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# REDD+ implementation in a high forest low deforestation area: Constraints on monitoring forest carbon emissions

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## ABSTRACT

Reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (REDD+), is still a promising mechanism of the UNFCCC for many tropical countries that would like to receive a fair financial compensation for their historical and current efforts to avoid forest conversion at the expense of more economically land uses. Brazil has a great opportunity to successfully participate in REDD+ not only because of its huge Amazon forest area (ca. 4 million $km^2$) but also because of its advanced forest monitoring system “PRODES”. However, this opportunity could be threatened due to the current differentiated monitoring capacities of most Brazilian Amazon states, markedly in High-Forest and Low-Deforestation (HFLD) regions. This is evident in the State of Amapá, which despite its political will to support actions towards the design of its REDD+ strategy, is still struggling with key technical aspects of forest monitoring. To address this issue and to strengthen the ongoing REDD+ design process we assessed a) land use and land cover (LULC) changes for period of 23 years (1985–2008); b) estimated $CO_2$ emissions associated to these LULC changes; c) identified the main drivers and agents of deforestation, and d) discussed policy implications for REDD+ implementation in a HFLD area. We applied a methodology, which is capable of reducing cloud cover using temporal filters on the classified images, detecting deforestation (and forest degradation) in areas as small as 1 ha, and used the decision tree method to identify different LULC types. This methodology was able to demonstrate that forest cover in northern Amapá has remained almost untouched during the observed period of 23-years. As many other HFLD areas, this region has a great potential to receive financial benefits from the REDD+ mechanism, especially from voluntary markets that are largely interested in the conservation value of these areas. However, the use of high accuracy LULC classification approaches, with appropriate Measuring, Reporting and Verification systems should be part of the REDD+ implementation strategy of HFLD areas towards having high standards for certified carbon, and therefore improved chances to receive better prices for carbon offsets. The potential of REDD+ to be a fair and efficient mechanism will also depend on the recognition of the historical efforts to avoid deforestation in HFLD areas, mainly by Federal Governments, as an incentive for low-carbon development.

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## 1. Introduction

The reduction of emissions from deforestation and forest degradation (REDD) in developing countries was officially recognised as an important and feasible global climate change mitigation strategy as a result of the negotiations at the 13th Conference of the Parties (COP13) of the United Nations Framework Convention on Climate Change (UNFCCC) in 2007 in Bali, Indonesia (CGEE, 2011; UNFCCC, 2007). Later in 2009, at COP 15 in Copenhagen, the role of forest conservation, the sustainable management of forests and the enhancement of forest carbon stocks were added to the initial concept, expanding the character of this mitigation tool (REDD+). More recently in 2013, at COP 19 in Warsaw, a comprehensive Framework for REDD+ was put forward (UNFCCC, 2016a) and was reinforced at COP 21 in Paris, by the agreement of 195 countries to take action to implement and support the existing framework concerning land use and forest (Article 5 of Paris Agreement) under the scope of UNFCCC (UNFCCC, 2016b).

The motivations for supporting the implementation of REDD+ mechanism included not only that a large quantity of global greenhouse gas (GHG) emissions comes from changes in forest cover (ca. 20%), but also that it may represent a cost-effective approach compared to other UNFCCC mitigation options proposed so far (Barua et al., 2014; Delacote et al., 2014; Ezzine-de-Blas et al., 2011). Although such mechanism is seen as a shot on one's own feet for some, others believe that it could be a bridge to a decreasing fossil fuel world (Houghton et al., 2015; Schaap, 2016; Wolosin et al., 2016). With low cost and quick results, the cease of deforestation and degradation aligned with regrowing and restoration of forests is estimated to reduce total emissions by as much as 5 Pg C $yr^{-1}$ (Houghton et al., 2015).

In Brazil, the REDD+ policy framework is evolving rapidly. The successful implementation of deforestation (PRODES) and degradation (DEGRAD) monitoring systems in the Brazilian Amazon (Angelsen, 2009, 2012; May et al., 2016) allowed the establishment of the national reference level, as well as REDD+ National Strategy (Brazil, 2016). However, the differentiated monitoring capacities between the Federal and Amazonian states, as well as the divergence on how to implement the mechanism nationally and sub-nationally, have slowed the pace of REDD+ implementation.

Despite the positive achievement of PRODES monitoring system for detecting Brazilian Amazon deforestation, it has also shown important monitoring limitations, such as: a) challenges in dealing with cloudy conditions; b) detecting clearings in small patches (areas smaller than 3 ha); c) monitoring land use change after first forest clearing; d) accounting for secondary forest regrowth and clearings; and e) not detecting the agents and drivers of change (Reimer et al., 2012). These limitations have historically affected proper estimation of annual deforestation rates for some Amazonian states, which have tried to fulfil these gaps by developing State level monitoring systems.

In the State of Amapá these limitations are of particular concern for REDD+ implementation because it has historically been the least deforested State of the Brazilian Amazon, with zero deforestation reported for several years during the period considered by the federal government (1996–2005) as the REDD+ baseline for the Amazon region (GCF, 2014). High accuracy classification approaches in regions with trajectories of low-deforestation rates as in the State of Amapá, can make a substantial difference on the economic return of the investment (Reimer et al., 2012), as well as on the design of a reliable Measuring, Reporting and Verification (MRV) system. Reliable MRV system is a requirement for implementation of the REDD+ mechanism and for achieving high certification schemes of forest carbon.

Proper estimation of annual deforestation rate is especially relevant for the North region of Amapá due to its high-forest and low-deforestation (HFLD) condition (Griscom et al., 2009; White and Minang, 2011) and the potential threat of forest encroachment from existing productive activities and anthropization due to higher migration dynamics. In addition, the State government policies are oriented to promote economic growth by encouraging agriculture expansion and improving the existing road infrastructure. It is expected, in the short term, to have the federal road BR-156 pavement completed and the binational bridge over the Oiapoque river opened, to facilitate the drainage of local agricultural production and the connection between Amapa and French Guyana (Picanço, 2014; SEMA, 2013). It has a high potential to change the current dynamics of land use of the region.

This study aimed at analysing the dynamics of the land use and land cover (LULC) changes and their associated carbon emissions in the northern region of the state of Amapá for a period of 23 years (1985–2008), to provide policy makers with technically sound information to address these issues. We sought to quantify land use and land cover (LULC) changes and their associated carbon emissions, identify the drivers and agents associated to forest conversion and discuss the implications of implementing REDD+ in a high forest low deforestation area.

## 2. Material and methods

### *2.1. Study site*

The study area encompasses a total area of 17.302,04 $km^2$ located in the northern region of the State of Amapá (02°24′32″ and 04°01′12″ North, and 51°38′59″ and 52°00′04″ West) (Fig. 1). It is almost entirely inserted in the Guiana Shield region cover, with vegetation consisting of Tropical Ombrophilous Submontane Forest (82.2%), Tropical Ombrophilous Lowland Forest (4.7%), Tree Savanna (3.1%) and Tropical Ombrophilous Alluvial Forest (0.7%). It is characterized by large-sized protected areas with a variety of natural landscapes, low-density population centres (i.e. < 5000 inhabitants), and limited access to remote areas, all of which had led to a naturally well-conserved forest and high levels of biodiversity and endemism, which is common in most of the Guiana Shield region (Hollowell and Reynolds, 2005; IEF, 2013).

Land is primarily public-owned and occupied by small landholders from land reform settlements, afro-descendants and indigenous people from community territories (Fig. 1). Due to the spatial concentration of the existing land uses and for purposes of simplifying the analysis, the study area was divided into three zones: i) northern, ii) south-eastern and iii) south-western (Fig. 2).

### *2.2. Land use and land cover changes*

#### *2.2.1. Data processing*

Land-use and land-cover (LULC) changes were multi-temporally analysed using a set of 49 Landsat-5 TM images (30 m pixel) that were acquired from the Catalogue of National Institute for Space Research (INPE) from the years 1985, 1989, 1991, 1997, 2000, 2004 and 2008 with a cloud cover percentage less than 30%. But for this study, we examined only the 14 images from the years 1985 and 2008. This dataset was processed using a combination of different images processing techniques, with the construction of a synthesis image for each year, according to the methodology described by IMAZON (2013).

Each synthesis image was constructed from a set of images co-registered using the triangulation algorithm for pixel interpolation and nearest neighborhood resampling, with 20 ground control points (GCPs), which gave a root mean square (RMS) error of 0.5 pixel. Each co-registered image was processed applying atmospheric, haze (Carlotto, 1999) and radiometric correction (Chander and Markham, 2003). We applied spectral mixture modelling (SMM) technique (Adams et al., 1993) to obtain four fraction images: green vegetation (GV), non-photosynthetic vegetation (NPV), soil (S) and cloud (C). Thereafter, we calculated the normalized difference fraction index (NDFI) (Souza et al., 2005), synthesising the fraction images, to generate scenes with better ability to detect damage to the forest canopy, and applied a temporal filter to remove clouds (Souza and Siqueira, 2013). To classify forest, non-forest (deforestation and forest

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