Remote Sensing of Environment 191 (2017) 95–109

Contents lists available at ScienceDirect

Remote Sensing of Environment

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

Using high spatial resolution satellite imagery to map forest burn severity across spatial scales in a Pine Barrens ecosystem

Ran Meng [a,*], Jin Wu [a], Kathy L. Schwager [b], Feng Zhao [c], Philip E. Dennison [d], Bruce D. Cook [e], Kristen Brewster [a,f], Timothy M. Green [b], Shawn P. Serbin [a]

[a] Environmental and Climate Sciences Department, Brookhaven National Laboratory, Bldg. 490A, Upton, NY 11973, USA
[b] Environmental Protection Division, Brookhaven National Laboratory, Bldg. 860, Upton, NY 11973, USA
[c] Department of Geographical Sciences, University of Maryland, 1165 Lefrak Hall, College Park, MD 20742, USA
[d] Department of Geography, University of Utah, 332 S 1400 E, Rm. 217, Salt Lake City, UT 84112, USA
[e] Code 618, Biospheric Sciences Branch, NASA/Goddard Space Flight Center, Greenbelt, MD 20742, USA
[f] Department of Environmental Science and Biology, State University of New York College at Brockport, Brockport, NY 14420, USA

ARTICLE INFO

Article history:
Received 20 June 2016
Received in revised form 9 January 2017
Accepted 15 January 2017
Available online 21 January 2017

Keywords:
Spectral library
Random Forests
Error matrix
Scale effect
Frequency distributions
High spatial resolution

ABSTRACT

As a primary disturbance agent, fire significantly influences local processes and services of forest ecosystems. Although a variety of remote sensing based approaches have been developed and applied to Landsat mission imagery to infer burn severity at 30 m spatial resolution, forest burn severity have still been seldom assessed at fine spatial scales (≤5 m) from very-high-resolution (VHR) data. We assessed a 432 ha forest fire that occurred in April 2012 on Long Island, New York, within the Pine Barrens region, a unique but imperiled fire-dependent ecosystem in the northeastern United States. The mapping of forest burn severity was explored here at fine spatial scales, for the first time using remotely sensed spectral indices and a set of Multiple Endmember Spectral Mixture Analysis (MESMA) fraction images from bi-temporal — pre- and post-fire event — WorldView-2 (WV-2) imagery at 2 m spatial resolution. We first evaluated our approach using 1 m by 1 m validation points at the sub-crown scale per severity class (i.e. unburned, low, moderate, and high severity) from the post-fire 0.10 m color aerial ortho-photos; then, we validated the burn severity mapping of geo-referenced dominant tree crowns (crown scale) and 15 m by 15 m fixed-area plots (inter-crown scale) with the post-fire 0.10 m aerial ortho-photos and measured crown information of twenty forest inventory plots. Our approach can accurately assess forest burn severity at the sub-crown (overall accuracy is 84% with a Kappa value of 0.77), crown (overall accuracy is 82% with a Kappa value of 0.76), and inter-crown scales (89% of the variation in estimated burn severity ratings (i.e. Geo-Composite Burn Index (CBI)). This work highlights that forest burn severity mapping from VHR data can capture heterogeneous fire patterns at fine spatial scales over the large spatial extents. This is important since most ecological processes associated with fire effects vary at the <30 m scale and VHR approaches could significantly advance our ability to characterize fire effects on forest ecosystems.

1. Introduction

Fire is a primary disturbance agent, driving changes in vegetation carbon stocks and shaping ecosystems, as well as influencing the temporal variability in carbon, water and energy fluxes (Bowman et al., 2009; Flannigan et al., 2000; Smith et al., 2016; Sugihara et al., 2006; Werf et al., 2010). In Atlantic coastal Pine Barrens ecosystems, a unique but imperiled ecosystem in the northeastern United States, fire-related management practices including prescribed fire and ecologically sensitive wildfire management must play a key role in restoration and preservation of the hydrological and ecological integrity of these ecosystems (Kurczewski and Boyle, 2000; Jordan et al., 2003). Discrimination of the severity of fire is thus one of the central questions in ecology for examining fire effects on key ecological processes (e.g. tree mortality, post-fire recovery, and intra-species/inter-species competition), and is especially important for fire-related forest management (Frolking et al., 2009; Lentile et al., 2006; Quintano et al., 2013; Sugihara et al., 2006). In wildfire research, the word ‘severity’ is used to refer the magnitude of change (e.g. extent of vegetation removal, soil exposure, and soil color alteration), caused by fire (Lentile et al., 2006). The Composite Burn Index (CBI) and its modified version GeoCBI have been widely used as means for ground measurements of fire severity (De Santis and Chuvieco, 2009a; Key and Benson, 2006). As an operational tool, (Geo)CBI visually assesses the magnitude of change by fire in

* Corresponding author.
E-mail address: ranmeng@bnl.gov (R. Meng).

http://dx.doi.org/10.1016/j.rse.2017.01.016

five strata (soils, understory vegetation, mid-canopy, overstory, and dominant overstory vegetation) and integrates these for an overall plot level burn severity rating between zero (unburned) and three (highest severity) (De Santis and Chuvieco, 2009a; Key and Benson, 2006). Although often used interchangeably (Keeley, 2009), a distinction exists between the term burn severity and fire severity, as suggested by Lentile et al. (2006): fire severity refers to short-term (e.g. about within one year following the fire) effects on the local environment, and burn severity refers to both short-term and long-term (up to ten years) effects, including ecological responses (e.g. vegetation recovery). In this study we focus on burn severity given the temporal period of study and scales of interest. Following Lentile et al. (2006) we define three levels of burn severity and use these throughout: consistent with traditional field interpretation of severity in forest ecosystems (Lentile et al., 2006; Veraverbeke et al., 2012) burned sites with >50% green crowns were classified as low severity, those with >50% brown and defoliated (bald) crowns as moderate severity, and those with >50% black (charred) or burned crowns as high severity (Fig. 1)

Compared with time and labor intensive field sampling, remote sensing provides a convenient and consistent way for mapping burned areas or assessing burn severity across large areas (Brewer et al., 2005; Lentile et al., 2006; White et al., 1996). Over the past three decades, a variety of remote sensing-based approaches have been developed and widely applied to Landsat mission imagery to infer burn severity at 30 m spatial resolution (Frolking et al., 2009; Lentile et al., 2006; Jin and Sader, 2005; White et al., 1996). These remote sensing-based approaches for assessing burn severity include remotely sensed spectral indices (SIs, e.g. Lu et al., 2015; Miller et al., 2009; Norton et al., 2009), radiative transfer models (RTM, e.g. Chuvieco et al., 2006; De Santis et al., 2009b), and linear spectral unmixing analysis (LSMA, e.g. Quintano et al., 2013; Riaño et al., 2002). While these remote sensing-based approaches do have some important limitations (for more details see Lentile et al., 2009 for the limitations of an NBR or other similar spectral indices based methods), the differenced Normalized Burn Ratio (dNBR, Key and Benson, 2006; Miller and Thode, 2007) and other spectral indices (Epting et al., 2005; Miller and Thode, 2007; Van Wagtendonk et al., 2004) have been used to assess burn severity across the United States starting as early as 1984 with the Monitoring Trends in Burn Severity Project (MTBS, http://www.mtbs.gov/; Eidenshink et al., 2007). While some previous work suggests the use of an RTM approach, which provides a more physically-based method to estimate burn severity from imagery (Chuvieco et al., 2006; De Santis et al., 2009b), others suggest LSMA is sufficient to assess burn severity (Lentile et al., 2009; Quintano et al., 2013; Smith et al., 2007). LSMA and similar may also be more easily scalable than RTM approaches. LSMA assumes that the reflectance of each mixed pixel can be linearly decomposed by a set of spectrally distinct components (i.e. endmembers) and thus the abundance of endmembers present in that pixel can be estimated (Drake et al., 1999). Recently an expanded version of the standard LSMA, the Multiple Endmember SMA or MESMA (Roberts et al., 1998) has been explored to map burn severity (Fernandez-Manso et al., 2016; Quintano et al., 2013). Compared to the typical LSMA technique, MESMA accounts for endmember within-class spectral variability and overcomes the limitation of using the same number of endmembers to model all pixels (Fernandez-Manso et al., 2016; Quintano et al., 2013).

These remote sensing-based approaches have proven effective for fire monitoring at larger spatial extents (i.e. ≥30 m), but fire effects on forest ecosystems show strong landscape heterogeneity, particularly for wildfires that are not fully stand-replacing or produce a patchy post-fire landscape. As such, post-fire forest structural characteristics and the fire-induced ecological effects often vary at fine spatial scales (≤5 m), and burn severity maps at 30 m (i.e. MTBS) are still too coarse

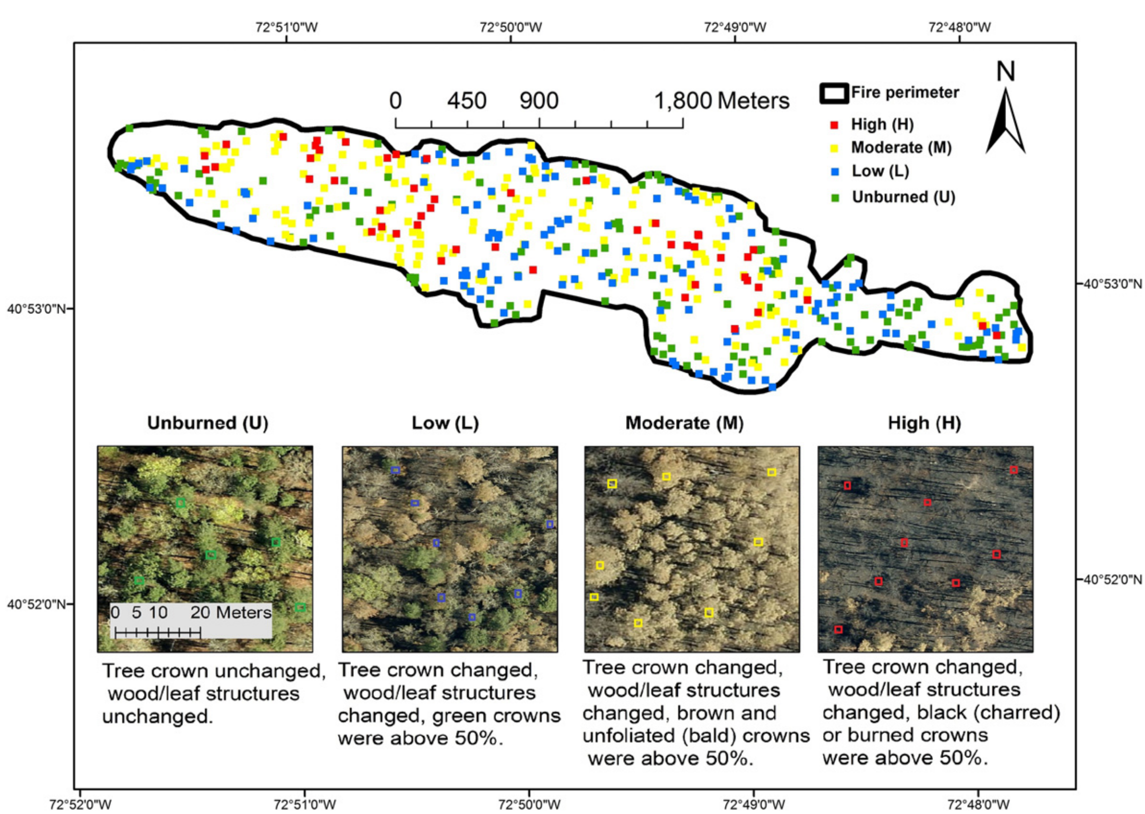

Fig. 1. Definitions of three burn severity levels and unburned classes used in this study. The background photo is the post-fire 0.10 m color aerial ortho-photos in 2012. Spatial distributions of validation points (U (136), L (131), M (190), and H (50) for accuracy assessment of forest burn severity mapping at the sub-crown scale are also shown on the fire perimeter map (see Section 3.5).