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Analysis of MODIS albedo changes over steady woody covers in France during the period of 2001–2013

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ABSTRACT

Using MODIS satellite data, this study examines the presence and causes of albedo trends in vegetation in France during the last decade. Special attention is paid to steady woody areas. During the last decade, 0.31% of the land surface of France has been identified as being affected by a sudden albedo shift due to land cover changes (LCC). Excluding these sudden changes in land cover, we show a significant (decreasing) albedo trends over 3.5% of France (p-value < 0.01). In most cases (84%), trends were identified in non-vegetated and non-steady vegetated covers; however, gradual albedo trends were observed in steady woody covers in over 0.1% of the surface area of France. The majority (59.9%) of these woody covers were broadleaved tree covers; the remainder was divided between needle-leaved and mixed tree covers and shrub cover. On average, in the steady woody covers affected by gradual albedo trends, the visible albedo shift was −0.0088 between 2001 and 2013, i.e., a loss of 20.1–29.8% depending on the woody cover type. This decrease in albedo was supported by a significant gradual increase (p-value < 0.05) in the normalized difference vegetation index (NDVI). This increase in greenness appears to be linked to the under-use of woody areas in France, leading to denser forests. The impact of these gradual albedo trends on the radiative forcing (RF) was estimated and compared to the impact of LCCs. During the 21st century in France, the impact on the radiative forcing of steady woody covers could reach $+0.2$ W.m^{-2}. This value is 2.5 times larger than IPCC estimates based on past vegetation changes.

1. Introduction

Forested areas have been receiving a lot of attention from the scientific community because they represent a dominant land cover (Latham et al., 2014) and provide economic, social, and environmental benefits to the human population. The consensus is that forests are becoming seriously endangered due to their close link with climate through various mechanisms (Betts, 2006). Because plants act like mediators, changes in the vegetation cover affect the flux exchanges between the land surface and the atmosphere and, therefore, impact the climate (Davin and de Noblet-Ducoudré, 2010). These flux exchanges are modified primarily due to changes in the biogeochemical and biogeophysical properties of the surface layer. Deforestation, for example, leads to the release of CO_2 into the atmosphere, therefore increasing greenhouse gas emissions (Schimel et al., 1996). In addition, changing the nature of the land cover can affect the climate by modifying biophysical variables, such as surface albedo, surface roughness, and evapotranspiration (Field et al., 2007; Bonan, 2008; Chapin et al., 2008; Anderson et al., 2011).

Surface albedo is an Essential Climate Variable (ECV), which is defined as the ratio of the radiation reflected from a surface to the total incoming radiation on the Earth's surface. Surface albedo and associated biophysical processes have a more significant impact on climate than biogeochemical processes because of their linear effect on the surface energy balance (Bala et al., 2006; Lee et al., 2011; Rotenberg and Yakir, 2010). Therefore, the loss of forest coverage increases the surface albedo, resulting in a climate cooling effect (Bonan, 1997; Davin and de Noblet-Ducoudré, 2010). The same feature leads to a decrease in evapotranspiration and surface roughness, leading to climate warming (Hahmann and Dickinson, 1997; Li et al., 2008). In fact, the cooling or warming of the atmosphere, and the resulting climate effect, is particularly sensitive to interactions between various biophysical processes, which have seasonal and geographic dependences.

Several recent investigations have highlighted the dependence of deforestation/afforestation climate impacts on latitude (Claussen et al., 2001; Pielke et al., 2002; Bala et al., 2007; Betts et al., 2007; Bonan, 2008; Wramneby et al., 2010). The impact of competitive effects between forest albedo and evapotranspiration on climate is relatively well understood at both high and low latitudes, but it remains that, at mid-latitudes, the interaction between temperate forests and climate response is more complex and uncertain (Sanderson et al., 2012). However, it should be highlighted that deforestation initiatives in temperate

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areas may have contributed to cooling in the past in the Northern Hemisphere (Brovkin et al., 1999; Bonan, 1997; Betts, 2001; Govindasamy et al., 2001; Bounoua et al., 2002; Feddema et al., 2005; Brovkin et al., 2006; Betts, 2008).

This study focuses on mainland France where the mean temperature in the coldest month can drop to −2 °C in some areas and the mean temperature in the warmest month can reach 25 °C in the Mediterranean areas. Due to its location and topography, France has a disparate climate, including oceanic, continental, Mediterranean, and mountain climates throughout its mainland (Joly et al., 2010). This makes France an ideal control area for temperate climates.

Forest albedos can be particularly low in the visible range for healthy fully-developed canopies absorbing most of the incoming solar radiation. This makes the forest environment warm (Sanderson et al., 2012), which acts to change the surrounding air temperature through radiative forcing. Changes in vegetation greenness have been shown to influence surface albedo (Tian et al., 2014). Therefore, vegetation albedo can be used as a proxy variable to track modifications in forest covers. Surface albedo can be accessed in two ways: modeling and remote sensing. However, any modeling approach has its own limitations and uncertainties when estimating the surface albedo (Liang, 2007). Satellite remote sensing techniques are able to provide the temporal continuity needed for information concerning surface properties. This continuity can help us reconstruct the historical background of land cover evolution at the landscape scale (Zhai et al., 2014). For this reason, satellite data are widely used to study surface characteristics, geographic regularity, and climate change at regional and global scales (Asner and Alencar, 2010; Zhao and Running, 2010). The Moderate Resolution Imaging Spectroradiometer (MODIS) satellite albedo product has a long history and has been widely used to study vegetation cover (e.g., Knyazikhin et al., 1998; Friedl et al., 2002; Zhang et al., 2003; Myhre et al., 2005; Loranty et al., 2011; Carrer et al., 2014; Mira et al., 2015). Therefore, in this study, we used the MODIS Bidirectional Reflectance Distribution Function (BRDF)/Albedo CMG gap-filled snow-free product (MCD43GF) to study the vegetation cover in France. This product is available from 2001 to 2013, which determined the temporal period for this study.

Studies on forests have focused on Land Use Cover Change (LUCC) programs, such as deforestation and afforestation, and on evaluating the disturbance or/and benefit of these shifts on climate. Afforestation has been proposed as a strategy to mitigate climate change. The climate benefits of such policies are often evaluated in terms of carbon sequestration potential without considering biophysical processes (Nabuurs et al., 2007). However, the impacts of biophysical factors, especially the surface albedo, are crucial to analyze the feedbacks of land cover change (LCC), such as deforestation, on climate at middle and high latitudes. Even changes less radical than deforestation may seriously affect the life cycle of forest ecosystems, and these changes need to be better defined.

The aim of this study is to investigate the possible occurrence and associated causes of gradual surface albedo trends in temperate forests in France during the last decade (2001−2013). In addition, this study seeks to evaluate the impact of surface albedo trends on the radiative forcing compared to sudden LUCC events. In Section 2, the data and the method used to detect the gradual albedo trends, as well as to evaluate their impacts, are described. Section 3 presents the results of the observed trends, and Section 4 summarizes the study and its conclusions.

2. Material and methods

2.1. The study area and study period

The study area covers all of mainland France and extends from 41°N to 51°N and from 5°W to 9°E in the Latitude-Longitude projection system. In France, >50% of the territory is dedicated to agriculture. After agriculture, forest is the main land cover occupying 28% of the entire surface (IGN, 2012; ONF, 2015). The forest cover in France represents

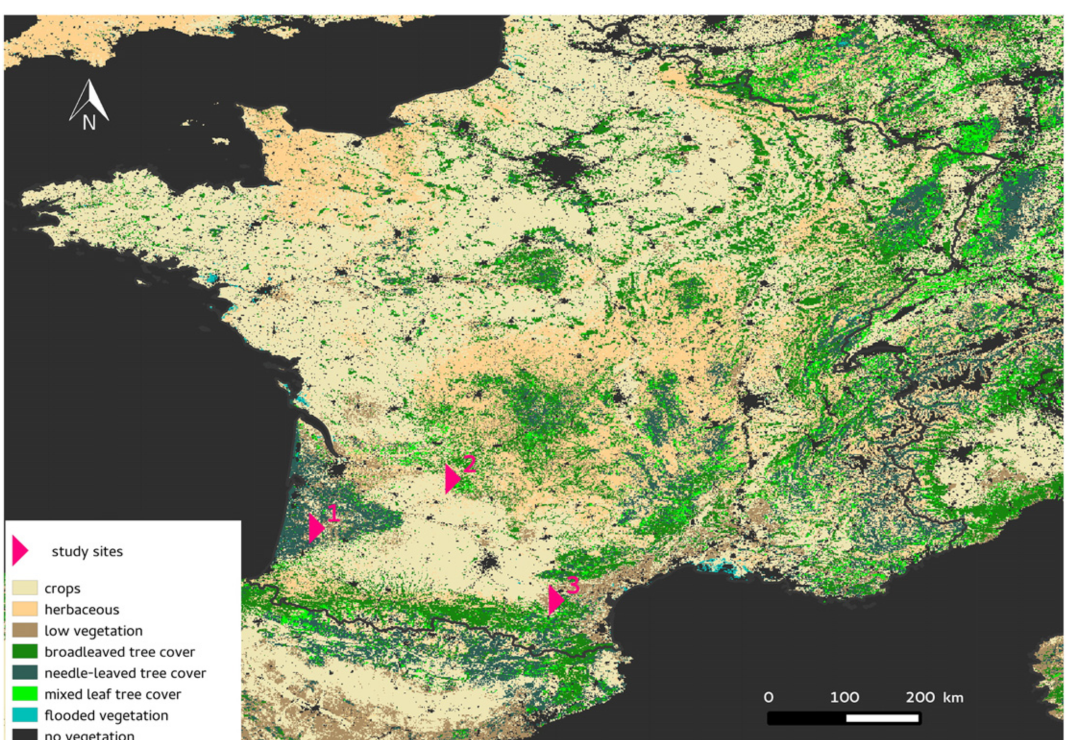

Fig. 1. The eight classes of land cover from the 2010 ESA-CCI land cover product.