

Assessment of Projected Precipitations and Temperatures Change Signals over Algeria Based on Regional Climate Model: RCA4 Simulations



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Abdelazim M. Negm, Abdelkader Bouderbala, Haroun Chenchouni, and Damià Barceló (eds.), *Water Resources in Algeria - Part I: Assessment of Surface and Groundwater Resources*, Hdb Env Chem (2020) 97: 135–160, DOI 10.1007/698_2020_526, © Springer Nature Switzerland AG 2020, Published online: 16 June 2020

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Abstract Algeria is the largest African and Mediterranean country. It is located in the southern seashores of the Mediterranean Sea. Its climate conditions are ranging from relatively wet to very dry which makes it confronted to high levels of rainfall deficits. The future rainfall evolution may be critical for human activities since increased temperatures may further exacerbate droughts and water shortages. In this study, the regional climate simulations RCA4 are evaluated over historical period 1951–2005 and then used to examine the rainfall and temperature projections over the end of the twenty-first century under two Representative Concentration Pathway (RCP4.5 and RCP8.5) scenarios. The historical simulations are evaluated against observations coming from the recent data sets of Climatic Research Unit (CRU). The trends in precipitation and temperature over historical (1951–2005) and projected future scenarios (2006–2060 and 2045–2100) was depicted by the estimation of the shifts of the three main climate zones existing in Algeria (Köppen–Gieger classification): warm temperate climates (C), steppe climate (BS), and desert climate (BW). Comparative to the mean climate zone surface areas derived from observations (1951–2005), all model simulations predict an expansion of desert climate zone at the expense of the temperate and steppe climate zones. This shift seems to particularly increase by the end of twenty-first century (2045–2100) under RCP8.5 scenario.

Keywords Climate change, Climate zone, Global warming, Precipitation and temperature, Regional climate simulations

1 Introduction

Given the ongoing aridification and/or sometimes very abrupt climate change, the current distribution of climate conditions at the global scale will be reorganized. Some climates will disappear completely, while others will appear in some regions [1]. This is particularly true over Mediterranean Basin due to its geographic location between dry (the Sahara) and wet regions of the Northern Europe [2, 3]. This basin is under the influence of the downward branch of the Hadley cell circulation in summer and of fluxes from the West in the Atlantic Ocean in winter [4]. It is a transition zone in which the competing influences of extratropical and tropical systems affect climate events modulated by their proximity to the Mediterranean Sea [5]. This region, which includes Algeria, has been considered as the region for which there is the widest consensus between projections and model types used by the International Panel on Climate Change (IPCC) about future decreases in total rainfall [6]. However, IPCC model resolution, which ranges from 100 to 200 km, does not allow a

sufficient level of regional detail, and a higher resolution can be achieved by using regional climate models. Regional models provide a finer representation of sub-regions of the planet while using global models to describe conditions at the edges of these subregions, among other things. As such, the power of supercomputers is essentially used to enhance spatial resolution. In this chapter, we examine climate in Algeria in terms of monthly mean precipitation and temperature using future projections of regional climate model (RCM) – RCA4 at 0.44° resolution used as part of the CORDEX-Africa program (Coordinated Regional climate Downscaling Experiment) under the RCP4.5 and RCP8.5 forcing scenario. The RCA4 regional climate model of Rossby Centre (SMHI) used the boundary conditions of nine atmosphere-ocean general circulation models (AOGCMs) from the Coupled Model Intercomparison Project-Phase 5 (CMIP5) to drive an ensemble of RCM simulations for African domain [7, 8]. To do so, we analyze precipitation and temperature trends, as well as the average climate trend observed in Algeria over the period from 1951 to 2005. These trends are compared with those estimated from the outputs of nine regional climate model simulations. It is then possible to test how well these models reproduce average climate and trends (of temperature and precipitation) over historical time and into the future (2005–2060 and 2045–2100). Two scenarios are primarily used for future projections, namely, RCP4.5 and RCP8.5. Since the precipitations and temperatures are used to define climate zones, the future change of these two climate variables is also evaluated by the shift in surface area of each climate zone as defined in Köppen-Geiger classification [9]. The shift in surface area of each climate zone is computed after constructing the mean map of climate zones for each three studied periods (1951–2005, 2006–2060, and 2045–2100).

2 Observational Data

We selected monthly temperature and precipitation data measured on a $0.5^\circ \times 0.5^\circ$ grid from the latest version of the Climatic Research Unit database (CRU Version TS.3.24) for the period from 1951 to 2005 of meteorological data based on stations measurements [10] with spatial coverage of Algeria. The University of East Anglia CRU database is one of the most widely used sources of climate data, providing temperature and precipitation data at a 0.5° resolution and temporal coverage from 1901 to 2015.

3 Regional Climate Model (RCM) Simulations

Regional climate model (RCM) simulations were used as part of the Coordinated Regional climate Downscaling EXperiment (CORDEX-Africa, <http://www.cordex.org/>). CORDEX is a numerical climate simulation coordinated experiment carried out jointly by several research centers to generate fine-scale climate data over

Table 1 RCA 4 Regional climate models and their AOGCM driving model

MCR	Driving model (AOGCM)
RCA4 (CanESM2)	CCCma (Canada)
RCA4 (CNRM-CM5)	CNRM-CERFACS (France)
RCA4 (CSIRO-MK3)	CSIRO (Australia)
RCA4 (IPSL-CM5A)	IPSL (France)
RCA4 (MIROC5)	MIROC (Japan)
RCA4 (HadGEM2-ES)	MOHC (UK)
RCA4 (MPI-ESM-LR)	MPI-M (Germany)
RCA4 (NorESM1-M)	NCC (Norway)
RCA4 (GFDL-ESM2M)	NOAA-GFDL (USA)

14 regional domains (South America, Central America, North America, Africa, Europe, South Asia, East Asia, Central Asia, Australasia, Antarctica, the Arctic region, the Mediterranean region (MED), the Middle East, and Southeast Asia) [11]. As part of CORDEX-Africa in its second phase, regional climate models including conditions at the edges of ten atmosphere-ocean (AO) general circulation models (GCM) from Phase 5 of the Coupled Model Intercomparison Project (CMIP5) produced new versions of the regional climate models for the African region. We used monthly precipitation and temperature simulations from the Rossby Centre by RCA4 Regional Climate Model for Africa. This database was obtained from the Swedish Meteorology and Hydrology Institute's (SMHI) regional model using boundary conditions of nine AOGCMs from the CMIP5 (see Table 1) [11, 12]. Simulated data as a whole ($0.44^\circ \times 0.44^\circ$) cover the period from 1951 to 2100, which is subdivided into two periods: the historical period (1951–2005) and the projection period (2006–2100). This latter period was forced by two Representative Concentration Pathway scenarios, RCP4.5 and RCP8.5, assuming boundary conditions from the AOGCMs [11].

3.1 Representative Concentration Pathways (RCPs)

Greenhouse gas (GHG) representative concentration pathways developed by the IPCC as part of Phase 5 of the Coupled Model Intercomparison Project (AR5) predict a somber future for humanity as a whole and a multitude of life forms [13]. RCPs are concentration evolution scenarios for GHG (carbon dioxide or CO_2 , methane or CH_4 , nitrous oxide or N_2O , etc.), aerosols, and chemically active gases in the atmosphere over the 2006–2100 period and extrapolated to 2300 [14]. All scenarios are assumed to be directly linked to CO_2 emissions; as carbon emissions increase, climate warms. Mankind is currently set on the worst-case pathway, RCP8.5, which should lead to a 2°C mean global warming by 2050 [14]. Four scenarios were selected from 300 published scenarios to cover the widest possible range of allowable future radiative forcing pathways. These four RCP scenarios are labeled according to their radiative forcing in 2100, namely, 2.6 W/m^2 ,

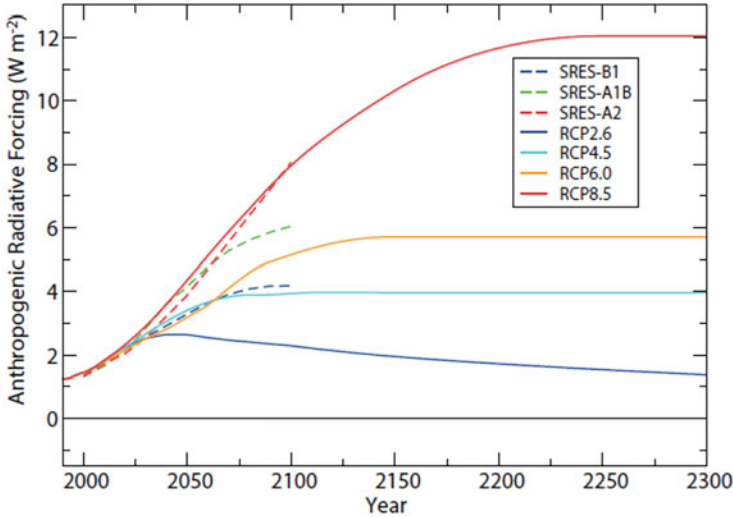


Fig. 1 Temporal evolution of anthropogenic radiative forcing between 2000 and 2300 for RCP scenarios (solid lines) and comparison with SRES scenarios used in AR4 (dashed lines). (From [14])

4.5 W/m², 6 W/m², and 8.5 W/m². Figure 1 shows the scenarios as well as the “SRES” scenarios previously used in the fourth Assessment Report (AR4) of 2007.

The most optimistic scenario, RCP2.6 (very low emissions ≈ 490 ppm CO₂ equiv), increases to 3 W/m² and then decreases to 2.6 W/m² by 2100. Scenarios RCP4.5 (low emissions ≈ 650 ppm CO₂ equiv.) and RCP6.0 (moderate emissions ≈ 850 ppm CO₂ equiv.) reach stable forcing values at 4.2 W/m² and 6.0 W/m², respectively, after 2100, while scenario RCP8.5 (very high emissions $\approx 1,370$ ppm CO₂ equiv.) reaches 8.3 W/m² in 2100 along an ascending trajectory. These scenarios are not associated with any specific socioeconomic scenario, unlike the former SRES scenarios. Rather, they are projections that could arise from more than one underlying socioeconomic scenario to produce similar GHG emission and radiative forcing values.

4 Methodology

Once the observation datasets have been regridded into the same resolution of RCA4 simulation outputs ($0.44^\circ \times 0.44^\circ$) using the first conservative remapping function of climate data operators (CDO) [15], we proceeded to the spatiotemporal variability analysis of precipitations and temperatures according to the two following stages:

- In the first stage, we produce mean climate maps, compute the mean surface area of each climate zone, and estimate linear trends over the historical period

(1951–2005) based on a precipitation and temperature dataset obtained from observation and simulation models.

- As a second step, we calculate the mean surface area of each climate zone and linear trends for the two future time periods (2006–2060 and 2045–2100) based on modeled monthly precipitation and temperature under the two RCP scenarios. Here, it must be recalled that the RCA4 simulations outputs in the future have been corrected using the quantile mapping (QM) bias correction algorithm [16, 17].

5 Results

5.1 *Spatiotemporal Variability of Precipitation and Temperature in Algeria over the 1951–2005 Observation Period*

As far as spatial variability is concerned, the mean interannual and monthly precipitation values derived from Climatic Research Unit (CRU TS3.24) data are presented in Figs. 2 and 3, respectively, and the spatial distribution of interannual mean and monthly mean temperatures are presented in Figs. 4 and 5, respectively.

We notice that the precipitation (Fig. 2) is characterized by a large spatial variation. The values of annual precipitation decrease when we move from North to South. The annual average precipitation is about 50 mm per year in the South, while it reaches 1,200 mm per year in the northeast of the country precisely at the stations of Jijel and El Kala. The annual average in coastal regions varies between 400 and 1,000 mm by increasing from the west to the east. The Eastern regions are thus better watered by rainfalls than western regions.

The examination of the monthly mean precipitation in Algeria over the study period (Fig. 3) allows us to divide the year into two marked seasons: the dry season, which extends from June till September, and the rainy season, which includes the eight remaining months of the year. Results show that the country seems that has a large rain distribution. Despite the rainy season begins in September, it is still disturbed by some periods of sirocco. The rainfall is well established in November, to increase until December, where the maximum is most frequently registered. Then, the monthly rainfall quantity decreases until June 1st, and the rain becomes rare or is reduced to some drops in some areas.

Figure 4 shows the annual temperature distribution over Algeria. We notice that the annual average temperatures of the country are divided according to three large geographical areas, from north to south as follows:

- The annual average temperature varies between 10 and 20°C, between the coast and the Tellian Atlas.
- Between the Tellian Atlas and Saharan Atlas, the annual average temperature varies between 20 and 22.5°C.

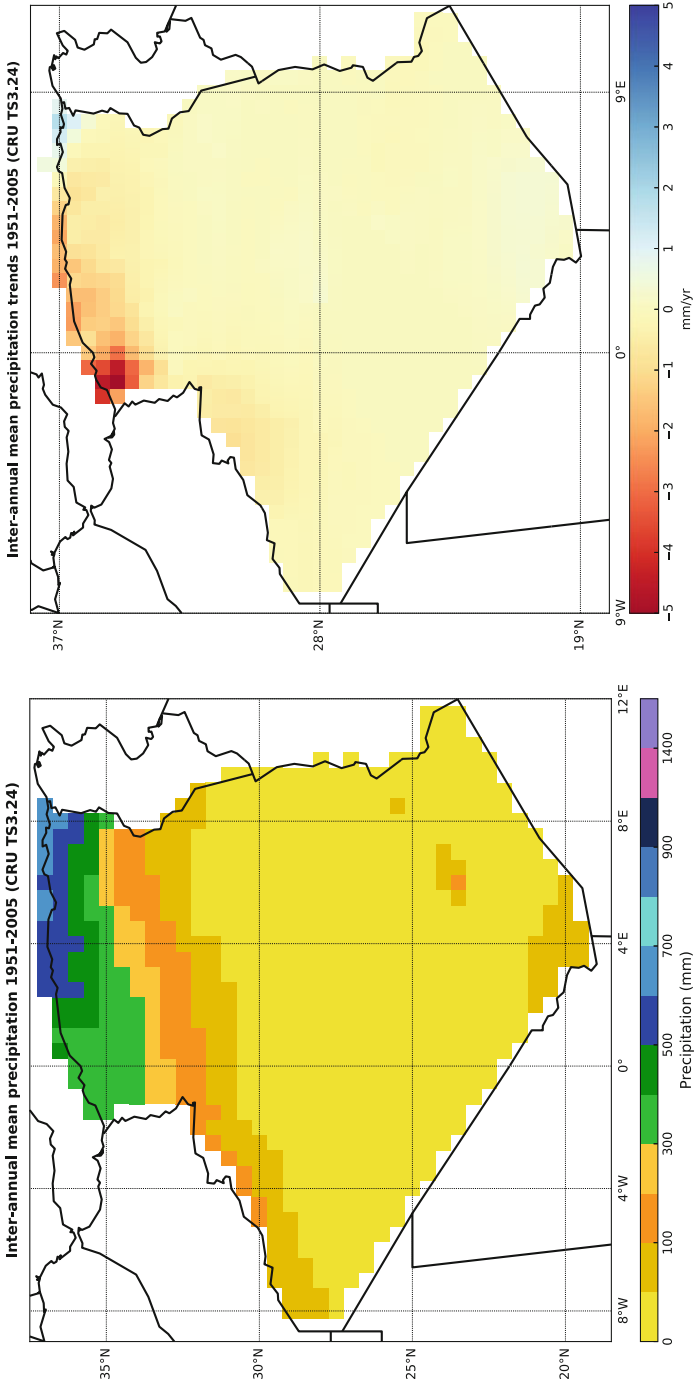


Fig. 2 Interannual mean precipitation in Algeria and related trends (1951–2005) (CRU TS3.24 at $0.5^\circ \times 0.5^\circ$)

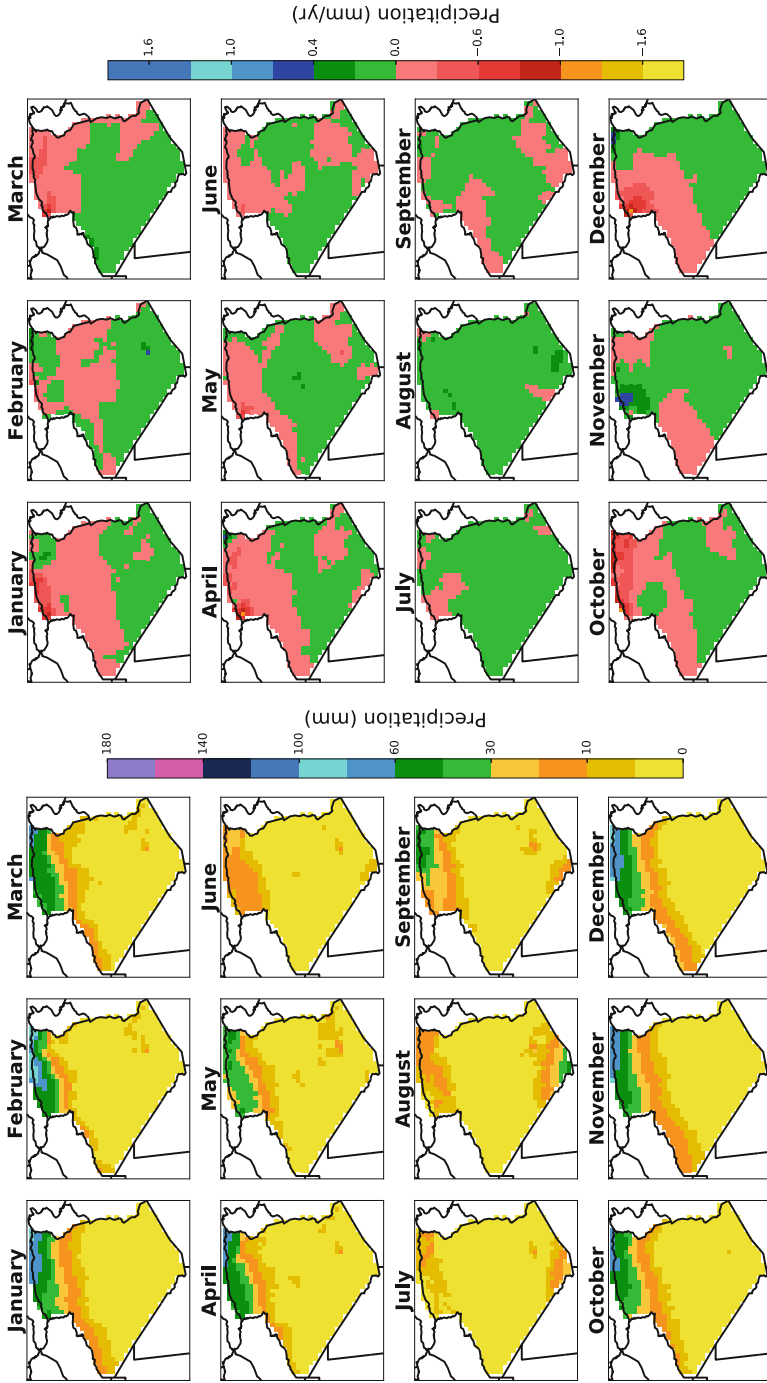


Fig. 3 Monthly mean precipitations in Algeria and related trends (1951–2005) (CRU TS3.24 at $0.5^\circ \times 0.5^\circ$)

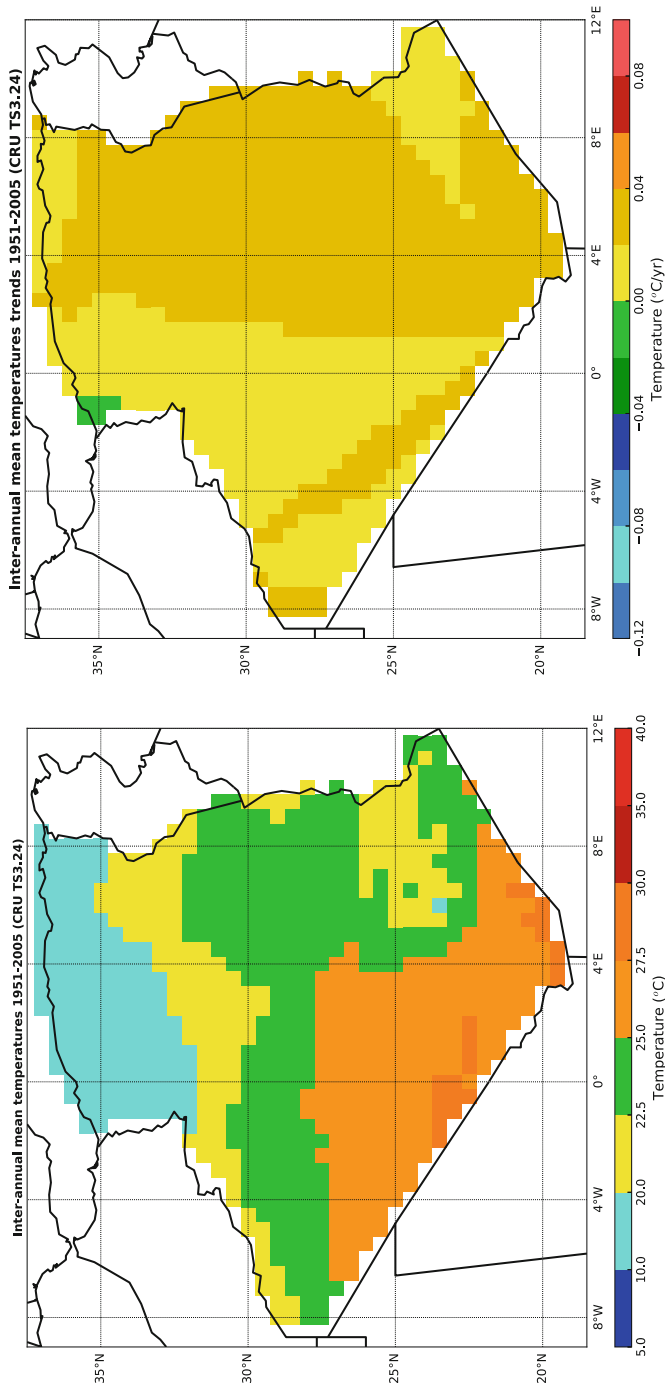


Fig. 4 Interannual mean temperatures in Algeria and related trends (1951–2005) (CRU TS3.24 at $0.5^\circ \times 0.5^\circ$)

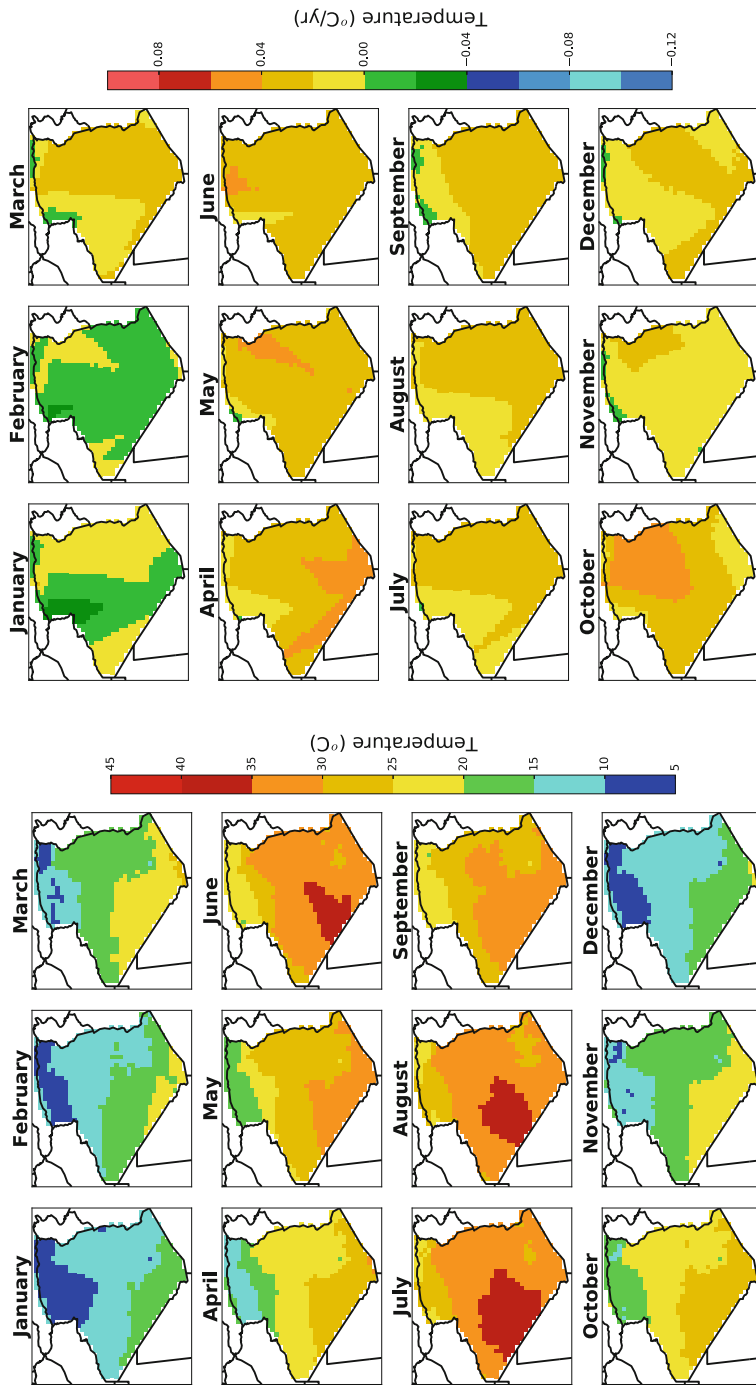


Fig. 5 Monthly mean temperatures in Algeria and related trends (1951-2005) (CRU TS3.24 at $0.5^\circ \times 0.5^\circ$)

- The annual average temperature in the Algerian Sahara varies between 22.5 and 30°C.

The monthly average temperatures in Algeria (Fig. 5), and concerning the winter temperatures, they vary between 5 and 10°C in the Western coastal cities and between 10 and 15°C in the eastern side, on plains and in the internal valleys. During the summer period, the coastal zone is refreshed by the marine winds; the average temperature varies between 25 and 35°C approximately.

However, the temperatures are particularly raised in the internal valleys and plains because of the enclosing and because of the exhibition to the Southern winds; they vary between 25 and 30°C in May, between 30 and 35°C in June, and between 30 and 40°C in the months of July and August. For the Southern part of the country, in desert, the temperature is ranged between 15 and 25°C in winter and reaches 35–40°C or even more in summer.

For temporal variability, results of the linear regression method applied to the interannual and monthly variability of precipitations and temperatures over the period from 1951 to 2005 are presented in the right sides of Figs. 2, 3, 4, and 5, respectively. The rates of increase and decrease were estimated from the slope of the linear regression line and are expressed as mm/year for precipitation and °C/year for temperature. Figure 2 (right side) shows the trend of interannual precipitation in Algeria during the period from 1951 to 2005.

This map shows that precipitations have decreased throughout the northern part of the country over this period. No change in precipitation trend is seen in the southern part of the country. The rate where annual rainfall decreases becomes smaller moving away from the coast and going from the West to the East. The rate of decrease of annual mean precipitation ranges from -1.5 mm/year in the Northwest to -0.5 mm/year in the northeastern part of the country. Between the coast and the Tell Atlas, the rate of decrease is roughly -1 mm/year.

From the maps of monthly precipitation trends (Fig. 3, on the right side), it is possible to subdivide the rate of decrease in the northern part of the country into two distinct segments: a -0.3 mm/year decrease in monthly precipitation from January to June and from October to December and a $+0.2$ mm/year increase during the other 3 months (July, August, and September). In the southern part of the country, a 0.2 mm/year increase is observed for nearly all months.

Figure 4 (right side) shows the trend in annual temperatures in Algeria over the period from 1951 to 2005. On this map, an increase in temperature is seen over the whole country, from $+0.02$ °C/year in the West to $+0.04$ °C/year in the eastern part of the country. The maps of monthly mean temperature trends in Algeria over the period from 1951 to 2005 (Fig. 5, right side) show an increase ranging from $+0.02$ °C/year to $+0.04$ °C/year for the whole of the country except for the months of January and February and a -0.02 °C/year decrease over nearly all of the country for these 2 months.

5.2 *Spatial Variability of Climate Zone Surface Areas in Algeria Over the 1951–2005 Observation Period*

The calculation detail overview and definition of all Köppen-Geiger classes applied here was briefly described in [18] or [19]. The Köppen climate zones are designated using a code of three letters. The first letter describes the main classes, in upper case, and indicates the vegetation group in the climate zone defined based on temperature and precipitation. The second letter, in lower case, accounts the distribution of precipitation at the annual scale. The third letter for temperature classes, also in lower case, reflects seasonal temperature variations. According to Zeroual et al. [20], the ten climate zones presented in the Table 2 have been observed in Algeria over the period 1951–2005. In this chapter, we are interested only in the surface areas of the main climatic zones, namely, warm temperate climates (C), steppe climate (BS), and desert climate (BW). Based on the Köppen-Geiger classification and the precipitation and temperature dataset taken from observations averaged over 1951–2005 period, we constructed a map of climate zones for this period and computed the surface extent of different climate zones. The surface area of each climate zone from 1951 to 2005 is presented in Table 3. Table 3 show that the desert climate (BW) extend over roughly 88.14% of the total surface area of the country, followed by the steppe climate (BS) zone, covering about 7.04%. The warm temperate climates (C) account for only about 4.83% of this area.

Table 2 Köppen -Geiger climate type observed in Algeria over the period 1951–2005

Type	Climate class	Third letter for temperature classification
<i>B</i>	Arid climates	
	<i>BS</i> : Steppe climate	<i>h</i> : Hot steppe/desert
	<i>BW</i> : Desert climate	<i>k</i> : Cold steppe/desert
<i>C</i>	Warm temperate climates	
	<i>Cs</i> : Warm temperate climate with dry summer	<i>a</i> : Hot summer
	<i>Cw</i> : Warm temperate climate with dry winter	<i>b</i> : Warm summer
	<i>Cf</i> : Warm temperate climate, fully humid	

Table 3 Surface area of each of the three main climatic zones observed over the period 1951–2005 (in % of total area)

Data	Climate zone in % of total area (1951–2005)		
	C	Bs	Bw
Climatic Research Unit (CRU)	4.83	7.04	88.14

5.3 Comparison of the Evolution of Observed and Simulated Precipitation and Temperatures During the Period from 1951 to 2005

Before examining the future evolution of precipitation and temperature, a comparison of climate (precipitation and temperature) observational data (CRU) from 1951 to 2005 and data from simulations from the nine climate models simulation of RCA4 (see Table 1) was carried out to test how well these models simulations reproduce observed climate and its evolution. Here, we should note that for this comparison, the monthly modeled precipitation and temperature were not bias corrected.

After building the maps of interannual precipitation and temperatures and monthly precipitation and temperatures and their trends over the 1951–2005 period derived using the nine climate models simulations, we notice that the climate model simulation RCA4-MIROC5 reproduces satisfactorily monthly mean precipitation as well as interannual and monthly mean temperatures, whereas climate model RCA4-NorESM1-M reproduces interannual mean precipitation.

As far as the temporal variability of annual and monthly precipitation and temperatures derived from climate models for the 1951–2005 period is concerned, the maps show that the rates of increase and decrease of monthly precipitation and monthly temperatures derived from climate model RCA4-NorESM1-M are in good agreement with observational data. However, observed annual precipitation trends are reproduced by the model RCA4-IPSL-CM5A and annual temperature trends are reproduced by the climate model RCA4-MPI-ESM-LR.

5.4 Spatial and Temporal Projected Variability of Precipitation and Temperature over the 2006–2060 and 2045–2100 Periods

Only results from the aforementioned models simulations, after bias correction for the two scenarios, are presented for each parameter (precipitation and temperature) and scale (annual and monthly).

As far as spatial variability is concerned, the distributions of interannual mean precipitation and temperature over the two projection periods (2006–2060 and 2045–2100) derived for the two scenarios are presented in Figs. 6 and 7.

Maps derived from the selected models show a decrease in interannual mean precipitation and an increase in interannual mean temperatures. Thus, for the two periods (2006–2060 and 2045–2100) and with both scenarios RCP4.5 and RCP8.5, the RCA4-NorESM1-M model predicts that mean precipitation will level off compared to the 1951–2005 time interval in the eastern and southern parts of the country and that they will decrease in the West. This decrease is greater for scenario RCP8.5

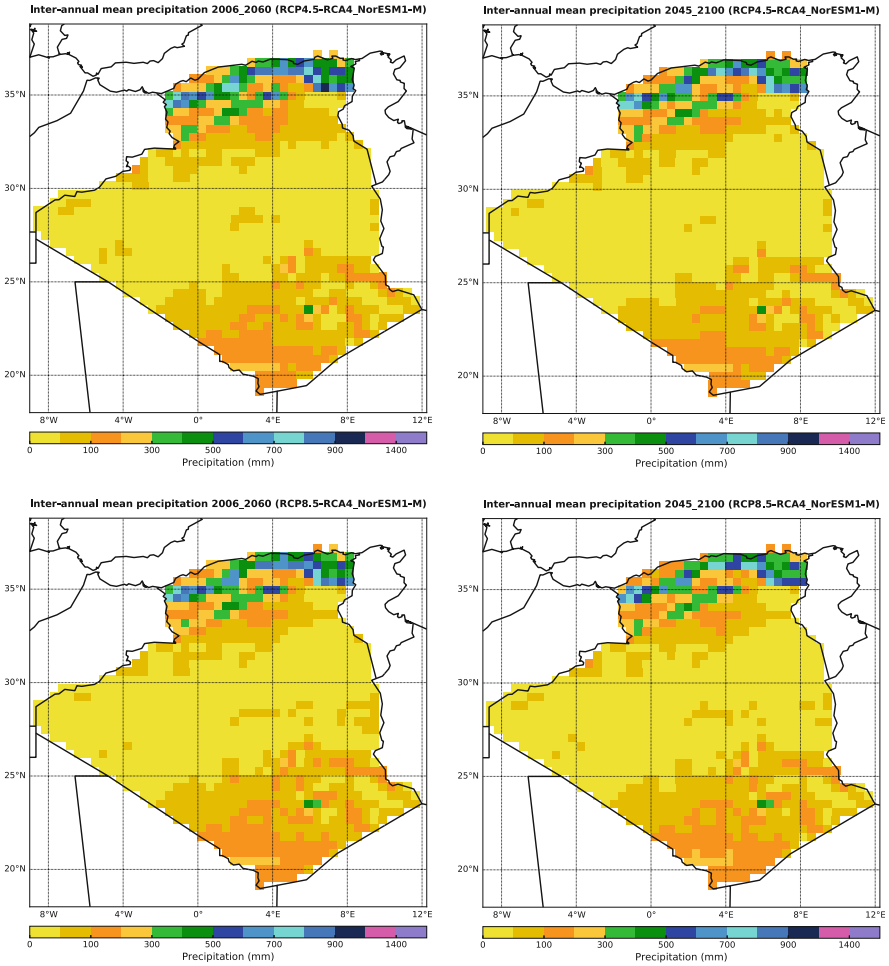


Fig. 6 Interannual mean precipitation in Algeria over the 2006–2060 and 2045–2100 time periods for the scenarios RCP4.5 and RCP8.5 (RCA4-NorESM1-M at a resolution of $0.44^\circ \times 0.44^\circ$)

compared to the scenario RCP4.5, as well as for the 2045–2100 projection period compared to the 2006–2060 period.

The increase in interannual mean temperatures for the two projection periods with the two scenarios (see Fig. 7) predicted using model RCA4-MIROC5 simulation is obvious in the coastal region of the country especially during the second time interval (2045–2100) under RCP8.5 scenario.

The monthly mean precipitation maps of Algeria generated using model RCA4-MIROC5 simulation for the 2006–2060 and 2045–2100 time intervals with the RCP4.5 and RCP8.5 scenarios (Fig. 8) show a slight decrease compared to the 1951–2005 reference time period in the western coastal region for all months. This

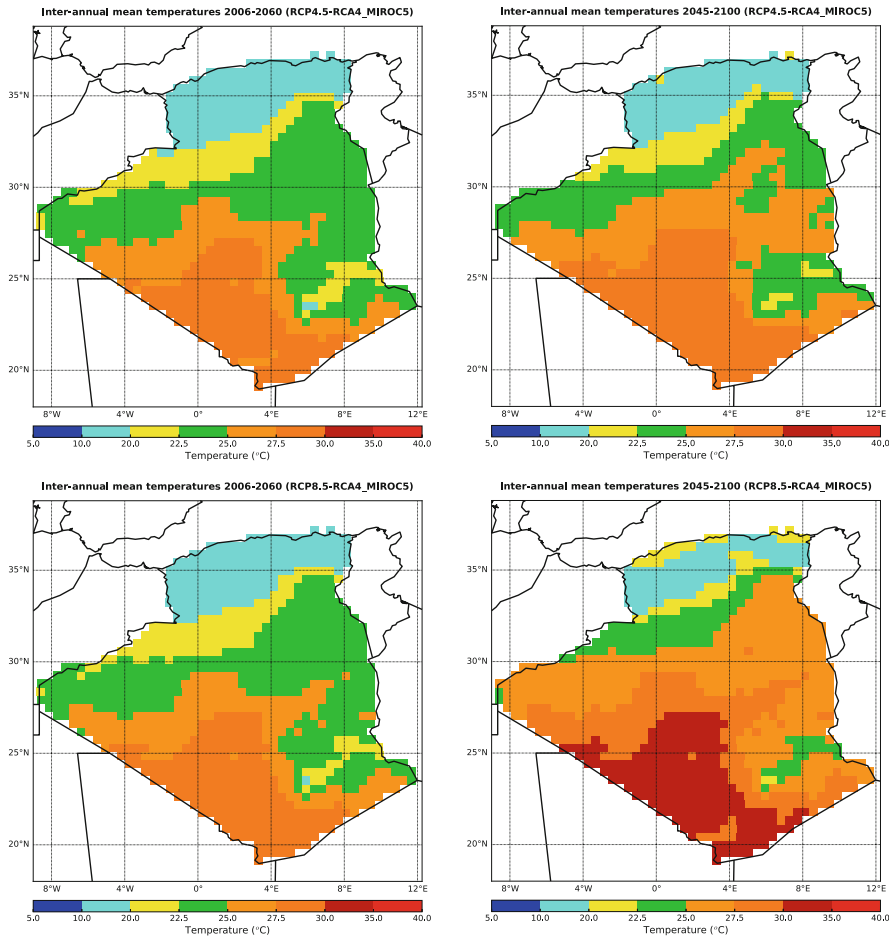


Fig. 7 Interannual temperatures in Algeria over the 2006–2060 and 2045–2100 time periods for the scenarios RCP4.5 and RCP8.5 (RCA4-MIROC5) at a resolution of $0.44^\circ \times 0.44^\circ$

decrease is marked for the months of November, December, and January during the second projection period (2045–2100) under RCP8.5 scenario.

The monthly mean temperature maps derived from model RCA4-MIROC5 simulation (Fig. 9) show an increase in temperature for all months. This increase is more marked for the second projection period (2045–2100) with the two scenarios RCP4.5 and RCP8.5 than for the first period (2006–2060).

As far as temporal variability over the two projection periods (2006–2060 and 2045–2100) is concerned, for both scenarios, the selected climate models predict a decrease in precipitation and an increase in temperature at the annual and monthly scales. The rates of decrease and increase are as follows:

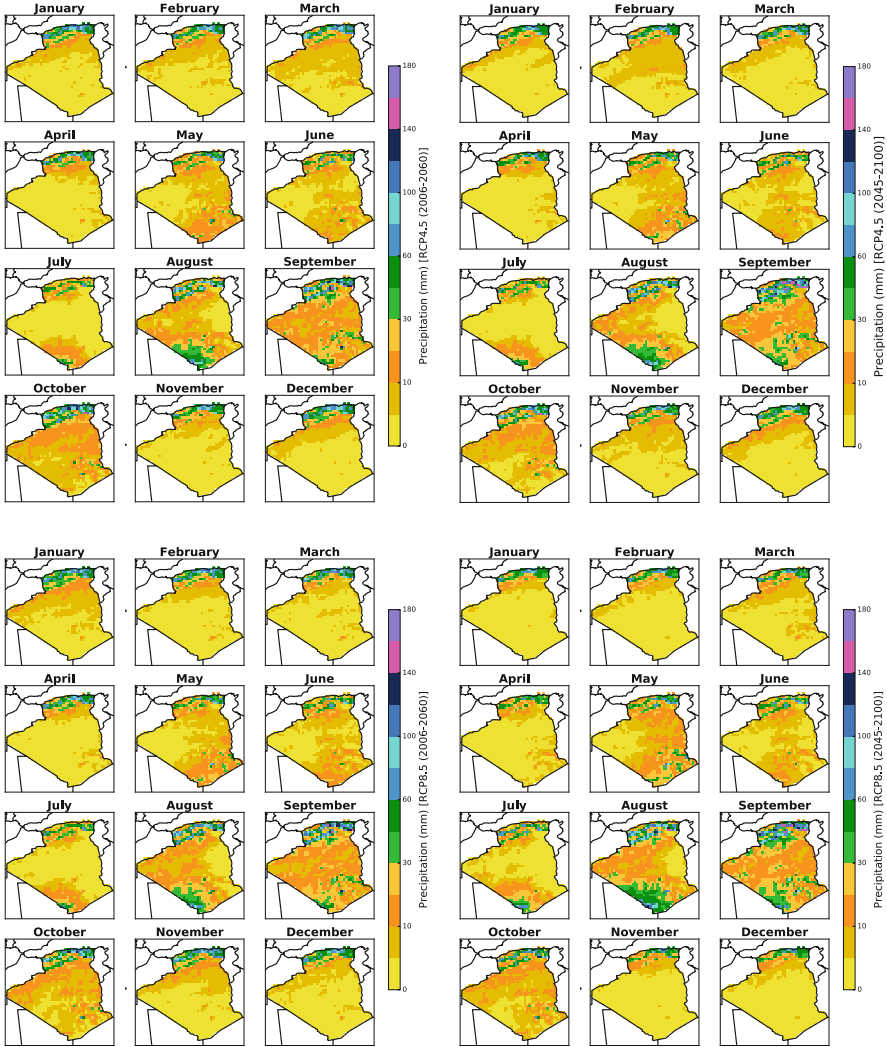


Fig. 8 Monthly precipitation in Algeria over the 2006–2060 and 2045–2100 time periods for the scenarios RCP4.5 and RCP8.5 (RCA4-MIROC5) at a resolution of $0.44^\circ \times 0.44^\circ$

1. According to climate model RCA4-IPSL-CM5A simulation, annual mean precipitation will decrease in the northern part of the country (Fig. 10) over the 2006–2060 time period at a rate of -0.5 to -1.5 mm/year with RCP4.5 scenario and of -1.5 to 2.5 mm/year with RCP8.5 scenario. During the second time period (2045–2100), the rate of decrease is nearly zero for scenario RCP4.5 and varies from 0.5 to -1.5 mm/year for scenario RCP8.5. No significant change in precipitation is seen for southern Algeria.

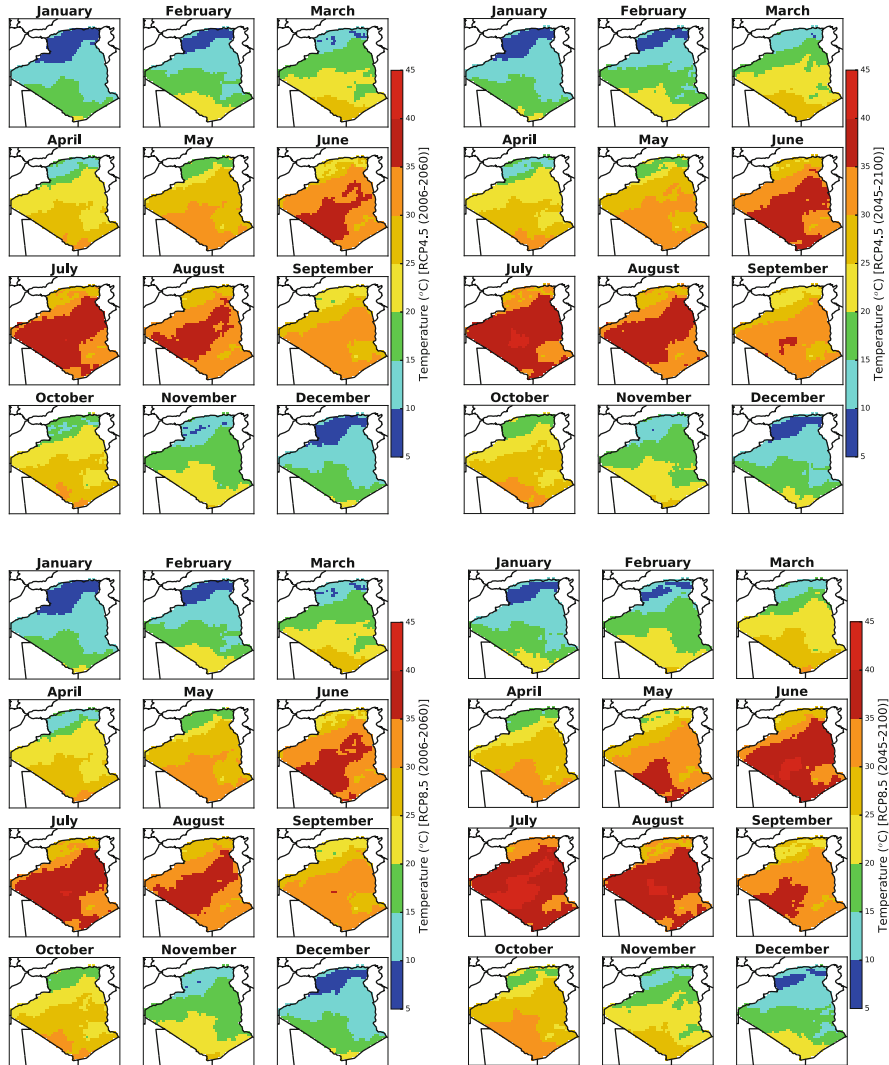


Fig. 9 Monthly temperatures in Algeria over the 2006–2060 and 2045–2100 time periods for the scenarios RCP4.5 and RCP8.5 (RCA4-MIROC5) at a resolution of $0.44^\circ \times 0.44^\circ$

2. According to climate model RCA4-MPI-ESM-LR simulation, mean annual temperatures will increase (Fig. 10) over the 2006–2060 time period at a rate of $+0.02^\circ\text{C}/\text{year}$ to $+0.04^\circ\text{C}/\text{year}$ in the North and of $+0.04^\circ\text{C}/\text{year}$ to $+0.06^\circ\text{C}/\text{year}$ in the South for the two scenarios. During the second time period (2045–2100), the rate of increase is $+0.02^\circ\text{C}/\text{year}$ over the whole country for the RCP4.5 scenario. For the RCP8.5 scenario, this rate ranges from $+0.04^\circ\text{C}/\text{year}$ to $+0.06^\circ\text{C}/\text{year}$ in the North and from $+0.06^\circ\text{C}/\text{year}$ to $+0.08^\circ\text{C}/\text{year}$ in the South.

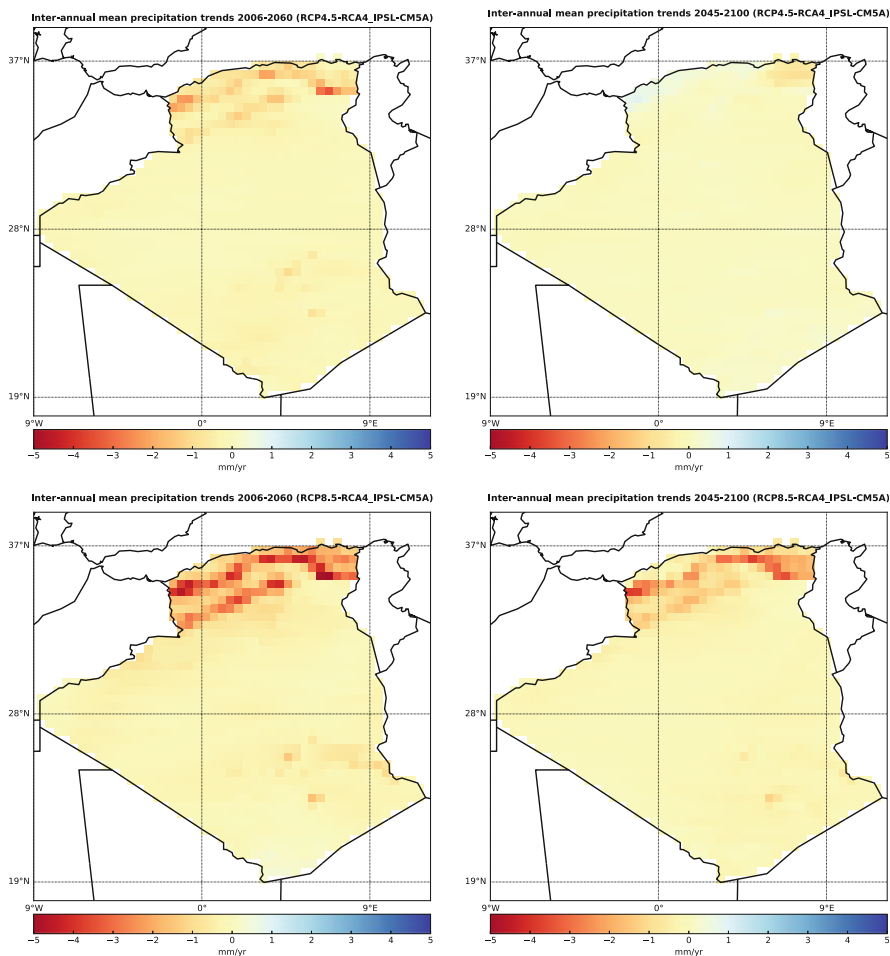


Fig. 10 Slopes of regression lines fitted to the temporal variability of annual precipitation over the 2006–2060 and 2045–2100 time periods for the scenarios RCP4.5 and RCP8.5 (RCA4-IPSL-CM5A) at a resolution of $0.44^\circ \times 0.44^\circ$

3. According to climate model RCA4-NorESM1-M simulation, monthly precipitation will decrease (Fig. 11) during the two periods with both scenarios. The rate of decrease is not synchronous for the different months, between regions, or between periods. This rate ranges from -0.3 mm/year to -0.8 mm/year, and it is higher for scenario RCP8.5 than for RCP4.5 for the six winter months (October to March).
4. According to climate model RCA4-MPI-ESM-LR simulation, annual mean temperatures will increase (Fig. 12) over the 2006–2060 time period at a rate of $+0.02^\circ\text{C}/\text{year}$ to $+0.04^\circ\text{C}/\text{year}$ in the North and of $+0.04^\circ\text{C}/\text{year}$ to $+0.06^\circ\text{C}/\text{year}$ in the South for the two scenarios. During the second time period (2045–2100),

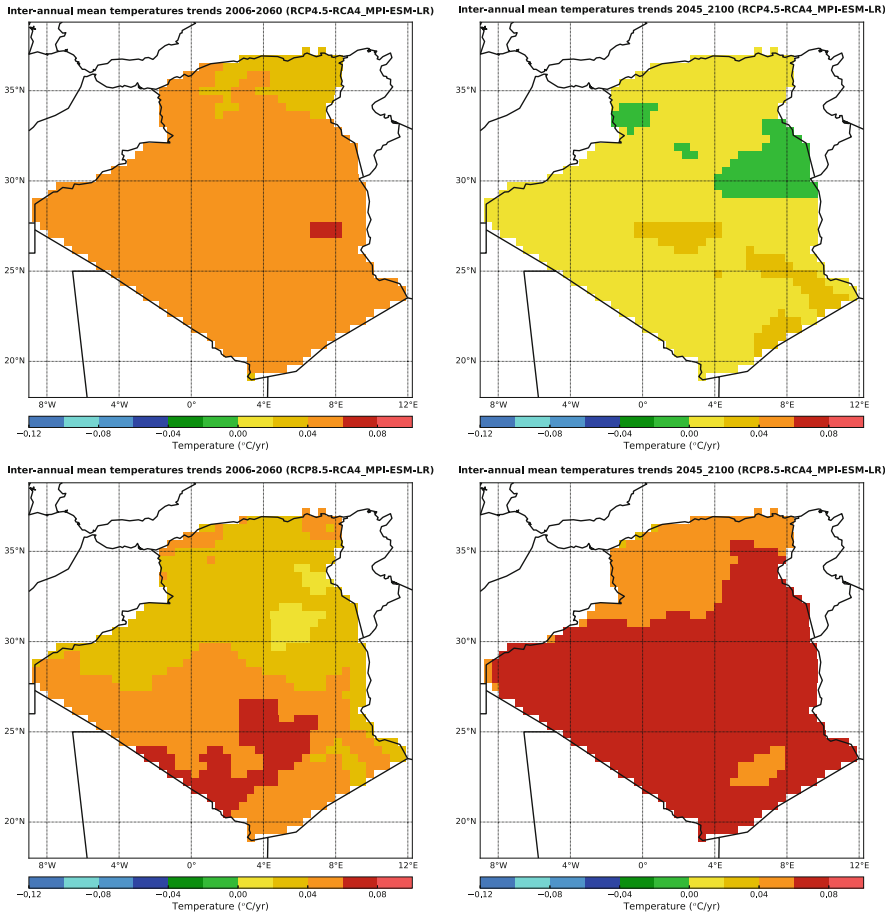


Fig. 11 Slopes of regression lines fitted to the temporal variability of annual temperatures over the 2006–2060 and 2045–2100 time periods for the scenarios RCP4.5 and RCP8.5 (RCA4-MPI-ESM-LR) at a resolution of $0.44^\circ \times 0.44^\circ$

the rate of temperature increase is $+0.02^\circ\text{C}/\text{year}$ over the whole country with scenario RCP4.5. For the RCP8.5 scenario, this rate is $+0.06^\circ\text{C}/\text{year}$ to $+0.08^\circ\text{C}/\text{year}$ in the North and $+0.06^\circ\text{C}/\text{year}$ to $+0.08^\circ\text{C}/\text{year}$ in the South.

5. According to climate model RCA4-NorESM1-M simulation, monthly mean temperatures will increase (Fig. 13) over the 2006–2060 time period at a rate of $+0.04^\circ\text{C}/\text{year}$ to $+0.06^\circ\text{C}/\text{year}$ for the months of February and May and of $+0.02^\circ\text{C}/\text{year}$ to $+0.04^\circ\text{C}/\text{year}$ for the other months for RCP4.5 scenario. For RCP8.5 scenario, over the 2006–2060 time period, the rate of increase will reach $+0.08^\circ\text{C}/\text{year}$ for the months of August and September in the northern part of the country and for the months of May and June in the South. For the other months, the rate of increase will range from $+0.02^\circ\text{C}/\text{year}$ to $+0.06^\circ\text{C}/\text{year}$. During the

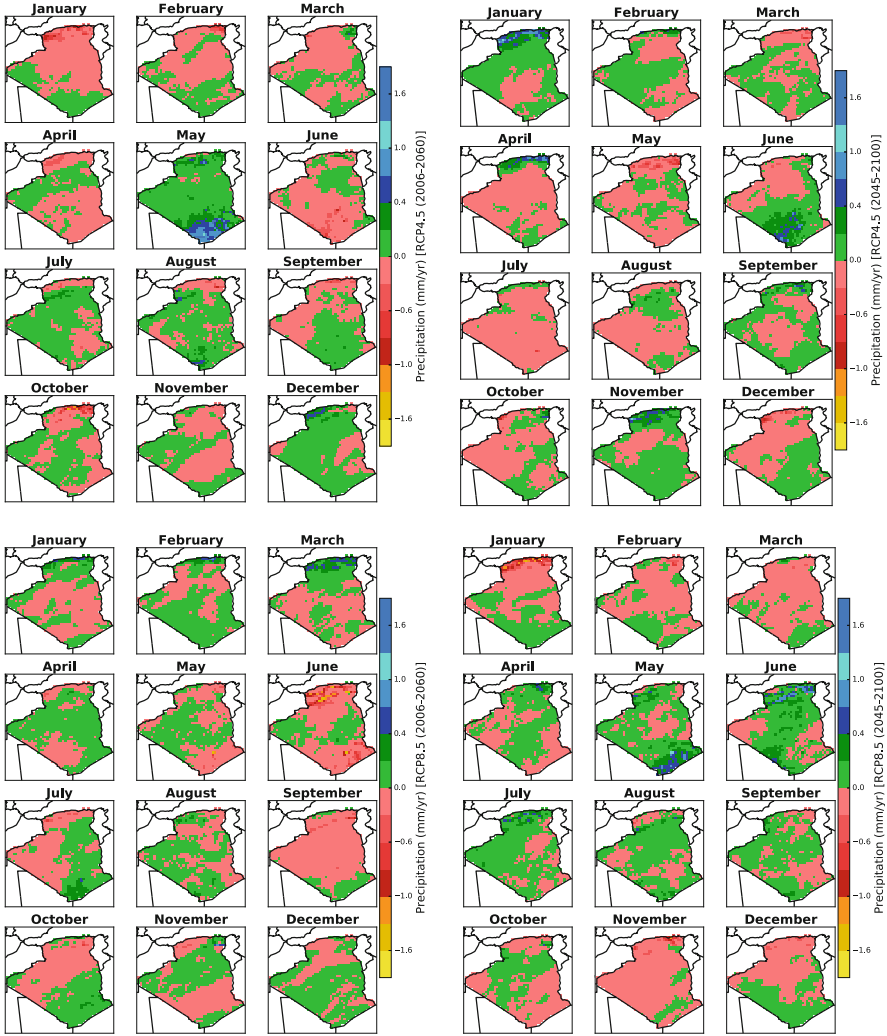


Fig. 12 Slopes of regression lines fitted to the temporal variability of monthly precipitation over the 2006–2060 and 2045–2100 time periods for the scenarios RCP4.5 and RCP8.5 (RCA4-NorESM1-M) at a resolution of $0.44^\circ \times 0.44^\circ$

second time period (2045–2100), the rate of increase will not exceed $+0.04^\circ\text{C}/\text{year}$ for RCP4.5 scenario for all months except for February and April, where a temperature decrease on the order of $-0.04^\circ\text{C}/\text{year}$ is predicted. For RCP8.5 scenario and during the second time period, the rate of increase ranges from $+0.02^\circ\text{C}/\text{year}$ to $+0.04^\circ\text{C}/\text{year}$ for the six winter months (October to March) and from $+0.04^\circ\text{C}/\text{year}$ to $+0.1^\circ\text{C}/\text{year}$ for the six summer months (April to September).

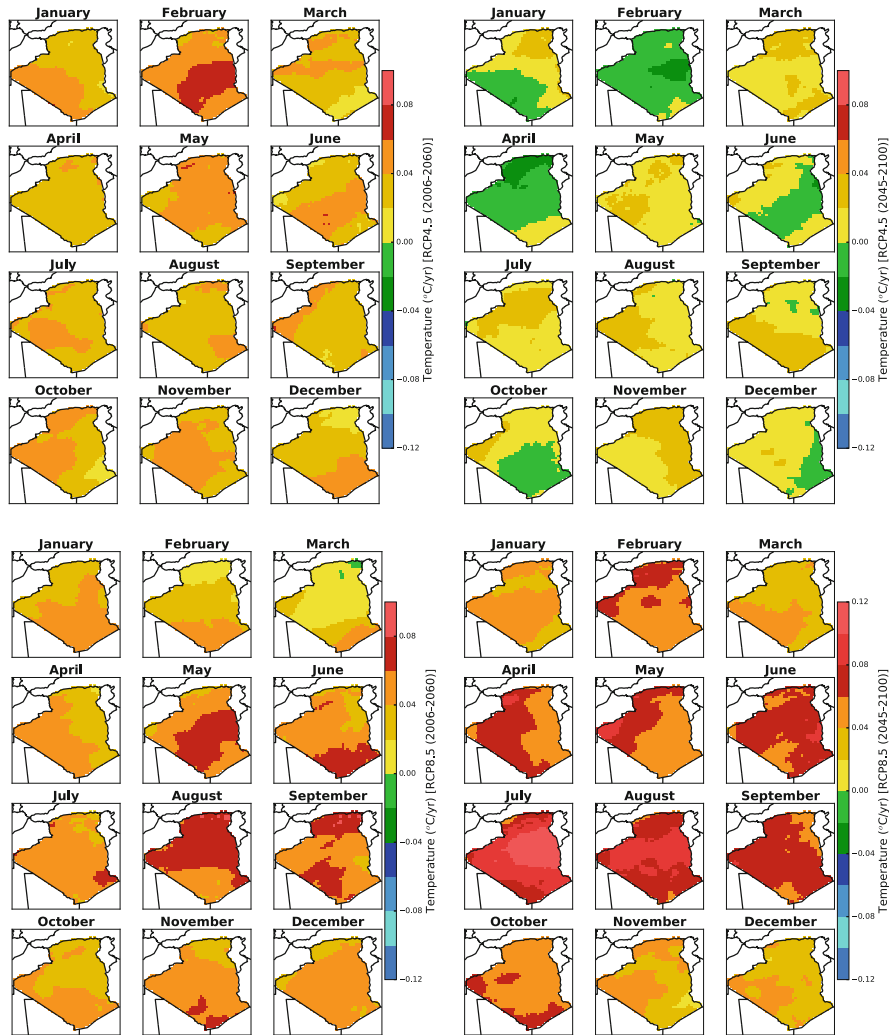


Fig. 13 Slopes of regression lines fitted to the temporal variability of monthly temperatures over the 2006–2060 and 2045–2100 time periods for the scenarios RCP4.5 and RCP8.5 (RCA4-NorESM1-M) at a resolution of $0.44^\circ \times 0.44^\circ$

5.5 Climate Zone Surface Areas and Their Projected Shifts for the 2006–2060 and 2045–2100 Periods

Once the modeled monthly precipitation and temperature of all models simulations were corrected using the quantile mapping (QM) bias correction algorithm and their averaged over 2006–2060 and 2045–2098 periods, we proceeded to the construction of climate zone map for each model simulation according to the Koppen-Geiger classification and computing the surface extent of each climate zones.

Results of shifts obtained from all models simulations (in % of total land area) between the three main climatic zones surface area of the periods 1951–2005 vs. 2006–2060 and 1951–2005 vs. 2045–2100 for the two scenarios are presented in Table 4. Projected shifts (in % of total land area) for all models simulations are similar for the desert climate (BW) and the warm temperate climate (C) zone, while we notice a considerable increase in surface area for the BW climate

Table 4 Shifts (in % of total land area) between the three main climatic zones surface area of the periods 1951–2005 vs. 2006–2060 and 1951–2005 vs. 2045–2100 for RCP 45 and RCP 85 scenarios

	2006–2060					
	RCP 45			RCP 85		
	C	BS	BW	C	BS	BW
CanESM (Canada)	−0.83	−0.52	1.33	−1.53	−0.08	1.6
CNRM-CM5 (France)	−2.46	−0.26	2.71	−1.12	0.07	1.04
CSIRO-MK3 (Australia)	−2.32	0.43	1.88	−2.01	0.44	1.54
IPSL-CM5A (France)	−2.99	−0.32	3.29	−2.71	−0.5	3.18
MIROC5 (Japan)	−1.66	0.42	1.23	−1.22	−0.34	1.54
HadGEM2-ES (UK)	−2.45	−0.09	2.52	−2.53	0.29	2.24
MPI-ESM-LR (Germany)	−2.44	−0.51	2.94	−2.19	0.21	1.97
NorESM1-M (Norway)	−2.04	0.24	1.79	−3.03	0.45	2.58
GFDL-ESM2M (USA)	−1.76	−0.23	1.98	−2.79	0.18	2.6
Mean	−2.106	−0.093	2.186	−2.126	0.080	2.032
	2045–2100					
	RCP 45			RCP 85		
	C	BS	BW	C	BS	BW
CanESM (Canada)	−2.29	−0.12	2.41	−3	0.15	2.84
CNRM-CM5 (France)	−2.57	−0.33	2.9	−2.84	0.13	2.69
CSIRO-MK3 (Australia)	−3.19	0.63	2.55	−3.59	0.55	3.03
IPSL-CM5A (France)	−3.71	−0.53	4.23	−4.45	−3.27	7.71
MIROC5 (Japan)	−2.32	0.78	1.53	−3.18	0.24	2.93
HadGEM2-ES (UK)	−3.15	0.49	2.65	−3.9	−0.35	4.24
MPI-ESM-LR (Germany)	−3.42	−1.35	4.75	−3.94	−0.6	4.54
NorESM1-M (Norway)	−3.26	0.19	3.06	−3.9	0.21	3.69
GFDL-ESM2M (USA)	−2.45	−0.26	2.7	−3.55	−0.76	4.29
Mean	−2.929	−0.056	2.976	−3.594	−0.411	3.996

Note that 1% corresponds to an area of 23,820 km²

zone and also a decrease in surface area of (C) zone. For steppe climate zone (BS), the projected shift was not found synchronous from one model simulation to another and from one scenario to another.

For (BW) and (C) climate zones, the shift of expansion and contraction between the main Koppen-Geiger climate class areas simulated by all models over the first projected period 2006–2060 is similar for both scenarios. However, the RCP8.5 scenario shows the largest shifts for the second projected period 2045–2100. In the observational period 1951–2006, a total of 88.14 % of the total land area of Algeria is covered by climates of type BW, followed by 7.04% BS climates and 4.83% C climates, respectively. Assuming an RCP8.5 scenario for the second projected period 2045–2100 (Table 4), the nine model projections result in increased ranges from +2.7% to +7.7% of BW climates zones area, as well as a decreased ranges from –4.45% to –2.84% of C climate zone area. The mean area of the nine RCM-RCA4 projections during the second period results in a small-decreased ranges from –0.05% for RCP4.5 to –0.4% for RCP8.5. Therefore, the desert zone expansion has been established at the expense of warm temperate zones.

6 Discussion and Conclusion

The spatial variability and temporal evolution of precipitation and temperature over Algeria were analyzed over 1951–2100 using a set of observational data and nine RCM RCA4 simulations from the CORDEX-Africa program. The analyses are done at annual and monthly time scales that lead to the three main findings:

1. Over the historical period 1951–2005, the long-term trends of precipitation and temperature are characterized by an increase in annual mean temperature of about +0.02°C/year in the western part of the country and of +0.04°C/year in the eastern part and in the same time a 0.5–1.5 mm/year decrease in annual mean precipitation in the northern part of the country. A range of 1–1.25°C of warming has been reported in the fifth IPCC report [14] over Algeria during 1901–2010. Similar magnitude of warming was also reported by Giorgi [21] and New et al. [22] over Mediterranean Basin at different time intervals from the twentieth century. The same trends were noted in various regions of the Mediterranean Basin, for instance, Zeroual et al. [23] in northern Algeria, Philandras et al. [24] for the eastern Mediterranean, and Driouech [25] for Morocco. In Lebanon, mean temperatures have changed little before 1970 and then increased substantially over the last 30 years [26]. Several studies have highlighted a decrease in precipitation in the southern part of the Mediterranean Basin over the second half of the twentieth century [21, 27, 28]. The fifth IPCC report also noted a decrease in precipitation in northern Algeria of about 2.5–5 mm/year per decade from 1951 to 2005 [29]. Raymond et al. [30] found similar results for total precipitation from September to April in northern Algeria.

2. As far as the future evolution (2005–2100) of the temporal variability of annual and monthly precipitation and temperature in Algeria is concerned, the study shows that all models project an increase in temperature and a decrease in precipitation during the 1945–2100 period especially under RCP8.5 scenario.
3. The current decrease in precipitation and increase in temperature and the anticipated shrinking of the surface area of the temperate climate zone will lead to numerous problems related, among other things, to food security and displacement of local populations in Algeria. These considerations must be included in future socioeconomic development plans. The rate at which such changes will occur in the future in Algeria's three climate zones deserves special attention.

Acknowledgment The authors acknowledge the use of temperature and precipitation gridded data from both the Climatic Research Unit (CRU) and the RCA4 regional climate model of Rossby Centre (SMHI).

Conflict of Interest The authors declare that they have no conflict of interest.

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