



Guianas: Guyana, French Guiana and Suriname - Appendix

Collection 5

Version 1.0



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Index

1 Country general characterization	3
1.1 Brief context of Guyana	3
1.2 Brief context of French Guiana	4
1.3 Brief context of Suriname	4
2 Other national mapping initiatives	4
3 Landsat image mosaics	5
3.1 Tiles division	5
3.2 Workspace processing	6
3.3 Blacklist	7
3.4 Mosaics results and quality	9
4 Classification	11
4.1 Definition of classification regions	11
4.2 Classification scheme	13
4.3. Legend	13
4.2 Feature Space	14
4.3 Classification algorithm, training samples and parameters	14
5 Post-classification	18
5.1 Gap-fill filter	18
5.3 Temporal filter	18
5.4 Spatial filter	19
5.5 Frequency filter	19
5.6 Incidents filter	20
5.7 Classification of Flooded Forest	20
5.8 Integration	20
6 References	21

1 Country general characterization

The Guianas (Guyana, Suriname and French Guiana) border Brazil in the south, Venezuela in the west and the Atlantic Ocean in the north, occupying an area of 441,906 km², which 211,157 km² are in Guyana, 146,523 km² in Suriname and 84,226 km² are from French Guiana. Together, the three countries are divided into 22 states (10 of the states are located in Guyana, 10 in Suriname and 2 in French Guiana), with French Guiana being the only one having a division by municipalities (42 in total) (Figure 1). With 97% of their territory occupied by Amazonian area and 90% covered with intact rainforest, it plays a critical role in mitigating climate change and in water regulation of the Amazon and Orinoco basins. About 35% of these regions are located in protected areas and indigenous territories; most of them in French Guiana (52% of the country), followed by Suriname (49%) and Guyana (19%).

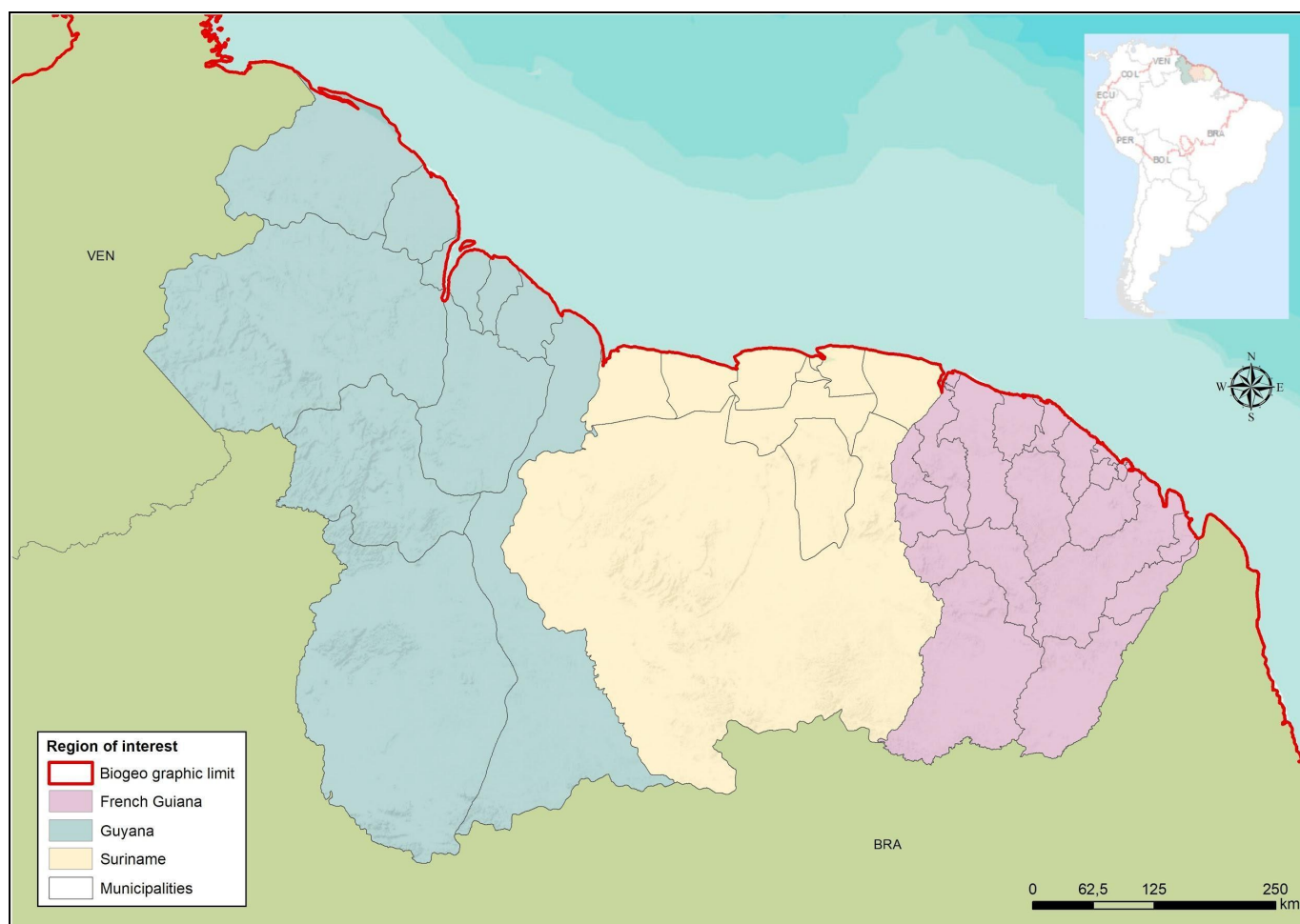


Figure 1. The location of Guianas with the division of countries (Guyana, Suriname and French Guiana), states and municipalities.

1.1 Brief context of Guyana

Guyana is a small and lightly populated country (approximately 785,034 people), most of the population is confined in coastal areas (World Population Review, 2020). Guyana is one of South America's poorest countries, where mining is one of its most important economic activities. Deforestation rates are likely low, Guyana lost about 0.3% of its forest cover annually in the first half of the 1990s.

Roughly 60% of the country area is classified as primary forest, which is highly biodiverse (Mongabay, 2006). According to the International Tropical Timber Organization, forests in Guyana can be broken down as rainforest (36%), montane forest (35%), swamp (15%), dry evergreen (7%), seasonal forest (6%), and mangrove forest (1%).

1.2 Brief context of French Guiana

The French Guiana population (around 295,784 people) is concentrated mainly around the capital Cayenne, the largest city, and the coastal regions (World Population Review, 2020). The country has a developing market economy, sustained by aid and technical assistance from France. The gross national income per capita is among the highest in South America and most of the labor force is employed in services and industry, in agriculture subsistence farming and pasture supporting mainly cattle, pigs, and poultry (Britannica, 2019). According to the French Guiana Environmental Profile published by Mongabay (2006), even though the rainforests of French Guiana are largely unexploited, more than 90% is forested and about 95% consists of primary forest. The annual deforestation rate in the country is less than 0.2% and it has actually declined by 17.4% since the end of the 1990s.

1.3 Brief context of Suriname

Suriname has extensive forest cover with an important savanna component in different landscapes at locations. The country population (584,700 people) is concentrated in the capital (Paramaribo) and coastal cities (World Population Review, 2020). Less than 1% of Suriname's land is cultivated, half of the farmland is planted with rice and some it is exported (Mongabay, 2006; FAO, 2005). Moreover, according to the Forest Legality Initiative (2016), Suriname's estimated annual deforestation rate is approximately 0.02%. However, the country is one of the top bauxite producers in the world (Britannica, 2019). In recent years the Surinamese government has recently taken steps to raise and keep the ecotourism industry strong.

2 Other national mapping initiatives

There are several national mapping initiatives of land cover and land use in Guyana, French Guiana, and Suriname, but cover only a few years or shorter time series (Table 1).

Table 1. General information about other national mapping initiatives in Guyana, French Guiana and Suriname.

País	Reference	Map type	Year	Link to download
Guyana	Guyana Lands and Surveys Commission (GLSC), Land Information and Mapping Division (LIM)	Resource map	2014	https://glsc.gov.gy/services/maps/#GLSC_Map_Catalog
Guyana	The National Land Use	National vegetation	2001	https://glsc.gov.gy/wp-con

	Plan of Guyana				tent/uploads/2017/05/National-Land-Use-Plan-Final-Oct-2013.pdf
Guyana	The National Land Use Plan of Guyana	Areas of deforestation	1990-2011		https://glsc.gov.gy/wp-content/uploads/2017/05/National-Land-Use-Plan-Final-Oct-2013.pdf
Guyana	The National Land Use Plan of Guyana Summary	Land use / Land cover	2012		https://glsc.gov.gy/wp-content/uploads/2017/05/Summary-Booklet-of-the-National-Land-Use-Plan.pdf
Guyana	WWF, ONF Guyane and Parc Amazonien de Guyane (PAG)	Land use summary	2015		https://www.geoguyane.fr/geonetwork/srv/fre/catalog.search#/metadata/3d681d4f-b8bd-48b2-80d2-04a215a8a099
French Guiana	(2008) Notices bibliographiques. EchoGéo. DOI: 10.4000/echogeo.7353	Land use	1998		https://journals.openedition.org/com/1102?file=1
French Guiana	(2011) V. Gond et al. DOI: 10.1016/j.jag.2011.01.004	Landscape types	2000		https://www.sciencedirect.com/science/article/pii/S0303243411000055#!
Suriname	GONINI National Land Monitoring System of Suriname	Land use and land cover after deforestation 2000-2017	2009, 2013, 2015 and 2017		https://www.gonini.org/
Suriname	GONINI National Land Monitoring System of Suriname	National land use and land cover	2015		https://www.gonini.org/
Suriname	GONINI National Land Monitoring System of Suriname	Vegetation	2010		https://www.gonini.org/

3 Landsat image mosaics

3.1 Tiles division

The Guianas were divided into 40 tiles (Figure 2). Later, these tiles were partitioned by country and region to facilitate the parameterization of satellite image mosaics according to the specificities of each environment, totaling 55 tiles processed for each year of the time series (Table 2).

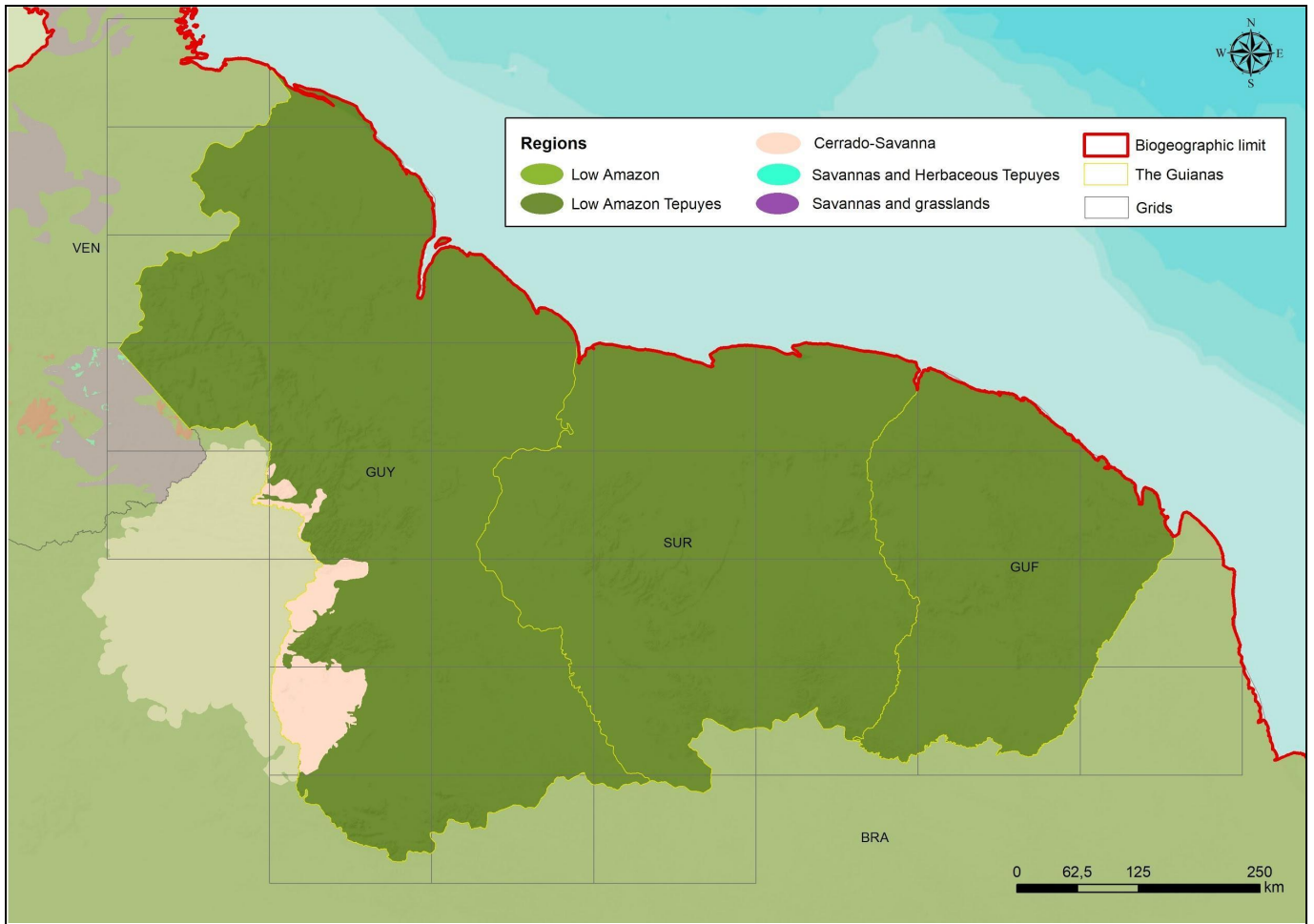


Figure 2. Scheme of regions and tiles used in the Guianas to partition the classification area, in the 1:250,000 scale.

Table 2. Total number of Landsat images mosaics processed by country, considering partition in tiles and regions

Country	Region	Number of mosaics processed per year
Guyana	Low Amazon	22
	Cerrado-Savanna	4
French Guiana	Low Amazon	12
Suriname	Low Amazon	17
Total		55

3.2 Workspace processing

Several tests were done to define the images' optimum period to compose the annual mosaics. Due to the high impact of clouds presence covering the Guianas territory, it was decided to restrict the image selection parameters to a minimum. In other words, the decision was to maintain a large window

for the selection of the initial and final dates of the mosaics and to avoid restricting the percentage of cloud cover. This increased the availability of images for composing the median mosaics.

The dates were selected individually for each of the 55 tiles and for each year. The criteria for selecting these dates were a maximum window of seven months between the months of May and November. The median value of the pixels selected during this broader period demonstrated to better accommodate the forest mapping difficulties presented in the more restrictive window tests (Figure 3). Finally, 36 preliminary annual mosaics (1985-2022) were generated for each of the three countries.

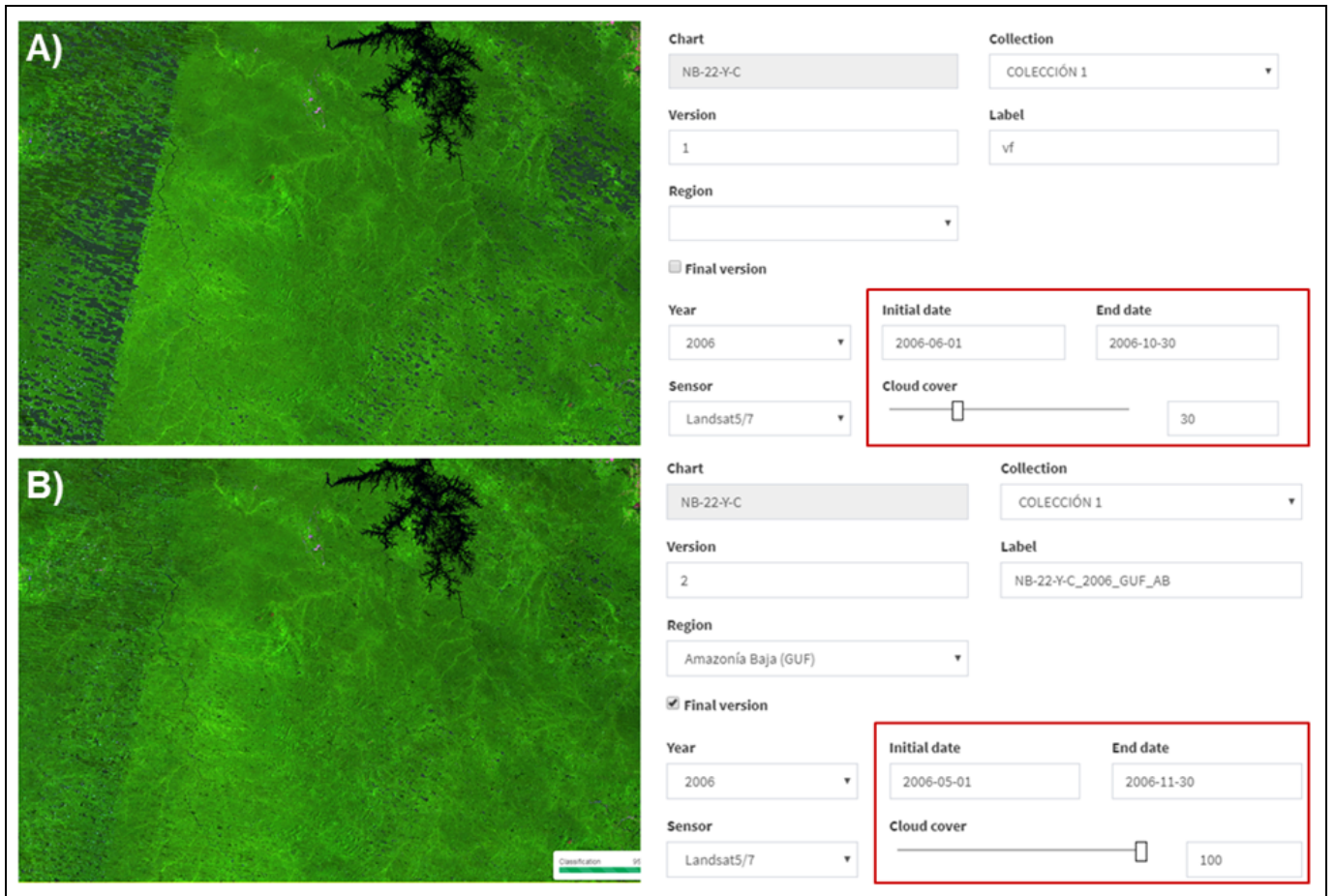


Figure 3. Example showing the effect of the parameters used to define the final annual mosaic composition used in the classification of pixels in the grid NB-22-Y-C in 2006. A) Example of a more restrictive window and how the clouds presence impact the image coverage B) The final result built with parameters chosen based on a large temporal window and non-restricted percentage of cloud cover.

3.3 Blacklist

In this stage, all the preliminary annual mosaics processed in the Workspace were visually assessed by a remote sensing specialist. The total number of mosaics considering the 55 tiles and 38-year time series was 2090 (988 in Guyana; 456 in French Guiana; and 646 in Suriname), 18% were reprocessed after excluding images with huge cloud interferences from the median mosaic (Table 3). The initial and final dates defined in the workspace were mostly adjusted - 63% of mosaics were generated using January and December as the temporal window to image selection.

Table 3. Total number of Landsat images mosaics processed by country, considering partition in tiles and the whole time series

Country	Number of mosaics processed in the workspace per country	Number and percentage of mosaics processed with the blacklist script
Guyana	988	226 (24%)
French Guiana	456	48 (11%)
Suriname	646	99 (16%)
Total	2090	373 (18%)

In conclusion, 38 annual mosaics (1985-2022) were generated for each of the three countries (Figures 4, 5 and 6).

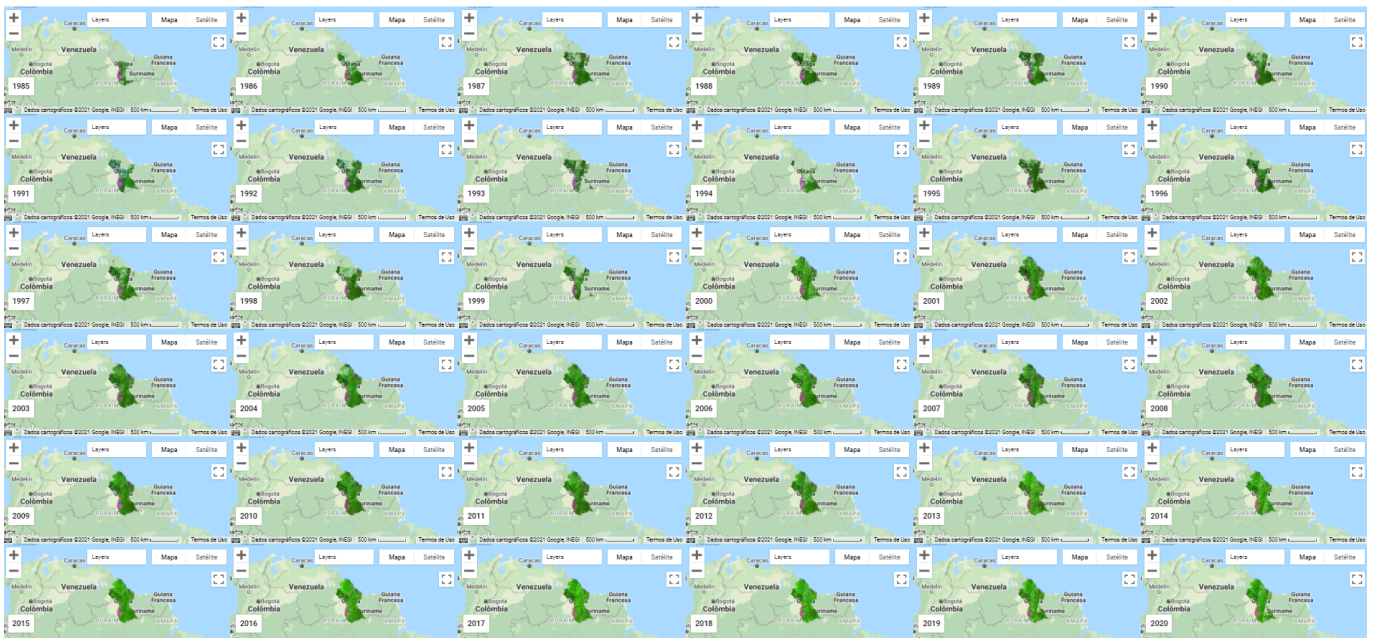


Figure 4. Annual mosaics from 1985 to 2022 of Guyana used in the Collection 5 classification.

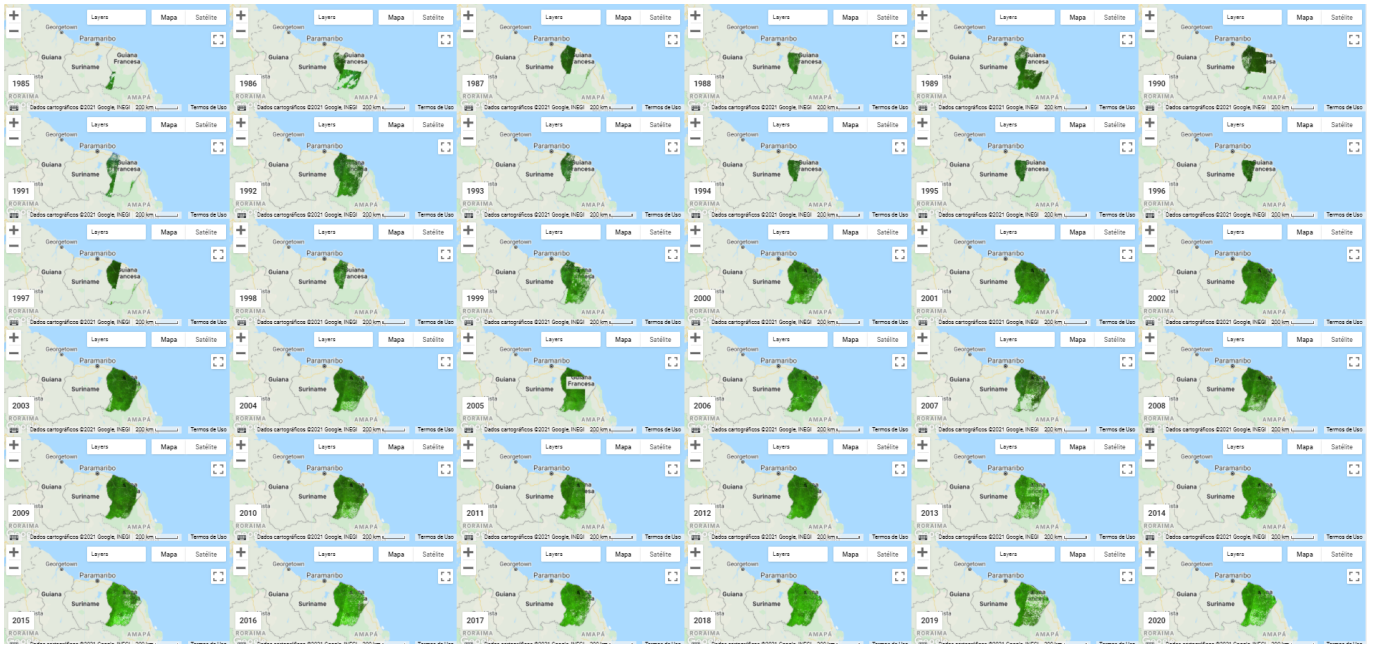


Figure 5. Annual mosaics from 1985 to 2022 of French Guiana used in the Collection 5 classification.

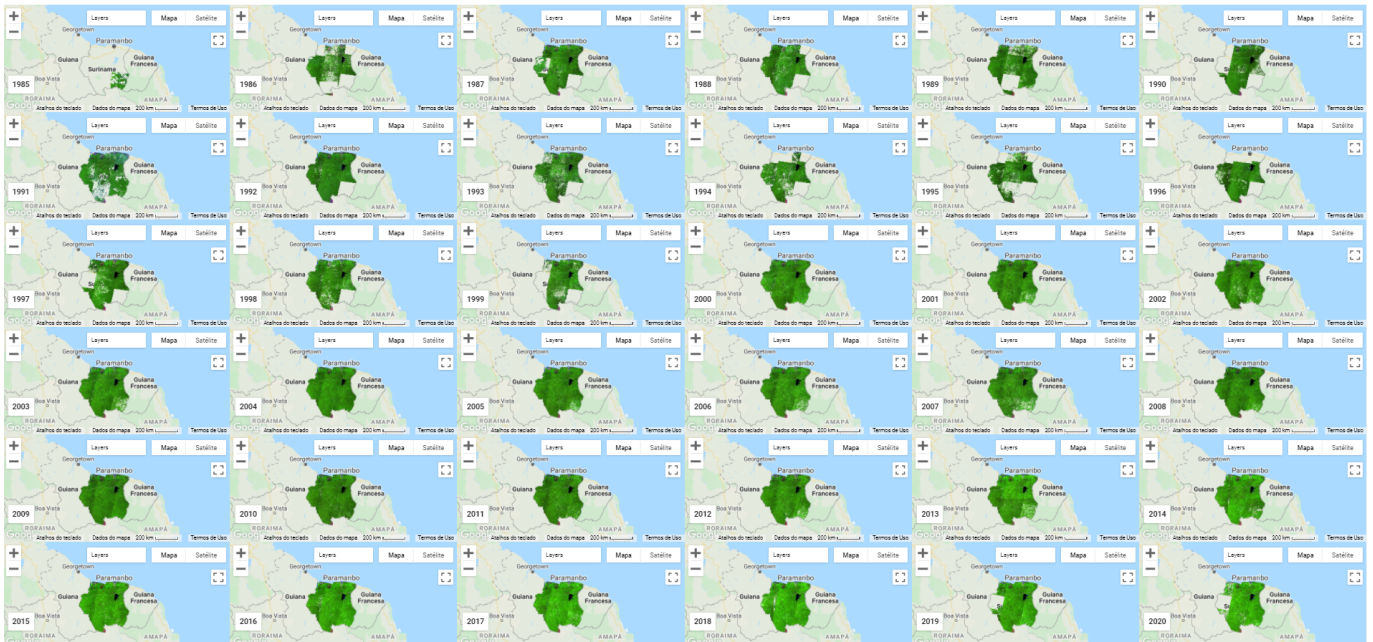


Figure 6. Annual mosaics from 1985 to 2022 of Suriname used in the Collection 5 classification.

3.4 Mosaics results and quality

Once the mosaics were ready, they were submitted to a quality evaluation based on the existence of cloud noises, bands noises or relief shadows. The mosaics for each tile in each year (1980 total) were evaluated in three classes, varying from good to poor, according to the following criteria: (a) Good represents mosaics which less than 10% of the chart area presented data not observed due to any type of noise evaluated; (b) Regular presents the mosaics with noised areas between 10 and 35% and (c) Poor where more than 35% of the chart presented values with noises. The quality majority of the

mosaics in the Guianas was good (44% as shown in the Figure 7) with the French Guiana being the country among the three that suffered most with noises in the images used (Table 4).

Mosaics quality in the Guianas

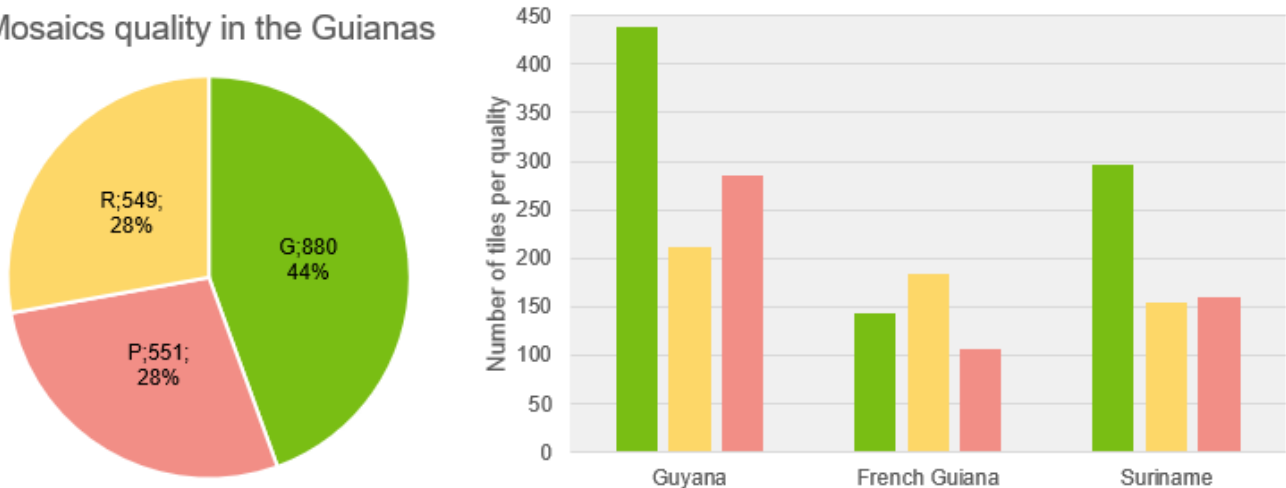


Figure 7. The pie chart shows the total number and percentage of the quality classes for the Guianas and the bar chart reveals the number of mosaics by quality class for each country separately. In green the good quality class is presented (good - G); the regular class is in yellow (regular - R); and the poor quality class in red (poor - P).

Table 4. Percentage of mosaics number by good, regular and poor quality related to mosaics total number processed by country

Quality	Guyana	French Guiana	Suriname	Total
Good (B)	47%	33%	49%	44%
Regular (R)	23%	42%	25%	28%
Poor (P)	30%	25%	26%	28%

The quality of the satellite image mosaics is clearly poorer in the years before 2000 and it increases when it comes close to the end of the time series (Figure 8). In Figures 9, it can be seen that the number of bad quality mosaics at the beginning of the time series is a repeated pattern in all three countries.



Figure 8. The bar chart reveals the number of mosaics by quality class per year. In green the good quality class is presented (; the regular class is in yellow; and the poor quality class in red.

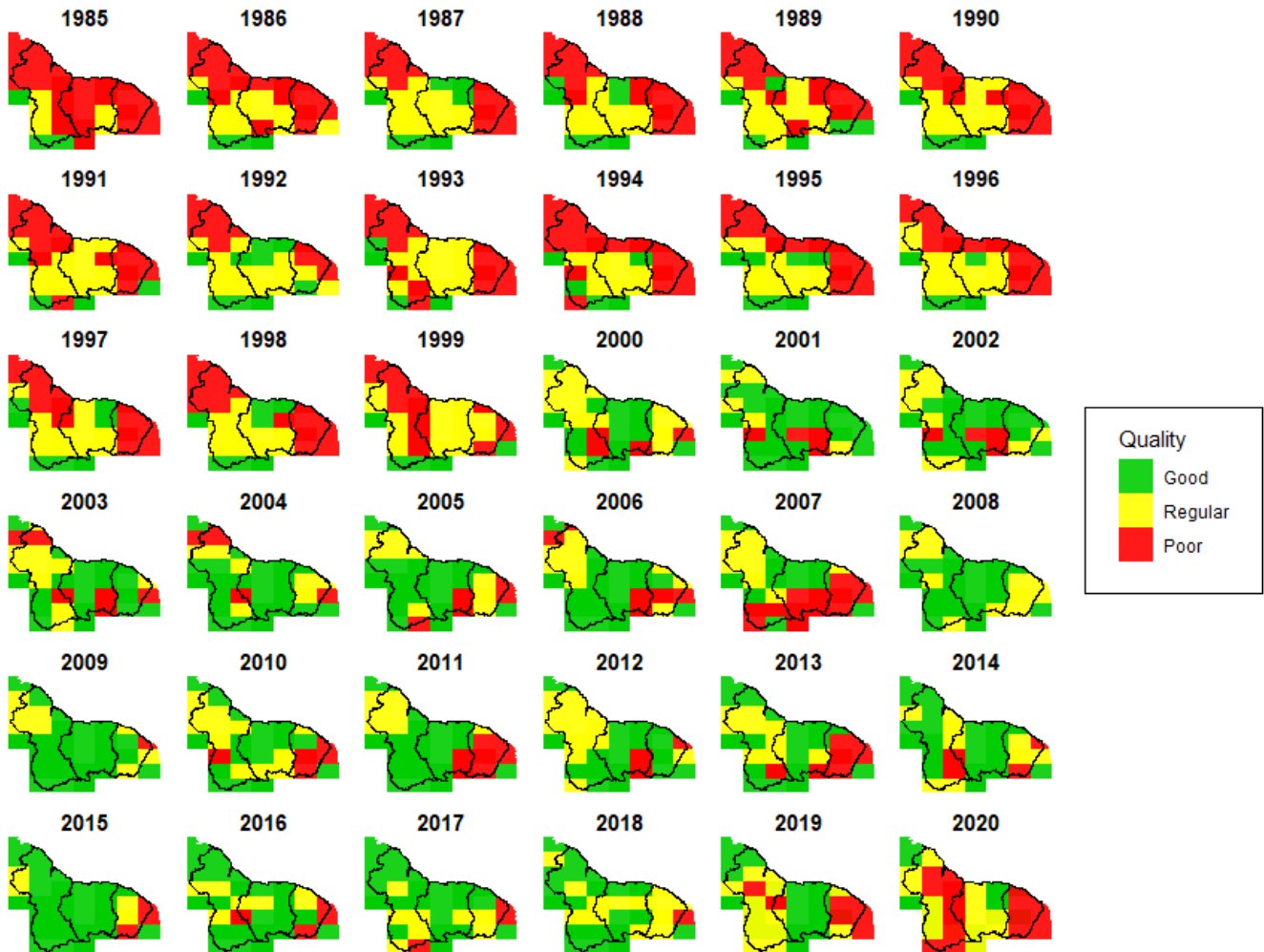


Figure 9. This figure shows the annual maps (1985-2022) of Guyana, French Guiana and Suriname divided by letters representing the mosaics processed for each country by quality classes. In green the good quality class is presented; the regular class is in yellow; and the poor quality class in red.

4 Classification

4.1 Definition of classification regions

The classification regions were defined mainly based on countries' relief shape and ecosystem characteristics. Human occupation (cities and farming) in the coastal zone was also considered. Regarding these aspects, four reference maps were combined to identify comparative areas with different environmental characteristics (Figure 10): (i) the Ecosystems of South America from the U.S. Geological Survey - Nature Conservancy (2008); (ii) the South American Landscape also from the Nature Conservancy (2005); (iii) the Shuttle Radar Topography Mission (SRTM) 90m digital elevation data from the National Aeronautics and Space Administration (NASA); and (iv) the world Ecoregions from Dinerstein *et al.* (2017).

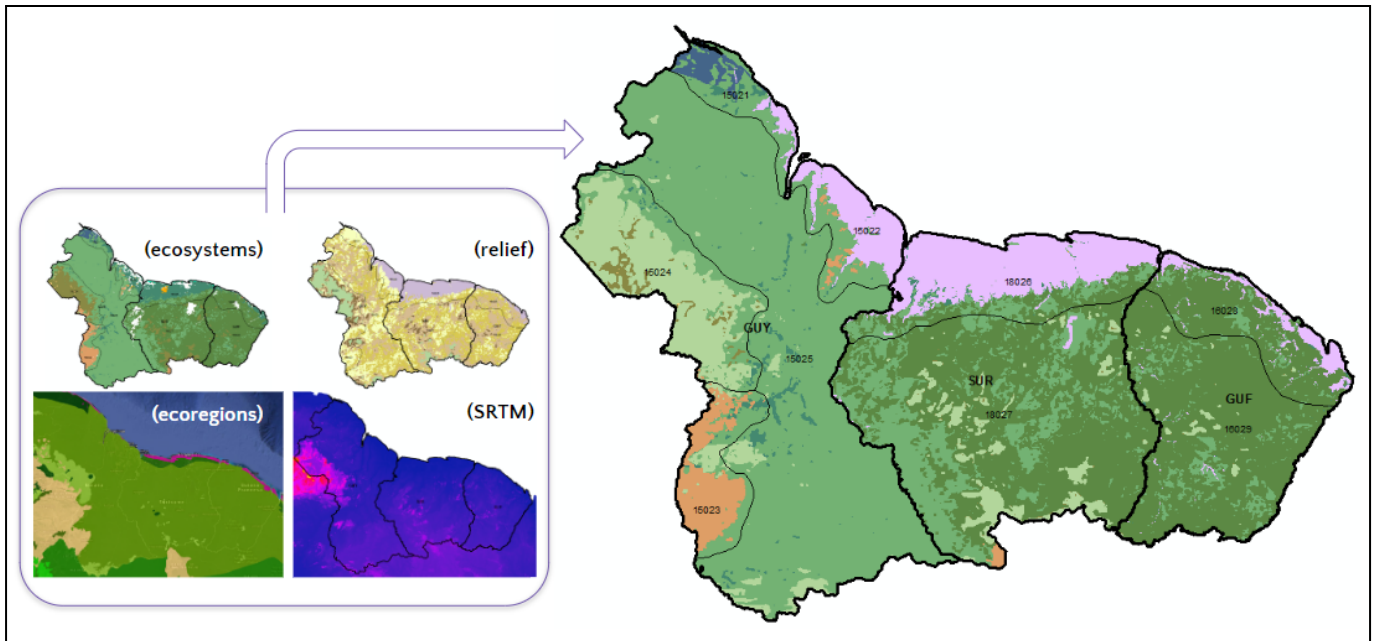


Figure 10. A scheme representing the combination of four reference maps used to define the classification regions.

Therefore, nine different classification regions were defined, which could be agglomerated in four main groups (coastal mosaic, forest mosaic, montane mosaic and non-forest mosaic). The location of each region, its limits and its main ecosystem characteristics are observed in Figure 11.

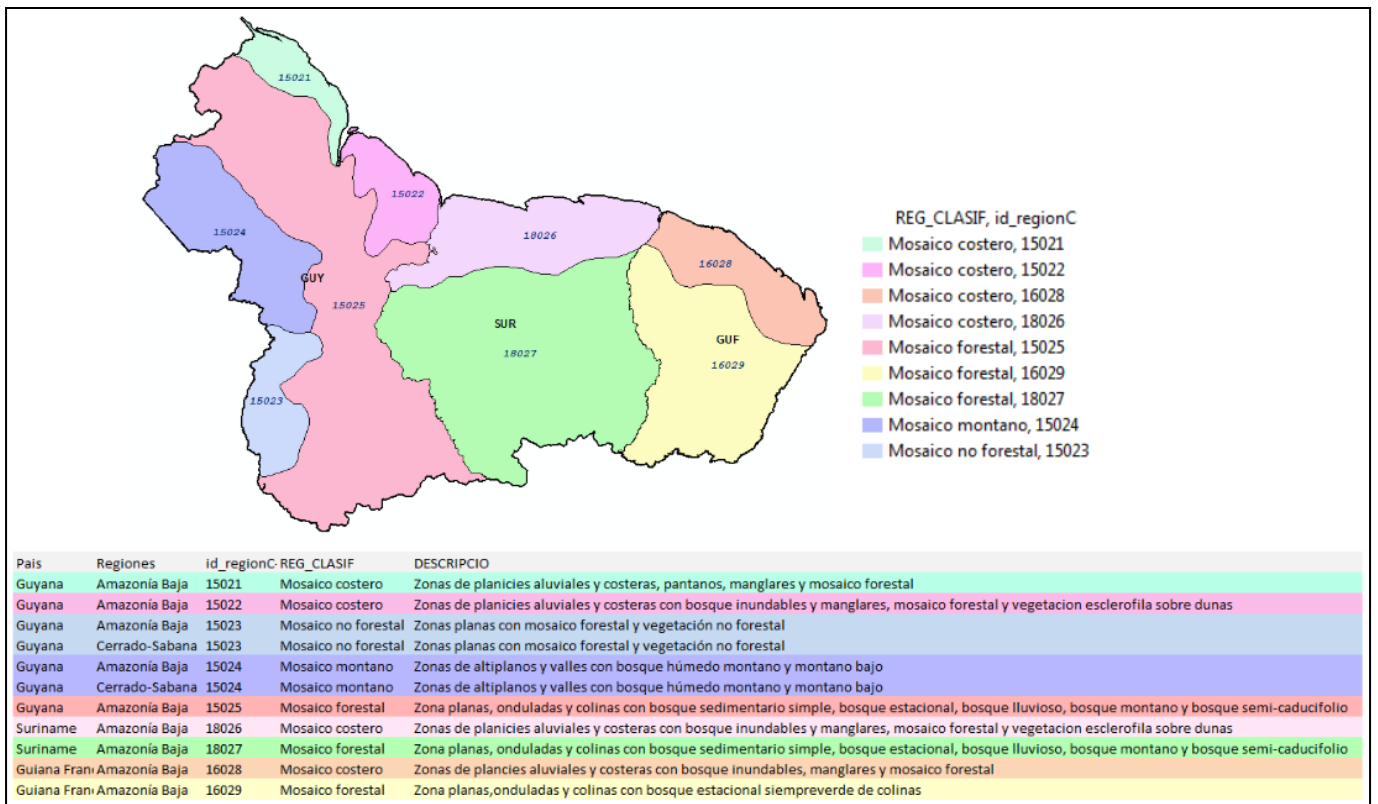


Figure 11. The regions used in the Guianas to partition the classification area.

4.2 Classification scheme

The classification scheme used for mapping the land use and land cover in Guyana, French Guiana and Suriname, followed all the standardized steps defined by MapBiomass Amazonia team in the Collection 5, as described in the General ATBD and presented in Figure 12.

Methodological steps

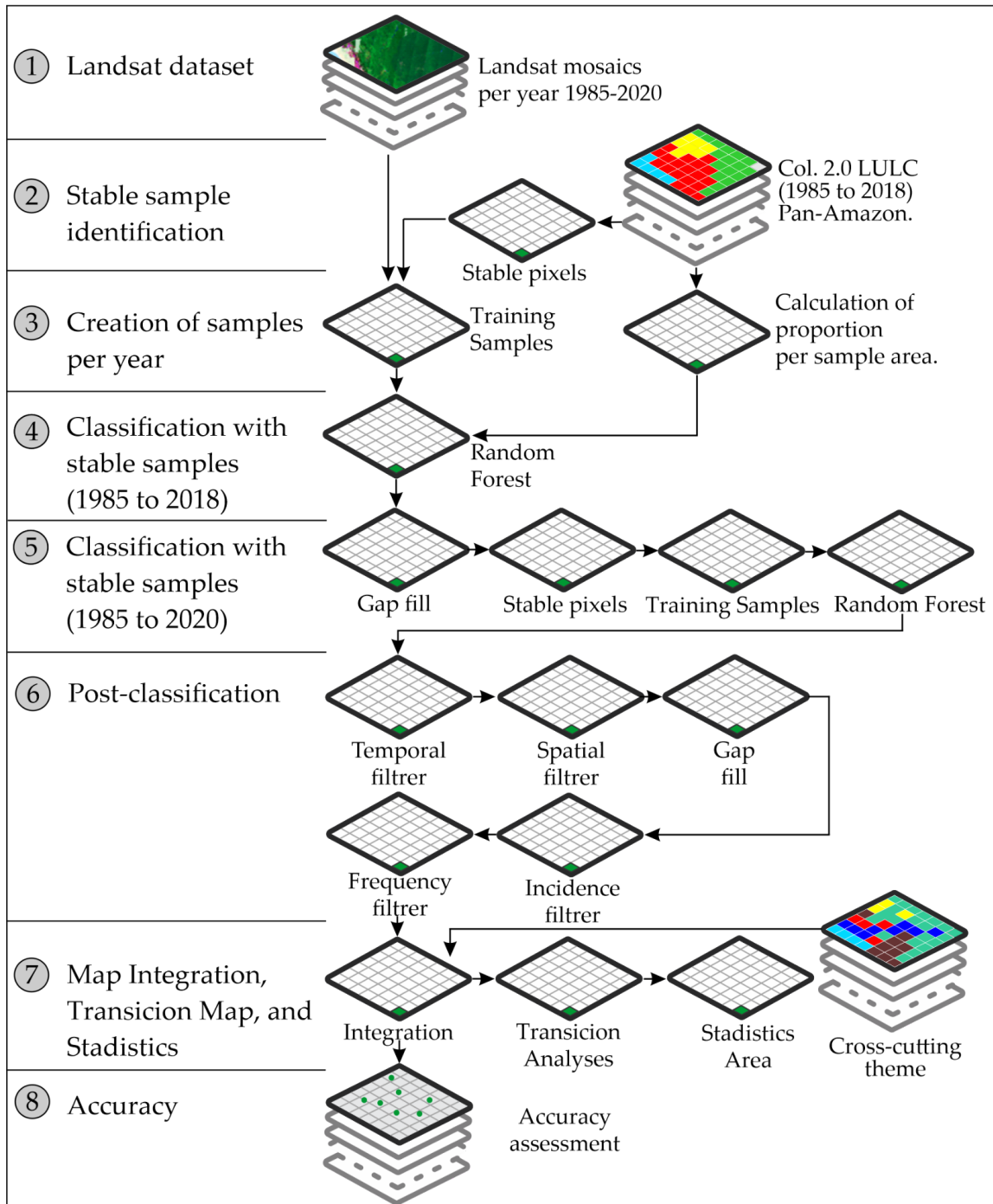


Figure 12. The classification steps to produce MapBiomass Collection 5 for Guyana, French Guiana and Suriname. The figure presents all classification steps, from step one (P01) to step fourteen (P14).

4.3. Legend

The Guianas legend was extracted from the general legend used by the MapBiomias Amazonia team (Figure 13), therefore the mapping classes are: Dense forest (3); Mangroves (5); Flooded Forest (6); Non-forest wetlands (11); Grasslands (12); Agriculture or pasture (21); Urban Infrastructure (24); Other non-vegetated areas (25) and River, lake and ocean (33).

GENERAL LEGEND (MAPBIOMAS AMAZONIA)	ID
1. Forest	1
1.1. Natural Forest	2
1.1.1. Dense Forest	3
1.1.2. Mangrove	5
1.1.3. Flooded Forest	6
2. Non-Forest Natural Formations	10
2.1. Non-Forest Wetland	11
2.2. Grassland	12
2.3. Other non-forest formations	13
2.4. Rock Outcrop	29
3. Farming	14
3.1. Pasture	15
3.2. Agriculture	18
3.3. Agriculture or Pasture	21
4. Non-Vegetated Areas	22
4.2. Urban Infrastructure	24
4.3. Other non-vegetated areas	25
4.4. Mining	30
5. Water Bodies	26
5.1. River, lake and ocean	33
5.2. Glaciar	34
6. No observado	27

Figure 13. General legend used by MapBiomias Amazonia Collection 5 - in black the classes adopted in the Guianas and in gray the classes of other Amazonian countries.

4.2 Feature Space

Feature space subset considered in the Collection 5 classification of Guyana, French Guiana and Suriname image mosaics was a list of 36 most important variables for the classification, selected for the Lower Amazon biome, a part of the total available bands of the MapBiomias Amazonia feature space - composed of 147 input variables, including the original Landsat bands, fractional and textural information derived from these bands (as described in the General ATBD).

4.3 Classification algorithm, training samples and parameters

After generating the image mosaics and feature space, the first step in the classification (P02) is to correct the stable areas mapped in Collection 2 (1985-2018) of the Guianas. This correction was made by region through visual interpretation of the Landsat images mosaics.

Then, in step P03 is selected a reference year to calculate the proportion of each stable class in the classification region and use the result to draw training samples on the Collection 2 stable area map. The year that best represents reality were identified for each region and the training samples number was standardized (Table 5).

Table 5. Collection 2 annual map selected as reference for calculating the proportion of stable areas per classification region.

Country	Regions		Step P03
	ID v1	ID v2	P03
Guyana	15021	50201	Reference year: 2013 Number of samples: 100-700
Guyana	15022	50202	Reference year: 2011 Number of samples: 100-700
Guyana	15023	50203	Reference year: 2015 Number of samples: 100-700
Guyana	15023	50903	Reference year: 2015 Number of samples: 100-700
Guyana	15024	50204	Reference year: 2013 Number of samples: 100-700
Guyana	15024	50904	Reference year: 2013 Number of samples: 100-700
Guyana	15025	50205	Reference year: 2013 Number of samples: 100-700
Suriname	18026	80206	Reference year: 2015 Number of samples: 100-700
Suriname	18027	80207	Reference year: 2015 Number of samples: 100-700
French Guiana	16028	60208	Reference year: 2001 Number of samples: 100-700
French Guiana	16029	60209	Reference year: 2001 Number of samples: 100-700

In the next step (P04) the machine learning algorithm called random forest ran to generate a preliminary classification of the complete Collection 5 time series (1985-2022). All regions were classified using 60 decision trees. With this first version ready, the gap-fill filter (P05) was applied, as described in the General ATBD.

After this filter, the classification cycle is repeated with the preliminary classification as the basis (no longer Collection 2). Therefore, the map of stable areas (P06) of the filtered preliminary classification is created. Consequently, the reference years are selected and stable training samples are drawn (P07) - Table 6. The selection process for the reference years was similar to that applied in P03.

Table 6. Preliminary classification annual map selected as reference for calculating the proportion of stable areas per classification region.

Country	Regions		Step P03
	ID v1	ID v2	P03
Guyana	15021	50201	Reference year: 2003 Number of samples: 100-700
Guyana	15022	50202	Reference year: 2018 Number of samples: 100-700
Guyana	15023	50203	Reference year: 2005 Number of samples: 100-700
Guyana	15023	50903	Reference year: 2005 Number of samples: 100-700
Guyana	15024	50204	Reference year: 2005 Number of samples: 100-700
Guyana	15024	50904	Reference year: 2010 Number of samples: 100-700
Guyana	15025	50205	Reference year: 2010 Number of samples: 100-700
Suriname	18026	80206	Reference year: 2002 Number of samples: 100-700
Suriname	18027	80207	Reference year: 2009 Number of samples: 100-700
French Guiana	16028	60208	Reference year: 2011 Number of samples: 100-700
French Guiana	16029	60209	Reference year: 2002 Number of samples: 100-700

The set of stable samples is evaluated by classification region to identify whether there is a need for sample complementation. Complementary training samples were selected for all regions, according to Table 7. Thus, the final set of training samples (stable + complementary) was used in the processing of the random forest in step P08. In this stage, 60 decision trees were also applied for the classification. After this, the following steps are post-classification filters.

Table 7. Number of complementary training samples selected per mapping class for each classification region.

Country	Regions		Number of complementary training samples
	ID v1	ID v2	
Guyana	15021	50201	Dense Forest: 500 Non-forest wetlands: 500 Agriculture or pasture: 500 River, lake and ocean: 500
Guyana	15022	50202	Dense Forest: 500 Non-forest wetlands: 500 Grasslands: 500 Agriculture or pasture: 500 Other non-vegetated areas: 500 River, lake and ocean: 500
Guyana	15023	50203	Dense Forest: 500 Non-forest wetlands: 500 Grasslands: 500 River, lake and ocean: 500
Guyana	15023	50903	Dense Forest: 500 Non-forest wetlands: 500 Grasslands: 500
Guyana	15024	50204	Dense Forest: 500 Grasslands: 500
Guyana	15024	50904	Dense Forest: 500 Grasslands: 500
Guyana	15025	50205	Dense Forest: 500 Grasslands: 500
Suriname	18026	80206	Dense Forest: 500 Non-forest wetlands: 500 Grasslands: 500 Agriculture or pasture: 500 River, lake and ocean: 500
Suriname	18027	80207	Dense Forest: 500 Grasslands: 500 Other non-vegetated areas: 500 River, lake and ocean: 500
French Guiana	16028	60208	Dense Forest: 500

Non-forest wetlands: 500
 Grasslands: 500
 Agriculture or pasture: 500
 Other non-vegetated areas: 500
 River, lake and ocean: 500

French Guiana 16029 60209

Dense Forest: 500
 River, lake and ocean: 500

5 Post-classification

5.1 Gap-fill filter

The gap-fill filter was used to fill possible no-data values as explained in the General ATBD. 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 (1985-2022).

The gap-fill filter is very important to generate complete maps, but it is necessary to be cautious with the information generated from it. The information for a pixel in a given year can refer to another period of time. In Figure 14, it can be seen that the class mapped in 2001 in a pixel from the 50202 region was repeated in all previous years until 1985 due to a lack of information in the image mosaics from 2000 to 1985.

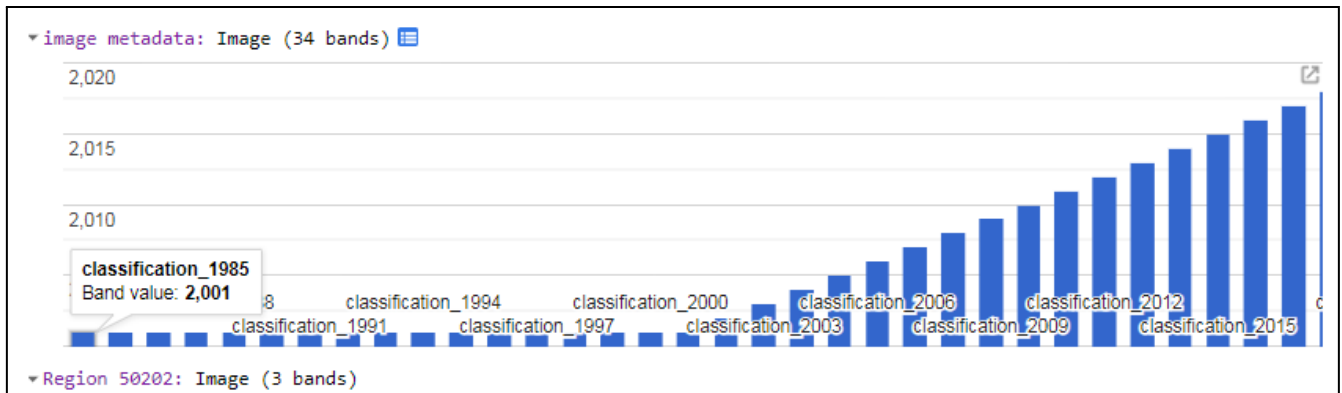


Figure 14. The figure presents the metadata (provided by the gap-fill filter script) of a random pixel in the 50202 classification region in Guyana as an example of the gap-fill filter application. The bar chart shows the gapped year on the X-axis and the replaced year on the Y-axis.

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. Another generic temporal rule is applied to the extremity of consecutive years.

In this case, 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.

In Guyana, French Guiana and Suriname the logic for prioritizing classes for the temporal filter were the same. The rule for the first year was executed for the native classes (3, 11 and 12), followed by the rule for the middle years executed for the classes 33, 12, 21, 3 and 25, and finally the temporal filter rule for the last year executed for the unnatural class (21). Some rules were applied more than once in different prioritizations to improve the temporal connection between the annual maps, as in the case of classes 3, 12 and 21. Below is the code with the temporal filter rules execution order used in the script.

```
order_exec_first = [3, 11, 12];
order_exec_last = [21];
order_exec_middle = [33, 12, 21, 3, 25];
```

5.4 Spatial filter

The generated after the classification were submitted filtering procedures. The spatial filter increases the spatial consistency between the classes eliminating the solitary group of pixels of a specific class in the middle of another class. This process was applied to all classes and the specific routine can be found in details on the ATBD general description.

5.5 Frequency filter

This filter takes into consideration the occurrence frequency throughout the entire time series. Thus, all class occurrence with less than a given percentage of temporal persistence 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 classification region in the Guianas have customized applications of frequency filters, see more details in Table 8. It is worth mentioning that the frequency filter was applied to correct not only native areas but also unnatural areas in the group of regions defined as coastal mosaic due to the old human occupation in these areas.

Table 8. Customized parameters of the frequency filter applied in each classification region.

Regions			Frequency filter parameters		
Country	ID v1	ID v2	Classes considered in the pixel mask eligible for filter application	Percentage to define the mask of eligible pixels to apply the filter	Percentage of temporal persistence applied
Guyana	15021	50201	Native classes	90	70
			Unnatural classes	70	50
Guyana	15022	50202	Native classes	90	70

			Unnatural classes	70	50
Guyana	15023	50203	Native classes	90	80
Guyana	15023	50903	Native classes	90	80
Guyana	15024	50204	Native classes	90	80
Guyana	15024	50904	Native classes	90	80
Guyana	15025	50205	Native classes	90	80
			Native classes	90	80
Suriname	18026	80206	Unnatural classes	70	50
Suriname	18027	80207	Native classes	90	80
			Native classes	90	80
French Guiana	16028	60208	Unnatural classes	70	50
French Guiana	16029	60209	Native classes	90	80

5.6 Incidents filter

The incident filter was applied to remove pixels that changed too many times in the 36 years of time span. This avoids changes in the border of the classes and helps to stabilize originally noise pixel trajectories. You can see the minimum changes and connections parameters details in the General ATBD.

5.7 Classification of Flooded Forest

Flooded forest was mapped as BETA version for the Guianas in the collection, resulting from the post classification. The NASA DEM: Digital Elevation 30m was used to identify coastal forest with less than 20m altitude and it was converted to flooded forest using an spatial mask.

5.8 Integration

The integration process of the annual maps of Mangroves and Urban Infrastructure was accomplished through hierarchical overlap on a pixel by pixel basis. Mangroves mapping, followed by urban infrastructure mapping has a prevalence in all other classes mapped in Guyana, French Guiana and Suriname.

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