Remote Sensing of Environment 113 (2009) 588–597

Contents lists available at ScienceDirect

Remote Sensing of Environment

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

Use of multitemporal SAR data for monitoring vegetation recovery of Mediterranean burned areas

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ARTICLE INFO

Article history:
Received 2 October 2007
Received in revised form 30 October 2008
Accepted 1 November 2008

Keywords:
SAR
Forest monitoring
Fires
Forest biomass

ABSTRACT

Remote sensing in the optical band is a well-established tool for monitoring changes in forested areas, although it can suffer from limitations, especially where frequent cloud cover occurs. The increased availability of space-borne radar imagery offers additional means for assessing the state of forests and monitoring their dynamics. In this study, the potential of multi-temporal space-borne SAR data for monitoring vegetation recovery over burned areas next to the Mediterranean coast is investigated. In particular, the study considers a set of ERS-SAR images, C-band and VV polarization, taken over the Castel Fusano pinewood, located near Rome, Italy, devastated in summer 2000 by a fire that burned about 350 ha of the wood. Starting from the analysis of the information contained in the variations, both in burnt and unburnt areas, of the inter annual multitemporal backscattering signatures, the study presents two different approaches, one more qualitative, the other one more quantitative, for the retrieval of the biomass re-growth after the fire. In the quantitative case, the inversion procedure computes the biomass re-growth rate by means of simulations carried out with the Tor Vergata scattering model. The obtained results are satisfactory as they are in agreement with simultaneous analysis based on optical data and in-situ measurement campaigns.

1. Introduction

The ability to detect fires and assess their impacts is an important component of being able to monitor, model and predict the potential effects of global climate change. In particular, the rate of biomass re-growth over burned areas can be a crucial factor in the assessment of damage resulting from a forest fire. In some cases the recovery process is very fast and after only a few years the burned areas will be completely repopulated. In other cases such a process can take even decades hence the environmental and economic impact of the fire is much greater. While there is a general understanding of how vegetation recovers after fire, the response over large areas can be complex because of variations in pre-fire vegetation cover, fire severity, and landscape-scale variations in topography and soil conditions.

Satellite data may provide the possibility to monitor vegetation recovery over large areas. Indeed, previous studies have shown how measurements from spaceborne payloads may be used either for the fire impact assessment or for the characterization of the forest recovery from the fire (Kasischke et al., 1994; Viedma et al., 1997; Bourgeau-Chavez et al., 1997; Pereira et al., 1997; Sun et al., 2002; Diaz-Delgado et al., 2003). In particular, optical satellite sensor data have been used successfully to map fire scars and post-fire recovery, however there are some limitations with this technology, the greatest being the inability to penetrate clouds. Moreover, spectral overlaps between fire scars and terrain shadows, water bodies, unburnt canopies, and vegetation in burnt areas create substantial difficulties in separating and discriminating fire classes (Zhang et al., 2000). This forces most fire-mapping methods to focus on the areas where vegetation distribution and topographic features are almost uniform.

When a systematic survey of an area is required, the use of Synthetic Aperture Radar (SAR) imagery (Oliver & Quegan, 1998) should also be considered. The C-band SAR data provided in the past decade by the European Space Agency's European Remote Sensing Satellites ERS-1 and ERS-2, and currently ENVISAT, are systematically available, even in the presence of clouds, at a relatively low cost. In fact, different studies have shown the potentialities of C-band space-borne radar in monitoring and assessing the extent and severity of wild fires (Bourgeau-Chavez et al., 1997; Bourgeau-Chavez et al., 2002; Menges et al., 2004; Gimeno et al., 2004; Antikidis et al., 1998; Tansey et al., 2004). Fire scars could be detected for 5 to 7 years after the fire event in Alaska with European Remote- Sensing Satellite (ERS). The backscatter of burnt forest was typically 3-6 dB brighter than adjacent unburned forest. The reasons for this increase were rough ground surfaces exposure and higher soil moisture (Bourgeau-Chavez et al., 1997). A more global assessment of SAR techniques for mapping fire scars occurring in boreal ecosystems is presented in Bourgeau-Chavez et al. (2002). The effects on savanna fires on SAR backscatter in northern Australia were investigated in Menges et al. (2004). It was concluded

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doi:10.1016/j.rse.2008.11.004

Fig. 1. Castel Fusano pinewood (in the red box) in an image acquired on 25/9/2000 by Landsat 5. The main Rome urban area is located a few kilometers away from the top-right corner. The geographic coordinates of the central point in the red box are: N41.72°, E12.33°. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

that only C-band SAR data were sufficiently affected by fire in this environment to detect and map fire scars while, despite the intensity of the fire, the resistance of vegetation types to fire damage resulted in insignificant changes to the L- and P-band SAR data. In Gimeno et al. (2004) a multitemporal analysis of SAR images acquired over an area affected by several fires during the years 2000 and 2001 in Central Portugal is presented. The results show how the temporal variations in the ERS–SAR backscatter coefficient permit the extraction of accurate and reliable information on the position and extent of burnt areas in Mediterranean forest environments. Additional information can also be provided by the measured level of coherence (Antikidis et al., 1998; Tansey et al., 2004). Indeed, over burned areas, volume backscattering significantly decreases and is replaced by surface backscattering which allows a much better correlation, resulting in higher coherence, between the two SAR images taken over the considered area. More recently Bourgeau-Chavez et al. (2007) attempted a step forward in retrieval techniques. Here the purpose is not limited to the scar detection but extended to the retrieval of spatially and temporally varying patterns of bio-physical parameters, in particular soil moisture, characterizing the burnt area. The technique developed is shown to be robust and was validated for multiple burn scars in two different areas of interior Alaska. In Kasischke et al. (2007) the effects of depth of burning and soil moisture on post-fire tree recruitment are also considered.

In our study we present a method where the inter annual variations of backscattering signatures are used to quantitatively retrieve temporal changes in the biomass values, characterizing the vegetation recovery process in a Mediterranean burnt area. We considered the very dramatic fire which occurred in the Castel Fusano pinewood, located a few kilometers away from the main urban area of Rome, Italy, on July 2000 (Monaco, 2001). About 350 ha was damaged during the fire, drastically modifying the local forest environment. A collection of 34 ERS–SAR images taken over the area of interest has been analysed. Such a data-set allowed us to examine the multi-temporal backscattering signature over a significant period of time starting approximately one year before the fire and ending three years after. To fully understand the signatures, other than the burnt ones, other types of areas located nearby, such as bare soil and unburnt pinewood, were examined. Due to temporal decorrelation effects the analysis has been limited to the backscattering amplitude. A twofold approach is proposed in the study with the purpose of estimating the biomass re-growth from multi-temporal SAR data. A first, more qualitative, technique basically exploits the different behaviour through time between burnt and unburnt areas. A more quantitative retrieval procedure, relying on simulations carried out with a microwave scattering model, is then presented.

2. The material

2.1. Study area

The Castel Fusano pinewood belongs to “Riserva Naturale Statale Litorale Romano”, a national natural reserve of the Roman coast, covering a region of about 15,900 ha located around the delta of the Tiber River, about 20 km away from the main Rome urban centre (Fig. 1). The reserve is characterized by different types of surroundings, typical of the coastal area of the Mediterranean: the arboreal vegetation is dominated by oaks and pines, with a large part of the park covered by the tall evergreen Mediterranean bush.

The Castel Fusano Park is located in the southern part of the Reserve, 5 km from the Tiber delta, and extends over an area of approximately 1100 ha; its main vegetation types are characterized by *Quercus ilex L.*, *Phillyrea latifolia L.*, *Pistacia lentiscus L.* and by *Pinus pinea L.* plantations, introduced near the coast as from 18th century. In fact, “the old pinewood” aging 130–150 years and “the young woodland” 50–70 years old, live side by side in the park. Until the 3rd of July, 2000, the pinewood was only slightly damaged by not particularly serious, although frequent, fires. Nevertheless, on the 3rd and 4th of July 2000, the pinewood was severely ruined by fire that burned about 350 ha of the wood: about 250 ha was completely destroyed, while other 100 ha was seriously