Journal of Business and Environmental Management (JBEM)

Volume 2, Number 2, 2023, Pages 69 – 80

Journal Home Page

https://journals.airsd.org/index.php/jbem

High-Resolution RCP Scenario for the 21st Century in the North-West region of Morocco, Future Projections for 2041-2060, 2061-2080 and 2081-2100

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ARTICLE INFO

Article History:

Received:	September	29, 2023
Revised:	October	20,2023
Accepted:	November	29,2023
Available Online:	December	30,2023

Keywords:

Climate, temperature, modelling, Extremes events, Future projections

ABSTRACT

Abstract. Climate model simulations of future climate are the basis for adaptation decisions, which the effectiveness will depend on the quality of the models. A set of climate models developed under the CMIP6 project and generated by the spatial bias correction disaggregation method (BCSD) using a statistical downscaling algorithm have been used [1]. These models are used to evaluate the future changes in thermal extremes projected by the climate models over the different time horizons with comparison to the 1981-2000 reference period. These projections are made under the scenario RCP 4.5 (optimistic). The examination of future climate change projections could confirm the result of warming over the entire North West region of Morocco. The increase in temperature could reached an average of 1.8 ° C to 2.5 ° C just in 2060. In the same sense of warming, the number of hot days and hot nights could increase year by year while a decrease could be noticed in the number of cold days and cold nights. The simulations for the 2080 and 2100 horizons revealed a situation that worsens year by year. The temperature anomaly could reached about 3°C and more. Thus, a climatic warming may be predicted in the future and generalized over the entire North West region.

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INTRODUCTION

Morocco is facing the challenge of climate change, due to the current trend in the occurrence of extreme weather events, their frequency, duration and intensity. Indeed, extreme weather events, including heat wave episodes, the number of hot days, the number of cold nights ..., will pose a challenge to him in the face of current changes that continues to accentuate the situation.

The frequency of extreme events will be multiplied. The first consequences of this disruption are already visible, just with a warming of +1.1 ° C, the number of heat waves has become 4.8 times more frequent [2]. Based on current trends in Morocco, it is reasonable to expect an increase in temperatures, even an increase in their variability and changes in the average thermal extremes. Indeed, the average maximum temperature has increased in recent decades; this increase is well generalized over the study area [3].

The most extreme event felt by all living beings in recent years, heat waves, which have experienced in recent years a visible and felt increase in Morocco. These last two years Morocco for the first time suffers from heat wave episodes with temperatures approaching 50 ° C in some areas and will persist for a long time and with hot nights whose temperature will exceed 30 ° C. Indeed, the increase in average temperatures of +1.1°C compared to the pre-industrial period [4] plus other factors such as the greenhouse effect accentuated by human activity, the chergui phenomenon... a non-linear relationship indicated by the IPCC, which will contribute to the increase of thermal extremes in terms of their intensity and duration.

Numerous studies in several disciplines seek to better understand the effects of climate change at extreme events, at local spatial scales and fine temporal resolutions. This study presents a study on the use of CMIP5 Generation of high resolution climate models to make future projections of different thermal climate indices at different time horizons 2060, 2080 and 2100 and using the RCP 4.5 scenario. Indeed, this is a dataset that was generated by the spatial bias correction disaggregation (BCSD) method using a statistical downscaling algorithm that handles high resolution general circulation climate models [1]. The BCSD downscaling method was compiled on 42 projections from 21 large-scale general circulation models (for each of the two scenarios RCP 4.5 and RC 8.5) over the historical period from 1971 to 2005 and the future period from 2006 to 2100.

The objective of this study is to assess future changes based on the study of a set of thermal climate indices for the 2041-2060, 2061-2080 and 2081-2100 time horizons with respect to the 1971-2005 reference period and under the RCP 4.5 scenario. For this, we focused on the following indices: maximum temperature, minimum temperature, and number of hot days, number of cold days, number of hot nights and number of cold nights.

MATERIAL AND METHODS

Database

Climate model data

The analysis of the evolution of climate extremes and future changes requires the use of future simulations based on several scenarios. Therefore, we were led to use simulations of one climate model obtained following the work done under the CMIP project 5.

It’s a general circulation model, composed of 6080 grid points of which 680 points that covered the region studied circled in red with a spatial resolution of 25 km × 25 km (Figure 1), and a history from 1971 to 2005 and two projections from 2006 to 2100 (two scenarios RCP8.5 and RCP4.5) covering the study area. This resolution allows us to simulate the future well at the regional scale and the results in most studies are significant [1].

MIROC-ESM-CHEM : In response to these issues, Earth System Models (ESMs), which is often used as a synonym for climate models coupled with biogeochemical components, are being developed by the Japan Agency for Marine Earth Science and Technology (JAMSTEC) in collaboration with, among others, the University of Tokyo and the National Institute for Environmental Studies (NIES) (18), The current version of the MIROC model takes into account the chemical component and the aerosol responsible component to reasonably produce the transient variations in surface air temperatures for the period 1850-2005.

The first database used in this study consists of daily simulated maximum and minimum temperature data from the NEX-GDDP project "NEX Global Daily Downscaled Climate Projections". The latter are data that cover our study area well. They are spread over the historical period from 1971 to 2005 and future from 2006 to 2100.

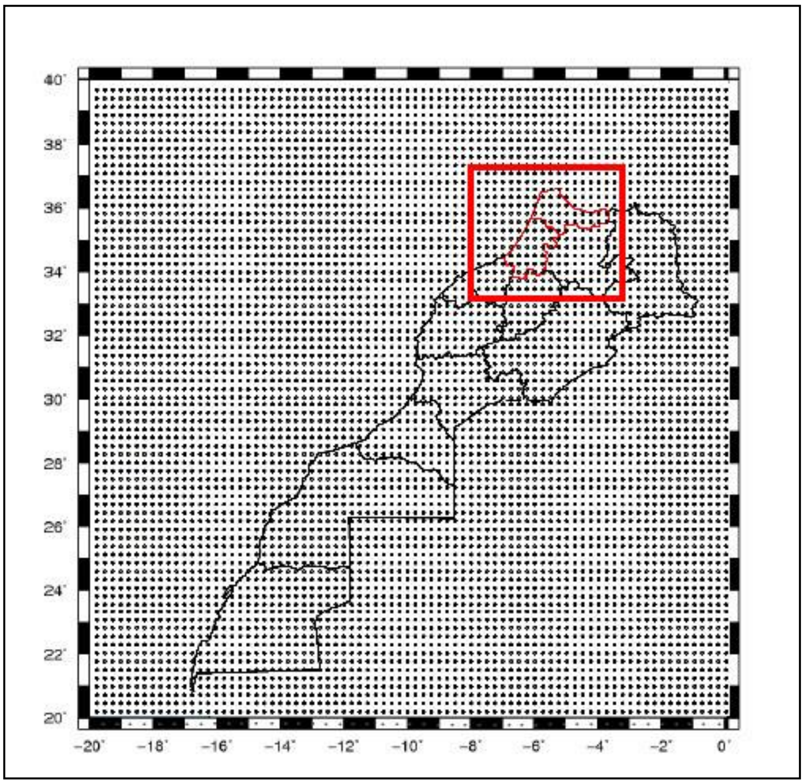


Figure 1. *The study area and grid point distribution.*

METHODOLOGY

This work was initially carried out by calculating a set of climatic indices on all the grid points that cover our study and over the period spanning from 1971-2005 and the three horizons 2041-2060, 2061-2080 and 2081-2100 and based on the following two meteorological parameters: daily maximum temperature and daily minimum temperature. After this calculation, we calculated the average per grid point for each index and over each period. This is to begin the most important part, which is based on the calculation of the difference between these averages per grid point over the three horizons 2041-2060, 2061-2080 and 2081-2100 compared to the reference period 1971-2005. This calculation will allow us to evaluate future changes in climate extremes. For this, we opted to use the ARCGIS software to map the results obtained based on the IDW interpolation method [5].

The Climate indices

In order to assess climate extremes in the future, the CCl Commission of the World Meteorological Organization and the ETCCDI Group have made available to the scientific community a set of climate indices based on two essential parameters, in particular temperature and precipitation, developed for the understanding of these phenomena. The calculation of the indices (Table 1) is based on the parameter themselves, on thresholds fixed, or calculated over a reference period. This calculation was carried out using the ClimPACT 2 platform running under the R software [3] [6] [7]:

Table 1. *Lists of indices used together with their definitions and units.*

indices	Definition	unit
Tmm	The daily average of the daily Mean temperature.	°C
Txm	The daily average of the daily maximum temperature.	°C
Tnm	The daily average of the daily minimum temperature.	°C
Tx90p	The percentage of hot days which is the percentage of days when the maximum temperature is above 90th percentile calculated over a reference period.	%
Tn90p	The percentage of hot nights which is the percentage of days when the minimum temperature is above 90th percentile calculated over a reference period.	%

Statistical Tools

Interpolation method : IDW

All the interpolation methods used by scientists today have been developed based on the theory that the closest points have more correlations and similarities than those that are further away.

In our case, we have opted for the use of the method Inverse Distance Weighting (IDW), for this, we already assume that the rate of correlations and similarities between the grid points is proportional to the distance between them which can be defined as an inverse function of distance of each point from the neighboring points. This method requires the existence of a set of points well distributed over the study area, for our case, our study area is well covered by 6080 grid points distributed and separated by 0.25° (~25km) [8][9].

The inverse distance weighting (IDW) method is one of the most widely adopted methods by climate change researchers for spatial plotting and has been implemented in many GIS packages including ARCGIS. It is a deterministic spatial interpolation model. The general principle of this method is that the attribute values of a given point pair are related to each other, but their similarity is inversely proportional to the distance between the two [10].

This method has only one disadvantage, the use of the IDW method in the processing of a large dataset will take a lot of time to perform the calculation. It taken can be up to 5 times longer than the fast average method [11].

$$Z_0 = \frac{\sum_{i=1}^{N} z_i . d_i^{-n}}{\sum_{i=1}^{N} d_i^{-n}} \quad (1)$$

Where

$Z_0 = The\ estimation\ value\ of\ variable\ z\ in\ point\ I.$

$z_i = The\ sample\ value\ in\ point\ I.$

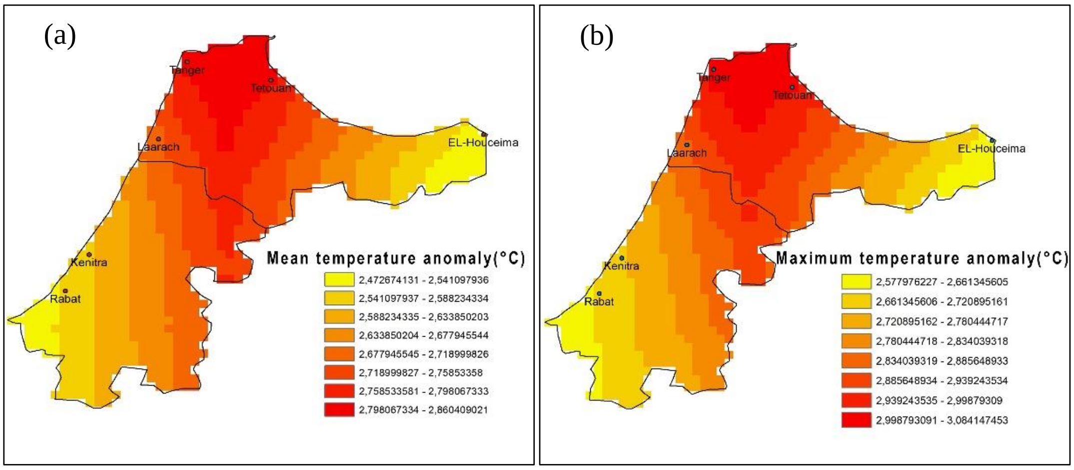
$d_i = The\ distance\ of\ sample\ point\ to\ estimated\ point.$

N = The coefficient that determines weigh based on a distance.

n= The total number of predictions for each validation case.

RESULTS AND DISCUSSION

In this section, we are interested in the future changes of climatic extremes in the North-West Region of Morocco based on all the climatic indices calculated using the two parameters, the maximum and minimum temperature, over three horizons 2041-2060, 2061-2080 and 2081-2100 compared to the reference period 1971-2005. This calculated difference will be mapped on the North West region using the ARCGIS software and the IDW Interpolation method.



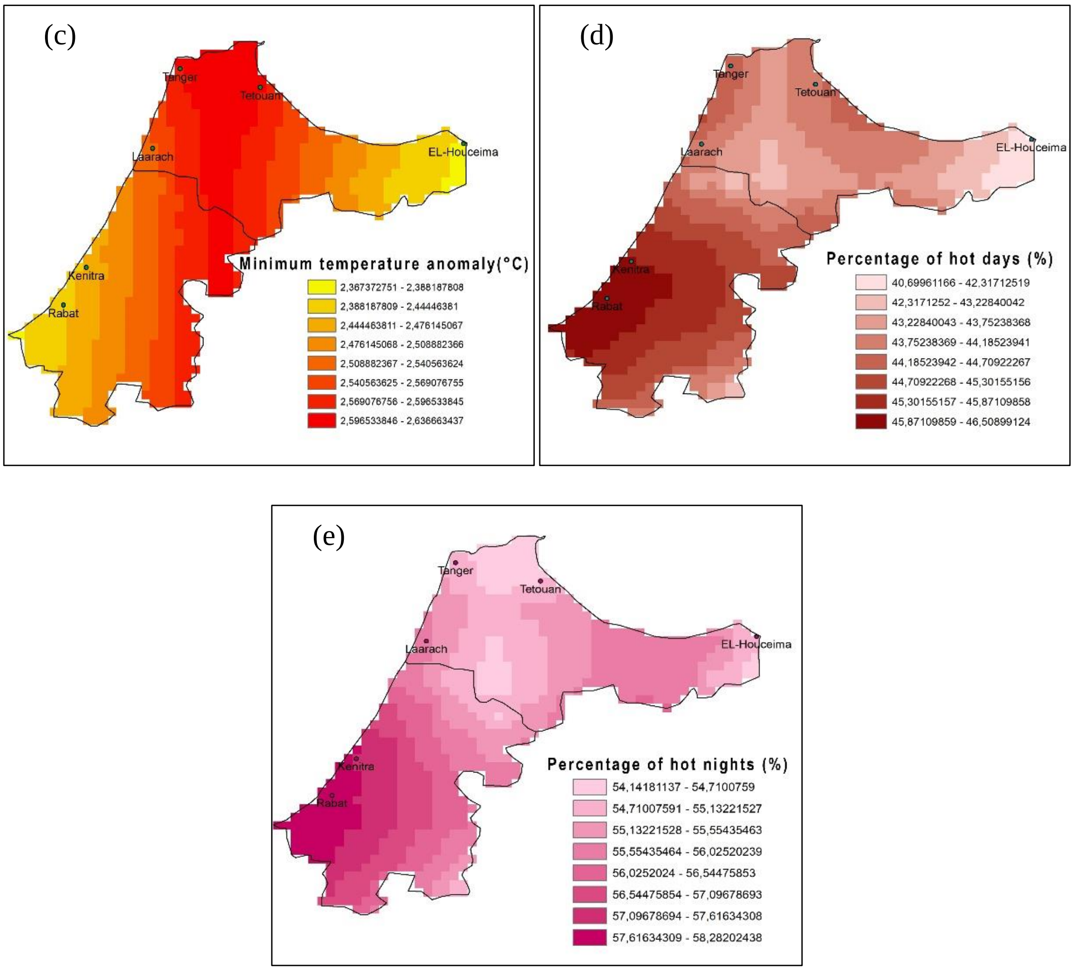


Figure 2. *Future projections of the mean, maximum and minimum temperature anomaly, the percentage of warm days and the percentage of warm nights projected by the MIROC-ESM-CHEM model under RCP 4.5 scenarios and for the 2041-2060 time horizon relative to the 1971-2005 Reference.*

According to the RCP 4.5 scenario, the MIROC model agrees on an increase of the mean temperature. A positive gradient is, clearly noticed going from the South to the North. The maximum increase is located, according to RCP 4.5, at the extreme NW of the study region where the anomaly of the average temperature could reach an average of 2.7°C in 2060, especially in Tanger and Tetouan (Figure2, a). This anomaly could vary over the region from 2.4°C to 2.8°C (Table2). The MIROC model agrees also on an increase of the mean maximum and mean minimum temperature. The same spatial patterns were noticed according to the mean temperature. A positive gradient is clearly, noticed going from South to North. The maximum increase in the mean maximum temperature anomaly is located, according to RCP 4.5, in the extreme northwest of the study area where the anomaly could vary between 2.5°C in El-Houceima and 3°C in Tangier (Figure2, b and c).

The future changes in the index of the percentage of hot days could indicate an evolution towards an intense warming over the study region. The model agrees that the Rabat-Kenitra region will receive the maximum increase under the RCP 4.5 scenario, while the Mediterranean coasts will be interested in the minimum of this increase (figure 2, d). Under the RCP4.5 scenario, the number of hot days could reach an increase ranging from 40 to 46% compared to the normal (1971-2005).

It should also be noted that an increase in the average temperature anomaly of 2.4°C in Rabat for example is equivalent to an increase in the percentage of hot days of almost 45%. While an increase of 2.7 ° in Tangier is equivalent to almost 43% increase in the percentage of hot days (Table 2).

According to the RCP4.5 scenario, the MIROC-ESM-CHEM model predicts an increase in the percentage of warm nights generalized over the entire study region. The maximum of the increase is localized in the Rabat-Kenitra region and could reach 58% of anomaly compared to the normal period (1971-2005).

The Mediterranean region is interested in the minimum increase which varies between 54% and 56%. It will be noted that the spatial distribution of the percentage of the number of hot nights follows almost the same configuration as that of the percentage of hot days (Figure 2, e).

In particular, an increase in the anomaly of the average temperature in Laarache of 2.6 °C is equivalent to an increase in the percentage of hot nights of 56% compared to the reference from 1971 to 2005. That is to say, it is normal is 30 days a year, an increase of almost 16 days could be expected on the horizon of 2060.

The results of these last five indices are summarized in the following table which indicates the ranges of increase of each index according to the scenario RCP 4.5, for the horizon 2041-2060 compared to 1971-2005:

Table 2. *Summary of the ranges of increase of the five climate indices (Tmm, Txm, Tnm, Tx90p and Tn90p), according to scenario RCP 4.5, for the horizon 2041-2060 compared to 1971-2005.*

Indices/Scenario	MIROC-ESM-CHEM (RCP 4.5)
	2041-2060 (reference 1971-2005)
Mean temperature anomaly (°C)	[2.4°C , 2.8°C]
Maximum temperature anomaly (°C)	[2.5°C , ~3.1°C]
Minimum temperature anomaly (°C)	[2.3°C , 2.6°C]
Percentage of hot days (%)	[40% , 46.5%]
Percentage of hot nights (%)	[54% , 58%]

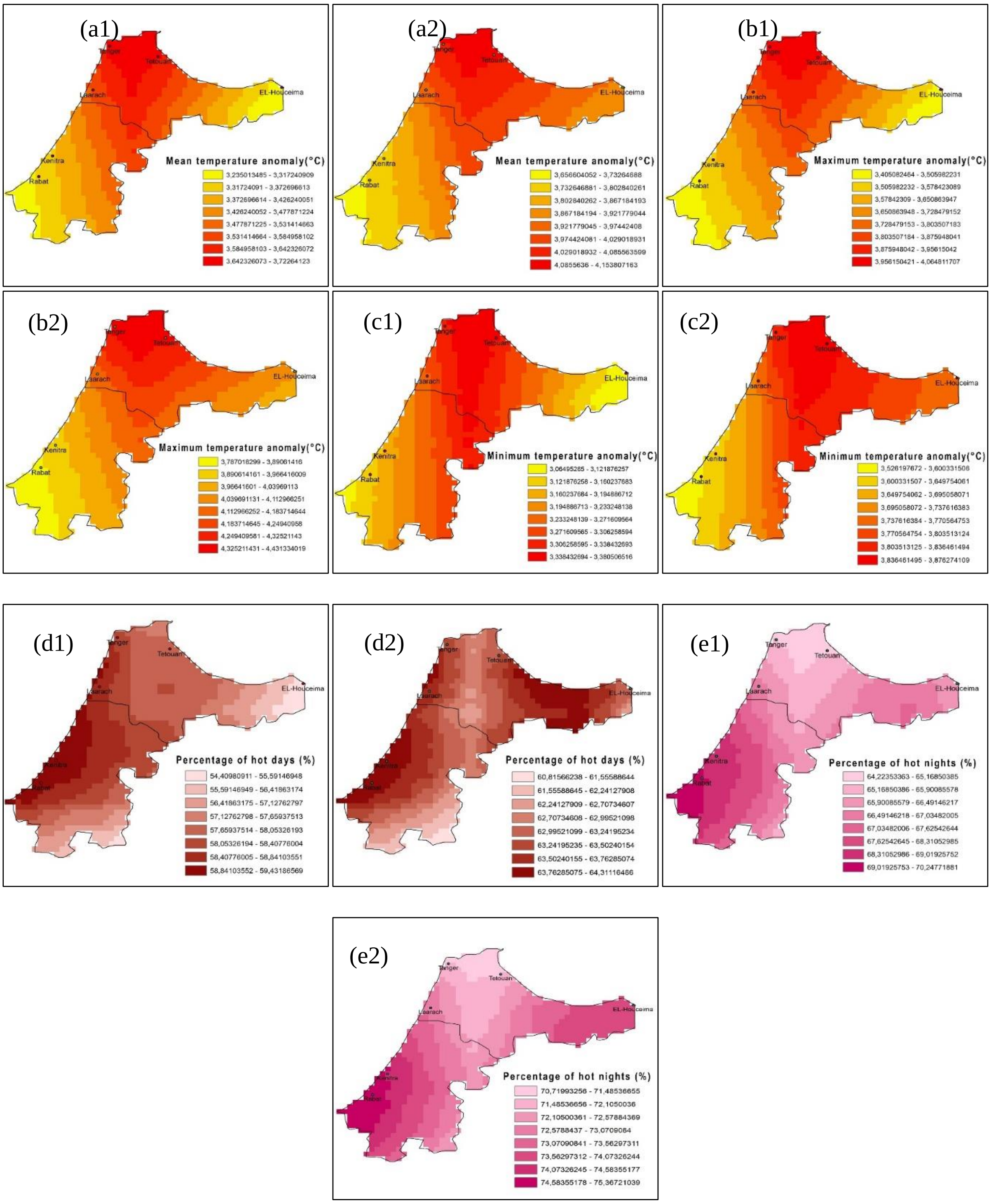


Figure 3. *Future projections of the mean, maximum and minimum temperature anomaly, the percentage of hot days and the percentage of hot nights projected by the MIROC-ESM-CHEM model according to the scenarios of RCP 4.5 and for the time horizon 2061-2080 (X1) and 2081-2100 (X2) compared to the reference 1971-2005.*

According to the five climate indices, the warming on the horizon 2061-2080 would also manifest itself in the form of an increase in the anomaly of the mean temperature (Figure 3, a1), which could vary between 3.2 °C (El-Houceima) and 3.7 °C (Tangier) and could intensify (Figure 3, a2) and reach 4.1 °C on the horizon of 2100 (Table 3). In the same direction of warming, the anomaly of the mean of maximum and minimum temperature could experience an increase by following the spatial trajectory of the average temperature (Figure 3, b1 and c1). The Tangier region remains always interested in the maximum of this anomaly.

The extremes of hot days would intensify on the horizon of 2061-2080 (Figure 3, d1), and the increases would then become more significant, varying between 54% in the extreme East and South of the study area and 59% on the coasts of Rabat and Kenitra. Going towards the horizon of 2100, this index would experience an increase exceeding 60% and could reach 64% in the Mediterranean coasts (between Tetouan and El-Houceima) and the coastal regions of the West and North-West of the study area (Figure 3, d2).

According to the scenario RCP4.5 and on the horizon 2060-2080, the extremes of hot nights could experience a generalized increase over the entire study region according to the MIROC model (Figure 3, e1). The maximum of the increase is located in the southeast of the study area and it concerns Rabat and Kenitra. This increase varies between 64% and 70% compared to the reference of 1971-2005. Towards the horizon 2081-2100, the situation is accentuated (Figure 3, e2) by passing a fouchette, which varies, from 70% to the north of the study region and 75% to the Southeast and the extreme East of the study region (Table 3).

Table 3. *Summary of the ranges of increase of the five climate indices (Tmm, Tm, Tnm, Tx90p and Tn90p), according to the scenario RCP 4.5, for the horizon 2061-2080 and 2081-2100 compared to 1971-2005.*

Indices/Scenario	MIROC-ESM-CHEM (RCP 4.5)	
	2061-2080	2081-2100
Mean temperature anomaly (°C)	[3.2°C , 3.7°C]	[3.6°C , 4.1°C]
Maximum temperature anomaly (°C)	[3.4°C , 4°C]	[3.7°C , 4.4°C]
Minimum temperature anomaly (°C)	[3°C , ~3.4°C]	[3.5°C , ~3.9°C]
Percentage of hot days (%)	[54% , ~60%]	[60% , 64%]
Percentage of hot nights (%)	[64% , 70%]	[70% , 75%]

Numerous studies have shown changes in thermal extreme events in the future could experience increases [12] [13] [14]. This increase in thermal extremes is similar to what is predicted by IPPC in the last AR6 report. According to this report, the reference value is set at a thermal extreme that would only happen 50 years before our influence on the climate. With the current global warming of +1.1°C in 2022 according to this report, the probability that a thermal extreme will recur over 10 years is 4.8 times. This observation converges with what is planned by the MIROC model. Moreover, an increase of 2.6° C towards the horizon 2041-2060 is equivalent to an increase of 43% of hot days and 56% of cold nights compared to the reference 1971-2005.

The scientific literature on climate change and its impacts in Morocco, or more broadly in

North Africa, is relatively numerous and diverse. The Mediterranean region [15] of which our study area is part, is the subject of numerous studies that have predicted a generalized rise in thermal extremes without exception. For the RCP 4.5 scenario, the warming is clearly more pronounced during all the years and the thermal extremes increase very significantly in the study area [16]. The most recent publication of high-resolution climate projections for northern Morocco [17], which analyzes the results of simulations carried out for RCP4.5 scenarios with different high spatial resolution models. The results obtained for various temperature indices indicate a clear global warming and confirm the results obtained from the increase in thermal extremes. The warming will be more marked in the areas east of the Atlas, under Saharan influence, than on the Atlantic and Mediterranean facades of which our study area is part.

In the Mediterranean basin, several studies have confirmed the results obtained from this generalized warming. [18] 19]all confirmed a global warming that could exceed +2°C just on the horizon of 2050 accompanied by an increase in thermal extremes without exception.

In short, the projections made with this regional climate model show an accentuation of this warming trend either in temperature or in temperature-related extremes. The study area (North-West of Morocco) is therefore likely to experience an exacerbation of intense and/or more frequent thermal conditions. In general, all models (climatic, hydrological, agricultural ...) have their own strengths and weaknesses. None of the regional climate models used in the framework of the CMIP5 or CMIP6 project shows better performance than the others for all variables and all regions of the world. It is therefore necessary to consider with caution the projections obtained with a single model, and when possible, it is preferable to take into account several models.

CONCLUSION

The analysis of thermal extremes shows that the study region could experience significant warming by 2041-2060. This warming is generally more accentuated under the scenario RCP 4.5 and going towards the horizons of 2061-2080 and 2081-2100.

This warming will be manifested by an increase in maximum temperatures, which could reach on average 2.8 °C, and minimum temperatures, which could reach on average 2.4°C. The future change will also be accompanied by an increase in the percentage of hot days, which will reach, on average 43% compared to the reference 1971-2005 by the horizon of 2041-2060. The percentage of hot nights will increase and could reach on average 56% of the reference over most of the study area. In the same direction of warming and going towards the horizons 2061-2080 and 2081-2100, the situation is intensifying and accentuating year by year.

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