



Data Fusion Strategy for Mapping Environment and Climate Variables of Brazil

Polina Lemenkova

► To cite this version:

Polina Lemenkova. Data Fusion Strategy for Mapping Environment and Climate Variables of Brazil. Tecno-Lógica, 2022, 26 (1), pp.15-34. 10.17058/tecnolog.v26i1.16793 . hal-03556311

HAL Id: hal-03556311

<https://hal.science/hal-03556311>

Submitted on 3 Feb 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License



DATA FUSION STRATEGY FOR MAPPING ENVIRONMENT AND CLIMATE VARIABLES OF BRAZIL

Polina Lemenkova

¹Université Libre de Bruxelles, École polytechnique de Bruxelles (Brussels Faculty of Engineering), Laboratory of Image Synthesis and Analysis (LISA). Building L, Campus de Solbosch, Avenue Franklin Roosevelt 50, Brussels 1000, Belgium.

*E-mail: polina.lemenkova@ulb.be or pauline.lemenkova@gmail.com

Recebido em: 12/07/2021
Aceito em: 09/11/2021

ABSTRACT

The study aims at utilizing the machine learning methods in cartography with a case study of climate and environmental mapping of Brazil. Rapid advances in machine learning applied to Earth observations have resulted in the application of scripting and programming languages for cartographic visualization and modelling. This research applies the Generic Mapping Tools (GMT) scripting toolset for advanced environmental mapping of Brazil. The data includes TerraClimate dataset of 2020. The GMT is an advanced cartographic tool that operates mapping from the console using scripts. Selected codes of the used scripts are presented in the research for technical explanation of the workflow. The results show correlation among the parameters and demonstrate climate and environmental trends notable for different biomes of Brazil: Amazônia, Caatinga, Cerrado, Pampa and Pantanal. The study presents 10 new maps made using GMT. Based on the obtained results, the increase of precipitation is notable in the Amazônia, along with the highest temperatures in the northern Brazil (Negro river basin) which corresponds to the increase in soil moisture and runoff. The evapotranspiration is higher in the southern regions than those in the north. On the contrast, the Caatinga region shows the minimal values of evapotranspiration, soil moisture and runoff. The main advantage of scripting cartography, demonstrated in this research, consists in automated data processing which pushes climate studies towards a data-driven research. Automated mapping technically facilitates the workflow due to the fast and smooth handling of various formats and types of data. The results contribute to the environmental analysis of climate in Brazil that has applications in agricultural and food studies and shows technical use of GMT.

Key words: Brazil. Environment. Geography. Cartography. Machine Learning. Sustainable Development.

1 Introduction

For environmental assessment, variables in the geospatial datasets are accommodated through thematic mapping using GIS and Remote Sensing (RS) methods [1-7]. Normally, climate variables include such parameters as temperature, soil moisture, evapotranspiration, precipitation, and vapor pressure deficit. Varied by different GIS approaches, normally cartographic visualization and methods of mapping are used in different environmental applications and tasks for data fusion and visualization.

At the same time, GIS differ in terms of functionality and approaches to handle spatial data using either conventional Graphical User Interface (GUI) or advanced machine learning applications of scripting or OBIA [8-12]. However, the

traditional GIS (such as ArcGIS, SAGA GIS, QGIS, ILWIS GIS) is not the exclusive method in which datasets can be integrated, assessed and visualized and used for environmental analysis [13-15].

Machine learning methods based on automatization in data processing recently achieved much attention in geospatial domains, including climate and environmental studies [16-17]. The machine based data processing includes such approaches as scripting cartographic tools (e.g. Generic Mapping Tools (GMT) or GRASS GIS) [18-19], deep learning algorithms [20-21], programming languages (e.g. Python or R) [22-23] and advanced statistical data analysis [24-25].

However, the application of scripting cartographic toolset GMT have not so far been sufficiently presented in the environmental and climate mapping of Brazil. At the same time,



GMT presents the advanced tools for thematic mapping and visualizing data as map series [26-27]. Specifically, the GMT operates mapping by scripting from the console. This facilitates mapping compared to the traditional GUI-based GIS approach. The GMT makes mapping fast, accurate and fine, which is achieved through the machine based data processing.

Using scripting and machine learning approaches in mapping enables to effectively visualize descriptive geographic datasets with coordinates and variables in multiple physical properties, to perform fusion of the multi-source data (e.g. netCDF, TIFF, txt, gmt), to technically integrate and overlay raster and vector layers and to visualize conceptual elements of the environmental landscapes. In such a way, scripting cartography presents a deep link between the technical data processing and geographical phenomena depicted on the maps.

Here this study reports on the use of the advanced cartographic machine learning method of GMT scripting for studying climate variability and its environmental effects of several biomes of Brazil observed using TerraClimate dataset: https://climate.northwestknowledge.net/TERRACLIMATE/index_directDownloads.php

TerraClimate is a project of the open source gridded data collection covering the Earth. It consists of environmental, meteorological and hydrological variables as time series, starting from 1958 until now. The data are downloadable on a monthly basis with high geospatial resolution, global coverage, and time repeatability of observations, which makes TerraClimate a valuable source for environmental and meteorological research. The climate grids are derived from the WorldClim project with metadata for the time-series analysis. The advantages of the TerraClimate datasets can be summarized as follows:

First, datasets of TerraClimate are free and open access, available for everyone to download for analysis, study, research or mapping.

1. Second, TerraClimate presents regular monthly climate reports which enable to perform statistical analysis of the data, e.g., model climate change fluctuation.
2. Third, TerraClimate includes hydrological variables for the ecological and environmental mapping and analysis of surface hydrological processes, such as runoff, actual evapotranspiration, soil parameters (for example, soil moisture), and climatic water deficit.
3. Forth, TerraClimate presents integration of spatial high-resolution climate data with high temporal

repeatability starting from 1958 up to now. It enables to perform time series analysis.

A series of climate model has been presented using TerraClimate data visualized from the NetCDF format to determine the correlation between variables (temperature, precipitation, soil moisture, runoff, Palmer Drought Severity Index (PDSI) and vapor pressure deficit). These datasets were used to demonstrate the connectivity between the environment and climate that led to the formation of various landscapes and biomes in Brazil. This study concludes by considering the implications of the presented maps and advanced cartographic visualization for a better understanding of the factors controlling the environmental patterns in Brazil: Amazônia, Caatinga, Cerrado, Pampa and Pantanal. The paper also discusses the role that climate variation plays in the formation of the ecological landscapes in South America.

2 Experimental and Methodological Part

This study uses the GMT to present a new series of maps demonstrating that the spread of such climate variables as temperature, soil moisture, precipitation and surface runoff well illustrates a correlation among these data showing the environmental variability in the important biomes of Brazil: Amazônia, Caatinga, Cerrado, Pampa and Pantanal [28].

For the visualization and mapping, data selection for climate and environmental parameters was determined for the year 2020. The TerraClimate dataset for climate mapping (Fig. 2–10), and a GEBCO high-resolution dataset (Figure 1) have been used for mapping to investigate the variations in the environmental, climate and elevation parameters over Brazil. The data were visualized in a spatial coverage of the whole country. Various cartographic color palettes were applied to better approximate the climate characteristics within the data extend for each of the maps.

Different regions of Brazil (Amazônia, Caatinga, Cerrado, Pampa and Pantanal) have been visualized using the TerraClimate and GEBCO datasets in order to demonstrate gradual changes in environmental and climate parameters according to the climate situation in 2020. The cartographic techniques used for all maps are described in Section 2.3 (Machine learning in cartography) which includes the most important codes of GMT. In order to enable comparison of maps, the TerraClimate and GEBCO data were visualized in the identical projection (Mercator) and spatial extent (Brazil), for instance, Fig. 2 and Fig 3 showing climate parameters on precipitation and temperature of Brazil for the year 2020.

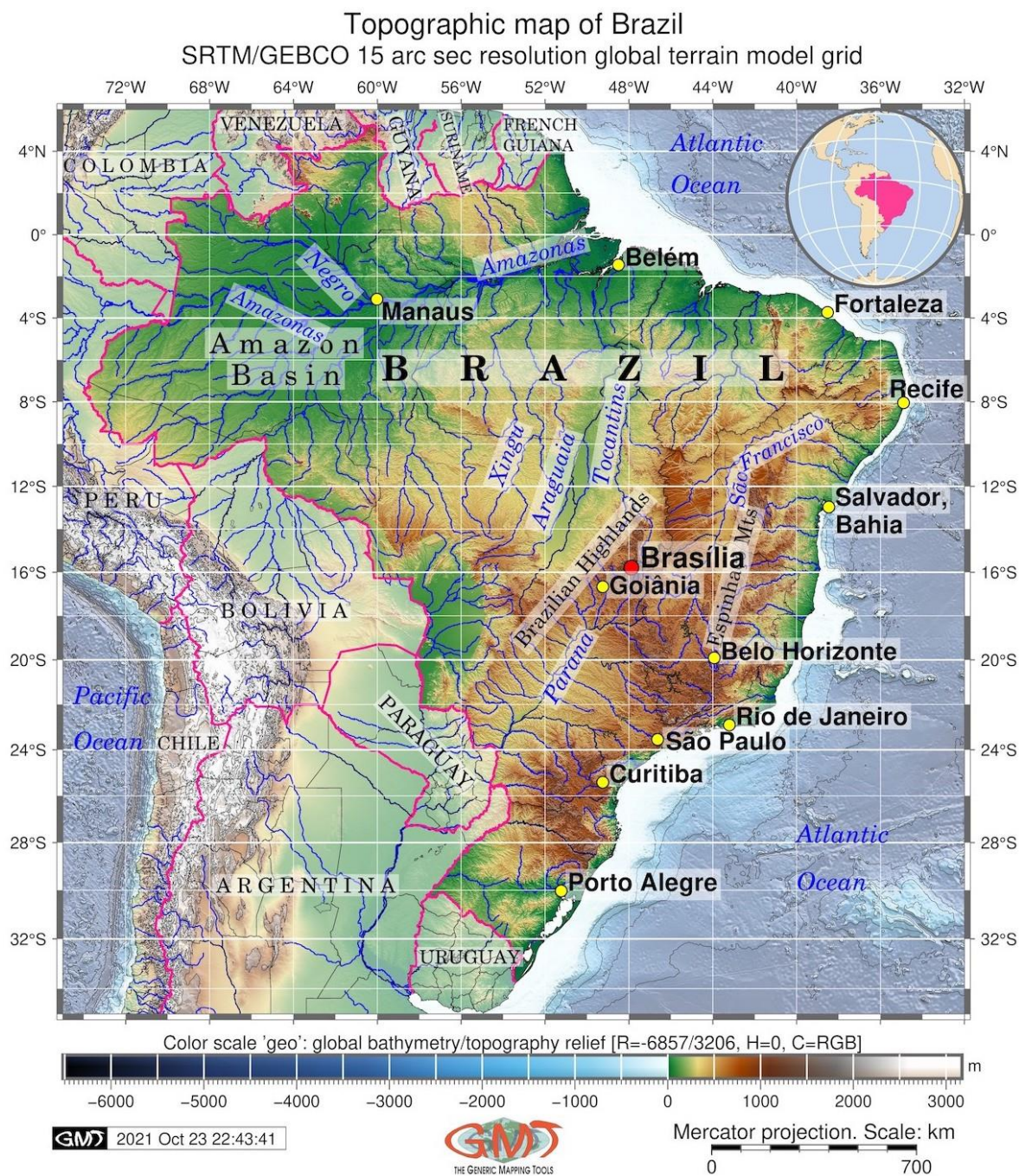


Figure 1 – Topographic map of Brazil. Mapping: GMT. Source: author.

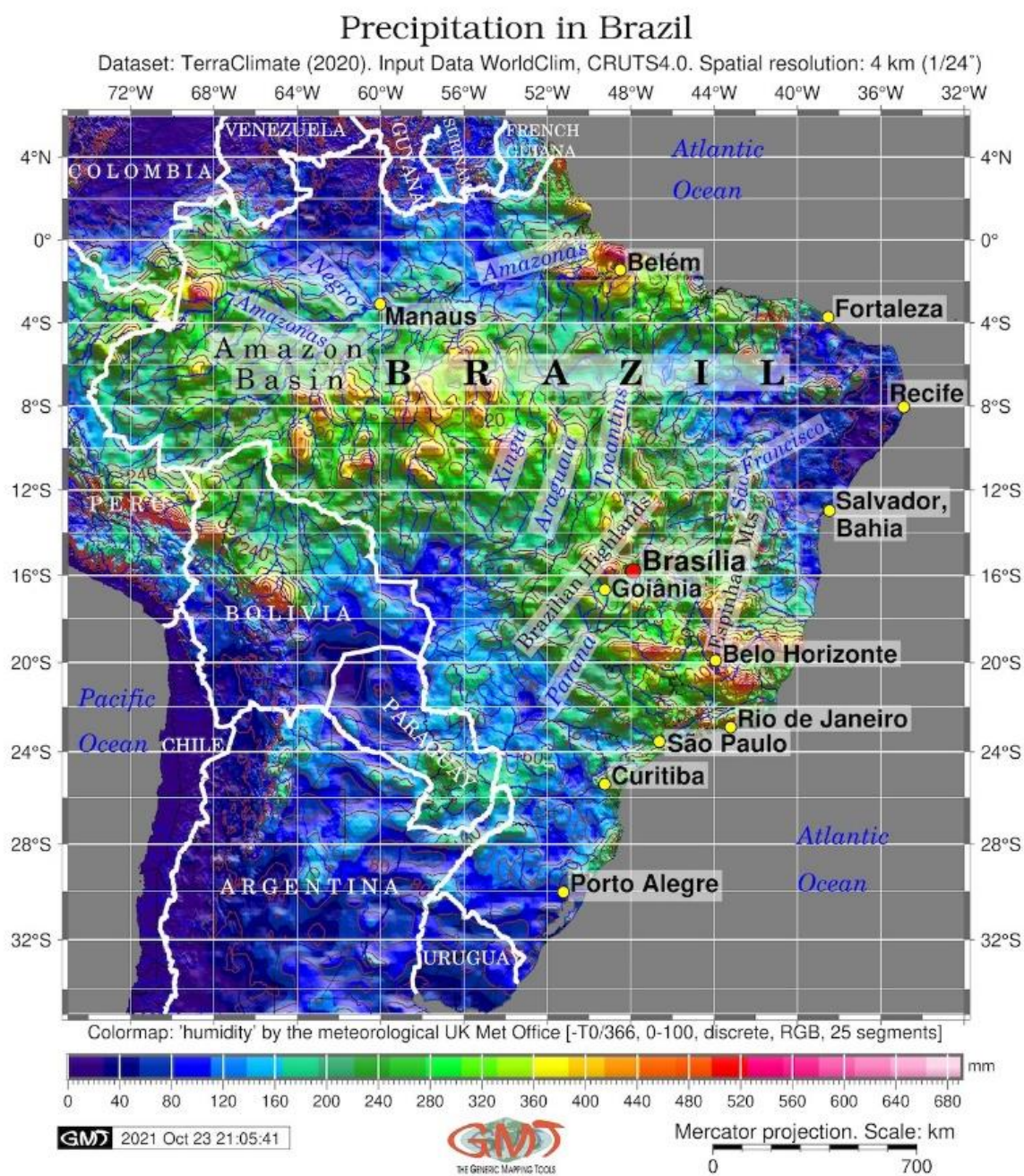


Figure 2 – Precipitation map of Brazil. Mapping: GMT. Source: author.

2.1 Study area

Brazil covers 47% of the South America which makes it the most significant country of the continent [29]. The exact geographical extent of the country is between 33°44'32"S to 5°16'20" N latitude, and between 73 59'32" W to 34°47'30" E longitude (Figure 1). Brazil has boundaries with all South American countries except for Chile and Ecuador [30]. The most important biomes of Brazil include Amazônia, Caatinga, Cerrado, Pampa and Pantanal. They have different climate and environmental setting, as briefly discussed below.

The Amazônia biome is formed by the Amazon, the 2nd longest river in the world and the largest one in Brazil [31]. The Amazon largely affects the environmental and climate setting of the country as observed in multiple remote sensing based studies [32-34]. Being the most influencing and significant hydrological network in the country, the Amazon is an important source of hydro-energy [35-36]. It stretches for about 6,840 km forming a dense, complex hydrological network of connected tributary rivers. The Amazon creates a habitat for thousands of unique jungle species and endangered rain forest plants including endemics of the Amazônia National Park, which makes it a precious region for biodiversity [37].

The Caatinga, located in the NE of Brazil, is presented by thorn xeric shrubland and seasonally dry forests, with rich and diversified biota in over the 2000 species [38], formed under the impact of dry climate and specific soils [39-40].

Cerrado, the vast tropical savanna ecoregion, is located in the central-western Brazil [41]. It includes massive grasslands covering ca. 25% of its surface, classified among the most threatened regions in South America [42-43] and reported for their environmental vulnerability [44]. The distribution of pastures in cerrado correlates with local climate setting where the higher scattered tree density is generally observed in regions with lower and concentrated rainfalls [45]. The geographical distribution of the cerrado generally corresponds to the Brazilian Highlands.

The Pampa presents a plain region in the southernmost of Brazil notable for temperate climate and evenly distributed precipitation pattern ranging from ca. 600 to 1,200 mm. The Pampa biome presents a grassland with high species richness and important role in food production in South America [46].

The Pantanal is the world's largest tropical wetland area and the flooded grasslands situated in the center of the Upper Paraguay River Basin, with area os 360,000 km² [47].

Such distinct geographical physical features of Brazil are presented in physiographic divisions with diverse biomes. Among them, the Pantanal, Pampa and Caatinga are the least studied in terms of ecological restoration, and Amazônia is the most studied region [48]. The diversity and uniqueness of the Brazilian environmental patterns are largely influenced by climate variations that deserve special studies and monitoring supported by the advanced cartographic outputs, as attempted in this study.

2.2 Data

Data mining, data integration and data fusion as new methods of environmental modelling with application to Brazil are presented in the existing literature [49-50]. Remote sensing grids, climate observations and geospatial coordinated data are considered as information sources in this study. Specifically, data used in this study are acquired from the open source TerraClimate project [51] which is received through the remote sensing Earth observations and climate modelling.

The application and actuality of the open data for environmental studies is explained by the following factors:

- free access of climate information which includes the metadata, descriptions and explanations of the TerraClimate project;
- transparent and reliable sampling of GMT techniques which provide a suite of maps based on the datasets that may be used to characterize climate changes at regional scales between various regions of Brazil.
- compatible formats of the raster grids presented as netCDF format that can be converted into acceptable graphical formats, e.g. TIFF or JPG;
- standardized individual sampling techniques of TerraClimate enables highlighting correlation between different data that results in a series of compatible maps and comparative visualized data.

In order to strike a correlation between the observed range change in environmental and climate datasets and topographic model with elevation changes in various regions of Brazil (Amazônia, Caatinga, Cerrado, Pampa and Pantanal), this study presented a series of compatible maps with identical projection and spatial extent covering Brazil using a scripting machine learning methods in GMT, as explained below.

Tmin (minimum temperature) of Brazil (average in 2020)

Dataset: TerraClimate (2020). Input Data WorldClim, CRUTS4.0. Spatial resolution: 4 km (1/24°)

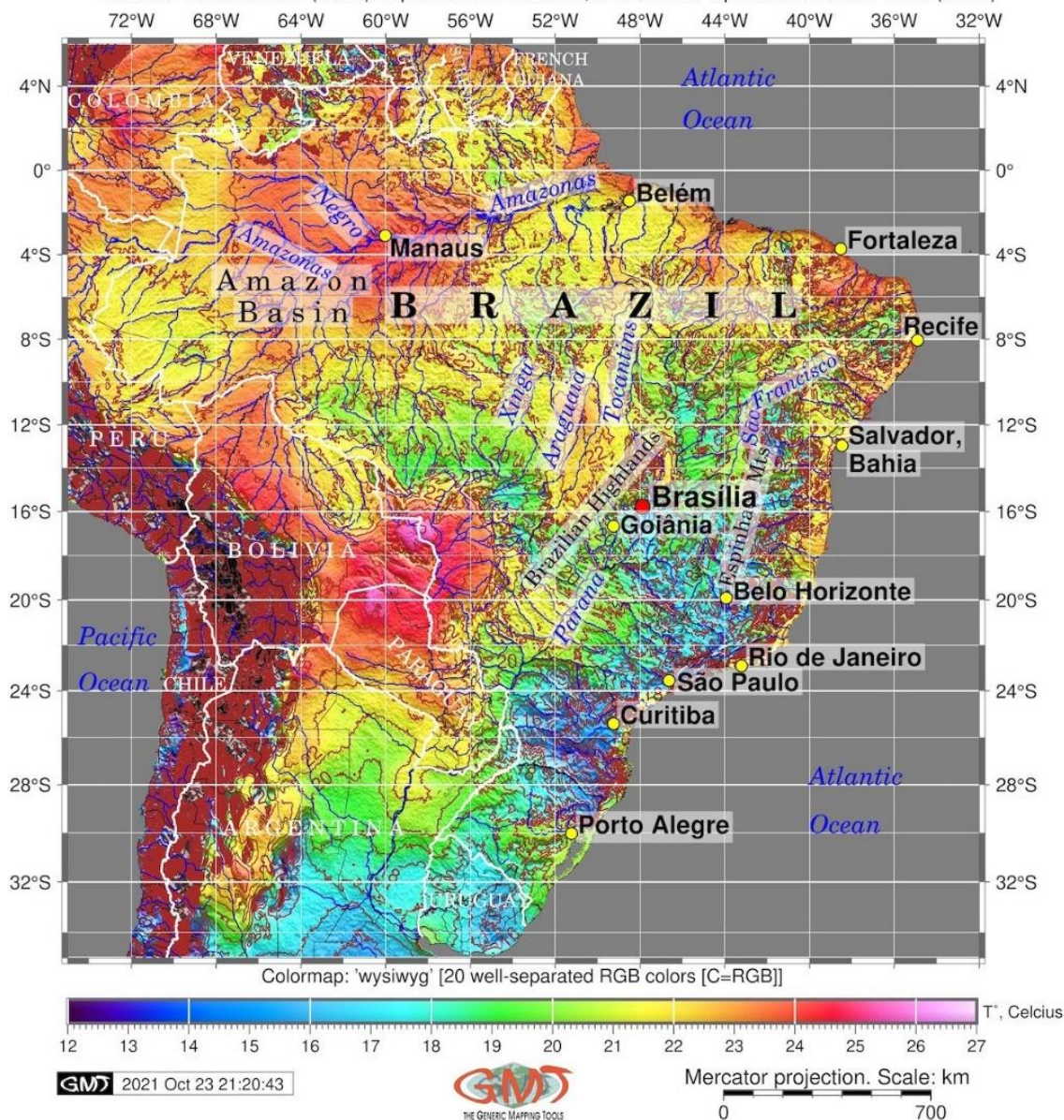


Figure 3 – Minimal temperature in Brazil. Mapping: GMT. Source: author.

Tmax (maximal temperature) in Brazil (average in 1960)

Dataset: TerraClimate (2020). Input Data WorldClim, CRUTS4.0. Spatial resolution: 4 km (1/24°)

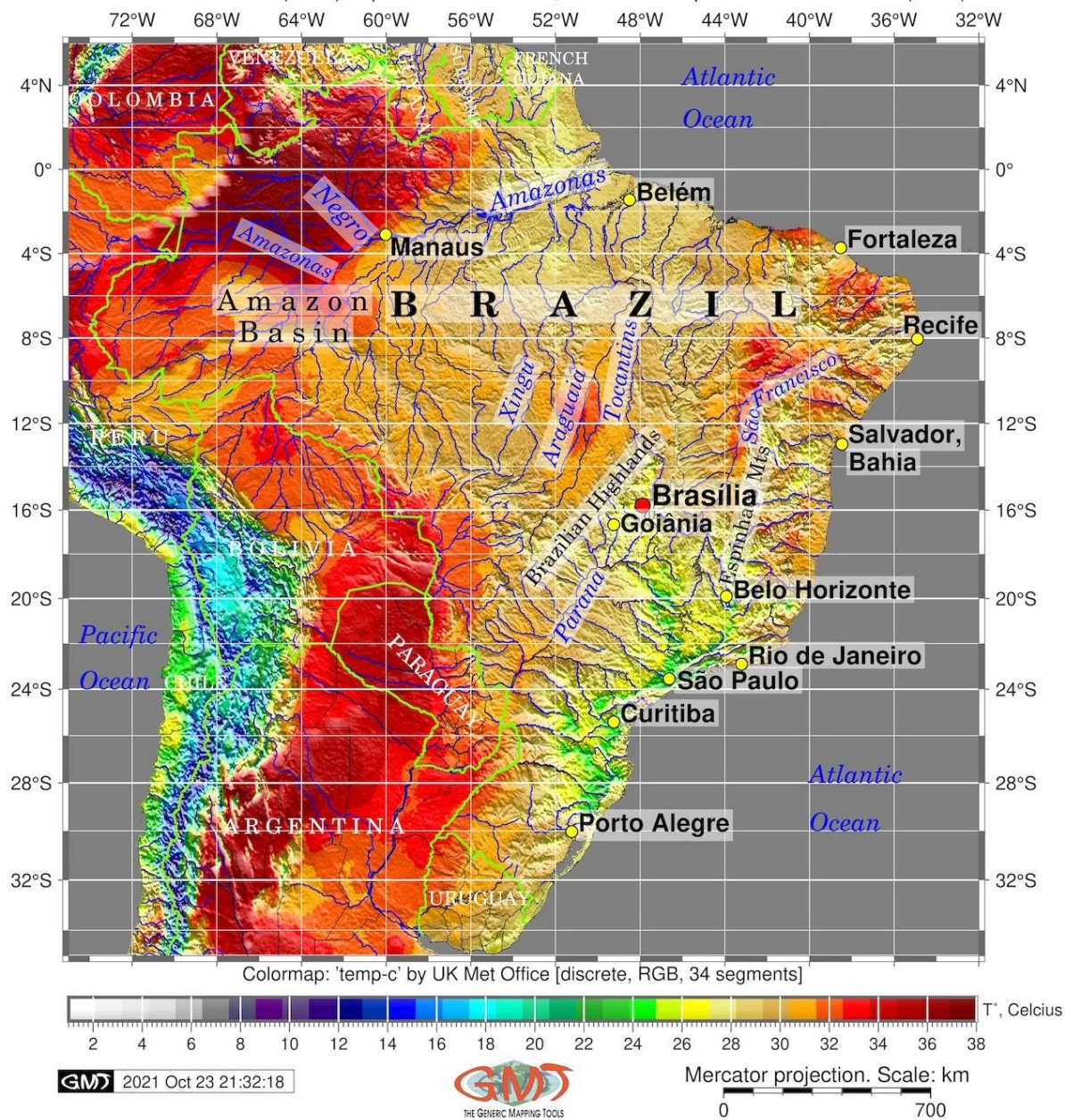


Figure 4 – Maximal temperature in Brazil. Mapping: GMT. Source: author.

Soil moisture map of Brazil (2020)

Dataset: TerraClimate (2020). Input Data WorldClim, CRUTS4.0. Spatial resolution: 4 km (1/24°)

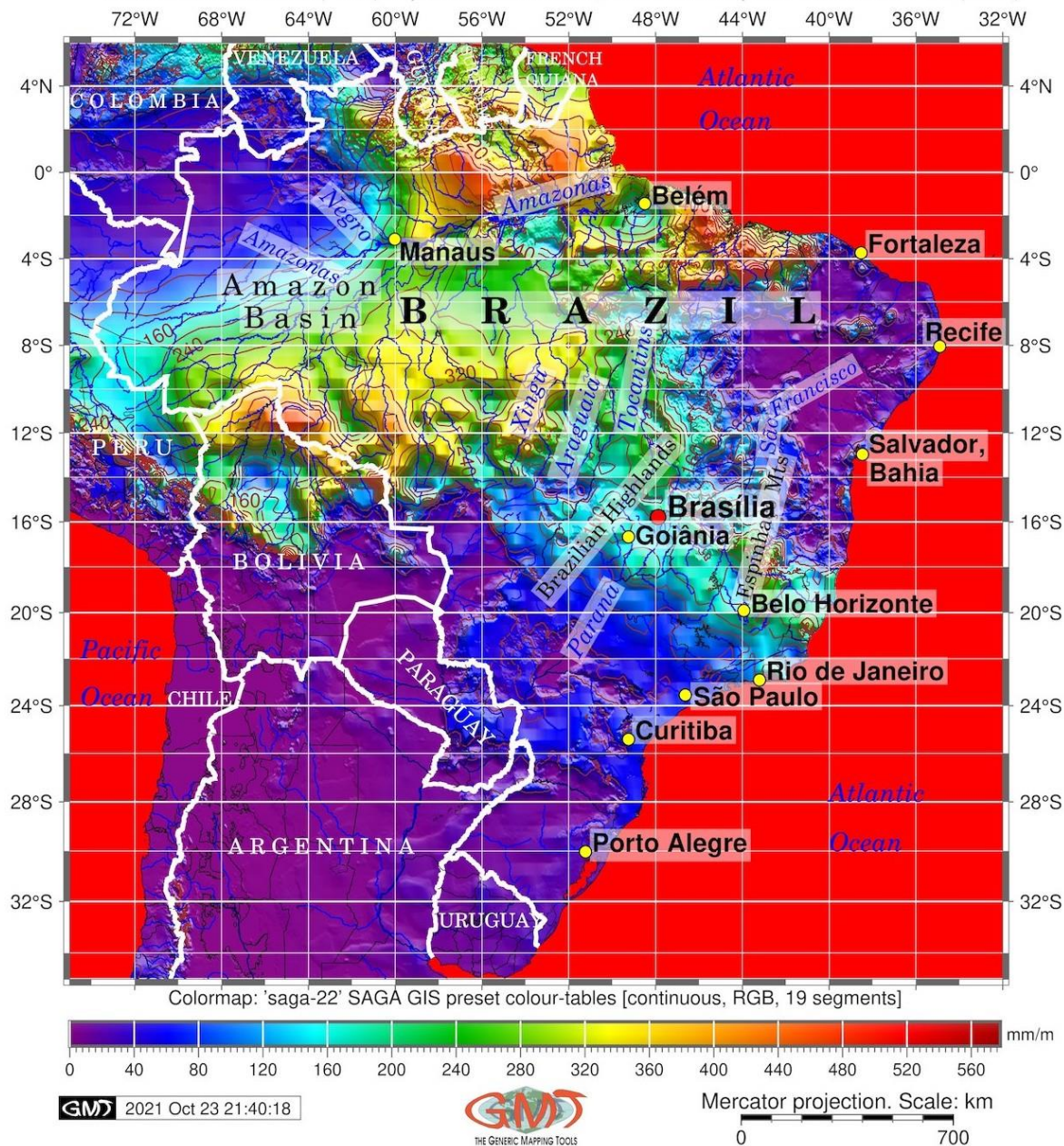


Figure 5 – Soil moisture map in Brazil. Mapping: GMT. Source: author.

2.3 Machine learning in cartography

With the rapid advances of methods of machine learning such as scripting and programming languages, their applications in cartography have recently developed in Earth and environmental sciences and now become an important approach of data processing, visualization and analysis [52-54].

By combining the knowledge on environmental and climate variations in the Brazil and a high-performance cartographic modelling by GMT using available techniques [55-57], a series of thematic maps has been established so as to visualize and analyse the variability of climate variables by the biomes in Brazil (including the min/max temperature, precipitation, runoff, PDSI, VPD and topography) and describe the specific trends and correlation of the climate variability in a cartographic and quantitative way. The data visualization and modeling methods used in this study included a variety of GMT modules used for stepwise plotting of layers using the following examples of snippets of codes:

1. Extracting a subset for the study area: `'gmt grdcut TerraClimate_tmax_2020.nc -R285/328/-35/6 -Gbr_tmax.nc'` (Here: map of maximal temperature). In this code a sequence of 'flags', with controlling parameters executed the module. For example, in the '-R' parameter of this expression, module 'grdcut' subsets the region from the whole original NetCDF file (TerraClimate_tmax_2020.nc) using the defined coordinates. In this case, '-R285/328/-35/6' means selecting the study from 75°W to 32°W (the system of 0° to 360°, that is 285 corresponds to the 75°W and 328 – to the 35°W) and from 35°S to 6°S.
2. Generating color palette: `'gmt makecpt -Cprecip3_16lev -V -T0/192 > pauline.cpt'`. In this code, GMT computed the color palette using range defined in '-T' flag, that is, from 0 to 192. The original color palette (precip3_16lev) was extended according to the real data range which was inspected by GDAL (using 'gdalinfo').
3. Making background image: `'gmt grdimimage br_aet.nc -Cpauline.cpt -R285/328/-35/6 -JM6i -I+a15+ne0.75 -Xc -P -K > $ps'`. The resulting image based on clipped data was then visualized as a background using the 'grdimimage' module. The

Mercator projections was used for all 10 maps by the "-JM6i" flag, where '6i' means a physical printing extent of the map set up as 6 inches. The flag '-I+a15+ne0.75' signifies the illumination added on the image as intensities of the output file in the (-1,+1) range and affects the ambient light.

4. Adding cities by the ptext module: `'gmt ptext -R -J -N -O -K -F+f10p,0,white+jLB+a-0 >> $ps << EOF 313.67 -23.85 São Paulo EOF'`. In this code, the flags '-R -J -N -O -K' mean continue plotting the image and overlay of the previous code; -R and -J mean continue using the same spatial extent and defined projection; -N means not clipping the image at the map boundary. The flag '-F+f10p,0,white+jLB+a-0' defines the appearance of the text: its font (e.g., type '0' signifies 'Helvetica'), size (here 10 pixels, f10p) color, location (here location 'left bottom') and rotation of the text. The text itself is written between the EOF expression, which is a standard Linux-defined 'end of file' definition for a compiler, which gives an indication that the file it was reading has ended.
5. Finding statistical information from GDAL: `'gdalinfo -stats br_runoff.nc'` (Here: runoff in Brazil for 2020).
6. Similar logic in the GMT language syntax has been used for plotting all the presented maps demonstrating the successful example of the machine learning applications in modern cartography. The machine learning approach in cartography provides important technical scripting support for mapping gridded raster datasets by automated visualizing that ensures precise and refined visualization in a fast and accurate way.

3 Results and discussions

3.1 Precipitation and temperature

To ascertain the comparative analysis of the distribution of background general climate variables, such as temperature and precipitation, in recent period in Brazil, data for 2020 were collected from the TerraClimate source and mapped accordingly (Figures 2, 3 and 4). Mapping climate variables is important for estimation and modelling of climate change which has been

considered as one of the greatest future challenges for world environment including food [58-59].

The maximal values of precipitation in 2020 were identified in the central and south-eastern coastal areas reaching up to 600 mm (bright pink colors in Figure 2), and selected spot in the Amazônia within the small areas (360-500 mm, yellow to orange colors), while regions adjacent to the northern neighbor countries (Venezuela, Guyana, Suriname) show lesser values (40-120 mm, blue-colored areas).

Annual temperatures in 2020 vary by biomes of Brazil with the minimal values noted in the southern coastal region (between Curitiba and Porto Alegre, at around 12-14°C) and selected areas in the Espinhaço Mountains, Figure 3. Accordingly, the maximal values detected in Pantanal and central Amazonia (over 32°C), Figure 4.

3.2 Soil moisture and runoff

The results on soil moisture and runoff show correlated values visualized in maps of Figures 5 and 6, accordingly. The data well indicate the increase in soil moisture to the north of Amazon river up to 520 mm/m (bright red colors, Figure 5) and moderate local increase in soil moisture in the SE regions of Brazil (Espinhaço Mountains, Brasília and the Goiás State).

More specifically, soil moisture map contains a sharp increased bend on the border with the north Bolivia and in the northern Brazil downstream of Manaus (as shown in Fig. 5) with the values reaching their maximum in soil moisture. Another region with notable increased soil moisture is located between the Belem and São Luís, Maranhão, which is caused by the dominating forested plain crossed by numerous rivers in the eastern part of the tropical rain forests of Amazônia.

Correspondingly, the runoff values in this region as well as in the central Amazônia have increased values (up to 350 mm, red colors in Figure 6), which is consistent in proportions with the soil moisture values observed in Figure 5. The lowest values of the soil moisture and runoff can be seen in around Caatinga (NE of Brazil) which well corresponds to the dry environmental setting in the area. In general, the change regions in the runoff as shown in the map in Figure 6 represent hydrological model that fits to changes in the precipitation map (Figure 2) and soil moisture (Figure 5), accordingly.

3.3. Evapotranspiration

Evapotranspiration is generally higher in the southern regions than those in the north (Figures 7 and 8). The average values based on TerraClimate dataset in the central Amazon basin is 55-108 mm/year (Figure 7) with a clearly visible increase of values in the Caatinga and Cerrado (108-162).

The values of the potential evapotranspiration are comparable with those of the actual evapotranspiration (Figure 8) by the comparative analysis of the two maps, with slightly increasing values southwards of Brazil and the lowest values of AET in Caatinga (NE of Brazil, values range 12 to 65, blue colors in Figure 8). A representative model in the changes of evapotranspiration fits to the PDSI (Figure 10) and temperature maps (Figures 3 and 4). Previous studies on evapotranspiration in Brazil also shown the role of these variables for environmental monitoring [60-61].

3.4 Vapor Pressure Deficit and Palmer Drought Severity Index

The values of Vapor Pressure Deficit (VPD) in Brazil range between the 0.6-1.0 (beige colors in Figures 9). Meanwhile, certain increase in the Caatinga region can be seen within the values from 1.4 to 1.8. The Pantanal shows the slight increase in VPD values rising from 1.6 to 2.0. The VPD shows the difference between maximal possible and actual real values of the air pressure showing the effects of plants transpiration.

Because VPD corresponds to the plant transpiration rates, it is also an excellent environmental indicator for plant production and agriculture. The PDSI is more pronounced in the dry regions compared to the Amazonia rainforests (Figure 10). The values of VPD are the highest in Caatinga where they reach 1.8. This results in a good correspondence between the changes in climate and hydrological parameters, and topographic elevations. These variables well correlate with the distribution of major biomes of Brazil and show a balance with the trends of the parameters: precipitation, soil moisture, VPD, PDSI, evapotranspiration, temperature range, and runoff.

Runoff in Brazil (2020)

Dataset: TerraClimate (2020). Input Data WorldClim, CRUTS4.0. Spatial resolution: 4 km (1/24°)

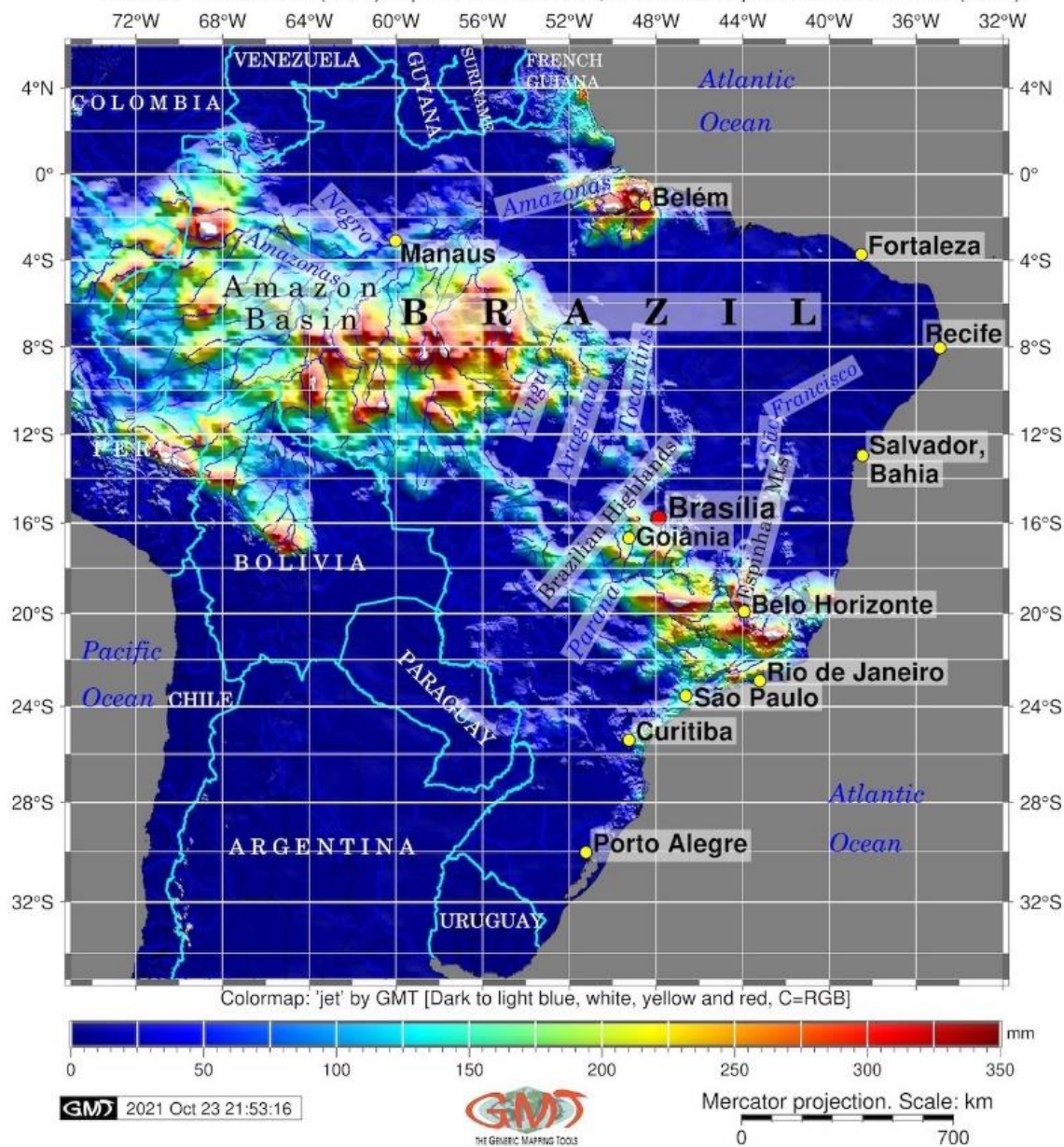


Figure 6 – Runoff in Brazil. Mapping: GMT. Source: author.

PET (Potential Evapotranspiration) in Brazil (2020)

Dataset: TerraClimate (2020). Input Data WorldClim, CRUTS4.0. Spatial resolution: 4 km (1/24°)

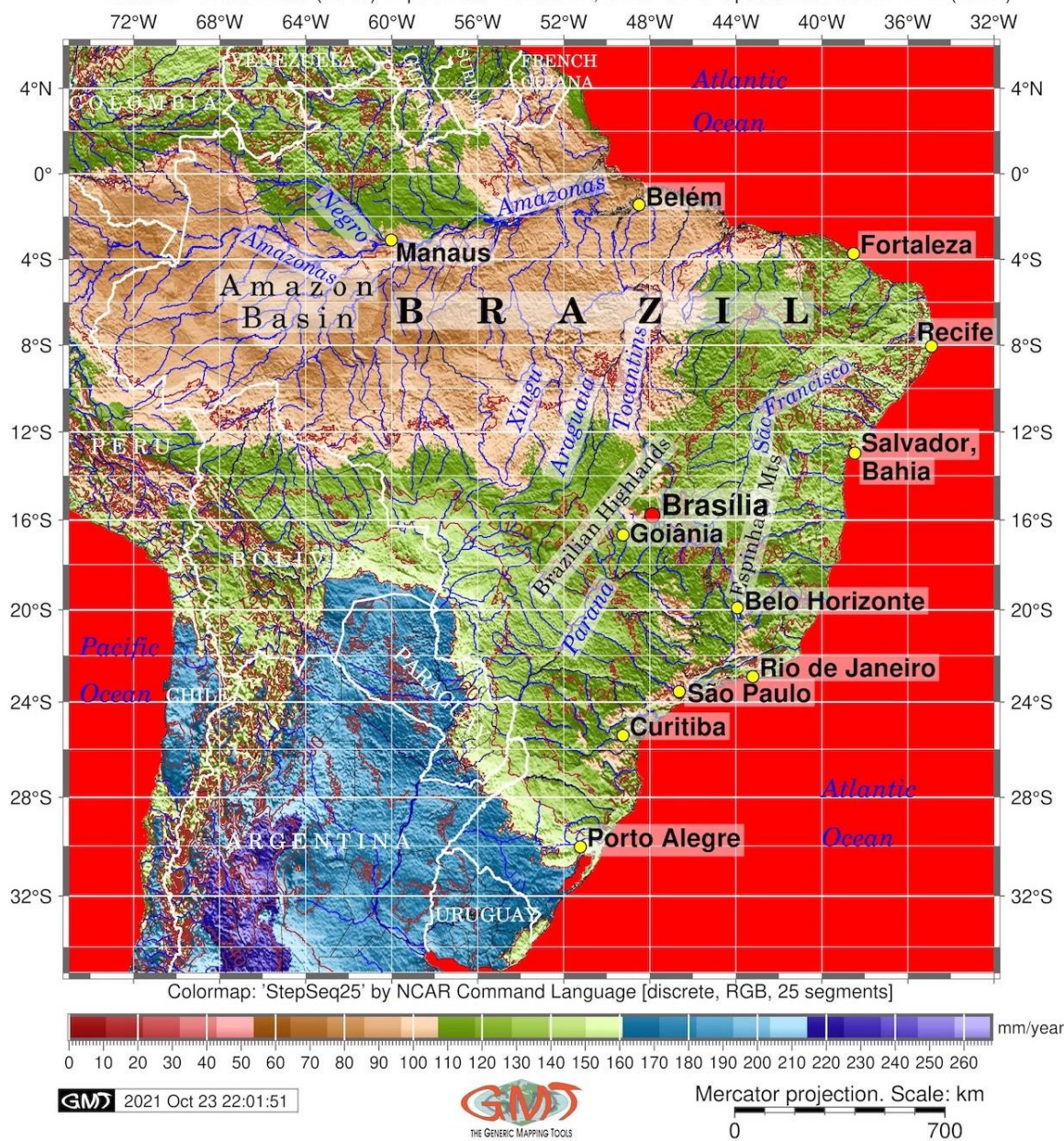


Figure 7 – Potential evapotranspiration (PET). Mapping: GMT. Source: author.

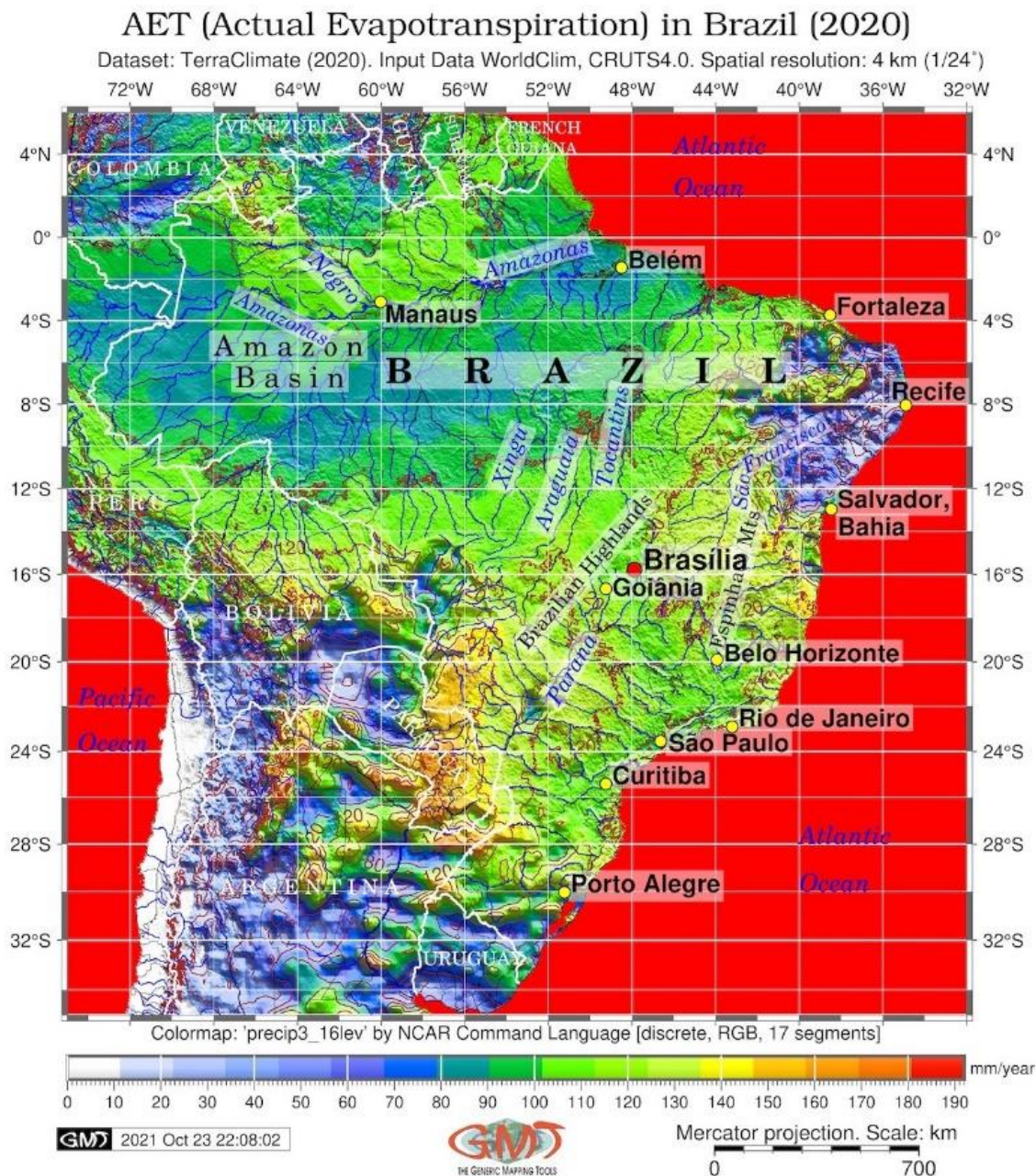


Figure 8 – Actual evapotranspiration (AET). Mapping: GMT. Source: author

VPD (Vapor Pressure Deficit) in Brazil (2020)

Dataset: TerraClimate (2020). Input Data WorldClim, CRUTS4.0. Spatial resolution: 4 km (1/24°)

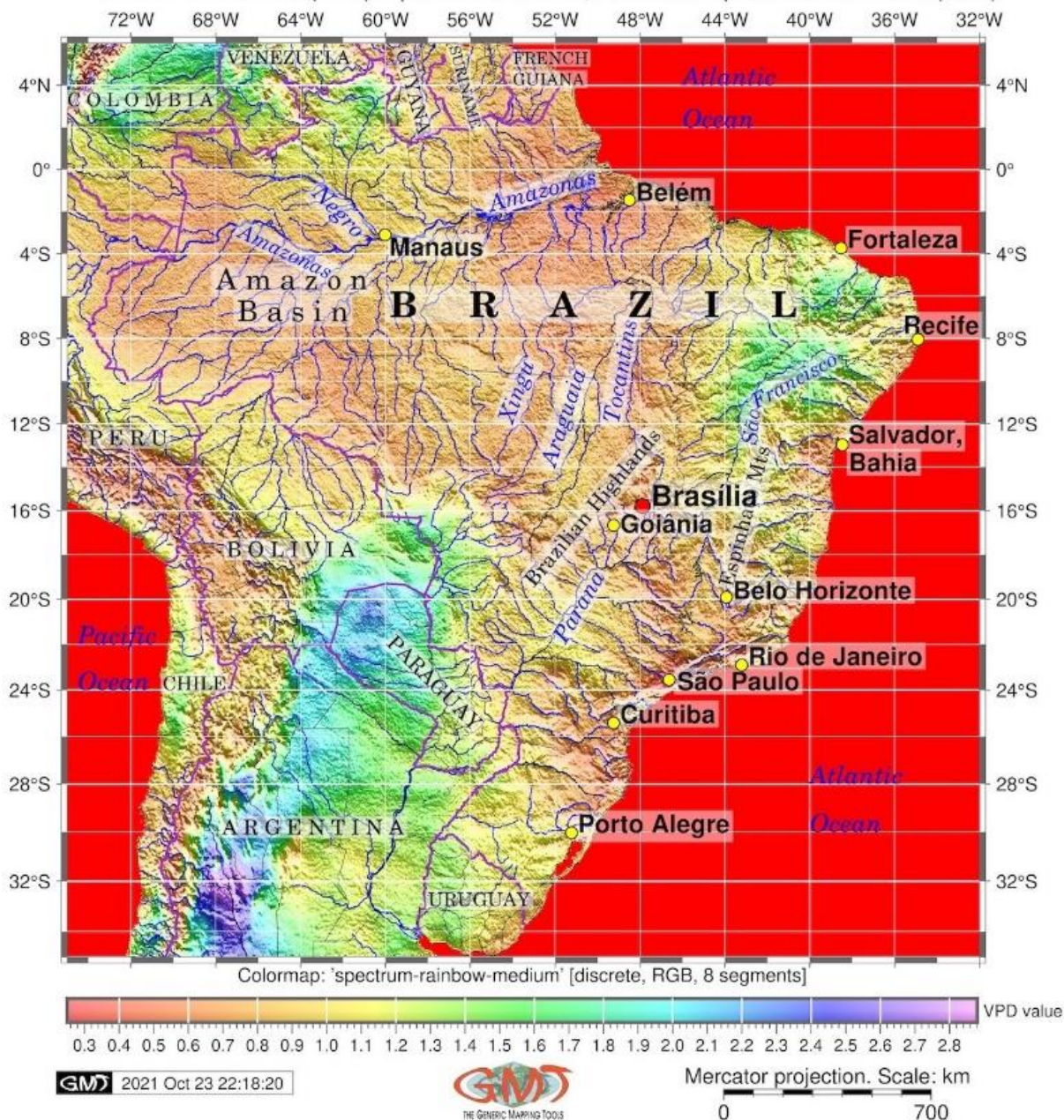


Figure 9 – VPD in Brazil (2020). Mapping: GMT. Source: author

PDSI (Palmer Drought Severity Index) in Brazil (2020)

Dataset: TerraClimate (2020). Input Data WorldClim, CRUTS4.0. Spatial resolution: 4 km (1/24°)

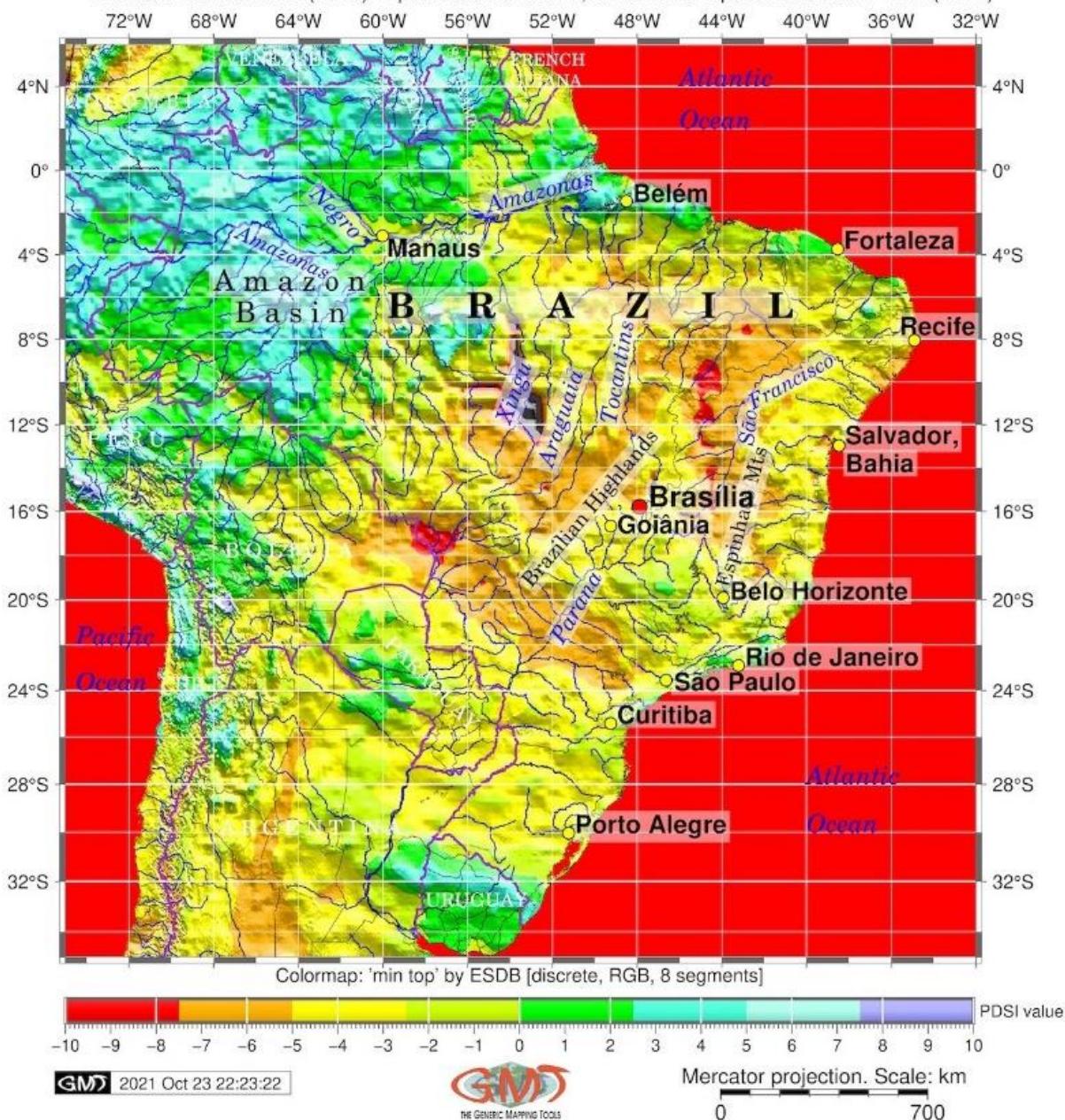


Figure 10 – PDSI in Brazil (2020). Mapping: GMT. Source: author

4 Conclusion

The demonstrated interplay among the climate and environmental factors serves climate modelling showing variations in surface temperature, precipitation, soil moisture and runoff and supports the existing studies on climate and environmental changes in Brazil. In turn, this corresponds to the distribution of PDSI and VPD over Brazil. Confirmation of topography-climate interactions over Brazil was provided by the series of plotted thematic maps using GMT scripting toolset. Spatial distribution of the climate and environmental parameters and their topographic locations have all been mapped using various color palettes aimed at highlighting general trends in changes over the main regions of Brazil.

Both datasets (obtained from GEBCO and TerraClimate, correspondingly) were visualized in the identical spatial scales and projection for compatibility reasons. The maps show complex trends in the environmental, climate and hydrological parameters in Brazil and clearly visible variations in climate variables across major biomes of the country: Amazônia, Caatinga, Cerrado, Pampa and Pantanal. Specifically, the maps show that the precipitation increases more in the rainforests of Amazon, which is followed by the Pantanal region on the border with Bolivia showing on average soil moisture increase with a clear decline of moisture south- and eastwards (Caatinga region). In regions showing the cerrado (savanna) biomes, which is the biologically richest savanna in the world, demonstrates the climate characteristics of the semi-humid tropical climate.

The importance of the climate change can be illustrated by its effects on land use and cover types which in turn causes degradation of soils and landscapes. As a result, such processes may negatively affect the food production. In view of this, this study contributes to the environmental analysis of Brazil and continues existing reports on climate modelling and monitoring maintaining policies on hazard mitigation and environmental protection [62–73]. The presented series of ten new maps made using scripting machine learning approach of GMT aims to illustrate the variability of the environmental setting in Brazil at regional scale.

Variation in trends and heterogeneities of the climate parameters may have various reasons (e.g., geologic origin or tectonic control, anthropogenic or topographic effects) which results in climate and environmental change. These parameters should be visualized to show correlations in environmental and

climate trends. Due to the limited possibilities of traditional GIS, a systematic mapping of thematic maps might be tedious and time-consuming work. Therefore, plotting a series of thematic maps requires advanced cartographic techniques for mapping rapidly yet effectively. These challenges necessitated application of the advanced technique of GMT which presents the machine learning approach for comprehensive mapping of climate parameters in Brazil based on all available data.

Acknowledgement

The author would like to express gratitude to the reviewers and editor for the review, remarks and editing of this manuscript.

ESTRATÉGIA DE FUSÃO DE DADOS PARA MAPEAMENTO DE VARIÁVEIS AMBIENTAIS E CLIMÁTICAS DO BRASIL

RESUMO: O estudo visa utilizar os métodos de machine learning em cartografia com um estudo de caso de mapeamento climático e ambiental do Brasil. Avanços rápidos no aprendizado de máquina aplicado às observações da Terra resultaram na aplicação de linguagens de script e programação para visualização e modelagem cartográfica. Esta pesquisa aplica o conjunto de ferramentas de script GMT para mapeamento ambiental avançado do Brasil. Os dados incluem o conjunto de dados TerraClimate de 2020. O GMT é uma ferramenta cartográfica avançada que opera o mapeamento a partir do console por meio de scripts. Trechos selecionados de códigos usados são apresentados na pesquisa para explicação técnica do fluxo de trabalho. Os resultados mostram correlação entre os parâmetros e demonstram tendências climáticas e ambientais notáveis para diferentes biomas do Brasil: Amazônia, Caatinga, Cerrado, Pampa e Pantanal. O estudo apresenta 10 novos mapas feitos em GMT. Com base nos resultados obtidos, o aumento da precipitação é notável na Amazônia, juntamente com as maiores temperaturas no norte do Brasil (bacia do rio Negro) que correspondem ao aumento da umidade do solo e do escoamento superficial. A evapotranspiração é geralmente maior nas regiões do sul do que nas do norte. Em contrapartida, a região da Caatinga apresenta os valores mínimos de evapotranspiração, umidade do solo e escoamento superficial. A principal vantagem da cartografia de

scripts, demonstrada nesta pesquisa, consiste no processamento automatizado de dados que impulsiona os estudos ambientais a serem baseados em dados. O mapeamento automatizado facilita tecnicamente o fluxo de trabalho devido ao manuseio rápido e suave de vários formatos e tipos de dados. Os resultados contribuem para a análise ambiental do clima no Brasil que tem aplicações em estudos agrícolas e de alimentos e mostra o uso técnico de GMT.

Palavras-chave: Brasil. Meio Ambiente. Geografia. Cartografia. Aprendizado de máquina. Desenvolvimento sustentável.

References

- [1] XIMENES, A.C.; AMARAL, S.; VIEIRA MONTEIRO, A.M.; ALMEIDA, R.M.; VALERIANO, D.M. Mapping the terrestrial ecoregions of the Purus-Madeira interfluvium in the Amazon Forest using machine learning techniques. *Forest Ecology and Management*, Vol. 488, 118960, 2021. <https://doi.org/10.1016/j.foreco.2021.118960>
- [2] CHAVES, M.E.D.; DE C. ALVES, M.; SÁFADI, T.; DE OLIVEIRA, M.S.; PICOLI, M.C.A.; SIMOES, R.E.O.; MATAVELI, G.A.V. Time-weighted dynamic time warping analysis for mapping interannual cropping practices changes in large-scale agro-industrial farms in Brazilian Cerrado, *Science of Remote Sensing*, Vol. 3, 100021, 2021. <https://doi.org/10.1016/j.srs.2021.100021>
- [3] SUETOVA, I.; USHAKOVA, L.; LEMENKOVA, P. Geoinformation mapping of the Barents and Pechora Seas, *Geography and Natural Resources*, Vol. 4, p. 138–142, 2005. <https://doi.org/10.6084/m9.figshare.7435535>
- [4] KLAUČO, M.; GREGOROVÁ, B.; STANKOV, U.; MARKOVIĆ, V.; LEMENKOVA, P. Determination of ecological significance based on geostatistical assessment: a case study from the Slovak Natura 2000 protected area, *Central European Journal of Geosciences*, Vol. 5, n. 1, p. 28–42, 2013. <https://doi.org/10.2478/s13533-012-0120-0>
- [5] LEMENKOVA, P.; SAGA GIS for Computing Multispectral Vegetation Indices by Landsat TM for Mapping Vegetation Greenness, *Contemporary Agriculture*, Vol. 70, n. 1–2, p. 67–75, 2021. <https://doi.org/10.2478/contagri-2021-0011>
- [6] ARVOR, D.; DUBREUIL, V.; RONCHAIL, J.; SIMÕES, M.; FUNATSU, B.M. Spatial patterns of rainfall regimes related to levels of double cropping agriculture systems in Mato Grosso (Brazil). *International Journal of Climatology*, 34, 2622–2633, 2014. <https://doi.org/10.1002/joc.3863>
- [7] FONSECA, L.M.G.; KÖRTING, T.S.; DO N. BENDINI, H.; GIROLAMO-NETO, C.D.; NEVES, A.K.; SOARES, A.R.; TAQUARY, E.C.; MARETTO, R.V. Pattern Recognition and Remote Sensing techniques applied to Land Use and Land Cover mapping in the Brazilian Savannah, *Pattern Recognition Letters*, Vol. 148, p. 54–60, 2021. <https://doi.org/10.1016/j.patrec.2021.04.028>
- [8] DE LIMA, C.E.S.; DE OLIVEIRA COSTA, V.S.; DOMICIANO GALVINCIO, J.; DA SILVA, R.M.; GUIMARÃES SANTOS, C.A. Assessment of automated evapotranspiration estimates obtained using the GP-SEBAL algorithm for dry forest vegetation (Caatinga) and agricultural areas in the Brazilian semiarid region. *Agricultural Water Management*, Vol. 250, 106863, 2021. <https://doi.org/10.1016/j.agwat.2021.106863>
- [9] KLAUČO, M.; GREGOROVÁ, B.; STANKOV, U.; MARKOVIĆ, V.; LEMENKOVA, P. Landscape metrics as indicator for ecological significance: assessment of Sitno Natura 2000 sites, Slovakia, *Ecology and Environmental Protection. Proceedings of the International Conference (Belarusian State University, March 19–20, 2014)*. Minsk, Belarus, 85–90, 2014. <https://doi.org/10.6084/m9.figshare.7434200>
- [10] LEMENKOVA P.; PROMPER C.; GLADE T. Economic Assessment of Landslide Risk for the Waidhofen a.d. Ybbs Region, Alpine Foreland, Lower Austria, In Eberhardt et al. (eds.). 11th International Symposium on Landslides & the 2nd North American Symposium on Landslides & Engineered Slopes (NASL). Protecting society through improved understanding: June 2–8, 2012. Canada, Banff, p. 279–285, 2012. <https://doi.org/10.6084/m9.figshare.7434230>
- [11] SCHENKE, H.W.; LEMENKOVA, P. Zur Frage der Meeresboden-Kartographie: Die Nutzung von AutoTrace Digitizer für die Vektorisierung der Bathymetrischen Daten in der Petschora-See, *Hydrographische Nachrichten*, Vol. 81, p. 16–21, 2008. <https://doi.org/10.6084/m9.figshare.7435538>
- [12] UTSUMI, A.G.; TARLÉ PISSARRA, T.C.; ROSALEN, D.L.; MARTINS FILHO, M.V.; SILVA ROLTA, L.H. Gully mapping using geographic object-based image analysis: A case study at catchment scale in the Brazilian Cerrado, *Remote Sensing Applications: Society and Environment*, Vol. 20, 100399, 2020. <https://doi.org/10.1016/j.rsase.2020.100399>
- [13] GAUGER, S.; KUHN, G.; GOHL, K.; FEIGL, T.; LEMENKOVA, P.; HILLENBRAND, C. (2007). Swath-bathymetric mapping. *Reports on Polar and Marine Research*, 557, 38–45. <https://doi.org/10.6084/m9.figshare.7439231>
- [14] KLAUČO, M.; GREGOROVÁ, B.; STANKOV, U.; MARKOVIĆ, V.; LEMENKOVA, P. Land planning as a support for sustainable development based on tourism: A case study of Slovak Rural Region, *Environmental Engineering and Management Journal*, Vol. 2, n. 16, p. 449–458, 2017. <https://doi.org/10.30638/eemj.2017.045>
- [15] LEMENKOVA, P.; Data-driven insights into correlation among geophysical setting, topography and seafloor sediments in the Ross Sea, Antarctic, *Caderno de Geografia*, Vol. 31, n. 64, p. 1–20, 2021. <https://doi.org/10.5752/p.2318-2962.2021v31n64p1>
- [16] SILVA COSTA, S. C.; KAZMERSKI, L. L.; DINIZ, A. S. A. C.; Impact of soiling on Si and CdTe PV modules: Case study in different Brazil climate zones, *Energy Conversion and Management*, Vol. X, n. 10, p. 100084, 2021. <https://doi.org/10.1016/j.ecmx.2021.100084>
- [17] MANCINI, M.; WEINDORF, D.C.; GODINHO SILVA, S.H.; CHAKRABORTY, S.; DOS SANTOS TEIXEIRA, A.F.; GUIMARÃES GUILHERME, L.R.; CURI, N. Parent material distribution mapping from tropical soils data via machine learning and portable X-ray fluorescence (pXRF) spectrometry in Brazil. *Geoderma*, Vol. 354, 113885, 2019. <https://doi.org/10.1016/j.geoderma.2019.113885>
- [18] LEMENKOVA, P.; Scripting cartographic methods of GMT for mapping the New Britain and San Cristobal Trenches, Solomon Sea, Papua New Guinea, *Revista da Casa da Geografia de Sobral*, Vol. 22, n. 3, p. 122–142, 2020. <https://doi.org/10.35701/rcgs.v22n3.717>

- [19] LEMENKOVA, P. GRASS GIS for topographic and geophysical mapping of the Peru-Chile Trench. *Forum Geografic*, Vol. 19, n. 2, p. 143–157, 2020. <https://doi.org/10.5775/fg.2020.009.d>
- [20] ARRUDA, V.L.S.; PIONTEKOWSKI, V.J.; ALENCAR, A.; PEREIRA, R.S.; MATRICARDI, E.A.T. An alternative approach for mapping burn scars using Landsat imagery, Google Earth Engine, and Deep Learning in the Brazilian Savanna. *Remote Sensing Applications: Society and Environment*, Vol. 22, 100472, 2021. <https://doi.org/10.1016/j.rsase.2021.100472>
- [21] ZUCATELLI, P.J.; NASCIMENTO, E.G.S.; SANTOS, A.Á.B.; ARCE, A.M.G.; MOREIRA, D.M. An investigation on deep learning and wavelet transform to nowcast wind power and wind power ramp: A case study in Brazil and Uruguay. *Energy*, Vol. 230, 120842, 2021. <https://doi.org/10.1016/j.energy.2021.120842>
- [22] LEMENKOVA, P. Statistical Analysis of the Mariana Trench Geomorphology Using R Programming Language, *Geodesy and Cartography*, Vol. 45, p. 57–84, 2019. <https://doi.org/10.3846/gac.2019.3785>
- [23] LEMENKOVA, P. Testing Linear Regressions by StatsModel Library of Python for Oceanological Data Interpretation, *Aquatic Sciences and Engineering*, Vol. 34, p. 51–60, 2019. <https://doi.org/10.26650/ASE2019547010>
- [24] ANTOLIN, L. A. S.; HEINEMANN, A. B.; MARIN, F.R.; Impact assessment of common bean availability in Brazil under climate change scenarios, *Agricultural Systems*, Vol. 191, 103174, 2021. <https://doi.org/10.1016/j.agsy.2021.103174>
- [25] DUBREUIL, V.; FANTE, K.P.; PLANCHON, O.; SANT'ANNA NETO, J.L. Climate change evidence in Brazil from Köppen's climate annual types frequency. *International Journal of Climatology*, Vol. 39, p. 1446–1456, 2019. <https://doi.org/10.1002/joc.5893>
- [26] LEMENKOVA, P. Exploring structured scripting cartographic technique of GMT for ocean seafloor modeling: A case of the East Indian Ocean, *Maritime Technology and Research*, Vol. 3, n. 2, p. 162–184, 2021. <https://doi.org/10.33175/mtr.2021.248158>
- [27] LEMENKOVA, P.; Cartographic Processing of the Multi-Source Geospatial Datasets by GMT for Mapping Variability in Geologic Setting and Bathymetry of the Pacific Ocean, *Mercator*, Vol. 20, p. 1–18, 2021. <https://doi.org/10.4215/rm2021.e20013>
- [28] DE NADAI FERNANDES, E.A.; SARRIÉS, G.A.; BACCHI, M.A.; MAZOLA, Y.T.; GONZAGA, C.L.; SARRIÉS, S.R.V. Trace elements and machine learning for Brazilian beef traceability. *Food Chemistry*, Vol. 333, 127462, 2020. <https://doi.org/10.1016/j.foodchem.2020.127462>
- [29] HUDSON, R. A.; LIBRARY OF CONGRESS. Federal Research Division. (1998) Brazil: A Country Study. Washington, D.C.: Federal Research Division, Library of Congress: For sale by the Supt. of Docs., U.S. G.P.O. [Pdf] Retrieved from the Library of Congress, <https://www.loc.gov/item/97036500/>
- [30] INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). *Geografia do Brasil* 5 vols. Rio de Janeiro: 1989.
- [31] UEREYEN, S.; KUENZER, C. A Review of Earth Observation-Based Analyses for Major River Basins. *Remote Sensing*, 11, 2951, 2019. <https://doi.org/10.3390/rs11242951>
- [32] FRAPPART, F.; CALMANT, S.; CAUHOPE, M.; SEYLER, F.; CAZENAVE, A. Preliminary results of ENVISAT RA-2-derived water levels validation over the Amazon basin. *Remote Sensing of Environment*, 100(2), 252–264, 2006. <https://doi.org/10.1016/j.rse.2005.10.027>
- [33] DA SILVA, J.S.; SEYLER, F.; CALMANT, S.; ROTUNNO FILHO, O.C.; ROUX, E.; MAGALHÃES ARAÚJO, A.A.; GUYOT, J.L. Water level dynamics of Amazon wetlands at the watershed scale by satellite altimetry, *International Journal of Remote Sensing*, 33(11), 3323–3353, 2012. <https://doi.org/10.1080/01431161.2010.531914>
- [34] BIRKETT, C. M., MERTES, L. A. K., DUNNE, T., COSTA, M. H., JASINSKI, M. J. Surface water dynamics in the Amazon Basin: Application of satellite radar altimetry, *Journal of Geophysical Research*, 107(D20), 8059, 2002. <https://doi.org/10.1029/2001JD000609>
- [35] DA SILVA SOITO, J.L.; VASCONCELOS FREITAS, M.A. Amazon and the expansion of hydropower in Brazil: Vulnerability, impacts and possibilities for adaptation to global climate change. *Renewable and Sustainable Energy Reviews*, Vol. 15, Issue 6, pp. 3165–3177, 2011. <https://doi.org/10.1016/j.rser.2011.04.006>
- [36] MENDES, C.A.B.; BELUCO, A.; CANALES, F.A. Some important uncertainties related to climate change in projections for the Brazilian hydropower expansion in the Amazon. *Energy*, Vol. 141, p. 123–138, 2017. <https://doi.org/10.1016/j.energy.2017.09.071>
- [37] AYRES, J. M.; DA FONSECA, G. A. B.; RYLANDS, A. B.; QUEIROZ, H. L.; PINTO, L. P.; MASTERSON, D.; CAVALCANTI, R. B. Os Corredores Ecológicos das Florestas Tropicais do Brasil. Sociedade Civil Mamiará, 2005 256p.: il., mapas, 2005. ISBN 85-85924-12-8.
- [38] LEAL, I.R.; DA SILVA, J.M.C.; TABARELLI, M.; LACHER, T.E.JR. Changing the Course of Biodiversity Conservation in the Caatinga of Northeastern Brazil. *Conservation Biology*, 19, 701–706, 2005. <https://doi.org/10.1111/j.1523-1739.2005.00703.x>
- [39] BARROSO, F.R.G.; DOS SANTOS GOMES, V.; CARVALHO, C.E.; LEDRU, M.P.; FAVIER, C.; ARAÚJO, F.S.; BREMOND, L. Phytoliths from soil surfaces and water reservoirs of the Brazilian semi-arid Caatinga. *Journal of South American Earth Sciences*, Vol. 108, 103180, 2021. <https://doi.org/10.1016/j.jsames.2021.103180>
- [40] BARROS DE SÁ, C.S.; KENJI SHIOSAKI, R.; DOS SANTOS, A.M.; DA SILVA CAMPOS, M.A. Salinization causes abrupt reduction in soil nematode abundance in the Caatinga area of the Submedio San Francisco Valley, Brazilian semiarid region. *Pedobiologia*, Vol. 85–86, 150729, 2021. <https://doi.org/10.1016/j.pedobi.2021.150729>
- [41] CREMON, É.H.; PEREIRA, A.C.; DE PAULA, L.D.L.; NUNES, E.D. Geological and terrain attributes for predicting soil classes using pixel- and geographic object-based image analysis in the Brazilian Cerrado, *Geoderma*, Vol. 401, 115315, 2021. <https://doi.org/10.1016/j.geoderma.2021.115315>
- [42] OLIVEIRA, P. S.; MARQUIS, R. J. The Cerrados of Brazil, New York Chichester, West Sussex: Columbia University Press, 2002. <https://doi.org/10.7312/oliv12042>
- [43] ALLAN, C. The Cerrados of Brazil: Ecology and Natural History of a Neotropical Savanna. *Economic Botany* 57(4), 656, 2003. [https://doi.org/10.1663/0013-0001\(2003\)057\[0656:DFABRE\]2.0.CO;2](https://doi.org/10.1663/0013-0001(2003)057[0656:DFABRE]2.0.CO;2)

- [44] LUO, D.; CALDAS, M.M.; GOODIN, D.G. Estimating environmental vulnerability in the Cerrado with machine learning and Twitter data. *Journal of Environmental Management*, Vol. 289, 112502, 2021. <https://doi.org/10.1016/j.jenvman.2021.112502>
- [45] SILVA, T.R.; PENA, J.C.; MARTELLO, F.; BETTIOL, G.M.; SANO, E.E.; MASCIA VIEIRA, D.L. Not only exotic grasslands: The scattered trees in cultivated pastures of the Brazilian Cerrado. *Agriculture, Ecosystems & Environment*, Vol. 314, 107422, 2021. <https://doi.org/10.1016/j.agee.2021.107422>
- [46] DE LIMA, D.O.; CROUZEILLES, R.; VIEIRA, M.V. Integrating strict protection and sustainable use areas to preserve the Brazilian Pampa biome through conservation planning. *Land Use Policy*, Vol. 99, 104836, 2020. <https://doi.org/10.1016/j.landusepol.2020.104836>
- [47] MARENGO J.A., OLIVEIRA G.S., ALVES L.M. (2015) Climate Change Scenarios in the Pantanal. In: BERGIER I., ASSINE M. (eds). *Dynamics of the Pantanal Wetland in South America. The Handbook of Environmental Chemistry*, Vol 37. Springer, Cham. https://doi.org/10.1007/698_2015_357
- [48] GUERRA, A.; REIS, L.K.; BORGES, F.L.G.; OJEDA, P.T.A.; PINEDA, D.A.M.; MIRANDA, C.O.; FURTADO DE LIMA MAIDANA, D.P.; ROCHA DOS SANTOS, T.M.; SHIBUYA, P.S.; MARQUES, M.C.M.; LAURANCE, S.G.W.; GARCIA, L.C. Ecological restoration in Brazilian biomes: Identifying advances and gaps, *Forest Ecology and Management*, Vol. 458, 117802, 2020. <https://doi.org/10.1016/j.foreco.2019.117802>
- [49] FREIRE DA SILVA, E.F.; DE MORAES NOVO, E.M.L.; DE LUCIA LOBO, F.; FARIA BARBOSA, C.C.; TRESSMANN CAIRO, C.; NOERNBERG, M.A.; DA SILVA ROLTA, L.H. A machine learning approach for monitoring Brazilian optical water types using Sentinel-2 MSI. *Remote Sensing Applications: Society and Environment*, 100577, 2021. <https://doi.org/10.1016/j.rsase.2021.100577>
- [50] COSTA, W.; FONSECA, L.; KÖRTING T. Classifying Grasslands and Cultivated Pastures in the Brazilian Cerrado Using Support Vector Machines, Multilayer Perceptrons and Autoencoders. In: Perner P. (eds) *Machine Learning and Data Mining in Pattern Recognition. MLDM 2015. Lecture Notes in Computer Science*, vol 9166, 2015. Springer, Cham. https://doi.org/10.1007/978-3-319-21024-7_13
- [51] ABATZOGLOU, J.; DOBROWSKI, S.; PARKS, S.; HEGEWISCH, K.C. TerraClimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958–2015. *Sci Data* 5, 170191, 2018. <https://doi.org/10.1038/sdata.2017.191>
- [52] DE CASTILHO BERTANI, T.; DE FÁTIMA ROSSETTI, D.; GURGEL ALBUQUERQUE, P.C. Object-based classification of vegetation and terrain topography in Southwestern Amazonia (Brazil) as a tool for detecting ancient fluvial geomorphic features. *Computers & Geosciences*, Vol. 60, p. 41-50, 2013. <https://doi.org/10.1016/j.cageo.2013.06.013>
- [53] LEMENKOV, V.; LEMENKOVA, P. Using TeX Markup Language for 3D and 2D Geological Plotting. *Foundations of Computing and Decision Sciences*, Vol. 46, n. 3, p. 43–69, 2021. <https://doi.org/10.2478/fcds-2021-0004>
- [54] SCHWALBERT, R.A.; AMADO, T.; CORASSA, G.; POTT, L.P.; VARA PRASAD, P.V.; CIAMPITTI, I.A. Satellite-based soybean yield forecast: Integrating machine learning and weather data for improving crop yield prediction in southern Brazil. *Agricultural and Forest Meteorology*. Vol. 284, 107886, 2020. <https://doi.org/10.1016/j.agrformet.2019.107886>
- [55] LEMENKOVA, P. Geomorphological modelling and mapping of the Peru-Chile Trench by GMT, *Polish Cartographical Review*, Vol. 51, n. 4, p. 181–194, 2019. <https://doi.org/10.2478/pcr-2019-0015>
- [56] LEMENKOVA, P. Geophysical Modelling of the Middle America Trench using GMT, *Annals of Valahia University of Targoviste. Geographical Series*, Vol. 19, n. 2, p. 73–94, 2019. <https://doi.org/10.6084/m9.figshare.12005148>
- [57] LEMENKOVA, P.; Gobi Altai, Khangai and Khentii Mountains mapped by a mixed-method cartographic approach for comparative geophysical analysis, *Mongolian Geoscientist*, Vol. 26, n. 52, p. 62–79, 2021. <https://doi.org/10.5564/mgs.v26i52.1512>
- [58] DA SILVA, E. H. F. M.; SILVA ANTOLIN, L. A.; ZANON, A. J. ANDRADE, A. S.; DE SOUZA, H. A.; DOS SANTOS CARVALHO, K.; VIEIRA, N. A.; MARIN, F. R.; Impact assessment of soybean yield and water productivity in Brazil due to climate change, *European Journal of Agronomy*, Vol. 129, n. 126329, 2021. <https://doi.org/10.1016/j.eja.2021.126329>
- [59] DEPAULA, G. The distributional effect of climate change on agriculture: Evidence from a Ricardian quantile analysis of Brazilian census data. *Journal of Environmental Economics and Management*, Vol. 104, 102378, 2020. <https://doi.org/10.1016/j.jeem.2020.102378>
- [60] CARAUTA, M.; TROOST, C.; GUZMAN-BUSTAMANTE, I.; HAMPF, A.; LIBERA, A.; MEURER, K.; BÖNECKE, E.; FRANKO, U.; DE ARAGÃO RIBEIRO RODRIGUES, R.; BERGER, T.; Climate-related land use policies in Brazil: How much has been achieved with economic incentives in agriculture? *Land Use Policy*, Vol. 109, n. 105618, 2021. <https://doi.org/10.1016/j.landusepol.2021.105618>
- [61] VILANOVA, R.S.; DELGADO, R.C.; DE ANDRADE, C.F.; DOS SANTOS, G.L.; MAGISTRALI, I.C.; DE OLIVEIRA, C.M.M.; TEODORO, P.E.; SILVA, G.F.C.; DA SILVA JUNIOR, C.A.; DE ÁVILA RODRIGUES, R. Vegetation degradation in ENSO events: Drought assessment, soil use and vegetation evapotranspiration in the Western Brazilian Amazon. *Remote Sensing Applications: Society and Environment*, Vol. 23, 100531, 2021. <https://doi.org/10.1016/j.rsase.2021.100531>
- [62] FERREIRA, L.B.; DA CUNHA, F.F.; DE OLIVEIRA, R.A.; FILHO, E.I.F. Estimation of reference evapotranspiration in Brazil with limited meteorological data using ANN and SVM – A new approach, *Journal of Hydrology*, Vol. 572, p. 556-570, 2019. <https://doi.org/10.1016/j.jhydrol.2019.03.028>
- [63] MONTOYA, M.A.; ALLEGRETTI, G.; SLEIMANN BERTUSSI, L.A.; TALAMINI, E. Renewable and Non-renewable in the energy-emissions-climate nexus: Brazilian contributions to climate change via international trade. *Journal of Cleaner Production*, Vol. 312, 127700, 2021. <https://doi.org/10.1016/j.jclepro.2021.127700>
- [64] HAMPF, A.C.; STELLA, T.; BERG-MOHNICKE, M.; KAWOHL, T.; KILIAN, M.; NENDEL, C. Future yields of double-cropping systems in the Southern Amazon, Brazil, under climate change and technological development, *Agricultural Systems*, Vol. 177, 102707, 2020. <https://doi.org/10.1016/j.agry.2019.102707>
- [65] EVANGELISTA-VALE, J.C.; WEIHS, M.; JOSÉ-SILVA, L.; ARRUDA, R.; SANDER, N.L.; GOMIDES, S.C.; MACHADO, T.M.; PIRES-OLIVEIRA,

J.C.; BARROS-ROSA, L.; CASTUERA-OLIVEIRA, L.; MIRANDA MATIAS, R.A.; MARTINS-OLIVEIRA, A.T.; SÃO BERNARDO, C.S., SILVA-PEREIRA, I.; CARNICER, C.; CARPANEDO, R.S.; EISENLOHR, P.V. Climate change may affect the future of extractivism in the Brazilian Amazon. *Biological Conservation*, Vol. 257, 109093, 2021. <https://doi.org/10.1016/j.biocon.2021.109093>

[66] CAVIGLIA-HARRIS, J. L. Agricultural innovation and climate change policy in the Brazilian Amazon: Intensification practices and the derived demand for pasture, *Journal of Environmental Economics and Management*, Vol. 90, p. 232-248, 2018. <https://doi.org/10.1016/j.jeem.2018.06.006>

[67] ALVES, L.M.; CHADWICK, R.; MOISE, A.; BROWN, J.; MARENGO, J.A. Assessment of rainfall variability and future change in Brazil across multiple timescales. *International Journal of Climatology*, Vol. 41 (Suppl. 1): E1875–E1888, 2021. <https://doi.org/10.1002/joc.6818>

[68] XAVIER, A.C.; KING, C.W.; SCANLON, B.R. Daily gridded meteorological variables in Brazil (1980–2013). *International Journal of Climatology*, Vol. 36, p. 2644–2659, 2016. <https://doi.org/10.1002/joc.4518>

[69] CARRANZA, T.; MANICA, A.; KAPOV, V.; BALMFORD, A. Mismatches between conservation outcomes and management evaluation in protected areas: A case study in the Brazilian Cerrado. *Biological Conservation*, Vol. 173, p. 10–16, 2014. <https://doi.org/10.1016/j.biocon.2014.03.004>

[70] CARRANZA, T.; BALMFORD, A.; KAPOV, V.; MANICA, A. Protected Area Effectiveness in Reducing Conversion in a Rapidly Vanishing Ecosystem: The Brazilian Cerrado. *Conservation Letters*, Vol. 7, p. 216–223, 2014. <https://doi.org/10.1111/conl.12049>

[71] D'AMICO, A.R.; CORTES FIGUEIRA, J.E.; CÂNDIDO-JR, J.F.; DRUMOND, M.A. Environmental diagnoses and effective planning of Protected Areas in Brazil: Is there any connection? *PLoS ONE*, Vol. 15(12), p. e0242687, 2020. <https://doi.org/10.1371/journal.pone.0242687>

[72] RYLANDS, A.B.; BRANDON, K. Brazilian protected areas. *Conservation Biology*, Vol. 19, p. 612–618. <https://doi.org/10.1111/j.1523-1739.2005.00711.x>

[73] ROCHA, G. F.; GUIMARÃES FERREIRA, L.; CLEMENTINO FERREIRA, N.; EDUARDO FERREIRA, M. Detecção de desmatamentos no bioma Cerrado entre 2002 e 2009: padrões, tendências e impactos. *Revista Brasileira de Cartografia*, Vol. 63, n. 3, p. 341–349, 2012.