Using mixture analysis for soil information extraction from an AVIRIS scene at the Walnut Gulch Experimental Watershed - Arizona

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Abstract: Spectral Mixture Analysis (SMA) has been used to extract qualitative and quantitative information about common features in an imagery at the subpixel level. At the Walnut Gulch Experimental Watershed (Arizona) this technique was used to produce the soil spectral map and quantify the fractions of each soil endmember on an AVIRIS image. SMA was applied on the base of image and reference endmembers. Four image endmembers (McAllister and Stronghold soils, green vegetation, and shade) were needed to model AVIRIS data on the base of image endmembers. There was a general agreement between field observation and the delineation of the boundaries of McAllister and Stronghold soil series through the spectral map generated by SMA. Dark soils (Graham and Epitaph soil series) and shade fractions was separated only in the spatial context. A technique called target test was used to detect for the presence of reference endmembers on AVIRIS data. On the base of six detected reference endmembers SMA was successfully applied for subset of image pixels.

Keywords: Endmember selection, spectroradiometry, target testing, image endmember, reference endmember, soil spectral map.

Introduction

Due to its ubiquitous presence, soil is present in almost all applications of image-based spectral mixture analysis (SMA). In many studies, however, most of the interest is given to the fraction of the vegetation endmember and its relationship to plant biophysical parameters (Dereck et al., 1996; Leeuwen et al., 1997). One of the few examples of the application of mixture analysis directly to soil is given by Huete and Escadafal (1991). These authors used SMA for soil biophysical information extraction in the region from 400 to 900 nm . They found that the variability of 46 soils from different types of environments could be explained by four independent basis curves, which in linear combination were able to reconstitute the experimental data set. These authors, however, did not use spectral mixture analysis to produce soil spectral maps.

Mixture analysis can be applied on the basis of spectra extracted from the image (image endmembers) and/or on the basis of pure spectra from lab or field (reference endmembers). When the spatial variability within a pixel is high, as in a semiarid scrubland, mixture analysis on the basis of image endmembers has been shown more accurate than maximum likelihood supervised classification (Fernandes et al. 1996)

The general objective of this study was to derive soil spectral maps of an AVIRIS scene at the Walnut Gulch Experimental Watershed using mixture analysis. The specific objectives are to: (a) evaluate the dimensionality of AVIRIS data (i.e., how many endmembers); (b) find the physical meaning of the dimensions (i.e., what feature in the ground each endmember represents); and (c) determine the spatial abundances of the endmembers throughout the AVIRIS scene of the Walnut Gulch Experimental Watershed.

Methodology

The study site is located within the Walnut Gulch Experimental Watershed, Tombstone, Arizona. The area of the Watershed imaged by AVIRIS is dominated by six soil series: McAllister, Stronghold, Graham, Tombstone, Baboquivari and Epitaph (Fig. 1). When considering the parent material, some of the major soils in this Watershed such as Stronghold and Tombstone were largely influenced by the presence of limestone, while others, such as Baboquivari and McAllister have as their parent material mixed fan alluvium. Graham and Epitaph soil series are dark soils originating from slope alluvium and residuum from basaltic rocks. FIG. 1

AVIRIS data were collected over the study area on May 14, 1991(dry season). The original image was displayed and each band was examined for noise. A total of 167 "good" bands resulted from this visual inspection . The original AVIRIS image came as a scaled radiance image and was processed to continental surface reflectance imagery by using the Atmosphere Removal Program

(ATREM) (Gao et al., 1996). The atmospheric model was midlatitude summer with derivation of water vapor using the default center channels for areas covered by soils (Gao et al., 1996).

Field Spectra Collection

Field spectra were collected for bare soils and other materials such as vegetation (grass, forbes, shrubs), rocks, and litter with an SE590 Spectron spectroradiometer for the range of 0.45 to 0.90 µm, with 10 nm sampling interval and 15º field of view. Each of the six soil series had one representative spectra except Stronghold which had three due to the differences in surface cover.

Spectral Mixture Analysis

The general form of the SMA equation for each band is:

$$P_c = \sum_{i=1}^{N} F_i R_{i,c} + E_c$$ with the constraint that

$$\sum_{i=1}^{N} F_i = 1$$

where P_c is the relative reflectance value in channel c of an image pixel; F_i is the fraction of the endmember i; $R_{i,c}$ is the relative reflectance of the endmember i in channel c; N is the number of endmembers; and E_c is the error for channel c of the fit of N spectral endmembers. The fraction images obtained through SMA can be rescaled to remove the contribution of an unwanted endmember such as shade.

For a better selection of reference and image endmembers, the soil field spectra were clustered and the spectral classes analyzed. Field spectra were collected for the interval from 0.45 to 0.90 µm. A 10 percent constant reflectance curve was tested as a shade image endmember.

To avoid use of extensive spectral libraries, target test analysis (Malinowski and Howery, 1980) was utilized to test for suspected reference endmembers in the AVIRIS scene:

$$[R]_{\text{real}} = [R]_A[T]$$

$$T_l = [\lambda]^{-1}[R]_A^t R_l$$

where $[R]_{real}$ is the real reference endmember spectra matrix, $[R]_A$ is the abstract reference endmember spectra matrix , [T] is the transformation matrix , T_l is a least squares column vector transformer for each of the n endmembers, and R_l is the associated target test column vector, containing the spectral signatures of the suspected reference endmembers. To determine if the spectral signatures of the suspected reference endmembers are present in the data set, we compute the predicted spectral signature R_p:

$$R_p = [R]_A T_l \, .$$

If each element of the predicted spectral signature is equal to the corresponding element of the test signature, within experimental error, then the suspected reference endmember is present in the data set and the column vector transformer T_l is included in the transformation matrix.

Results and Discussion

Mixture Analysis Using Image Endmembers

The cluster analysis showed that four soil classes can be separated from the field spectra. One of the spectral classes encompasses Stronghold, Tombstone and Baboquivari soil series while the other soil series (McAllister, Graham, and Epitaph) fall in three different classes. These results gave the starting point for the selection of image endmembers through the location of pixels where the soil field spectra were collected. In addition to the soil image endmember, a green vegetation image endmember was included in the model. The visual inspection of the error image was used as the criterion for selecting the best combination of image endmembers. The best combination of image endmembers was given by the spectra of pixels extracted from the following areas: McAllister soil, Stronghold soil, Graham soil and green vegetation. The fact that Graham and Epitaph are spectrally too dark made the modeled shade spectra useless. Thus, the visual inspection of the error images from the models that included modeled shade, Graham and Epitaph soils, presented no significant differences when mixed with the other selected image endmembers (McAllister, Stronghold, and green vegetation). The combined average rms error after applying mixture analysis to the 167 AVIRIS bands was 2.6 % reflectance.

The fraction images were rescaled to remove the contribution of green vegetation and soil spectral maps were produced for each of the soil image endmembers. Figures 2 and 3 present the spectral maps for Graham and McAllister soils. The map for McAllister fraction image shows that most of pixels containing more than 70% of this soil are located in the left portion of the AVIRIS image. These results agreed with field observations of the spatial distribution of McAllister soil. However, areas occupied by Baboquivari and part of the area occupied by Stronghold were misclassified as containing a high proportion of McAllister. Pixels having less than 30 % of McAllister soil are located in the upper left corner, and in the middle bottom of the AVIRIS image. The map for Graham soil/shade image endmember shows that pixels with more than 70 % of the area covered by this endmember correspond to areas occupied by Graham and Graham Lampshire soils. Areas with more than 35 % of Graham soil/shade image endmember that are close to Graham soil were associated to Epitaph soil series (compare to Fig. 1). Since Graham, Graham Lampshire and Epitaph soils do not occur in the left side nor in the upper part of the AVIRIS image, the spectral map for these portions was highly influenced by topographic shade. Thus, shade occurrence was less in the gentler slope areas occupied by McAllister than in the Stronghold areas which are more affected by the slope.

FIG. 2
FIG. 3
FIG. 1

Mixture Analysis Using Reference Endmembers

Target testing was applied to the AVIRIS image to detect the presence of reference endmembers. Since most of the spectral library (including all spectra other than soils) was collected for the range 0.45 to 0.90 µm, we used a subset spectral range of the AVIRIS data for modeling the image on the basis of reference endmembers. Target testing successfully predicted the presence of at least seven reference endmembers: McAllister, Stronghold, and Graham soils, dry forbes, litter, dry grass, and green vegetation (given by the spectra of walnut leaf). Figure 4 presents two examples of the results of target testing. The error in the predicted spectra occurred mostly in the NIR and was attributed to the uneven correction of the atmospheric effect by ATREM

FIG. 4

The seven reference endmember spectra were used for modelling 46 bands of AVIRIS data in the inteval from 0.45 to 0.90 µm. Spectral mixture analysis, however, could not be successfully applied to the combination of the seven reference endmembers. Smith et al. (1994) pointed out that the input of a high number of reference endmembers can result in an unstable solution for the fraction due to the loss of contrast between endmembers. Roberts et al. (1992) suggested the use of a subset of AVIRIS data in mixture analysis as one way to work with the high number of reference endmembers.

In this study, a subset of nine pixels extracted from each of the following soils; McAllister, Stronghold, and Graham were used for spectral recomposition on the basis of the reference endmembers detected by target testing. Six of the seven reference endmembers were found on those pixels. As an example, the spectra from pixels extracted from McAllister were mixed with the spectra from litter and dry forbes (Fig 5a). Figure 5b shows the contribution of each material for the mixed spectra of McAllister soil. The average rms error for the fit of the model for these pixels was 2.5 % reflectance. Fractions of green vegetation as low as 10 % were detected in pixels extracted from Stronghold and Graham soils.

FIG. 5a
FIG. 5b

Conclusions

The SMA produced soil spectral maps with good agreement with field results for the following image endmembers: McAllister, Stronghold, and Graham soils. Graham and shade fractions were spectrally similar but could be separated in the spatial context of Graham soil/Shade spectral map.

Target testing showed that there were at least seven reference endmembers in the AVIRIS image: McAllister, Stronghold, and Graham soils, dry forbes, litter, dry grass and green vegetation (walnut). Spectral mixture analysis, however, could not be run simultaneously for the seven reference endmembers. Spectral mixture analysis, when applied to a subset of pixels, detected the presence and quantified the fractions of six of the seven reference endmembers identified using target testing.

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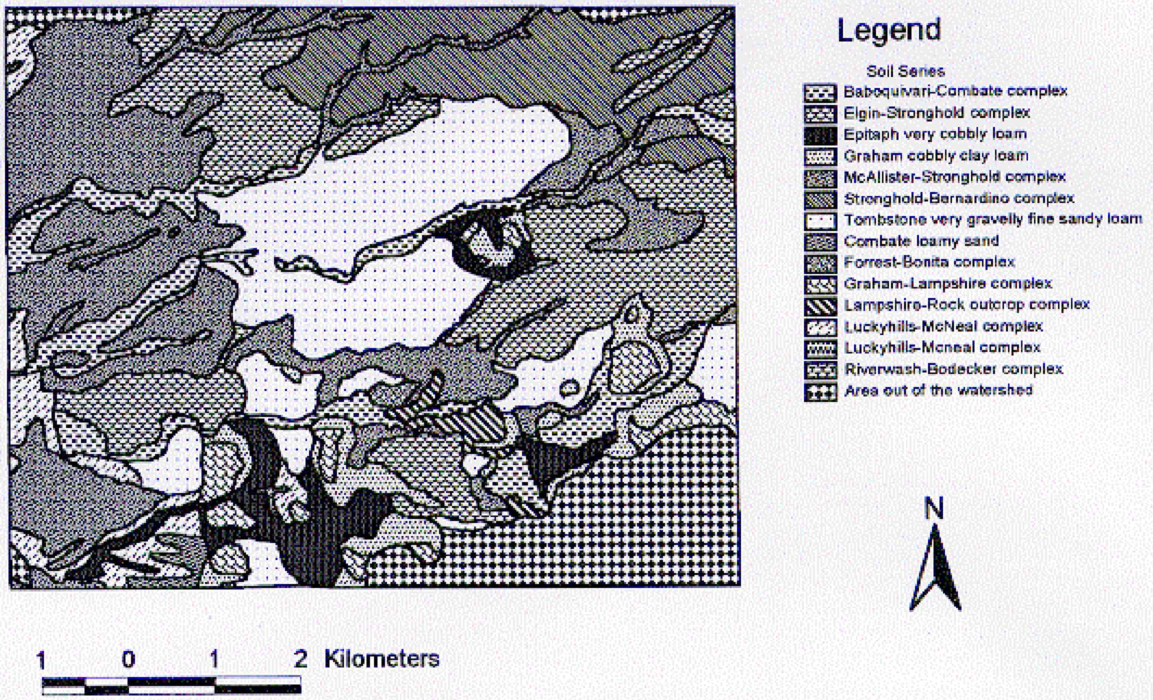

Figure 1. Soil map of the area of the Walnut Gulch Experimental Watershed imaged by AVIRIS

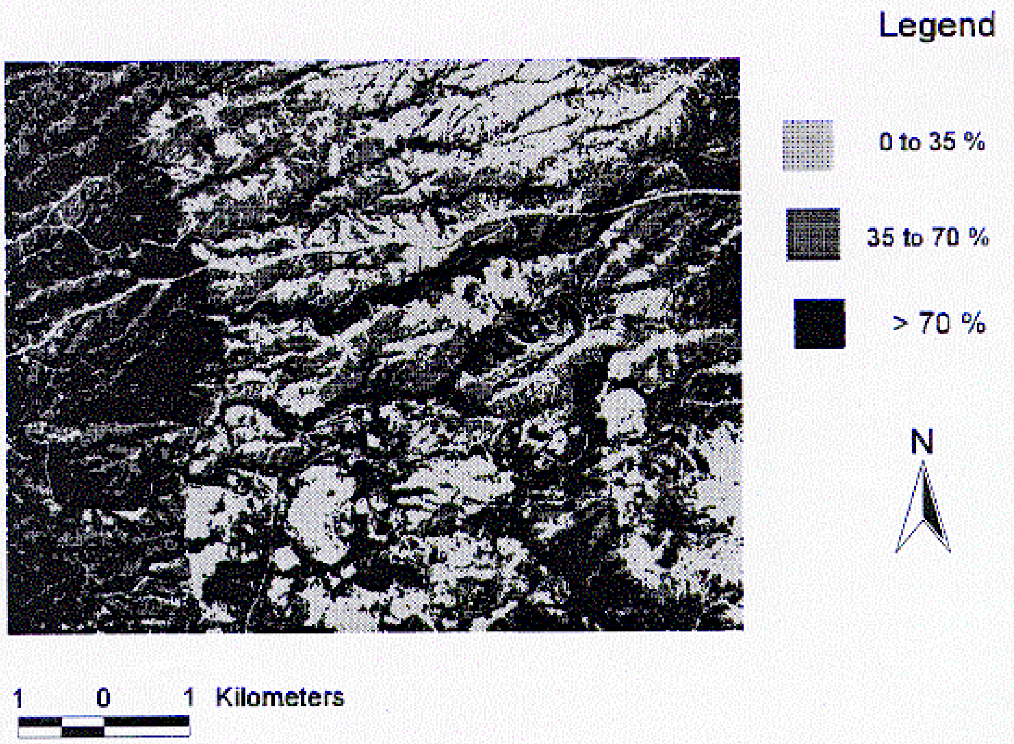

Figure 2. Soil spectral map for McAllister image endmember

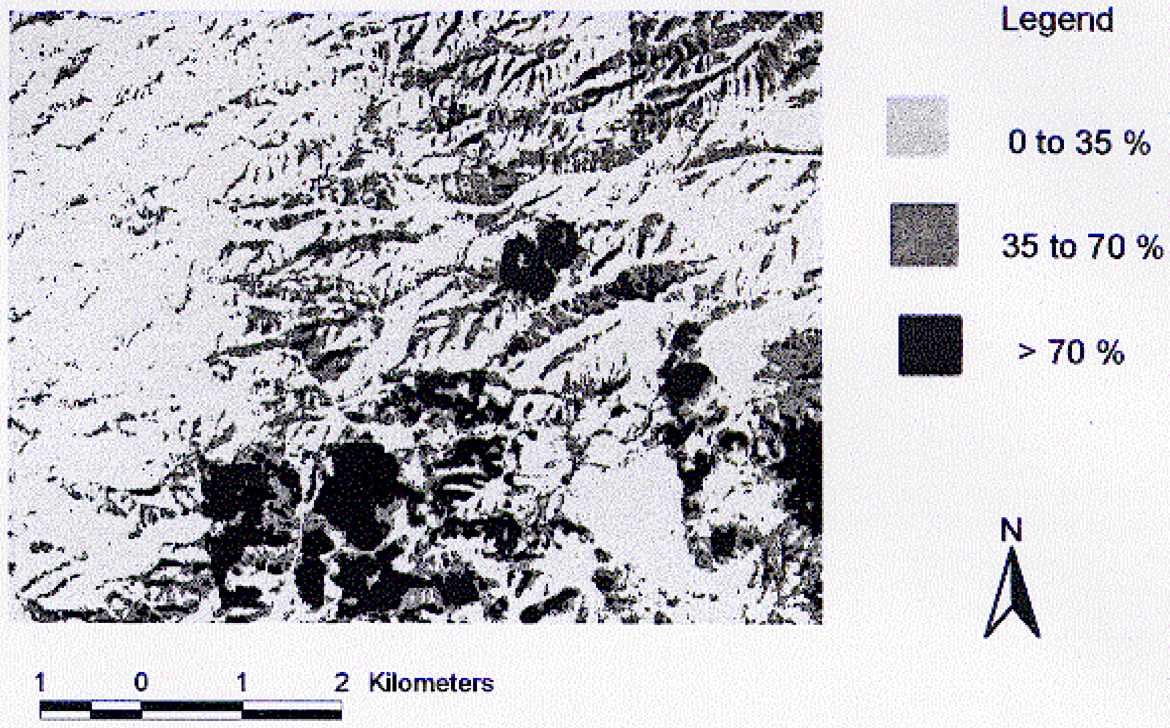

Figure 3. Spectral map for Graham soil/shade image endmember

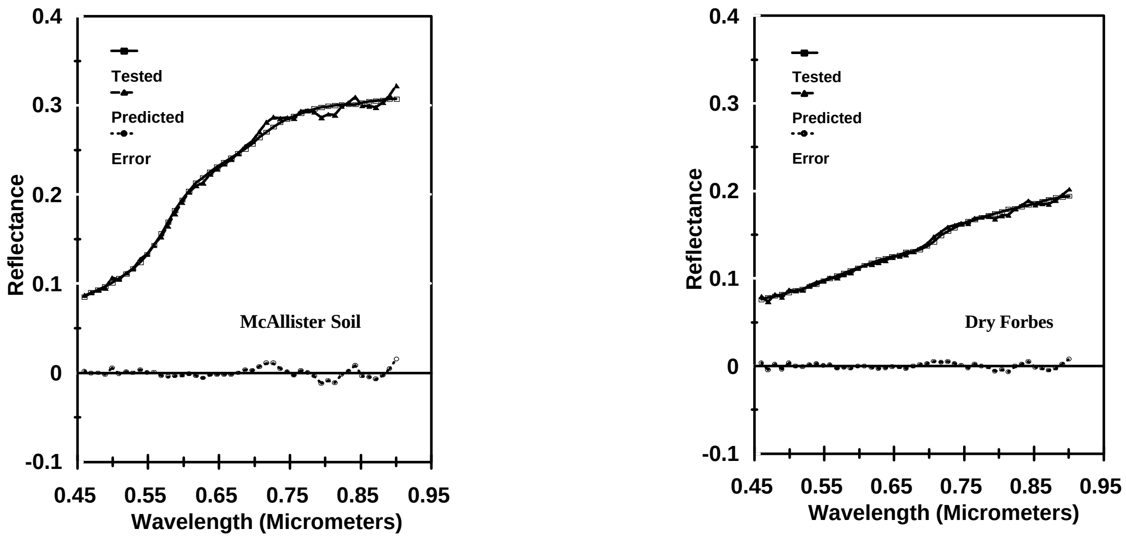

Figure 4. Target testing results for McAllister soil and dry forbes

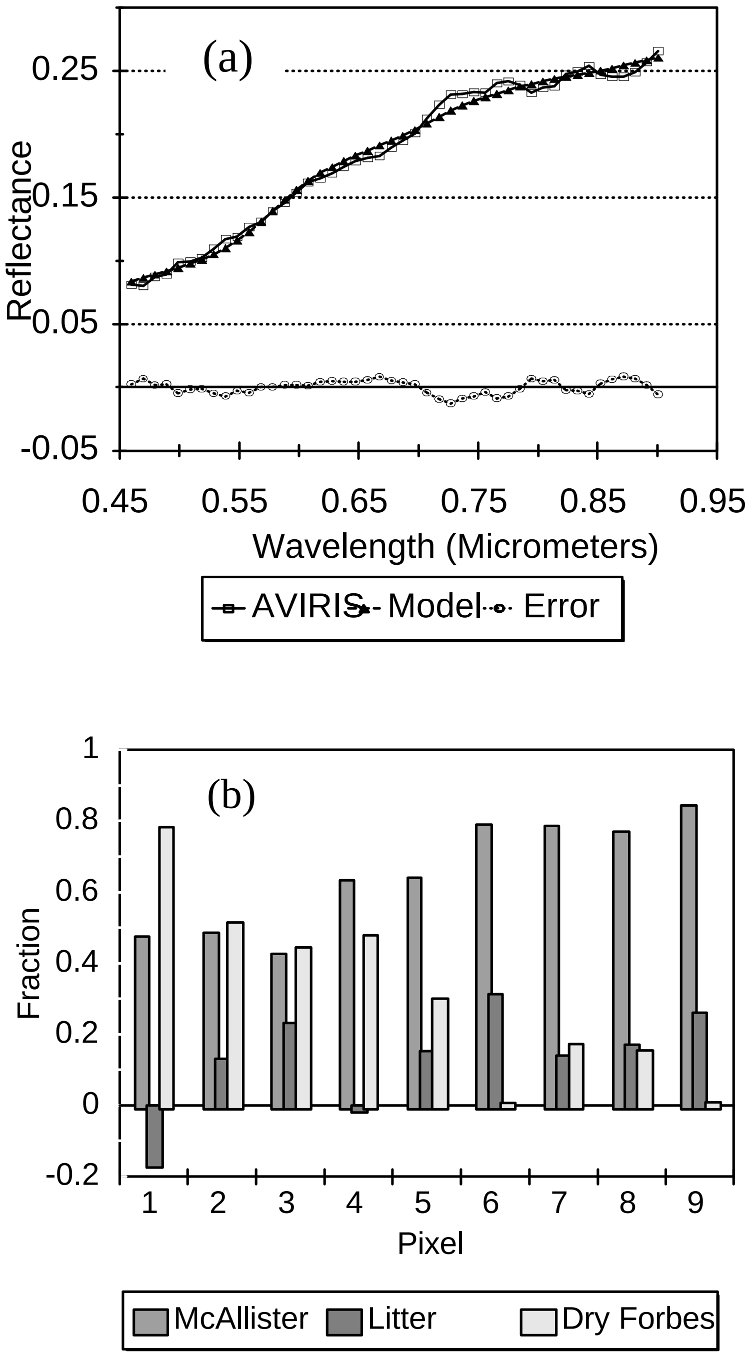

Figure 5. Spectral pixel recomposition (a) and reference endmember fractions (b) for the subset of pixels used as McAllister image endmember