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Observed and future changes in precipitations and air temperatures in the central region of Algeria

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Abstract

The IPCC reports indicate the Mediterranean basin and North Africa among the most vulnerable regions to future climate change. The latter phenomenon is up to now poorly studied in some of these areas; it is the case of Algeria, the largest country in the whole area. Using recorded climatic data and future projections, this study analyses the recent observed climate and characterizes the future changes in the central region of Algeria. Methodology is based on data analysis, calculation of anomalies and statistical trend tests. The past climate is represented by 56 years (1952-2007) of monthly observed temperatures and precipitations. Climate projections for the distant future (2071-2100) were obtained from the ARPEGE-Climate model of *Météo-France* run under the medium A1B SRES scenario. During the observed climatic period, there are no trends concerning the rainfall regime but positive trend in temperatures are detected and concerns only summer and autumn. Under future climatic conditions, monthly precipitation decrease and monthly temperatures increase throughout the year. Seasonal rainfall decrease by -16% in winter and by -28% in summer and increase in seasonal temperatures is by +1.7°C in winter and reached +3.8°C in summer.

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Introduction

Climatically, the Mediterranean region is characterized by moderate temperatures, precipitation dominance in winter and dry summers (Wigley, 1992). The northern part is relatively more temperate and humid, while the southern part, where the Maghreb countries, is warmer and drier (Rosenzweig and Tubiello, 1997). Past analyses (Kostopoulou and Jones, 2005) and GCM simulations for the next decades (Giannakopoulos *et al.* 2009) show that this region is experiencing increasing temperatures and large changes in the frequency of extreme climatic events for both temperature and rainfall (Ventrella *et al.* 2011). Changes in the recent climate are different from the North-West to the Northeast of Africa. Temperature has a general tendency to increase throughout the zone (Hertig and Jacobeit, 2008). Conversely, observed climate shows a decreasing trend of precipitation (Gerstengarbe and Werner 2007, Born *et al.*, 2008). Studies carried out in Algeria show that this decrease concerns the western regions in comparison with the East regions of the country (Hamlaoui-Moulai *et al.*, 2013; Meddi and Talia, 2008).

As mentioned in the fifth IPCC report (Niang *et al.* 2014), the annual and seasonal drying/warming signal over the northern African region is a consistent feature in the climate change projections for the 21st century under the A1B and A2 scenarios (Giorgi and Lionello 2008; Barkhordarian *et al.* 2013). According to the IPCC (2007), forecast using scenarios A2 and B2, the warming of the European continent during the periods 2020, 2050 and 2080 compared with the period 1961-1990 is 0.1 to 0.4°C per decade.

Studies show that warming towards the end of the 21st century during the summer in the southern regions of the continent will be twice as large as in the north of the continent (Rosenzweig and Tubiello 1997, Hulme & Carter 2000, Parry 2000; Alpert *et al.*, 2008). In North Africa, the REMO regional dynamic model predicts a temperature increase of about 2 to 3°C by 2050 with the medium A1B scenario (Paeth *et al.*, 2009). The application of different models (regional and global) by Patricola and Cook (2010) in northern Africa shows a very strange warming of around 6°C across the western area towards the end of the 21st century in comparison with the 20th century. Applied in Tunisia and Algeria, the ARPEGE model of Météo-France with scenario A1B predicts an average warming of 3.5°C and 3.2°C respectively in the two regions at the end of the 21st century (Lhomme *et al.*, 2009, Chourghal *et al*, 2015). For rainfall, projections according to IPCC scenario A1B (2007) indicates a decrease in average precipitation over the year in Europe the Mediterranean basin. This decline would be the most significant in summer, around 24% under scenario A1B, and more marked from 2050-2060 (Nefzi, 2012). In the North African zone, some projections using a set of simulations of GCM models (Giorgi and Lionello, 2008), and others based on regional treatments (Paeth *et al.*, 2009), show a decline in winter precipitation, and much drier summers (Viner *et al.*, 2006).

Researches on climate evolution conducted in Algeria are very rare. In the present study we aims to acknowledge the observed climate trend and to complete and improve the available information on its future changes in the region. This is accomplished through a more and detailed analysis of monthly and seasonal rainfall and thermal regime from the past to the future using a reasonably complete dataset and by the mean of appropriate statistical methods for the study of climatic trend which allow more accurate and most complete information.

Materials and methods

Study site and observed climate

Algiers (lat. 36.77°N, long. 3.22°E, alt. 24m) is a coastal region located in the central part of the North, occupying vast lands on Metidja plain known for its deep and fertile soils and its huge agricultural potential (Seltzer 1949). The annual rainfall in the Algiers region is around 600mm. Its climate is strongly influenced by its proximity to the Mediterranean Sea. It is mild, wetter and the risk of frosts is lower in comparison with the interior regions of the country (Fig. 1). Observed climate is represented by fifty six years (1952 to 2007), of monthly average precipitations and temperatures collected from the "*Office Nationale de la Météorologie (ONM)*", located in Algiers.

Fig. 1. Location of the study area.

Simulated data and future climate

Climate simulation is accomplished by the ARPEGE-Climate model of Météo-France Version 4, (Déqué 2007) with a 50km resolution. The ARPEGE-Climate coupled model was selected for its ability to reproduce in an acceptable manner the main characteristics of the Mediterranean climate (Déqué *et al.*, 1994).

The model generates a first 56-year series representing the present climate, covering the period 1952-2007 for the region and a second set of data representing the possible future climate in the region from1971 to 2100 according to the SRES A1B scenario (IPCC, 2001), which represents a median characterization of atmospheric CO_2 concentration evolution and economic growth. The correction of simulated variables is made by the variable correction method, also known as Quantile-Quantile bias or QQ correction. Basically, the method consists in plotting a model value against an observed one, both corresponding to the same probability (Déqué 2007). More details on the QQ correction method are provided by Déqué (2007).

Trends in the recent past climate

Linear trends using the Sen's estimate (Sen, 1968) and Mann–Kendal test (Mann, 1945) are calculated for the seasonal average temperatures and precipitations derived from the whole period (1952-2007).

The Mann-Kendall test

The Mann-Kendall test is applicable in cases when the data values *xi* of a time series can be assumed to obey the model:

$$x_i = f(t) + \varepsilon_i \qquad (1)$$

Where *f(t)* is a continuous monotonic increasing or decreasing function of time and the residuals ε_i can be assumed to be from the same distribution with zero mean. It is therefore assumed that the variance of the distribution is constant in time. The null hypothesis of no trend, *Ho*, is tested i.e., the observations *xi* are randomly ordered in time, against the alternative hypothesis, *H1*, where there is an increasing or decreasing monotonic trend. The presence of a statistically significant trend is evaluated using a computed statistic *Z*. A positive (negative) value of *Z* indicates an upward (downward) trend at different significance levels. Method details are presented in Appendix A.

The Sen's method

The Sen's method can be used in cases where the trend can be assumed to be linear. This means that *f(t)* in equation (1) is equal to:

$$f(t) = Qt + B \qquad (2)$$

Where Q is the slope and B is a constant. To get the slope estimate *Q* in equation (1), we first calculate the slopes of all data value pairs:

$$Q_j = \frac{x_j - x_k}{j - k} \qquad (3)$$

Where *j*>*k*, if there are *n* values *xj* in the time series we get as many as *N* = *n(n-1)/2* slope estimates *Qi*. The Sen's estimator of slope is the median of these *N* values of *Qi*. The *N* values of *Qi* are ranked from the smallest to the largest and the Sen's estimator is:

$$Q = \left[Q_{(N+1)/2}\right], \text{ if N is old}$$

Or *(4)*

$$Q = \left[Q_{\left(\frac{N}{2}\right)} + Q_{(N+2)/2}\right], \text{ if N is even}$$

To obtain an estimate of B in equation (6) the *n* values of differences *xi* – *Qti* are calculated. The median of these values gives an estimate of B. The estimates for the constant B of lines of the 99% and 95% confidence intervals are calculated by a similar procedure.

Detecting future changes in climate

The future climate (2071-2100) is compared to the present one by calculating the average monthly anomalies. For temperatures, they are defined as the differences (δ) in inter-annual monthly means between the future scenario and the actual one;

$$Tf = Tc + \delta t \quad (5)$$

For the precipitations, they are defined as their ratio (ρ):

$$Pf = Pc \times \rho P \quad (6)$$

Where Tf and Pf are the monthly values of temperature and precipitation for the future climate (subscript f) and Tc and Pc those of the current climate (subscript c). Once the monthly anomalies are calculated, those of the seasons are deducted directly by considering the four seasons as follows: autumn (September-November), winter (from December to February) spring (from Mars to May) and summer (from June to August).

Results

Characteristics of observed climate

The annual precipitation of Algiers is 679.4mm with a standard deviation of 180.7mm, confirming their great variability over time.

Monthly inter-annual precipitation gradually increases from autumn to winter, then decreasing from spring to summer (Fig. 2). The maximum seasonal rainfall is calculated on winter (273.6mm) and the rainiest month in December (104.5mm). The minimum seasonal rainfall is related to the summer (24.4 mm) with almost no rainfall in July (3.3mm).

The mean rainfall difference between dry and wet season is significant and is around 248.8mm (Table 1).

Table 1. Observed seasonal precipitations and temperatures in Algiers (1952-2007).

Seasons	Precipitations (mm)	Temperatures (°C)
Winter	273.6	11.4
Spring	171.2	15.2
Summer	24.4	23.9
Autumn	210.3	19.1
Annual value	679.4	17.4

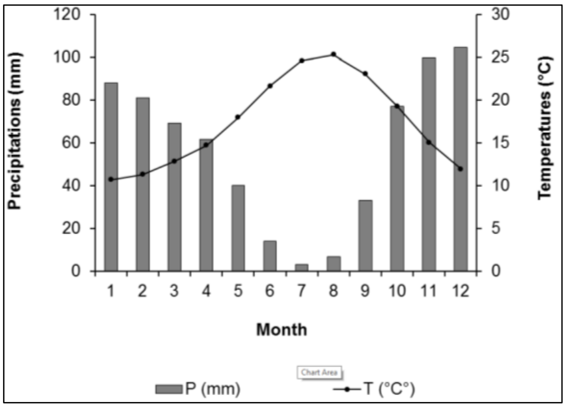

Fig. 2. Mean monthly observed values of precipitation and air temperature for Algiers (1952-2007).

Inter-annual mean temperature is 17.4±0.6°C and monthly inter-annual temperatures gradually decrease from autumn to winter and then increase from spring to summer between a minimum of 10.7°C in January and a maximum of 25.3°C in August.

Mean seasonal temperature takes its minimal and maximal values respectively in winter (11.3±1.4°C) and Summer (23.8±1.2°C). The average temperature difference between summer and winter is about 12.5°C (Table 2).

Table 2. Values of Sen's and Mann-Kendall tests for seasonal precipitations in Algiers (1952-2007).

Seasons	Statistical test					
	Time series	Sen's slope			Mann-Kendall	
		Treds _56 years	Qmin95	Qmax95	Test Z	Signif.
Winter	1952-2007	-1.888	-5.5261	2.4950	-0.64	
Spring	1952-2007	1.444	-1.129	5.196	1.14	
Summer	1952-2007	-0.038	-0.808	0.693	-0.07	
Autumn	1952-2007	-0.020	-5.393	4.329	0.00	

Trends in recent observed climate

The observed climate analysis shows an average annual warming of +0.5°C and a decrease in the annual rainfall of -3%. The Mann-Kendall test shows a nil value for autumn, negatives values concerning winter and summer (-0.64, -0.07) and a positive value for spring (+1.14). The Sen's tests confidence intervals of slope Q at 95%, calculated on seasonal precipitation, all pass through the value 0 (Fig. 3). The values for spring are nevertheless close to the positive tendency.

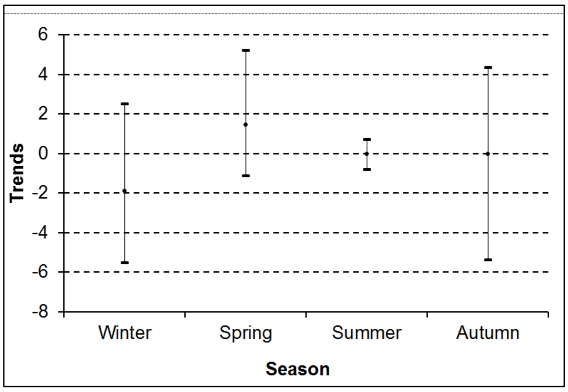

Fig. 3. Statistical trends of seasonal precipitations in Algiers (1952-2007).

For temperatures, the Mann-Kendall test indicates a very highly significant positive trend (i.e. with a level of confidence 99.9%) during summer (+4.16) and a significant positive trend for autumn (+1.7) (Table 3). The test values for the two other seasons are positive without reaching the inferior level of significance, and therefore, temperatures concerning these, seem to be unchanged. For the autumn the results of the test are very close to the significance rate. In Sen's tests for temperatures, confidence interval of slope Q is above zero only for summer (Fig. 4).

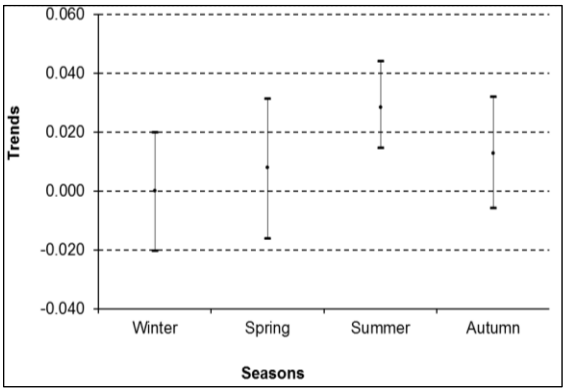

Fig. 4. Statistical trends of seasonal temperatures in Algiers (1952-2007).

Table 3. Values of Sen's and Mann-Kendall tests for seasonal temperatures in Algiers (1952-2007).

Seasons	Time series	Statistical test				
		Sen's			Mann-Kendall	
		Treds _56 years	Qmin95	Qmax95	Test Z	Signif.
Winter	1952-2007	0.000	-0.020	0.020	0.00	
Spring	1952-2007	0.008	-0.016	0.031	0.84	
Summer	1952-2007	0.029	0.015	0.044	4.16	***
Autumn	1952-2007	0.013	-0.006	0.032	1.70	+

Future changes in precipitations and temperatures

The future climate (2071-2100) is compared to the present one by calculating the mean monthly anomalies (Table 4). The calculated anomalies indicate a decrease in the Algiers rainfall regime of -18%. Except for the increase indicated by the anomalies in October (+6%), monthly precipitation decreases along the year with a maximum decrease in June and July (> 40%). The decrease in rainfall is maximum in summer (-28%) and minimum in autumn (-7%). Precipitation decrease is also very high in spring (-23 %) and High in winter. Fig. 5, shows changes in seasonal precipitations and temperatures between current and future climate scenarios. Summer seems to be even drier in Algiers, and spring is also strongly affected.

In Algiers, the ARPEGE model foresees an average annual temperature of 20.8°, which corresponds to an average annual warming of 2.7°C by the end of the 21st century. Anomalies calculated between current and future scenarios indicate that the future temperature increases systematically throughout the year from early winter to late summer then decrease again in autumn. Its takes the minimum in January with + 1.3°C, the maximum in July and August with +3.9°C. Warming is minimum in winter (+1.7°C) and maximum in summer with an expected increase in the mean temperature of 3.8°C. Autumn is also likely to undergo a significant warming (+2.9°C).

Table 4. Mean monthly anomalies of the future climate: *P* is precipitation; *T* is mean temperature.

Seasons	Months	P(%)	T(°C)
	Dec.	-17	+1.5
	Jan.	-11	+1.3
	Feb.	-19	+2.4
Winter		-16	+1.7
	Mar.	-23	+1.7
	Apr.	-28	+2.7
	May	-17	+3.7
Spring		-23	+2.7
	Jun	-44	+3.5
	Jul.	-41	+3.9
	Aug.	0	+3.9
Summur		-28	+3.8
	Sep.	-5	+3.1
	Oct.	6	+3
	Nov.	-23	+2.5
Autumn		-7	+2.9

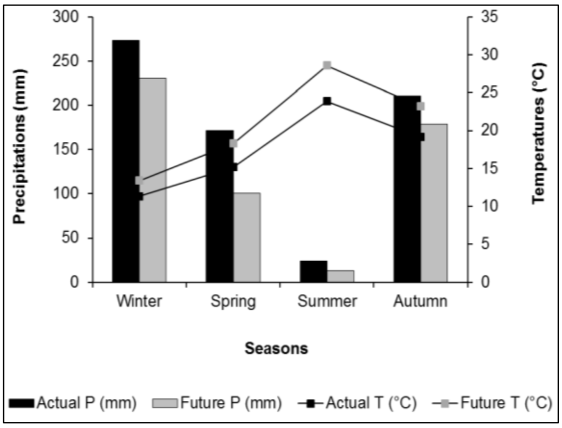

Fig. 5. Mean seasonal values of precipitation and air temperature for current and future scenarios in Algiers.

Discussion

The average annual cycles of temperature and precipitation have typical Mediterranean characteristics (Table 1). Summers months are hot and dry and those of winters are mild and wet. Precipitations and temperatures are quite mild due to the effect of the Mediterranean Sea which borders the region.

Concerning the observed climate, a non-significant decrease in annual precipitation and a significant warming characterizes the observed climate during the period 1952-2007. The Mann-Kendall test results for seasonal precipitations remain statistically insignificant at a 95% confidence level, and therefore, insufficient to indicate a positive or negative trends (Table 2).

The Sen's tests results confirm the non-existence of tendencies regarding rainfall in Algiers during the historical period 1952-2007. For temperatures the Mann-Kendall test indicates a very highly significant positive trend (i.e. with a level of confidence 99.9%) during summer and a significant positive trend for autumn (Table 3). The Sen's tests results confirm these results only for the summer.

The calculated anomalies indicate a decrease in the Algiers rainfall regime (Table 4). Thereby, our results confirm the IPCC conclusions (2007, 2013), concerning the future reduction of precipitation in the southern part of the Mediterranean basin. Summer seems to be even drier in Algiers, and spring is also strongly affected. The decline in winter precipitation projected in the Mediterranean and North Africa region (Giorgi and Lionello, 2008, Paeth *et al.*, 2009) is confirmed in our study. Future temperature increases systematically throughout the year. Our results confirm those of Goodess *et al.* (2009) and Kjellström *et al.* (2011), who report that warming is important from the beginning of spring and becomes very significant in summer.

Conclusion

Our results indicate a change in the recent observed climate of Algiers region. Annual rainfall decreased by almost 3%, but analysis of the evolution of monthly and seasonal mean values of precipitation indicates that changes in rainfall patterns are not significant. This is confirmed by the Mann-Kendall and Sen's tests results, which show that there are no positive or negative tendencies concerning the Algiers rainfall during the period 1952-2007. However, spring values of these statistical tests are nevertheless close to the positive tendency.

Conversely, the analysis of the thermal regime indicates an annual warming of +0.5°C in the region, during the examined period of the recent past climate. The Mann-Kendall test indicates a very highly significant positive trend for summer and a significant positive trend for autumn. The Sen's tests results confirm these results only for the summer and values test for autumn are very close to the significance rate.

ARPEGE Climatic projections for the region of Algiers, show a decrease of -18% in average annual rainfall. The monthly precipitation decreases systematically throughout the year with the exception of October, where projections show a slight improvement. The ARPEGE model foresees a mean warming of 2.7°C by the end of the 21st century. This increase in temperatures will affect every month throughout the year. In terms of seasons, summer and spring are projected to become even warmer and drier in future climatic conditions.

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Appendix

The Mann-Kendall test methodology.

In the Mann-Kendall, first the statistic S is computed following formula:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad (A1)$$

Where *xj* and *xk* are the annual values in years *j* and *k*, *j* > *k*, respectively, and

$$sgn(x_j - x_k) = \begin{cases} 1 & if\ x_j - x_k > 0 \\ 0 & if\ x_j - x_k = 0 \\ -1 & if\ x_j - x_k < 0 \end{cases} \quad (A2)$$

Second, we compute the variance of S as follows:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right] \quad (A3)$$

Here *q* is the number of tied groups and *tp* is the number of data values in the *p* th group.

The values of *S* and *VAR (S)* are used to compute the test statistic *Z* as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S-1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases} \quad (A4)$$

The statistic *Z* has a normal distribution. The presence of a statistically significant trend is evaluated using the *Z* value. A positive (negative) value of *Z* indicates an upward (downward) trend. To test for either an upward or downward monotone trend (a two-tailed test) at α level of significance, *Ho* is rejected if the absolute value of *Z* is greater than Z1-α/2, where Z1-α/2 is obtained from the standard normal cumulative distribution tables. Different significance levels ☐ can be used (0.1, 0.05, 0.01 and 0.001 and in our study we use 0.05 α = 0.5.