TECHNIQUES FOR AVIRIS DATA NORMALIZATION IN AREAS WITH PARTIAL VEGETATION COVER

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ABSTRACT

Several normalization procedures were developed to aid in analyzing AVIRIS data of the Iron Hill, Colorado carbonatite complex. The procedures include 1) a flat field correction suitable for use in areas with moderate vegetation cover, 2) a method for approximate calibration to percent reflectance based on the flat field normalization spectrum, and 3) a first order vegetation "removal" strategy. Each procedure uses relative absorption band depth images to provide a basis for correcting the AVIRIS data without _a priori_ knowledge of surface targets.

INTRODUCTION

Semiarid areas with moderate to heavy vegetation cover present special problems for airborne imaging spectrometer data analysis. Available ground targets for use in spectral calibration commonly are very small or contain patchy vegetation that is difficult to characterize. Moreover, few image pixels have an "average" amount of vegetation cover so that simple first order corrections (e.g. Kruse, 1988) to remove atmospheric and solar components in radiance measurements generally cause serious distortions in the spectral curve shapes.

This paper describes several methods of data analysis applied to Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data of the Iron Hill carbonatite complex in southwestern Colorado. The Iron Hill carbonatite is dolomitic and has relatively low rare-earth element (REE) content on the order of 100-500 ppm (Nash, 1972). Associated alkaline igneous rocks include pyroxenite, uncompahgrite, nepheline syenite, ijolite and fenitized granite. Visible and near-infrared spectra of samples from the carbonatite display CO_3 absorption bands centered near 2.32 µm, reflecting the dolomitic composition, an intense, broad Fe^{2+} doublet in the 1.25 µm region, and weak Nd^{3+} features located between 0.7 and 0.9 µm. Where exposed, the alkaline rocks exhibit Mg-OH features in the 2.3-2.4 µm region (Rowan and others, 1986). More commonly, however, the alkaline rocks are marked by dark micaceous soils that have weak Mg-OH absorption features which are further diluted by partial vegetation cover. The vegetation in the area is highly variable in amount, with sagebrush and grasses typically comprising about 30-80 percent of most upland surfaces. Dense coniferous tree cover occurs on the highest elevations, and the presence of a broad absorption band near 2.31 μm in the sagebrush and conifer spectra presents a significant problem for discerning the CO_3 features of the carbonatite.

Three full segments and one partial segment of AVIRIS data were acquired over Iron Hill in September, 1989. The data were radiometrically corrected using laboratory calibration measurements (Vane and others, 1987) and provided in the JPL unresampled spectral format. The data analysis procedures described below consist of a series of FORTRAN programs within the REMAPP image processing software system developed at the U.S. Geological Survey.

FLAT FIELD CORRECTION

Flat field correction refers to a data normalization technique in which the radiance spectrum of a ground target is divided through an entire data set to remove the atmospheric and solar radiance components. Previous flat field corrections have typically involved the selection of a ground target that is 1) situated near the average scene elevation, and 2) relatively free of mineral and vegetation absorption features. An additional consideration is the size of the flat field target, as the use of targets which are too small can diminish the effective signal to noise of the data. An alternative to the use of a single ground target that avoids the signal to noise problem is the use of an average spectrum of the entire data set (Kruse, 1988).

For the Iron Hill study area a classification technique using relative band depth (RBD) images (Crowley and others, 1989) was developed to identify pixels that exhibit both low vegetation cover and low mineral absorption intensity. The technique locates and utilizes individual pixels distributed over the entire image, hence it has been termed a "distributed" flat field (DFF) correction. It avoids the necessity for large uniform ground targets, and incorporates a sufficient number of pixels to avoid signal to noise degradation.

To perform the distributed flat field correction for the Iron Hill study area, an RBD image was constructed by using AVIRIS channels 18+40/29 to provide an index of green vegetation cover. Similarly, RBD index images were generated to map 2.20 μm absorption (channels 192+206/199), characteristic of many clays and other Al-OH-bearing minerals, and 2.315 μm absorption (channels 203+217/210), commonly associated with dolomitic carbonate rocks and Mg-OH-bearing minerals. The classification procedure first examined the vegetation index RBD image to identify pixels that have low vegetation cover. Corresponding pixels that have low DN values in both the 2.20 and 2.315 RBD images (i.e., weak or absent mineral absorption) were then averaged to produce a normalization spectrum for use in the DFF correction. In principle any number of

RBD images can be combined in the procedure. In the Iron Hill study area, approximately 200 pixels were identified in the DFF classification procedure, which was a substantially greater number than could be obtained from any single usable ground target. Figure 1 shows three AVIRIS spectra extracted from the DFF corrected data set, including an area within the carbonatite stock, and two different exposures of clay-rich soils. Notice that the DFF correction permits kaolinitic clays to be distinguished from illite/smectite clays, a separation which was not possible using an ordinary flat field correction based on a single discrete ground target.

CALIBRATION TO REFLECTANCE USING THE DFF SPECTRUM

Airborne imaging spectrometer data have been successfully calibrated to percent reflectance by using ground spectral measurements of bright and dark calibration targets (Roberts and others, 1985). To perform this type of calibration, DN's of the target areas are regressed against the known ground reflectance values, providing a gain and offset correction for each spectral channel. Problems with the method include the difficulty in locating suitable ground targets and the practical problem of measuring targets <u>in situ</u> for every dataset.

An attempt was made to circumvent these problems by using the distributed flat field normalization spectrum obtained from the entire image as described above. If this spectrum is taken to represent a spectrally flat target having some estimated brightness, an approximate calibration to reflectance can be performed. Experience indicates that the actual brightness of most soil/vegetation mixtures is probably in the range of about 25-50 percent reflectance. Thus, if an intermediate brightness level is selected, for example 35 percent, a scalar can be calculated for each AVIRIS channel by dividing this assumed reflectance by the actual DFF spectrum DN. The scalars may then be applied channel by channel to calibrate the radiance data to reflectance. Figure 2 compares spectra for a 10 by 10 pixel area within the carbonatite stock calibrated by using three different assumed DFF reflectance levels.

FIRST ORDER VEGETATION REMOVAL

A series of programs were developed to perform a second normalization to the flat field corrected data set with the goal of compensating for the vegetation spectral component in each pixel. At the center of the procedure are two assumptions: The first is that the vegetation consists of a single major cover type. At Iron Hill this assumption appears to be reasonable as mixed sagebrush and grass is the principal cover type in nearly all areas with significant soil and rock exposures. The second assumption is that a linear relationship exists between digital numbers in the vegetation index RBD image and the percent vegetation cover, at least over some portion of the total index DN range.

To perform the normalization, a target area was selected that contained approximately 100 percent sagebrush and grass cover (Table 1). This selection was based on an examination of the vegetation index image in conjunction with aerial photography. The target area's mean DN value in the vegetation index image was used to calculate the equation of a line defining the relation between index DN's and percent cover. The AVIRIS spectrum of the 100 percent vegetation area was subsequently scaled according to the estimated amount of vegetation in each image pixel, and then subtracted from the spectrum for the pixel. At this stage the spectra represent (ideally) only the exposed minerals within each pixel, the vegetation having been "removed." The final step in the procedure is a correction for the dilution of the mineral spectra due to the original vegetation component. This involves a second application of the vegetation index, in which the mineral spectrum is multiplied by a factor that is the reciprocal of the percent exposure (the complement of the percent vegetation). The individual steps in the vegetation correction procedure are summarized in Table 1. Figure 3 shows two pairs of spectra that illustrate the effects of the procedure.

DISCUSSION AND CONCLUSIONS

Several AVIRIS data normalization and calibration procedures have been described that have particular relevance to moderately vegetated study areas. A "distributed" flat field (DFF) correction makes use of selected pixels within an image that have optimum characteristics of low vegetation cover and low mineral absorption. At the Iron Hill locality this correction produced much better results than other flat field corrections involving an average spectrum of the entire dataset, or the spectrum of a single discrete ground target.

The DFF normalization spectrum can also be used to calibrate imaging spectrometer data to percent reflectance by assuming that the spectrum represents a spectrally flat target of intermediate brightness. Preliminary results at Iron Hill indicate that this calibration method can yield a good first order calibration to percent reflectance, particularly when the image data have already been corrected for channel to channel radiometric offsets related to detector sensitivity variations. This ability to obtain an approximate calibration without reliance on ground spectral measurements should provide a very useful starting point for more accurate calibration efforts, such as those based on linear modeling of mixtures of field spectra.

A third procedure was designed to provide a first order "defoliant" for AVIRIS data. The principal objective of the procedure is to generate image products in which characteristic spectral attributes of different lithologic units (such as 2.20 µm band intensity) are enhanced and the complicating effects of variable vegetation cover suppressed. The procedure does not require _a priori_ assumptions about the mineral absorption characteristics of an area and is much less demanding computationally than algorithms that "unmix" numerous spectral components within individual pixels. On the other hand, the resulting spectral signatures are only approximate, and most useful in parts of an image that contain the single vegetation cover type around which the procedure is designed.

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Fig. 1. (Next Page) Spectra of three 10 x 10 pixel ground targets in the Iron Hill study area extracted after the Distributed Flat Field correction. Note the characteristic 2.17 µm feature in kaolinite, which was not apparent in spectra produced by standard flat field normalization techniques. Y axis shows digital numbers. The spectra are offset for clarity.

Fig. 2. (Next Page) Three spectral plots showing the effects of different assumed brightness levels of the DFF spectrum when used to perform an approximate calibration to percent reflectance. The upper curve represents a carbonate-rich exposure in the Iron Hill study area and an assumed DFF brightness of 45 percent. The lower two curves are for the same target using assumed brightnesses of 35 and 25 percent, respectively. Y axis is in reflectance units.

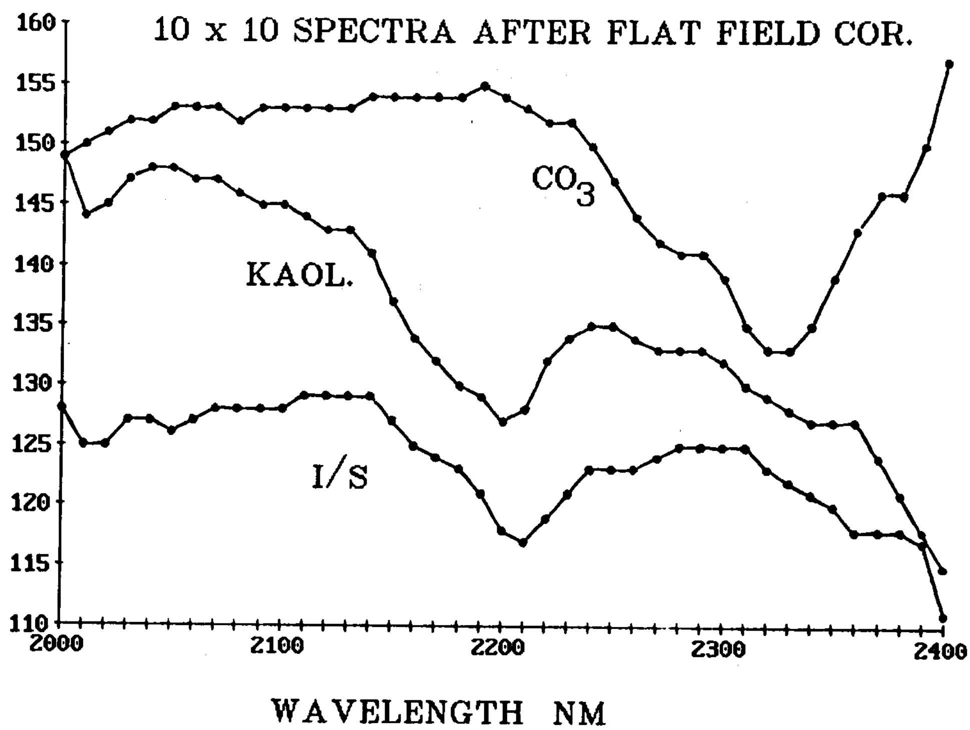

FIGURE 1.

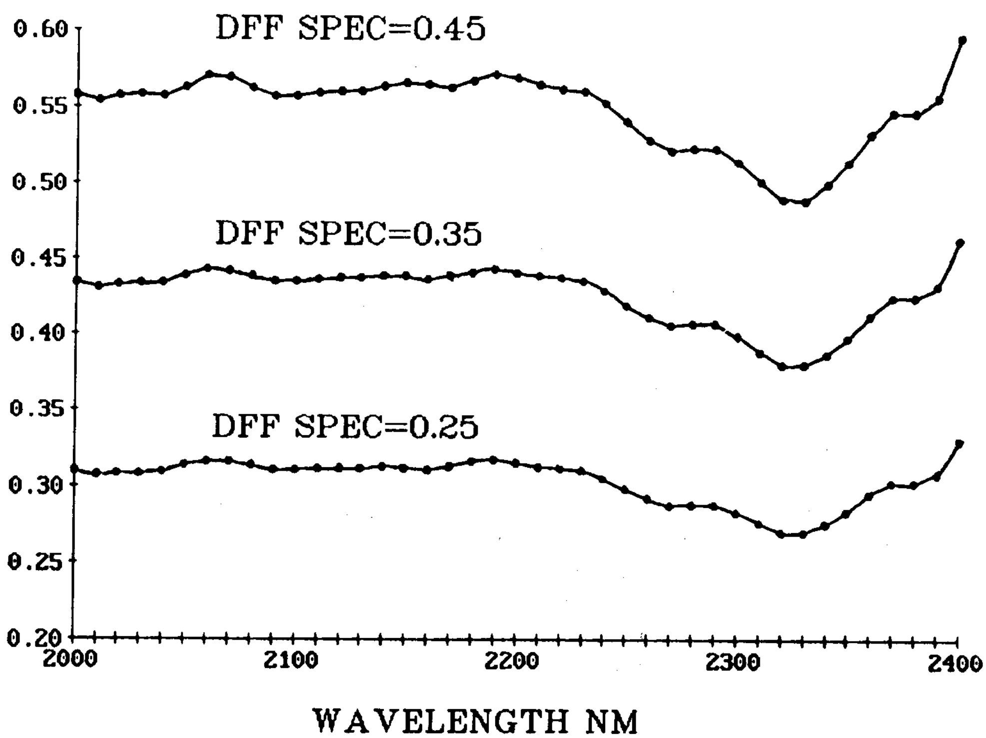

FIGURE 2.

Table 1. Steps in Vegetation Removal Procedure.

1). Construction of vegetation index image; identification of 100% vegetation covered target area. Calculation of linear relation between index DN's and percent cover.

2). Distributed flat field correction followed by equal energy normalization (See Kruse, 1988).

3). For every pixel, scale the 100% vegetation spectrum by the percent vegetation in that pixel as determined by the equation in step (1).

4). Correct the equal-energy data set produced in (2) pixel by pixel by subtracting the scaled vegetation spectrum for each pixel.

5). Rescale the data set produced in (4) by the reciprocal of the percent exposure in each pixel (vegetation dilution correction).

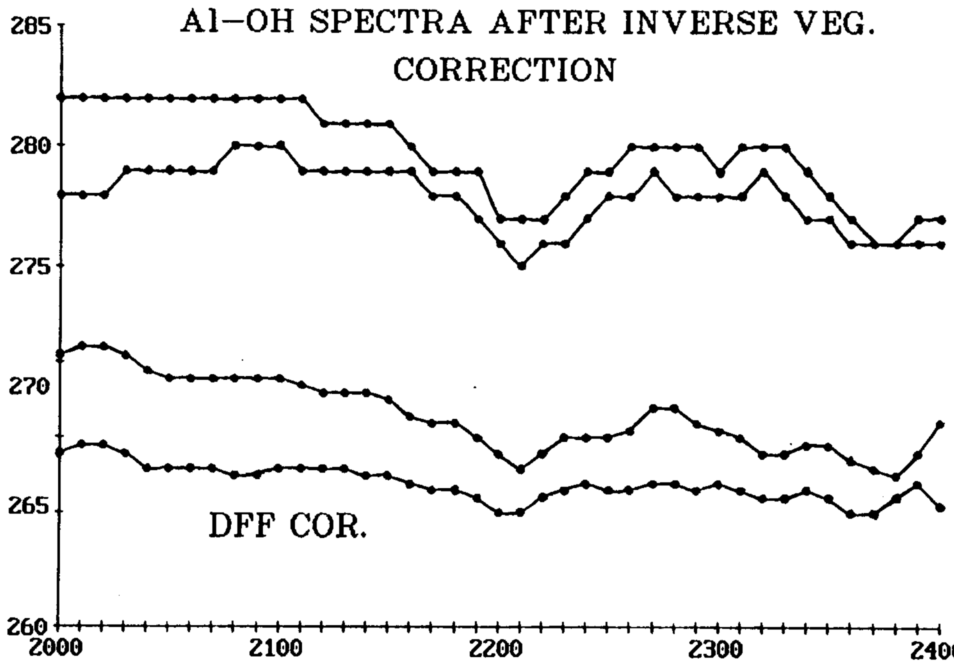

Fig. 3. Spectra of two partially vegetated targets within the same lithologic unit showing Al-OH absorption features before and after the first order vegetation correction. Prior to the correction (bottom curves), the two targets exhibit different 2.20 µm absorption intensities associated with different amounts of vegetation cover. Removal of the variable vegetation component has "equalized" the absorption intensities in the postcorrection (upper) spectra. Y axis is in digital numbers; X axis shows wavelength in nanometers. The spectra are offset for clarity.