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Assessing the role of Mediterranean evergreen oaks canopy cover in land surface albedo and temperature using a remote sensing-based approach

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A B S T R A C T

Modifications in vegetation cover can have an impact on the climate through changes in biogeochemical and biogeophysical processes. In this paper, the tree canopy cover percentage of a savannah-like ecosystem (*montado/dehesa*) was estimated at Landsat pixel level for 2011, and the role of different canopy cover percentages on land surface albedo (LSA) and land surface temperature (LST) were analysed. A modelling procedure using a SGB machine-learning algorithm and Landsat 5-TM spectral bands and derived vegetation indices as explanatory variables, showed that the estimation of *montado* canopy cover was obtained with good agreement (R^2 = 78.4%). Overall, *montado* canopy cover estimations showed that low canopy cover class (MT_1) is the most representative with 50.63% of total *montado* area. MODIS LSA and LST products were used to investigate the magnitude of differences in mean annual LSA and LST values between contrasting *montado* canopy cover percentages. As a result, it was found a significant statistical relationship between *montado* canopy cover percentage and mean annual surface albedo ($R^2 = 0.866$, $p < 0.001$) and surface temperature ($R^2 = 0.942$, $p < 0.001$). The comparisons between the four contrasting *montado* canopy cover classes showed marked differences in LSA ($\chi^2 = 192.17$, $df = 3$, $p < 0.001$) and LST ($\chi^2 = 318.18$, $df = 3$, $p < 0.001$). The highest *montado* canopy cover percentage (MT_4) generally had lower albedo than lowest canopy cover class, presenting a difference of −11.2% in mean annual albedo values. It was also showed that MT_4 and MT_3 are the cooler canopy cover classes, and MT_2 and MT_1 the warmer, where MT_1 class had a difference of 3.42 °C compared with MT_4 class. Overall, this research highlighted the role that potential changes in *montado* canopy cover may play in local land surface albedo and temperature variations, as an increase in these two biogeophysical parameters may potentially bring about, in the long term, local/regional climatic changes moving towards greater aridity.

1. Introduction

The effects of historical land cover change around the globe, and particularly in the Mediterranean region, are considered to be one of the major drivers contributing to widespread global environmental and climate changes (Devaraju, Bala, & Modak, 2015; Reale & Dirmeyer, 2000; Turner, Lambin, & Reenberg, 2007). Land cover transformation, such as deforestation to promote agricultural lands and/or pastures for livestock production, have an impact on the climate through changes in biogeochemical (e.g., atmospheric CO_2 concentrations) and biogeophysical (e.g. land surface albedo, land surface temperature, roughness length, evapotranspiration) processes (Betts, Falloon, Goldewijk, & Ramankutty, 2007; Devaraju

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et al., 2015; Li et al., 2015). Regarding the effects of land cover change in these two processes, recent studies have posited that changes in biogeophysical processes play a more regional/local role than biogeochemical ones (Li et al., 2015; Pongratz, Reick, Raddatz, & Claussen, 2010).

The implications of land cover change on climate, by altering biogeophysical properties, have been researched in numerous studies (e.g. Davin and De Noblet-Ducoudré, 2010; Kvalevag, Myhre, Bonan, & Levis, 2010; Zhu & Zeng, 2015). These studies have found that surface albedo and evapotranspiration are the dominant biogeophysical forces of land cover change on climate. The key role played by vegetation cover in climate is mainly expressed through its influence on energy and water balances (Bonan, 2008; Pitman, 2003). It is as such that land surface albedo (LSA), land surface temperature (LST), and evapotranspiration (ET) are considered key biogeophysical factors in the entire surface energy and water balance (Dirmeyer & Shukla, 1994; Friedl, 2002; Lu, Chen, Wilske, Sun, & Chen, 2011; Mallick, Singh, Shashtric, Rahman, & Mukherjee, 2014). Therefore, changing vegetation type and cover can modify LSA, LST, and ET parameters, and hence alter the micrometeorological conditions (Bonan, 2008).

Previous studies have shown that forest cover decrease in the Mediterranean region over the past 2000 years has contributed to the dryness of the present climate (Arribas, Gallardo, Gaertner, & Castro, 2003; Gates & Ließ, 2001; Reale & Dirmeyer, 2000). Forests have lower albedo levels than shrubs, dry crops, grasslands and bare soils. As a result, the conversion of forests to these land cover types can lead to increases in surface albedo, and may potentially feed back into the local/regional climate (Bonan, 2008). An increase in surface albedo leads to a reduction in net radiation, energy fluxes (sensible and latent), convective clouds and precipitation, leading to a drier atmosphere (Pitman, 2003). On the other hand, the slight decrease in surface temperature due to albedo increase is outweighed by a surface warming associated with a decrease in surface roughness, latent heat flux, rooting systems and evapotranspiration rate (Doughty, 2012; Lejeune, Davin, Guillod, & Seneviratne, 2015; Pitman, 2003).

In arid and semi-arid areas such as the Mediterranean region, tree canopy cover plays a fundamental role in several ecosystem processes (e.g. water recycling, surface cooling). Taking that into consideration, it is important to quantify the impacts of the decrease in Mediterranean tree cover in a set of key biogeophysical parameters that have a powerful effect on the magnitude and directions of local/regional climate changes. Indeed, Lindner et al. (2010) suggest that the mean annual temperature for the Mediterranean region will increase on average 4–5 °C in summer. The same authors pointed out that a 50% decrease in rainfall during the summer season is expected to occur, which combined with an increase in temperature may lead to increased levels of dryness and arid conditions. A reduction in precipitation patterns due to climate change may reduce the vital ecophysiological conditions of trees, which may consequently contribute to forest decline. On the other hand, forest cover reduction due to land use changes can affect local hydrological processes by reducing evapotranspiration, thereby leading to drops in precipitation as well as to a decrease in forest cover (Gates & Ließ, 2001).

Tree cover mapping has been recognized by the scientific community as an important task in studies focused on land surface and atmosphere interactions (e.g. Xiao, 2014). It is a core variable to understanding the fluxes between land surface and the lower boundary of the atmosphere, such as exchanges of radiation, heat, carbon, and water (Bonan, 2008; Davin and De Noblet-Ducoudré, 2010). Therefore, the availability of accurate and up-to-date spatial information on the tree cover fraction and on its spatio-temporal patterns is essential to understanding the role of trees in regulating these land surface-atmosphere fluxes. Consistent and comprehensive tree cover information at high temporal and spatial resolutions is required to support more detailed studies on the effects of biogeophysical impacts of vegetation cover change. Established methods, such as plot-based studies and aerial photo-interpretation, can be used for tree cover mapping. However, these tasks are often time consuming, excessively expensive, and limited in providing spatially continuous information over large territories (Xie, Sha, & Yu, 2008). Using remote sensing technology, tree cover mapping can be gathered with a lower level of field data, making it more cost-effective (Ahmed, Franklin, Wulder, & White, 2015; Rogan & Chen, 2004). In addition to its cost-effectiveness, satellite remote sensing provides a potentially useful tool for simultaneously quantifying the spatio-temporal dynamics of tree cover changes and for assessing the resulting effects on biogeophysical properties (Xiao, 2014). Considerable efforts have been made to develop remote sensing-based approaches for different ecoregions and for distinct spatial scales based on high-medium spatial resolution satellite data, by extracting the fraction of tree canopy cover at pixel level (e.g. Carreiras, Pereira, & Pereira, 2006; Hansen et al., 2013; Leinenkugel, Wolters, Oppelt, & Kuenzer, 2015; Yang, Weisberg, & Bristow, 2012). Moreover, remote sensing has also been widely used for estimating surface albedo and temperature with various satellite platforms in recent decades (Li et al., 2013; Qu et al., 2015).

In this study, a savannah-type evergreen oak woodland known as *montado* (in Portugal) or *dehesa* (in Spain), was used as a case study because it represents one of the most characteristic and important ecosystems existing in the Mediterranean basin. *Montado*/*dehesa* woodlands constitute an agroforestry system dominated by holm oak (*Q.* [*ilex*] *rotundifolia*) and/or cork oak (*Quercus suber*) presenting high spatial variability in tree densities, usually with an understory mosaic of annual crops, grasslands, and shrublands (Joffre, Rambal, & Ratte, 1999). It is estimated that this ecosystem covers an area of about 3.5×10^4 to 4.0×10^4 km^2 in the southwest of the Iberian Peninsula (Olea & San Miguel-Ayanz, 2006). Despite its socio-economic and environmental importance, *montado* ecosystems have been undergoing a severe decline (Godinho, Gil, Guiomar, Neves, & Pinto-Correia, 2016), which has been manifested by a progressive decrease in tree cover (Plieninger & Schaar, 2008). This declining trend in the *montado* ecosystem is mainly related to environmental constraints (e.g. drought) (Pelegrín, Peguero, Camarero, Fernández-Cancio, & Navarro, 2008), diseases (Camilo-Alves, Clara, & Ribeiro, 2013), and to inappropriate and ineffective management practices (Godinho et al., 2016).

The main goal of this study was to develop an effective remote sensing-based methodological approach to demonstrate the direct role of *montado* canopy cover in regulating local land surface biogeophysical properties. The high-resolution global map of tree cover produced by Hansen et al. (2013) has been recently widely used in numerous scientific researches, including those focused on understanding biogeophysical Earth systems dynamics (e.g. Alkama & Cescatti, 2016). However, Hansen et al.'s tree cover data underestimated tree cover in *montado* ecosystems. Thus, to overcome the limitations and uncertainties of these data, the first objective of this study was to develop an approach to accurately estimate the percentage of *montado* canopy cover at Landsat pixel level. In an attempt to elucidate the biogeophysical impacts of potential *montado* canopy cover decrease, the second objective of this study was to investigate the magnitude of differences in LSA and LST between contrasting *montado* canopy cover percentages. In order to address this issue, the space-for-time analogy was adopted, where spatial differences in surface albedo and temperature between areas with contrasting *montado* canopy cover can be interpreted as the climate signal of hypothetical *montado* tree changes (Alkama & Cescatti, 2016; Zhao & Jackson, 2014).