Atmospheric Emitted Radiance Interferometer, Part I: Status, Basic Radiometric Accuracy, and Unexpected Errors and Solutions

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Introduction

Continuous, high spectral resolution, sky emission observations became a reality this year at the Southern Great Plains (SGP) Central Facility. This was made possible by the new operational Atmospheric Emitted Radiance Interferometer (AERI), equipped with a Stirling mechanical cooler that eliminates the need for cryogens to cool the two semiconductor detectors. Installation of the new AERI was eventful also because it led to the detection of a small, but important, radiometric error in the prototype AERI. Fortunately, it was possible to largely remove the error by reprocessing the data from April 1994 onward, using a correction based on comparisons between the new AERI and the prototype gathered in April 1995.

This paper presents information on the status of the AERIs for Atmospheric Radiation Measurement (ARM), information on their basic radiometric calibration accuracy, discussion of the prototype AERI radiometric error and its correction, and a newly identified source of radiometric error that can result from dust on the external scene viewing mirror. An instrument modification designed to essentially eliminate errors from scattering of radiation by a dusty scene mirror is described. Scientific analyses of AERI data relating to aerosol effects and conclusions about accurately establishing the atmospheric state for spectroscopic evaluations are contained in Part II, a companion paper by Knuteson et al. (1996).

AERI Status

The first operational AERI, AERI-01, now provides continuous high spectral resolution (0.5 cm^{-1}) downwelling radiance observations (3.3-19 µm) every 10 minutes from the Central Facility of the SGP Site. Plans are in motion to provide similar observing capabilities from the four SGP Boundary Facilities, from the Tropical Western Pacific (TWP) ARCS, and from the North Slope of Alaska (NSA) and Adjacent Arctic Ocean (AAO) ice sheet. The two instruments for the NSA/AAO will have an extended spectral range (to 24 µm) to allow study of emission by the pure-rotational water band, which shows extensive line structure in the extremely dry conditions of the arctic and is important for defining emission to space from the upper atmosphere. The complement of seven new AERIs will be provided in groups of two to three and will all be installed by mid-1998. Also, automated temperature and water vapor retrievals offering detailed characterization of the boundary layer up to 700 mb every 10 minutes will soon be available from the SGP Central Facility and will be implemented at the other sites as well (Feltz et al. 1996).

Radiometric Accuracy

The AERI radiometric calibration, based on routine observations of two reference blackbodies between every sky view, is capable of very high accuracy (absolute accuracy <0.5% of ambient blackbody radiance, and reproducibility <0.2 %). One hot blackbody and one ambient blackbody are used to avoid the operational difficulties and radiometric errors often associated with maintaining a cold blackbody in humid, ambient environments (Revercomb et al. 1994). The blackbodies are identical, nearly isothermal, cavities with a shape which reduces the painted surface reflectance by about a factor of 13 (0.996 mean longwave emittance, 0.993 shortwave). The nature of the percent radiance errors attributable to the combined uncertainties in the effective temperature and emissivity of the reference blackbodies is shown in Figure 1 for an ambient blackbody temperature of 300 K (near the high end of its range) and a hot blackbody of 333 K (normal SGP AERI). The higher accuracy for scenes near the temperature of the ambient blackbody is caused by the low effective emissivity uncertainties of the ambient blackbody (effective emissivity very near unity), the weak dependence on hot blackbody characteristics (zero at 300 K), and the lack of error growth from extrapolation to lower radiances.

A breakdown of the uncertainties for these accuracy estimates, along with the traceability of the reference blackbody effective temperature to NIST and the effective emissivities to the National Physical Laboratory, England (NPL) is illustrated in Figure 2. The quantities that are directly traceable with transfer standards are 1) temperature (traceable to NIST with a Guildline 9540 Platinum Resistance Thermometer used at UW as a transfer standard), 2) resistance of a set of stable resistors (traceable to NIST through a UW Instrumentation Lab secondary resistance standard), and 3) reflectance of blackbody diffuse black paint witness samples (traceable to NPL via Labsphere measurements with a transfer reflectance standard).

Blackbody temperature measurements are made at three representative points within the cavity wall using YSI 46041 Super-stable Precision Thermistors (<0.01 K drift at 70°C over 100 months) with vendor absolute calibration of 0.05°C. The electronics used to readout the thermistors are calibrated separately with the calibrated stable resistor set, and the complete blackbody temperature readout system is calibrated end-to-end at five temperatures over the range from -40 to +80°C. For these calibration measurements the guildline transfer standard is mounted in an aluminum plug which is conductively coupled to the blackbody cavity. Isothermal conditions are established at each of the five points using a temperature controlled chamber with a thermal isolation container enclosing the blackbody. These end-to-end tests directly account for the effects of thermistor self heating and lead to an absolute accuracy of ±0.03°C, including long-term drift and fitting the calibration coefficients to the data. The purpose of the independent electronics calibration is to allow for the exchange of blackbodies between readout electronics, without any loss of accuracy.

Temperature gradients also contribute to the total uncertainty of the effective temperature of the hot blackbody. The gradients are kept small by thermal design (<0.4°C when running 40°C above ambient), and also are routinely measured using the set of three thermistors in each blackbody. The gradients are characterized and accounted for using test verified thermal models, coupled with optical models of the influence of cavity segments on the total emitted blackbody radiance. It is estimated that after accounting for these effects the uncertainty increases to ±0.04°C.

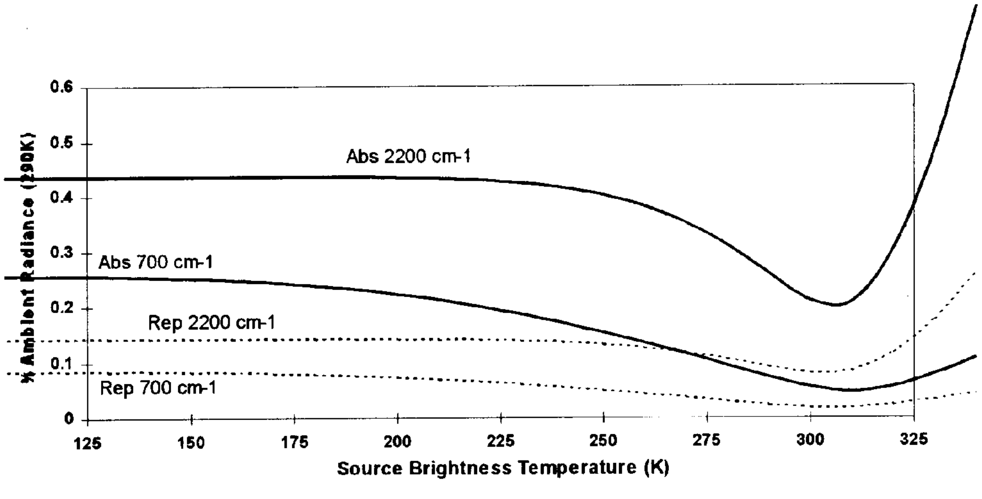

Figure 1. AERI calibration absolute uncertainty (Abs) and reproducibility (Rep) in terms of percent of ambient (290 K) radiance, resulting from reference blackbody effective temperature and emissivity errors.

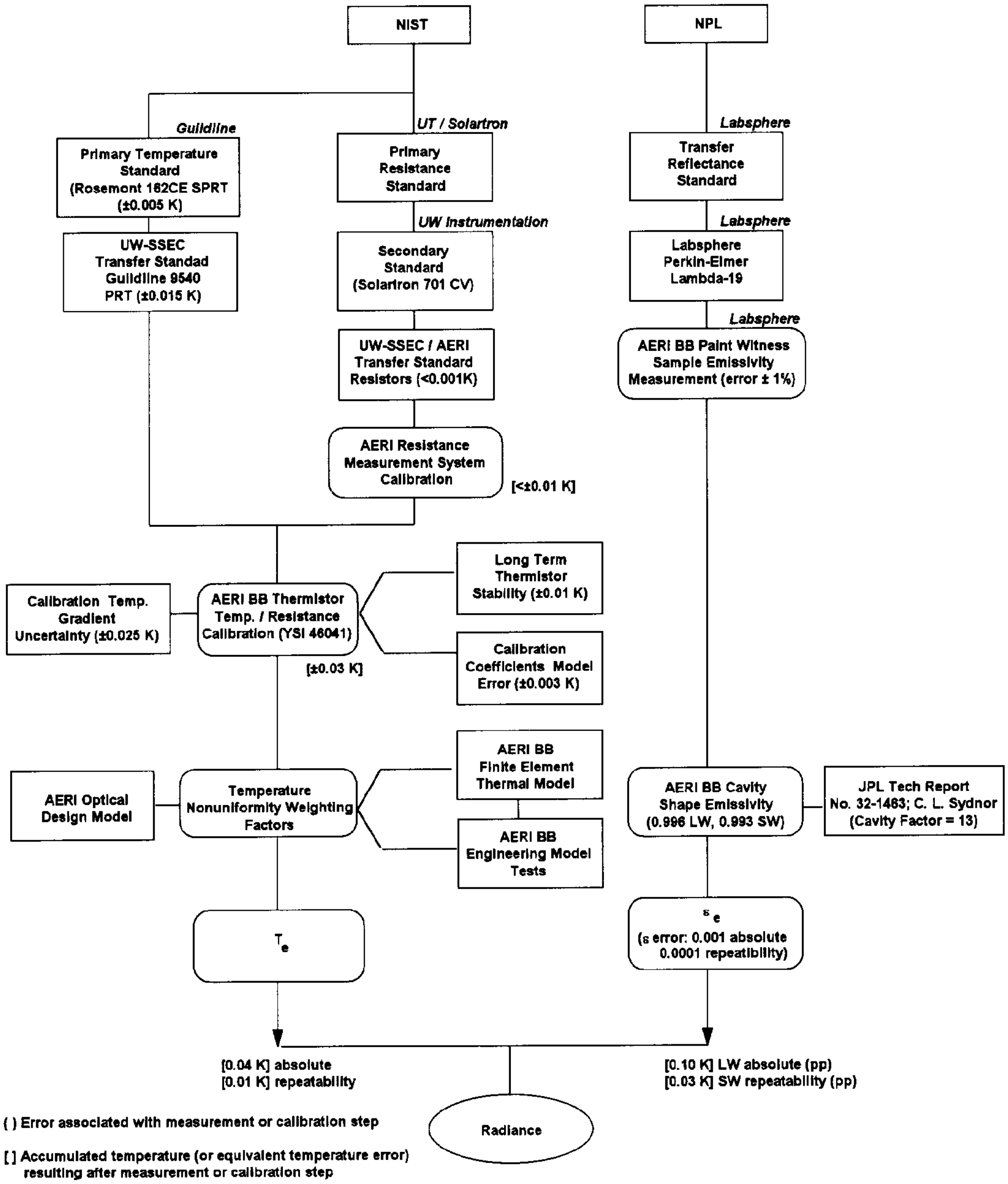

Figure 2. AERI blackbody calibration traceability and error assessment.

Effective emissivity uncertainties for the hot blackbody are somewhat larger than the temperature errors for the longwave regions where a 0.1 % emissivity error corresponds to about an 0.1°C temperature error (about 0.0°3 C for the shortwave region). The emissivity uncertainty is dominated by the uncertainty of the paint emissivity measurements (±1%). Because of the cavity enhancement factor of about 13, this translates into an absolute uncertainty of about ±0.1%. Of course there is uncertainty in the modeled cavity factor, but it is a small contributor.

Other sources of error include longwave band detector non-linearity, and errors associated with scattering which can modify the instrument field-of-view. Detector non-linearity is negligible in the shortwave band and in the longwave band, the order 1% effect is remove by a correction algorithm in the routine processing. The residual uncertainty is expected to be less than 0.2 %. A solution for minimizing the effects of scattering is presented below, which discusses this recently recognized sensitivity. Also, as discussed below, we have experienced radiometric errors on the prototype instrument related to an unexpected obstruction of the sky view. This type of error should be avoidable in the future.

Supporting validation for these uncertainty estimates is provided in Figure 3 by intercomparisons of spectra calibrated using the standard Hot (60°C) and Ambient blackbodies with spectra using Ambient and Liquid Nitrogen blackbodies (not used operationally). The uncertainties associated with these two types of calibration are largely independent for cold sky radiances, because of the large differences in the nature of the liquid nitrogen and the hot blackbodies. The region of elevated differences in the atmospheric window of the longwave band is characteristic of the influence of the thin "cirrus" cloud formed over the liquid nitrogen blackbody (the large, generally zero-mean, differences in the regions 525-575 cm^{-1}, 2320-2380 cm^{-1}, and isolated spikes near 667 cm^{-1} and between 1400 and 1500 cm^{-1} are noise, caused by reduced instrument responsivity from absorption by the zinc selenide windows and gases inside the instrument). In general, the agreement is excellent and in good agreement with expectations.

Prototype Sky View Obstruction and Data Correction

An April 1995 comparison of the AERI-01 to the prototype led to the discovery of an unexpected obstruction to the sky view of the AERI-00, as configured at the SGP, that caused erroneously large window region radiances (about 2 to 4% of ambient radiance). Fortunately, the obstruction was stable and it has been possible to correct existing data from the SGP to eliminate the error over the time period from April 1994 to July 1995. However, this radiometric error did lead to an erroneous conclusion about aerosols in our 1995 Science Team paper (Revercomb et al. 1995). Because expected calibration errors are much smaller than 2 to 4% (Section 3) and because a series of tests failed to find any calibration or other radiometric problems, these generally elevated window region radiances were attributed to the ubiquitous presence of aerosols at the SGP CART site. Our reassessment of aerosol signatures in AERI data, based on the corrected AERI-00 data, is included in Part II (Knuteson et al. 1996).

Since a detailed description of the correction process and accuracy is available from the ARM Experiment Center along with the corrected data set, only a brief summary is included here. Basically, the simultaneous clear sky observations of the two instruments with the obstruction unchanged was used to define the effective area of the obstruction. The effective radiating temperature of the obstruction was estimated with sufficient accuracy from temperature measurements close to the scene mirror and at the top of the sky viewing enclosure. The uncertainties in this process are reasonably small, because the enclosure surrounding the source of the obstruction was quite isothermal.

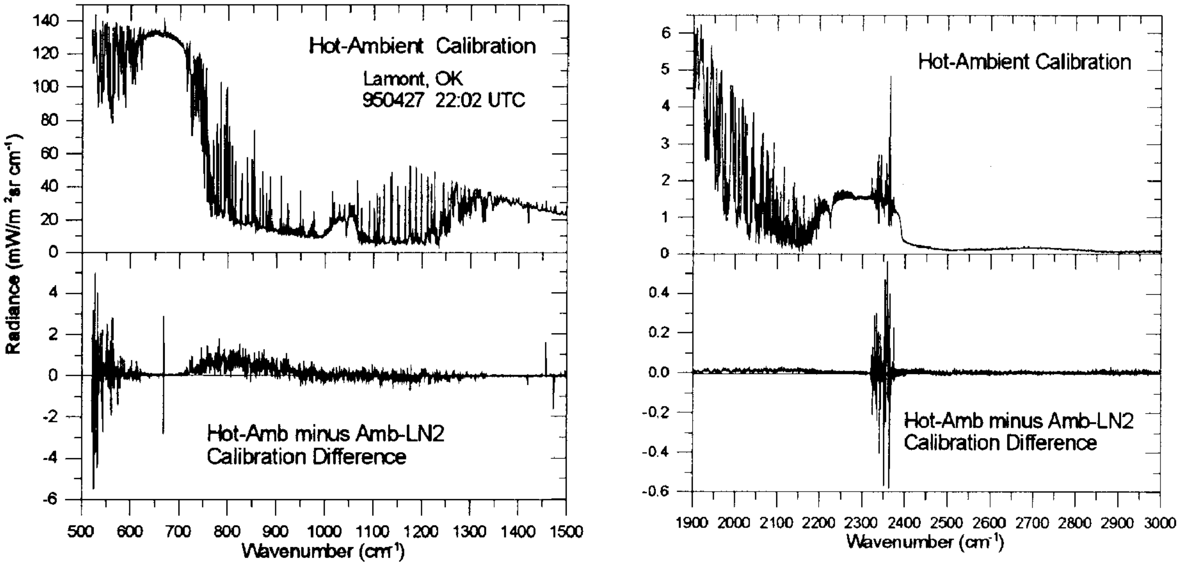

Figure 3. Comparison of AERI-01 spectrum calibrated using the standard hot and ambient blackbodies to that calibrated using liquid nitrogen and ambient blackbodies.

Overall, conservative estimates show that the uncertainty in the correction causes errors that are less than 1% of the ambient blackbody radiance, and should not be important for most applications of the data.

Unanticipated AERI-01 Error Source and the Solution

Comparisons of the new operational AERI-01 with the AERI-00 prototype from May to July 1995 (obstruction removed) generally showed excellent agreement. This gave us confidence that both instruments were working properly.

However, as the year progressed beyond summer into the dryer atmospheres of autumn, the window radiance did not appear to drop to levels as low as expected from past observations. Upon investigation, we found a gradual decline in the instrument responsivity, and a trip to the SGP site showed the reason to be a heavy layer of accumulated dust on the external scene viewing mirror. A loss of responsivity itself would not compromise the AERI calibration, since it is routinely calibrated for every sky view. But, for this dusty scene mirror case, the loss of responsivity is accompanied by scattering that enlarges the field of view. This was shown to lead to an error, because the source of scattered radiance changed as the scene mirror was moved to view the calibration blackbodies. The enhanced exposure of the AERI-01 to dust accumulation is a consequence of its new configuration in which the calibration subsystem extends through the wall of the Optical Trailer to minimize the perturbation of the atmospheric gas column being observed. The short-term solution to eliminate the problem (which grew to about 4% in the longwave window) was to clean the mirror and a new mirror was actually installed on 29 December 1995.

The long-term solution, which will also help deal with diamond dust at the NSA site and with sea spray in the TWP site, has been largely implemented at the SGP site. It involves two fundamental principles; first, protecting the scene mirror and calibration sources from contamination, and second, providing matched field-of-views (FOVs) to the sky and to the blackbodies. Matching the FOVs will minimize the effects of any scattering, because it will result in nearly equal scattering contributions from calibration and sky views that are eliminated in the calibration process. The implementation consists of a cylindrical “can” with a viewing hole, mounted on and moving with the scene mirror shaft and a new sky FOV limiter at the same distance from the scene mirror and of the same size as the blackbody apertures. The can both provides the scene mirror with protection from contamination and creates a reasonably isothermal source for any scattered radiation. In addition, the can is “sealed” with a close tolerance to the blackbodies, thereby providing constant dust protection for the blackbodies (the can seals off the blackbodies when the sky is viewed and seals from the ambient environment when the blackbodies are viewed). We also plan to implement a periodic mirror cleaning procedure, possibly guided by monitoring the responsivity (a standard AERI product).

Summary

The AERI is proving to be a robust operational instrument at the SGP site and a valuable record of data extending back to April 1994 already exists for science analyses. Our conclusions about aerosols and water vapor are reported in Part II (Knuteson et al. 1996) and the status of the UW temperature and humidity retrievals from AERI are reported in Feltz et al. (1996). The AERI radiometric calibration has been proven to be very accurate, in general; two pitfalls which could compromise the performance in ARM field applications have been recognized and solutions incorporated. We look forward to exciting new data sets as more AERIs come on line at the boundary sites of the SGP CART, at the TWP, and at the NSA/AAO over the next couple of years.

References

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