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# THE EFFECTS OF AVIRIS ATMOSPHERIC CALIBRATION METHODOLOGY ON IDENTIFICATION AND QUANTITATIVE MAPPING OF SURFACE MINERALOGY, DRUM MTNS., UTAH

Fred A. Kruse<sup>1, 2</sup> and John L. Dwyer<sup>2, 3</sup>

<sup>1</sup>Center for the Study of Earth from Space (CSES), Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado, Boulder  
Campus Box 449, Boulder Colorado 80309-0449

<sup>2</sup>Department of Geological Sciences, University of Colorado, Boulder

<sup>3</sup>Hughs STX Corporation, Sioux Falls, South Dakota

## 1. INTRODUCTION

The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) measures reflected light in 224 contiguous spectral bands in the 0.4 to 2.45  $\mu\text{m}$  region of the electromagnetic spectrum (Porter and Enmark, 1987). Numerous studies have used these data for mineralogic identification and mapping based on the presence of diagnostic spectral features. Quantitative mapping requires conversion of the AVIRIS data to physical units (usually reflectance) so that analysis results can be compared and validated with field and laboratory measurements. This study evaluated two different AVIRIS calibration techniques to ground reflectance; an empirically-based method and an atmospheric model based method to determine their effects on quantitative scientific analyses. Expert system analysis and linear spectral unmixing were applied to both calibrated data sets to determine the effect of the calibration on the mineral identification and quantitative mapping results. Comparison of the image-map results and image reflectance spectra indicate that the model-based calibrated data can be used with automated mapping techniques to produce accurate maps showing the spatial distribution and abundance of surface mineralogy. This has positive implications for future operational mapping using AVIRIS or similar imaging spectrometer data sets without requiring *a priori* knowledge.

## 2. The Drum Mountains Site

The Drum Mountains, located in the semi-arid terrain of west-central Utah were selected for study because of the good exposure of diverse rock types and alteration mineralogy. The detailed geology of the area is well documented (Baily, 1974; Lindsey, 1979). Extensive amounts of remotely sensed imagery and ground-based data including ground spectral measurements have been collected from all rock units and alteration types, and many rock and soil samples have been analyzed in the laboratory. Rocks exposed in the study area include limestones, dolomites, and shales which overlie a heterogeneous sequence of quartzite and argillite. Volcanic rocks, hydrothermally altered in places, occur in fault contact and overlying the sedimentary units and some carbonate rocks adjacent to the volcanics have been bleached and recrystallized. Contact metamorphism has resulted in development of calcsilicate mineralization in the central part of the study area.

## 3. Calibration of AVIRIS data

### 3.1 Empirical Line Method Calibration

The Drum Mountains AVIRIS data were calibrated to apparent reflectance using the empirical line method (Roberts et al., 1985). AVIRIS radiance spectra for ground targets were used in a linear regression to calculate coefficients to linearly transform the aircraft spectra to match the ground spectra. This method requires *a priori* knowledge in the form of field measurements, which were acquired for both light and dark ground targets. Gains and offsets were calculated to force the AVIRIS spectra to match the field spectra. These gains and offsets were then used to calibrate the Drum Mountains AVIRIS data to apparent reflectance.

### 3.2 Atmospheric Model-based Calibration

The other calibration technique applied to the Drum Mountains AVIRIS data involved the use of a radiative transfer model-based technique (Gao and Goetz, 1990). Apparent reflectance spectra were first obtained by dividing each AVIRIS spectrum by the solar irradiance curve above the atmosphere. A number of theoretical water vapor transmittance spectra for the 0.94 and 1.1  $\mu\text{m}$  water vapor bands were calculated for varying amounts of atmospheric water vapor using an approximate radiative transfer code called "Simulation of the Satellite Signal in the Solar Spectrum (5S)" (Tanre et al., 1986) and the Malkmus (1967) narrow band spectral model. The modeled spectra are run through the three-channel ratioing method to generate a lookup table of water vapor concentrations that can be used to convert the AVIRIS apparent reflectance measurements to total column water vapor. The output of this procedure is an image showing the spatial distribution of various water vapor concentrations as derived for each pixel of the AVIRIS data. The water vapor image is then used along with transmittance spectra derived for each of the atmospheric gases  $\text{CO}_2$ ,  $\text{O}_3$ ,  $\text{N}_2\text{O}$ ,  $\text{CO}$ ,  $\text{CH}_4$ , and  $\text{O}_2$  using the Malkmus narrow band model and 5S model to produce scaled surface reflectance (Gao and Goetz, 1990). This model-based technique produces total water vapor column images and reflectance calibrated AVIRIS data without *a priori* knowledge.

## 4. Comparison of Calibration Results and Scientific Validation

### 4.1 Reflectance Spectra

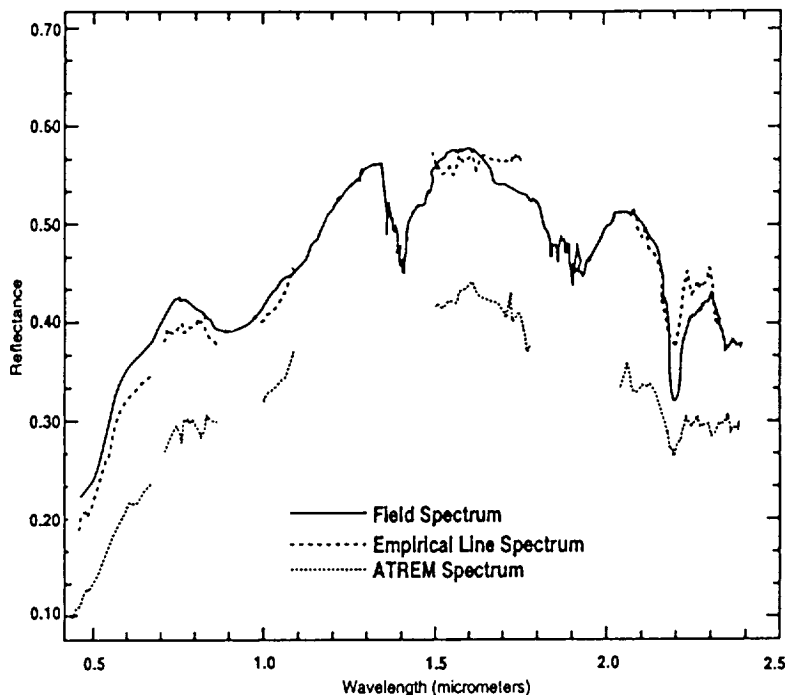
The results of the two calibration techniques described above were compared by extracting reflectance spectra from calibrated AVIRIS images and comparing with field and laboratory spectra. Figure 1 shows a field spectrum compared to AVIRIS spectra extracted from both the empirical line (EL) calibrated and atmospheric model (AM) calibrated data. Note that the EL AVIRIS spectrum matches the position and shape of the laboratory spectrum (particularly at 2.2  $\mu\text{m}$ ) more closely than the AM AVIRIS spectrum. The EL spectra, also were consistently brighter than the AM spectra and absorption features near 0.9 and 2.2  $\mu\text{m}$  in the AM spectrum were consistently suppressed as compared to the EL spectrum. These general characteristics were observed for several different areas using the two AVIRIS calibration methods. Initially, the suppression of the 0.9  $\mu\text{m}$  feature was attributed to model-based calibration error caused by the assumption made in the AM method that most materials are spectrally flat in the 0.9 region. Subsequently, the AVIRIS data were recalibrated using only the 1.14  $\mu\text{m}$  water band and the resulting spectra were virtually indistinguishable. Thus, the suppression of the 0.94  $\mu\text{m}$  band must be attributed to some other cause. In fact, it appears that perhaps it is the EL method that is enhancing the absorption bands rather than the AM method suppressing them.

### 4.2 Automated Feature Extraction and Expert System Analysis

Thematic image products were generated showing the distribution of major mineral constituents for the Drum Mountains site using an expert system approach. The expert system is an absorption feature based technique that uses rules built from a spectral library to identify unknown minerals in imaging spectrometer data (Kruse et al., 1993). The success of this approach depends on having high-quality, well calibrated spectral data. Once the data are properly calibrated, the procedure is to treat each pixel individually and sequentially to remove a continuum (normalize), extract the features, and to compare the features found in the AVIRIS data to the feature rules. The result of these analyses is a new data cube consisting of a single image for each endmember showing the degree of match to the rules (Kruse et al., 1993).

Image maps derived from both the EL and AM calibrated AVIRIS data using the expert system techniques were compared to conventional geologic maps for the Drum Mountains site (Bailey, 1974, Lindsey, 1979). In general, these images showed good correspondence to known mineralogy for distinct lithologic units. For example, areas of dolomite could be easily distinguished from the Prospect Mountain Quartzite, which contains primarily clay minerals. In addition, previously unmapped mineralogical variation was mapped within the different units. While the details of these image maps has not been verified in the field, samples from selected units (Tremper, 1991) indicate that to the first order the mineralogy being mapped using the imaging spectrometers is accurate. Limitations are likely related to the relatively low signal-to-noise-ratios of the 1990 AVIRIS data. Very similar mineralogical results were obtained using both the EL and the AM calibrated data. The expert system results from the AM data were

Figure 1. Comparison of an EL calibrated and AM calibrated spectrum for the same pixel to a field spectrum. Portions of the AVIRIS spectra in the atmospheric water bands have been masked.



noticeably noisier, however, as would be expected based on the previous descriptions of how this calibration suppresses absorption features.

#### 4.3 Linear Spectral Unmixing

Spectral mixing is a consequence of the mixing of materials having different spectral properties within the ground field-of-view (GFOV) of a single image pixel. Boardman (1992) addressed the mixing problem using singular value matrix decomposition (SVD) to linearly unmix AVIRIS data. This technique assumes that most mixing is on the macroscopic scale, and thus linear. To the first order, this model appears to adequately represent the surface geologic conditions.

Linear spectral unmixing was applied to each of the calibrated Drum Mountains AVIRIS data sets using endmember spectral libraries derived from the two calibrated data sets using the expert system. The output of the unmixing process was an image data cube of endmember abundances, an abundance sum image, and a root-mean-square (rms) error image. Interactive analysis of these images showed that each library explained most of the spectral variation in the Drum Mountains AVIRIS data in its respective calibrated data set. In general, similar results were obtained using both the EL and the AM calibrations. The locations and relative abundances of specific minerals were very similar (see Slide 4). There were some obvious differences between the images. For example, the two "illite" images show differences in absolute abundances. The EL image shows a crescent shaped area of high concentrations (yellow) along the right edge of the image. The AM image shows a similar shaped area, however, the concentrations are somewhat lower (purple and blue). These differences are attributable to degeneracy of the AM spectral endmember library caused by increased similarity of spectra by suppression of spectral features.

### 5. DISCUSSION AND SIGNIFICANCE OF THE RESULTS

Comparison of reflectance spectra and derived thematic maps from the empirical- vs model-based calibrations demonstrated that both data sets contained basically the same mineralogical information about the ground surface. The empirical line method, however, emphasized mineral absorption features, thus it was better suited to analysis using absorption-feature-based techniques. In particular, more consistent results were obtained when this reflectance data was analyzed using an expert-system approach. While similar endmember spectra were

identified using the atmospheric model, suppression of the absorption bands in the AM calibrated data (relative to the EL data) caused less effective mapping of spectral variation. Once unique endmember spectra were identified, however, linear spectral unmixing worked equally well on both calibrated data sets, producing very similar results.

The significance of this research is that it demonstrates that a model-based calibration method for imaging spectrometer data requiring no *a priori* knowledge can be used to produce reflectance data for quantitative scientific analysis. This achieves the goal of being able to extend analysis techniques developed for analysis of one area to analysis of a second, unknown area. With the advent of imaging spectrometers, model-based calibration methods, and the quantitative techniques outlined here, imaging spectrometers can be used to extract ground surface characteristics without having to first conduct a field survey.

## 6. ACKNOWLEDGMENTS

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