Climatology and significant trends in maximum, minimum and average air temperatures in Alagoas, Northeast Brazil

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Research Article

Keywords: air temperature, cluster analysis, Mann-Kendall, climate change

Posted Date: September 7th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1667095/v1

Additional Declarations: No competing interests reported.

Version of Record: A version of this preprint was published at Theoretical and Applied Climatology on January 11th, 2023. See the published version at https://doi.org/10.1007/s00704-023-04358-8.

Abstract

The increase in air temperature can generate several environmental and socioeconomic impacts, so the main objective of this study was to characterize the monthly and annual profiles of maximum, minimum and average air temperatures and to identify whether there are significant trends in the time series of each, for the state of Alagoas, Brazil. For this, monthly data on maximum and minimum air temperatures (1980 to 2013) were used for 98 of the 102 municipalities in Alagoas. With the data in hand, the average air temperature was calculated and cluster analysis was applied to determine homogeneous sub-regions of the average air temperature. Trend analyzes were verified using nonparametric Mann-Kendall (sign of trend), Sen (magnitude of trend) and Pettitt (beginning of trend) tests. Analysis of variance (ANOVA) was used to verify differences between the decennial averages air temperatures. The statistical significance adopted was 5%. The results showed that the state of Alagoas has four sub-regions with homogeneous characteristics according to average air temperature. Sub-region 4 (S4), located in the Sertão (scrubland region) of Alagoas, had the highest average, maximum and minimum air temperatures, monthly and annually. Annually, significantly increasing trends were observed at 5% in the four sub-regions, with emphasis on S4, with increases above 1.0°C/décade in average, maximum and minimum temperatures. It is noteworthy that throughout the state of Alagoas, a significant trend of increase in the average air temperature was identified during the 34 years analyzed, highlighting the possible impacts of climate change.

Introduction

Air temperature is one of the main climatic elements, with large direct effects on many physiological processes that occur in living orgamisms, thus being fundamental in several sectors of the economy and areas of knowledge, such as agriculture, environmental analysis and geosciences, among others (Medeiros et al., 2005). The increase in temperature can cause several ecological and social problems, especially for economically vulnerable regions such as Northeast Brazil (NEB) (Marengo et al., 2017). Understanding the relationship between climate change and anthropogenic activities has become a matter of central importance in several areas of science (Fischer et al., 2013; King et al., 2015; Schleussner et al., 2016).

Mahlstein et al. (2011) argued that most global warming in the last half of the 20th century can be attributed to human influence, especially the intensification of greenhouse gas (GHG) emissions. The increase of these gases in the atmosphere has increased along with urban development and industrialization. Argüeso et al. (2014) found that the influence of urbanization on the air temperature occurs at a local scale, and that it can contribute to larger scale warming by changing the energy balance (on the surface) and intensifying the emission of GHGs.

In the tropical region, the air temperature is on average higher than in other regions of the globe, and also presents less variability. However, possible trends and/or changes can cause changes in the most diverse sectors of the environment and society. One of the consequences is that the increase in temperature is causing a rise in sea level, representing a major challenge mainly for socioeconomic adaptation in coastal areas (Schaeffer et al., 2012; Jevrejeva et al., 2019). The warming of the air also favors greater frequency and magnitude of some extreme meteorological and hydrological events, such as an increase in the intensity of precipitation in some regions, and droughts in others (Orlowsky and Senevirtne, 2012).

Several studies point to forecasts that air temperature will increase at the global level due to human actions. Schleussner et al. (2016) assessed the main impacts of climate change at warming levels of 1.5°C and 2°C, including extreme weather events, water availability, agricultural yields, sea level rise and risk of coral reef loss, mainly in tropical regions, and that an increase of 0.5°C can still generate relevant impacts in these respects. The Intergovernmental Panel on Climate Change (IPCC), in its fifth Assessment Report (AR5) on global climate change, stated that global warming is unequivocal (IPCC, 2014). Among the main conclusions of this report was an increase in the average global air temperature between 1880 and 2012 on the order of 0.85°C, with the last three decades being the warmest since 1850, and that if GHG are not reduced drastically, the temperature increase could reach 4.8°C by 2100. Recently, the sixth report (AR6) of the IPCC (2021) was released, which found that the temperature increase in the last 50 years has occurred faster than in the last two millennia, and that global warming of 1.1°C has occurred in the past 150 years, with the burning of fossil fuels being the main cause. It is also noteworthy that at the current trend of GHG emissions, the planet will warm by 1.5°C in all scenarios, reaching this increase as early as the 2030s.

In this context, Marengo and Bernasconi (2015) warned that the increase in air temperature favors an increase in drought in the NEB region, resulting in a reduction in the amount of soil water, an increase in aridity, which together with the misuse of the soil may increase the risk of desertification in parts of NEB. Da Silva et al. (2018), using data from 1980 to 2013, obtained similar results regarding the increase in air temperature indices for NEB. Costa et al. (2020) analyzed the indices of climatic extremes for NEB from 1961 to 2014 and found, in recent decades, significantly decreasing trends in the number of cold days and nights, and increases in the number of hot days and nights.

The variations in maximum, minimum and average air temperatures by sub-regions of the state of Alagoas (in NEB) are not yet fully known. Therefore, in addition to a better understanding of regional and temporal characteristics of air temperature, it is necessary to verify if there is a trend with statistical significance in spatial (by sub-regions) and temporal (monthly, annual and by decades) variability in order to improve understanding and contribute to future studies of the influences of these variabilities on the environment, economy and society, among other aspects. Hence, the main objective of this study was to characterize the monthly, annual and decennial profiles of maximum, minimum and average air temperatures, by sub-regions, in the state of Alagoas, NEB, and to identify whether there are significant trends in the time series in each case.

Material And Methods

Study area

The state of Alagoas (between latitudes 8°48'S and 10°30'S and longitudes 38°15'W and 35°09'W), located in the NEB region, has 102 municipalities, divided into three mesoregions, Leste (east), Agreste (wilderness) and Sertão Alagoano (scrublands), according to the Brazilian Institute of Geography and Statistics (IBGE, 1990). Altitudes are below 850 m above sea level, and more than 80% of the state is below 300 m (Fig. 1). The area is 27,779,343 km², which represents 0.3% of Brazilian territory (Assis et al., 2007).

According to the Köppen classification, the state has two climatic types: tropical rainy (A) and semiarid (B) to the east and west, respectively (Alvares et al., 2013). On the coast, water availability is greater compared to the west, which has predominance of water deficit for most of the year (Cabral Júnior and Bezerra, 2018; Medeiros et al., 2021; Rodrigues et al., 2021). These characteristics also affect the type of vegetation, with the presence of the Atlantic Forest Biome and the Caatinga Biome being observed in the state (IBGE, 2004).

Data

Initially, the latitude and longitude data for each municipal centroid point were tabulated, totaling 102 (number of municipalities in Alagoas). From this information, monthly data of maximum and minimum air temperatures was extracted, from 1980 to 2013, in 98 of the 102 municipalities in Alagoas.

These data are freely available at https://utexas.app.box.com/v/Xavier-etal-IJOC-DATA and were organized and validated by Xavier et al. (2015), who used different databases from different research institutions in Brazil to expand and improve the temporal and spatial distribution of meteorological data, with spatial resolution of 0.25° x 0.25°.

Methodological procedures

With the data, the average air temperature (tmed) was calculated from the values of maximum temperature (tmax) and minimum temperature (tmin). Then, cluster analysis (multivariate statistical technique) was used to define which centroid points belonged to a given sub-region with approximately homogeneous tmed characteristics. The spatial and temporal distributions of air temperatures were computed using the inverse distance weighted (IDW) interpolation method.

Cluster analysis

Cluster analysis defines different groups that present elements with similar characteristics within each cluster. To obtain the similarity between the groups, the Euclidean distance method was used, which according to Mimmack et al. (2001) is one of the measures indicated for the regionalization of climate data, being expressed by:

$$d\left(X_i, X_j\right) = \left[\sum_{k=1}^{p} \left(X_{i,k} - X_{j,k}\right)^2\right]^{\frac{1}{2}} \quad (1)$$

Where: $X_{i,k}$ and $X_{j,k}$ are the elements to be compared,$X_i \neq X_j = 1, \ldots, n$ (total number of the sample), of the Kth variable of each sample element; and p represents the number of variables.

The hierarchical approach was used, whose linkage method was the same as adopted by Ward (1963) (minimum variance), based on analysis of variance. The sum of squares within each group was verified from the square of the Euclidean distance of each element belonging to each group, according to Eq. 2.

$$w = \sum_{g=1}^{G} \sum_{i=1}^{n_g} \| X_i - \bar{X}_g \| = \sum_{g=1}^{G} \sum_{i=1}^{n_g} \sum_{k=1}^{k} \left(X_{i,k} - \bar{X}_{g,k} \right) \quad (2)$$

Where: W represents the Ward linkage function, given by the sum of squares within each group (G_i) (measure of homogeneity); G is the number of elements in group G_i in step k of the grouping process; $X_{i,k}$ is the vector of observations of the k-th element that belongs to the i-th group; and $\bar{X}_g$ is the centroid of group G_i.

Trend analysis (Mann-Kendall; Sen and Pettitt)

Mann-Kendall test

With the monthly time series of 34 years of data and air temperatures for the state of Alagoas (Tmax, tmin and tmed), statistical tests were applied to analyze signs and characteristics of trends (increase or decrease in air temperature), for each municipality of Alagoas.

For each time series of air temperatures (monthly and annual), we determined whether there was a significant trend from the nonparametric test proposed by Mann-Kendall (Mann, 1945; Kendall, 1975; Kendall and Gibbons, 1990). The test's steps are defined in equations 3, 4, 5 and 6.

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i=1} sign(x_j - x_i) \quad (3)$$

Where: S is the result of the sum of the counts of $(x_j - x_i)$; x_j is the first value after x_i; and $n$is the number of time series data elements. The following values are assigned to each data pair:

$$sign = \begin{cases} +1 if \left(x_j - x_i\right) > 0 \\ 0 if \left(x_j - x_i\right) = 0 \\ -1 if \left(x_j - x_i\right) < 0 \end{cases} \quad (4)$$

The probability distribution of the S statistic tends to normality when there are large samples of observations (n), with zero mean and variance given by:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p\left(t_p - 1\right)\left(2t_p + 5\right)\right] \quad (5)$$

Where: t_p is the number of data elements with equal values in a certain group; and *q* is the number of groups containing equal values in the data series in group *p*.

The Mann-Kendall test statistic is based on the value of the ZMK variable, calculated according to Eq. 6:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, if S > 0 \\ 0, if S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, if S < 0 \end{cases} \quad (6)$$

Sen's test

From the Mann-Kendall test alone it is not possible to verify the magnitude of the trend. Therefore, it became necessary to apply Sen's nonparametric statistical estimator (1968), which calculates this magnitude, based on Eq. 7.

$$S_e = \frac{x_j - x_i}{j - i} \text{ for i = 1, 2, 3 ..., N.} \quad (7)$$

Where x_j and x_i are the values of x at instants j and i respectively, for j > i.

The average intensity of the trend was obtained by the median of the N values of the slope of Sen (S_e), that is, the increase or decrease as a function of time.

Pettitt test

To complement the trend analysis, the Pettitt test was adopted (Pettitt, 1979), also a nonparametric statistical test, which identifies the time when there was a break in the temporal structure. The procedure establishes whether the time series, subjected to a test of homogeneity of two subsamples, $X_1,\ldots,X_t$ and $X_{t+1},\ldots, X_T$, belong to the same population and identifies if there are significant differences in the mean between the two. For that, the frequency that a data element from the first sample is greater than that from the second was counted through Eq. 8.

$$U_{t,N} = U_{t-1,N} + \sum_{j=1}^{N} sgn\left(x_t - x_j\right) \text{ for t= 2, 3, ..., N.} \quad (8)$$

From the Pettitt test, it is possible to identify the existence of a sudden change in the time series. The critical value of the $k_{(t)}$ statistic and the p-value of the (p) statistic are given by the equations:

$$K_{(t)} = Max_{1 \le t \ge N} \left|U_{t,N}\right| \text{ for t= 2, 3, ..., N.} \quad (9)$$

$$p = 2e^{\frac{-6(K_{N})^2}{N^2+N^3}} \text{ for t= 2, 3, ..., N.} \quad (10)$$

Analysis of variance (ANOVA) and Tukey test

Finally, ANOVA was applied to identify the existence of air temperature change over decades, comparing the average air temperature by decades (1980–1989, 1990–1999 and 2000–2010). This analysis was performed for tmax, tmin and tmed. The F-test statistic consists of the relationship between the mean squares of the variable decades with 3 degrees of freedom and the residual (Hirsch et al., 1992; Montgomery and Runger, 2003; Hoffmann, 2011). The assumptions of normality (Shapiro-Wilk), independence (Durbin-Watson) and homoscedasticity (Bartlett) were verified by the analysis of residuals.

The multiple comparison test proposed by Tukey (1949), which consists of defining significant differences between the means (Hoffmann, 2011), was also used as a way to complement the analyses, because ANOVA is limited to only identifying whether or not there is a significant difference.

In all tests applied in this study, a level of statistical significance of 5% and/or 1% was considered, and the analyes were performed using the free statistical software R 3.3.1.

Results And Discussion

The cluster analysis provided the division of sub-regions with homogeneous characteristics in the state of Alagoas, considering the average monthly air temperature. From the cluster 4 onwards, the sum of squares remained approximately constant (Fig. 2-a), so this was the number considered to subdivide the state into four sub-regions, whose municipal centroid points were grouped and demonstrated through a dendrogram (Fig. 2-b), with the respective cutout (red line) used to divide the number of groups according to the Euclidean distance method and the hierarchical grouping using Ward's linkage technique. The number of municipalities belonging to each sub-region is shown in Table 1.

Alagoas has 102 municipalities, 30.4% of them in Sub-region 1 (S1), which is located in the east of the state, covering most of the coastline. Sub-region 2 (S2) has 31.4% of the municipalities, characterized by higher altimetry, in average terms, reaching over 700 m at some points, most of them located in the north of the state on the border with the state of Pernambuco, located predominantly on the Borborema Plateau, as already described by Côrrea et al. (2010) and Monteiro and Côrrea (2020). Sub-region 3 (S3) has the largest number of municipalities (33.3%), with predominance of depressions, occupying the south and central-west of the state. Sub-region 4 (S4) has only 5 municipalities, located in the west of the state between the municipalities of S3, in the Sertão de Alagoas.

Figures 4 and 5 show the spatial and temporal variability of the average air temperature in Alagoas. The highest values were recorded in the months between December and March, (Southern Hemisphere summer), with temperatures above 28°C, while the winter (June, July and August) presented the lowest average temperatures, oscillating 21 and 23°C (Fig. 4).

For the months of transition seasons, April-May and October-November, temperatures varied most frequently in the range between 24 and 26°C. However, they had their own seasonal characteristics, in which in the autumn months there is successive cooling of the air with the approach of winter and the opposite occurring in spring. These variations are expected as a function of the geographic location and the apparent annual movement of the sun, according to Medeiros et al. (2005) and Cabral Júnior et al. (2013).

In annual terms (Fig. 5), in most of Alagoas the average annual temperature was 25°C, with the lowest and highest average values varying, respectively, between 23.5 and 26.3°C. S2 stands out for having the lowest mean temperature, and the municipality of Chã Preta, which is located on the Borborema Plateau, had the lowest average annual temperature (23.5°C). In turn, the highest temperatures were concentrated in the west, with São José da Tapera and the other four S4 municipalities having the highest yearly average (26.3°C).

The average maximum temperatures were also analyzed (Figs. 6 and 7). The highest monthly average values occurred in the months between November and March, when temperatures exceeded 30°C, with 34.1°C being the maximum value, covering the entire summer period. On the other hand, the winter period (JJA) had the lowest average maximum temperatures, below 27°C, except in S4 (Fig. 6). The April-May and September-October period had similar variation, with temperatures in the range between 27 and 32.5°C.

In most of Alagoas the annual averages of maximum temperatures oscillated between 29 and 30°C, with the lowest and highest average values ranging, respectively, between 28 (in S2) and 31.5°C (in S2) (Fig. 7). S4 (with 5 municipalities) stood out for having the highest annual values of maximum temperature, on average.

For the average minimum temperatures (Figs. 8 and 9), the variation was from 17.5 to 24°C, with highest average monthly values in the months between December and April, exceeding 24°C during the summer period. and part of autumn. The lowest temperatures occurred between the months of June and September, which includes the entire winter and the beginning of spring, varying between 17.5 and 20°C for the entire state, with the exception of the extreme east, which had temperatures close to 21°C (Fig. 8).

For the transition months, May and October-November, temperatures varied, but with similar values in May and November in most of the state, with temperatures around 21°C, while October stood out with predominance of temperatures below 21°C.

In average terms of the annual minimums (Fig. 9), in most of Alagoas the annual minimum temperature oscillated between 20 and 21°C, with variation of 3°C between the lowest and highest annual values, respectively 19.1 and 22.1°C. Again, S2 had the lowest average annual minimum temperature, with the municipalities of Chã Preta (19.1°C), São José da Laje (19.4°C) and Mata Grande (19.7°C) standing out as the coolest. The highest average annual minimum temperatures were found in S4, while the highest minimum temperatures were recorded in S1, with the municipalities of Japaratinga, Porto de Pedras, Porto Calvo and São Miguel dos Milagres, all located in the northeast of the state, having the highest average annual value (22.1°C).

It is noteworthy, for the spatial variations, that in S2 the lowest averages of the average, maximum and minimum air temperatures were identified in all months, mainly attributed to the relief factor (higher altitude). The average monthly temperatures were mainliy below 26°C. On the other hand, S4 stood out for being the hottest (lower altitude), with annual average temperatures exceeding 21°C (minimum), 26°C (average) and 31°C (maximum). In this sense, Lucena et al. (2022) described the importance of the relief effect for variations in the thermal regime, indicating the inverse relationship of altitude with air temperature, even at very close points.

S1 and S3 had the lowest thermal amplitudes. What differentiated them was that the thermal amplitude was greatest in S3 (between summer and winter) and also had the greatest differences between the averages of the points within the group, when compared to S1, with the exception of the northeast portion of the state (located in S1), mainly for the minimum temperature, with the greatest thermal difference in comparison with the rest of the sub-region. S3 also had the highest values of minimum annual temperature in the state. This lower thermal amplitude of S1 compared to the other sub-regions of Alagoas can be attributed to the combined influence of the relief effect on the climate (lower altitudes and low altimetric variations), the sea breezes and also the higher rainfall (Lyra et al., 2014; Silva et al., 2022). Therefore, the concentration of a greater amount of water vapor in the air favors smaller thermal amplitudes (Almeida, 2016).

Increasing trends in mean, maximum and minimum air temperatures for the entire state of Alagoas (Fig. 10) were observed. This trend was statistically significant at 5% in the four sub-regions. In S1, the average temperature increased between 0.04 and 0.06°C.year^{-1} in all its points (municipalities), similar to what occurred for the maximum temperature, with the exception of the municipalities of Japaratinga, São Miguel dos Milagres, Porto Calvo and Porto de Pedras, which recorded increases between 0.02 and 0.04°C.year^{-1}. The largest magnitudes of increase in S1 were recorded for the minimum temperature. Most points in this sub-region had an increase between 0.07 and 0.08°C.year^{-1}.

For S2, the average temperature increases ranged from 0.02 to 0.09°C.year^{-1}, while for maximum temperature the municipality of Palmeira dos Índios stood out with an increase of 0.09°C.year^{-1}. The minimum temperature recorded in most points of S2 increased below 0.07°C.year^{-1}.

In S3, the average temperature always increased by more than 0.06°C.year^{-1}. For the maximum temperature, the easternmost points had the smallest increases (0.04 to 0.06°C.year^{-1}). In the vicinity of S4, increases above 0.1°C.year^{-1} were recorded, with emphasis on the municipality of Piranhas, with an increase of 0.13°C.year^{-1}, while for the minimum temperature, in most points the increase was in the range of 0.08 to 0.10°C.year^{-1}.

The warmest sub-region (S4) showed the highest increases in maximum (0.14°C.year^{-1}), average (0.13°C.year^{-1}) and minimum (0.10°C.year^{-1}) temperatures, together with the municipalities of Piaçabuçu and Olho d'Água Grande, in the S3. In average terms, these results indicate significant increases on the order of 1.4°C, 1.3°C and 1°C per decade, in the maximum, average and minimum air temperatures, respectively.

The 10-year variability of the air temperature in Alagoas (Fig. 11) consisted of an increasing sequence of the averages, maximums and minimums of air temperature for practically the entire state, in the 1980s, 1990s and 2000s. Differences were only noted between the 80s and 90s, with an increase of more than 1°C in most of the state, while between 1990 and 2000 there is a smaller variation. S4, the warmest sub-region, had the greatest increases in average temperature, of 1.0°C.decade^{-1}, while the maximum difference was 1.3°C.decade^{-1} and the minimum was 0.8 ° C.decade^{-1}, with a total increase of 2.7°C in the average temperature in theh entire period studied.

The results presented in this work indicate impacts on air temperature that may be associated with regional and/or global climate changes, according to the series of increases in air temperature for the entire state of Alagoas. Marengo (2014) indicated, through projections made until 2100, that there will be an increase in temperature and heat waves in all regions of Brazil, corroborating the results of the 6th Assessment Report (AR6) recently published by the IPCC (IPCC, 2021), which indicated the rate of warming is accelerating. The IPCC also warns that global average surface temperatures have increased faster since 1970 than in any other 50-year period for at least the last 2000 years, as well as the possibility of a warming trend of 1.5°C, in the medium term.

Several studies have confirmed that the increase in air temperature needs to be better understood and dealt with, so that viable planning strategies for mitigation and socio-environmental adaptation are possible. In Brazil, Cavalcante et al. (2020), studying the state of Ceará, found an increasing pattern for the period 1994–2015 in relation to the period 1961–1990, on the orders of 0.7°C, 0.4°C and 0.6°C on average for maximum, minimum and average temperatures, respectively. Ávila et al. (2014) found significant trends in the maximum annual air temperature for the state of Minas Gerais in 37 of the 43 evaluated municipalities, while for the minimum, 27 municipalities were identified, both with a tendency to increase up to 1°C, and with a increase up to 1.5°C per decade in minimum temperature. Wanderley et al. (2014), for the municipality of Rio Largo (state of Alagoas), identified a positive trend in daytime (maximum) temperature, with a 10-year increase of 0.48°C, similar to the results found here for this municipality (0.5°C .decade^{-1}).

In the state of Paraíba, Dantas et al. (2015) found, for the municipality of Campina Grande, positive magnitudes of the maximum of maximum and minimum daily temperatures of 0.05 and 0.018°C.year^{-1}, respectively, arguing that the intense urban expansion was a possible cause of this change. Fragomeni et al. (2020) reiterated the impacts of the increase in average temperature, which contributes to thermal discomfort and vulnerability to diseases. Therefore, the results of this study contribute to a better temporal and spatial understanding and can be used for regional management strategies and policies.

Part of the results found here also showed that the highest magnitudes of trends in air temperature increase in Alagoas were not in the coastal zone (greatest population density), the highest values were observed in the semiarid region, which is affected by irregular precipitation (Mutti et al., 2020; Medeiros et al., 2021; Rodrigues et al., 2021) and by high values of reference evapotranspiration (ET_0) (Cabral Júnior and Bezerra, 2018; Rocha Júnior et al., 2020). Therefore, an increase in the average air temperature contributes to an increase in ET_0 (Cabral Júnior et al., 2019), which in turn may be intensifying drought events (Marengo et al., 2017; Cabral Júnior and Bezerra, 2018). In line with this, Huang et al. (2016) and Vale et al. (2022) warned that due to the high vulnerability of semiarid regions to climate change, any change in the thermal and rainfall regime can have disastrous consequences for agricultural productivity and the general well-being of the population.

Conclusions

According to the results found in this work, we can conclude that:

1. The state of Alagoas has four sub-regions according to the average air temperature, here designated sub-regions 1 (S1), 2 (S2), 3 (S3) and 4 (S4).
2. S4 was the sub-region with the highest air temperature values, with a monthly average above 28 °C in the summer months, and an annual average temperature of 26.3 °C. On the other hand, S2 presented the lowest average monthly air temperatures, below 26 °C in most of its municipalities, with the lowest average annual temperature in Alagoas (23.5 °C) occurring in winter in the sub-regions with the highest altitudes.

3. S1 had the lowest thermal amplitudes, associated with the joint influence of geographic location, relief configuration, sea breeze and also greatest rainfall, although S3 had a similar amplitude, but with higher and greater differences internally (between municipalities).
4. Significant trends of increase in average, maximum and minimum temperatures were found for the entire state of Alagoas, with emphasis on the sub-regions located in the west of the state, especially S4, with increases of 1.3, 1.4 and 1 $°C.decade^{-1}$, respectively.
5. The increase in air temperature in Alagoas may be aggravating vulnerability in this area, especially in the semiarid region (west of the state), which in turn is already characterized by the predominance of water deficit.

Declarations

Funding: The authors have not received any specific funding.

Conflicts of interest/Competing interests: The authors declare no competing interests.

Ethics approval/declarations: Not applicable.

Consent to participate: Not applicable.

Consent for publication: Not applicable.

Availability of data and material/ Data availability:

The datasets analyzed in the present study are available at https://utexas.app.box.com/v/Xavier-etal-IJOC-DATA are described in Xavier et al. (2015) [https://utexas.app.box.com/v/Xavier-etal-IJOC-DATA]. For statistical analysis, the free software R [https://cran.r-project.org/bin/windows/base/] was used.

Code availability: Not applicable.

Author Contribution:

JSS: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing original draft, review and editing, Visualization. **JBCJ:** Conceptualization, Methodology, Data curation, Software, Formal analysis, Investigation, Writing original draft, review and editing, Visualization, Overall supervision. **DTR:** Conceptualization ,Methodology, Software, Review and Editing. All authors read and approved the final manuscript.

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Tables

Tables 1 is available in the Supplementary Files section.

Figures

Fig 1

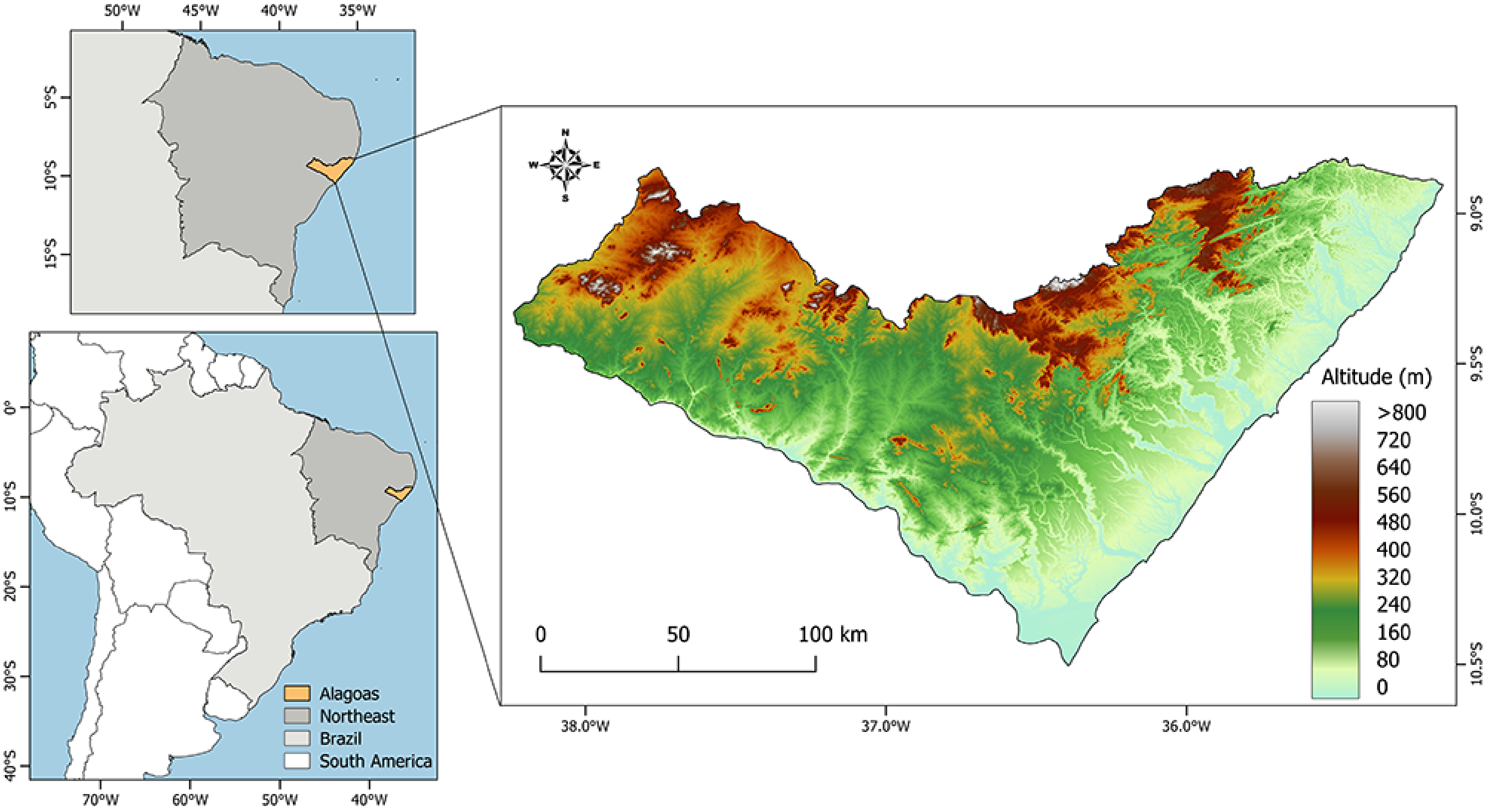

Figure 1

Location and hypsometry of the study area (Alagoas state), Northeast region of Brazil.

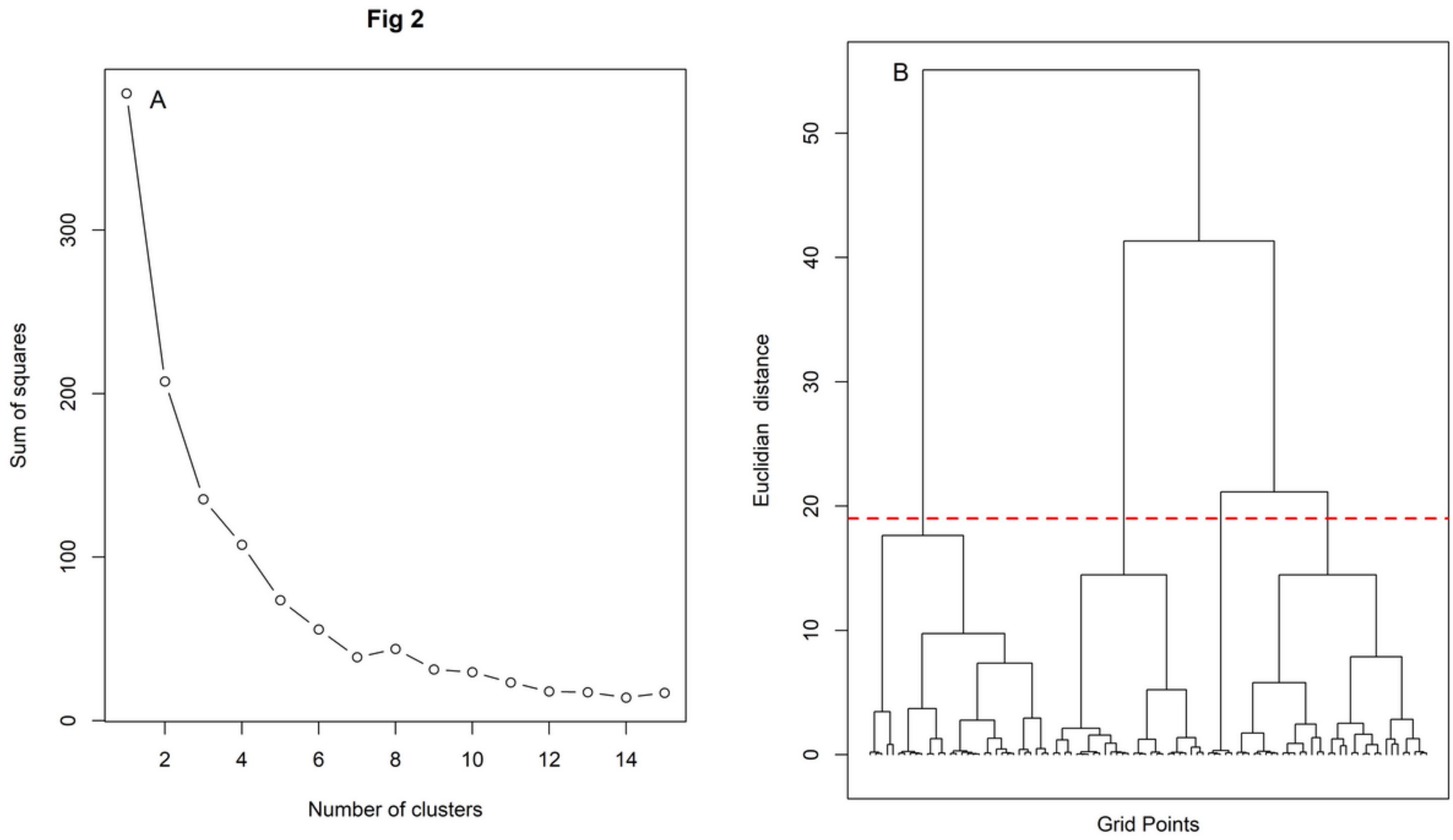

Figure 2

Cluster number (a) and dendrogram (b) referring to the four groups based on average monthly air temperature from the cluster analysis, considering the Euclidean distance and the Ward connection method, for the state of Alagoas from 1980 to 2013.

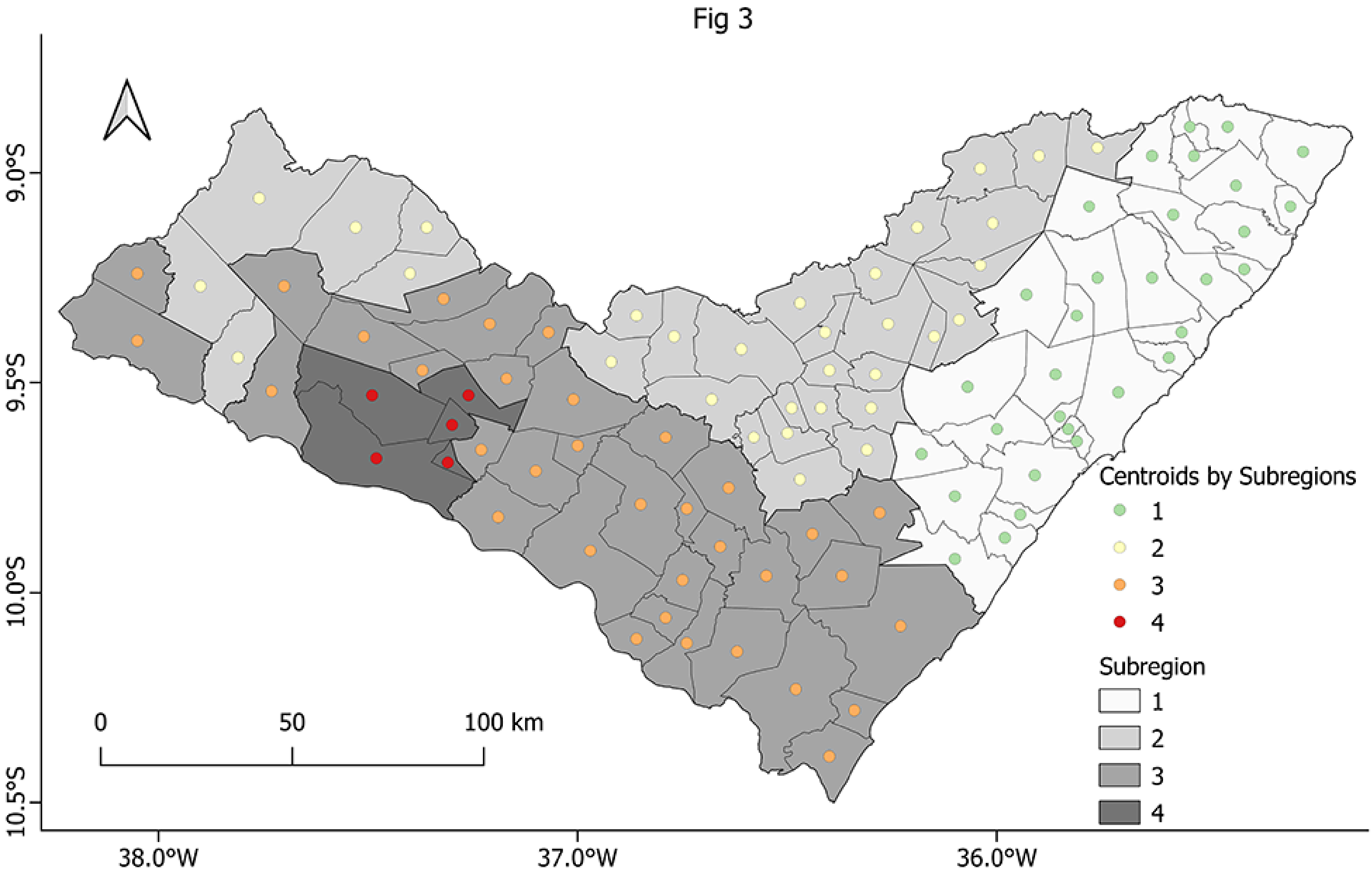

Figure 3

Sub-regions according to the average air temperature distributed in the state of Alagoas, defined with the location of the homogeneous groups.

Fig 4

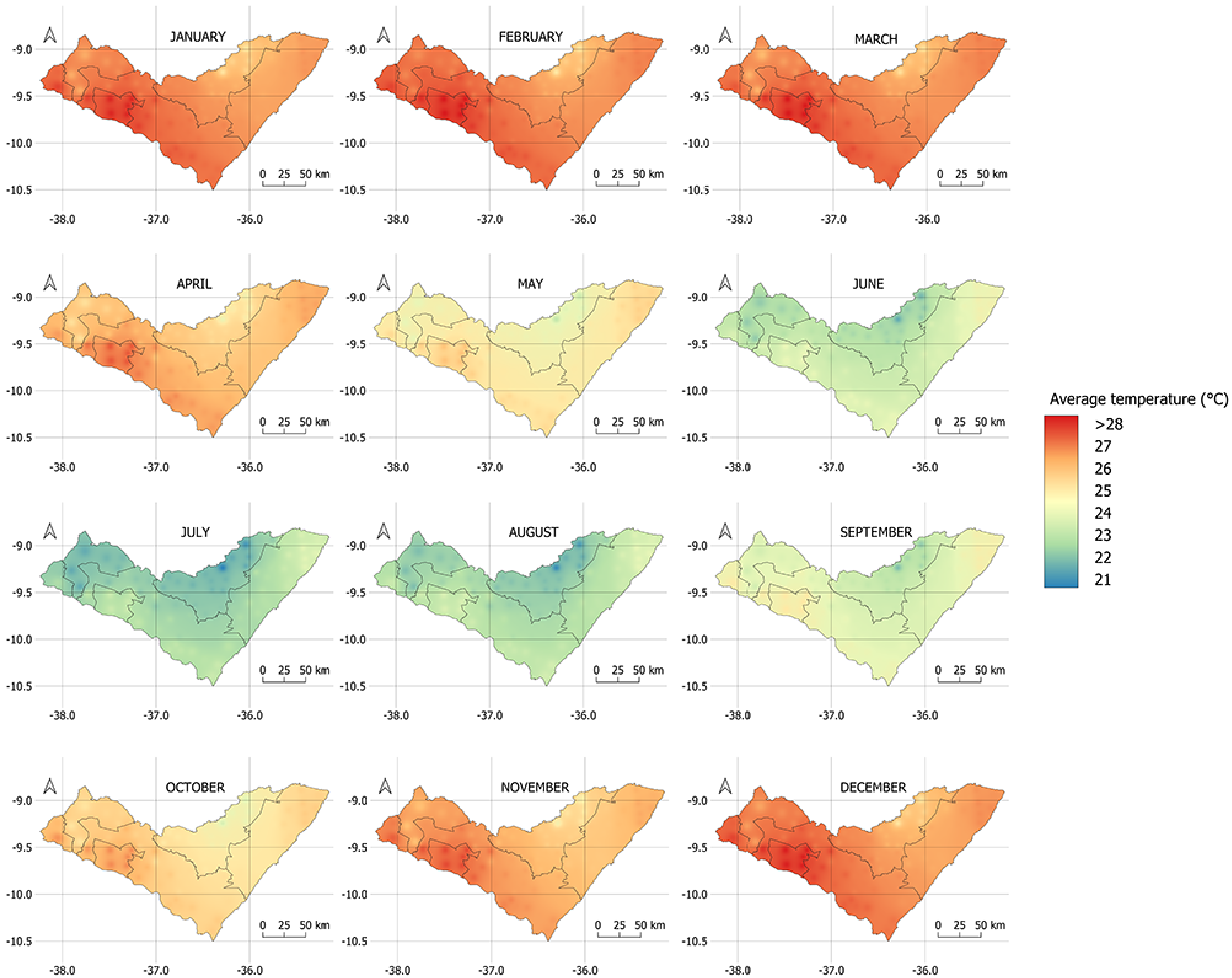

Figure 4

Monthly spatial distribution of mean air temperature for the state of Alagoas from 1980 to 2013.

Fig 5

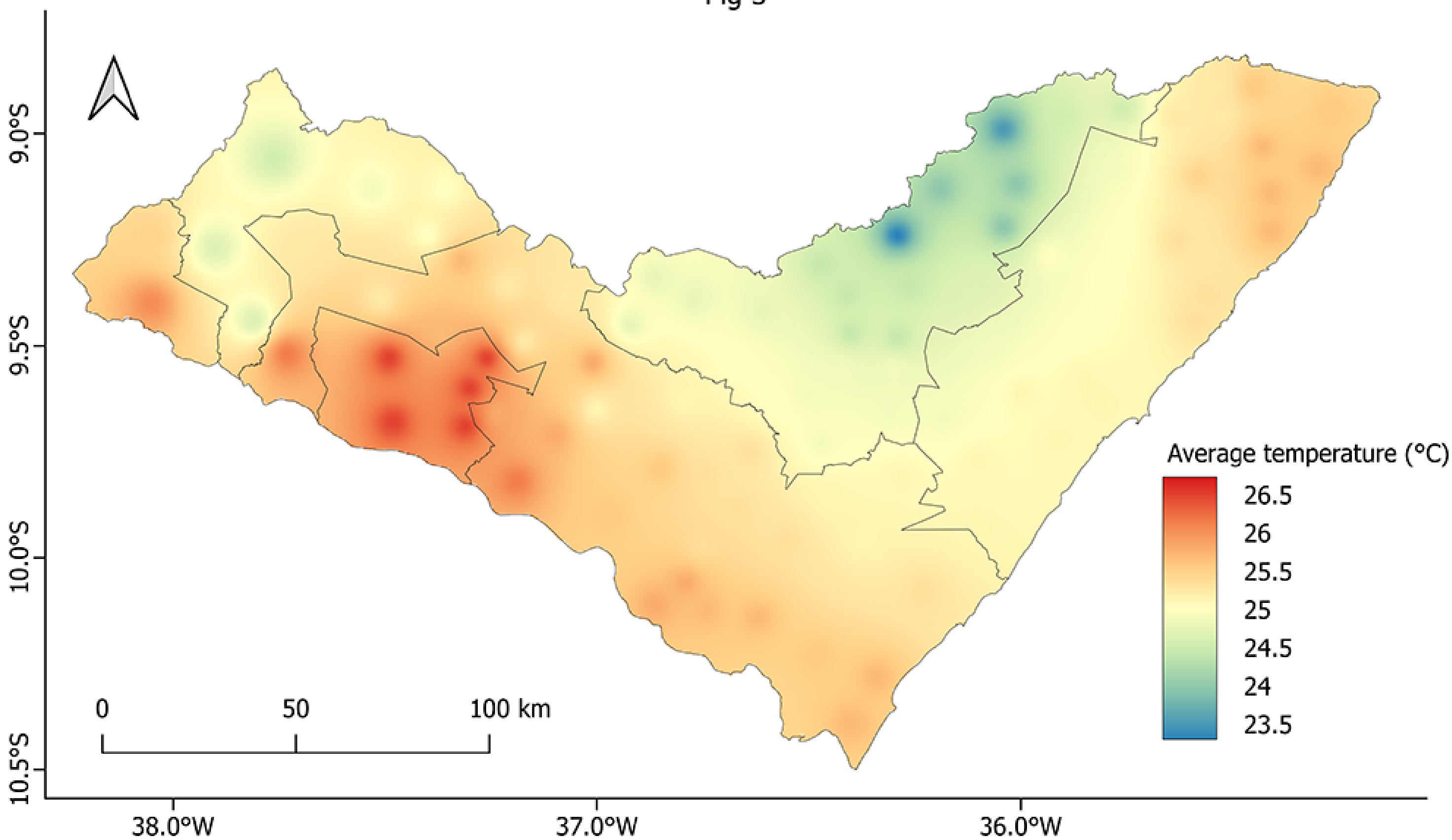

Figure 5

Annual spatial distribution of mean air temperature in the state of Alagoas from 1980 to 2013.

Fig 6

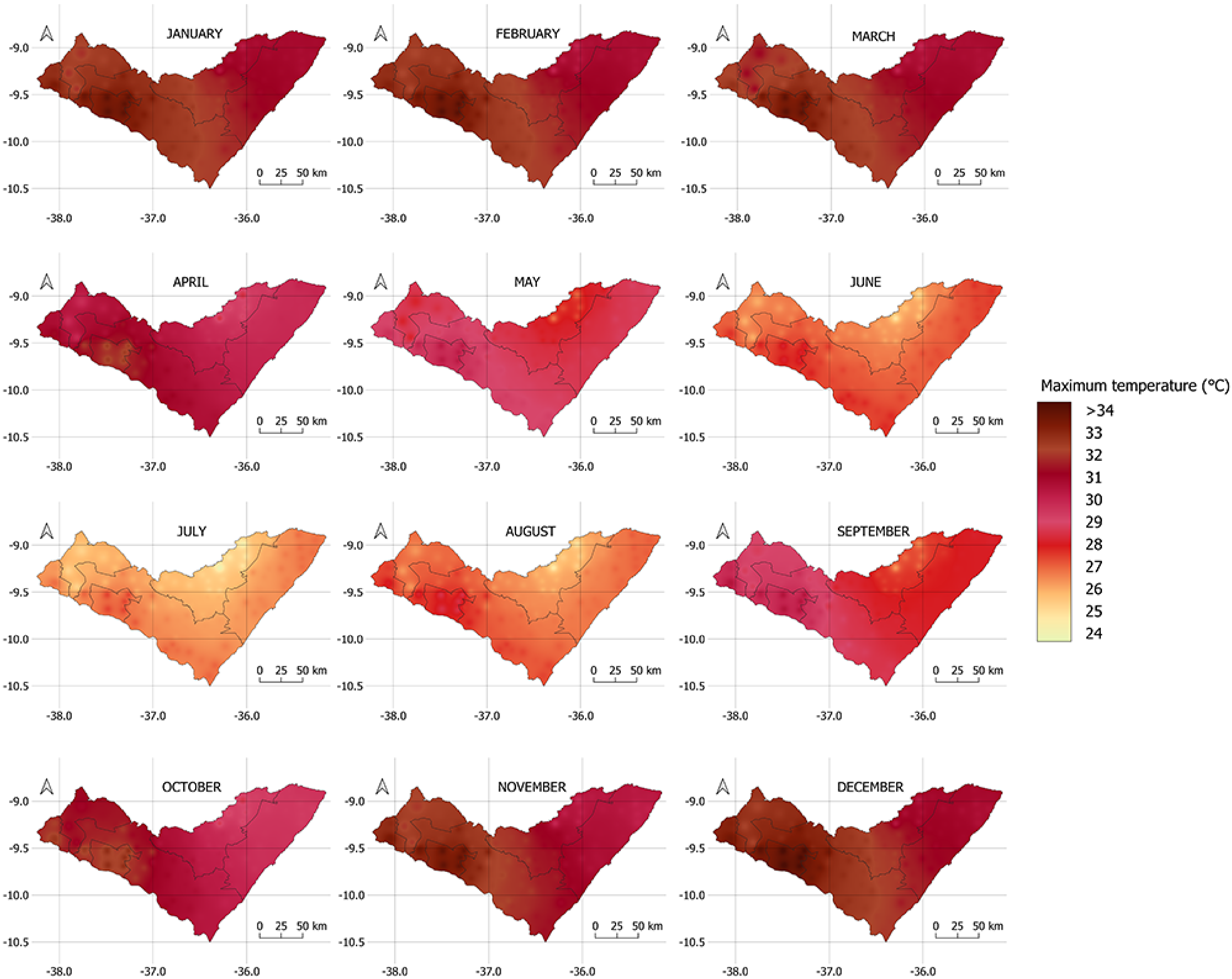

Figure 6

Monthly spatial distribution of maximum air temperature for the state of Alagoas from 1980 to 2013.

Fig 7

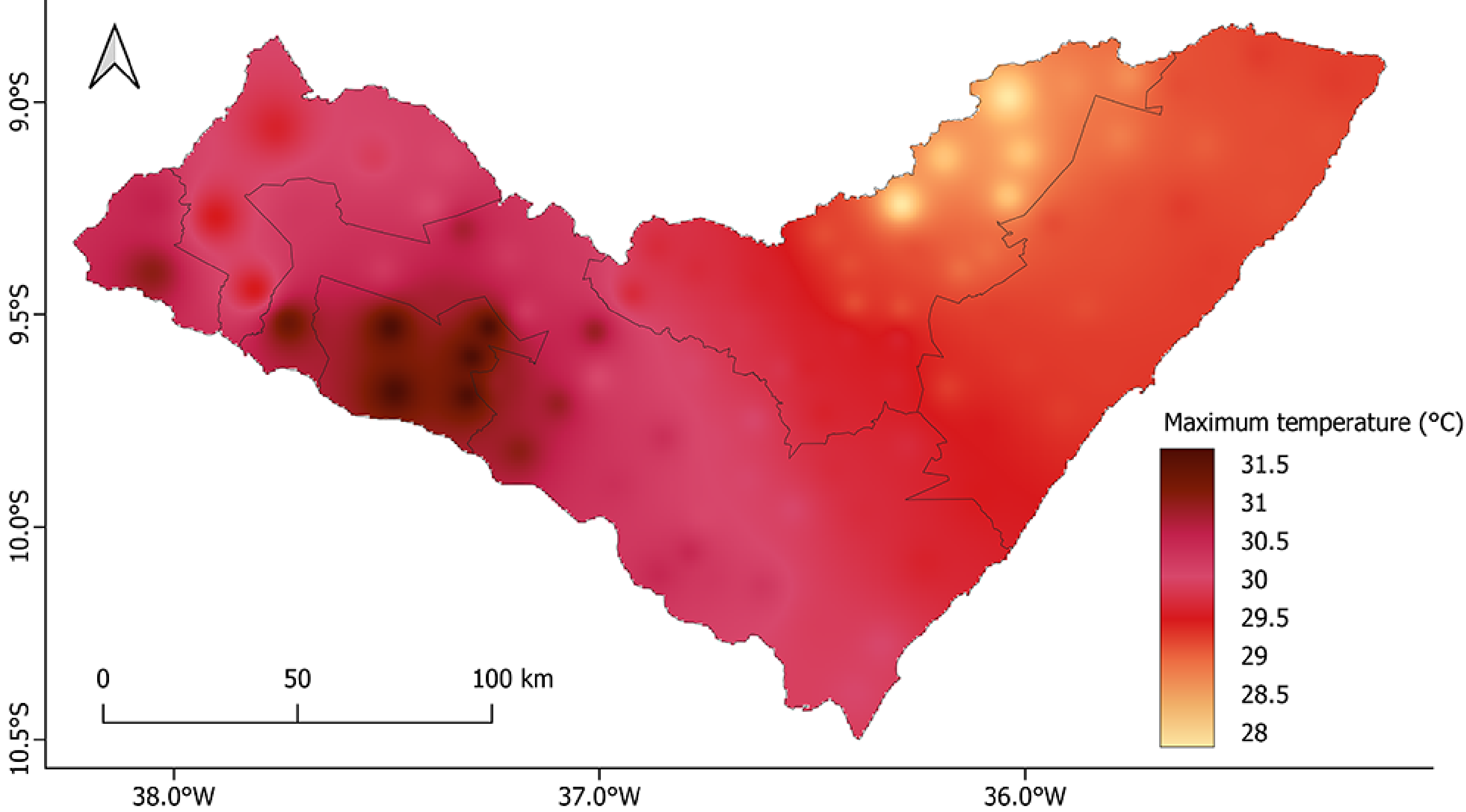

Figure 7

Annual spatial distribution of maximum air temperature for the state of Alagoas from 1980 to 2013.

Fig 8

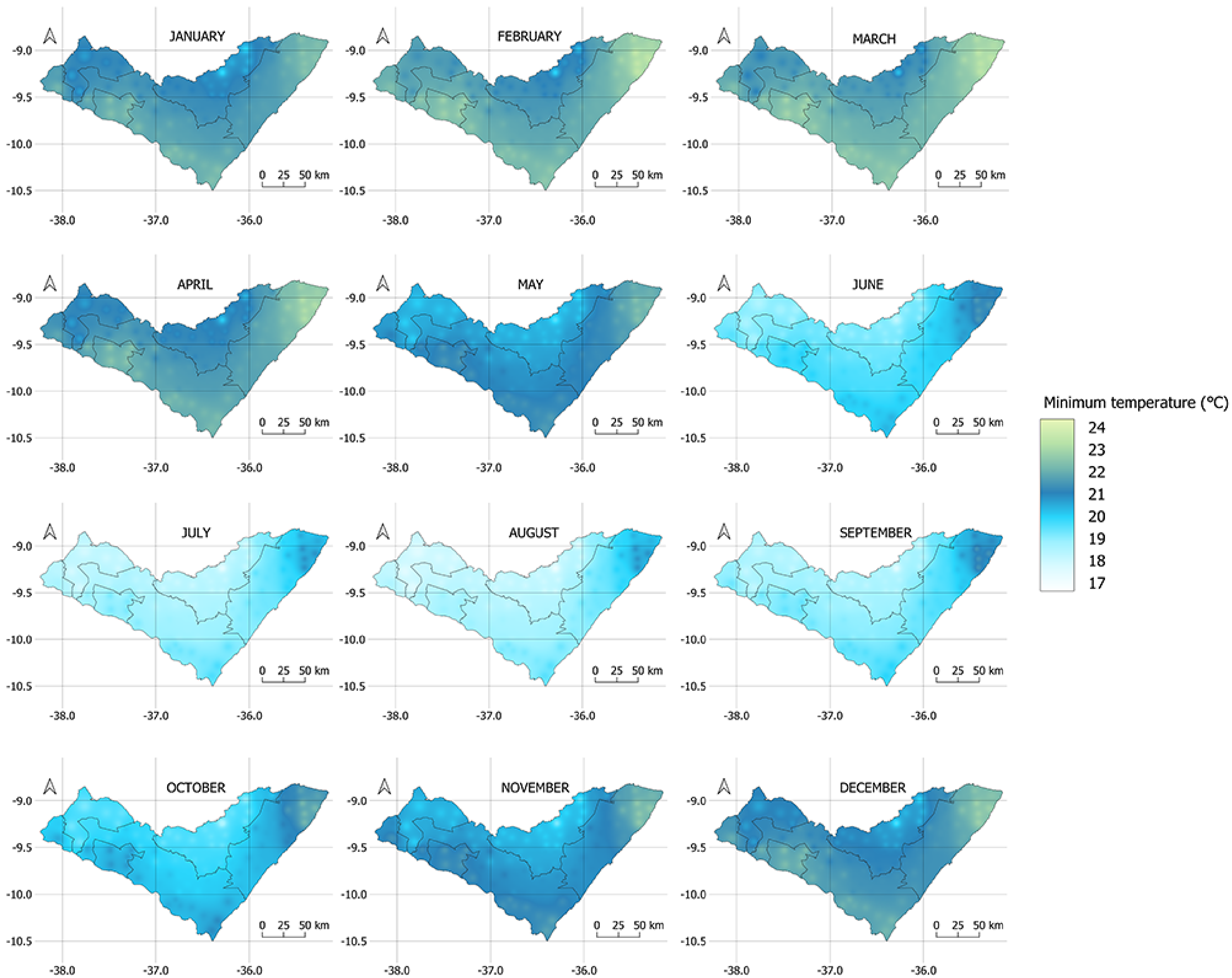

Figure 8

Monthly spatial distribution of minimum air temperature for the state of Alagoas from 1980 to 2013.

Fig 9

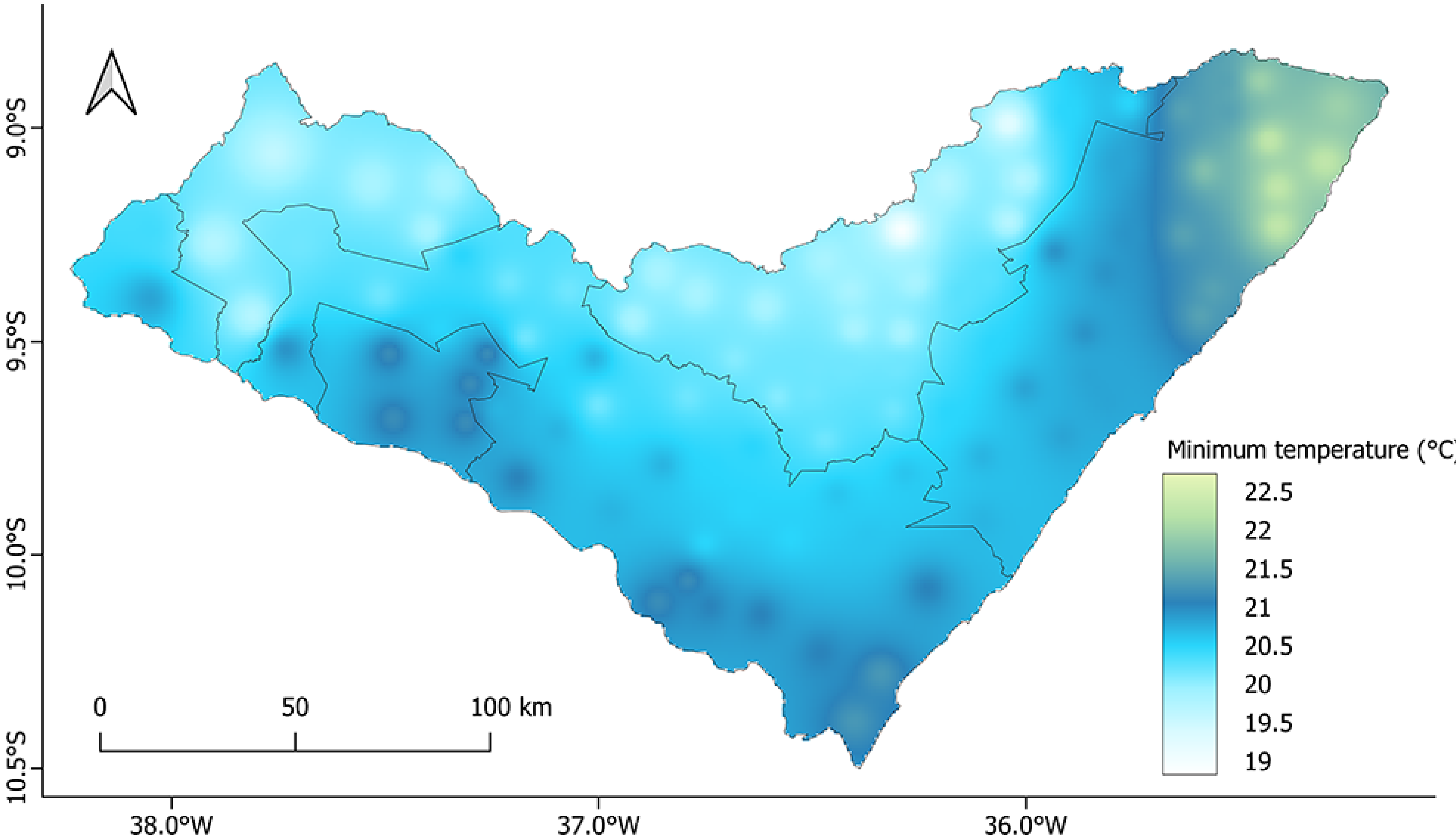

Figure 9

Annual spatial distribution of minimum air temperature for the state of Alagoas from 1980 to 2013.

Fig 10

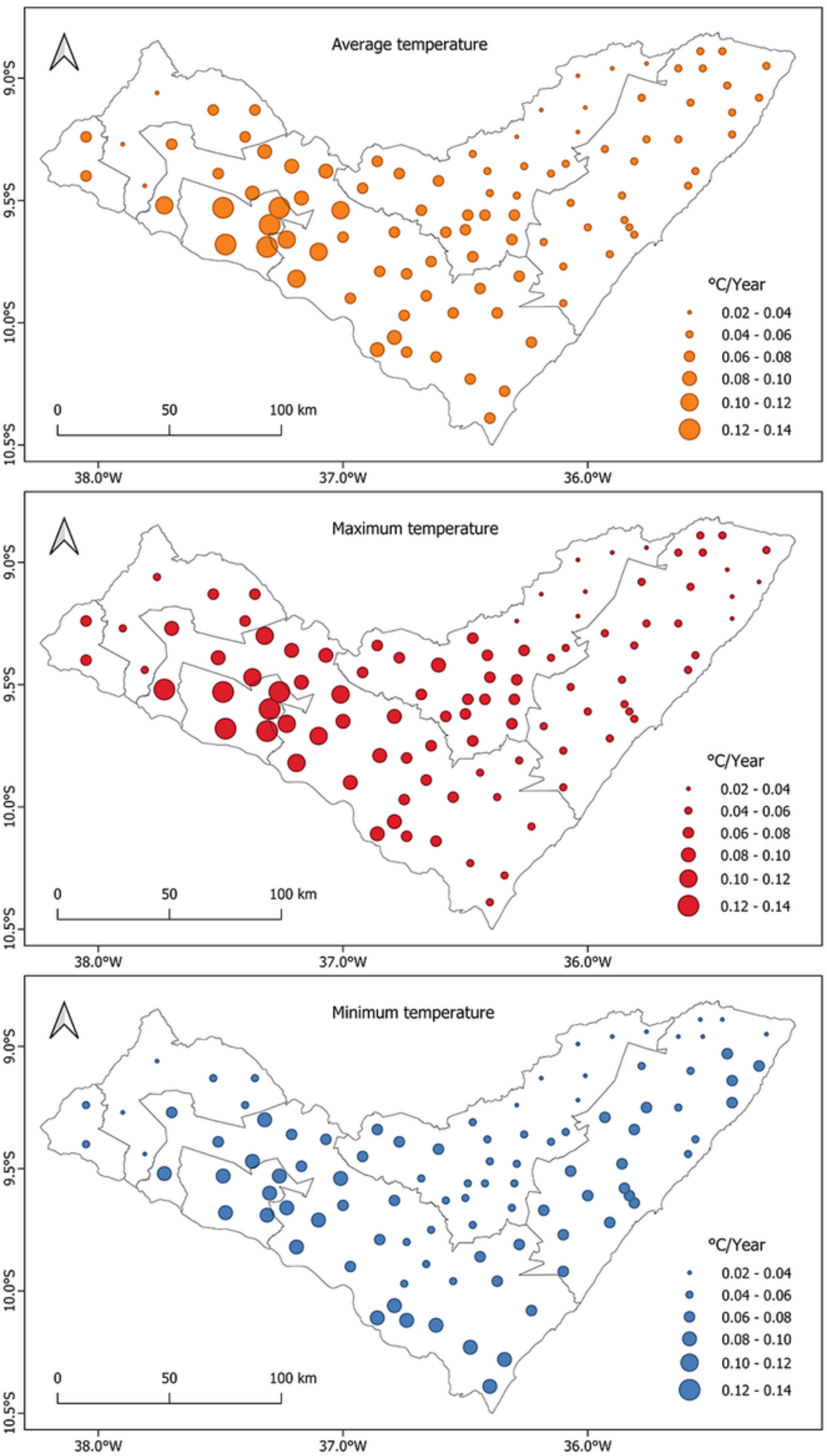

Figure 10

Annual trends of mean, maximum and minimum air temperatures for the state of Alagoas between 1980 and 2013 at 95% confidence interval.

Fig 11

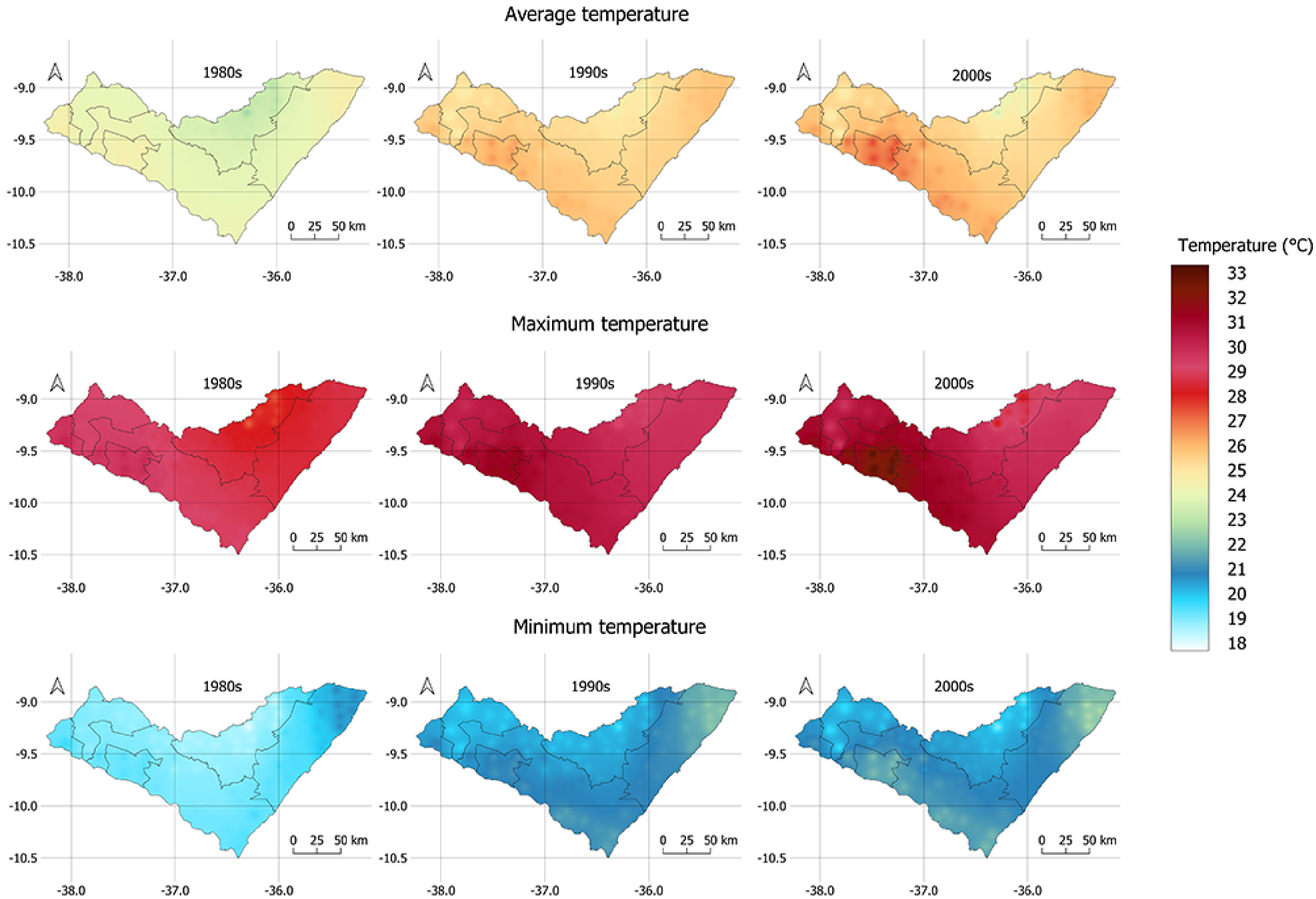

Figure 11

Spatial distribution, by decades, of average, maximum and minimum air temperatures for the state of Alagoas.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Tab1.jpg