MAPPING THE DISTRIBUTION OF WILDFIRE FUELS USING AVIRIS IN THE SANTA MONICA MOUNTAINS

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1 Introduction

Catastrophic wildfires, such as the 1990 Painted Cave Fire in Santa Barbara or Oakland fire of 1991, attest to the destructive potential of fire in the wildland/urban interface. For example, during the Painted Cave Fire, 673 structures were consumed over a period of only six hours at an estimated cost of 250 million dollars (Gomes et al., 1993). One of the primary sources of fuels is chaparral, which consists of plant species that are adapted to frequent fires and may actually promote its ignition and spread of through volatile organic compounds in foliage (Philpot, 1977). As one of the most widely distributed plant communities in Southern California (Weislander and Gleason, 1954), and one of the most common vegetation types along the wildland urban interface, chaparral represents one of the greatest sources of wildfire hazard in the region.

An ongoing NASA funded research project was initiated in 1994 to study the potential of AVIRIS for mapping wildfire fuel properties in Southern California chaparral. The project was initiated in the Santa Monica Mountains, an east-west trending range in western Los Angeles County that has experienced extremely high fire frequencies over the past 70 years (Office of Emergency Services, 1995). The Santa Monica Mountains were selected because they exemplify many of the problems facing the southwest, forming a complex mosaic of land ownership intermixed with a diversity of chaparral age classes and fuel loads. Furthermore, the area has a wide diversity of chaparral community types and a rich background in supporting geographic information including fire history, soils and topography. Recent fires in the Santa Monica Mountains, including several in 1993 and the Calabasas fire of 1996 attest to the active fire regime present in the area. The long term objectives of this project are to improve existing maps of wildland fuel properties in the area, link AVIRIS derived products to fuel models under development for the region, then predict fire hazard through models that simulate fire spread. In this paper, we describe the AVIRIS derived products we are developing to map wildland fuels.

2 Background

A number of studies have focused on fire hazard assessment (Cosentino et al., 1981; Burgan and Shasby, 1984; Yool et al., 1985; Chuvieco and Congalton, 1989 and Stow et al., 1993; Clarke et al., 1994). In general, remote sensing has been used to classify vegetation into fuel classes then combined through a GIS with collateral information such as slope, aspect, elevation and fire history to assess hazard (Cosentino et al., 1981; Burgan and Shasby, 1984; Yool et al., 1985; Chuvieco and Congalton, 1989 and Stow et al., 1993). For example, Chuvieco and Congalton (1989) used Landsat Thematic Mapper data to classify vegetation by fuel class then used elevation, slope, aspect and proximity to roads to generate a fire hazards index. Burgan and Shasby (1984) merged Landsat MSS, aerial photography and digital elevation data to map seven fuel classes near Missoula Montana. Fuel classes were assigned to a National Fire Danger Rating (NFDR) fuel model to calculate the Energy Release Component (ERC) (heat energy/unit area) for each image element, which was then used as a measure of hazard. Changes in fuel moisture were modeled from digital topography (e.g. insolation) and weather data to predict changes in moisture content. Cohen (1991) used laboratory reflectance data of several chaparral dominants to monitor spectral changes in foliage through a growth season. He evaluated the tasseled cap as a means of monitoring seasonal drying in vegetation as changes in greenness, brightness and wetness. Stow et al., (1993) extended the use of the tasseled cap to analyze a pair of TM scenes from the beginning and end of the 1986-1987 growing season in Southern California. Differences were stratified by vegetation community type, stand age (fire history), and slope and aspect. They found that end of season changes in greenness for mixed chaparral varied with stand age and matched field measures of total and live standing biomass, although seasonal changes in illumination were the most dominant differences.

Imaging spectrometry, through improved characterization of the chemistry and physical properties of natural surfaces and atmospheres has the potential of significantly improving our ability to map fuels and predict fire hazard. Important fuels properties and associated remotely sensed measures are summarized in Table 1. Important AVIRIS capabilities include: 1) the ability to retrieve apparent surface reflectance in a spatially variable atmosphere, providing temporally robust measures of surface properties; 2) canopy liquid water retrievals, providing direct estimates of moisture content and; 3) improved classification of vegetation. When combined with spectral mixture models to estimate the areal proportions of live and dead crown components, these tools provide a new, unique approach to fire hazard assessment. The importance of collateral information (e.g. fire history, digital topography) for fire hazard assessment is clear: canopy depth, stand age and surface winds are all parameters of critical importance to fire modeling, yet cannot be derived from remote sensing. For this reason, GIS is a significant component of our research effort. Important GIS layers are also described in Table 1.

Table 1. Important fuel properties

Fuel Property	**Remotely Sensed Measure**
Total Fuel Load (kg/ha)	
Live fuels (Green leaves, live stems)	NDVI, Green Vegetation Fraction* , Liquid Water
Dead fuels (litter, stems, twigs)	Non-Photosynthetic Vegetation (NPV)*
Vertical Structure of Fuels	Shade Fraction*
Percent Moisture Content	
Live	Equivalent Liquid Water Thickness**
Dead	na
Species Composition	Classification
Ignition Properties	
Indirect Measures of Above	
Collateral Information (GIS)	
Fire history (Stand age), soils (Site quality), DEM (Insolation, moisture, site quality)	

* From Spectral Mixture Analysis (SMA), Adams et al., (1993); Roberts et al., (1993)

** Green et al., (1993); Roberts et al., (1997a).

3 Methods

3.1 Data

In order to map fuels and monitor seasonal and interannual changes in vegetation, seasonal pairs of AVIRIS data were acquired in the spring and fall of 1994, 1995 and 1997. Due to poor atmospheric conditions during the spring of 1996, no AVIRIS scenes were acquired at that time. However, AVIRIS data were acquired on 17 and 23 October, 1996, before and after the Calabasas fire. In order to cover the entire range, at least two flight lines were flown with each date, one due east and one due west. A minimum of 17 scenes were required to cover the entire range for each date.

Supporting field data for image analysis and accuracy assessment were acquired during several field campaigns in 1995, 1996 and 1997. Field data included spectral reflectance measurements of a homogeneous ground target at Zuma beach during each AVIRIS overpass using an Analytical Spectral Devices (ASD) full range instrument on loan from JPL. Additional spectral data were acquired to develop a regionally specific spectral library for the area (Roberts et al., 1997b) consisting of soils and plant spectra of all chaparral and non-chaparral dominants during the spring and fall (see Gardner, 1997 and Ustin et al., 1998). Additional leaf and branch spectra were collected in the field for later measurement using a Cary-5 laboratory spectrometer at UC Davis. Data for accuracy assessment included close to 300 polygons covering all dominant natural cover types in the region. Data recorded for each polygon included percent cover and species composition. Initial accuracy assessment is summarized in Gardner (1997).

3.2 AVIRIS Processing

Scenes acquired in fall 1994, spring 1995, both dates in 1996 and spring 1997 were processed to retrieve surface reflectance, map column water vapor and equivalent liquid water thickness using the approach of Green et al., (1993). Once processed to apparent reflectance, spectral fractions for green vegetation , non-photosynthetic vegetation, soils and shade were mapped using simple spectral mixture analysis and reference endmembers (Adams et al., 1993; Roberts et al., 1993, 1997c; Ustin et al., 1998). Reference endmembers for the simple models were selected using the approach described by Smith et al. (1990) and Roberts et al., (1997c) from regionally specific spectral libraries developed for the Santa Monica Mountains. During this process, three sets of three endmember models (GV-NPV-shade, GV-Soil-Shade, NPV-Soil-Shade) were generated for each image, then compared to select the model that provided the minimum RMS error and generated physically reasonable fractions for each endmember. A similar approach, based on minimum RMS is described by Painter et al., (1998).

Species maps were generated for each image using Multiple Endmember Spectral Mixture Analysis (MESMA: Roberts et al., 1998), using the modified approach described by Gardner (1997) and Roberts et al., (1997b). MESMA differs from simple spectral mixture models in that it allows the number and types of endmembers to vary on a per-pixel basis. In this manner, it overcomes some of the errors inherent in simple mixture models (e.g., fraction errors, endmember ambiguity), while significantly increasing the number of materials that can be mapped as distinct from their spectra. To date, MESMA has been applied to map snow grain size and snow covered area (Painter et al., 1997), semi-arid vegetation (Okin et al., 1998) and chaparral (Gardner, 1997; Roberts et al., 1997b;1998) and is currently being applied to boreal forest and temperate rain forest. Vegetation maps developed using MESMA are currently limited to fall 1994 and fall 1996 because the spring library is still being organized. All AVIRIS products, including maps of column water vapor, liquid water, spectral fractions and vegetation dominants were coregistered to a georeferenced SPOT Image available from the U.C. Santa Barbara Map and Imagery Library, resampled to a 20 meter resolution.

3.3 GIS Layers

GIS layers developed for the study included a digital elevation model, fire history from 1925 to 1996 and 1930s vegetation (Weislander and Gleason, 1954; Office of Emergency Services, 1995). Fire history maps, developed by the Los Angeles County Fire Department, were processed to develop maps showing the age of the last fire and fire frequency since 1925.

4 Results

A summary of the data developed for this project is shown in Table 2. Fully georeferenced products are available for the entire range (17+ scenes) for fall 1994, spring 1995, fall 1996 (pre and post Calabasas fire) and spring 1997. Spectral fractions have been generated for all of the images described. MESMA-derived vegetation maps have only been generated for fall images. Fuels, destructively harvested by the USDA forest service in 1995, have been located in the GIS. These are currently being used to develop a model that relates AVIRIS fraction images, vegetation cover and liquid water to fuels sampled on the ground. A specific, near-term objective has been to develop fuels layers for the Calabasas area before and after the fire in 1996, and use these data as inputs into a fire-spread model to simulate the Calabasas fire. The fire spread simulation will be conducted by Dr. Jim Bossert, of Los Alamos National Laboratory.

Table 2. AVIRIS products. Products are labeled as none, incomplete (inc) or complete (com). Incomplete means some, but not all scenes have been processed. Complete processing covers the entire range.

Date	Reflectance Retrieval		Spectral Fractions				MESMA	Georeferencing
	Liquid Water	Water Vapor	GV	NPV	Soil	Shade		
940411	Inc	Inc	None	None	None	None	None	None
941019	Com	Com	Com	Com	Com	Com	Com	Com
950509	Com	Com	Com	Com	Com	Com	Com	Com
950526	Inc	Inc	None	None	None	None	None	None
951012	Inc	Inc	None	None	None	None	None	None
951020	Inc	Inc	None	None	None	None	None	None
951026	Inc	Inc	None	None	None	None	None	None
961017	Com	Com	Com	Com	Com	Com	Com	Com
961023	Com	Com	Com	Com	Com	Com	Com	Com
970407	Com	Com	Com	Com	Com	Com	Com	Com

Some of the potential of liquid water and spectral fractions as indicators of fire hazard are illustrated for the Calabasas fire (Figs. 1& 2). Liquid water was mapped for 17 October and 23 October, several days before and after the fire (Fig. 1). The fire began in the north-central portion of the region, in an area dominated by grasslands and coastal sagebrush, mapped as having low liquid water (Fig. 1). It spread rapidly southwards until it reach the vicinity of Malibu Canyon where it slowed significantly, then crossed through rugged terrain and moved rapidly to the coast. Once at the coast it burned west and northwest, burning chaparral to the northwest and coastal sagescrub and grasslands to the west. On the post-fire liquid water image (Fig.1, right frame), the fire scar is clearly indicated by a region of low liquid water due to the removal of most green vegetation. Spectral fractions of the same region (Fig. 2) provide more detailed information regarding surface cover before and after the fire. For example, the region where the fire started (northeast portion of image) was modeled as consisting of high fractions of NPV and low fractions of GV and soil (Fig 2., a to c). Once it progressed to the coast, the fire was restricted primarily to regions mapped as having low GV and higher NPV fractions, a noteworthy exception being the central portion of the area, which consisted of hard chaparral and had higher GV and lower NPV fractions. The post-fire image shows the fire-scar as consisting primarily of soil, which had replaced either GV or NPV depending on the vegetation type.

5 Summary

AVIRIS has the potential of significantly improving our capability to assess fire hazard through improved mapping of vegetation and fuels properties. Critical AVIRIS capabilities include robust retrieval of apparent surface reflectance, the capability of mapping canopy liquid water and improved classification of vegetation. Spectral mixture analysis, applied to reflectance data using reference endmembers adds additional relevant information including estimates of green (live) and non-photosynthetic fuels. In this paper, we describe the data layers we have been developing from AVIRIS which will be used to assess fire hazard and simulate fire spread in the Santa Monica Mountains. Near-term objectives of this project include integrating AVIRIS products with field measures of wildland fuels, then incorporation of spatially explicit maps of fuels in a fire spread model. One key objective will be to test the sensitivity of fire spread simulations to fuels using the pre and post Calabasas AVIRIS data sets.

6 Acknowledgements

Support for this research was provided by grants from the National Aeronautics and Space Administration, Terrestrial Ecosystems and Biogeochemical Dynamics Branch, and Solid Earth and Natural Hazards program (NAGW-4626-I and NAG2-1140). Computer equipment was supplied as part of a start-up package at U.C. Santa Barbara in the Department of Geography and through a UCDRD grant for collaborative research with Los Alamos National Laboratory (STB/UC:97-50). Coregistration software was kindly supplied by J. Steven Cothern of the University of Washington. Field spectral measurements were collected using equipment on loan from the Jet Propulsion Laboratory. A portion of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

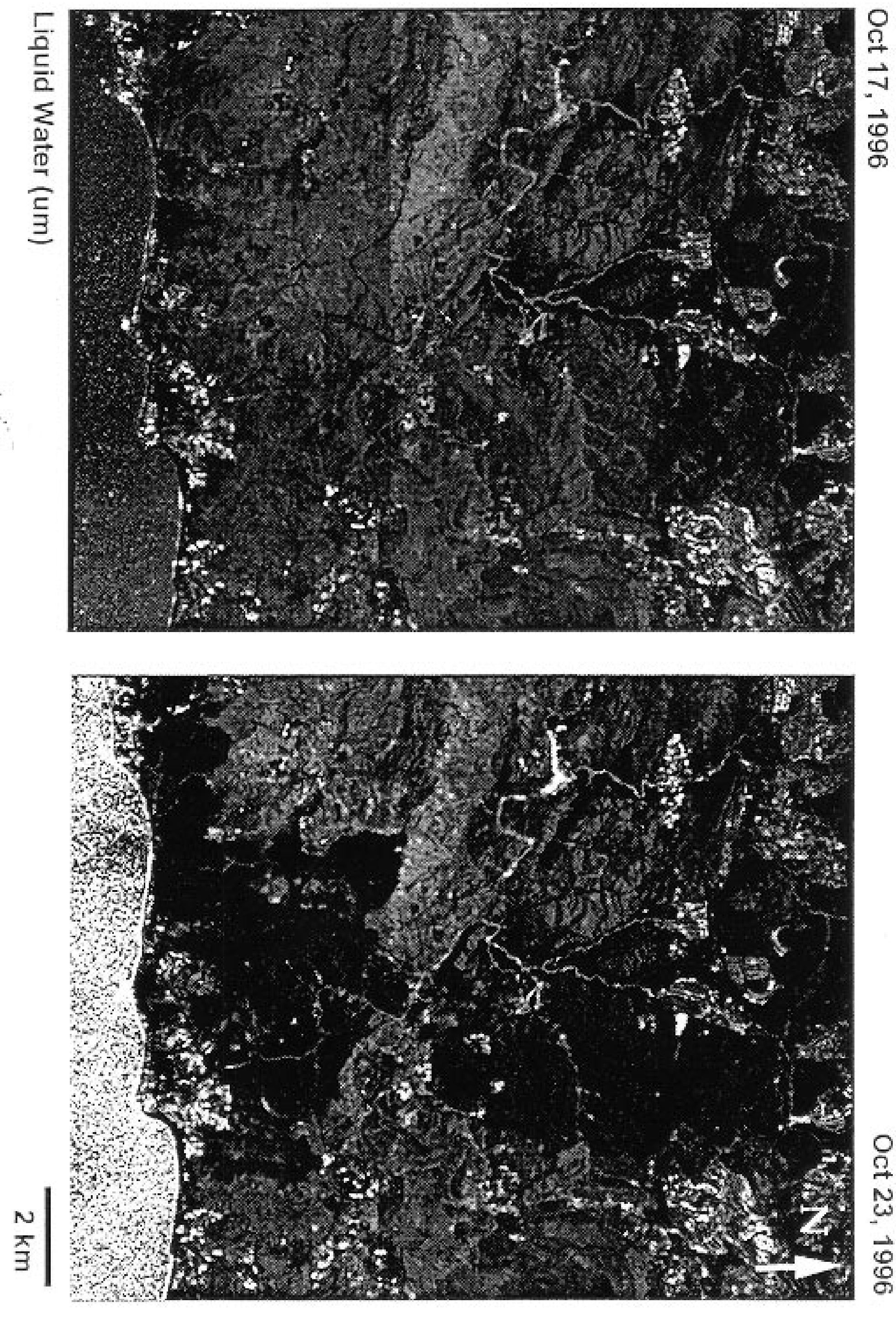

Figure 1. Equivalent liquid water images of the Calabasas area before and after the Calabasas fire.

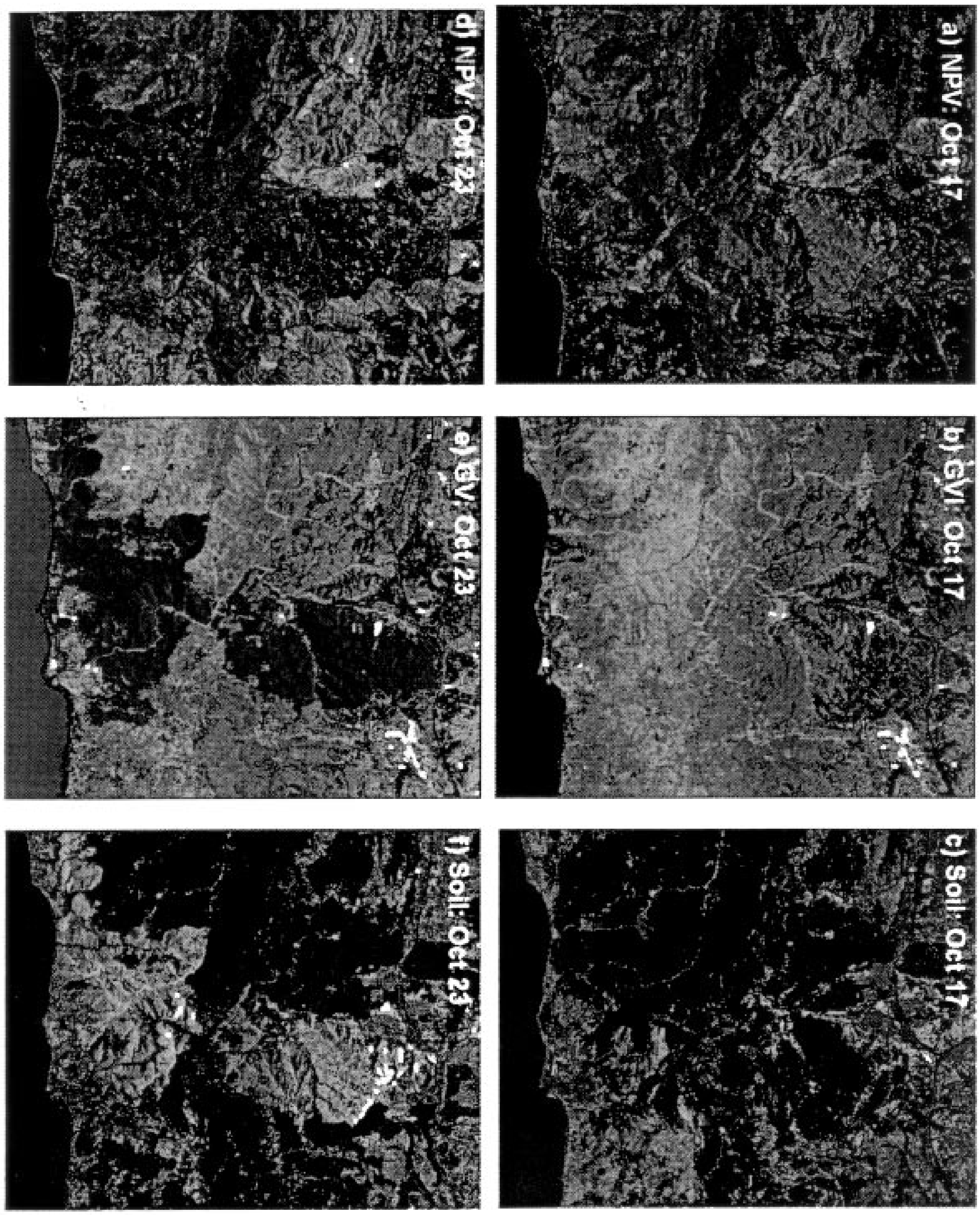

Figure 2. Fraction images for NPV, GV, and Soil for the Calabasas are before and after the fire.

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