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# Land use and land cover change impacts on the regional climate of non-Amazonian South America: A review

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ABSTRACT

Land use and land cover change (LUCC) affects regional climate through modifications in the water balance and energy budget. These impacts are frequently expressed by: changes in the amount and frequency of precipitation and alteration of surface temperatures. In South America, most of the studies of the effects of LUCC on the local and regional climate have focused on the Amazon region (54 studies), whereas LUCC within non-Amazonian regions have been largely undermined regardless their potential importance in regulating the regional climate (19 studies). We estimated that 3.6 million km$^2$ of the original natural vegetation cover in non-Amazonian South America were converted into other types of land use, which is about 4 times greater than the historical Amazon deforestation. Moreover, there is evidence showing that LUCC within such fairly neglected ecosystems cause significant reductions in precipitation and increases in surface temperatures, with occasional impacts affecting neighboring or remote areas. We explore the implications of these findings in the context of water security, climatic extremes and future research priorities.



**Contents**



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## 1. Introduction

Land use and land cover change (LUCC) affects climate through changes in moisture and energy budgets (Pielke et al., 2011; IPCC, 2014a; Mahmood et al., 2014). In South America, most of the focus on these impacts has been directed at deforestation of the Amazon forests (e.g., Pires and Costa, 2013). By contrast, non-Amazonian South America has received less attention despite experiencing the highest transformation rates in the tropics (Marris, 2005; Hansen et al., 2013). This is a significant problem because the loss of native ecosystems can modify the local and regional surface–climate coupling through feedback processes, and increase the risks imposed by climate extremes in an area that sustains a human population of over 200 million (Grimm and Tedeschi, 2009).

Non-Amazonian South America, also referred to as non-Amazonian ecosystems, covers an area of more than 12 million km$^2$ and is characterized by a high diversity of biomes including tropical rainforests, tropical savannas, grasslands, shrublands, deserts and a wide array of woodland formations that are distributed according to rainfall, temperature, soil properties and disturbance regimes. Precolonial pressures upon these biomes were expressed through settlement, cultivation, grazing, hunting and burning by indigenous people (Knapp, 2007). However, these changes were temporary and therefore relatively rapidly reversed by ecological succession (Armesto et al., 2010). Since 1500 and especially since 1900, the expansion of European agriculture has resulted in widespread ecosystem transformations. Global demand for food commodities such as soybeans and beef has pushed the expansion of the agro-pastoral frontier into former natural and seminatural areas (Richards et al., 2012). Recent studies have shown high LUCC rates in tropical savannas of Brazil (hereafter referred as Cerrado) (Sano et al., 2010), grasslands in Argentina (Baldi et al., 2006), Atlantic Forests in eastern Brazil (Joly et al., 2014) and the dry forests in the Paraguayan Chaco (Huang et al., 2009). Of the 542,000 km$^2$ of deforestation in South America between 2000 and 2012, 42% occurred in the Amazon region and 58% in the non-Amazonian region (Hansen et al., 2013).

Changes in land use and land cover can have profound impacts on land surface climate feedbacks by altering the exchange of heat, moisture, momentum, trace-gas fluxes and albedo (Bonan, 2008). Cumulatively, they can impact the climate at a local (Montecinos et al., 2008; Hidalgo et al., 2010; Mohamed et al., 2011), regional (Pitman et al., 2004; Roy et al., 2007; Fairman et al., 2011) and even global scales (Bounoua et al., 2002; Snyder et al., 2004; Avissar and Werth, 2005; Feddema et al., 2005; Lawrence et al., 2012). Many of the studies addressing climatic impacts of LUCC focus on the tropical forests, particularly in the Amazon region. Results suggest that tree removal produces a drier and warmer climate due to reductions in evaporative cooling with implications to vegetation dynamics, river discharge and climate extremes (McGuffie et al., 1995; Rocha et al., 2004; D'Almeida et al., 2007; Sampaio et al., 2007; Costa and Pires, 2010; Pires and Costa, 2013; Stickler et al., 2013). However, evidence relating climate and LUCC in other ecosystems of tropical and subtropical South America is scarce and dispersed. The high conversion rates of natural vegetation and the vulnerability of ecosystems to climate variability create an increasing need to identify signals and patterns of the impacts of LUCC on the regional climate. This will better inform climate science and natural resource management. It's been argued that climate impacts induced by LUCC are significantly comparable to those resulting from anthropogenic greenhouse gases (Pielke et al., 2002), particularly at local to regional scales, in which people and ecosystems are mostly affected (Mahmood et al., 2010). Though there is a good understanding of the major biogeophysical feedbacks of Amazon deforestation, land surface climate interactions and their consequences in non-Amazonian South America are much less understood.

In this paper, we review the modeling and empirical evidence that shows the climatic impacts of LUCC in non-Amazonian ecosystems of South America. First, we estimate the original and remaining amount of natural vegetation in the Amazon and in six non-Amazonian ecosystems. We then assess the impacts of LUCC on the climate of non-Amazonian South America and evaluate the implications and potential risks with regard to climate change and future research priorities.

## 2. Methods

### 2.1. Delimiting the Amazon and non-Amazonian South America

We focused on six broad ecosystems, collectively referred as non-Amazonian South America. We also considered the Amazon biome as defined by WWF (2010) to compare surface climate feedback studies between Amazonian and non-Amazonian South America. We defined non-Amazonian ecosystems in South America based on two criteria: 1) they must be located outside the area covered by the Amazon biome and 2) they must exhibit at least one peer-reviewed study describing impacts of land use and land cover change (LUCC) on local or regional climate (see Section 2.4). We geographically delimited them using Olson et al. (2001), MMA/IBAMA (2011a), and MMA/IBAMA (2011b). The final selection covered an area of about 6.3 million km$^2$ and included: 1) Dry Chaco, 2) Cerrado, 3) Temperate Grasslands, 4) Chilean Matorral, 5) Tropical Dry Forests and 6) Atlantic Forest (Fig. 1). These ecosystems represent a variety of functional groups including moist forests, dry broadleaf forests, grasslands, savannas, shrublands, mediterranean forests, and xeric shrublands. All of them have been subjected to extensive anthropogenic modification (Olson et al., 2001; Friedl et al., 2010).

### 2.2. Estimating potential and current natural vegetation cover

LUCC information in South America is highly fragmented and localized. For this reason, we estimated potential and current natural vegetation extent for both regions using different sources: 1) peer-reviewed publications, 2) technical reports and 3) the Collection 5 MODIS Global Land Cover Type for year 2012 (Friedl et al., 2010). We first defined potential forest cover (natural) in the Amazon region as the total area described in WWF (2010) without considering savanna ecoregions as classified by Olson et al. (2001). Then we extracted areas covered by evergreen broadleaf forests in these savannas according to Collection 5 MODIS Global Land Cover Type for year 2012. This procedure added those forests (e.g., gallery forests) distributed in areas dominated by savanna vegetation (e.g., Beni Savannas in Fig. 1) inside the Amazon region and gave us the approximate potential extent of dense moist tropical forest in the Amazon.

We obtained the potential historical natural vegetation extent in non-Amazonian South America from regional and local studies. We used Olson et al. (2001) classification for the Dry Chaco, Temperate Grasslands and the Atlantic Forest; MMA/IBAMA (2011b) for the Cerrado; MMA/IBAMA (2011a) for the Caatinga; Portillo-Quintero and Sánchez-Azofeifa (2010) for the Tropical Dry Forests; and Luebert and Pliscoff (2006) for the Chilean Matorral. We included Caatinga into Tropical Dry Forests as suggested by Portillo-Quintero and Sánchez-Azofeifa (2010). However we presented vegetation change