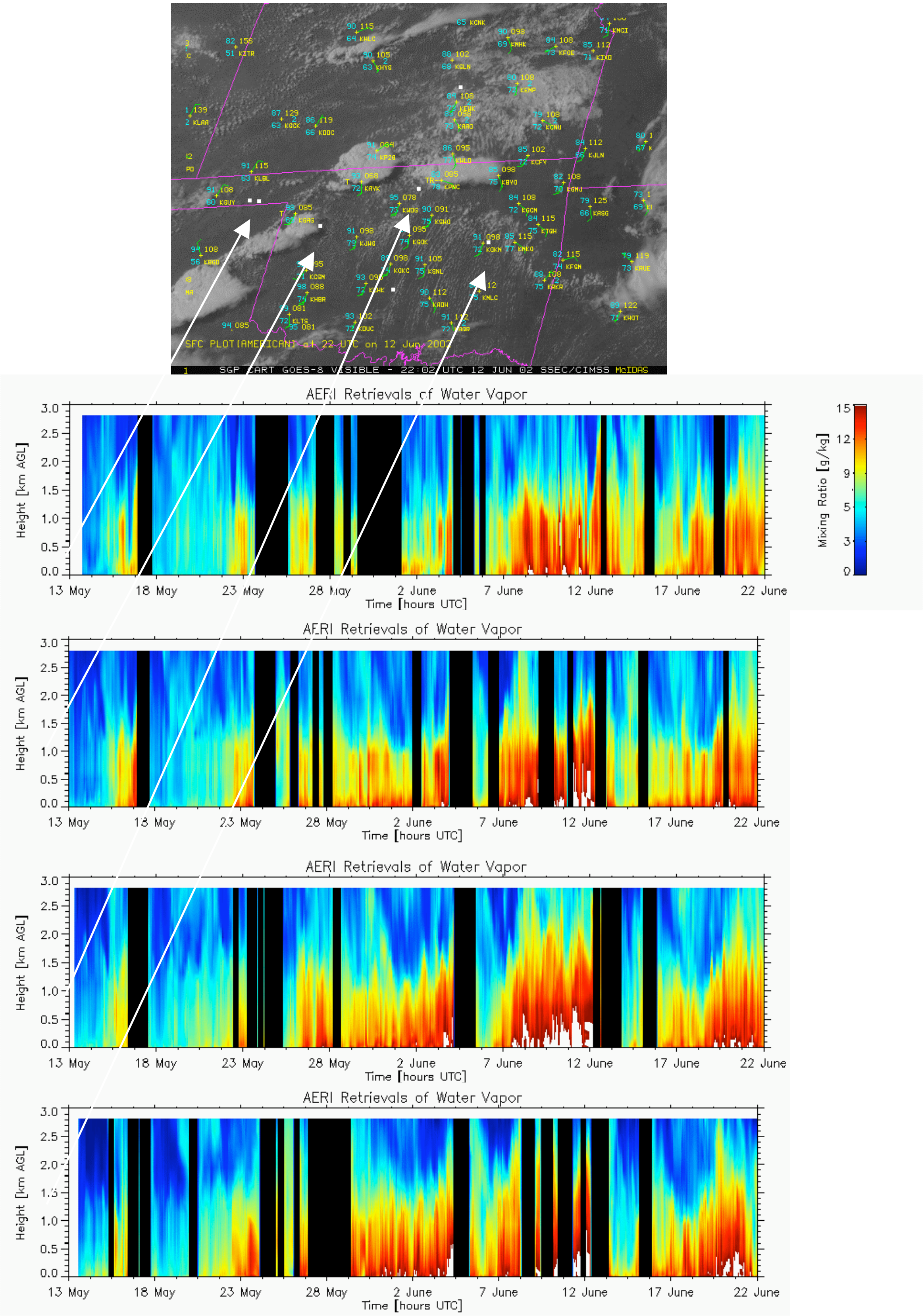

Figure 5: A series of AERI derived water vapor profiles from west to east respectively from Balko, OK (IHOP); Vici, Oklahoma; Lamont, Oklahoma; and Morris, Oklahoma.

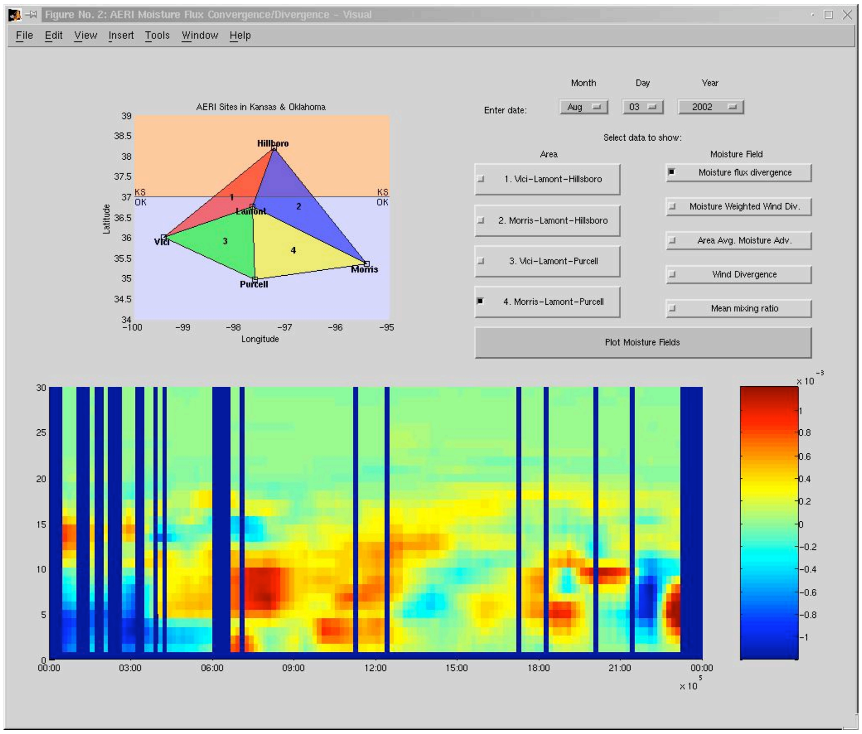

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Figure 6: A screenshot of a Matlab application which calculates various moisture terms between three collocated AERI/wind profiler stations. Pictured is a moisture flux divergence calculation from 3 August 2002. Missing data is indicated in dark blue within the cross section.

E. Increased Temporal Resolution of AERI Measurements for Better Cloud Retrievals

The initial goal of the AERI instruments was to characterize the clear-sky IR emission from the atmosphere, and thus a temporal sampling was chosen (8-10 min per spectrum) to minimize random noise in the AERI observations. This sampling strategy is inadequate for sampling cloud radiative properties (Turner et al. 2003), or to capture fast (i.e., 1 min) fluctuations in water vapor in the boundary layer. The development of a set of noise filtering tools, which utilize a principal component analysis of the spectra (Huang and Antonelli, 2001), allow the AERI to be run at much higher (less than 1 min) temporal resolution and maintain the same noise level and calibration accuracy as the nominal 10-min AERI data was developed under this grant. The University of Wisconsin-Madison deployed the AERI in its mobile AERIBago in this rapid-scan mode during both the CRYSTAL-FACE experiment in Southern Florida and at the ARM SGP site as part of the Texas 2002 and AWEX 2003 experiments. Examples of cloud property retrievals from the rapid-scan data demonstrate the clear superiority of the faster temporal resolution over the nominal resolution. Temperature and moisture retrievals (Feltz et al. 2003) from the rapid-scan data also demonstrate fluctuations in the boundary layer thermodynamical profile that are lost due to averaging with the nominal sampling strategy.

1) AERI Cloud Property Detection Benefits

Cloud fields, and thus cloud optical properties, have a range of spatial and temporal scales. When the cloud field is broken, and especially when there are more than one cloud layer, rapid sampling of the radiative field is required in order to successfully retrieve cloud properties from the measured radiance. If the averaging period is too long, then the received signal could be a convolution of the radiance from both the upper and lower level clouds, making the retrieval of cloud properties extremely difficult. Therefore, given the nominal sampling strategy of the AERI, retrievals of cloud properties are restricted to periods where the cloud field is uniform over the AERI's averaging interval (currently 8-10 minutes).

An example that highlights the necessity for rapid sampling in multi-layer cloud conditions is given in Fig 7. In this figure, the black lines denote the downwelling radiance (converted to brightness temperature) at 900 cm^{-1} for the rapid scan mode (a 12 s sky dwell approximately every 40 s). This data was then post-processed back up to the nominal AERI resolution of a 3 min sky dwell every 8 minutes; these data are indicated by the red dots. The data cover a 42 h window from the CRYSTAL-FACE experiment.

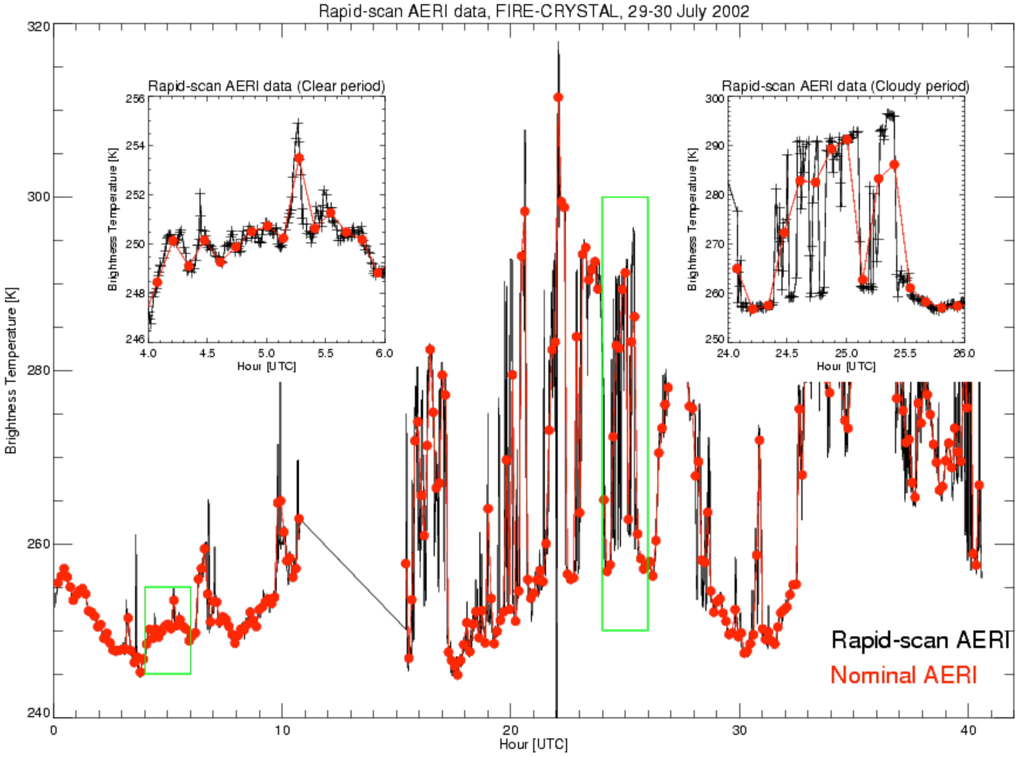

Figure 7: A time series of AERI microwindow brightness temperature measured at 900 cm^{-1} on July 29-30, 2002 during the CRYSTAL experiment in southern Florida. The temporal sampling is less than one minute for the rapid scan AERI mode while brightness temperatures are calculated for the normal ten-minute resolution mode.

The sky condition was clear during the first few hours of the scene, during which the noise-filtered rapid-scan data and nominally sampled AERI data agree very well (see left inset box). However, in the middle of the period, a two-layered cloud system advected over the site, with a cirrus cloud overlying a broken lower layer. If the nominal sampling strategy of the AERI is used, many of the samples are shown to have a brightness temperature between the temperature of the lower and upper levels (which are approximately 293 K and 258 K, respectively -- see right-hand inset image). However, with the rapid scan data collected by the AERI, many more samples are found where only one cloud layer is in the scene during the instrument's sky dwell period, and thus the retrieved cloud properties will be much more accurate.

2) AERI THERMODYNAMIC RETRIEVAL BENEFITS

Temperature and moisture profiles were calculated with the rapid scan AERI CRYSTAL data set (Fig. 8). The retrieval technique and profile applications are described in Feltz et al. 2003. The variation of the water vapor structure within the PBL is very important for detection of boundary layer turbulence. The current ten-minute time resolution, which the DOE ARM AERI systems are configured for, under samples the boundary layer turbulent plumes. Detection of the PBL thermodynamic boundary layer plumes is important for Large Eddy Simulation (LES) validation and initialization. LES studies provide a method to take observed PBL structure and parameterize the processes within numerical weather prediction models. Rapid scan AERI temperature and moisture retrievals should provide a new source of data for LES studies.

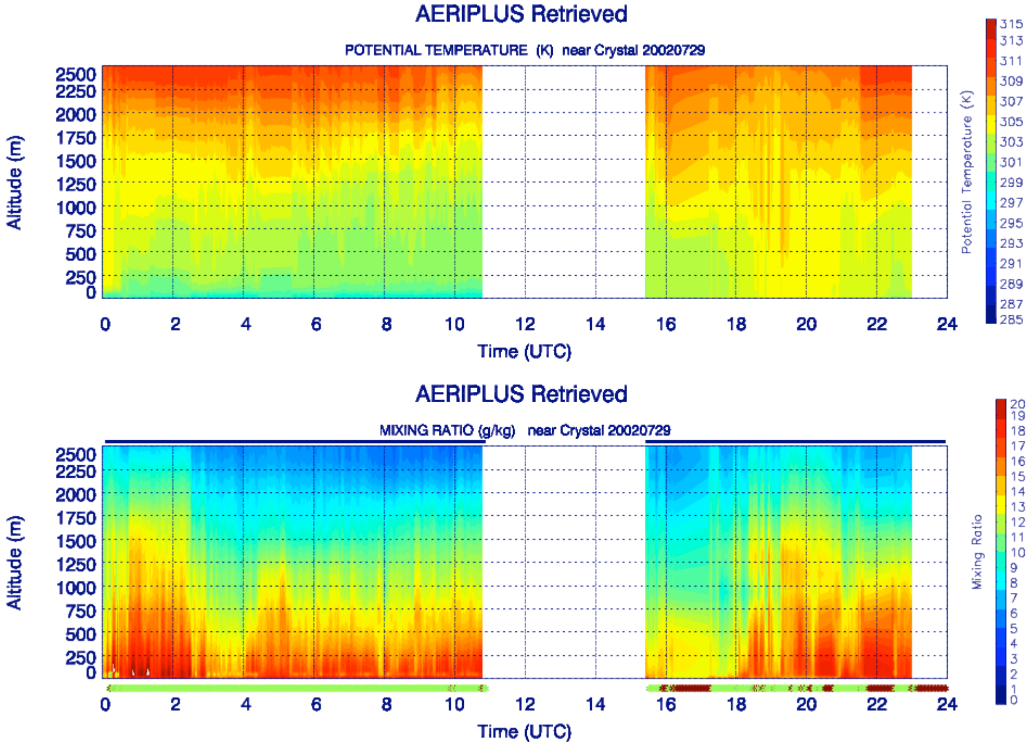

Figure 8: A time-height cross-section of rapid scan AERI retrieved potential temperature and water vapor mixing ratio for 29 July 2002 during the CRYSTAL campaign in southern Florida.

F. Publications and Presentations Under Previous Support

Peer Reviewed

Clough, S.A., M.W. Shephard, E.J. Mlawer, J.S. Delamere, M.J. Iacono, K. Cady-Pereira, S. Boukabara and P.D. Brown, Atmospheric Radiative Transfer Modeling: a Summary of the AER Codes, *Journal of Quantitative Spectroscopy and Radiative Transfer*, 2004. In press

Feltz, W. F., W.L. Smith, R.O. Knuteson, H.E. Revercomb, H.M. Woolf, and H.B. Howell, 1998: Meteorological applications of temperature and water vapor retrievals from the ground-based atmospheric emitted radiance interferometer (AERI). *J. Appl. Meteor.,* **37**, 857-875.

Feltz, W. F. and J. R. Mecikalski, 2002: Monitoring High Temporal Resolution Convective Stability Indices Using the Ground-based Atmospheric Emitted Radiance Interferometer (AERI) During the 3 May 1999 Oklahoma/Kansas Tornado Outbreak. *Wea. Forecasting,* **17**, 445-455.

Feltz, W. F., D. Posselt, J. Mecikalski, G. S. Wade, and T. J. Schmit, 2003: Rapid Boundary Layer Water Vapor Transitions. *Bull. Amer. Meteor. Soc*., **84**, 29-30.

Feltz, W. F., H. B. Howell, R. O. Knuteson, H. M. Woolf, and H E. Revercomb, 2003: Near Continuous Profiling of Temperature, Moisture, and Atmospheric Stability using the Atmospheric Emitted Radiance Interferometer (AERI). . *J. Appl. Meteor.,* **42**, 584-597.

Feltz, W.F., D.D. Turner, H.B. Howell, W.L. Smith, R.O. Knuteson, H.M. Woolf, R. Mahon, and T. Halter, 2005: Retrieving temperature and moisture profiles from AERI radiance observations: AERIPROF value added product technical description. DOE ARM Technical Report, TR-066, Available from http://www.arm.gov/publications/tech_reports/arm-tr-066.pdf

Ferrare, R. A., D. D. Turner, L. A. Heilman, W. F. Feltz, O. Dubovik, and T. P. Tooman, 2001: Raman Lidar Measurements of the Aerosol Extinction-to-Backscatter Ratio Over Northern Oklahoma. *J. Geophy. Res.,* **106**, D17, 20 333-20 347.

Hawkinson, J. A., W. F. Feltz, S. A. Ackerman, 2005: A Comparison Study Using the GOES Sounder and Cloud Lidar and Radar Retrieved Cloud Top Heights. *J. Appl. Meteor.*, 44, 1234-1242.

Kahn, B.H., A. Eldering, S.A. Clough, E.J. Fetzer, E. Fishbein, M.R. Gunson, S-Y. Lee, P.F. Lester, and V. Realmuto, Near micron-sized cirrus cloud particles in high-resolution infrared spectra: An orographic case study, *Geophys. Res. Lett. 30* (8), 2003.

Knuteson, R., F. Best, D. DeSlover, B. Osborne, H. Revercomb, and W. Smith, Sr., 2004: Infrared land surface remote sensing using high spectral resolution aircraft observations, *Adv. Space Res.*, Vol. **33**, 2004 (in press).

Knuteson, R. O., F. A. Best, N. C. Ciganovich, R. G. Dedecker, T. P. Dirkx, S. Ellington, W. F. Feltz, R. K. Garcia, R. A. Herbsleb, H. B. Howell, H. E. Revercomb, W. L. Smith, J. F. Short, 2003: Atmospheric Emitted Radiance Interferometer (AERI): Part I: Instrument Design, *J. Atmos. Oceanic Technol.,* **21**, 1763-1776.

Knuteson, R. O., F. A. Best, N. C. Ciganovich, R. G. Dedecker, T. P. Dirkx, S. Ellington, W. F. Feltz, R. K. Garcia, R. A. Herbsleb, H. B. Howell, H. E. Revercomb, W. L. Smith, J. F. Short, 2003: Atmospheric Emitted Radiance Interferometer (AERI): Part II: Instrument Performance, *J. Atmos. Oceanic Technol.,* **21**, 1777-1789.

Mecikalski, J. R., K. M. Bedka, D. D. Turner, and W. F. Feltz, 2005: Evidence for the Presence of Roll Structures in the Convective Boundary Layer using Thermodynamic Profiling Instruments, *J. Geophy. Res.*, In Review

Revercomb, H. E., D. D. Turner, D. C. Tobin, R. O. Knuteson, W. F. Feltz, J. Barnard, J. Bösenburg, S. Clough, D. Cook, R. Ferrare, J. Goldsmith, S. Gutman, R. Halthore, B. Lesht, J. Liljegren, H. Linné, S. Melfi, J. Michalsky, V. Morris, W. Porch, S. Richardson, B. Schmid, M. Splitt, T. Van Hove, E. Westwater, and D. Whiteman, 2003: The Atmospheric Radiation Measurement (ARM) Program's Water Vapor Intensive Operational Periods: Overview, Accomplishments, and Future Challenges. *Bull. Amer. Meteor. Soc*., **84**, 217-236.

Schmit, T. J., W. F. Feltz, W. P. Menzel, J. Jung, J. P. Nelson III, and G. S. Wade, 2002: Validation and Use of GOES Sounder Moisture Information. *Wea. Forecasting*, **17,** 139-154.

Turner, D.D., R. A. Ferrare, L. A. Heilman, W. F. Feltz, and T. P. Tooman, 2002: Automated Retrievals of Water Vapor and Aerosol Profiles Over Oklahoma from an Operational Raman Lidar. *J. Atmos. Oceanic Tech.* , **19**, 37-50.

Turner, DD, BM Lesht, SA Clough, JC Liljegren, HE Revercomb, and DC Tobin. 2003. "Dry Bias and Variability in Vaisala RS80-H Radiosondes: The ARM Experience ." *J. Atmos. Oceanic Tech.* **20**, 117–132.

Weckwerth, T. M., D. B. Parsons, S. E. Koch, J. Moore, M. A. LeMone, C. Flamant, B. Geerts, J. Wang, W. F. Feltz, 2003: An Overview of the International H_2O Project (IHOP_2002) and Some Preliminary Highlights. *Bull. Amer. Meteor. Soc.*, **85**, 253–277.

Presentation and Conference References

Clough, SA, JS Delamere, MJ Iacono, EJ Mlawer, MW Shephard, HE Revercomb, DC Tobin, DD Turner, and J-J Morcrette. 2003. "Radiation models for ARM: updates and validations." In *Proceedings of the Thirteenth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, Ed. by D. Carrothers, Department of Energy, Richland, WA.

Clough, SA, JS Delamere, MJ Iacono, EJ Mlawer, MW Shepard, HE Revercomb, DC Tobin, DD Turner, and JJ Morcett. 2003. "Radiation Models for ARM: Updates and Validations." In *Thirteenth Atmospheric Radiation Measurement (ARM) Program Science Team Meeting*, Ed. by D. Carrothers, U.S. Department of Energy, Richland, WA.

Delamere, JS, SA Clough, EJ Mlawer, S Boukabara, and KE Cady-Pereira. 2002. "An Update on Radiative Transfer Model Development at Atmospheric & Environmental Research, Inc." In *Proceedings of the Twelfth ARM Science Team Meeting*, Ed. by D. Carrothers, U.S. Department of Energy, Richland, WA.

DeSlover, D. H., RO Knuteson, DD Turner, DN Whiteman, and WL Smith. 2002. "AERI and Raman Lidar Cirrus Cloud Optical Depth Retrieval to Validate Aircraft-Based Cirrus Measurements." In *Proceedings of the Twelfth ARM Science Team Meeting*, Ed. by D. Carrothers, U.S. Department of Energy, Richland, WA.

Feltz, W. F., R. O. Knuteson, H. B. Howell, R. Petersen, 2001: AERIplus retrieval developments at the SGP, NSA, and TWP sites. *Eleventh ARM Science Team Meeting Proceedings*, Atlanta, Georgia, 19-23 March 2001, Ed. by D. Carrothers, U.S. Department of Energy, Richland, WA.

Feltz, W. F., T. J. Schmit, J. Hawkinson, D. Tobin, and S. Wetzel-Seeman, 2001: Validation of GOES and MODIS atmospheric products and radiances using DOE ARM data. Preprints, *Eleventh Conference on Satellite Meteor. And Oceanography,* 15-18 October, 2001, Madison, WI.

Feltz, W. F., H. B. Howell, H. H. Woolf, R. Tanamachi, R. Torn, J. Mecikalski, and R. O. Knuteson, 2002: AERIplus Retrieval Algorithm Improvements: Increased Vertical Resolution, Automated Moisture Flux, and Turbulence/LES Studies. Twelfth ARM Science Team Meeting Proceedings, St. Petersburg, Florida, 8-12 April 2002, Ed. by D. Carrothers, U.S. Department of Energy, Richland, WA (preprints).

Feltz, W. F., D. D. Turner, R. O. Knuteson, and R. G. Dedecker, 2003: Rapid Scan AERI Observations: Benefits and Analysis. Optical Remote Sensing Conference, Quebec City, Canada, 2-6 February 2003 (preprints).

Feltz, W. F., D. Posselt, J. Mecikalski, G. S. Wade, and T. J. Schmit, 2003: 12 June 2002 June 2002 Rapid Water Vapor Transitions During the IHOP Field Program. Preprints, Symp. On Observing and

Understanding the Variability of Water in Weather and Climate, 9-13 February 2003. Boston, MA, American Meteorological Society,

Feltz, W. F., J. P. Nelson III, T. J. Schmit, and G. S. Wade, 2003: Validation of GOES-8/11 Sounder Derived Products During IHOP 2002 Field Experiment. Preprints, Symp. Twelfth Conference on Satellite Meteorology and Oceanography, 9-13 February 2003. Boston, MA, American Meteorological Society,

Feltz, W. F., R. O. Knuteson, D. D. Turner, R. G. Dedecker 2003: Rapid Scan AERI Observations: Benefits and Analysis. Thirteen ARM Science Team Meeting Proceedings, Denver, Colorado, 31 March - 04 April 2003, Ed. by D. Carrothers, U.S. Department of Energy, Richland, WA (preprints).

Feltz, W. F., H. B. Howell, H. Woolf, D. D. Turner, and R. O. Knuteson, 2003: AERI boundary layer thermodynamic profiling: improvements in vertical and temporal resolution during IHOP and Texas 2002. 6th International Tropospheric Profiling: Needs and Technologies, Leipzig, Germany, (preprints).

Ferrare, R. A., M. B. Clayton, W. F. Feltz, J. A. Ogren, E. Andrews, and D. D. Turner, 2003: Measurements of water vapor and aerosol profiles over the ARM SGP site. 6th International Tropospheric Profiling: Needs and Technologies, Leipzig, Germany, 14-20 September 2003 (preprints).

Knuteson, RO, RG Dedecker, WF Feltz, BJ Osborne, HE Revercomb, and DC Tobin. 2003. "Infrared land surface emissivity in the vicinity of the ARM SGP central facility." In *Proceedings of the Thirteenth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, Ed. by D. Carrothers, Department of Energy, Richland, WA.

Knuteson, R. O., P. Antonelli, F. Best, S. Dutcher, W. Feltz, and H. Revercomb, 2003: Scanning high-resolution interferometer sounder (S-HIS) measurements during the International Water Vapor Project (IHOP). 6th International Tropospheric Profiling: Needs and Technologies, Leipzig, Germany, 14-20 September 2003 (preprints).

Mlawer, EJ, JS Delamere, SA Clough, MA Miller, KL Johnson, TR Shippert, CN Long, MH Zhang, RA Ferrare, RT Cederwall, RG Ellingson, SC Xie, JA Ogren, and JJ Michalsky. 2003. "Recent developments on the broadband heating rate profile value-added product." In *Proceedings of the Thirteenth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, Ed. by D. Carrothers, Department of Energy, Richland, WA.

References

Feltz, W. F., W. L. Smith, H. Ben Howell, R. O. Knuteson, H. M. Woolf, and H. E. Revercomb, 2003b: "Near-Continuous Profiling of Temperature, Moisture, and Atmospheric Stability Using the Atmospheric Emitted Radiance Interferometer (AERI)," *J. of Appl. Meteor.*, **42**, 584-597.

Huang, H.-L. and P. Antonelli, 2001: Application of principal component analysis to high-resolution infrared measurement compression and retrieval. J. Appl. Meteor., **40**, 365-388.

Turner D. D., S. A. Ackerman, B.A. Baum, H.E. Revercomb, and P. Yang, 2003: Cloud phase determination using ground-based AERI observations at SHEBA. *J. Appl. Meteor*, **42**, 701-715.

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