Application Report
Colombia Temperature-Precipitation Patterns (1990-2023)

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1 INTRODUCTION

Colombia's immense biodiversity is closely tied to its climatic variability, with temperature and precipitation as key factors shaping its diverse ecosystems [1], [2]Colombia's unique geography creates distinct weather, from the cold Andean mountains to the warm Amazon. Besides being a Tropical Country near the equator and not having seasons, this weather variance influences both its rich biodiversity and the cultural practices of its people. This rainfall pattern's variability is intensified by Colombia's complex topography, making the analysis of these variables essential for understanding and preserving its natural and cultural landscapes.

In this project, official precipitation data from meteorological stations across Colombia was used, obtained from the official website of IDEAM, the national authority for environmental monitoring. Additionally, the Oceanic Niño Index (ONI), a key metric for assessing the intensity of the El Niño-Southern Oscillation (ENSO) phenomenon, was included with monthly data frequency. ENSO, driven by temperature fluctuations in the Pacific Ocean, profoundly impacts global weather patterns, notably affecting Colombia's rainfall distribution. This phenomenon was selected due to its critical role in driving interannual climate variability in Colombia and its historical association with some of the country's most extreme weather events.[3], [4], [5]. In Colombia, during a La Niña phase (ONI $\leqslant$ -0.5), rainfall typically intensifies, leading to wetter-than-average conditions and an increased likelihood of severe weather events. Conversely, in an El Niño phase (ONI $\geqslant$ 0.5), the country experiences prolonged dry spells, often resulting in droughts and markedly reduced rainfall. These ONI thresholds serve as critical indicators, allowing for the prediction and management of these contrasting climatic extremes.

However, in some regions, particularly remote areas near Colombia's Amazon in the southeast, continuous or sufficient records were not available. To fill this gap, Level 3 satellite datasets providing precipitation and temperature estimates were used (Terraclimate and CHIRPS, see data report for more details). The official Colombia rainfall datasets from 1990 to 2023 with a monthly basis record frequency and auxiliary data from before-mention satellite datasets, were integrated to construct the map presented in Figure 9. Combining in situ and remote data enabled a more comprehensive spatial and temporal representation of the climatic variables, especially in areas where ground measurements are scarce or unavailable.

2 SOLUTION

The map consists of three key sections. The main layout feature is a bivariate classification of precipitation and temperature, illustrating how these two variables interact across Colombia. Creating an effective colour ramp to represent the combinations of values posed a challenge, which was resolved by using vectorization and post-distribution shape analysis through histograms. The two additional sub-maps provide essential context: the first shows the distribution of stations used in the study, emphasizing the IDEAM measurement network, and the second displays monthly precipitation isoregions. This regional breakdown is essential for understanding Colombia's weather, where distinct rainfall patterns arise not from traditional seasons shifting but from macroclimatic influences such as ENSO and the country's diverse topography. Finally, the analysis includes a review of the IDEAM in situ precipitation data, underscoring the value of local measurements, their consistency in data recording and how they can work for refining climate related level 3 datasets.

3 ANALYSIS PROCESSES

For this project, 2 Python scripts were used to access, process, and manipulate the original data. Techniques for vectorization, classification, and styling were applied to represent both polygons and point clouds in the map with SuperMap iDesktopX 11. For a detail process description of these scripts, please refer to *data description* documents and video explanation.

Additionally, a model builder was developed in SuperMap to automate the isohyets generation and analysis process (see Figure 1). The main dataset had an original dimensionality of 262,532 points with 25 attributes (columns), corresponding to 427 stations from 1950 to 2023, distributed across the 32 departments (Colombia's first-level administrative level). This work strengthened Colombia's climate analysis and established a foundation for future studies integrating in situ and satellite data through SuperMap software's suite.

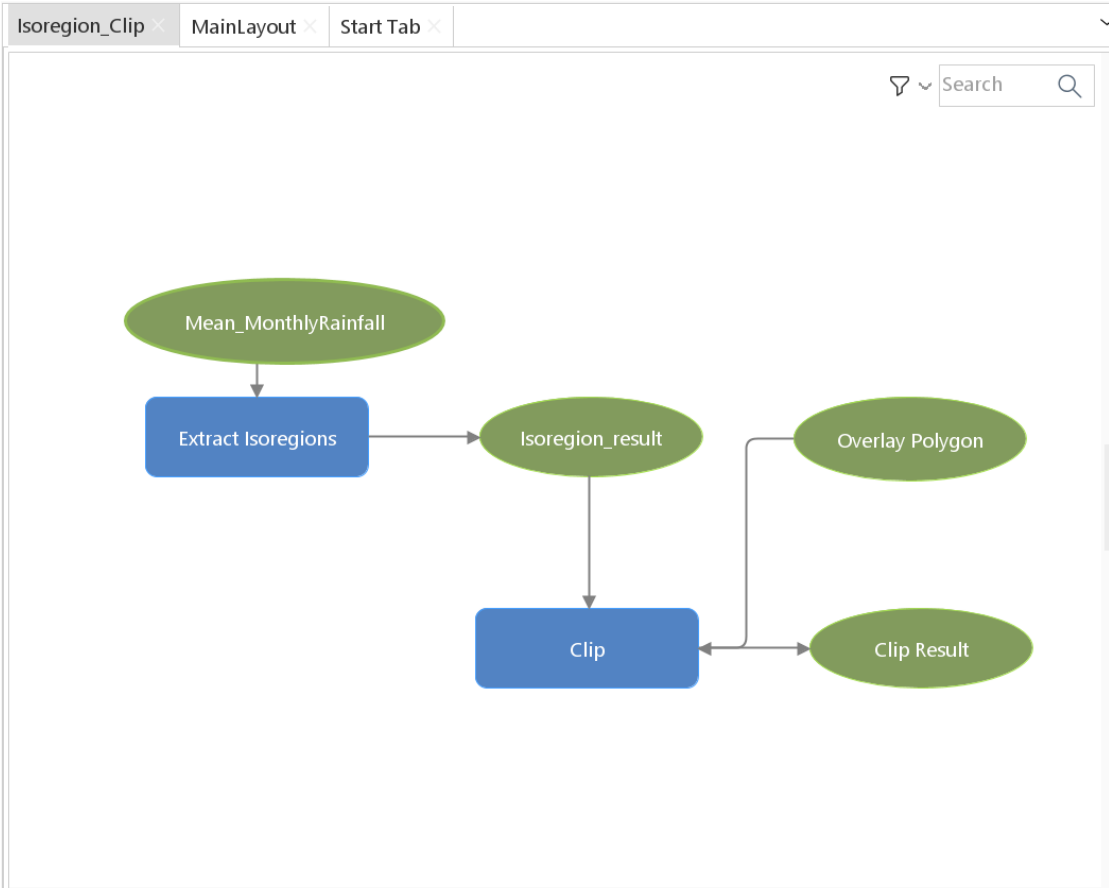

Figure 1 Model Builder in SuperMap for monthly isohyets generation.

3.1 Missing Records Analysis

Monthly rainfall records from IDEAM's official monitoring network were downloaded for analysis (available [6]). Selection criteria, including record length, data accessibility, and cut-off dates, meant that not all available stations were used; however, a substantial sample was processed to ensure broad representation across all Colombian departments.

For each station, the expected number of monthly records was calculated based on the first and last recorded dates. This expected count often differs from the actual records due to occasional gaps in data acquisition. For instance, a station with 10 years of records would ideally contain 120 data points, though interruptions in data collection might reduce the total.

Finally, the completeness percentage for each station was aggregated at the department level to provide an overview of data reliability across regions. This departmental completeness metric offers critical insights into data consistency, supporting more robust climate analyses on a regional scale.

3.2 Rainfall Anomalies

The multiannual monthly mean was calculated for each station, creating a time index by month and year. This index was then joined with ONI values from NOAA records, allowing the identification of each period's Niño or Niña phase. This resulted in a column indicating the ENSO phase type for each time index.

Using this table, multiannual monthly means were calculated separately for records associated with El Niño and La Niña phases. Finally, for each station, the mean values were subtracted from those recorded during extreme ENSO phases, as indicated by the ONI, to determine the anomaly for each phase at each station.

3.3 Vectorisation

Using multi-year raster records from the TerraClimate and CHIRPS level 3 remote sensing datasets, representative rasters of Colombia's temperature and precipitation patterns were generated. These rasters provide a comprehensive view of these two key climatic variables across Colombian territory.

Each pixel from these raster datasets was then vectorized into a point format (see Figure 2), with precipitation and mean temperature values retained for each point through stacking. This transformation allowed for the efficient handling of both spatial and attribute data for further analysis.

A total of 16 classes were created by categorizing each variable into four distinct levels. This classification scheme facilitated the construction of a bivariate map, visually capturing the interplay between temperature and precipitation across Colombia, with each combination of temperature and precipitation levels represented by a unique class.

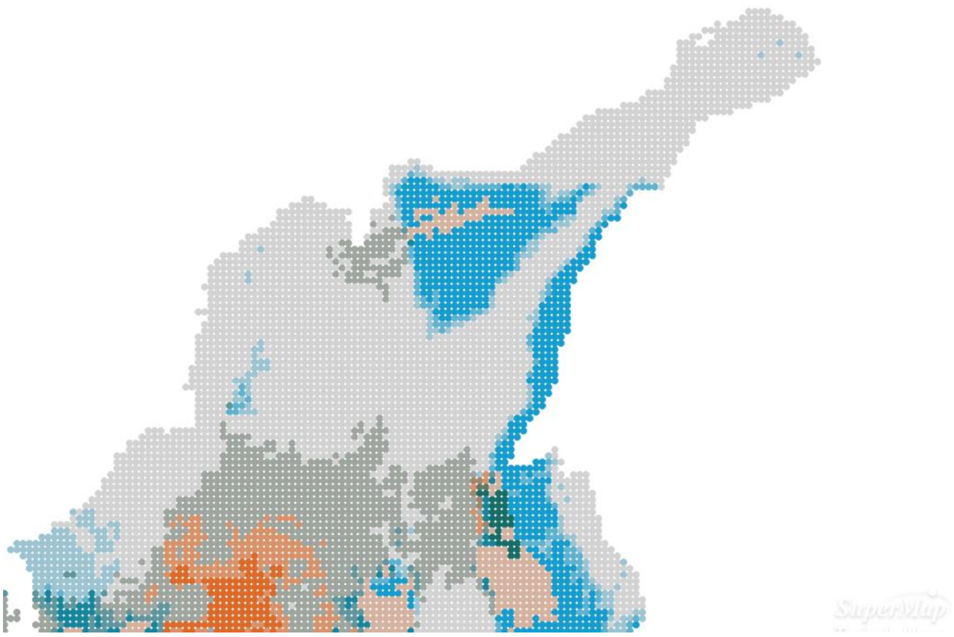

Figure 2 Vectorisation as point cloud from Raster level 3 data classified by bivariate analysis of temperature and precipitation.

4 RESULTS

Bivariate Classes: The bivariate map features 16 classes derived from the distribution of precipitation and temperature variables, with a difference of more than 20°C and 600 mm of rainfall across different regions in the country around the year. The point cloud was generated in Python using *rasterio* library and subsequently classified in SuperMap. This analysis reveals arid zones in the northern part of the country, with notable exceptions such as the Sierra Nevada de Santa Marta. In the southeastern region, before transitioning into the Amazon, similar arid conditions are also observed. The central region showcases high variability in climatic conditions, influenced by the presence of the three mountain ranges (Andes Mountains branches). Each of these geographic features plays a crucial role in shaping the local climate and ecosystems. See Figure 3.

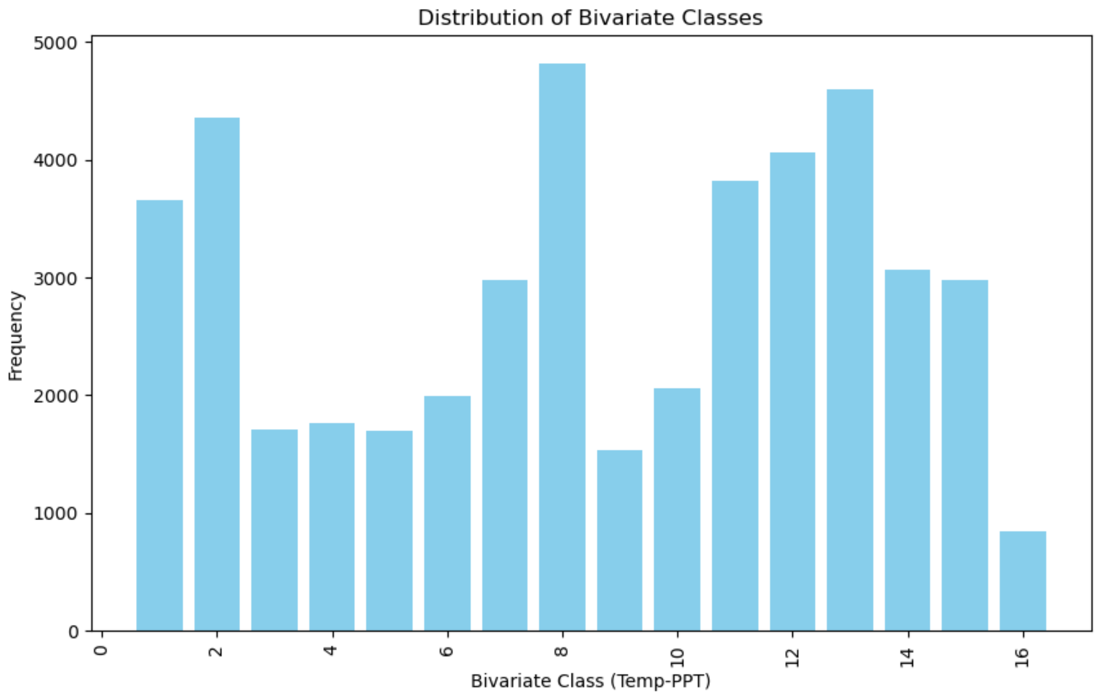

Figure 3 Histogram of bivariate data for class pair definition on variables rainfall-temperature.

The 16 classes come from 4 level classifications (low, mid-low, mid-high and high) in each variable represents the behaviour in temperature and precipitation according to the range that was found in the data. Each class description can be found in Table 1 and in the legend presented on Figure 4.

Table 1 Classes description for temperature precipitation bivariate mapping

Class	Description
1	Low Temperature | Low Precipitation
2	Low Temperature | Mid-Low Precipitation
3	Low Temperature | Mid-High Precipitation
4	Low Temperature | High Precipitation
5	Mid-Low Temperature | Low Precipitation
6	Mid-Low Temperature | Mid-Low Precipitation
7	Mid- Low Temperature | Mid-High Precipitation
8	Mid-Low Temperature | High Precipitation
9	Mid-High Temperature | Low Precipitation
10	Mid-High Temperature | Mid-Low Precipitation
11	Mid-High Temperature | Mid-High Precipitation
12	Mid-High Temperature | High Precipitation
13	High Temperature | Low Precipitation
14	High Temperature | Mid-Low Precipitation
15	High Temperature | Mid-High Precipitation
16	High Temperature | High Precipitation

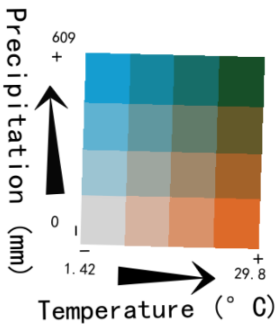

Figure 4 Bivariate Map legend made in SuperMap for Colombia's Temperature and precipitation analysis.

Multiannual Monthly Isoregions: Isoregions represent areas with similar precipitation levels, helping to illustrate the distribution of rainfall across a region. In this analysis, the precipitation range spans from 0 to nearly 700 mm. Notably, the eastern part of Colombia experiences marked rainy seasons, particularly in June, July, and August. Conversely, the western regions typically register higher precipitation levels, with peak values occurring in March, April, and May. These isoregions provide valuable insights into the temporal and spatial variability of rainfall, contributing to a better understanding of regional climatic patterns and their implications for biodiversity and human activities. See Figure 5 for the result.

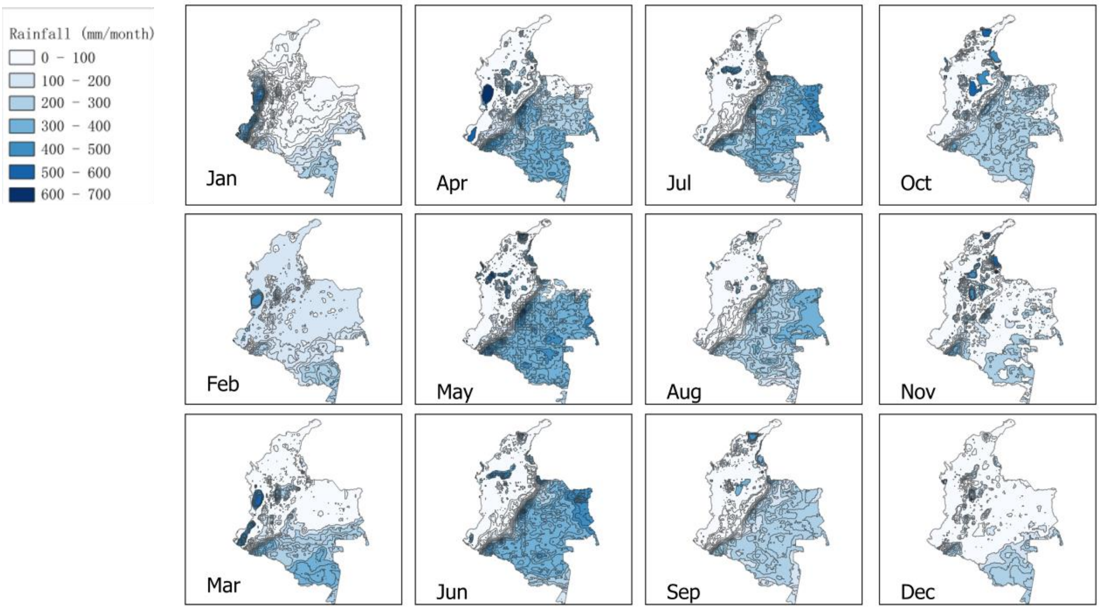

Figure 5 Multiannual monthly isohyets (rainfall isoregions) across Colombia, generated from CHIRPS pentad data sources, GEE and SuperMap

Aggregated Map of Station Distribution: This map illustrates the spatial distribution of the 427 stations from which monthly precipitation data were downloaded. It clearly shows that the central region of Colombia has the highest concentration of stations, reflecting a more extensive network for monitoring precipitation. In contrast, the Amazon region and the Eastern Plains have fewer stations, indicating a sparser distribution of meteorological resources in these areas. This disparity in station distribution highlights the challenges of obtaining comprehensive precipitation data in less populated and more remote regions. See Figure 6 for more details.

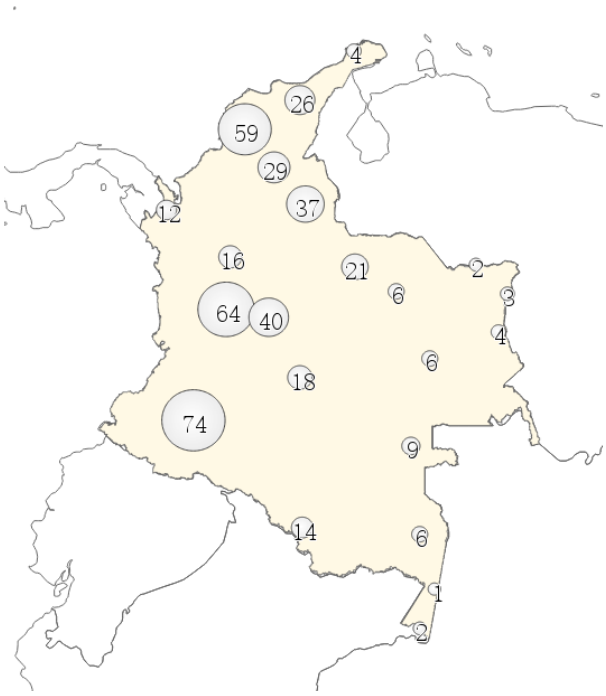

Figure 6 Data aggregation of downloaded stations from IDEAM network.

Anomalies due to ENSO histogram: More than 50% of the precipitation anomalies fall between -20 and 8 mm, indicating a significant range of variability influenced by climatic patterns. These data were temporally related to the ONI records from NOAA, which serve as crucial indicators for identifying El Niño and La Niña events. Specifically, a threshold of +0.5°C in the ONI indicates an El Niño event, while a threshold of -0.5°C signifies a La Niña event. This relationship underscores the impact of ENSO phenomena on precipitation anomalies in the region, reflecting the broader climatic shifts that occur during these periods. See Figure 7 for more details.

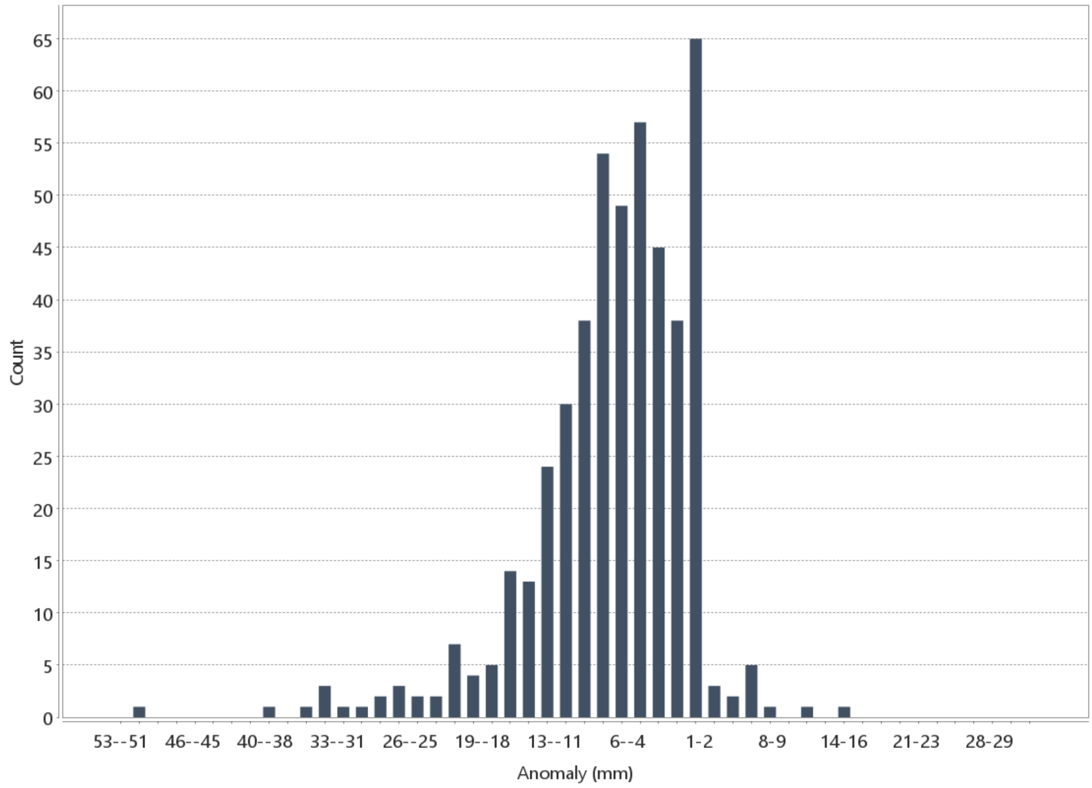

Figure 7 Rainfall anomalies histograms due to ENSO accross Colombia

Count bar diagram grouped by Colombia's admin level 1: In the count bar diagram, the top three departments with the highest precipitation records are Meta, Bolívar, and Cesar. This is particularly interesting because none of these departments have the highest number of monitoring stations. Conversely, in the top three departments with the fewest records, two of them—Amazonas and Guainía—are in the eastern region of Colombia, consistent with the spatial distribution observed in the previous maps. This discrepancy highlights the challenges of data availability and variability in precipitation across different regions of the country. See Figure 8 for more information.

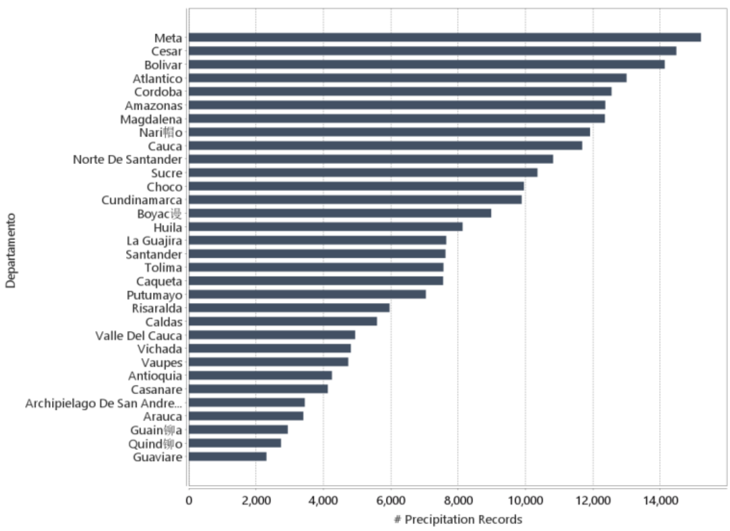

Figure 8 Count bar of the number of monthly records grouped by admin level 1

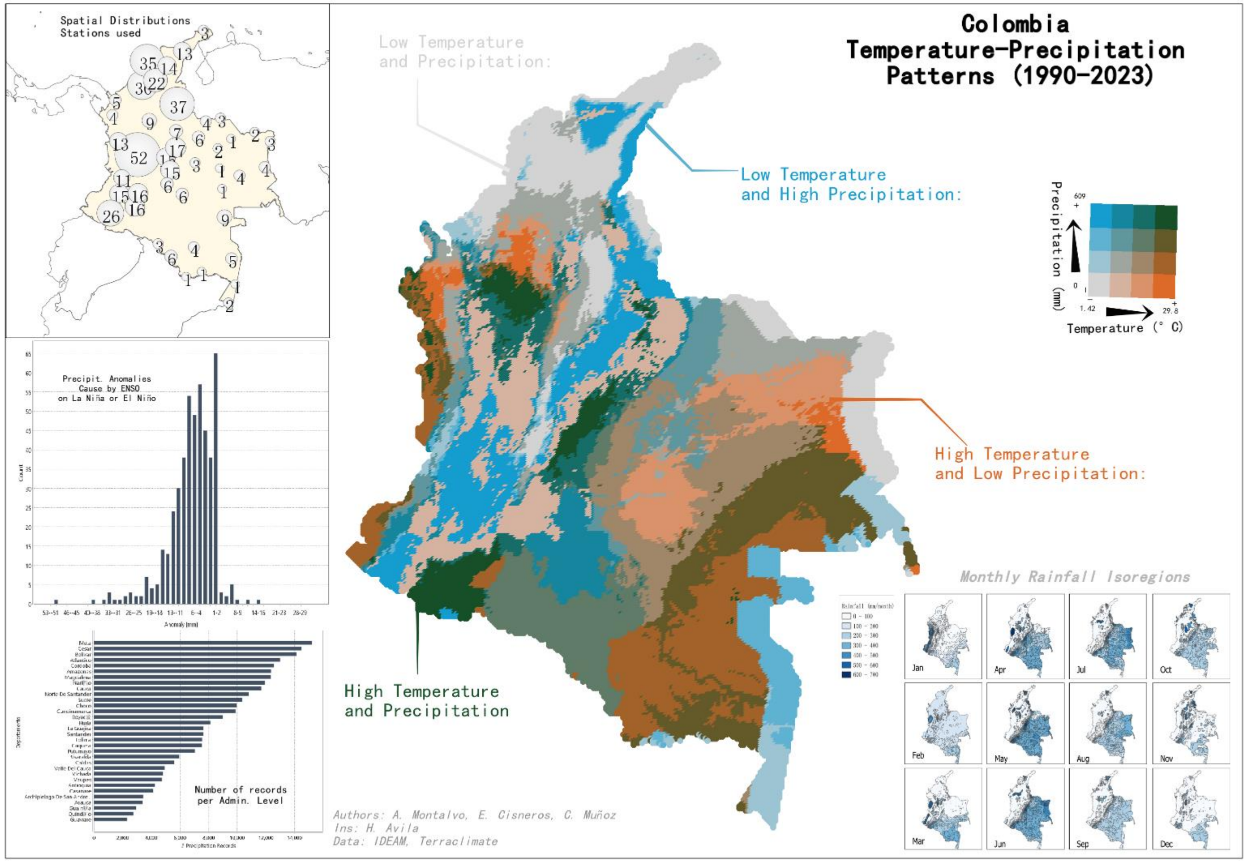

Figure 9 Main Map Result, with Bivariate Classification, Data aggregation and Diagrams.

5 REFERENCES

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