Apparent Surface Reflectance of the DOE ARM SGP CART Central Site Derived from AVIRIS Spectral Images

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1.0 Introduction

The primary objective of the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Program at the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) is to acquire in situ and remote sensing data to improve cloud and atmospheric radiative models and parameterizations. As a consequence of this program, a large number of atmosphere and surface measurements are being acquired at the ARM SGP CART central site. NASA's Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) overflew this site on August 1, 1997. AVIRIS measures the upwelling spectral solar radiance from 400 to 2500 nm at 10-nm intervals. From 20 km altitude, these calibrated spectra are acquired as images of 11 by up to 800 km with 20-by-20 m spatial resolution. These data were acquired at the ARM SGP CART Central Site to first investigate derivation of atmospheric parameters from the measured spectra, second study the variation of these parameters, and third demonstrate the inversion of the calibrated radiance spectra to apparent surface reflectance. These objectives have been pursued with AVIRIS data at other sites for atmospheric water vapor (Conel et al. 1988, Gao et al. 1990, Green et al. 1991, Green et al. 1995) and derivation of apparent surface reflectance (Green et al. 1988, Green et al. 1990, Gao et al. 1993, Green et al. 1993, Clark et al. 1995, and Green et al. 1996).

2.0 AVIRIS data

On August 1, 1997, two intersecting AVIRIS flight lines were acquired over the ARM SGP CART Central Site (Table 1). Analysis has concentrated on the portion of the North-South flight line that includes the Central Site (Figure 1). This image contains agricultural fields both cleared and planted as well as roads, structures and sections of a river. A set of AVIRIS calibrated radiance spectra were extracted from vegetated and soil targets in this image (Figure 2). Both the atmosphere and surface cover are modifying the upwelling spectral radiance measured by AVIRIS near the top of the atmosphere and 20,000 m altitude. Atmospheric radiation measurement is the primary objective of the ARM program. Effects of atmospheric scattering dominate toward 400 nm, while atmospheric water vapor absorptions are present at 940, 1140, 1400, 1900 and 2500 nm. Surface reflectance modifies the upwelling radiance across the entire spectra in these clear sky AVIRIS measurements.

Table 1. Start and stop latitude, longitude and time for the AVIRIS flight lines.

Flight Date	Start Latitude	Stop Latitude	Start Longitude	Stop Longitude	Start Time	Stop Time
f970801	+036.800	+036.533	-98.033	-97.300	17.516	17.616
f970801	+036.350	+036.800	-97.566	-97.416	17.716	17.800

3.0 Characterization of the Atmosphere

The first objective of this investigation was to pursue the derivation of atmospheric parameters from the AVIRIS calibrated radiance. Water vapor is the principle atmospheric parameter of interest because of the range of variability through space and time as well as the strong absorption bands present in much of the solar reflected spectrum. An inversion algorithm that uses a nonlinear least squares fit between the measured AVIRIS spectrum with a MODTRAN (Kneizys et al. 1987, Berk et al. 1989, and Anderson et al. 1995) modeled spectra at the 940 nm water vapor band was applied. This algorithm simultaneously parameterizes the surface liquid water expressed in plant leaves, the background spectral reflectance as well as the water vapor. Close fits were achieved between the AVIRIS measured spectra and the MODTRAN modeled spectra with small residual errors (Figure 3). The algorithm operates on each spectrum and was applied to the entire DOE ARM SGP CART Central Site AVIRIS image (Figure 4). Total column water vapor amounts ranging from 38 to 41 mm precipitable water vapor were derived throughout the AVIRIS data set. The algorithm was not applied to regions with standing water present on the surface where the upwelling radiance at 940 nm approached zero. The second objective of this investigation was fulfilled by exploring the spatial variation of water vapor in the AVIRIS image. A histogram of the derived water vapor was calculated to show the range and frequency of water vapor derived from the AVIRIS spectra (Figure 5). A significant patchiness was measured in the water vapor image with gradients from 39 to 41 mm present at lateral scales of 500 m. This variation in water vapor provides the basis for the requirement to calculate the total column water vapor for every spectrum in the image. A single average value for the entire image is not sufficient.

In addition to the water vapor absorption at 940 nm, liquid water absorbs energy at 980 nm. To solve for the water vapor, the liquid water must be accounted for as a parameter in the nonlinear least square parameter fit (Green et al. 1991). If the liquid water was uncompensated, the water vapor would be over estimated in areas of vegetation. The image of liquid water derived from AVIRIS at the ARM SGP CART Central Site shows variation from 0.0 mm liquid water in cleared agricultural fields to 5.2 mm equivalent liquid water in some crops and in raparian vegetation (Figure 6).

4.0 Derived Apparent Surface Reflectance

The third objective of the investigation was to demonstrate the inversion of the calibrated AVIRIS radiance spectra to the apparent spectral reflectance of the surface. This inversion compensates for the atmospheric and solar irradiance components present in the total upwelling radiance measured by AVIRIS. The apparent reflectance is essential to derive surface material composition for research and applications based on the expressed molecular absorption and particle scattering characteristics. The apparent surface reflectance also contributes to the reflected radiance that is absorbed and scattered in the atmosphere and is therefore relevant to the ARM objectives. For this reflectance inversion, the radiance at AVIRIS is expressed in terms of the solar, surface and atmospheric contributions for a plane parallel atmosphere and surface (Equation 1). This equation is solved for surface reflectance with respect to a horizontal 100% lambertion target (Equation 2). For each spectrum in the AVIRIS image, this equation is constrained by the latitude, longitude, time, and surface elevation. The equation is additionally constrained by the AVIRIS derived atmospheric water vapor. The well mixed gases of the atmosphere are constrained with the surface pressure height. Ozone is constrained by measurement from the TIROS Operational Vertical Sounder. Finally, aerosols are constrained regionally to be an estimate of the visibility with feedback from the AVIRIS water vapor fit. With these constraints the equation is solved for each spectrum in the AVIRIS image.

$$L_t = F_0 \rho_a / \pi + F_0 T_d \, \rho T_u / \pi / (1 - S\rho) \qquad \text{Equation (1)}$$

L_t	total upwelling spectral incident at AVIRIS.
F_0	exoatmospheric solar irradiance.
ρ_a	atmospheric reflectance.
T_d	downward direct and diffuse transmittance of the atmosphere.
ρ	apparent lambertion surface reflectance
T_u	upward total atmospheric transmittance to the AVIRIS.

$$\rho_g = 1 / [\{(F_0 T_d T_u / \pi) / (L_t - F_0 \rho_a / \pi)\} + S] \qquad \text{Equation (2)}$$

For the ARM SGP CART Central Site, the apparent surface reflectance was calculated for all AVIRIS spectra. Spectra from different types of vegetation and soils show good compensation for the atmosphere (Figure 7). Vegetation spectra show the expected absorption of chlorophyll and ancillary pigments in the 400 to 700 nm region and the absorption of liquid water at 980, 1190, 1450, 2000, and 2500 nm. The soils show weak absorptions of chlorophyll from mixed vegetation in the 20 by 20 m spatial resolution. One example soil spectrum shows a strong carbonate absorption at 2300 nm in the solar reflected spectrum.

5.0 Conclusion

The objectives of this investigation were first to derive atmospheric parameters from AVIRIS calibration radiance spectra, second to examine the variability of the atmosphere, and third to invert the AVIRIS measured radiance to apparent surface reflectance. These objectives were achieved with respect to the atmospheric parameter of total column water vapor and apparent surface reflectance at the DOE ARM SGP CART Central Site. The water vapor images and derived apparent surface reflectance data are available to contribute directly to the ARM objectives at this site. Future research will pursue the derivation of atmospheric aerosols and investigation of the change in the atmosphere between the two AVIRIS flight lines.

6.0 Acknowledgments

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7.0 References

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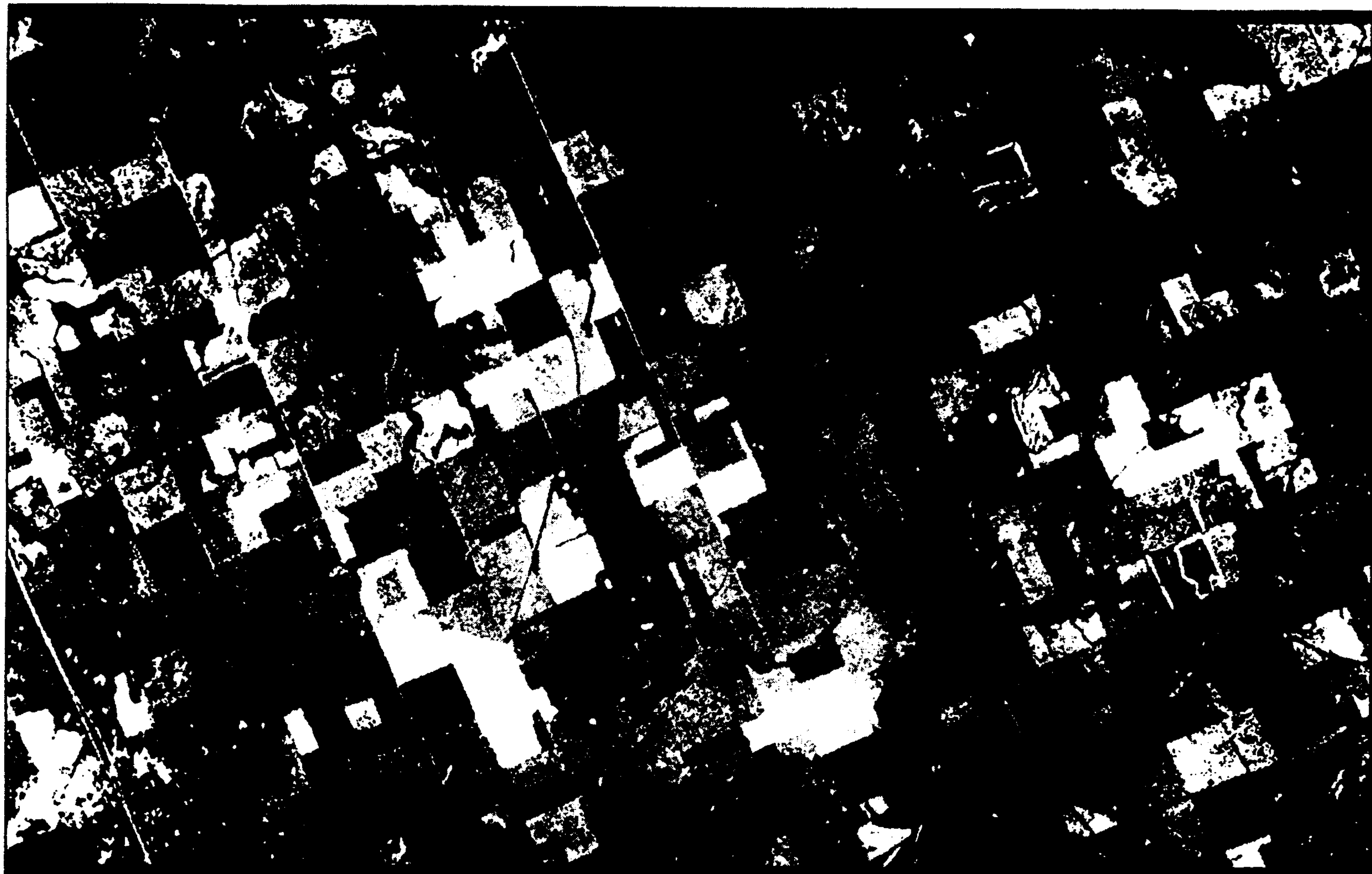

Figure 1. A portion of the AVIRIS image flight lines of the DOE ARM SGP CART Central Site in Oklahoma. The image is a single channel from AVIRIS centered at 550 nm. The 11 km width and 20 km length in conjunction with the 20 m spatial resolution show the range of cover types present at this site.

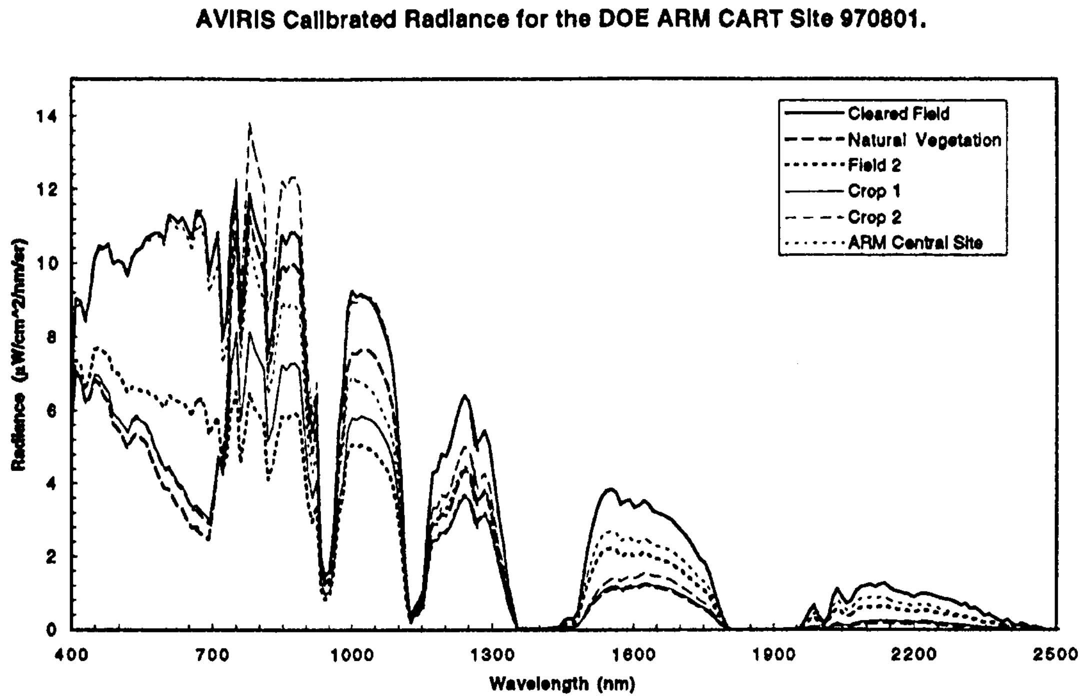

Figure 2. AVIRIS Radiance spectra from vegetation and soil targets in the DOE ARM SGP CART Central Site measured on the 1st of August 1997.

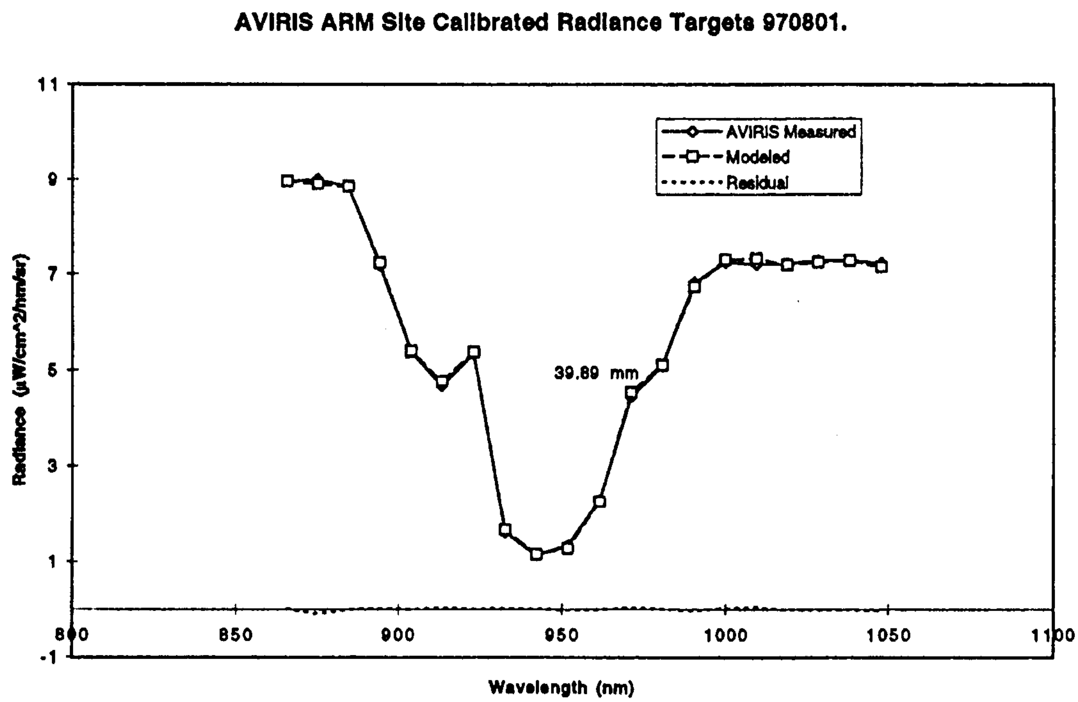

Figure 3. Water vapor inversion algorithm spectral fit for a target in the DOE ARM SGP CART Central Site AVIRIS spectral image.

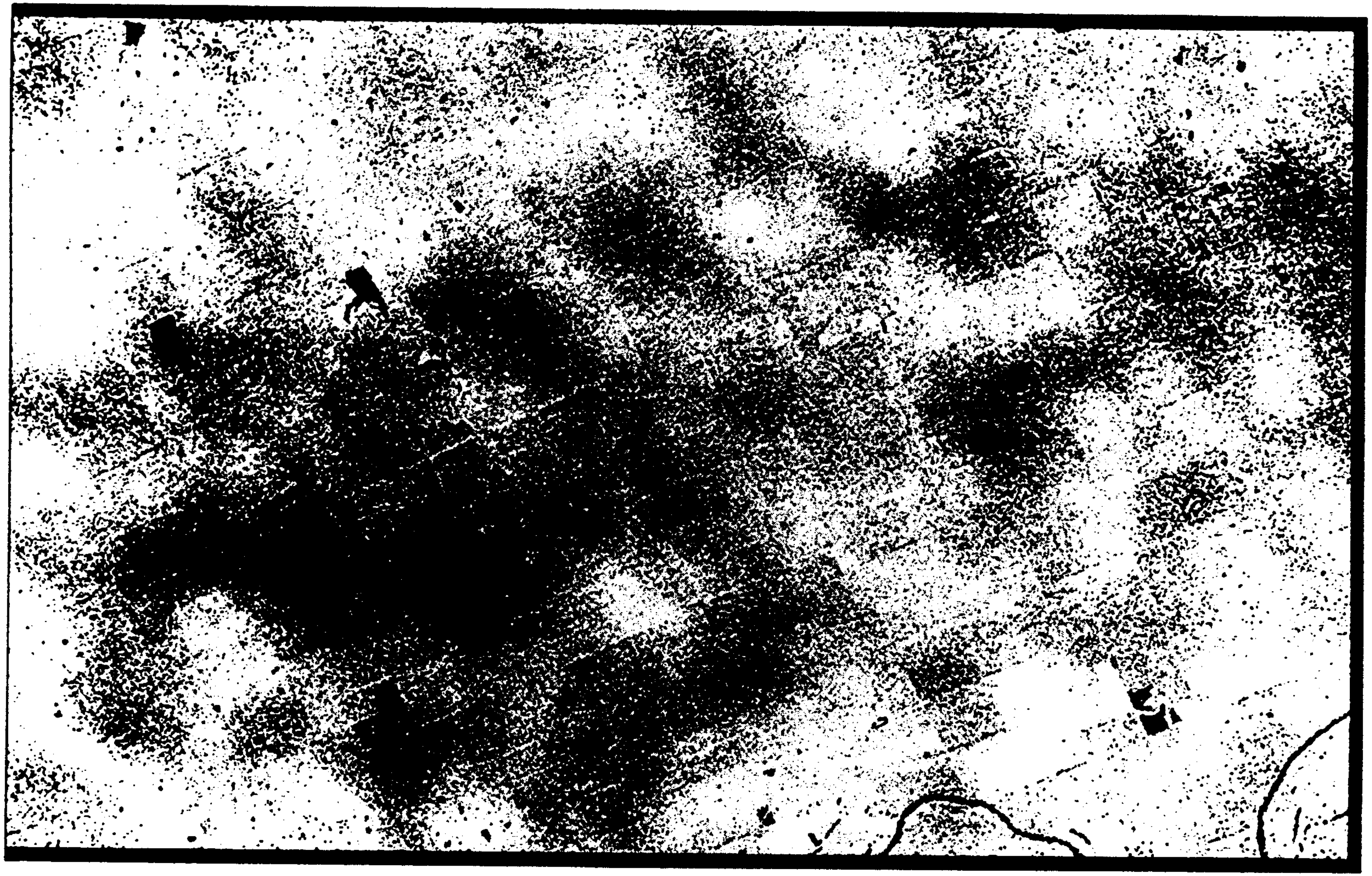

Figure 4. AVIRIS water vapor image for the DOE ARM CART Central site. The range is from 38 to 41 mm of precipitable water vapor. Areas of standing liquid water were excluded from the inversion and are shown as dark.

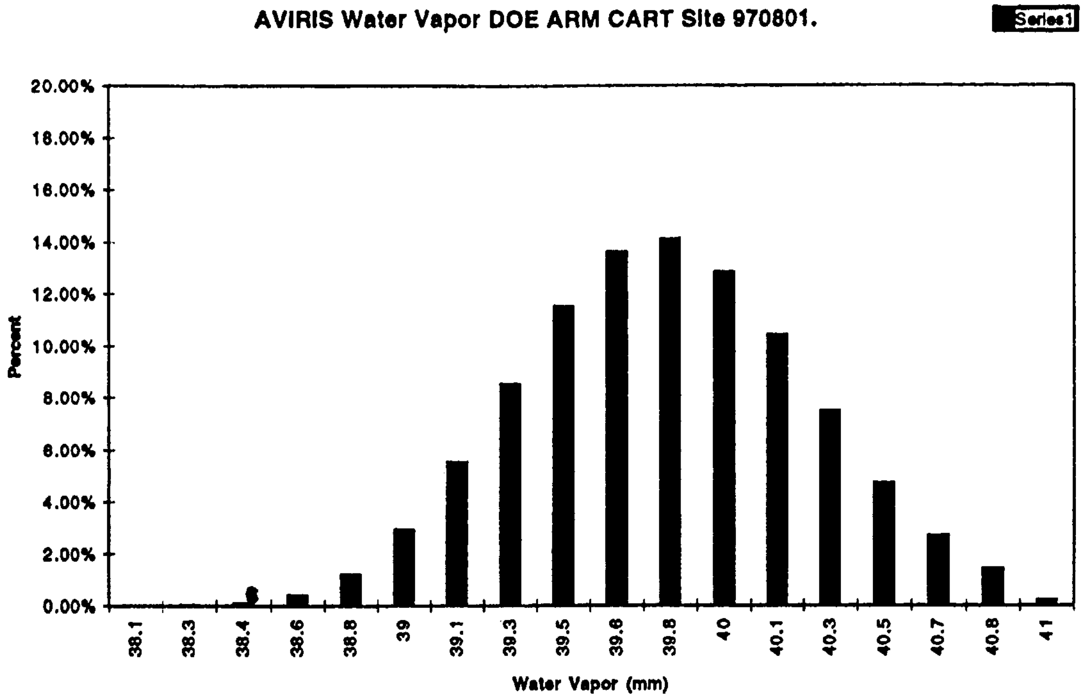

Figure 5. Histogram of the frequency distribution of water vapor derived from AVIRIS spectra of the DOE ARM SGP CART Central site on the August 1, 1997.

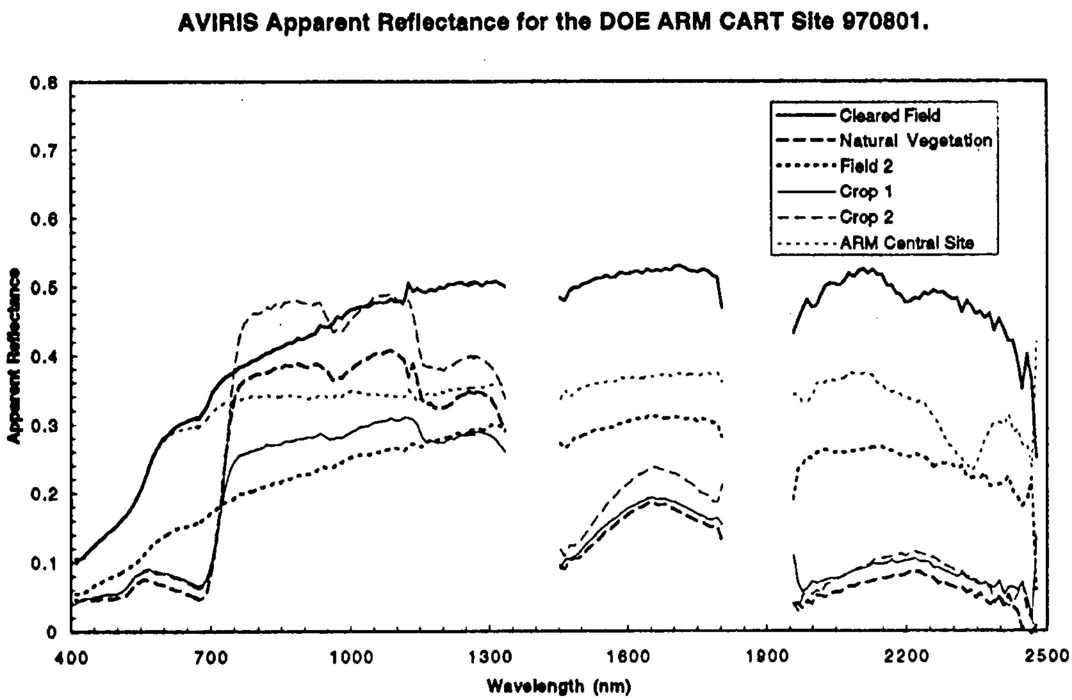

Figure 7. Apparent surface reflectance for soil and vegetation targets in the DOE ARM SGP CART Central Site on the August 1, 1997.

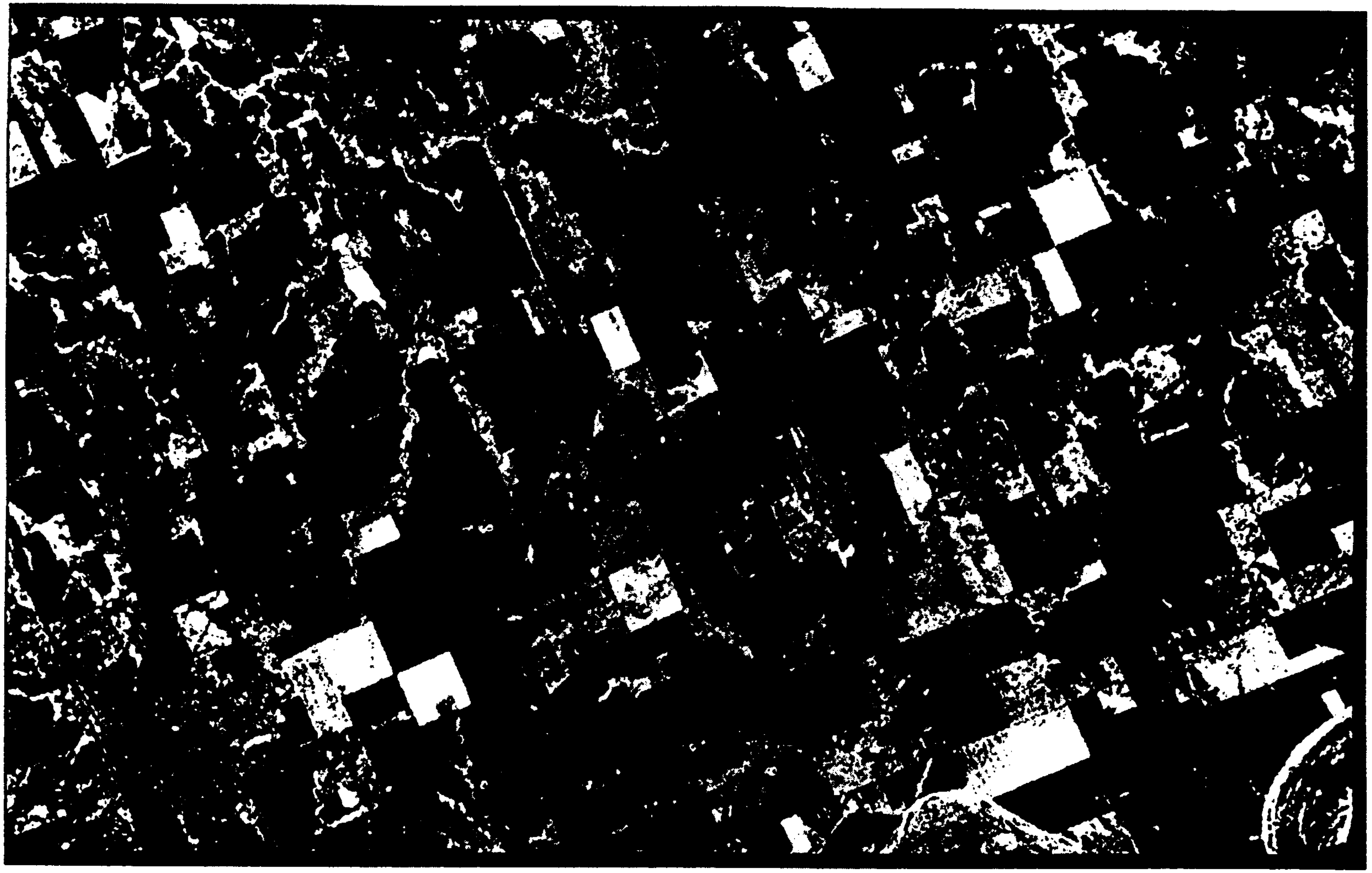

Figure 6. AVIRIS liquid water image for the DOE ARM SGP CART Central Site. The range is from 0.0 to 5.2 mm equivalent liquid water.