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## DETERMINATION OF SEMI-ARID LANDSCAPE ENDMEMBERS AND SEASONAL TRENDS USING CONVEX GEOMETRY SPECTRAL UNMIXING TECHNIQUES

Roberta H. Yuhas<sup>1,2</sup>, Joseph W. Boardman<sup>1</sup>, and Alexander F.H. Goetz<sup>1,2</sup>

<sup>1</sup> Center for the Study of Earth from Space (CSES)  
Cooperative Institute for Research in Environmental Sciences (CIRES)

<sup>2</sup> Department of Geological Sciences  
Campus Box 449, University of Colorado  
Boulder, Colorado 80309-0449

### 1. INTRODUCTION

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data were acquired during three consecutive growing seasons (26 September 1989, 22 March 1990, and 7 August 1990) over an area of the High Plains east of Greeley, Colorado (40° 20' N and 104° 16' W). A repeat visit to assess vegetation at its peak growth was flown on 6 June 1993. This region contains extensive eolian deposits in the form of stabilized dune complexes (small scale parabolic dunes superimposed on large scale longitudinal and parabolic dunes). Due to the dunes' large scale (2-10 km) and low relief (1-5 m), the scaling and morphological relationships that contribute to the evolution of this landscape are nearly impossible to understand without the use of remote sensing. Additionally, this area and regions similarly situated could be the first to experience the effects caused by global climate change (Hansen *et al.*, 1988). During the past 10,000 years there were at least four periods of extensive sand activity due to climate change, followed by periods of landscape stability, as shown in the stratigraphic record of this area (Forman, *et al.*, 1992).

### 2. STUDY SITE CHARACTERISTICS

The dune complexes found along the South Platte River of northeastern Colorado occupy a region of semi-arid grasslands. It is this vegetation that currently stabilizes the dunes and prevents reactivation of the underlying sands. Due to the low mean annual precipitation (33 cm) of the region, the dominant vegetation community is that of the shortgrass prairie. Species commonly found include blue grama, needle-and-thread, and buffalo grass, along with other graminoids and perennial forbs (sage, yucca, and cacti).

The soils in the uplands are predominantly sandy, ranging from sand to sandy clay loam, while those along the terraces of the South Platte River range from clay loams to clays. The latter soils are much thicker and are used for commercial dryland and irrigated farming (alfalfa, corn, etc.), while the former soils cover proportionally more area but are used primarily for grazing due to their infertile nature. Because these soils occur adjacent to each other, the AVIRIS images analyzed in this study contain a wide range of vegetation cover amounts (ranging from 0% in overgrazed, fallow field, or blowout areas to 100% in irrigated fields).

### 3. METHODS

#### 3.1 Atmospheric Correction/Conversion to Apparent Reflectance

The radiance values of all four of the AVIRIS scenes used in this study were converted to apparent reflectance and atmospherically corrected using the scaled surface reflectance method of Gao known as ATREM (Gao, *et al.*, 1993). In this method a

modeled path radiance spectrum is subtracted from the AVIRIS radiance spectrum. This result is then divided by the solar irradiance curve above the atmosphere to obtain the apparent reflectance spectrum. Next, the integrated water vapor amount is derived from the 0.94  $\mu\text{m}$  and 1.14  $\mu\text{m}$  water vapor absorption features of the corrected spectrum on a pixel-by-pixel basis. This is done using a three-channel ratioing technique. Finally, the calculated atmospheric water vapor transmittances are divided into the apparent reflectance value of each pixel, resulting in an atmospherically corrected image across the entire 0.4-2.5  $\mu\text{m}$  region.

### 3.2 Spectral Unmixing Using Convex Geometry

A new method of spectral unmixing (Boardman, 1993) was used for the analyses of the apparent reflectance spectra. This new method, based upon the concepts of convex geometry, is unique because it derives estimates of the number of endmembers and their pure spectral signatures using only the data contained in the AVIRIS image. In this application, the data were spatially and spectrally subsetted. A 256x256 pixel region, covering approximately the same area on the ground, was extracted from each atmospherically corrected dataset. Then a nearly-homogeneous area was identified within each subscene. Bands with high standard deviations (denoting high noise content) in this subregion were eliminated from further processing. Also, spatial regions that were cloud-covered or otherwise not of interest were masked out. These areas appear black in the output images.

The convex-geometric unmixing takes advantage of the scatter of the points in spectral-space introduced by spectral mixing. The method is briefly outlined here. Its goal is to geometrically determine the lowest dimensional subspace that spans the data. The data are subjected to a modified principal components transformation, to separate signal from isotropic noise and to determine the inherent dimensionality of the data. Then the data are projected into this lower-dimensional subspace for analysis. If the data prove to be  $n$ -dimensional,  $n+1$  endmembers are needed to unmix them. Those points that lie as outermost points in the data cluster are used to define a multidimensional polygon (simplex) of  $n+1$  points. The best-fit simplex determines the correct endmembers (simplex vertices) which enclose all data points and gives estimates of the spectra of the pure endmember materials. In order to interpret the results, the projected spectra must be transformed back to the original coordinate system (224-band space). The analyst then interprets the spectra and associated greyscale endmember fractional abundance images, where the abundances are positive and sum to unity.

## 4. RESULTS

The four datasets were examined for both seasonal and temporal changes. These results are given below.

### 4.1 22 March 1990 Results

Because of the lower signal-to-noise ratio and lack of a D-spectrometer signal in this data, only 117 original bands were used in this analysis. After running the procedure outlined above, 63,913 datapoints were clustered in a 3-dimensional simplex. Therefore, the number of inherent endmembers needed to describe this scene was four. These were spectrally determined from the vertices of the simplex to be: shade/water, sand/soil, vegetation with some chlorophyll absorption (i.e., photosynthesizing, and thus, alive), and dried grass (standing dead). When the fractional abundance image of each endmember was viewed, the results were shown to correspond well with ground observations and prior knowledge of the area. The sand/soil endmember was most abundant in the barren areas of the dunes, and the photosynthesizing vegetation was present in low-lying areas where the water table is high, and, thus, where the plants begin to grow early in the spring. Through ground observation, this was determined to be grass species normally found in a tallgrass community. The dried grass endmember was found in the majority of the scene

and reflects the dead shortgrass prairie species that were left standing from the previous year's growing season. The shade/water endmember shows both water in an irrigation ditch (brighter, but fewer, pixels on this fractional abundance image) and the shade caused by the topographic relief of the area (minimal). Because the topography of the landscape is quite varied between dune and interdune areas, the shade/water endmember shows the morphology of the landscape well.

#### **4.2 7 August 1990 Results**

151 original bands were used in this analysis, resulting in a simplex encompassing 62,626 datapoints in 5-dimensional space. The six endmembers derived from this analysis were interpreted as: shade/water, sand/soil, dried grass (standing dead), very green vegetation, moderately green vegetation, and a minimally green vegetation (woody plant) (see Slide 8). Due to the higher signal-to-noise ratio of the data and all 224 bands present, the spectra show much better structure and a higher information content. By looking at the spatial representation of the results in the form of fractional abundance images, four endmembers were determined to be the same endmembers as derived in the 22 March 1990 data. The shade/water endmember is very similar to the previous result, as is the sand/soil endmember. Some of the landscape originally covered by only sand/soil has been replaced by vegetation and appears less bright in this fractional abundance image. The dried grass (standing dead) endmember was once again represented, although the spatial pattern has changed to become less dominant, especially on and in the areas immediately surrounding the largest dunes. The final endmember to be represented again appeared in the previous image as the tallgrass community vegetation. Now, however, instead of appearing just weakly photosynthesizing, this endmember is the most green vegetation in the scene (very green vegetation). Its abundance has spread out to the areas immediately surrounding the dunes where water tends to pool due to a high water table level. Because this image was taken in August, during the vegetation growing season, two more endmembers are present in the landscape. These are the moderately and the minimally green vegetation endmembers. The moderately green endmember represents growing shortgrass vegetation species, while the minimally green endmember represents sage, a woody forb. Different range management practices are clearly seen on this set of images, too, especially the boundary between sage and shortgrass dominated landscapes.

#### **4.3 26 September 1989 Results**

In the analysis of this data, 149 original bands were used. Assuming that the landscape did not change much between 1989 and 1990, the results were analyzed to see if the onset of vegetation senescence could be detected due to seasonal change, even though this dataset is not in time order with the ones above. 60,490 datapoints were located within a 5-dimensional simplex, and the six endmembers found were interpreted to match those found in the 7 August 1990 data. This is not to say that the spatial distribution or the spectral signature of these endmembers did not change, however. The chlorophyll absorption is reduced in all of the growing vegetation species except those found in the high water table areas. However, even these species showed changes in their SWIR regions beyond 1.45  $\mu\text{m}$ . These effects are caused by the onset of senescence in the vegetation due to seasonal change. The sand/soil endmember shows greater reflectance in the 1.0  $\mu\text{m}$  region and decreased reflectance in the region beyond 1.5  $\mu\text{m}$  when compared with the August results. The standing dead shortgrass endmember has much greater reflectance across the spectrum. Spatially this endmember does not appear to be as distinct as in either of the other two scenes because the vegetation that is on the dunes has evolved into this endmember. This is the same reason that the sand/soil endmember appears spatially similar to the results seen in March 1990 (before a lot of vegetation began to grow on the dunes). The tallgrass species are also not showing up spatially as well, possibly due to senescence. The shortgrass species appear to be more mixed in with the sage in this image, possibly due to the longer time that they had to grow (almost two months additional time since the August scene). Sage areas have also been taken over by the standing shortgrass dead, another indicator that this hypothesis may be correct.

#### 4.4 6 June 1993 Results

178 original bands were used to derive a 6-dimensional simplex with seven endmembers, enclosing 54,405 datapoints. Because the data had higher signal-to-noise than any other dataset analyzed here, and this was the time of peak growth for the vegetation (thus creating more ephemeral endmembers), the analysis indicated a very high inherent dimensionality in the data. At least fifteen endmembers were indicated, but limitations in the current unmixing routine result in inefficiency above 6-dimensions. Because of this, incomplete unmixing resulted. At least four of the endmembers showed signs of being vegetation, two appeared to be water or shadow related, while the final one was a new sand/soil endmember never before seen. When the data were viewed after the first part of the analysis was complete, many different areas of the dunes, corresponding to potentially different vegetation regimes, were observed. The scene also had more cloud cover than any of the others analyzed, and complete removal of the atmospheric water features may not have occurred. By using the fractional abundance endmember images, the seven endmembers were tentatively named: water/shadow/water vapor, wet sand/soil, very green vegetation (tallgrass?), growing sage, moderately green vegetation (sunflower?), growing shortgrass species, and new sand/soil. More work needs to be done to understand the complexity of this scene and to permit higher dimensional analyses.

#### 4.5 Conclusions

The results derived from the scenes above show the power of this approach. Seasonal change can be detected well, both spatially and, more importantly, spectrally. As the winter landscape progresses to that of summer, the number of landscape endmembers also reflects that change. Then as the season turns to fall, the vegetation senescences, the endmembers once again become more similar, and the landscape composition becomes simpler. Temporal changes are also detected well by this method.

The benefit of this approach is that the entire process is independent of user-provided data. The conversion to reflectance and removal of atmospheric effects can be done without the input of field measurements taken concurrently with the overflight of the AVIRIS sensor. The automated spectral unmixing scheme described above also stands alone with no need for observer data. This is a great plus since in traditional spectral unmixing, the set of endmembers is determined by the user, and therefore the success of the results depends on the accuracy of this dataset to the actual physical system being observed. With the scheme outlined above, there is at least a first approach to understanding imaging spectrometry data without necessarily having to visit the field site first.

#### 5. ACKNOWLEDGMENTS

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#### 6. REFERENCES

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## SLIDE CAPTIONS

<u>Slide No.</u>	<u>Caption</u>	<u>Senior Author</u>
1	3-component RGB image of the study area; AVIRIS data collected in August 1990. Blue = AVIRIS band 12; green = band 48; red = band 213.	Beratan
2	Jasper Ridge example: The five endmember spectra and their corresponding abundance images.	Boardman
3	Color composites of the simulated and actual TM scenes.	Kalman
4	Selected linear spectral unmixing results for both the empirical line and atmospheric-model calibrated data.	Kruse
5	Classification map, produced by a self-organizing ANN.	Merényi
6	A two-band image showing the spatial relationship between the derived lignin and water fractions across the site.	Wessman
7	(A) shows the composite rendered on the digital elevation model with tags (B–E) for the location of the enlarged subareas of the horizontal (non-rendered) composite. (B)–(E) show zoom-up (=factor 5) parts with different aspect and slope angles.	Meyer
8	Fractional abundance images and associated spectra of semi-arid landscape endmembers, August 7, 1990.	Yuhas
9	AVIRIS image cube of Rogers Dry Lake, CA, calibration site.	Green
10	AVIRIS image cube of Moffett Field, CA, data set showing San Francisco Bay and Moffett Field runways.	Green
11	The classified June 2nd image next to a vegetation map (mapped in the field) for comparison.	Sabol, Jr.
12	AIRSAR views of Aeolian terrain.	Blumberg

