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Analysis of average annual temperatures and rainfall in southern region of the state of Rio Grande do Sul, Brazil

Análise anual de temperatura média e precipitação para a região sul do Rio Grande do Sul

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ABSTRACT

This work aimed to analyze the average temperature and rainfall in the Southern and Steppe regions of the State of Rio Grande do Sul, Brazil, obtained by three global climate models regionalized by the Eta model (CANESM2, HADGEM2-ES and MIROC5) for the historical period, and two future climate scenarios (RCP 4.5 and RCP 8.5), subdivided into three periods: F1 (2006-2040), F2 (2041-2070), and F3 (2071-2099). The analysis was conducted by applying the trend tests Mann Kendall's, Sen's Slope and Pettitt's to the dataset. The study noted an increase in temperature, and that the highest temperatures will occur at the end of the century. For the three climate models, temperatures will be milder in the RCP 4.5 scenario, mostly, when compared to the RCP 8.5. For those scenarios, a significant increase up to 0.95°C/year was observed in the temperature of all series, with the years of change in the mean values occurring between 2048 and 2060. The projections also suggest that there may be an increase in the average accumulated rainfall in the future periods analyzed, with exception of the result found with CANESM2 model at the RCP 8.5 scenario, which showed a significant decrease of annual rainfall in all series, ranging approximately from -3,1 to -6,6 mm/year. Those significant changes in mean of the rainfall series are expected for the late 2070's. With exception of this result, most cities and models indicate an increase in rainfall regimes, with clear variations between models and scenarios.

Keywords: climate models; RCP 4.5 and RCP 8.5; climate changes; ETA regional model; nonparametric trend tests.

RESUMO

Este trabalho teve como objetivo analisar a temperatura média e a precipitação da região sul e Campanha do estado do Rio Grande do Sul, obtidas por três modelos climáticos globais regionalizados pelo modelo ETA (CANESM2, HADGEM2-ES e MIROC5) para o período histórico e dois cenários climáticos futuros, RCP 4.5 e RCP 8.5, subdivididos em três períodos: F1 (2006–2040), F2 (2041–2070) e F3 (2071–2099). A análise foi conduzida aplicando-se os testes de tendência Mann-Kendall, *Sen's Slope* e Pettitt. Foi observado o aumento na temperatura média; as maiores temperaturas ocorrerão no final do século. Sob os três modelos, as temperaturas serão mais amenas no cenário RCP 4.5 quando comparadas às do cenário RCP 8.5, no geral. Nesses cenários foram identificadas tendências de aumento na temperatura de até 0,95°C/ano em todas as séries, com mudança abrupta entre 2048 e 2060. As projeções também indicam aumento na precipitação média acumulada nos períodos futuros, com exceção dos resultados obtidos com o CANESM2 sob o cenário 8.5, cuja precipitação demonstrou diminuição significativa em todas as séries, variando entre -3 e -6 mm/ano. Ademais desse resultado, grande parte dos municípios e modelos indica o aumento nos regimes pluviométricos, com claras variações entre modelos e cenários.

Palavras-chave: modelos climáticos; RCP 4.5 e 8.5; mudanças climáticas; modelo regional ETA; testes de tendência não paramétricos.

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Introduction

Climate variability can change the economic and social dynamics of a population (Gomes Junior and Ely, 2021), since it is closely linked to power generation, agricultural activities, tourism and, even if indirectly, to the entire productive sector. Climate changes can be perceived through variations that occur over time, such as the increase in the air temperature, strong storms, floods, among others (Queiroga et al., 2022).

Due to the climate changes, it is reported that this may result in more extreme events occurring around the world (Yuan et al., 2017), so the importance of researches like this on this topic can be highlighted, especially at tropical regions, where rainfall events have greater intensity and, consequently, potential to flooding (Oliveira, 2019). Regarding extreme weather events, there is a high occurrence of rainfall extremes that affect the southern and steppe region of the state of Rio Grande do Sul (RS), in the Southern of Brazil. For example, Kulman et al. (2014) assessed the occurrence of drought in the RS in the period of 1981 to 2011, and concluded that there were 22 occurrences of drought in the municipality of Bagé, in Steppe region of RS, being considered the region with the highest recurrence of drought events. Brondani et al. (2013), in a study about the occurrence of droughts and water supply problems in the municipality of Bagé, concluded that the city residents of Bagé have noticed the existence of drought in the municipality at least in the last 25 years, which has caused lack of water for public supply. According to Fernandes et al. (2021), the 2019/2020 drought event occurred in the first quarter of 2020 with great intensity and expansion, as we can see through the impacts caused on the population in the municipality of Pelotas, during the summer of 2019/2020. The Santa Bárbara Dam, mainly responsible for supplying the municipality, reached the historical level of retreat, being 4,40 meters below the normal level since its construction (Diário Popular, 2021; Silveira, 2020). In addition, drought events have frequently occurred in different regions of the RS along the recent decades, which have directly affected agricultural activities and, consequently, the gross domestic product in the RS (Braz et al., 2017).

As mentioned by Quesada-Montano et al. (2018), the occurrence and magnitude of droughts and floods have increased in many locations in the world, causing, as a consequence thereof, impacts related to the environment, society and economy (Winsemius et al., 2018). Thereby, not only drought events have occurred in the RS, but also flood events have been more frequently observed. Based on the flooding records, Pereira and Nunes (2018) separated the events of intense precipitation into "cases of attention" and "cases of alert" and both showed a positive trend in Pelotas in the period (1964-2013).

According to Nedel et al. (2012), the climate in the RS state suffers interference from extreme weather events because it is influenced by atmospheric systems that favor the occurrence of some natural disasters, such as droughts and floods. There are scientific evidences that the El Niño-Southern Oscillation (ENSO) phenomenon has high interference on the climatic anomalous rainfall in the RS state (Rao and Hada, 1990; Grimm et al., 1998; Britto et al., 2008), and despite some monthly variation, in general, the periods of El Niño (La Niña) are associated with precipitation above (below) the normal in RS (Grimm, 2009).

According to Miguel (2017), climate models are computational tools applied to meteorology and climate sciences, to carry out studies about the changes in atmospheric phenomena, and allowing researchers to simulate the past, the present climate, and the future climatic variability and its changes and projections for the globe. For example, Ongoma et al. (2018) investigated future changes in temperature and rainfall over equatorial east Africa by applying trend tests on a dataset obtained by CMIP5 multimodel ensemble, considering the Representative Concentration Pathway (RCP) 4.5 and RCP 8.5 scenarios, and the results showed a significant increase in both variables until the end of the century, especially in 1-day and 5-day events of rainfall.

To explicitly simulate the smaller scales controlled by local aspects it is necessary to refine the grid of general circulation climate models, which can be done with the use of regional climate modeling (Marengo et al., 2010; Chou et al., 2012). Many studies of regional climate modeling simulating future scenarios for South America can be found. Chou et al. (2014a; 2014b) assessed climate change in South America according to two global climate models downscaled by the Eta model, and they found, in general, that the climate change response of the Eta simulations nested in HADGEM2-ES is larger than the Eta nested in MIROC5. Using the same regional model, Dereczynski et al. (2020) found that simulated trends are compared to observed trends using extreme temperatures and precipitation indices for South America. Some of these specifically address RS. Cera and Ferraz (2015) used the RegCM3 model and found that future climate data (2070-2086) maintained the same precipitation trend as the present climate for southern RS. Tejadas et al. (2016) employed an optimistic and pessimistic scenario according to IPCC AR4 (the Fourth Assessment Report of the Intergovernmental Panel on Climate Change) and found anncreasee in the streamflow at the Mangueira lake watershed, in the south of RS, between 2030-2070.

Silva et al. (2020) analyzed the future scenarios of the Brazilian hydrographic regions (HR) according to different regional climate models. RS is inserted in two hydrographic regions, Uruguay to the west and South Atlantic to the east. The results show that Uruguay HR will present smaller increase in temperature in relation to the present climate than the South Atlantic HR. As for the precipitation, the authors found no significant differences in both RH with respect to the present climate.

The southern half of Rio Grande do Sul has agriculture and livestock as the main base of its economy, the first being linked to the climatic conditions of the region, as this is a fundamental factor for the proper development of crops, thus ensuring good results (Radin and Matzenauer, 2016).

Therefore, the purpose of this study was to analyze the average annual temperature and the annual rainfall data generated by three general circulation models regionalized by using the Eta model for the Southern and the Steppe regions of the state of Rio Grande do Sul. Further, anomaly trends were also assessed for the rainfall annual data sets.

Material And Methods

Study area

The state of Rio Grande do Sul is located in the southern region of Brazil (Figure 1). The state is divided into nine functional planning regions and the two regions under study account for a total population of 1,103,276 inhabitants (FEE, 2015). The climate of Rio Grande do Sul is classified as Humid Mesothermal, being influenced by the polar air masses and the Tropical Continental and Atlantic zones, where the summers are hot and the winters rigorous (SEPLAG, 2020).

Projeta data

Numerical daily data on rainfall and monthly averaged air temperature are generated by the Center for Weather Forecast and Climate Studies of the National Institute for Space Research (CPTEC/INPE)

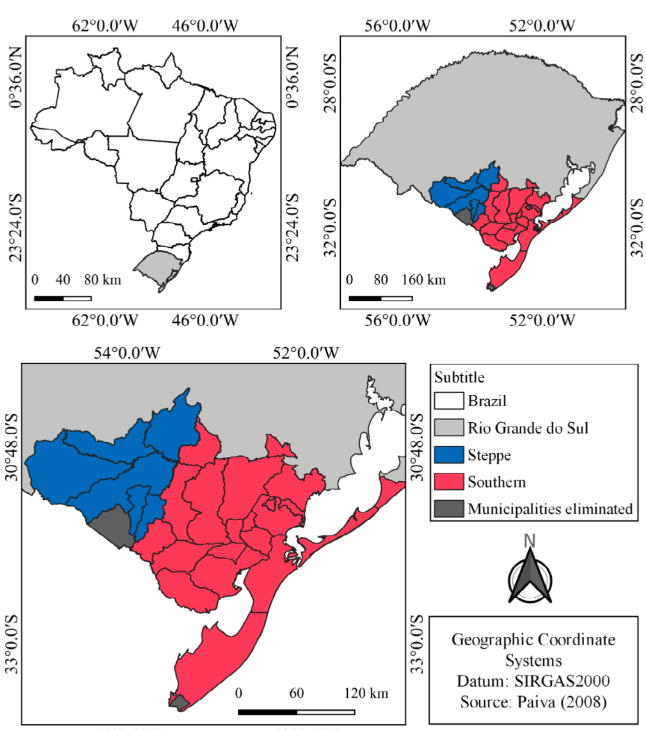

Figure 1 – Map of Rio Grande do Sul, and of the Southern and Steppe regions.
Source: elaborated by the authors.

and posted on the PROJETA (Climate Change Projections for South America Regionalized by the Eta Model) Platform (Chou et al., 2014a, 2014b; Lyra et al., 2018) (available at: https://projeta.cptec.inpe.br), with a 20-km resolution grid.

According to Moura et al. (2010), ETA is a mesoscale model of primitive equations, and its version that runs on CPTEC/INPE is hydrostatic, with 28 vertical layers covering practically all South America. The ETA model was developed by the University of Belgrade together with the Institute of Hydrometeorology of Yugoslavia (Vieira et al., 2015). The PROJETA platform, on the other hand, aims to automate the data of climate projections from the ETA model, offering a simple platform with quick results to requests made by users, thus reducing waiting time (Hölbig et al., 2018).

Series of three general circulation models: CANESM2 (Arora et al., 2011; Chylek et al., 2011), HADGEM2-ES (Martin et al., 2011), and MIROC5 (Watanabe et al., 2010) were regionalized according to the Eta model (Mesinger et al., 2012), for the base period, which comprises the years from 1961 to 2005, and for the projections of two future climate scenarios, RCP (Representative Concentration Pathways) (Van Vuuren et al., 2011) 4.5 and 8.5 (optimistic and pessimistic scenarios, respectively), which cover the years from 2006 to 2099. For better understanding, future scenarios have been subdivided into F1 (2006 to 2040), F2 (2041 to 2070), and F3 (2071 to 2099). Projections were obtained by city, totaling 27 cities, part of the Steppe and Southern regions. The analysis by cities is useful because it meets the needs of decision makers in each municipality, as pointed out in Nunes and Silva (2013) and Pereira and Nunes (2018). The coordinates of the three models used to download each one can be seen in Figure 2.

Annual analysis of average temperature and total rainfall

For the analysis of the annual numerical data of rainfall and average temperature, the annual averages for each model were calculated, considering the base period, as well as the future periods for climate scenarios RCP 4.5 and RCP 8.5. Thus, the annual averages of the base period were compared with the annual averages of future projections for each city.

To detect trends in these variables, considering all series, Mann-Kendall and Sen's Slope nonparametric trend tests were applied. The Mann-Kendall (MK) test (Mann and Whitney, 1947; Kendall, 1975) is widely used to detect time trends in hydrometeorological series (Zamani et al., 2017), while Sen's Slope (SS) test (Sen, 1968) provides the magnitude of the trend, when it is statistically significant.

The Pettitt test (Pettitt, 1979) is a nonparametric homogeneity test used to identify a significant turning point in the series of a variable. It verifies if two observations belong to the same population, locating the point of sudden change in its mean. This test is widely used, for example, in studies carried out by Lima et al. (2021) and Ribeiro et al. (2021).

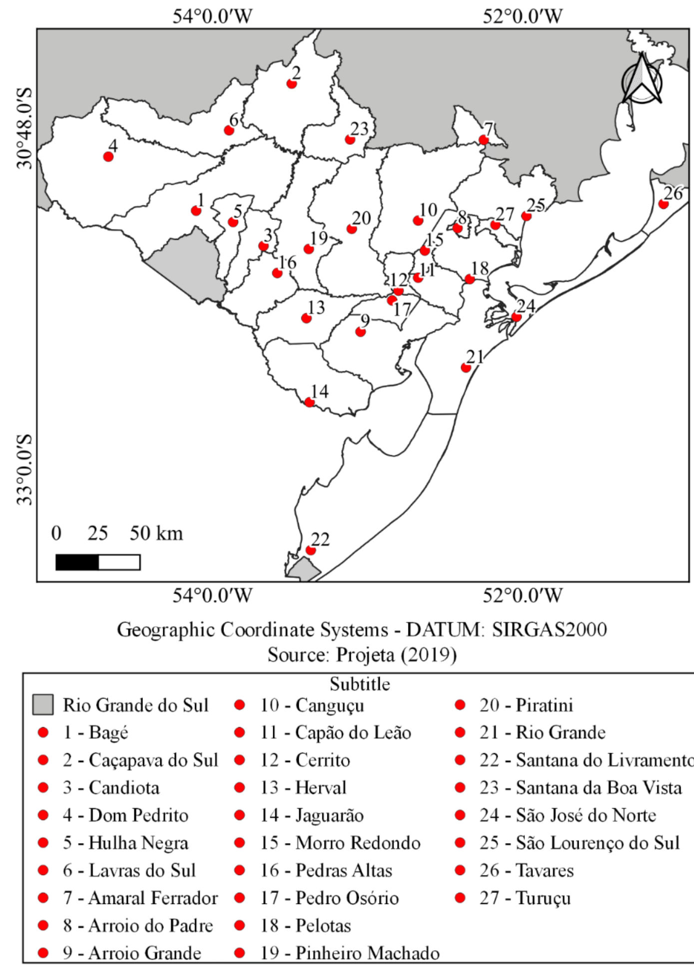

Figure 2 – Points of the climate models in each city in the study area.
Source: elaborated by the authors.

Anomalies

The anomalies of a variable are usually positive or negative departures from the normal climatology mean for a season and study area (Fazel-Rastgar, 2020). Thus, the average annual value of each future (F1, F2 and F3) was considered for each model regionalized by the Eta model for scenarios RCP 4.5 and RCP 8.5, and also for the base period (Lopes et al., 2021).

Results and Discussion

Analysis of the average temperatures of the southern and steppe regions of RS

The results of the trend tests are shown in Table 1. In general, the application of the MK test to the base period series indicated that, for the CANESM2-ETA and HADGEM2-ES-ETA models, the series of all cities show a significant trend of increasing average annual temperatures, with the exception of Tavares for the HADGEM2-ES-ETA model. This partially agrees with Sansigolo and Kayano (2010), who, considering the average of data observed over the entire RS, found a non-significant trend (1960-2006) for the maximum temperature, but a significant positive trend for the minimum temperature. The IPPC AR5 (IPCC, 2013) also indicates a positive trend for the 1901-2012 period. Conversely, the MIROC5-ETA model did not predict a significant trend for any city for the base period. For future scenarios RCP 4.5 and 8.5, all models indicate an average annual temperature increase trend.

In the temperature analysis for the Steppe region, in the RCP 4.5 and 8.5 scenarios, the CANESM2-ETA (Figure 3A), HADGEM2-ES-3TA (Figure 3B) and MIROC5-ETA (Figure 3C) models indicate a trend of temperature increase average for future periods for both scenarios, with scenario RCP 8.5 presenting higher values when compared to RCP 4.5. For the RCP 4.5 scenario, the MK test indicated a significant trend of average temperature increase for the MIROC5-ETA model, which was also observed for

Table 1 – Results of Mann-Kendall, Sen's Slope and Pettitt nonparametric tests applied to the series of average annual temperatures for the cities in the Steppe and Southern regions of RS.

Scenario	Mann-Kendall's test	Sen's Slope test	Pettitt's test	
	Significant temporal trend[1]	Magnitude of the trend[2] (min. – max.)	No. of series	Year(s) (Changing point)[1]
	CANESM2-ETA Model			
Current (Base)	In all series	0.0163 – 0.02141	18	1976; 1983.
RCP 4.5	In all series	0.0206 – 0.02231	27	2055; 2056; 2057.
RCP 8.5	In all series	0.0351 – 0.95312	27	2048; 2049; 2050
	HADGEM2-ES-ETA Model			
Current (Base)	In all series, except for Tavares	0.01422 – 0.0256	16	1968; 1972; 1973; 1984
RCP 4.5	In all series	0.01305 – 0.02140	27	2056; 2058
RCP 8.5	In all series	0.01473 – 0.04415	27	2048; 2052; 2054; 2058.
	MIROC5-ETA Model			
Current (Base)	None of the series	-	-	-
RCP 4.5	In all series	0.0096 – 0.0113	27	2036; 2054; 2057.
RCP 8.5	In all series	0.01875 – 0.0526	27	2044; 2048; 2049; 2057.

[1]at 5% significance level; [2]°C.year^{-1}.
Source: elaborated by the authors.

the RCP 8.5 scenario, but it is smaller when compared to the other models for the same scenario, as observed by Chou (2014b), where the MIROC5 model presented lower values when compared to HADGEM2-ES.

The analysis of annual average temperatures for the RCPs 4.5 and 8.5 scenarios of the CANESM2-ETA (Figure 3D), HADGEM2-ES-ETA (Figure 3E) and MIROC5-ETA (Figure 3F) models for the southern region indicate an increased temperature trend by the end of the century. For the RCP4.5 scenario, the CANESM2-ETA model presents values above 20°C, this analysis being very similar to that observed for the same scenario and model in the Steppe region, where the same trend was observed by Anjos et al. (2018), who used the same models in an analysis for the municipality of Pelotas, located in the southern region. The MK test results were the same for the municipalities in this region. The HADGEM2-ES-ETA model for the two scenarios, when compared to the others, has a lower average tendency of increase when compared to the others. As for the MIROC5-ETA model, the MK test revealed that the rising trends are significant for the Southern region in both future climate scenarios.

The average temperature results observed for the Southern and Steppe regions for the two future scenarios corroborate Bravo et al. (2011), who, when analyzing the projections of 20 Global Climate Models (GCM) for AR4 considering two futures (2030 and 2070) and two scenarios — A2 (more pessimistic) and B2 (more optimistic) — for the Taim region (Santa Vitória do Palmar and Rio Grande), found projections that suggest an increase in temperature for all the months of the years analyzed, but with discrepancy between the results of the models used.

Therefore, studies covering the Southern and Steppe regions, and involving Rio Grande do Sul as a whole, agree with these results, indicating a growing increase in temperature, from 1 to 3°C, on average, until the end of this century. The results of the IPCC AR5 indicate positive trends of this order of magnitude over the studied region (Collins et al., 2013).

Analysis of annual rainfall in the steppe and southern regions

The results of the trend tests are shown in Table 2. In general, the MK test applied to the base period series indicated that the CANESM2-ETA and HADGEM2-ES-ETA models found that no city had a significant trend to increase or decrease total annual rainfall.

This, in general, is consistent with the results of the IPCC's AR5 for 1951-2010 (Hartmann et al., 2013). For 1960-2006 over the entire RS, Sansigolo and Kayano (2010) also did not find any significant trend in annual total numbers of observed precipitation. Cera and Ferraz (2015) analyzed the precipitation trend (1982-2006) of observed data and the data simulated by the RegCM3 model, both at grid points, and over the study region a spatially heterogeneous behavior was observed, with most of the points having a positive trend (with or without statis-

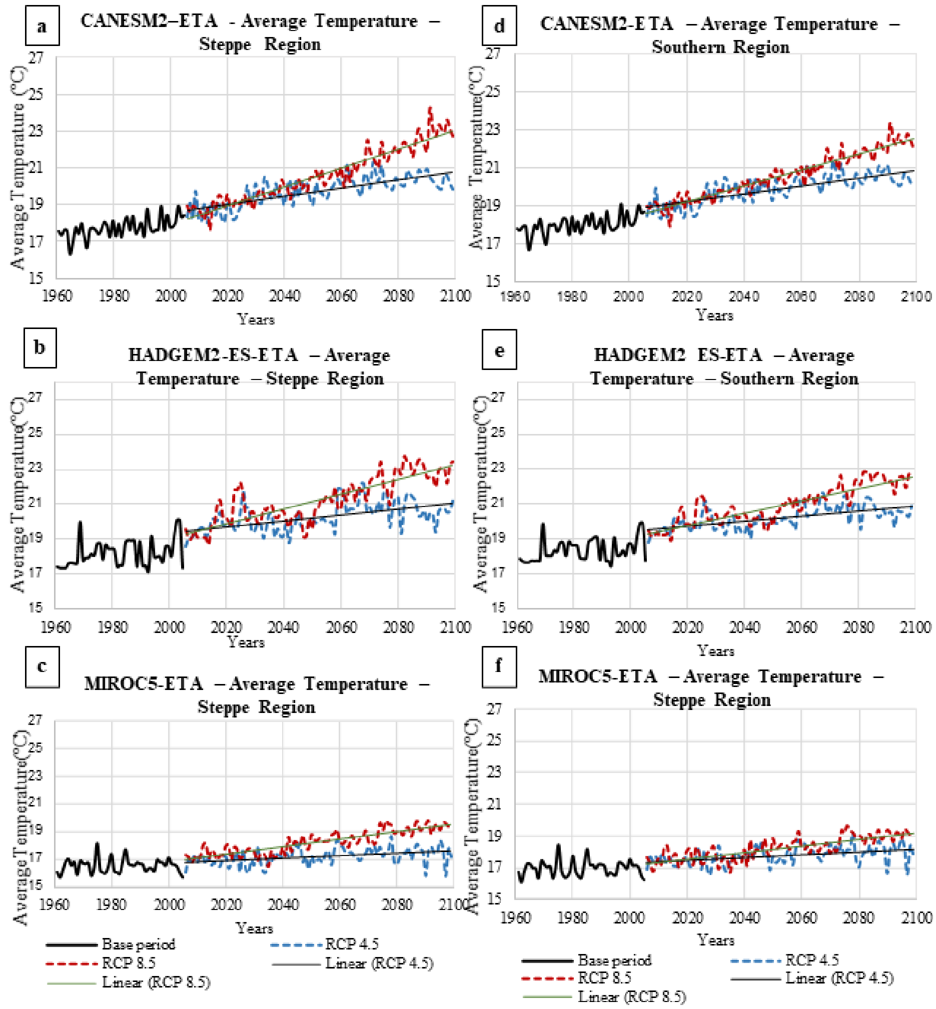

Figure 3 – Annual average temperature for base and future periods (F1, F2 and F3) for scenarios RCP 4.5 and RCP 8.5 for: (A) CANESM2-ETA model for Steppe region. (B) HADGEM2-ES-ETA model for Steppe region. (C) MIROC5-ETA model for Steppe region. (d) CANESM2-ETA model for the Southern region. (E) HADGEM2-ES-ETA model for the Southern region. (F) MIROC5-ETA model for the Southern region.
Source: elaborated by the authors.

tical significance) and some points in the Southern region of RS having a negative trend.

The simulated data, on the other hand, showed positive trends with significance between 90 and 99.9%. Salviano et al. (2016) used grid points data from CRU (Climatic Research Unit) and identified a significant positive trend (1961-2011) in the studied region only in three months (February, April and May).

Caballero et al. (2018) analyzed data in the city of Pelotas, on 1982-2015, and also found no significant trend in annual total figures. The MIROC5-ETA model, on the other hand, found a significant trend for both regions for the base period. For future scenario of RCP 4.5, few cities (CANESM2-ETA and HADGEM2-ES-ETA) or none (MIROC5-ETA) showed a trend in the series. For the RCP 8.5 scenario, the series of all cities indicate a trend towards increase in total annual rainfall, except for the city of Tavares (HADGEM2-ES-ETA), which may have occurred due to its geographical position, and may thus suffer interference from local circulations, more difficult to be detected by climate models.

The results of the SS test (Table 2) indicate the magnitudes of the significant trends of total annual rainfall for the base period, ranging from 4.82 to 9.32 mm/year for the MIROC5-ETA model. For cities that showed trends for the RCP 4.5 scenario, the magnitudes ranged from 2.079 to 3.01 mm/year. For the RCP 8.5 scenario, they ranged from -6.632 to 3.68 mm/year. The RCP 8.5 scenario of the IPCC AR5 over the study region shows a positive trend but without 90% agreement between the models for the periods 2046-2065 and 2081-2100 (Collins et al., 2013). The results of the Pettitt's test show that, for the base period, the MIROC5-ETA model could detect the trend changing point

Table 2 – Results of Mann-Kendall, Sen's Slope and Pettitt nonparametric tests applied to the series of average annual rainfall for the cities in the Steppe and Southern regions of RS.

	Mann-Kendall's test	Sen's Slope test	Pettitt's test	
	Significant temporal trend[1]	Magnitude of the trend[1,2] (min. – max.)	No. of series[3]	Year(s) (Changing point)[1]
	CANESM2-ETA Model			
Current (Base)	No cities	-	-	-
RCP 4.5	3 cities	2.092 – 2.949	3	2039; 2050.
RCP 8.5	All cities	-6.632 – -3.189	27	2068
	HADGEM2-ES-ETA Model			
Current (Base)	No cities	-	-	-
RCP 4.5	5 cities	2.079 – 3.01	4	2062; 2065
RCP 8.5	26 cities	1.294 – 6.13	26	2029; 2032; 2033; 2034; 2074; 2076
	MIRO C5 Model			
Current (Base)	All cities	4.819 – 9.32	27	1985; 1986; 1987; 1989; 1990
RCP 4.5	No cities	-	-	-
RCP 8.5	All cities	-5.84; 2.33 – 3.68	27	2058; 2059; 2061; 2068.

[1]at a 5% significance level; [2]mm/year; [3]no. of series for which the changing point was significant.
Source: elaborated by the authors.

in the series of all 27 cities, and this generally occurred between 1980 and 1990. For scenario RCP 4.5, it was possible to detect the year of significant trend changing point over the series of total annual rainfall for the future period in only 3 (CANESM2-ETA) and 4 (HADGEM2-ES-ETA) of the 27 series, in years of the F1 and F2 periods. For the scenario RCP 8.5, the test detected the trend changing point in practically all series, in years within all future periods: F1, F2 and F3.

Many researchers have been using Pettit's test in association with other tests to analyze statistical changes in temperature and rainfall time series, and also in other variables as streamflow, evapotranspiration, wind speed, etc., although studies including climate models on their investigation are scarce in Brazil. Penereiro e Meschiatti (2018) investigated temporal trends in temperature and rainfall series in Brazil by applying MK's and Pettitt's test, and found increasing trends of both variables in the majority of series with significant trend all over the country. Using MK's and Pettitt's tests, Ouhamdouch et al. (2020) found significant increasing trends in evapotranspiration and streamflow at the Essaouira basin, Morocco, expected to the late 2050's (F2 period), when under the RCP 8.5 scenario of an ensemble of models including CANESM2.

Also, while investigating the human influence in hydrological and meteorological variables in the northwest of Iran from scenarios generated by the CANESM2 model, Dariane and Pouryafar (2021) found through MK's and Pettitt's test results that, under the RCP 8.5 scenario, the study area will face a notable increasing trend in the average temperature and a decreasing trend in the precipitation and streamflow, with an abrupt change especially in the years between 2050 and 2100. A last example of application of Pettitt's test is a dataset of climate variables obtained by climate models is the study conducted by Sane et al. (2019) in a river basin in the southwest of Senegal, which found significant trends and the moment of the abrupt change in the streamflow series simulated for this basin.

Of course, despite the clear and important differences between the studies' locations and their climatological particularities, it is clear that the use of nonparametric trend tests like MK, SS and Pettitt can be helpful to investigate the observed time series of the variables and their projections under different future scenarios.

Figure 4 showed the average annual rainfall values for the Southern and Steppe regions in the base period with the three general models. According to the MK test, no city showed a trend in the series for the base period with the CANESM2-ETA and HADGEM2-ETA models, the opposite of what was indicated by the MIROC5-ETA model, which still indicated lower average annual precipitation for the base period.

The three futures of the RCP 4.5 e 8.5 scenarios according to the CANESM2-ETA model are shown in Figure 5. Comparing the base period with future scenario F1, there are signs that, in some cities, the average rainfall range will remain the same (Dom Pedrito, Lavras do Sul, Bagé, and others) and will increase in others (Amaral Ferrador, Herval, Piratini, among others). For the F2 period, it was observed that in some cities the average rainfall will remain in the same range, while, in others, there will be an increase. In F3, there will be a decrease in rainfall in three cities. The MK test applied to the CANESM2-ETA model for the RCP 4.5 climate scenario found a significant trend of increasing rainfall only for the cities of Amaral Ferrador, São Lourenço do Sul, and Turuçu. Of these, São Lourenço do Sul is one of the cities that suffers the most from flooding issues.

The results of the CANESM2-ETA for the RCP 8.5 scenario, F1 period of this projection, shows an annual rainfall increase similar to that of the RCP 4.5 scenario, but includes a greater number of cities with values between 1,900 and 2,100 mm. In the second future period (F2), there is an increase in rainfall in several cities, when compared to F1. For F3, there is a decrease in rainfall, when compared to F1 and F2, in practically all cities in the region.

The MK test applied to the total annual rainfall series of the CANESM2-ETA model for the RCP 8.5 scenario, indicated a downward trend for all cities, due to the behavior of future F3 in the series. Although there are increases between future periods F1 and F2, when the series are analyzed for the entire future period (2006-2099), the test indicates a decrease due to the behavior of the variable in future F3.

The results of total average annual rainfall with the HADGEM2-ES-ETA model for the three future periods in the RCP 4.5 and 8.5 scenario (Figure 6) are varied. In the F2 period, there is an increase in the total accumulated rainfall range in most cities. In the periods F2 and F3, there is a change in the average accumulated rainfall range. Despite the differences between the future periods in the HADGEM2-ES-ETA model and the RCP 4.5 scenario, the MK test indicated a significant trend of increasing total annual rainfall over the century only for the cities of Arroio Grande, Capão do Leão, Jaguarão, Rio Grande and São José do Norte. According to Chou et al. (2014b), this positive trend of increased advantage was already expected for the study region, and Anjos et al. (2018) also observed the trend of increased precipitation in their study for the municipality of Pelotas using the same climate models applied in this study.

For the RCP 8.5 scenario, the HADGEM2-ES-ETA model found, for the F1 period, an increase in average total annual rainfall in Dom Pedrito

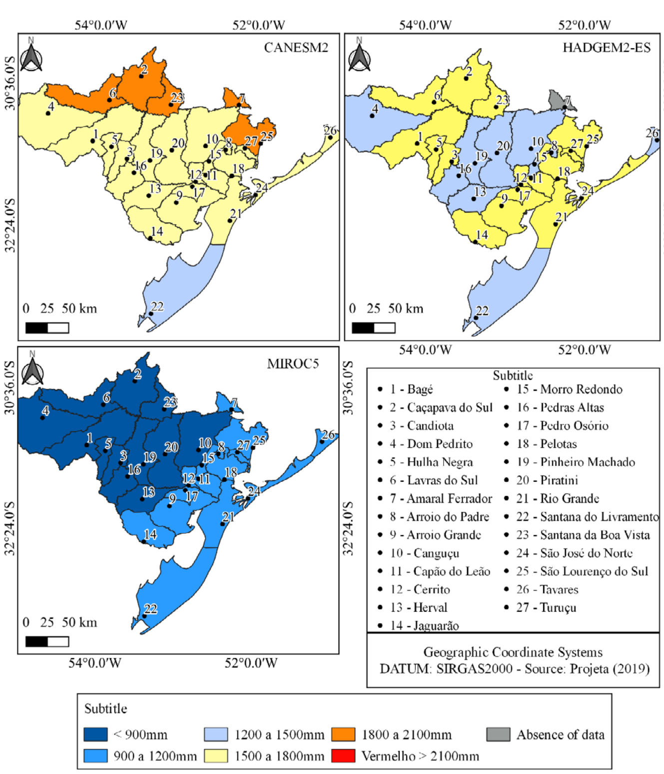

Figure 4 – Average rainfall for cities in the Southern and Steppe regions, in the base period (1961-2005), for the three regional climate models.
Source: elaborated by the authors.

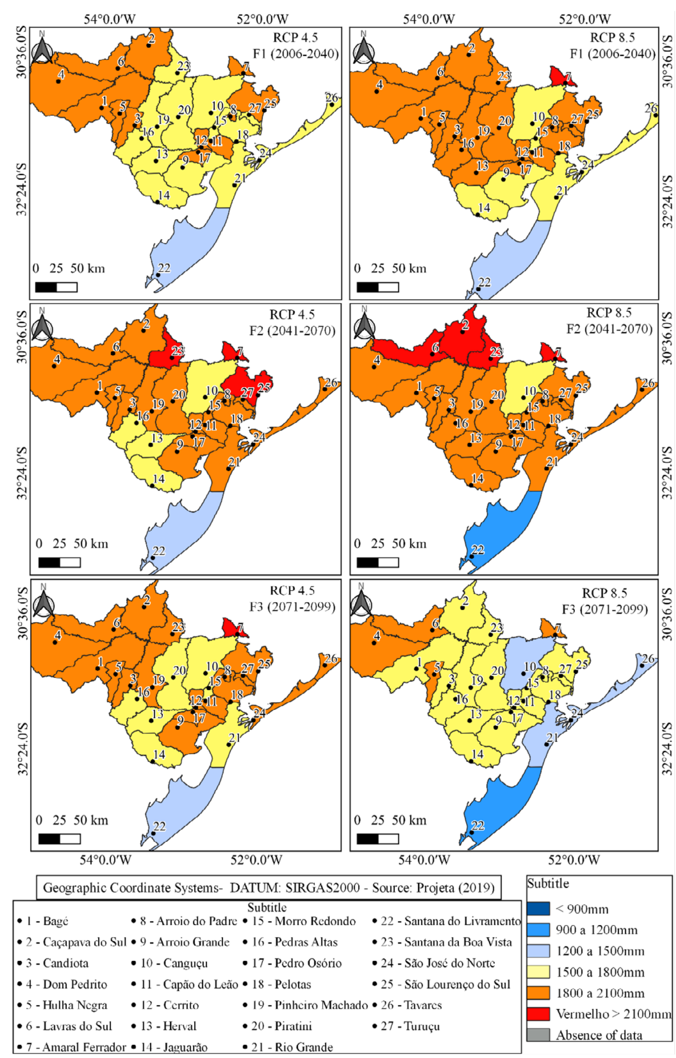

Figure 5 – Average total annual rainfall for cities of the Southern and Steppe regions, according to the CANESM2-ETA model, scenario RCP 4.5 and RCP 8.5, for the three future periods (F1, F2 and F3).
Source: elaborated by the authors.

and Pedras Altas, and a decrease for Rio Grande and São José do Norte, when compared to the base period. Comparing the F1 and F2 periods, there are projections of increased rainfall in most cities. Comparing the F3 period with the F2 period, most cities tend to maintain the same range of average total annual rainfall values, when compared to the base period. The trend analysis at the level of significance considered by the MK test for the HADGEM-ES-ETA model and the RCP 8.5 scenario, suggested a significant trend of increasing total annual rainfall over the century for all cities, except for the city of Tavares, which showed no trend.

The projections of the MIROC5-ETA model for scenario RCP 4.5 (Figure 7) were different from the other models, in addition to finding no decrease in average rainfall for future periods F2 or F3, as happened in some cities in the other models. The analysis of the base period to the F1 period shows that the great trend is for the same average rainfall ranges of the base period to be kept, except in four cities, which increased the annual average of rainfall, and Piratini, which is the only city in which the average is lower in the F1 period than in the base period. Despite these increases in total annual rainfall between the base period and future periods, they are not significant, according to the MK test, when analyzing the entire series of future climate scenario RCP 4.5 with the MIROC5-ETA model.

Analyzing the RCP 8.5 scenario, the MIROC5-ETA model (Figure 7) found increasing rainfall when comparing the F1 period with the base period. For the F2 period, there was an increase in the city

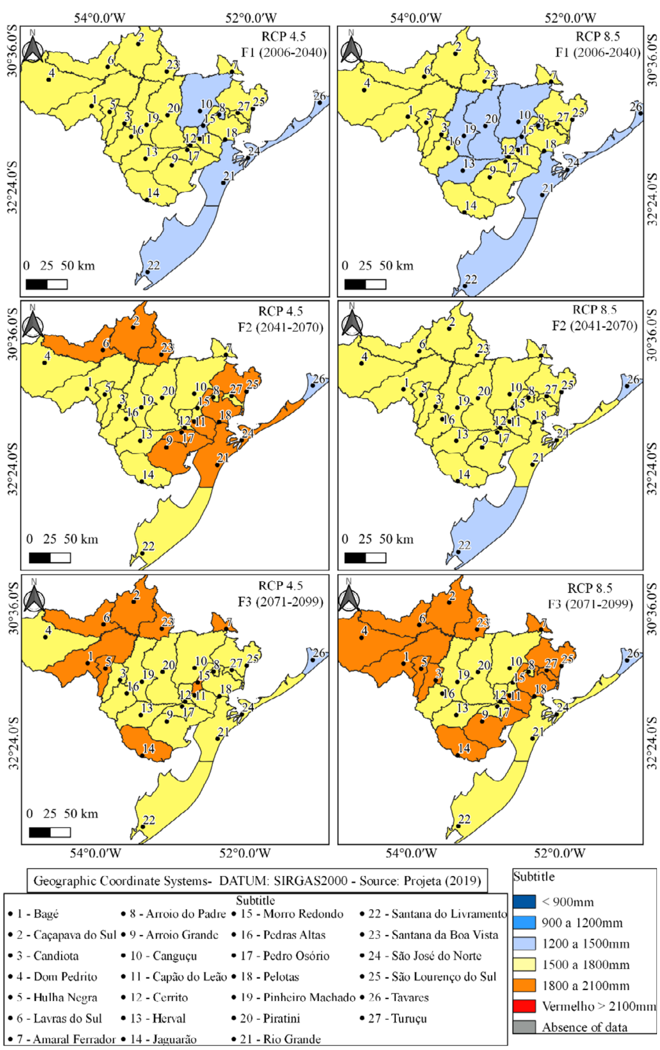

Figure 6 – Average total annual rainfall for cities of the Southern and Steppe regions, according to the HADGEM2-ES-ETA model, scenario RCP 4.5 and RCP 8.5, for the three future periods (F1, F2 and F3).
Source: elaborated by the authors.

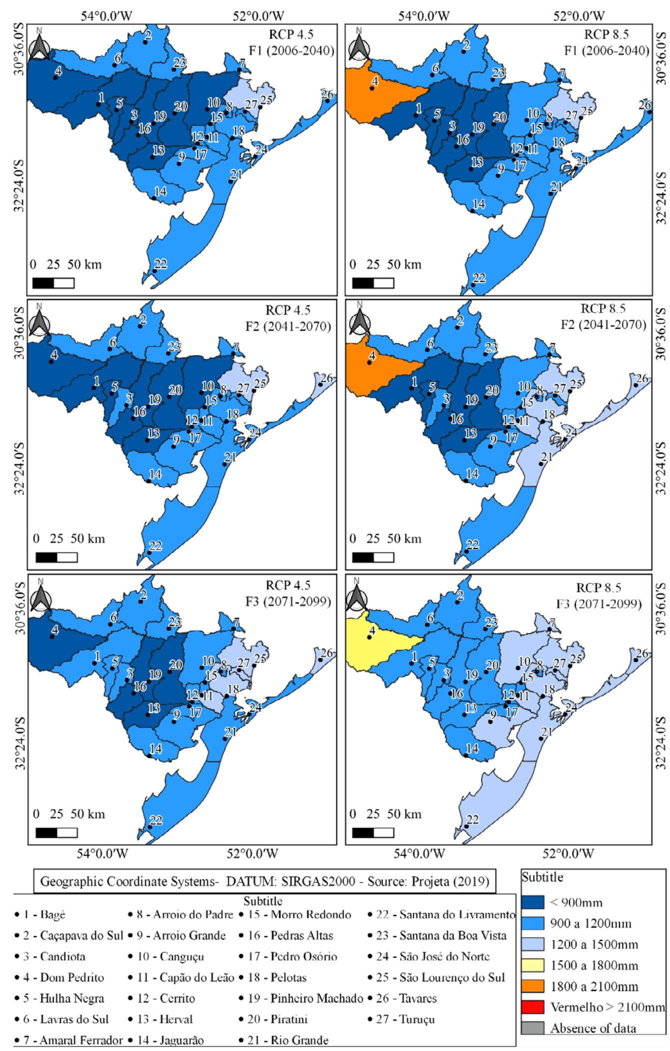

Figure 7 – Average total annual rainfall for cities of the Southern and Steppe regions, according to the MIROC5-ETA model, scenario RCP 4.5 and RCP 8.5, for the three future periods (F1, F2 and F3).
Source: elaborated by the authors.

of Candiota. When comparing the F2 and F3 periods, there are only increases in total annual rainfall, observed in ten cities. It is important to note that the city of Dom Pedrito, which had the highest total annual rainfall value, increased even more in the last future period, going up to the range of 1,500 to 1,800 mm.

These increases between different future periods justify the significant trend detected by the MK test. Contrary to what was found for scenario RCP 4.5, the MIROC5-ETA model found, for scenario RCP 8.5, a significant trend of increasing rainfall in virtually all cities, except Dom Pedrito, which showed a significant trend of decreasing rainfall throughout the century.

There are no great similarities between the three models and the scenarios of the projections, and the MIROC5-ETA model differs from the others in that it does not show decreases in total average annual rainfall in future periods when compared to the base period. In addition, for some cities, higher rainfall values were observed in the most pessimistic scenario (RCP 8.5).

The values of total annual rainfall of the climate models bring some uncertainty when it comes to inferring the trend of rainfall regimes for the cities, as some tend to increase, others show peaks of increase and then decrease, and others remain constant for much of the time. The same was observed by Bravo et al. (2011), who, in addition to assess-

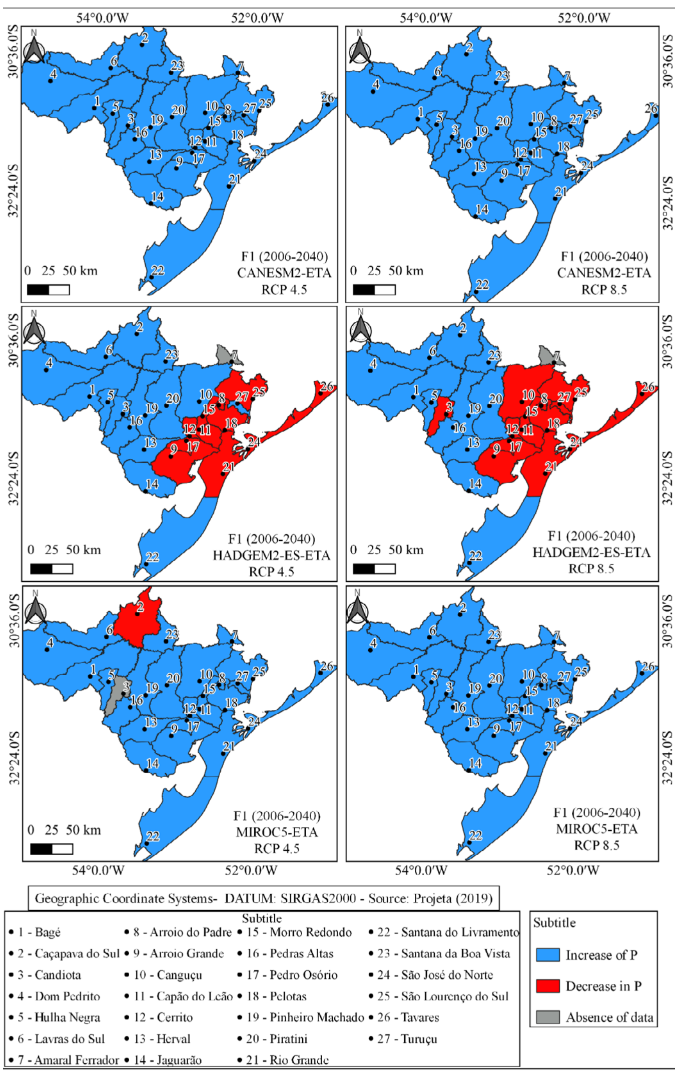

Figure 8 – Anomalies in total annual rainfall (R) for scenario RCP 4.5 and 8.5 with the three regional climate models (CANESM2-ETA, HADGEM2-ES-ETA and MIROC5-ETA) for future F1.
Source: elaborated by the authors.

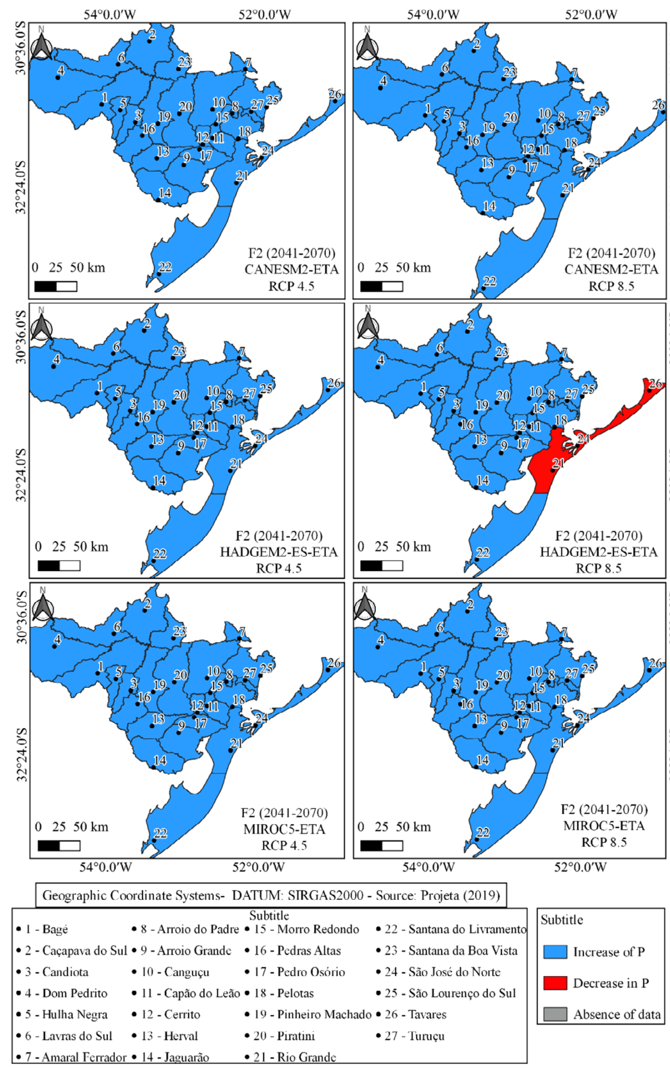

Figure 9 – Anomalies in total annual rainfall (R) for scenario RCP 4.5 and 8.5 with the three regional climate models (CANESM2-ETA, HADGEM2-ES-ETA and MIROC5-ETA) for future F2.
Source: elaborated by the authors.

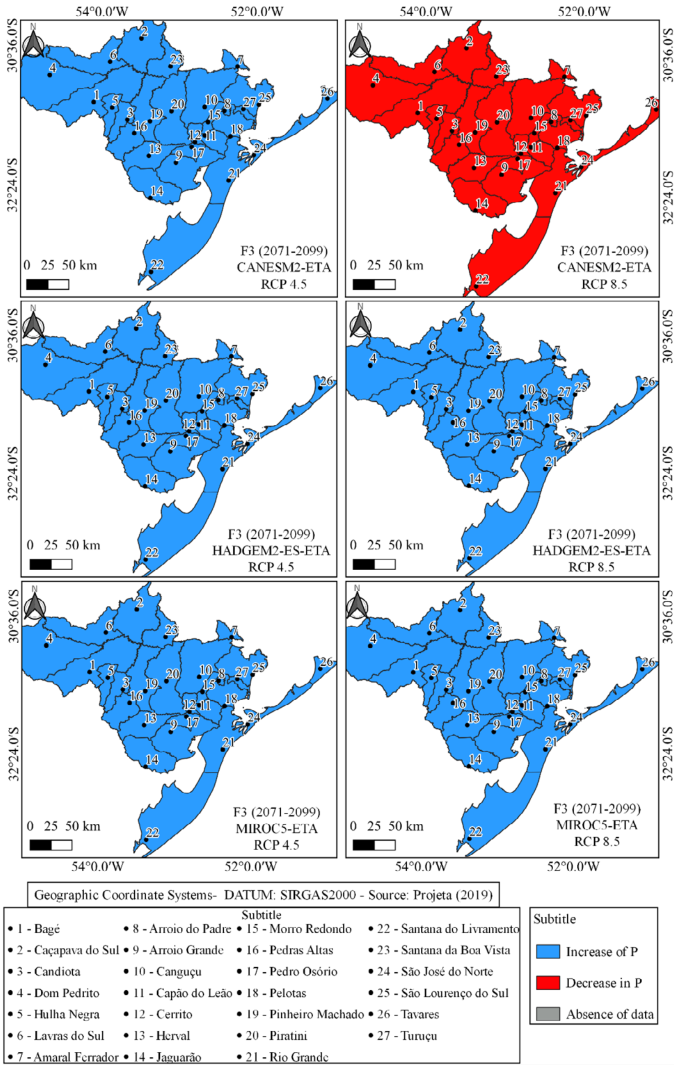

Figure 10 – Anomalies in total annual rainfall (R) for scenario RCP 4.5 and 8.5 with the three regional climate models (CANESM2-ETA, HADGEM2-ES-ETA and MIROC5-ETA) for future F3.
Source: elaborated by the authors.

ing temperature projections, found both an increase and a decrease in rainfall regimes, and observed uncertainties, especially in long-term future periods (2070). Gonçalves and Back (2018), when researching rainfall trends in the southern region of Brazil in the period from 1976 to 2015, considered the series stationary, since 83% did not have any significant trends of increase or decrease in rainfall volume.

The three models suggest an increase in rainfall for a large part of the Steppe region, including the city of Bagé, which, as already mentioned, has recurring periods of drought. Thus, it can be expected that, in the coming years, when compared to the base period, there will be greater water availability in the city and in the adjacent regions.

The cities of Pelotas and São Lourenço do Sul may also experience an increase in rainfall. The two cities have already suffered serious flooding problems, including the municipality of São Lourenço do Sul, which in 2011 presented an event of large volumes of precipitation that ended up affecting approximately 15 thousand people (Rocha, 2011). Therefore, it is extremely important to carry out periodic climate models and forecasts, as a way to issue alerts to the population, in order to avoid or minimize the occurrence of impacts arising from these extreme events.

Anomalies

In the RCP 4.5 scenario, for the first period (F1) (Figure 8), there are signs of positive rainfall anomalies for all cities in the projections of the CANESM2-ETA and MIROC5-ETA models. As for the HADGEM2-ES-ETA model, there are negative anomalies for some cities in the Southern region.

The calculation of anomalies in the RCP 8.5 scenario for the F1 period, represented in Figure 8, with the three climatic models, according to the projections of the CANESM2-ETA and MIROC5-ETA models, indicate positive anomalies for all cities. The HADGEM2-ES-ETA model, on the other hand, presents negative anomalies for 14 cities. This result, when compared to scenario RCP 4.5, is different, since for the same model only positive anomalies were observed in the same period.

For the second period (F2) in the RCP 4.5 scenario (Figure 9), anomaly calculations are positive for all cities, in the three models. In the last future period (F3) (Figure 10), for the same scenario, the projection is the same as the F2 future period, with the three models suggesting positive anomalies for rainfall averages.

For the F2 period (Figure 9), the CANESM2-ETA and MIROC5-ETA models indicate positive anomalies for all cities. The HADGEM2-ES-ETA model projects positive anomalies, except for the cities of São José do Norte, Rio Grande and Tavares. Figure 10 presents the anomalies found for the F3 period. The HADGEM2-ES and MIROC5 models project that annual rainfall anomalies will be positive for all cities.

The CANESM2 model, however, does not have the same projection, finding that the anomaly will be negative for cities in the Southern region, differing from that projected in scenario RCP 4.5, which indicated positive anomalies for the 27 cities. This result of negative precipitation anomaly of the CANESM2 model for the RCP 8.5 scenario and of positive anomaly of the same model for the RCP 4.5 scenario is in accordance with what was observed by Anjos et al. (2018) for the municipality of Pelotas, which makes up the southern region.

Conclusions

The present study carried out in the South region and Rio Grande do Sul Campaign using the CANESM2, HADGEM2-ES and MIROC5 models regionalized by the ETA model and made available on the PROJETA Platform, indicate a possible increase in the average temperature until the end of the 21st century, regardless of which path of greenhouse gas emissions and preservation of the environment humankind chooses to follow, since the two scenarios of future climate projections (RCP 4.5 and RCP 8.5) indicate this increase. However, the average annual temperatures will be milder according to the projection of scenario RCP 4.5, and harsher when considering a more pessimistic scenario (RCP 8.5).

Analyzing the total annual rainfall averages in the different periods (base and future), it is concluded that there are indications that rainfall may increase in volume over time in the two future scenarios, whereas in RCP 8.5 this increase can be repeatedly observed. There are also models that project a decrease in rainfall after a peak period. Therefore, a probable increase in total annual rainfall is foreseen in the future, when compared with the values of the base period. The analysis concludes that the anomalies can be positive or negative in the total future annual rainfall in both projections, however, there is a predominance of positive anomalies for the periods, scenarios and models analyzed.

Contribution of authors:

CARDOSO, I.P.: Conceptualization, Methodology, Writing — Review and Editing, Writing — Original Draft, Software, Investigation.; SIQUEIRA, T.M.: Formal Analysis, Conceptualization, Supervision, Methodology, Software, Writing — Review and Editing, Data Curation, Investigation.; TIMM, L.C.: Formal Analysis, Conceptualization, Supervision, Methodology, Writing — Review and Editing, Investigation.; RODRIGUES, A.A.: Methodology, Writing — Review and Editing, Conceptualization, Investigation.; Nunes, A.B.: Writing — Review and Editing, Formal Analysis, Investigation.

References

Anjos, R.R.; Siqueira, T.M.; Silveira, V.C. da; Leandro, D.; Corrêa, L.B.; Buske, D.; Weymar, G.J., 2018. Análise de tendência de temperatura e precipitação e cenários de mudanças climáticas para Pelotas (RS). Revista Ibero-Americana de Ciências Ambientais, v. 9, (8), 93-108. http://doi.org/10.6008/CBPC2179-6858.2018.008.0009.

Arora, V.K.; Scinocca, J.F.; Boer, G.J.; Christian, J.R.; Denman, K.L.; Flato, G.M.; Kharin, V.V.; Lee, W.G.; Merryfield, W.J., 2011. Carbon emission limits required to satisfy future representative concentration pathways of greenhouse gases. Geophysical Research Letters, v. 38, (5), 1-6. https://doi.org/10.1029/2010GL046270.

Bravo, J.M.; Marques, D. da M.; Tassi, R.; Cardoso, A., 2011. Avaliação de projeções de anomalias de temperatura e precipitação em cenários climáticos futuros na região do sistema hidrológico do Taim, RS. In: XIX Simpósio Brasileiro de Recursos Hídricos.

Braz, D.F.; Pinto, L.B.; Campos, C.R.J., 2017. Ocorrência de eventos severos em regiões agrícolas do Rio Grande do Sul. Geociências, v. 36, (1), 89-99.

Britto, F.P.; Barletta, R.; Mendonça, M., 2008. Regionalização sazonal e mensal da precipitação pluvial máxima no estado do Rio Grande do Sul. Revista Brasileira de Climatologia, v. 3, 83-99. https://doi.org/10.5380/abclima.v3i0.25425.

Brondani, A.R.P.; Wollmann, C.A.; Ribeiro, A. de A., 2013. A percepção climática da ocorrência de estiagens e os problemas de abastecimento de água na área urbana do município de Bagé-RS. Revista do Departamento de Geografia , v. 26, 214-232. https://doi.org/10.7154/RDG.2013.0026.0011.

Caballero, C.B.; Ogassawara, J.F.; Dorneles, V.R.; Nunes, A.B., 2018. A precipitação pluviométrica em Pelotas/RS: tendência, sistemas sinóticos associados e influência da ODP. Revista Brasileira de Geografia Física, v. 11, (4), 1429-1441. https://doi.org/10.26848/rbgf.v11.4.p1429-1441.

Cera, J.C.; Ferraz, S.E.T., 2015. Variações climáticas na precipitação no Sul do Brasil no clima presente e futuro. Revista Brasileira de Meteorologia, v. 30, (1), 81-88. https://doi.org/10.1590/0102-778620130588.

Chou, S.C.; Lyra, A.; Mourão, C.; Dereczynski, C.; Pilotto, I.; Gomes, J.; Bustamante, J.; Tavares, P.; Silva, A.; Rodrigues, D; Campos, D.; Chagas, D.; Sueiro, G.; Siqueira, G.; Marengo, J., 2014a. Assessment of climate change over South America under RCP 4.5 and 8.5 downscaling scenarios. American Journal of Climate Change, v. 3, 512-525. https://doi.org/10.4236/ajcc.2014.35043.

Chou, S.C.; Lyra, A.; Mourão, C.; Dereczynski, C.; Pilotto, I.; Gomes, J.; Bustamante, J.; Tavares, P.; Silva, A.; Rodrigues, D.; Campos, D.; Chagas, D.; Sueiro, G.; Siqueira, G.; Nobre, P.; Marengo, J., 2014b. Evaluation of the Eta simulations nested in three global climate models. American Journal of Climate Change, v. 3, (5), 438-454. https://doi.org/10.4236/ajcc.2014.35039.

Chou, S.C.; Marengo, J.A.; Lyra, A.A.; Sueiro, G.; Pesquero, J.F.; Alves, L.M.; Kay, G.; Betts, R.; Chagas, D.J.; Gomes, J.L.; Bustamnte, J.F.; Tavares, P., 2012. Downscaling of South America present climate driven by 4-member HadCM3 runs. Climate Dynamics, v. 38, 635-653. https://doi.org/10.1007/s00382-011-1002-8.

Chylek, P.; Li, J.; Dubey, M.K.; Wang, M.; Lesins, G., 2011. Observed and model simulated 20th century Arctic temperature variability: Canadian earth system model CanESM2. Atmospheric Chemistry and Physics, v. 11, 22893-22907. https://doi.org/10.5194/acpd-11-22893-2011.

Collins, M.; Knutti, R.; Arblaster, J.; Dufresne, J.-L.; Fichefet, T.; Friedlingstein, P.; Gao, X.; Gutowski, W.J.; Johns, T.; Krinner, G.; Shongwe, M.; Tebaldi, C.; Weaver, A.J.; Wehner, M., 2013. Long-term climate change: projections, commitments and irreversibility. In: Stocker, T.F.; Qin, D.; Plattner, G.-K.; Tignor, M.; Allen, S.K.; Boschung, J.; Nauels, A.; Xia, Y.; Bex, V.; Midgley, P.M. (Eds.), Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 1029-1136.

Dariane, A.B.; Pouryafar, E., 2021. Quantifying and projection of the relative impacts of climate change and direct human activities on streamflow fluctuations. Climatic Change, v. 165, (1), 34. https://doi.org/10.1007/s10584-021-03060-w.

Dereczynski, C.; Chou, S.C.; Lyra, A.; Sondermann, M.; Regoto, P.; Tavares, P.; Chagas, D.; Gomes, J.L.; Rodrigues, D.C.; Skansi, M. M., 2020. Downscaling of climate extremes over South America – Part I: Model evaluation in the reference climate. Weather and Climate Extremes, v. 29, 100273. https://doi.org/10.1016/j.wace.2020.100273.

Diário Popular, 2021. Barragem Santa Bárbara recupera nível ideal para captação de água (Accessed on June 17, 2021) at.: https://www.diariopopular.com.br/geral/barragem-santa-barbara-recupera-nivel-ideal-para-captacao-de-agua-158182.

Fazel-Rastgar, F., 2020. Synoptic climatological approach associated with three recent summer heatwaves in the Canadian Arctic. Journal of Water and Climate Change, v. 11, (S1), 233-250. https://doi.org/10.2166/wcc.2020.281.

Fernandes, V.R.; Cunha, A.P.M. do A.; Pineda, L.A.C.; Leal, K.R.D.; Costa, L.C.O.; Broedel, E.; França, D. de A.; Alvalá, R.C. dos S.; Selichi, M.E.; Marengo, J., 2021. Secas e os impactos na região Sul do Brasil. Revista Brasileira de Climatologia, v. 28, 561-584. https://doi.org/10.5380/rbclima.v28i0.74717.

Fundação de Economia e Estatística (FEE), 2015. COREDES (Accessed on June 17, 2021) at:. https://arquivofee.rs.gov.br/perfil-socioeconomico/coredes/#:~:text=O%20PERFIL%20SOCIOECON%C3%94MICO%20RS%20%E2%80%93%20COREDES,munic%C3%ADpios%20com%20o%20do%20Estado.

Gomes Junior, E.C.; Ely, D.F., 2021. Métodos estatísticos não-paramétricos como ferramenta no monitoramento pluviométrico. Revista da Casa da Geografia de Sobral, v. 23, 38-53. https://doi.org/10.35701/rcgs.v23.770.

Gonçalves, F.N.; Back, A.J., 2018. Análise da variação espacial e sazonal e de tendências na precipitação da região sul do Brasil. Revista de Ciências Agrárias (Online), v. 41, (3), 11-20. https://doi.org/10.19084/RCA17204.

Grimm, A.M., 2009. Variabilidade interanual do clima no Brasil. In: Cavalcanti, I.F.A.; Ferreira, N.J.; Silva, M.G.A.J.; Dias, M.A.F.S. (Eds.), Tempo e clima no Brasil. Oficina de Textos, São Paulo, pp. 353-374.

Grimm, A.M.; Ferraz, S.E.T.; Gomes, J., 1998. Precipitation anomalies in Southern Brazil associated with El Niño and La Niña events. Journal of Climate, v. 11, 2863-2880. https://doi.org/10.1175/1520-0442(1998)011<2863:PAISBA>2.0.CO;2.

Hartmann, D.L.; Klein Tank, A.M.G.; Rusticucci, M.; Alexander, L.V.; Brönnimann, S.; Charabi, Y.; Dentener, F.J.; Dlugokencky, E.J.; Easterling, D.R.; Kaplan, A.; Soden, B.J.; Thorne, P.W.; Wild, M.; Zhai, P.M., 2013. Observations: atmosphere and surface. In: Stocker, T.F.; Qin, D.; Plattner, G.-K.; Tignor, M.; Allen, S.K.; Boschung, J.; Nauels, A.; Xia, Y.; Bex, V.; Midgley, P.M. (Eds.), Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 159-254.

Hölbig, C.A.; Mazzonetto, A.; Borella, F.; Pavan, W.; Fernandes, J.M.C.; Chagas, D.J.C.; Gomes, J.L.; Chou, S.C., 2018. PROJETA platform: accessing high resolution climate change projections over Central and South America using the Eta model. Agrometeoros, v. 26, (1), 71-81. https://doi.org/10.31062/agrom.v26i1.26366.

Intergovernmental Panel on Climate Change (IPCC), 2013. Climate change 2013: the physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Kendall, M.G., 1975. Rank correlation methods, 4th ed. Charles Griffin, London, 272 pp.

Kulman, D.; Reis, J.T.; Souza, A.C. de; Pires, C.A. da F.; Sausen, T.M., 2014. Occurrence of drought in Rio Grande do Sul in the period 1981 to 2011. Ciência e Natura, v. 36, (3), 441-449. https://doi.org/10.5902/2179460X13205.

Lima, P.R.C. de; Andrade, A.E. de; Oliveira, J.V.P. de; Lucena, D.B., 2021. Identificação de tendências nas séries temporais de precipitação na microrregião do Alto Sertão Paraibano. Revista AIDIS de Ingeniería y Ciencias Ambientales, v. 14, (1), 1-18. https://doi.org/10.22201/iingen.0718378xe.2021.14.1.63570.

Lopes, A.B.; Vieira, M.R.S.; Lima Filho, A.A. de; Silvestrim, E.G.; Silvestrim, F.G., 2021. Anomalias na precipitação de quatro municípios do Amazonas, Brasil. Research, Society and Development. v. 10, (14), e196101421766. https://doi.org/10.33448/rsd-v10i14.21766.

Lyra, A.; Tavares, P.; Chou, S.C.; Sueiro, G.; Dereczynski, C.P.; Sondermann, M.; Silva, A.; Marengo, J.; Giarolla, A., 2018. Climate change projections over three metropolitan regions in Southeast Brazil using the non-hydrostatic Eta regional climate model at 5-km resolution. Theoretical and Applied Climatology, v. 132, 663-682. https://doi.org/10.1007/s00704-017-2067-z.

Mann, H.B.; Whitney, D.R., 1947. On a test of whether one of two random variables is stochastically larger than the other. Annals of Mathematical Statistics, v. 18, (1), 50-60. https://doi.org/10.1214/aoms/1177730491.

Marengo, J.A.; Ambrizzi, T.; Rocha, R.P.; Alves, L.M.; Cuadra, S.V.; Valverde, M.C.; Torres, R.R.; Santos, D.C.; Ferraz, S.E.T., 2010. Future change of climate in South America in the late XXI century: intercomparison of scenarios from three regional climate models. Climate Dynamics, v. 35, 1073-1097. https://doi.org/10.1007/s00382-009-0721-6.

Martin, G.M.; Bellouin, N.; Collins, W.J.; Culverwell, I.D.; Halloran, P.R.; Hardiman, S.C.; Hinton, T.; Jones, C.D.; McDonald, R.E.; McLaren, A.J.; O'Connor, F.; Roberts, M.J.; Rodriguez, J.M.; Woodward, S.; Best, M.J.; Brooks, M.E.; Brown, A.R.; Butchart, N.; Dearden, C.; Derbyshire, S.H.; Dharssi, I.; Doutriaux-Boucher, M.; Edwards, J.M.; Falloon, P.D.; Gedney, N.; Hewitt, H.T.; Hobson, M.; Huddleston, M.R.; Hughes, J.; Ineson, S.; Ingram, W.J.; James, P.M.; Johns, T.C.; Johnson, C.E.; Jones, A.; Jones, C.P.; Joshi, M.; Keen, A.B.; Liddicoat, S.; Lock, A.P.; Maidens, A.V.; Manners, J.C.; Milton, S.F.; Rae, J.; Ridley, J.K.; Sellar, A.; Senior, C.A.; Totterdell, I.; Verhoef, A.; Vidale, P.L.; Wiltshire, A., 2011. The hadGEM2 family of Met Office unified model climate configurations. Geoscientific Model Development, v. 4, 723-757. https://doi.org/10.5194/gmd-4-723-2011.

Mesinger, F.; Chou, S.C.; Gomes, J.L.; Jovic, D.; Bastos, P.R.; Bustamante, J.F.; Lazic, L.; Lyra, A.A.; Morelli, S.; Ristic, I.; Veljovic, K., 2012. An upgraded version of the Eta model. Meteorological and Atmospheric Physics, v. 116, 63-79. https://doi.org/10.1007/s00703-012-0182-z.

Miguel, J.C.H., 2017. Tecnopolíticas das mudanças climáticas: modelos climáticos, geopolítica e governamentalidade. História, Ciências, Saúde-Manguinhos, v. 24, (4), 969-987.

Moura, R.G. de; Herdies, D.L.; Mendes, D.; Mendes, M.C.D., 2010. Avaliação do modelo regional ETA utilizando as análises do CPTEC e NCEP. Revista Brasileira de Meteorologia, v. 25, (1), 46-53. https://doi.org/10.1590/S0102-77862010000100005.

Nedel, A.; Sauden, T.M.; Saito, S.M., 2012. Zoneamento dos desastres naturais ocorridos no estado do Rio Grande do Sul no período 1989 – 2009: granizo e vendaval. Revista Brasileira de Meteorologia, v. 27, (2), 119-126. https://doi.org/10.1590/S0102-77862012000200001.

Nunes, A.B.; Silva, G.C., 2013. Climatology of extreme rainfall events in eastern and northern Santa Catarina State, Brazil: present and future climate. Revista Brasileira de Geofísica, v. 31, (3), 413-425. https://doi.org/10.22564/rbgf.v31i3.314.

Oliveira, L.F.C., 2019. (Ed.). Chuvas extremas no Brasil: modelos e aplicações. Ed. UFLA, Lavras.

Ongoma, V.; Chen, H.; Gao, C.; Nyongesa, A.M.; Polong, F. 2018. Future changes in climate extremes over Equatorial East Africa based on CMIP5 multimodel ensemble. Natural Hazards, v. 90, 901-920. https://doi.org/10.1007/s11069-017-3079-9.

Ouhamdouch, S.; Bahir, M.; Ouazar, D.; Goumih, A.; Zouari, K., 2020. Assessment the climate change impact on the future evapotranspiration and flows from a semi-arid environment. Arabian Journal of Geosciences, v. 13, 82. https://doi.org/10.1007/s12517-020-5065-x.

Penereiro, J.C.; Meschiatti, M.C., 2018. Tendências em séries anuais de precipitação e temperaturas no Brasil. Engenharia Sanitária e Ambiental, v. 23, (2), 319-331. https://doi.org/10.1590/S1413-41522018168763.

Pereira, R.S.; Nunes, A.B., 2018. Estudo climático dos eventos de precipitação associados a alagamentos urbanos no Estado do Rio Grande do Sul. Revista Brasileira de Geografia Física, v. 11, (6), 2010-2017. https://doi.org/10.26848/rbgf.v11.6.p2010-2017.

Pettitt, A.N., 1979. A non-parametric approach to the change-point problem. Journal of the Royal Statistical Society: Series C (Applied Statistics), v. 28, (2), 126-135. https://doi.org/10.2307/2346729.

Queiroga, A.A.; Luz, M.B.; Filgueira, HJ. A., 2022. A redução de riscos de desastres (RRD) e a resiliência na segurança alimentar e nutricional. Territorium, (29 I), 139-148. https://doi.org/10.14195/1647-7723_29-1_12.

Quesada-Montano, B.; Di Baldassarre, G.; Rangecroft, S.; Van Loon, A.F., 2018. Hydrological change: Towards a consistent approach to assess changes on both floods and droughts. Advances in Water Resources, v. 111, 31-35. https://doi.org/10.1016/j.advwatres.2017.10.038.

Radin, B.; Matzenauer, R., 2016. Uso das informações meteorológicas na agricultura do Rio Grande do Sul. Agrometeoros, v. 24, (1), 41. https://doi.org/10.31062/agrom.v24i1.24880.

Rao, V.B.; Hada, K., 1990. Characteristics of rainfall over Brazil: Annual variations and connections with the Southern Oscillation. Theoretical and Applied Climatology (Online), v. 42, 81-91. https://doi.org/10.1007/BF00868215.

Ribeiro, M.E.; Bortolin, T.A.; Mendes, L.A.; Santa Rita, L.C.S., 2021. Análise de Séries Hidrológicas na Bacia Hidrográfica afluente à Usina Hidrelétrica Castro Alves, RS. Revista Brasileira de Geografia Física, v. 14, (4), 2042-2058. https://doi.org/10.26848/rbgf.v14.4.p2042-2058.

Rocha, G., 2011. Cidade do RS sofre pior inundação em 70 anos. Folha de S.Paulo (Accessed on December 18, 2021) at:. https://www1.folha.uol.com.br/fsp/cotidian/ff1203201120.htm.

Salviano, M.F.; Groppo, J.D.; Pellegrino, G.Q., 2016. Análise de Tendências em Dados de Precipitação e Temperatura no Brasil. Revista Brasileira de Meteorologia (Online), v. 31, (1), 64-73. https://doi.org/10.1590/0102-778620150003.

Sane, M.; Sambou, S.; Diatta, S.; Leye, I.; Ndione, D.; Sauvage, S.; Sanchez-Perez, J.M.; Kane, S., 2019. Trends and shifts in time series of climate data generated by GCM from 2006 to 2090. International Journal of Scientific & Engineering Research, v. 10, (5), 212-229. https://doi.org/10.14299/ijser.2019.05.01.

Sansigolo, C.A.; Kayano, M.T., 2010. Trends of seasonal maximum and minimum temperatures and precipitation in Southern Brazil for the 1913-2006 period. Theoretical and Applied Climatology, v. 101, 209-216. https://doi.org/10.1007/s00704-010-0270-2.

Secretaria de Planejamento, Governança e Gestão (Seplag), 2020. Clima, temperatura e precipitação. Atlas Socioeconômico Rio Grande do Sul. 5. Ed. Secretaria de Planejamento, Governança e Gestão, Departamento de Planejamento Governamental, Porto Alegre, 125 pp.

Sen, P.K., 1968. Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association, v. 63, (324), 1379-1389.

Silva, G.K.; Silveira, C.S.; Silva, M.V.M.; Marcos Júnior, A.D.; Souza Filho, F.A., Guimarães, S.O., 2020. Análise de projeções das mudanças climáticas sobre precipitação e temperatura nas regiões hidrográficas brasileiras para o século XXI. Revista Brasileira de Ciências Ambientais, v. 55, (3), 420-436. https://doi.org/10.5327/Z2176-947820200624.

Silveira, A., 2020. Barragem Santa Bárbara em Pelotas atinge nível mais baixo da história. Correio do Povo (Accessed on December 17, 2021) at:. https://www.correiodopovo.com.br/not%C3%ADcias/cidades/barragem-santa-b%C3%A1rbara-em-pelotas-atinge-n%C3%ADvel-mais-baixo-da-hist%C3%B3ria-1.423776.

Tejadas, B.E.; Bravo, J.M.; Sanagiotto, D.G.; Tassi, R.; Marques, D.M.L.M., 2016. Projeções de vazão afluente à Lagoa Mangueira com base em cenários de mudanças climáticas. Revista Brasileira de Meteorologia, v. 31, (3), 262-272. https://doi.org/10.1590/0102-778631320150139.

Van Vuuren, D.P.; Edmonds, J.; Kainuma, M.; Riahi, K.; Thomson, A.; Hibbard, K.; Hurtt, G.C.; Kram, T.; Krey, V.; Lamarque, J.; Masui, T.; Meinshausen, M.; Nakicenovic, N.; Smith, S.J.; Rose, S.K., 2011. The representative concentration pathways: an overview. Climatic Change, v. 109, 5. https://doi.org/10.1007/s10584-011-0148-z.

Vieira, R.M.G.; Dereczynski, C.P.; Chou, S.C.; Gomes, J.L.; Paiva Neto, A.C., 2015. Avaliação das previsões de precipitação do modelo Eta para Bacia do Rio São Francisco em Minas Gerais, Brasil. Anuário do Instituto de Geociências, v. 38, (2), 15-23. https://doi.org/10.11137/2015_2_15_23.

Watanabe, M.; Suzuki, T.; O'ishi, R.; Komuro, Y.; Watanabe, S.; Emori, S.; Takemura, T.; Chikira, M.; OGura, T.; Sekiguchi, M.; Takata, K.; Yamazak, D.; Yokohata, T.; Nozawa, T.; Hasumi, H.; Tatebe, H., Kimoto, M., 2010. Improved climate simulation by MIROC5: mean States, variability, and climate sensitivity. Journal of Climate, v. 23, (23), 6312-6335. https://doi.org/10.1175/2010JCLI3679.1.

Winsemius, H.C.; Jongman, B.; Veldkamp, T.I.; Hallegatte, S.; Bangalore, M.; Ward, P.J., 2018. Disaster risk, climate change, and poverty: assessing the global exposure of poor people to floods and droughts. Environment and Development Economics, v. 23, (3), 328-348. https://doi.org/10.1017/S1355770X17000444.

Yuan, X.C.; Wei, Y.-M.; Wang, B.; Mi, Z., 2017. Risk management of extreme events under climate change. Journal of Cleaner Production, v. 166, 1169-1174. https://doi.org/10.1016/j.jclepro.2017.07.209.

Zamani, R.; Mirabbasi, R.; Abdollahi, S.; Jhajharia, D., 2017. Streamflow trend analysis by considering autocorrelation structure, long-term persistence, and Hurst coefficient in a semi-arid region of Iran. Theoretical and Applied Climatology, v. 129, (1-2), 33-45. https://doi.org/10.1007/s00704-016-1747-4.