Estimation of Aerosol Optical Depth and Additional Atmospheric Parameters for the Calculation of Apparent Reflectance from Radiance Measured by the Airborne Visible/Infrared Imaging Spectrometer

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ABSTRACT

The Airborne Visible/Infrared Imaging Spectrometer measures spatial images of the total upwelling spectral radiance from 400 to 2500 nm through 10 nm spectral channels. Quantitative research and application objectives for surface investigations require inversion of the measured radiance to surface reflectance or surface leaving radiance. To calculate apparent surface reflectance, estimates of atmospheric water vapor abundance, cirrus cloud effects, surface pressure elevation and aerosol optical depth are required. Algorithms for the estimation of these atmospheric parameters from the AVIRIS data themselves are described. From these atmospheric parameters we show an example of the calculation of apparent surface reflectance from the AVIRIS-measured radiance using a radiative transfer code.

1.0 INTRODUCTION

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data are acquired as 11 by up to 100 km images with 20 by 20 m spatial resolution. For each spatial element, 224 spectral channels are measured covering the region from 400 to 2500 nm. AVIRIS data are calibrated with respect to their spectral, radiometric and geometric characteristics in the laboratory (Chrien et al., 1990, Chrien et al., 1993); these calibrations are validated in-flight (Conel et al., 1988, Green et al., 1990a, Green et al., 1993). A valid calibration of AVIRIS is required for the radiative transfer based algorithms described.

In this paper, an AVIRIS data set acquired on the 2nd of June 1992 over a portion of the San Francisco peninsula that included the Jasper Ridge ecological preserve is examined. This AVIRIS scene covers 10 by 11 km and includes a variety of vegetated and unvegetated surface cover types. Figure 1 shows an AVIRIS measured radiance spectrum for a green grass area in this scene. The shape of this spectrum results from the solar irradiance, molecular and aerosol scattering of the atmosphere, gas absorption of the atmosphere, illumination geometry and the reflectance of the surface. The algorithms presented to estimate the atmospheric characteristics and to calculate apparent surface reflectance use the MODTRAN2 (Berk et al., 1989) radiative transfer code in conjunction with a non linear least squares spectral fitting (NLLSSF) procedure.

2.0 WATER VAPOR

Over most of the 400 to 2500 nm spectral range the strongest atmospheric absorber is water vapor (Green et al., 1989). In addition to absorbing strongly in this spectral range, the abundance of water vapor in the terrestrial atmosphere varies significantly both spatially and temporally. For example, greater than 20 percent variation in the spatial and temporal distribution of water vapor has been described for four AVIRIS data sets acquired at 12 minute intervals over the same site (Green et al., 1991a).

To compensate for water vapor absorption in AVIRIS spectra, a determination of total path water vapor is required for each spatial element. Water vapor algorithms for AVIRIS have been developed (Conel et al 1988, Green et al 1989, Green, et al. 1991a) based initially on the LOWTRAN7 (Kneizys et al., 1987) and currently on the MODTRAN2 (Berk et al., 1989) radiative transfer code. The latest water vapor algorithm fits the AVIRIS measured radiance for the 940 nm water band to a radiance spectrum generated by the radiative transfer code. A NLLSSF procedure is used with parameters allowing the atmospheric water vapor amount, the reflectance magnitude, the reflectance slope and a scaled surface leaf liquid water absorption spectrum to vary. Figure 2 shows the fit between the AVIRIS measured and the NLLSSF spectrum for the 940 water vapor absorption over the green grass target in the Jasper Ridge AVIRIS data. Over vegetated targets, leaf water absorption in this spectral region must be compensated in the algorithm to avoid incorrect estimation of the atmospheric water vapor. When applied to the entire AVIRIS Jasper Ridge data set a range in atmospheric water vapor from 9 to 22 precipitable millimeters of atmospheric water vapor was mapped.

3.0 CIRRUS CLOUDS

The presence of cirrus clouds will affect the radiance arriving at AVIRIS, and yet such cloud influence may be difficult to detect. The spectral bands in the strong atmospheric water vapor absorption region return signal only when high albedo targets such as cirrus clouds are present in the upper atmosphere. Based on this hypothesis, a cirrus cloud detection algorithm has been tested using the 1380 nm spectral channel of AVIRIS (Gao et al., 1991). On extremely low humidity days or at high altitudes some surface reflected signal may be measured at 1380 nm. Therefore, the AVIRIS channels located in the stronger water vapor absorption regions at 1880 or 2500 nm may provide more unambiguous cirrus cloud detection.

4.0 PRESSURE ELEVATION

In order to compensate for atmospheric absorption due to well mixed atmospheric gases and the effect of atmospheric molecular scattering, an estimate of the surface pressure elevation is required. An algorithm has been developed to estimate the surface pressure elevation (Green et al, 1991b and Green et al., 1993) from the AVIRIS measured radiance. This algorithm assesses the strength of the 760 nm oxygen absorption band measured in the AVIRIS data. The oxygen band strength is calibrated to surface pressure elevation using the oxygen band model in the MODTRAN2 radiative transfer code. Parameters constraining the pressure elevation, the reflectance magnitude and the reflectance slope in the 760 nm spectral region are allowed to vary in the fit. When applied to the entire Jasper Ridge AVIRIS data set, pressure elevations were calculated that ranged from 0 m towards the San Francisco Bay to 800 m in the mountains on the peninsula. These estimates are consistent with the topography of the region.

5.0 AEROSOL OPTICAL DEPTH

Under low visibility conditions the radiance scattered from atmospheric aerosols may comprise a significant proportion of the total radiance reaching AVIRIS. A NLLSSF algorithm has been developed to estimate the aerosol optical depth directly from the measured radiance. This algorithm optimizes the fit between the AVIRIS measured radiance and a MODTRAN2 modeled radiance with the aerosol optical depth as the primary fitting parameter. Parameters modeling the reflectance magnitude, the reflectance slope and leaf chlorophyll absorption are also included in the fitting algorithm. For the Jasper Ridge data an assumption of aerosol type was required. The MODTRAN2 rural aerosol model was used. Aerosol optical depths at 500 nm were calculated for the entire Jasper Ridge AVIRIS data set that ranged from 0.27 in the peninsula mountains to 0.53 near the San Francisco bay. An example of the fit achieved is given in Figure 3.

6.0 REFLECTANCE CALCULATION

Calculation of surface spectral reflectance from the total upwelling radiance measured by AVIRIS using a radiative transfer code has been pursued since the flights of AVIRIS in 1989 (Green, et al. 1990b, Green, et al. 1991b, Green et al. 1993). Using the water vapor, pressure elevation and aerosol optical depth estimates derived in the previous algorithms, the two way transmitted radiance and atmospheric path radiance spectrum are calculated for each spatial element with MODTRAN2. Computer lookup tables are used to accelerate these calculations. With these determined parameters the surface reflectance is calculated directly. Figure 4 shows the calculated reflectance spectra for the green vegetation target. The AVIRIS measured radiance for this target is shown in Figure 1. Inspection of this calculated reflectance spectrum shows compensation for the solar irradiance, atmospheric absorption and atmospherically scattered radiance.

7.0 CONCLUSION

Algorithms are described that allow estimation of the absorption and scattering characteristics of the atmosphere from sensor measured radiance. With estimation of these atmospheric parameters, apparent surface reflectance may be calculated from the measured radiance. The algorithms described use the MODTRAN2 radiative transfer code for modeling the absorption and scattering properties of the atmosphere. To analyze these sensor measured data with a radiative transfer code such as MODTRAN2, an accurate spectral, radiometric and geometric calibration of the data is required. As these algorithms are further validated, they will offer an approach to provide apparent surface reflectance data directly to the users of the AVIRIS data.

8.0 ACKNOWLEDGMENTS

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9.0 REFERENCES

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10.0 FIGURES

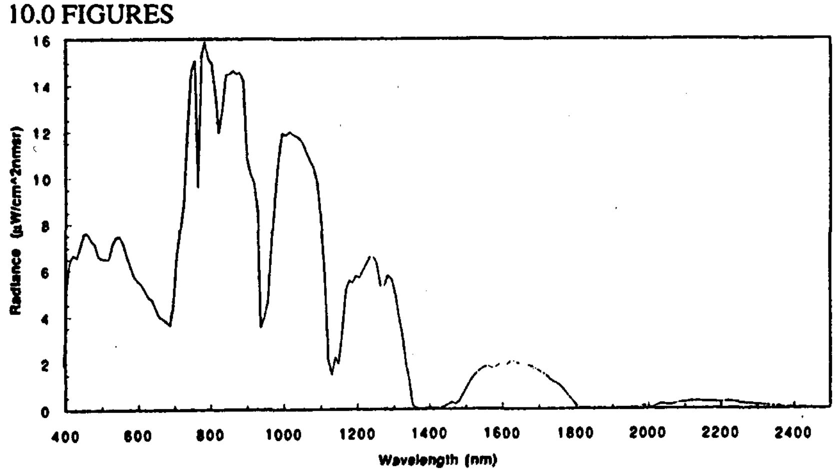

Figure 1. AVIRIS measured upwelling radiance spectrum of a green grass target at Jasper Ridge, CA.

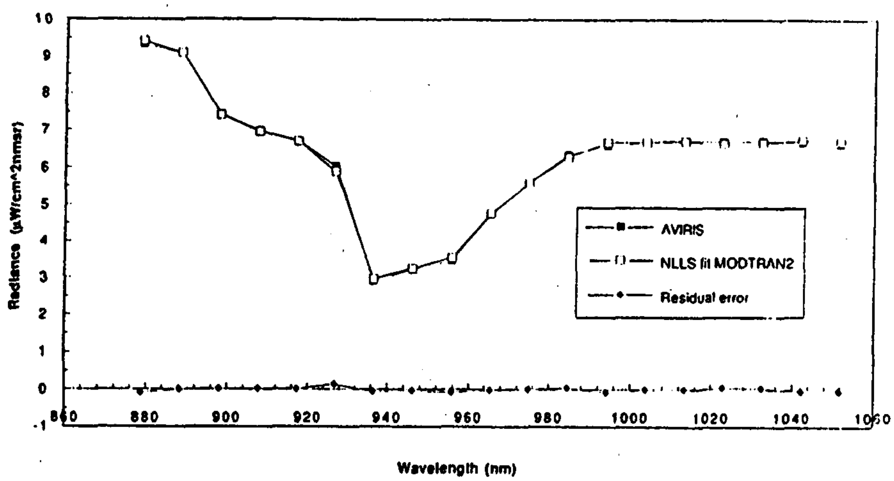

Figure 2. Fit and residual between an AVIRIS measured radiance spectrum and a NLLSSF spectrum for estimation of total path atmospheric water vapor.

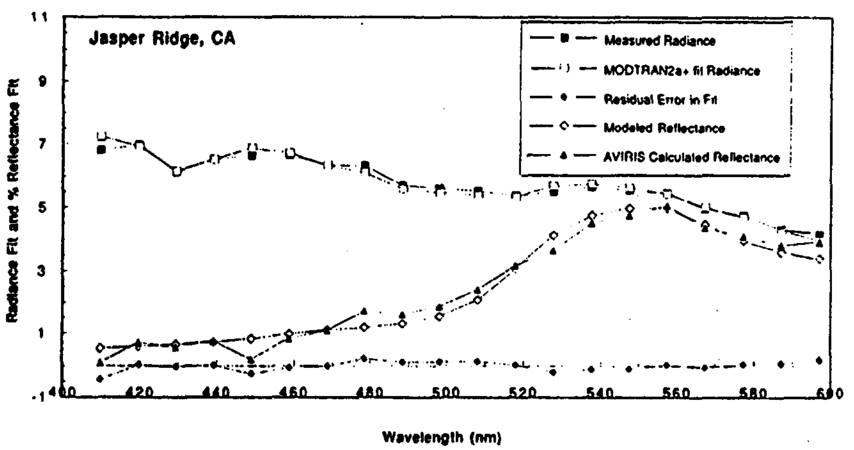

Figure 3. The nonlinear least squares fit between the AVIRIS measured radiance and the MODTRAN2 modeled radiance for estimation of aerosol optical depth. The modeled reflectance required for this fit in the 400 to 600 nm spectral region is also shown as is the resulting AVIRIS calculated reflectance.

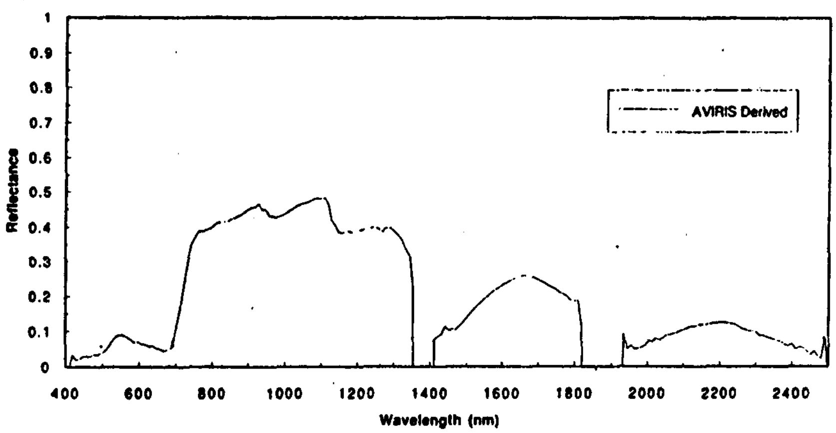

Figure 4. Calculated apparent surface reflectance for the green grass target.