COLLECTION 1 BOLIVIA

Algorithm Theoretical Basis Document (ATBD)

MapBiomas Fire

August 2026

Specialist Team

Carla Llanos

Carolyn Ordoñez

Ariel Reinaga C.

Jhonatan Choque

Verónica Huanaco R.

Efrain Tinta G.

Bernardo Condori C.

Uziel Luna V.

Maribel Quenta C.

Teresa Mamani Q.

Adrien Marzec

Alvaro Colque A.

Analysis and Remote Sensing Specialists

Marcelo Char

Sara Espinoza

Alejandra Tancara

Yanine Domínguez

Eva Mollinedo

Yoshelin Varón

Armando Rodríguez Montellano

Technical Component Lead for MapBiomas Fire

Kevin M. Centellas A.

Project Coordinator for MapBiomas Bolivia

Saúl Cuéllar

Institution

Fundación Amigos de la Naturaleza (FAN)

Km. 7 1/2 Doble Vía a La Guardia

Santa Cruz - Bolivia

Phone: (591-3) 3556800

www.fan-bo.org

How to cite:

Theoretical Basis Document on Algorithms (ATBD) – MapBiomas Fire Bolivia Collection 1.

Index

List of Figures

List of Tables

1. Introduction

1.1. Document Objective

This document describes the theoretical basis, rationale, and methods applied to produce annual burned area maps from 1995 to 2025 as part of **Collection 1** of the MapBiomas Fire initiative.

This document describes the Landsat image classification methods (Landsat 5, 7, 8, and 9), the image-processing architecture, and the approach used to integrate the biomes and regions present in the country. It also provides historical context and background information, together with a general description of the satellite imagery dataset.

1.2. MapBiomas Fire Bolivia

The MapBiomas Bolivia network was launched in July 2023 to support the understanding of land-use and land-cover (LULC) dynamics throughout the national territory. Subsequently, it implemented its second initiative, or module, called MapBiomas Water, with the aim of obtaining annual and monthly data on water bodies and glaciers nationwide. In 2026, the network launched its third initiative, MapBiomas Fire, which provides users with free national annual burned area maps covering a 31-year time series.

The network is developed within the following framework:

1. The use of cloud-processing technology to handle large volumes of spatial data through Google Earth Engine algorithms.
2. The production of fully free and replicable data and methodologies that are improved annually and released as collections.
3. A multidisciplinary technical team whose experience supports the mapping of the entire national territory; and
4. The support of institutions and funders that champion the network's vision.

MapBiomas Fire Bolivia presents **Collection 1** of annual burned area maps for 1995–2025. The methodology uses deep learning algorithms based on a Deep Neural Network (DNN) model and Landsat satellite imagery at 30-meter spatial resolution.

The MapBiomas Bolivia initiative, under the technical coordination of Fundación Amigos de la Naturaleza (FAN) and in partnership with WCS, TIERRA, and ACEAA, presents **Collection 1 of MapBiomas Fire**. This collaborative effort has consolidated a historical series of annual and monthly burned area maps.

MapBiomas collections aim to contribute to the development of rapid, reliable, collaborative, and low-cost methods for processing large-scale datasets and generating historical time series of annual maps. All data, processes, code, statistics, and other analyses are freely accessible through the MapBiomas Bolivia platform at http://bolivia.mapbiomas.org

The data products and sub-products generated for Collection 1 are as follows:

1. National annual burned area from 1995 to 2025.

2. Burned areas according to the MapBiomas Land Cover and Land Use classes (Collection 3).
3. Annual burned area frequency in Bolivia.
4. Monthly burned area in Bolivia from 1995 to 2025.
5. Cumulative burned area in Bolivia.
6. Annual burned area by scar size
7. Year of the last fire occurrence

Products can be accessed free of charge on the network's website at bolivia.mapbiomas.org .This document is hosted in the ATBD download section (https://bolivia.mapbiomas.org/en/download-of-atbds), and the classification algorithms are available in the MapBiomas Bolivia GitHub repository. bolivia.mapbiomas.orgATBD download sectionrepository

1.3. Google Earth Engine, Google Colab, and Google Cloud

MapBiomas Fire Bolivia burned area maps are processed using Google tools such as Google Earth Engine, Google Colab, and Google Cloud. Google Earth Engine (GEE) is a cloud platform for global-scale scientific analysis of geospatial datasets. Its main components are:

- Catalogs of publicly available remote sensing sensor data.
- Petabyte-scale cloud computational processing infrastructure.
- JavaScript and Python APIs to interact with GEE servers.
- An online integrated development environment (IDE) that allows application development using scripts[1], called the Code Editor[2].

These components make GEE an ideal tool for processing the large volumes of data required for satellite image classification and burned area mapping. Additionally, GEE enables shared methodologies to be applied to the same datasets, allowing third parties interested in evaluating concepts or methodologies to replicate the processes.

To complement this capability, Google Colab is a powerful and flexible tool that allows complex classification tasks to be executed using cloud computing infrastructure to process large volumes of information.

This workflow also benefits from Google Cloud storage infrastructure, which provides the capacity to store and organize data in a structured manner in Google Cloud Storage buckets. This process is essential for ensuring replicability and improving project management. The use of buckets for data organization also enables version control and secure access to inputs and results.

Data visualization and analysis are further enhanced through Looker Studio, a powerful tool that transforms cloud-processed data into interactive reports and dashboards. Looker Studio facilitates the creation of dynamic charts and interactive maps, allowing the technical team to explore, analyze, and interpret burned area information intuitively and compare results with reference data.

[1] https://developers.google.com/earth-engine/
[2] code.earthengine.google.com

1.4. Other Mapping Initiatives

In recent years, various tools have been developed for burned area mapping, some at a global scale, using increasingly robust approaches. These initiatives share an interest in addressing one of the most urgent issues of our time: understanding the current state and impacts of fire in the context of climate change. They have contributed to deforestation detection, terrestrial ecosystem monitoring, improved forest degradation detection, conservation, and hotspot monitoring. The most relevant initiatives are listed below:

- **MODIS Fire and Thermal Anomalies (NASA/FIRMS):** An initiative that uses MODIS (Terra/Aqua) and VIIRS (Suomi NPP, NOAA-20) satellite data to identify hotspots in near-real time. The FIRMS portal allows global downloading and visualization of hotspots. Detection is based on temperature and spectral brightness algorithms and is updated every 3 hours, depending on sensor orbits. Coverage includes the entire land surface.
- **Fire Information for Resource Management System (FIRMS) – Global:** It is a NASA service for detecting active fires using thermal imagery. It includes an API and access via Google Earth Engine and GIS platforms. It is widely used by governments, NGOs, researchers, and professionals in natural resource management, environmental monitoring, emergency response, research, and land-use planning.
- **Global Forest Watch Fires (GFW Fires):** A World Resources Institute (WRI) platform that combines satellite data (VIIRS and MODIS) with tree-cover layers and fire alerts, particularly useful in tropical regions. It is designed to detect, visualize, and analyze active fires, agricultural burning, and deforestation in near-real time, especially in tropical regions such as the Amazon (including Bolivia, Brazil, Colombia, and others).
- **Copernicus Emergency Management Service (CEMS) – European Forest Fire Information System (EFFIS):** A European system for monitoring forest fires in Europe, the Mediterranean, and Latin America using data from Sentinel-2, Sentinel-3, MODIS, VIIRS, and Meteosat/MSG. Its objective is to provide precise, up-to-date, and harmonized wildfire information for prevention, detection, monitoring, and impact assessment. It maintains a database of wildfire events dating back to 2000.
- **GEOGloWS / GEO Global Agricultural Monitoring (GEOGLAM-Fire):** An initiative within the Group on Earth Observations (GEO) that integrates fire data to assess impacts on crops and agricultural ecosystems. Applications include detecting and quantifying fires on agricultural lands, intersecting VIIRS hotspots with agricultural layers (e.g., rice, soy, and corn) to assess losses, and estimating emissions from agricultural biomass burning.
- **GOFC-GOLD Fire Mapping and Monitoring:** An international group supported by NASA and FAO that develops standards and data networks for global fire monitoring, supporting regional satellite observation networks. Its objective is to improve global and regional capacity to observe, map, model, and understand fire regimes in natural and productive ecosystems through satellite data, standardized methodologies, and collaborative networks.
- **Global Wildfire Information System (GWIS):** A joint initiative between Copernicus and FAO that provides integrated wildfire data on a single global platform. Its objective is to harmonize worldwide wildfire information and improve countries' capacity to monitor, prevent, and manage fire-related events. Geographic coverage includes all continents, with a special focus on critical areas such as the Amazon, sub-Saharan Africa, Mediterranean Europe, Australia, and Central Asia.

- **INPE – Queimadas (Brazil):** Brazil's hotspot and forest fire monitoring system, launched in 1998. It uses sensor data such as MODIS, VIIRS, and GOES to detect and report the near-real-time locations and extents of hotspots across Brazil and South America. The data generated are publicly available and updated daily, enabling continuous monitoring of fire dynamics.

2. Methodology

The MapBiomas processing chain is entirely based on Google technology. MapBiomas Bolivia uses GEE to:

- Process satellite images on cloud computing infrastructure.
- Develop JavaScript and Python scripts.
- Store generated data using cloud storage.
- Deploy results (mosaics, annual burned area maps, statistics, methodological information, etc.) via a public web consultation platform accessible at bolivia.mapbiomas.org.

The **MapBiomas Fire Bolivia Collection 1** workflow is summarized in Figure 1 and consists of four stages:

1. Pre-classification
2. Sampling Strategy
3. Classification
4. Post-classification

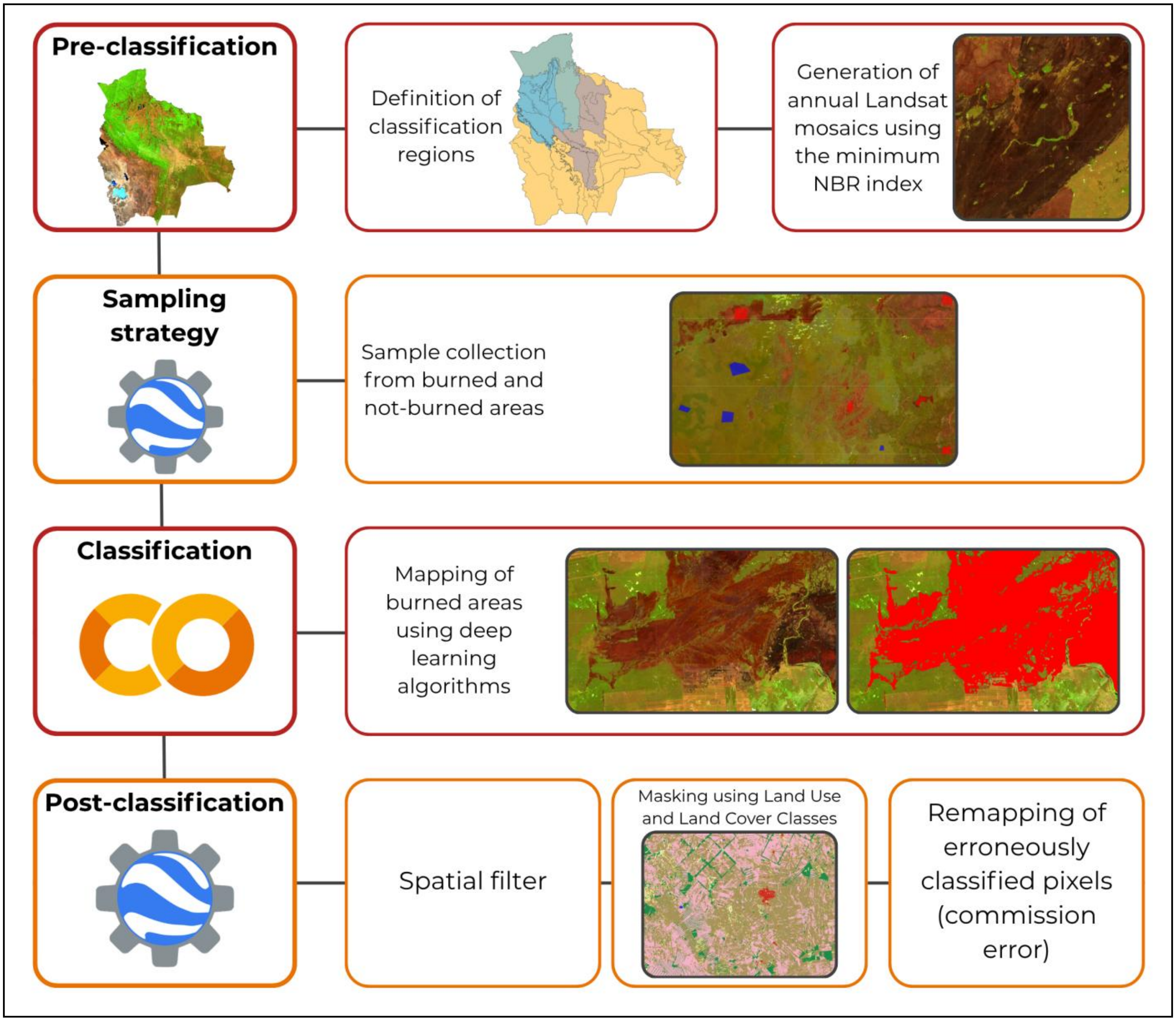

Figure 1. Methodological summary of MapBiomas Fire Bolivia Collection 1

2.1. Delimitation of Working Regions

The working area encompasses the entire territory of Bolivia, with an official area of 1,098,581 km².

To ensure model accuracy across Bolivia's diverse ecosystems, the national territory was divided into 44 classification regions (Figure 2). This approach allows algorithmic parameters to be adapted to the specific characteristics of critical biomes such as the Amazon, Chaco, Pantanal, and Chiquitano.

The regional division also corresponds to the allocation of working areas among the four institutions that worked on **MapBiomas Fire Bolivia Collection 1**:

- Conservación Amazónica (ACEAA): 2 regions
- Wildlife Conservation Society (WCS): 13 regions
- TIERRA: 6 regions
- Fundación Amigos de la Naturaleza (FAN): 23 regions

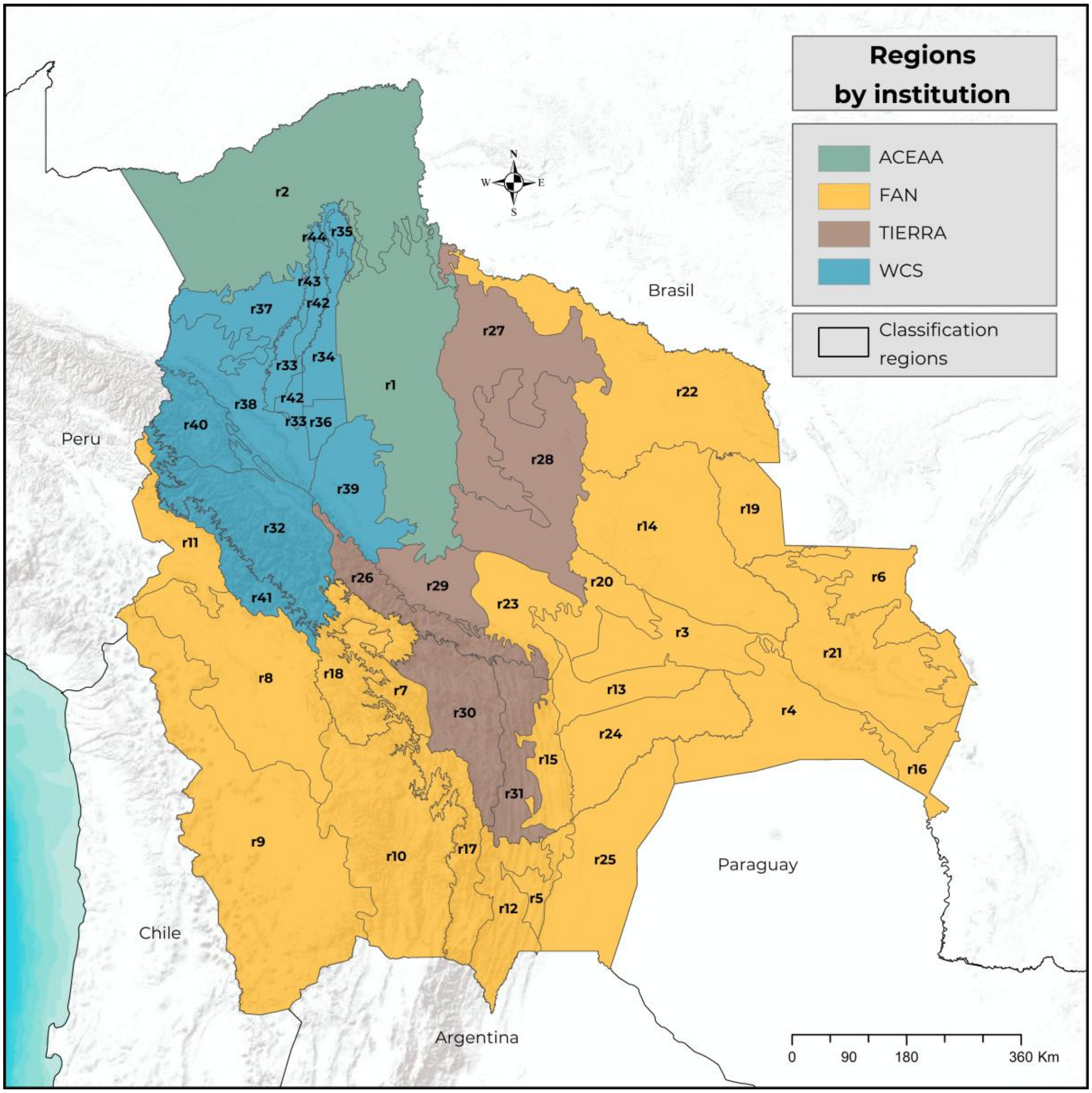

Figure 2. Delimitation of classification regions by responsible institution

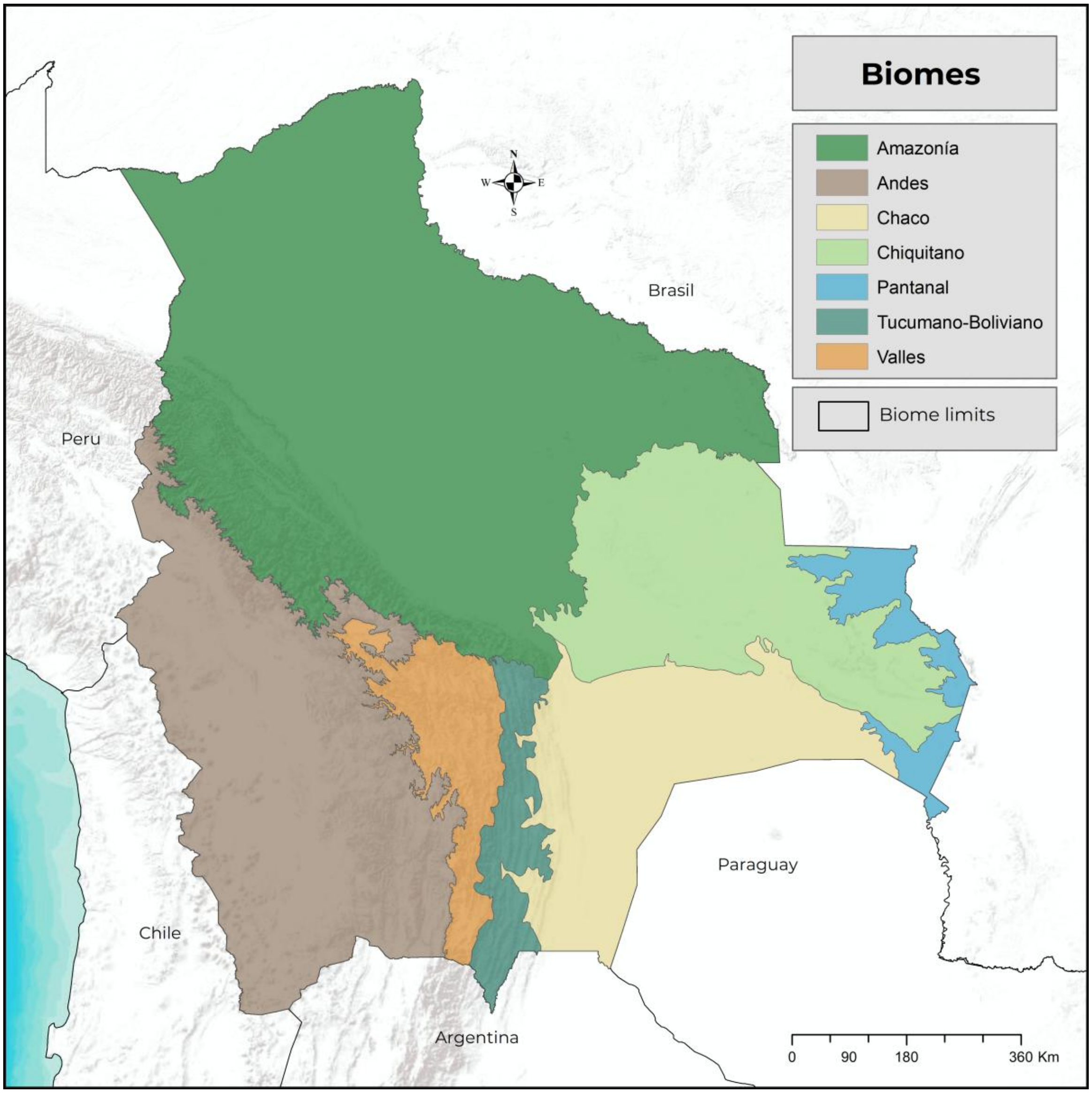

Figure 3. Location and boundaries of the biomes identified in Bolivia

2.2. Generation of Annual Mosaics

Through Google Earth Engine, surface reflectance (SR) data from the Landsat[3] Collection 2 Tier 1 catalog (30 m × 30 m) are used, with a 16-day revisit interval from 1995 to 2025 across the following satellites:

- Landsat 5: 1995 to 1998
- Landsat 5 and 7: 1999 to 2012
- Landsat 7 and 8: 2013 to 2021
- Landsat 8 and 9: 2022 to 2025

[3] https://developers.google.com/earth-engine/datasets/catalog/landsat/

Landsat surface reflectance data are accompanied by two bit-mask quality assessment bands (QA_PIXEL and QA_RADSAT), which indicate pixels with radiometric and instrumental issues, including confidence indicators. We used the QA_PIXEL band to select and mask pixels with high-confidence classifications (67–100%) for cloud and shadow. We then used QA_RADSAT to exclude pixels with radiometric saturation in any surface reflectance band.

An annual statistical approach was used to summarize the data and optimize classification without discarding pixel-level spectral information. This approach enabled the creation of annual mosaics by composing all 16-day images into a single Quality Mosaic (QM) using the minimum NBR (Normalized Burn Ratio) spectral index.

Pixels with the lowest NBR values within the multiband image were selected, and their spectral information was used to compose the annual Quality Mosaic (QM). In addition to spectral information, scene metadata were retained, including the date on which each pixel exhibited its lowest NBR value. The NBR Quality Mosaic performed well in differentiating burned from unburned land cover and land use across the classification regions of Bolivia (Figure 3).

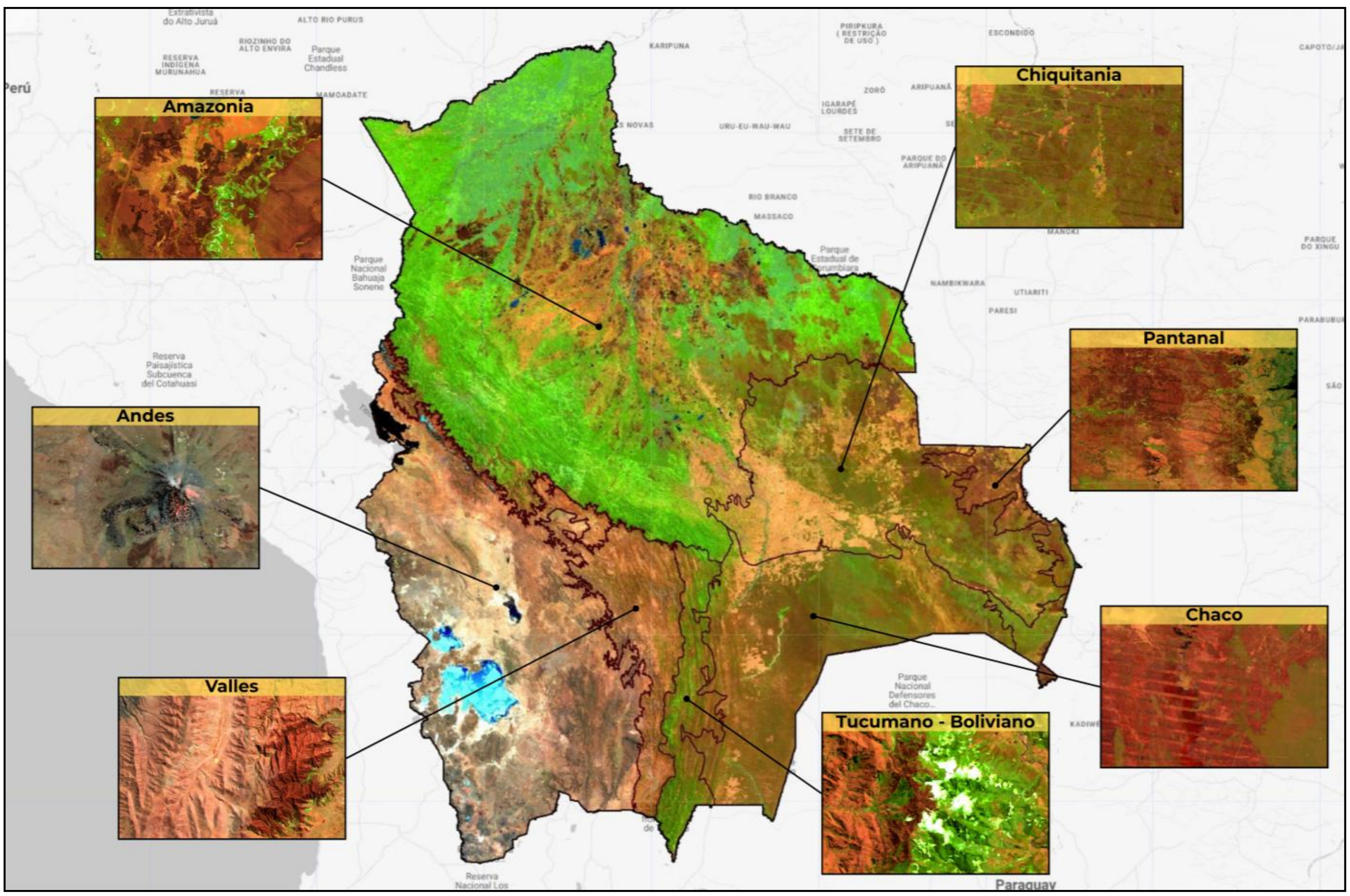

Figure 4. False-color composite (SWIR1, NIR, Red) of Landsat mosaics and detail of burn scars by biome

2.3. Collection of Training Samples

A spectral library was created based on the manual delineation of burned and unburned areas to serve as training samples. These samples were stratified by Landsat sensor (collected in different years) and by biome/region. Training samples were collected across all 44 classification regions, ensuring representation of the distinct spectral characteristics of each region.

Inputs used during this stage included:

- MapBiomas Land Cover and Land Use Collection 3 (1995–2025), used to identify different types of land cover and land use.
- Global Annual Burned Area Map (GABAM) (30m spatial resolution) (1995–2021).
- Fire CCI Burned Area Climate Data Record, Version 5.1 (2000–2020).
- MODIS Burned Area (MCD64A1) (500m spatial resolution) (2000–2025).
- Fire Information for Resource Management System (FIRMS) fire scars (1 km spatial resolution) (2000–2025).

2.4. Classification

The classification model applied was a Deep Neural Network (DNN), a computational framework capable of deep learning and visual pattern recognition. Specifically, a Multi-Layer Perceptron Network (MLPN) architecture was implemented, incorporating multiple layers of interconnected computational units, or "neurons." Each node in one layer connects to nodes in the next, forming three primary types of layers: input, hidden, and output (Hu & Weng, 2009).

For the DNN model, the input layer corresponded to the Red, NIR, SWIR1, and SWIR2 spectral bands, while the output layer consisted of two classes: burned and unburned. The burned area mapping algorithm[4] involves two main steps: training and prediction.

2.4.1. Training Phase

During training, parameters established through previous testing by MapBiomas Fire Brazil were used: learning rate (0.001), batch size (1,000), number of iterations (7,000), and classification inputs (Arruda et al., 2021). Classification inputs consisted of surface reflectance (SR) spectral data from annual Quality Mosaics, using burned and unburned training samples. Based on the spectral library, the following spectral bands were used as inputs for the burned area classification model: Red (0.65 μm), Near-Infrared (0.86 μm), Shortwave Infrared 1 (1.6 μm), and Shortwave Infrared 2 (2.2 μm). These Landsat bands were selected for their sensitivity to fire events across various land covers and land uses. Training input data were split into two sets: 70% of the samples for training and 30% for testing, to estimate the DNN algorithm's ability to map burned areas with high precision.

[4] Alencar et al., "Long-Term Landsat-Based Monthly Burned Area Dataset for the Brazilian Biomes Using Deep Learning", 2022.

2.4.2. Prediction Phase

Classification was performed using Landsat annual Quality Mosaics for each region and sensor (Landsat 5, 7, 8, and 9). This approach leveraged the capabilities of DNNs to achieve precise and efficient burned area mapping across Bolivia's diverse biomes and regions.

A spatial filter was applied to remove noise and define a minimum mapping unit. Burned areas smaller than or equal to approximately 0.36 hectares (4 pixels) were filtered out to eliminate isolated noise pixels.

2.5. Post-classification

Following classification evaluation, post-classification masks were applied to reduce commission errors in land-cover and land-use types with spectral signatures similar to those of recently burned areas, such as water bodies, urban areas, and specific regional/biome cover types. Specific biome rules were defined to remove pixels erroneously classified as burned within MapBiomas Bolivia Collection 3 LULC classes. The specific rules for each biome are detailed in Table 1.

Región	Clases	Región	Clases	Región	Clases
r1	33,24,23,25,68,31	r16	33,24,25,23	r31	23, 24, 33, 68, 29
r2	33,24,23,25,68	r17	29,33,24,68,25	r32	23,24,30,33
r3	33,23,24,25	r18	29,33,24,25,68	r33	23,33
r4	33,29,24	r19	33,24	r34	24,25,33,68
r5	23, 24, 25, 33, 68	r20	33,24,23,25	r35	23,33
r6	33,24	r21	24, 25, 30, 33	r36	24,33,25
r7	29,33,68,25,24	r22	33,24	r37	24,33,68,23
r8	23, 24,30, 25, 33, 68	r23	33,24,23,31,68	r38	23,24,25,30,33,68
r9	24, 25, 29, 30, 33, 34, 61, 68	r24	33,23,24,68,25	r39	24,25,33,68,23
r10	29,33,68,24,68,25	r25	33,24,23,25,68	r40	24,25,29,30,33,68,23
r11	29,33,34,25,24,68	r26	33,25	r41	N/A
r12	33,23,24,25,29	r27	33, 24, 23	r42	33,24,25
r13	23, 24, 25, 33, 68	r28	33, 23, 24, 25	r43	23,33
r14	33,24,30	r29	23,24,33,31	r44	23,33
r15	23, 24, 25, 33, 68	r30	33, 25, 29, 23, 24, 68		

Table 1. Land cover and land use classes masked by working region

Finally, the post-processing step included recovering burn-date information from the annual mosaic constructed using minimum NBR, identifying the specific month in which the fire scar was mapped. Additionally, the ReMap tool was incorporated to reclassify pixels that, after the entire process, were still erroneously classified as burned, ensuring that they were excluded from the final product. These pixels were reassigned the value 13 across all regions without losing the monthly timestamp of the burned pixel from the annual mosaic.

2.6. Classification Evaluation

Burned-area classifications were evaluated through both visual inspection and statistical analysis. Visual inspection involved comparing classified scars in detail against the original Landsat mosaics to verify accuracy. Identified discrepancies were recorded and used to refine the training samples. Statistical analyses were performed to validate the classification results against benchmark burned area products.

Classified scars were compared with multiple reference datasets used as validation baselines, including MODIS MCD64A1 (500 m), GABAM high-resolution global burned area maps (30 m), FireCCI (250 m), and FIRMS (1,000 m).

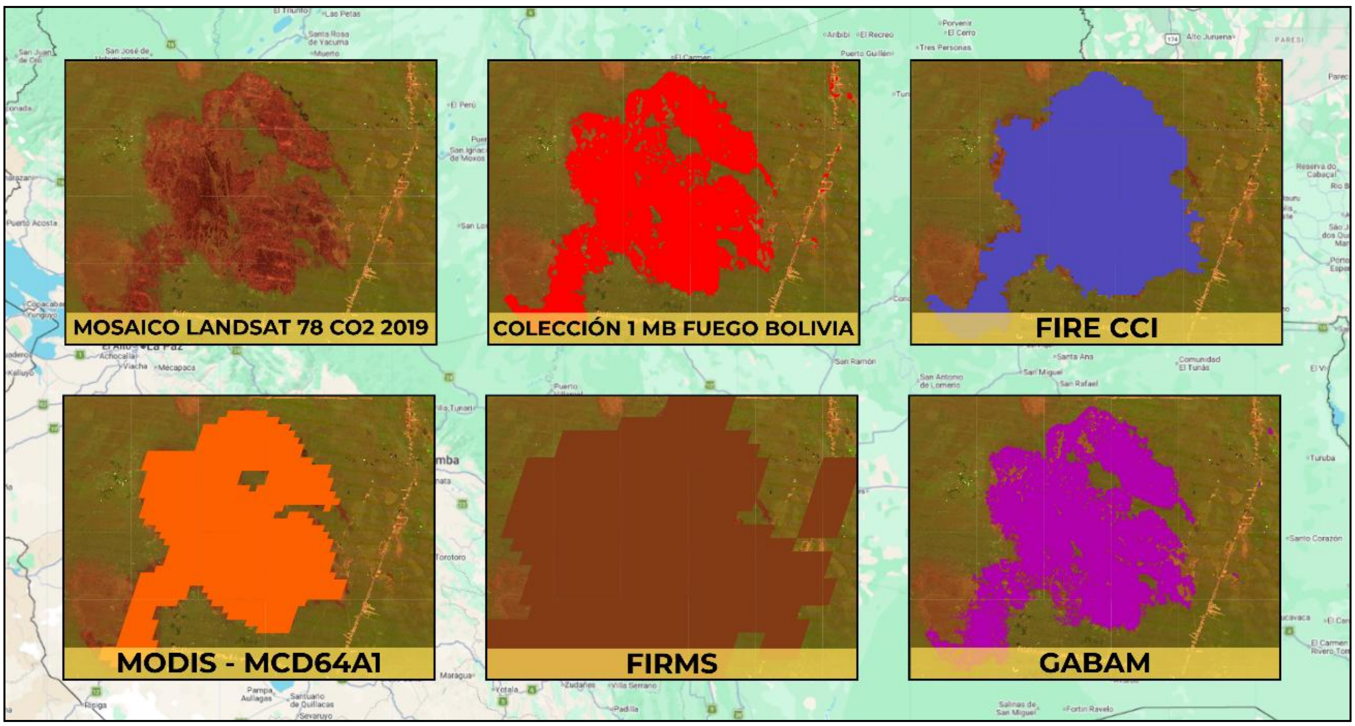

Figure 5. Comparisons of Landsat 7/8 Collection 2 Mosaics (2019), MapBiomas Fire Bolivia Collection 1 (30m), FIRECCI (250m), MODIS MCD64A1 (500m), FIRMS (1000m), and GABAM (30m**)**

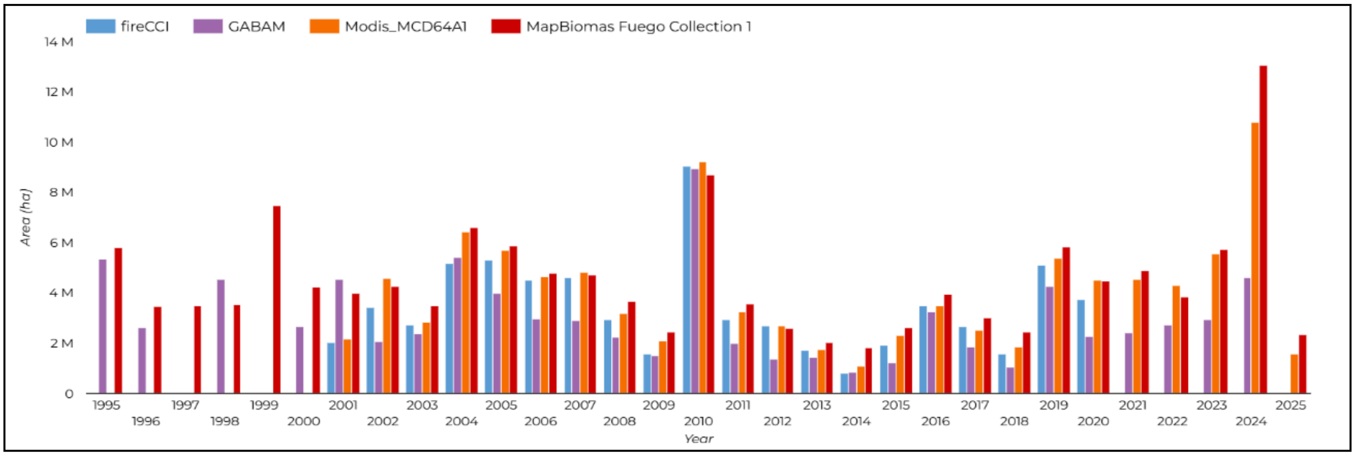

Figure 6. Annual burned area from the FIRE CCI (250 m), GABAM (30 m), MODIS MCD64A1 (500 m), and MapBiomas Fire Collection 1 (30 m) products

3. Map-Derived Products

Using annual burned area maps, surface-area sub-products in hectares (ha) are calculated on both annual and monthly bases.

3.1. Annual Burned Area

Annual burned area data from 1995 to 2025 indicate the areas mapped as burned for each year. The product also includes Annual Burned Cover, representing the annual burned area for each land-cover or land-use class, where each pixel contains the MapBiomas Collection 3 code of the burned class.

3.2. Monthly Burned Area

Monthly burned area data covering 1995 to 2025, with pixel values retrieved from the annual mosaic based on satellite image acquisition dates. Monthly Burned Area data indicate the month, from 1 (January) to 12 (December), in which the fire occurred for each pixel within the 1995–2025 period.

3.3. Annual Burned Area by Scar Size

Annual data on burned scar sizes from 1995 to 2025, categorized into eight different size intervals. A single scar is defined as all continuously connected pixels during the current year.

3.4. Cumulative Burned Area

Cumulative burned area data are constructed by incrementing burned area each year, counting each pixel only once regardless of multiple fire occurrences. These data represent areas with at least one fire event across different periods. Cumulative Burned Area by land cover and land use represents the total area with at least one fire event, classified according to the MapBiomas Bolivia Collection 3 land-cover class of the final year.

3.5. Fire Frequency Data

Burned area frequency maps represent the number of times the same pixel was mapped as burned during a given period. Fire frequency data are aggregated into a single map with 27 classes for the 1995–2025 period. Class 1 represents pixels burned once (in a single year), Class 2 represents pixels burned twice (in two years), and so forth, including the corresponding MapBiomas Bolivia Collection 3 land-cover classes for the final year.

3.6. Year of Last Fire Occurrence

Year of Last Fire Occurrence data represent the year in which each pixel was last burned, covering 1995 to 2025. Each pixel contains the year in which it was last mapped as burned up to the corresponding year.

4. Practical Considerations and Challenges

MapBiomas Bolivia **Collection 1** burned scar maps serve as a strategic monitoring instrument reflecting the country's fire history over 31 years. Producing this multi-annual volume of information enables applications for estimating trends in burned-scar monitoring, understanding factors that influence fire dynamics, and assessing fire seasonality.

A standardized methodology was employed that is replicable in other areas of the world. Cloud-based platforms such as Google Earth Engine, together with open-source technologies, have proven promising for large-scale accessibility and processing of extensive time series, subject to adjustments, particularly for units susceptible to misclassification, such as understory areas in the Bolivian territory.

The experience gained in producing this collection and exchanging ideas with various MapBiomas country teams resulted in greater efficiency in processing time. Collaboration within a multidisciplinary team enabled the refinement of a methodology tailored to the specific needs of each territory.

The use of Deep Neural Network (DNN) deep learning algorithms as classifiers, combined with a flexible mapping protocol, allows each country initiative to define its feature and sample space and adjust working regions to improve classification.

Post-classification filters reduced the effects associated with low satellite image quality and availability, particularly at the beginning of the time series, during the years analyzed with the Landsat 5 sensor (1995–2012).

The project aims to improve national mapping accuracy by prioritizing transition zones between the Chiquitano and Amazon biomes, where understory areas dominate, as well as regions with low-intensity fire scars. By utilizing new remote sensing technologies, the initiative aims to generate a high-quality product that extends the historical series back to 1985, providing a comprehensive view of fire dynamics nationwide.

5. References

- Alencar, A. A. C., V. L. S. Arruda, W. Vieira, D. E. Conciani, D. P. Costa, N. Crusco, S. G. Duverger, et al. (2022). “Long-Term Landsat-Based Monthly Burned Area Dataset for the Brazilian Biomes Using Deep Learning.” Remote Sensing, 14, 2510. https://doi.org/10.3390/rs14112510https://doi.org/10.3390/rs14112510
- European Space Agency (ESA). (2021). Fire_cci Burned Area Climate Data Record v5.1 [Dataset]. Retrieved from https://esa-fire-cci.org/https://esa-fire-cci.org/
- Giglio, L., C. Justice, L. Boschetti, & D. Roy. (2015). MCD64A1 MODIS/Terra+Aqua Burned Area Monthly L3 Global 500m SIN Grid V006 [Dataset]. NASA Land Processes Distributed Active Archive Center. https://doi.org/10.5067/MODIS/MCD64A1.006
- Instituto Nacional de Pesquisas Espaciais (INPE). (2025). AQUA M-T Satellite Hotspots (1999–2014) [Dataset]. Retrieved from http://www.inpe.br/queimadas/bdqueimadas/http://www.inpe.br/queimadas/bdqueimadas/
- Long, Tengfei, Zhang, Zhaoming, & He, Guojin. (2021). “30 m Resolution Global Annual Burned Area.”
- MapBiomas. (2025). MapBiomas Land Cover and Land Use Collection 3 [Dataset].
- NASA. (2025). Fire Information for Resource Management System (FIRMS). NASA Earth Science Data and Information System (ESDIS). Retrieved from https://earthdata.nasa.gov/earth-observation-data/near-real-time/firmshttps://earthdata.nasa.gov/earth-observation-data/near-real-time/firms