Global and Planetary Change 146 (2016) 1–9

Contents lists available at ScienceDirect

Global and Planetary Change

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

Effect of land cover change on snow free surface albedo across the continental United States

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ARTICLE INFO

Article history:
Received 11 July 2016
Received in revised form 13 September 2016
Accepted 14 September 2016
Available online 15 September 2016

Keywords:
Autoregression
Climate change
Cropland
Forest
MODIS
NLCD

ABSTRACT

Land cover changes (e.g., forest to grassland) affect albedo, and changes in albedo can influence radiative forcing (warming, cooling). We empirically tested albedo response to land cover change for 130 locations across the continental United States using high resolution (30 m-×-30 m) land cover change data and moderate resolution (~500 m-×-500 m) albedo data. The land cover change data spanned 10 years (2001 − 2011) and the albedo data included observations every eight days for 13 years (2001 − 2013). Empirical testing was based on autoregressive time series analysis of snow free albedo for verified locations of land cover change. Approximately one-third of the autoregressive analyses for woody to herbaceous or forest to shrub change classes were not significant, indicating that albedo did not change significantly as a result of land cover change at these locations. In addition, ~80% of mean differences in albedo arising from land cover change were less than ±0.02, a nominal benchmark for precision of albedo measurements that is related to significant changes in radiative forcing. Under snow free conditions, we found that land cover change does not guarantee a significant albedo response, and that the differences in mean albedo response for the majority of land cover change locations were small.

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1. Introduction

Several scenario-based implementations of climate models have indicated that extra-tropical deforestation produces cooler surface air temperatures (Wickham et al., 2013), suggesting that removal of forest in temperate and boreal climates may be a climate warming mitigation strategy (Bala et al., 2007; Betts et al., 2007). The cooler surface temperatures realized from the scenario-based implementations of climate models are attributed to increases in albedo resulting from forest removal. Forests tend to be darker (lower albedo) than the herbaceous vegetation (grasslands, croplands) that replaces them in the scenarios, and the higher albedo of the herbaceous vegetation results in a negative radiative forcing (i.e., cooling). Unlike tropical regions, where the cooling effects of forest transpiration and carbon uptake tend to dominate over the positive radiative forcing (i.e., warming) effect of a lower albedo, in temperate and boreal regions the positive radiative forcing effect of a lower forest albedo tends to dominate over the cooling effects of transpiration and carbon uptake because photosynthesis is only seasonally active (Bonan, 2008).

Implicit in the scenario-based implementation of climate models is the assumption that albedo will change as land cover changes. Differences between characteristic albedos in climate models for herbaceous vegetation and broadleaf deciduous or needleleaf evergreen trees are commonly 0.05 or greater (see, for example, Hollinger et al. (2010)). Advances in availability of remotely sensed albedo and land cover products provide the opportunity to empirically quantify the response of albedo to land cover change.

Surface albedos are modeled using radiative transfer functions in climate models (Dorman and Sellers, 1989; e.g., Oleson et al., 2010). More recently, studies have focused on measurement of albedo from satellite-based platforms, such as the Moderate Resolution Imaging Spectroradiometer (MODIS) (Gao et al., 2005). MODIS albedo data are potentially useful for understanding relationships between albedo and land cover because of their moderate spatial resolution and high temporal resolution (Schaaf et al., 2002). Albedo data derived from MODIS have been: 1) compared to field measurements (Stroeve et al., 2005; Jin et al., 2003; Román et al., 2009; Cescatti et al., 2012; Wang et al., 2014); 2) compared to albedo derived from climate models (Oleson et al., 2003; Tian et al., 2004; Wang et al., 2004; Lawrence and Chase, 2007; Matsui et al., 2007); 3) used to develop global albedo databases (Gao et al., 2005, 2014; Carrer et al., 2014; Ghimire et al., 2014), and; 4) used to quantify surface radiative forcing of land cover related albedo change (Barnes and Roy, 2008, 2010; Ghimire et al., 2014).

The objective of this research is to explicitly estimate the effect of land cover change on albedo by identifying and verifying areas of homogeneous land cover change and then testing for a significant linear trend (slope) using autoregressive (time series) techniques. Our research

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http://dx.doi.org/10.1016/j.gloplacha.2016.09.005
0921-8181/Published by Elsevier B.V.

objective is different in several ways from Barnes and Roy (2008, 2010) and Ghimire et al. (2014), who examined the effect of land cover related albedo change on radiative forcing. In this research we use higher resolution land cover data, verify the apparent land cover change in the temporal maps using independent reference data, and test for significance of albedo response to land cover change.

2. Methods

2.1. Study area and data

We used the Multi-Resolution Land Characteristics (MRLC) Consortium National Land Cover Database (NLCD) (Homer et al., 2015) and the MODIS Collection 5 BRDF/Albedo product (MCD43A3) to evaluate the effect of land cover change on albedo. Whereas the MCD43A3 is a global product, the NLCD only covers the continental United States, and therefore our study area was a set of verifiable locations of land cover change within the continental United States.

NLCD is a Landsat-based land cover product for the nominal dates of 2001, 2006, and 2011 (Homer et al., 2015). There are 16 land cover classes mapped in NLCD at a spatial resolution of 30 m-×-30 m. The NLCD classification matches closely the International Geosphere - Biosphere Program (IGBP) land cover classification systems (http://www.mrlc.gov/nlcd11_leg.php versus http://glcf.umd.edu/data/lc). Production of NLCD relies on up to 3 dates (spring, summer, fall) of Landsat scenes for each date and several ancillary datasets. Land cover change is based on spectral modeling of the temporal Landsat data and reclassification of areas identified as change (Jin et al., 2013). The NLCD data were downloaded from http://www.mrlc.gov.

The MODIS MCD43A3 product provides albedo data every eight days (46 dates/year) from mid-February 2000 to present. MCD43A3 includes black- and white-sky albedo for the seven MODIS bands and visible (0.3–0.7 μm), near-infrared (0.7–5.0 μm), and shortwave (0.3–5.0 μm) portions of the electromagnetic spectrum. Development of the MODIS albedo product is described in Lucht et al. (2000) and the database, upon its original release, is described in Schaaf et al. (2002). The nominal resolution of the MCD43A3 product is 500 m-×-500 m, but the actual spatial resolution is ~463.3 m-×-463.3 m (USGS, 2010). We downloaded the MCD43A3 data from http://e4ftl01.cr.usgs.gov/MOTA.

Soil data were also needed to determine if the magnitude of albedo change arising from land cover change was attributable to soil color. The soil data we used were provided by the U.S. Environmental Protection Agency's (US EPA) EnviroAtlas project (http://enviroatlas.epa.gov). These data are a 30 m-×-30 m raster version of the United States Department of Agriculture (USDA), National Resource Conservation Service (NRCS), Soil Survey Geographic database (SSURGO). The vector-to-raster conversion of the SSURGO data and maintenance of the numerous SSURGO soil attributes was developed by the U.S. Geological Survey (USGS) Earth Resource and Observation Science (EROS) center. SSURGO is the most detailed soil dataset available, developed from field sampling and mapping at approximately 1:15,000 to 1:30,000 scales (Reybold and TeSelle, 1989). However, SSURGO data were not available for all locations across the continental United States, and therefore the raster version of the SSURGO soils data we used includes STATSGO soil data where SSURGO data are missing. STATSGO data were developed by generalizing more detailed soil maps to a nominal 1:250,000 scale (Reybold and TeSelle, 1989).

2.2. Processing

The contrasting spatial resolutions of NLCD (30 m-x-30 m) and MCD43A3 (~463.3 m-×-463.3 m) were reconciled to create areas of homogeneous land cover and land cover change at the spatial resolution of MCD43A3 (Wickham et al., 2015). The spatial resolution was set at 480 m-×-480 m because it is very close to the actual pixel size of the MCD43A3 data and it is an integral of the NLCD pixel size. A grid of 480 m-×-480 m cells was created in the NLCD projection (Albers Equal Area) and spatially aligned to the NLCD data so that they had spatially coincident reference (i.e., lower left corner) coordinates. Once aligned, GIS neighborhood functions were used to identify cells in the 480 m-×-480 m grid where the number of NLCD land cover classes was equal to one (i.e., homogeneous). These cells were then used as a mask to extract areas of homogeneous land cover at the spatial resolution of the MCD43A3 data. The extraction was done individually for each NLCD date (2001, 2006, 2011), and the spatial resolution was then devolved to 480 m-×-480 m. The 480 m-×-480 m versions of NLCD at each date were conflated into a single map to identify areas of homogeneous change at the spatial resolution of the MCD43A3 data.

The MCD43A3 data were re-projected into the NLCD geometric space (Albers Equal Area) using nearest neighbor rules to preserve the original pixel values and NLCD reference information to control the geometric precision of the re-projection. The output pixel size of the re-projection was 480 m-×-480 m. Prior to projecting the MCD43A3 into the NLCD geometric space, information on data quality (MCD43A2) was used to mask (remove) data that were not identified as good quality or retrieved in the presence of snow for each image date. Analysis of albedo response to land cover change was restricted to snow free MCD43A3 data that were identified as good quality. The MCD43A3 data from 2001 through 2013 were used in the analysis. For each pixel, there were potentially 598 observations (46 dates/year ∗ 13 years). However, cloud cover and shadow effects limit the availability of high quality observations (Fang et al., 2007). The number of available snow free good quality observations ranged from 208 to 540 for the sites examined.

2.3. Analysis

To support time series analysis of albedo, class-specific land cover changes from the 480 m-×-480 m NLCD map were extracted and converted to Keyhole Markup language Zipped (KMZ) files for overlay on Google Earth™. These locations were examined by using the time series imagery in Google Earth™ to verify the apparent land cover changes identified in the NLCD data. Only land cover changes that could be confirmed in Google Earth™ were included. We focused on land cover changes among the following NLCD classes: deciduous forest, evergreen forest, shrubland, grassland, pasture, and cropland. Some of the land cover changes were common (evergreen forest to shrubland) and others were more rare (evergreen forest to cropland). We selected 20 sites (pixels) to examine the relationship between albedo and land cover change for common land cover change classes. We deemed 20 to be a sufficient sample size to characterize the albedo response for a class-specific land cover change. We selected all available (verifiable) sites for the less common land cover changes. Use of 20 sites for common land cover change classes and all verifiable sites for less common land cover change classes resulted in a total of 130 sites for examination of albedo response to land cover change. Sites selected for common land cover change classes were spread geographically (Fig. 1).

Specific NLCD land cover changes were identified by combining the three NLCD eras (2001, 2006, 2011) into a single map using GIS software. We focused on single-class changes (e.g., evergreen forest [2001], evergreen forest [2006], cropland [2011]) rather than multiple-class changes (evergreen forest, shrubland, cropland). Further, we focused on changes that occurred between 2006 and 2011 because the Google Earth™ imagery database is richer after 2006 than before 2006. Separate maps of each land cover change class were converted to KMZ files for selection of specific sites (pixels).

Once the sites were selected, following Nash et al. (2014, p155), we used univariate autoregression (Proc Autoreg; SAS/ETS, 1999) of albedo versus time (Fig. 2). The univariate autoregressive model of albedo versus time for sites with verified land cover change tests the null hypothesis that albedo does not change significantly in response to land cover change. The order of the autoregressive error model was set to 47