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Issues in Absolute Spectral Radiometric Calibration: Intercomparison of Eight Sources

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1. Introduction

The application of atmospheric models to AVIRIS and other spectral imaging data to derive surface reflectance requires that the sensor output be calibrated to absolute radiance (Green et al, 1996; Chrien et al, 1996; Gao et al, 1993). Uncertainties in absolute calibration are to be expected, and claims of ±2% accuracy have been published (Chrien et al, 1996). Measurements of accurate surface albedos and cloud absorption to be used in radiative balance calculations depend critically on knowing the absolute spectral-radiometric response of the sensor. The Earth Observing System project is implementing a rigorous program of absolute radiometric calibration for all optical sensors (Butler and Johnson, 1996a) Since a number of imaging instruments that provide output in terms of absolute radiance are calibrated at different sites, it is important to determine the errors that can be expected among calibration sites. Another question exists about the errors in the absolute knowledge of the exoatmospheric spectral solar irradiance (Nekel and Labs, 1984).

2. Data collection

In order to determine the extent of agreement among laboratory radiometric standards, we performed a round robin set of measurements with an Analytical Spectral Devices Inc. (ASD) FieldSpec™-FR spectroradiometer (www.asdi.com), that covers the range 350-2500 nm continuously to determine the agreement among radiometric sources at several NASA centers, Los Alamos National Lab and the University of Arizona. Both spheres and illuminated panels were measured and compared to the NIST-traceable radiance values documented for the sources.

2.1 Instrument calibration

The FieldSpec was calibrated using a NIST-traceable standard 1000 W quartz halogen lamp, controlled by a regulated power supply (Optronics Laboratories) placed 50 cm from a 10" x 10" Spectralon® (Labsphere Inc.) panel and viewed at 45° from the panel normal. The FieldSpec instrument feeds light through an optical fiberbundle with an acceptance angle of 25°. The irradiance from the bulb at the flat panel is not uniform because the bulb is emitting a spherical waveform. Instrument no. 607 was used throughout the study that extended from February through September 1997. Calibration at the ASD factory was repeated five times from October 1996 through September 1997. In September 1997, the error associated with the non-uniform panel illumination was discovered and the fiberoptic bundle was moved toward the panel until no further change in radiance was noted. The absolute error of the earlier measurements amounted to 3.5% and all these were corrected accordingly. The precision of the corrected measurements, as defined by the RMS error, was better than ± 2% at wavelengths greater than 500 nm. At shorter wavelengths, the error increased (fig. 1).

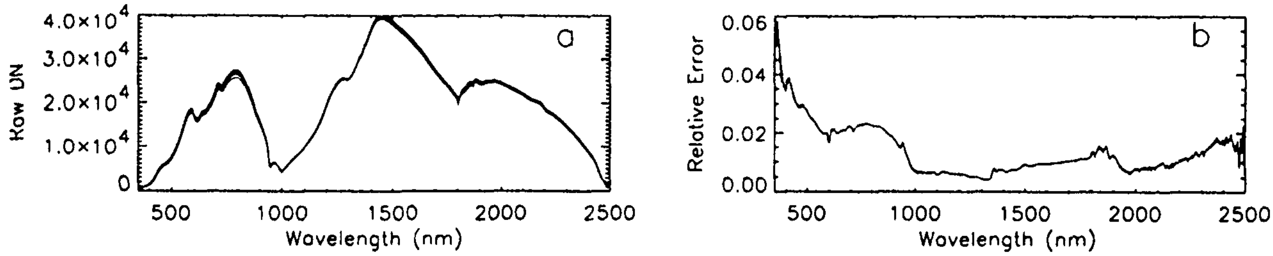

Fig. 1. (a) Raw DN plots of the five calibrations of FieldSpec no. 607 made between October 1996 and September 1997. (b) RMS calibration error derived from the five calibration spectra plotted in (a).

In each of the measurements described below, ASD calibration closest in time was used for comparison. The instrument was switched on at least 90 minutes before each measurement. A measurement consisted of an average of 50-100 ms spectra and 50 dark measurements. The VNIR data were corrected for the temperature-sensitive gain in the 750-1000 nm region with a parabolic fitting routine called "pcorrect" (www.asdi.com)

2.2 Los Alamos National Laboratory

Two visits on April 8 and May 29, 1997 were made to the DOE Los Alamos National laboratory (LANL) to measure the sphere being used to calibrate the MTI optical sensor. The 30 cm diameter sphere was constructed and calibrated by Labsphere Inc. and subsequently recalibrated by NIST. The FieldSpec fiberoptic was positioned 6 cm from the sphere entrance. The sphere was then rotated 14 degrees from normal to match the calibration configuration at both Labsphere and NIST. The sphere is continuously flushed with dry nitrogen. Figure 2 shows the ratio of the two different measurements made 51 days apart showing a precision of 1% or better at wavelengths longer than 600 nm.

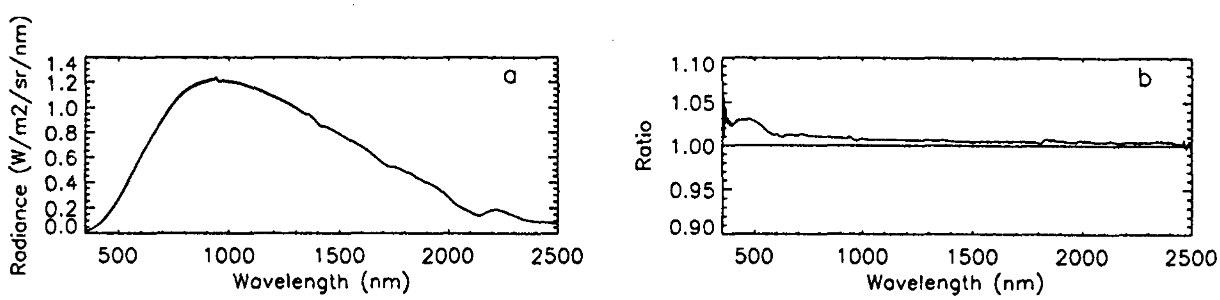

Fig. 2. (a) Radiance of the LANL sphere taken 51 days apart. (b) Radiance of the radiance spectra.

The absolute measurements, however, show greater differences. The calibration for the wavelengths covered are given for only 19 points chosen by NIST and Labsphere. In contrast the FieldSpec provides data at 1194 wavelengths before resampling to 1 nm intervals. Figure 3 shows the 19 values measured by Labsphere and NIST as well as the continuous spectrum measured with FieldSpec. The Labsphere and ASD measurements are nearly identical between 500 and 2300 nm. The greatest discrepancy between the ASD measurements and the NIST prediction is 5% between 500 and 2000 nm. The continuous spectrum shows significant departures from the values interpolated between the 19 points, particularly near 2200 nm.. These are associated with the spectral reflectance of Spectralon® and, if not accounted for, could cause the Spectralon spectral features to be superimposed on sensor data.

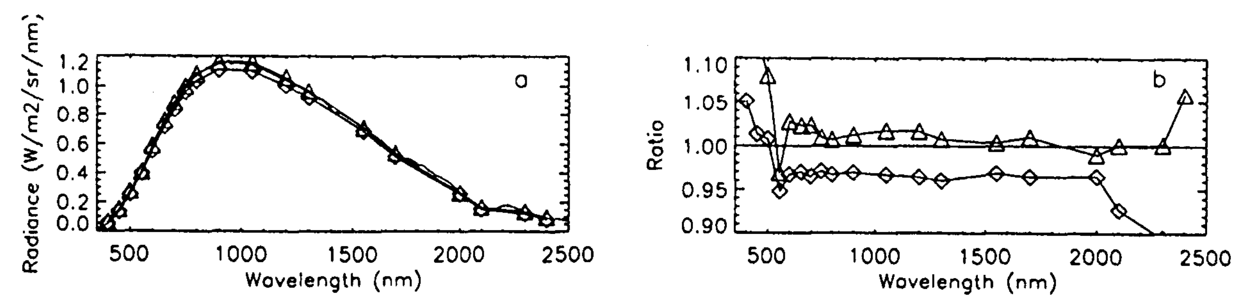

Fig. 3. (a) Radiance measured from the LANL sphere. Squares represent the NIST calibration, triangles the Labsphere calibration and the continuous curve the ASD FieldSpec. (b) Ratios of the Labsphere and NIST calibrations against the ASD FieldSpec measurement.

2.3 Jet Propulsion Laboratory

At the NASA Jet Propulsion Lab (JPL), measurements were made of the AVIRIS laboratory lamp and Spectralon standard on June 4, 1997. The setup, including lamp and power supply, is equivalent to the ASD calibration configuration. This setup differs in geometry from the AVIRIS ER-2 field calibration system (Chrien et al, 1996) and we were not able to measure the AVIRIS calibrator successfully. The comparisons of the JPL and ASD FieldSpec measurements are shown in figure 4. The agreement is better than 2% between 700 and 2500 nm but departs significantly at shorter wavelengths.

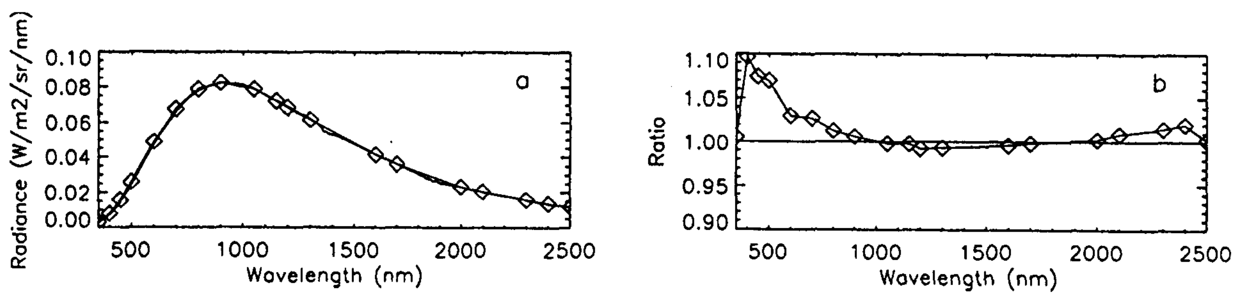

Fig. 4. (a) Radiance from the JPL lamp and Spectralon panel. The lamp calibration, traceable to NIST, is represented by squares and the continuous curve is the ASD FieldSpec measurement. (b) Ratio of the measurement and calibration values.

2.4 Goddard Space Flight Center

The Goddard Space Flight Center (GSFC) was visited on June 13, 1997. At GSFC there are three different spheres used for calibration of a variety of imaging instruments. The largest is approximately 1.8 m in diameter containing 12 lamps of 200W each, and coated with barium sulfate. The second is a 1.2 m diameter hemisphere, coated with barium sulfate and containing 12 lamps of 100 W each. The SeaWifs calibration sphere is 1.2 m in diameter and also coated with barium sulfate.

The 1.8 m sphere and the hemisphere have continuous calibration with wavelength, while the SeaWifs sphere is only calibrated to 1160 nm. The FieldSpec-measured and calibration values provided by GSFC are shown in figure 5. These spheres were not flushed with dry nitrogen and the effects of the humidity are dramatic. The fact that a photon that exits the sphere has been scattered off the sphere wall many times, adds as much as 50 m to the path the photon travels through the atmosphere. In the ratio plot of the 1.8 m sphere /FieldSpec comparison, the atmospheric O_2 absorption at 762 nm is visible. Water vapor features affect the majority of the SWIR spectrum which argues strongly for dry gas flushing of the large spheres. In both the sphere and the hemisphere plots, the disagreements are greater than 5% in the visible region of the spectrum and greater than 10% in and around the water vapor absorption features.

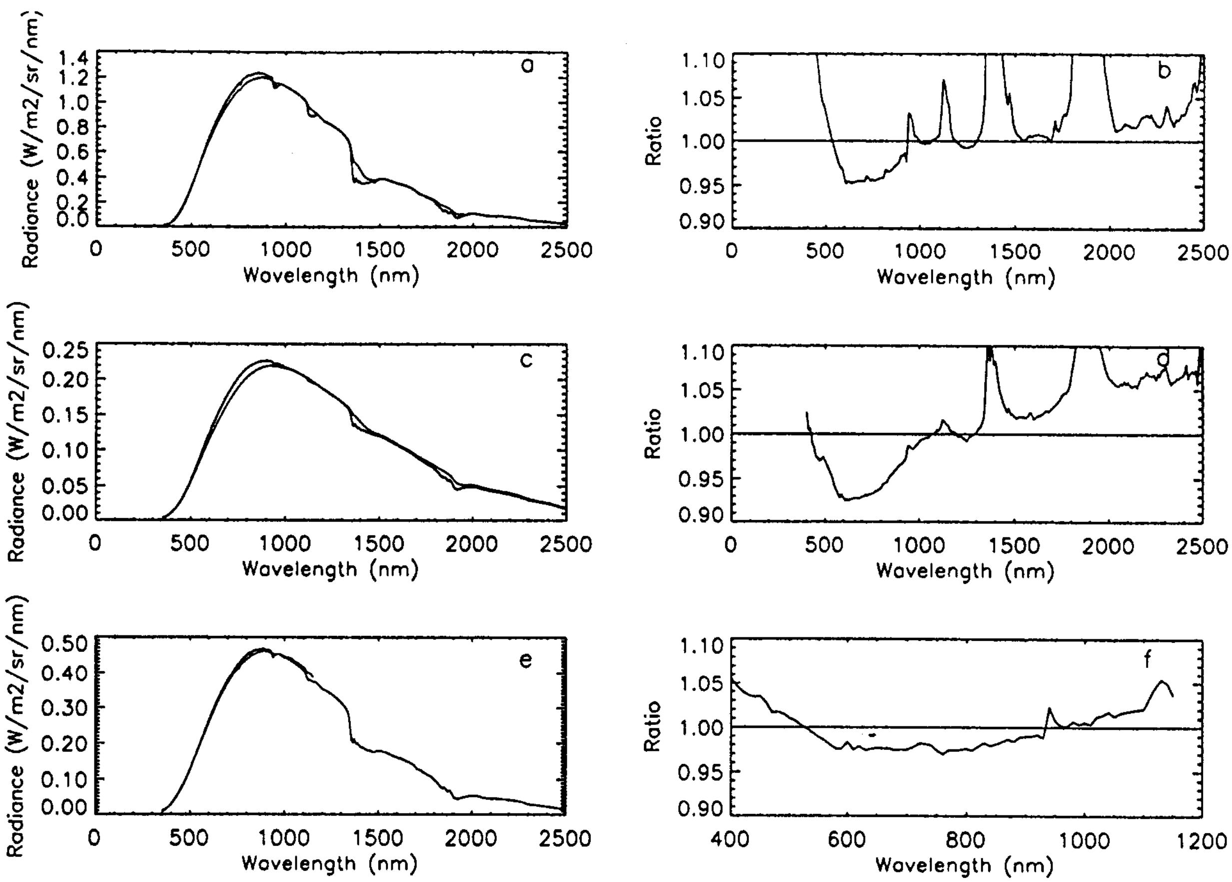

Fig. 5. Measurements of three GSFC spheres with the accompanying calibration values on the left and the ratio of the values on the right. The measurements were taken on a very humid day.

2.5 University of Arizona

The University of Arizona (U of A) calibration laboratory is located in the Optical Sciences Center. Measurements were made on September 22, 1997. The U of A sphere contains 10-150 W bulbs and two quantum efficiency transfer radiometers. This facility is one taking part in the EOS calibration round-robin (Butler and Johnson, 1996b). The laboratory is equipped with VNIR and SWIR filter radiometers that have been calibrated against a NIST standard bulb. Figure 6 shows the comparison of the sphere radiance as measured with the filter radiometers covering 16 wavelengths and the ASD Fieldspec. The ratio plot shows that there is a significant and consistent disagreement of 5 to 12% throughout the spectral region. The cause of this disagreement is not understood.

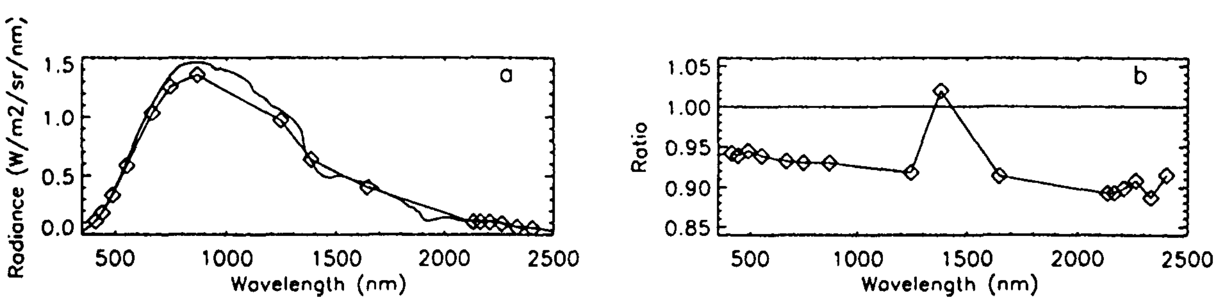

Fig. 6. (a) Measurements and calibration values for the University of Arizona sphere. (b) Ratio of the U of A values and the ASD FieldSpec measurements.

2.6 Ames Research Center

In February, 1997, 2 spheres and two standard lamp-panel combinations were measured. An Epply standard lamp calibration determined from the ASD FieldSpec measurement was used to calibrate the Solar Spectral Flux Radiometer (SSFR). Measurements of downwelling spectral irradiance at 21 km were made with the SSFR mounted in the ER-2. Figure 7 shows the measurement as compared to the MODTRAN-modeled irradiance (Anderson et al, 1995; Berk et al, 1989). For comparison, the top-of- atmosphere (TOA) irradiance is also plotted (Nekel and Labs, 1984). The agreement between the modeled and measured irradiances is better than 5% longward of 500 nm.

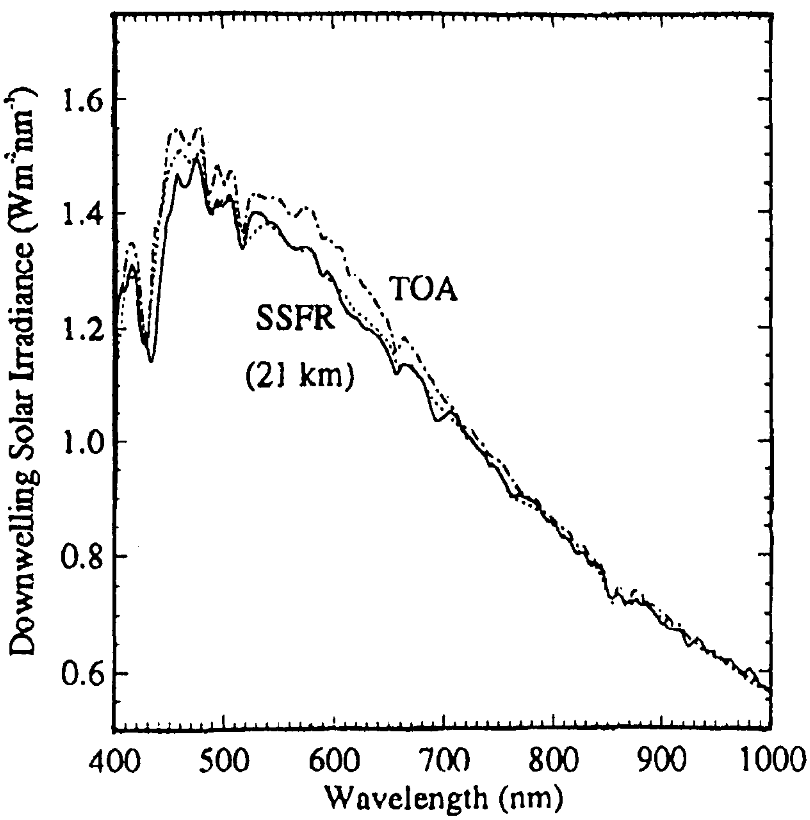

Fig. 7. Downwelling solar irradiance as measured from the ER-2 at 21 km altitude with the NASA Ames Research Center SSFR scanning spectrometer (solid). The dashed line is the exoatmospheric solar irradiance (Nekels and Lab, 1984) and the dotted line the MODTRAN modeled irradiance.

3. Summary and conclusions

The informal round robin measurement of radiometric sources conducted here shows the relative accuracy in absolute calibration of important sources for image sensor calibration is variable but usually within ±5% at wavelengths longer than 500 nm. However, interpolating radiance values between the NIST standard wavelengths can lead to significant errors for instruments like AVIRIS that cover the entire spectral range continuously. The measurements were made possible by the availability of a long-term precise, portable spectroradiometer.

Spheres, especially large ones, have variable output in the spectral regions affected by water vapor absorption. These spheres should be flooded with dry nitrogen to eliminate absorption and to keep water from being adsorbed in the barium sulfate coating. The discrepancies in the U of A sphere measurements have yet to be understood. Since all the other measurements were closer by approximately a factor of two, the discrepancy is particularly puzzling.

4. Acknowledgments

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