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A time-integrated MODIS burn severity assessment using the multi-temporal differenced normalized burn ratio ($dNBR_{MT}$)

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ABSTRACT

Burn severity is an important parameter in post-fire management. It incorporates both the direct fire impact (vegetation depletion) and ecosystem responses (vegetation regeneration). From a remote sensing perspective, burn severity is traditionally estimated using Landsat's differenced normalized burn ratio (dNBR). In this case study of the large 2007 Peloponnese (Greece) wildfires, Landsat dNBR estimates correlated reasonably well with Geo composite burn index (GeoCBI) field data of severity ($R^2 = 0.56$). The usage of Landsat imagery is, however, restricted by cloud cover and image-to-image normalization constraints. Therefore a multi-temporal burn severity approach based on coarse spatial, high temporal resolution moderate resolution imaging spectroradiometer (MODIS) imagery is presented in this study. The multi-temporal dNBR ($dNBR_{MT}$) is defined as the 1-year integrated difference between burned pixels and their unique control pixels. These control pixels were selected based on time series similarity and spatial context and reflect how burned pixels would have behaved in the case no fire had occurred. Linear regression between downsampled Landsat dNBR and $dNBR_{MT}$ estimates resulted in a moderate-high coefficient of determination $R^2 = 0.54$. $dNBR_{MT}$ estimates are indicative for the change in vegetation productivity due to the fire. This change is considerably higher for forests than for more sparsely vegetated areas like shrub lands. Although Landsat dNBR is superior for spatial detail, MODIS-derived $dNBR_{MT}$ estimates present a valuable alternative for burn severity mapping at continental to global scale without image availability constraints. This is beneficial to compare trends in burn severity across regions and time. Moreover, thanks to MODIS's repeated temporal sampling, the $dNBR_{MT}$ accounts for both first- and second-order fire effects.

1. Introduction

Biomass burning is a major disturbance in almost all terrestrial ecosystems (Pausas, 2004; Riano et al., 2007). At landscape level, wildland fires partially or completely remove the vegetation layer and affect post-fire vegetation composition (Epting and Verbyla, 2005). The fire-induced vegetation depletion causes abrupt changes in carbon, energy and water fluxes at local scale (Amiro et al., 2006), thereby influencing species richness, habitats and community composition (Capitaino and Carcaillet, 2008). Accurate estimates of post-fire effects are therefore of paramount importance. To name these post-fire effects the terms fire severity and burn severity are often interchangeably used (Keeley, 2009) describing the amount of damage (Chafer, 2008), the physical, chemical and biological changes (Lee et al., 2008) or the degree of alteration (Eidenshink et al., 2007) that fire causes to an ecosystem. Some authors, however, suggest a clear distinction between both terms by considering the fire disturbance continuum (Jain et al., 2004), which addresses three different temporal fire effects phases: before, during and after the fire. In this context, fire severity quantifies the short-term fire effects in the immediate post-fire environment whereas burn severity quantifies both the short- and long-term impact as it includes response processes (e.g. resprouting, delayed mortality; Lentile et al., 2006; Key, 2006). Fig. 1 represents a summary of post-fire effects terminology.

In remote sensing studies burn severity is traditionally estimated using Landsat imagery (Key and Benson, 2005; French et al., 2008). A popular approach, partly because of its conceptual simplicity, can be found in rationing band reflectance data. In this respect the normalized burn ratio (NBR) has become accepted as the standard spectral index to assess burn severity (Lopez-Garcia and Caselles, 1991; Key and Benson, 2005; French et al., 2008; Veraverbeke et al., in press-a). The NBR relates to vegetation moisture content by combining the near infrared (NIR) and mid infrared

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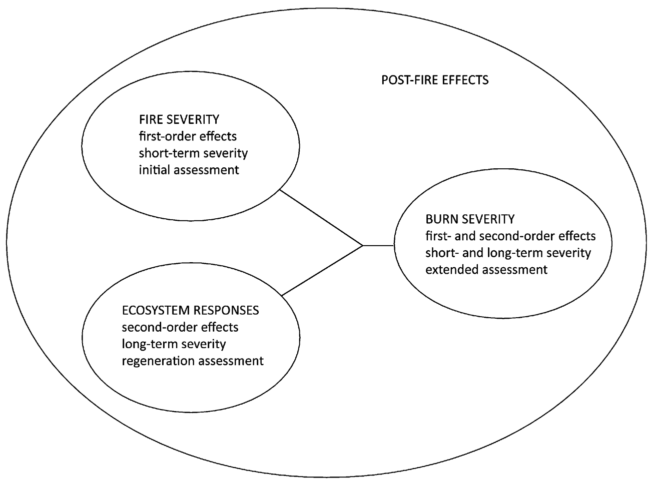

Fig. 1. Schematic representation of post-fire effects terminology (Veraverbeke et al., in press-a).

(MIR) spectral regions. Generally, pre- and post-fire NBR images are bi-temporally differenced, resulting in the differenced NBR (dNBR).

The dNBR method relies on Landsat imagery and thus depends on image availability, which is limited to infrequent images over small areas due to Landsat's 16-day revisiting cycle and cloud cover (Ju and Roy, 2008). Bi-temporal studies are even more hampered as they require an effective image-to-image normalization (Coppin et al., 2004) including the removal of phenological, atmospheric and bi-directional reflectance distribution function (BRDF) effects (Verbyla et al., 2008; Veraverbeke et al., 2010). As a result Landsat-based burn severity studies have proven to be valuable for obtaining detailed information over specific fires, however, the magnitude of the observed dNBR change heavily depends on assessment timing (Key, 2006; Veraverbeke et al., in press-b). This temporal dissimilarity limits the comparison between bi-temporal dNBR assessments of different fires (Eidenshink et al., 2007; Verbyla et al., 2008), especially when a comparison between different ecoregions is required (Eidenshink et al., 2007; French et al., 2008). The use of high temporal, coarse spatial resolution data possibly provides a sound alternative to Landsat dNBR estimates. In addition, their repeated temporal sampling allows quantifying both the direct fire impact and regeneration processes. To date few studies have implemented coarse resolution time series to assess burn severity. In this context it is worth mentioning the effort of Lhermitte et al. (in review), who illustrated the potential of time series data to account for inter- and intra-annual post-fire vegetation dynamics. In their method each burned pixel is compared with an unburned control pixel. These control pixels were selected based on pre-fire time series similarity and spatial context.

The aim of this study is to present a multi-temporal dNBR ($dNBR_{MT}$) burn severity assessment as an alternative for traditional Landsat dNBR mapping. The method incorporates both the direct fire impact and vegetation regeneration (Lentile et al., 2006). Moderate resolution imaging spectroradiometer (MODIS) time series are used over the large 2007 Peloponnese (Greece) wildfires. $dNBR_{MT}$ estimates are compared with Landsat and field data.

2. Data and study area

2.1. Study area

The study area is situated at the Peloponnese peninsula, in southern Greece (36°30′–38°30′N, 21°–23°E) (see Fig. 2). The topography is rugged with elevations ranging between 0 and 2404 m above sea level. The climate is typically Mediterranean with hot, dry summers and mild, wet winters. For the Kalamata meteorological station (37°4′N, 22°1′E) the average annual temperature is 17.8 °C and the mean annual precipitation equals 780 mm.

After a severe drought period several large wildfires of unknown cause have struck the area in the 2007 summer. The fires were the worst natural disaster of the last decades in Greece, both in terms of human losses and the extent of the burned area. The fires consumed more than 175 000 ha, which consisted of 57% shrub land, 21% coniferous forest, 20% olive groves and 2% broadleaved forest (Veraverbeke et al., in press-b).

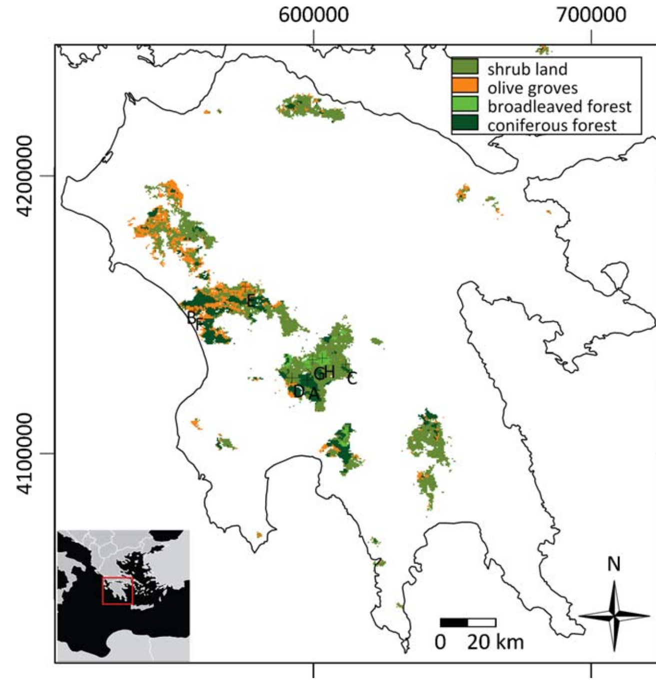

Fig. 2. Pre-fire land cover types of the burned areas (Veraverbeke et al., in press-a). The locations of the example pixels shown in Fig. 7 are also indicated (A–H).

2.2. Field data

150 Geo composite burn index (GeoCBI) plots were sampled 1 year post-fire, in September 2008. The GeoCBI is a modification of the composite burn index (CBI) (De Santis and Chuvieco, 2009). It is an operational tool used in conjunction with the Landsat dNBR approach to assess burn severity in the field (Key and Benson, 2005). The GeoCBI divides the ecosystem into five different strata, one for the substrates and four vegetation layers. These strata are: (i) substrates, (ii) herbs, low shrubs and trees less than 1 m, (iii) tall shrubs and trees of 1–5 m, (iv) intermediate trees of 5–20 m and (v) big trees higher than 20 m. In the field form, 20 different factors can be rated (e.g. soil and rock cover/color change, % LAI change, char height) but only those factors present and reliably rateable, are considered. The rates are given on a continuous scale between zero and three and the resulting factor ratings are averaged per stratum. Based on these stratum averages, the GeoCBI is calculated in proportion to their corresponding fraction of cover, resulting in a weighted average between zero and three that expresses burn severity. As the field data were collected 1 year post-fire, it is an extended assessment. Additional information on the field data can be found in Veraverbeke et al. (in press-b).