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The Forests of the Amazon and Cerrado Moderate Regional Climate and Are the Key to the Future

Michael T. Coe[1], Paulo M. Brando[1,2], Linda A. Deegan[1], Marcia N. Macedo[1], Christopher Neill[1], and Divino V. Silvério[2]

Abstract

The role of tropical forests in climate is most often expressed in terms of the carbon they keep out of the atmosphere if deforestation is avoided or the carbon they remove from the atmosphere as they grow. The direct role of forests, particularly in the tropics, in maintaining low surface temperatures and relatively high precipitation has been underappreciated. Recent studies in the Brazilian agricultural frontier indicate that tropical deforestation, for pasture and crop production, has led to significant regional climate change in the last 40 years of a scale much larger than that attributed to the carbon released from deforestation. Deforestation reduces net surface radiation and evapotranspiration, thus increasing sensible heat flux and land surface temperature. In Mato Grosso state, the temperature of the forested Xingu Indigenous Park is 3°C cooler than the surrounding mosaic of pasturelands, croplands, and remaining forest fragments. In the neighboring state of Rondônia, rainfall has significantly decreased and the dry season lengthened as deforestation occurred. Numerical model studies strongly suggest that Brazil's agricultural frontier will be much warmer and dryer in coming decades as greenhouse gas concentrations increase. Thus, in Brazil, it is becoming clear that, because of their capacity to moderate regional climate, preserving tropical forests will be a key component of mitigating exogenously driven future climate change.

Keywords

forests, future, climate, Cerrado, Amazon

Since the mid-1970s, Brazil's Amazon–Cerrado agricultural frontier (Figure 1) has been the planet's largest and most important zone of deforestation, agricultural expansion, and agricultural intensification. Through policy, applied research, and infrastructure development, Brazil has transformed itself from a food importer to one of the world's agricultural powerhouses. Currently, Brazil is second in beef and soy production, third in corn production, and is the top producer in many other commodities such as coffee and sugar cane (Ministry of Agriculture, Brazil [MAPA], 2016; U.S. Department of Agriculture, 2016).

As a result of this agricultural transformation, by 2008, more than 750,000 km^2 of the Brazilian Amazon and 825,000 km^2 of the Cerrado had been deforested (Ministry of the Environment, Brazil [MMA], 2015; Noojipady et al., 2017; Ometto, Aguiar, & Martinelli, 2011). In response, Brazil made specific efforts to combat deforestation through greater enforcement of existing environmental laws, expansion of the protected area system, and industry-led initiatives to combat deforestation (e.g., the soy and beef moratoriums). Together, these efforts greatly reduced Amazon deforestation rates in the mid- and late-2000s, while soy and corn production increased (Gibbs, Munger, et al., 2015; Gibbs, Rausch, 2015; Macedo, 2012; Nepstad et al., 2014). This apparent success was achieved in part by shifting cropland expansion onto already cleared pastures in lieu of clearing new forest areas (DeFries, Herold, Verchot, Macedo, & Shimabukuro, 2013; Macedo, 2012; Macedo & Castello, 2015). It was also connected to intensification of cropping by adoption of soy–corn double-cropping systems. As an

[1]Woods Hole Research Center, Falmouth, MA, USA
[2]Instituto de Pesquisa Ambiental da Amazônia, Belém, Pará, Brazil

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Corresponding Author:
Michael T. Coe, Woods Hole Research Center, Falmouth, MA 02540, USA.
Email: mtcoe@whrc.org

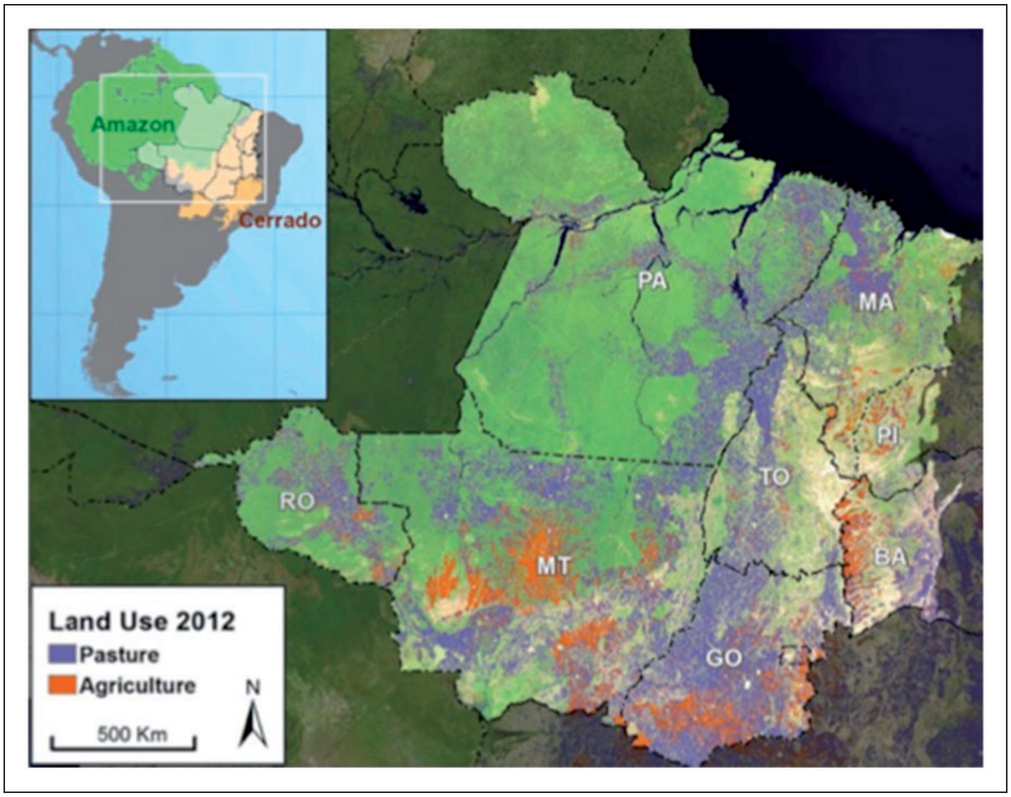

Figure 1. Map of the Amazon–Cerrado agricultural frontier, with crops (red), pasture (purple), forest (green), and savanna (beige).

example, in Mato Grosso state—one of the most active frontiers of agricultural expansion in the early 2000s–double-cropping increased by a factor of 6 to include over half of all croplands by 2011 (Spera et al., 2014). Despite increased intensification and decreased deforestation rates, some deforestation continued, and by 2016, an additional 50,000 km^2 of the Amazon and 40,000 km^2 of the Cerrado had been deforested. This process has transformed much of the Amazon and Cerrado biomes into a complex mosaic of humid rainforests, drought deciduous forests and woodlands, grasses, and intensive croplands and pastures (Figure 1), with significant consequences for the regional climate.

Deforestation, fragmentation, and conversion to agriculture create novel climates at local and continental scales because the new vegetation generally has shallower roots, a shorter growing season, lower water demand, and higher albedo than the natural vegetation it replaced. In Brazil, we have seen how deforestation, primarily by decreasing evapotranspiration (ET) and the surface albedo, increases regional temperature (Figures 2a and B) and may decrease precipitation.

In the process of photosynthesizing and building carbon reserves, forests and woodlands draw water from the soil and release it to the atmosphere. Over the course of a year, a healthy forest returns roughly 2/3 of the incoming precipitation and solar radiation to the atmosphere as ET (Arantes, Ferreira, & Coe, 2016; Lathuiliere, Johnson, & Donner, 2012; Panday, Coe, Macedo, Lefebvre, & Castanho, 2015; Spera, Galford, Coe, Macedo, & Mustard, 2016). A single large tree in the Amazon returns about 500 l of water per day to the atmosphere. In total, forests return about 100 to 150 mm of water to the atmosphere each month across the entire Amazon and Cerrado. This high rate of ET occurs even during a long dry season because mature trees can access water stored deep in the soil column (Panday et al., 2015; Silvério et al., 2015).

This ET flux represents an enormous amount of energy equal to roughly 120 W/m^2. Every square meter of forest removes the heat equivalent of about two 60-W bulbs burning 24 hr per day. Thus, the high ET of forests essentially acts like a very large and powerful air conditioner that maintains relatively low surface temperatures. Cohn points out in this issue that the air conditioning that forests provide positively impacts crop yields (Cohn, 2017). As a recent review by Ellison et al. (2017) has shown, these forest–climate interactions occur throughout the globe at some scale.

In the Amazon and Cerrado environments, we have seen that conversion of forests to pastures and crops decreases annual mean ET by roughly one third (Arantes et al., 2016; Lathuillière et al., 2012; Panday et al., 2015; Spera et al., 2016). Because of this change in ET, the sensible heat flux increases, the annual mean surface temperature increases by more than 5°C locally

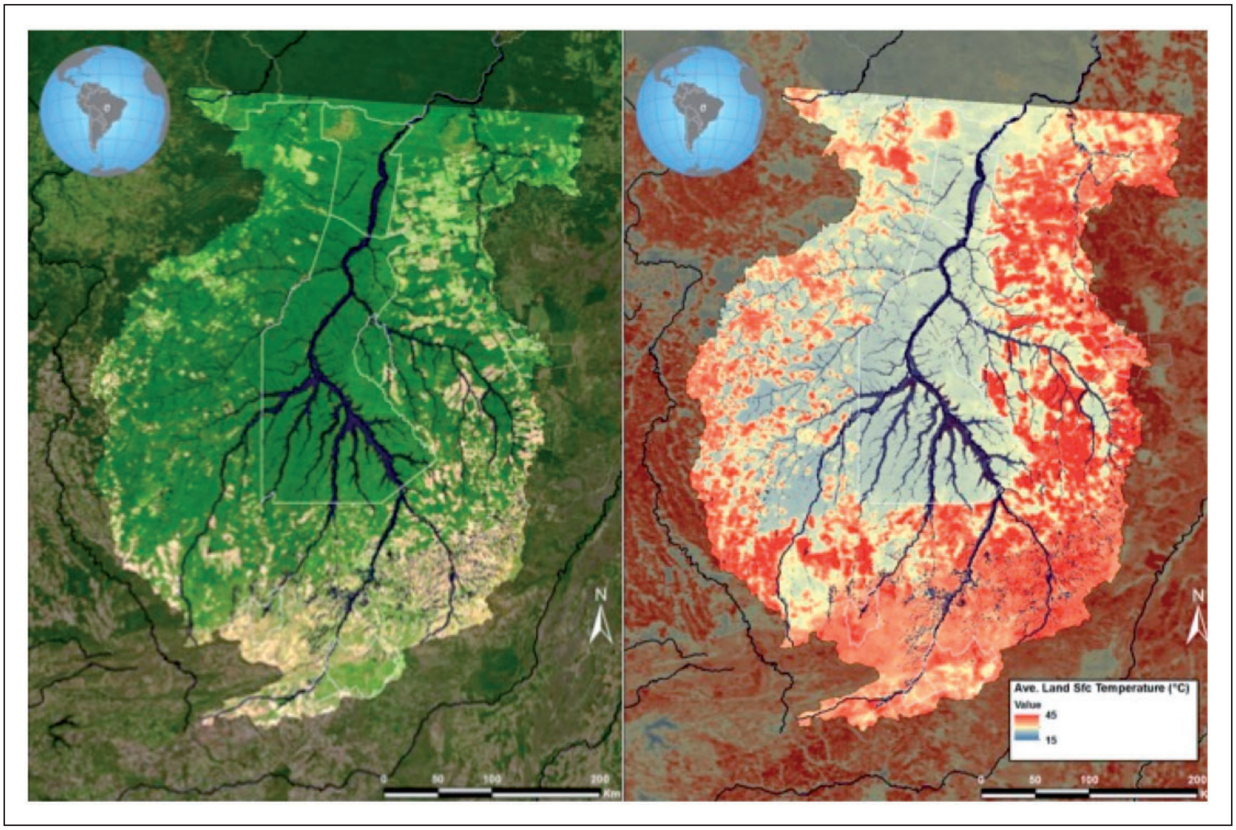

Figure 2. The 176,000 km^2 Upper Xingu watershed in Mato Grosso, Brazil. The landscape (left image) is a mosaic of forests (green) and pasture and agriculture (beige). It also contains the Xingu Indigenous Reserve (white outline in center of watershed), which is nearly 100% forested. The annual mean surface temperature for the period 2001 to 2011 (right image) derived from MODIS data (MOD16a; Mu et al., 2011) shows that coolest conditions (light blue) correspond to the most forested regions and hottest conditions (red) are associated with deforested regions.

(Panday et al. 2015, Silvério et al., 2015), soil moisture increases by about 30%, and stream flow increases 3- to 4-fold (Dias, Macedo, Costa, Coe, & Neill, 2015; Hayhoe et al., 2011; Riskin et al., 2017; Neill et al., 2017). Thus, while at the global scale, we worry (rightfully) about keeping greenhouse gas-driven climate changes to less than 2°C, large areas of the Amazon and Cerrado have already experienced much greater changes due to deforestation alone (Figures 2a and b).

These changes have important consequences for the fragmented forest landscape and for biodiversity (Brawn, 2017). Excessive heat and dryness kills trees along forest edges and facilitates grass invasion (Silvério et al., 2013). Grasses, in turn, can fuel large, intense fires that greatly increase tree mortality (Brando et al., 2014). Damage from windstorms is also greatest near edges (Laurance & Curran, 2008). These processes systematically erode forests inward from forest–agricultural edges—and in the Amazon and Cerrado agricultural frontier, there are an ever-growing number of edges. The 176,000 km^2 Upper Xingu watershed alone (Figure 2) had over 92,000 km of forest edge in 2011 (Brando et al., 2014). During a strong drought in 2010, over 10% of the forests in this watershed burned, both outside and inside protected areas (Brando et al., 2014). Although the drought set the stage for these forest fires, they would not have occurred on that scale without human-derived ignition sources and the man-made hotter and dryer climate at forest edges.

Evidence now suggests that these local changes in the energy and water balance alter wind and rain patterns in the agricultural frontier (Berbert & Costa, 2003, Butt, de Oliveira, & Costa, 2011; Knox, Bisht, Wang, & Bras, 2011), which can affect crop production and forest health over the entire region. Continued deforestation and degradation could significantly reduce annual rainfall and shorten the rainy season throughout the Amazon and Cerrado regions. Once the deforested area crosses a (still unknown) threshold, a reduction and redistribution of continental scale precipitation may occur (Berbert & Costa, 2003; Bonan, DeFries, Coe, & Ojima, 2004; Coe, Costa, & Soares-Filho, 2009; Coe et al., 2013; Costa & Pires, 2010; Costa, Yanagi, Souza, Ribeiro, & Rocha, 2007; Oliveira, Costa, Soares-Filho, & Coe, 2013; Pires

& Costa, 2013; Spracklen, Arnold, & Taylor, 2012; Spracklen & Garcia-Carreras, 2015; Stickler et al., 2013). This could significantly increase drought stress and the vulnerability of remaining Amazon forests to fire and drought (Brando et al., 2014). It may also jeopardize the productivity of, and investments in, expansion and intensification of Amazon and Cerrado rainfed cropland agriculture (Oliveira et al., 2013).

Brazil has aggressively pursued agricultural intensification in the Amazon and Cerrado biomes (Spera, 2017), which has positively impacted its productivity (Goldsmith, 2017), economy, and the well-being of its people (VanWey, Spera, de Sa, Mahr, & Mustard, 2013). At the same time, this region has become the keystone of Brazil's National Climate Change Plan, which aims to reduce carbon emissions by ending illegal deforestation, protecting the carbon contained in remaining Amazon forests and Cerrado woodlands, and restoring between 12 and 20 million ha of forestlands. What is becoming clear is that the forests themselves are a key component of the climate system and, therefore, of the goals that Brazil is attempting to achieve. The success or failure of the simultaneous push for greater agricultural production, and reduced forest carbon emissions will depend strongly on preserving remaining forests or even reforesting cleared areas.

Finally, accelerating greenhouse gas-driven climate changes are expected to result in a warmer and dryer climate for much of the Amazon and Cerrado agricultural frontier (Duffy, Brando, Asner, & Field, 2015). Significantly reducing large-scale deforestation and forest degradation has been very difficult to achieve and maintain over the long term but given the moderating affect of forests on climate, this is precisely what must occur in order to avoid potentially catastrophic climate change in this region. Thus, over the next decades, the pathways chosen by Brazil to pursue their often-competing development and carbon emissions objectives will determine whether the region's forests continue to sustain regional climate and rainfall or whether the climate crosses a tipping point that forces a shift in Brazil's conservation, agriculture, and development strategies.

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