Automated Climate Map Generation in QGIS and PyQGIS Supported by Prompt Engineering and Generative AI: Application to the Baixo São Francisco Region

Subtitle: AI Prompts used for elaboration of Climate Change Maps for Maximum Temperature, Minimum Temperature, and Precipitation Based on Different IPCC Scenarios and Periods from the ACCESS-CM2 Model (CMIP6 – WorldClim v2.1)

Authors

Carlos Eduardo Pacheco Lima (Embrapa Hortaliças), Environmental Engineer, PhD in Soils and Plant Nutrition (Correspondent Author – email: carlos.pacheco-lima@embrapa.br)

Marcus Aurélio Soares Cruz (Embrapa Tabuleiros Costeiros), Civil Engineer, PhD in Water Resources and Environmental Sanitation

Júlio Roberto Araújo de Amorim (Embrapa Tabuleiros Costeiros), Graduated in Chemical Technology and Agronomic Engineering, Specialist in Alternative Technologies in Agronomy and Farmland Drainage, Master in Agricultural Engineering

Mariana Rodrigues Fontenelle (Embrapa Hortaliças), Biologist, PhD in Agricultural Microbiology

Date:

May 2025

Table of Contents

1. Introduction

This document outlines a structured workflow for automating the generation of climate maps tailored to the Baixo São Francisco region. By integrating QGIS software with generative artificial intelligence tools—such as ChatGPT and GitHub Copilot—and leveraging the Python programming language via PyQGIS, the process enables the efficient execution of multiple geospatial tasks: raster clipping, band separation, batch renaming, automated styling, saving QGIS project files (.qgz), and the export of high-volume layouts representing key climatic variables, namely maximum temperature, minimum temperature, and precipitation.

The input data are sourced from the ACCESS-CM2 climate model, part of the Coupled Model Intercomparison Project Phase 6 (CMIP6), and distributed by WorldClim v2.1. These data span a range of emissions scenarios (SSP126, SSP245, SSP370, SSP585) and both historical and projected timeframes extending to the year 2100. Each map reflects the monthly average for a given variable and is generated at a spatial resolution of approximately 1 km^2 (30 arc-seconds).

The overarching aim of this automated methodology is to promote standardization, reproducibility, efficiency, and adaptability in the processing of large climate datasets—enabling their effective application in planning, analysis, and decision-making within agricultural and environmental contexts.

2. General Methodology

The automated climate map generation process involves the following steps, repeated for each variable, scenario, and period:

1. Importing multi-band raster datasets, with 12 bands representing the months of the year.
2. Spatial clipping of the raster, using the vector mask of the Baixo São Francisco region.
3. Separating monthly bands into individual single-band raster files.
4. Standardized file naming, based on variable, scenario, period, and month.
5. Applying customized symbology, using predefined QGIS style files manually adjusted per variable.
6. Generating batch of monthly map layouts, including title, legend, scale bar, coordinates, grid frame, and footer with metadata.
7. Exporting maps in PNG format, at publication-quality resolution.

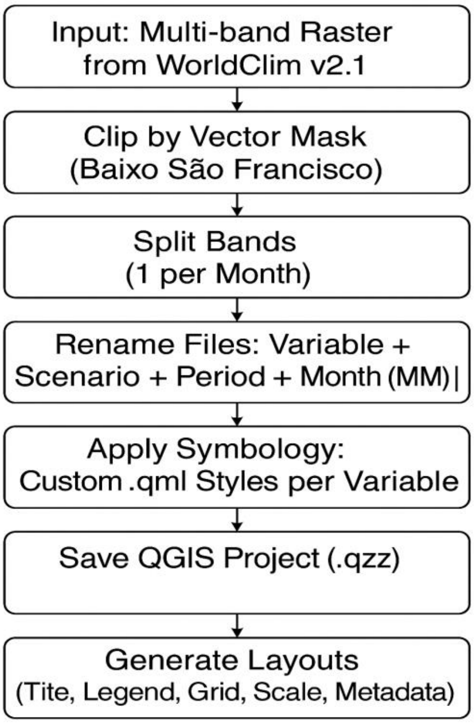

Figure 1: Automated Climate Map Generation Process in QGIS

All the procedures were carried out with automation using Python scripts, developed with the support of Prompts Engineering for the ChatGPT and GitHub Copilot artificial intelligences (AI), as well as the Google Colab collaborative platform, where pre-tests and corrections were carried out.

The spatialization processes were carried out in the open-access software QGIS, using the PyQGIS environment.

Prompt engineering played a central role in guiding the development of automation scripts using generative AI tools. Each step of the workflow was incrementally structured as a series of prompts to generate scripts via ChatGPT, supported by GitHub Copilot in VS Code. Prompts were crafted to specify tasks such as raster layer import, spatial clipping, monthly band extraction, file renaming, symbology application, and layout creation.

The methodology presented here can be applied to generate monthly and seasonal Climate Change maps for agricultural planning, risk analysis, and vulnerability assessment from multi-band Raster images. By automating the production of standardized maps based on IPCC scenarios and WorldClim data, this approach supports decision-making processes related to climate adaptation in various crops, especially those sensitive to temperature and precipitation changes.

The integration of AI into geospatial workflows opens new opportunities for research and innovation in climate impact studies. By combining open-source GIS tools with prompt-driven automation, the methodology described ensures replicability, scalability, and efficiency. Its application in the Baixo São Francisco region can serve as a reference for other territories and variables, fostering climate resilience in agricultural systems. In this case, 720 maps were generated in just three days of work.

2.1 First steps in QGIS

- Import maximum temperature, minimum temperature, and precipitation data from ACCESS-CM2 via WorldClim v2.1. Open them as a raster layer in QGIS.
- Follow this path: open layers - raster layers and then shapefile layer (with the boundaries of the Lower São Francisco region)
- Open the scripts and run them in the following order: cut layer by mask layer - separate bands from multiple raster layers - rename multiple raster layers - save project - apply symbology to multiple predefined raster layers - create dynamic layouts for multiple raster layers opened in QGIS.
- In QGIS, open the following path: Extensions - Python Terminal – Editor.
- Open the scripts and run

3. Prompt engineering (Applied to ChatGPT and GitHub Copilot environment)

ChatGPT

3.1 Historical data (1970–2000)

- Clip the 12 rasters using the Baixo São Francisco region mask.
- Use standardized naming:
    - Historical Maximum Temperature (ºC)_(three-letter abbreviation of the month)
    - Historical Minimum Temperature (ºC) _(three-letter abbreviation of the month)
    - _Historical Precipitation (mm) _(three-letter abbreviation of the month)
- Apply the appropriate color scheme for each variable (define the range and the type of color scheme).
- Save QGIS project files:
    - e.g., Maximum_Temperature_Historical.qgz

- Create dynamic layouts for each month with full cartographic elements for all raster images opened in QGIS changing the IPCC scenario, period and name of month according to the name of the opened raster layers.
- Export all layout as a PNG image.

Prompt for GitHub Copilot

- Analyze and improve the attached script by correcting any errors.

3.2 SSP1 2.6 - Period 2021–2040

- Import maximum temperature, minimum temperature and precipitation data form ACCESS-CM2 via WorldClim v2.1.
- Clip the raster layer using the Baixo São Francisco region mask.
- Split the 12-band raster layer, one per month, renaming the new raster layer as the three-letter abbreviation of the month.
- Rename the 12-raster layers according to the climate variable, as follow: jan = Minimum Temperature (ºC)_(three-letter abbreviation of the month). Do the same for all climate variables changed (ºC) by (mm) in the case of precipitation.
- Apply the appropriate color scheme for each variable (define the range and the type of color scheme).
- Save QGIS project files:
    - e.g., Maximum_Temperature_Historical.qgz
- Create dynamic layouts for each month with full cartographic elements for all raster images opened in QGIS changing the IPCC scenario, period and name of month according to the name and metadata of the opened raster layers.
- Export all layout as a PNG image.
- **May attach the initial script and prompt the AI to adapt it for each IPCC scenario, time period, and climate variable as needed.**

Prompt for GitHub Copilot

- Analyze and improve the attached script by correcting any errors.

Repeating the same process, updating only the file names and project names according to the other periods by just changing the opened layer names and the Layout titles according to the worked period, IPCC scenario and month.

3.3 SSP1 2.6 - Period 2041–2060

3.4 SSP1 2.6 - Period 2061–2080

3.5 SSP1 2.6 - Period 2081–2100

Use the same steps described in 3.2 item for all periods.

3.6 SSP2 4.5 – 2021-2040

- Load multi-band raster data for maximum temperature, minimum temperature, and precipitation for SSP245.
- Clip the raster layer using the Baixo São Francisco region mask (.shp file).
- Separate the 12 monthly bands into individual single-band raster files.
- Use the naming pattern: jan = Minimum Temperature (ºC)_(three-letter abbreviation of the month). Do the same for all climate variables changed (ºC) by (mm) in the case of precipitation.
- Apply customized symbology for each variable (define the range and the type of color scheme desired).
- Save QGIS project files:
  - MaximumTemperature_SSP245_Historical.qgz, etc.
- Create full dynamics monthly layouts (title, legend, grid, coordinates, scale, metadata), changing the period, the IPCC scenario and the month name.
- Export the layouts of all open layers in QGIS at once as PNG files.
- **Or simply attach the first script developed and ask the AI to adapt it to the IPCC scenario, period, and variable you are working on.**

Prompt for GitHub Copilot

- Analyze and improve the attached script by correcting any errors.

3.7 SSP2 4.5 - Period 2041–2060

- Repeat the same process for the 2041–2061 period, changed, where is necessary, 2021-2040 by 2041-2060.

3.8 SSP2 4.5 - Period 2061–2080

3.9 SSP2 4.5 - Period 2081–2100

- Follow the exact same workflow for each period.
- Adapt file and project names accordingly.

Examples:

- Precipitation_SSP245_2081-2100.qgz

3.10 SSP3 7.0 – Period 2021 to 2040

- Load multi-band raster files for maximum temperature, minimum temperature, and precipitation for SSP370 from WorldClim v2.1.
- Apply spatial clipping using the Baixo São Francisco shapefile mask.
- Split the rasters into 12 monthly single-band files.
- Use standardized names:
    - MaximumTemperature (ºC)_ (three-letter abbreviation of the month)
    - MinimumTemperature (ºC) _(three-letter abbreviation of the month)
    - Precipitation_SSP370 (mm) _(three-letter abbreviation of the month)
- Apply the appropriate color scales manually (define the range and color scheme).
- Save QGIS project files:
    - e.g., MaximumTemperature_SSP370_2021_2040.qgz
- Create one layout per month at once using the following model (attach the model of layout created before - .qpt files).
- Export all maps once at a time as a PNG image.
- **Repeat the process using the adapted version of the initial script.**

Prompt for GitHub Copilot

- Analyze and improve the attached script by correcting any errors.

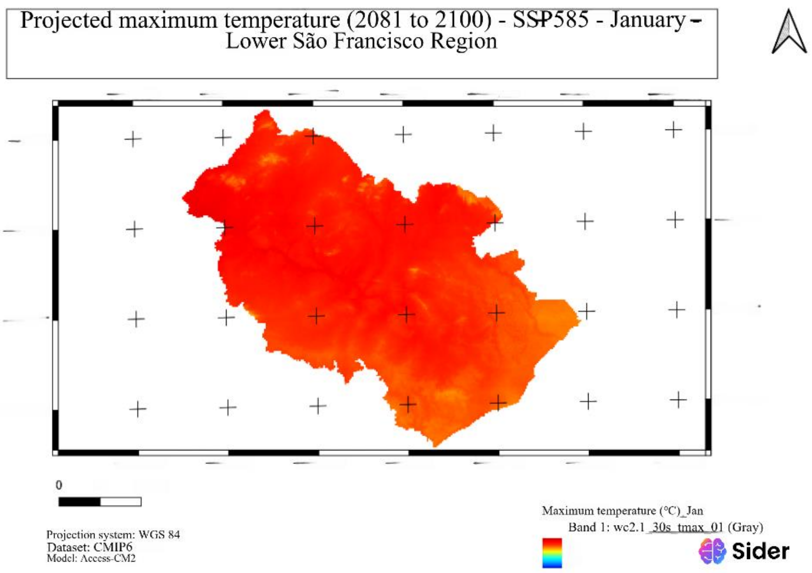

Figure 2: Example of a Monthly Precipitation Map Layout (Generated in QGIS)

3.11 SSP3 7.0 Period 2041–2060

- Repeat the full procedure for this period.

- File naming examples:
    - Precipitation_SSP370_2041-2060.qgz

3.12 SSP3 7.0 Period 2061–2080

3.13 SSP3 7.0 Period 2081–2100

- Apply the same methodology as above.
- Only update the filenames and project names accordingly.

Examples:

- Precipitation_SSP370_2081-2100.qgz

3.14 SSP5 8.5 – Period 2021-2040

- Import multi-band raster datasets for maximum temperature, minimum temperature, and precipitation under SSP5 8.5.
- Clip the raster using a file of Baixo São Francisco regional shapefile mask.
- Separate the 12 monthly bands into individual single-band files naming jan., feb, mar, apr…dec.
- Rename using a naming convention:
    - Maximum Temperature (ºC)_ (three-letter abbreviation of the month)
    - Minimum Temperature (ºC) _(three-letter abbreviation of the month)
    - Precipitation_SSP370 (mm) _(three-letter abbreviation of the month)
- Apply the appropriate color ramp for each variable (automatized adjusted for range and color scheme – Temperature for maximum and minimum temperature and Blues for precipitation).
- Save project files with names like:
    - Maximum_Temperature_SSP585_Historical.qgz, etc.
- Generate monthly dynamic layouts including all cartographic elements and using the model generated before (insert the model - .qpt).
- Export all 12 layouts as a PNG at once.
- **Apply the same logic using the original script as a base..**

Prompt for GitHub Copilot

- Analyze and improve the attached script by correcting any errors.

3.15 Period 2041–2060

- Repeat the same workflow, updating file and project names to:
    - eg. Precipitation_SSP585_2041-2060.qgz

3.16 Period 2061–2080

3.17 Period 2081–2100

- Maintain the same steps: import → clip → split → rename → style → save → layout → export.
- Example name:
    - Precipitation_SSP585_2081-2100.qgz

4. Applications in Agriculture:

The generated data are particularly valuable for **agroclimatic zoning**, **crop yield forecasting**, **climate risk analysis**, and **irrigation planning**. Being able to compare different emission scenarios over time enables the agricultural sector to make informed decisions, plan adaptations, use of resilient agriculture systems, and implement mitigation strategies. Public policies also can be elaborated using the results.

5. Final Considerations

Automating the processing of climate data through QGIS and PyQGIS offers a fast, robust, efficient, and highly replicable solution for building regional climate scenarios. By generating systematic monthly maps across multiple variables and timeframes, this approach directly benefits environmental studies, territorial planning, and climate impact assessments.

Benefits of Automation:

- **Speed and Standardization:** Hundreds of files are processed faster than traditional methods and named consistently, with unified symbology and formatting.
- **Reproducibility:** Scripts can be adapted and reused for other regions and datasets.
- **Scalability:** The method is suitable for multiple climate models and future projections.
- **Interoperability:** The output maps can support hydrological, ecological, and agricultural modeling systems.

6. Future Perspectives:

Further development of this approach could include:

- **Integration with AI-based predictive models**
- **Interactive platforms for visualizing and downloading maps**

- **Enhanced map styling for communication with non-technical audiences**
- **Incorporation of socioeconomic layers for vulnerability assessment**

Ultimately, automating climate data workflows using AI and prompt engineering is more than a technical improvement—it's a strategic tool for supporting sustainability, innovation, and climate resilience at regional and national scales.

Appendix 1

Table 1. Automated climate map generation structure in QGIS using CMIP6 – ACCESS-CM2 data from WorldClim v2.1

IPCC Scenario (SSP)	Periods	Climate Variables	Number of Maps Generated	Raster Format	Spatial Resolution
Historical	1970–2000	Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
		Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
		Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
		Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
SSP1-2.6	2021–2040	Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)

	2041–2060	Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
	2061–2080	Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
	2081–2100	Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
SSP2-4.5	2021–2040	Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
	2041–2060	Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
	2061–2080	Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
	2081–2100	Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
SSP3-7.0	2021–2040	Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
	2041–2060	Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)

	2061–2080	Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
	2081–2100	Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
SSP5-8.5	2021–2040	Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
	2041–2060	Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
	2061–2080	Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
	2081–2100	Tmax, Tmin, Precipitation	36	Single-band monthly (.tif)	1 km^2 (30 arc-sec)
Total	17 scenarios/periods	Tmax, Tmin, Precipitation	720	Single-band monthly (.tif)	1 km^2 (30 arc-sec)

Notes:
- Tmax = Maximum Temperature; Tmin = Minimum Temperature
- Each monthly raster was automatically styled, renamed, and inserted into a standard layout (.qpt), with high-resolution PNG export.