Exploring Spectral and Functional Trait Variation at Leaf & Canopy Scales Across California Ecosystems

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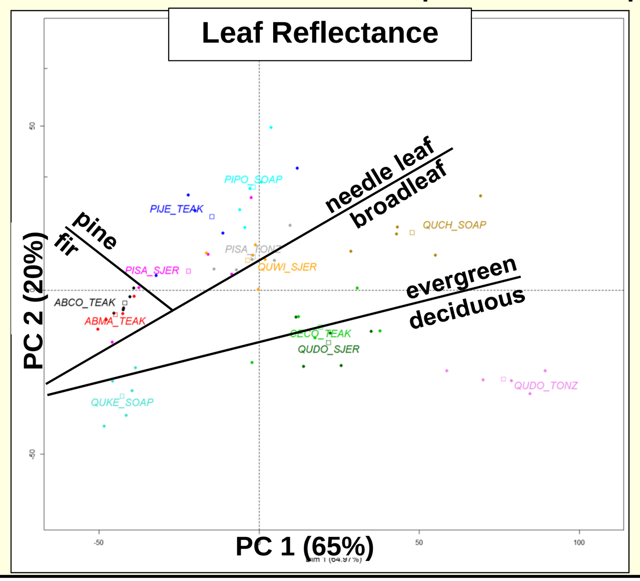
Abstract

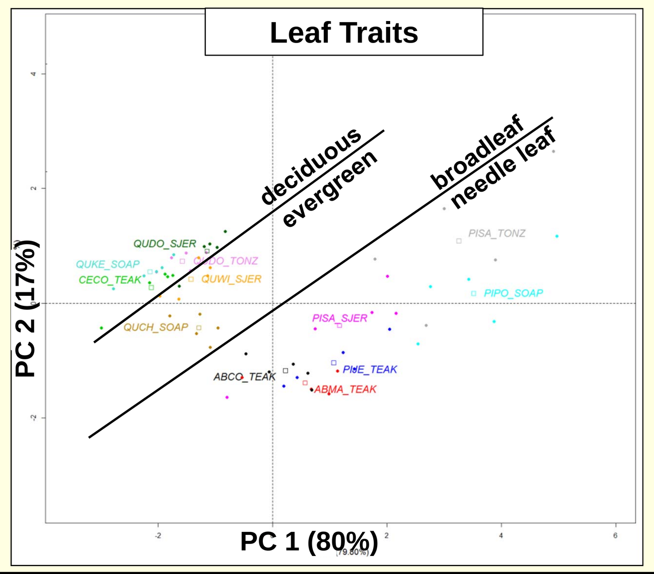
Imaging spectroscopy data have been successfully used to map a wide range of canopy and leaf-level biochemical and biophysical properties across a diverse set of ecosystems. These maps provide critical insights into the spatial patterns and drivers of biodiversity and ecosystem processes, and can be used to refine inputs to both ecosystem and climate models. However, the availability of such datasets has been mostly limited to single acquisitions over relatively small extents compared to those acquired by multispectral sensors. The Hyperspectral Infrared Imager (HyspIRI) mission would provide the first global, monthly imaging spectroscopy dataset to the scientific community. In support of this mission, our research objectives are to 1) evaluate the expression of plant functional traits and types within imaging spectroscopy data and 2) to assess the feasibility of retrieving canopy biochemistry with these data over large, heterogeneous regions. During the 2013 and 2014 preparatory science airborne campaigns, we collected leaf spectral and functional trait measurements, as well as canopy structural measurements and field surface spectra at sites representing a wide range of ecosystems and environmental conditions. Using these data, we examined patterns of variation in leaf-level functional traits (i.e., pigments, water, dry matter, thickness) and leaf spectra, considering their relation to common plant functional types. We also evaluated our ability to estimate these traits both singularly and in combination using partial least squares regression analysis. At canopy scale, we used data collected by the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) to quantify spectral variability across our study sites. We investigated spatial patterns in canopy biochemistry across sites using existing spectral indices and metrics. Lastly, we begin to extend our analysis to more explicitly consider important sources of spectral variation which make canopy biochemistry retrieval challenging.

Leaf-level Spectral & Trait Variation

- Principal Components Analysis shows greater variation in leaf-level spectra than in five leaf traits (leaf mass area, water content, total chlorophyll, carotenoids & leaf thickness)
  - Leaf Reflectance: 5 components explain 99% variance
  - Leaf Traits: 3 components explain 99% variance



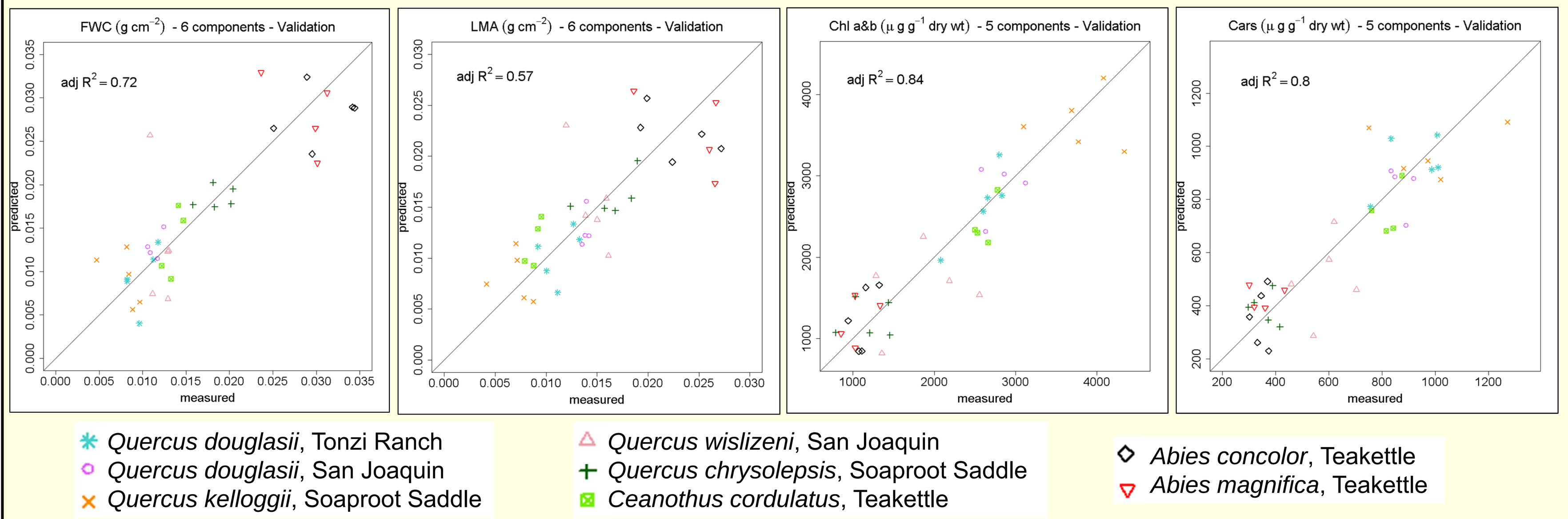
Both data sets show clustering by species, site and conventional functional types.



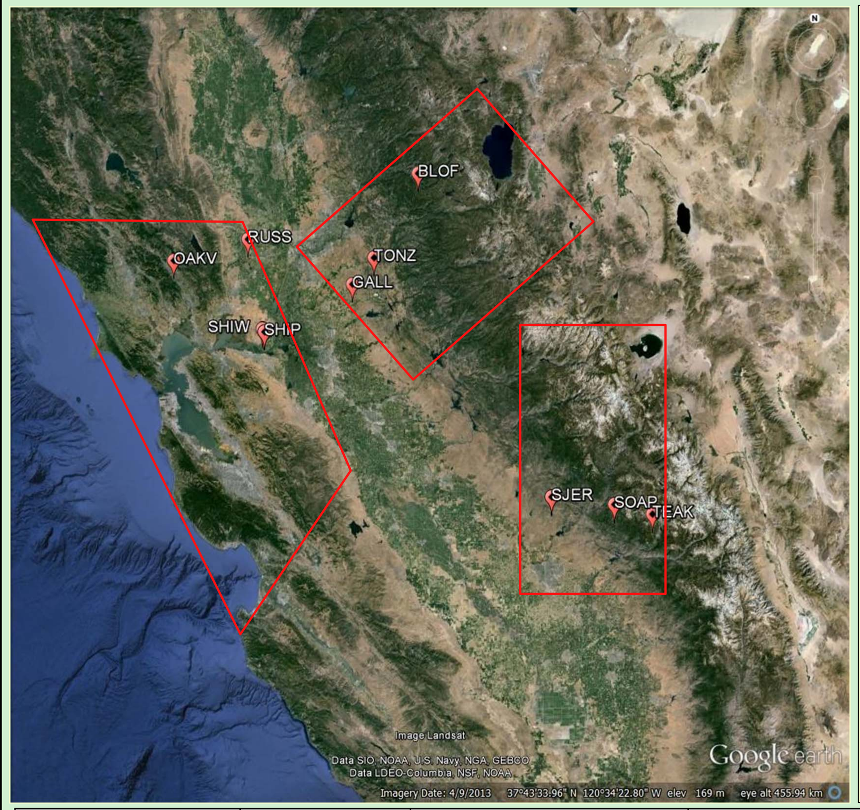
Estimating Leaf Functional Traits

- Leaf-level traits were estimated using leaf reflectance spectra and partial least squares regression (PLSR).
- # of included components was selected based on minimization of the PRESS statistic.
- Final models were cross-validated using a leave-one-out procedure.
- When traits were estimated as a multi-response model, R^2 and RMSE values were not significantly different.

Examples of Predicted vs. Measured Leaf Trait Values (n=37, June data)



Study Sites & Field Data Collection



MEASUREMENTS

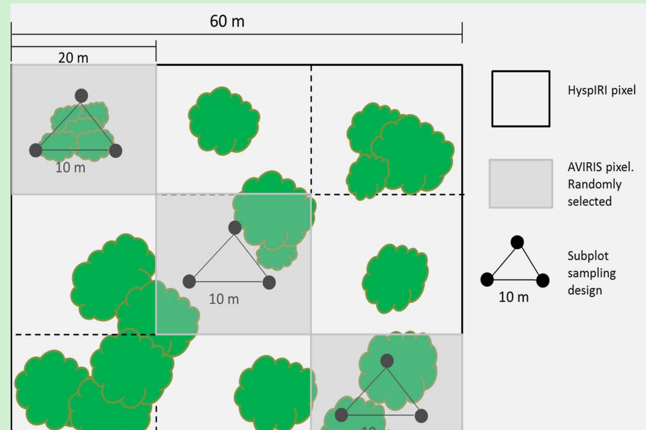
Spectra
- Hemispherical leaf reflectance and transmittance
- Directional leaf reflectance
- Reflectance for soil, rock, understory vegetation, & non-photosynthetic vegetation

Leaf Traits
- water content
- dry mass per unit area
- thickness
- pigments (chlorophyll & carotenoids)
- carbon & nitrogen

Structure & Composition
- leaf area index or biomass
- canopy cover or gap fraction
- plot-level inventory (forested sites)
  - species
  - ground cover fraction
  - diameter at breast height
  - canopy height
  - canopy base height
  - crown width

SITE	HYSPIRI BOX	ECOSYSTEM	FOCAL SPECIES	DATA COLLECTION (Spring, Summer, Fall) *planned
Sherman Island Wetland (SHIW)	Bay	restored wetland	*Typha spp.* *Schoenoplectus acutus*	SP-13, SM-13, F-13, SP-14, SM-14, F-14
Sherman Island Pasture (SHIP)	Bay	grazed pasture	*Lepidium latifolium*	SP-13, SM-13, F-13, SP-14, SM-14, F-14
Oakville Vineyard (OAKV)	Bay	agricultural	*Vitis vinifera*	SM-13
Russell Ranch (RUSS)	Bay	agricultural	*Zea mays* *Triticum spp.*	SP-13, SM-13, SP-14, SM-14
Blodgett Forest (BLOF)	Tahoe	mixed broadleaf/conifer forest	*Quercus kelloggii* *Abies concolor* *Calocedrus decurrens* *Pinus ponderosa*	F-13 SP-14, SM-14, F-14*
Tonzi Ranch (TONZ)	Tahoe	oak savanna woodland	*Quercus douglasii* *Pinus sabiniana*	SP-13, SM-13, F-13, SP-14, SM-14, F-14
Gallo Vineyard (GALL)	Tahoe	agricultural	*Vitis vinifera*	SM-13,SP-14, SM-14
San Joaquin Experimental Range (SJER)	Yosemite/NEON	oak savanna woodland	*Quercus douglasii* *Quercus wislizeni* *Pinus sabiniana*	SP-13, SM-13, F-13, SP-14, SM-14, F-14*
Soaproot Saddle (SOAP)	Yosemite/NEON	mixed broadleaf/conifer forest	*Quercus kelloggii* *Quercus chrysolepsis* *Pinus ponderosa* *Calocedrus decurrens* *Arctostaphylos spp.*	SP-13, SM-13, F-13, SP-14, SM-14, F-14*
Teakettle Experimental Forest (TEAK)	Yosemite/NEON	high elevation conifer forest	*Abies concolor* *Abies magnifica* *Ceanothus cordulatus* *Pinus jeffreyi*	SP-13, SM-13, F-13, SM-14, F-14*

Plots & subplots were selected at sites for concurrent leaf reflectance, LAI & inventory measurements in areas dominated by focal species and across a range of canopy densities.



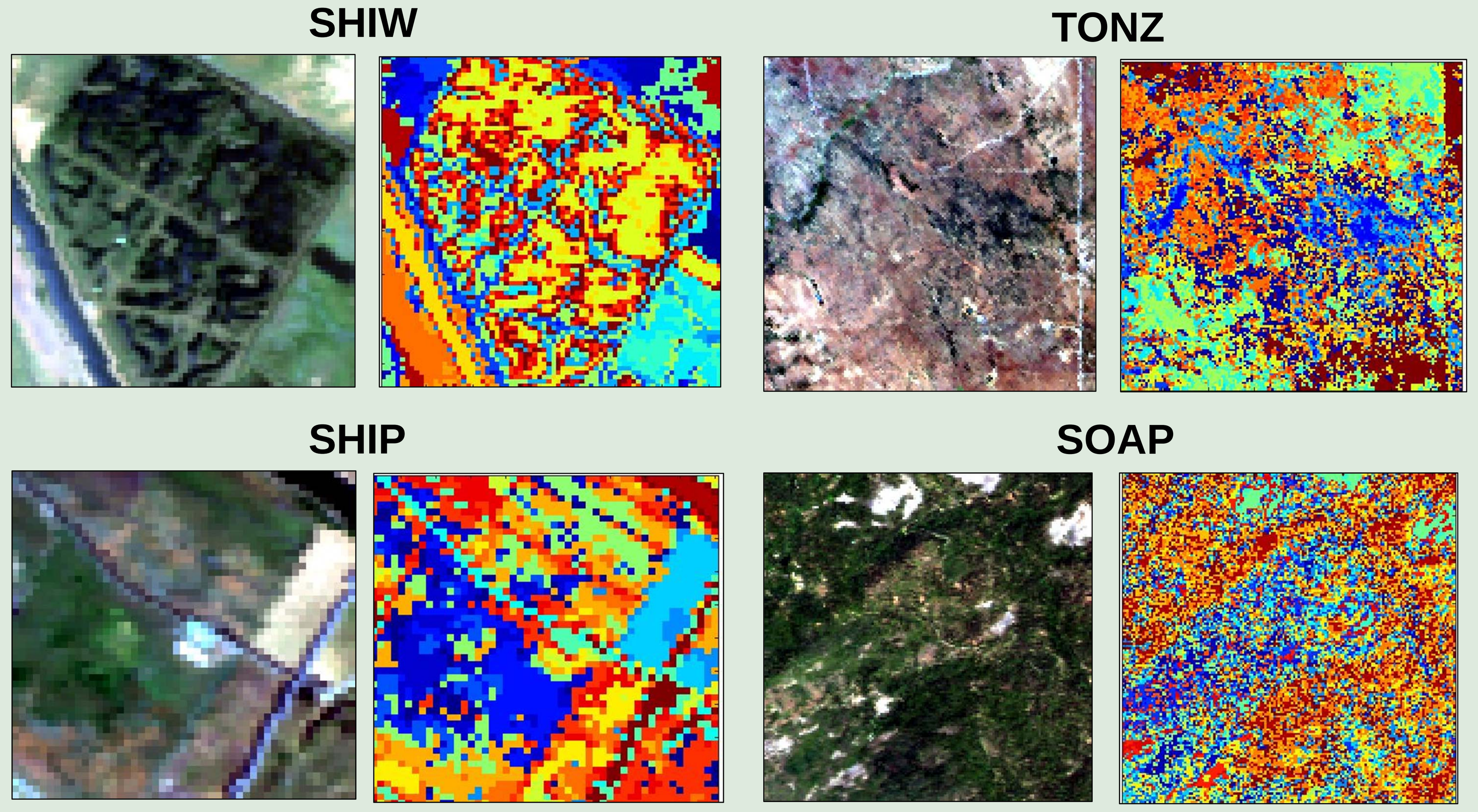
Inventory plots are centered on subplots with a 20 m radius.

Canopy-level Spectral Variation

What spectral groups exist within image data?

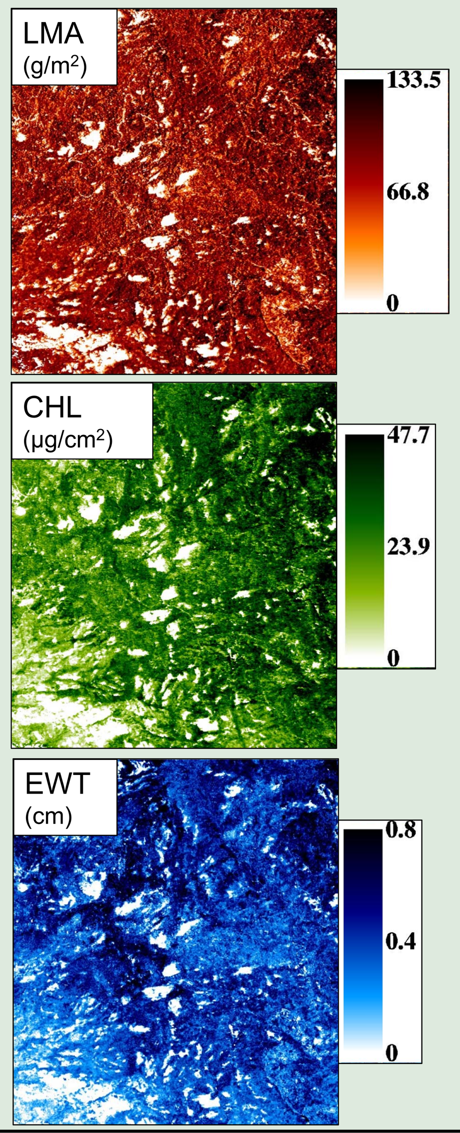
- Data dimensionality for June 2013 AVIRIS imagery of selected sites were calculated using the Hyperspectral Signal Subspace Identification by Minimum Error (HySime) algorithm (Bioucas-Dias & Nascimento, 2008).
- HySime selects a set of eigenvectors that minimize the least squares error (both minimizing the power of the signal projection error & the power of the noise projection).
- The number of dimensions estimated corresponds closely to the number of spectral endmembers or data clusters within the image.

SITE	SIGNAL SUBSPACE DIMENSION
SHIW	18
SHIP	17
BLOF	21
TONZ	18
SJER	10
SOAP	20
TEAK	22

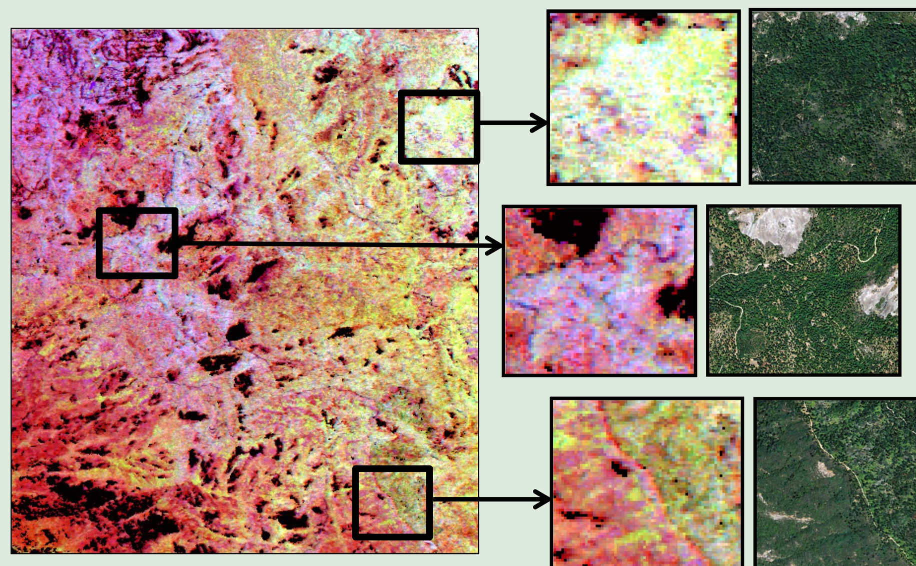


True color composite and cluster images for four sites. Cluster images were created using Ward's Agglomerative Clustering with *n* clusters equal to the HySime data dimensionality estimate. Spatial information was also included with similar weighting to a single data component. The HYPERACTIVE Matlab toolbox was used to create these maps (Fong & Hu, 2007).

Canopy-level Trait Variation



- Maps show canopy leaf mass area (LMA, g/m²), total chlorophyll concentration (CHL, µg/cm²), and equivalent water thickness (EWT, cm) estimated for the Soaproot Saddle site.
  - CHL & LMA were calculated using optimized normalized difference indices from le Maire et al., 2008 (710 & 925 nm, 2260 & 1490 nm, respectively).
  - EWT was calculated by spectral feature fitting (Roberts et al., 1997).
- RGB composite of scaled variables shows the spatial variation in dominant canopy leaf traits.



high density mixed conifer with thick understory

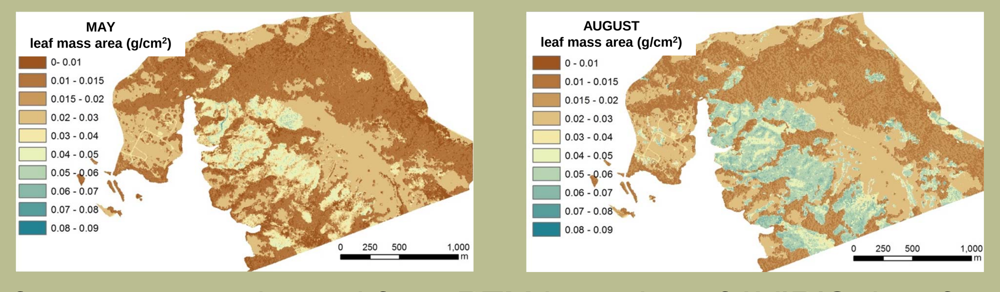
medium density mixed conifer with light understory

evergreen shrub & oak (left) & low density mixed conifer with thick understory (right)

R: LMA, G: CHL, B: EWT

Addressing Challenges in Retrieving Canopy Biochemistry

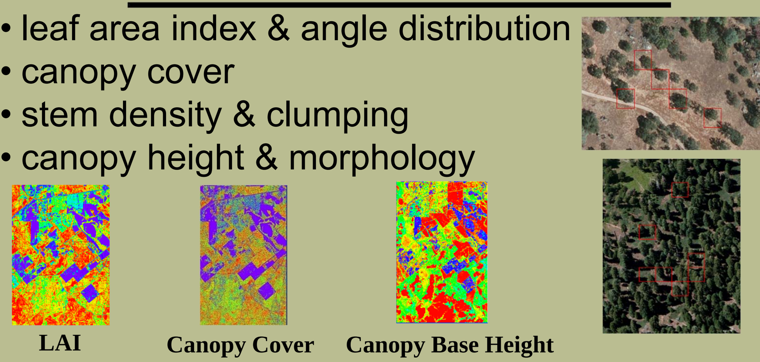
Radiative transfer modeling (RTM) is a powerful tool for estimating plant functional traits (e.g., LAI, pigments, water content) at canopy scale. Still, the effects of pixel composition and canopy structure reduce the accuracy and precision of these estimates. To successfully use RTMs over a wide range of ecosystems and in spectrally diverse scenes, such as will be collected by HyspIRI, we must find a reliable method for addressing these effects. Our future research will evaluate several approaches to account for pixel composition and canopy structure.



Leaf mass area estimated from RTM inversion of AVIRIS data for spring and summer at Jasper Ridge Biological Preserve.

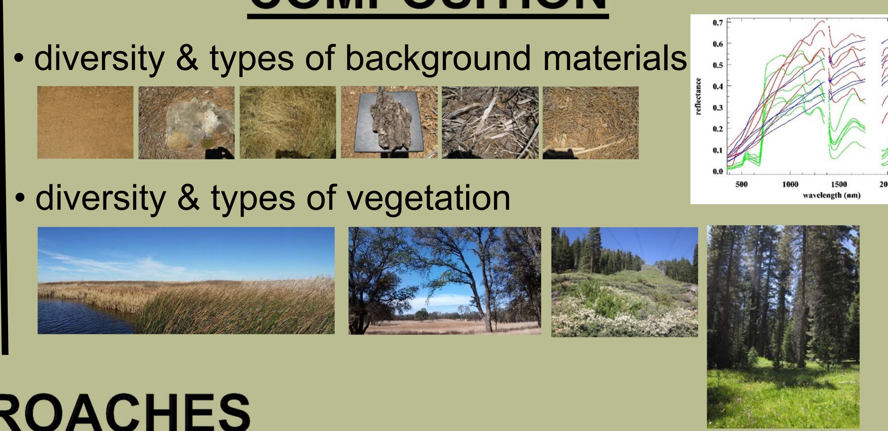
CANOPY STRUCTURE

- leaf area index & angle distribution
- canopy cover
- stem density & clumping
- canopy height & morphology



COMPOSITION

- diversity & types of background materials
- diversity & types of vegetation



PROPOSED APPROACHES

- Explicitly test the effect of different structural parameters within RTM simulations
- Estimate sub-pixel composition and cover using spectral un-mixing
- Constrain RTM inversions for both pixel- and object-levels using prior information (e.g., image clusters, structural types, plant functional types)

References

Bioucas-Dias & Nascimento, 2008, *IEEE Trans*

Fong & Hu, 2007, *HYPERACTIVE manual*

le Maire et al., 2008, *RSE*

Roberts et al., 1997, *RSE*

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CSTARS