MapBiomas General "Handbook"

Algorithm Theoretical Basis Document (ATBD)

Collection 4

Version 2.0

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Executive Summary

MapBiomas initiative was formed in 2015 by universities, NGOs and companies to develop a fast, reliable, collaborative and low-cost method to produce an annual temporal series of land cover and land use maps of Brazil from 1985 to 2018. This mapping initiative is organized by biomes (Amazon, Atlantic Forest, Caatinga, Cerrado, Pampa and Pantanal) and cross-cutting themes (Pasture, Agriculture, Forest Plantation, Coastal Zone, Mining and Urban Infrastructure), involving a wide range of specialists from from remote sensing, geography, geology, ecology, environmental and forestry engineering, computer science, human science, journalists, designers among others.

MapBiomas has produced three sets of digital annual maps of land cover and land use (LCLU), named Collections. The satellite image classification methods and algorithms for each Collection evolved over the years. The Collection 1 published in 2016, which consisted on the first step of the mapping process, covered the period of 2008 to 2015 and focused on seven LCLU classes: forest, agriculture, pasture, forest plantation, mangrove, and water. The Collection 2 released in 2017, by applying empirical decision tree classification, encompassed the period of 2000 through 2016 and included 27 LCLU classes with subclasses of forest, savanna, grasslands, mangroves, beaches, urban infrastructure and more. The Collection 2.3 was based on a new approach of random forest machine learning to overcome empirical calibration of the input parameters for image classification. In 2018, the Collection 3 also based on the random forest algorithm, but included a more robust sampling designed for training the classifier, expanded the mapping period for 1985 through 2017. Finally, in 2019, Collection 4 was produced including 2018 in the time series and other new approaches and methods such as: 1) use of deep learning for aquaculture mapping, 2) a per scene based analysis for the Amazon biome, 3) collection of 100 thousand samples for accuracy assessment and area estimation, 4) reduction and better selection of feature space variables.

The objective of this Algorithm Theoretical Basis Document (ATBD) is to provide the users of the MapBiomas data the understanding of the methodological steps and computational algorithms to produce Collection 4 and describe the datasets, statistics produced as well. All the MapBiomas maps and datasets are freely available at the project platform (http://mapbiomas.org).

1. Introduction

1.1. Scope and content of the document

The objective of this document is to describe the theoretical basis, justification and methods applied to produce annual maps of land cover and land use (LCLU) in Brazil from 1985 to 2018 of the MapBiomas Collection 4.

This document covers the image classification methods of Collection 4, the image processing architecture, and the approach to integrate the biomes and cross-cutting theme maps. In addition, the document presents a historical context and background information, as well as a general description of the satellite imagery dataset, feature inputs, and of the accuracy assessment method applied.

The algorithms and specific procedures applied in each biome and cross-cutting theme are present in the appendices.

1.2. Overview

The MapBiomas project was launched in July 2015, aiming to contribute with the understanding of LCLU dynamics in Brazil. These LCLU maps produced in this project were based on the Landsat Data Archive (LDA) available in the Google Earth Engine platform, encompassing the years from 1985 through the present days. The MapBiomas mapping efforts were divided in Collections for the following periods:

- Collection 1: 2008 through 2015 (launched in April 2016).
- Collection 2: 2000 through 2016 (launched in April 2017).
- Collection 2.3: a revised version of Collection 2.0 (launched in December 2017).
- Collection 3: 1985 through 2017 (launched in August 2018).
- Collection 4: 1985 through 2018 (launched in August 2018).

The Collection 2.3 marked the transition from empirical decision tree classification approach to random forest machine learning classifier, from Collection 2 to Collection 3. Besides the annual classifications of digital maps, MapBiomas aims to contribute with the development of a fast, reliable, collaborative and low-cost method to process large-scale datasets to generate historical time-series of LCLU annual maps. In addition, the project also produced a web-based platform MapBiomas Workspace (http://workspace.mapbiomas.org) to facilitate the implementation of the image processing method. All data, classification maps, software, statistics and further analyses are openly accessible through the MapBiomas Platform (http://mapbiomas.org). All these are possible thanks to: i) Google Earth Engine Platform which provides access to data, image processing standard algorithms, and the cloud computing facility; ii) to organizations that are part of MapBiomas network that shared knowledge and mapping tools; and iii) to visionary funding agencies that support the project.

The products of the MapBiomas Collection 4 are the following:

• Biome maps (Amazon, Atlantic Forest, Caatinga, Cerrado, Pampa and Pantanal) and cross-cutting theme maps (Pasture, Agriculture, Forest Plantation, Coastal Zone, Mining and Urban Infrastructure);
• Pre-Processed feature mosaics generated from LDA collections (Landsat 5, Landsat 7 and Landsat 8).
• Image processing infrastructure and algorithms (scripts to run in Google Earth Engine, MapBiomas Workspace and source code).
• LCLU transition statistics and spatial analysis with political, watershed, protected areas, and other categorical maps.
• Quality assessment of the Landsat mosaics. Each scene may have a proportion of clouds and other interferences. Thus, each pixel in a given year was classified according to the number of available observations, which may vary from 0 to 23 observations per year. The quality assessment of the Landsat mosaics are available at MapBiomas website.

The MapBiomas project had also expanded to other regions and is now running in the Chaco region and in the Pan-Amazon countries. These new project areas also follow the mapping protocol of MapBiomas Brazil with a few adjustments to cope with peculiarities of these ecosystems. Detailed information about these MapBiomas initiatives can be found at the ATBD of these regions.

1.3. Region of Interest

MapBiomas was created to produce LCLU annual maps for the entire Brazilian territory, thus covering all six official biomes of the country: Amazon, Atlantic Forest, Caatinga, Cerrado, Pampa and Pantanal (Figure 1). The division by biomes and helps to classify distinct LCLU classes and patterns across the country (Table 1). The project was also divided by cross-cutting themes: Agriculture, Pasture, Forest Plantation, Mining and Urban Infrastructure. Although the Coastal Zone is not considered a biome officially, this region that covers dunes, beaches and mangroves along the Brazilian coast was treated as such.

For MapBiomas initiative, to produce a 1:1.000.000 map of the limits of the biomes the official map of biomes published by IBGE (1:5.000.000) was refined based on the Brazilian boundaries map 1:250.000 and the physiognomies map 1:1.000.000, both from IBGE.

Figure 1. Brazilian biomes mapped in the MapBiomas project to generate the Collection 4 products (source: IBGE, 2012).

Table 1. Land cover and land use characteristics of the Brazilian biomes.

Biome	Area (km^2) (Country %)	Land Cover	Land Use
Amazon	4,196,943 (49.29%)	Evergreen forest, with enclaves of savanna, natural grassland, and extensive wetland and surface water.	Cattle ranching, agriculture, mining, logging and non-timber forestry production.
Atlantic Forest	1,110,182 (13.04%)	Small isolated forest fragments covering 7% of the biome (Morellato & Haddad, 2000), mostly old secondary growth, surrounded by croplands, pasture, forest plantation, and urban infrastructure.	Agriculture, cattle ranching, urban, forest plantation, artificial water reservoir.

Caatinga	844,453 (9.92%)	Woody and deciduous forest, with at least 50% of the original converted (de Oliveira et al., 2012).	Agriculture, cattle ranching, smallholder livestock production, urbanization.
Cerrado	2,036,448 (23.92%)	Mosaic of savanna, grassland and forest, 50% of the native vegetation cover has already been converted (PPCerrado/Inpe).	Agriculture, cattle ranching.
Pampa	176,496 (2.07%)	Natural grassland, with scattered shrub and trees, rock outcrop formations (Roesch et al., 2009).	Agriculture (rice, soy, perennial crops), livestock production (in natural grasslands), forest plantation, and urbanization.
Pantanal	150,355 (1.76%)	Savanna, grassland and wetland	Agriculture, cattle ranching and ecotourism.

1.4. Key Science Applications

MapBiomas was originally designed to fill gaps in greenhouse gas emission estimates of the LCLU change sector in Brazil. However, other scientific applications can be derived with an annual time-series history of LCLU maps produced, including:

- Mapping and quantifying LCLU transitions.
- Quantification of gross and net forest loss and gain.
- Monitoring of regeneration and secondary growth forests.
- Monitoring of water resources and their interaction with LCLU classes.
- Monitoring agriculture and pasture expansion.
- Monitoring natural disasters.
- Expansion of infrastructure and urbanization.
- Identification of desertification process.
- Regional planning.
- Management of Protected Areas.
- Monitoring of Forest Concessions.
- Infectious disease risk modeling.
- Climate modeling.
- Species distribution modeling

2. Overview and Background Information

2.1 Context and Key Information

This section addresses complementary contextual and key information relevant to the understanding of the MapBiomas products and methods to generate the Collections.

2.1.1. MapBiomas Network

MapBiomas is a multi-institutional initiative of the Greenhouse Gas Emissions Estimation System (SEEG - http://seeg.eco.br/en/) promoted by the Climate Observatory (a network of 40+ NGOs working on climate change in Brazil - http://www.observatoriodoclima.eco.br/en/). The co-creators of the MapBiomas involve NGOs, universities and technology companies (list of all organizations involved in the Annex I).

Organizations play specific or multiple roles as well as contributes to the overall development of the project. Each biome and cross-cutting theme (Agriculture, Pasture, Forest Plantation, Coastal Zone, Mining and Urban Infrastructure) has a lead organization, as shown in the box below.

Biome coordination:

• **Amazon** – Institute of Man and Environment of the Amazon (IMAZON).

• **Atlantic Forest** – Foundation SOS Atlantic Forest and ArcPlan.

• **Caatinga** – State University of Feira de Santana (UEFS) and Plantas do Nordeste Association (APNE).

• **Cerrado** – Amazon Environmental Research Institute (IPAM).

• **Pampa** – Federal University of Rio Grande do Sul (UFRGS).

• **Pantanal** – Institute SOS Pantanal and ArcPlan.

Cross-cutting theme coordination:

• **Pasture** – Federal University of Goias (LAPIG/UFG).

• **Agriculture and Forest Plantation** – Agrosatelite.

• **Coastal Zone and Mining** – Vale Technological Institute (ITV) and Solved.

• **Urban Infrastructure** – Terras.

Two geospatial tech companies, Terras and Ecostage, are responsible for the workspace/backend and dashboard/website/frontend of the MapBiomas, respectively. Google provides the cloud computing infrastructure that allows data processing, analysis and storage through Google Earth Engine.

Funding to implement and operationalize the MapBiomas Initiative comes from Arapyaú Institute, Children's Investment Fund Foundation (CIFF), Climate and Land Use Alliance (CLUA), Good Energies Foundation, Gordon & Betty Moore Foundation, Humanize, Institute for Climate and Society (iCS), and Norway's International Climate and Forest Initiative (NICFI).

Since both Climate Observatory and MapBiomas are not institutions, the initiative receives the generous institutional management to operational and financing tasks from partners which include Arapyaú Institute, Avina Foundation, World Resources Institute (WRI), The Nature Conservancy (TNC) and Instituto Democracia e Sustentabilidade (IDS).

The project also has an independent Scientific Advisory Committee (SAC) composed by:

• Dr. Alexandre Camargo Coutinho (Embrapa)
• Dr. Edson Eygi Sano (IBAMA)
• Dr. Gilberto Camara Neto (INPE)
• Dr. Joberto Veloso de Freitas (Brazilian Forest Service)
• Dr. Matthew C. Hansen (Maryland University)
• Dr. Mercedes Bustamante (University of Brasília)
• Dr. Timothy Boucher (TNC)

2.1.2. Remote Sensing Data

The imagery dataset used in the MapBiomas project, across Collections 1 to 4, was obtained by the Landsat sensors Thematic Mapper ™, Enhanced Thematic Mapper Plus (ETM+) and the Operational Land Imager and Thermal Infrared Sensor (OLI-TIRS), on board of Landsat 5, Landsat 7 and Landsat 8, respectively. The Landsat imagery collections with 30 pixel resolution were accessible via Google Earth Engine, and source by NASA and USGS.

The MapBiomas has mostly used Collection 1 Tier 1 from USGS and top of the atmosphere reflectance (TOA), which underwent through radiometric calibration and orthorectification correction based on ground control points and digital elevation model to account for pixel co-registration and correction of displacement errors. Except the Amazon biome that has used Landsat scenes and Surface Reflectance.

2.1.3 Google Earth Engine and MapBiomas Computer Applications

MapBiomas image processing chain is based on Google technology, which includes image processing in cloud computing infrastructure, programming with Javascript and Python via Google Earth Engine, and data storage using Google Cloud Storage. Google Earth Engine is defined by Google as: “a platform for petabyte-scale scientific analysis and visualization of geospatial datasets, both for public benefit and for business and government users.”

The MapBiomas project has developed the following computer applications based on Google Earth Engine:

• Javascript scripts - these computer codes were written directly in the Google Earth Engine Code Editor and were used to prototype new image processing algorithms and test large-scale image processing to be implemented in the Workspace environment for Collections 1 and 2. Most of the image classification and post-classification of Collections 3 and 4 were written in Javascript, except Caatinga and Amazon biomes that used Earth Engine Python API.

• Python scripts – This category of code was used to optimize image processing of large datasets in Google Earth Engine. In addition, the map integration, post-classification tasks and statistical analysis were all performed in Earth Engine Python API.

• WebCollect: a front-end web application to allow image analysts to collect and interpret sample points (*i.e.,* at the pixel level) by visual interpretation of Landsat color composite images. The main application of the WebCollect is to derive reference LCLU classes for accuracy assessment.

• Workspace - a web-based application to allow general user with no-programming experience to access imagery collections, process them,manage and store the results in databases and map assets (*i.e.*, new collections) (Figure 2). The biome maps of Collections 1 and 2 were produced using the Workspace application. The Workspace environment allows to manage each image individually, define and store image classification parameters on a per map sheet basis (Figure 2). The biome teams of analysts can work simultaneously to set the image classification parameters, pre-process and evaluate the results and later submit tasks to large-scale image processing to generate the final products, which are Landsat image mosaics, LCLU maps, transition analysis and statistics. All these products are then publicly available on the web platform named MapBiomas Dashboard. More details on how the Workspace was used to parameterize the image processing and the classification, and control the processing workflow by biome teams are presented in the specific ATBDs of Collections 1 and 2 of the biomes.

• Mapbiomas.org (Dashboard). The web-platform of the MapBiomas initiative presents the Landsat image mosaics and its quality, land cover and land use annual maps of the Collection 4, transitions analysis, statistics, and all the methodological information about the ATBDs, tools, scripts, and accuracy analysis. All the maps and Landsat mosaics of the MapBiomas Collections are publicly available to download at the MapBiomas website (http://mapbiomas.org/).

Figure 2. MapBiomas Workspace interface. Brazil is divided in map charts of 1 degree and 1.5 degree to establish classification parameters and store them in a database.

2.2 Historical Perspective: Existent Maps and Mapping Initiatives

The existing LCLU mapping efforts that cover all Brazil, before MapBiomas, were neither frequent and nor updated (Annex II) and sometimes have lower resolution. MapBiomas and the available global and national land cover products can be used complementary but there are potential advantages of MapBiomas maps. First, the MapBiomas maps reconstructed the entire Landsat time-series (>35 years) on an annual basis. The classification scheme is also more relevant for national applications because it follows the Brazilian vegetation classification legend (IBGE, 2012). In addition, MapBiomas has the potential to monitor primary forest changes (*i.e.,* deforestation and forest degradation), secondary forest regrowth, and land use classes (pasture, agriculture, forest plantation, mining and urban infrastructure) along this time series. All products from MapBiomas, as well as methods and tools to produce the maps, are publicly available on the internet, allowing its reproduction in other contexts, as it is already happening in all other Amazonian countries (Peru, Ecuador, Bolivia, Colombia, Venezuela, Guyanas and Suriname - http://amazonia.mapbiomas.org/) and the Chaco region (Argentina, Bolivia and Paraguay - http://chaco.mapbiomas.org/), involving and training local institutions. Most recently, will be expanded to Uruguay and Indonesia.

2.2.1. International land cover and land use data

Mapping initiatives at the global level complement national mapping efforts (Annex II). The USGS in collaboration with the University of Maryland produced global land cover and tree cover layers. USGS also produces a MODIS land cover map at 500m pixel scale. The GlobCover Portal is another initiative from the European Space Agency (ESA) which produced land cover maps with MERIS sensor at 300m spatial resolution for two periods: December 2004 - June 2006 and January - December 2009. Global Forest Watch (GFW) and Google Earth Engine provide the Global Forest Change (GFC) maps from 2000 to 2014 derived from the Landsat imagery at 30 m resolution produced by University of Maryland (Global Land Cover Facility - GLCF). The National Geomatics Center of China (NGCC) produced GlobeLand30 - a high-resolution (30 m) full coverage land cover maps for years 2000 and 2010. Finally, Japan Aerospace Exploration Agency (JAXA) also produced a forest/non-forest map for 2007-2010 using a 25m-resolution PALSAR mosaic. There are other global products that were produced using lower spatial resolution (>500m) but are not presented here because their resolutions limits applications to assess MapBiomas products, which are produced at 30m Landsat pixel.

2.2.2. National land cover and land use data

The RadamBrasil Project was the first national initiative to map vegetation of the entire country of Brazil. This project was conducted from 1975 to 1980 based on airborne radar imagery, visual interpretation and extensive and detailed field work, involving several dozens of organizations. The RadamBrasil Project produce maps at 1:250.000 scale, and it is still a solid reference for scientific and technical studies about vegetation (Cardoso, 2009).

In 2004, the Minister of Environment launched the natural vegetation map of Brazil developed in the context of Probio (*Projeto de Conservação e Utilização Sustentável da Diversidade Biológica Brasileira*) providing updated information about land cover in Brazil, considering that only the Amazon and Atlantic Forest biomes were being monitored after RadamBrasil project. The Brazilian biome boundaries (IBGE, 2004a) were used as reference for national mapping initiative. The Probio project was based on Landsat imagery acquired in 2002, with minimum mapping unit varying from 40 to 100 hectares, and mapping scale of 1:250.000. Accuracy assessment was based on digital imagery products at 1:100.000, with a minimal overall accuracy of 85%. The land cover classes followed IBGE manual for vegetation mapping (IBGE, 2004b). The Probio project updated forest change mapping for the year 2008 for all biomes and for the years 2009, 2010 and 2011 depending on the biome.

In the context of the National Inventories of GHG Emissions and Removals, the Ministry of Science and Technology commissioned the production of land cover and land use maps of Brazil for the years 1994, 2002 and 2010 (also 2005 for the Amazon). Those maps were produced by FUNCATE based on segmentation and visual interpretation of Landsat Imagery and identifying natural vegetation (forest and no-forest), agriculture, pasture, silviculture, urban areas and water.

More recently IBGE have published a platform to monitor LCLU in Brazil making available maps for 2000, 2010, 2012 and 2014 on a 1 km resolution and covering the classes of forests, savannas, agriculture, pasture, urban areas and water and mosaics of those classes.

2.2.3. Regional and biomes land cover data

There are also reference maps at the biome scale and though the cross-cutting themes. For example, the PRODES and the TerraClass maps are available for the Amazon biome, and more recently in the Cerrado biome for some years. There are also maps available for subareas of the Pampa biome, at the state level (e.g. Rio Grande do Sul state). These reference land cover and land use maps for the biomes and cross-cutting themes are presented in the Annex II.

3. Methodological description

The methodological steps of Collection 4 are presented in the Figure 3 and detailed above. The first step was to generate annual Landsat image mosaics based on specific periods of time to optimize the spectral contrast and discriminate the LCLU classes across the biomes (see the biome Appendices for detailed information). The second step was to establish the spectral feature inputs derived from the Landsat bands to run the random forest classification. The acquisition of training samples started with the selection of temporally stable samples. Once selected each biome and cross-cutting theme may adjust their training data set according to its statistical needs. Based on the adjusted training data set, the random forest classifier was run. Following that, spatial and temporal filters were applied to remove classification noise and stabilize the classification. The LCLU maps of each biome and cross-cutting themes were integrated based on prevalence rules to generate the final map of Collection 4. Accuracy assessment analysis were based on acquisition of 100 thousand independent samples per year from 1985 to 2018. The validation methodology followed the good practices proposed by Olofsson et al. (2014), Stehman et al. 2014 and Stehman & Fody, 2019. The MapBiomas annual LCLU maps were used to derived the transition analysis (with spatial filter application) and statistics. The statistical analysis covered different spatial categories, such as biome, state, municipality, watershed and protected areas.

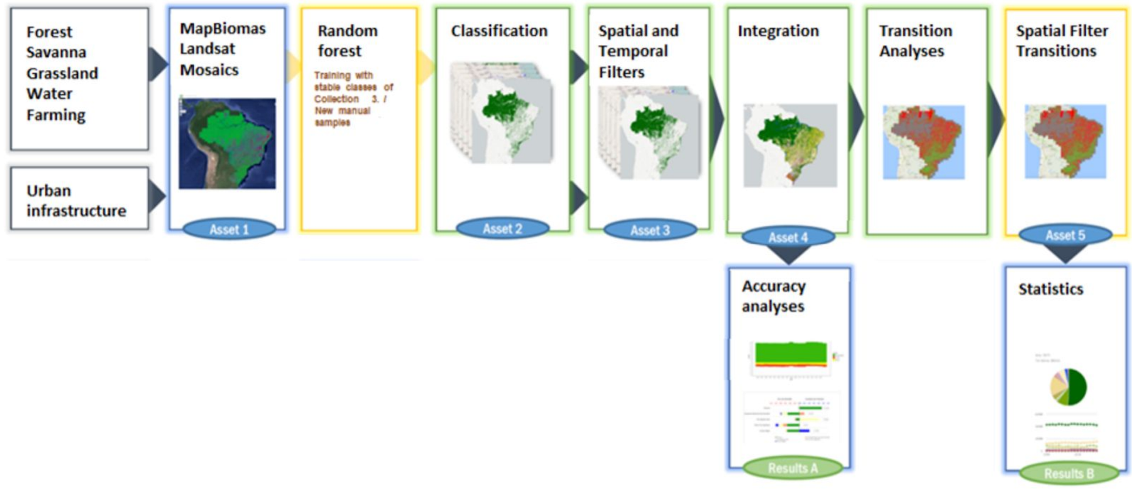

Figure 3. Methodological steps of Collection 4 to implement MapBiomas algorithms in the Google Earth Engine.

3.1. Mapping unit/charts

The mapping unit adopted in the MapBiomas project was defined based on the subdivision of the International Chart of the World to the Millionth on the 1:250,000 scale. Each rectangle of this subdivision covers an area of 1°30' of longitude by 1° of latitude, totalizing 558 charts (or sheets) for the Brazilian territory (Figure 4). Charts intercepting more than one biome were processed separately, with parameters adjusted for the specificities of the portions of each biome and were subsequently concatenated in the post-classification step.

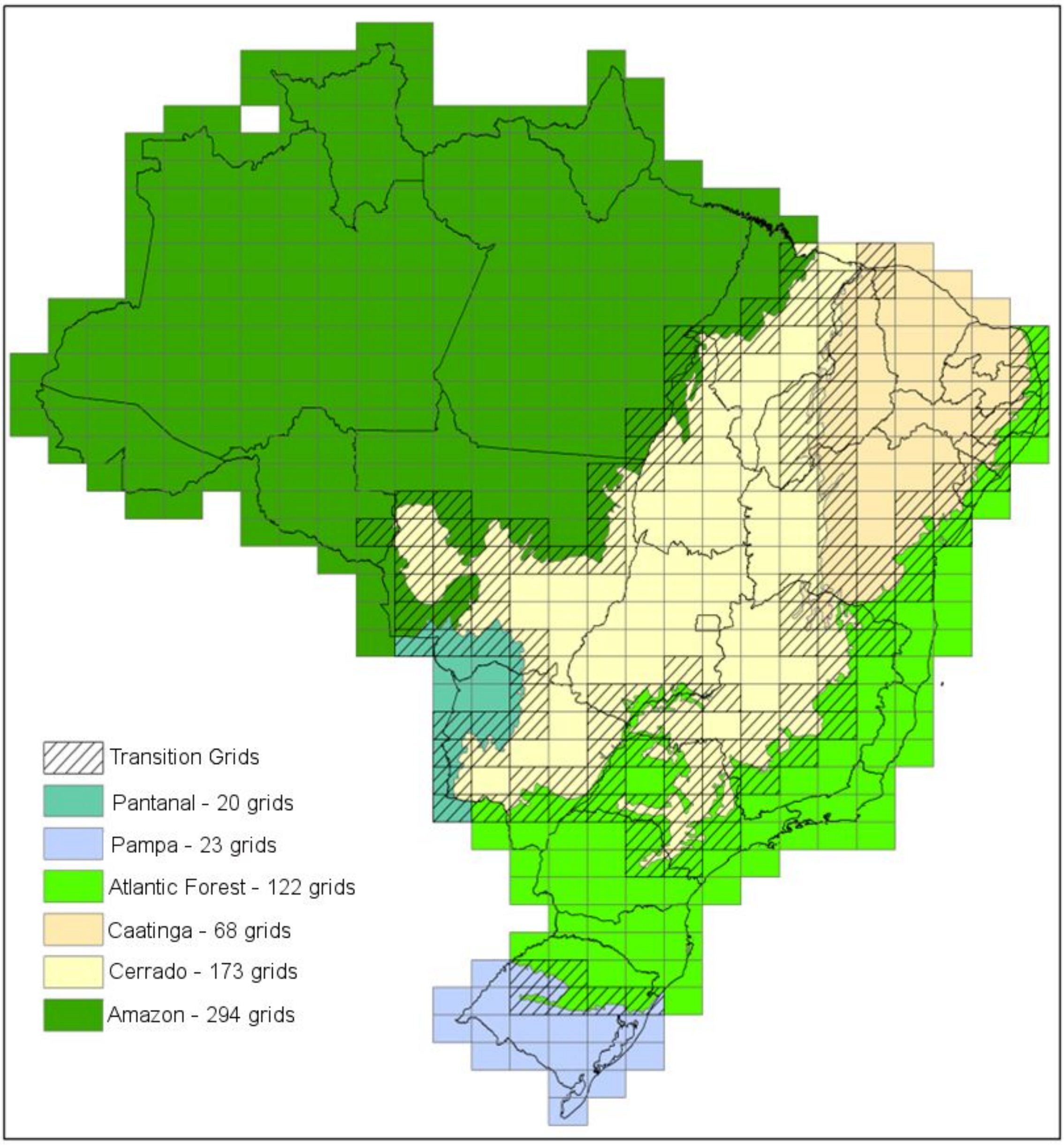

Figure 4: Distribution and number of the charts along the Brazilian biomes used for processing Landsat images within the MapBiomas Workspace environment.

3.2. Landsat Mosaics

All biomes generated Landsat cloud free composites based on specific periods of time in order to optimize the spectral contrast to help within the discrimination of LCLU classes. The cloud/shadow removal script takes advantage of the quality assessment (QA) band and the GEE median reducer. When used, QA values can improve data integrity by indicating which pixels might be affected by artefacts or subject to cloud contamination (USGS, 2017). In conjunction, GEE can be instructed to pick the median pixel value in a stack of images. By doing so, the engine rejects values that are too bright (e.g., clouds) or too dark (e.g., shadows) and picks the median pixel value in each band over time.

For each chart, specific temporal mosaic of Landsat images was built, based on the following selection criteria/parameters: 1. The selected Landsat data must allow an annual analysis, and 2. The period for Landsat scenes selection (t0 and t1 in day/month/year) must provide enough spectral contrast to better distinguish LCLU classes.

The Amazon biome as well as the Pasture, Agriculture and Forest Plantation processed Landsat imagery in a per scene basis (more details available in the Appendices).

3.3. MapBiomas feature space

The total available bands of the MapBiomas feature space is composed of 104 input variables, including the original Landsat bands, fractional and textural information derived from these bands (Table 2). Table 2 presents the formula or the description to obtain these feature variables, as well as highlighted in green all the bands, indices and fractions available in the feature space. In addition, statistical reducers were used to generate temporal features such as:

- Median - Median of the pixel values of the best mapping period defined by each biome.
- Median_dry = median of the quartile of the lowest pixel NDVI values.
- Median_wet = median of the quartile of the highest pixel NDVI values.
- Amplitude = amplitude of variation of the index considering all the images of each year.
- stdDev = standard deviation of all pixel values of all images of each year.
- Min = lower annual value of the pixels of each band.

Table 2. List, description and reference of bands, fractions and indices available in the feature space.

			Reducer						
	band or index name	**formula**	**median**	**median_dry**	**median_wet**	**amplitude**	**stdDev**	**min**	**Reference**
bands	blue	B1 (L5 e L7); B2 (L8)							
	green	B2 (L5 e L7); B3 (L8)							
	red	B3 (L5 e L7); B4 (L8)							
	nir	B4 (L5 e L7); B5 (L8)							
	swir1	B5 (L5 e L7); B6 (L8)							
	swir2	B7 (L5); B8 (L7); B7 (L8)							
	temp	B6 (L5 e L7); B10 (L8)							
index	ndvi	(nir - red)/(nir + red)							
	evi2	(2.5 * (nir - red)/(nir + 2.4 * red + 1)							
	cai	(swir2 / swir1)							
	ndwi	(nir - swir1)/(nir +							

		swir1)							
	gcvi	(nir / green - 1)							
	hall_cover	(-red*0.017 - nir*0.007 - swir2*0.079 + 5.22)							
	pri	(blue - green)/(blue + green)							
	savi	(1 + L) * (nir - red)/(nir + red + 0,5)							
	textG	('median_green') .entropy(ee.Kernel .square({radius: 5}))							
fraction	gv	fractional abundance of green vegetation within the pixel							
	npv	fractional abundance of non-photosynthetic vegetation within the pixel							
	soil	fractional abundance of soil within the pixel							
	cloud	fractional abundance of cloud within the pixel							
	shade	100 - (gv + npv + soil + cloud)							
MEM index	gvs	gv / (gv + npv + soil + cloud)							
	ndfi	(gvs - (npv + soil))/(gvs + (npv + soil))							
	sefi	(gv+npv_s - soil)/(gv+npv_s + soil)							
	wefi	((gv+npv) - (soil+shade)) /((gv+npv) + (soil+shade))							
	fns	((gv+shade) - soil) / ((gv+shade) + soil)							
slope		ALOS DSM: Global 30m							

Each biome executed a feature selection mechanism to choose the most appropriate subset of variables to later ran the random forest algorithm. Each biome and cross-cutting themes selected their own feature variables and more details are available in the Appendices.

3.4. Classification

3.4.1. Legend

MapBiomas aims to classify the LCLU classes at the Landsat pixel level. The Collection 4 legend is described in Table 4. The Annex III presents the cross reference of the MapBiomas LCLU classes with classes from other classification schemes (*i.e.*, FAO, IBGE and National GHG Emissions Inventory). The Annex IV presents the classification scheme of the previous collections of MapBiomas.

Table 4. Classes of land cover and land use of MapBiomas Collection 4 in Brazil.

ID	COLLECTION 3 CLASSES	NATURAL/ ANTHROPIC	LAND COVER/ LAND USER	BIOMES/ THEMES
1	**1. Forest**	NATURAL/ ANTHROPIC	COVER/USE	-
2	1.1. Natural Forest	NATURAL	COVER	-
3	1.1.1. Forest Formation	NATURAL	COVER	BIOMES
4	1.1.2. Savanna Formation	NATURAL	COVER	BIOMES
5	1.1.3. Mangrove	NATURAL	COVER	THEMES
9	1.2. Forest Plantation	ANTHROPIC	USE	THEMES
10	**2. Non Forest Natural Formation**	NATURAL	COVER	-
11	2.1. Wetland	NATURAL	COVER	BIOMES
12	2.2. Grassland Formation	NATURAL	COVER	BIOMES
32	2.3. Salt Flat	NATURAL	COVER	THEMES
29	2.4. Rocky Outcrop	NATURAL	COVER	BIOMES
13	2.5. Other non Forest Natural Formation	NATURAL	COVER	BIOMES
14	**3. Farming**	ANTHROPIC	USE	-
15	3.1. Pasture	ANTHROPIC	USE	THEMES
18	3.2. Agriculture	ANTHROPIC	USE	THEMES
19	Annual and Perennial Crop	ANTHROPIC	USE	THEMES
20	Semi-perennial Crop	ANTHROPIC	USE	THEMES
21	3.3. Mosaic of Agriculture and Pasture	ANTHROPIC	USE	BIOMES
22	**4. Non vegetated area**	NATURAL/ ANTHROPIC	COVER/USE	-
23	4.1. Beach and Dune	NATURAL	COVER	THEMES
24	4.2. Urban Infrastructure	ANTHROPIC	USE	THEMES
30	4.3. Mining	ANTHROPIC	USE	THEMES

25	4.4. Other Non Vegetated Area	NATURAL/ ANTHROPIC	COVER/USE	BIOMES
26	**5. Water**	NATURAL/ ANTHROPIC	COVER/USE	-
33	5.1. River, Lake and Ocean	NATURAL	COVER	BIOMES
31	5.2. Aquaculture	ANTHROPIC	USE	THEMES
27	6. Non Observed	NONE	NONE	NONE

3.4.2. Sample collection

Samples for the training and calibration of the random forest classifier were extracted from classes that did not change their values across all years of Collection 3.1 (stable classes). When necessary, additional samples were collected. For the Amazon, Pasture and Agriculture a different sampling design was used (see more details in the Appendices).

3.4.3. Classification

Random forest demands the definition of a few classification parameters, such as number of trees, a list of variables, and training samples. The minimum number of trees in the random forest classifier was 25. The amount of variables and the number of training samples are detailed described in the biomes and cross-cutting appendices.

3.5. Post-classification

Due to the pixel-based classification method and the long temporal series, a chain of post-classification filters was applied. The first post-classification action involves the application of temporal filters. Then, a spatial filter was applied followed by a gap fill filter. The application of these filters remove classification noise. These pos-classification procedures were implemented in the Google Earth Engine platform and are described in more detailed below.

3.5.1. Gap fill

The Gap fill filter was used to fill possible no-data values. In a long time series of severely cloud-affected regions, it is expected that no-data values may populate some of the resultant median composite pixels. In this filter, no-data values ("gaps") are theoretically not allowed and are replaced by the temporally nearest valid classification. In this procedure, if no "future" valid position is available, then the no-data value is replaced by its previous valid class. Up to three prior years can be used to fill in persistent no-data positions. Therefore, gaps should only exist if a given pixel has been permanently classified as no-data throughout the entire temporal domain.

3.5.2. Spatial filter

Spatial filter was applied to avoid unwanted modifications to the edges of the pixel groups (blobs), a spatial filter was built based on the "connectedPixelCount" function. Native to the GEE platform, this function locates connected components (neighbours) that share the same pixel value. Thus, only pixels that do not share connections to a predefined number of identical neighbours are considered isolated. In this filter, at least five connected pixels are needed to reach the minimum connection value. Consequently, the minimum mapping unit is directly affected by the spatial filter applied, and it was defined as 5 pixels (~0.5 ha).

3.5.3. Temporal filter

The temporal filter uses sequential classifications in a three-to-five-years unidirectional moving window to identify temporally non-permitted transitions. Based on generic rules (GR), the temporal filter inspects the central position of three to five consecutive years, and if the extremities of the consecutive years are identical but the centre position is not, then the central pixels are reclassified to match its temporal neighbour class. For the three years based temporal filter, a single central position shall exist, for the four and five years filters, two and there central positions are respectively considered.

Another generic temporal rule is applied to extremity of consecutive years. In this case, a three consecutive years window is used and if the classifications of the first and last years are different from its neighbours, this values are replaced by the classification of its matching neighbours.

3.5.4. Frequency filter

This filter takes into consideration the occurrence frequency throughout the entire time series. Thus, all class occurrence with less than given percentage of temporal persistence (eg. 3 years or fewer out of 33) are filtered out. This mechanism contributes to reducing the temporal oscillation associated to a given class, decreasing the number of false positives and preserving consolidated trajectories. Each biome and cross-cutting themes may have constituted customized applications of frequency filters, see more details in their respective appendices.

3.5.5. Incident filter

An incident filter were applied to remove pixels that changed too many times in the 34 years of time spam. All pixels that changed more than eight times and is connected to less than 6 pixels was replaced by the MODE value of that given pixel position in the stack of years. This avoids changes in the border of the classes and helps to stabilize originally noise pixel trajectories. Each biome and cross-cutting themes may have constituted customized applications of incident filters, see more details in its respective appendices.

3.5.6. Integration

The integration of the maps of each biome with the maps of cross-cutting themes was accomplished through hierarchical overlap of each mapped class (Table 5), according to specific prevalence rules. Biomes prevalence rules details are described in the Appendices. The integration process was made on a pixel by pixel basis. However, there were specific integration rules as follow:

(1) Class 18 (Agriculture) classified by the biomes will be converted to 19 (Annual and Perennial Crop) and 22 (Non Vegetated Area) to 25 (Other Non-Vegetated Area)

(2) For all other biomes that have classified 9 (Forest Plantation), 15 (Pasture), 19 (Annual and Perennial Crop) and 20 (Semi-perennial Crop) they are maintained with these classes but have a prevalence equal to 21 (Mosaic Agriculture and Pasture).

(3) Using Biomes classes 9 (Forest Plantation), 15 (Pasture), 19 (Annual and Perennial Crop) and 20 (Semi perennial Crop) as a tie between overlapping cross-cutting Agriculture and Pasture themes

(4) In cases of overlapping between classes of the cross-cutting themes Agriculture and Pasture, the Biomes classes of Forest Plantation (9), Pasture (15), Annual and Perennial Crop (19) and Semi Perennial Crop (20) were used to decide between Agriculture or Pasture classes.

Table 5. Collection 4 general prevalence rules for integrating biomes and crosscutting themes maps.

ID	COLLECTION 3 CLASSES	PREVALENCE ID
1	**1. Forest**	18
2	1.1. Natural Forest	-
3	1.1.1. Forest Formation	10
4	1.1.2. Savanna Formation	11
5	1.1.3. Mangrove	2
9	1.2. Forest Plantation	6
10	**2. Non Forest Natural Formation**	-
11	2.1. Wetland	13
12	2.2. Grassland Formation	14
32	2.3. Salt flat	4

29	2.4. Rocky outcrop	
13	2.3. Other non Forest Natural Formation	14
14	**3. Farming**	-
15	3.1. Pasture	15
18	3.2. Agriculture	9
19	Annual and Perennial Crop	9
20	Semi-perennial Crop	9
21	3.3. Mosaic of Agriculture and Pasture	17
22	**4. Non vegetated area**	
23	4.1. Beach and Dune	1
24	4.2. Urban Infrastructure	8
30	4.3. Mining	7
25	4.4. Other Non Vegetated Area	16
26	**5. Water**	-
33	5.1. River, Lake and Ocean	5
31	5.2. Aquaculture	3
27	6. Non Observed	-

3.5.7. Spatial Filter on Integrated Maps

A spatial filter similar to the one described in 3.5.1 was applied in the integrated maps to remove isolated classes with less than half hectares as well as noise resulting from eventual Landsat data misregistration.

3.5.8. Transition Maps

The pixel by pixel class differences between the maps follow the periods: (A) any consecutive years (e.g. 2001-2002); (B) five-year periods (e.g. 2000-2005); (C) Forest Code period (2008-2017); (D) Forest Code approval (2012-2017); (E) National GHG Inventory (1994-2002; 2002-2010); (F) all the years (1985-2018). The class transitions represent land use changes available in maps and Sankey diagrams in the MapBiomas web-platform.

3.5.9. Spatial Filter on Transition Maps

A spatial filter similar to the one described in 3.5.1 was applied in the transition maps. The target is to eliminate single pixels or streams of pixels in the border of different classes derived from the creation of transition maps. The general rules for this filter were: (i) pixels with only one neighbor pixel in the same transition class; (ii) stream of up to five pixels with two or one neighbor pixel in the same transition class.

3.5.10. Statistics

Zonal statistics of the mapped classes were calculated for different spatial units, such as the biomes, states and municipalities, as well as watersheds and protected areas (including indigenous lands and conservation units) were included in the zonal statistics. A toolkit in the Google Earth Engine is available to insert user-defined polygons and download the LCLU maps (https://drive.google.com/open?id=1xyGPmsKt14PI1X-bY6pVlAZ6oWtWiDX5).

3.6. Validation Strategies

The validation strategy was based in two approaches: (i) comparative analyses with reference maps existed for specific biomes/regions and years, and (ii) accuracy analyses based on statistical techniques using independent sample points with visual interpretation along the entire Brazil and for the entire time series.

3.6.1. Validation with reference maps

The spatial agreement analyses with reference maps were conducted by each biome and cross-cutting themes, according with their availability (more details available in the Appendices).

3.6.2. Validation with independent points

The accuracy analysis was performed based on ~75,000 pixel samples to each one of the years in the entire of Brazil (Figure 5) based on visual interpretation of Landsat data. Each sample was inspected by three independent interpreter, in case of confusion a senior interpreter decided the final class of the pixel. This evaluation was based on the web platform Temporal Visual Inspection (TVI - tvi.lapig.iesa.ufg.br), developed by LAPIG/UFG. The TVI platform allowed the evaluation of all the classes mapped by MapBiomas Collection 4. The interpreters had access to Landsat images, MODIS and precipitation time-series, and Google Earth. The sampling design considered as minimum unit of analysis a group of four IBGE charts and six slope classes according with SRTM data (Shuttle Radar Topography Mission) (Figure 6). The accuracy analysis was based as proposed by Stehman et al. 2014 and Stehman & Fody, 2019, using population error matrix and the global, user and producer accurancies.

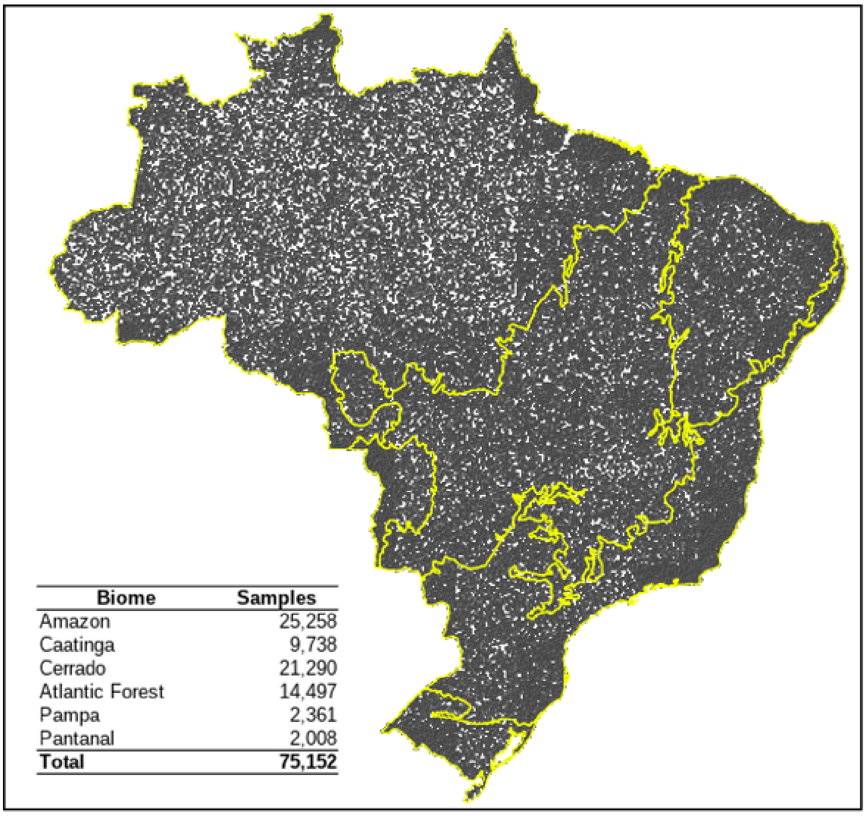

Figure 5. Independent random points in the Brazilian biomes used for accuracy analysis of MapBiomas Collection 4.

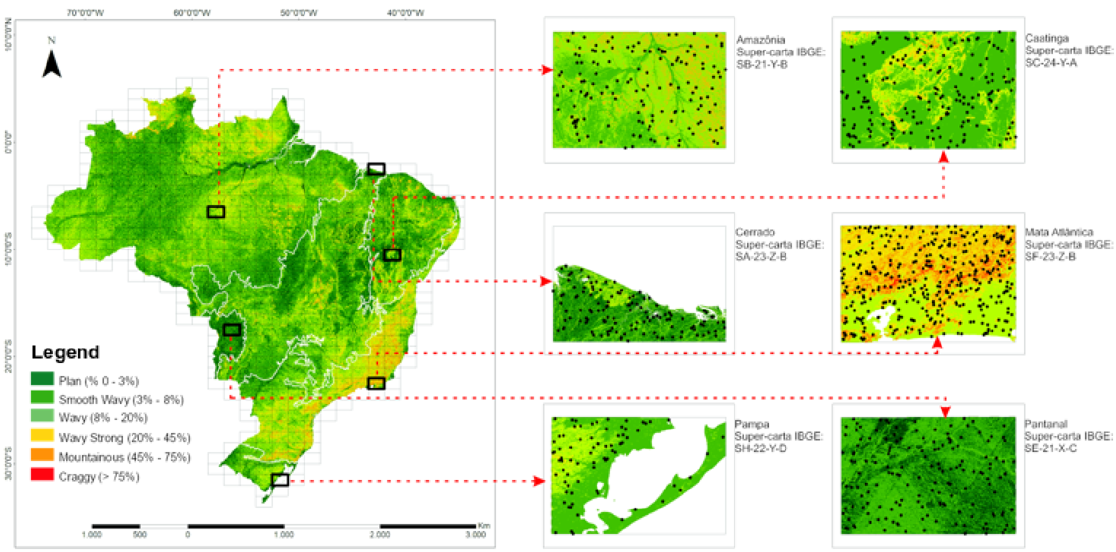

Figure 6. Slope map used in the sampling design with examples in each biome.

The global accuracy for each level of LCLU classes in the Collection 4 legend was calculated for each year, class and biome (more details can be explored in the MapBiomas web-platform. At Level 1 classes the LCLU mapping product in the Collection 4 presented 89% of global accuracy and 10% of allocation disagreement with 1% of area disagreement. At Level 2 the global accuracy was 87.6% with 9.5% of allocation disagreement and 2.9% of area disagreement. Finally at the Level 3 the global accuracy was 85.2% with 10.4% of allocation disagreement and 4.4% of area disagreement. The global accuracy was stable over the mapped period, varying across biomes from 65% to 95% (Figures 7 and 8).

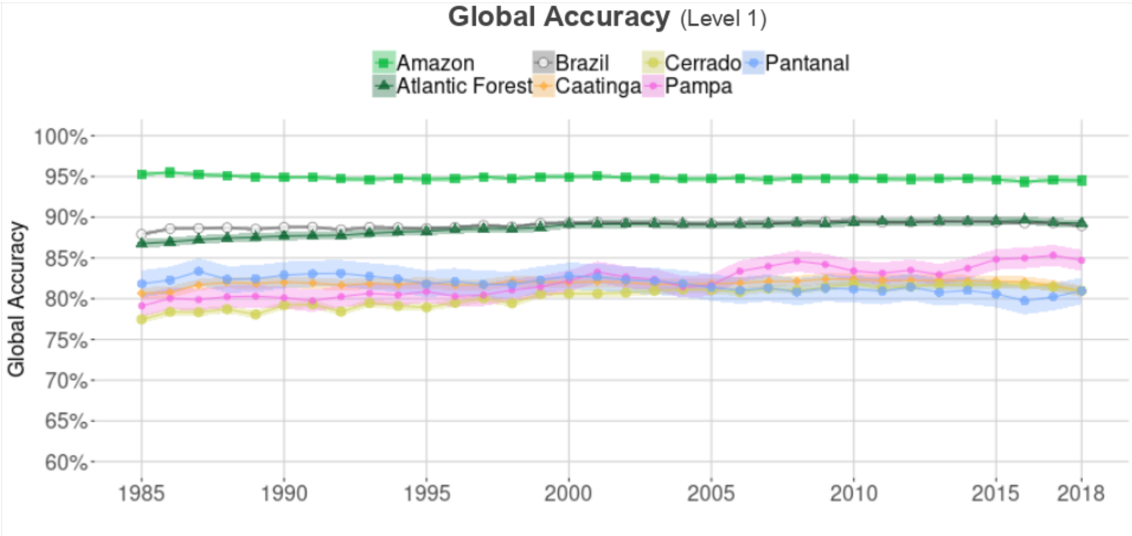

Figure 7. Global accuracy in the level 1 of Collection 4 legend by biome and in Brazil.

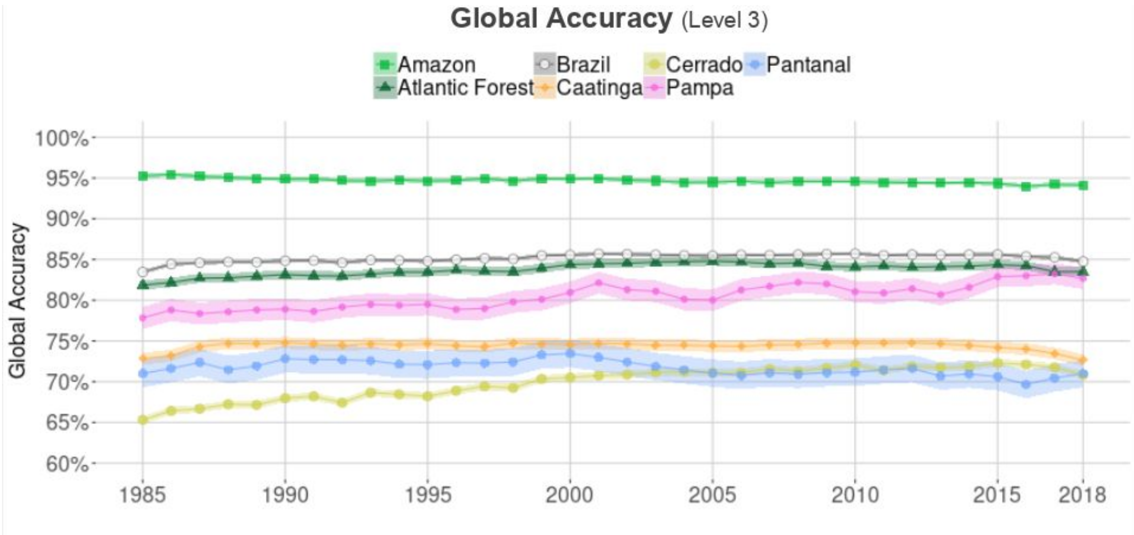

Figure 8. Global accuracy in the level 3 of Collection 4 legend by biome and in Brazil.

4. Map Collections and Analysis

The MapBiomas Collections produced so far are listed and summarized below:

• Collection 1 - comprised the period of 2008 to 2016 and was based on empirical decision trees for the biomes and Coastal Zone them, random forest classification for the Pastureland and Agriculture themes. Before launching collection 1 a Beta Collection was produced to test the methodology used in Collection 1.

• Collection 2 - comprised the period of 2000 to 2016 and was based on empirical decision trees for the biomes and Coastal Zone them, random forest classification for the Pastureland and Agriculture themes.

• Collection 2.3 - comprised the period of 2000 to 2016 and was based on random forest decision trees for all biomes and the Coastal Zone, Pasture and Agriculture themes.

• Collection 3 - comprised the period of 1985 to 2017 and was based on random forest decision trees for all biomes and the Coastal Zone, Urban Infrastructure, Mining, Pasture and Agriculture themes.

• Collection 4 - comprised the period of 1985 to 2018 and was based on random forest decision trees for all biomes and the Coastal Zone, Urban Infrastructure, Mining, Pasture and Agriculture themes.

5. Practical Considerations

The Collection 4 resulted not only in a longer time series, adding the year 2018, but more spatially and temporally consistent annual LCLU maps of Brazil. Significant improvements were done in the Collection 4 by improving the random forest classification, such as smoothing of transitions between charts and biomes, as well as the variations in the areas of each class mapped along the time series. However, challenges still remain and more improvements will be done in the next MapBiomas collection. On the other hand, the programming codes for running the MapBiomas algorithms are publicly available and accessible through mapbiomas.org.

6. Concluding Remarks and Perspectives

The proposal algorithms for pre-processing and classifying Landsat imagery hold promise for revolutionizing the production of LCLU maps at a large scale. Thanks to Google Earth Engine and open source technology it is possible to access and process large scale datasets of satellite imagery such as the one generated by MapBiomas project. The replication of this type of project is viable for other areas of the planet. The MapBiomas initiative has already expanded to other regions such as Pan-Amazon and Chaco, as well as other tropical forest regions, such as Indonesia. In addition, the project team will keep improving the next collections with subsequent years (2019 and so long). Future developments include using the entire spectral-temporal information of Landsat data in a per pixel basis and integration with other sensors such as Sentinel-2 and AWiFs-Resourcesat. The data produced are important not only for estimating greenhouse gas emissions, but also for subsidizing several public policies.

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APPENDIX

Appendix 1 - Amazon biome

Appendix 2 - Atlantic Forest biome

Appendix 3 - Caatinga biome

Appendix 4 - Cerrado biome

Appendix 5 - Pampa biome

Appendix 6 - Pantanal biome

Appendix 7 - Agriculture and Forest Plantation

Appendix 8 - Pasture

Appendix 9 - Coastal Zone and Mining

Appendix 10 - Urban Infrastructure - in progress

ANNEX

Annex I: MapBiomas Network

MapBiomas is an initiative of the Greenhouse Gas Emissions Estimation System (SEEG) from the Climate Observatory's and is produced by a collaborative network of co-creators made up of NGOs, universities and technology companies organized by biomes and cross-cutting themes.

Biomes Coordination:

- Amazon – Institute of Man and Environment of the Amazon (IMAZON)
- Caatinga – State University of Feira de Santana (UEFS), Plantas do Nordeste Association (APNE), and Geodatin.
- Cerrado – Amazon Environmental Research Institute (IPAM)
- Atlantic Forest – Foundation SOS Atlantic Forest and ArcPlan
- Pampa – Federal University of Rio Grande do Sul (UFRGS)

- Pantanal – Institute SOS Pantanal and ArcPlan

Cross-cutting Themes Coordination:

- Pasture – Federal University of Goias (LAPIG/UFG)
- Agriculture – Agrosatelite
- Coastal Zone and Mining – Vale Technological Institute (ITV) and Solved
- Urban infrastructure – Terras App

Technology Partners:

- Google
- EcoStage
- Terras App

Financing:

- Arapyaú Institute
- Children's Investment Fund Foundation (CIFF)
- Climate and Land Use Alliance (CLUA)
- Good Energies Foundation
- Gordon & Betty Moore Foundation
- Humanize
- Institute for Climate and Society (iCS)
- Norway's International Climate and Forest Initiative (NICFI).

Institutional Partners:

- Arapyaú Institute
- WRI Brasil
- Institute for Democracy and Sustainability (IDS)
- AVINA Foundation
- The Nature Conservancy (TNC)
- Climate, Forest and Agriculture Coalition

Technical and Scientific Coordination: Carlos Souza (IMAZON)

General Coordination: Tasso Azevedo (SEEG/OC)

The project counts on an Independent Committee of Scientific Advice composed by renowned specialists:

- Alexandre Camargo Coutinho (Embrapa)
- Edson Eygi Sano (IBAMA)
- Gilberto Camara Neto (INPE)
- Joberto Veloso de Freitas (Brazilian Forestry Service)
- Matthew C. Hansen (Maryland University)
- Mercedes Bustamante (University of Brasília)

- Timothy Boucher (TNC)

Annex II: Mapping initiatives at global scale, in Brazil, biomes and cross-cutting themes, period/years mapped and respectively references/sources (in portuguese).

Nome do Mapa/Produto	Descrição	Escala	Ano do Mapa
Mapa de Limite dos Biomas 1:1.000.000	Adaptação do Mapa de Limites de Biomas 1:5.000.000 produzido pelo IBGE, refinado a partir do Mapa de Limites do território 1:250.000 (IBGE) e o mapa de fitofisionomias 1:1.000.000 (IBGE).	1:1000000 mil	2016
Mapa de Uso do Solo do Brasil	Mapa de uso do solo baseado em Modis (250mt) com comparaçÕes entre os anos 2000, 2010 e 2012	1:250 mil	2000, 2010, 2012
Terra Class Cerrado	Mapeamento do Uso e Cobertura da Terra do Cerrado	1:250 mil	2013
Uso e cobertura vegetal do Estado do Rio Grande do Sul – situação em 2002.	Mapa de Cobertura vegetal do Rio Grande do Sul - ano base 2002, obtido por interpretação visual de imagens Landsat. Nível de detalhe compatível com escala 1:250.000	1:250 mil	2002
Uso e cobertura vegetal do Estado do Rio Grande do Sul – situação em 2009.	Mapa de Cobertura vegetal do Rio Grande do Sul - ano base 2009, obtido por interpretação visual de imagens Landsat. Nível de detalhe compatível com escala 1:250.000	1:250 mil	2009
Uso e cobertura vegetal do Estado do Rio Grande do Sul – situação em 2015.	Mapa de Cobertura vegetal do Rio Grande do Sul - ano base 2015, obtido por interpretação visual de imagens Landsat. Nível de detalhe compatível com escala 1:250.000	1:250 mil	2015
Atlas da Mata Atlântica	Mapeamento das formações florestais e ecossistemas associados, ano de referência 2016	1:50.000	2016
Mapeamento da Bacia do Alto Paraguai	Monitoramento do uso e cobertura vegetal da Bacia do Alto Paraguai, que inclui o Pantanal e suas cabeceiras. Dados disponíveis para 2002, 2008, 2010, 2012 e 2014	1:250.000 adaptado para 1:50.000	2014

Mapa dos manguezais da região norte do Brasil	Mapa das áreas de manguezal do Oiapoque-AP até a Ponta de Tubarão-MA gerado a partir da classificação de imagens Landsat e ALOS PALSAR do ano de 2008	1:100.000	2008
Mapa dos manguezais da região nordeste do Brasil	Mapa das áreas de manguezal da Ponta de Tubarão-MA até o sul do Estado da Bahia a partir da classificação de imagens Landsat e ALOS PALSAR do ano de 2008	1:100.000	2008
Mapas da agricultura anual para a amazônia	Mapas que incluem as culturas de algodão, milho e soja, cultivados em larga escala, para os anos/safra: 2000/2001, 2006/2007 e 2013/2014, 2016/2017	1:100.000	2000/2001, 2006/2007, 2013/2014 e 2016/2017
Mapas da agricultura anual para o cerrado (projeto: Geospatial analyses of the annual crops dynamic in the Brazilian Cerrado biome: 2000 to 2014)	Mapas que incluem as culturas de algodão, milho e soja, cultivados em larga escala, para os anos/safra: 2000/2001, 2006/2007 e 2013/2014.	1:100.000	2000/2001, 2006/2007 e 2013/2014
Mapa de florestas plantadas	Mapa de florestas plantadas para o Brasil	1:100.000	2014
III Inventário Nacional de Emissões de Gases de Efeito Estufa (setor LULUCF)	Mapa das áreas de agricultura (anual, semi-perene e perene)	1:250.000	1994, 2002, 2010, 2016
Canasat	Mapa da cana-de-açúcar para o centro-sul do Brasil	1:100.000	2003 a 2015
Mapas de Cobertura Vegetal dos Biomas Brasileiros - ProBio	LEVANTAMENTO DA COBERTURA VEGETAL E DO USO DO SOLO DO BIOMA CAATINGA	1:100.000	2002-2004
Mapeamento Florestal do Estado de Sergipe	Levantamento da cobertura Florestal do Estado de Sergipe	1:250.000	2010
Mapas da Agricultura do Cerrado	Map of the cultivated area of 1st crop season of soybean, corn, and cotton in the Cerrado biome	1:100.000	2000/2001, 2006/2007 e 2013/2014
Mapeamento de uso da terra para o Cerrado e Mata Atlântica	Mapeamento de uso da terra para o Cerrado e Mata Atlântica. Baseado em imagens de alta resolução RapidEye com resolução de 5m.	1:25.000	2013
Atlas da Mata Atlântica	Mapeamento detalhado com 1ha para o Estado de São Paulo	1:50.000	2014
Atlas da Mata Atlântica	Mapeamento detalhado com 1ha para o Estado do Rio de Janeiro	1:50.000	2014
Atlas da Mata Atlântica	Mapeamento detalhado com 1ha para o Estado do Paraná	1:50.000	2014

Atlas da Mata Atlântica	Mapeamento detalhado com 1ha para o Estado de Santa Catarina	1:50.000	2014
Global Distribution of Mangroves USGS	This dataset shows the global distribution of mangrove forests, derived from earth observation satellite imagery	1:50.000	1997-2000
Mapa Síntese de Pastagens do Brasil - v8	Mapeamento de áreas de pastagem, a partir de compilação de dados TerraClass Amazon; Funcate;PROBIO; Canasat e TNC. Os mapeamentos que o compõem são: Bioma Pantanal - Mapeamento da Bacia do Alto Paraguai para 2014; Bioma Caatinga (Mapeamento Lapig - Versão 2 2014-2016) - Esse mapeamento classificou as áreas de pasto limpo, pasto sujo e área degradada (solo exposto); Bioma Mata Atlântica (Mapeamento Lapig 2014-2016) - Esse mapeamento classificou as áreas de pasto limpo, pasto sujo e área degradada (solo exposto); Bioma Pampa - Mapeamento realizado pelo IBGE para oestado do Rio Grande do Sul (2012); Bioma Amazônia - Mapeamento TerraClass Amazônia 2014; Bioma Cerrado - Mapeamento TerraClass Cerrado 2013.	1:250.000	2016
Prodes	O projeto PRODES realiza o monitoramento por satélites do desmatamento por corte raso na Amazônia Legal e produz, desde 1988, as taxas anuais de desmatamento na região, que são usadas pelo governo brasileiro para o estabelecimento de políticas públicas. As taxas anuais são estimadas a partir dos incrementos de desmatamento identificados em cada imagem de satélite que cobre a Amazônia Legal. A primeira apresentação dos dados é realizada para dezembro de cada ano, na forma de	1:250.000	2016

	estimativa. Os dados consolidados são apresentados no primeiro semestre do ano seguinte.		
Terra Class Amazônia	Como principal resultado deste mapeamento é possível entender a dinâmica de uso e cobertura da Amazônia Legal Brasileira. Para isto já foram mapeados cinco anos de uso e cobertura (2004, 2008, 2010, 2012 e 2014) permitirão uma análise evolutiva de uma década que se inicia no ano da implantação do Plano de Prevenção e Controle do Desmatamento na Amazônia Legal (PPCDAm). Com estes resultados é possível fazer uma avaliação da dinâmica do uso e ocupação das áreas desflorestadas nestes 10 anos da implementação do PPCDAm.	1:250.000	2014
Global Forest Change 2000–2015	Results from time-series analysis of Landsat images in characterizing global forest extent and change from 2000 through 2015. For additional information about these results, please see the associated journal article (Hansen et al., Science 2013).	1:250.000	2015
Land Cover Rondônia 1984 -2010	This project is part of a collaborative research effort between UCSB, Salisbury University (Maryland) and North Carolina State University. Under the direction of principal investigators Jill Caviglia-Harris, Daniel Harris (Salisbury), Erin Sills (NCSU) and Dar Roberts (UCSB), we have been active in the production and management of a gapless annual Landsat imagery archive (1984-2009) covering the majority of the state of Rondonia	1:250.000	2010

Atlas dos Manguezais do Brasil	O Atlas dos Manguezais do Brasil é fruto da parceria entre a Diretoria de Ações Socioambientais e Consolidação Territorial de UCs (DISAT) do Instituto Chico Mendes de Conservação da Biodiversidade e o Projeto "Conservação e Uso Sustentável Efetivos de Ecossistemas Manguezais no Brasil", implementado pelo Programa das Nações Unidas para o desenvolvimento – Brasil (PNUD), com o apoio do Fundo Global para o Meio Ambiente (GEF).		2013

Annex III: Cross-reference of MapBiomas land use/land cover classes in the Collection 4 with FAO, IBGE and National GHG Emissions Inventory classes.

Level 1	Level 2	Level 3	Biomes	IBGE (1999; 2012) Classes	FAO (2012) Classes	GHG National Inventory (2015) Classes
Forest	Natural Forest Formation	Forest Formation	Amazon	Da, Db, Ds, Dm, Ha, Hb, Hs, Ld, La, Aa, Ab, As, Am, Fa, Fb, Fs, Fm, Ca, Cb, Cs, Cm, Vsp	FDP, FEP, FSP, FEM, FDM, FSM	FMN, FM, FSec
			Caatinga	Td, Cs, Cm, Fm, Fs, Pa, As, Fb, Pf, Pm, Fa, Cb, Ds, Am, Ab, Sd	FEP, FEM	FMN, FM
			Cerrado	Aa, Ab, As, Cb, Cm, Cs, Da, Dm, Ds, F, Ml, Mm, P, Sd, Td	FEP, FDP, FSP	FMN, FM
			Atlantic Forest	D, A, M, F, C, Pma	FEP, FSP	FMN, FM
			Pampa	Da, Db, Ds, Dm, Ma, Ms, Mm, Ml, Fa, Fb, Fs, Fm, Ca, Cb, Cs, Cm, P, Pa,	FEP, FDP, FSP	FMN, FM

				Pm		
			Pantanal	Ca, Cb, Cs, Fa, Fb, Fs, SN, Sd, Td, Pa	FEP, FSP	FMN, FM
		Savanna Formation	Amazon			
			Caatinga	Ta, Sa,	FDP,FSP, FDM, FSM	FMN, FM
			Cerrado	Sa, Ta	WS	FMN, FM
			Atlantic Forest	Sd, Td, Sa, Ta	FDP, FSP, WS	FMN, FM
			Pampa			
			Pantanal	Sa, Sp, Sa, Sg, Td, Ta, Tp	FDP, FSP, WS	FMN, FM
		Mangroves		Pf	FEP, FEM	FMN, FM
	Forest Plantation			R	FPB, FPC, FPM	Ref
Non Forest Formation	Non-Forest Formation in Wetland		Amazon			
			Caatinga			
			Cerrado			
			Atlantic Forest			
			Pampa	P, Pa, Pm	OM	GNM, GM, GSec
			Pantanal	Tg, Sp, Pa, Tp		GNM, GM, GSec
	Grassland Formation		Amazon			
			Caatinga	Tp, Sg, Rm, Sp, Tg, Rl	WG, OG, WS	GNM, GM, GSec
			Cerrado	Sp, Sg, Tp, Tg	WG, OG	GNM, GM, GSec
			Atlantic Forest	Sp, Sg, Tp, Tg, E, Pa	WS,OG	GNM, GM, GSec
			Pampa	E, Ea, Ep, Eg, T, Ta, Tp, P, Pa, Pm	WG, OG	GNM, GM, GSec
			Pantanal	Sg, Sp	WG, OG	GNM, GM, GSec
	Salt flat					
	Rocky outcrop		Amazon			
			Caatinga			
			Cerrado			
			Atlantic Forest	Ar	OX	
			Pampa	Ar	OX	
			Pantanal			
	Other Non-Forest Formation		Amazon	Sd, Sa, Sp, Td, Ta, Lb, Lg	FDP, WS, FSP	GNM, GM, GSec, FMN, FM
			Caatinga			

			Cerrado			
			Atlantic Forest			
			Pampa			
			Pantanal			
Farming	Pasture			AP, PE, PS	OP, OG	Ap
	Agriculture	Annual and Perennial Crop		ATp, ATc	OCA, OCP, OCM	Ac
		Semi-perennial Crop		ATc	OCA, OCP	Ac
		Crops mosaic (Caatinga)		ATpc	OCA, OCM, OP, OG	Ac
	Mosaic of Agriculture and Pasture			AP, PE, PS, ATp, ATc, ATpc	OCA, OCM, OP, OG	Ac, Ap
Non vegetated area	Beach and Dune			Dn		
	Urban Infrastructure					S
	Mining			MCA	OQ	O
	Other non vegetated area		Amazon			S
			Caatinga			
			Cerrado			
			Atlantic Forest			
			Pampa			
			Pantanal		OX	
Water	River, Lake and Ocean				IRP, IRS, IL, ID	A, Res
	Aquaculture					
Non Observed						NO

Annex IV: Classes of land cover and land use of of Collections 1.0, 2.0, 2.3 and 3.0 of MapBiomas

Collection 1 Classes
Forest
Forest in Coastal Zone
Forest Plantation
Agriculture
Pasture
Water
Other
Non-Observed

Collection 2 Classes
1. Forest
1.1. Natural Forest Formations
1.1.1. Dense Forest
1.1.2. Open Forest
1.1.3. Mangrove
1.1.4. Flooded Forest
1.1.5. Degraded Forest
1.1.6. Secondary Forest
1.2. Silviculture
2. Non-Forest Natural Formations
2.1. Non-forest Natural Wetlands
2.2. Grasslands
2.3. Other non-forest natural formations
3. Farming
3.1. Pasture
3.1.1. Pastude in natural grasslands
3.1.2. Other pasture
3.2. Agriculture
3.2.1. Annual crops
3.2.2. Semi-Perennial crops

3.2.3. Mosaic of crops
3.3 Agriculture or Pasture
4. Non-Vegetated areas
4.1. Dunes and Beach
4.3. Other non-vegetated areas
4.2. Urban Infrastructure
5. Water
6. Non-Observed

Collection 2.3 Classes
1. Forest
1.1. Natural Forest
1.1.1. Natural Forest Formation
1.1.2. Savanna Formation
1.1.3. Mangrove
1.2. Forest Plantations
2. Non-Forest Natural Formations
2.1. Non-forest Natural Wetlands
2.2. Grasslands
3. Farming
3.1. Pasture
3.2. Agriculture
3.3 Agriculture or Pasture
4. Non-Vegetated areas
4.1. Beach and dune
4.3. Other non-vegetated areas
4.2. Urban Infrastructure
5. Water
6. Non-Observed

Collection 3 Classes
1. Forest
1.1. Natural Forest
1.1.1. Forest Formation
1.1.2. Savanna Formation
1.1.3. Mangrove
1.2. Forest Plantation
2. Non Forest Natural Formation
2.1. Wetland
2.2. Grassland
2.3. Salt flat
2.3. Other non forest natural formation
3. Farming
3.1. Pasture
3.2. Agriculture
3.2.1. Annual and Perennial Crop
3.2.2. Semi-perennial Crop
3.3. Mosaic of Agriculture and Pasture
4. Non vegetated area
4.1. Beach and Dune
4.2. Urban Infrastructure
4.3. Rocky outcrop
4.4. Mining
4.5. Other non vegetated area
5. Water
5.1. River, Lake and Ocean
5.2. Aquaculture
6. Non Observed