P1.12

CHARACTERIZATION OF CLOUDS, FIRES AND SMOKE PLUMES IN HYPERSPECTRAL IMAGES

Michael K. Griffin*, Su May Hsu, Hsiao-hua K. Burke and J. William Snow
MIT Lincoln Laboratory, Lexington, MA

1. INTRODUCTION

Hyperspectral imaging (HSI) sensors have been used for more than a decade to aid in the detection and identification of diverse surface targets, topographical and geological features. Techniques for scene characterization can utilize individual or combinations of spectral bands to identify specific features in an image. This paper deals primarily with the problem of characterization of a partially smoke- or cloud-filled atmosphere. Proper analysis of the scene allows further sensing of underlying surface features such as actively burning and burn scarred regions. Both a physics-based and a semi-automated feature extraction (principal components analysis, PCA) approach are used for identifying and characterizing features in a set of AVIRIS scenes dominated by areas of smoke plumes, clouds and burning grassland as well as burnt vegetation. A combination of the two approaches is used to both discriminate (PCA) and classify (physics based) various features in a smoke/cloud filled scene.

An AVIRIS scene chosen for initial testing of the two algorithms was collected on 20 August 1992 in the foothills east of Linden, CA[1]. A typical AVIRIS scene covers a 10km x 10km area at 20m pixel resolution and 224 contiguous spectral bands of data over the range 400 to 2500 nm. The scene consists of a grass fire producing a thick plume of smoke extending toward the east (see Fig. 1a). A cloud produced by the thermal properties of the fire overlies the smoke plume. Northwest of the main fire, two smoldering fires produce a thin veil of smoke that covers much of the upper half of the scene. The southwest portion of the scene is cloud and smoke free. This scene (identified as the Linden scene in this paper) provides a variety of atmospheric and surface features from which to orient and characterize. A plot of the apparent reflectance (ratio of reflected to incoming solar radiance) of various identified features in the scene is shown in Fig. 1b. The legend displays the user identified features. The cloud is significantly brighter than the smoke over the entire spectral region. The hot area is brightest in the spectral region 2000 to 2500 nm, while the fire pixels are bright for wavelengths greater then 1150 nm.

2. PRINCIPAL COMPONENT ANALYSIS (PCA)

To reduce the HSI data dimensionality and therefore the computational complexity, feature extraction can be performed on the spectral data before application of image pixel clustering. Principal component analysis is generally used to de-correlate data and maximize the information content in a reduced number of features[2][3]. The covariance matrix is first computed over the pixel spectra contained in the HSI data cube of interest. Eigenvalues and eigenvectors are then obtained for the covariance matrix. Using the eigenvectors as a new coordinate system, the HSI data cube is then transformed into principal components, also called eigenimages. The eigenimages associated with large eigenvalues contain most of the information while the eigenimages associated with small eigenvalues are noise-dominated. Thus principal component transform allows determination of the inherent dimensionality and segregation of noise components of the HSI data. The components are ranked in descending order of the eigenvalues (image variances). Since backgrounds constitute the majority of information in the scene, they are contained in the first few principal components. Anomalies, which comprise only a small fraction of the scene, are in higher numbered principal components. Fig. 2 displays the 1st, 2nd and 5th principal components of the AVIRIS data for the Linden Scene. The first component shows the overall intensities of features such as bright clouds and smoke plumes over backgrounds. A dark area which appears to be the source of the thick smoke is apparent in the 2nd component. In the 5th component, a small fraction of the image pixels are in contrast to the image backgrounds.

Since the principal components are orthogonal and thus de-correlated, different image features can be separated from the components with appropriate thresholds to the pixel histogram distribution.

2.1 Physics-based analysis

Utilizing the diverse spectral and spatial information afforded by HSI observations of a scene, formulas can be developed relating the spectral measurements to discriminate and identify specific features in a scene (i.e., clouds, smoke, lakes, etc.). Equations for the discrimination of clouds, large and small particle smoke, high temperature surface regions and areas of burnt vegetation have been derived. A brief description of the phenomenology follows. Ultimately, these formulas can be used to classify regions identified by the PCA routine as having similar properties.

2.2 Clouds

Clouds are typically the brightest feature in an AVIRIS image. The reflectance from clouds is nearly invariant in the visible and near-IR window regions, since the size of the scatterers in the cloud are much larger (size parameter >> 1) than the sensor wavelengths. This is in contrast to atmospheric aerosols whose particle

* *Corresponding author's address:* Michael K. Griffin, S4-257, MIT Lincoln Laboratory, 244 Wood St., Lexington, MA 02420-9185, Voice: 781-981-0396, Email: griffin@ll.mit.edu

size tends to be at or near the observed wavelengths of radiation and therefore the scattering effects vary significantly with wavelength throughout the visible and near-IR. This information can be used to discriminate clouds from darker background objects and from bright but spectrally variable smoke plumes and fires.

A three step approach is used to isolate clouds in an AVIRIS scene. The first step removes dark background objects such as rivers, lakes and vegetation from consideration by applying a threshold to the 640 nm reflectance image. A threshold of 0.20 has been observed to eliminate a large portion of the background scene. The second step takes advantage of the spectral invariability of cloud. A ratio of the 640 and 860 nm reflectance images is obtained and all pixels with ratios less than 0.70 are eliminated. It has the effect of removing much of the smoke and vegetation that display distinct changes over the range of frequencies from 640 to 860 nm. Finally, to isolate the cloud from the surrounding thick smoke, a channel in the 1600 nm window region is used. A threshold of 0.35 was obtained from observation of the spectral characteristics in this region. Those remaining pixels with reflectance values above 0.35 were designated cloud.

2.3 Hot Spots

Areas of active burning or smoldering fires have distinct spectral characteristics of their own. Fig. 1b shows the effect high surface temperatures have on the measured radiance. Both the curves representative of the hot area and active fire display gradually increasing radiance (apparent reflectance) in the SWIR region. Non-physical reflectances greater than one in Fig. 1b are an indication of a combination of both solar and a significant thermal component to the measured radiance. A high surface temperature (> 400 K) is needed to produce a significant thermal component at these wavelengths[4]. Reflectance differences greater than 0.1 between channels in the SWIR (2200 nm) and the NIR (1095 nm) allowed the discrimination of these features.

2.4 Smoke plumes

As described above, the reflectance characteristics of smoke plumes vary systematically with wavelength. Also, smoke from smoldering fires may contain larger particles than that from more intense fires; the particles have had more time to coagulate. Therefore, it is useful to separate the smoke category into two subcategories: large and small particle smoke. In the Linden scene, small particle smoke is produced by the main fire near the center of the scene and is quite opaque in the visible and near-IR wavelengths. Observations of the spectral signature of small particle smoke indicate that a comparison of visible and SWIR channels provide a method of discrimination. When the difference between the reflectances at 490 nm and 2200 nm is greater than 0.02, small particle smoke is indicated.

Large particle smoke, observed as the large thin plume emanating from the two small fires in the upper left of the Linden scene, is relatively transparent to observations in the visible and near-IR. An empirical relationship was derived using visible channels only to isolate areas with large particle smoke. When the reflectance at 430 nm is greater than 0.18 and the ratio of the reflectance at 430 and 510 is greater than 1.2, then large particle smoke is indicated.

2.5 Burn Index

Biomass burning not only produces detectable smoke plumes but results in burn scars having spectral signatures that are distinct from that of undisturbed vegetation. Vegetation indices have been developed which highlight the change from low to high reflectance in the visible and near-IR spectral region. The Normalized Difference Vegetation Index (NDVI) is commonly used to categorize various surface vegetation types as well as separate vegetative from non-vegetative features (water, snow, etc.). The NDVI cannot be used under cloudy or smoky conditions since both tend to mask the underlying signal at these wavelengths. In an effort to obtain information about the spatial extent of biomass burning, a burn index (BI) was devised that can be used to detect areas of burnt vegetation using wavelengths that are more transparent to smoke. The formula used here for burn scar detection is

$$BI = \frac{\rho_{1100} - \rho_{2200}}{\rho_{1100} + \rho_{2200}}$$

where ρ_n represents the reflectance at a wavelength of n nanometers. Before application of the BI, a cloud and thick smoke mask is applied to the scene. The BI, like the NDVI, has the capability to discriminate between vegetation types, but with the added benefit of operating even under moderately smoky conditions. Fig. 3 shows the result of application of the BI to the Linden scene. A large burn scar is observed under the thin smoke plume in the upper left quadrant of the image.

3. COMPARISON OF RESULTS

Fig. 4 displays the results from application of the above two techniques to the Linden scene. Fig. 4b represents a composite of the results from applying the physics-based formulas to the AVIRIS data. Features identified in Fig. 4b were matched to classes derived from application of the PCA technique to the Linden scene and are shown in Fig. 4a. Two classes for which formulas have not been derived (visually identified as fire and shadow) are indicated in the PCA composite. Both techniques seem to provide good individual characterizations of the Linden scene, even to the differentiation of large particle (darker magenta) and small particle (lighter magenta) smoke.

4. SUMMARY

Two techniques for characterization of atmospheric features were applied to an AVIRIS scene. A feature extraction technique based upon principal component analysis was used to separate distinct feature classes in an AVIRIS image. The PCA does not provide information on the identity of the resultant classes, only that they are distinguished in the analysis of the image. To identify these features, a physics based approach which utilizes the unique characteristics of the spectral signatures of the features is applied. Results are matched with the PCA classes to provide feature identification. The techniques were in agreement as to separation of classes and the general shape of the observed features for the Linden CA scene. It is likely a combination of the two techniques with the inclusion of the burn index, could provide a useful tool for the characterization and identification of scenes containing clouds, smoke and active fires from HSI data.

5. REFERENCES

[1] Gao, B.-C., Y. Kaufman and R. Green, "Remote Sensing of Smoke, Clouds and Fire Using AVIRIS Data," *Proc. of the Fifth Annual JPL Airborne GeoScience Workshop*, JPL Publication 93-16, Pasadena, CA, 1993, pp. 61-64.

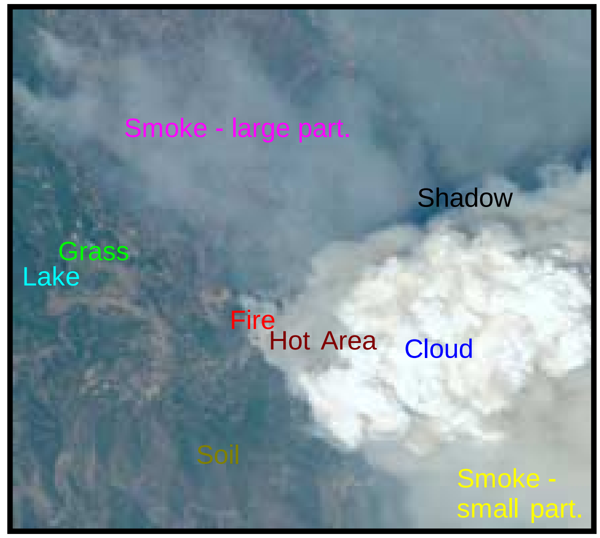
[2] Geladi, P. and H. Grahn, Multivariate Image Analysis, John Wiley & Sons, New York, 1997.

[3] Richards, J., Remote Sensing Digital Image Analysis, Springer-Verlag, Berlin, 1994, 133 p..

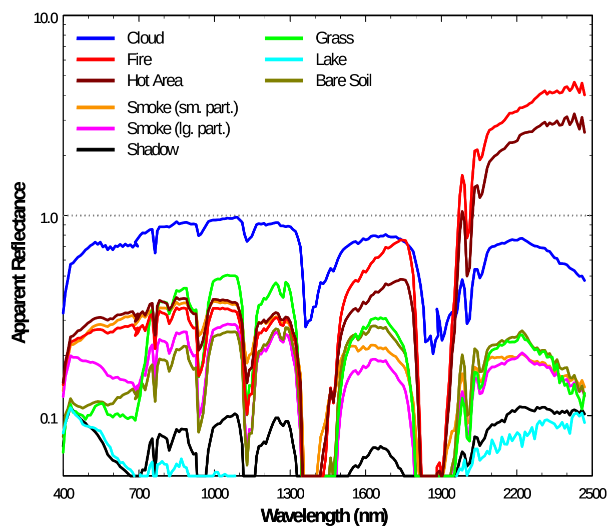
[4] Green, R., "Estimation of Biomass Fire Temperature and Areal Extent from Calibrated AVIRIS Spectra," *Proc. of the Seventh Annual JPL Airborne GeoScience Workshop*, JPL Publication 96-16, Pasadena, CA, 1996, pp.105-113.

6. ACKNOWLEDGMENTS

The authors wish to thank CAPT Frank Garcia at DUSD (S&T), program manager for the Hyperspectral Technology Assessment Program (HTAP) at Lincoln Laboratory, and Dr. Ed Howard of the NOAA GOES program for their support of this effort. This work was sponsored by the Department of Air Force under Contract F19628-00-C-0002. Opinions, interpretations, conclusions and recommendations are those of the authors and not necessarily endorsed by the United States Air Force.



(a)



(b)

Figure 1. a) AVIRIS RGB image for the Linden, CA scene collected on 20-Aug-1992, denoting location of various features of interest and b) a plot of the spectral distribution of the apparent reflectance for those features.

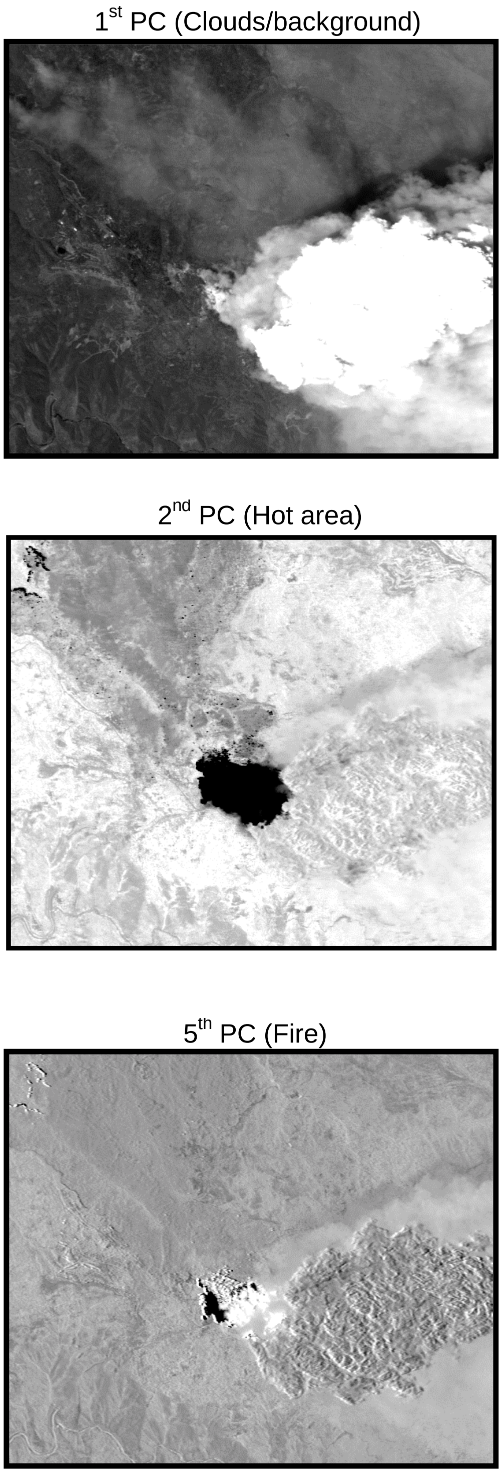


Figure 2. The 1st, 2nd and 5th principal components of AVIRIS data for the Linden scene.

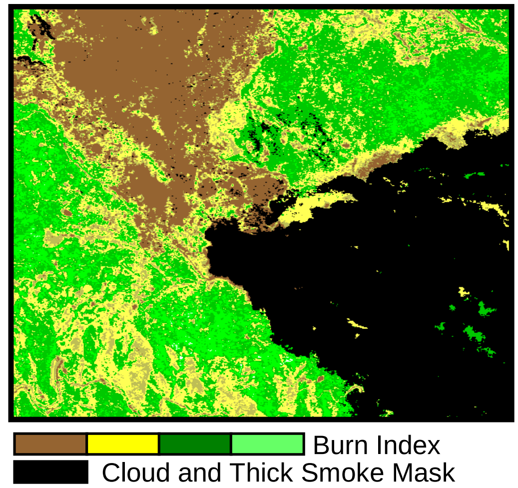


Figure 3. Application of the Burn Index to the Linden AVIRIS scene. Brown areas in upper left quadrant are indicative of burn scars. Cloud and thick smoke regions have been masked out (black).

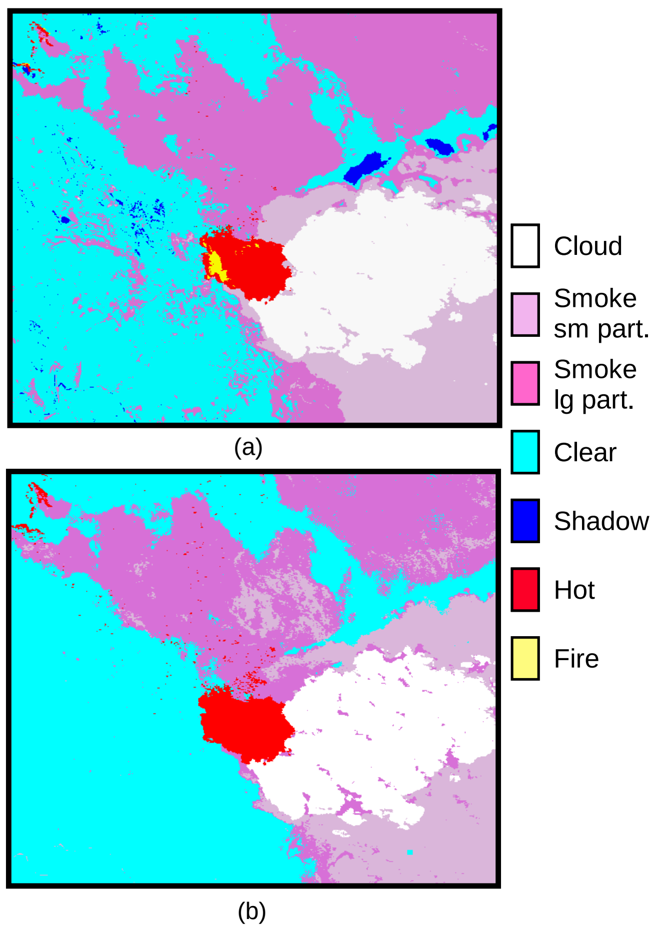


Figure 4. Composite results of the image characterization for the Linden AVIRIS image from (a) PCA and (b) physics based techniques.