Observatory of the dynamics of interactions between societies and environment in the amazon

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Introduction

The Amazon region, one of the most diverse terrestrial and aquatic ecosystems in the world, provides numerous essential ecosystem services, including food production, biodiversity conservation, carbon storage, hydrology and climate regulation (Laurance et al. 2001a). In the five past decades, considerable public investments have encouraged economic growth in the Amazon region, leading to record expansion of the agricultural sector but also important development within the mining sector and hydroelectric dams (Ferreira et al. 2014). These rapid changes threaten Amazonian ecosystems and services provided (Fearnisde 2002, Laurance et al. 2001b). The Amazon basin environment is now considered to be in transition to a disturbance-dominated regime (Davidson et al., 2012). The impacts of deforestation and agricultural development in the Amazon on local (Dubreuil et al. 2012) and regional (Funatsu et al. 2012, Swann et al. 2015, Khanna et al. 2017) climate and hydrosystems are of particular concern.

Because of its acknowledged importance for global environmental and climate issues, the Amazon region as attracted researchers from around the world for decades. Different networks have been structured between European and Brazilian researchers with specific focus related to climatic and land cover and land use changes and their relationships and effects upon sustainable development, human well-being health, terrestrial and aquatic ecosystems. ODYSSEA has proposed to promote exchange between these independent networks with the objective of capitalizing a broad know-how and knowledge on different facets of the Amazonian environmental and social interface.

WP#3 gathers scientists engaged in the collection of environmental data and the development of monitoring and analysis tools in different and contrasted sites in the Brazilian Amazon. One of the main challenges is to bring these scientists to exchange their knowledge and know-how, in view of developing a relevant monitoring system and a set of indicators at the landscape level that permits assessing ecosystems and the state of natural resources.

This report consists in a first step toward this objective. It is organized into 4 main parts. The first section is related to some indicators of climatic and hydrological changes deduced from datasets from specific regions in the Amazon, namely the Mato Grosso and Pará states. Section 2 explores new methodologies to follow environmental changes with an application to deforestation dynamics in protected areas and an application to detect fires. Section 3 exposes environmental changes related with land use changes and their implications upon soil sustainability, water resource dynamics, from the example of Mato Grosso and Pará state. Section 4 presents the data available for ODYSSEA project that could be mobilized to produce a set of indicators.

The report is based on data available in the team and a synthesis of some of the activities conducted by the ODYSSEA network. The ODYSSEA scientific animation around WP3 activities aims at building of a more systematic review framed by the available historical data (see section 4), in view of a peer international publication. This report is a first step toward this goal.

Section 1 Indicators of Climatic and hydrological changes

In the last few decades, anthropogenic activities have impacted Amazonian ecosystems and threatened the numerous essential services they provide. This issue is particularly significant in the regions of the basin that have undergone intense land cover and land use changes, especially related to the rapid advance of a very dynamic pioneer frontier in the so-called “Arc of deforestation” (e.g., Dubreuil et al. 2005, Arvor et al. 2012, Morton et al. 2006, Brando et al. 2014, Arvor et al. 2016).

Here, we propose a first analysis of climatic and hydrologic changes for two regions of the Amazon affected by intense land cover and land use changes: the state of Mato Grosso and the area of Santarem (state of Pará). While the Mato Grosso study is based on remote sensing analysis and has a regional scope, the study in the Santarém region is based on in situ data and has a rather local scope. We chose to highlight these two contrasted methodological approaches to illustrate the variety of environmental works conducted in WP#3. Both approaches, however, converge in results to detect significant changes in the last few decades.

Changes in Annual Rainfall in the Southern Amazon

Study site

In the present analysis, the Southern Amazon includes the Brazilian states of Mato Grosso and Rondônia and northern Bolivia (Figure 1). Its climate is characterized by a well-defined rainy season that lasts from September/November to April/May, and is primarily controlled by the South American monsoon system (SAMS) (Zhou et al. 1998, Gan et al. 2004, Gan et al. 2005, Liebmann et al. 2007, Silva et al. 2012, Vera et al. 2006, Marengo et al. 2012). This seasonal behavior is mainly driven by synoptic atmospheric patterns, i.e., (1) the high pressure of the Brazilian and South Atlantic anticyclone from May to September; and (2) the interactions between the Intertropical Convergence Zone and the South Atlantic Convergence Zone during austral summer (Espinoza et al. 2009). Beyond these seasonal mechanisms, rainfall is influenced by: (1) the atmospheric flow of water vapor from the Atlantic Ocean and connections with the Atlantic and Pacific sea surface temperatures (Ronchail et al. 2002, Yoon and Zeng 2010, Marengo et al. 2016, Molina-Carpio et al. 2017); and (2) a large hydrological recycling process above the forests (Salati et al. 1979, Makarieva et al. 2013, Boers et al. 2017, Zemp et al. 2017). The large uncertainty of the ocean and continent surface coupling (Yoon and Zeng 2010, Liebmann et al. 2001, Yin et al. 2014) drives regional and interannual rainfall variability, while the strong heterogeneity of the structure and intensity of the convection related to evapotranspiration influences fine/local spatio-temporal variability. The intense land use changes, mainly characterized by high deforestation rates, that have taken place in this pioneer active frontier region in the last four decades partly explain the observed trend toward increased seasonality (Durieux et al. 2003) and a shortening of the rainy season (Fu et al. 2013, Boisier et al. 2015). Such trends may have irreversible ecological impacts (Zemp et al. 2017) and affect agricultural activities, which depend on the quantity of rainfall and temporal patterns (Arvor et al. 2014, Cohn et al. 2016, Arvor et al. 2017).

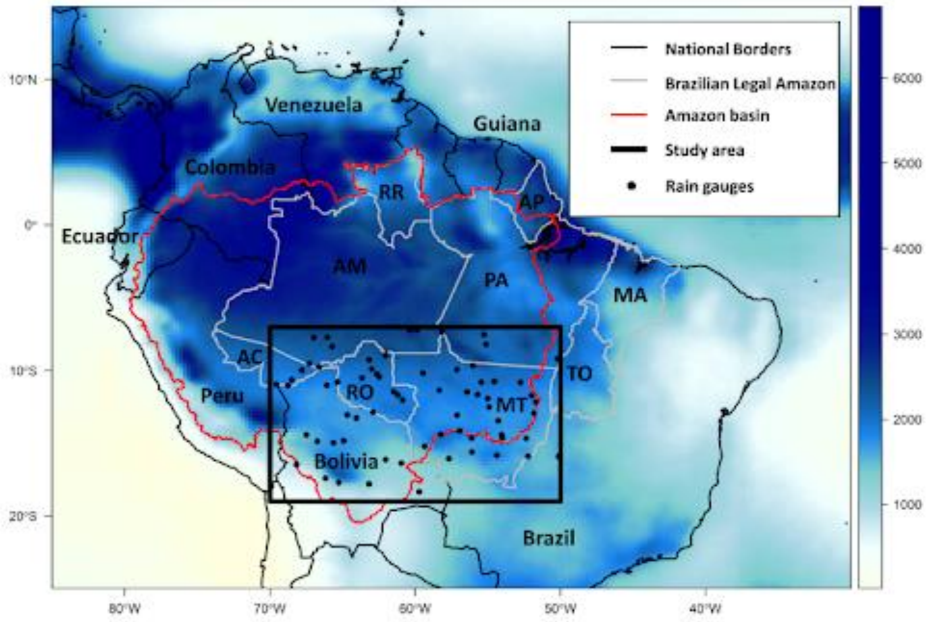

Figure 1 : Mean annual rainfall (1983–2014, computed per calendar year) in the Amazon measured using the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks—Climate Data Record (PERSIANN-CDR) data with location of the study area (southern Amazon). The acronyms stand for Brazilian states: AC: Acre, AM: Amazonas, AP: Amapa, MA: Maranhão, MT: Mato Grosso, PA: Pará, RO: Rondônia, RR: Roraima, TO: Tocantins

Objective

The objective is to assess changes in annual precipitations in the southern Amazon since the early 1980s with remote sensing data.

Data

The Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks—Climate Data Record (PERSIANN-CDR) product was recently released by the National Oceanic and Atmospheric Administration (NOAA; Ashouri et al. 2015, Sorooshian et al. 2014). It consists of daily precipitation estimates based on infrared and daytime visible imagery from geostationary satellites, and is built on neural networks classification and approximation techniques (Hsu et al. 1997, Hsu et al. 1999). The spatial coverage ranges from 60°S to 60°N and the spatial resolution is of 0.25° in latitude and in longitude. Data are available for the 1983–delayed present period. For this study we used data for the period 1983–2014.

Method

The annual precipitations were computed on a pixel-by-pixel basis for each hydrological year of the dataset (1983 to 2013 with the end of year 2013 occurring in 2014). Finally, we calculated the averages and trends for each of the four metrics of the rainy season computed over the 1983–2013 time period. Trends were computed based on the Mann-Kendall test (e.g., Debortoli et al. 2015). Here we present only the coefficient t (*tau*) of Mann–Kendall, which varies from -1 to +1. The value of -1 (+1) indicates a trend of continuous decrease (continuous growth) in the study period. The value 0 indicates that there is no trend. Finally, a *p-value* of less than 0.05 was used to assess whether trends were significant.

Results

Patterns of annual rainfall are consistent with those found in other studies on rainfall regimes in the Amazon (Debortoli et al. 2015, Espinoza et al. 2009). The regions with the highest variability are southern Pará, southern Amazonas and Bolivia. The remote sensing estimates made it possible to highlight specific regions such as the Serra do Cachimbo in southern Pará, which appears to be rainier than the surrounding areas.

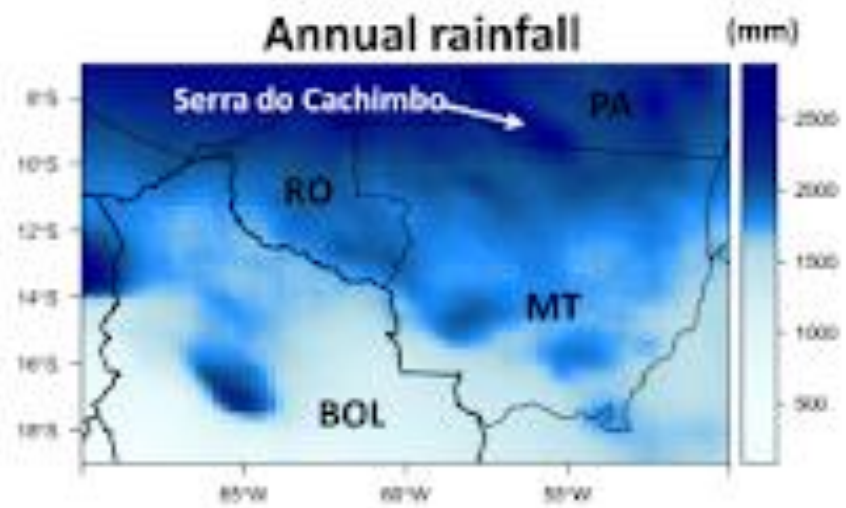

Figure **2**. Mean annual rainfall in the southern Amazon estimated from PERSIANN-CDR for the 1983–2013 time period. (PA = Pará, MT = Mato Grosso, RO = Rondônia, BOL = Bolivia)

Concerning long-term changes in rainfall patterns, annual amounts tend to decrease regionally, although trends vary strongly in the study area and are mainly statistically insignificant, except for regions in Bolivia and western Mato Grosso.

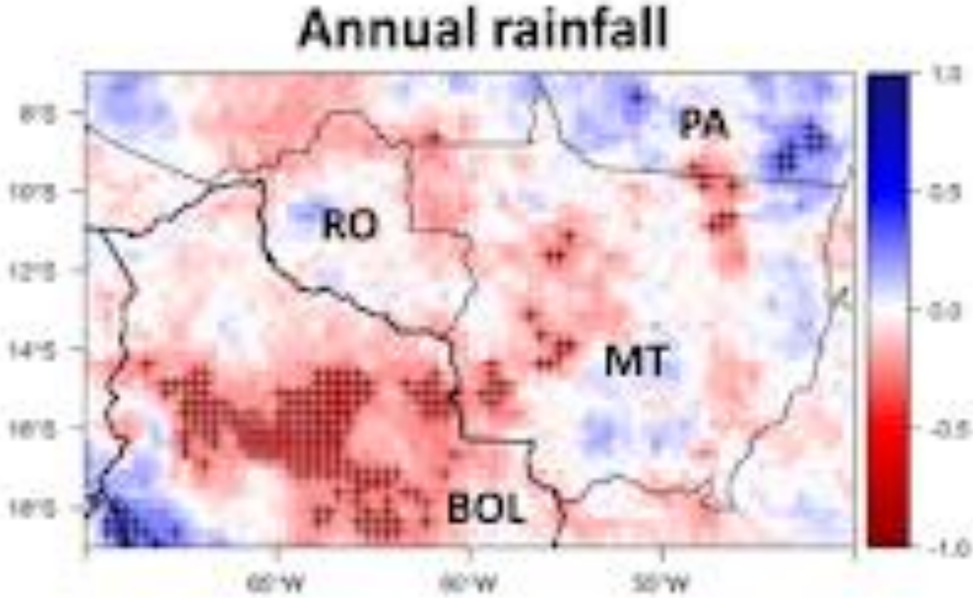

Figure **3**. Trends in annual rainfall in the southern Amazon estimated from PERSIANN-CDR for the 1983–2013 time period. The trends correspond to the t of Mann–Kendall. Significant trends are indicated with crosses (PA = Pará, MT = Mato Grosso, RO = Rondônia, BOL = Bolivia).

Perspectives

In the Southern Amazon, the temporal patterns of precipitations may be more important than annual rainfall for some human activities, especially agriculture. For example, the adoption of single-or double-cropping systems depends on the length of the rainy season. We thus intend to perform a similar analysis but integrating indicators of the onset, demise and length of the rainy season. These indicators will be computed based on the Anomalous Accumulation method proposed by Liebmann et al. (2001).

Changes in hydrological cycles in the region of Santarem, state of Para

Here we analyzed the rainfall and water level records from the Santarém site, and more precisely from the region of the Lago Grande de Curuai. This analysis supports the definition of potential scenarios we aim to develop with local stakeholders in this region. Indeed these changes may have impacts on agricultural practices in the region, in particular in relation with cattle ranching activities which are directly related with floodplain natural pastures exploitation (see section 3).

Study site

The floodplain extends from west to east between 56.10 ° W and 55.00 ° W and from south to north between 2.3 ° S and 1.9 ° S, on the right bank of the Amazon river in front of the city of Óbidos (Figure 4). Several channels connect it with the Amazon, only the one located further downstream is permanent and can function either as an entrance or a water outlet depending on the difference in water level between the Amazon and the floodplain. It is composed of different water bodies temporarily interconnected with different qualities of water especially in terms of suspended matter, dissolved organic carbon. The flood extent varies nearly linearly with the water level measured in Curuai ranging between 500 km2 and 2500 km2 for a water level varying between 3 and 11.5 m. In the south, the floodplain receives inputs from several small rivers (igarapés) that drain a total area of about 1400 km2 (Bonnet et al., 2008). Vegetation cover in the floodable areas is distributed between alluvial forest and natural pastures. In uplands, cover is distributed between primary and secondary forests, crops and pastures.

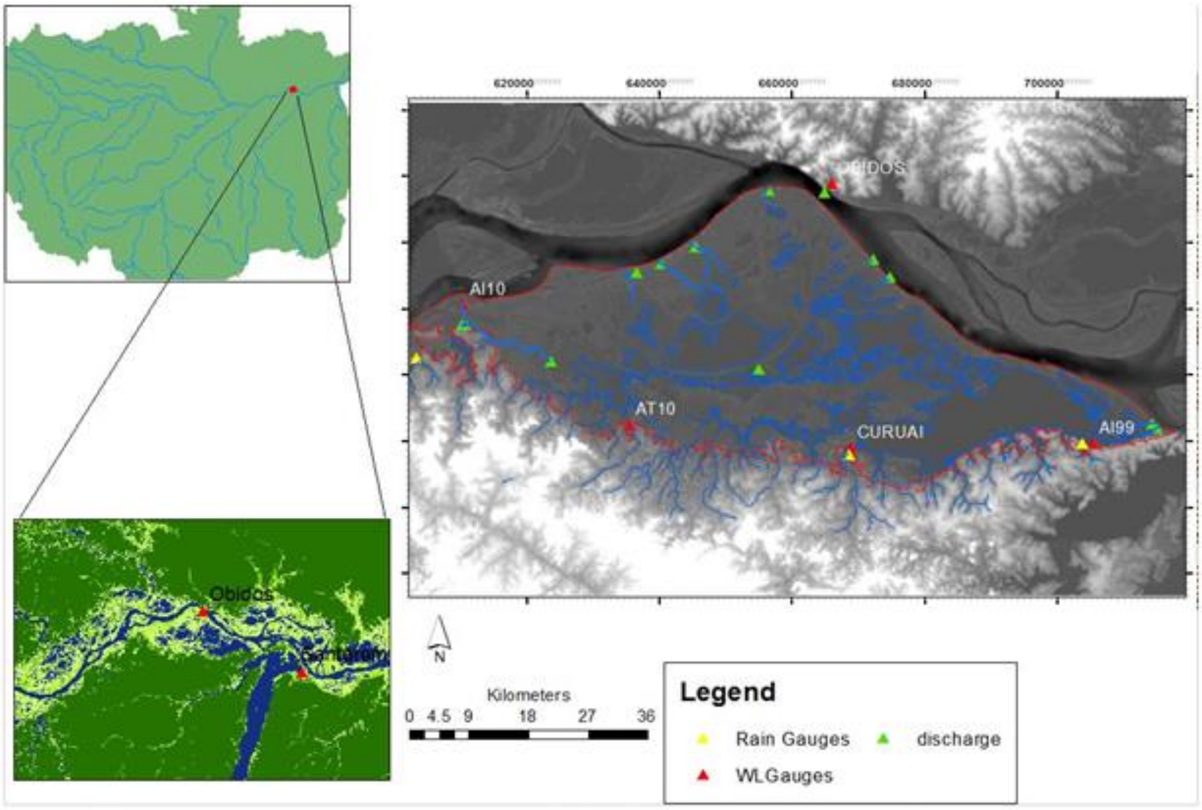

Figure **4**. The Curuai floodplain site. Water level gauge and rainfall data collected in Curuai are explored here to detect changes in floodplain hydrological dynamics and rainfall temporal distribution.

Rainfall distribution in the last few decades

Over the period from 1971 to 2016, the annual rainfall amount measured at Curuai ranges between 958 (in 1983) and 2836 (in 1988) mm, with a mean value of 1883 mm (Figure 5).

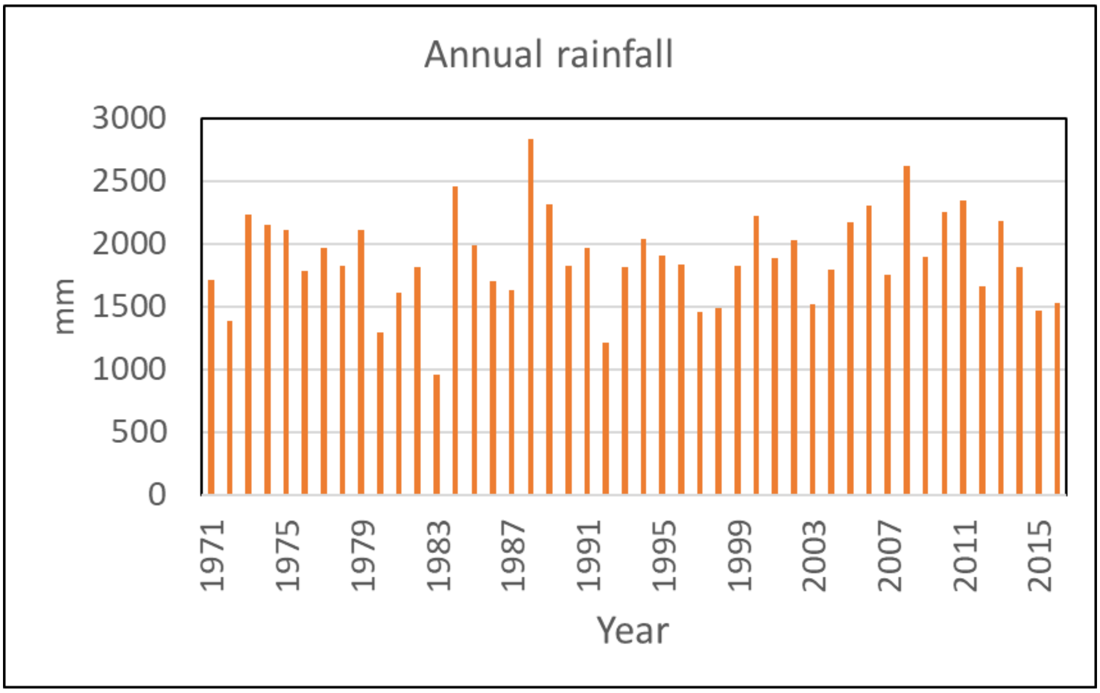

Figure **5** : Annual rainfall amount from 1971 to 2016 measured at Curuai.

As reported from longer time series, there is no systematic unidirectional long-term trends towards drier or wetter conditions (Marengo, 2009). Conversely, rainfall distribution is relatively cyclic with a succession of relatively wet and dry periods of approximately 10 years (Figure 6).

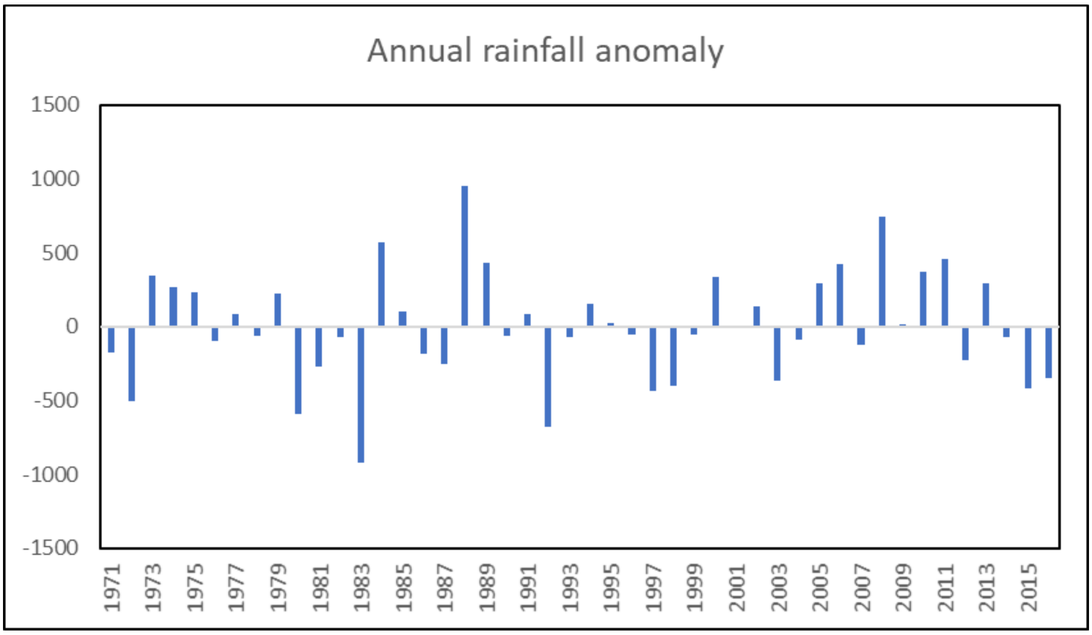

Figure **6**. Anomaly computed from the long-term mean value

At the basin scale, Gloor et al, (2013) reported an intensification of annual rainfall amount for the 2001-2010 period of about 10% when compared to the 1981-1990 period. Here we registered an increase of 4% between these two periods.

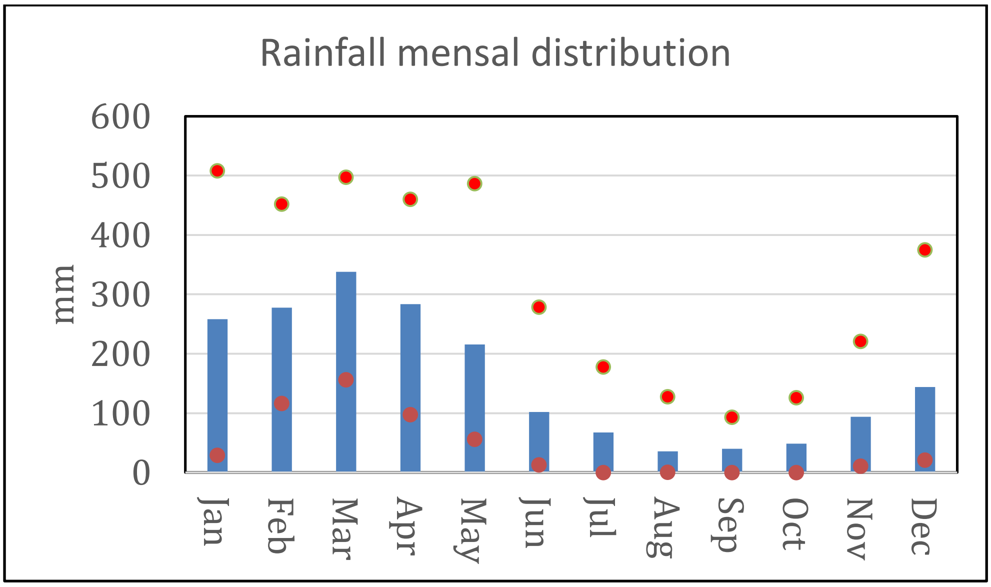

Figure **7** : Mean mensal rainfall over the 1971 to 2016 period with min and max

Rainfall from January to May represents about 70% of the total amount each year (Figure 7), March being the wettest month of the year. However, monthly amounts present strong interannual variations, with potential impacts upon crops. While December, July, August and October are nearly 20% drier over the 2001-2010 than over the 1981-1990 period, March and April are roughly 30% wetter. Consequently, the cumulative amount changed significantly between 1981-1990 and 2001-2010 periods (Figure 8). For example, 1400 mm (representing ~70% of the annual amount) was reached by the end of May during the 1981-1990 period, while today it is reached in April.

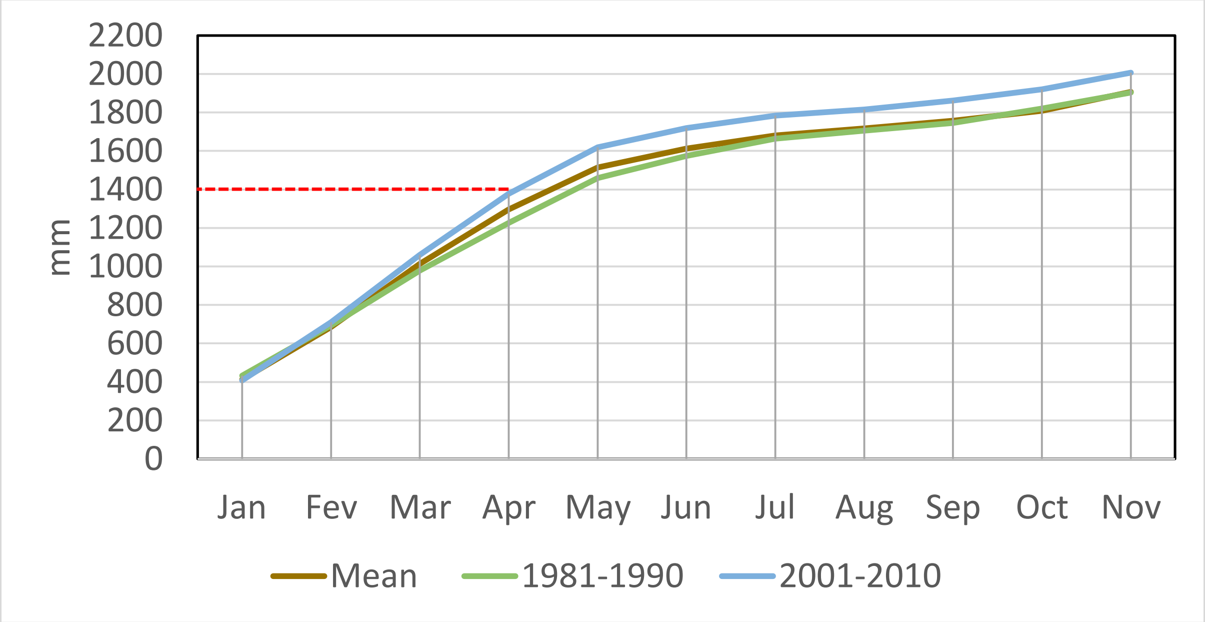

Figure **8**. Mean cumulative rainfall amount for the 1981-1990, 2001-2010 periods and for the whole period from 1981 to 2016

Water level dynamics changes in the last 30 years

The water level measured at the Curuai gauge reflects the water level measured at the Óbidos gauge, the most downstream gauge station along the Amazon River. As reported in other Amazonian floodplain studies, each year, the floodplain had a large seasonal variation in storage because of the large variations in the mainstream's water level. Floodplain water storage begins early in November and lasts until June. From June until the end of the water year, the floodplain storage decreases (Figure 10).

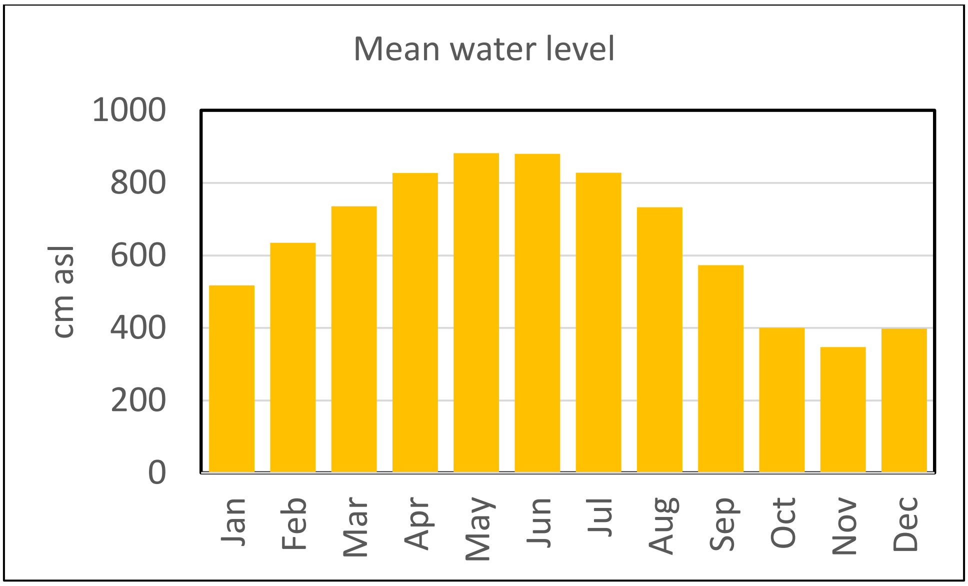

Figure **9**. Mean water level based on the 1981-2016 period

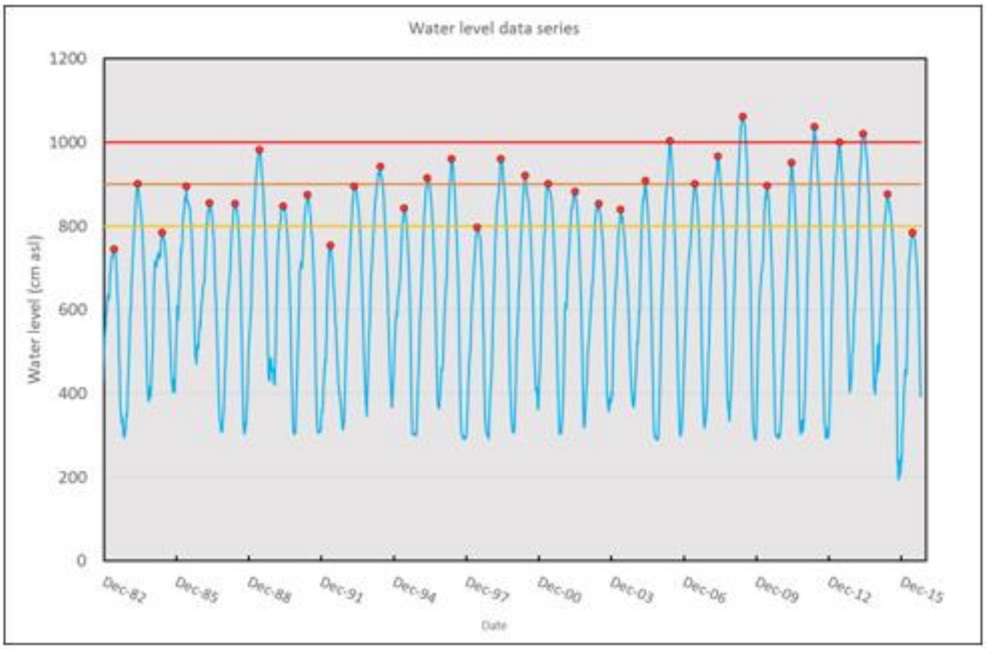

Figure **10**. Water level measured at the Curuai gauge

Similarly, as rainfall time series, there is no unidirectional long-term trend towards higher or lower flood (drought) peaks over the period of records (1982-2016) (Figure 10). But because of rainfall intensification since 2001 at the basin scale (Gloor et al, 2013), the maximum water levels attained each year during the period 2001-2016 are significantly higher than during the period 83-2000 (Kruskal-Wallis test, $p < 0.03$). The water level median value was 875 cm for the first period against 908 cm for the second period. In contrast, the minimum levels achieved did not differ significantly between the two periods with a median value of 317 and 310 cm for the first and second periods, respectively. From 1989, flood maximum water level regularly exceeded 900 cm and from 2006 exceeded 1000 cm.

The rising or flushing rate (i.e. the water level variation within a given time-period) varies significantly interannually and between the two considered periods. The WL mean rise between January 1st and April 1st is 335 ± 79 cm (equivalent to a mean daily WL variation rate of 3.7 ± 0.8 cm/day) over the 1983-2016 period. It was 308 cm during the 1983-2000 period, while it was 368 over the second period (2001-2016). Similarly, the mean WL decrease between September 1st and November 1st over the first period was 287 cm, while it was 348 cm over the second. Thus, water level rises and decreases quicker during the 2001-2016 period than during the 1983-2000 period. But there is no statistically significant relationship between the rising or decreasing WL rate and the maximum or minimum water level reached each year.

Section 2 New methodologies to follow environmental changes

Deforestation dynamics in Protected Areas of Brazil: Comparing two sources of derived remote sensing data

Problem

Tropical deforestation and forest disturbance related with land use changes are one of the great concerns of the research community since it leads to the destruction and degradation of natural ecosystems with severe implications on the decline of global biodiversity (Arima et al., 2005; Arima et al., 2008). Brazil, with the largest continuous region of tropical rain forest in the world located in Brazilian Legal Amazon (BLA), is among the countries with the highest modifications. The long history of deforestation in BLA is strictly linked with the colonization policies implemented since the early 1960s, the investments in infrastructure (i.e. an intensive road building) and the fiscal incentives to promote economic activities, particularly those related with large-scale cattle ranching and agriculture (Carvalho et al, 2002; Kirby et al., 2006).

Objective

The objective is to analyze deforestation dynamics in Protected Areas (PAs) of BLA and in a buffer zone, in the period 2002-2016, through two different datasets: Forest Cover

Loss produced by Hansen Global Forest Change Dataset (HD) and Deforestation maps (PD) make available by the Brazilian National Institute for Space Research (INPE) through PRODES project. Moreover, it intends to understand if global data, produced with automated methods, have enough accuracy that can be used at a regional scale allowing to reduce time consuming in the production of local data using a combination of automated and manual methods.

Study site and data

An intensive network of Protected Areas cover Brazil (Figure 11), especially after the year 2000 when it was implemented the Brazilian National System of Nature Conservation Units (Law 9.985 July 18, 2000; Decree 4.340, August 22, 2002; Decree 5.746, April 5, 2006) (SNUC, 2011; Walker et al., 2009) with the purpose of halting the spread of deforestation. They delimit large natural and semi-natural areas, contributing to the protection of species, habitats, territories and traditional human populations (Nogueira et al., 2017). Data includes Forest cover loss produced by Hansen dataset, available yearly that quantifies any tree cover loss (considering any type of forest and dynamic) against a baseline of year 2000 forest cover and deforestation data produced by PRODES Project that detects only large-scale deforestation of disturbed and undisturbed primary forest, old grow forests of dense humid tropical forest biome.

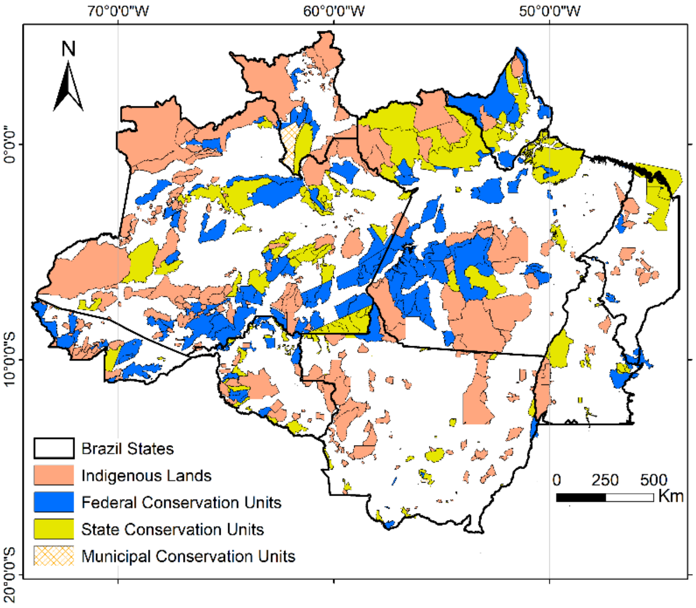

Figure **11**. Study area: network of Protected Areas (Conservation Units and Indigenous Lands)

Results

In BLA, the PAs are characterized by several forest loss fluctuations between 2002-2016 (Figure 12). The trend of annual forest loss extent was different for HD and PD. The first increased from 176 847.6 ha in 2002 to 707 263.0 ha in 2016, and from 479 742.9 ha in 2002 to 702 947.95 ha in 2016, inside and outside PAs respectively, while the second decreased from 250 057.1 ha in 2002 to 97 053.3 ha in 2016, and 465 762.3 ha to 201 390.6 ha. Outside PAs, both datasets presented higher forest loss.

Results can be explained by different forest definitions adopted. The HD considers all forest types and forest dynamics while PD considers only forest losses associated with Primary forest. This can contribute to an overestimation of HD data when compared with PD. Additional analysis are being done according to the level of protection of PAs (Integral, Sustainable-Use, Indigenous Lands, and Environment Protection Areas), as well as, the development of a fragmentation indicator that allows having a perspective in BLA of the level of forest fragmentation of protected areas and the effectiveness of the protection measures.

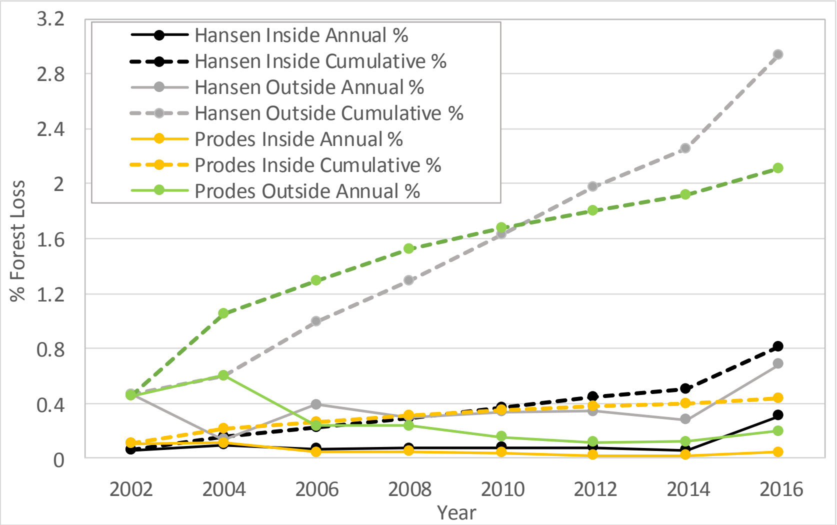

Figure **12**. Annual and cumulative forest loss inside and outside Protected Areas in Brazilian Legal Amazon

Detection of burned areas using Classification Trees and Genetic Programming: A case study in Brazil

Problem

Every year, large areas of tropical savannas and woodlands burn in Africa and Brazil due to natural conditions and land management practices induced by human activities. Given the impacts on forests and the high level of greenhouse gas emissions produced, it is important to find efficient methods that define historic regimes, and that contribute to the definition of management strategies that minimize the emissions. Thus, it is important to develop tools for accurately and frequently mapping burned areas over large extents. A valuable source of data that have been widely used in the development of automated and semi-automated methods for burning detection are the Landsat TM (Thematic Mapper), ETM+ (Enhanced Thematic Mapper Plus) and OLI (Operational Land Imager) (Melchiori et al., 2014; Bastarrika et al., 2011; Liu et al., 2014). However, frequently errors in the burned areas detection are founded resulted from the inefficiency of the algorithms used or errors in the training dataset used for train the classifier. As human experts are responsible to collect manually sample points or observations from different burned and unburned areas, errors of labeling can frequently occur.

Objective

The objective of the work is to use two different methods, Classification trees and Genetic Programming to map burned areas in tropical savannas and compare it in terms of accuracy. Additionally, it intends to find a methodology that be able of dealing with the problem linked to the mislabeling of the training data, and improve spatial accuracy of the burned area.

Study site and data

A Landsat OLI image located on Brazil was selected, corresponding to Path/Row 225/64 and freely downloaded from GLOVIS archive of the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center (Figure 13). This image corresponds to an area located in eastern Amazon which lies south of the Amazon River, and is drier than the central and western parts of the Amazon with annual rain between 1500 mm and 2000 mm and average temperatures ranging from 23ºC to 30 ºC. Vegetation is characterized by lowland Amazon forest (tall trees of up to 40 m in height) in the north and submontane dense and open forests in the south. The region is subject to frequent, severe and extensive fire events. The image was acquired on February 28, 2015.

A Landsat OLI image consists of nine different bands, of which band 8 is a panchromatic band (of low spectral resolution, covering most of the visible range) and band 9 is a cirrus band (used only for cloud detection). Therefore, we have used only the first seven bands, covering Ultra Blue, Blue, Green, Red, Near Infrared (NIR) and two different Shortwave Infrared (SWIR) spectral ranges. The image was geometrically corrected to UTM-Zone 22 South, DatumWGS84 for a spatial resolution of 30 m.

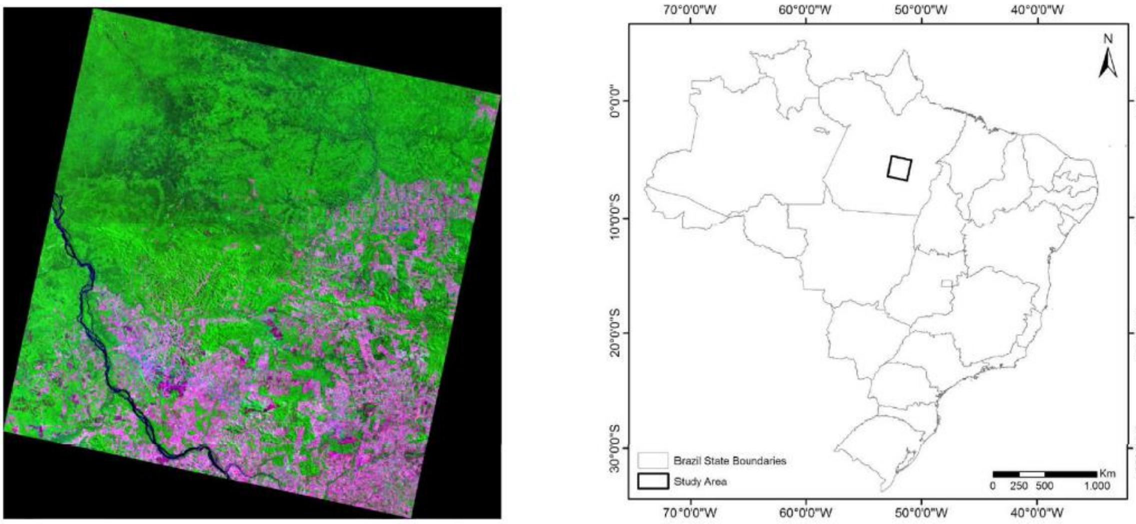

Figure **13**. Landsat 8 OLI image (on the left) and map of Brazil with the location of the study area and the distribution of the administrative regions (on the right). The tilted black square shows the location of the Landsat image

Visual inspection of the combination of bands 7, 5 and 4 allows depicting burned areas very clearly. This is the combination used for displaying the image in Figure 13.

A dataset was assembled from the Landsat image for training and testing the methods presented. For that, a human expert manually collected several sample points, or observations, from different burned and unburned areas. An effort was made in order to obtain a balanced data set, in order to cover not only the different non-burned land cover types, but also have a large diversity of burn scars, as they do not all have the same spectral characteristics.

Method

Two methods were used and compared for classifying burned areas: Classification trees (CART) (Breiman, 2014) and Genetic Programming (StdGP) (Koza, 2010). Classification trees are a non-parametric method based on a binary recursive partitioning which has been applied successfully to remote sensing data for burned area mapping in Africa. The new method GP is a young and successful paradigm of evolutionary computation, and it is a non-parametric method for the automated learning of computer programs, using Darwinian selection and Mendelian genetics as sources of inspiration. As during the step of classification, it was detected mislabeling errors in the training dataset an improved to the standard GP (StdGP) was done trying to minimize errors in the classification results. The new method (ImpGP) is an improvement to the standard GP. In fact, the main difference between the new method and the StdGP, is that the first uses not only the regular labeled data of the reference training dataset (with labeling errors) but also an extend set of unlabeled data that seems to improve results.

Results

Results show that both methods (CART and StdGP) present low accuracy in classifying burned areas (Figure 14 and Table 1). During training step, some pixels of natural woodlands and regenerating patches were wrongly labeled as burned areas. As consequence, both classifiers (CART and StdGP) classify as burned large areas of these two classes showing the difficulty of the methods of dealing with the labeling errors. In opposition, the new model ImpGP was not affected producing very clean classify images with high precision in accuracy values and in the spatial location comparison of the burned areas in the Landsat image and classification map. In spite of the study needs deep research and must be applied to other regions, the results are encouraging.

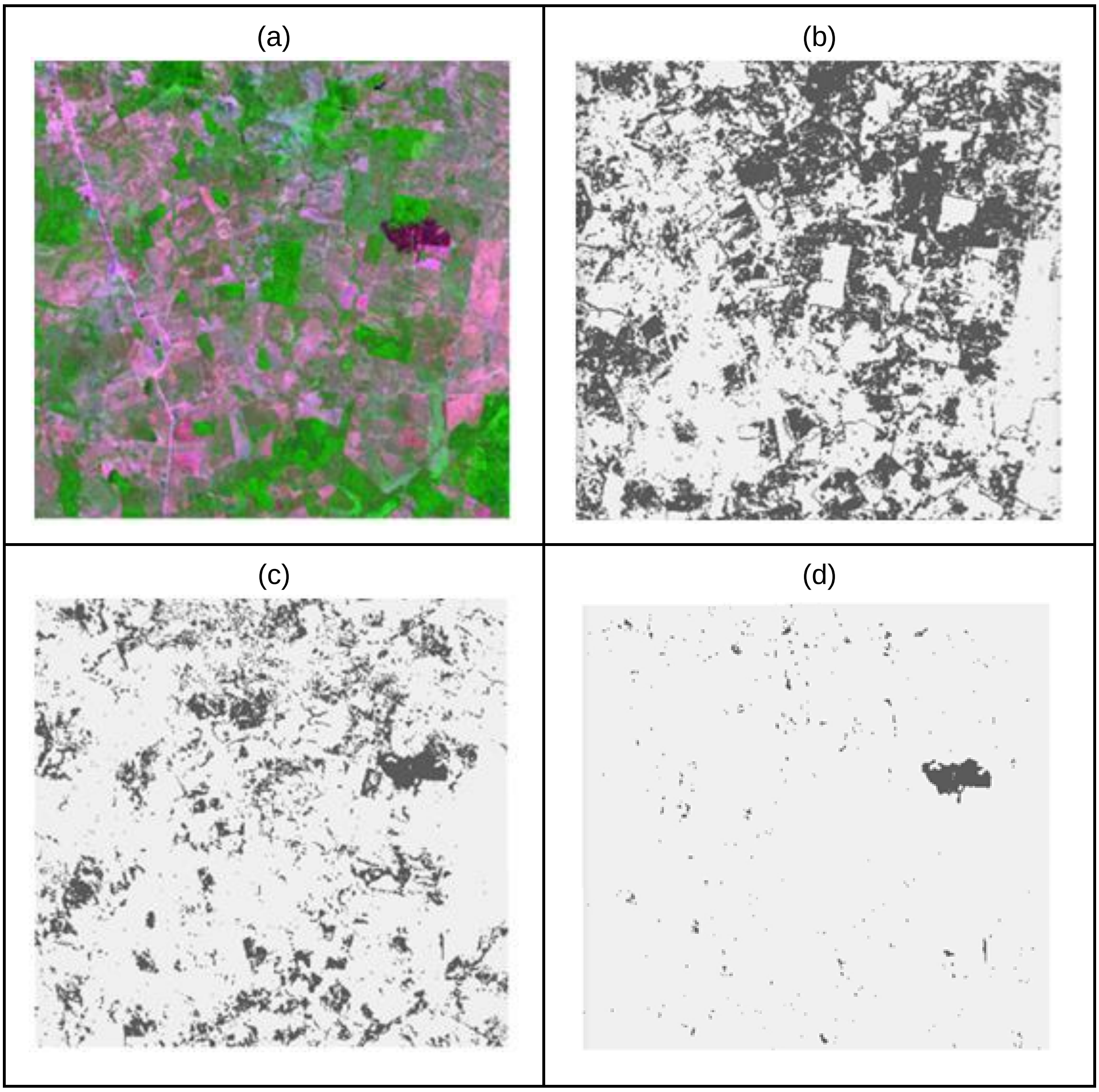

Figure **14**. Original Landsat Image (RGB-754) (a), Classification by CART (b), Classification by StdGP (c), Classification by improved GP (ImpGP).

Method	**Accuracy (%)**	**Kappa**
CART	95.49	0.23
StdGP	97.58	0.37

ImpGP	99.43	0.70

Table 1. Overall accuracy and Kappa values obtained by the three models (CART, StdGP, ImpGP).

Section 3 Land use change and societal challenges

Land use sustainability on the Southeastern Amazon agricultural frontier

The rapid expansion of cultivated areas in the Southeastern Amazon has long been pointed out as a major threat to the environment (Dubreuil, 2002; Fearnside, 2002; Morton et al., 2006). This is especially true in the state of Mato Grosso where the area covered by soybean crops grew from 1.5 to 8.9 million hectares from 1990 to 2015 (IBGE, 2016) while 139,917 km² of forests were cleared between 1988 and 2015, i.e. 33.8% of total deforestation in the Legal Amazon (INPE, 2016). Nonetheless, the last decade has been marked by a decoupling of deforestation and soybean production (Macedo et al., 2012), since deforestation rates in Mato Grosso experienced a 90% decrease between 2004 and 2014 (from 11,814 to 1075 km_2/year; INPE, 2016) whereas crop production continued to increase thanks to the adoption of intensive agricultural practices (from 14.5 to 26.5 million tons of soybean; IBGE, 2016).

Such evolution raised optimistic expectations towards enhanced land use sustainability (Galford et al. 2013; Hecht 2012; Lapola et al. 2013; Martinelli et al. 2010; Nepstad et al. 2014). Nonetheless, land use sustainability in the Amazon is often approached from an environmental perspective, for example assessing how the adoption of new agricultural practices may contribute to maintain ecosystem services such as climate regulation through the reduction of greenhouse gas emissions (Galford et al., 2013). Yet, at a time when a new integrated governance model with complementary socioeconomic and environmental policies is being promoted (Arvor et al. 2016), other dimensions of sustainability deserve to be considered in order to get a better overview of the level of sustainability on the Amazon agricultural frontier. In this regard, a special attention must be paid to interrelated issues that embody both challenges and opportunities created by the development of frontier regions (Gardner 2014).

Objective

The objective is to analyze recent land use changes in the Southeastern Amazon agricultural frontier in order to raise underexplored questions about the forthcoming challenges that the Brazilian Amazon agricultural sector should address to confirm its recent progress towards land use sustainability. In order to achieve this objective, we consider that sustainability deals with analyzing society-environment interactions with respect to the possibility of continuing the observed trajectories into the future (Haberl et al. 2004). In this regard, assessing land use sustainability of society-environment interactions implies not only the consideration of (1) how socio-economic activities affect natural ecosystems, i.e. which driving forces for which environmental impacts, but also (2) how these changes impact on society and (3) how society can cope with them (Haberl et al., 2004).

The adoption of new agricultural practices: a sustainable pathway in a context of global change?

New agricultural practices towards sustainable intensification

While crop expansion has long been the main pillar of agricultural growth in the Amazon (Fig. 15), the adoption of new agricultural practices currently represents the main pathway to increase crop production with limited impacts on wildlands. In this regard, the Low Carbon Agriculture Plan (ABC Plan) launched by the Brazilian government in 2010 includes six programs to support the adoption of environmentally friendly practices (R$10 billion of loans had already been allocated to farmers by February 2015; Ministerio da Agricultura, 2015). Amongst the main technologies promoted, no-tillage practices, nitrogen fixation, integrated crop-livestock-forestry systems and the restoration of degraded pastures are of particular importance. The wide and rapid generalization of no-tillage practices in Brazil (31.811 million hectares in 2012; FEBRAPDP, 2015), especially in the Cerrado biome, is quite impressive. It consists in leaving the soil profile undisturbed, sowing successive crops in between the stubble of the previous one. Thus, no-tillage is usually accompanied by the use of a second crop (usually maize, cotton, sorghum or millet) sown after the soybean harvest in order to improve the soil's quality by limiting the loss of chemical products (e.g. improving nitrogen fixation) and organic matter via erosion and by retaining water for a longer period (Landers, 2001; Scopel et al., 2005). In the main agricultural municipalities of Mato Grosso, such as Sorriso or Lucas do Rio Verde, the CONAB (Companhia Nacional de Abastecimento) estimates that 90% of the area planted with soybean is sown under no-tillage conditions.

More recently, integrated systems (IS) have been encouraged due to their environmental benefits (Lemaire et al. 2014; Salton et al. 2014). Four types of IS are usually defined: crop-livestock systems, livestock-forestry systems, crop-forestry systems and crop-livestock-forestry systems. At the Brazilian scale, the goal is to reach a total of 4 million ha cultivated with IS by 2020 (MAPA and MAPA, 2012), i.e. 6% of the total national cropped area of 66.4 million ha. According to Gil et al. (2015), IS already cover about 500,000 ha in Mato Grosso, among which crop-livestock systems are largely dominant, accounting for 89% of the state's IS area. Integrated systems based on an interannual rotation between pasture and crop are also part of a process to restore degraded pastures. IS thus represent important opportunities for sustainable intensification, as the restoration of degraded pastures is a major priority to improve the land use sustainability of the Amazon agricultural sector, especially with regards to greenhouse gas emissions and economic enhancement of degraded areas (Galford et al., 2013). Pastures currently represent the main land use in the Amazon and Cerrado biomes (Lapola et al., 2013), of which about 50% in the Cerrado biome and more than 60% in the Amazon biome are degraded pastures (Strassburg et al., 2014). The same authors indicated that both the conversion of part of these pastures to croplands and the increase in pasture productivity (from 32-34% to 49-52% of its potential at Brazilian scale) would enable demands for meat, crops, wood and biofuels to be met until 2040 without additional deforestation. This process of pasture conversion to croplands is already underway since it accounted for 49% of crop expansion in Mato grosso during the 2000-2013 period (Cohn et al. 2016), and even 91% for the 2006-2010 period (Macedo et al., 2012). Nonetheless, the conversion of pasture to crops seems to evolve slower than expected since only 1/7 of pasture agronomically suitable for cultivation had been converted by 2013 (Cohn et al. 2016).

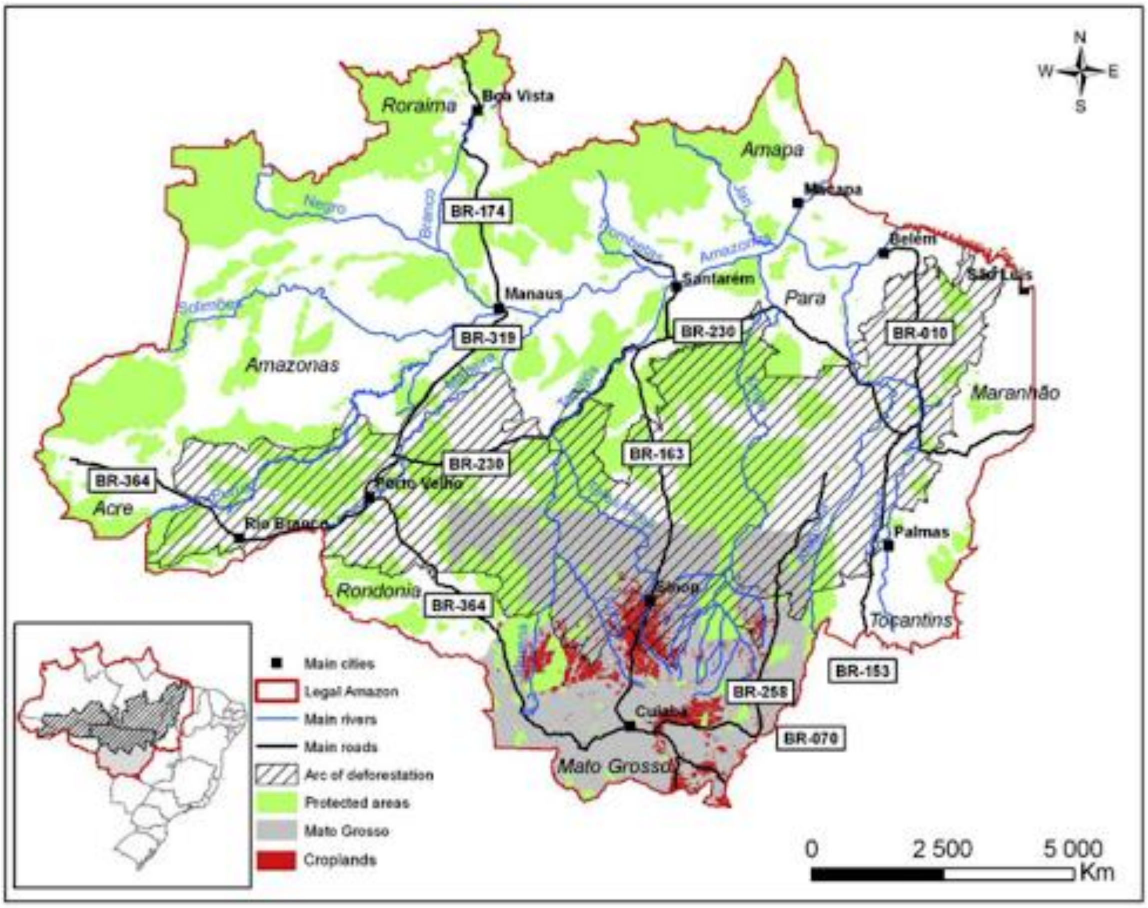

Figure **15**. Location of the State of Mato Grosso in the "Legal Amazon", showing the main roads, rivers, croplands, protected areas, and the arc of deforestation according to the Brazilian Institute of Environment (Portuguese acronym IBAMA)

The generalization of double cropping systems: a sustainable strategy in a context of climate change?

Despite the efforts to support the adoption of new environmentally friendly agricultural practices, the fact is that the main evolution observed during the last decade refers to the rapid generalization of intensive practices such as double cropping systems (from 35% to 62% of the net cropped area between 2000 and 2007; Arvor et al., 2012). Actually, even some environmental agricultural practices such as no-tillage were widely and rapidly adopted by farmers firstly because it facilitates the cultivation of two commercial crops per rainy season (especially soybean and maize or soybean and cotton). Whereas the generalization of double cropping systems may be considered as an effective strategy to reduce pressure on forests, it raises new important environmental issues that may counterbalance the benefits from deforestation reduction. First, the production of soybean, maize and cotton requires to use large amounts of agrochemical products which may affect Amazonian biodiversity (Schiesari et al., 2013). At state level, the consumption of agrochemicals increased almost fivefold between 2000 and 2013, from 18,078 to 87,520 tons of active ingredient, i.e., 17% of total agrochemicals consumption in Brazil (IBAMA, 2014) (Fig. 16). This increase is primarily explained by the expansion of cropped areas but it is also the result of agricultural intensification. The mean use of agrochemicals increased from 3.8 to 6.7 kilograms of active ingredient per hectare to support a large increase in maize yields (from 3 to nearly 6 tons by hectare during the last decade) and the rapid expansion of cotton areas from 257 to 613 thousand hectares from 2000 to 2014 (IBGE, 2016). Indeed, nearly 80% of insecticides sold in Brazil is dedicated to cotton production (Pires et al., 2005) since farmers are used to apply up to 17 rounds of insecticides and fungicides, using 41 different insecticides to cultivate cotton (Ofstehage, 2016). In an area dominated by single-cropped soybean with some fields double-cropped with maize, studies evidenced that concentrations of nitrate and phosphate in soils and groundwater of cultivated watersheds remain relatively low, similar to those observed in forest areas, and with low risk of losses to waterways (Neill et al., 2013; Riskin et al., 2013). However, these results should be considered carefully since results may vary significantly in areas where cotton is widely cultivated. Indeed, the authors warn about the long term capacity of soils to adsorb fertilizers on the long term in a context of increased erosion due to soil compaction and overall increased use of agrochemicals, as it is the case for cotton (Neill et al., 2013).

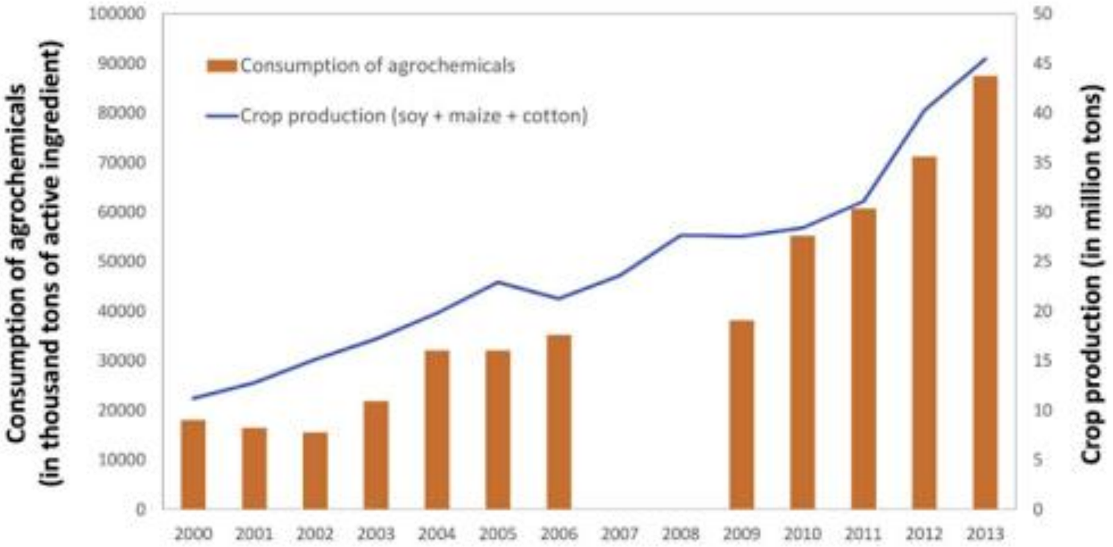

Figure **16**. Comparative evolution of crop production (soy + maize + cotton) and the consumption of agrochemicals in Mato Grosso from 2000 to 2013 (no data available for 2007 and 2008)

Second, many pivot irrigation systems were installed and numerous artificial ponds were created on river networks to ensure water supply for maize and cotton crops, which are harvested in June and July at the beginning of the dry season. In the municipality of Sorriso (9345 km_2, most important soybean producer in Mato Grosso), Arvor et al. (2016a) and Arvor et al. (2016b) identified 571 artificial water bodies covering a total of 20.8 km_2 based on visual inspection on Google Earth (Fig. 17). Whereas the impact of the construction of numerous water dams on Amazonian rivers is being actively considered (Fearnside, 2016), the potential negative effects of the multiplication of such ponds on hydrology, biodiversity and global warming on the long term and on large scales are still understudied.

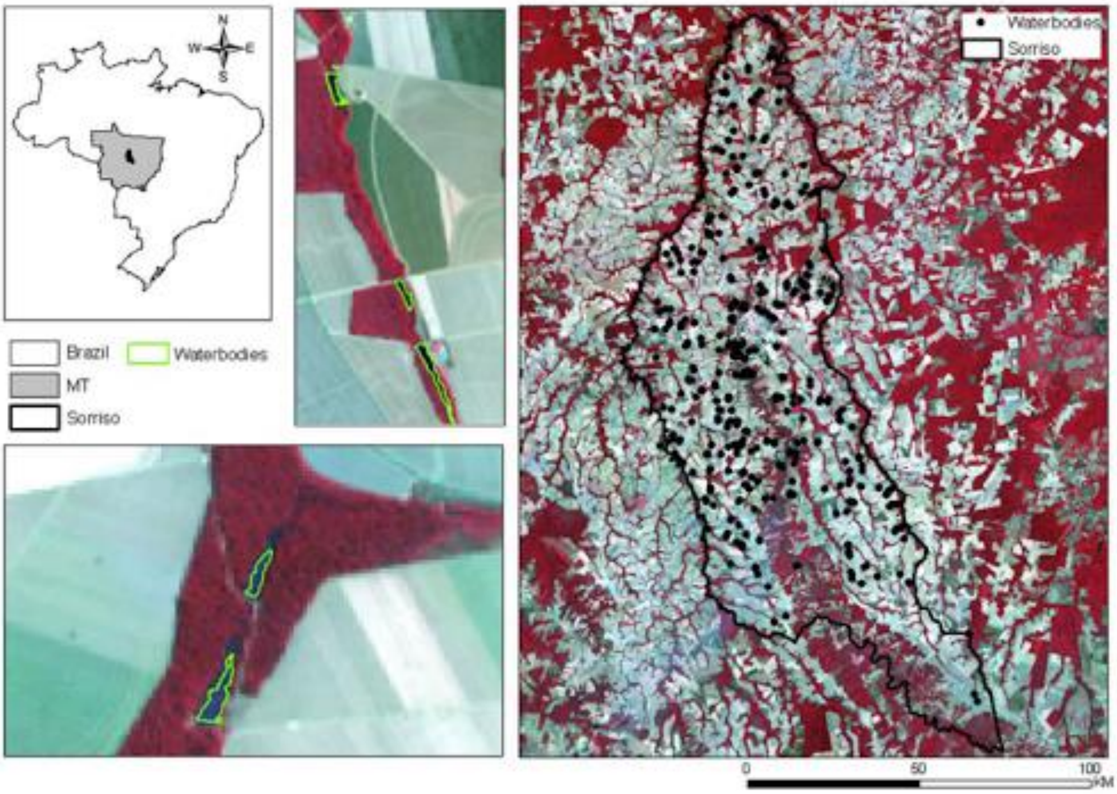

Figure **17**. Location of artificial ponds in the municipality of Sorriso (Mato Grosso) observed on Landsat 8 images in 2014.

Finally, the adoption of intensive practices was proven to be related to environmental (e.g. slope, elevation, temperature, precipitation) and socio-economic (e.g. soy logistics costs) variables (Spera et al., 2014; VanWey et al., 2013). Arvor et al. (2014) also evidenced that regular and abundant rainfall was a key factor that enabled the adoption of double cropping practices in Mato Grosso. However, the overall Amazon basin ecosystem is now considered “in transition to a disturbance-dominated regime”, involving important changes in water cycles (Davidson et al., 2012). Many studies have predicted that the high deforestation rates observed during the past decades could induce a shorter rainy season due to a delayed onset in the southern Amazon (Butt et al. 2011; Debortoli et al., 2015; Dubreuil et al. 2011; Fu & Li, 2004; Fu et al., 2013). Consequently, beyond the fact that any change in rainfall regimes might lead to substantial losses in productivity (Lapola et al., 2011; Oliveira et al., 2013), it could also revert the tendency towards the adoption of double-cropping intensive practices in the long term (Arvor et al., 2014; Cohn et al., 2016), calling into question the sustainability of the current intensification process.

Assessing how farmers will adapt to climate change thus represents a huge challenge to be addressed to ensure land use sustainability of the Amazon agricultural sector. Local Environmental Knowledge (LEK) has been proven to be of major importance to ensure adaptation to ever-changing environmental conditions (Fernandez-Llamazares et al., 2015). However, in a context of a young agricultural frontier, still inhabited by the first generation of settlers who are often themselves the worthy heirs of pioneer families used to migrate towards better life conditions, one might question the ability of farmers to define new strategies based on their LEK and thus question their resilience in the face of global environmental change.

Hydrological changes and cattle ranching sustainability in floodplains

Cattle has been introduced in the Amazon during the 17th century to help resources exploration and transport. Strongly supported by public investments, cattle ranching for meat production in the Brazilian Amazon is extremely significant since 1990. The bovine livestock size has been increasing since, placing the region in second rank after the Central West region in terms of number of heads (Figure 18 after IBGE, 2016).

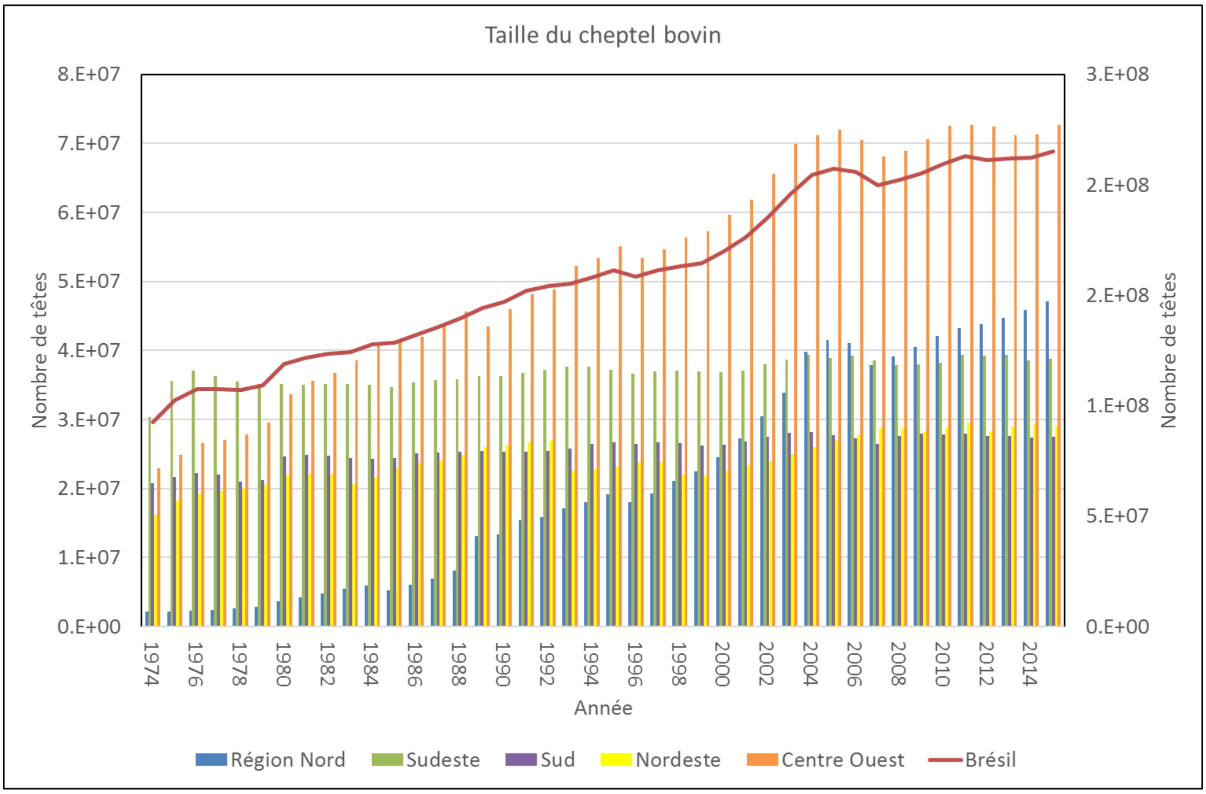

Figure **18** : livestock evolution in Brazil

Cattle ranching activity is shared by different types of producers, from the largest ones who have herds of more than 1000 heads to the smallest with herds of less than 10 heads. For the latter, livestock is a form of security savings, the sale of a beast allowing them to respond financially quickly to an unexpected event.

Várzea areas which offer extensive natural pastures, are particularly suitable for extensive bovine livestock farming and fattening. The cattle raising activity is rhythmed by the seasonal hydrological dynamics (**Erreur ! Source du renvoi introuvable.**). The livestock remains in the várzea as long as the pasture are emerged and is moved to upland regions when inundated.

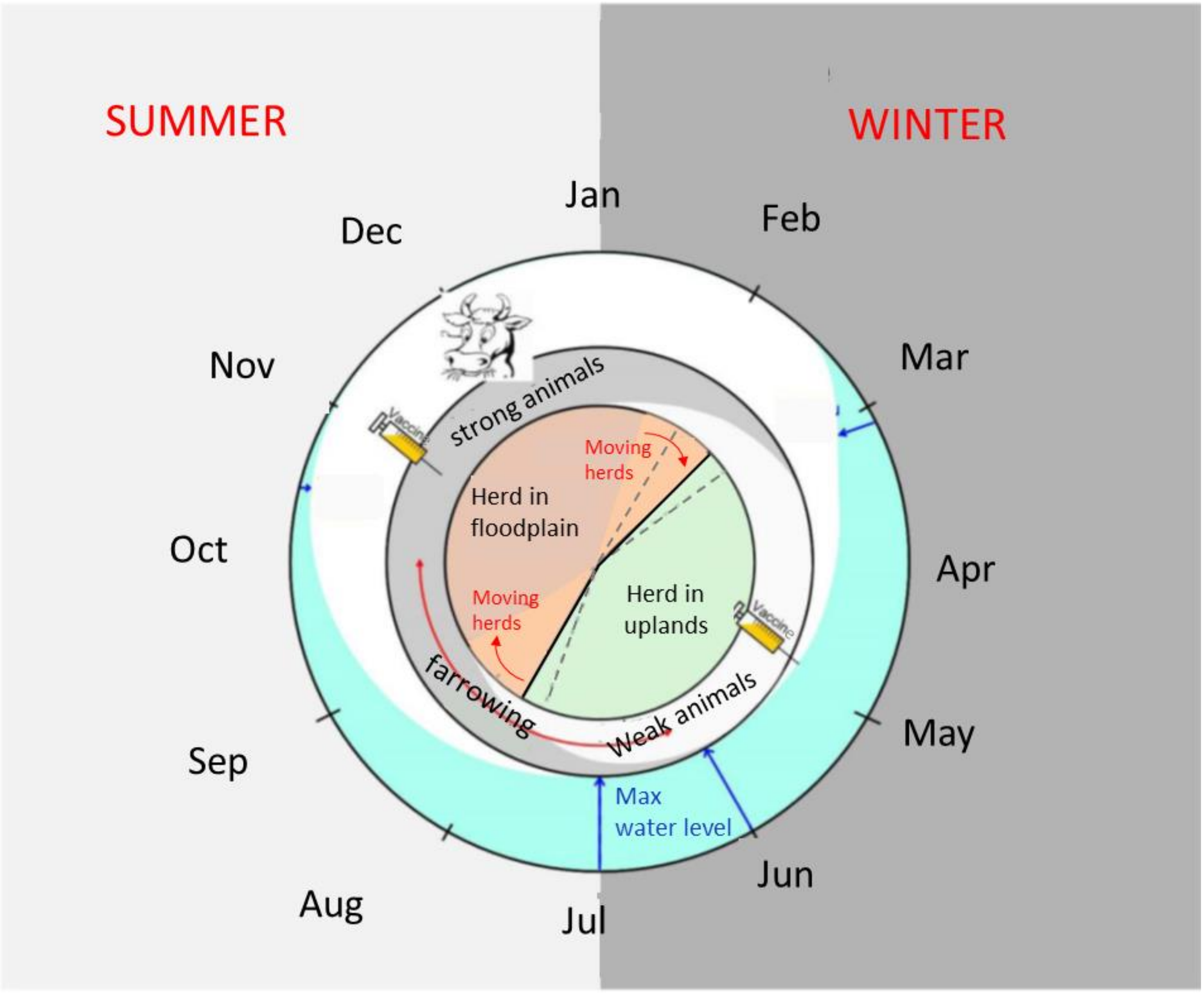

Figure **19**. Cattle raising calendar adapted from (Haentjens, 2015)

However, variations in river hydrological variations, even slight as observed in the last 30 years, may have impacts on this activity.

The floodplain being very flat environments, even small variations in the water level induce a large flood extent changes. Taken the Curuai floodplain as a representative example, the flood extent (S) is linearly related with water level (Z) according to the following equation S=216 Z – 35 km^2 (Bonnet et al, 2008). The difference in maximum water level registered between 1983-2000 and 2001-2015 periods of about 0.6 m induces a flood extent variation of 129.6 km^2. Natural pastures in the Curuai floodplain with an altitude of 900 cm or less, thus potentially flooded each year, represent 78% of the total natural pasture extent in the floodplain local watershed (Figure 20). The flood extent variation observed between the two periods represents 21% of the natural pastures' extent with altitude greater than 700 cm above sea level, which are accessible from September to March.

Hydrological changes between the two periods also reduced the emersion duration of pastures: by 15 days for those with an altitude of less than 700 m, by one month for pastures with altitude less than 800 m and by 12 days for pastures with altitude less than 900 m.

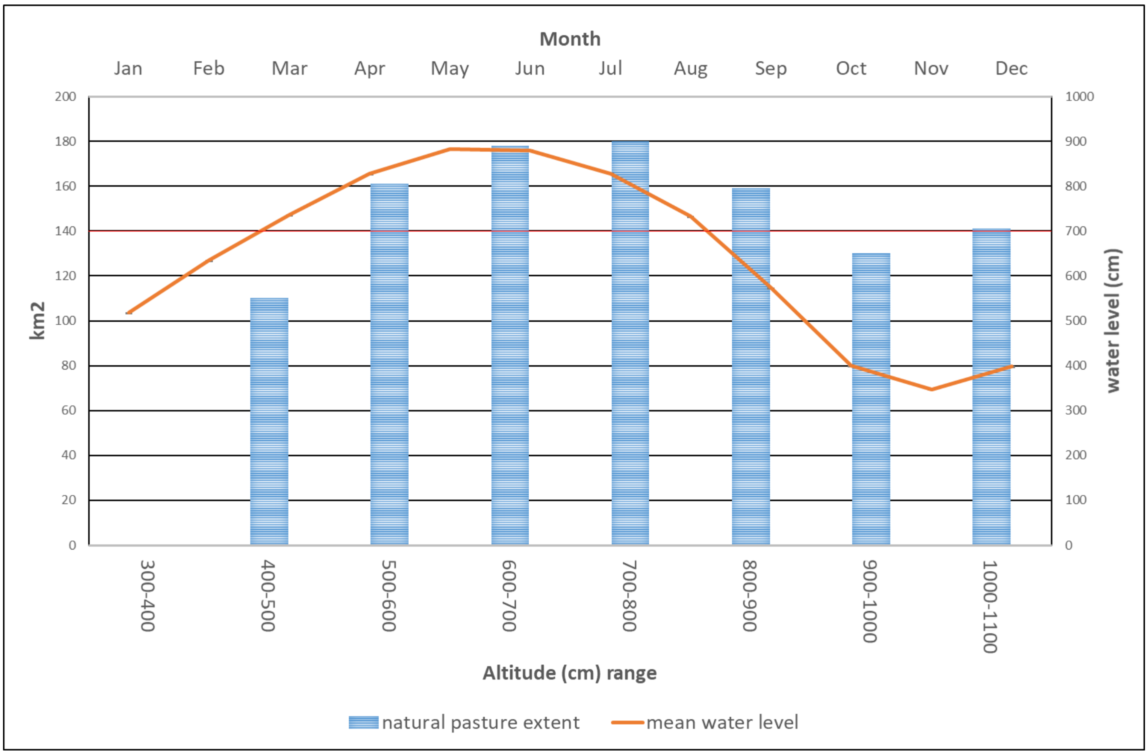

Figure **20**. Natural pasture areas in function of altitude

The exploration time of natural pasture for livestock has thus been significantly reduced between the two periods while in the same time livestock size increased significantly since 1990. These trends have several socio-environmental consequences. It pushed the farmers at opening new pastures in uplands. In Curuai, the extent of artificial pasture was multiplied by a factor 3 between 1997 and 2014 at the expense of rainforest (Peres, 2016). While the duration of natural pasture emersion is diminishing, herds are moved toward artificial pastures earlier, where they remain longer. Maintaining healthy livestock is thus demanding more care, more workforce and is most costly than previously.

Agricultural development in the Amazon: opportunities and threats for society

Land use sustainability in the Amazon is often approached from an environmental perspective (Galford et al., 2013), yet other dimensions of sustainability deserve to be better considered. On the one hand, we discuss how the rapid development of the agricultural sector in the Amazon frontier has brought major social advances, although it remains dominated by high social inequality, especially with regards to land tenure (Lapola et al., 2013). On the other hand, we argue that the recent trend towards agricultural intensification could lead to major health concerns which are still too rarely considered.

Towards a decoupling of soybean production and Human Development Index?

In Mato Grosso, official statistics indicate a significant positive relationship between the Human Development Index (HDI) and soybean production at municipality level. The HDI increased continuously from 1991 to 2010, i.e. during the period of rapid frontier expansion, and remained higher in areas of soybean cultivation (Fig. 21A). However, the HDI difference between “non-soybean areas” (i.e. municipalities where soybean production is null) and “soybean areas” is being reduced, as is also confirmed by the scatterplots relating HDI and soybean production (Fig. 21B). Furthermore, a covariance analysis evidences that the linear models observed for each year (1991, 2000 and 2010) are significantly different, which may be interpreted as a decreasing influence of soybean production on HDI. These results thus indicate that, similarly to Macedo et al. (2012) who evidenced a recent decoupling between soy production and deforestation in Mato Grosso, HDI is also being decoupled from soy production, which could be the result of (i) efficient social policies promoted during the 2000s (Fome zero, Bolsa Familia, etc.; Hall, 2006) and (ii) the diversification of economic and agricultural activities which reduces dependency on a single commodity such as soybean. In this regard, this trend should be considered as a progress towards land use sustainability related to the consolidation of the Southern Amazon agricultural frontier. However, these results need to be validated in the long term. At the scale of the Brazilian Amazon, Rodrigues et al. (2009) evidenced a boom-and-bust development pattern on the frontier: "relative standards of living, literacy, and life expectancy increase as deforestation begins but then decline as the frontier evolves, so that pre- and post-frontier levels of human development are similarly low". Indeed, development projects in the Amazon region traditionally have little scope for long-lasting development, despite being attractive to an extremely mobile and vulnerable population (Barcellos et al., 2010). Yet, the boom-and-bust hypothesis in the Amazon has recently been contradicted (Caviglia-Harris et al., 2016; Tritsch & Arvor, 2016; Weinhold et al., 2015). Commodity-based agricultural activities on the Southeastern Amazon agricultural frontier may actually reverse the trend towards a bust pattern, through the accumulation of wealth, the establishment of intensive commercial activities and the reinforcement of local institutions that may warrant long term economic and social development. Nonetheless, the last (2005-2006) fall in commodity prices that caused a two-year decrease (2006-2007) in soybean cultivated areas in Mato Grosso emphasized the latent weaknesses of the current agricultural model, especially with regards to the indebtedness of farmers (Arvor, 2009).

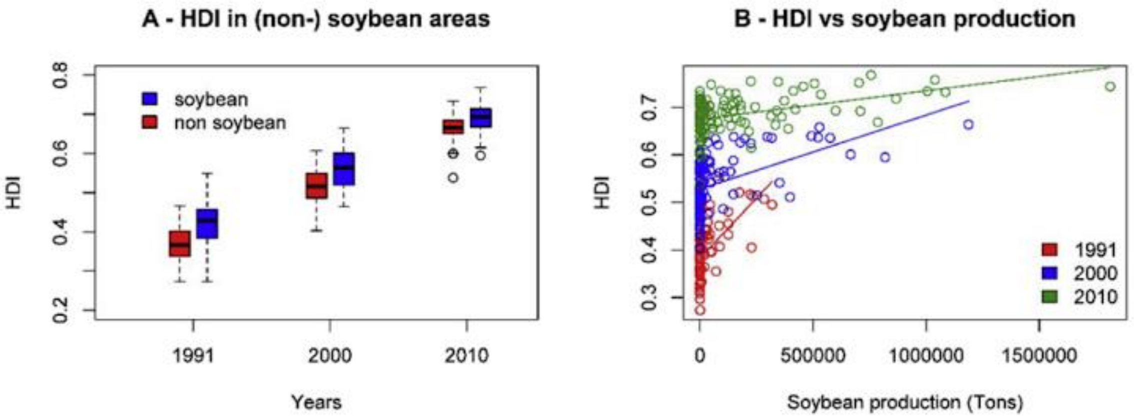

Figure **21**. Evolution of the Human Development Index (HDI) at municipality level in Mato Grosso. (A) Comparative evolution of the HDI in soybean and non-soybean municipalities in 1991, 2000 and 2010. (B) Scatterplots relating HDI to soybean production at the three same dates. The pairwise nested model comparison F-tests all led to p-values < 4.10-4 (source: soybean production; Human Development Index; IDHM, 2013).

Agricultural intensification: a threat to human health

The recent land use changes also raise major health concerns. Actually, a new epidemiological profile emerged during the last decades (Fig. 22). While the first stages of deforestation promoted epidemics of vector-borne diseases, such as leishmaniosis and malaria, due to the contact with vector's ecological niches (Stefani et al., 2013), the subsequent conversion of wildlands to large single crop areas reduced the incidence of such diseases, especially in Northern Mato Grosso where new cases of malaria decreased drastically (Atanaka-Santos et al., 2007; Hahn et al., 2014). On the contrary, violence, which is partially expressed by homicide rates, arose quickly in the end of 1990's. The expansion of the frontier was accompanied by illegal appropriation of land parcels, conflicts with indigenous and other traditional population groups, and rapid urbanization promoted by the expulsion of rural population to city peripheries (Souza et al., 2015). After a rapid increase during the 1990's decade, homicide rates have stabilized at high levels. Moreover, cancer mortality rate rose steadily in Mato Grosso state since 1995, due to genetic, demographic and nutritional conditions but also potentially because of high level of exposure to agrochemicals as it has already been evidenced in other areas of intensive agriculture (INSERM, 2013).

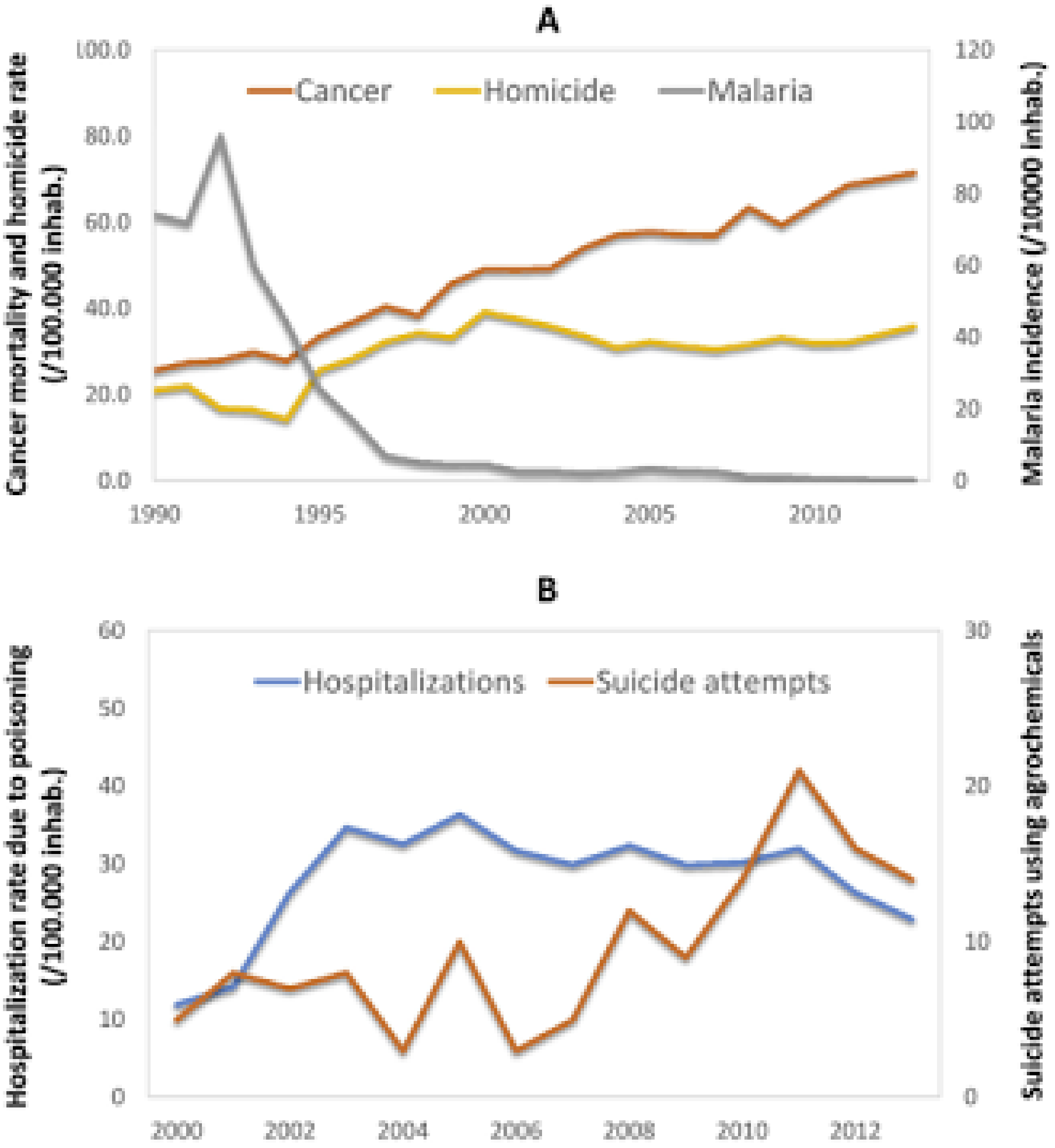

Figure **22**. (A) Malaria incidence in Mato Grosso, according to the Annual Parasite Index (API-SIVEP), calculated as the number of positive blood slides per 1000 inhabitants, and cancer mortality and homicide rates, expressed by the number of deaths per 100,000 inhabitants (SIM), and (B) Hospitalization rates in Mato Grosso, calculated by the number of hospital discharges due to poisoning events per 100,000 inhabitants (SIH), and suicide attempts using agrochemicals as registered by the health notification system (SINAN).

As mentioned previously, the use of agrochemicals increased rapidly in the last decades to support the agricultural intensification process and the diversification to maize and overall cotton crops in Mato Grosso. Considering that (i) Brazilian farmers are still allowed to use large amounts of agrochemicals banned in other countries, mainly in Europe and the United States, and (ii) applications are often carried out by plane, it raises important health issues such as acute poisoning and other diseases caused by chronic exposure to agrochemicals for populations working and living in intensive agricultural areas (Recena et al., 2006). First studies led in the neighboring state of Mato

Grosso do Sul evidenced a close relationship between crop production and health exposure issues (Recena et al., 2006). The role of insecticides such as organophosphates and carbamates as a main cause of human intoxication occurring in crop fields has been pointed out (Belo et al., 2012). Such studies should now be applied to other states such as Mato Grosso where the situation is quite worrying and needs to be better considered to take into account the social dimension of land use sustainability. Poisoning became a threatening health problem in Mato Grosso, as revealed by the occurrence of hospitalizations due to poisoning, which increased sharply in the early 2000s (Fig. 22B). The occurrence of an annual mean of 100 notifications of poisoning due to the exposure to agrochemicals (SINAN, 2015), and 860 hospitalizations due to poisoning in the recent years (2010-2013) (SIH, 2015) are worth of concern. This data is certainly underestimated as, according to the Health Ministry, for each recorded case of poisoning notification, other fifty were not registered (Pires et al., 2005). Water and soil contamination, air pollution due to biomass burning (forest and plantation) and temporary crop production were associated with the large use of agrochemicals in the cerrado biome (Soares & Porto, 2007). Similarly, while some studies have evidenced the depressive effects of agrochemical exposure that can lead to suicide (Freire & Koifman, 2013; Pires et al., 2005), it has been observed an increase in the number of suicide attempts using agrochemicals, varying from five cases per year in 2000 to over fifteen in the 2010s.

Section 4 Data compilation and availability

An important task in WP#3 is the collection and compilation of existing data and their availability to the scientific community and civil society. For Brazil, two types of data were identified during the research developed under the ongoing projects:

1) Free datasets available through internet platforms, at global, regional and local scale, and produced by Brazilian and International Institutions;

2) Data produced by the research teams involved in ODYSSEA project and other ongoing projects (For example, in situ collections, satellite images, and statistical data). In this case, data availability have some restrictions according owners.

Data obtained and produced, according with the point 2, are described and organized in a table containing different types of information, such as, Name of the Project that provides the data, Theme name, Type of data, Geographic area, Data description, Coordinate system, and Period of data. This organization allows identifying easily which data is being used by each project, which facilitates collaborations between research teams. A list with some of the existing data was done in WP#3 (Table 2). Some of these data are free of charge and others are collected and produced inside the projects mentioned. The table is continuously moving and will be updated always the project teams have more information to add. All data produced during the project can be integrated in the open source platform developed in WP#5. Besides making available data produced during the project, the platform provides tools that facilitate data exchanges between researchers. Additionally, it provides the end-users with functions of discovery, visualization and access to the tools produced by the project and to the cartographic products.

ID	Sitio ODYSSEA	Área geográfica	Tema	Subtema	Variável	Descrição	Resolução espacial	Período	Responsável	Projeto	Propriedade	Publicação de referencia (doi/link/ISBN,...)
1	Macapá	Amapá	Biosfera	Vegetação	Estrutura florestal	Série de imagens de alta resolução	ca. 2 m	2015	P. Couteron	BIOMAP	Difusão restrita	-
2	Macapá	Amapa	Geosfera	Geomorfologia	Unidades de paisagem	Mapas da paisagem derivados do SRTM	ca. 1 km		P. Couteron	BIOMAP	Difusão aberta	-
3	Macapá	Amapa	Biosfera	Forestas	Biomassa	Parcelas amostragem florestal de campo	Parcelas	2009	Eleneide Doff Sotta/ IEF	BIOMAP	Difusão restrita	-
4	Macapá	PA_Jari	Biosfera	Vegetação	biomassa (arvores)	diametro das arvores (acima de 10 cm dap) em 15 parcelas de 1 ha em floresta manejadas	-	2000-2015	Eleneide Doff Sotta/ IEF	GUIAMAFLOR	difusão restrita	-
5	Belém	PA_Paragominas	Biosfera	Vegetação	biomassa (arvores)	diametro das arvores (acima de 10 cm dap) em 18 parcelas de 1 ha em floresta manejadas	-	2004-2017	Lilian Blanc; Plinio Sist	TmFO	Difusão restrita	-

6	Benfica	PA_Benfica	Biosfera	Vegetação	Densidade das plantas	Matriz de abundância/densidade das plantas de 70 transectos categorizadas por forma de vida e grupos ecologicos	-	2003-2004	Danielle Mitja;Izildinha Miranda	BIODAM;BIOSOL	Difusão restrita	-
7	BR163	MT	Biosfera	Agricultura	Tipos de cultura	Mapa das areas agricolas baseado nos dados do MODIS	250m	2001-2007	Damien Arvor	DURAMAZ	Difusão restrita	-
8	BR163	Amazonia	Atmosfera	Precipitações	Acumulo anual	Totais anuais de precipitações computados a partir de dados TRMM	0.25°	1998-2015	Damien Arvor	DURAMAZ2	Difusão restrita	-
9	BR163	Amazonia	Atmosfera	Precipitações	Data de inicio da estação chuvosa	Datas de inicio da estação chuvosa computados a partir de dados TRMM (Metodologia do Liebmann)	0.25°	1998-2015	Damien Arvor	DURAMAZ2	Difusão restrita	-
10	BR163	Amazonia	Atmosfera	Precipitações	Data de fim da estação chuvosa	Datas de fim da estação chuvosa computados a partir de dados TRMM (Metodologia do Liebmann)	0.25°	1998-2015	Damien Arvor	DURAMAZ2	Difusão restrita	-

11	BR163	Amazonia	Atmosfera	Precipitações	Duração da estação chuvosa	Duração da estação chuvosa computados a partir de dados TRMM (Metodologia do Liebmann)	0.25°	1998-2015	Damien Arvor	DURAMAZ 2	Difusão restrita	-
12	BR163	Amazonia	Atmosfera	Precipitações	Acumulo anual	Totais anuais de precipitações computados a partir de dados PERSIANN	0.25°	1983-2015	Damien Arvor	DURAMAZ 2	Difusão restrita	-
13	BR163	Amazonia	Atmosfera	Precipitações	Data de inicio da estação chuvosa	Datas de inicio da estação chuvosa computados a partir de dados PERSIANN (Metodologia do Liebmann)	0.25°	1983-2015	Damien Arvor	DURAMAZ 2	Difusão restrita	-
14	BR163	Amazonia	Atmosfera	Precipitações	Data de fim da estação chuvosa	Datas de fim da estação chuvosa computados a partir de dados PERSIANN (Metodologia do Liebmann)	0.25°	1983-2015	Damien Arvor	DURAMAZ 2	Difusão restrita	-
15	BR163	Amazonia	Atmosfera	Precipitações	Duração da estação chuvosa	Duração da estação chuvosa computados a partir de dados PERSIANN (Metodologia do Liebmann)	0.25°	1983-2015	Damien Arvor	DURAMAZ 2	Difusão restrita	-

16	BR163	Sorriso	Biosfera	Landsat Spectral Class	Mapas de classes de uso do solo approximado pelo Landsat Spectral Classifier (Baraldi et al. 2006)	-	30m	2015	Damien Arvor	DURAMAZ 2	Difusão restrita	-
17		AMAZONIA (FLORESTA)		INTEGRIDADE ECOSISTEMICA	Mapa de Integridade Ecossistémica	-	1km	2010	Margareth Simões	Robin	Difusão restrita	-
18	Macapá	Amapa	Biosfera	Forestas	Biomassa	Parcelas amostragem florestal de campo	Parcellas	2009	-	BIOMAP	Difusão restrita	
19	Brasil	Planicie do Lago Curuaí	Hidrosfera	Biodiversidade aquática e qualidade de água	Biodiversidade aquática e qualidade de água	Amostragem de pontos	samples	2013-presente	Marie-Paule Bonnet	ODYSSEA e BloomAlert	Difusão restrita	
20	Brasil	Planicie do Lago Janauca	Hidrosfera	Biodiversidade aquática e qualidade de água	Biodiversidade aquática e qualidade de água	Amostragem de pontos	samples	2008-2011	Marie-Paule Bonnet	ODYSSEA e BloomAlert	Difusão restrita	
21	Brasil	Brasil	Biosfera	Remanescentes florestais e desmatamento	Prodes - Monitoramento de Desmatamento na Amazônia Legal	Monitoramento de desmatamento da Amazônia Legal de 1997, 1999 a 2015	0.000539 deg	1997, 1999-2015	Instituto Nacional de Pesquisas Espaciais (INPE)	Projeto PRODES	Difusão aberta	http://maps.csr.ufmg.br/

22	Brasil	Brasil	Biosfera	Remanescentes florestais e desmatamento	TerraClass	Mapeamento do Uso e Cobertura da terra na Amazônia Legal e no Cerrado realizado pelo projecto TerraClass	60 m	2014	Instituto Nacional de Pesquisas Espaciais (INPE)	Projeto TerraClass Amazôni	Difusão aberta	http://maps.csr.ufmg.br/
23	Brasil	Brasil	Biosfera	Remanescentes florestais e desmatamento	Perda de Cobertura Vegetal por ano	Dados de perda de cobertura vegetal no Brasil entre os anos de 2001 e 2013	30m	2001-2013	Hansen et al. (2013) Link para Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend (2013) High-Resolution Global Maps of 21st-Century Forest Cover Change. Science 342(6160):850-853. Data available on-line from: <http://earthenginepartners.appspot.com/science-2013-gl obal-forest/download_v1.1.html>.download: http://earthenginepartners.appspot.com/science-2013-glo	Hansen Global dataset	Difusão aberta	http://maps.csr.ufmg.br/
24	Brasil	Brasil	Biosfera	Recursos Naturais	Biomassa Acima e Abaixo do solo	Biomassa acima e abaixo do solo em toneladas de carbono por hectare.	500m	2016	Soares-Filho BS, Rajão R, Merry F, Rodrigues H, Davis J, Lima L, Macedo M, Coe M, Carneiro A, Santiago L (2016) Brazil’s Market for trading forest certificates. Plos One 11(4): e0152311. doi:10.1371/journal.pone.0152311		Difusão aberta	http://maps.csr.ufmg.br/

25	Brasil	Brasil	Biosfera	Recursos Naturais	Altura da Copa das Árvores - Dossel	Dados de dossel das árvores maiores do que 5 metros no Brasil, do ano 2000 e com range de 0 a 100	30m	2000	Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova SA, Tyukavina A, Thau D, Stehman SV, Goetz SJ, Loveland TR, Kommareddy A, Egorov A, Chini L, Justice CO, Townshend JRG (2013) High-Resolution Global Maps of 21st-Century Forest Cover Change. Science 342:850–53. Data available on-line from: <http://earthenginepartners.appspot.com/science-2013-gl		Difusão aberta	http://maps.csr.ufmg.br/
26	Brasil	Brasil	Biosfera	Recursos Naturais	Altimetria	Mosaico de Imagens SRTM de resolução 90 metros para o Brasil	90m	2000	CGIAR Consortium for Spatial Information (CGIAR-CSI)		Difusão aberta	http://srtm.csi.cgiar.org/ or http://maps.csr.ufmg.br/
27	Mundo	Mundo	Biosfera	Recursos Naturais	Imagens de Satélite	Acesso a Imagens de Satélite Landsat/MODIS/CBERS/RapidEye/ResourceSat-1-LISS3	Variável /Satélite	1973-2016	Instituto Nacional de Pesquisas Espaciais (INPE)/United States Geological Survey	-	Difusão aberta	http://www.dgi.inpe.br/catalogo/ or http://earthexplorer.usgs.gov/ or http://glovis.usgs.gov/
28	Bacias Amazónia, Orinoco e Congo	Amazon, Orinoco and Congo Basins	Hidrosfera	Recursos Naturais	Dados hidrológicos, sedimentológicos, fisicoquimicos e geoquimicos	Acesso a diferentes tipos de dados: Dados diáros de precipitação (1980-2009); Quantidade de concentração de sedimentos estimado a partir de satélite etc.	Pontos	2003 - present	Laboratoire des Mécanismes de Transferts en Géologie-UMR 5563 CNRS-UPS-IRD	SO HYBAM	Difusão aberta	http://www.ore-hybam.org/index.php/eng

29	Brazil	Brazil	Hidrosfera	Recursos Naturais	Dados hidrológicos	Acesso a dados hidrológicos (p.e., qualidade de água, balanço hidrico, eventos hidrológicos críticos), incluindo séries históricas, e geopespaciais (conjuntos de dados geográficos, imagens de satélite e outros serviços)	Samples or station	1960 to present	Agência Nacional de Águas	HidroWeb Sistemas de Informações Hidrológicas	Difusão aberta	http://www.snirh.gov.br/hidroweb/

Table 2. List of datasets available inside ongoing projects.

References

Arima E.Y., R.T. Walker, S.G. Perz, M. Caldas (2005), Loggers and forest fragmentation: behavioral models of road building in the Amazon Basin, Annals of the Association of America Geographers, 95 (3), 525-541. DOI: 10.1111/j.1467-8306.2005.00473.x

Arima E.Y., R.T. Walker, M. Sales, Jr C. Sousa, S. Perz (2008), The fragmentation of the space in the Amazon Basin: Emergent road networks, Photogrammetric Engineering & Remote Sensing, 74 (6), 699-709.

Arvor, D.; Dubreuil, V.; Simões, M.; Bégué (2012) A. Mapping and spatial analysis of the soybean agricultural frontier in Mato Grosso, Brazil, using remote sensing data. *GeoJournal*, *78*, 1–18.

Arvor, D.; Dubreuil, V.; Ronchail, J.; Simões, M.; Funatsu, B.M. (2014) Spatial patterns of rainfall regimes related to levels of double cropping agriculture systems in Mato Grosso (Brazil): Spatial patterns of rainfall regimes in Mato Grosso. *Int. J. Climatol.*, *34*, 2622–2633.

Arvor, D.; Tritsch, I.; Barcellos, C.; Jegou, N.; Dubreuil, V. (2017) Land use sustainability on the South-Eastern Amazon agricultural frontier: Recent progress and the challenges ahead. *Appl. Geogr.*, *80*, 86–97.

Arvor, D.; Daugeard, M.; Tritsch, I.; De Mello-Thery, N.A.; Thery, H.; Dubreuil, V. (2016) Combining socioeconomic development with environmental governance in the Brazilian Amazon: The Mato Grosso agricultural frontier at a tipping point. *Environ. Dev. Sustain.,* 1–22, doi:10.1007/s10668-016-9889-1.

Arvor, D. (2009). Developpement, crises et adaptation des territories du soja au Mato Grosso: l'exemple de Sorriso. Confins Revue Franco-bresilienne de Geographie/Revista Franco-brasilera de Geografia. http://dx.doi.org/10.4000/confins.5934.

Arvor, D., Meirelles, M., Dubreuil, V., et al. (2012). Analyzing the agricultural transition in Mato Grosso, Brazil, using satellite-derived indices. Applied Geography, 32, 702-713. http://dx.doi.org/10.1016/j.apgeog.2011.08.007

Arvor, D., Daher, F., Corpetti, T., Laslier, M., & Dubreuil, V. (2016). In C. M. U. Neale, & A. Maltese (Eds.), Monitoring of artificial water reservoirs in the Southern Brazilian Amazon with remote sensing data (p. 999816). Edinburgh, UK

Ashouri, H.; Hsu, K.L.; Sorooshian, S.; Braithwaite, D.K.; Knapp, K.R.; Cecil, L.D.; Nelson, B.R.; Prat, O.P. (2015) PERSIANN-CDR Daily Precipitation Climate Data Record from multisatellite observations for hydrological and climate studies. *Bull. Am. Meteorol. Soc.*, *96*, 69–83.

Atanaka-Santos, M., Souza-Santos, R., & Czeresnia, D. (2007). Spatial analysis for stratification of priority malaria control areas, Mato Grosso State, Brazil. Cadernos de Saúde Pública, 23, 1099-1112

Barcellos, C., Feitosa, P., Damacena, G. N., & Andreazzi, M. A. (2010). Highways and outposts: Economic development and health threats in the central Brazilian Amazon region. International Journal of Health Geographics, 9, 30. http://dx.doi.org/10.1186/1476-072X-9-30

Bastarrika A., E. Chuvieco, M.P. Martin (2011) Mapping burned areas from landsat tm/etm+ data with a two-phase algorithm: balancing omission and commission errors, Remote Sens. Environ. 115 (4), 1003–1012.

Belo, M. S. S. P., Pignati, W., Dores, E. F. G., Moreira, J. C., & Peres, F. (2012). Uso de agrotoxicos na produção de soja do estado do Mato Grosso: Um estudo preliminar de riscos ocupacionais e ambientais. Revista Brasileira de Saúde Ocupacional, 37, 78-88. http://dx.doi.org/10.1590/S0303-76572012000100011

Boers, N.; Marwan, N.; Barbosa, H.M.J.; Kurths, J. (2017) A deforestation-induced tipping point for the South American monsoon system. *Sci. Rep.*, *7*, doi:10.1038/srep41489.

Boisier, J.P.; Ciais, P.; Ducharne, A.; Guimberteau, M. (2015) Projected strengthening of Amazonian dry season by constrained climate model simulations. *Nat. Clim. Chang.*, *5*, 656–660.
Bonnet, M.P., G. Barroux, J.M. Martinez, F. Seyler, P. Moreira-Turcq, G. Cochonneau, J.M. Melack, G. Boaventura, L. Maurice-Bourgoin, J.G. León, E. Roux, S. Calmant, P. Kosuth, J.L. Guyot, P. Seyler (2008) Flooplain hydrology in an Amazon floodplain lake (Lago grande de Curuai) - *Journal of Hydrology*, 349(1-2): 18-30

Brando, P.M.; Balch, J.K.; Nepstad, D.C.; Morton, D.C.; Putz, F.E.; Coe, M.T.; Silverio, D.; Macedo, M.N.; Davidson, E.A.; Nobrega, C.C.; et al. (2014) Abrupt increases in Amazonian tree mortality due to drought-fire interactions. *Proc. Natl. Acad. Sci. USA*, *111*, 6347–6352.

Breiman L. (1984) Classification and Regression Trees, Chapman & Hall/CRC.

Carvalho G.O., D. Nepstad, D. McGrath, M.del C.V. Diaz, M. Santilli, A.C. Barros (2002) Frontier expansion in the Amazon: balancing development and sustainability, Environment: Science and Policy for Sustainable Development, 44 (3), 34-44.

Butt, N., de Oliveira, P. A., & Costa, M. H. (2011). Evidence that deforestation affects the onset of the rainy season in Rondonia, Brazil. Journal of Geophysical Research. http://dx.doi.org/10.1029/2010JD015174.

Caviglia-Harris, J., Sills, E., Bell, A., Harris, D., Mullan, K., & Roberts, D. (2016). Busting the boomebust pattern of development in the Brazilian Amazon. World Development, 79, 82e96. http://dx.doi.org/10.1016/j.worlddev.2015.10.040.

Cohn, A., Gil, J., Berger, T., Pellegrina, H., & Toledo, C. (2016). Patterns and processes of pasture to crop conversion in Brazil: Evidence from Mato Grosso state. Land Use Policy, 55, 108-120. http://dx.doi.org/10.1016/j.landusepol.2016.03.005.

Cohn, A.S.; VanWey, L.K.; Spera, S.A.; Mustard, J.F. (2016) Cropping frequency and area response to climate variability can exceed yield response. *Nat. Clim. Chang.*, *6*, 601–604.

Davidson, E.A.; de Araujo, A.C.; Artaxo, P.; Balch, J.K.; Brown, I.F.; Bustamante, M.C.M.; Coe, M.T.; DeFries, R.S.; Keller, M.; Longo, M.; et al. (2012) The Amazon basin in transition. *Nature*, *481*, 321–328.

Debortoli, N.S.; Dubreuil, V.; Funatsu, B.; Delahaye, F.; de Oliveira, C.; Rodrigues-Filho, S.; Saito, C.H.; Fetter, R. (2015) Rainfall patterns in the Southern Amazon: A chronological perspective (1971–2010). *Clim. Chang.*, *132*, 1–20

Dubreuil, V.; Debortoli, N.; Funatsu, B.; Nedelec, V.; Durieux, L. (2012) Impact of land-cover change in the Southern Amazonia Climate: A case study for the region of Alta Floresta, Mato Grosso, Brazil. *Environ. Mon. Assess.*, *184*, 877–891.

Dubreuil, V., Debortoli, N. S., Funatsu, B., Ned elec, V., & Durieux, L. (2011). Impact of land-cover change in the Southern Amazonia climate: A case study for the region of Alta Floresta, Mato Grosso, Brazil. Environmental Monitoring and Assessment, 184, 877e891. http://dx.doi.org/10.1007/s10661-011-2006-x.

Dubreuil, V.; Bariou, R.; dos Passo, M.; Ferrand, R.; Nedelec, V. (2005) Evolution de la frontière agricole dans le Centre Ouest du Mato Grosso. *Cah. Agric.*, *14*, 217–224.

Durieux, L. (2003) The impact of deforestation on cloud cover over the Amazon arc of deforestation. *Remote Sens. Environ.*, *86*, 132–140.

Espinoza Villar, J.C.; Ronchail, J.; Guyot, J.L.; Cochonneau, G.; Naziano, F.; Lavado, W.; De Oliveira, E.; Pombosa, R.; Vauchel, P. (2009) Spatio-temporal rainfall variability in the Amazon basin countries (Brazil, Peru, Bolivia, Colombia, and Ecuador). *Int. J. Climatol.*, *29*, 1574–1594.

Fearnside, P.M. (2002) Soybean cultivation as a threat to the environment in Brazil. *Environ. Conserv.*, *28*, 23–38.

Fearnside, P. M. (2016). Environmental and social impacts of hydroelectric dams in Brazilian Amazonia: Implications for the aluminum industry. World Development, 77, 48e65. http://dx.doi.org/10.1016/j.worlddev.2015.08.015.

FEBRAPDP. (2015). Federaçao Brasileira de Plantio Direito e Irrigação

Fernandez Llamazares, A., Díaz-Reviriego, I., Luz, A. C., Cabeza, M., Pyhala, A., & € Reyes-Garcia, V. (2015). Rapid ecosystem change challenges the adaptive capacity of Local Environmental Knowledge. Global Environmental Change, 31, 272-284. http://dx.doi.org/10.1016/j.gloenvcha.2015.02.001.

Freire, C., & Koifman, S. (2013). Pesticides, depression and suicide: A systematic review of the epidemiological evidence. International Journal of Hygiene and Environmental Health, 216, 445-460.

Fu, R., & Li, W. (2004). The influence of the land surface on the transition from dry to wet season in Amazonia. Theoretical and Applied Climatology, 78, 97-110. http://dx.doi.org/10.1007/s00704-004-0046-7.

Fu, R., Yin, L., Li, W., Arias, P. A., Dickinson, R. E., Huang, L., et al. (2013). Increased dry-season length over southern Amazonia in recent decades and its implication for future climate projection. Proceedings of the National Academy of Sciences, 110, 18110-18115. http://dx.doi.org/10.1073/pnas.1302584110.

Funatsu, B.M.; Dubreuil, V.; Claud, C.; Arvor, D.; Gan, M.A. (2012) Convective activity in Mato Grosso state (Brazil) from microwave satellite observations: Comparisons between AMSU and TRMM data sets. *J. Geophys. Res. Atmos.*, *117*, doi:10.1029/2011JD017259.

Galford, G. L., Soares-Filho, B., & Cerri, C. E. P. (2013). Prospects for land-use sustainability on the agricultural frontier of the Brazilian Amazon. Philosophical Transactions of the Royal Society B Biological Sciences, 368, 20120171. http://dx.doi.org/10.1098/rstb.2012.0171

Gan, M.A.; Kousky, V.E.; Ropelewski, C.F. (2004) The South America Monsoon Circulation and Its Relationship to Rainfall over West-Central Brazil. *J. Clim.*, *17*, 47–66.

Gan, M.A.; Rao, V.B.; Moscati, M.C.L. (2005) South American monsoon indices. *Atmos. Sci. Lett.*, *6*, 219–223.

Gardner, T. A., Godar, J., & Garrett, R. (2014). Governing for sustainability in agricultural-forest frontiers: A case study of the Brazilian Amazon. Stockholm Environment Institute, 12

Gil, J., Siebold, M., & Berger, T. (2015). Adoption and development of integrated crop-livestock-forestry systems in Mato Grosso, Brazil. Agriculture, Ecosystems & Environment, 199, 394-406. http://dx.doi.org/10.1016/j.agee.2014.10.008.

Gloor, M, Brienen, R. J. W., Galbraith, D.T. R. , Feldpausch, Schöngart, Guyot, J-L, Espinoza, J.C. J. Lloyd, J.and O. L. Phillips. Intensification of the Amazon hydrological cycle over
the last two decades; Geophysical Research Letters, Vol. 40, 1729–1733, doi:10.1002/grl.50377, 2013

Hahn, M. B., Gangnon, R. E., Barcellos, C., Asner, G. P., Patz, J. A., & Chowell, G. (2014). Influence of deforestation, Logging, and Fire on malaria in the Brazilian Amazon. PLoS One, 9, e85725. http://dx.doi.org/10.1371/journal.pone.0085725.

Hall, A. (2006). From Fome zero to Bolsa Familia: Social policies and poverty alleviation under Lula. Journal of Latin American Studies, 38, 689e709. http://dx.doi.org/10.1017/S0022216X0600157X.

Haberl, H., Fischer-Kowalski, M., Krausmann, F., Weisz, H., & Winiwarter, V. (2004). Progress towards sustainability? What the conceptual framework of material and energy flow accounting (MEFA) can offer. Land Use Policy, 21, 199-213. http://dx.doi.org/10.1016/j.landusepol.2003.10.013.

Hecht, S. B. (2012). From eco-catastrophe to zero deforestation? Interdisciplinarities, politics, environmentalisms and reduced clearing in Amazonia.

Environmental Conservation, 39, 4-19. http://dx.doi.org/10.1017/S0376892911000452

Hsu, K.; Gao, X.; Sorooshian, S.; Gupta, H.V. (1997) Precipitation estimation from remotely sensed information using artificial neural networks. *J. Appl. Meteorol. Climatol.*, *36*, 1176–1190.

Hsu, K.; Gupta, H.V.; Gao, X.; Sorooshian, S. (1999) Estimation of physical variables from multichannel remotely sensed imagery using a neural network: Application to rainfall estimation. *Water Resour. Res.*, *35*, 1605–1618.

IBGE. (2016). Instituto Brasileiro de Geografia e Estatistica.

IDHM. (2013). Atlas do Desenvolvimento Humano no Brasil.

INPE. (2016). Projeto PRODES

INSERM. (2013). Pesticides: Effets sur la sante, 161 pp, ISBN:978-2-85598-906-X

Khanna, J.; Medvigy, D.; Fueglistaler, S.; Walko, R. (2017) Regional dry-season climate changes due to three decades of Amazonian deforestation. *Nat. Clim. Chang.*, *7*, 200–204.

Kirby K.R., W.F. Laurance, A.K. Albernaz, G. Schroth, P.M. Fearnside, S. Bergen, E.M. Venticinque, C. da Costa (2006) The future of deforestation in the Brazilian Amazon. Futures, 38, 432-453. doi.org/10.1016/j.futures.2005.07.011

Koza J.R. (2010) Human-competitive results produced by genetic programming, Genet. Program. Evol. Mach. 11 (3–4), 251–284.

Landers, J. (2001). How and why the Brazilian zero tillage explosion occurred. In D. E. Stott, R. H. Mohtar, & G. C. Steinhardt (Eds.), Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24e29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory (pp. 29-39).

Lapola, D. M., Martinelli, L. A., Peres, C. A., Ometto, J. P. H. B., Ferreira, M. E., Nobre, C. A., et al. (2013). Pervasive transition of the Brazilian land-use system. Nature Climate Change, 4, 27-35. http://dx.doi.org/10.1038/nclimate2056.

Lapola, D. M., Schaldach, R., Alcamo, J., Bondeau, A., Koch, J., Koelking, C., et al. (2011). Impacts of climate change and the end of deforestation on land use in the Brazilian Legal Amazon. Earth Interactions, 15, 1-29.

Laurance, W.F.; Williamson, G.B. (2001a) Positive Feedbacks among Forest Fragmentation, Drought, and Climate Change in the Amazon. *Conserv. Biol.*, *15*, 1529–1535.

Laurance, W.F.; Cochrane, M.A.; Bergen, S.; Fearnside, P.F.; Delamônica, P.; Barber, C.; D'Angelo, S.; Fernandes, T. (2001b) The Future of the Brazilian Amazon. *Science*, *291*, 438–439.

Lemaire, G., Franzluebbers, A., Carvalho, P. C., de, F., & Dedieu, B. (2014). Integrated cropelivestock systems: Strategies to achieve synergy between agricultural production and environmental quality. Agriculture, Ecosystems & Environment, 190, 4-8. http://dx.doi.org/10.1016/j.agee.2013.08.009

Liebmann, B.; Marengo, J. (2001) Interannual Variability of the Rainy Season and Rainfall in the Brazilian Amazon Basin. *J. Clim.*, *14*, 4308–4318.

Liebmann, B.; Camargo, S.J.; Seth, A.; Marengo, J.A.; Carvalho, L.M.V.; Allured, D.; Fu, R.; Vera, C.S. (2007) Onset and end of the rainy season in South America in observations and the ECHAM 4.5 Atmospheric General Circulation Model. *J. Clim.*, *20*, 2037–2050.

Liu Y., Q. Dai, J. Liu, S. Liu, J. Yang, (2014) Study of burn scar extraction automatically based on level set method using remote sensing data, PLoS One 9 (2), 1–11.

Macedo, M. N., DeFries, R. S., Morton, D. C., Stickler, C. M., Galford, G. L., & Shimabukuro, Y. E. (2012). Decoupling of deforestation and soy production in the southern Amazon during the late 2000s. Proceedings of the National Academy of Sciences, 109, 1341-1346. http://dx.doi.org/10.1073/pnas.1111374109

Makarieva, A.M.; Gorshkov, V.G.; Sheil, D.; Nobre, A.D.; Li, B.L. (2013) Where do winds come from? A new theory on how water vapor condensation influences atmospheric pressure and dynamics. *Atmos. Chem. Phys*, *13*, 1039–1056.

MAPA, M. D. A. (2012). Plano Setorial de Mitigação e de Adaptação as Mudanças Climaticas para a Consolidação de uma Economia de Baixa Emissão de Carbono na Agricultura: plano ABC. Ministerio da Agricultura, Pecuaria e Abastecimento/ Ministerio do Desenvolvimento Agr.

Marengo, J.A.; Espinoza, J.C. (2016) Extreme seasonal droughts and floods in Amazonia: Causes, trends and impacts: Extremes in Amazonia. *Int. J. Climatol.*, *36*, 1033–1050.

Marengo, J.A.; Liebmann, B.; Grimm, A.M.; Misra, V.; Dias, P.L.S.; Cavalcanti, I.F.A.; Carvalho, L.M.V.; Berbery, E.H.; Ambrizzi, T.; Vera, C.S.; et al. (2012) Recent developments on the South American monsoon system. *Int. J. Climatol.*, *32*, 1–21.

Marengo, J.A., (2009) Long-term trends and cycles in the hydrometeorology of the Amazon basin since the late 1920s. *Hydrol. Process*. DOI: 10.1002/hyp

Martinelli, L. A., Naylor, R., Vitousek, P. M., & Moutinho, P. (2010). Agriculture in Brazil: Impacts, costs, and opportunities for a sustainable future. Current Opinion in Environmental Sustainability, 2, 431-438. http://dx.doi.org/10.1016/j.cosust.2010.09.008

Melchiori A.E., A.W. Setzer, F. Morelli, R. Libonati, P. d. A. Candido, S. C. d. Jesus, (2014) A Landsat-TM/OLI Algorithm for Burned Areas in the Brazilian Cerrado: Preliminary Results, Imprensa da Universidade de Coimbra, Coimbra, pp.1302–1311.

Ministerio da Agricultura. (2015). Plano ABC libera R$ 2,5 bi em credito

Molina-Carpio, J.; Espinoza, J.C.; Vauchel, P.; Ronchail, J.; Caloir, B.G.; Guyot, J.L.; Noriega, L. (2017) Hydroclimatology of the Upper Madeira River basin: spatio-temporal variability and trends. *Hydrol. Sci. J.*, *62*, 911–927.

Morton, D.C.; DeFries, R.S.; Shimabukuro, Y.E.; Anderson, L.O.; Arai, E.; Espirito-Santo, F.D.B.; Freitas, R.; Morisette, J. (2006) Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. *Proc. Natl. Acad. Sci. USA*, *103*, 14637–14641.

Neill, C., Coe, M. T., Riskin, S. H., Krusche, A. V., Elsenbeer, H., Macedo, M. N., et al. (2013). Watershed responses to Amazon soya bean cropland expansion and intensification. Philosophical Transactions of the Royal Society B Biological Sciences, 368, 20120425. http://dx.doi.org/10.1098/rstb.2012.0425

Nepstad, D., McGrath, D., Stickler, C., Alencar, A., Azevedo, A., Swette, B., et al. (2014). Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. Science, 344, 1118-1123. http://dx.doi.org/10.1126/science.1248525

Nogueira E.M., A.M. Yanai, S.S. de Vasconcelos, P.M.L. de Graça, P.M. Fearnside, (2017) Carbon stocks and losses to deforestation in protected áreas in Brazilian Amazonia.

Regional Environmental Changes, advance online publication, doi:10.1007/s10113-017-1198-1

Ofstehage, A. (2016). Farming is easy, becoming Brazilian is hard: North American soy farmers' social values of production, work and land in Soylandia. Journal of Peasant Studies, 43, 442e460. http://dx.doi.org/10.1080/03066150.2014.998651

Oliveira, L. J. C., Costa, M. H., Soares-Filho, B. S., & Coe, M. T. (2013). Large-scale expansion of agriculture in Amazonia may be a no-win scenario. Environmental Research Letters, 8, 024021. http://dx.doi.org/10.1088/1748-9326/8/2/024021

Pires, D. X., Caldas, E. D., & Recena, M. C. P. (2005). Uso de agrotoxicos e suicídios no Estado do Mato Grosso do Sul, Brasil. Cadernos de Saúde Pública, 21, 598e604. http://dx.doi.org/10.1590/S0102-311X2005000200027

Recena, M. C. P., Pires, D. X., & Caldas, E. D. (2006). Acute poisoning with pesticides in the state of Mato Grosso do Sul, Brazil. Science of The Total Environment, 357, 88-95. http://dx.doi.org/10.1016/j.scitotenv.2005.04.029

Riskin, S. H., Porder, S., Neill, C., Figueira, A. M. S., Tubbesing, C., & Mahowald, N. (2013). The fate of phosphorus fertilizer in Amazon soya bean fields. Philosophical Transactions of the Royal Society B Biological Sciences, 368, 20120154. http://dx.doi.org/10.1098/rstb.2012.0154

Rodrigues, A. S. L., Ewers, R. M., Parry, L., Souza, C., Verissimo, A., & Balmford, A. (2009). Boom-and-bust development patterns across the Amazon deforestation frontier. Science, 324, 1435e1437. http://dx.doi.org/10.1126/science.1174002.

Ronchail, J.; Cochonneau, G.; Molinier, M.; Guyot, J.L.; De Miranda Chaves, A.G.; Guimarães, V.; de Oliveira, E. (2002) Interannual rainfall variability in the Amazon basin and sea-surface temperatures in the equatorial Pacific and the tropical Atlantic Oceans. *Int. J. Climatol.*, *22*, 1663–1686.

Salati, E.; Dall'Olio, A.; Matsui, E.; Gat, J.R. (1979) Recycling of water in the Amazon Basin: An isotopic study. *Water Resour. Res.*, *15*, 1250–1258.

Salton, J. C., Mercante, F. M., Tomazi, M., Zanatta, J. A., Concenço, G., Silva, W. M., et al. (2014). Integrated crop-livestock system in tropical Brazil: Toward a sustainable production system. Agriculture, Ecosystems & Environment, 190, 70-79. http://dx.doi.org/10.1016/j.agee.2013.09.023

Schiesari, L., Waichman, A., Brock, T., Adams, C., & Grillitsch, B. (2013). Pesticide use and biodiversity conservation in the Amazonian agricultural frontier. Philosophical Transactions of the Royal Society B Biological Sciences, 368, 20120378. http://dx.doi.org/10.1098/rstb.2012.0378

Scopel, E., Douzet, J. M., Macena Da Silva, F. A., Cardoso, A., Alves Moreira, J. A., Findeling, A., et al. (2005). Impacts des systemes de culture en semis direct avec couverture veg etale (SCV) sur la dynamique de l 'eau, de l'azote mineral et du carbone du sol dans les Cerrados bresiliens. Cahiers Agricultures, 14, 71-75.

SIH. (2015). Sistema de Informaçao Hospitalar

Silva, V.B.S.; Kousky, V.E. (2012) The South American Monsoon System: Climatology and Variability. In *Modern Climatology*; Wang, S.Y.S., Ed.; InTech: Rijeka, Croatia, pp. 123–152.
.
SINAN. (2015). Sistema de Informaçao de Agravos de Notificação

SNUC (2011) Sistema Nacional de Unidades de Conservação da Natureza (SNUC) e Plano Estratégico Nacional de Áreas Protegidas (PNAP). Ministério do Meio Ambiente, Secretaria de Biodiversidade e Florestas, Departamento de Áreas Protegidas, Brasília, 80.

Soares, W. L., & Porto, M. F. (2007). Atividade agrícola e externalidade ambiental: uma analise a partir do uso de agrot oxicos no cerrado brasileiro. Ciencia & Saúde Coletiva, 12, 131-143.

Sorooshian, S.; Hsu, K.; Braithwaite, D.; Ashouri, H.; (2014) NOAA CDR Program. *NOAA Climate Data Record (CDR) of Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN-CDR), Version 1 Revision 1 [1983–2008]*; NOAA National Centers for Environmental Information: Asheville, NC, USA,.

Souza, P., Xavier, D., Rican, S., de Matos, V., & Barcellos, C. (2015). The expansion of the economic frontier and the diffusion of violence in the Amazon. International Journal of Environmental Research and Public Health, 12, 5862-5885. http:// dx.doi.org/10.3390/ijerph120605862.

Spera, S. A., Cohn, A. S., VanWey, L. K., Mustard, J. F., Rudorff, B. F., Risso, J., et al. (2014). Recent cropping frequency, expansion, and abandonment in Mato Grosso, Brazil had selective land characteristics. Environmental Research Letters, 9, 064010. http://dx.doi.org/10.1088/1748-9326/9/6/064010

Stefani, A., Dusfour, I., Corea, A. P. S. A., Cruz, M. C. B., Deassy, N., Galardo, A., et al. ^ (2013). Land cover, land use and malaria in the Amazon: A systematic literature review of studies using remotely sensed data. Malaria Journal, 12, 192. http://dx.doi.org/10.1186/1475-2875-12-192

Strassburg, B., Latawiec, A. E., Barioni, L. G., Nobre, C. A., da Silva, V. P., Valentin, J. F., et al. (2014). When enough should be enough: Improving the use of current agricultural lands could meet production demands and spare natural habitats in Brazil. Global Environmental Change, 28, 84-97. http://dx.doi.org/10.1016/j.gloenvcha.2014.06.001

Swann, A.L.; Longo, M.; Knox, R.G.; Lee, E.; Moorcroft, P.R. (2015) Future deforestation in the Amazon and consequences for South American climate. *Agric. For. Meteorol.*, *214–215*, 12–24.

Tritsch, I., & Arvor, D. (2016). Transition in environmental governance in the Brazilian Amazon: Emergence of a new pattern of socio-economic development and deforestation. Land Use Policy, 59, 446e455. http://dx.doi.org/10.1016/j.landusepol.2016.09.018.

Vera, C.; Higgins, W.; Amador, J.; Ambrizzi, T.; Garreaud, R.; Gochis, D.; Gutzler, D.; Lettenmaier, D.; Marengo, J.; Mechoso, C.R.; et al. (2006) Toward a Unified View of the American Monsoon Systems. *J. Clim.*, *19*, 4977–5000.

VanWey, L. K., Spera, S., de Sa, R., Mahr, D., & Mustard, J. F. (2013). Socioeconomic development and agricultural intensification in Mato Grosso. Philosophical Transactions of the Royal Society B Biological Sciences, 368, 20120168. http://dx.doi.org/10.1098/rstb.2012.0168

Walker R., N.J. Moore, E. Arima, S. Perz, C. Simmons, M. Caldas, D. Vergara, C. Bohrer (2009) Protecting the Amazon with protected areas. PNAS, 106, 10582-10586.

Weinhold, D., Reis, E. J., & Vale, P. M. (2015). Boom-bust patterns in the Brazilian Amazon. Global Environmental Change, 35, 391e399. http://dx.doi.org/10.1016/j.gloenvcha.2015.09.013.

Yin, L.; Fu, R.; Zhang, Y.F.; Arias, P.A.; Fernando, D.N.; Li, W.; Fernandes, K.; Bowerman, A.R. (2014) What controls the interannual variation of the wet season onsets over the Amazon? *J. Geophys. Res. Atmos.*, *119*, 2314–2328.

Yoon, J.H.; Zeng, N. (2010) An Atlantic influence on Amazon rainfall. *Clim. Dyn.*, *34*, 249–264.

Zemp, D.C.; Schleussner, C.F.; Barbosa, H.M.J.; Hirota, M.; Montade, V.; Sampaio, G.; Staal, A.; Wang-Erlandsson, L.; Rammig, A. (2017) Self-amplified Amazon forest loss due to vegetation-atmosphere feedbacks. *Nat. Commun.*, *8*, doi:10.1038/ncomms14681.

Zhou, J.; Lau, K.M. (1998) Does a Monsoon Climate Exist over South America? *J. Clim.*, *11*, 1020–1040.