ADVANCES IN FOREST FIRE RESEARCH

2022

Edited by
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A rule-based semi-automatic method to map burned areas using Landsat and Sentinel-2 images – incorporating vegetation indices into the mapping algorithm

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Keywords:

Burned land mapping, rule-based, vegetation indices, Landsat, Sentinel-2

Abstract

At local or regional scales, where Landsat has been extensively applied to monitor burned areas, semi- or fully-automated methods are not very common. Koutsias et al. (2013) developed and improved (2021) a semi-automatic method to map burned areas consisted of a set of rules that are valid especially when the post-fire image has been captured shortly after the fire. However, the rule-based approach is not free of errors that eventually create limitations to adopt this method for reconstructing the fire history in a fully automated mode. In this work, we improved the method by incorporating vegetation indices. The vegetation indices evaluated were the: (i) Normalized Difference Vegetation Index (NDVI), (ii) Ratio Vegetation Index (RVI), (iii) Normalized Burn Ratio (NBR), (iv) Normalized Difference Water Index (NDWI) and (v) Shortwave Infrared Water Stress Index (SIWSI).

1. Introduction

There is a long history of mapping burned areas and other forest disturbances using satellite images of multiple resolutions either at research level to develop and improve the mapping methods or to create operational products at global scale (Chuvieco et al. 2019). Maps of fire occurrence can improve our understanding for the protection and restoration of fire-affected natural ecosystems worldwide. Satellite-based remote sensing has been an ideal tool to create maps of fire scars by collecting and processing the required data, as it covers large spatial and temporal extents within a cost- and time-efficient framework (Koutsias et al. 1999).

At global scale, there are unique fire-products, such as those based on MODIS (Justice et al. 2002), however they are mostly devoted to continental scale studies. However, at regional scales, such systematic fire products are not very common mainly due to cost constraints on gathering and processing medium or high-resolution satellite data series that until almost a decade ago were not freely available at no cost although recently such products have started to appear (Hawbaker et al. 2020).

Currently, United States Geological Survey (USGS) archived Landsat images are freely available to the public from the USGS Earth Resources Observation and Science (EROS) Center (http://glovis.usgs.gov/). These historical archives cover large spatial and temporal extents at continental scale and provide a unique opportunity to overcome cost constraints when reconstructing fire history globally at low-to-high spatial resolution. However, one problem that exists is how to process successfully with high accuracy the time series of satellite images consisting of thousands of images without the human interference. The training phase of an algorithm, when needed, is a time-consuming procedure that if omitted would be an advantage of the approach by saving processing time and cost. This is a critical issue in cases where many satellite images need to be analyzed, such as for the spatially explicit reconstruction of fire history, where thousands of images might be used in the processing chain.

2. Mapping burned areas at local scale

2.1. The rule-based approach

There have been efforts to develop automatic or semi-automatic techniques to map burned areas using medium-high resolution satellite images such as those of Landsat satellites (Bastarrika et al. 2014; Hawbaker et al. 2020; Koutsias et al. 2013), Sentinel-2 data (Roteta et al. 2019). Recently, USGS delivered to the users Landsat Level-3 Burned Area (BA) that contains two acquisition-based raster data products that represent burn classification and burn probability using Surface Reflectance data from the U.S. Landsat Analysis Ready Data (ARD) (Hawbaker et al. 2020).

Koutsias et al. (2013) developed a semi-automatic method to map burned areas using multi-temporal acquisitions of Landsat satellite data, considering a pre- and post-fire image as a pair of images that could minimize spectral confusion with unburned surfaces. The proposed method consisted of a set of rules that are valid especially when the pre- and post-fire image has been captured shortly before and after the fire event respectively when the signal has its highest separability from other land cover types.

2.2. Improvement of the method

The rule-based approach is not free of errors (e.g. omission or commission), that eventually create limitations to adopt this method for reconstructing the fire history in a fully automated mode. Therefore, the development of completely automatic techniques to successfully map the burned areas is a challenge. In this work we improved further the method by incorporating vegetation indices.

To revise the old set of rules and create the revised rules we followed the same methodology as in the original paper from Koutsias et al. (2013) where the rules had been developed on the basis of spectral properties of burned areas as compared to the pre-fire unburned vegetation and to the spectral signatures of other land cover types found in post-fire satellite scenes. Therefore, sampling plots that correspond to burned surfaces were located on the post-fire Landsat images to capture the whole variability found within the burned area class. Additionally, other important land cover types were delineated on the satellite images using the pan-European CORINE 2000 Land Cover database.

The digital VI values of the sampling plot pixels were extracted and simple statistics were generated to characterize the spectral properties of the various land cover categories including the burned area class. Histogram and signature data plots were created to graphically represent the spectral profiles for all land cover types including burned areas. It was also used to compare them with patterns of unburned vegetation when using multi-temporal satellite images and with other land cover types when using only single-date post-fire satellite images.

2.3. Vegetation indices

A Vegetation Index (VI) is usually a linear transformation of two or more spectral bands aiming to enhance the spectral signal of the original spectral channels by creating a new spectral space which is sensitive to variations of vegetation attributes as for example leaf area index (LAI), percent green cover, chlorophyll content, green biomass and ab-sorbed photosynthetically active radiation (APAR). In our study we chose few of them that are considered typical and have been extensively applied for vegetation studies or in remote sensing of wildland fires, it is beyond our purpose to make an extensive evaluation of vegetation indices concerning their phenology between low and high fire-prone areas. The vegetation indices chosen were the: (i) Normalized Difference Vegetation Index (NDVI), (ii) Ratio Vegetation Index (RVI), (iii) Normalized Burn Ratio (NBR), (iv) Normalized Difference Water Index (NDWI) and (v) Shortwave Infrared Water Stress Index (SIWSI).

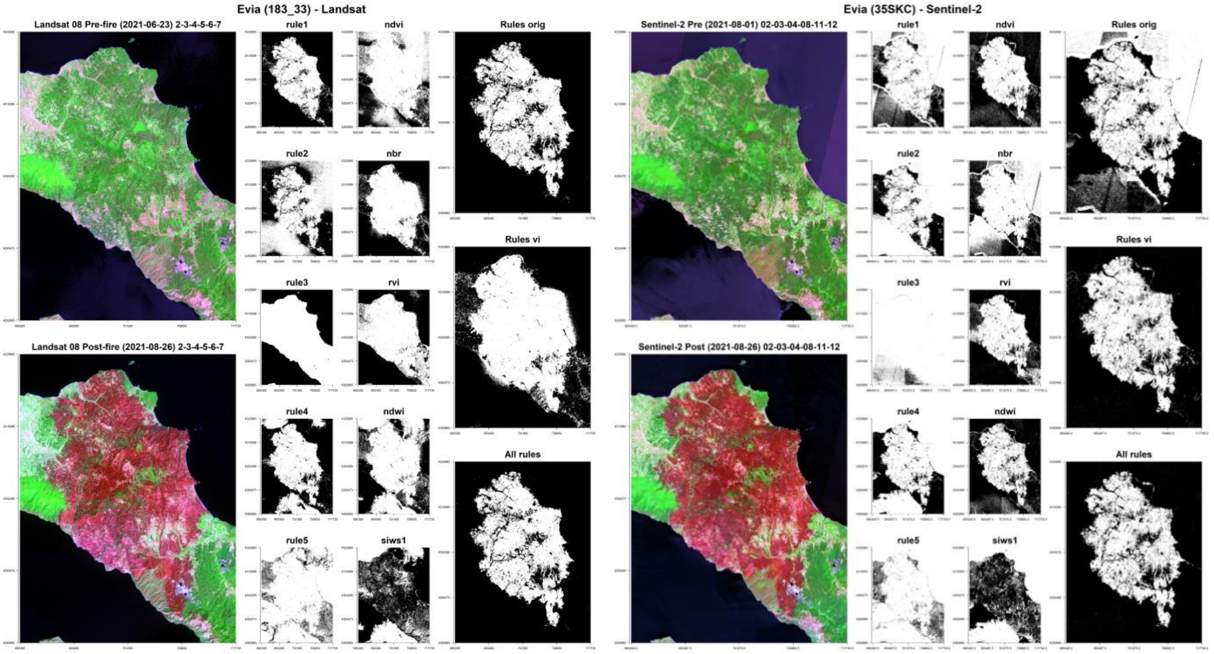

Figure 1- Mapping of burned areas with the rule-based approach as improved by the incorporation of the vegetation indices for Landsat and Sentinel-2 data.

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