

**Final Technical Report:
Modeling and Prediction of Wildfire Hazard in Southern California, Integration of
Models with Imaging Spectrometry**

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Introduction:

Large urban wildfires throughout southern California have caused billions of dollars of damage and significant loss of life over the last few decades. Rapid urban growth along the wildland interface, high fuel loads and a potential increase in the frequency of large fires due to climatic change suggest that the problem will worsen in the future. Improved fire spread prediction and reduced uncertainty in assessing fire hazard would be significant, both economically and socially. Current problems in the modeling of fire spread include the role of plant community differences, spatial heterogeneity in fuels and spatio-temporal changes in fuels.

In this research, we evaluated the potential of Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and Airborne Synthetic Aperture Radar (AIRSAR) data for providing improved maps of wildfire fuel properties. Analysis concentrated in two areas of Southern California, the Santa Monica Mountains and Santa Barbara Front Range (Figure 1). Wildfire fuel information can be divided into four basic categories: fuel type (Anderson, 1982), fuel load (live green and woody biomass), fuel moisture and fuel condition (live vs senesced fuels). To map fuel type, AVIRIS data were used to map vegetation species using Multiple Endmember Spectral Mixture Analysis (MESMA, Roberts et al., 1998a) and Binary Decision Trees (Roberts et al., 1998b). Green live biomass and canopy moisture were mapped using AVIRIS through analysis of the 980 nm liquid water absorption feature (Roberts et al., 1998c) and compared to alternate measures of moisture and field measurements (Ustin et al., 1998; Serrano et al., 2000). Woody biomass was mapped using L and P band cross polarimetric data acquired in 1998 and 1999 (Dennison et al., 1999, 2000; Dennison 1999). Fuel condition was mapped using spectral mixture analysis to map green vegetation (green leaves), non-photosynthetic vegetation (NPV; stems, wood and litter), shade and soil. Summaries describing the potential of hyperspectral and SAR data for fuel mapping are provided by Roberts et al. (1999a) and Dennison et al. (1999; 2000).

To utilize remotely sensed data to assess fire hazard, fuel-type maps were translated into standard fuel models accessible to the FARSITE fire spread simulator. The FARSITE model (Finney, 1998), and BEHAVE (Andrews, 1986) are considered industry standards for fire behavior analysis. Anderson (1982) level fuels map, generated using a binary decision tree classifier are available for multiple dates in the Santa Monica Mountains and at least one date for Santa Barbara. Fuel maps that will fill in the areas between Santa Barbara and the Santa Monica Mountains study sites are in progress, as part of a NASA Regional Earth Science Application Center, the Southern California Wildfire Hazard Center (C. Lee, PI). Species-level maps, were supplied to fire managing agencies (Los Angeles County Fire, California Department of Forestry). Research results were published extensively in the refereed and non-refereed literature (see publication list and attached reprints). Educational outreach included funding of several graduate students, undergraduate intern training and an article featured in the California Alliance for Minorities Program (CAMP) Quarterly Journal (Roberts, 1999).

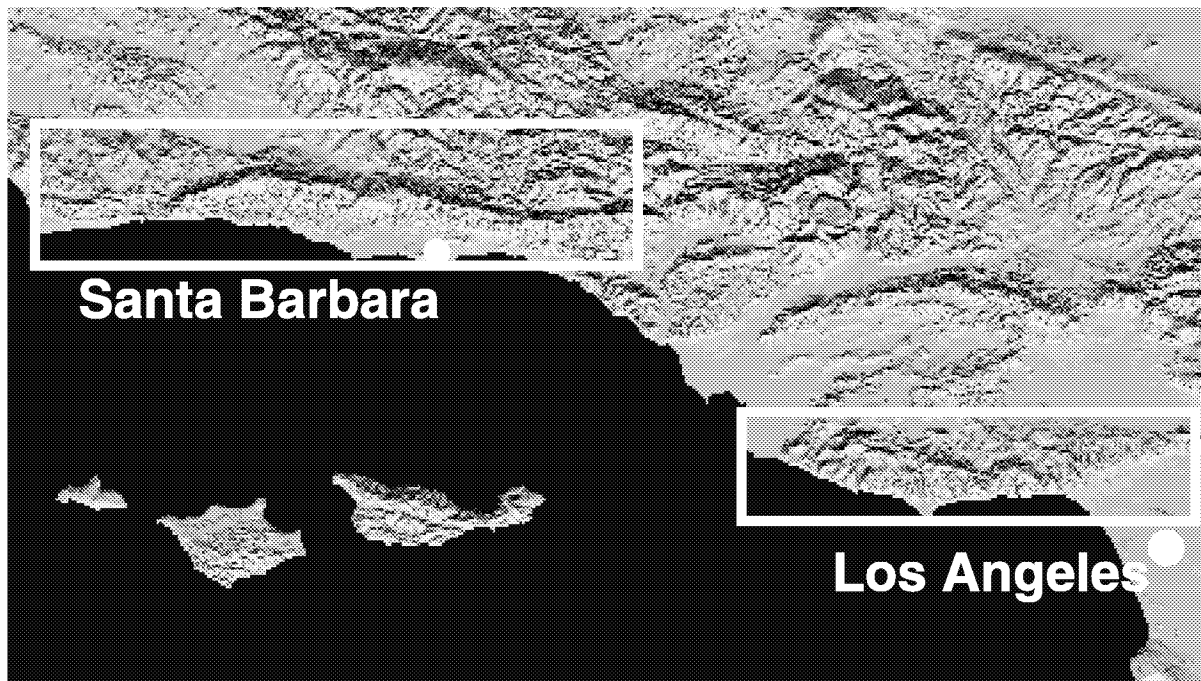


Figure 1) Primary study sites

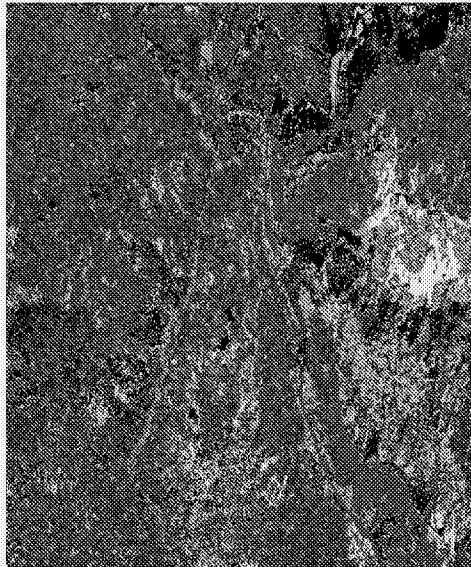
Research Results:

Results will be summarized with reference to the four categories of fuels information: fuel type; biomass; moisture and fuel condition.

Fuel Type:














Different vegetation species have different ignition and combustion properties based on their chemistry and structure. Fuel type includes fuel characteristics that are unique to a species. Examples include surface-to-volume ratio and typical fuel loadings (Anderson, 1982). Fuel type was mapped either by cross walking species-level maps to Anderson fuels, or directly by mapping Anderson level fuels using a binary decision tree classifier. Species level maps were generated using MESMA and a spectral library developed from a combination of field and laboratory spectra and 4-meter spectra derived from high resolution AVIRIS (Roberts et al., 1998a, 1999b). Species level maps for 4-meter and 20 meter resolution AVIRIS data are shown in Figure 2. Several hard chaparral and soft chaparral species were mapped including two species of *Ceanothus* (*spinosus* and *megacarpus*), *Adenostoma fasciculatum* and *Artemisia californica*. Additional regions were mapped as mixed hard or soft chaparral where two or more species were intermixed below a 4 meter resolution. Riparian vegetation and oak woodlands were not mapped to species level due to insufficient knowledge of the distribution of different tree species in these communities. *Eriogonum* and *Salvia* were mapped to the generic level. *Persea americana* was included as a non-native tree common in parts of the range. These mapped species were cross walked to Anderson fuels and used to simulate the Corral

Canyon portion of the 1996 Calabasas Fire using a next generation fire model, in collaboration with Los Alamos National Laboratory (Bossert et al., 2000). The spectral library was made accessible to other projects and used to map changes in chaparral community structure by Rogan et al. (in press).



**High Resolution AVIRIS
Run 6, Scene 4 (October 5, 1998)**

Map Legend

	Riparian		Artemisia californica
	Quercus		Eriogonum sp
	Ceanothus spinosus		Salvia sp
	Ceanothus megacarpus		Mixed Soft Chaparral
	Adenostoma fasciculatum		Senesced Grass
	Mixed Hard Chaparral		Rock/Soil/Road/Urban
			Persea americana

AVIRIS 20 meter Data

October 23, 1996

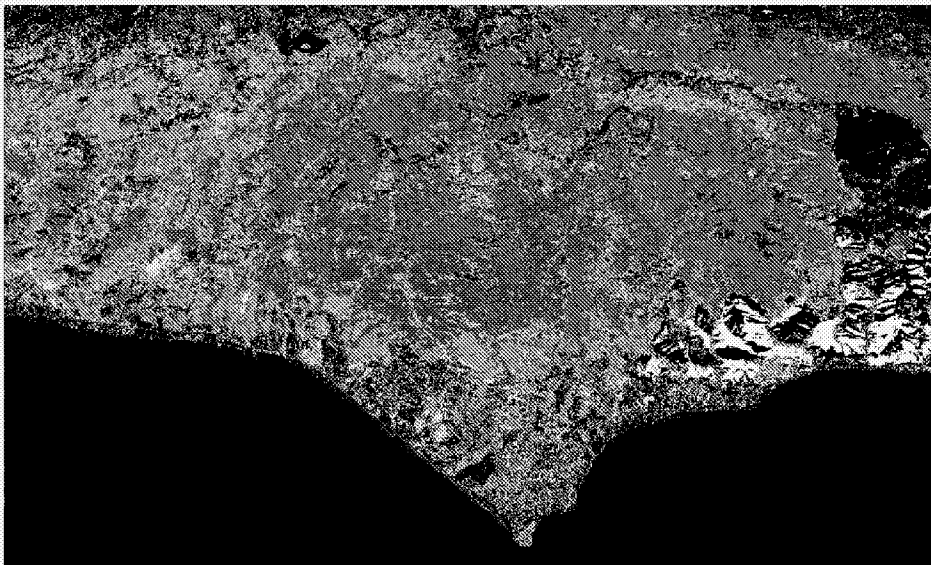


Figure 2) Species-level maps generated using MESMA for 4 meter and 20 meter resolution data.

As an alternate means of mapping fuels, a decision tree classifier (Roberts et al. 1998b) was employed using spectral fractions derived from a simple mixture model and liquid water retrieved from AVIRIS as inputs (Figure 3). Comparison of this map to maps currently used by the National Park Service in the Santa Monica Mountains (Franklin et al., 1995) were quite favorable, with major differences occurring primarily in areas burned since 1993.

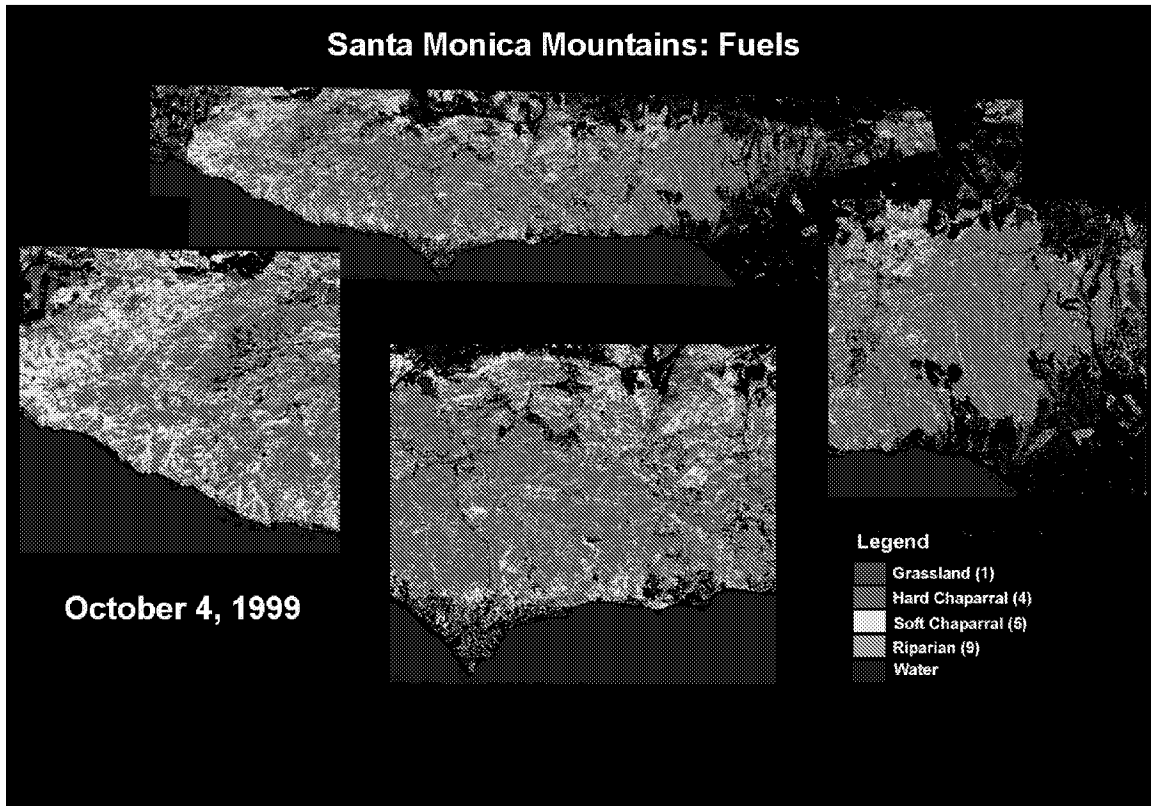


Figure 3) AVIRIS 1999 data mapped to Anderson level fuels using a BDT.

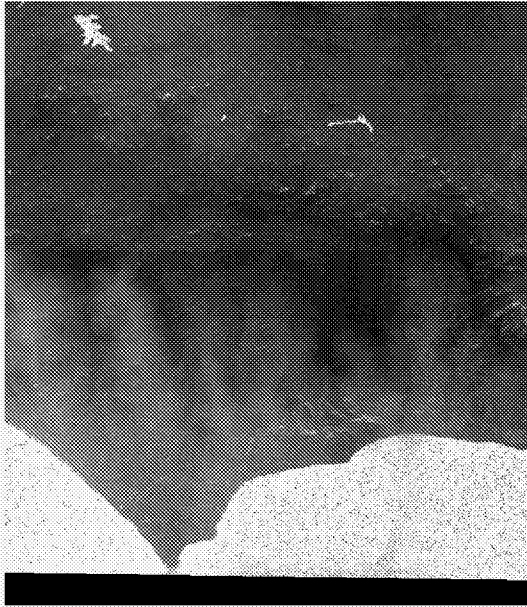
Fuel Biomass and moisture

Live fuels and leaf moisture

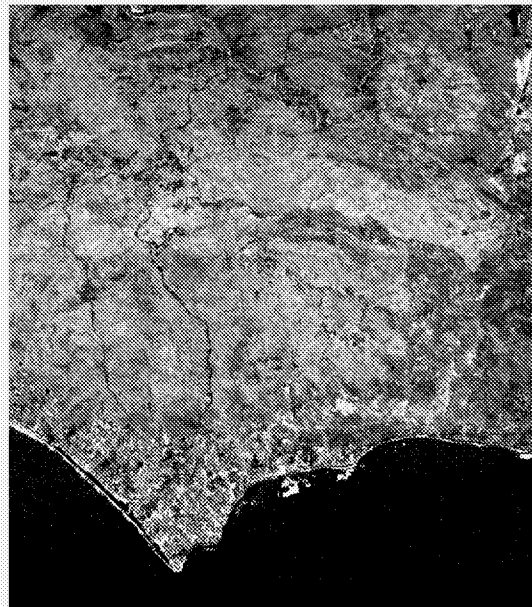
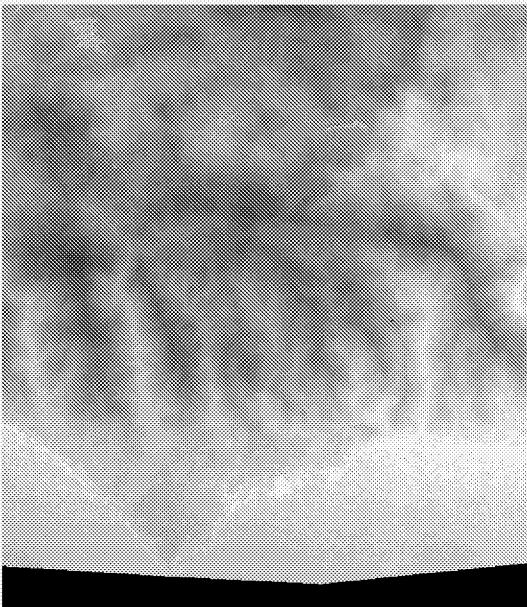
Fuel moisture is potentially the most important fuel property controlling fire hazard (Pyne et al., 1996). Canopy liquid water can be measured through reflectance retrieval. In order to retrieve surface reflectance it is necessary to fit water vapor and liquid water as they vary spatially. The result is a map that shows spatial variation in column water vapor and equivalent liquid water thickness (Figure 4). Water vapor (Left), is largely controlled by fine scale topographic variation and resembles an inverted digital elevation model (Low elevations have a longer path and thus higher water vapor, high elevations have a shorter path and low water vapor). Liquid water is primarily restricted to water in green leaves (Roberts et al., 1997; Ustin et al., 1998). Canopy liquid water varies primarily as a function of the water content of leaves within the canopy and the number of leaves light encounters as it scatters through the canopy. As the number of leaves within a canopy increases, the expression of liquid water in spectra increases as

well. Roberts et al. (1998c) investigated the potential of liquid water as a surrogate measure for LAI and found a linear correlation up to LAI exceeding eight, much higher than alternative methods of determining LAI using greenness measures. Using LAI data derived from broadleaf deciduous and coniferous forest and associated liquid water maps from those areas, a relationship was developed between LAI and liquid water and applied to Santa Monica Mountains data acquired in 1998 (Figure 5). Serrano et al., (2000), when comparing EWT to several alternate measures of canopy moisture (Water Index: Penuelas et al., 1993; Normalized Difference Water Index: Gao, 1996) and the Normalized Difference Vegetation Index found that the WBI was most sensitive to the relative water content of canopies.

October 23, 1996



April 7, 1997



Water Vapor (0-255 = 6000 to 18000 um)

Liquid Water (0-255 = 0 to 3000 um)

Figure 4) Water vapor and liquid water images for October 23, 1996 and April 7, 1997. Lower humidities in the fall result in lower column water vapor in the October image. Most natural vegetation shows higher liquid water in the spring. The Calabasas fire scar is clearly evident as a region of low liquid water in both image dates. Soft chaparral and grasslands show significantly lower liquid water in the fall relative to spring, whereas hard chaparral shows only moderate changes..

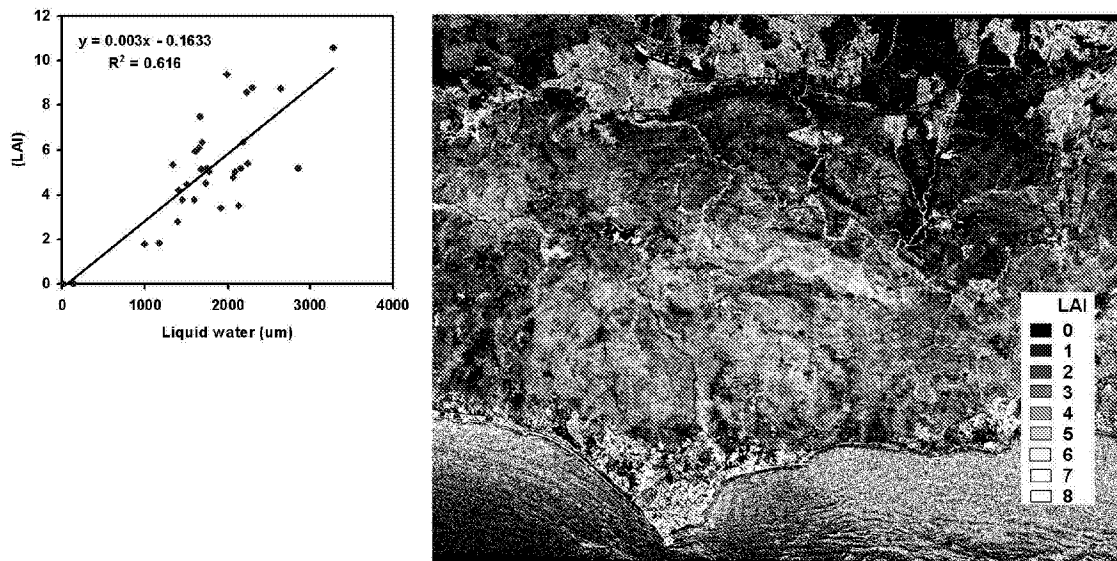


Figure 5) LAI vs Liquid water applied to 1999 AVIRIS data. The relationship between LAI and liquid water was developed using broadleaf deciduous plants and conifers.

Woody biomass

Measures of woody biomass aid in the determination of the amount of fuel available to a wildfire. Dennison (1999) and Dennison et al. (1999, 2000) investigated the potential of Airborne SAR as a means of measuring live woody biomass. Airborne SAR and hyperspectral data complement each other in that hyperspectral data is sensitive to green live biomass and moisture content in leaves, while SAR backscatter is sensitive to the larger structural elements of canopies and their dielectric properties. Based on typical chaparral biomass measurements, SAR would not be expected to saturate in either L or P band and is thus ideally suited for mapping wood biomass in low biomass chaparral. Comparison of L and P backscatter to different aged stands of hard chaparral, soft chaparral and grasslands demonstrated the feasibility of SAR in chaparral (Figure 6; Dennison et al., 1999).

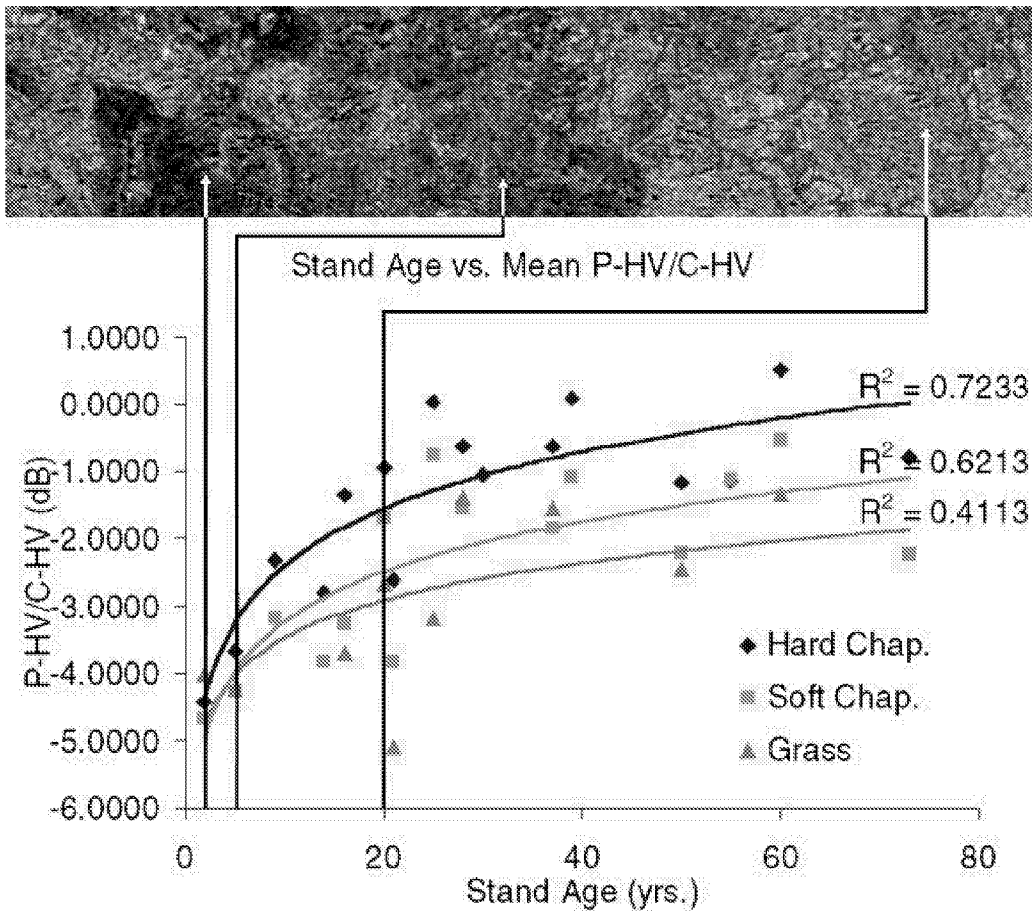
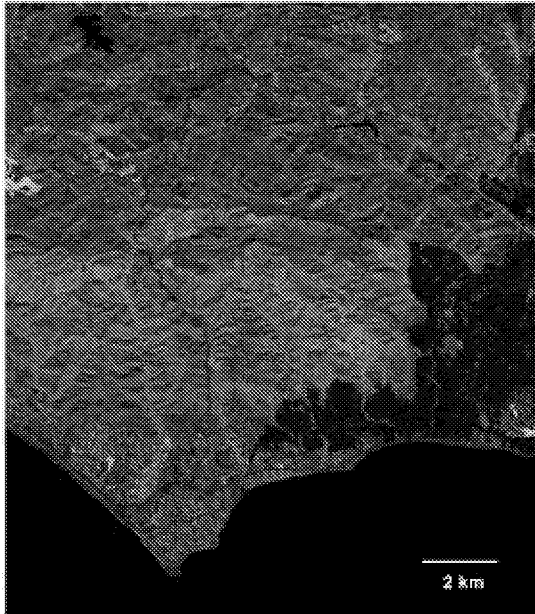


Figure 6) Radar backscatter plotted against stand age. From Dennison et al., 1999.

Fuel Condition

Fuel condition can be defined as the proportion of live canopy components to dead canopy components. Live canopy components require a higher input of energy before combustion can take place and are the primary fuels for chaparral fires. Fuel condition was mapped using Spectral Mixture Analysis (Adams et al., 1993). It is a potentially valuable tool for fire hazard research in that it can describe the areal proportions of live green and non-photosynthesizing canopy components. An example, comparing fall and spring models for the SMM is shown to the right (Figure 7). Non-Photosynthetic Vegetation (NPV), Green Vegetation (GV) and soil fractions are shown as red, green and blue, respectively. High soil fractions occur in urban areas, along roads and within the fire scar of the Calabasas fire. High GV fractions occur during both seasons in oak woodlands, riparian areas and hard chaparral. Grasslands are characterized as having high NPV fractions in both seasons (red) while soft chaparral retains foliage in the spring but has dropped most leaves by fall and thus has a mixture of NPV and GV.

October 23, 1996



April 7, 1997

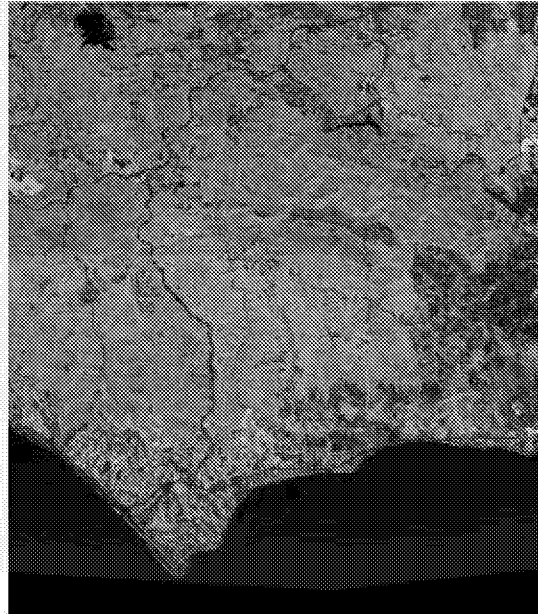


Figure 7) Spectral mixture model of a fall and spring pair of AVIRIS images. Red is NPV fraction, green is GV fraction, and blue is soil fraction.

Time Series:

Time series analysis provides an important measure of post-fire recovery and fuel development (Riano et al., 2001). All of the fuel measures described above have been generated for a time series of AVIRIS images acquired primarily over the Santa Monica Mountains (1994 to present), and more recently over Santa Barbara (1998 to present). High quality radiance and reflectance products generated from AVIRIS have the advantage in that they provide a standardized product and thus are ideally suited for change detection studies (Roberts et al. 1997). Examples of multitemporal changes in liquid water, green vegetation and NPV are provided for data acquired in fall 1994, 1996 and 1999 (Figure 8).

Santa Monica Mountains Time Series

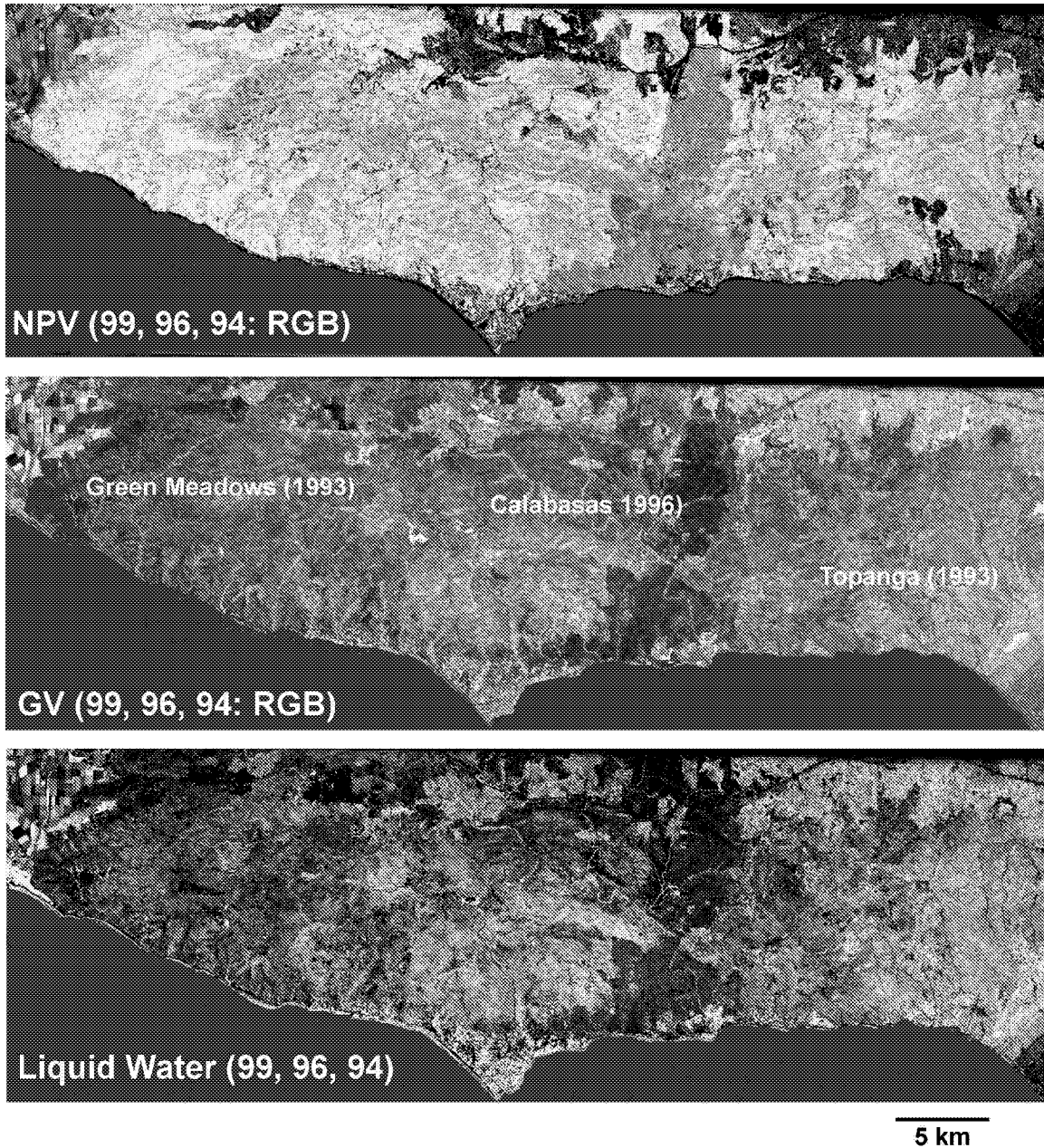


Figure 8) Time series showing changes in NPV, GV, and Liquid water. A lack of color denotes an area that has undergone no changes. Fire scars are either yellow (low value in 1994), magenta (low value in measure in 1996), red (low in 1994 and 1996) or blue (high in 1994, low all other years). Much of the overlap zone between the Topanga and Calabajas fires is red while the northern portion of the Calabajas fire scar is blue (denoting little recovery since 1996).

Education:

Graduate and undergraduate students funded in part during this project include:

UC Santa Barbara:

Phillip Dennison: Masters/PhD student, Masters thesis supported by SENH entitled "An Examination of the Relationship Between Chaparral Biomass and Radar Backscatter", UCSB masters thesis.

Research results published in Dennison et al., 1999 and Dennison et al. 2000.

Diego Pedreros: Undergraduate thesis supported by SENH entitled "Wildfire-streamflow interactions in a chaparral watershed", unpublished UCSB Senior Thesis.
later published as Loaiciga et al. 2001

Jason Leroy:

UC Davis

Alicia Orueta Palacios: PhD student, thesis entitled, publications include Palacios-Orueta and Ustin, 1998 and Palacios et al., 1999.

Lydia Serrano: visiting PhD student from Spain, research results published in Serrano et al., 2000.

David Riano: visiting PhD student from Spain research results published in Riano et al., 2001.

Other educational activities: Roberts (1999), article describing wildfire research in CAMP quarterly (CAMP on Fire!).

Publications:

Bossert, J.E. R.R. Linn, J.M. Reisner, J.L., Winterkamp, P. Dennison and D. Roberts, 2000, Coupled atmosphere-fire behavior model sensitivity to spatial fuels characterization, Third Symposium on Fire and Forest Meteorology, Amer. Meteor. Soc. 80th Annual Meeting, Long Beach, CA, 9-14 January, 2000. pp. 21-26.

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Professional Presentations:

Bossert, J.E. R.R. Linn, J.M. Reisner, J.L., Winterkamp, P. Dennison and D. Roberts, 2000, Coupled atmosphere-fire behavior model sensitivity to spatial fuels characterization, presented at the Third Symposium on Fire and Forest Meteorology, Amer. Meteor. Soc. 80th Annual Meeting, Long Beach, CA, 9-14 January, 2000

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Appendix I:

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