AVIRIS Inflight Calibration Experiment Results for 2001

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1.0 INTRODUCTION

The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) (1998a) is calibrated each year in the laboratory (Chrien et al. 1990, 1995, 1996, 2000). To assess the validity of the laboratory calibration in the flight environment, an inflight calibration experiment is conducted (Conel 1988, Green et al. 1990, 1992, 1993a, 1995, 1996, 1998b, 1999, 2000, 2001). For the inflight calibration experiment, a homogeneous surface calibration target is designated where the surface spectral reflectance, atmospheric aerosol and water vapor properties are measured. These measurements are used to predict the upwelling radiance incident at the AVIRIS instrument aperture with radiative transfer model calculations. The predicted radiance is compared and analyzed with respect to the AVIRIS measured radiance to understand the state of the AVIRIS calibration in the flight environment. AVIRIS airborne data calibration is traced to the laboratory measurements using the signal of the onboard calibrator (Green et al. 1993b). In 2001 the principal inflight calibration experiments occurred on February 7 at Salar de Arizaro, Argentina and on June 6 at Rogers Dry Lake, California. The measurements and results of these inflight calibration experiments in 2001 are described in this paper.

2.0 ARGENTINA EXPERIMENT

AVIRIS was deployed on the Twin Otter aircraft platform to Argentina in January and February 2001 as part of science validation effort for the Hyperion spaceborne imaging spectrometer onboard the NASA New Millennium EO-1 spacecraft. For inflight calibration validation of both Hyperion and AVIRIS, the Salar de Arizaro, a high altitude dry salt lakebed, was selected. Salar de Arizaro is located 24 degrees south latitude and 67 degrees west longitude at an elevation of 3700 m in the Andes of northwestern Argentina. Figure 1 shows a Landsat Thematic Mapper image of Salar de Arizaro with the general location of the calibration site indicted. Figure 2 shows a picture taken from the surface Salar de Arizaro on February 6, 2001. The surface is bright and uniform at the meter scale and greater; however, there is considerable microtopography reflectance variability at the 0.3-meter scale and finer.

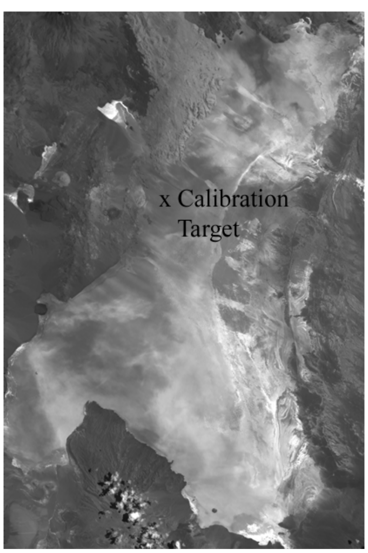

Figure 1. Landsat image of Salar de Arizaro Argentina with the AVIRIS inflight calibration site indicated.

Figure 2. A picture of the surface of Salar de Arizaro on February 6, 2001.

2.1 Surface Measurements

At the Salar de Arizaro calibration site, both surface and atmospheric measurements were acquired. A calibration target was established with dimensions of 300 by 60 m on the dry salt lake surface. At each end of the calibration target, demarcation tarps were placed to allow unambiguous location of the target in the AVIRIS image data. Surface reflectance measurements were acquired with a field spectrometer (Analytical Spectral Devices Inc., Full Range Spectrometer) in the period from 40 minutes before to 40 minutes after the AVIRIS overflight of the calibration target. A spectralon (Labsphere Inc.) reflectance standard was measured at the beginning, middle, and end of each transect down the length of the calibration target. The measured data were calibrated to reflectance using the spectralon target and a bidrectional reflectance correction factor for the 35-degree solar zenith angle at the time of the data acquisition. Figure 3 shows the average spectrum and the standard deviation and the standard deviation of the average of the 1824 spectra measured. The spectral reflectance of the Salar de Arizaro calibration target is exceptionally bright over the entire spectral range, however the microtopography induces large spectrum-to-spectrum reflectance differences. Figure 4 shows the reflectance value at 900 nm for all measured spectra and reveals the extreme spectrum-to-spectrum variability of the surface. To assess the effect of this variability, an average spectrum was calculated from all the odd spectra and all the even spectra. These two average spectra agreed at the 0.002 reflectance level, indicating enough spectra were measured for the average spectrum to accurately represent the reflectance of the calibration target. This agreement is also consistent with the calculation of the standard deviation of average for the measured spectra (Taylor 1982) and shows a knowledge of the average reflectance of the calibration target at the 0.002 reflectance level.

In addition to the surface reflectance, the atmospheric characteristics were measured with a sun tracking solar radiometer (Professor John Reagan, University of Arizona). The solar intensity was measured from sunrise through local solar noon in the 10 wavelength of the radiometer (370, 400, 440, 520, 620, 670, 780, 870, 940, 1030 nm). Figure 5 shows the measurements from this instrument at the calibration target on Salar de Arizaro. These data were used to calculate the instantaneous optical depths on February 7, 2001. Figure 6 shows the derived instantaneous optical depths for the 9 non water vapor wavelength measurements. The measurement from 940 nm was used to estimate the water vapor (Bruege et al. 1992, Reagan et al. 1987).

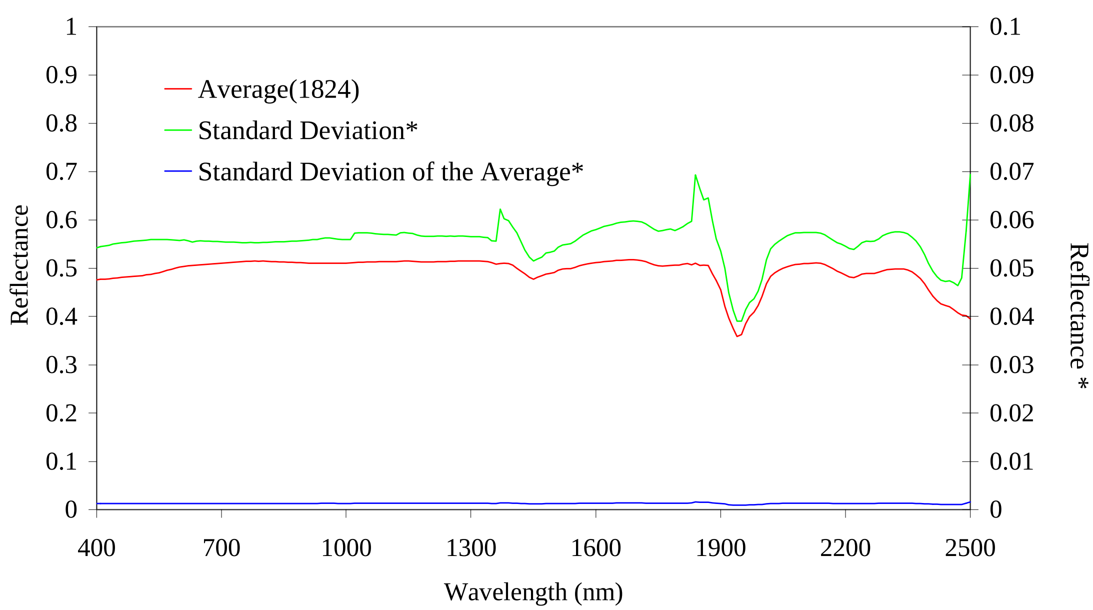

Figure 3. Average reflectance spectrum for Salar de Arizaro on February 7, 2001. The standard deviation and standard deviation of the average are shown as well.

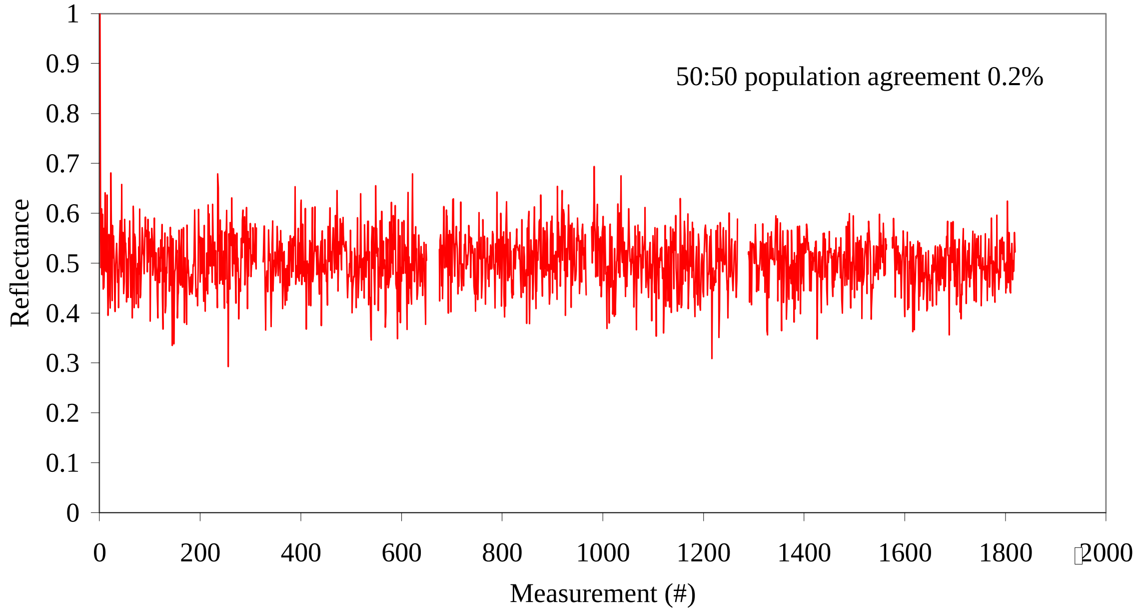

Figure 4. Reflectance at 900 nm for all 1824 measurements of the calibration target on Salar de Arizaro. The surface microtopography causes large spectrum-to-spectrum variability.

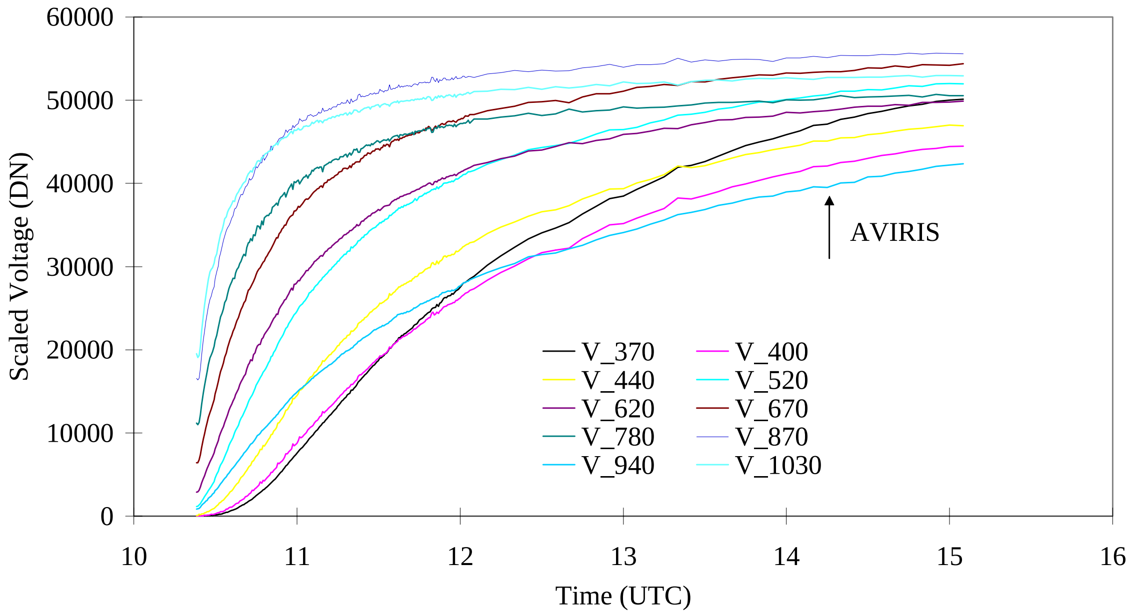

Figure 5. Measurements from the sun tracking solar radiometer at Salar de Arizaro on February 7, 2001.

2.2 AVIRIS Measurements

On February 7, 2001 at 14:22 UTC, AVIRIS acquired data over the calibration target on the Salar de Arizaro. Figure 7 shows a georectified AVIRIS image that includes the calibration target. One of demarcation tarps is evident immediately adjacent to the east-west road and the other south of the road. From the AVIRIS measured data, the average calibrated radiance spectrum was extracted for the Salar de Arizaro calibration target and is shown in Figure 8.

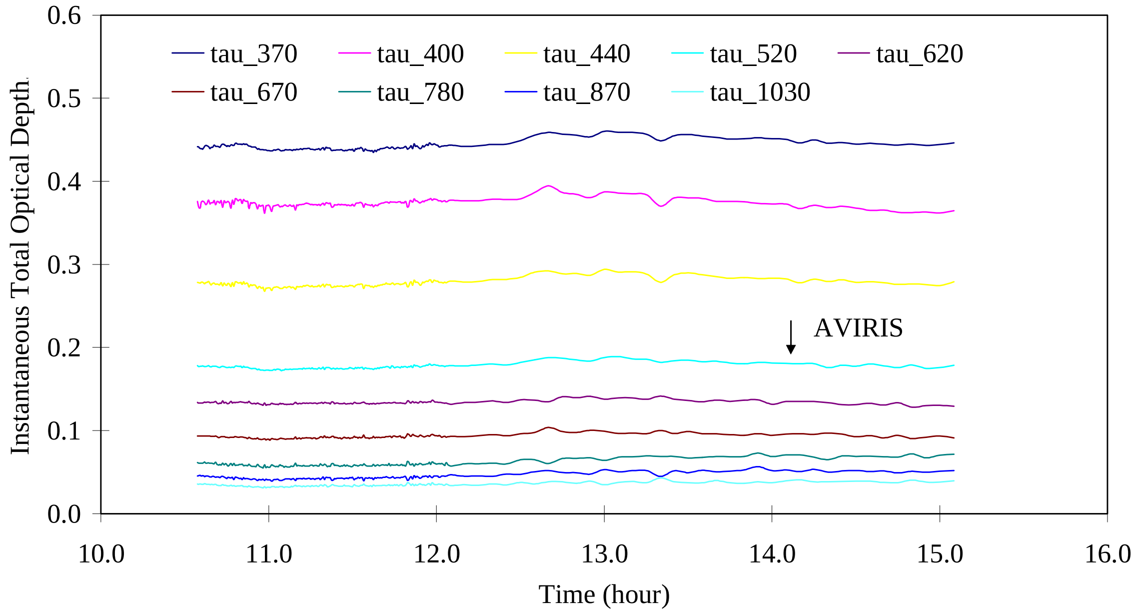

Figure 6. Calculated instantaneous total optical depths for February 7, 2001 at Salar de Arizaro.

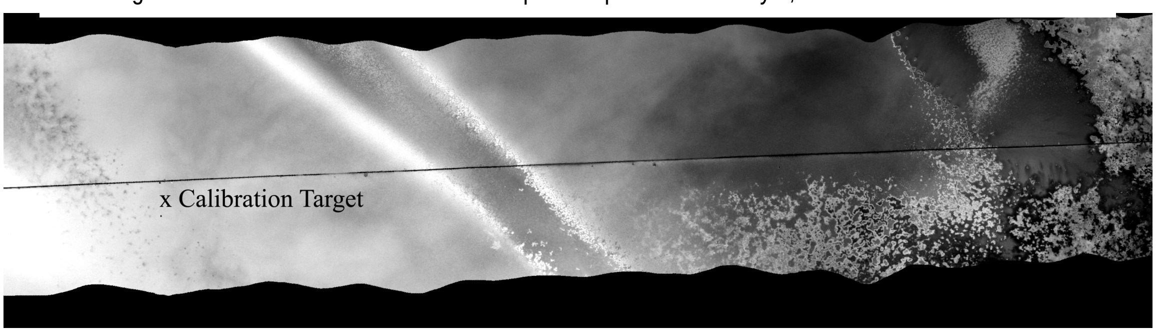

Figure 7. AVIRIS image of calibration target on Salar de Arizaro.

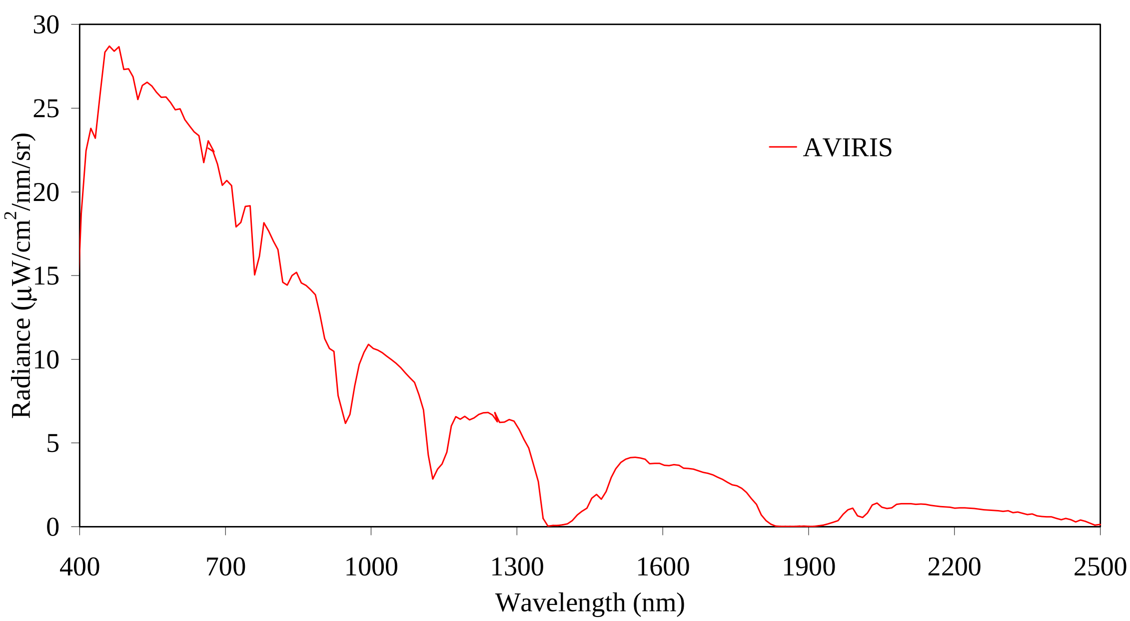

Figure 8. Average radiance spectrum measured by AVIRIS for the calibration target on Salar de Arizaro.

2.3 Modeled Radiance

To predict the radiance incident at AVIRIS over the calibration target, the MODTRAN radiative transfer code (Berk et al. 1989, Anderson et al. 1995) was used. MODTRAN was constrained by the latitude, longitude, elevation, and time as well as the surface spectral reflectance, optical depths, and water vapor derived from the solar radiometer measurements. The MODTRAN mid-latitude summer atmospheric model was used with visibility scaled to 100 km. This visibility gave the best agreement between the measured total optical depths and the corresponding MODTRAN calculated total optical depths. A water vapor amount of 8.13 precipitable mm was used based upon the solar radiometer measurements at 940 nm wavelength. Carbon dioxide was constrained to a mixing ratio of 371 ppm by the Mauna Loa values for February 2001 (Keeling and Whorf 2001). Ozone was constrained to 263 dobsin units by the Total Ozone Mapping Spectrometer (TOMS) satellite instrument measurements (McPeters 2001). Figure 9 shows the MODTRAN modeled radiance for AVIRIS over the calibration target on February 7, 2001.

2.4 Results

To assess the inflight calibration of AVIRIS, the AVIRIS measured spectrum for the calibration target was compared to the MODTRAN predicted spectrum. The comparison is shown in Figure 10. In general, there is good agreement across the spectral ranges. This figure also shows a ratio of the AVIRIS spectrum to the MODTRAN spectrum. The features in the ratio result from a combination of uncertainties that include: AVIRIS laboratory calibration, change in AVIRIS calibration in the flight environment, the MODTRAN model, and the atmospheric and solar parameters internal to the MODTRAN code. Overall, the average absolute agreement between the MODTRAN and AVIRIS spectra of the calibration target is 96 % excluding the regions of strong atmospheric absorption.

In addition to inflight radiometric calibration, the inflight radiometric precision of AVIRIS was assessed. Radiometric precision was calculated as the noise equivalent delta radiance (NEdL) for AVIRIS on the Salar de Arizaro flight. The NEdL is calculated as the standard deviation of the AVIRIS dark signal in units of radiance. For the Arizaro calibration target data (and all AVIRIS data), the dark signal was automatically measured immediately before and after the flight line data acquisition. Figure 11 shows the calculated AVIRIS NEdL for the Salar de Arizaro data set. The NEdL may be viewed as the precision error bars in radiance due to the AVIRIS instrument for any measured radiance spectrum.

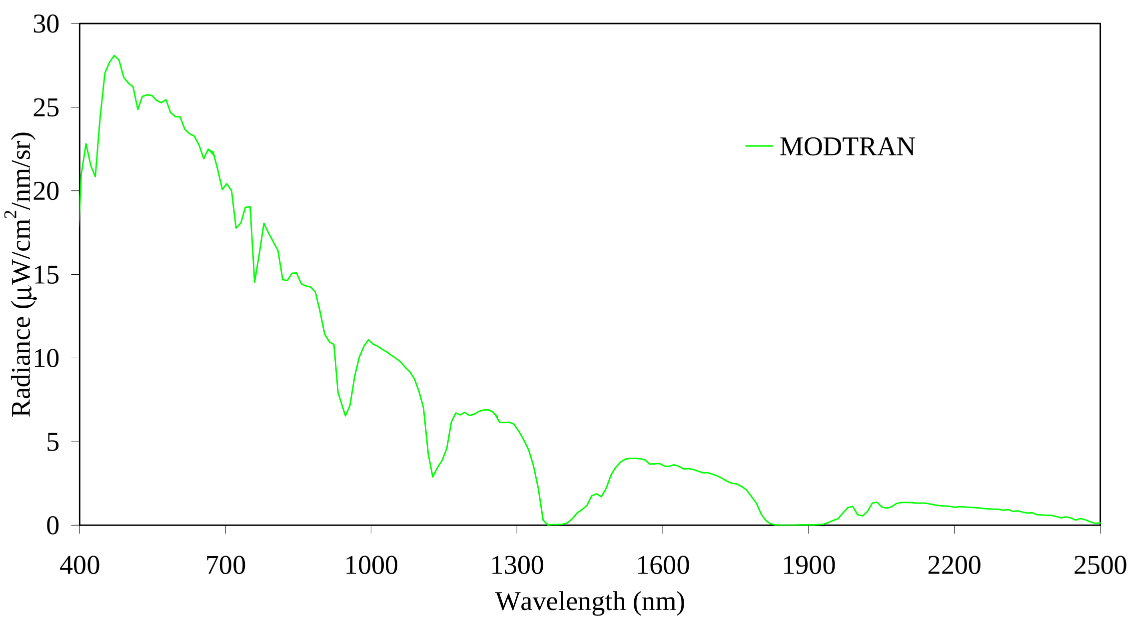

Figure 9. MODTRAN modeled radiance for the Salar de Arizaro calibration target on February 7, 2001.

For bright signal targets, the NEdL increased due to the photon noise contributions to the uncertainty in the measurement.

3.0 CALIFORNIA EXPERIMENT

On June 6, 2001, an AVIRIS inflight calibration experiment was conducted at a site on Rogers Dry Lake, California. Rogers Dry Lake is a large silt composition playa located 35 degrees north latitude and 117.8 degrees west longitude—about 2 hours drive north of Los Angeles. Figure 12 shows an AVIRIS

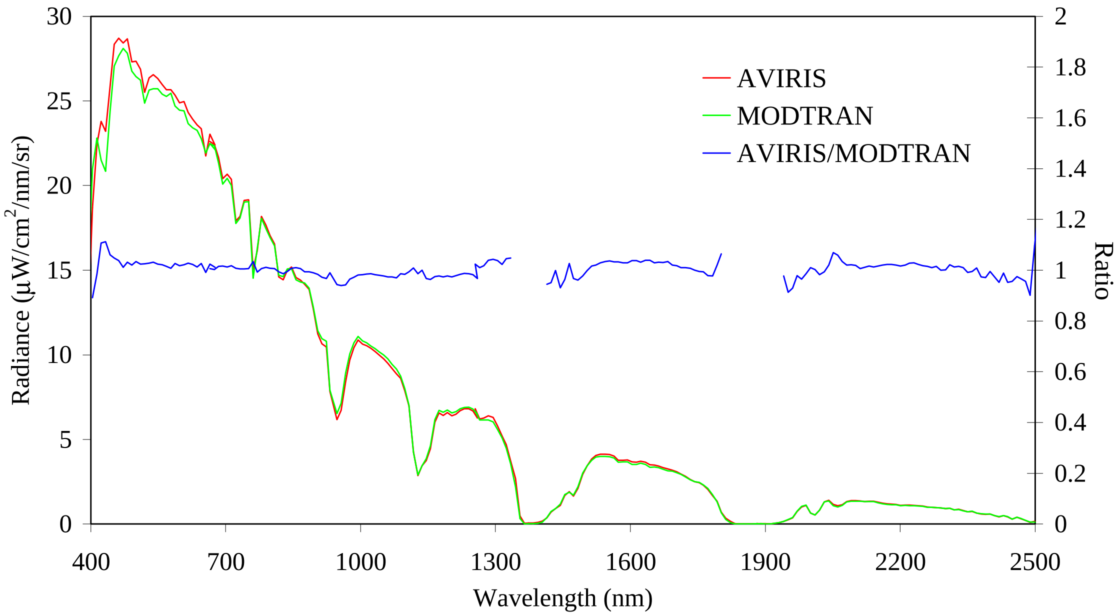

Figure 10. AVIRIS measured and MODTRAN modeled radiance spectra for the calibration target on Salar de Arizaro, Argentina.

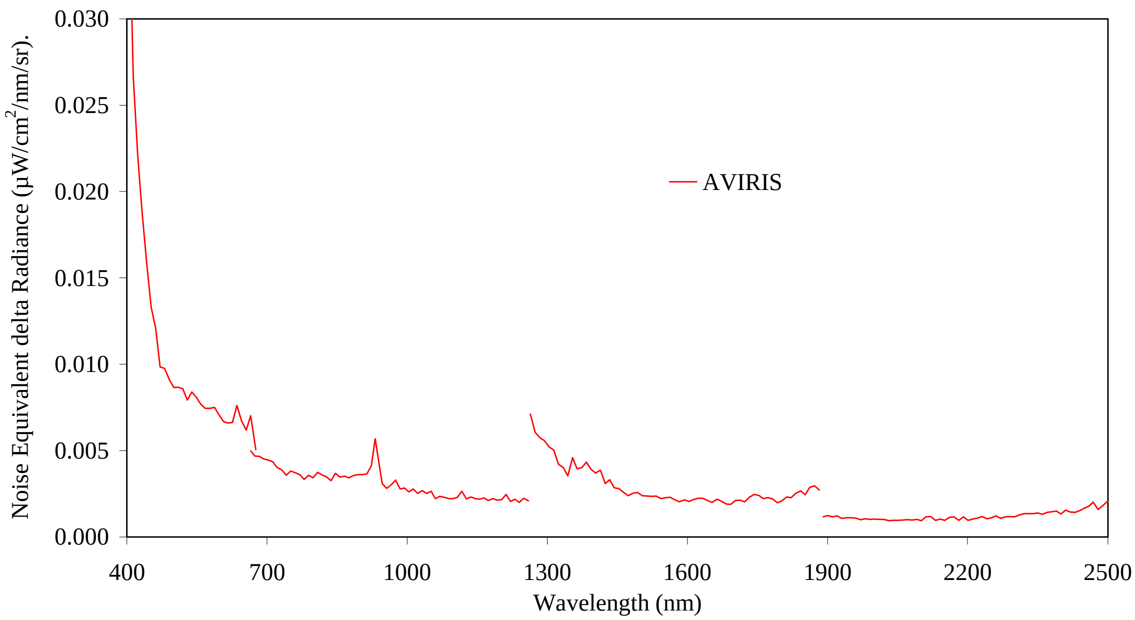

Figure 11. Calculated NEdL for AVIRIS in the flight environment over the calibration target of Salar de Arizaro.

image of the northern portion of Rogers Dry Lake, California. The location of the surface calibration target for the inflight calibration experiment is also shown.

3.1 Surface Measurements

A calibration target was designated on the surface of Rogers Dry Lake. The dimensions were 240 by 40 m with blue demarcation tarps placed on the surface 20 m beyond each end of the long axis of the target. Surface measurements of the calibration target were acquired with field spectrometer (Analytical Spectral Devices Inc., Full Range Spectrometer). These measurements were acquired in the period 30 minutes before and after the AVIRIS overflight of the calibration target. A spectral reflectance standard (Spectralon, Labsphere Inc.) was measured at the beginning, middle, and end of each transect of the calibration target. The data were reduced to surface reflectance with the spectral reflectance standard and accommodation for the bidirectional reflectance of the reflectance standard for the 43-degree solar illumination zenith angle. Figure 13 shows the average reflectance of the calibration target. Also shown are the standard deviation and the standard deviation of the average for the 1029 measurements of the calibration target. The standard deviation of the average is below 0.001 reflectance over the almost the entire spectral range. This indicates excellent knowledge of the average reflectance of the calibration target. Figure 14 shows the reflectance value for each spectrum at wavelengths of 500, 1000, 1500, and 2000 nm for all 1029 measurements. The spectrum-to-spectrum variation is small and consistent with the standard deviation of the set of calibration target reflectance measurements.

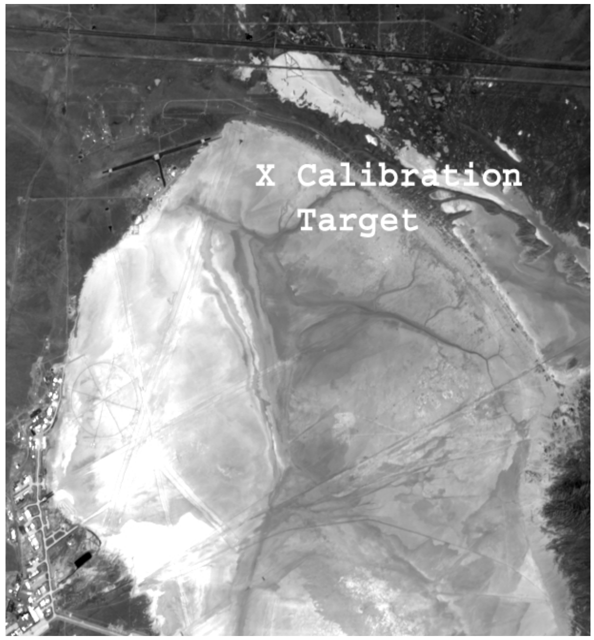

Figure 12. AVIRIS image of the northern portion Rogers Dry Lake, California acquired on June 6, 2001 with the calibration target area indicated.

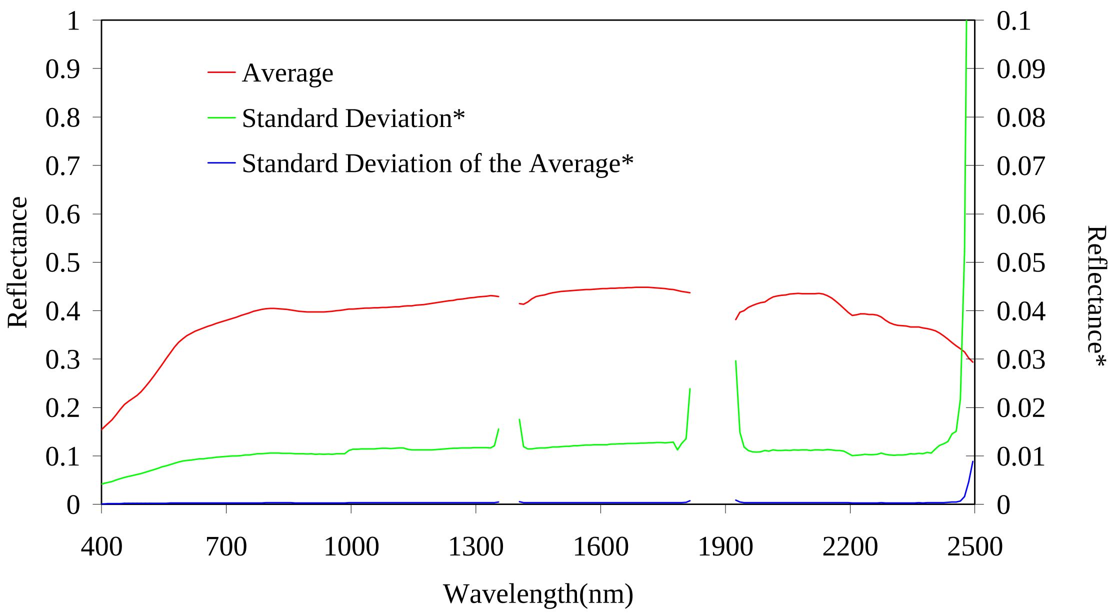

Figure 13. Average reflectance of the Rogers Dry Lake calibration target measured on June 6, 2001. The standard deviation and standard deviation of the average are shown for the 1029 measurements acquired as well.

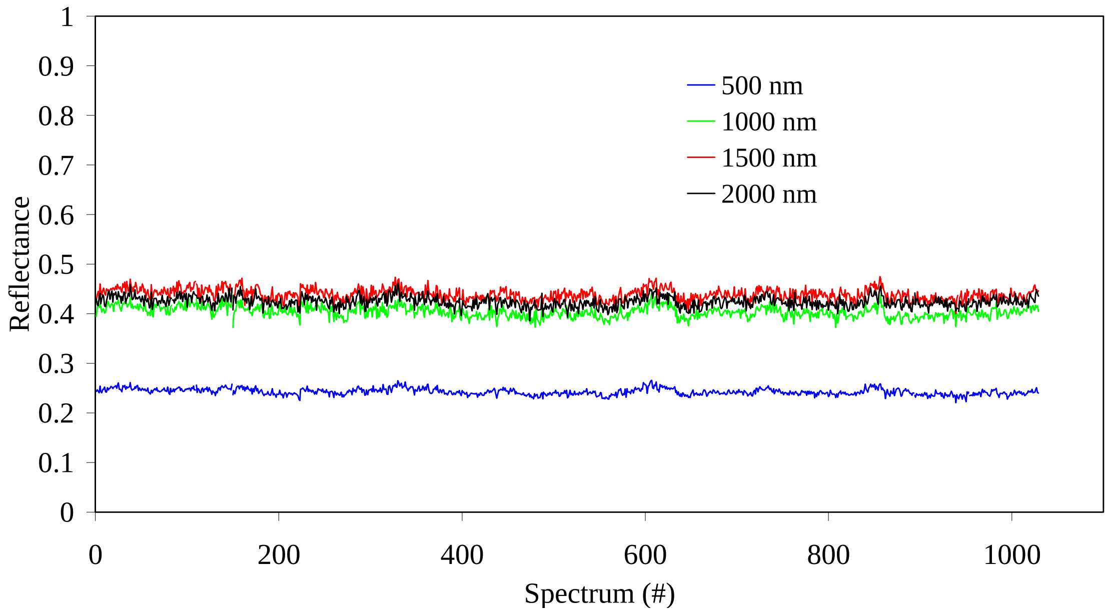

Figure 14. Reflectance values at wavelengths 500, 1000, 1500, and 2000 nm for the 1029 measurements of the calibration target. Only small spectrum to spectrum variation is present confirming the homogeneity of the site.

In addition to the surface reflectance, a sun tracking solar radiometer was set up adjacent to the calibration target to measure the atmospheric aerosol properties and atmospheric water vapor. On June 6, 2001 this instrument failed. As a fallback, measurements from the Aeronet (Holben et al. 1998) site at the NASA Dryden Research Center on the western side of Rogers Dry Lake were used. Table 1 shows the Aeronet aerosol optical depths and the calculated Rayleigh and total optical depths. A water vapor value of 15.1 precipitable mm was also derived for the time of the AVIRIS overflight.

3.2 AVIRIS Measurements

AVIRIS acquired data over the calibration target on Rogers Dry Lake at 16:38:17 UTC on June 6, 2001. The demarcation tarps were identified in the AVIRIS data and the average radiance spectrum was extracted for the calibration target. Figure 15 shows a portion of the AVIRIS image with the demarcation tarps in the center. Figure 16 shows the average AVIRIS spectrum for the calibration target.

Table 1. Optical depths for June 6, 2001 at Rogers Dry Lake, California

	Optical Depth		
Wavelength (nm)	Aerosol	Rayleigh	Total
340	0.105	0.64	0.74
380	0.078	0.40	0.48
440	0.051	0.22	0.27
500	0.047	0.13	0.17
670	0.033	0.039	0.073
870	0.026	0.013	0.040
1020	0.032	0.0073	0.039

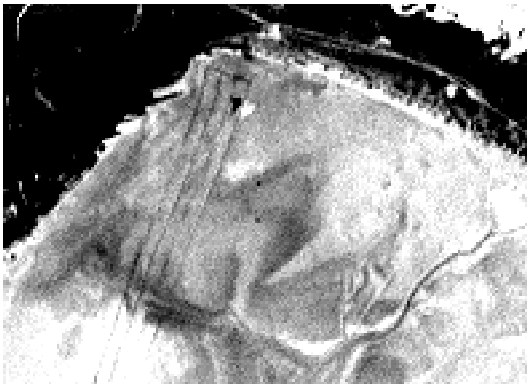

Figure 15. A subset of the AVIRIS measured image that shows the calibration target on the surface of Rogers Dry Lake. The demarcation tarps are evident one above the other in the center of the subset image.

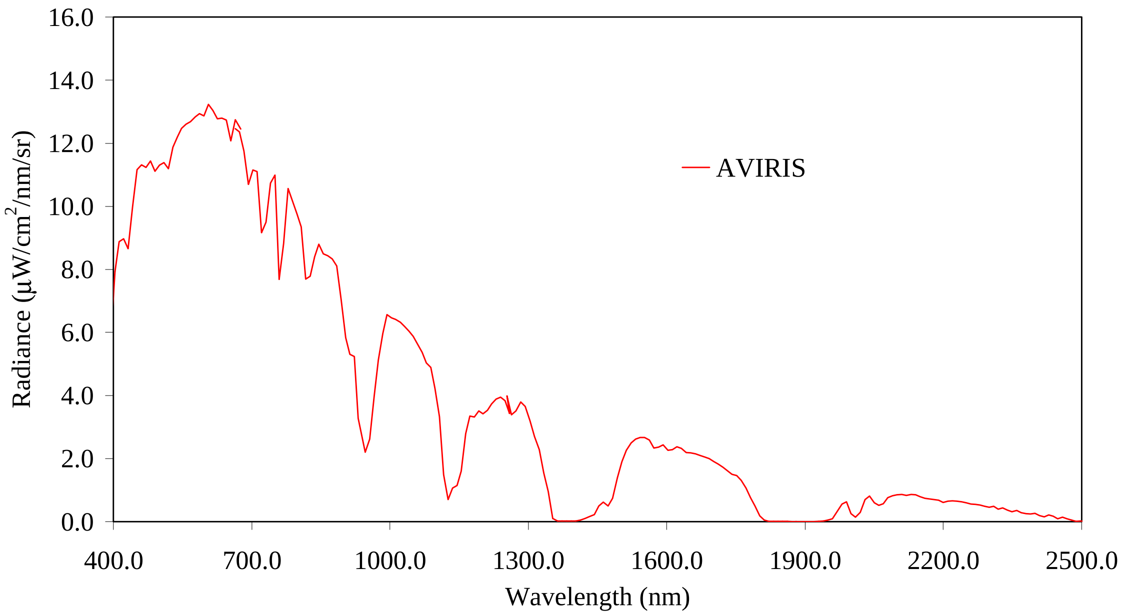

Figure 16. Average AVIRIS spectrum measured for the calibration target on Rogers Dry Lake, California, on June 6, 2001.

3.3 Modeled Radiance

The MODTRAN radiative transfer code was used to model the upwelling radiance incident at AVIRIS over the Rogers Dry Lake calibration target. MODTRAN was constrained by the latitude, longitude, elevation, and time as well as the measured surface reflectance, the optical depths and water vapor determinations. A MODTRAN visibility of 150 km with the mid latitude summer atmospheric model gave a good match with the in situ measured optical depths. Atmospheric carbon dioxide was constrained to a mixing ratio of 371 ppm consistent with the Mauna Loa values for June 2001 (Keeling and Whorf 2001). Ozone was constrained to 313 dobsin units by the TOMS satellite instrument measurements (McPeters 2001). Figure 17 shows the modeled upwelling radiance.

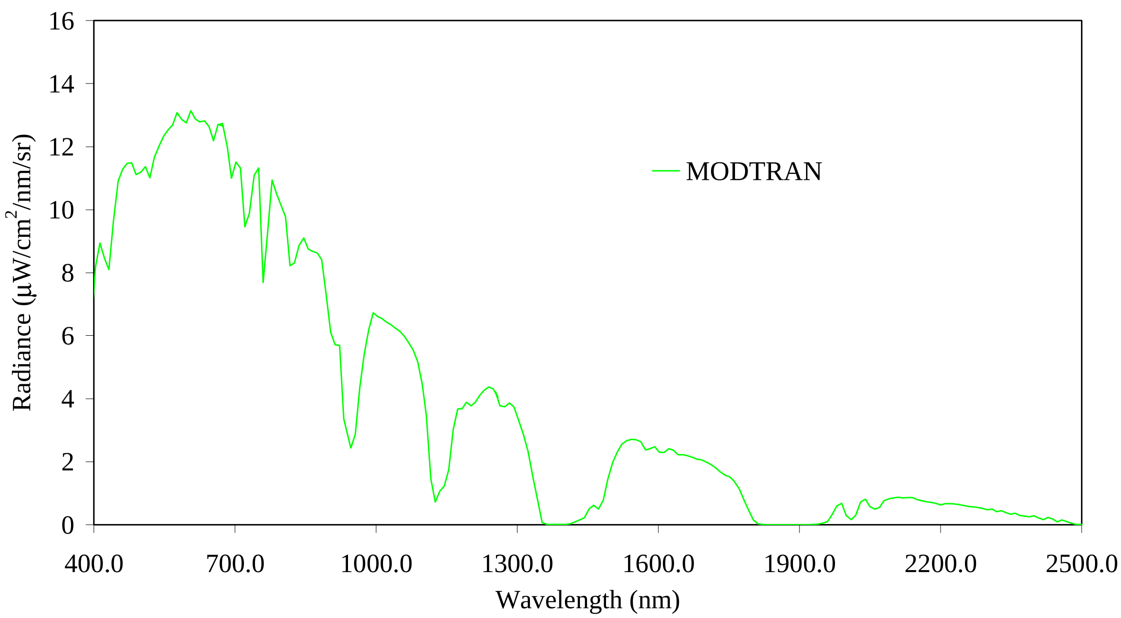

Figure 17. MODTRAN modeled radiance for the AVIRIS inflight calibration experiment on Rogers Dry Lake, California, on June 6, 2001.

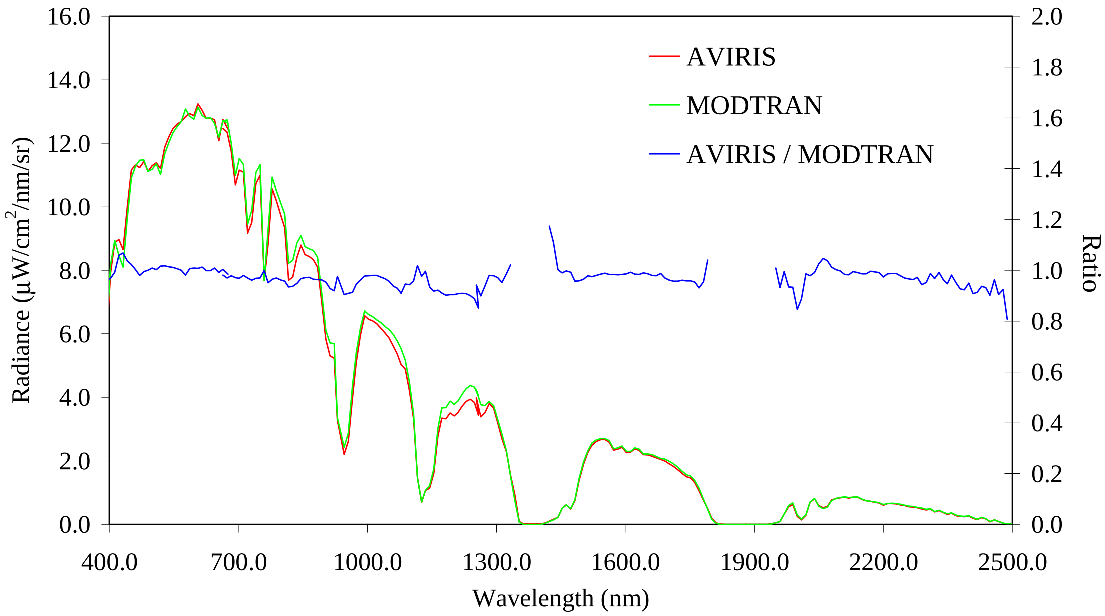

Figure 18. Comparison of the AVIRIS measured and MODTRAN modeled radiance spectra for the calibration target on Rogers Dry Lake, California, on June 6, 2001.

3.4 Results

To assess the inflight calibration of AVIRIS the measured radiance is compared to the modeled radiance. Figure 18 shows this comparison and a ratio of the AVIRIS measured to the MODTRAN modeled spectrum. Exclusive of the strong water vapor absorption regions of the spectrum the average absolute agreement is better than 96%.

The inflight radiometric precision of AVIRIS was assessed for June 6, 2001 inflight calibration experiment. The NEdL was calculated as the standard deviation of the AVIRIS dark signal in units of radiance. Figure 19 shows the calculated AVIRIS NEdL for this Rogers Dry Lake calibration experiment.

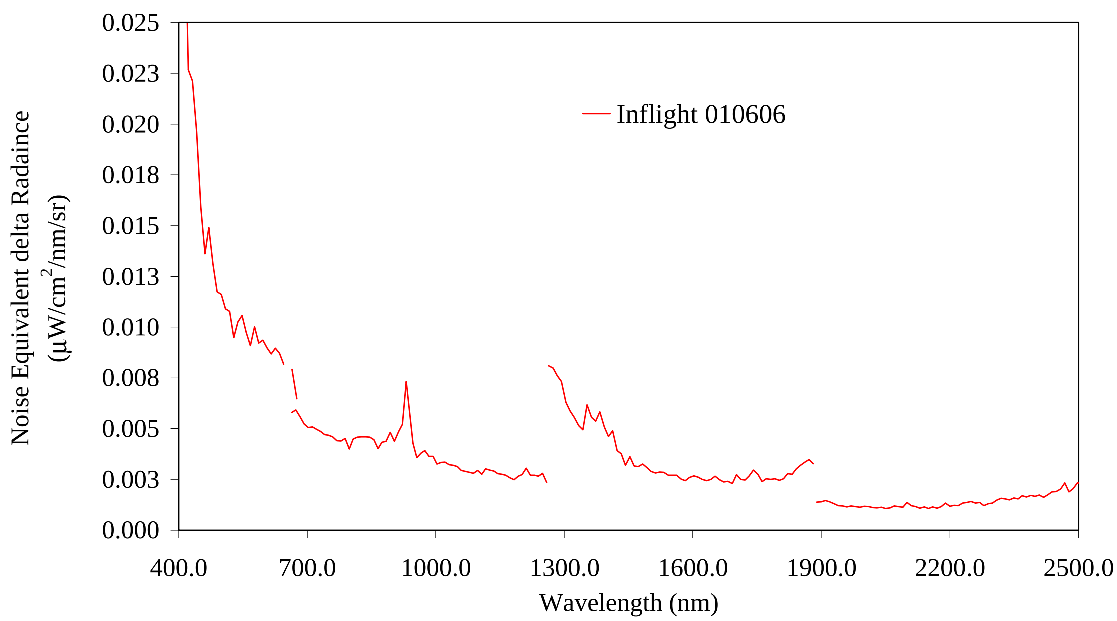

Figure 19. Calculated inflight dark signal NEdL for the June 6, 2001 calibration experiment.

4.0 CONCLUSION

The measurements, analyses, and results from two AVIRIS inflight calibration experiments of 2001 have been presented. The first experiment was conducted at 3700 m on the dry salt lake of Salar de Arizaro, Argentina on February 7, 2001. This was the first ever calibration experiment at a site of this altitude. In general, simpler atmospheres are expected at higher altitudes. The surface reflectance of Arizaro was also unusual with very high reflectance across the AVIRIS spectral range specifically including the blue portion of the spectrum. At the Arizaro calibration target, measurements of surface reflectance, atmospheric optical depths, and water vapor were acquired. These measurements were used to constrain the MODTRAN radiative transfer code and predict the radiance incident at AVIRIS at the time of the AVIRIS overflight. Comparison of the AVIRIS measured and MODTRAN predicted radiance showed an average absolute agreement of better than 96 percent exclusive of the strong atmospheric water absorption bands. AVIRIS inflight precision was also assessed through calculation of the dark signal noise equivalent delta radiance. Noise equivalent delta radiance is the radiance uncertainty due to the AVIRIS instrument.

A second AVIRIS inflight calibration experiment was conducted at Rogers Dry Lake, California on June 6, 2001. Surface measurements were acquired of the reflectance at atmospheric properties and used to constrain the MODTRAN radiative transfer code and predict the radiance at AVIRIS. Comparison of the AVIRIS measured to the MODTRAN predicted showed an average absolute agreement of better than 96 percent exclusive of the spectral regions of strong atmospheric water vapor absorption. The AVIRIS inflight instrument precision uncertainty was calculated as the noise equivalent delta radiance.

The results from these two AVIRIS inflight calibration experiments are consistent with the corresponding results of the past few years. There are a combination of factors that currently inhibit matches between AVIRIS measurements and MODTRAN prediction much better than 96 percent. These factors include: AVIRIS laboratory calibration, change in AVIRIS calibration in the flight environment, uncertainty in the surface measurements, assumptions in the MODTRAN radiative transfer calculations, and uncertainty in the solar and atmospheric parameters used within MODTRAN. It is hoped with improvements to the AVIRIS onboard calibrator and improvements to the MODTRAN constraining atmospheric and solar parameters, the level of agreement will improve.

5.0 REFERENCES

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6.0 ACKNOWLEDGMENTS

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