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Sensitivity of spectral reflectance values to different burn and vegetation ratios: A multi-scale approach applied in a fire affected area

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ABSTRACT

The aim of our study was to explore the spectral properties of fire-scorched (burned) and non fire-scorched (vegetation) areas, as well as areas with different burn/vegetation ratios, using a multisource multiresolution satellite data set. A case study was undertaken following a very destructive wildfire that occurred in Parnitha, Greece, July 2007, for which we acquired satellite images from LANDSAT, ASTER, and IKONOS. Additionally, we created spatially degraded satellite data over a range of coarser resolutions using resampling techniques. The panchromatic (1 m) and multispectral component (4 m) of IKONOS were merged using the Gram-Schmidt spectral sharpening method. This very high-resolution imagery served as the basis to estimate the cover percentage of burned areas, bare land and vegetation at pixel level, by applying the maximum likelihood classification algorithm. Finally, multiple linear regression models were fit to estimate each land-cover fraction as a function of surface reflectance values of the original and the spatially degraded satellite images.

The main findings of our research were: (a) the Near Infrared (NIR) and Short-wave Infrared (SWIR) are the most important channels to estimate the percentage of burned area, whereas the NIR and red channels are the most important to estimate the percentage of vegetation in fire-affected areas; (b) when the bi-spectral space consists only of NIR and SWIR, then the NIR ground reflectance value plays a more significant role in estimating the percent of burned areas, and the SWIR appears to be more important in estimating the percent of vegetation; and (c) semi-burned areas comprising 45–55% burned area and 45–55% vegetation are spectrally closer to burned areas in the NIR channel, whereas those areas are spectrally closer to vegetation in the SWIR channel. These findings, at least partially, are attributed to the fact that: (i) completely burned pixels present low variance in the NIR and high variance in the SWIR, whereas the opposite is observed in completely vegetated areas where higher variance is observed in the NIR and lower variance in the SWIR, and (ii) bare land modifies the spectral signal of burned areas more than the spectral signal of vegetated areas in the NIR, while the opposite is observed in SWIR region of the spectrum where the bare land modifies the spectral signal of vegetation more than the burned areas because the bare land and the vegetation are spectrally more similar in the NIR, and the bare land and burned areas are spectrally more similar in the SWIR.

1. Introduction

The assessment of the diverse consequences of fire activity on the environment, economy, society and atmosphere, requires a decision support system that is based on advanced and powerful monitoring tools. A critical issue affecting fire management is the lack of spatially explicit observations of fire occurrence that allow a detailed description of fire incidence. At short-term temporal scales (e.g., previous 30–40 years), tools to obtain spatially explicit information on burned areas have included field surveys, aerial photography, and satellite remote sensing (Morgan et al., 2001). The latter is an ideal alternative for collecting and processing the required information because it provides the necessary tools to gather information from Earth's surface in a relatively inexpensive and timely fashion (Koutsias and Karteris, 1998). Periodic spectral data in the visible and infrared part of the electromagnetic spectrum, acquired from various satellite sensors, offer an unlimited basic source of information. Using computer-assisted processing and interpretation, these data can contribute to a better, cost-effective, objective, and time-saving method to monitor and map areas affected by wildland fires (Koutsias et al., 1999).

Much progress has been made since satellite remote sensing of burned areas commenced almost three decades ago (Richards and Milne, 1983). Many characteristic examples of satellite remote sensing studies of burned land mapping and monitoring can be

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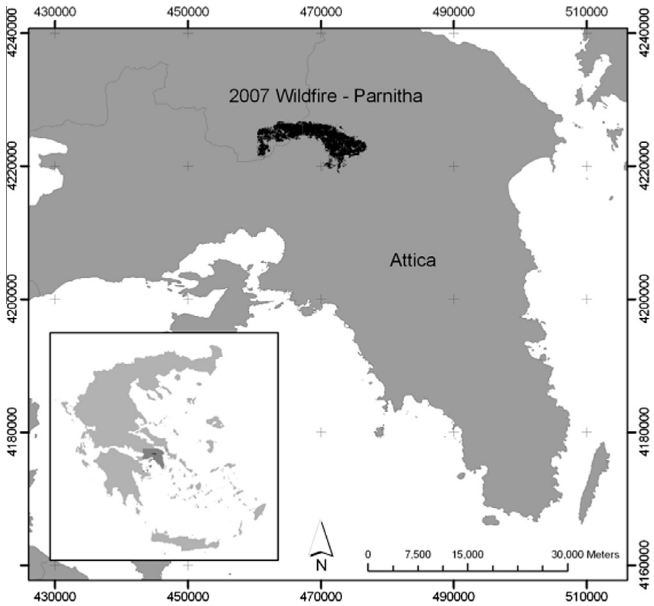

Fig. 1. Location of study area and fire scar perimeter of the 2007 wildfire in Parnitha, Attica, Greece.

found in the literature (Barbosa et al., 1999; Chuvieco and Martin, 1994; Garcia and Chuvieco, 2004; Hudak and Brockett, 2004; Justice et al., 2002; Kasischke and French, 1995; Koutsias, 2003; Koutsias et al., 2009; Laris, 2005; Pereira, 2003; Riáno et al., 2002; Roy et al., 2002; Salvador et al., 2000; Stroppiana et al., 2012, 2009, 2002; Veraverbeke et al., 2012a). Studies of burned area mapping at local, regional, and global scales have achieved very high classification accuracies (Lentile et al., 2006). However, there are still various limitations to be resolved. Therefore, burned land mapping remains an active topic of remote-sensing research (Stroppiana et al., 2012).

There is a general consensus among scientists that spectral confusion between burned areas and other land cover types may be summarized as follows (Caetano et al., 1994; Chuvieco and Congalton, 1988; Karteris, 1995; Koutsias et al., 1999; Pereira et al., 1997): (i) confusion between burned land and water bodies, especially in cases of topographically shadowed areas, recently burned surfaces, mixed land–water and water-vegetation pixels; (ii) confusion between burned land and urban areas, although this can be eliminated by masking out well-defined urban areas; (iii) confusion between burned land and shadows as a result of either irregular terrain, found especially in mountainous areas, or the presence of cloud shadows; and (iv) confusion between slightly burned land and unburned vegetation that is associated mainly with mixed pixels.

The spectral properties of fire affected areas (burned areas) are determined mainly by the removal of above-ground vegetation and the deposition of charcoal/ash as the direct result of the burning (Chuvieco and Congalton, 1988; Pereira et al., 1997; Rogan and Franklin, 2001). According to Epting et al. (2005), fire causes substantial spectral changes in the post-fire spectral signal by consuming vegetation, destroying leaf chlorophyll, exposing soil, charring stems, and altering above- and below-ground moisture. In burned areas soil reflectance is high and little vegetation remains, therefore the bare ground signature ''dilutes'' the vegetation signature as stated by Norton et al. (2009). All these factors are responsible for the strong modification of the spectral behavior of the ''burned category pixels'' compared to the pre-fire situation.

There is an agreement among scientists (Epting et al., 2005; Jensen, 2000; Koutsias and Karteris, 2000; Pereira et al., 1997; Van Wagtendonk et al., 2004; White et al., 1996) that in forest ecosystems, such as those found in the Mediterranean, a strong decrease in the reflectance of the ''burned category pixels'' is observed in the near- infrared region (NIR) of the spectrum of the post-fire satellite image. This reduction is due to the destruction of the leaf structure of the vegetation that reflects large amounts of the incident solar radiation in this spectral region. In addition, a strong increase in the reflectance of the ''burned category pixels'' is observed in the short-wave infrared region (SWIR) of the post-fire satellite image. The replacement of the vegetation layer with charcoal reduces water content, which absorbs the radiation in this spectral region. As a consequence, burned areas are expected to have higher reflectance than those of healthy vegetation.

This particular spectral behavior of burned areas in NIR and SWIR region of the electromagnetic spectrum was the basis for the successful use of the Normalized Burn Ratio (NBR) index (Key and Benson, 1999, 2006), a modification of Normalized Difference Vegetation Index (NDVI) by replacing red with SWIR, originally proposed by Lopez Garcia and Caselles (1991) who underlined the post-fire radiometric changes occurring in the SWIR, later verified by Koutsias and Karteris (2000). The replacement of the red channel with SWIR channels, that are sensitive to leaf water content because of absorption of the electromagnetic energy in this wavelength, has a long history in remote sensing (Ji et al., 2011). In fire mapping studies, NBR, which attempts to maximize reflectance change due to fire (Lozano et al., 2007), has been found to be very successful as, for example, in sagebrush steppe where the relative differenced NBR (RdNBR) provided the highest accuracy to delineate fire severity, although the Soil Adjusted Vegetation Index (SAVI) showed the highest overall accuracy in delineating burned versus unburned areas (Norton et al., 2009). Recently, Veraverbeke et al. (2012a) found that SAVI outperformed the NDVI in environments with a single vegetation type, while NDVI was more accurate in estimating vegetation cover in environments with heterogeneous vegetation layers and a single soil type. Therefore it becomes clear the importance of soil reflectance and the role of the so-called Soil Adjusted Vis that attempts to minimize the influence of the background variability (Veraverbeke et al., 2012a). Additional to NBR, Veraverbeke et al. (2012b, 2012c) proposed the SWIR-MIR and VSWIR (visible to short-wave infrared)-MTIR (mid to thermal infrared) band combinations since such data will soon be available at pixel sizes smaller than 100 m from future satellite sensors such as the Hyperspectral Infrared Imager (HyspIRI) (Veraverbeke et al., 2012b, 2012c).

The aim of our study was to explore and characterize the spectral properties of fire-scorched (burned) and non fire-scorched

Table 1
Satellite images used in the study and their characteristics.

	Date	Spatial resolution (m)	Spectral resolution
IKONOS PAN	08 July 2007	1	1, Panchromatic
IKONOS Multi	08 July 2007	4	4, Blue, Red, Green, NIR
LANDSAT TM	05 September 2007	30	6, Blue, Red, Green, NIR, SWIR (except TIR)
ASTER VNIR	20 July 2007	15	3, Green, Red, NIR
ASTER SWIR	20 July 2007	30	6, SWIR