Calibration of ARM Spectral Shortwave Radiometers

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Abstract

Absolute calibration of spectral shortwave radiometers is typically performed using National Institute of Standards & Technology (NIST) or NIST-traceable spectral lamps. In this paper, we compare 18 spectral irradiance lamps from NIST and three commercial vendors all using the same spectrometer to assess their agreement with each other and the NIST standards. The NIST procedure is followed for the 1000W FEL lamps from NIST, Optronics, and EG&G. A modified calibration procedure developed by LI-COR is followed for their 200W tungsten-halogen lamps. Results are reproducible from one day to the next to about 0.2% using the same spectrometer. Measurements taken four months apart using two similar, but different spectrometers were reproducible to 0.5%. The comparisons suggest that even NIST standards may disagree with each other well beyond their stated accuracy. Some of the 1000W commercial lamps agreed with the NIST lamps to within their stated accuracy, but not all. Surprisingly, the lowest cost lamps from LI-COR agreed much better with the NIST lamps than their stated accuracy of 4%, typically within 2%. We conclude that we can transfer the calibration from a standard lamp to a spectral radiometer with about 2% added uncertainty.

Introduction

The broadband measurements in the Atmospheric Radiation Measurement (ARM) Program and elsewhere have painted a fairly consistent picture of an overestimation of shortwave radiation by clear-sky models relative to the best shortwave measurements available (e.g., Kato et al. 1997). Key to resolving this discrepancy is to find where in the shortwave spectrum the model overestimates occur. To this end, we require very accurate spectral irradiance measurements throughout the shortwave. Central to good spectral measurements is careful calibration of the instruments and then proper operation in the field.

A first attempt to compare ten calibration lamps of two different types from three manufacturers yielded results that were typically far apart in some parts of the spectral range between 400 nm and 1050 nm, even though the lamps were stated to be accurate to 4% or better in this spectral range. Figure 1 is a comparison of these ten lamps by ratioing the stated spectral irradiance of the one NIST lamp that we had in August 1997 to the manufacturer's stated spectral irradiances of their lamps. One EG&E lamp (GS0939) is within 1% of the NIST standard, but only for the 400 to 700 nm range. LI-COR 200W lamps operated in the ASRC LI-COR calibrator show a nearly constant offset with wavelength, but are close to their stated 4% accuracy.

We report here on a second, more careful and extensive study to resolve the issues regarding absolute spectral calibration in December 1997. We compared thirteen 1000W FEL lamps, including four NIST standards, four from EG&G, a manufacturer of secondary standards, and five secondary standards from Optronics. We also compared to the NIST group a set of five LI-COR 200W quartz-halogen lamps operating at conditions different from the NIST recommended configuration, but presumably equivalent to it.

Comparison of 1000W FEL Lamps

At the beginning and end (and sometimes in the middle) of each day of the December comparison, we measured the sensitivity of our 512-channel diode array spectrometer to the spectral irradiance of one or two lamps. Figure 2 contains plots of these ratios for the 4 days of the comparison. In general, the ratios are within 0.1 to 0.2%. This demonstrates the stability of the power supply and the output of the lamp, the stability of the spectrometer, and our ability to position the lamps at the same distance with the same orientation.

Based on the relative agreement among three of the NIST lamps (403, 404, and 405), we took their average responsiveness in counts/Wm^{-2} nm^{-1} to develop a working standard for these comparisons. Figure 3 shows the ratio of the working standard irradiance to each of the four NIST

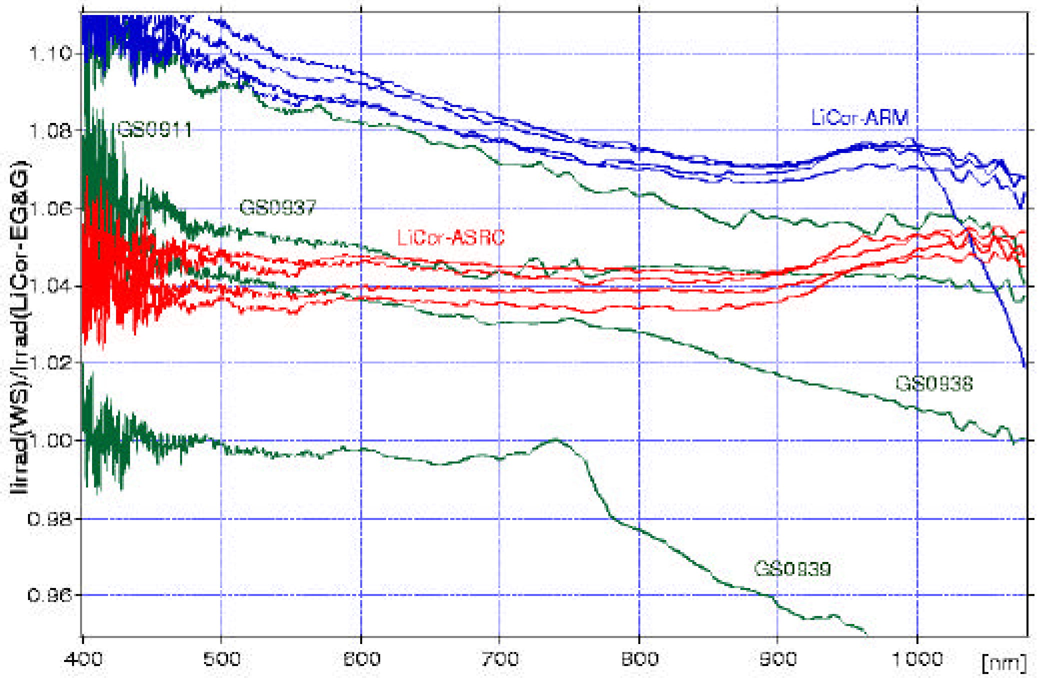

Figure 1. Ratio of NIST standard lamp F340 irradiance to irradiance of nine secondary sources in August 1997 run. (For a color version of this figure see *http://www.arm.gov/docs/documents/technical/ conf_9803/michalsky-98.pdf*).

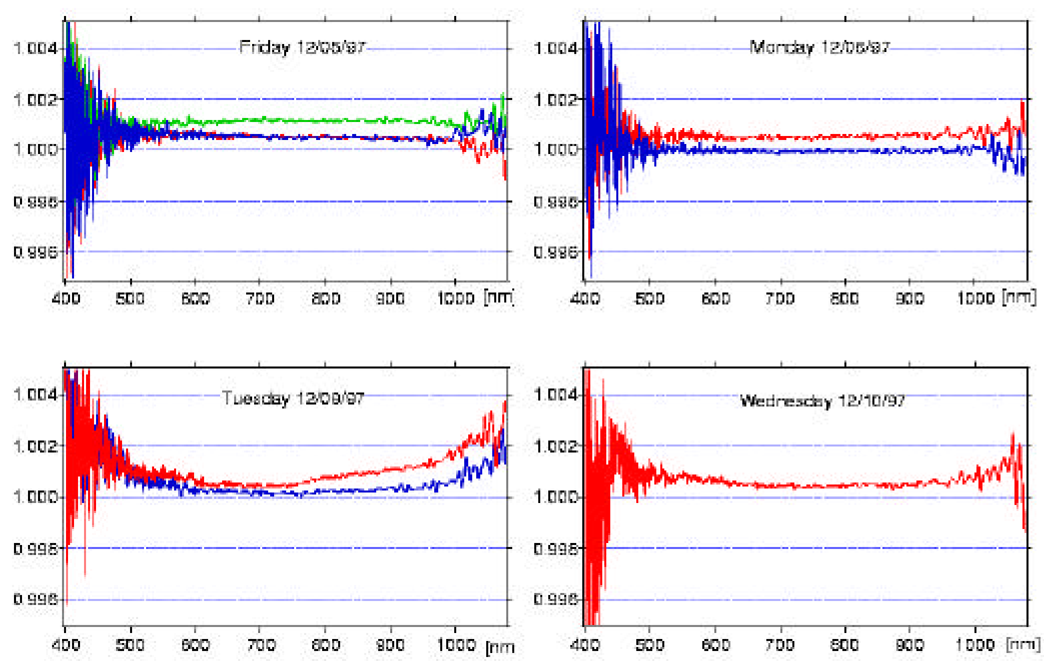

Figure 2. Ratio of spectral sensitivity in counts/Wm^{-2} nm^{-1} at beginning and end of each day's run for one or two lamps. (For a color version of this figure see *http://www.arm.gov/docs/documents/technical/conf_9803/ michalsky-98.pdf*).

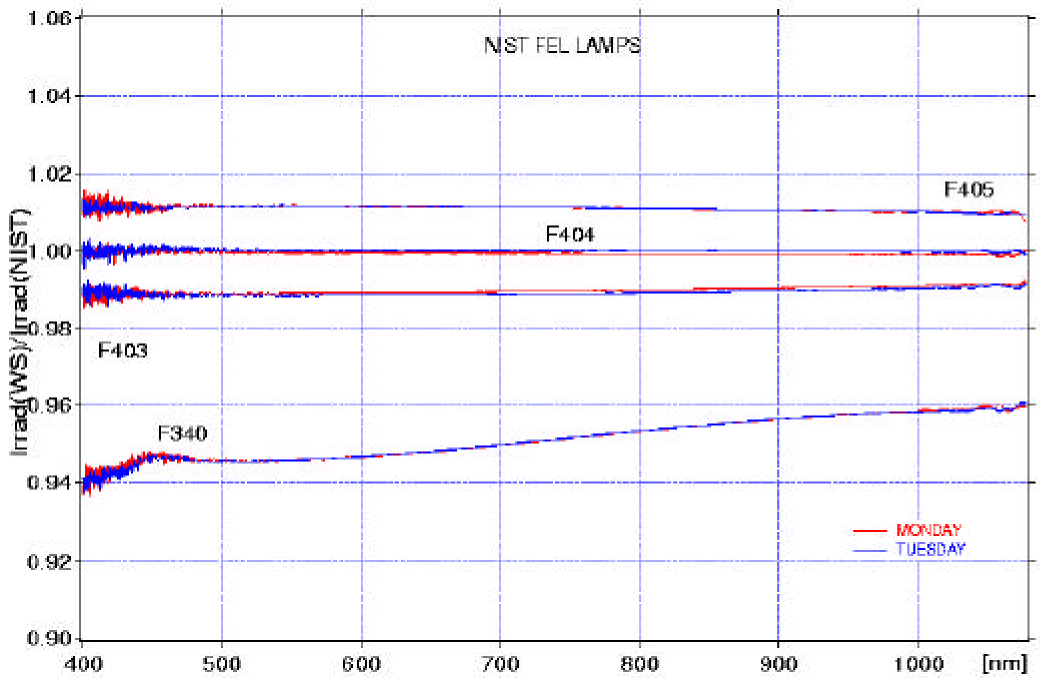

Figure 3. Ratio of NIST working standard irradiance to each NIST lamp irradiance. Two colors for two different days. (For a color version of this figure see *http://www.arm.gov/docs/documents/technical/conf_9803/michalsky-98.pdf*).

lamps. Lamps 403, 404, and 405 are almost within 1% of the working standard. This should not be much of a surprise because these three lamps serve as the basis for the working standard, but it does confirm that they are consistent. Since the NIST uncertainty at the two standard deviation levels is about 1.1% or smaller over these wavelengths, lamp 340 is clearly an outlier with variations with wavelength between 4% and 6%. This lamp was the standard adopted in Figure 1 of this paper, thus explaining many of the discrepancies in that figure. The red and blue lines represent the experiment on two different days, leading one to conclude that these results are repeatable to about 0.2%.

Optronics and EG&G buy NIST standard lamps and use them to calibrate 1000W FEL lamps to sell as secondary standards to customers. These are calibrated following the NIST recommended procedures of positioning the lamps at 50 cm from the spectrometer used for calibration transfer. Conditions are the same other than the fact that the lamps from these two companies operate at a slightly lower constant current of 8.000 amps versus the NIST lamps that operate at 8.200 amps.

The company states a transfer accuracy of about 1%, which yields an overall uncertainty of about 1.6% when added to the NIST uncertainty.

Figures 3 and 4 are similar in that Optronics lamps are compared to the working standard based on the three NIST lamps. Three of the lamps are within 2% of the NIST and show a constant offset with wavelength. A fourth and a fifth lamp show a similar wavelength dependence, i.e., almost neutral, but with a 3.5% and 8% offset. One could conclude that three lamps are ‘close enough’ although they fall outside the expected 1.6% uncertainty, but the other two are clearly outliers. It would seem that if one buys a single lamp from NIST or Optronics, one cannot conclude with much conviction the accuracy about measurements because there are outliers from both sources.

Figure 5 is a plot similar to Figures 3 and 4, except that it covers the four FEL lamps that we tested from EG&G Gamma Scientific. GS937 falls within the expected uncertainty limits at all wavelengths and is nearly independent of wavelength. GS911 and GS938 are within the uncertainty limits at some wavelengths, but not others and their wavelength dependencies are similar, but offset from one another by about 4%. GS939 is clearly an outlier, reinforcing the previous conclusion that a single lamp does not give one confidence in the verity of that lamp. The blue and red lines represent the experiment repeated with a 4-month interval between runs with different spectrometers of the same design. The results are reproducible at the 0.5% level on average.

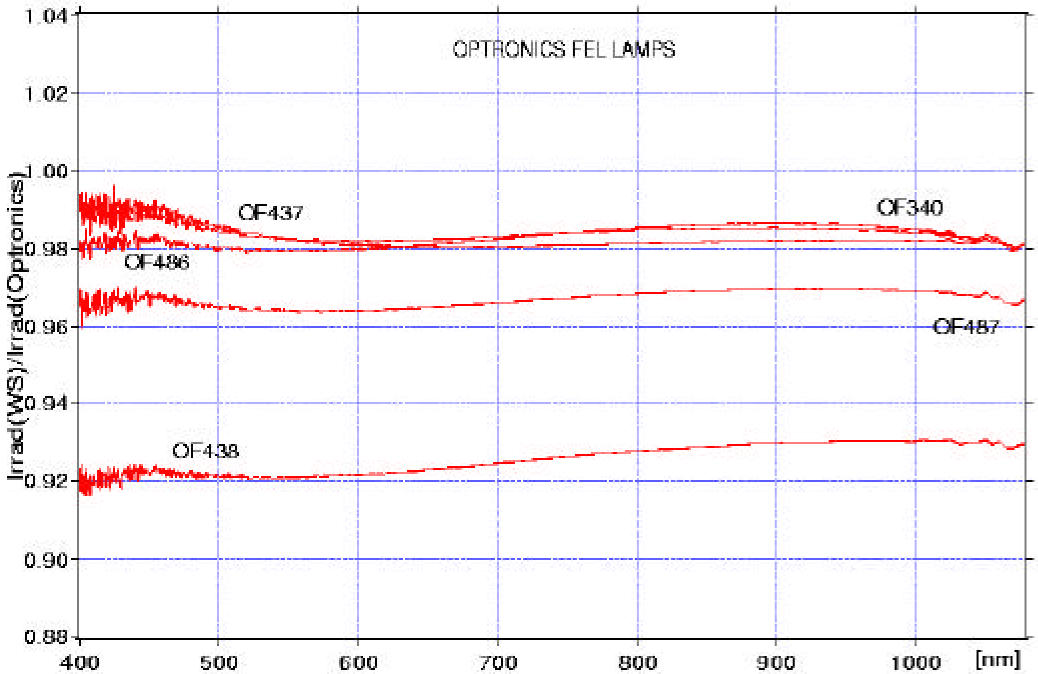

Figure 4. Ratio of NIST working standard to each Optronics 1000W FEL lamp tested. (For a color version of this figure see *http://www.arm.gov/docs/ documents/technical/conf_9803/michalsky-98.pdf*).

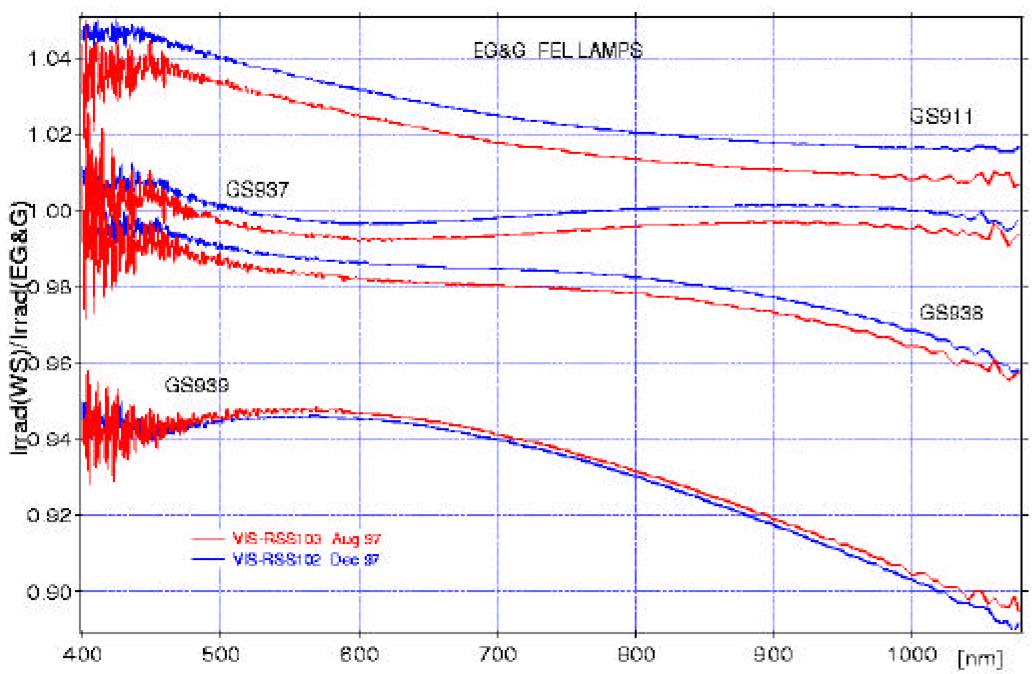

Figure 5. Ratio of NIST working standard to each EG&G 1000W FEL lamp tested. Two colors are from tests 4 months apart using different, but similar spectrometers. (For a color version of this figure see *http://www.arm. gov/docs/documents/technical/conf_9803/michalsky-98.pdf*).

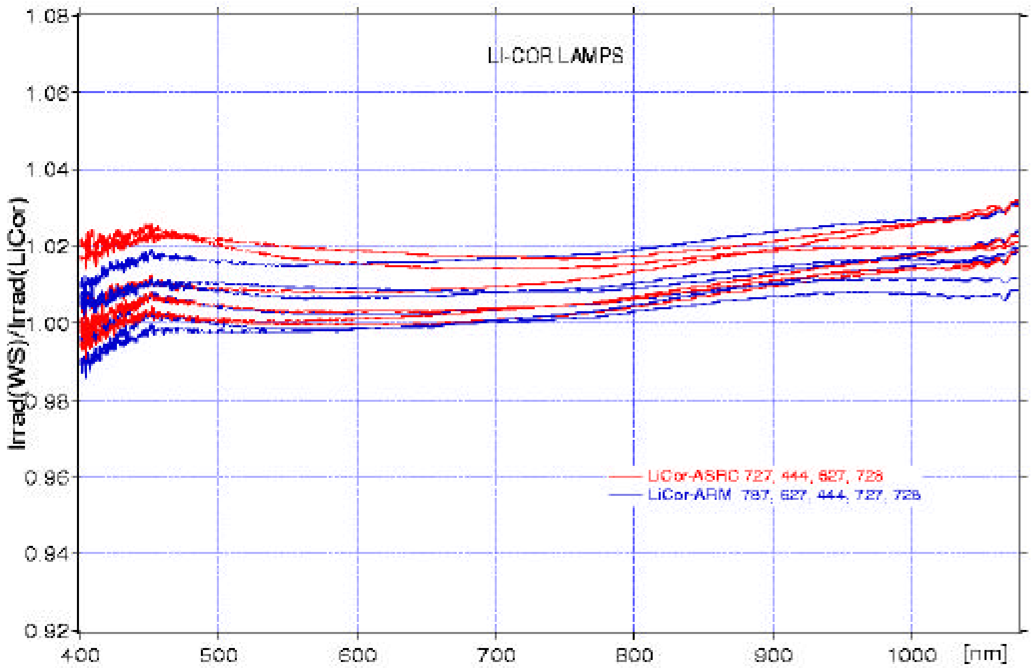

Figure 6. Ratio of NIST working standard to several LI-COR 200W tungsten-halogen lamps in two different LI-COR calibrators. (For a color version of this figure see *http://www.arm.gov/docs/documents/technical/conf_9803/michalsky-98.pdf*).

Comparison of 200W LI-COR Lamps

LI-COR has developed a self-contained optical radiation calibrator. The lamp used is a 200W tungsten-halogen cycle lamp that operates at constant power. The operating distance from the filament of the lamp is 20 cm, which is about 11 mm beyond the front surface of the box allowing adaptor plates to be built that will hold the detector rigidly at the fixed 20-cm distance. Within the box are the power supplies, electronics, and baffles to reject extraneous light.

As seen in Figure 1, the LI-COR calibrator labeled Atmospheric Sciences Research Center (ASRC) and the one labeled ARM gave very different results. It was found upon return to the factory that the shunt resistor used to measure current in the ARM unit was out of tolerance and was subsequently replaced. The LI-COR lamps operating in two different calibrator housings compared to the working standard is displayed in Figure 6.

The mean bias error from the working standard is only about 1% with all values within 3% for this wavelength range. The stated uncertainty of these lamps is 4%. There is no outlier and the lamps seem to operate equivalently in either calibrator housing.

Summary and Conclusions

Adopting three reasonably consistent NIST lamps as a working standard, we have compared 18 irradiance standards from four manufacturers using a diode-array spectrometer. One NIST lamp was outside the uncertainty limits set by NIST using this working standard. All of the Optronics lamps were outside the uncertainty using this working standard, although three of the five were close and were almost independent of wavelength. Three of the four EG&G lamps were outside the uncertainty limits at some or all the wavelengths. Finally, the LI-COR lamps were all within their stated uncertainty using both calibrators.

We also addressed a few other issues that contribute uncertainty at the 0.5% or smaller level. Out-of-band rejection was estimated using laser lines to measure the slit function. We estimate less than 0.2% error from this source. Linearity was not tested. We noticed a very slight instability in the wavelength registration of the spectrometer that is correctable to 0.5% or better. We looked at temperature effects on the spectrometer foreoptic, which appears to be around a 0.2% effect. Based on these effects and those discussed in the paper, we estimate our ability to transfer a calibration to a field instrument at the 2% level. The measurement uncertainty is larger since the uncertainty of the lamp output must be added to this. Finally, we are investigating the accuracy of field calibration based on a robust estimate using a number of Langley calibrations that may rival or exceed lamp calibration accuracy.

Reference

Kato, S., T. P. Ackerman, E. E. Clothiaux, J. H. Mather, G. G. Mace, M. L. Wesely, F. Murcray, and J. Michalsky, 1997: Uncertainties in modeled and measured clear-sky surface shortwave irradiances. *J. Geophys. Res.*, **102**, 25,881-25,898.