MapBiomas Urban Module - Collection 11 - Version 1.0

Algorithm Theoretical Basis Document (ATBD)

Surface Urban Heat Island (SUHI) Intensity, 2020-2024

Team authors

Clara Dias	USP/FAU
Breno Malheiros de Melo	USP/EESC
Edimilson Rodrigues dos Santos Junior	USP/EESC
Julio Cesar Pedrassoli	UFBA/POLI
Mayumi Hirye	USP/FAU
Talita Micheleti	USP/FAU

São Paulo, 2026

1. Overview

The MapBiomas Surface Urban Heat Island (SUHI) product provides spatially explicit estimates of surface urban heat island intensity for urban areas across Brazil for the 2020–2024 period. The product is derived from Landsat Collection 2 Level-2 Land Surface Temperature (LST) data and MapBiomas Collection 10 Land Use and Land Cover information and was processed in Google Earth Engine (GEE).

SUHI intensity is calculated as the difference between the Land Surface Temperature of each urban pixel and the mean Land Surface Temperature of its corresponding Background Reference Area (BRA). The BRA is defined within a 5-km buffer surrounding each urban area and is restricted to selected non-urban land-cover classes from MapBiomas Collection 10. This approach provides a local thermal reference for each urban area and allows SUHI intensity to be expressed as a temperature difference in degrees Celsius (°C).

Landsat Surface Temperature observations are subjected to quality-control procedures to remove observations affected by clouds, cloud shadows, snow/ice, dilated clouds, and higher Surface Temperature uncertainty. At least two valid observations are required for each pixel within each analysis period. Surface Temperature and SUHI are calculated independently for two periods of the year and subsequently aggregated over 2020–2024.

The methodology produces pixel-level SUHI maps and spatial summaries for Brazilian municipalities and 2022 census tracts. Because the product is based on Land Surface Temperature, it represents differences in surface thermal conditions at the time of Landsat observation and should not be interpreted as a direct measurement of near-surface air temperature, nighttime urban heat island intensity, or human thermal comfort.

The complete methodological procedures, input datasets, quality-control criteria, aggregation methods, product limitations, and output products are described in the following sections of this ATBD. The SUHI processing and analysis code is available on GitHub (https://github.com/ma-hirye/Published/blob/main/SUHI_v5_NT_Analytics_v2_3classes.ipynb), and the resulting data can be accessed and explored through the MapBiomas Platform (https://plataforma.mapbiomas.org/projects/mapbiomas/).

2. Introduction

Urbanization modifies land-surface characteristics through changes in vegetation cover, surface materials, moisture availability, and the proportion of built-up and impervious surfaces. These transformations can generate spatial differences in surface temperature between urbanized areas and their surroundings, commonly described as Surface Urban Heat Islands (SUHI).

The MapBiomas Urban Module provides spatially explicit information on urban areas across Brazil based on MapBiomas land-use and land-cover data. Within this context, the Surface Urban Heat Island product extends the characterization of Brazilian urban areas by incorporating information on their surface thermal patterns. The product covers urban areas across Brazil for the 2020–2024 period and is based on Landsat Collection 2 Level-2 Land Surface Temperature data combined with MapBiomas Collection 10 land-use and land-cover information.

This Algorithm Theoretical Basis Document (ATBD) describes the conceptual and methodological basis used to generate the MapBiomas Surface Urban Heat Island intensity product. It documents the input datasets, Land Surface Temperature processing and quality-control procedures, definition of urban areas and Background Reference Areas, calculation of SUHI intensity, temporal aggregation, spatial statistics, output products, and methodological limitations.

The document is organized as follows. Section 2 presents the conceptual basis of Surface Urban Heat Islands and the distinction between Land Surface Temperature and air temperature. Section 3 describes the input datasets. Sections 4 to 6 document the processing of Landsat Surface Temperature, the definition of urban areas and Background Reference Areas, and the calculation of SUHI intensity. Sections 7 and 8 describe temporal aggregation, spatial statistics, quality control, and spatial coverage. Sections 9 to 11 present the output products, methodological limitations, and the relationship between the SUHI product and the underlying Landsat Surface Temperature product.

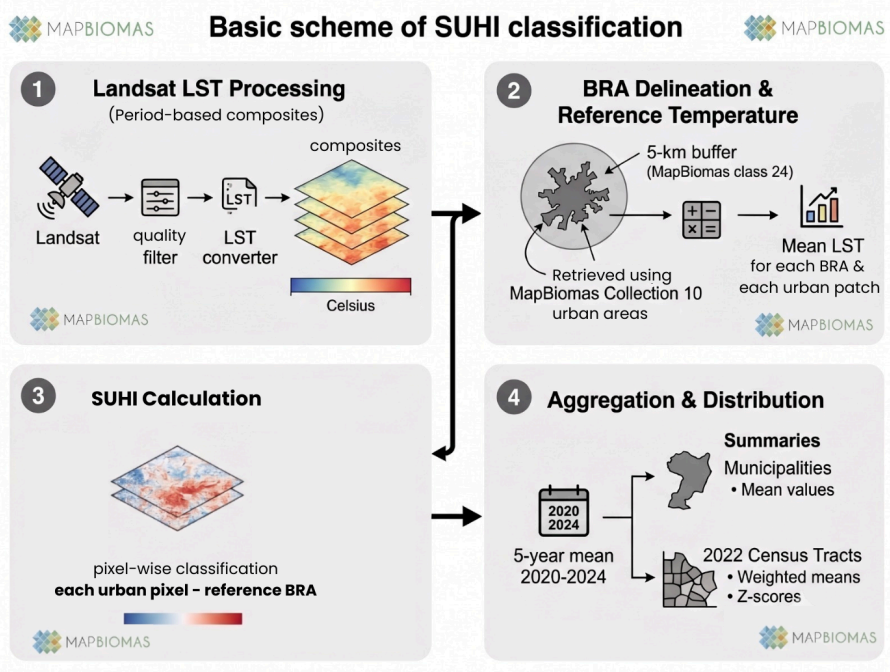

Figure 1. Basic scheme of SUHI classification.

Figure 1. Basic scheme of SUHI classification

3. Conceptual basis

3.1. Surface Urban Heat Islands

Surface Urban Heat Islands (SUHI) refer to the thermal contrast in Land Surface Temperature (LST) between urbanized areas and their non-urban surroundings. Unlike the atmospheric urban heat island, which is generally characterized using near-surface air temperature, SUHI is observed through the thermal response of land surfaces and can be investigated using remotely sensed thermal infrared data (Weng, 2009). In this ATBD, the mapped quantity is specifically SUHI, as it is derived from remotely sensed LST rather than near-surface air temperature measurements. Consequently, the product represents differences in land surface thermal conditions at the time of the Landsat overpass and should not be interpreted as a direct estimate of 2-m air temperature.

SUHI intensity is expressed relative to the corresponding Background Reference Area (BRA). Positive values indicate that an urban pixel is warmer than the mean surface temperature of its associated BRA, values close to zero indicate similar surface temperatures, and negative values indicate that the urban pixel is cooler than its surrounding reference area during the same analysis period.

3.2. Surface Temperature versus Air Temperature

The Landsat Collection 2 Level-2 thermal products provide estimates of Land Surface Temperature (LST) derived from thermal infrared observations of the Earth's surface. Unlike air temperature measured by meteorological stations, LST represents the temperature of the land surface itself.

Land Surface Temperature is strongly influenced by land-cover characteristics, surface materials, vegetation, soil moisture, shading, and incoming solar radiation. These properties make LST particularly suitable for characterizing spatial patterns of urban thermal environments and quantifying thermal contrasts between built-up and non-built-up surfaces.

Because the SUHI product is based on LST, it should be interpreted as an indicator of relative surface thermal conditions rather than a direct measure of atmospheric heat exposure or near-surface air temperature.

3.3. Background Reference Area (BRA)

The Surface Urban Heat Island is calculated by comparing the surface temperature of each urban pixel with the mean surface temperature of a surrounding Background Reference Area (BRA). The BRA represents the local non-urban thermal reference against which urban temperatures are evaluated.

Rather than restricting the BRA exclusively to native vegetation, the MapBiomas methodology defines the reference area using selected non-urban land-cover classes from MapBiomas Collection 10. These include natural vegetation as well as agricultural and other permeable land-cover classes. This approach was adopted because, in many Brazilian urban and peri-urban regions, native vegetation is absent or occupies only a small proportion of the surrounding landscape.

By including representative non-built surfaces—such as forests, grasslands, pastures, croplands, planted forests and other agricultural areas—the BRA provides a pragmatic estimate of the thermal conditions surrounding each urban area while avoiding comparison with impervious or built-up surfaces. This definition allows the methodology to be applied consistently across the wide diversity of Brazilian landscapes.

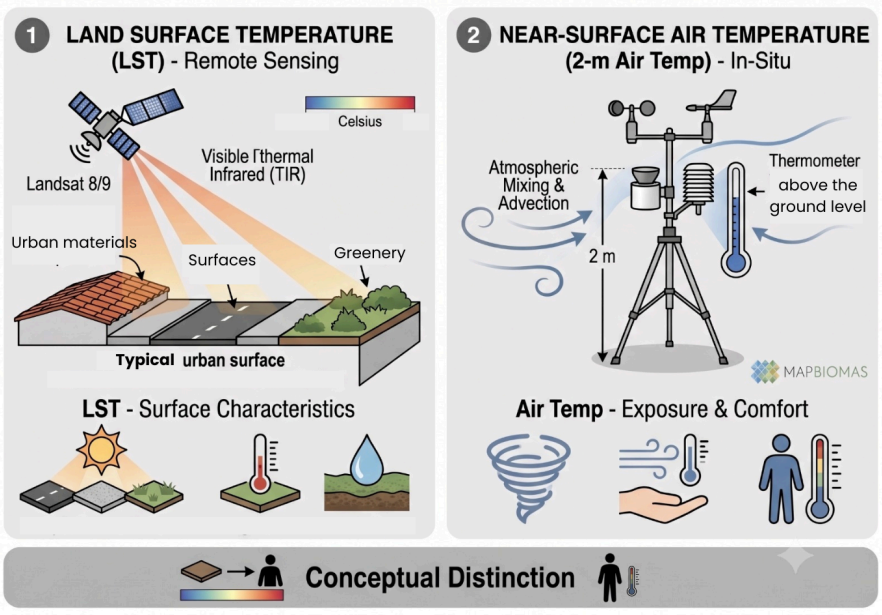

Figure 2. Conceptual distinction between land surface temperature and air temperature

4. Input datasets

4.1. Landsat Collection 2 Level-2 Surface Temperature

The SUHI product is derived from the Landsat Collection 2 Tier 1 Level-2 Surface Temperature products available in Google Earth Engine. The processing workflow was developed to support observations from Landsat 5 TM, Landsat 7 ETM+, Landsat 8 OLI/TIRS, and Landsat 9 OLI-2/TIRS-2. However, for the 2020–2024 product described in this document, the effective observations are obtained from Landsat 8 and Landsat 9.

The processing uses the Surface Temperature (ST) product together with the associated quality assessment bands (QA_PIXEL and ST_QA) to remove observations affected by clouds, cloud shadows, snow, or low-quality thermal retrievals. Surface Temperature values are converted from the original scaled digital numbers to degrees Celsius before the temporal compositing procedure.

4.2. MapBiomas Collection 10 Land Use and Land Cover

MapBiomas Collection 10 Land Use and Land Cover data are used for two distinct purposes within the SUHI methodology.

First, urban areas are identified from the MapBiomas urban class and constitute the target areas where SUHI is calculated.

Second, MapBiomas land-cover classes are used to define the Background Reference Area (BRA). For each urban area, a 5-km buffer is generated and only selected non-urban land-cover classes are retained as valid reference surfaces. These classes include natural vegetation, grasslands, agricultural areas, planted forests, pastures, and other permeable land-cover types, while urbanized areas and other unsuitable classes are excluded.

The eligible BRA classes are:

3, 4, 9, 12, 15, 18, 19, 20, 21, 29, 35, 36, 39, 40, 41, 46, 47, 48, 49, 50, and 62.

This definition was adopted to provide a representative non-urban thermal reference across the diversity of Brazilian landscapes, including urban regions where native vegetation is scarce or absent.

4.3. Census and administrative data

Municipal boundaries and 2022 Brazilian census tracts are used to generate the aggregated statistical products distributed together with the pixel-based SUHI maps.

The census-tract summaries were produced using the official 2022 IBGE census tract boundaries. In the accompanying technical-note analyses, additional demographic variables from the 2022 Demographic Census are combined with the SUHI product to assess population exposure. For these analyses, census tracts with less than 5% urbanized area are excluded to avoid summarizing SUHI over predominantly non-urban sectors.

5. Landsat Surface Temperature Processing

5.1. Spatial and temporal filtering

The Landsat Collection 2 Tier 1 Level-2 Surface Temperature archive is filtered spatially to the study area and temporally according to the analysis period. The processing workflow supports Landsat 5 TM, Landsat 7 ETM+, Landsat 8 OLI/TIRS, and Landsat 9 OLI-2/TIRS-2 imagery. For the 2020–2024 product described in this document, the effective observations are obtained from Landsat 8 and Landsat 9.

Surface Temperature composites are generated independently for two analysis periods within each year (Section 4.5).

5.2. Cloud, shadow, snow/ice, and low-quality observation masking

Clouds and cloud shadows can affect the retrieval and interpretation of Landsat-derived Surface Temperature, requiring explicit quality screening (Cook et al., 2014). Quality filtering is therefore performed using the quality assessment bands provided with the Landsat Collection 2 Level-2 products.

Cloud, cloud shadow, snow/ice, and dilated cloud pixels are identified using the QA_PIXEL band. The implemented mask uses the cloud confidence (bits 8–9), cloud shadow confidence (bits 10–11), snow/ice confidence (bits 12–13), and dilated cloud flag (bit 1). Pixels affected by medium- or high-confidence cloud, cloud shadow, or snow/ice contamination, as well as pixels flagged as dilated clouds, are excluded.

An additional quality filter is applied using the ST_QA band. The uncertainty values are converted to kelvin by multiplying the band values by 0.01. For Landsat 8 and Landsat 9, only observations with uncertainty less than or equal to 3 K are retained.

5.3. Surface Temperature conversion

For Landsat 8 and Landsat 9, Surface Temperature is obtained from the ST_B10 band. The Level-2 scaling factors provided with the product are applied as

$$ST(K)=DN\times 0.00341802+149.0$$

where DN is the digital number stored in the ST_B10 band. Surface Temperature is subsequently converted to degrees Celsius by subtracting 273.15.

5.4. Temporal compositing

After quality filtering, the number of valid Surface Temperature observations is counted for each pixel and analysis period. Pixels are retained only when at least two valid observations are available.

The mean Surface Temperature is then calculated from the remaining valid observations. The workflow also stores the total number of observations, the number of valid observations, the minimum day of year, and the median day of year associated with the retained observations.

5.5. Analysis periods

The processing workflow divides each calendar year into two analysis periods based on the seasonal transition dates adopted in the processing code. The first period extends from 20 March, corresponding to the beginning of austral autumn, to 22 September, corresponding to the beginning of austral spring. The complementary period extends from 1 January to 19 March and from 23 September to 31 December. These dates follow the seasonal reference dates adopted from the Brazilian National Institute of Meteorology (INMET) in the processing workflow.

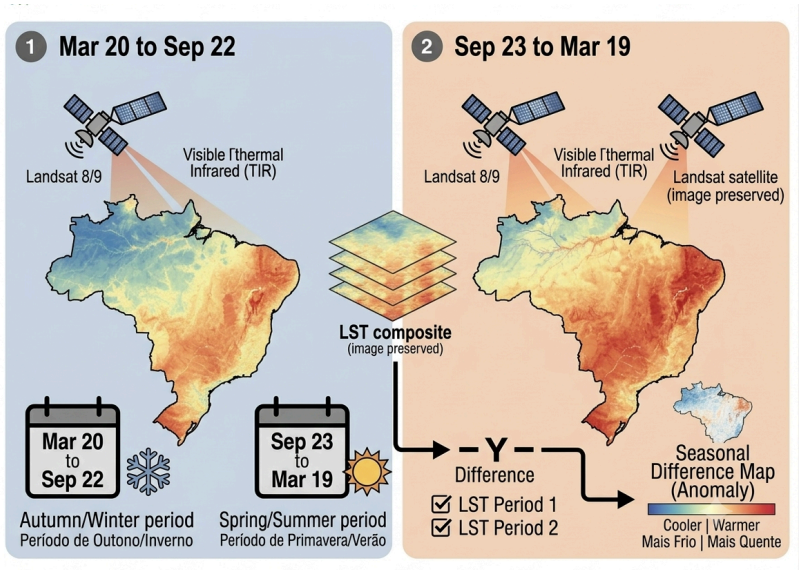

Figure 3. Example of seasonal/period Surface Temperature composite

Independent Surface Temperature composites are generated for each period and subsequently used in the SUHI calculation.

6. Urban Areas and Background Reference Areas

6.1. Urban-area delineation

Surface Urban Heat Island intensity is calculated for urban areas identified using MapBiomas Collection 10 Land Use and Land Cover data. For each urban area, the surrounding non-urban environment is characterized through the definition of a Background Reference Area (BRA), which provides the local thermal reference used in the SUHI calculation.

6.2. Background Reference Area (BRA)

For each urban area, a Background Reference Area (BRA) is defined using a 5-km buffer surrounding the urban polygon. The BRA is intended to represent the local non-urban thermal background against which urban surface temperatures are compared.

The BRA is constrained using MapBiomas Collection 10 land-cover information. Only selected non-urban land-cover classes are retained, while urban areas, water bodies, and other non-eligible land-cover classes are excluded from the reference area.

The eligible BRA classes are:

3, 4, 9, 12, 15, 18, 19, 20, 21, 29, 35, 36, 39, 40, 41, 46, 47, 48, 49, 50, and 62.

These classes include natural vegetation, grasslands, agricultural areas, planted forests, pastures, and other permeable land-cover types. This definition was adopted to provide a representative non-urban thermal reference across the diversity of Brazilian landscapes, including urban and peri-urban regions where native vegetation is scarce or absent. Consequently, the BRA represents nearby non-built surfaces, rather than exclusively native vegetation.

The mean Surface Temperature is calculated independently for each BRA and for each analysis period. These values are subsequently used as the reference temperature in the SUHI calculation.

7. Surface Urban Heat Island Calculation

7.1. Pixel-level SUHI intensity

Surface Urban Heat Island (SUHI) intensity is calculated for each urban pixel as the difference between its mean Land Surface Temperature (LST) and the mean LST of the corresponding Background Reference Area (BRA) during the same analysis period.

The SUHI intensity is computed as

$$SUHI(p,u,s)=LSTurban(p,s)-Mean(LSTBRA(u,s))$$

where:

p is an urban pixel;

u is the corresponding urban area;

s is the analysis period;

LSTurban mean Land Surface Temperature of urban pixel p during period s; and

LSTBRA mean Land Surface Temperature of the Background Reference Area associated with urban area u during period s

Positive SUHI values indicate that the urban pixel is warmer than its surrounding background reference, whereas negative values indicate that it is cooler. Because SUHI represents the difference between two temperature values, the result is expressed in degrees Celsius (°C).

7.2. Annual computation

The SUHI calculation is performed independently for each year and for each of the two analysis periods.

For every year, the mean Surface Temperature of each Background Reference Area is calculated and used as the reference temperature for all urban pixels associated with that urban area during the corresponding analysis period. The resulting annual SUHI images constitute the basis for the subsequent multi-year aggregation described in Section 7.

8. Five-year aggregation and spatial statistics

8.1. Five-year mean (2020–2024)

The annual SUHI maps are aggregated over the 2020–2024 period by calculating the mean of the available values for each pixel, ignoring missing values. The resulting five-year mean images contain the two analysis-period bands, ST_w_5y and ST_s_5y.

8.2. Municipal statistics

Municipal products summarize the SUHI values observed within urbanized areas. The presentation and project assets indicate municipal-level mean SUHI values and

data-coverage metrics. Exact reducers, area weighting, handling of multipart urban areas, and the denominator used for percentage-valid calculations should be documented from the statistics scripts before the ATBD is finalized.

8.3. Census-tract statistics

The five-year SUHI data are summarized by 2022 census tract, with the tract value represented by the mean of valid SUHI pixels intersecting the tract. For exposure-oriented analyses, tracts with urbanized area <=5% of the tract area are excluded. Census population can then be associated with the retained tracts to estimate the population living in areas with SUHI values above selected reference levels, including above the municipal mean.

8.4. Relative classification within municipalities

The technical-note workflow also standardizes tract-level SUHI relative to the municipal distribution using a weighted municipal mean and weighted standard deviation, with the amount of valid mapped area in each tract used as the weight. A z-score is then computed for each tract.

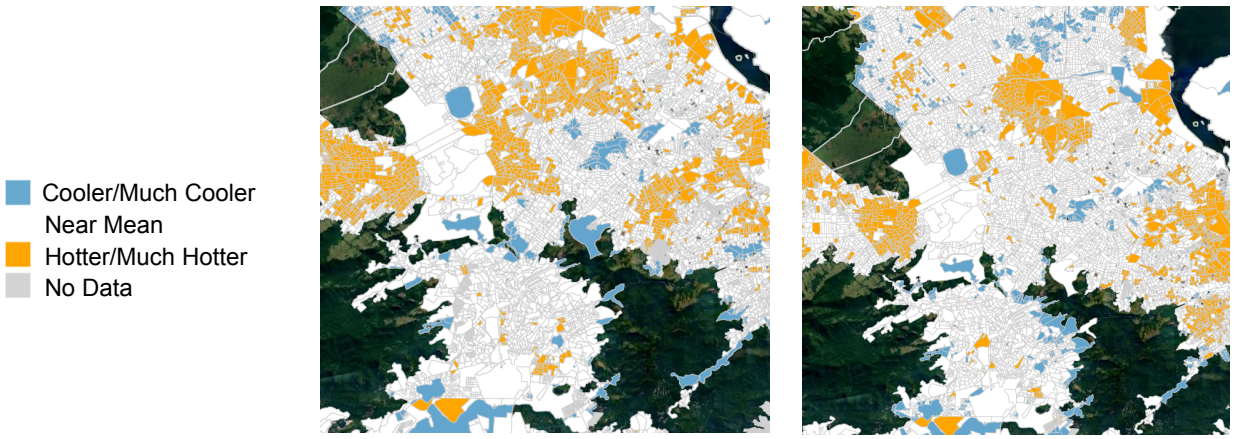

Figure 4. Example of census-tract SUHI statistics and relative classes

9. Quality Control and Spatial Coverage

9.1. Pixel-level quality control

The quality of the SUHI product depends directly on the quality of the input Land Surface Temperature observations. Three quality-control procedures are applied during processing:

masking of clouds, cloud shadows, snow/ice, and dilated clouds using the QA_PIXEL band;
filtering of Surface Temperature observations based on the ST_QA uncertainty band; and
retention of pixels with at least two valid observations within each analysis period.

Only observations meeting all three criteria are used to generate the Surface Temperature composites and the subsequent SUHI products.

9.2. Spatial coverage

The availability of valid SUHI estimates depends on the number of valid Landsat Surface Temperature observations after quality filtering. Consequently, spatial coverage varies across Brazil according to cloud conditions and the availability of cloud-free observations.

For the analyses presented in the accompanying Technical Note, urban areas were considered only when at least 50% of their pixels contained valid SUHI estimates.

9.3. Interpretation of spatial coverage

Cloud occurrence is not spatially uniform across Brazil. Regions with persistent cloud cover generally have fewer valid Landsat Surface Temperature observations, which may reduce the spatial coverage of the SUHI product and the temporal representativeness of the resulting averages.

These differences in data availability should be considered when interpreting spatial patterns and comparing results among municipalities or census tracts.

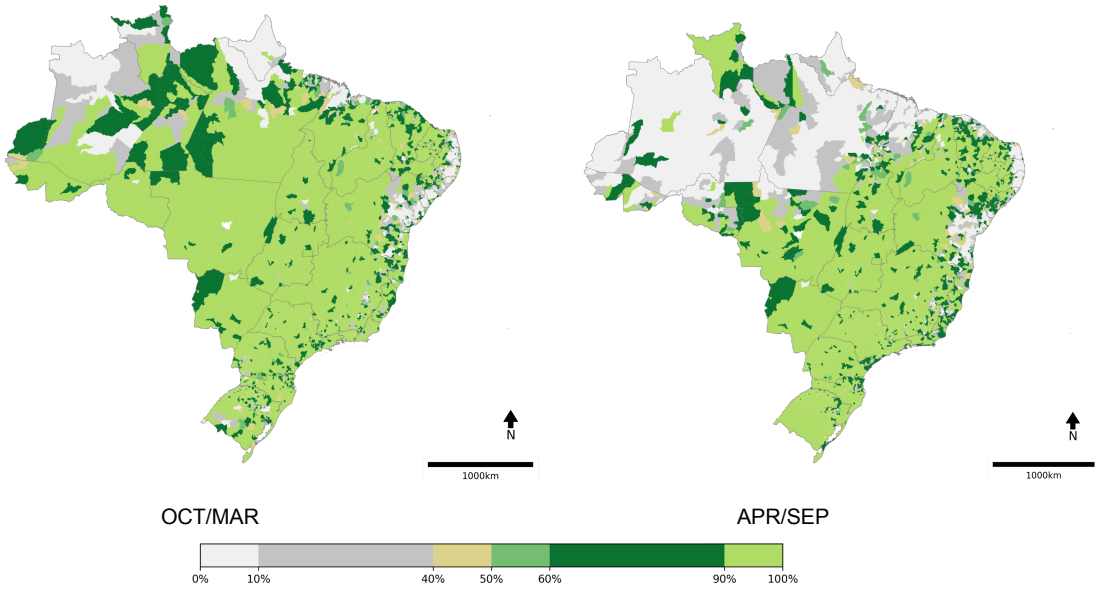

Figure 5. Percentage of valid SUHI data by municipality for both annual periods

10. Validation and Accuracy Assessment

The SUHI product is derived from the USGS Landsat Collection 2 Level-2 Surface Temperature product and does not involve the fitting of an empirical or statistical prediction model. The processing workflow applies quality filtering to the Landsat observations, generates temporal Surface Temperature composites, defines a Background Reference Area (BRA), and calculates SUHI intensity as the difference between urban Surface Temperature and the corresponding BRA mean Surface Temperature.

Quality control is currently based primarily on the quality information provided with the Landsat Surface Temperature product and on the spatial and temporal coverage criteria described in this ATBD. Consequently, uncertainties and limitations associated with the underlying Landsat Surface Temperature product also affect the resulting SUHI estimates.

An independent validation framework specifically designed for the MapBiomas SUHI product has not yet been fully consolidated. The development of an appropriate validation and accuracy-assessment methodology is therefore an ongoing methodological priority. Such a framework should assess the reliability of the resulting SUHI estimates independently from the quality-control procedures applied to the input Landsat data and should account for the characteristics of a nationally consistent, remotely sensed surface-temperature difference product.

Until this validation framework is established, the product should be interpreted considering the quality-control criteria, observation availability, spatial coverage, and methodological limitations documented in this ATBD. The absence of a consolidated independent validation framework should not be interpreted as an independent accuracy assessment of the SUHI estimates.

11. Output Products

The SUHI workflow generates pixel-based and aggregated products derived from the annual Surface Temperature composites and Background Reference Area statistics.

The principal outputs are summarized in Table above.

Product	Description
Background Reference Area statistics	Mean Land Surface Temperature calculated for each Background Reference Area (BRA), independently for each analysis period. These values constitute the thermal reference used in the SUHI calculation.
Pixel-level SUHI maps	Surface Urban Heat Island intensity (°C) calculated for every urban pixel for each year and analysis period, together with the corresponding five-year (2020–2024) aggregated products.
Municipal statistics	Summary statistics of the pixel-level SUHI values aggregated for the urban areas of each municipality.
Census-tract statistics	Summary statistics of the five-year SUHI values aggregated to the official 2022 Brazilian census tracts, together with the derived variables used in the accompanying Technical Note.

This ATBD documents the Surface Urban Heat Island intensity product developed within the MapBiomas Urban Module using MapBiomas Collection 10 land-use and land-cover data and Landsat Surface Temperature observations for the 2020–2024 period. The methodology and outputs described here therefore correspond specifically to this product version. Future updates or subsequent MapBiomas collections may incorporate methodological revisions, additional observation years, or updated input datasets, which should be documented in the corresponding product documentation.

12. Methodological Limitations

12.1. Land Surface Temperature versus air temperature

The SUHI product is derived from Land Surface Temperature (LST) and therefore represents the thermal behavior of the Earth's surface at the time of the Landsat overpass. It should not be interpreted as a measure of near-surface air temperature, nighttime urban heat island intensity, or human thermal comfort.

12.2. Observation availability

The availability of valid Surface Temperature observations depends on cloud conditions and on the quality filtering applied during processing. Consequently, the

number of observations contributing to the temporal composites may vary among pixels and regions, potentially affecting the spatial coverage and temporal representativeness of the resulting SUHI estimates.

12.3. Background Reference Area

SUHI is a relative metric, and its magnitude depends on the definition of the Background Reference Area (BRA). The MapBiomas methodology defines the BRA using selected non-urban land-cover classes within a 5-km buffer surrounding each urban area. As a result, the SUHI values should be interpreted relative to the selected local reference rather than as absolute measures of urban warming.

12.4. Spatial aggregation

Municipal and census-tract statistics represent averages of the underlying pixel-level SUHI values. Consequently, they do not capture the full spatial variability of thermal conditions within each municipality or census tract.

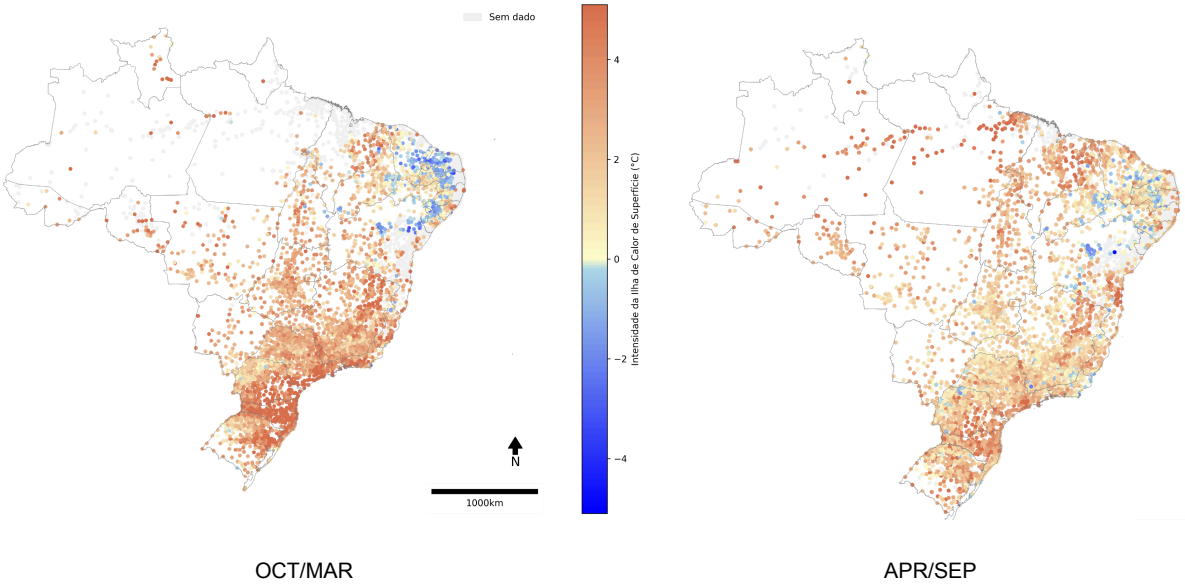

Figure 6. Mean Surface Urban Heat Island intensity in Brazilian municipalities (2020–2024)

13. Practical Considerations

The interpretation and application of the SUHI product should consider the spatial and temporal availability of valid Landsat Surface Temperature observations. Cloud cover and other quality-screening criteria may reduce the number of valid observations available for individual pixels and consequently affect spatial coverage. For analyses based on municipal summaries, only urban areas meeting the minimum valid-data

coverage criterion described in this ATBD should be considered. For population-exposure analyses based on 2022 census tracts, the urban-area coverage criterion described in Section 7.3 should also be applied.

The SUHI product is intended to support spatial analyses of surface thermal contrasts within and among Brazilian urban areas. Because it represents Land Surface Temperature differences rather than near-surface air temperature, its use should remain consistent with the interpretation and limitations described in this ATBD. In particular, the product should not be interpreted as a direct measure of air-temperature exposure or human thermal comfort.

Reproducibility of the methodology is supported by the documentation of the processing steps and input datasets in this ATBD and by the availability of the processing and analysis code referenced in the Executive Summary.

Further methodological development should prioritize the consolidation of an independent validation and accuracy-assessment framework for the SUHI product. Future methodological revisions should be documented together with the corresponding product version.

14. Relationship to the Landsat Surface Temperature Product

The SUHI product is derived directly from the Landsat Collection 2 Level-2 Surface Temperature product distributed by the United States Geological Survey (USGS). The methodology consists of quality filtering, temporal compositing, calculation of Background Reference Area temperatures, and computation of pixel-wise temperature differences between urban areas and their corresponding reference areas.

No empirical model is fitted and no statistical prediction of temperature is performed. Consequently, the quality of the SUHI product depends primarily on the quality of the underlying Landsat Surface Temperature observations and on the methodological choices adopted for defining the Background Reference Area and temporal aggregation.

The characteristics and known limitations of the Landsat Collection 2 Level-2 Surface Temperature product are documented by the USGS and apply to the input data used in this methodology.

15. Conclusions and Perspectives

The MapBiomas Surface Urban Heat Island product provides a nationally consistent characterization of surface thermal contrasts between urban areas and their surrounding Background Reference Areas for the 2020–2024 period. By integrating Landsat Collection 2 Level-2 Surface Temperature data with MapBiomas Collection 10

land-use and land-cover information, the methodology enables pixel-level SUHI estimates and their aggregation for municipalities and 2022 census tracts across Brazil.

The product should be interpreted as a measure of differences in Land Surface Temperature rather than near-surface air temperature. Its spatial and temporal coverage is influenced by the availability of valid Landsat observations and by the characteristics of the Background Reference Areas used in the calculation. These considerations, together with the limitations described in this ATBD, should be taken into account when interpreting and applying the resulting SUHI estimates.

Further methodological development should focus on consolidating an independent validation and accuracy-assessment framework for the SUHI product. Future revisions of the methodology, input datasets, or temporal coverage should be documented in the corresponding product version.

References

Cook, M., Schott, J. R., Mandel, J., & Raqueno, N. (2014). Development of an Operational Calibration Methodology for the Landsat Thermal Data Archive and Initial Testing of the Atmospheric Compensation Component of a Land Surface Temperature (LST) Product from the Archive. Remote Sensing, 6, 11244-11266. https://doi.org/10.3390/rs61111244

Earth Resources Observation and Science (EROS) Center. (2020). Landsat Collection 2 Level-2 Surface Temperature. U.S. Geological Survey. https://doi.org/10.5066/P9OGBGM6

U.S. Geological Survey (USGS). Landsat Collection 2 Surface Temperature. https://www.usgs.gov/landsat-missions/landsat-collection-2-surface-temperature

Weng, Q. (2009). Thermal Infrared Remote Sensing for Urban Climate and Environmental Studies: Methods, Applications, and Trends. ISPRS Journal of Photogrammetry and Remote Sensing, 64(4), 335-344.

Xian, G., et al. (2023). Characterizing Urban Heat Islands Across 50 Major Cities in the United States. U.S. Geological Survey Fact Sheet 2023-3048.

MapBiomas Project. Collection 10 – Land Use and Land Cover Maps of Brazil.

IBGE. Malha dos Municípios

IBGE. Setores Censitários 2022