Remote Sensing of Environment 167 (2015) 152–167

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Relationships between dominant plant species, fractional cover and Land Surface Temperature in a Mediterranean ecosystem

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ARTICLE INFO

Article history:
Received 11 June 2014
Received in revised form 4 January 2015
Accepted 16 January 2015
Available online 18 February 2015

Keywords:
HyspIRI
AVIRIS
MASTER
Mediterranean ecosystems
Multiple Endmember Spectral Mixture Analysis
Classification
Land Surface Temperature
Spectroscopy

ABSTRACT

The Hyperspectral Infrared Imager (HyspIRI) is a proposed satellite mission that combines a 60 m spatial resolution Visible-Shortwave Infrared (VSWIR) imaging spectrometer and a 60 m multispectral thermal infrared (TIR) scanner. HyspIRI would combine the established capability of a VSWIR sensor to discriminate plant species and estimate accurate cover fractions with improved Land Surface Temperatures (LST) retrieved from the TIR sensor. We evaluate potential synergies between Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) maps of dominant plant species and mixed species assemblages, fractional cover, and MODIS/ASTER Airborne Simulator (MASTER) LST utilizing multiple flight lines acquired in July 2011 in the Santa Barbara, California area. Species composition and green vegetation (GV), non-photosynthetic vegetation (NPV), impervious, and soil cover fractions were mapped using Multiple Endmember Spectral Mixture Analysis with a spectral library derived from 7.5 m imagery. Temperature-Emissivity Separation (TES) was accomplished using the MASTER TES algorithm. Pixel-based accuracy exceeded 50% for 23 species and land cover classes and approached 75% based on pixel majority in reference polygons. An inverse relationship was observed between GV fractions and LST. This relationship varied by dominant plant species/vegetation class, generating unique LST–GV clusters. We hypothesize clustering is a product of environmental controls on species distributions, such as slope, aspect, and elevation as well as species-level differences in canopy structure, rooting depth, water use efficiency, and available soil moisture, suggesting that relationships between LST and plant species will vary seasonally. The potential of HyspIRI as a means of providing these seasonal relationships is discussed.

1. Introduction

The Hyperspectral Infrared Imager (HyspIRI) has the potential to reduce uncertainties in land–energy–atmosphere interactions and improve our knowledge of ecological effects of climate change. Much of the climate-relevant potential of HyspIRI is derived from independent analysis of the reflected solar spectrum (Visible-Near-Infrared/Short-Wave Infrared, or VSWIR) or the emitted spectrum (Thermal Infrared, or TIR). Examples include improved VSWIR estimates of biophysical properties such as surface albedo, leaf area index (LAI: Asner, 1998; Roberts et al., 2004; Schlerf & Atzburger, 2006), Leaf Mass per Area (LMA: Asner et al., 2011; Serbin, Singh, McNeil, Kingdon, & Townsend, 2014), and fractional cover (Roberts, Smith, & Adams, 1993) and important physiological/biochemical properties such as canopy moisture (Sims & Gamon, 2003; Ustin et al., 1998), light use efficiency (LUE: Gamon, Penuelas, & Field, 1992), nitrogen (Asner & Vitousek, 2005; Martin, Plourde, Ollinger, Smith, & McNeil, 2008; Ollinger, Richardson, Martin, Hollinger, & Frolking, 2008; Townsend, Foster, Chastain, & Currie, 2003), lignin–cellulose (Kokaly & Clark, 1999; Serbin et al., 2014), chlorophyll (Asner, Martin, & Suhaili, 2012; Ustin et al., 2009), or photosynthetic capacity (Serbin, Dillaway, Kruger, & Townsend, 2012). The TIR is critical for quantifying canopy temperature, a fundamental control on rates of photosynthesis, respiration, and transpiration (Gates, 1980) as well as a means for partitioning surface energy balance into latent and sensible heat components, critical elements of the hydrological cycle (Anderson et al., 2011, 2008). Broad measures of canopy greenness combined with air and leaf temperatures, provide measures of plant water stress (Moran, Clarke, Inoue, & Vida, 1994). Because photosynthetic capacity is temperature modulated, VSWIR-derived measures of photosynthetic capacity combined with TIR leaf temperatures offer a mechanistic means toward estimating carbon uptake (Serbin et al., 2012).

Ecosystem composition is an important factor for determining ecosystem response to disturbance and climate change (Schimel et al., 2015). Plant species have a strong impact on biogeochemical cycles (Asner & Vitousek, 2005; Ollinger & Smith, 2005), photosynthetic rates (Robakowski, Li, & Reich, 2012), LMA (Asner et al., 2011), and water use efficiency (McCarthy, Pataki, & Jenerette, 2011; Scherrer,

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http://dx.doi.org/10.1016/j.rse.2015.01.026

Bader, & Korner, 2011). The combination of leaf-level differences in biochemistry, anatomy, and canopy-level differences in plant architecture and their impacts on scattered, reflected, and emitted radiation have enabled plant species to be discriminated spectrally in the VSWIR (Baldeck et al., 2013; Castro-Esau, Sanchez-Azofeifa, Rivard, Wright, & Quesada, 2006; Clark, Roberts, & Clark, 2005; Dennison & Roberts, 2003a; Feret & Asner, 2011; Goodenough et al., 2003; Youngentob et al., 2011) and TIR (da Luz & Crowley, 2007; Ullah, Schlerf, Skidmore, & Hecker, 2012). Furthermore, plant species have been shown to have distinct canopy temperatures, in part due to differences in water use, and in part due to differences in plant architecture (Leuzinger & Korner, 2007; Leuzinger, Vogt, & Korner, 2010). Topographic factors, such as slope and aspect, can have a strong impact on plant distributions, but would also be expected to impact temperature through radiation balance.

Few studies have combined the power of VSWIR imaging spectrometry and TIR remote sensing to explore species-level relationships. In this paper, we use paired Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and MODIS-ASTER Airborne Simulator (MASTER) data to evaluate the relationship between plant species/vegetation class, fractional cover, and Land Surface Temperature (LST). The study was conducted in the area surrounding Santa Barbara, California, USA consisting of a mixture of natural vegetation, agriculture, and urbanized areas, using data acquired on July 19, 2011. Plant species and vegetation classes were mapped using Multiple Endmember Spectral Mixture (MESMA: Roberts et al., 1998), which was also used to generate cover fractions for non-photosynthetic vegetation (NPV), green vegetation (GV), soil, impervious surface, and shade. Relationships between the GV fraction and LST as it varied with plant species were evaluated.

2. Methods

2.1. Study site

The study was conducted in the Santa Barbara area, including three 49-km-long east–west flight lines extending from the coast to the crest of the Santa Ynez range (Fig. 1, Runs 20 to 22). A fourth, 43-km-long north–south flight line (Run 19) was also analyzed, and overlapped with the western edge of the east–west lines. All flightlines were acquired on July 19, 2011.

The study area has a Mediterranean climate, characterized by cool winters, warm summers, winter precipitation, and summer drought. Elevation ranges from sea level to a height of 1310 m along the crest of the Santa Ynez Mountains, dropping to 220 m in the interior Santa Ynez Valley. The east–west orientation of the mountains, cold currents along the coast and general pattern of winter storms create a highly contrasting environment with moderate temperatures along the coast, higher temperature extremes in the interior, and high spatial variation in precipitation including significant orographic enhancement on the south facing side of the Santa Ynez Range and a modest rain shadow in the interior. For example, based on a pair of weather stations deployed by UCSB (Roberts, Bradley, Roth, Eckmann, & Still, 2010), the interior station recorded an average annual precipitation of 337 mm from 2007 to 2013, while the coastal station recorded 445.5 mm. 2011 was the wettest year in this time period, with the coastal station receiving 651 mm.

These strong environmental gradients result in significant diversity in vegetation over a relatively short distance. Progressing along Run 19 from north to south (Fig. 1), the interior is dominated by a mixture of open grasslands, oak savannas, open pine forest, and shrublands. Common species include evergreen needle leaf shrubs such as chamise (*Adenostoma fasciculatum*), evergreen and deciduous shrubs such as purple sage (*Salvia leucophylla*), California sage brush (*Artemisia californica*), coyote brush (*Bacharis pilularis*) and California buckwheat (*Eriogonum fasciculatum*), and broadleaf and needle leaf trees including coast live oak (*Quercus agrifolia*), blue oak (*Q. douglasii*), valley oak (*Q. lobata*) and gray pine (*Pinus sabiniana*). Introduced European grasslands are dominated by a mixture of introduced grass and herbaceous species, some natives and large stands of invasive black mustard (*Brassica nigra*). Moving south, the valley floor is dominated by agriculture, including annual and perennial crops (vineyards), bare soil, and a few small urban centers. Highest elevations along the Santa Ynez range are dominated by a mixture of evergreen needle leaf (chamise) and broadleaf shrubs, including several species of Ceanothus (*Ceanothus*

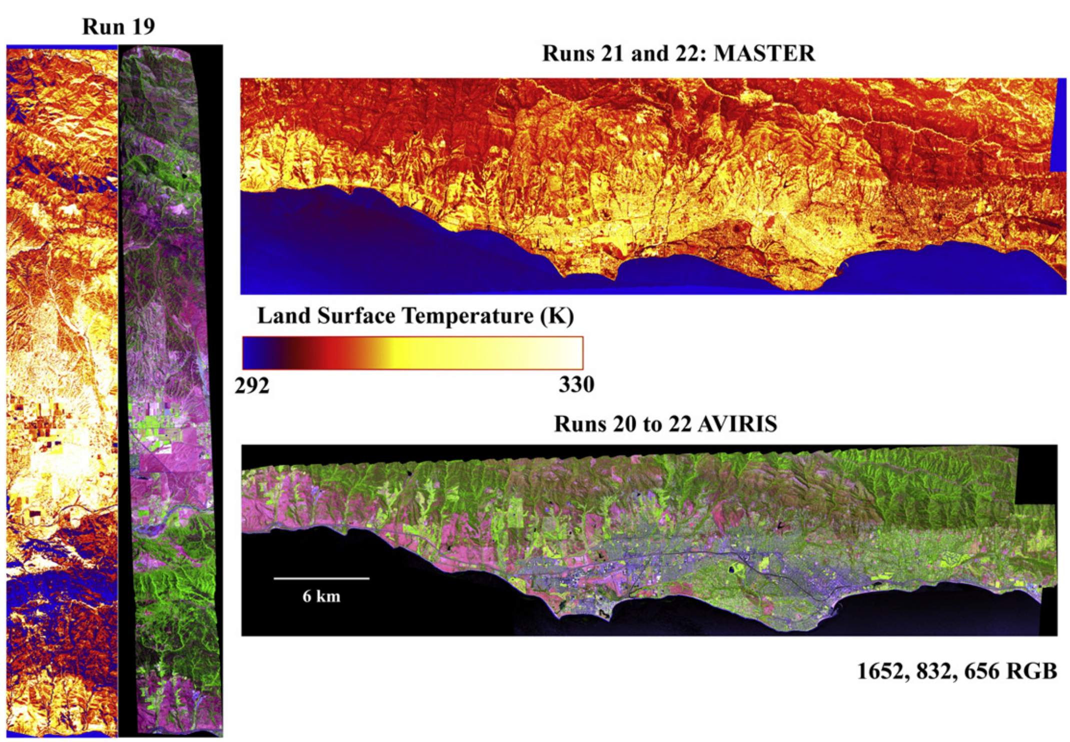

Fig. 1. Study site showing AVIRIS reflectance in three bands (indicated wavelengths are in nm) and MASTER LST for Runs 19 to 22.