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Short communication

Combination of Landsat and Sentinel-2 MSI data for initial assessing of burn severity

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ABSTRACT

Nowadays Earth observation satellites, in particular Landsat, provide a valuable help to forest managers in post-fire operations; being the base of post-fire damage maps that enable to analyze fire impacts and to develop vegetation recovery plans. Sentinel-2A MultiSpectral Instrument (MSI) records data in similar spectral wavelengths that Landsat 8 Operational Land Imager (OLI), and has higher spatial and temporal resolutions. This work compares two types of satellite-based maps for evaluating fire damage in a large wildfire (around 8000 ha) located in Sierra de Gata (central-western Spain) on 6–11 August 2015. 1) burn severity maps based exclusively on Landsat data; specifically, on differenced Normalized Burn Ratio (dNBR) and on its relative versions (Relative dNBR, RdNBR, and Relativized Burn Ratio, RBR) and 2) burn severity maps based on the same indexes but combining pre-fire data from Landsat 8 OLI with post-fire data from Sentinel-2A MSI data. Combination of both Landsat and Sentinel-2 data might reduce the time elapsed since forest fire to the availability of an initial fire damage map. Interpretation of *ortho*-photograph Pléiades 1 B data (1:10,000) provided us the ground reference data to measure the accuracy of both burn severity maps. Results showed that Landsat based burn severity maps presented an adequate assessment of the damage grade (κ statistic = 0.80) and its spatial distribution in wildfire emergency response. Further using both Landsat and Sentinel-2 MSI data the accuracy of burn severity maps, though slightly lower (κ statistic = 0.70) showed an adequate level for be used by forest managers.

1. Introduction

Forest Mediterranean ecosystems are greatly affected by fires (San-Miguel-Ayanz et al., 2016). Accurate knowledge of fire-damaged areas is fundamental for fire management, planning and monitoring vegetation restoration (Brewer et al., 2005). Satellite-based data, particularly Landsat data, is becoming key information to map damaged area (both burned area and burn severity level) accurately and quasi-immediately after fire (Chen et al., 2015; Fang and Yang, 2014; Quintano et al., 2013). Sentinel-2 MultiSpectral Instrument (MSI) records data in similar spectral wavelengths that Landsat 8 Operational Land Imager (OLI), has a higher spatial resolution (10/20 m vs 30 m) and a higher temporal resolution (5 days revisited −considering both Sentinel-2A and Sentinel-2B- vs 16 days). Fernandez-Manso et al. (2016) and Navarro et al. (2017), among others, have evaluated burn severity based on Sentinel-2 MSI data successfully. Additionally, recent studies (Shoko and Mutanga, 2017; van der Werff and van der Meer, 2016) have showed the suitability and even superiority of Sentinel-2 MSI data in natural resources applications.

Threshold-based classification of Normalized Burn Ratio difference (dNBR) (Key and Benson, 2006) has turned into a methodological reference to obtain burn severity maps (Soverel et al., 2010). However, scene selection for the multitemporal approach is not always easy. Ideally, scene pairs should represent similar phenology and moisture and they should not exhibit between-scene land-cover changes. Additionally, they should be cloud-free, and they should not contain the fire scar near the scene edge (Key and Benson, 2006). The aim of this study is to validate the combined used of Sentinel-2 MSI and Landsat 8 OLI data to obtain a burn severity map based on dNBR, or on its relative versions. In this way the process of finding the scenes could be greatly reduced compared to using just Landsat data, and an initial fire damage map would be available almost immediately after fire. We

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will compare the accuracy of two types of burn severity maps: based exclusively on Landsat data (as usual) and based on both Landsat and Sentinel-2 MSI data. This is the first Landsat/Sentinel-2 MSI based study that assesses burn damage in Mediterranean ecosystems.

2. Materials

The study area was located in Sierra de Gata (central-western Spain) where a wildfire burned 79.50 km^2 from 6 to 11 August 2015 (Fig. 1). Climate is Mediterranean. Affected vegetation was mainly a combination of shrubland and forest dominated by *Pinus pinaster* Ait. and *Quercus pyrenaica* Wild.

Burn severity maps based exclusively on Landsat data were obtained from two USGS Landsat 8 OLI surface reflectance images (path/row 203/32, higher-level data product on demand), acquired on 6 August 2015 and on 7 September 2015 respectively. Additionally, a post-fire Sentinel-2A MSI image acquired on 21 August 2015 (tile number T29TPE, level-1C) was downloaded from www.earthexplorer.usgs.gov.

As in most research studies and official burn severity maps, three burn severity levels were considered: high, moderate and low. Interpretation of *ortho*-photograph Pléiades 1 B data (1:10,000) acquired on 15 August 2015 enabled us to obtain 305 photo-interpreted plots used to measure the accuracy of the burn severity maps: 90 unburned, 60 low burn severity, 75 moderate burn severity and 90 high burn severity. The acquisition times of Pléiades 1 B (11:39 UTC), Landsat 8 OLI (11:07 UTC) and Sentinel-2A MSI data (11:21 UTC) are quite similar, and the small differences did not impact on the accuracy measurement process of burn severity maps.

3. Methods

Both Landsat 8 OLI surface reflectance images were subset to the selected forest fire and pre- and post-fire NBR images were calculated (NBR_pre_L, NBR_post_L, respectively). Next, we computed dNBR, Relative dNBR (RdNBR) (Miler and Thode, 2007) and Relativized Burn Ratio (RBR) (Parks et al., 2014) and denoted them respectively by dNBR_L, RdNBR_L, and RBR_L

The level-1C Sentinel-2A MSI image (Top of Atmosphere, TOA, Reflectance) was converted to surface reflectance image (or Botton of Atmospehre, BOA, Reflectance) by using Sen2Cor tool provided by the European Space Agency (ESA). The surface reflectance image was subset to the selected fire and NBR was computed. We denoted it by NBR_post_S.

Regridding was applied to match the spatial resolution of Sentinel-2A MSI image to Landsat 8 OLI data. Storey et al. (2016) alerted of a temporary misalignment between Sentinel-2A MSI image to Landsat 8 OLI data, that

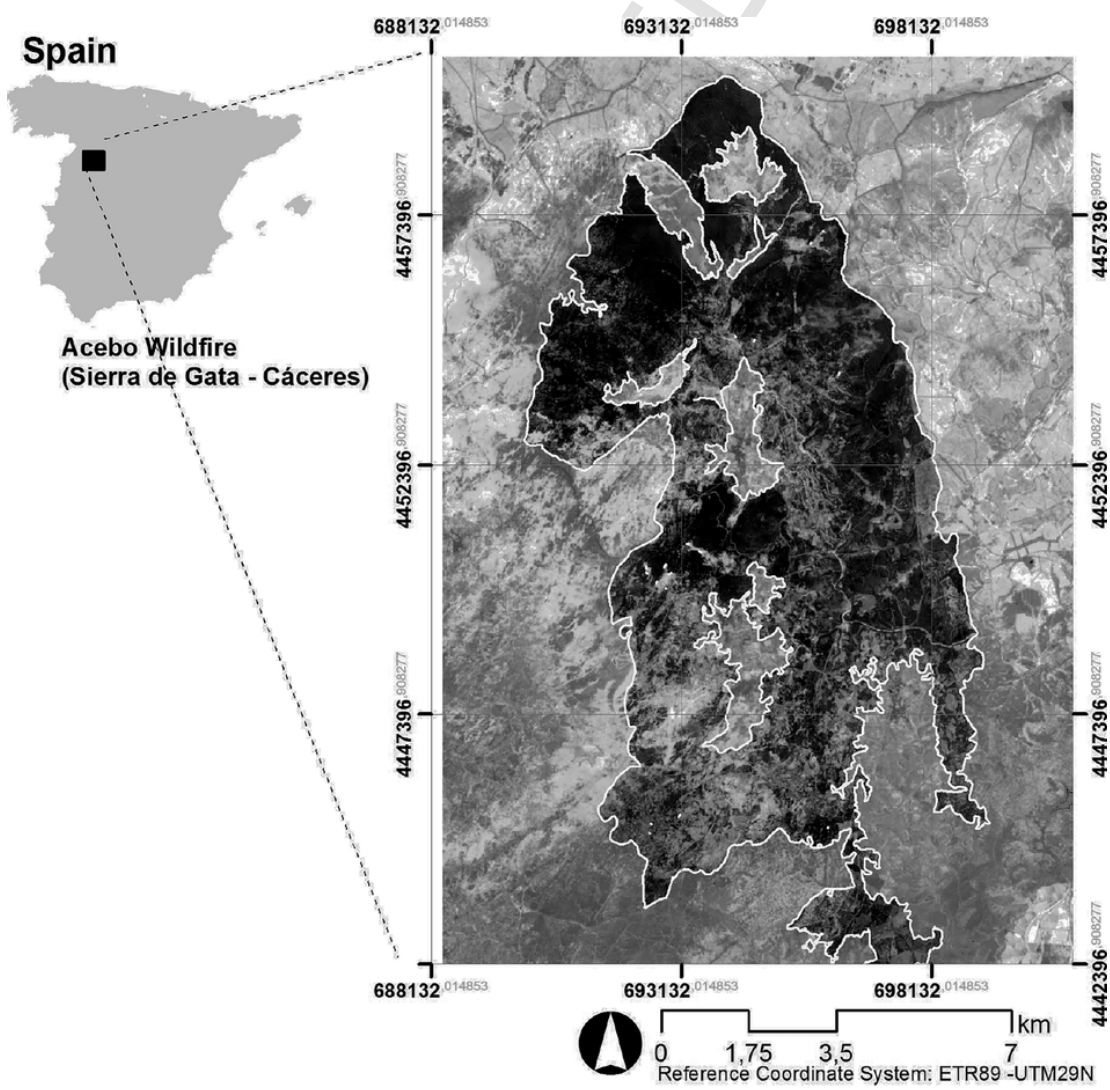

Fig. 1. Location of study area.

vary geographically. However, no misalignment was observed between these two types of remote sensed data in our study area. Finally, combining NBR_pre_L and NBR_post_S, dNBR, RdNBR, and RBR images were obtained as well. We denoted them respectively by dNBR_LS, RdNBR_LS, and RBR_LS.

Burn severity maps from dNBR, RdNBR and RBR images were obtained by applying the threshold levels recommended by Botella and Fernández-Manso (in press), who adapted the methodology proposed by Key and Benson (2006) to Spain. Error matrixes of burn severity estimates were calculated from the 305 photo-interpreted sampling plots. Overall accuracy (OA), producer's accuracy (PA), user's accuracy (UA) and κ statistic were computed as well (Congalton and Green, 2009). A Z-test enabled us to check whether κ statistic differences between the two burn severity maps had statistical significance.

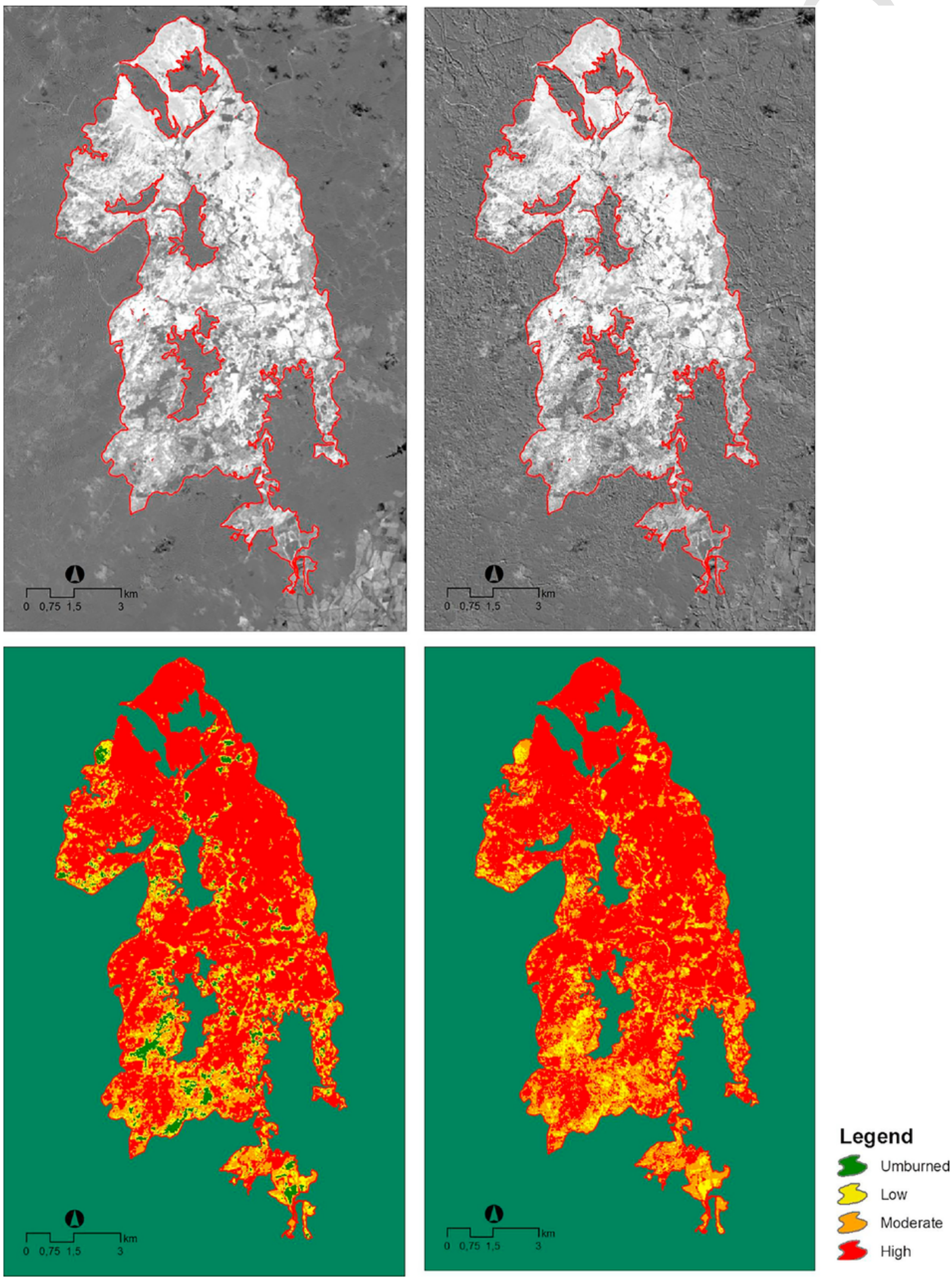

Fig. 2. Upper: difference normalized burned ratio, dNBR; left: from Landat data (dNBR_L8), right: from Landsat and Sentinel data (dNBR_L8_S2A); lower: burn severity estimates; left: from dNBR_L8; right: from dNBR_L8_S2A.

Table 1
Accuracy measurement of burn severity maps based on dNBR_L, dNBR_LS, RdNBR_L, RdNBR_LS, NBR_L, and NBR_LS.

		dNBR_L	dNBR_LS	RdNBR_L	RdNBR_LS	RBR_L	RBR_LS
PA	Total	0.77	0.68	0.81	0.74	0.81	0.73
	U	0.93	1.00	0.95	0.93	0.94	0.94
	L	0.66	0.50	1.00	0.43	0.82	0.40
	M	0.68	0.48	0.76	0.58	0.76	0.58
	H	0.82	0.82	0.77	1.00	0.77	1.00
UA	Total	0.77	0.70	0.85	0.74	0.82	0.73
	U	0.77	0.77	1.00	0.77	0.90	0.75
	L	0.77	0.40	0.77	0.30	0.77	0.30
	M	0.69	0.69	0.69	1.00	0.69	1.00
	H	0.87	0.87	0.87	0.87	0.87	0.87
OA		0.79	0.72	0.84	0.77	0.83	0.76
κ statistic		**0.71**	**0.62**	**0.80**	**0.69**	0.76	0.70
σκ		0.001	0.001	0.001	0.001	0.001	0.001
Z		**1.990**		**2.562**		1.455	

PA: producer's accuracy; UA: user's accuracy; OA: overall accuracy; σκ: variance of κ statistic; dNBR_L: Normalized Burn Ratio difference based exclusively on Landsat 8 OLI data; dNBR_LS: Normalized Burn Ratio difference based on both Landsat 8 OLI and Sentinel-2 MSI data; RdNBR_L: Relative Normalized Burn Ratio difference based exclusively on Landsat 8 OLI data; RdNBR_LS: Relative Normalized Burn Ratio difference based on both Landsat 8 OLI and Sentinel-2 MSI data; RBR_L: Relativized Burn Ratio based exclusively on Landsat 8 OLI data; RBR_LS: Relativized Burn Ratio based on both Landsat 8 OLI and Sentinel-2 MSI data; U: unburned; L: low bur severity; M: moderate burn severity; H: high burn severity.
Bold: burn severity maps based on Landsat data exclusively and based on Landsat and Sentinel-2 MSI data have significant differences.

4. Results

Fig. 2 (upper) displays dNBR_L8 and dNBR_L8_LS. Visually both images are quite similar. However, we can appreciate some differences between the burn severity maps obtained from them (Fig. 2, lower). The map based exclusively on Landsat data shows some unburned areas inside the fire perimeter that were labeled as low burn severity level on the burn severity map based on dNBR_L8_LS image.

Accuracy measurements are shown on Table 1. Accuracy of burn severity maps based on the combination of Landsat and Sentinel-2 data reached the values of 0.62, 0.69 and 0.70, respectively, when dNBR_LS, RdNBR_LS and RBR_LS were classified. Burn severity maps based exclusively on Landsat data had a κ statistic higher than burn severity maps based on both Landsat and Sentinel-2 data (0.71, 0.80 and 0.76). However, there were not significant differences between the bun severity maps based on RBR_L and RBR_LS ($Z < 1.96$). Burn severity maps based on the relative versions of dNBR had higher accuracy than maps based on dNBR. Particularly, the highest accuracy was reached when RdNBR_L image were classified ($\kappa = 0.80$), followed by RBR indexes (0.76, 0.70, there was not significant difference between these two κ values). PA values for low and moderate burn severity levels were higher when burn severity maps based exclusively on Landsat data were taken into account. Similarly, UA values for low burn severity level are lower for burn severity maps based on both Landsat 8 OLI and Sentinel-2A MSI data. These differences show a higher degree of misclassification at low than at high burn severity levels.

5. Discussion

The differences between the burn severity maps displayed in Fig. 2, particularly at low severity and unburned classes, point to some misclassification problems at low severity levels, that are showed in Table 1 as well. Misclassification problems at low severity pixels are common and have been reported by different studies (Cocke et al., 2005; Sunderman and Weisberg, 2011; Stambaugh et al., 2015). Among the main possible causes of the visual differences found between the burn severity maps on this study we might mention: 1) reflectance calibration differences between Landsat 8 OLI and Sentinel-2 MSI data, and 2) the threshold levels used to obtain the burn severity estimation based on both Landsat and Sentinel-2 data should be carefully tested, though they showed very promising results (Botella and Fernández-Manso 2017)(Botella and Fernández-Manso, in press). Additional research is necessary to perform such threshold revision. We leave it for future work.

From a forest manager's perspective the most common reason for estimating burn severity is, however, to identify areas that need to be recovered (Cocke et al., 2005). For that reason, discriminating accurately the high burn severity level from the rest of levels may supply the key information. Both burn severity maps are quite similar when taking into account the high burn severity level. However, the burn severity map based on the combination of Landsat and Sentinel-2 data may be operative as a preliminary emergency map, as it allows an accurate initial approximation of fire damage level. Emergency maps help forest managers to minimize the potentially harmful effects of excessive post-fire erosion (Miller and Yool, 2002).

6. Conclusion

We developed an operative method based on the combination of Landsat 8 OLI and Sentinel-2 MSI data to obtain emergency burn severity maps that allow accurate initial approximation of fire damage level. This work proved that in case of unavailability of a pre-fire or a post-fire Landsat image, one of them could be substituted for a Sentinel-2 MSI image to obtain an initial burn severity map. In our study, the burn severity map based exclusively on Landsat data showed higher accuracy than the burn severity map based on both Landsat and Sentinel-2 data, though maps based on both sensors reached a more than acceptable level of accuracy ($\kappa = 0.70$). Future research should adjust the used classification thresholds.

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