CHARACTERIZING CHAPARRAL FUELS USING COMBINED HYPERSPECTRAL AND SYNTHETIC APERTURE RADAR DATA

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Introduction

Modeling fire behavior requires an understanding of the three elements of the "fire environment triangle": topography, meteorology, and fuel properties (Countryman, 1972). Techniques are readily available for determining topographic and meteorologic variables over large areas. Mapping fuel properties is much more difficult because of high spatial and temporal variability. Four fuel properties are essential for fire behavior modeling: fuel type, fuel loading, fuel condition, and fuel moisture. Fuel type describes species-specific combustion properties including surface area-to-volume ratio, relative amounts of herbaceous and woody fuels, and phenology. Fuel loading is the biomass of component fuels, segregated by size class. Biomass of live herbaceous material is particularly important in chaparral, because the structure and chemistry of chaparral leaves make live materials more combustible than in other vegetation types (Philpot, 1977). Fuel condition represents the relative amounts of live and dead (or senesced) fuels. Live fuels contain more moisture that must be driven off before the fuel undergoes combustion. Finally, fuel moisture is the amount of liquid water present in live and dead fuels. The moisture of dead fuels can be predicted from meteorological variables, but live fuel moisture is much more difficult to estimate.

Optical remote sensing techniques have demonstrated some ability to spatially characterize chaparral fuels. Coarse resolution Advanced Very High Resolution Radiometer (AVHRR) imagery is used to generate Normalized Difference Vegetation Index (NDVI) for the entire contiguous United States, assessing departure from average greenness (Burgan et al., 1996). Landsat Thematic Mapper (TM) data have been used to map fuels in Southern California (Cosentino et al., 1981; Yool et al., 1985; Stow et al., 1993). Advanced spectral techniques can provide species levels vegetation maps (Gardner, 1997; Roberts et al., 1998a; Roberts et al., 1998b), fraction of non-photosynthetic vegetation (NPV) (Roberts et al., 1993), and canopy water content (Ustin et al., 1998), from Advanced Visible/Near Infrared Imaging Spectrometer (AVIRIS) data. Although these applications show great promise, optical remote sensing is restricted in its ability to reveal certain chaparral fuel characteristics. Short visible and near infrared wavelengths are easily scattered or absorbed within the canopy. Fuel characteristics such as large woody biomass, critical for fire modeling efforts, can only be determined using longer wavelength synthetic aperture radar (SAR) systems. AIRSAR L-HV and P-HV backscatter response from canopy scattering in chaparral increases with stand age (Dennison et al., 1999a) and 10-hour fuel size class (0.64-2.54 cm diameter) woody biomass (Dennison et al., 1999b). The aforementioned optical and radar studies and addressed only one or two fuel properties, and are not able to directly produce inputs for fire behavior modeling. This paper presents a combined hyperspectral/SAR approach for measuring all four fuel properties for use in fire behavior modeling.

Study Area

The Santa Monica Mountains extend 70 km westward from the Los Angeles Basin to Point Mugu, California. The range is dominated by fire-adapted chaparral vegetation communities, including drought-senescent "soft" chaparral and evergreen "hard" chaparral. The Santa Monica Mountains have experienced extremely high fire frequency over the past 70 years (Office of Emergency Services, 1995), including the devastating Green Meadow Fire in 1993 and the Calabasas Fire in 1996. Extensive geographic information system (GIS) data, including fire history, topography and soils data layers, have been developed for the Santa Monica Mountains by the National Park Service (NPS) Santa Monica Mountains National Recreation Area.

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 or ecosystem. Examples include surface-to-volume ratio and typical fuel loadings. Detailed fuel sampling of vegetation species can be used to "crosswalk" a species map to fuel type. Vegetation species maps created from AVIRIS data have been produced using Multiple Endmember Spectral Mixture Analysis (MESMA) (Roberts et al., 1998a). MESMA allows endmembers from a spectral library to vary on a per pixel basis. Recent additions to a regionally-specific spectral library have increased the accuracy of MESMA vegetation maps in the Santa Monica Mountains (Roberts et al., 1999). The regionally-specific spectral library includes leaf-level laboratory spectra; leaf-, branch-, and canopy-level field spectra; and high- and low-resolution AVIRIS image endmembers. Improved MESMA vegetation maps have been crosswalked to traditional Anderson fuel model classes and to custom fuel model classes developed specifically for the Santa Monica Mountains (Anderson, 1982; Reggelbrugge and Conard, 1996). Anderson fuel models 1, 4, and 6 can be used to describe vegetation in the Santa Monica Mountains roughly corresponding to grass, hard chaparral, and soft chaparral (Figure 1). These fuel model maps can serve as inputs for fire behavior models even without addition fuel properties using typical fuel loadings and assuming uniform fuel condition and moisture.

Fuel Loading

Fuel loading describes biomass of chaparral fuels, which can be broken down in to several size-classes. Fuel amount is typically partitioned into classes based on whether the fuel is alive or dead and on the time required for the fuel to come to moisture equilibrium with its environment. Large diameter fuels take longer to come to equilibrium than small diameter fuels. Fuel loading can be mapped using complimentary hyperspectral and SAR data. AVIRIS equivalent liquid water thickness measures liquid water absorption between 865 and 1035 nanometers. Liquid water contained in leaves is the major terrestrial component of equivalent liquid water thickness (Roberts et al., 1997). AVIRIS equivalent liquid water thickness has been shown to be strongly related to green leaf biomass in *Populus* stands (Roberts et al., 1998c). Figure 2 displays measured AVIRIS equivalent liquid water thickness for biomass sample sites in the Santa Monica Mountains. Relationships between equivalent liquid water thickness and herbaceous biomass may be species dependent. The lone point dominated by *Ceanothus spinosus* possesses an equivalent liquid water thickness that is very different from the other species displayed. Synthetic aperture radar measures scattering from structural components of the vegetation canopy. AIRSAR L-HV and P-HV backscatter increase with 10-hour (0.64-2.54 cm diameter) fuel size class woody biomass (Figure 3) (Dennison et al., 1999b). There is also a relationship between P-HV backscatter and stand age as derived from a fire history of the Santa Monica Mountains (Dennison et al., 1999a). Backscatter increases with increasing stand age, and presumably biomass. The relationship between backscatter and stand age strengthens for slower-maturing hard chaparral when a MESMA vegetation map is used to segregate vegetation into grass, soft chaparral, and hard chaparral (Figure 4).

Fuel condition

Fuel condition is the relative amounts of live and dead fuel present. Liquid water must be evaporated before a fuel can reach combustion temperatures. Live fuels require much more preheating than dead fuels. While a combined AVIRIS equivalent liquid water thickness/AIRSAR cross-pol backscatter approach can measure biomass of live herbaceous and woody plant materials, it is less sensitive to dead plant materials that contain much smaller amounts of liquid water. Fuel condition is readily available from AVIRIS simple spectral mixture analysis using generic green vegetation (GV), non-photosynthetic vegetation (NPV) and soil endmembers. Normalized for shade fraction, the ratio of GV to NPV indicate relative fractions of live and dead fuels. Spectral mixture analysis cannot be able to provide information about fuel condition underneath hard chaparral canopies; however, vegetation below these dense canopies is sparse and not a major influence on the total fuel load (Regelbrugge and Conard, 1996). Fuel condition is much more important in soft chaparral and grasslands, which senesce during dry conditions.

Fuel Moisture

Fuel moisture is potentially the most important fuel property controlling fire hazard (Pyne et al., 1996). While dead fuel materials come to moisture equilibrium with their environment, live fuel moisture depends on many factors, including vegetation species, the health of the vegetation, and the availability of soil moisture. A direct measure of the spatial and temporal variations in live fuel moisture would be invaluable for fire behavior modeling. AVIRIS equivalent liquid water thickness demonstrates seasonal fluctuations related to changes in live fuel moisture. Because equivalent liquid water thickness can only measure the total amount of water present, time series data and field sampling of live fuels will be necessary to map live fuel moisture. The Wildland Fire Hazard Center, a NASA Regional Earth Science Applications Center (RESAC), has begun an effort to sample live fuel moisture at 8 sites in the Santa Monica Mountains. These data will be used to match trends in AVIRIS data and in a series of 6 EO-1 Hyperion images beginning Fall 2000. Isolating fuel moisture is the greatest challenge in a comprehensive description of wildland fuels, but will also offer the greatest benefit for fire behavior modeling.

Fire Behavior Modeling

Fuel type, produced using an October 17, 1996 AVIRIS scene, was used to model the Corral Canyon section of the Calabasas Fire. The Calabasas Fire burned a north-south swath from Calabasas to Malibu on October 21-22, 1996. A MESMA vegetation species map was crosswalked to custom fuel models developed for Southern California chaparral. The spatial distribution of fuel models for *Ceanothus megacarpus, Adenostoma fasciculatum*, and coastal sage scrub are shown in Figure 5. A 4 meter per second south wind was used for the model run, which is slightly greater than ambient wind modeled for Coral Canyon for the afternoon of October 22, 1996 (Jim Bossert, pers. comm.). A 10-meter USGS DEM supplied slope and aspect. The model was run at a 20 meter resolution.

The modeled fire consumed most of Corral Canyon within 3 hours of its ignition (Figure 5). Topography appears to be the dominant factor determining simulated fire spread, which is not surprising considering the steepness of the canyon. The modeled fire progressed more rapidly through coastal sage scrub (magenta) than through higher biomass *Ceanothus megacarpus* (blue). The actual fire required only 1 hour to burn Corral Canyon, however, the FARSITE model cannot take fire-induced meteorology into account. More realistic simulations using the more advanced FIRETEC model have been run on the same dataset at Los Alamos National Laboratory (Bossert et al., 2000). Running several test fires using different fuel properties could help establish the sensitivity of fire behavior models to these parameters.

Conclusions

Combined AVIRIS and AIRSAR data can be used to map fuel type, fuel amount, fuel condition, and fuel moisture in Southern California chaparral found in the Santa Monica Mountains. MESMA species maps can be used to determine fuel type. AVIRIS equivalent liquid water thickness and AIRSAR cross-pol backscatter have demonstrated abilities for mapping fuel loading. Fuel condition can be described using a ratio of GV and NPV fractions produced from a simple mixing model. Time series equivalent liquid water thickness data will hopefully reveal spatial and temporal fluctuations in fuel moisture. Fuel property information will serve as valuable inputs for fire behavior modeling.

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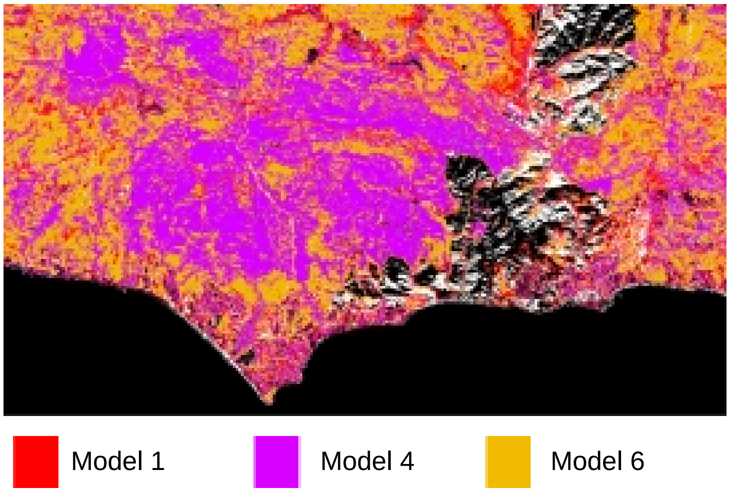

Figure 1. A MESMA vegetation species map crosswalked to standard fuel models. The black and white shaded area is the fire scar from the Calabasas Fire, which began two days prior to this October 23, 1996 AVIRIS flight.

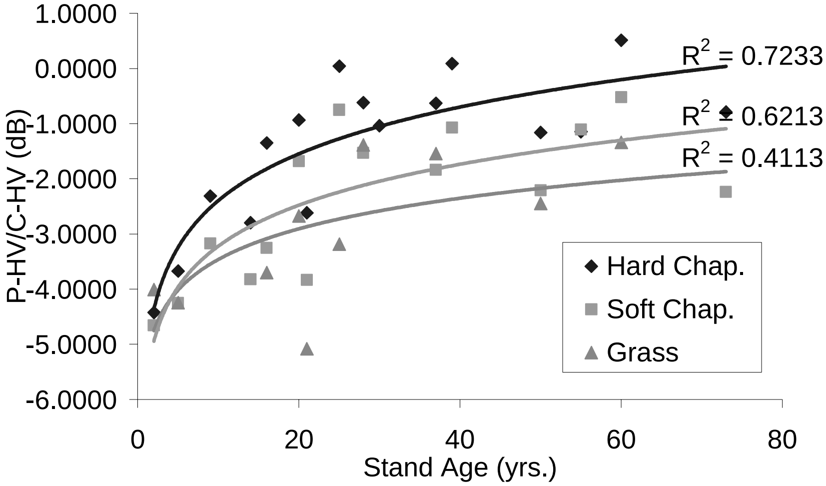

Figure 4. The relationship between stand age and cross-pol backscatter from a May 1998 AIRSAR scene strengthens when vegetation is separated into hard chaparral, soft chaparral, and grass.

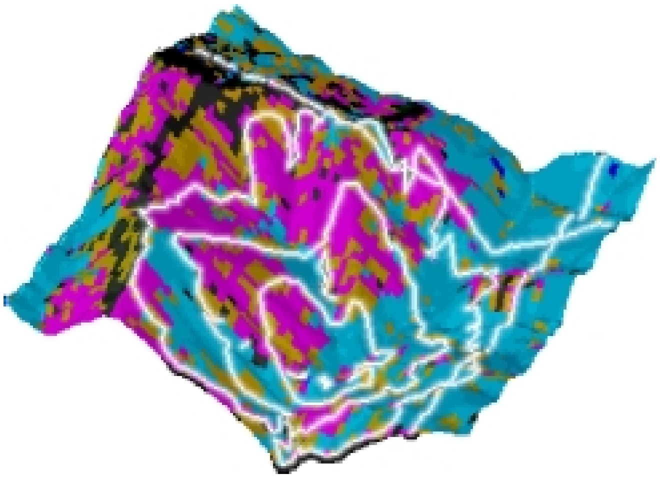

Figure 5. A FARSITE simulation of the Coral Canyon section of the Calabasas Fire, October 22, 1996. Custom fuel models developed from fuel sampling were used to crosswalk from a MESMA vegetation map to fuels. *Ceanothus* is blue, *Adenostoma fasciculatum* is brown, and mixed soft chaparral is magenta. White lines indicate fire perimeters at 1-hour intervals.

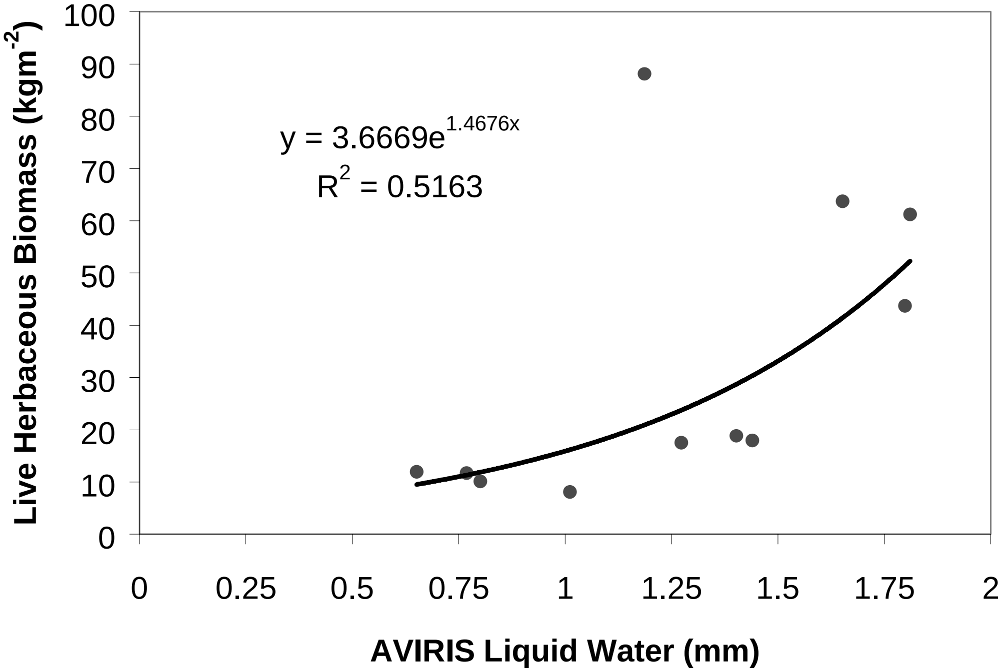

Figure 2. Equivalent liquid water thickness vs. live herbaceous biomass measured at sample plots in the Santa Monica Mountains. The outlier is *Ceanothus spinosus*.

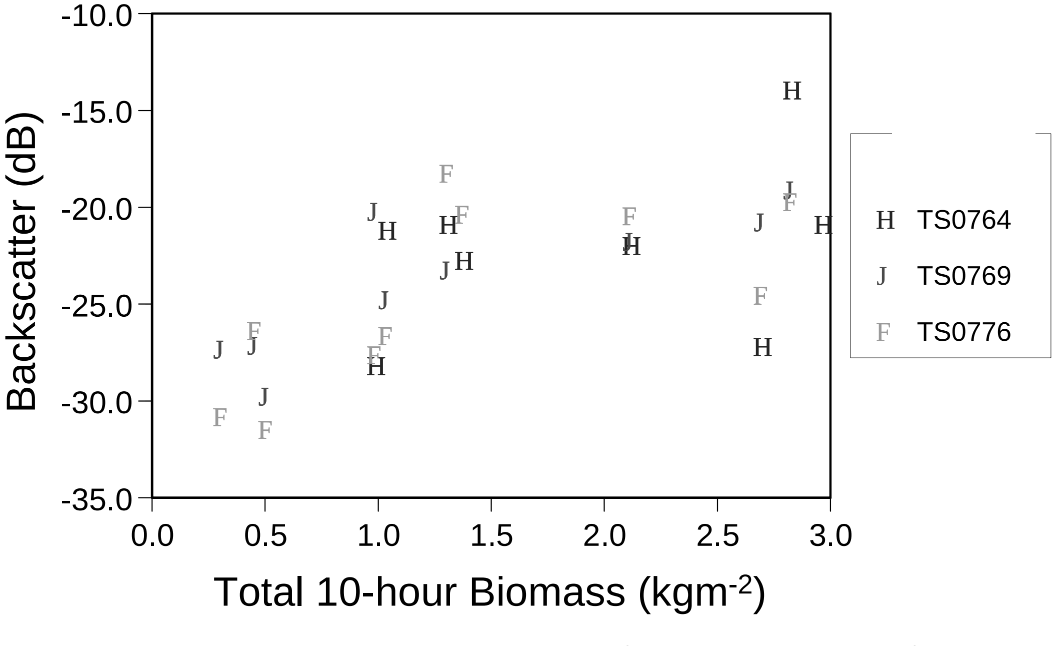

Figure 3. Total live and dead 10-hour biomass vs. P-HV backscatter from three 1999 TOPSAR flightlines.