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CLIMATE DYNAMICS OF SOUTHERN REGION OF MOZAMBIQUE: STATISTICS AND FOURIER ANALYSIS

DINÂMICA CLIMÁTICA DA REGIÃO SUL DE MOÇAMBIQUE: ESTATÍSTICA E ANÁLISE DE FOURIER

DINÁMICA CLIMÁTICA DE LA REGIÓN SUR DE MOZAMBIQUE: ESTADÍSTICAS Y ANÁLISIS DE FOURIER

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Abstract: In this study, we evaluate the climate behavior of the southern region of Mozambique in the face of the evidences of climate change at global level. Time series of precipitation, maximum and minimum temperatures related to 1960-2018 were used. The data was provided by the Instituto Nacional de Meteorologia (INAM) – Mozambique, collected from fifteen gauge stations. We have applied Statistics and Fourier analysis to assess the periodicity, long-term variability and trend of the time series. Besides, the rainy season behavior was also assessed. The results of the analyzes are related to the current global climate observations and projections contained in the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC-AR5), the latest IPCC full report by the moment of this study. Overall, the signal of climate change in Mozambique is visible. Precipitation did not show a significant trend in its variability. However, a slight decrease is noticeable in the provinces of Gaza and Inhambane. The rainy season showed a tendency to a late start and an early end, resulting in a decrease of the season length, which has dropped on average about 16 days. Extreme temperatures, on the other hand, showed a clear upward trend, with the increase being more pronounced in the minimum temperature than the maximum temperature. The maximum temperature increased by about 0.7 °C and the minimum temperature increased by about 1.5 °C during the analyzed period. These results are in line with the observations and projections contained in the IPCC-AR5 regarding the Austral Africa which include Mozambique.

Keywords: Climate variability and trend. Rainy season. Fourier analysis. Southern Mozambique.

Resumo: Neste estudo, avaliou-se o comportamento climático da região sul do Moçambique face às evidências de mudança climática ao nível global. Foram utilizadas séries temporais de precipitação e de temperaturas extremas da região referentes ao período entre 1960 e 2018. Os dados foram fornecidos pelo Instituto Nacional de Meteorologia (INAM) – Moçambique, colectados em quinze estacões meteorológicas. Foram aplicados métodos estatísticos e a análise de Fourier para avaliar a periodicidade, a variabilidade a longo termo e a tendência das séries temporais. Por sua vez, o comportamento da época chuvosa também foi avaliado. Os resultados das análises são confrontados com as atuais observações e projeções globais do clima constantes no quinto relatório de avaliação do Painel Intergovernamental sobre Mudanças Climáticas (IPCC-AR5), o mais recente relatório completo do IPCC até o momento deste estudo. Em geral, o sinal de mudança climática em Moçambique é visível. A precipitação não apresentou tendências significativas na sua variabilidade, porém, uma ligeira diminuição é notável principalmente para as províncias de Gaza e Inhambane. A época chuvosa mostrou uma tendência para um início tardio e um fim precoce, resultando na diminuição da duração da época, que caiu em média cerca de 16 dias. Já as temperaturas extremas apresentaram clara tendência para o aumento, sendo que o aumento é mais acentuado para a temperatura mínima do que para a temperatura máxima. A temperatura máxima aumentou em cerca de 0.7 ºC e a temperatura mínima aumentou em cerca de 1.5 °C ao longo do período analisado. Estes resultados convergem para as observações e projeições constantes no IPCC-AR5 a respeito da África Austral que inclui Moçambique.

Palavras-chave: Variabilidade e tendência climática. Época chuvosa. Análise de Fourier. Sul de Moçambique.

Resumen: En este estudio, se evaluó el comportamiento climático de la región sur de Mozambique frente a la evidencia del cambio climático a nivel global. Se utilizaron series temporales de precipitación y temperaturas extremas en la región para el período entre 1960 y 2018. Se llevó a cabo el comportamiento de la temporada de lluvias, el análisis de la variabilidad a largo plazo y la determinación de la tendencia de las fluctuaciones de precipitación y las temperaturas extremas. Los resultados de los análisis están en línea con las actuales observaciones y proyecciones climáticas globales contenidas en el quinto informe de evaluación del Panel Intergubernamental sobre Cambio Climático (IPCC-AR5). En particular, los efectos del cambio climático en Mozambique son visibles. La precipitación no mostró tendencias significativas en su variabilidad. Sin embargo, una ligera disminución es notable principalmente para las provincias de Gaza e Inhambane. La temporada de lluvias mostró una tendencia hacia un inicio tardío y un final temprano, lo que resultó en una disminución en la duración de la temporada. Las temperaturas extremas, por otro lado, mostraron una clara tendencia al alza, con un aumento más pronunciado para la temperatura mínima que para la temperatura máxima. La temperatura máxima aumentó en aproximadamente 0,7 °C y la temperatura mínima aumentó en aproximadamente 1,5 °C durante el período analizado. Estos resultados convergen con las observaciones y proyecciones contenidas en el IPCC-AR5 sobre el sur de África, que incluye a Mozambique.

Palabras-clave: Variabilidad y tendencia climática. Estación lluviosa. Análisis de Fourier. Sur de Mozambique.

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INTRODUCTION

Many extreme climate events currently occurring have been linked to a possible global climate change, and this topic has been of much debate worldwide. According to the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC-AR5), evidences of climate change have significantly grown in recent years, in observations made in the atmosphere and on the surface (HARTMANN *et al.*, 2013a). The implications of climate change are evident in the socio-economic, environmental, health, agriculture, and among others areas. In particular for Mozambique, several extreme events (cyclone Eline in 2000, cyclone Fávio in 2007, flood in the northern region of the country in 2014, drought in the southern and central regions in 2015 and the recent cyclones Idai and Keneth in 2019) had caused catastrophic consequences, with huge economic losses including death of hundreds of people.

Among the climate observations, air temperature and precipitation regimes are the most important. According to IPCC (2014), the global mean surface air temperature over land and oceans shows from a linear trend, an increase of about 0.85 °C, during the period from 1880 to 2012. The diurnal temperature range has been decreasing since 1950, with a rapid increase in minimum temperature compared to the increase in maximum temperature. On the contrary to the global mean surface air temperature that shows an upward trend on its variability, the global average of precipitation does not present a clear trend, it shows an increase in some regions and a decrease in others. In particular, during the period from 1901 to 2005 a decreasing rainfall tendency was observed in the Sahel region of Africa (CHRISTY; NORRIS; MCNIDER, 2009).

For specific region, the climate variables may show singular trends, which are different from the global behavior. For example, air temperature is the most evidenced parameter in discussions about global climate change, admitting the occurrence of global warming caused by the intensification of CO_2 concentration due to the industrial development and to the technological advancements (IPCC, 2001). However, for specific regions, analyzes in certain periods show singular warming rates in the mean temperature (IPCC, 2007, 2014). Besides, precipitation is less representative with great variability, both spatially and temporarily, it is significantly influenced by local factors, and globally, it does not present clear trend.

This uncertainty is a concern for several sectors of activity, especially for a developing country. For instance, in Mozambique, the agricultural sector is the most sensitive to climate change. The majority of population practice agriculture conditioned by the climate regime, without any mechanization. The knowledge of climate variability in a particular region is crucial for decision making. In particular for agriculture, the knowledge of the regimes of precipitation and temperature is a determining factor to ensure better productivity.

Even with some advancement on climate studies in Mozambique (MAVUME, 2008; MCSWEENEY *et al.*, 2010; QUEIROZ *et al.*, 2007), given the climate diversity, investigations about the evolution of these climate parameters in connection with the global climate change is still necessary. It is important to understand the current scenario of climate dynamics in the three major regions of Mozambique (northern, central and southern). However, this study is only limited to the southern region of the country, where the In Situ data availability is relatively significant.

The main objective of this research is to evaluate the climate scenario of the southern Mozambique in connection with the global climate change. We have applied statistics and spectral analysis to the time series of precipitation, maximum and minimum temperatures. Specifically we have determined the periodicity, long term variability and trend of the time series. In addition, the rainy season behavior is also assessed, taking into account the following parameters: (i) the total precipitation of the rainy season; (ii) the duration of the rainy season; (iii) the average intensity of precipitation, and (iv) the occurrence of dry days within the rainy season (Indian summer). Results are related to the global observations and projections contained in the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC-AR5), the latest IPCC full report available by the moment of this research.

DATA AND METHODS

Characterization of the study region

The study area is the southern region of Mozambique, located between the parallels 21° 05'S and 26° 52'S and the meridians 31° 20'E and 35° 20'E. It comprises the provinces of

Maputo, Gaza and Inhambane, on south of the Save River, and on the southeastern coast of Africa (Figure 1).

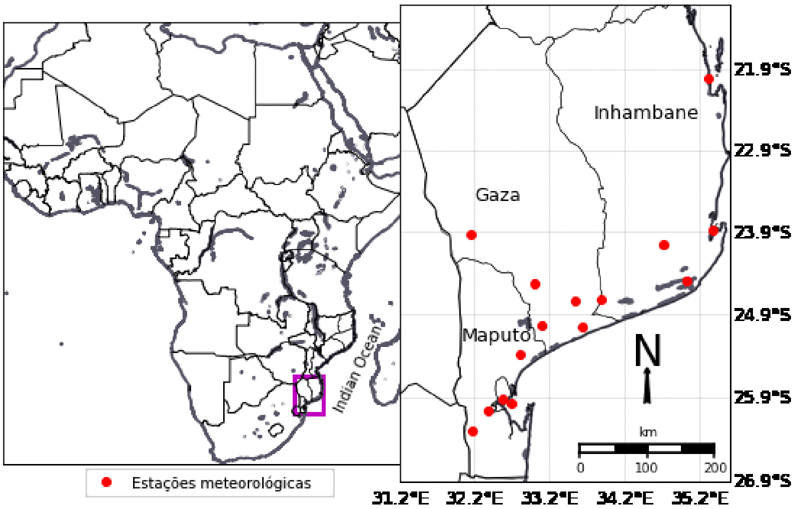
The climate in Mozambique is tropical, with two seasons, one is hot and rainy, starting from October to April, and the other is cold and dry, starting from May to September. The southern region of Mozambique is in general the driest one over all the country with an annual mean rainfall of less than 800 mm, decreasing to 300 mm in the Pafuri region. The annual average temperatures in the southern provinces range from 24 to 26 °C, and on the coastal area the annual mean air temperature increases gradually, from south to north (QUEIROZ *et al.*, 2007).

The weather and climate systems which have more influence in the southern region of Mozambique are: the semi-permanent high pressure centers of the Atlantic and the Indian Oceans along the tropic of Capricorn, the cold fronts from the south and the tropical cyclones. In addition to the two high pressure centers, a low pressure center or depression of thermal origin is formed on the continent. As these systems tend to move eastward, the Atlantic high pressure system is bended by the continent's system stretching and creating a high pressure ridge which has a significant influence on the weather in the southern Mozambique. The wind direction turns to the southeast, carrying cold and humid air, which often generates rainfall mainly in the highlands, if there is significant moisture transportation.

The cold fronts are associated with the right arm of the South Atlantic anticyclone, which carries a cold and humid air from the sea side to the continent. For this reason, these fronts move eastwards together with the anticyclone, invading cyclically the southern region of Mozambique, especially during the winter.

The cyclones that affect the region occur from November to April and they originate in the eastern side of Madagascar and in some occasions in the Mozambique Channel (MAVUME, 2008). This implies that coastal countries like Mozambique and South Africa are the most vulnerable. This phenomenon is associated with very strong winds, as well as a strong atmospheric instability intensified by the warm waters from the Mozambique Channel, generating heavy precipitation, mainly in the coastal region of the country. Mavume (2008) showed that there is a tendency to an increased frequency of this phenomenon.

Figure 1 - Map of the study area. The detail shows the southern region of Mozambique. The red dots represent the conventional meteorological stations used in the study.



Source: Elaborated by the authors (2020)

The ENSO (El-Niño South-Oscillation) phenomenon also presents remarkable and well distinct effects within the Mozambican territory. With El-Niño, the southern and central regions experience a prolonged dry period, while excessive rainfall is observed in the north. The reverse happens with La-Niña, where the southern and central regions experience a prolonged rainy period while scarcity is observed in the north (REASON; JAGADHEESHA, 2005).

Climate series

The climate data used for this study consists of daily records of precipitation, maximum and minimum temperatures from fifteen meteorological stations distributed throughout the southern region of Mozambique. The data was provided by the Instituto Nacional de Meteorologia (INAM) and corresponds to the period of 1960 - 2018.

The meteorological stations are distributed in the three provinces of southern Mozambique as follows: five stations in Maputo, six in Gaza and four in Inhambane. Table 1 shows the list of gauge stations and their respective geographical positions. The stations are not uniformly distributed throughout the region. Once they are all conventional, they are only present in inhabited areas that are mostly the coastal areas. However, the spatial distribution does not affect our objectives since we are only interested in assessing the temporal climate signal.

Table 1 - List of meteorological stations and their respective geographical positions.

#	ID	Station Name	Latitude (ºS)	Longitude (ºE)	Elevation (m)
1	GZ-MANJ	Manjacaze	24.72	33.88	65
2	GZ-MACI	Macie	25.03	33.10	56
3	GZ-XAI	Xai-Xai	25.05	33.63	4
4	GZ-MANIQ	Maniquenique	24.73	33.53	13
5	GZ-CHOK	Chokwe	24.52	33.00	33
6	GZ-MASSG	Massingir	23.92	32.16	252
7	IB-INHAM	Inhambane	23.87	35.38	14
8	IB-INHAR	Inharrime	24.48	35.02	43
9	IB-PAND	Panda	24.05	34.72	150
10	IB-VILA	Vilânculos	22.00	35.32	20
11	MP-UMBE	Umbeluzi	26.05	32.38	12
12	MP-MANH	Manhiça	25.37	32.80	35
13	MP-OBS	Map/Observatório	25.97	32.70	47
14	MP-MAV	Map/Mavalane	25.92	32.57	39
15	MP-CHANG	Changalane	26.30	32.18	100

Source: Elaborated by the authors (2020)

Determination and characterization of the rainy season

The beginning and end dates of the rainy season were determined for each year and for each province in the study region. Several models are found in the literature for determining the beginning and end of the rainy season, such as the criteria used by Amekudzi *et al*. (2015), Marengo *et al*. (2001), Ndomba (2010) and Sansigolo (1989).

In this work, we have adopted a new and simple approach for estimating the beginning and end dates of the rainy season. In this new approach we start by determining a reference interval of wet months of the year using the climate data. For this purpose we have considered the ombrothermic diagram proposed by Bagnouls and Gaussen (1957), which is based on the regimes of temperature and precipitation throughout the year, taking into account the favorable and unfavorable states for the development of natural vegetation. In the ombrothermic diagram the abscissa indicates the months of the year, and the ordinates (main and secondary axes) indicate the average monthly precipitation *P* in mm and the average monthly temperature *T* in °C respectively. The scale is arranged so that the temperature values correspond to half of the precipitation, for example, 20 °C in temperature axis corresponds to 40 mm in precipitation axis. From this arrangement, the months whose precipitation column is below the temperature curve, that is, if $P < 2T$, they are considered dry months, meaning that the potential evaporation exceeds the precipitation. On the other hand, if $P \geq 2T$, the months are considered wet. These relationships are also used in the Köppen-Trewartha's climate classification criteria for defining the limits of dry regions in the climate group B (BELDA *et al*., 2014).

Although the Bagnouls and Gaussen criterion may seem to be old for the definition of dry and wet periods, the fact that the relationship used is based on the favorable and unfavorable factors for the development of natural vegetation (comparing precipitation and the potential evaporation) makes it update itself (does not lose validity over time). It updates even in a warming climate, since the relative humidity of an air parcel is directly related to the temperature at which it is found (VAREJÃO-SILVA, 2006), then a change in temperature over time, in turn, it changes the air demand for water vapor to reach saturation. Thus, this culminates in a new precipitation regime, adjusting to such a change.

Given the reference interval of wet months throughout the year, for each year, the beginning of the rainy season was considered to be the first day with a record of at least 1 mm of precipitation within the month whose total precipitation is equal to or greater than twice the average temperature of the same month ($P \geq 2T$), counting from the starting month of the pre-established reference range of wet period. In this particular case the starting month was September. The end date was determined by the reverse procedure. The algorithm for executing this method was implemented in FORTRAN.

Having the beginning and end dates determined, the duration of the rainy season in days was determined by the summation of the days, from the beginning date up to the end date of the rainy season:

$$D_{epoch} = (365 + d_{end}) - d_{initial},$$

where D_{epoch} is the duration of the rainy season in days, $d_{initial}$ and d_{end} are the Julian dates of beginning and end of the rainy season, respectively.

The total precipitation P_{total} during the rainy season in millimeters (mm) is calculated by the summation of the daily precipitation occurred during the rainy season:

$$P_{total} = \sum_{i=d_{initial}}^{365+d_{end}} P_i,$$

where P_i is the daily precipitation.

The average intensity of precipitation I_{prec} during the rainy season in millimeters per day (mm/day) is defined as the ratio between the total precipitation and the season duration:

$$I_{prec} = \frac{P_{total}}{D_{epoch}}.$$

For the Indian summer events, it was considered the occurrence of at least ten consecutive days without precipitation within the rainy period. This assessment is important since the water needs of plants can, in periods of up to ten days, be satisfied by the soil moisture (MACHADO *et al*., 1996).

Fourier analysis

In the Fourier analysis also known as spectral analysis, a signal (time series) is transformed from time domain to frequency domain. In the frequency domain, the signal is represented by the Fourier spectrum which allows the identification of individual variability patterns composing the original signal, that is, each frequency of the spectrum stores a particular variability pattern of the original signal whose significance is determined by its respective amplitude or power. Frequencies with high amplitude store more significant patterns of variability of the original signal. On the other hand, regardless of amplitude, high frequencies in the Fourier spectrum are associated with a short-term variability, while low frequencies are associated with a long-term variability in the original signal.

There are many purposes for which spectral analysis can be applied in Earth sciences (GHADERPOUR, 2018; GRZESICAA; WIĊCEKA, 2016; KALICINSKY *et al*., 2020). In this work we have applied this technique for determining the periodicity and the long term variability pattern of the time series. Considering that a given time series can be represented by a generic function $x(t)$, the relationship that allows this function to be transformed from the time domain to the frequency domain, denoted as $X(f)$, is called Fourier Transform (BRACEWELL, 1999):

$$X(f) = \int_{-\infty}^{+\infty} x(t) e^{-i2\pi ft} dt.$$

The meteorological or climate elements are, from the statistical point of view, continuous and random variables. However, since the climate observations are made at discrete time intervals, the result is a discrete time series, so that we will make use of the Discrete Fourier Transform (DFT). The DFT is applied in a discrete series, both periodic and non-periodic. The DFT of a discrete sequence x_k with N samples, denoted by X_n, is calculated by the following relationship:

$$X_n = \sum_{k=0}^{N-1} x_k e^{-i\frac{2\pi}{N}nk}, \quad 0 < n < N-1.$$

The computational implementation of the DFT was performed through the Fast Fourier Transform (FFT) in Python. In the frequency domain the signal is represented by the Fourier spectrum which relates the frequency and the amplitude of the signal. For each frequency f_n, its amplitude A_n is determined by the expression:

$$A_n = \sqrt{\mathrm{Re}(X_n)^2 + \mathrm{Im}(X_n)^2}, \quad 0 < n < N-1.$$

Here, the climate data is sampled monthly, so the frequency is given in cycle/month instead of the fundamental unit of cycle/second. Considering the period of 1960 – 2018, with the sampling interval of Δt = 1 month, we have N = 696 observations, and thus the n-th frequency in cycle/month will be:

$$f_n = \frac{n}{N\Delta t} = \frac{n}{696 \times 1} = 0.00144n, \quad 0 < n < N-1.$$

In the inverse Fourier transform, that is, in the transition from the frequency domain back to the time domain, the spectrum was filtered in order to attenuate the effect of high frequencies. The low frequency content allows determining the long term variability pattern of the series. In this particular case, frequencies ranging from 0.0 to 0.0083 cycles/month were selected in order to define a decadal variability.

Estimation of linear trends and uncertainties

There are several different methods of calculating linear trends and their uncertainties (HARTMANN *et al*., 2013b). The trend of the climate series was calculated using the linear regression technique (HEUMANN; SCHOMAKER; SHALABH, 2016). This method is also adopted for general use in the IPCC reports for trend calculation. The technique determines a straight line that best fits the dispersion of time series data.

Consider that the line to be adjusted is:

$$T_t = at + b,$$

where T_t is the data estimated in the period of time t, a is the angular coefficient of slope of the straight line, which sign determines the trend direction, either an increase or a decrease of the values in the time series, and b is the linear coefficient, which defines the point of intersection of the straight line with the data axis. The constants a and b are obtain by the ordinary least squares solution and are expressed as follow:

$$a = \frac{\sum_{n=1}^{N}(t_n - \bar{t})(Y_n - \overline{Y})}{\sum_{n=1}^{N}(t_n - \bar{t})^2}, \quad b = \overline{Y} - a\bar{t},$$

where Y_n is the value of the time series observed at the time t_n, N is the number of observations, $\overline{Y}$ is the average value of the time series, and $\bar{t}$ is the average value of t.

Confidence intervals for the trend estimation were computed assuming a Student's t-distribution of the residual variability in observations with regard to the straight line $e_n = Y_n - (at_n + b)$. Here we are not going deep into this topic, more details may be referred to Hartmann *et al*. (2013b) and Heumann, Schomaker and Shalabh (2016).

Furthermore, t-test was performed for assessing the statistical significance of changes in the observed climate averages between two different periods (the first and the last thirty years of the studied period 1960 – 2018).

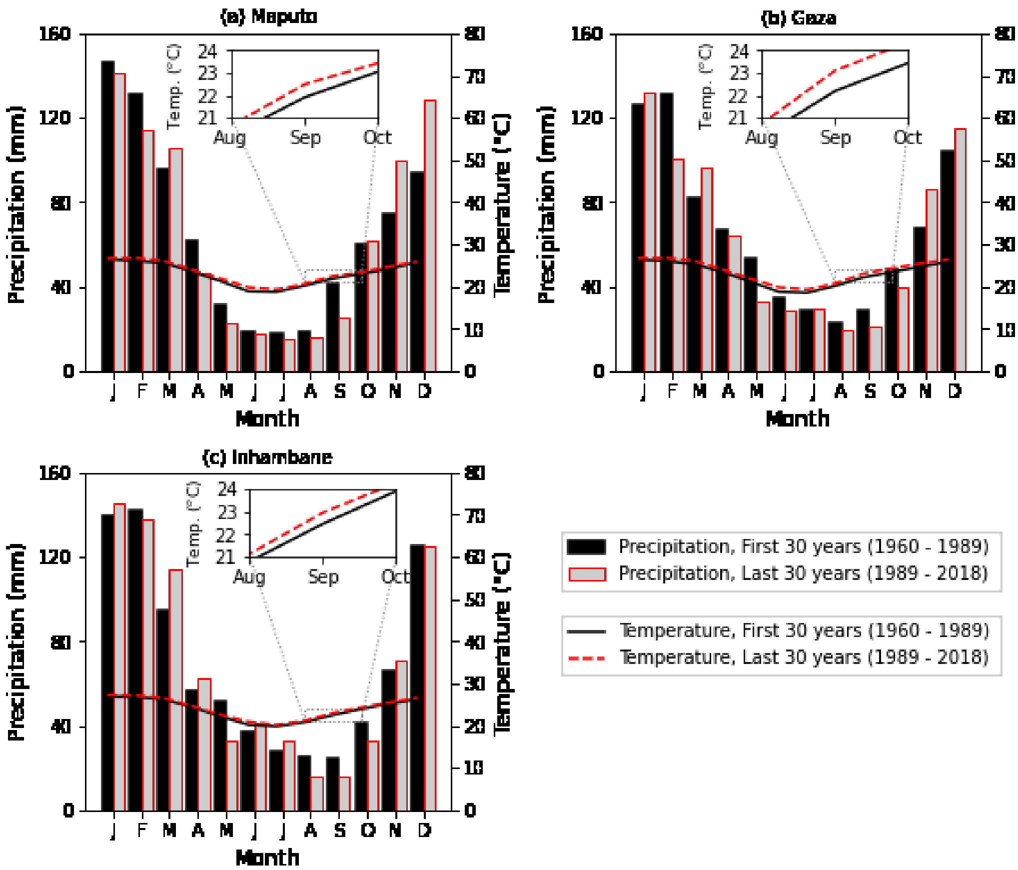
RESULTS AND DISCUSSIONS

Seasonality

The occurrence of precipitation and temperature throughout the year has been assessed for the first thirty years (1960 - 1989) and the last thirty years (1989 - 2018) of the entire evaluated period (1960 - 2018). By splitting this period we wanted to assess how seasonality would change in a warming climate. The southern region of Mozambique has clearly shown two distinct seasons as expected (QUEIROZ *et al*., 2007), one relatively cold and dry and the other relatively hot and wet. Figure 2 shows the ombrothermic diagrams of the three provinces in the study region, and these diagrams show a relatively short winter and a long summer. The dry and relatively cold period extends from May to September, with the month of August being the driest and July the coldest of the year in the region. The rainy and relatively hot period extends from October to April, being the months of January and February the most humid and the warmest of the year.

Based on the Köppen's criteria for climate classification, the patterns of precipitation and temperature shown in the diagrams indicate a climate of type Aw for the southern region of Mozambique, which corresponds to the tropical humid climate with a dry season in the winter, having Savanna as the typical vegetation.

Figure 2 *- Ombrothermic diagrams of the three provinces in the southern region of Mozambique: (a) Maputo, (b) Gaza, (c) Inhambane. The bars represent the precipitation (mm) and the curve represents the temperature (°C). Averages computed for the first and the last thirty years of the period 1960 – 2018.*



Source: Elaborated by the authors (2020)

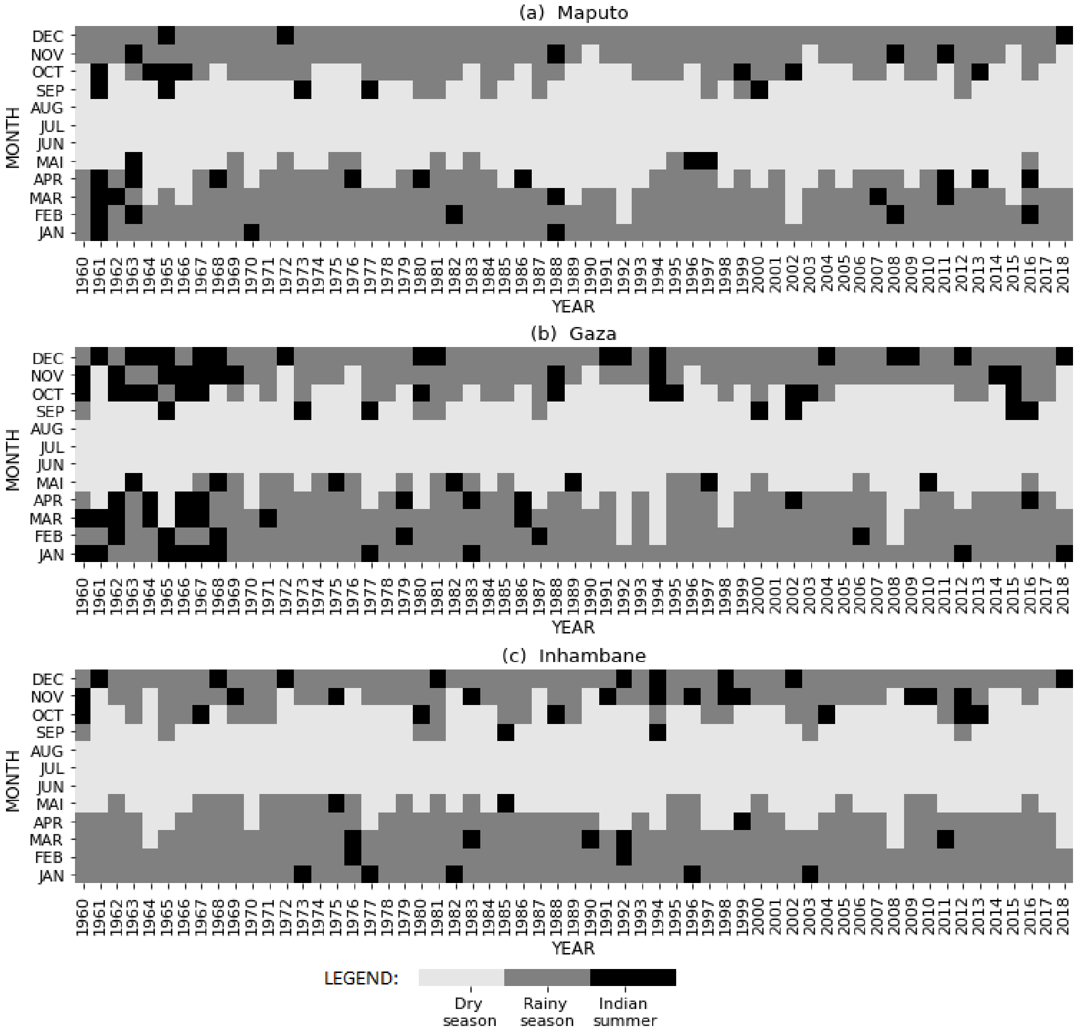
From Figure 2 it is possible to observe changes in the monthly averages of both precipitation and temperature when comparing the first and the last thirty years. In particular for temperature we observe from the zoomed part inside the graphs an upward shift of the monthly averages (represented by the red dashed curve) in all provinces, confirming the warming in the region (99% confidence level). Shifts in monthly averages of precipitation do not present uniform behavior just as expected. Unlike temperature, precipitation is by nature a variable with considerable variability, both spatial and temporal. Thus, regarding precipitation our t-test for significance did not find sufficient evidence to reject the null hypothesis ($p<0.79$).

Using the proposed methodology for determining the beginning and end of the rainy season, we found the beginning date being on average into the first week of October and the end date being on average into the last week of April. These results are similar to those reported by Queiroz *et al*. (2007). Figure 3 shows the occurrence of dry, rainy and Indian summer periods in the southern Mozambique over the period of 1960 - 2018. The occurrence of sequences of at least 10 dry days (Indian summer) within the rainy season has been identified in some years and it presents an approximately uniform distribution throughout the evaluated period, with greater predominance in the province of Gaza.

Periodicity

The periodicity was determined from the Fourier spectrum, considering monthly time series of precipitation, the maximum and minimum temperatures. For both precipitation and temperatures, it was possible to identify the frequency of $f = 0.083$ cycles per month as the most significant in all cases, corresponding to the periodicity $T = 1/f$ of 12 months, which is the annual variability as expected. A small semiannual variability (six months) was also observed at the frequency of approximately $f = 0.166$ cycles per month, being more pronounced for temperatures than for precipitation. Figure 4 shows the Fourier spectrum of precipitation and the maximum and minimum temperatures for the three provinces of the study region. We can see from the figure that the other frequencies are obfuscated by the annual frequency power in such a way that they have become relatively insignificant.

Figure 3 - Occurrence of dry, rainy and Indian summer periods in the southern region of Mozambique: (a) Maputo, (b) Gaza and (c) Inhambane. The data is related to 1960-2018.

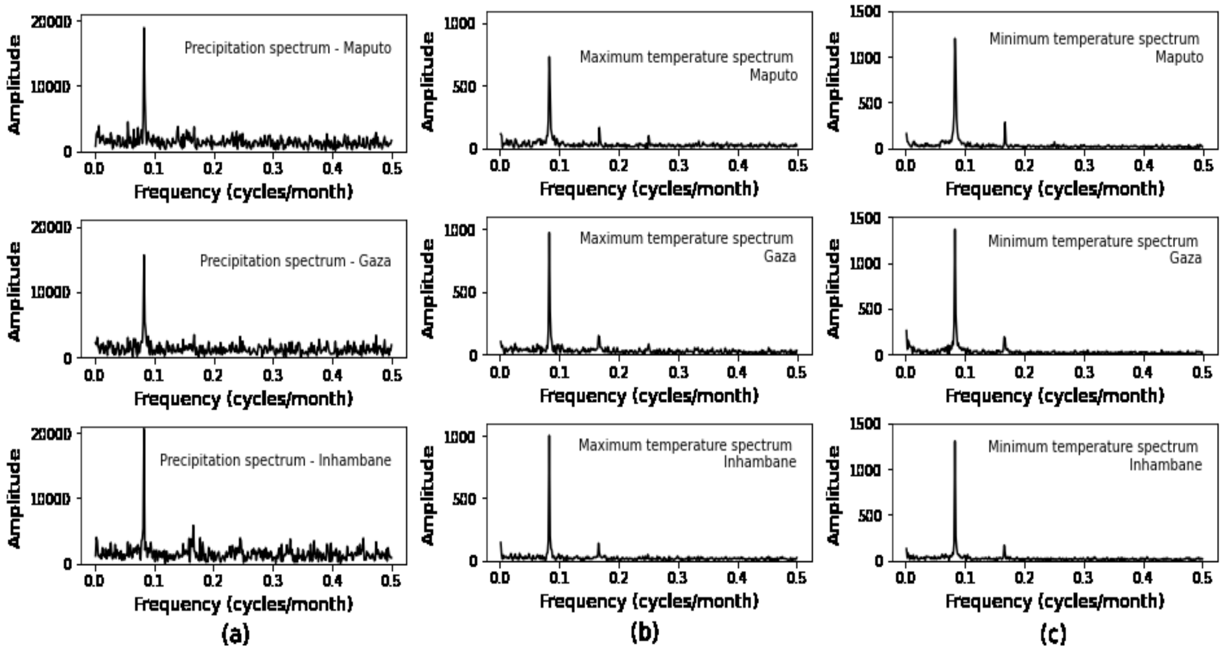


Source: Elaborated by the authors (2020)

Long term variability and trend

Within the variability patterns of the beginning and end dates of the rainy season (Figure 3), we can observe a certain predominance of seasons with a late start and an early end along the latest years, although not very significant. For this reason, the duration of the rainy season showed a slight downward trend over the evaluated period (90% confidence level), and this fact is illustrated in Figure 5(b). The calculation of linear trend showed a drop of around 16 days in the rainy season length of the southern Mozambique, during the period of 1960 – 2018, within the uncertainty range of 7 to 25 days (50% confidence level) as can be seen in Table 2. A comparison between the averages of the first and the last thirty years of the studied period is shown in Table 3. From this table we can see that the duration of the rainy season has dropped from an average of 191 days to an average of 175 days (90% confidence).

Figure 4 - *Fourier spectrum of (a) precipitation, (b) maximum temperature and (c) minimum temperature, in the three provinces of the southern region of Mozambique: Maputo (upper panels), Gaza (intermediate panels) and Inhambane (lower panels). The most significant periodicity corresponds to the annual variability at the frequency of approximately 0.083 cycles per month. Original data is related to 1960 – 2018.*



Source: Elaborated by the authors (2020)

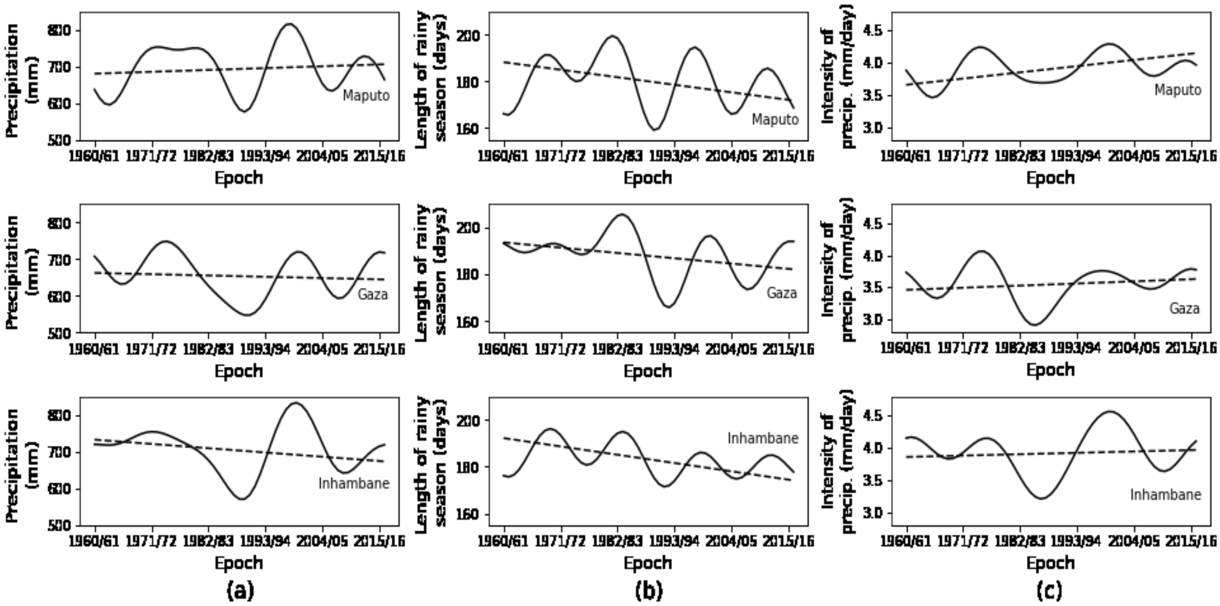
Table 2 – *Trend of the rainy season's parameters (confidence intervals computed for 50% confidence level in all parameters). Data related to 1960 - 2018.*

	Rainy season total precipitation (mm)	Rainy season length (days)	Intensity of precipitation (mm/day)
Maputo	25.57 ± 75.13	-16 ± 10	0.49 ± 0.39
Gaza	-17.86 ± 69.64	-12 ± 13	0.17 ± 0.34
Inhambane	-59.29 ± 74.19	-18 ± 11	0.11 ± 0.39
All Region	-17.19 ± 66.00	-16 ± 9	0.26 ± 0.32

Source: Elaborated by the authors (2020)

The total precipitation during the rainy season fluctuates without a clear trend. From Figure 5(a) and Table 2 we can notice a slight tendency to a decreasing rainfall in the provinces of Gaza and Inhambane, and a slight increase in Maputo, nevertheless, we have low confidence (21%), we did not find enough evidences to reject the null hypothesis. The comparison between the averages of precipitation during the first and the last thirty years of the studied period (Table 3) has also shown no statistically significant differences ($p<0.79$).

Figure 5 – Rainy season behavior in the three provinces of the southern region of Mozambique: Maputo (upper panels), Gaza (intermediate panels) and Inhambane (lower panels). The decadal variability (solid curve) and the linear trend (dashed line) of: (a) the total precipitation during the rainy season, (b) the rainy season length, and (c) the average intensity of precipitation. The data is related to 1960-2018.



Source: Elaborated by the authors (2020)

Table 3 - Climate averages of the rainy season's parameters for the first and the last 30 years of the period of 1960 - 2018 in the southern region of Mozambique (t-test for statistical significance in the observed differences is shown in the bottom of the table).

Rainy season total precipitation (mm) [1]		
Province	First 30 years (1960 - 1989)	Last 30 years (1988 - 2017)
Maputo	692	687
Gaza	659	633
Inhambane	696	687
All region	682	669
Rainy season length (days) [2]		
Province	First 30 years (1960 - 1989)	Last 30 years (1988 - 2017)
Maputo	186	172
Gaza	196	180
Inhambane	191	175
All region	191	175
Rainy season precipitation intensity (mm/day) [3]		
Province	First 30 years (1960 - 1989)	Last 30 years (1988 - 2017)
Maputo	3.78	4.03
Gaza	3.42	3.59
Inhambane	3.69	4.00
All region	3.63	3.88

[1] (t_value=0.24, df=58, p<0.79)
[2] (t_value=1.98, df=58, p<0.10)
[3] (t-value=0.88, df=58, p<0.40)

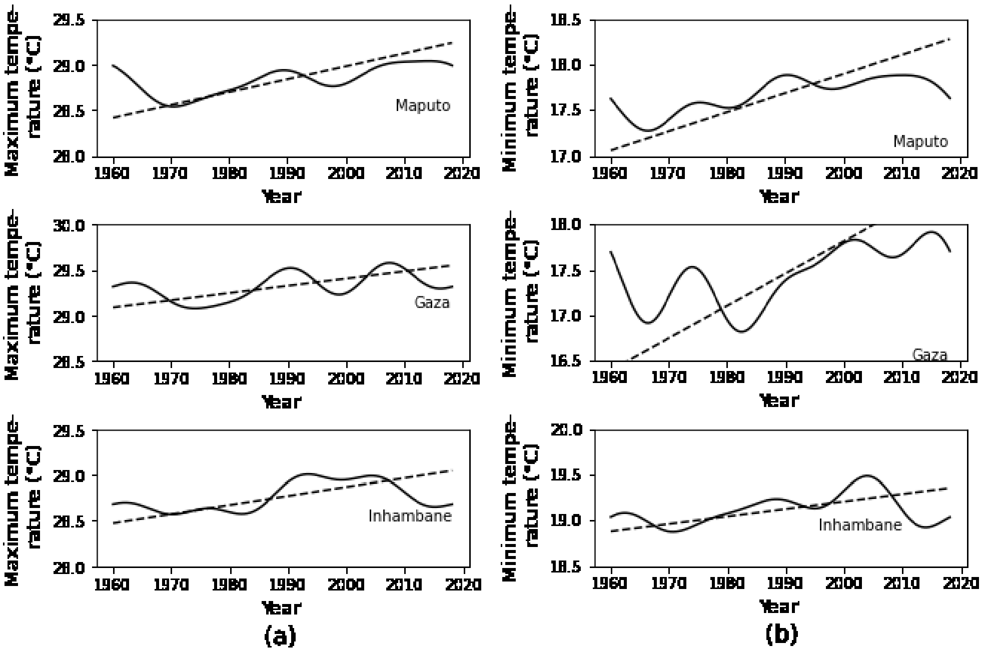
Source: Elaborated by the authors (2020)

The average of precipitation intensity during the rainy season showed a tendency to an increase, and it is more evident in the province of Maputo as can be seen in Figure 5(c) and Table 2 (60% confidence). This scenario demonstrates that the decrease of the duration of the rainy season along the studied period is significant. In other words, the average intensity of precipitation tends to increase as a result of a significant decrease in the duration of the rainy season as compared to that of total precipitation. Therefore, one hypothesis can be admitted from this result, it is likely that the occurrence of precipitation in the recent years is more associated with the occurrence of extreme events, since it tends to occur with greater intensity in a relatively short period. For instance, Mavume (2008) has found an increasing tendency in frequency and intensity of tropical cyclones reaching Mozambique in the recent decades.

The greatest deviation of precipitation along the entire period was recorded in the rainy season of 1999/2000, where it exceeded the climatological average by almost 100%, as can be seen in Figure 7(a). This scenario was due to the occurrence of three tropical cyclones consecutively in the year of 2000: Eline in February, Glória in March and Hudah in April. Collectively, these three cyclones had caused the most devastating impact on the history of Mozambique before the recent cyclones Idai and Keneth in 2019.

On the other hand, the maximum and minimum temperatures showed a clear upward trend (99% confidence level). This observation is valid for the three provinces of the southern Mozambique, as can be seen in Figure 6 and Table 4. The linear trend showed that during the period under analysis, the maximum temperature in the southern Mozambique has increased by about 0.7 °C within the uncertainty range of 0.39 to 1.01 °C. Analyzing the three provinces separately in the region, there is a minimum increase of 0.51 ± 0.383 °C in the province of Gaza and a maximum of 0.87 ± 0.357 °C in the province of Maputo. On the other hand, the minimum temperature in entire region has increased by about 1.51 °C within the uncertainty range of 1.13 to 1.89 °C. Assessing each province for the minimum temperature trend, Gaza has presented the greatest increase of about 2.38 ± 0.546 °C. All these uncertainties were computed for 90% confidence level.

***Figure 6** - Decadal variability (solid curve) and the linear trend (dashed line) of (a) maximum temperature and (b) minimum temperature in the three provinces of the southern region of Mozambique: Maputo (upper panels), Gaza (intermediate panels) and Inhambane (lower panels). The data is related to the period of 1960-2018.*



Source: Elaborated by the authors (2020)

***Table 4** – Trend in the annual mean temperature and precipitation (confidence intervals computed for 90% confidence level in all variables). Data related to 1960 - 2018.*

	Maximum temperature (°C)	Minimum temperature (°C)	Daily temperature (°C)	Annual Precipitation (mm)
Maputo	0.87 ± 0.357	1.34 ± 0.328	1.11 ± 0.297	-10.40 ± 187.377
Gaza	0.51 ± 0.383	2.38 ± 0.546	1.45 ± 0.352	-68.32 ± 168.331
Inhambane	0.73 ± 0.338	0.80 ± 0.471	0.76 ± 0.373	-87.55 ± 182.081
All Region	0.70 ± 0.310	1.51 ± 0.382	1.11 ± 0.302	-55.43 ± 161.115

Source: Elaborated by the authors (2020)

In addition, a comparison between the temperature averages of the first and the last thirty years of the studied period (Table 5) shows an average increase of 0.4 °C in the maximum temperature and an average increase of 0.8 °C in the minimum temperature. Therefore, the minimum temperature has been increasing with a slightly higher rate than the maximum temperature (99% confidence level). This implies that the diurnal temperature range has been decreasing along the last decades. Christy *et al*. (2009) also verified this scenario for the eastern part of Africa.

Table 5 - Climate averages of precipitation, maximum and minimum temperatures for the first and the last thirty years of the period of 1960 - 2018 in the southern region of Mozambique (t-test for statistical significance in the observed differences is shown in the bottom of the table).

Annual mean precipitation (mm) [1]		
Province	First 30 years (1960 - 1989)	Last 30 years (1988 - 2017)
Maputo	791	794
Gaza	794	765
Inhambane	831	827
All region	805	790
Annual mean maximum temperature (°C) [2]		
Province	First 30 years (1960 - 1989)	Last 30 years (1988 - 2017)
Maputo	28.6	29.0
Gaza	29.2	29.5
Inhambane	28.5	29.0
All region	28.8	29.2
Annual mean minimum temperature (°C) [3]		
Province	First 30 years (1960 - 1989)	Last 30 years (1988 - 2017)
Maputo	17.4	18.0
Gaza	16.8	18.0
Inhambane	19.0	19.3
All region	17.7	18.5

[1] (t_value=0.27, df=58, p<0.79)
[2] (t_value=4.09, df=58, p<0.01)
[3] (t-value=5.71, df=58, p<0.01)

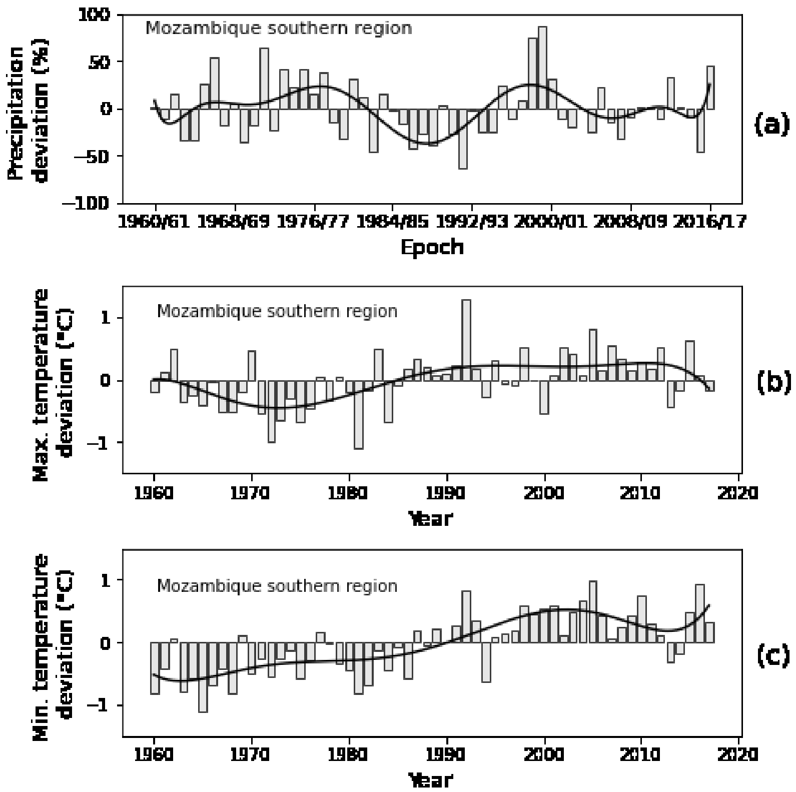
Source: Elaborated by the authors (2020)

The warming rate is of at least 0.12 °C per decade for the maximum temperature and of at least 0.25 °C per decade for the minimum temperature. For the whole country (Mozambique), McSweeney *et al*. (2010) have found an increase of 0.6°C during the period of 1960 - 2006, and an average rate of 0.13°C per decade in the mean annual temperature.

An important aspect to focus attention on is the fact that a greater slope of warming occurred during the period between the 70s and 90s decades, for approximately 20 years (see Figure 6). The mean surface air temperature had increased significantly during that period, and from the 90s on, the warming continues but at a reduced rate. Figure 7 shows in panels (b) and (c) the maximum and minimum temperature anomalies over the analyzed period, respectively. If we had evaluated the temperature anomalies only over the last three decades, starting from 1992, there would be no significant trends in temperature variability. On average, temperatures in the region have remained high and approximately stable as if it tends to stabilize over the last three decades, and 1992 was the warmest year along the entire evaluated period.

At global scale, the IPCC-AR5 also reported an observed reduction in surface warming trend over the period 1998 to 2012 as compared to the period 1951 to 2012 (IPCC, 2014). The IPCC explanation by "medium confidence" about this fact is that, it is due to a reduced trend in radiative forcing and a cooling contribution from natural internal variability, which includes a possible redistribution of heat within the ocean.

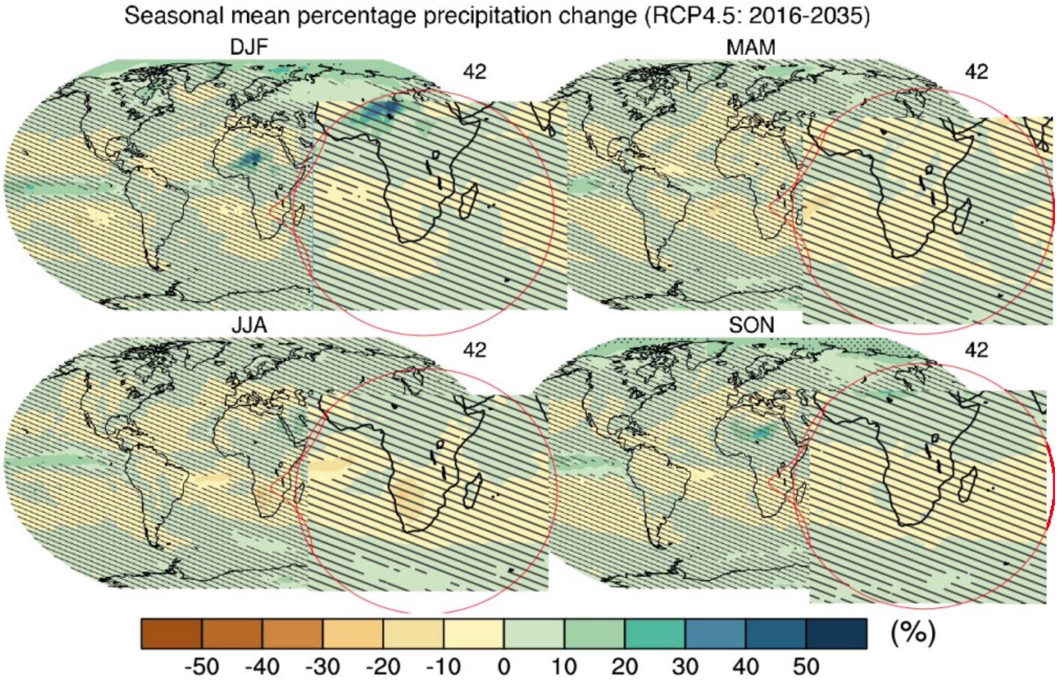
Figure 7 – *Climate deviations along the period of 1960 - 2018 relative to 1975 - 2004, in the southern region of Mozambique; (a) Total precipitation during the rainy season, (b) annual mean maximum temperature and (c) annual mean minimum temperature. The vertical bars represent the deviations and the solid curve corresponds to their polynomial fit of degree ten.*



Source: Elaborated by the authors (2020)

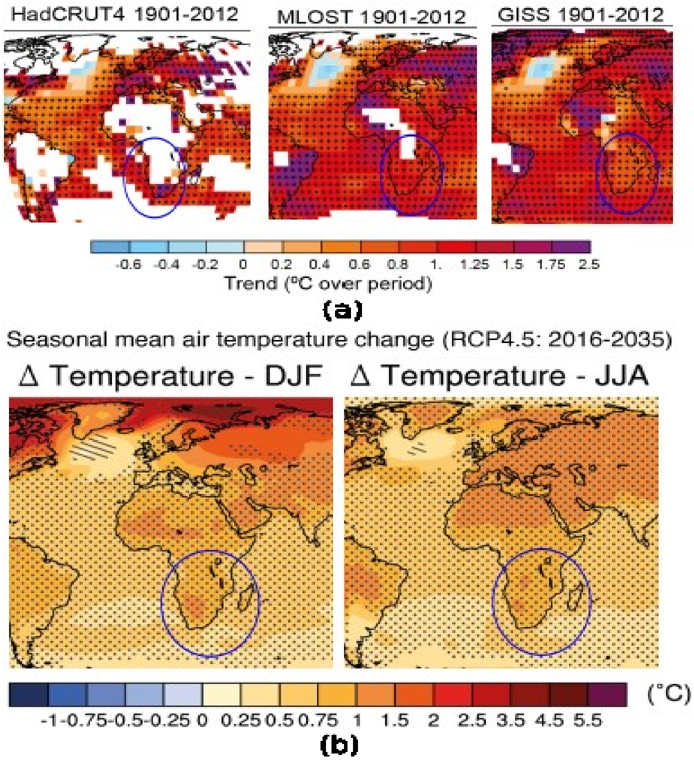
It is important to note that these trends both for precipitation and temperatures converge to the IPCC-AR5 observations and projections for the Austral Africa which include Mozambique. In particular, the projections for precipitation during the period of 2016 – 2035 pointed to a slight decrease of about -10% as can be observed in Figure 8 (HARTMANN *et al.*, 2013a), however, a slight increase of the same order is also expected in the summer months (DJF) for the southern Mozambique. Figure 9 illustrates temperature anomalies (HARTMANN *et al.*, 2013a) and there was an increase of about 0.8 °C in observations from 1901 to 2012 (see Figure 9a), and it is still expected to continue increasing by about 0.8 °C in the projections for the period of 2016 – 2035 (see Figure 9b). Both projections are based on the intermediate scenario of greenhouse gas emission policy designated by the acronym RCP4.5.

Figure 8 *- CMIP5 multi-model ensemble mean of projected changes (%) in precipitation for 2016 – 2035 relative to 1986 – 2005 under RCP4.5 scenario, for the four seasons. The number of CMIP5 models used is indicated in the upper right corner. Central and Southern Africa is surrounded in red. On average the diagrams indicate negative anomalies (-10%) in Mozambique, however a positive anomaly is also expected for summer months (DJF) in the southern Mozambique. The seasons are indicated at the top of each diagram (Source: HARTMANN et al., 2013a).*



Source: Hartmann *et al*. (2013a)

***Figure 9 -** Global trends in surface air temperature: (a) observed anomalies analyzing three databases (HadCRUT4, MLOST and GISS) from 1901 to 2012, where the white areas indicate incomplete or missing data; (b) CMIP5 multi-model ensemble mean of projected changes in summer (DJF) and winter (JJA) seasons for the period of 2016 – 2035 relative to 1986 – 2005 under RCP4.5 scenario. In all images the areas surrounded in blue include the southern region of Mozambique (Source: HARTMANN et al., 2013a).*



Source: Hartmann *et al*. (2013a)

CONCLUSIONS

Overall, the obtained results are in line with the observations and projections reported by the IPCC-AR5 regarding the Austral Africa, which includes Mozambique. In the southern region of Mozambique the rainy season extends from the first week of October to the last week of April. It tends to a late start and an early end, leading to a decrease of the duration of rainy season, which has dropped, on average, about 16 days during the period of 1960 - 2018. The total precipitation during the rainy season did not present clear trend. Analyses in the three provinces separately have shown that the province of Gaza presents the lowest rainfall of the southern region of Mozambique. Although there was some frequency of dry events during the rainy season, in general, the rainfall regime throughout the region (fluctuating around an average of 669 mm) is still favorable for the development of the main crops practiced under dry land conditions (such as maize, cassava, peanuts, etc.) as long as these events do not occur in the phases of greatest water need of the plant. On the other hand, there was a clear indication of warming, that is, an increase in temperatures along the studied period. The maximum temperature has increased by about 0.7 °C and the minimum temperature has increased by about 1.5 °C during the period of 1960 - 2018. The warming rate is of at least 0.12 °C per decade for maximum temperature and of at least 0.25 °C per decade for minimum temperature, implying that the diurnal temperature range has been decreasing due to the rapid increase in minimum temperature compared to the maximum. In addition, we have noticed a certain reduction in the warming rate during the last three decades and the highest rate over the entire period (1960 - 2018) was verified during the interval between the 70s and 90s decades.

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