INFLIGHT RADIOMETRIC CALIBRA11ON OF AVIRIS IN 1994

Robert O. Green1 ,2, James E. Conel1, Mark Helmlinger1, and Jeannette van den Bosch1

1Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, 2University California, Santa Barbara, CA 93106

1. INTRODUCTION

The AVIRIS sensor must be calibrated at the time it measures spectra from the ER-2 airborne platform in order to achieve research and application objectives that are both quantitative and physically based. AVIRIS is radiometrically calibrated in the laboratory prior to each flight season (Chrien 1990). However, the operational environment inside the Q-bay of the ER-2 at 20 km altitude differs from that in the AVIRIS laboratory with respect to temperature, pressure, vibration and high frequency electromagnetic fields. Experiments at surface calibration targets are used in each flight season to confirm the accuract of AVIRIS radiometric calibration inflight (Conel, et rd. 1988; Green, et al. 1988,1990,1992, 1993). For these experiments, the MODTRAN radiative transfer code (Berk, et al. 1989) is constrained using in situ measurement to independently predict the upwelling spectral radiance arriving at AVIRIS for a specific calibration target. AVIRIS calibration is validated inflight by comparing the MODTRAN predicted radiance to the laboratory calibrated radiance measured by the AVIRIS sensor for the same time over the calibration target. In this paper, we present radiometric calibration results for the AVIRIS inflight calibration experiment held at the beginning of the 1994 flight season.

2. INFLIGHT CALIBRATION Experiment

On April 5th, 1994 an inflight calibration experiment was held at Lunar Lake, Nevéda located 130 km east of Tonopah at 38.38 degrees north latitude and 115.98 degrees west longitude. Lunar Lake is a small dry lake approximately 3 km in diameter located at 1600 m elevation. This dry lake was selected because it is one of the highest dry lakes in North America. The high elevation assures an atmosphere that is straight forward to model with less water vapor and aerosols than lower elevation sites.

On a portion of the dry lake surface a calibration target was designated for comparison of the MODTRAN predicted radiance to the AVIRIS measured radiance. This target was 40 by 200 m in dimension with the long axes in down the center of the AVIRIS flight line. In the half hour proceeding and following the AVIRIS data acquisition, the surface spectral reflectance was measured using field spectrometer that covers the AVIRIS spectral range. A total of 40 measurements were acquired evenly spaced over the target and averaged to determine the calibration target spectral reflectance (Figure 1).

At the calibration target solar radiometer measurements were acquired from sunrise through local solar noon with a solar radiometer that measures 10 discrete spectral channels in the range from 370 to 1050 run. These data were reduced with the Langley technique to generate atmospheric optical depths for the calibration target. The optical depths were used to select the midlatitude summer atmospheric model and adjust the visibility to 250 km in MODTRAN. With these constraints the MODTRAN atmospheric model optical depths agreed closely with the measured optical depths (Figure 2). Data from the radiometer channel centered at 940 run were analyzed to derive the total column water vapor (Reagan, et al. 1987, Bruegge, et al. 1990). A value of 4.9 +- 0.2 precipitable mm was determined and used to constrain the water vapor profile in MODTRAN. MODTRAN was run with the spectral surface reflectance, optical depth and water vapor determined to predict the upwelling spectral radiance at the time of the AVIRIS overflight of the target at 18:10 UTC (Figure 3). An updated exo-atmospheric solar irradiance spectrum (Green and Gao 1993) was used in MODTRAN. The MODTRAN predicted radiance was convolved to AVIRIS spectral resolution and compared to the AVIRIS laboratory calibrated radiance for the calibration target (Figure 4). An absolute average agreement across the spectral range was 95.3 percent excluding the regions of near zero radiance at 1400 and 1900 nm.

AVIRIS inflight radiometric precision or signal-to-noise was also determined with data from this calibration experiment. Noise was estimated as the standard deviation of the dark spectra measured at the end of each image line. Uncalibrated AVIRIS signal was taken from the Lunar Lake calibration target. This signal was scaled to the AVIRIS reference radiance (Green, et al. 1988) and divided by the noise to give the AVIRIS inflight signal-to-noise for 1994 in comparison to that in 1993 (Figure 5). In 1994, the signal-to-noise in the 400 to 600 run spectral region is shown to be significantly improved duc to the installation of a new focal plane in the first spectrometer. AVIRIS continues to show exceptionally high signal-to-noise performance inflight "across the spectral range. This performance is expected to further improve with installation of new focal planes for the 1995 flight season.

3. RADIOMETRIC CALIBRATION ERROR DISCUSSION

The residual 4.7 percent disagreement in radiometric calibration shown between the AVIRIS laboratory calibrated radiance and MODTRAN predicted radiance for the calibration target is attributed to several sources: 1) AVIRIS laboratory standard and calibration procedure errors, 2) errors in the in situ measurements and data reduction and, 3) imprecision in the MODTRAN model and calculation of upwelling spectral radiance.

4. CONCLUSION

The inflight calibration experiment at Lunar Lake, Nevada on April 5, 1994 shows 95.3 percent agreement at the calibration target between the MODTRAN predicted radiance and AVIRIS laboratory calibrated radiance. The 1994 inflight signal-to-noise is shown to equal the 1993 performance over most of the spectral range and improved between 400 and 600 rum The AVIRIS sensor continues to demonstrate high inflight radiometric calibration accuracy and precision across the spectral range. This level of radiometric performance is required to achieve the physically based objectives of research and application with AVIRIS measured spectra. Work is ongoing to continue to improve the radiometric calibration accuracy and precision of AVIRIS.

S. ACKNOWLEDGMENTS

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6. REFERENCES

Berk, a., L. S. Bernstein, and D.C. Robertson, "MODTRAN: A moderate resolution model for LOWTRAN 7", Final report, GL-TR-0122, AFGL, Hanscomb APB, MA, 42 pp., 1989

Bruegge, C.J., J.E.Conel, J.S. Margolis, R. O.Green, G. Toon, V. Carrere, R.G. Holm, and G. Hoover, In-situ atmospheric water-vapor retrieval in support of AVIRIS validation, SPIE Vol. 1298, Imaging spectroscopy of the terrestrial environment 1990.

Chrien,T.G., R.O.Green, and M.Eastwood, Laboratory spectral and radiometric calibration of the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), SPIE Vol. 1298, Imaging spectroscopy of the terrestrial environment 1990.

Conel, J.E., R.O.Green, R.E. Alley, C.]. Bruegge, V, Carrere, J.S. Margolis, G. Vane, T.G. Chrien, P.N. Slater, S.F. Biggar, P.M. Teillet, R.D. Jackson and M.S. Moran, In-flight radiometric calibration of the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), SPIE Vol. 924, Recent Advance in sensors, radiometry and data processing for remote sensing, 1988.

Green, R.O., G. Vane, and J.E.Conel, Determination of aspects of the in-flight spectral, radiometric, spatial and signrd-to-noise performance of the Airborne Visible/Infrared Imaging Spectrometer over Mountain Pass, Ca., in Proceeding of the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Performance Evaluation Workshop, JPL Pub. 88-38,162-184,1988.

Green, R.O., J.E. Conel, V. Carrere, C.J. Bruegge, J.S. Margolis, M.Rast, and G, Hoover, "Inflight validation and Calibration of the Spectral and Radiometric Characteristics of the airborne visible/infrared imaging spectrometer (AVIRIS)," Proc. SPIE Conference on Aerospace Sensing, Imaging Spectroscopy of the Terrestrial Environment, Orlando, Florida, 16-20 April, 1990.

Green, R. O., J. E. Cone], C. J., Bruegge, J. S. Margolis, V. Carrere, G. Vane and G. Hoover, "In-flight Calibration of the Spectral and Radiometric Characteristics of AVIRIS in 1991 ", ~~Proc.~~ Third Annual Airborne Geoscience Workshop, JPL Publication 92-14, 1992a SUMMARIES

Green, Robert O. and Bo-Cai Gao, "A proposed Update to the Solar Irradiance Spectrum Used in LOWTRAN and MODTRAN", Proc. Fourth JPL Airborne Geoscience Workshop, in press, 1993.

Reagan, J. A., K. Thome, B. Herman, and R. Gall, Water vapor measurements in the 0.94 micron absorption band: calibration, measurements and data applications, Proc. IGARSS, Ann Arbor, 18-21 May 1987.

7. FIGURES

Figure 1. Average calibration target spectral reflectance +- 1 standard deviation.

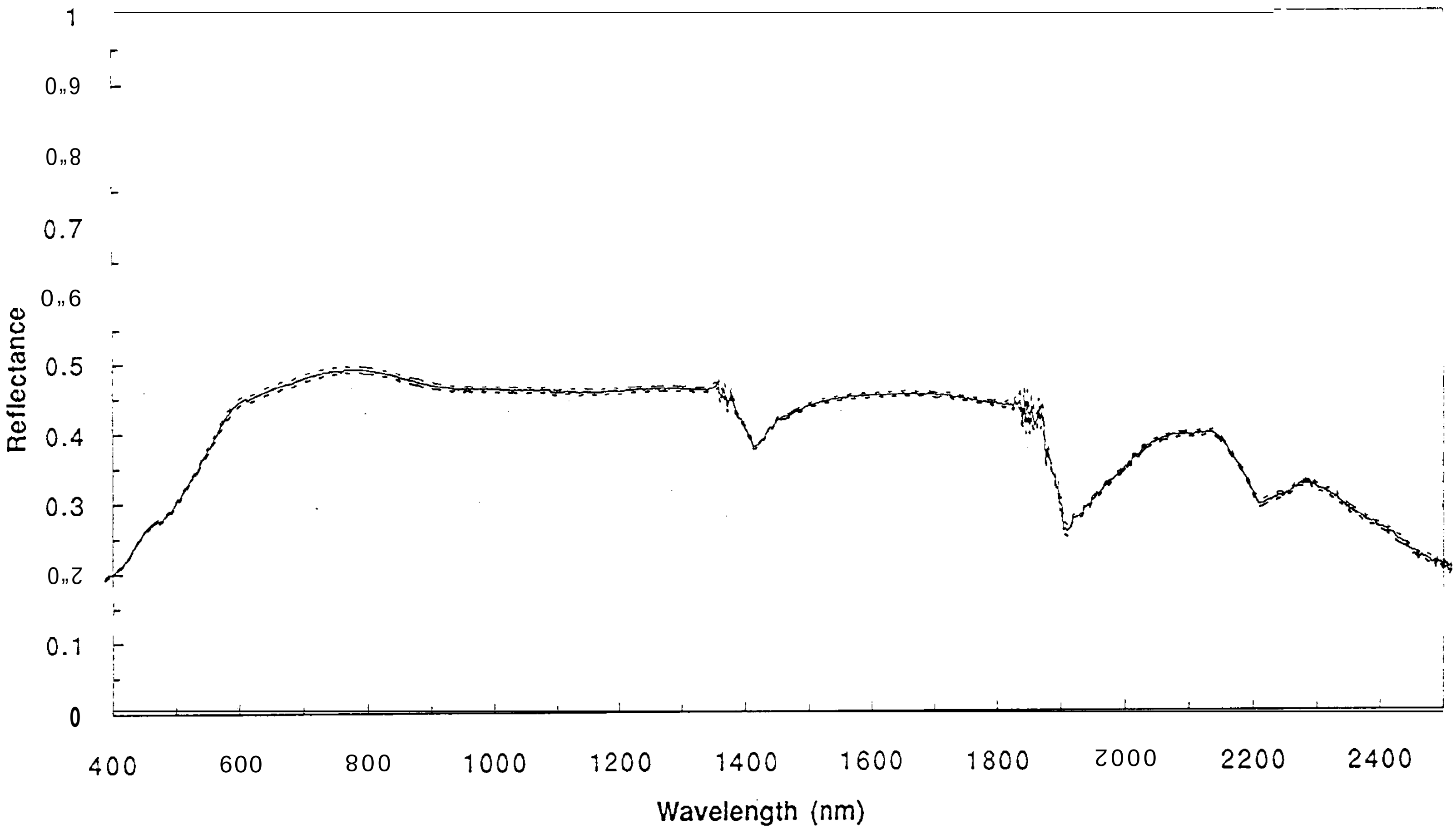
Figure 2. Measured discrete optical depths with the MODTRAN spectral optical depths for the calibration experiment atmosphere.

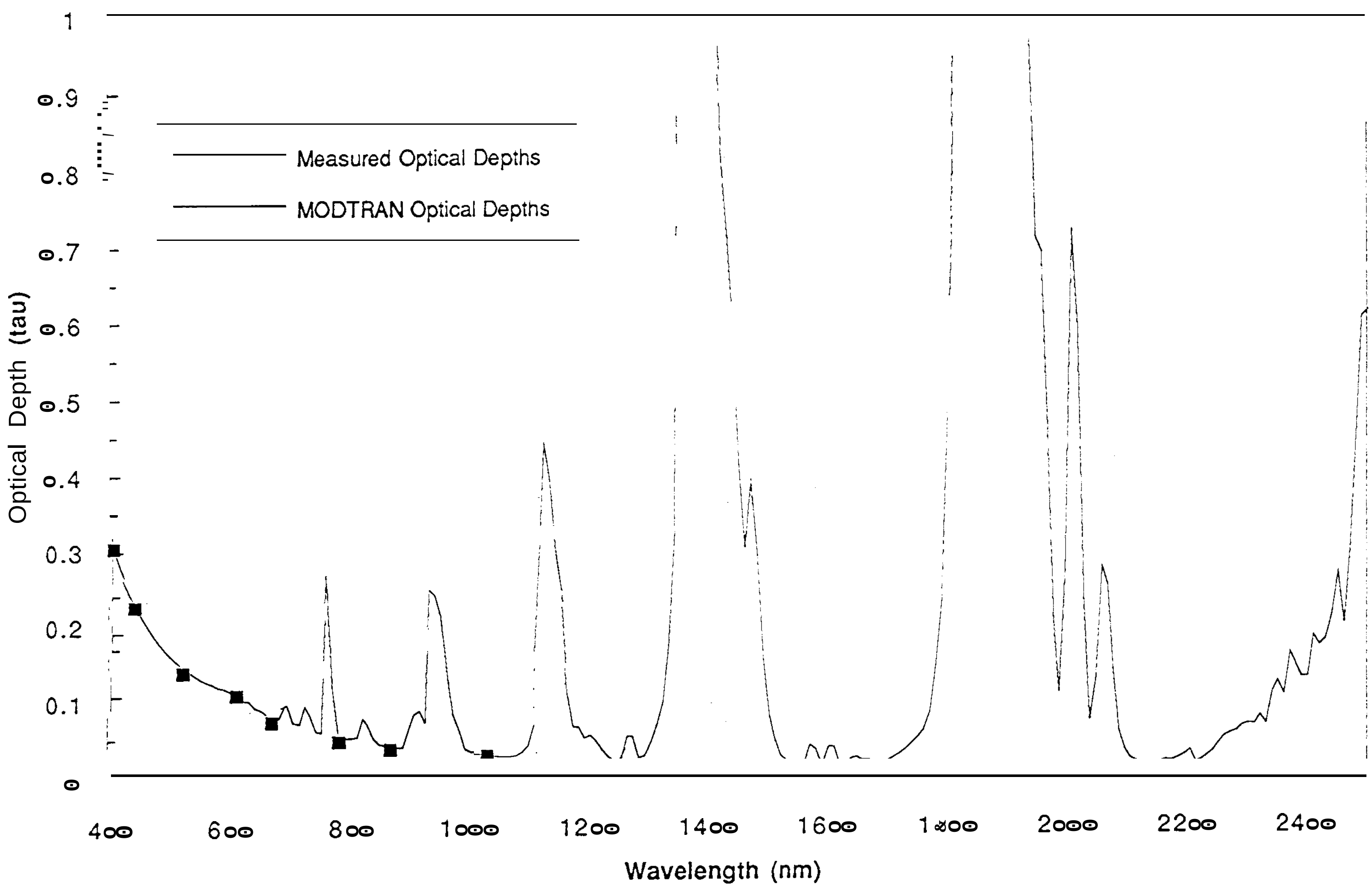
Figure 3. MODTRAN predicted radiance for the calibration target at the time of AVIRIS over flight.

Figure 4. Comparison of the MODTRAN predicted radiance and AVIRIS laboratory calibrated radiance for the Lunar Lake calibration target at 18:10 UTC on April 5, 1994.

Figure 5. AVIRIS inflight signal-to-noise in 1994 in comparison to 1993 at AVIRIS reference radiance.

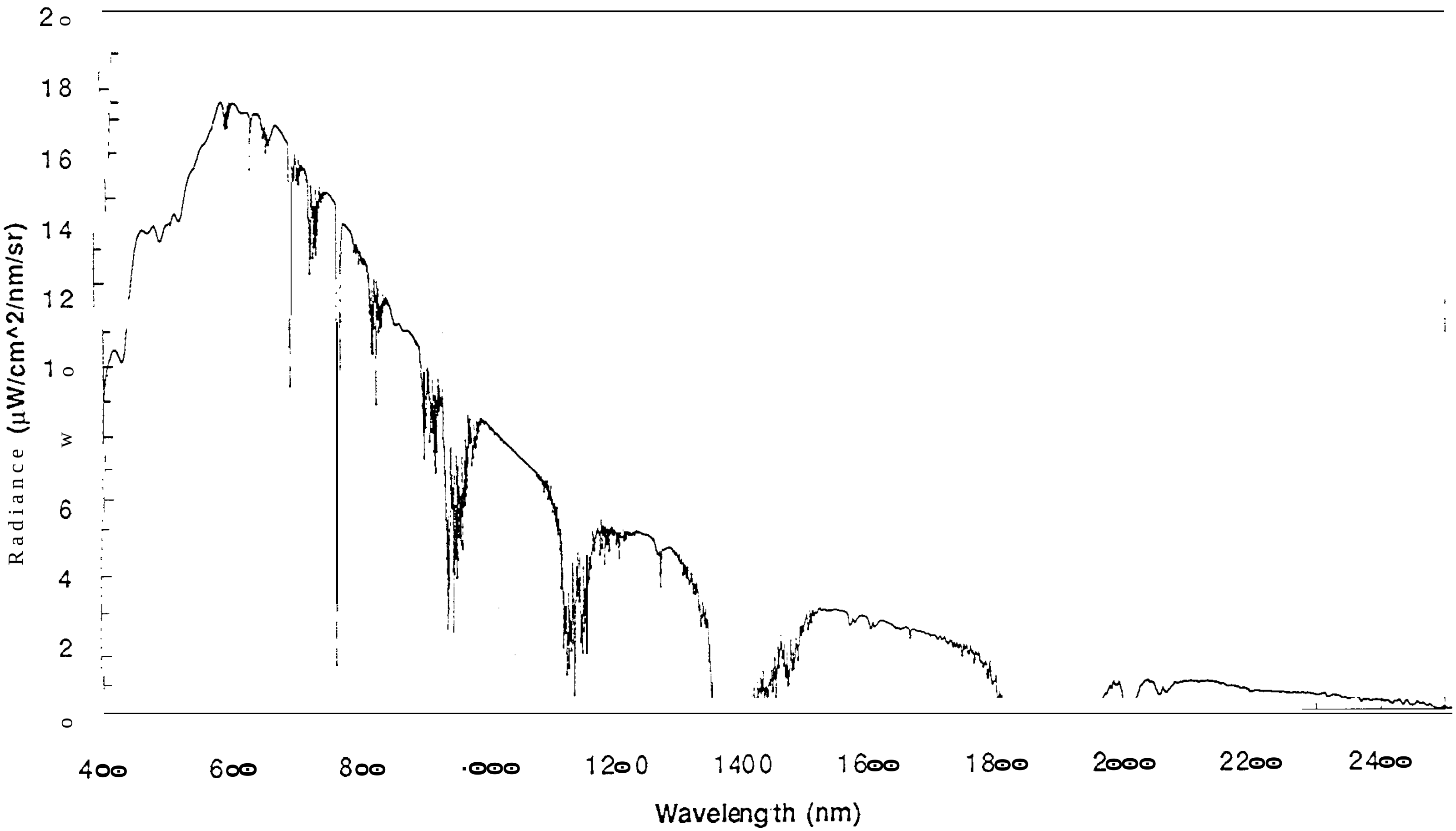
Calibration Target Reflectance Lunar Lake, CA 940405



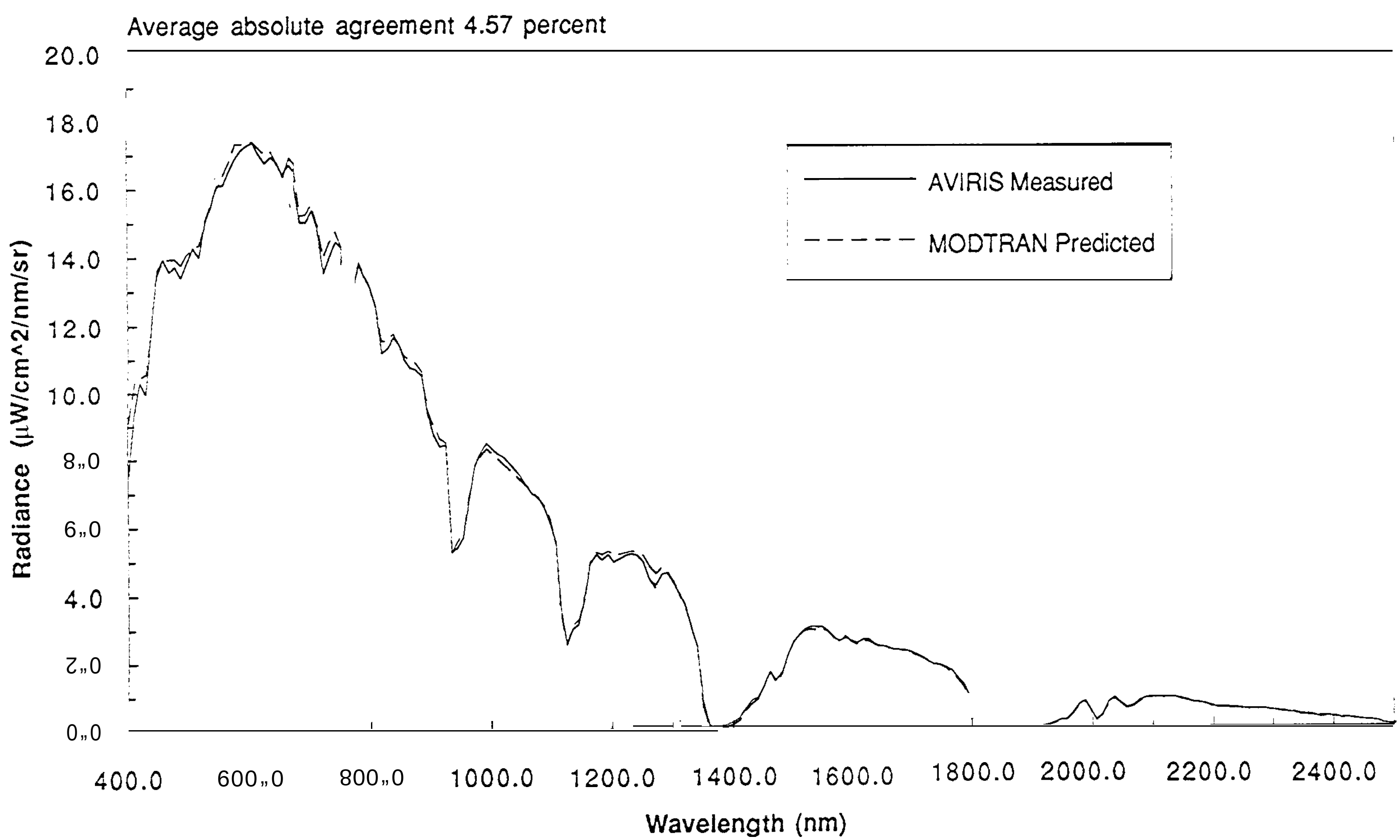


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Optical Depth (tau)
Measured Optical Depths
MODTRAN Optical Depths
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
Wavelength (nm)

MODTRAN Modeled Radiance, Lunar Lake, CA 940405



AVIRIS Calibration Experiment: Lunar Lake, NV 5 April 1994



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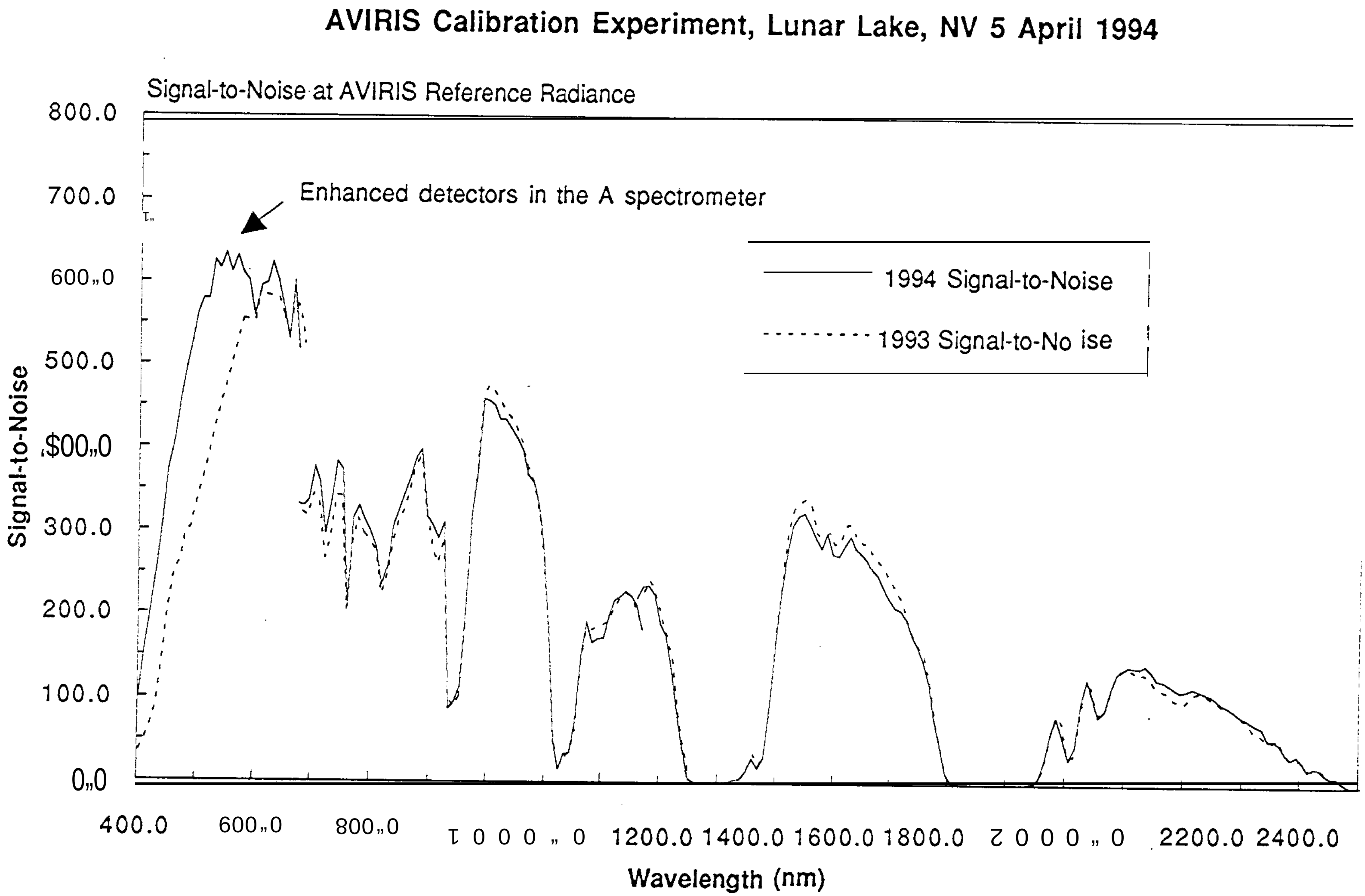
AVIRIS Calibration Experiment, Lunar Lake, NV 5 April 1994
Signal-to-Noise at AVIRIS Reference Radiance
Enhanced detectors in the A spectrometer
1994 Signal-to-Noise
1993 Signal-to-No ise
Signal-to-Noise
Wavelength (nm)
800.0
700.0
600.0
500.0
300.0
200.0
100.0
400.0
800.0
1200.0 1400.0 1600.0 1800.0
2200.0 2400.0