Estimating Canopy Water Content of Chaparral Shrubs using Optical Methods

Submitted by
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California chaparral ecosystems are exceptionally fire adapted and typically are subject to wildfire at decadal to century frequencies. The hot dry Mediterranean climate summers and the chaparral communities of the Santa Monica Mountains make wildfire one of the most serious economic and life-threatening natural disasters faced by the region. Additionally, the steep fire-burned hillsides are subject to erosion, slumpage, and mud slides during the winter rains. The Santa Monica Mountain Zone (SMMZ) is a 104,000 ha east-west trending range with 607 m of vertical relief and located in the center of the greater Los Angeles region. A series of fires in the fall of 1993 burned from Simi Valley to Santa Monica within a few hours. Developing techniques to monitor fire hazard and predict the spread of fire is of major concern to the region. One key factor in the susceptibility to fire is the water content of the vegetation canopy. The development of imaging spectrometry and remote sensing techniques may constitute a tool to provide this information.

At least four distinct chaparral communities exist in the mountains which are found in a complex spatial mosaic across this range. These species exhibit different sensitivities to fire and responses to post-fire because of differences in their growth patterns, density, biomass and litter accumulations, and water contents. These shrub communities are known as chamise chaparral (often nearly pure stands of *Adenostoma fasciculatum*). *Ceanothus* chaparral is typically mid-successional and is dominated by one or more species of *Ceanothus* (California lilac). Broadleaf chaparral, which is generally the most diverse, is often composed of several shrub species. Lastly, the coastal region may be dominated by Coastal sage (*Salvia*) species. This latter community tends to maintain the highest foliar density and is greenest to the eye.

We obtained spectral measurements in the field (ASD-2500nm range) and the lab (CARY 5E) on the dominant chaparral species at canopy and leaf scales and compared these to estimates of water content in concurrently acquired AVIRIS images in June and October, 1995 to examine how well variation in canopy water contents can be estimated using optical sensors. Measurements were made at three sites, Zuma Ridge, Castro Crest and Encino Reservoir, which were chosen as representative of the dominant communities and presenting plants of the major species in different stages of growth (Table 1). The three sites are Zuma Ridge, a coastal site with young sage and mixed chaparral vegetation, Castro Crest, a mountain site with medium above ground biomass accumulation and mixed chaparral vegetation, and Encino Reservoir, an inland site on the eastern edge of the reservoir with old growth *Ceanothus* vegetation, with high biomass chaparral shrubs, 3 to 4 meters tall. The Forest Service Fire Lab and the Los Angeles County Fire District harvested above ground canopy biomass from 15 5m x 5m plots. Total plot biomass was weighed in the field. A subsample of the biomass was measured for water content, leaf mass and stem mass (in different stem size categories) for the June data acquisition. The ASD spectrometer was mounted on a bucket truck and above canopy spectra were acquired at the three sites. Water content was estimated for the canopy within the field of view of the ASD. The following species were recorded at these sites:

Table 1. Species found at the three sites.

Zuma: MALA, ARCA, SALE, ERAR
Castro: ADFA, CEOL, ARGL
Encino: CEME, and DRY GRASS

Acronym	Latin name	Family	Common name
MALA	Rhus laurina	Anacardiaceae	Laurel Sumac
ARCA	Artemisia californica	Asteraceae	Coastal Sagebrush
SALE	Salvia leucophylla	Lamiaceae	Purple Sage
ERAR	Eriogonum cinereum	Polygonaceae	Ashy Leaf Buckwheat
ADFA	Adenostoma fasciculatum	Rosaceae	Chamise, Greasewood
CEOL	Ceanothus oliganthus	Rhamnaceae	Hairy-leaf Ceanothus
ARGL	Arctostaphylos glandulosa	Ericaceae	Eastwood Manzanita
CEME	Ceanothus megacarpus	Rhamnaceae	Big Pod Ceanothus

Methods

Field Radiometric Data

For all three sites, seven above canopy locations were chosen and measured from the bucket truck for the radiometric measurements. Species, canopy height, and spectrometer height were recorded. A Spectralon panel was mounted on a tripod attached to the bucket and adjusted normal to the ground using a leveling device taped to the corner of the standard for calibrating to surface reflectance. Corrections for Spectralon were post-processed to produce absolute 100% reflectance.

Laboratory Radiometric Data

For most of the species, both leaf reflectance and transmittance were measured in the lab on a CARY 5E spectrophotometer with a 150mm Labsphere Integrating sphere with a Spectralon surface. The wavelengths range from 400 nm to 2500 nm with an interval of 2 nm. We acquired reflectance spectra for all the species; for ADFA and ARCA which have needle-like leaves, the transmittance could not be measured so only the infinite reflectance of an optically thick sample was obtained.

Laboratory biophysical Measurements

Some samples of fresh leaves, stems and flowers were collected in the field to calculate water content. For large plant leaves, the fresh weight of 3.46 cm^2 disks was measured, which were cut using a cork borer and immediately weighed using a portable electronic balance; for small leaves, we weighed entire blades, the area of which was later measured using a Canon Video Visualizer RE-650 camera and a digitizer. The stems and flowers of some plants were also processed. All the samples were dried at 70°C for four days before dry weights were measured. Assuming that FW is the fresh weight, DW the dry weight, and S the leaf area, water content (WC) was calculated, as were the equivalent water thickness (EWT), the leaf specific weight (LSW) and the specific leaf area (SLA) which is the reciprocal of the leaf specific weight:

$$WC = \frac{FW - DW}{FW} \qquad EWT = \frac{FW - DW}{S} \qquad LSW = \frac{1}{SLA} = \frac{DW}{S}$$

WC is the water mass over fresh mass, EWT and LSW are respectively the water and dry matter masses per unit leaf area, expressed in $g.cm^{-2}$; in consequence, the SLA is provided in $cm^2.g^{-1}$.

Data Analysis

Three methods for estimating canopy water content were applied to the laboratory and field data sets. The first method applied a modified version of the PROSPECT model (Jacquemoud et al., 1996), which predicts several leaf chemistry variables including water thickness from the reflectance data. The second method used a continuum removal technique to fit a curve to the water absorption feature (Clark and Roush, 1984). The third method used a new technique, termed by Smith et al. (1994) Foreground/Background Analysis (FBA). In a modified form described by Pinzon et al. (1995, 1996), FBA relates optical properties to canopy biochemical concentrations in three steps. First, the Gram-Schmidt orthogonalization procedure was used to extract the bands that explain most of the spectral variation for water absorption. Second, the samples were stratified into different reflectance ranges by defining an FBA vector that permits their hierarchical classification. Finally, FBA was used to find new vectors that best relate leaf reflectance to water content. These results from each of these methods were compared for accuracy of the assessment and all three methods gave reasonably good predictions at the leaf and canopy levels. The significance of differences among the methods will be discussed. The methods were then applied to the calibrated AVIRIS datasets from June 1995 and spatial estimates of above ground canopy water contents were obtained.

Table 2. Leaf biophysical measurements predicted by the PROSPECT model. Leaf thickness, pigment content and water content are estimated from 40 fresh leaves measured in the CARY spectrophotometer from this experiment.

Variable	Unit	Range	Mean	Std. Dev.
leaf thickness	mm	86.4-780.0	194.5	114.9
SLA	cm2 g-1	73.9-535.3	224.6	93.4
Water Content	%Fresh Wt.	44.9-92.4	66.4	11.0
Water Concentration	g cm-2	0.0046-0.0405		
Chlorophyll α	μg cm-2	12.8-64.2	36.9	11.4
Chlorophyll β	μg cm-2	3.7-21.3	11.7	3.8
Carotenes	μg cm-2	3.7-19.4	10.5	3.6
Cellulose	%Dry Wt.	9.1-37.2	19.7	6.4
Cellulose	g cm-2	0.00031-0.00545		
Hemicellulose	% Dry Wt.	0.3-38.8	15.2	10.0
	g cm-2	0.00002-0.00332		
Lignin	% Dry Wt.	1.1-27.5	10.2	6.4
	g cm-2	0.00003-0.00305		
Protein	% Dry Wt.	7.4-36.8	20.0	7.0
	g cm-2	0.00048-0.00172		
Starch	% Dry Wt.	0.0-10.0	2.0	2.1
	g cm-2	0.0000-0.00098		
Total Carbon	% Dry Wt.	38.5-52.3	47.4	2.9
	g cm-2	0.00079-0.00665		
Total Nitrogen	% Dry Wt.	1.2-5.9	3.4	1.1
	g cm-2	0.00009-0.00033		

An example of the results of the PROSPECT model run is shown in Figure 1a for one randomly selected leaf from the dataset. The predicted and measured liquid water estimates for 40 leaf samples measured on the CARY spectrophotometer in the lab are shown in Figure 1b. A summary of the predicted foliar biochemical composition from the CARY laboratory spectra for the 40 leaf samples is shown in Table 2. The results of the three leaf and canopy spectral analysis methods were compared to equivalent path leaf water thickness estimates obtained from the atmospheric calibration of AVIRIS data obtained using the method of Green et al. (1995). These results were also compared to the field measured canopy water content and biomass data provided by the Forest Service. Results support the use of AVIRIS image analysis techniques for estimating spatial variation in water content.

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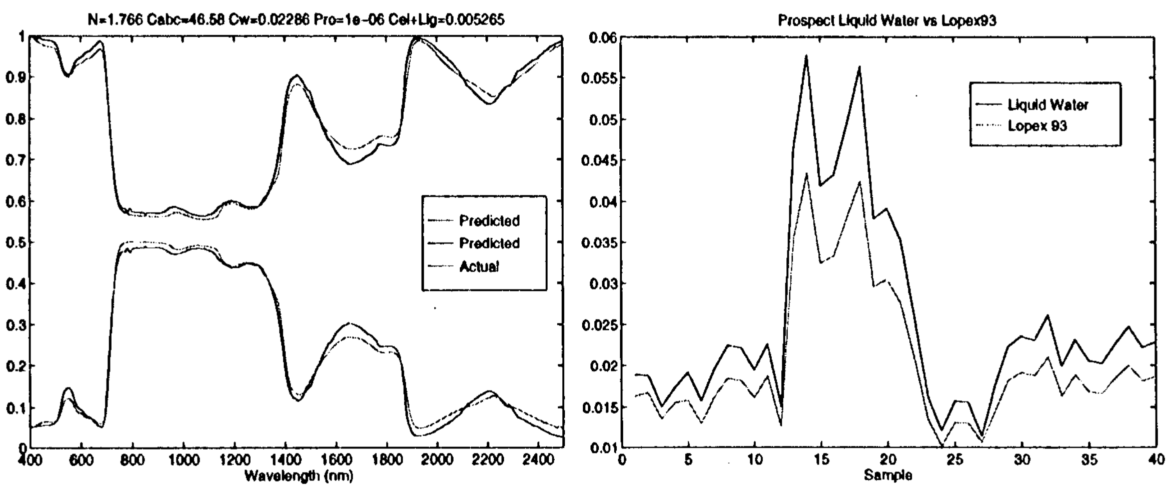
Figure 1a (left) shows the fit between the measured leaf reflectance and transmission using the revised PROSPECT model. Figure 1b (right) shows the predicted and measured liquid water estimates ($g.cm^{-2}$) for 40 leaf samples of various chaparral shrub species that were measured on the CARY spectrophotometer.



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