Agricultural and Forest Meteorology 232 (2017) 118–127

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

Surface albedo raise in the South American Chaco: Combined effects of deforestation and agricultural changes

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ARTICLE INFO

Article history:
Received 21 October 2015
Received in revised form 12 August 2016
Accepted 17 August 2016

Keywords:
Albedo change
Deforestation
Land use
Agricultural management
Energy budget
Radiative forcing
Semiarid dry forest

ABSTRACT

Deforestation affects climate and the energy balance of the Earth not only through the release of greenhouse gases but also through shifts in the physical properties of the surface. These physical effects can be strongly dependent not only on the deforestation event but on the land use choices and management that follow it. Here we explored how the albedo and radiation balance of the dry subtropical Chaco forests of South America changed over the last decade in response to both deforestation and land use/management. For the whole region we analyzed changes in the mean annual albedo derived from MODIS imagery and their relation with the dominant land use trajectories for a 12-year period (2000–2012). In two focal areas we identified how specific land uses and management shifts affected the seasonality of surface albedo and green vegetation cover, quantifying their associated radiation budget changes and radiative forcing effects. Deforestation accounted for 83% of the regional albedo increase observed in Chaco, yet, land use and land management changes were also a main driver of albedo shifts, explaining the rest of the albedo rise occurred in the region. Albedo raises increased the mean annual outgoing shortwave energy flux at the top of the atmosphere producing a biophysical cooling effect which was strongly dependent on the land use choice and agricultural management, ranging from $-8\,W\,m^{-2}$ in silvopastoral systems to $-17\,W\,m^{-2}$ under single annual cropping schemes. These values are equivalent to a reduction in atmospheric CO_2 of 12–27 Mg C ha^{-1}, or 15–55% of the typical emissions that accompany deforestation in this region. Land use and management choices in the Chaco region produce strong divergences in the resulting albedo seasonality that should not be ignored in the assessment of their net climatic effects and the discussion of possible mitigation actions.

1. Introduction

The effects of deforestation on climate are now widely recognized (Bright et al., 2015; Zhao and Jackson, 2013). It has been shown that deforestation may affect the climate through changes in biogeochemical processes (e.g. carbon cycling) which involve global and large time scales, and through changes in surface biophysical properties (i.e. albedo, latent/sensible heat partition, canopy conductance and surface roughness among others) which usually manifest with fast reactions, at global, regional and/or local scales and may counteract or enhance biogeochemical processes (Baldocchi and Ma, 2013; Bonan, 2008; Dixon et al., 1994; Rotenberg and Yakir, 2010). However, a key aspect that has been poorly explored so far is related to how the different purposes of deforested areas and the agricultural practices applied to them may modulate these climatic effects (Boisier et al., 2013; Bright et al., 2015; Jeong et al., 2014; Luyssaert et al., 2014). How does the climatic forcing change if deforested areas are devoted to grain or forage production? Does single vs. double cropping (i.e. one or two crops per year) have similar climatic effects? These are important questions that need to be answered in order to better understand the effect of human decisions on climate.

Similar to the carbon release after deforestation, which produce a biogeochemical perturbation in radiation balance of the earth (Myhre et al., 1998), the change in surface albedo that usually accompanies deforestation is a key climatic aspect that may over-

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http://dx.doi.org/10.1016/j.agrformet.2016.08.015
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come the global effects over the carbon cycle (Beltrán-Przekurat et al., 2011; Betts, 2000; Bonan, 2008; Zhao and Jackson, 2013). Forests usually present lower albedo than agriculture lands (Loarie et al., 2010) and as a consequence, deforestation reduces the amount of shortwave (SW) solar radiation captured by the ecosystem, resulting in a albedo biophysical cooling (Betts, 2000; Bright et al., 2014, 2015). Deforestation may also affect the energy budget and global climate through more complex atmospheric effects (Davin and Noblet-Ducoudré, 2010). For instance, this land-cover change may alter the radiation budget in longwave component, since forest have significantly higher heat transfer capacity than agriculture systems (Jackson et al., 2008), but this effect would be mostly absorbed by the lower atmosphere without generating net changes in the global radiation budget (Lee, 2010). In addition, this land-cover change may modify planetary albedo in different directions if the lower evapotranspiration of agriculture systems (Nosetto et al., 2012) translates into decreased cloud formation (Werth and Avissar, 2002), something that can be particularly relevant in the humid tropics (Davin et al., 2007). Deforestation may also affect energy balance and impact on local climate through changes in evapotranspiration rates (Lee, 2010), but its comparison with global effects are more difficult to quantify (Davin et al., 2007). In addition, in arid/sub-humid areas with high radiation load, the changes in the radiation balance that follows vegetation changes are likely more important than evapotranspiration contrasts between different vegetation covers because they tend to evapotranspire most of rainfall inputs (Rotenberg and Yakir, 2010; Santoni et al., 2010).

In order to compare both global effects (albedo and carbon) the metric "radiative forcing" is widely used, referring to the change in net irradiance at the tropopause level and giving a measure of the global warming/cooling potential of any anthropogenic or natural forcing (Davin et al., 2007; Forster et al., 2007; Ward and Mahowald, 2015). Several studies have shown that when albedo and carbon effects are considered the net outcome becomes highly dependent on the climatic context. While in boreal and tropical regions net cooling and net warming are respectively the expected results (Betts, 2000), in temperate regions the net outcome is more uncertain and highly dependent on local conditions (e.g. crop choice, management practices, etc.) (Bala et al., 2007; Jackson et al., 2008; Salazar et al., 2015). Particularly, the expansion of agriculture into subtropical dry forests is of key relevance because of its current magnitude and relatively high biophysical vs. biogeochemical effects associated to the high radiation levels and smaller total carbon pools of these regions (Anderson et al., 2011; Jackson et al., 2008). Recent studies evidenced the strong biophysical effects of the replacement of temperate dry forests by annual crops in central Argentina (Houspanossian et al., 2013).

The albedo biophysical climatic forcing associated to the different purposes of deforested areas (i.e. land uses) and its different management practices have been poorly considered, despite of the strong contrasts they may present. Globally, deforested areas are mainly devoted to two land uses: forage production (with perennial pastures) or grain production (with annual crops) (Foley et al., 2005). These land uses present canopies with different biophysical properties given by contrasting morphological, architectural, phenological, and chemical properties (Ahmad and Lockwood, 1979), that may result in different radiative forcings (Davin et al., 2007). For example, grain production systems usually include a fallow period each year with no vegetation cover, which creates noticeable contrasts of albedo and roughness with active vegetation covers (e.g. perennial pastures) (Nosetto et al., 2012). In addition, the changes that occur within the same land use and that do not result in a land use change are also able to modify the radiative forcing with a similar magnitude than land cover change (Luyssaert et al., 2014). Besides irrigation, whose climatic effects have been the main focus of attention (Lobell et al., 2006), the effects of other land management changes aspects such as sowing dates and phenology, tillage system, or crop species choice, have been hardly considered (Davin et al., 2014; Jeong et al., 2014; Luyssaert et al., 2014; Zhang et al., 2013). Recent studies have shown that management changes may strongly impact local, regional and global climate through shifts in surface albedo and other surface properties (Davin et al., 2014; Jeong et al., 2014; Luyssaert et al., 2014). Although land cover changes explained most of land transformations in the last century (Ramankutty et al., 2008), it is expected that land management changes will become highly relevant in the near future as increasing food demand and technological changes operate under limited land availability (Ramankutty et al., 2002) and a higher climate variability (Sadras et al., 2003).

In southern South America, a continuous advance of the agricultural frontier into the dry subtropical forests (semiarid Chaco) has been taking place in the last decades (Vallejos et al., 2015), being the cleared areas mostly devoted to pastures, for cattle ranching, and grain annual crops (Houspanossian et al., 2016). Given the large areal extension of the Chaco and the large diversity of land users (Baldi et al., 2015), different management strategies are also commonly observed within each land use option. For instance, in ranching systems, open pastures, based on perennial species coexist with silvopastoral schemes based on native tree species or planted exotic ones (Glatzle, 2004; Glatzle and Stosiek, 2002). On the other hand, in the last decade many agricultural farmers have changed their management strategies replacing double crop systems (i.e. a winter/spring crop followed by a summer crop) by late summer single crops, in order to improve soil moisture conditions and reduce farming risks (Giménez et al., 2015). Understanding how the different land trajectories observed in the last decade modify the radiation budget becomes particularly relevant in a region like the Chaco that has a high solar radiation load and shows fast environmental changes.

The goal of this work was to analyze the effects of the different land trajectories observed in the Chaco dry forests on the surface albedo and the radiation budget. For this purpose, we performed two analyses at different spatial scales (regional and local). At the regional scale, we analyzed the spatial and temporal variability of the surface albedo for the whole Chaco region and its relation with land trajectories. At the local scale, we focused in how the different land uses and management practices affect the seasonality of surface albedo and green vegetation cover and, through remote sensing and radiative modeling, we quantified the radiation budget changes and the radiative forcing associated to these transformations. We performed this local analysis in two focal areas of the Chaco region (Santiago del Estero, Argentina and Filadelfia, Paraguay).

2. Materials and methods

2.1. Study region

The semiarid Chaco region is a vast sedimentary plain of 61.3 M hectares in size that extends through the north-central part of Argentina, east of Bolivia and the western part of Paraguay (Olson et al., 2001) (Fig. 1). This region is one of the flattest semiarid sedimentary areas of the planet, with a very large fraction of the land with slopes <0.1% (Jobbágy et al., 2008). Soils are derived from massive accumulation of fine loess and alluvial sediments during the Quaternary (Pennington et al., 2000). The region presents a monsoonal climate with strong seasonality (dry winters, rainy summers) (Minetti, 1999), with high temperatures in summer and winter frosts. The average annual rainfall decreases in northeast-southwest direction from about 1000 to 400 mm y^{-1}. Potential

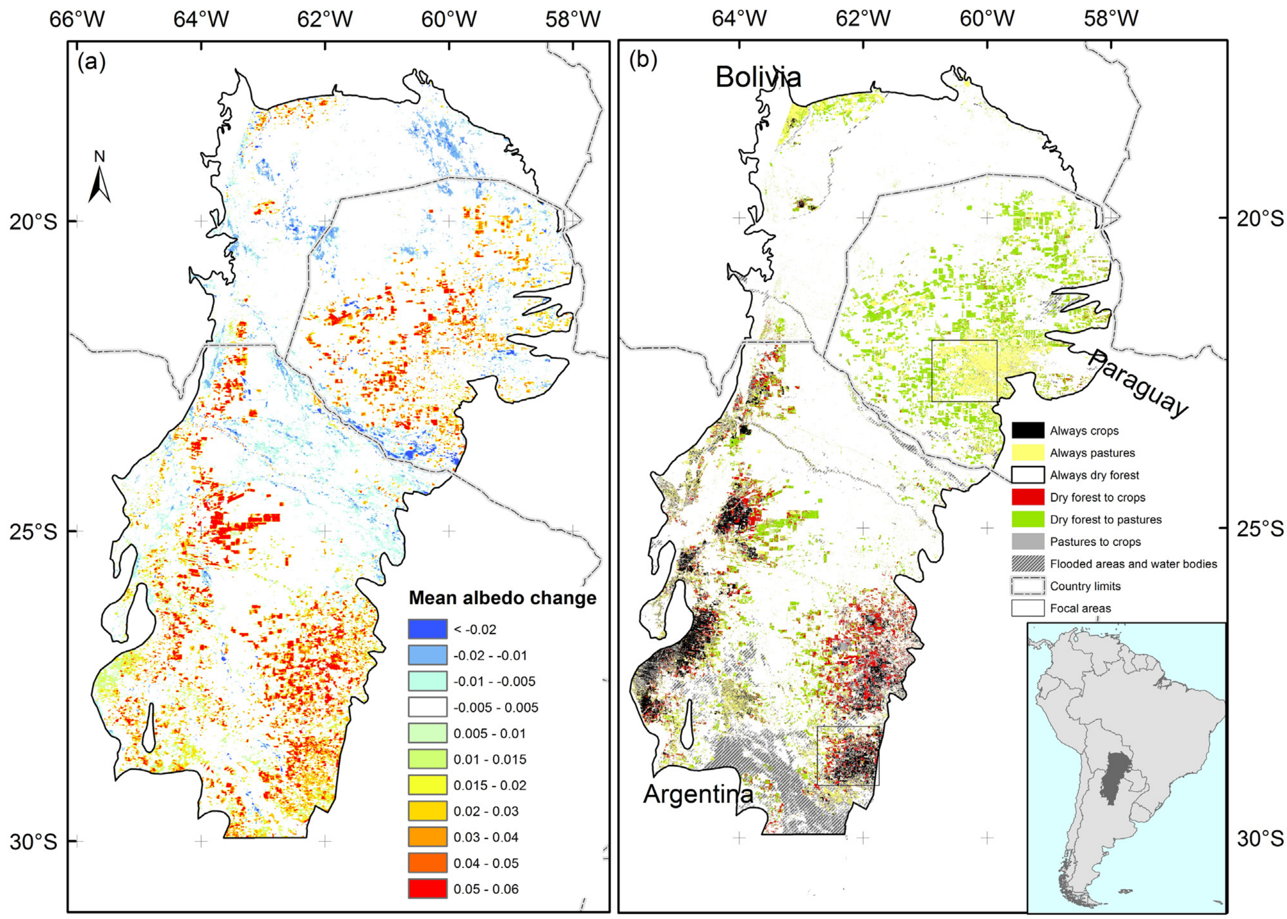

Fig. 1. (a) Mean albedo change (%) over a 12 years period (2000–2012) across South American semiarid Chaco estimated as the slope of linear regressions (mean annual albedo vs. time) multiplied by the numbers of years analyzed. Only those pixels with significant changes ($p < 0.05$) are shown. (b) Land use classifications in semiarid Chaco in two periods (2001 and 2012). Focal areas of local scale analysis are showed.(For interpretation of the references to color in the text, the reader is referred to the web version of this article.)

evapotranspiration increases from south to north, with annual averages between 1000 and 1700 mm y^{-1}. Vegetation in the region is therefore subject to low soil moisture and frost in the dry season and high summer temperatures during part of the wet season. Mean annual solar radiation at the ground ranges from 210 Wm^{-2} in the south to 220 Wm^{-2} in the north of the region.

Native vegetation is dominated by broadleaf, deciduous, or semi-deciduous forests, classified as subtropical dry forests (Gentry, 1995). According to fire and grazing history and other causes, some areas could become open savannas or dense woodlands (Dussart et al., 1998). Currently, there are large continuous areas of natural or semi-natural dry forest (Vallejos et al., 2015), where dominant economic activities are extensive cattle ranching, charcoal extraction, and selective logging (Gasparri and Grau, 2009; Rueda et al., 2013). Soybean is the dominant grain crop followed by maize for summer crops, while winter and spring crops (wheat and barley) are also common but to a lesser extent (Calviño et al., 2003; Calviño and Monzon, 2009). Most grain crop systems apply no-till sowing and use transgenic seed varieties, herbicides and fertilizers (Devani et al., 2006). Livestock systems usually involve the use of implanted pastures which are in some cases incorporated into a silvopastoral system with native or exotic tree species (Glatzle, 1999). In Argentina, agricultural systems have their origin and imprint in the mixed –rainfed crops and pastures- schemes of the Pampas (Viglizzo et al., 2011). By contrast in Paraguay, livestock systems widely prevail, based mainly on rainfed implanted pastures (Glatzle, 1999).

2.2. Regional analysis of albedo in the Chaco

In order to characterize the regional pattern of albedo changes we used the MODIS MCD43A3 albedo product (Collection 5), which derives from the daily surface reflectance product (MOD09 series), corrected for atmospheric molecular scattering, ozone absorption, and aerosols (Vermote et al., 2002). This albedo product represents an 8-day composite with a spatial resolution of 500 m and combines reflectance data from Terra and Aqua satellites in order to compute, through the integration of a bidirectional reflectance distribution function, the black-sky albedo and white-sky albedo in seven spectral narrow bands and three broadbands (visible 0.3–0.7 μm, near-infrared 0.7–5.0 μm and shortwave 0.3–5.0 μm). The black-sky albedo represents the directional-hemispherical reflectance, which operates under direct illumination (no diffuse component). The white-sky albedo represents the bi-hemispherical reflectance and operates under diffuse illumination (no direct component). Albedo products from MODIS have been thoroughly validated with field observations and other satellite data (Tsvetsinskaya et al., 2006). We used MODIS tiles H12V10 and H12V11, which cover most of the semiarid Chaco. For each MODIS tiles, we compiled the temporal series of black-sky shortwave albedo, and their respective quality bands, from June 1, 2000 to May 31, 2012. Using this information we estimated the mean annual albedo for each growing season (i.e. from June 1 to May 31 of the following year) considering only the pixels with high quality data. In order to quantify temporal changes in albedo, we performed linear regression analysis of the temporal trend of the annual albedo values for the 12 years period for each individual pixel. Based on this analysis, we generated regional maps of the slope of the relationship albedo vs. time and of the significance (p-value) of the relationship. Only those pixels where this relationship was statistically significant ($p < 0.05$) were considered.

In order to understand the spatial variation of albedo and its relation with the main land trajectories of the Chaco, we used an external database of land cover and land use classifications developed for two time periods 2001–2002 and 2012–2013 (Fig. 1b) (Houspanossian et al., 2016). This database has a 250-m spatial resolution and high overall accuracy (77% for 2001–2002 classification and 90% for 2012–2013 classification) and covers the entire region. We characterized the albedo for the following land trajectories: always dry forest and savannas (always dry forests), always pasture, always crop, dry forest to pasture, dry forest to crop and pasture to crop. The first three trajectories correspond to areas that were classified as the same cover in both classification periods. The trajectory of deforestation of dry forest to crop (and to pasture) corresponds to areas that were deforested between 2003 and 2004 according to Vallejos et al. (2015) deforestation database and were classified as crop (or as pasture) in 2012 land cover classification. The pasture to crop trajectory corresponds to those areas that changed from pasture class (in 2001 land cover classification) to crop class (in 2012 land cover classification). Note that the inverse trajectory (i.e. from crop to pasture) was detected in a negligible area and was not considered in this study.

To characterize the albedo trends in each trajectory we performed a random selection of pixels. The initial number of random pixels selected ($n = 1000$) was restricted by a spatial condition in which only those pixels that were away at least 1500 m from pixels of a different class were considered. After this filtering, we had ~400 pixels per trajectory. In order to estimate the proportion of albedo trend we estimated the amount of random samples for each trajectory with significant positive, negative and nil (not significant) slope of the relationship albedo vs. time.

2.3. Radiation budgets and radiative forcing at the local scale

We computed the biophysical and radiation budget changes for different land transformations developed in two focal areas of the Chaco region (Bandera, Argentina and Filadelfia, Paraguay; Fig. 1b). At each of these areas, we selected plots completely occupied by dry forests and savannas ($n = 20$) or agriculture ($n = 40$). In the Argentinean focal area, agricultural plots selected were devoted to livestock production based on perennial pastures ($n = 20$) and to grain production that developed double cropping between June 1, 2000 and May 31, 2004 ($n = 20$) and single summer cropping between June 1, 2009 and May 31, 2012 ($n = 20$). It is important to highlight that this land management change (i.e. from double to single cropping) has been applied by most farmers of this region in the last decade in order to improve moisture conditions of the most profitable summer crop. With this aim, and beyond the elimination of the winter crop, land management changes also involved a delay in the sowing month of the summer crop from October–November to December–January, changing the cropping scheme from early summer to late summer (Giménez et al., 2015; Volante et al. in Press). In the Paraguayan focal area, all selected agricultural plots were devoted to livestock production based on open perennial pastures (i.e. with no tree cover, $n = 20$) and on silvopastoral systems ($n = 20$) where native or implanted trees are combined with perennial pastures. All selected plots were larger than 3×3 km. To ensure that our sampled pixels were fully occupied by a unique land cover/land management type, we used core pixels at each plot excluding a ~1 km-wide edge zone. Plots selection was based on high resolution Google Earth (www.earth.google.com) images following Clark et al. (2010) criteria, and the seasonality of the green vegetation cover, derived from de Normalized Difference Vegetation Index (NDVI). Note that double and single cropping strategies considered in this work were analyzed in the same plots but in different time-periods (June 1, 2000–May 31, 2004 for double cropping and June 1, 2009–May 31, 2012 for single cropping). For the rest of the trajectories considered, we analyzed the whole period (June 1, 2000–May 31, 2012).

For the different selected plots of each focal area, we characterize the seasonal dynamic of albedo and the green vegetation cover and we estimated the radiation balance using a Column Radiation Model (CRM) (Houspanossian et al., 2013; Randerson, 2006). Albedo data used were the same described in the above section; the NDVI data used derived from the MOD13Q1 MODIS product. The MOD13Q1 product is generated from the daily surface reflectance product (MOD09 series). The MOD13Q1 product has a temporal integration of 16 days and a spatial resolution of 250 m. To ensure a high quality of MODIS pixels, we performed a filtering based on the quality bands of MODIS products (Justice et al., 1998). CRM is a standalone version of the radiation model used in the NCAR Community Climate Model. We developed all the simulations following Houspanossian et al. (2013) methodology. We parameterized the ground surface with biophysical data obtained from MODIS sensors. We used the MODIS products for albedo (described in previous section). To capture both diurnal and seasonal variations in solar geometry, the runs were performed hourly and integrated over the day, every 8 days and for a period of 12 years (June 1, 2000–May 31, 2012), resulting in 78840 simulations as a whole. For all the simulations, we used monthly mean profiles of atmospheric temperature, specific humidity, ozone concentration, cloud cover and cloud liquid water content from the European Centre for Medium-Range Weather Forecasts 40 years Reanalysis product (Uppala et al., 2005). The average aerosol optical depth was estimated to be 0.070 for the Argentinean focal area and 0.065 for the Paraguayan focal area, based on the 550 nm aerosol band from MODIS MOD08 Aerosol product (Remer et al., 2005). The results of the radiation budget are presented for the tropopause level, which corresponds to the 200 mbar pressure level in the model. We estimated the radiative forcing as the difference in the outgoing shortwave radiation flux between agriculture lands and dry forest. All MODIS data used in this work were downloaded from NASA's Earth Observing System (http://reverb.echo.nasa.gov/reverb).

In order to compare the radiative forcing associated with albedo change with the carbon effect of deforestation, we calculated the amount of carbon that would need to release as CO_2 into the atmosphere to produce a similar radiative forcing. We calculated the local contribution of a given surface that is deforested to global radiative forcing by dividing our radiative forcing estimate at the top of the atmosphere by the earth's surface area (Betts, 2000). We used a radiative forcing efficiency of 5.35 (Myhre et al., 1998) to relate the previous estimate to the change in carbon stock through the following relationship.

$$RF = 5.35 \ln(1 + \Delta C/C_0) \quad (1)$$

where C_0 is the present day CO_2 concentration (385 ppmv, Menon et al., 2010) and ΔC is the globally averaged atmospheric CO2 change that would be required to produce a certain global radiative forcing, which is related to terrestrial carbon stock change ΔC_t through the expression:

$$\Delta C_t = 2(M_c/M_a)m_a(\Delta C/C_0) \quad (2)$$

where M_c and M_a are the molecular mass of carbon and dry air, ma is the mass of the atmosphere, and the factor of 2 accounts for an airborne emissions fraction of 0.5 (Schimel et al., 1995).

3. Results

3.1. General patterns of albedo change in the semiarid Chaco

Significant albedo changes were observed during the 12-year study period in the semiarid Chaco (Fig. 1a). Albedo increases were observed in 6.6 M ha of the region (11% of the study area), while drops in albedo were registered in 3.7 M ha (4% of the study area). The extension of albedo increases associated to areas experiencing deforestation summarized 4 M ha (Fig. 1a and b). The next big contributor of albedo increases (2 M ha) were areas that had been already deforested at the beginning of the analyzed period, including areas that were always under crops (0.4 M ha) or pastures (0.8 M ha) or that transitioned from pastures to crops (0.8 M ha). Albedo increases were also observed in dry forest areas without land cover change (0.6 M ha), which correspond entirely to frequently flooded territories, according to external classifications of coverage (Brakenridge et al., 2011). Interestingly, the totality of the albedo decreases occurred under dry forest without land cover changes. The territories that did not display changes in albedo during the study period correspond to dry forests (87%, 45 M ha), agricultural areas deforested previous to 2001 (10%, 3.7 M ha) and agricultural areas deforested between 2001 and 2012 (3%, 1.7 M ha).

The greatest intensity of albedo changes was observed in those trajectories that involved land cover or land use changes. Those areas that switched from dry forest to crop and from dry forest to pasture showed mean albedo increases of 0.049 ± 0.010 and 0.041 ± 0.010, respectively (Table 1, Fig. 2). The transition from pasture to crop also increased the albedo by 0.020 ± 0.007, on average (Table 1, Fig. 2). Agricultural covers remaining as crops during the study period also showed small but significant albedo increases (0.011 ± 0.007, $p < 0.05$). Dry forest and pastures were the only covers without temporal trends in albedo (Table 1, Fig. 2).

3.2. Albedo and radiation budgets under different land covers and land managements

The analysis at the local scale allowed us to deepen the characterization of land covers and land management effects on the surface albedo and the radiation balance. In the Argentinean focal area, we found that the albedo increase that follows deforestation was significantly higher where deforested areas were devoted to grain production, based on annual crops, than in areas devoted to livestock production, based on pastures ($p < 0.05$, Fig. 3a). This albedo increase translated into higher annual averaged outgoing shortwave (SW) flux at the tropopause level (42, 52 and 57 W m^{-2} for dry forests, pastures and croplands, respectively, $p < 0.05$, Fig. 4a). Given these contrasts, the replacement of native dry forests by grain production systems yielded a stronger biophysical cooling than livestock systems based on open perennial pastures (−15 vs. −10 W m^{-2}, Fig. 4b). These decreases in the amount of radiative energy that is captured by the earth-atmosphere system would be equivalent to a reduction in the amount of CO_2 released to the atmosphere of 23.5 and 15.6 Mg C ha^{-1} for croplands and pastures, respectively.

The two grain cropping strategies evaluated in the Argentinean focal area (i.e. double: winter/early summer cropping vs. single: late summer single cropping) also showed different albedo patterns (Fig. 3a), which translated into different radiative forcings (Fig. 4b). The higher albedo (0.162 vs. 0.181) of single cropping compared to double cropping resulted in higher annual shortwave outgoing fluxes (Fig. 4b). These differences resulted into a stronger biophysical cooling of the single cropping strategy (−17 W m^{-2}) compared to double cropping (−13 W m^{-2}), being the carbon emission equivalence of 27 and 20 Mg C ha^{-1}, respectively. At the intra-annual scale, the highest differences in the outgoing SW flux were observed during spring (September–November) and early summer (December) when approached 5.7 and 7.1 W m^{-2}, respectively (Fig. 4b, $p < 0.05$).

In the Paraguayan focal area, the two management strategies of pastures evaluated also created significant differences of radiative forcing. The replacement of dry forests by both, open pastures and silvopastoral systems, led to biophysical cooling with a stronger effect in the open pasture system (−8.4 vs. −15.4 W m^{-2}, Fig. 4d). In carbon units, the radiative cooling of open pastures would be equivalent to a reduction in CO_2 emissions of 25 Mg C ha^{-1}, and of 12 Mg C ha^{-1} if silvopastoral systems are considered. These contrasts resulted from the higher albedo of open pastures compared to silvopastoral systems (0.176 vs. 0.139, $p < 0.05$), which translated into higher annually averaged SW fluxes (58 vs. 50 W m^{-2}, Fig. 4c).

4. Discussion

During the last 12 years, the South American Chaco experienced profound territorial and agricultural transformations that raised the surface albedo. While most of the area with increased albedo was subject to deforestation, land use and land management changes that took place in areas that were already deforested explained a large additional regional albedo rise. Considering the extension (area involved, Fig. 1) and intensity (magnitude of change, Table 1) of albedo increases of the different land transformations, we estimated that 83% of regional albedo rise was due to deforestation while the rest corresponded to changes in land use and land management. Given the high radiation load of the Chaco region and the magnitude of albedo changes involved, these transformations led to strong radiation budget shifts (Fig. 4), which have the potential to modify the local and regional climate, as observed in other regions (Lee et al., 2011; Li et al., 2015).

Beyond the deforestation event, management decisions for both crops and pastures had a greater effect on albedo than the choice of pastures vs. crops. In agreement with this finding, eddy covariance observations evidenced similar impacts of land management and land cover changes reflected on mean annual surface temperatures (Luyssaert et al., 2014). Other recent studies have shown the importance of land management decisions on climate (Davin et al., 2014; Jeong et al., 2014; Loarie et al., 2011; Lobell et al., 2006; Luyssaert et al., 2014; Zhang et al., 2013). As expected for pastures systems, silvopastoral covers showed the lower albedo change after deforestation, likely because they preserve a proportion of trees that tend to decrease the overall albedo in relation to cleared surfaces as open pastures (Bright et al., 2014; Houspanossian et al., 2013). In grain cropping systems, the higher albedo of single summer crops compared to double winter/summer crops (Fig. 3) would be partially related to a longer fallow period in the first case (~270 vs. ~30 days), during which the stubble covering the soil surface in the widespread adopted no-till systems of the region (Viglizzo and Jobbágy, 2010) favors surface reflectivity (Davin et al., 2014). Additionally, the delay in the sowing date of summer crops under single cropping schemes (Fig. 3b), led to a stronger difference in the outgoing SW flux (outgoing $SW_{single} - SW_{double} = 5.14$ W m^{-2} during Oct.–Jan.) than the one observed during the development of the winter crop in the double-crop system (outgoing $SW_{single} - SW_{double} = 1.5$ W m^{-2} during Jun.–Set.). It is interesting to highlight that both, the replacement of double by single crop schemes and the delay of summer crops sowing date, has been increasing steadily in the region over the last decade (Giménez et al., 2015) and are likely explaining the positive albedo trend observed in agriculture croplands during the study period (Fig. 2). In addition, we speculate that similar crop management transformations may become very common in other agricultural areas worldwide, due to higher

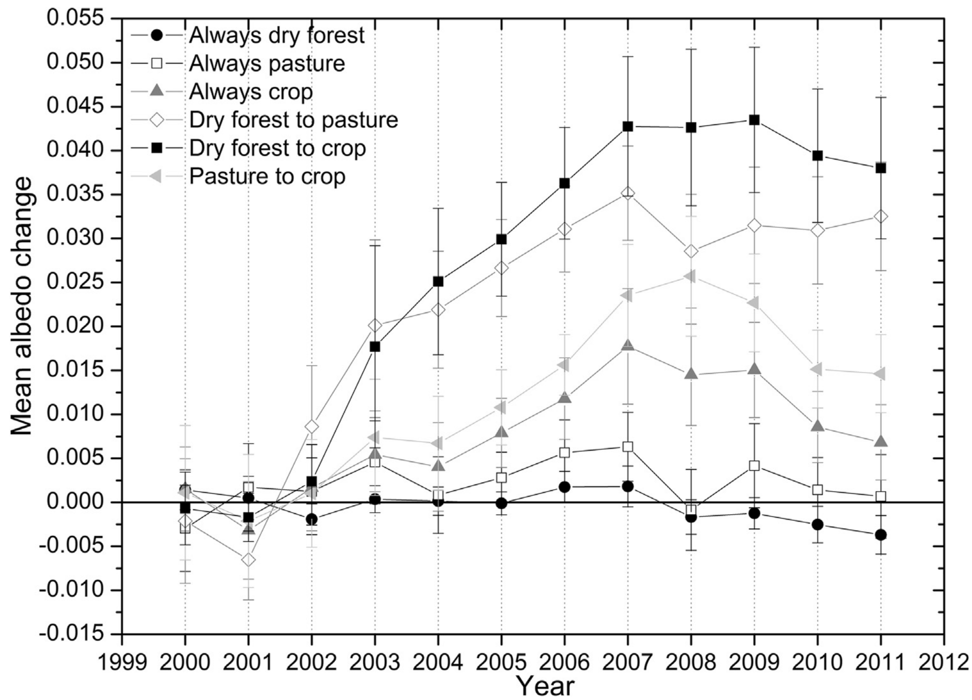

Fig. 2. Mean annual albedo changes relative to June 1, 2000 to May 31, 2002 average of randomly selected pixels for each land trajectories. Bars indicate standard deviation. The first three trajectories (always dry forest, always pasture and always crop) correspond to areas that were classified as the same cover in both classification periods in Houspanossian et al. (2016). The trajectory of deforestation of dry forest to crop (and to pasture) corresponds to areas that were deforested between 2003 and 2004 according to Vallejos et al. (2015) deforestation database and were classified as crop (or as pasture) in 2012 land cover classification. The pasture to crop trajectory corresponds to those areas that changed from pasture class (in 2001 land cover classification) to crop class (in 2012 land cover classification).

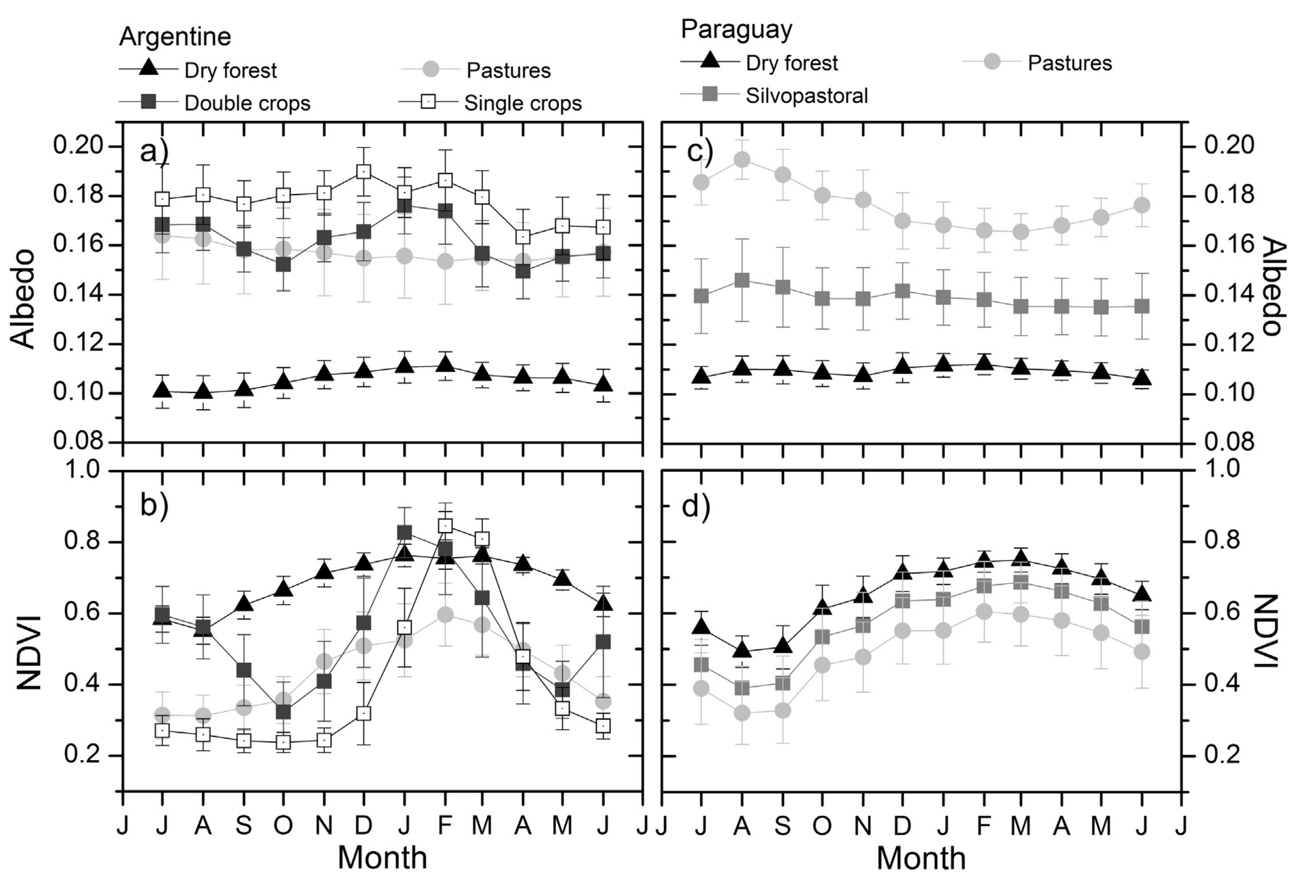

Fig. 3. Mean monthly values and standard deviation (bars) of surface albedo and NDVI in the Argentinean (a–b) and Paraguayan (c–d) focal areas.

Table 1
Temporal albedo changes for different land trajectories in the Semiarid Chaco. Land trajectories are described in Fig. 1.

Trajectory	Surface area (M ha)	Mean albedo (2000–2002)	Mean albedo (2009–2012)	Proportion of albedo trend (%)		
				(+)	(o)	(−)
Always dry forest	48.7	0.112	0.109	1	94	5
Always crop	1.5	0.160	0.170	27	73	–
Always pasture	5.4	0.160	0.162	19	81	–
Dry forest to pasture	3.7	0.112	0.151	89	11	–
Dry forest to crop	2.0	0.115	0.158	95	5	–
Pasture to crop	1.4	0.149	0.168	100	–	–

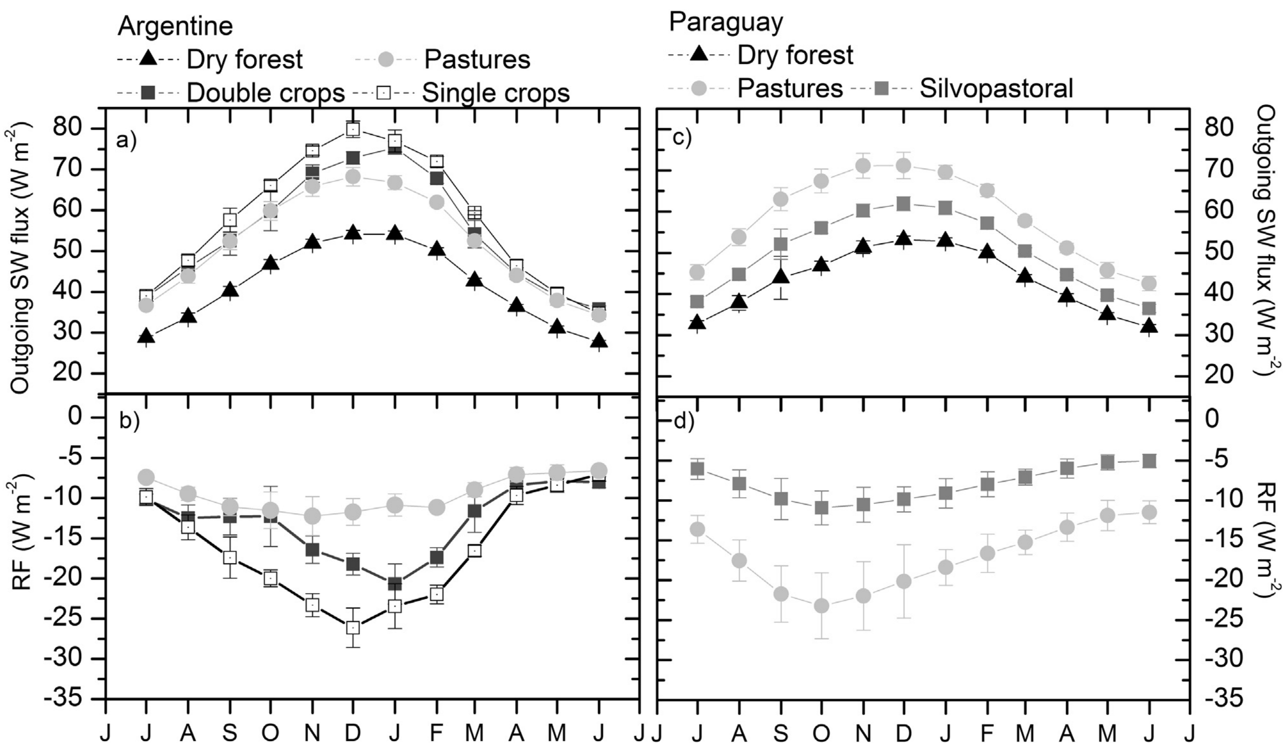

Fig. 4. Mean monthly outgoing shortwave (SW) flux (a–c), and radiative forcing of land use changes (b–d) at the tropopause level in the Argentinean (left panels) and Paraguayan (right panels) focal areas. Monthly averages (n = 12 years) and standard deviation (bars) are shown.

expected climatic fluctuations (IPCC, 2014; Marengo et al., 2009) and the generally risk-averse response of farmers.

Land use choices after deforestation not only affect the magnitude of albedo shifts but also their seasonality as well (Fig. 5). The relationships between albedo and NDVI, a surrogate of green leaf area (Paruelo et al., 1997), helps to understand how canopy structures influence the albedo and its temporal dynamics (Fig. 5). On one side, with the greening of pastures during spring, the highly reflective dead biomass of these canopies becomes gradually covered by a new cohort of green leaves that reduce the albedo. By contrast in the case of crops, an on-off dynamics takes place, in which accumulated stubble with high visible albedo (Daughtry et al., 2005) gets covered by the rapidly expanding green leaves that raises the short-infrared albedo (Ahmad and Lockwood, 1979). Additionally, crop canopies (e.g. maize and soybean) usually have more planophilous leaves than pasture canopies, which associated to the greater vegetation cover reached by crops in the growing season (Fig. 5), lead to a reduced radiation transmittance and higher reflectance in crops compared to pastures systems (Sinoquet and Andrieu, 1993). Noticeably, forest canopies, regardless of their greenness, sustain very low albedo throughout the year as a result of their complex perennial woody structure.

The net radiative forcing resulting from the replacement of dry forests by agriculture becomes difficult to quantify when both albedo biophysical cooling and carbon biogeochemical warming effects are considered. This is in part due to the highly variable agriculture management developed by farmers and on the other hand, due to the different conservation stages of native forests, which affect their carbon pools and uptake and to some extent their albedo and energy dissipation rates (Bright et al., 2014; Gasparri and Baldi, 2013; Houspanossian et al., 2013). The few existing carbon budgets for dry forests in the study region suggest total (above and belowground) carbon stocks of 49–81 Mg C ha^{-1}(Bonino, 2006; Gasparri et al., 2008; Kim, 2011). According to these numbers and to our radiative forcing estimates for each land use and management, the biogeochemical effect of dry forests deforestation is likely overcoming the biophysical effect mediated by the albedo increase. If grain crops systems are established after deforestation, between 20 and 27 Mg C ha^{-1} of carbon emissions would be offset by the albedo change. However, if livestock systems are established after deforestation, this value would be reduced to 12–25 Mg C ha^{-1}, depending on whether silvopastoral or open pastures are implemented. Additionally, given that silvopastoral systems generate the lowest carbon release after deforestation (Marchesini et al., 2014; Somovilla Lumbreras, 2014), we may speculate that this land use and management option will generate the lower net climatic impact. Livestock systems can produce an additional climate warming effect associated to methane emission which has not been

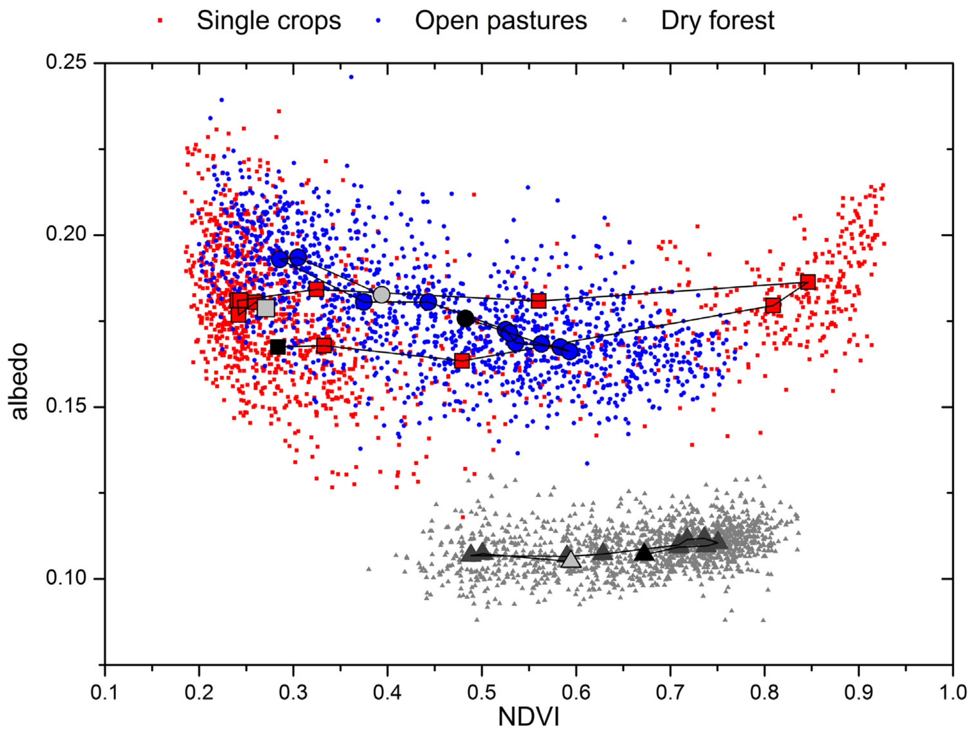

Fig. 5. Relationships between albedo and NDVI for single crops (red squares), open pastures (blue circles), and dry forest (grey triangles), for study sites used in Fig. 3. Each data point represents a single MODIS date (one every 16 days from June 1, 2009 to May 31, 2012) for a single site (20 sites for each cover). Note that albedo 8-days data was averaged to match the 16-days interval of NDVI data. Larger symbols represent monthly means for each land cover, and series start with the light marker (June) and end with the dark marker (May). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

evaluated in Chaco (IPCC, 1996; Tubiello et al., 2015), but given the very low animal density (<0.12 heads ha^{-1}) this effect would not be significant. Soil carbon changes after deforestation in Chaco are highly uncertain and probably dependent on the land cover and management applied after deforestation (Bonino, 2006; Kim, 2011). Although deforestation of Chaco dry forests may involve a strong carbon-mediated impact on climate (Gasparri et al., 2008), our results suggest that the consideration of albedo effects and their trajectory under different land use and management options should be an important part of any full accounting of climatic effects.

Although deforestation produces a albedo biophysical cooling effect on climate at global scale (Betts, 2000), deforestation may also impact climate at the local scale (Baldocchi and Ma, 2013; Lee et al., 2011; Li et al., 2015). In this sense, the observed higher surface temperatures in agricultural land compared to dry forests (>2 °C, Houspanossian et al., 2013), contrasts with the lower radiation load of agricultural lands resulting from the higher albedo (Fig. 3). As documented in other regions (Li et al., 2015; Rotenberg and Yakir, 2010; Rotenberg and Yakir, 2011; Wickham et al., 2012), this pattern is explained by the higher capacity of forests to dissipate both sensible and latent heat to the atmosphere which helps to keep canopies cooler, while in agricultural systems this capacity is dependent of use/management (Luyssaert et al., 2014). This changes in local climate may strongly impact different biogeochemical processes (Davidson and Janssens, 2006) and it should be carefully considered together with the most well-known global effects computed at the tropopause level.

Some natural processes may also affect albedo patterns, as is the case of the negative temporal trends observed in some parts of the study region (Fig. 1a, blue pixels). For example, the albedo decrease observed in the border between southeastern Bolivia and west Paraguay (20.2°S; 62.0°W) is associated to post-fire vegetation recovery (Baldi et al., 2008; Houspanossian et al., 2013). Changes in surface water (i.e. flooding fluctuations), driven by rainfall variability, are also common in some areas of the Chaco and probably explain albedo changes in some areas of the region (Kuppel et al., 2015; Loarie et al., 2010). This is particularly common in Chaco paleo-river beds, which display frequents water and salt accumulation in the surface and associated vegetation shifts. Although the climatic implications of these natural processes remain poorly explored, climatic models suggest a higher frequency and intensity of extreme events (i.e. droughts and wet periods) for the region (IPCC, 2014), which could turn natural fires and flooding into more frequent events.

5. Conclusions

We showed that the profound land transformations experienced by the South American Chaco during the last 12 years left their imprint in the regional pattern of surface albedo. Although deforestation accounted for 83% of the regional albedo increase observed in Chaco, we found that land use and management changes were also an important driver of albedo shifts, explaining the rest of the albedo rise occurred in the region. The albedo change triggered by deforestation strongly impacted the radiation balance and led to a albedo biophysical cooling effect that can counterbalance between 15% and 55% of the carbon biogeochemical warming effect, depending on the land use/land management applied to deforested areas. Albedo biophysical effects and the key influence that land use and management can have once deforestation occurred should be part of the discussion of climatic warming mitigation actions.

Acknowledgements

This work was funded by grants from the National Research Council of Argentina (CONICET- PIP 112-201101-00217 and PIP 112-201501-00609), the International Research Development

Center (IDRC-Canada, Project 106601-001), the ANPCyT (PICT 2014-2790) and the Inter-American Institute for Global Change Research (IAI, CRN II 3095), which is supported by the US National Science Foundation (Grant 448 GEO-0452325). We especially thank Maria Vallejos for the supply of deforestation database.

References

Anderson, R.G., et al., 2011. Biophysical considerations in forestry for climate protection. Front. Ecol. Environ. 9, 174–182.
Bala, G., et al., 2007. Combined climate and carbon-cycle effects of large-scale deforestation. Proc. Natl. Acad. Sci. 104 (16), 6550.
Baldi, G., et al., 2008. Long-term satellite NDVI data sets: evaluating their ability to detect ecosystem functional changes in south america. Sensors 8, 5397–5425.
Baldi, G., Houspanossian, J., Murray, F., Rueda, C.V., Jobbágy, E.G., 2015. Cultivating the dry forests of South America: diversity of land users and imprints on ecosystem functioning. J. Arid Environ. 123, 47–59.
Baldocchi, D., Ma, S., 2013. How will land use affect air temperature in the surface boundary layer? Lessons learned from a comparative study on the energy balance of an oak savanna and annual grassland in California, USA. Tellus B 65.
Beltrán-Przekurat, A., Pielke, R.A., Eastman, J.L., Coughenour, M.B., 2011. Modelling the effects of land-use/land-cover changes on the near-surface atmosphere in southern South America. Int. J. Climatol. 32 (8), 1206–1225.
Betts, R.A., 2000. Offset of the potential carbon sink from boreal forestation by decreases in surface albedo. Nature 408 (6809), 187–190.
Boisier, J.P., de Noblet-Ducoudré, N., Ciais, P., 2013. Inferring past land use-induced changes in surface albedo from satellite observations: a useful tool to evaluate model simulations. Biogeosciences 10 (3), 1501–1516.
Bonan, G.B., 2008. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. Science 320 (5882), 1444.
Bonino, E.E., 2006. Changes in carbon pools associated with a land-use gradient in the Dry Chaco, Argentina. For. Ecol. Manag. 223, 183–189.
Brakenridge, G.R., Kettner, A.J., Slayback, D., Policelli, F., 2011. The Surface Water Record: Dartmouth Flood Observatory. University of Colorado, Boulder, CO, USA.
Bright, R.M., et al., 2014. Climate change implications of shifting forest management strategy in a boreal forest ecosystem of Norway. Global Change Biol. 20 (2), 607–621.
Bright, R.M., Zhao, K., Jackson, R.B., Cherubini, F., 2015. Quantifying surface albedo and other direct biogeophysical climate forcings of forestry activities. Global Change Biol. 21 (9), 3246–3266.
Calviño, P.A., Monzon, J.P., 2009. Farming systems of Argentina: yield constraints and risk management. In: Sadras, V.O., Calderini, D.F. (Eds.), Crop Physiology: Applications for Genetic Improvement and Agronomy. Academic Press, San Diego, p. 55e70.
Calviño, P.A., Andrade, F.H., Sadras, V.O., 2003. Maize yield as affected by water availability, soil depth, and crop management. Agron. J. 95 (2), 275–281.
Clark, M.L., Aide, T.M., Grau, H.R., Riner, G., 2010. A scalable approach to mapping annual land cover at 250 m using MODIS time series data: a case study in the Dry Chaco ecoregion of South America. Remote Sens. Environ. 114 (11), 2816–2832.
Daughtry, C.S.T., Hunt Jr, E.R., Doraiswamy, P.C., McMurtrey III, J.E., 2005. Remote sensing the spatial distribution of crop residues. Agron. J. 97 (3), 864–871.
Davidson, E.A., Janssens, I.A., 2006. Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. Nature 440 (7081), 165–173.
Davin, E.L., Noblet-Ducoudré, N., 2010. Climatic impact of global-scale deforestation: radiative versus nonradiative processes. J. Clim. 23 (1), 97–112.
Davin, E.L., de Noblet-Ducoudré, N., Friedlingstein, P., 2007. Impact of land cover change on surface climate: relevance of the radiative forcing concept. Geophys. Res. Lett. 34 (13), L13702.
Davin, E.L., Seneviratne, S.I., Ciais, P., Olioso, A., Wang, T., 2014. Preferential cooling of hot extremes from cropland albedo management. Proc. Natl. Acad. Sci. 111 (27), 9757–9761.
Devani, M.R., Ploper, D., Pérez, D., 2006. Evolución y estado actual de la producción de soja en el noroeste argentino., Estación Experimental Agroindustrial Obispo Colombres (EEAOC) Las Talitas, Tucumán, Argentina.
Dixon, R.K., et al., 1994. Carbon pools and flux of global forest ecosystems. Science 263 (5144), 185–190.
Dussart, E., Lerner, P., Peinetti, R., 1998. Long-term dynamics of two populations of Prosopis caldenia Burkart. J. Range Manag. 51, 685–691.
Foley, J.A., et al., 2005. Global consequences of land use. Science 309 (5734), 570–574.
Forster, P., et al., 2007. Changes in atmospheric constituents and in radiative forcing. In: Solomon, S. (Ed.), Climate Change 2007: The Physical Science Basis Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
Gasparri, N.I., Baldi, G., 2013. Regional patterns and controls of biomass in semiarid woodlands: lessons from the Northern Argentina Dry Chaco. Reg. Environ. Change 13 (6), 1131–1144.
Gasparri, N.I., Grau, H.R., 2009. Deforestation and fragmentation of Chaco dry forest in NW Argentina (1972–2007). For. Ecol. Manag. 258, 913–921.
Gasparri, N.I., Grau, H.R., Manghi, E., 2008. Carbon pools and emissions from deforestation in extra-tropical forests of Northern Argentina between 1900 and 2005. Ecosystems 11, 1247–1261.
Gentry, A., 1995. Diversity and floristic composition of Neotropical dry forests. In: M.H, Bullock, S.H., Medina, E. (Eds.), Seasonally Dry Tropical Forests. Cambridge University Press, Cambridge.
Giménez, R., Mercau, J.L., Houspanossian, J., Jobbágy, E.G., 2015. Balancing agricultural and hydrologic risk in farming systems of the Chaco plains. J. Arid Environ. 123, 81–92.
Glatzle, A., Stosiek, D., 2002. Country Pasture/forage Resource Profile of Paraguay. FAO, Rome, Italy.
Glatzle, A., 1999. Compendio para el manejo de pasturas en el Chaco. Estacion Experimental Chaco Central (MAG-GTZ), Chaco central, Paraguay, 188 pp.
Glatzle, A., 2004. Sistemas Productivos En El Chaco Central Paraguayo: Características Particularidades. INTTAS, Loma Plata, Paraguay.
Houspanossian, J., Nosetto, M., Jobbágy, E.G., 2013. Radiation budget changes with dry forest clearing in temperate Argentina. Global Change Biol. 19 (4), 1211–1222.
Houspanossian, J., Giménez, R., Baldi, G., Nosetto, M., 2016. Is aridity restricting deforestation and land-uses in the South American Dry Chaco? Journal of Land Use Science, in press.
IPCC, 1996. Intergovernmental Panel on Climate Change. Report of the twelfth session of the intergovernmental panel on climate change. Reference manual and workbook of the IPCC 1996 revised guidelines for national greenhouse gas inventories, Mexico City.
IPCC, 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, United Kingdom and New York, NY, USA.
Jackson, R.B., et al., 2008. Protecting climate with forests. Environ. Res. Lett. 3, http://dx.doi.org/10.1088/1748-9326/3/4/044006.
Jeong, S.-J., et al., 2014. Effects of double cropping on summer climate of the North China Plain and neighbouring regions. Nat. Clim. Change 4 (7), 615–619.
Jobbágy, E.G., Nosetto, M.D., Santoni, C., Baldi, G., 2008. El desafío ecohidrológico de las transiciones entre sistemas leñosos y herbáceos en la llanura Chaco-Pampeana. Ecología Austral 18, 305–322.
Justice, C.O., et al., 1998. The moderate resolution imaging spectroradiometer (MODIS): land remote sensing for global change research. IEEE Trans. Geosci. Remote Sens. 36, 1228–1249.
Kim, J.H., 2011. Trading Carbon and Water Through Vegetation Shifts. Duke University, Durham, pp. 172.
Kuppel, S., Houspanossian, J., Nosetto, M., Jobbágy, E., 2015. What does it take to flood the Pampas?: Lessons from a decade of strong hydrological fluctuations. Water Resour. Res. 51 (4), 2937–2950.
Lee, X., et al., 2011. Observed increase in local cooling effect of deforestation at higher latitudes. Nature 479 (7373), 384–387.
Lee, X., 2010. Forests and climate: a warming paradox. Science 328 (5985), 1479.
Li, Y., et al., 2015. Local cooling and warming effects of forests based on satellite observations. Nat. Commun. 6.
Loarie, S.R., Lobell, D.B., Asner, G.P., Field, C.B., 2010. Land-cover and surface water change drive large albedo increases in south america. Earth Interact. 15 (7), 1–16.
Loarie, S.R., Lobell, D.B., Asner, G.P., Mu, Q., Field, C.B., 2011. Direct impacts on local climate of sugar-cane expansion in Brazil. Nat. Clim. Change 1 (2), 105–109.
Lobell, D.B., Bala, G., Duffy, P.B., 2006. Biogeophysical impacts of cropland management changes on climate. Geophys. Res. Lett. 33 (6).
Luyssaert, S., et al., 2014. Land management and land-cover change have impacts of similar magnitude on surface temperature. Nat. Clim. Change 4 (5), 389–393.
Marchesini, V.A., Fernández, R.J., Reynolds, J.F., Sobrino, J.A., Di Bella, C.M., 2014. Changes in evapotranspiration and phenology as consequences of shrub removal in dry forests of Central Argentina. Ecohydrology 8 (7), 1304–1311.
Marengo, J.A., Jones, R., Alves, L.M., Valverde, M.C., 2009. Future change of temperature and precipitation extremes in South America as derived from the PRECIS regional climate modeling system. Int. J. Climatol. 29 (15), 2241–2255.
Menon, S., Akbari, H., Mahanama, S., Sednev, I., Levinson, R., 2010. Radiative forcing and temperature response to changes in urban albedos and associated CO2 offsets. Environ. Res. Lett. 5 (1), 014005.
Minetti, J.I., 1999. Atlas Climático del Noroeste Argentino, Facultad de Filosofía y Letras de la Universidad Nacional de Tucumán, Tucumán, Argentina.
Myhre, G., Highwood, E.J., Shine, K.P., Stordal, F., 1998. New estimates of radiative forcing due to well mixed greenhouse gases. Geophys. Res. Lett. 25, 2715–2718.
Nosetto, M.D., Jobbágy, E.G., Brizuela, A.B., Jackson, R.B., 2012. The hydrologic consequences of land cover change in Central Argentina. Agric. Ecosyst. Environ. 154, 2–11.
Olson, D.M., et al., 2001. Terrestrial ecoregions of the world: a new map of life on Earth. Bioscience 51 (11), 933–938.
Paruelo, J.M., Epstein, H.E., Lauenroth, W.K., Burke, I.C., 1997. ANPP estimates from NDVI for the central grassland region of the United States. Ecology 78 (3), 953–958.
Pennington, T.R., Prado, D.E., Pendry, C.A., 2000. Neotropical seasonally dry forests and Quaternary vegetation changes. J. Biogeogr. 27 (2), 261–273.
Ramankutty, N., Foley, J., Norman, J.M., McSweeney, 2002. The global distribution of cultivable lands: current patterns and sensitivity to possible climate change. Global Ecol. Biogeogr. 11, 377–392.

Ramankutty, N., Evan, A.T., Monfreda, C., Foley, J.A., 2008. Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000. Global Biogeochem. Cycles 22 (1).
Randerson, J.T., et al., 2006. The impact of boreal forest fire on climate warming. Science 314 (5802), 1130–1132.
Remer, L.A., et al., 2005. The MODIS aerosol algorithm, products, and validation. J. Atmos. Sci.—Spec. Sect. 62, 947–973.
Rotenberg, E., Yakir, D., 2010. Contribution of semi-arid forests to the climate system. Science 327, 451–454.
Rotenberg, E., Yakir, D., 2011. Distinct patterns of changes in surface energy budget associated with forestation in the semiarid region. Global Change Biol. 17, 1536–1548.
Rueda, C.V., Baldi, G., Verón, S.R., Jobbágy, E.G., 2013. Human appropriation of primary production in the Dry Chaco. Ecologia Austral 23 (1), 44–54.
Sadras, V., Roget, D., Krause, M., 2003. Dynamic cropping strategies for risk management in dry-land farming systems. Agric. Syst. 76 (3), 929–948.
Salazar, A., Baldi, G., Hirota, M., Syktus, J., McAlpine, C., 2015. Land use and land cover change impacts on the regional climate of non-Amazonian South America: a review. Global Planet. Change 128, 103–119.
Santoni, C.S., Jobbágy, E.G., Contreras, S., 2010. Vadose transport of water and chloride in dry forests of central Argentina: the role of land use and soil texture. Water Resour. Res. 46 (10), W10541.
Schimel, D., et al., 1995. Radiative forcing of climate change. In: Houghton, J.T. (Ed.), Climate Change 1995. The Science of Climate Change. Cambridge Univ. Press, Cambridge, pp. 65––131.
Ahmad, S.B., Lockwood, J.G., 1979. Albedo Prog. Phys. Geogr. 3 (4), 510, http://dx.doi.org/10.1177/030913337900300403.
Sinoquet, H., Andrieu, B., 1993. The geometrical structure of plant canopies: characterization and direct measurement methods. In: Varlet-Grancher, C., Bonhomme, R., Sinoquet, H. (Eds.), Crop Structure and Light Microclimate: Characterization and Applications. INRA, Paris, pp. 131––158.
Somovilla Lumbreras, D., 2014. Efecto de los cambios en el uso del suelo sobre la materia orgánica edáfica, en masas de bosque seco de la provincia de San Luis (Argentina), Valladolid, Palencia España, 178 pp.
Tsvetsinskaya, E.A., Schaaf, C.B., Gao, F., Strahler, A.H., Dickinson, R.E., 2006. Spatial and temporal variability in moderate resolution imaging spectroradiometer–derived surface albedo over global arid regions. J. Geophys. Res. 111, D20106.
Tubiello, F.N., et al., 2015. The contribution of agriculture, forestry and other land use activities to global warming, 1990–2012. Global Change Biol. 21 (7), 2655–2660.
Uppala, S.M., et al., 2005. The ERA-40 re-analysis. Q. J. R. Meteorol. Soc. 131 (612), 2961–3012.
Vallejos, M., et al., 2015. Transformation dynamics of the natural cover in the Dry Chaco ecoregion: a plot level geo-database from 1976 to 2012. J. Arid Environ. 123, 3–11.
Vermote, E.F., El Saleous, N.Z., Justice, C.O., 2002. Atmospheric correction of MODIS data in the visible to middle infrared: first results. Remote Sens. Environ. 83 (1–2), 97–111.
Viglizzo, E.F., Jobbágy, E.G., 2010. Expansion De La Frontera Agropecuaria En Argentina Y Su Impacto Ecologico-Ambiental. Ediciones INTA, Buenos Aires, pp. 102.
Viglizzo, E.F., et al., 2011. Ecological and environmental footprint of 50 years of agricultural expansion in Argentina. Global Change Biol. 17 (2), 959–973.
Volante, J., et al., in press, Expansión agrícola en Argentina, Bolivia, Paraguay, Uruguay y Chile entre 2000–2010. Caracterización espacial mediante series temporales de índices de vegetación. Revista de Investigaciones Agropecuarias.
Ward, D.S., Mahowald, N.M., 2015. Local sources of global climate forcing from different categories of land use activities. Earth Syst. Dynam. 6 (1), 175–194.
Werth, D., Avissar, R., 2002. The local and global effects of Amazon deforestation. J. Geophys. Res. 107, 8087.
Wickham, J.D., Wade, T.G., Riitters, K.H., 2012. Comparison of cropland and forest surface temperatures across the conterminous United States. Agric. Forest Meteorol. 166–167, 137–143.
Zhang, R., Wang, Y.f., Pan, X.p., Hu, Y.x., 2013. Diurnal and seasonal variations of surface albedo in a spring wheat field of arid lands of Northwestern China. Int. J. Biometeorol. 57 (1), 67–73.
Zhao, K., Jackson, R.B., 2013. Biophysical forcings of land-use changes from potential forestry activities in North America. Ecol. Monogr. 84 (2), 329–353.