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Regional Climate Models in the Simulation of the Drought of the 1970's and 1980's Years in Senegal (In West Africa)

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Abstract

West Africa was hit by an unprecedented drought in the 1970's and 1980's years, with dramatic consequences for surface and groundwater resources. In the context of climate change, there are many studies for the prediction of the increase in the occurrence of these droughts. To predict this situation in the Senegalese region, it is necessary to use regional climate models, which carrying out the study. This work deals with the interest to examine the capacity of the RCMs (regional climate models) in order to reproduce the deficit on the 1970's year rainfall in Senegal. In this work, we used daily precipitation data from five (5) regional climate models to characterize the droughts in Senegal by using the SPI (Standardized Precipitation Index) on different time scales (3, 6, 12 and 24 months). For this purpose, the index was calculated over two distinct periods: 1951-1969 and 1970-1990. The results show that the period 1970-1990 was drier than the period 1951-1969. For the zonal average, the results show that the North of Senegal was more affected by this deficit rainfall than the South part. The analysis of the interannual variability of rainfall for some stations in Senegal shows that the drought did not start at the same time throughout the zone.

Keywords

Climate Change, Drought, SPI (Standardised Precipitation Index), Senegal

1. Introduction

Extreme processes in the climate system continue to manifest themselves, particularly in terms of natural hazards whose impacts are felt around the world with particularly adverse consequences for humanity [1]. Drought, one of these extreme events, has an impact on surface and groundwater resources, agriculture and natural ecosystems [2]. It also affects more people than any other form of natural disasters [3]. Senegal (in West Africa), was hit by an unprecedented drought in the 1970's and 1980's, caused by the famine, population migration and even triggering a conflict between Senegal and Mauritania in 1989 [4]. It is in this context that numerous studies have been carried out, such as the works of [5]-[7], which have shown the severity of this drought.

Furthermore, in recent decades there has been an increase in extreme weather events leading the [8] to state that West Africa is likely to experience an increase in dry episodes. For this reason, recent work uses climate models to study how the characteristics of wet and dry periods of precipitation will change in the future [9]. However, the use of such models requires consideration of their ability to represent the current climate. The objective of the paper is to provide a new approach to the validation of climate models by using past extreme climate events as a validation indicator, which is why we are interested in the capacity of the models to represent or to reproduce the 1970's rainfall deficit in Senegal.

In this work, the SPI will be used to characterize this drought over the period 1951-1990, which has distinct sub-periods: wet period 1951-1969 and dry period 1970-1990.

The rest of this paper is organized as follows: in Section 2, we give the description of the study area, the datasets, and the methodology. Section 3 presents our many results. The discussions and conclusion are introduced in Sections 4 and Section 5 respectively.

2. Data and Methods

2.1. Data

In this work, our study area (Senegal) is divided into three zones (North, Centre and South) (**Figure 1**). Indeed, these zones are characterised by different climatic conditions. Daily rainfall data from 5 RCMs (Coordinated Regional Downscaling Experiment-Africa) are used for the period 1951-2005. These data are interpolated to a 0.44˚ (50 km) grid forcing the Rossby Centre Regional Atmospheric Model (RCA4). This model was developed by the Swedish Meteorological and Hydrological Institute (SMHS) and is based on CMIP5 GCMs (global climate model) (CanESM2, CNRM, MIROC, CSIRO, GFDL) to perform dynamic downscaling. Daily data from the Global Precipitation Climatology Project (GPCP) [10] over the period 1980-2005 are taken to evaluate the ability of RCMs (regional climate model) to simulate summer rainfall in Senegal. These data are a combination of in situ Measurements and satellite estimates on a 50 km grid. Indeed, several studies have used these datasets (GPCP) and concluded that they provide a very good representation of the climatology in West Africa [11] [12].

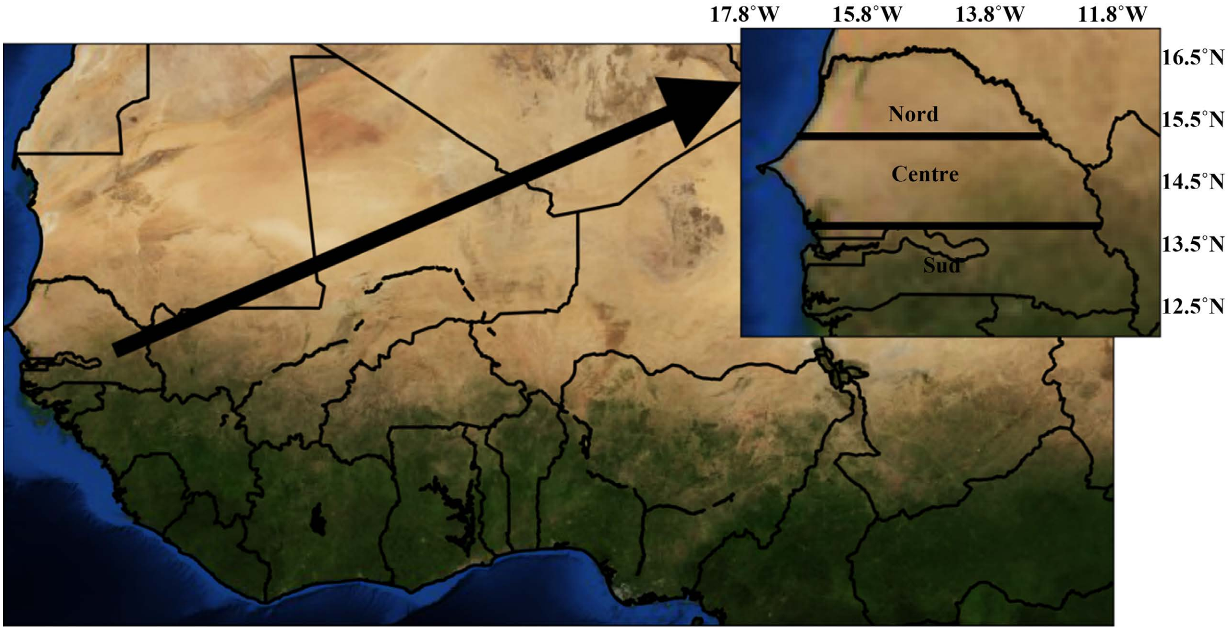


Figure 1. Topography of the study area (Senegal).

2.2. Methods

In our study, the SPI will be used to characterize the deficit rainfall for the period 1951-1990. The methodology adopted in this study is as follows.

First, we will study the climatology by studying the seasonal cycle of precipitation through the Hovmöller diagram. Then we will proceed to the validation of our simulated data over the period 1980-2005 using the GPCP data as reference for this purpose the bias analysis will be carried out to check if our models tend to underestimate or overestimate the rainfall. The correlation and root mean square error (RMSE) will also be calculated to evaluate the models. Then, to evaluate the annual precipitation trends in a spatial way, the Mann-Kendall test will be used. Finally, to spatially characterize rainfall over the period 1951-1990 using the SPI. Indeed, the study of the rainfall deficit for this period is justified by the fact that this period comprises two very interesting sub-periods: one wet (1951-1969) and the other dry (1970-1990).

2.2.1. The Bias' Calculation

The bias allows us to assess whether the models tend to overestimate or underestimate precipitation. It also gives us information about the accuracy of the models. The bias is calculated as follows:

$$\text{Bias} = \left(P_i - P_s\right)/P_s \quad (1)$$

Where P_i represents observed data and P_s represents simulated data. The smaller the bias (close to 0), the better the model, if it is positive, the models overestimate precipitation and if the bias is negative, they underestimate it.

2.2.2. Correlation and Root Mean Squared Error (RMSE)

The correlation gives us the link between two variables through the coefficient of determination R^2, this coefficient evaluates the performance of the model in relation to the level of variation present in the data. The closer it is to 1, the better our models perform. It is calculated as follows:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - y_m)} \quad (2)$$

The RMSE (root mean square error) provides us with the errors of the simulated values (models) compared to the observations. This index gives an indication of the dispersion of the quality of our models. It is obtained as follows:

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)}{n}} \quad (3)$$

Where n is the number of measurements, y_i is the value of the ith observation in the GPCP data set, $\hat{y}_i$ is the i-th predicted value of the simulated data, y_m is the average of the values in the GPCP dataset.

It is crucial to recognize the limitations of the scores used for model evaluation. For example, R^2 can be misleading as it may increase with the addition of unnecessary variables to the model. Bias, although useful for measuring the systematic trend of predictions, does not provide information about the dispersion of errors. Similarly, RMSE, while useful for quantifying the overall accuracy of predictions, can be disproportionately influenced by outliers. Therefore, although these scores are valuable tools, it would be beneficial to use multiple validation metrics to address the limitations of each score.

2.2.3. Mann-Kendal's Test

The Mann-Kendal's test [13] is used to examine the existence of a linear trend (increasing or decreasing) in a time series. The null hypothesis H_0 corresponds to "there is no trend". If the p-value < α, were α is chosen significance level, the H_0 hypothesis is rejected and it is concluded that there is a significant trend at the chosen level. Mann-Kendall's rate (τ_M) uses the same assumptions as Spearman's corelation coefficient R, but they are often different. In the case where the Spearman's coefficient is considered as a standard Pearson linear correlation coefficient, i.e. it can be interpreted in term of the share explained variance part, when the Spearman's coefficient R is calculated from the ranks.

The Kendall's coefficient τ_M represents also the difference between the probability that two variables have the same order in the observed data compared to the probability that these two variables have a different order, this leads that the Kendall's coefficient τ_M is expressed as:

$$\tau_M = \frac{2S}{n(n-1)} \quad (4)$$

with $S = \sum_{k=1}^{n-1}\sum_{k+1}^{n} sign(x_i - x_j)$.

Where S is the value of the statistical test that gives us an indication of whether the trend is up or down and n is the length of the dataset and x_j and x_k indicate the observations at times i and j.

The correlation test for the rank is based on the number P of pairs (X_i, X_j) for which ($X_j > X_i$, $j > i$, $i = 1, \ldots, N - 1$). Under the null hypothesis (H_0) of stationarity time series, the variable ω defined by:

$$\omega_n = \frac{4P}{n(n-1)} - 1 \tag{5}$$

follows a centred normal distribution with variance equal to:

$$\sigma^2 = \frac{2(2n+5)}{9n(n-1)} \tag{6}$$

For a given first-order risk α, the acceptance of H_0 is defined by the membership of ω_n in the interval:

$$\left[-\sigma_n Z_{1-\alpha/2}; \sigma_n Z_{1-\alpha/2}\right] \tag{7}$$

where $Z_{1-\alpha/2}$ denotes the fractil of order 1- $\alpha/2$ of a standard normal random variable.

Thus, the alternative hypothesis is that of a trend.

The slope estimator of the Kendal test is the median of N values of Q_i, where

$$Q_i = \frac{x_k - x_j}{k - j}, 1, 2, 3, \cdots, N, k > j$$

Thus, if some zero values of Q_i lie between an equal number of negative and positive values of Q_i, the slope is zero.

2.2.4. The SPI Index

The SPI index developed by [14] is used to calculate and quantify precipitation anomalies over multiple time scales. it is calculated as follows:

$$\text{SPI} = \left(P_i - P_m\right)/\sigma \tag{8}$$

With P_i the rain of the month or year i, P_m and σ respectively represent the mean and the standard deviation of the series considered. This index was validated by [15] as an essential tool for measuring droughts. To classify drought conditions, [11] introduced a criterion based on index values (**Table 1**). To do this, we calculated the SPI of 3 months, 6 months, 12 months and 24 months. The 3-month SPI shows a comparison between total precipitation over a given 3-month period and total precipitation for that same 3-month period for the entire series. For the 6-month SPI, it shows precipitation trends over a season and into the medium term. For the 12-month and 24-month SPI, they provide a representation of long-term precipitation.

The SPI index is calculated at each point of the grid for all our models over the periods 1951-1969 and 1970-1990, the idea is to be able to make a comparison of the SPI of these two periods, [16] showed that the drought started in West Africa especially in Senegal in the 69's and ended in the 90's, the objective is to study the ability of our climate models to represent this rainfall deficit of the 1970s in a spatial and temporal manner.

Although the Standardized Precipitation Index is a useful tool for assessing drought, it only quantifies precipitation deficits. Indeed, the Standardized Precipitation Index may not account for other important factors such as evapotranspiration, temperature, or soil water retention, which could also influence drought.

Table 1. Classification of drought sequences by SPI value.

SPI	Dry sequences	SPI	Wet sequences
−0.99 < SPI < 0	Slightly dry	0 < SPI < 0.99	Slightly damp
−1.49 < SPI < −1	Moderately dry	1 < SPI < 1.49	Moderately damp
−1.99 < SPI < −1.5	Severely dry	1.50 < SPI < 1.99	Severely damp
SPI < −2	Extremely dry	2 < SPI	Extremely damp

3. Results

3.1. Climatological Studies and Analysis of Biases in the Models

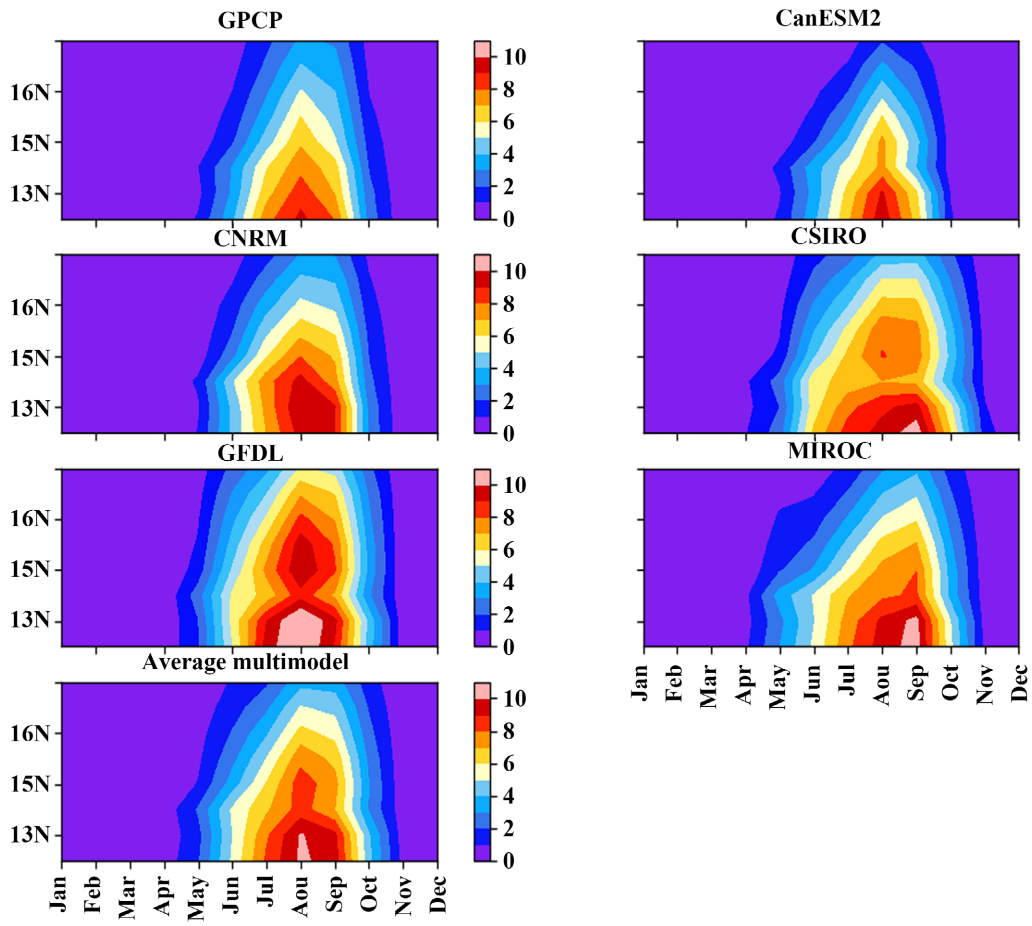


Figure 2. Hovmöller diagram for the period 1980-2005 of the seasonal cycle of precipitation expressed in mm for GPCP observations and models.

Figure 2 shows the seasonal rainfall cycle averaged over the period 1980-2005. The GPCP data represents well the West African Monsoon cycle which starts in early June and ends around September-October with maximum rainfall in July, August and September.

For the models as well as their ensemble mean, the results show that their seasonal cycle presents the same structure with the observations (GPCP) with the maximum rainfall in August contrary to the CNRM and MIROC models where the maximum is noticed in September.

For validation purposes, the average precipitation simulated by the regional climate models is compared to the GPCP data. Figure 3 shows the biases of RCMs with respect to GPCP observations over the period 1980-2005. The results show that the CanESM2 model (Figure 3(a)) simulates a dry bias in most of the country. Indeed, they quite significantly underestimate the rainfall on the west coast of Senegal, but there is a slight overestimation of the rainfall a little in the centre and a part of the south. For the CNRM and MIROC models, there are wet biases over most of the country, but on the west coast, precipitation is underestimated. For the GFDL and CSIRO models, they exhibit wet biases throughout Senegal, these biases are more important in the central and western parts of the country up to more than 100%. However, the mutlimodel MCR mean greatly reduces the intensity of wet and dry biases and improves the performance of each model taken each.

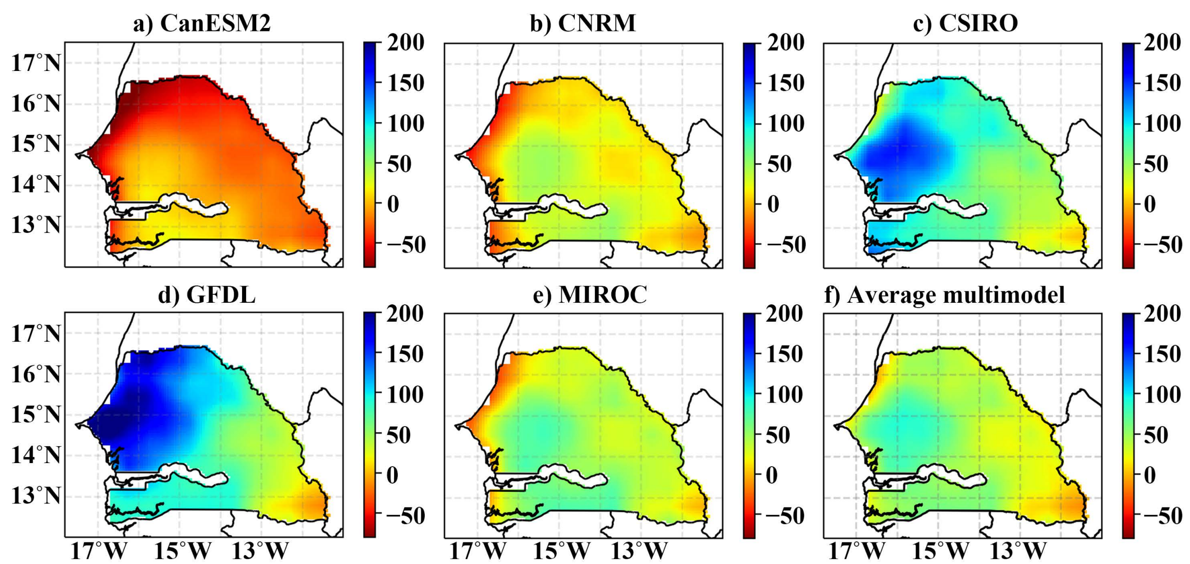


Figure 3. Bias of the 5 models used and their multimodel average.

3.2. Spatial Analysis of Correlation and Root Mean Square Error

The analysis of the results shows that the precipitation data from the models are well correlated with the GPCP data (observation) with a range between 0.65 and 0.9 (Figure 4). The spatial analysis also shows that the two datasets are strongly correlated in the south and central part of the country for all models. It can also be seen that the CNRM model and the ensemble mean are the most correlated with the observations.

To check the significance of this correlation, we calculated the P-value at a 95% confidence level, the analysis reveals that the correlations are significant for all models with P-values well below 0.05 (Figure 5). These new results show the performance of the models in the study of climate for our study area.

In order to calculate the error of the model-simulated precipitation values with respect to the GPCP observation data, we calculated the root mean square error (RMSE).

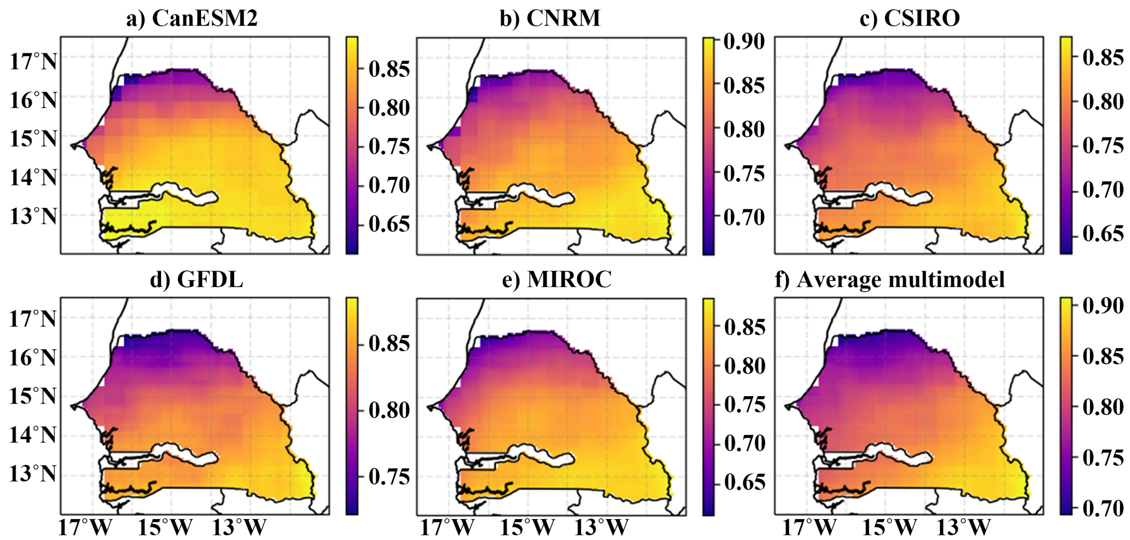


Figure 4. Correlation between observations (GPCP) and models for the period 1980-2005 of monthly precipitation.

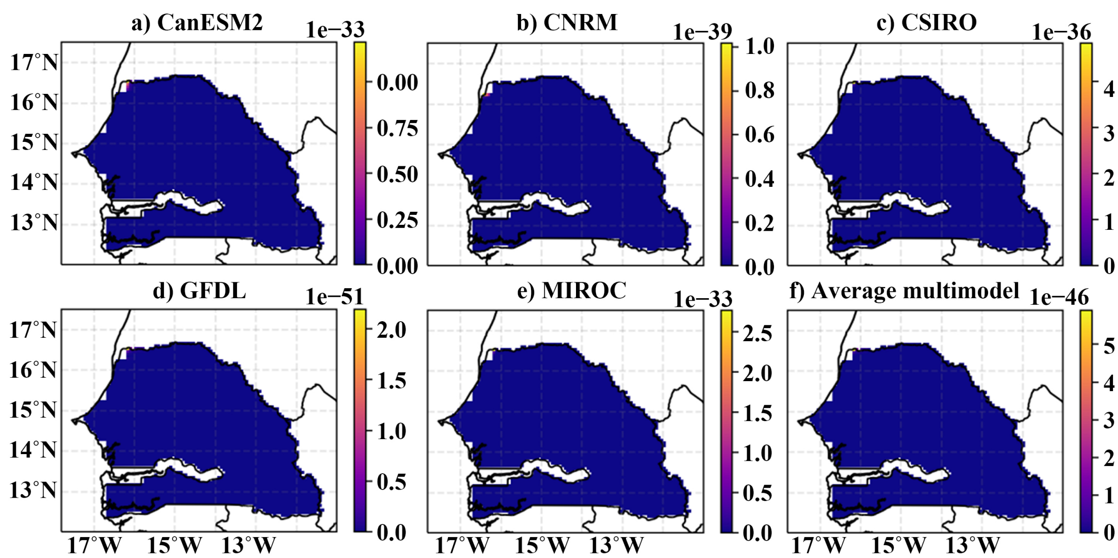


Figure 5. P-value calculated for the 5 models at 95% confidence level.

The results show that the RMSE is between 1 and 6 for the models. Indeed, the GFDL and CSIRO models have the highest RMSE values especially in the central-western part of the country with values between 4 and 6 (Figure 6), this could be due to the fact that these two models tend to overestimate rainfall. In contrast, the other models have low RMSE values, between 1 and 3 over most of the country. Furthermore, when analysing the multi-model average, it can be seen that it has considerably reduced the RMSE, since over almost the entire country the mean square error is less than 2.

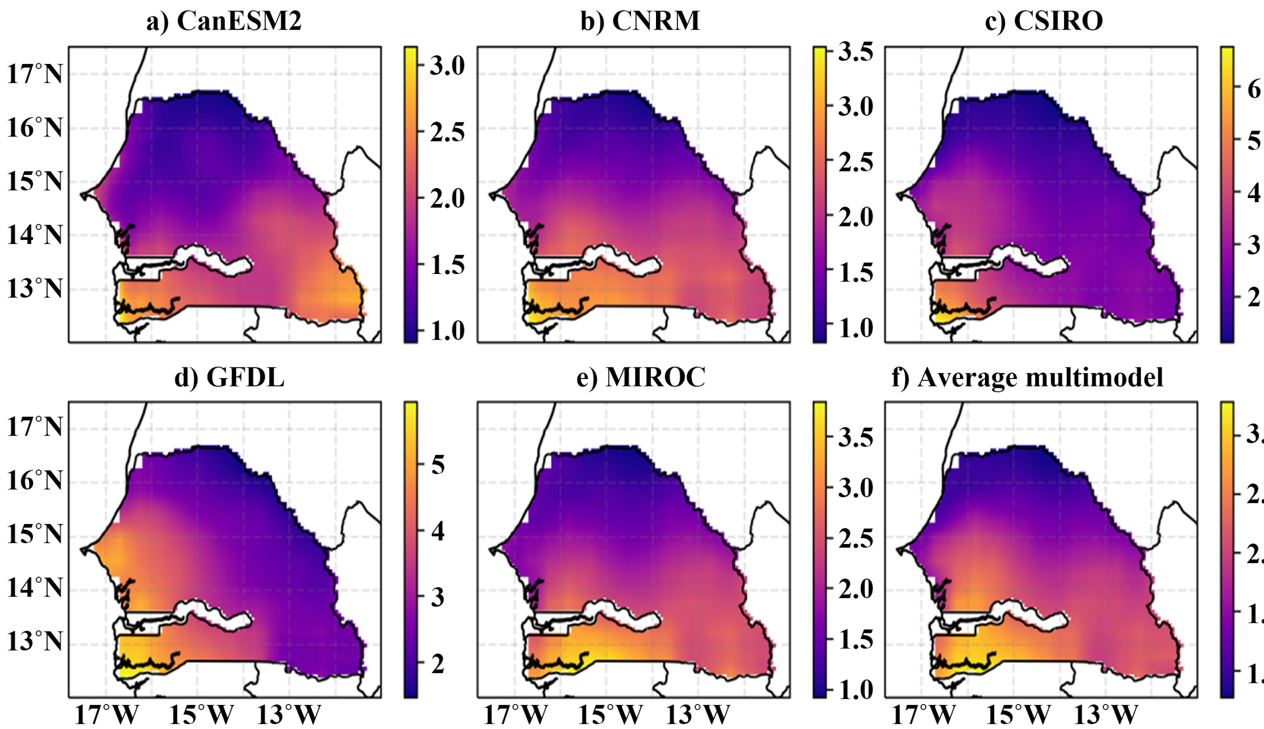


Figure 6. Calculation of the root mean square error (RMSE) for the 5 models.

3.3. Analysis of Annual Precipitation Trends for the 5 Models

The Kendal's test was conducted to detect an increasing or decreasing trend in our simulated data (models) for the period 1951-1990. For this, the test slopes as well as the P-value that give the meaning have been calculated (Figure 7). The results show that the trend in precipitation varies from one model to another during the period 1951-1990. Indeed, calculating the slope at the 95% significance threshold shows that the CanESM2 models (Figure 7(a)) and GFDL (Figure 7(g)) as well as the overall average show a downward trend in annual precipitation over our entire study area, this decrease is more significant in the West with a decrease of −3 mm/year.

For the CNRM (Figure 7(c)) and CSIRO (Figure 7(e)) models, the slopes show a decrease in precipitation in most of the country, unlike the MIROC model Figure 7(i)), where there is an increasing trend in annual precipitation over most of our study area. However, this decrease, or increase is only significant for the CanESM2 (Figure 7(b)) models (significant decrease in precipitation on the west coast), GFDL (Figure 7(h)) (significant decrease on a small part in the north of the country), and for the multimodel average (Figure 7(l)) (significant decrease over a small area in the north of the country). In addition, all other white Figures show that the trends are not significant.

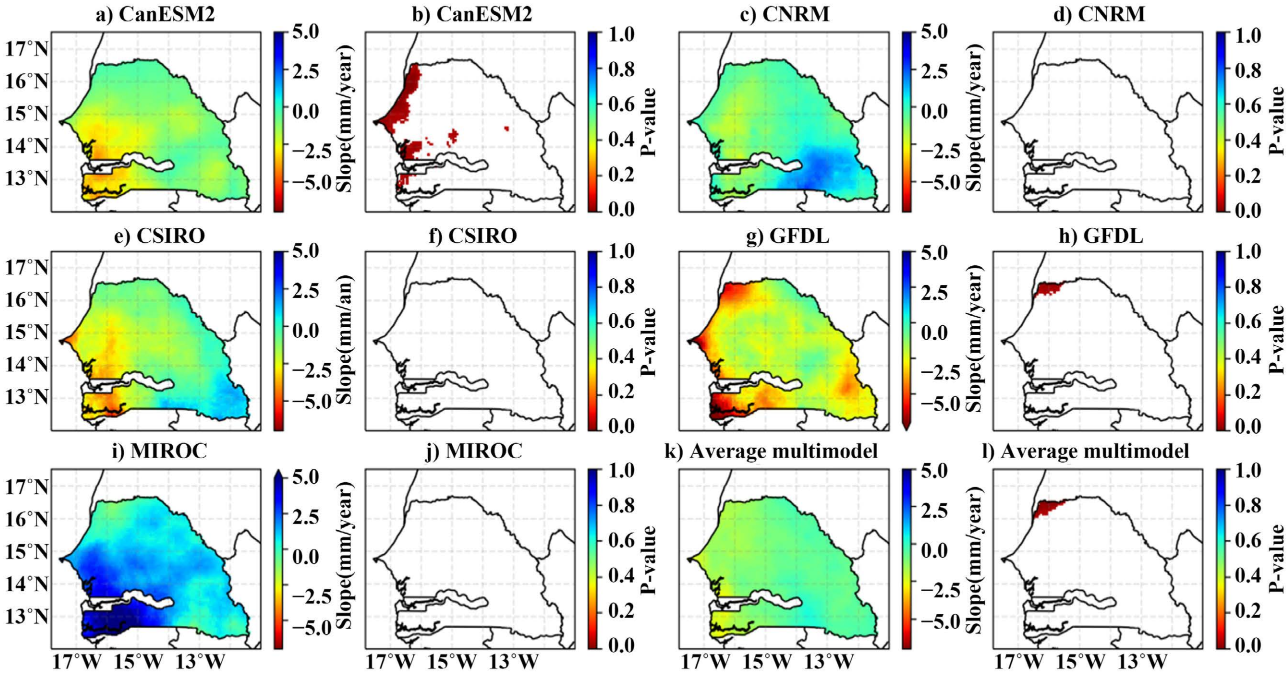


Figure 7. Slope and P-value for the different models as well as the multi-model average using the Kendal's test.

3.4. SPI Spatial Analysis

The calculation and analysis of the SPI is carried out on the overall average of the 5 models. Indeed, this choice is justified by the fact that the multi-model average gives more robust results than taking models individually. The SPI-3 index calculated for each sub-period (1951-1969 and 1970-1990) shows that the period 1970-1990 was slightly drier (Figure 8). In fact, according to Figure 8(a), precipitation was normal for most of our field of study, with the exception of a little to the north and centre where it was surplus (slightly wet). On the other hand, for Figure 8(b), we noted a drier condition in the south-west with a SPI below −0.025 (slightly dry), for the centre and south-In the east of the country, precipitation was quite normal compared to the north where it was somewhat humid. However, while it is noted that precipitation in the 1970-1990 period was normal or slightly wet in some areas, it remains lower than in the 1951-1969 period.

For SPI-6 effective for studying precipitation over different seasons (Figure 9), we find that the period 1970-1990 was drier than the previous period (1951-1969), this rainfall deficit is marked in the centre and southwest with a SPI below −0.1 (Figure 9(b)) However, precipitation slightly to the south and north was relatively normal.

Figure 10(a) shows that precipitation was almost normal in most of the country, except in the west and centre, where SPI-12 is slightly wet. In contrast, for the period 1970-1990, Figure 10(b) shows a much drier state over most of our study area with index values below −0.2. The SPI-12 index, particularly related to stream flows, at groundwater levels at extended time scales shows that groundwater has been affected by these drier conditions.

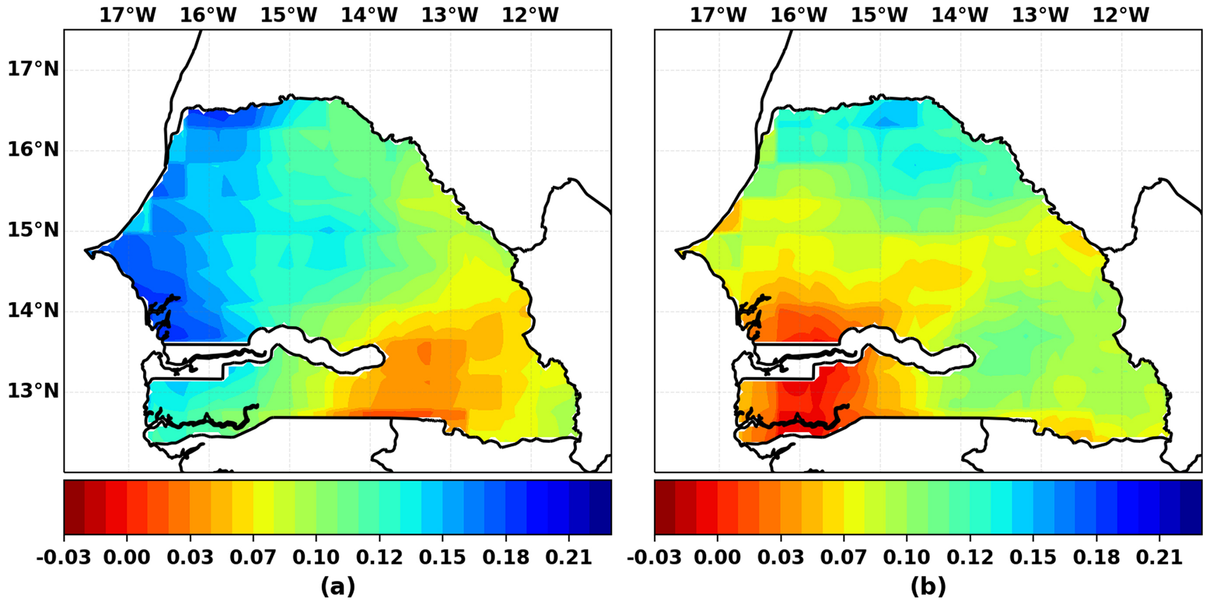


Figure 8. Spatial evolution of SPI-3 calculated from the world average for each period: 1951-1969 (a), 1970-1990 (b).

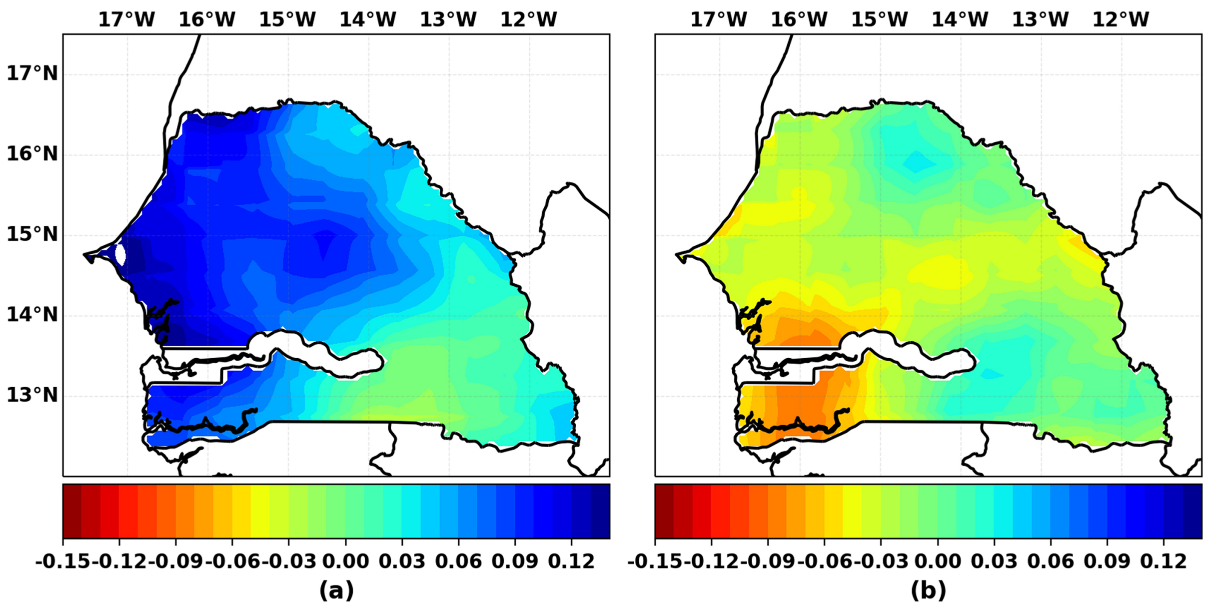


Figure 9. Spatial evolution of SPI-6 calculated from the world average for each period: 1951-1969 (a), 1970-1990 (b).

In the long term (24-month calculation scale), the results of the analysis show a significant increase in dry sequences over most of our study area over the period 1970-1990 (Figure 11(b)) for the SPI-24 index unlike to period 1951-1969 where precipitation was normal to see wet as in the central-western region.

The influence of the time scale on drought characterization is evident. Indeed, on longer time scales (SPI-12, SPI-24), the intensity of drought increases. The results also showed that RCM are able to reproduce the drought of the 1970's and 1980's using the SPI index as an indicator. The SPI values calculated at different time scales show that droughts in Senegal were generally of moderate intensity.

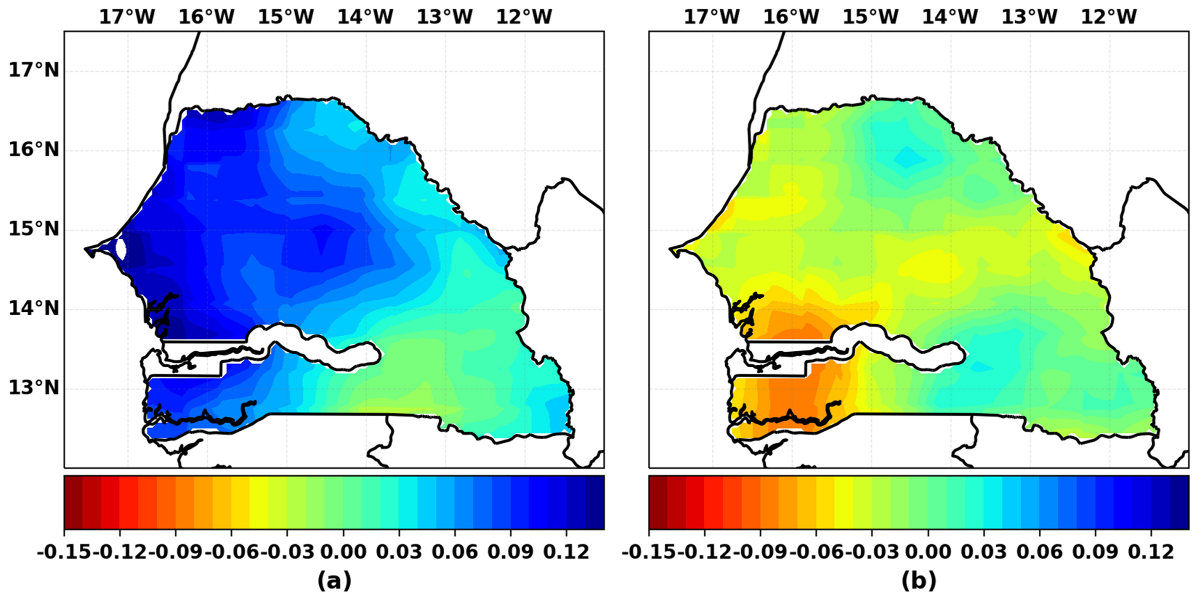


Figure 10. Spatial evolution of SPI-12 calculated from the world average for each period: 1951-1969 (a), 1970-1990 (b).

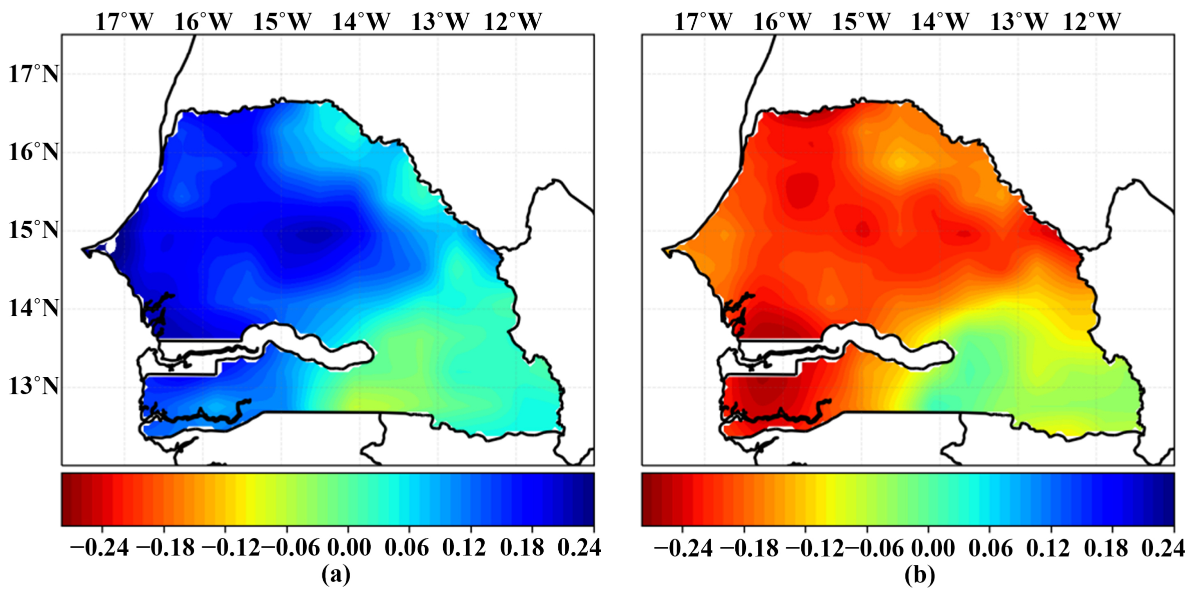


Figure 11. Spatial evolution of SPI-24 calculated from the world average for each period: 1951-1969 (a), 1970-1990 (b).

The distribution of SPI for the sub-periods (1951-1969 and 1970-1990) is illustrated in **Figure 12**. The SPI calculated from the multimodel average shows that the average SPI of 3 months and 6 months for the period 1970-1990 moves to the left (becoming drier) and widens (more extreme), involving more variability. For SPI-12 and 24, they show a shift in their distribution from right to left showing a decrease in wet sequences and an increase in dry sequences. These new results confirm earlier observations that the period 1970-1990 was drier than that of 1951-1969.

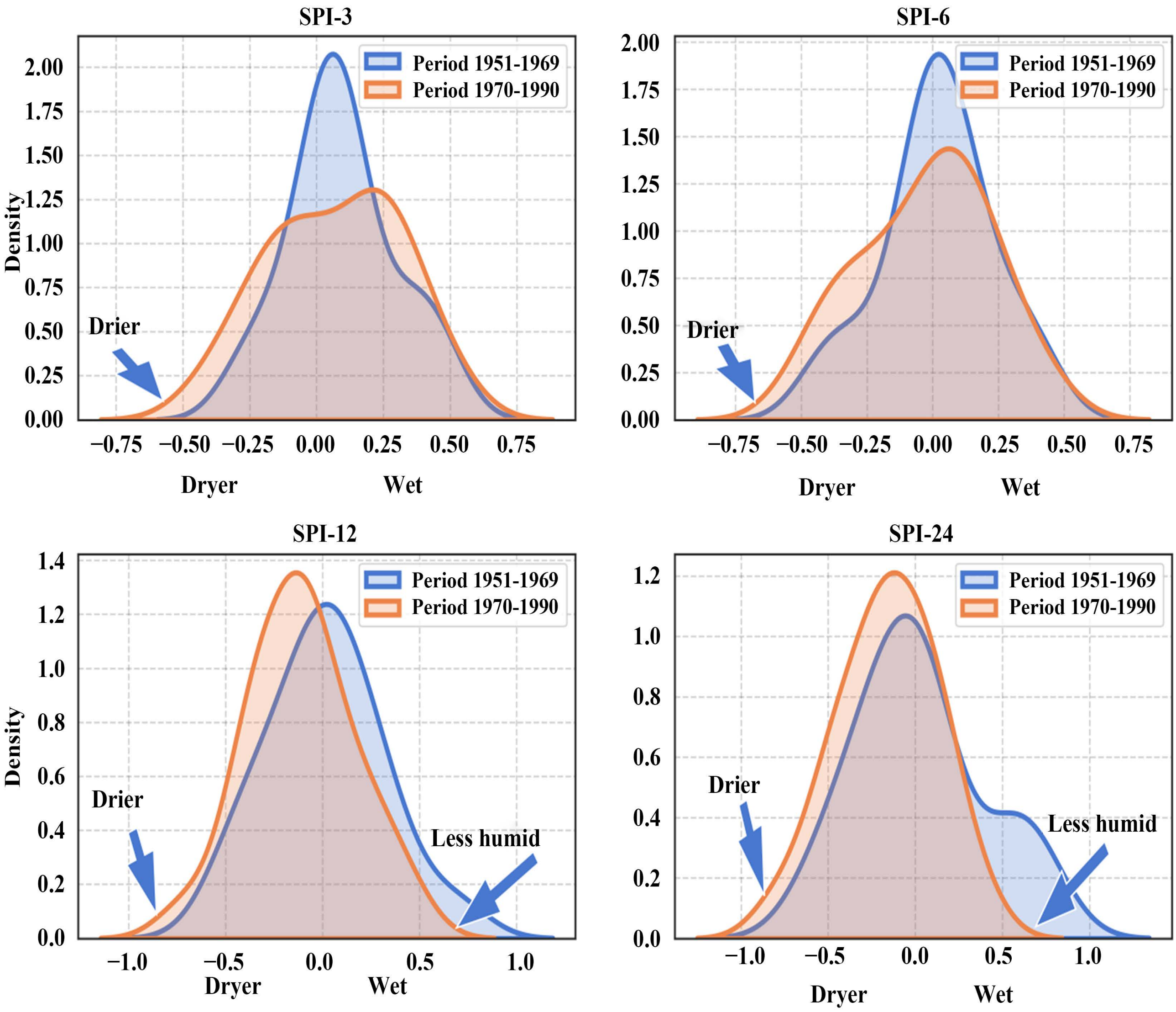


Figure 12. Standard Precipitation Index (SPI) probability density function for the two periods (1951-1969 and 1970-1990).

Figure 13 shows the zonal mean for SPI 3, 6, 12 and 24 months during the period 1970-1990, in fact, for SPI-3, it increases at latitudes with fairly low values, for SPI-6, there is an increase to 12˚N and 13.5˚N, followed by a slight decrease (slightly dry). In contrast, the zonal mean of SPI-12 and 24 shows a significant decrease compared to the latitude 13.5˚N, these observations lead us to affirm that the droughts of the 1970's and 1980's were more severe in the North than in the South.

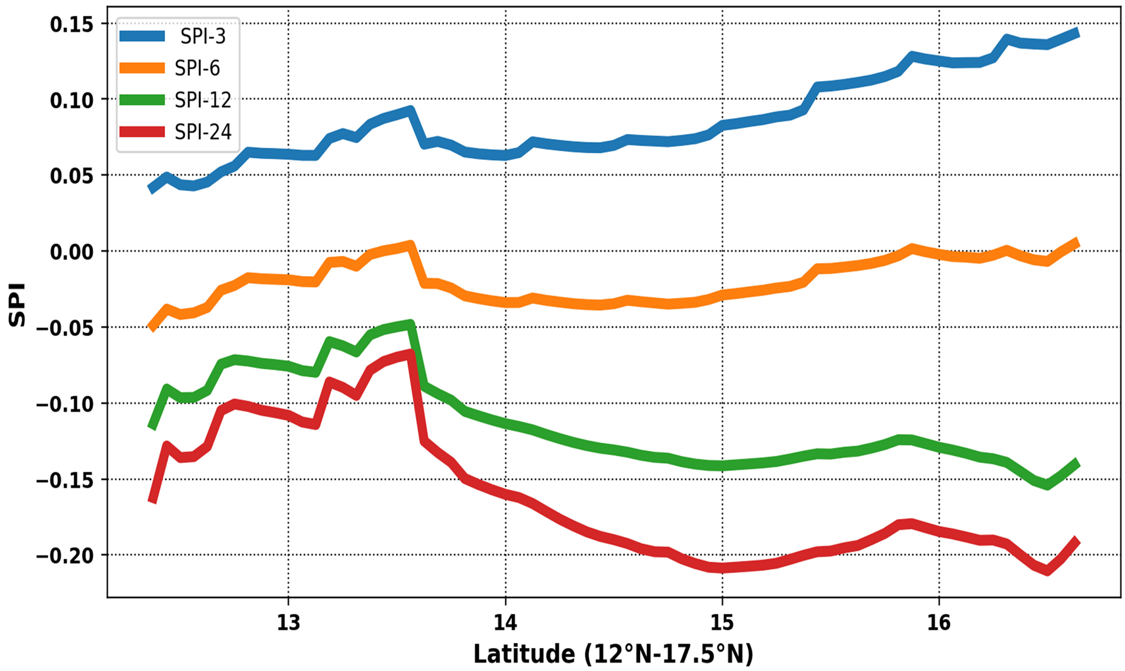
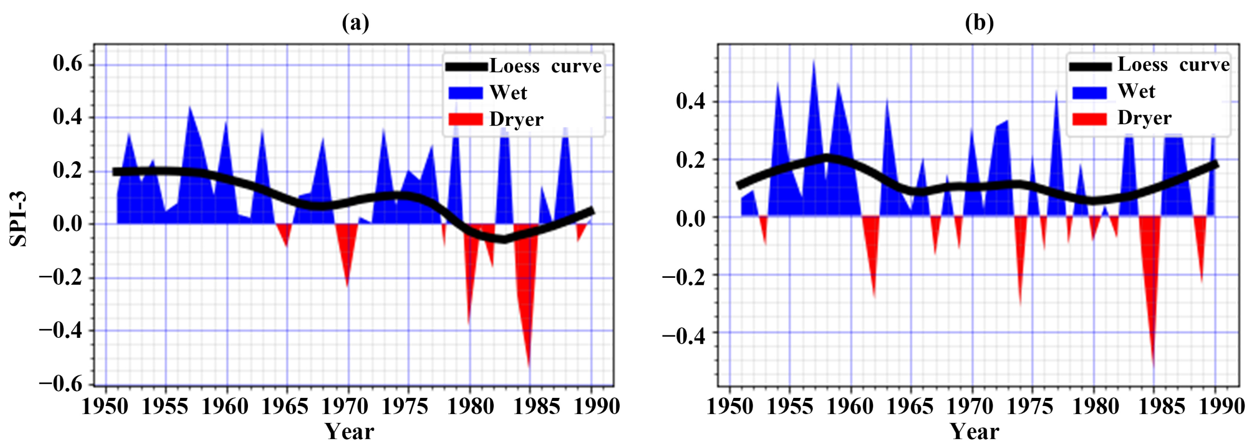


Figure 13. Zonal average of SPI with multimodel mean for the period 1970-1990.

3.5. Interannual Evolution of SPI

To study the interannual evolution of rainfall, four stations (Dakar, Linguère, Matam and Podor) located in the centre and north of our study area were chosen. Firstly, this choice is justified by the fact that the north is more affected by drought. Secondly, to see the capacity of our models to reproduce this deficit on an interannual scale.

The results show that the period 1951-1990 contains more wet years than dry years (Figure 14), indeed using the loess curve, we clearly see that on average the SPI-3 index is positive (slightly wet) for the 4 stations. Figure 15 corresponds to the SPI-6 index. The analysis shows a fairly large presence of dry sequences especially for the stations of Linguère and Matam (Figure 15(b) and Figure 15(c) respectively), indeed, these dry years are much more present from the 1970s onwards.



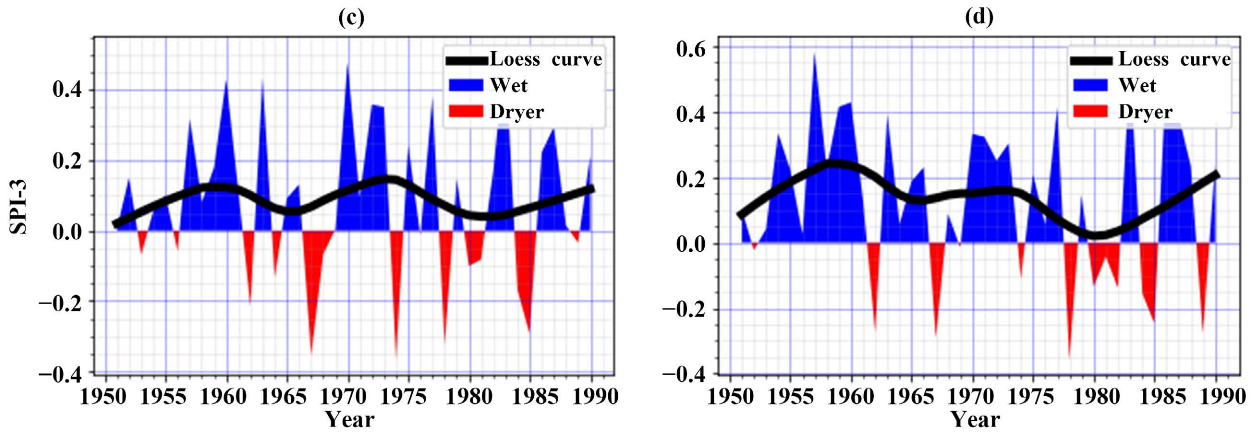


Figure 14. Annual rainfall trends for SPI-3 (calculate from the multi-model average): Dakar (a), Linguère (b), Matam (c) and Podor (d).

The Loess curve shows a decrease in wet sequences from 1970 for the 4 stations followed by an increase in the index in the 85's for the Dakar station (Figure 15(a)) and in 1980 for the other stations.

For the SPI-12 index, there is a strong presence of dry years much larger than wet years from 1970, the loess curve even shows a decrease in the trend of the index from the 1970's for stations (Figure 16). The inter-annual evolution of the SPI-24 index shows a sharp increase in dry sequences especially from 1970 onwards, the loess curve reveals a downward trend of the index before 1970 for the 4 stations (Figure 17).

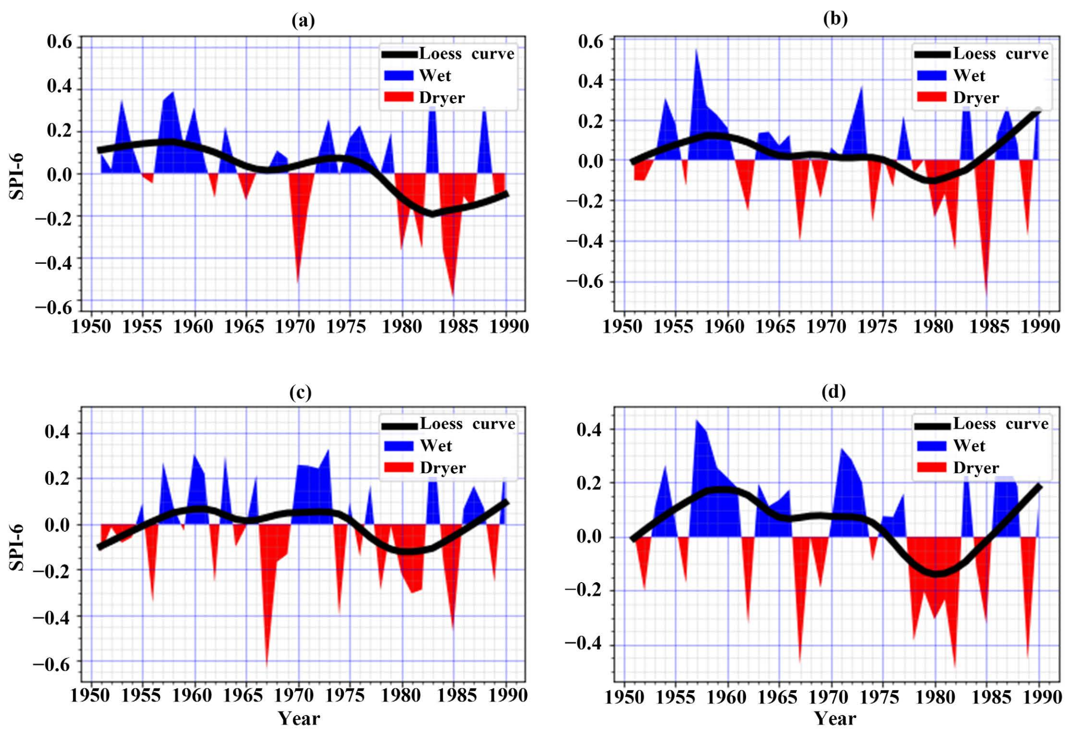


Figure 15. Annual rainfall trends for SPI-6 (calculate from the multi-model average): Dakar (a), Linguère (b), Matam (c) and Podor (d).

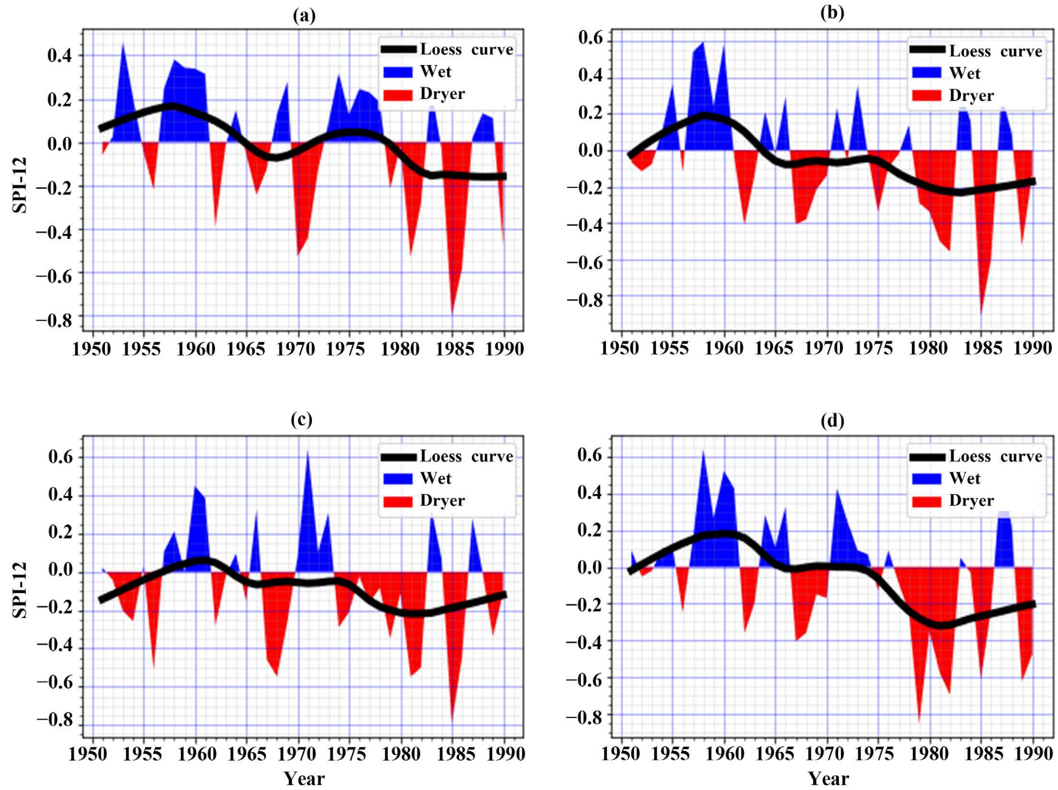


Figure 16. Annual rainfall trends for SPI-12 (calculate from the multi-model average): Dakar (a), Linguère (b), Matam (c) and Podor (d).

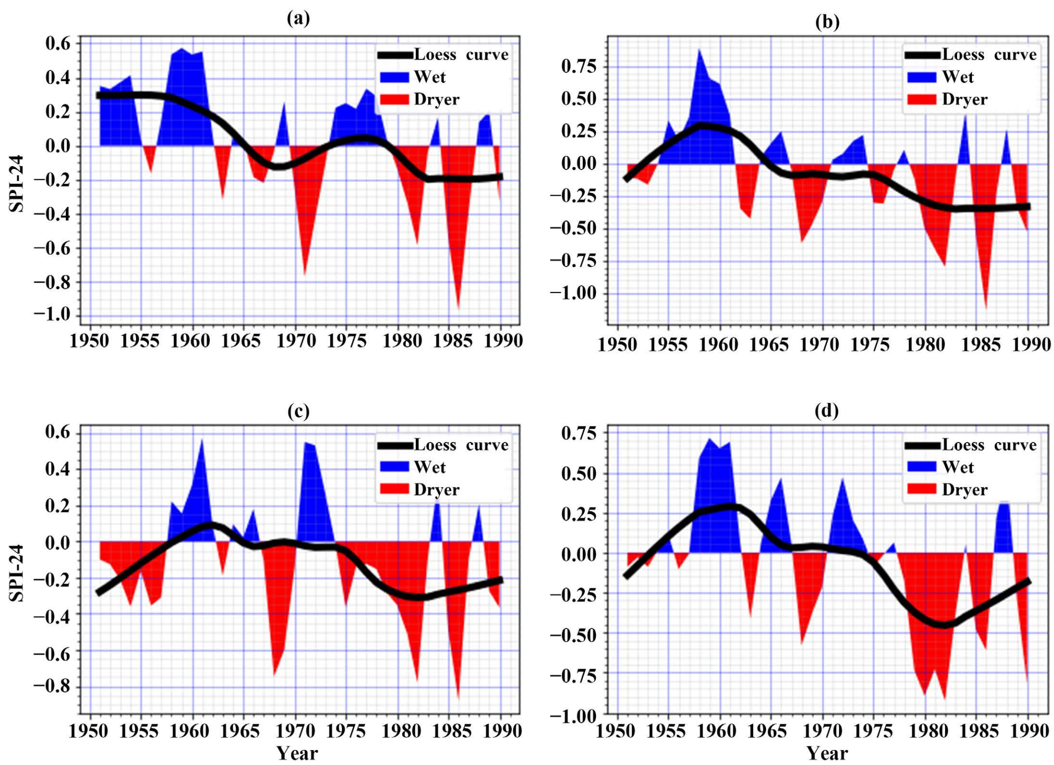


Figure 17. Annual rainfall trends for SPI-12 (calculate from the multi-model average): Dakar (a), Linguère (b), Matam (c) and Podor (d).

4. Discussion

Through the analysis of daily precipitation data from 5 regional climate models, the main objective of this work was to study the ability of climate models to reproduce the drought of the 1970's and 1980's. For this purpose, the 5 models are validated by the GPCP observation data, their calculated bias. The results show that most models simulate wet bias (overestimation), but using the multimodel mean, it is found to improve model performance and significantly reduce bias. For the seasonal cycle, the models have a structure consistent with the observation data with a maximum in august. The study of the correlation between simulated and observed monthly precipitation shows significant correlation values. Indeed, these results demonstrate the performance of RCMs in simulating monthly precipitation, especially in highly rainy areas where high correlation values are observed. However, the results for RMSE indicate that in regions experiencing heavy precipitation, high RMSE values are observed. This could be due to difficulties in accurately reproducing extreme precipitation events, such as heavy rains or intense droughts, as well as high variability in precipitation. For the Kendal's test, trend analysis shows that most of the models as well as the multimodel mean show a decrease in precipitation patterns over the period 1951-1990, these observations are consistent with studies by [17].

The spatial characterization of the mean values of the indices SPI-3, SPI-6, SPI-12 and SPI-24 over different periods (1951-1969 and 1970-1990) highlights the moisture over the period 1951-1969 and a rainfall deficit from the 1970's onwards showing that the models manage to reproduce this decrease in precipitation, these results are corroborated by numerous studies [18] [19]. The analysis of standardized precipitation indices (SPI-12 and SPI-24) reveals a shift of distributions to the left, indicating a decrease in wet sequences and an increase in dry sequences over time. These findings, corroborating previous observations, confirm that the period from 1970 to 1990 was characterized by a more pronounced drought compared to the period from 1951 to 1969. This trend towards drier conditions had raised concerns regarding its implications for the region, particularly concerning agriculture, water availability, and the potential for conflict. The zonal average of the different SPI shows that the southern zone (South Sudanese climate) is less affected by droughts than the northern zone (Sahelian climate) This is due to the position of the FIT where the south of the country receives more precipitation than the north and is therefore less subject to dry episodes, these results are in agreement with the studies of [20] on the spatial distribution of rain at the country level. It is also relevant to use different time scales to calculate the SPI. Indeed, as regards the intensity of the drought, the results obtained show that it increases for SPI-12 and SPI-24 contrary to SPI-3, these results show the usefulness of using several time scales to characterize the dry sequences, these observations are consistent with those of [6] which shows that the longer the chosen time, the more the statistical index varies little and allows to define with more precision the dry episodes. Analysis of the interannual variability of SPI for some central and northern stations shows that drought did not start at the same time across the country. Indeed, the results have shown that the central and northern parts experienced hydrological droughts, which even led to conflicts between Senegal and Mauritania in the 1980s over a territorial dispute in the Senegal River valley region, rich in fishery resources.

The results of this article prove that RCMs can be used to study droughts spatially and temporally, in particular by using the multimodel average to calculate the SPI, rather than studying each model separately, they could be used to model future climate droughts in a climate change. With the increase in extreme events and the latest [21] report that is alarming, especially for developing countries. It would be important to deepen this work by conducting a comparative study between the SPI and SPIE index in order to investigate a likely future occurrence of drought sequences that negatively impact crop yield and coverage.

5. Conclusions

Spatial-temporal study of the drought of the 70's and 80's through the regional climate models of the cordex program using the standardised precipitation index (SPI) at different time scales shows that the RCM (regional climate model) manages to reproduce the rainfall deficit that had previously occurred. The analysis of the biases shows that the models overestimate the rain (wet bias) with the exception of the CanESM2 model which tends to underestimate, moreover they manage to represent the seasonal cycle of the rain. The results of the trend detection (Kendal's test) in the simulated precipitation data show that the 1951-1990 period was confronted with a decrease in annual totals, as shown by most of our models.

The spatial analysis of the SPI at different time stages reveals that the period 1951-1969 was much wetter than that of 1970-1990 (therefore dry), SPI-12 and 24 show that this decrease was more intense in the north than in the south this is explained by the positioning of the FIT (inter tropical front).

The methodology adopted in the article is evidence that RCM (regional climate model) is robust for spatial or temporal study of drought, these models could be used to provide a drought management response, because, according to the [21] report, 2021 Senegal is seriously threatened by these extreme events. This methodology can be used to contribute to the study of the frequency and severity of dry sequences in a climate change context. To do this, we need finer resolution models, bias corrections and to continue to improve the understanding of the occurrence mechanisms of drought by combining the statistical and dynamic approach (El Niño, La Niña or Amo Phenomenon).

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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