Inflight Calibration Experiment Results for AVIRIS on the 6th of May 2002 at Rogers Dry Lake, California

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INTRODUCTION

Calibration of any optical remote measurement is required in order to: 1) extract information directly from the measured spectral radiance, 2) compare measurements acquired at different times and from different regions, 3) compare measurements with measurements from other instruments, and 4) derive information from measurements using physically based computer models.

The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) (1998a) measures the total upwelling spectral radiance in the spectral range from 370 to 2510 nm at ~10 nm sampling and spectral response function. These spectra are measured as images with a 20 by 20 m spatial resolution and an 11 km swath with up to 1000 km image length from NASA’s ER-2 aircraft flying at 20 km altitude. On the Twin Otter aircraft flying at 4 km altitude, the spatial resolution is 4 by 4 m with a 2 km swath and up to 200 km image length. Each year AVIRIS is spectrally, radiometrically, and spatially calibrated in the Laboratory (Chrien et al. 1990, 1995, 1996, 2000).

Laboratory calibration and characterization is essential, but not sufficient to assure that measurements acquired in the operational airborne environment are calibrated. To assess and validate the calibration of AVIRIS in the flight environment an inflight calibration experiment is orchestrated usually at the beginning, middle and end of the flight season (Conel 1988, Green et al. 1990, 1992, 1993a, 1995, 1996, 1998b, 1999, 2000, 2001, 2002). For the inflight calibration experiment AVIRIS measurements are acquired over an extended area homogeneous surface calibration target. At the time of the AVIRIS measurements the surface reflectance and atmospheric conditions at the calibration target are measured. The surface and atmospheric measurements are used to constrain an atmospheric radiative transfer code and predict the upwelling spectral radiance arriving at AVIRIS. The quality of AVIRIS inflight calibration is assessed based on a comparison of the predicted incident total upwelling spectral radiance and the AVIRIS measured incident total upwelling spectral radiance. This paper reports the results of the principle AVIRIS inflight calibration experiment of 2002.

FIELD MEASUREMENTS

The primary inflight calibration experiment for AVIRIS in 2002 was orchestrated on a clear sky day at Rogers Dry Lake, California on the 6th of May. Rogers Dry Lake is located about 100 km North of Los Angeles, California at 34.9° North latitude and 117.8° West longitude. Figure 1 shows an AVIRIS image of Rogers Dry Lake with the surface
calibration target location indicated. The calibration target was designated on the surface as a visually homogeneous area of 200 by 40 meters of the dry lakebed surface. Large blue plastic demarcation tarpaulins were located 20 m beyond each end of the target. The elevation of the surface calibration target was 707 m.

Figure 1. AVIRIS image of Rogers Dry Lake, California with region of surface calibration target indicated.

At the calibration target the surface spectral reflectance was measured in the period \(+\sim 30\) minutes of the AVIRIS airborne measurements with a portable field spectrometer (Analytical Spectral Devices Inc., Full Range Spectrometer). This field spectrometer measures the range from 350 to 2500 nm and reports the spectra at 1 nm spectral sampling. Spectra of both the calibration target and a known reflectance standard (Spectralon, Labsphere Inc.) were acquired. The measurements were reduced to reflectance as ratios of the calibration target and reflectance standard measurements. The ratios were further corrected for the absolute spectral reflectance of the standard and the bidirectional reflectance distribution function for the solar zenith angle under which the measurements were acquired. Figure 2 shows the average reflectance of the calibration target, the standard deviation, and the standard deviation of the mean (Taylor 1982) for these measurements. The standard deviation is less than 0.02 reflectance and the standard deviation of the mean is less than 0.005 reflectance. The standard deviation of the mean indicates the accuracy to which the average reflectance of the calibration target is known. The average reflectance of the surface calibration target is required to predict the total upwelling spectral radiance incident at AVIRIS.
Adjacent to the calibration target on the surface of Rogers Dry Lake atmospheric measurements were acquired with a 10 channel solar radiometer (University of Arizona, Reagan Instrument). This instrument measures the solar intensity in 10 spectral channels centered at 370, 400, 440, 520, 620, 670, 780, 870, 940, and 1030 nm. These measurements were acquired from sunrise through local solar noon. Figure 3 show a plot of these measurements for the morning of the 6th of May 2002. Figure 4 shows a plot of the natural log of intensity versus airmass. Using the Langley method the average total optical depth of the atmosphere at each spectral channel was calculated. With an absolute calibration of the solar radiometer the instantaneous optical depths was calculated as well. The instantaneous derived optical depths for the 6th of May 2002 AVIRIS inflight calibration experiment are shown in Figure 5. This solar radiometer measures a spectral channel centered at the 940 nm atmospheric water vapor absorption band. These data were used to calculated the average and instantaneous total column water vapor (Reagan 1987, Bruegge et al. 1992). A value of 9.27 mm precipitable water vapor was derived for the time of the AVIRIS overflight.

Other properties of the atmosphere required for the AVIRIS inflight calibration experiment were the amounts of atmospheric carbon dioxide and ozone. Values for these constituents of the atmosphere were extracted from available global data sets. A value of 375 ppm was obtained for carbon dioxide (Keeling, C. D and T. P. Whorf 2002). A value of 375 Dobson units was obtained for ozone in the Rogers Dry Lake, California region on the 6th of May 2002. These parameters provide further constraint of the atmosphere for
prediction of total upwelling spectral radiance incident at AVIRIS over the Rogers Dry Lake, California calibration target.

Figure 3. Solar radiometer measurements for the 6th of May 2002 at the AVIRIS inflight calibration experiment.
MODELED RADIANCE

To predict the total upwelling spectral radiance incident at AVIRIS over the calibration target at the time of the overflight the surface and atmospheric measurements were used to constrain the MODTRAN radiative transfer code (Berk et al. 1989, Anderson et al. 1995). The mid-latitude summer atmospheric model was used and the visibility parameter adjusted until a good match was obtained between the measured total optical depths and the corresponding MODTRAN atmospheric model optical depths. Figure 6 shows the measured and MODTRAN optical depths for a visibility of 75 km. The MODTRAN radiative transfer code was constrained for these optical depths as well as water vapor, ozone, carbon dioxide, and surface spectral reflectance and used to predict the radiance incident at AVIRIS over the calibration target at the time of the AVIRIS overflight. Figure 7 shows the predicted upwelling spectral radiance at full MODTRAN spectral resolution. In Figure 8 the predicted radiance was convolved to the AVIRIS spectral response functions. This spectrum of the predicted upwelling spectral radiance
over the calibration target provides the basis to assess the radiometric calibration of AVIRIS in the operational flight environment.

Figure 6. Comparison of the measured and MODTRAN model total optical depths for the AVIRIS inflight calibration experiment on the 6th of May 2002 at Rogers Dry Lake, California.
Figure 7. Predicted total upwelling spectral radiance for the calibration target at Rogers Dry Lake, California at the time of the AVIRIS overflight on the 6th of May 2002.

Figure 8. MODTRAN predicted radiance incident at AVIRIS convolved to the AVIRIS spectral response functions.
AVIRIS MEASUREMENTS

AVIRIS measurements of the calibration target on the surface of Rogers Dry Lake, California were acquired at 17:59 UTC on the 6th of May 2002. Figure 9 shows the location of the calibration target between the demarcation tarpaulins in a red over blue channel ratio of a subset of the AVIRIS image. The AVIRIS measurements for the 40 by 200 m area of the calibration target were extracted and averaged. Figure 10 shows the average total signal, end-of-scan-line dark signal, and total minus dark signal for the calibration target. These measured data were calibrated to spectral radiance with the laboratory derived radiometric calibration coefficients and spectral calibration parameters shown in Figure 11. The ratio of the onboard calibrator signal between the time of laboratory calibration and acquisition of these data was used to compensate for changes between the laboratory and operational flight environment (Green 1993b). Figure 12 shows the AVIRIS calibrated radiance for the Rogers Dry Lake, California calibration target at 17:59 UTC on the 6th of May 2002.

Figure 9. A subset of the AVIRIS Rogers Dry Lake, California image showing location of calibration target between demarcation tarpaulins on the surface. This a ratio of an AVIRIS red channel over a blue channel.
Figure 10. AVIRIS average total signal, end-of-scan-line dark signal, and total minus dark signal for the calibration target.

Figure 11. AVIRIS laboratory derived radiometric calibration coefficients and spectral calibration parameters for the year 2002.
INFLIGHT RADIOMETRIC CALIBRATION VALIDATION

With the MODTRAN predicted and AVIRIS measured radiance for the calibration target, the accuracy of the AVIRIS calibration may be assessed in the flight environment. Figure 13 shows both the predicted and measured radiance for the Rogers Dry Lake, California calibration target on the 6th of May 2002. The ratio of these two radiance spectra is also shown. The deviations of the ratio from 1.0 are attributed to several sources including: 1) AVIRIS calibration standards, 2) AVIRIS stability, 3) the MODTRAN radiative transfer code, and 4) the atmosphere and solar parameters used by MODTRAN. Even with these uncertainties, the absolute average agreement between the MODTRAN predicted and AVIRIS measured radiance was greater than 96 percent excluding the regions of strong water vapor absorption at 1400 and 1900 nm. In these water vapor regions of the spectrum the radiance was close to zero and a valid comparison was not possible. The good agreement between the in situ measurement constrained MODTRAN predicted radiance and the AVIRIS measured radiance for the calibration target show that AVIRIS was well calibrated in the flight environment. The on-board calibrator data acquired before and after every AVIRIS flight line were used to maintain and monitor the calibration of AVIRIS over the full 2002 flight season.
Figure 13. Comparison of the MODTRAN predicted and AVIRIS measured spectral radiance for the calibration target on the surface of Rogers Dry Lake, California on the 6th of May 2002.

AVIRIS RADIOMETRIC PRECISION

In addition to AVIRIS radiometric accuracy, the radiometric precision was assessed in the flight environment. Dark signal radiometric precision is determined by calculating the standard deviation of dark signal measured at the end of each AVIRIS scan line. This provides an estimate of the dark signal noise for each AVIRIS spectral channel. Figure 14 shows this dark signal radiometric precision as noise equivalent delta radiance. This parameter was calculated as the product of radiometric calibration coefficients and the AVIRIS dark signal noise measured on the 6th of May 2002 in the flight environment.

Signal-to-noise ratio is another common measure of instrument precision performance. The AVIRIS signal-to-noise ratio was calculated from the high signal of the onboard calibrator measured for the Rogers Dry Lake, California calibration target flight line. The dark signal noise contribution and the photon noise contribution based on an understanding of AVIRIS detector instrument throughput properties were used. Figure 15 shows the inflight signal-to-noise ratio calculated for AVIRIS at the AVIRIS reference radiance. The AVIRIS reference radiance was specified in the original AVIRIS proposals as the radiance from an 0.5 reflectance surface illuminated with a 23.5 degree solar zenith angle and is shown in Figure 16. The AVIRIS signal-to-noise ratio continues to reach 1000 in the visible and near infrared portion of the spectrum and reach 400 in the short wavelength infrared portion of the spectrum near 2200 nm.
Figure 14. AVIRIS inflight radiometric precision for the 6th of May 2002 calculated from the end-of-scan-line dark signal measurements.
CONCLUSION

The principle AVIRIS inflight calibration experiment of the 2002 flight season was orchestrated at Rogers Dry Lake, California on the 6th of May. The experiment assessed the inflight radiometric calibration and precision of AVIRIS. A calibration target was designated on the surface of Rogers Dry Lake where both surface and atmospheric measurements were acquired. These in situ measurements were used to constrain the MODTRAN radiative transfer code and predict the total upwelling spectral radiance incident at the AVIRIS from the surface calibration target. The corresponding AVIRIS measured data for the calibration target were extracted and calibrated to upwelling spectral radiance based on the laboratory calibration coefficients and the onboard calibrator. A comparison of the MODTRAN predicted radiance showed good agreement with the AVIRIS measured radiance for the Rogers Dry Lake, California calibration target. An average absolute agreement of better the 96% was obtained excluding the strong water vapor absorption bands at 1400 and 1900 nm.

The inflight radiometric precision of AVIRIS was derived from the dark signal measurements acquired at the end of every scan line and the onboard calibrator high signal data. The inflight dark signal radiometric precision was reported as noise-equivalent-delta-radiance. The inflight signal-to-noise ratio was calculated from the onboard calibrator high signal data and reported at the AVIRIS reference radiance. The AVIRIS signal-to-noise ratio reaches 1000 in visible and near infrared portion of the spectrum and reaches 400 near 2200 nm in the short wavelength infrared.
The results of this inflight calibration experiment showed AVIRIS to be well calibrated and possess high precision in the operational flight environment. Excellent radiometric calibration and high precision are required to pursue scientific research and applications with imaging spectroscopy measurements. The radiometric calibration of AVIRIS is expected to improve in 2004 with inclusion of an ultrastable onboard calibrator. The radiometric precision of AVIRS is also expected to improve in 2004 with completion of the AVIRIS foreoptics refurbishment.

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