Combined analysis of temperature and rainfall variability as they relate to climate indices in Northern Algeria over the 1972–2013 period

Ayoub Zeroual, Ali A. Assani and Mohamed Meddi

ABSTRACT

Many studies have highlighted breaks in mean values of temperature and precipitation time series since the 1970s. Given that temperatures have continued to increase following that decade, the first question addressed in this study is whether other breaks in mean values have occurred since that time. The second question is to determine which climate indices influence temperature and rainfall in the coastal region of Northern Algeria. To address these two questions, we analyzed the temporal variability of temperature and annual and seasonal rainfall as they relate to four climate indices at seven coastal stations in Algeria during the 1972–2013 period using the Mann–Kendall, Lombard, and canonical correlation (CC) analysis methods.The annual and seasonal maximum, minimum and mean temperatures increased significantly over that time period. Most of these increases are gradual, implying a slow warming trend. In contrast, total annual and seasonal rainfall did not show any significant change. CC analysis revealed that annual and seasonal temperatures are negatively correlated with the Western Mediterranean Oscillation (WeMOI) climate index that characterizes atmospheric circulation over the Mediterranean basin. On the other hand, rainfall is positively correlated with a large-scale atmospheric index such as the Southern Oscillation Index.

Key words | canonical correlation analysis, coastal stations, Lombard method, Mann–Kendall test, rainfall, temperature

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INTRODUCTION

Algeria has been subjected to a persistent drought over the last several decades, although the intensity of this drought changes from one region to the next (Taibi *et al.* 2015). A growing number of studies have attempted to characterize this drought and determine its possible climate causes (e.g. Medjerab & Henia 2005; Meddi & Meddi 2007; Meddi & Talia 2008; Meddi *et al.* 2010). Some of these studies have shown that breaks in mean values of rainfall time series occurred during the 1970s (e.g. Meddi *et al.* 2010) and that these breaks are part of a regional trend observed throughout the Mediterranean basin (e.g. Xoplaki *et al.* 2000; Brunetti *et al.* 2001; Knippertz *et al.* 2003; Rodrigo & Trigo 2007). The fundamental question raised by these various studies is whether other breaks in mean values occurred after the 1970s to explain the persistence of the drought in some regions of Algeria.

In the current climate warming context, there is a tendency to link this drought event with increasing temperature. However, to our knowledge, no study to date has compared the temporal variability of temperature and rainfall measured at the same stations in Algeria, even though such a comparison would make it possible to link breaks in temperature series and in rain series. This type of analysis will highlight any existing covariation between temperature and rainfall in Algeria.

Finally, it is generally recognized that the two main factors accounting for the temporal variability of temperature and rainfall in the Mediterranean basin are the North Atlantic

doi: 10.2166/nh.2016.244

Oscillation (NAO) in most of the Western Mediterranean region (Xoplaki *et al.* 2000; Trigo *et al.* 2004), and the El Niño-Southern Oscillation (ENSO) in the Eastern Mediterranean, where the influence of NAO is weak (Yakir *et al.* 1996).

For Algeria, Meddi *et al.* (2010) found a negative correlation between these indices and annual rainfall measured at seven stations located in the Macta and Tafna watersheds, in the northwest part of the country. In general, the influence of these latter two climate indices on the temporal variability of temperature and precipitation has been highlighted in many regions of the Mediterranean basin (e.g. Kutiel *et al.* 1996; Maheras *et al.* 1999; Dünkeloh & Jacobeit 2003). However, other studies have shown that these two indices were not correlated with temperature and precipitation in several parts of the Mediterranean basin, and proposed a couple of regional climate indices that better account for the general atmospheric circulation in this basin. Two such regional climate indices were put forth: the Mediterranean Oscillation (MOI), reflecting zonal circulation (Conte *et al.* 1989), and the Western Mediterranean Oscillation (WeMOI), which reflects meridian (North–South) atmospheric circulation in the western part of the basin (Martin-Vide & Lopez-Bustins 2006). Taibi *et al.* (2015) observed a significant correlation between high-intensity seasonal rainfall and the MOI in Western Algeria.

Given the foregoing, the three goals of the study are as follows:

1. To analyze long-term trends in temperature and rainfall in the coastal region of Algeria since the 1970s.
2. To constrain the nature (sharp or gradual) and timing of breaks in mean values of temperature and rainfall series.
3. To analyze the relationship between climate indices and climate variables in order to identify those climate indices which are most strongly correlated with climate variables since the 1970s in the coastal region of Algeria.

STUDY AREA

The study is restricted to the seven climate stations located on the Mediterranean coast of Northern Algeria, because of the availability of continuous temperature and rainfall data measured since 1972. Moreover, this region is predicated on major issues and challenges pertaining to water resource management as a result of population densification and rapid growth, rapidly developing intensive agriculture which consumes large amounts of water, and the presence of numerous dams used for irrigation purposes. Climate in this region is typically Mediterranean, with hot and dry summers and mild and rainy winters (Kottek *et al.* 2006). In Northern Algeria, annual precipitation increases from west to east, ranging from 300 mm in the west to 1,500 mm in the east (Zeroual *et al.* 2013). Precipitation also decreases away from the coast. The largest amount of rain falls during the winter season, from September to February. Mean monthly temperatures range from 11 °C (in January) to 26 °C (in July and August). The location of the seven weather stations is shown in Figure 1, and their characteristics are presented in Table 1.

METHODOLOGY

Data

The data analyzed were taken from the National Meteorology Office (NMO) and National Hydraulic Resources Agency (NHRA) database (NMO: www.meteo.dz/index.php; NHRA: www.anrh.dz/). The following temperature and rainfall time series were analyzed for each of the seven stations:

- At the annual scale, a mean maximum temperature series consisting of the mean value of the highest monthly temperatures observed (from September to August) for each year over the period from 1972 to 2013. At the seasonal scale, two mean maximum temperature series consisting of the mean value of the highest monthly temperatures observed in winter (September–February) and summer (March–August) for each year from 1972 to 2013. Three series were also produced (one annual series and two seasonal series) in the same way for both minimum temperatures and mean temperatures.
- Finally, as regards rainfall, a total annual rainfall series was produced consisting of the sum of monthly rainfall amounts (September–August) measured each year from 1972 to 2013, and two total seasonal rainfall series

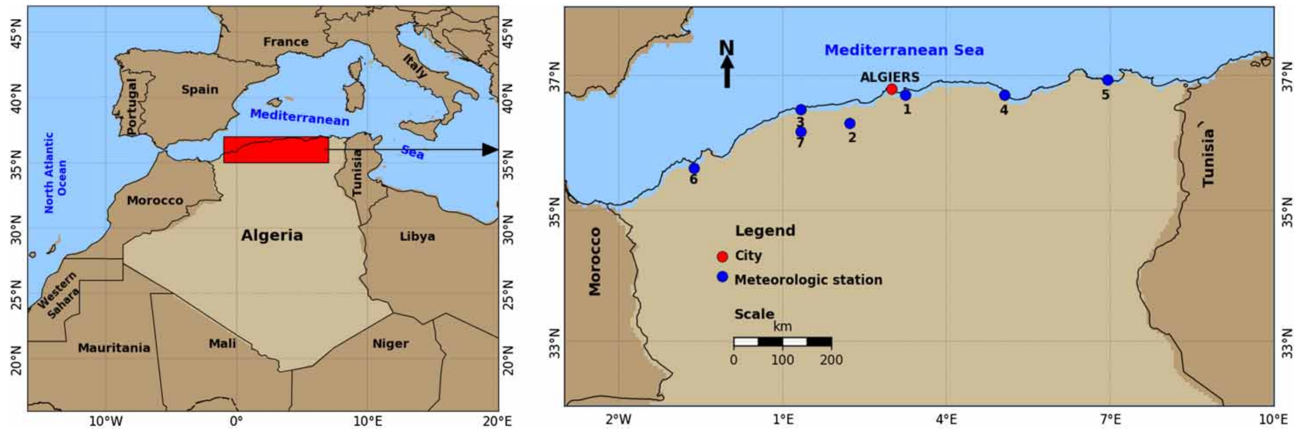

Figure 1 | Location of weather stations included in the study.

Table 1 | Names, geographic coordinates, elevation and inter-annual mean precipitation and temperature for the seven stations considered in the study (1972–2013)

Station name		Latitude (N)	Longitude	Elevation (m)	Inter-annual mean precipitation (mm)	Inter-annual mean temperature (°C)
1	Alger Dar el beida	36°43′	3°E 5′	24.00	627	17.8
2	Miliana	36°18′	02°E14′	715.0	744	17.3
3	Tenes	36°30′	01°E20′	18.00	466	18.5
4	Soummam	36°43′	5°E36′	06.09	660	17.8
5	Skikda	36°52′	6°E56′	07.00	722	18.5
6	Es senia	35°38′	−0°W36′	89.90	340	17.8
7	Cheliff	36°13′	1°E 20′	143.0	350	19.3

were produced consisting of the sum of rainfall amounts measured in winter (September–February) and summer (March–August) of each year from 1972 to 2013.

Four climate indices were selected which have been shown by several authors to influence temperatures and rainfall in Algeria. These include the following:

1. The NAO, which measures variations in pressure over the North Atlantic Ocean basin. It is expressed as the difference in pressure between Lisbon, in Portugal, and Reykjavik, in Iceland, by taking the variation in the pressure deviation between these two locations with respect to the mean value.
2. The ENSO, an ocean-atmosphere phenomenon that reflects large-scale fluctuations in atmospheric pressure and surface water temperature in the tropical Pacific basin in the southern hemisphere and affects climate at the global scale. The ENSO index is calculated from the difference in pressure measured between Tahiti and Darwin.
3. The MOI, which reflects the barometric, thermal and precipitation variability between the Eastern and Western ends of the Mediterranean basin and is specific to this basin. The associated index is derived from the normalized difference in pressure between Algiers and Cairo.
4. The WeMOI, much more localized than the MOI, which measures the difference in pressure between northern Italy and the southwestern part of the Iberian Peninsula. Its index (WeMOI) is derived from the difference in pressure measured at the Padua (northern Italy) and San Fernando (southwestern Spain) stations.

For each of these four climate indices, three time series were produced, as follows:

1. A series of annual means consisting of the mean of the index values over 12 months (September–August) from 1972 to 2013.

2. A series of winter seasonal means consisting of the mean of the index values for the six winter months (September–February) from 1972 to 2013.
3. A series of summer seasonal means consisting of the mean of the index values for the six summer months (March–August) from 1972 to 2013.

Analysis of long-term trends in temperature and rainfall using the Mann–Kendall method

Long-term analysis of climate variables was carried out using the Mann–Kendall (MK) method (Mann 1945; Kendall 1975). This method was selected because of its widespread use in hydrology and climatology (Yue *et al.* 2002) and the fact that it yields similar results to those obtained with the Spearman rank coefficient of correlation method. According to Mann (1945) and Kendall (1975), this rank-based non-parametric test can be used to determine whether the correlation between time and a given variable is significant or not. Given a sample $(x_1, x_2, \ldots\ldots\ldots\ldots\ldots x_n)$ of values that are independent from a random variable X for which the stationarity or long-term trend must be assessed, the MK statistic is defined as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sig(X_i - X_j) \tag{1}$$

where X_i and X_j are sequential values of X and n is the sample size. The test statistic is obtained by counting, for each $(X_i - X_j)_{i<j}$ pair, the number of cases where the second value is greater than the first, and the number of cases where the second value is less than the first, then subtracting these two numbers. The presence of a statistically significant trend is assessed using the Z score value as follows:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\mathrm{var}(S)}} & si\, S > 0 \\ 0 & si\, S = 0 \\ \dfrac{S+1}{\sqrt{\mathrm{var}(S)}} & si\, S < 0 \end{cases} \tag{2}$$

A positive (negative) Z score reflects an increasing (a decreasing) long-term trend, and its significance is compared with the critical value or significance threshold for the test. The critical Z score values when using a 95% confidence level are -1.96 and $+1.96$ standard deviations. The p-value associated with a 95% confidence level is 0.05. If the Z score is between -1.96 and $+1.96$, the p-value will be larger than 0.05 and the null hypothesis cannot be rejected.

Analysis of breaks in mean values of temperature and rainfall series using the Lombard method

Because the MK method cannot detect the timing and nature (sharp or gradual) of breaks in mean values of statistical series, the Lombard method (Lombard 1987; Quessy *et al.* 2011) was applied as a second step. This method was used because it can bring out both sharp and gradual breaks in series. Thus, unlike all the other methods used in climatology and hydrology to detect breaks in mean (e.g. the Pettitt method), the Lombard method is a general method. These other specific methods can only detect sharp breaks in mean values, which makes them less useful than the Lombard method. We have described this method in some of our previous work (e.g. Assani *et al.* 2011)**.** Given a series of observations, noted $X_1, \ldots, X_n$, where X_i is the observation taken at time $T = i$. These observations are supposed to be independent. One question of interest is to see whether the mean of this series has changed. If μ_i refers to the theoretical mean of X_i, then a possible pattern for the mean is given by Lombard's smooth-change model where:

$$\mu_i = \begin{cases} \theta_1 & \text{if} \quad 1 \le i \le T_1 \\ \theta_1 + \dfrac{(i-T_1)(\theta_2-\theta_1)}{T_2-T_1} & \text{if} \quad T_1 < i \le T_2 \\ \theta_2 & \text{if} \quad T_2 < i \le n \end{cases} \tag{3}$$

In other words, the mean changes gradually from θ_1 to θ_2 between times T_1 and T_2. As a special case, one has the usual abrupt-change model when $T_2 = T_1 + 1$.

In order to test formally whether the mean in a series is stable or rather follows model (1), one can use the statistical procedure introduced by Lombard (1987). To this end, define R_i as the rank of X_i among $X_1, \ldots\ldots, X_n$. Introduce the Wilcoxon score function $\phi(u) = 2u - 1$ and define the rank score of X_i by:

$$Z_i = \frac{1}{\sigma_\phi}\left\{\phi\left(\frac{R_i}{n+1}\right) - \bar{\phi}\right\}, \quad i \in \{1, \ldots, n\} \tag{4}$$

where:

$$\phi = \frac{1}{n}\sum_{i=1}^{n}\phi\left(\frac{i}{n+1}\right) \quad \text{and} \quad \sigma_\phi^2 = \frac{1}{n}\sum_{i=1}^{n}\left\{\phi\frac{i}{n+1} - \bar{\phi}\right\}^2 \tag{5}$$

Lombard's test statistic is:

$$S_n = \frac{1}{n^5}\sum_{T_1=1}^{n-1}\sum_{T_2=T_1+1}^{n} L_{T_1T_2}^2 \tag{6}$$

where:

$$L_{T_1,T_2} = \sum_{j=T_1+1}^{T_2}\sum_{i=1}^{j} Z_i \tag{7}$$

At the 95% confidence interval, one concludes that the mean of the series changes significantly according to a pattern of type (3) whenever $S_n > 0.0403$. This value corresponds to the theoretical (critical) values (see Lombard 1987) defining the significance level at 5% for the test. Note that the equation proposed by Lombard (1987) to detect multiple abrupt changes in the mean of a statistical series was also applied. This formula confirmed results obtained using Equation (3). It is important to note that the assumptions regarding the MK method (see Sneyers 1975) and Lombard method (see Lombard 1987; Quessy *et al.* 2011) are valid for this application. Among these hypotheses, we checked for autocorrelation between values in analyzed hydrological series. Statistically significant autocorrelation was removed by using the pre-whitening procedure (Storch & von Navarra 1995), in order to make the residuals time-independent.

Analysis of the relationship between climate variables and climate indices using canonical correlation analysis

The last step consisted of using canonical correlation (CC) analysis to constrain the relationship between climate variables and climate indices at the seven stations analyzed. CC is a widely used method in climatology and hydrology for analyzing the correlation between two groups of variables, including a group of independent variables and a group of dependent variables. In this study, the group of independent variables consists of the four climate indices, and the group of dependent variables, of temperature (maximum, minimum and mean) and rainfall. CC analysis consists of extracting canonical axes (V and W) from the two groups, where V axes are the canonical axes extracted from the group of dependent variables and W axes are the axes extracted from the group of independent variables. These axes are then correlated to one another in the order $V1$ to $W1,\ldots,Vn$ to Wn. The interpretation of CC results rests mainly on the matrix of canonical coefficients of structure, through which canonical axes may be linked to the original variables. A detailed description of this method is presented in Afifi & Clark (1996), among others. CC was applied to a matrix consisting of nine columns (stations + four climate variables + four climate indices) and 294 rows (seven stations × 42 years). This total number of rows warrants the use of CC even though there are fewer than 45 years of observation for climate variables (1972–2013). It should be noted that temperature and precipitation data have been standardized, as were climate index data.

RESULTS

Temporal variability of temperature and rainfall

Results of the long-term trend analysis of temperature and rainfall (Figure 2) using the MK method are presented in Figure 3. For maximum temperatures at the annual scale, aside from the Tenes station, the temporal variability of temperature is characterized by a significant positive long-term trend. For minimum and mean temperatures, the long-term trend is statistically significant for all stations. However, for the Tenes station this long-term trend is negative, meaning that a significant decrease in minimum and mean temperatures is observed at this station, unlike the other six stations. At the seasonal scale, for both winter and summer the long-term trend is nearly identical to that observed at the annual scale. Thus, the temporal variability of temperature is characterized by an increase in maximum, minimum and mean temperatures, except for the Tenes station, where these temperatures tend to decrease significantly over time. In contrast, the long-term trend of summer maximum

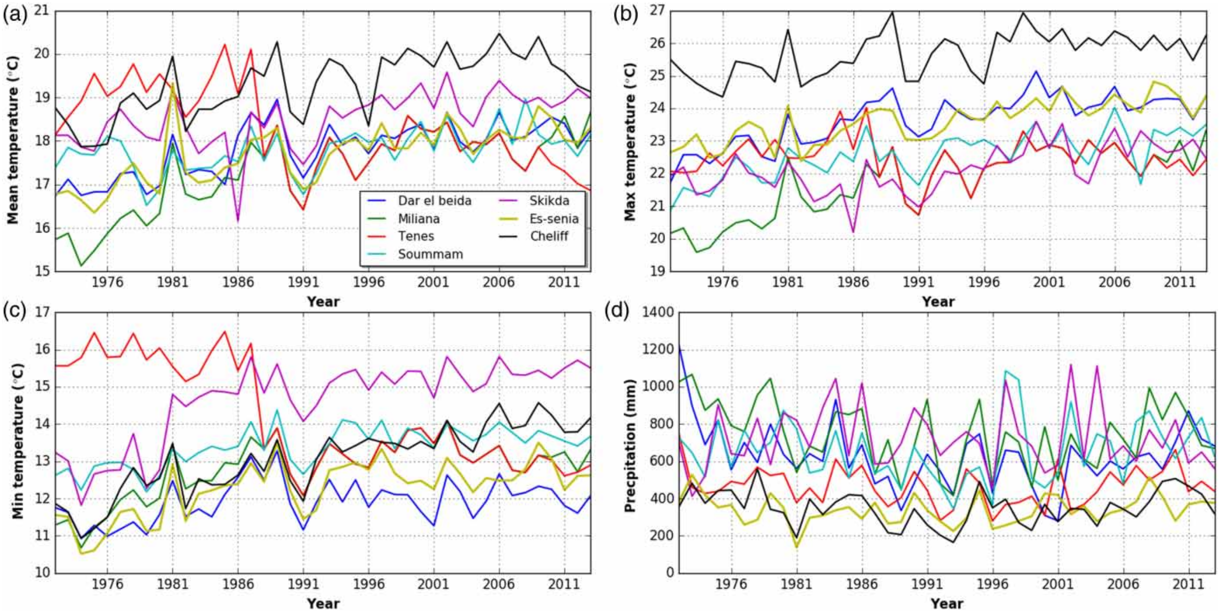

Figure 2 | Inter-annual variation of annual mean temperature (°C); annual mean maximum temperature (°C), annual mean minimum temperature (°C) and total annual precipitation (mm).

temperatures at that station is positive, and that for mean temperatures is not significant. The long-term trends of winter maximum temperature at the Chlef station and of winter mean temperature at the Soumman station are not statistically significant. As far as rainfall is concerned, the long-term trend is not statistically significant at any of the stations, at both the annual and seasonal scales. Thus, despite a generalized change in temperature, total rainfall has neither increased nor decreased over time.

The Lombard method was used to constrain the timing of breaks in mean values of temperature and rainfall series. Results obtained using this method are shown in Tables 2–4. These results are consistent with the results of the long-term trend analysis. All temperature series characterized by a significant long-term trend show a significant break in mean values, except for the maximum temperature series for the Tenes station. For maximum temperatures, it is interesting to note that most of these breaks are gradual, except winter temperatures at the Es-Senia and Skikda stations. Most of these breaks began in the early 1970s and ended towards the end of the 1990s or the early 2000s. For minimum and mean temperatures, nearly all breaks are also gradual, but they are not synchronous with breaks in maximum temperatures, although they also began in the 1970s. The gradual nature of the breaks reflects a slow change in mean values of temperature, implying that the warming trend observed along the Mediterranean coast of Algeria is slow. For rainfall, none of the series show a break in mean values, which is also consistent with results obtained using the MK method.

Relationship between temperature, rainfall and climate indices

CC results used to analyze the relationships between temperature, rainfall and climate indices are presented in Tables 5–8. Table 5 reveals that the first three CC coefficients are statistically significant both at the annual and seasonal scales. For coefficients of structure, temperatures are significantly correlated with V1 at the annual scale (Table 5), and this correlation is positive. Rainfall is not correlated to any statistically significant canonical axes. As far as climate indices are concerned, WeMOI is negatively correlated with W1, and MOI is positively correlated with W3. The fact that V1 is correlated with W1 implies that temperatures are negatively correlated with WeMOI. Applying the same reasoning at the seasonal scale, minimum and mean temperatures are negatively correlated with the MOI and WeMOI indices. Maximum temperature and rainfall are not significantly correlated with any climate index. In

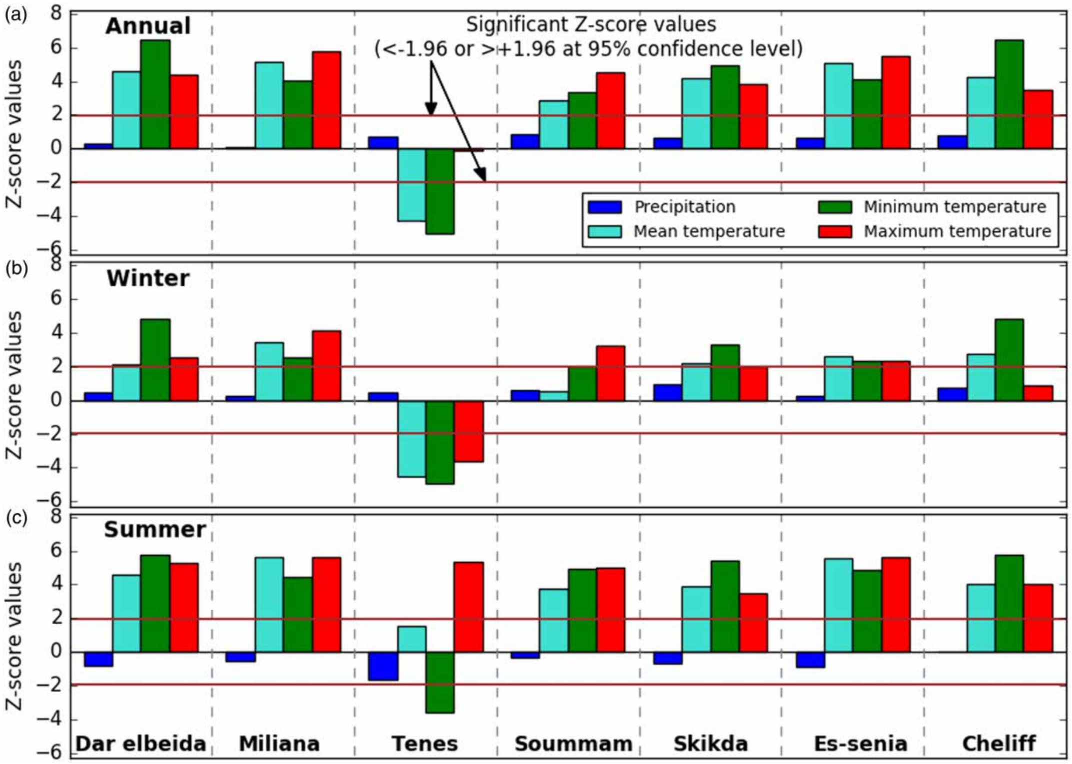

Figure 3 | Z scores derived from the MK method for temperature and rainfall series for the period 1970–2013. The two red lines represent the theoretical critical n values of the MK test at the 5% probability level. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/nh.2016.244.

Table 2 | Results of the analysis of temperature and rainfall using the Lombard method at the annual scale for the 1972–2013 time period

	T_{max}		**T_{min}**		**T_{mean}**		**Rainfall**	
Stations	**S_n**	**T_1–T_2**	**S_n**	**T_1–T_2**	**S_n**	**T_1–T_2**	**S_n**	**T_1/T_2**
Alger Dar El Beida	**0.1956**	1973–1988	**0.0540**	1979–1980	**0.1645**	1973–1988	0.0116	–
Miliana	**0.2413**	1973–1999	**0.1388**	1973–1986	**0.2156**	1973–1999	0.0231	–
Tenes	0.0014	–	**0.2288**	1986–1989	**0.1744**	1987–1988	0.0040	–
Soummam	**0.1701**	1973–1999	**0.1435**	1979–1986	**0.0946**	1992–1993	0.0079	–
Skikda	**0.1835**	1991–1996	**0.2041**	1978–1985	**0.1953**	1991–1996	0.0039	–
Es Senia	**0.2568**	1972–2005	**0.1580**	1972–1988	**0.2072**	1972–2001	0.0077	–
Chlef	**0.1366**	1974–2000	**0.2908**	1973–1986	**0.2040**	1973–2000	0.0072	–

S_n values of Lombard test.

Significant values of S_n are shown in bold. T_1 and T_2 are the years of start and end, respectively, of significant changes in mean values of a given series.

summer, temperatures are negatively correlated with WeMOI and rainfall is negatively correlated with the Southern Oscillation Index (SOI). Finally, it is interesting to note that rainfall and SOI are positively correlated with the fourth canonical axis both for winter (Table 6) and at the annual scale (Table 5).

DISCUSSION

Comparison of the temporal variability of temperature and rainfall as they relate to climate indices at seven coastal stations in Northern Algeria produced the following three significant findings:

Table 3 | Results of the analysis of temperature and rainfall using the Lombard method at the annual scale for the 1972–2013 time period

	T_{max}		T_{min}		T_{mean}		Rainfall	
Stations	S_n	T_1–T_2	S_n	T_1–T_2	S_n	T_1–T_2	S_n	T_1–T_2
Alger Dar El Beida	**0.0719**	1972–1986	**0.1890**	1972–2008	**0.0447**	1972–1984	0.0110	–
Miliana	**0.1404**	1972–1988	**0.0597**	1972–1986	**0.104**	1972–1986	0.0124	–
Tenes	**0.1827**	1986–1987	**0.2496**	1986–1987	**0.2364**	1986–1987	0.0071	–
Soummam	**0.0937**	1972–1994	**0.0417**	1981–1982	0.0040	–	0.0098	–
Skikda	**0.0478**	1992–1993	**0.1070**	1981–1982	**0.0501**	1974–1976	0.0010	–
Es Senia	**0.0543**	1992–1993	**0.0487**	1979–1980	**0.0573**	1975–1976	0.0165	–
Chlef	0.0082	–	**0.1890**	1972–2008	**0.0732**	1975–1976	0.0044	–

S_n values of Lombard test at the winter seasonal scale.
Significant values of S_n are shown in bold. T_1 and T_2 are the years of start and end, respectively, of significant changes in mean values of a given series.

Table 4 | Results of the analysis of temperature and rainfall using the Lombard method at the annual scale for the 1972–2013 time period

	T_{max}		T_{min}		T_{mean}		Rainfall	
Stations	S_n	T_1–T_2	S_n	T_1–T_2	S_n	T_1–T_2	S_n	T_1–T_2
Alger Dar El Beida	**0.2421**	1972–1999	**0.2816**	1972–2001	**0.1976**	1984–1985	0.0079	–
Miliana	**0.2655**	1972–1998	**0.1644**	1972–1986	**0.2717**	1972–1999	0.0058	–
Tenes	**0.2610**	1972–1998	**0.1322**	1986–1986	**0.0292**	–	0.0291	–
Soummam	**0.1916**	1972–1999	**0.2375**	1976–1998	**0.1542**	1990–1998	0.0049	–
Skikda	**0.1765**	1995–1996	**0.2441**	1972–2001	**0.1938**	1994–1996	0.0067	–
Es Senia	**0.2761**	1972–2001	**0.2181**	1973–1195	**0.2412**	1972–2001	0.0100	–
Chlef	**0.1683**	1974–1998	**0.2816**	1972–2001	**0.1650**	1972–1999	0.0047	–

S_n values of Lombard test at the summer seasonal scale.
Significant values of S_n are shown in bold. T_1 and T_2 are the years of start and end, respectively, of significant changes in mean values of a given series.

1. The long-term trend of the temporal variability of temperature is characterized by a significant increase during the period from 1972 to 2013 both at the annual and seasonal (winter and summer) scales. A warming trend of 0.2–0.4 °C per decade in Northern Algeria has also been observed from 1975 to 2004, according to the fourth IPCC report (Solomon *et al.* 2007). Similar results were found in the Mediterranean region by Giorgi (2002) and New *et al.* (2001) for various periods during the 20th century. However, Brunetti *et al.* (2006) noted a positive trend of mean temperatures of about 1 K per century over the whole of Italy and that maximum temperature trends are stronger than minimum temperature trends during the last 50 years. The same trends were observed in several regions of the Mediterranean basin, for instance in the Eastern Mediterranean (Philandras *et al.* 2015) and in Morocco (Driouech 2006). Mean temperature did not change very much prior to the 1970s, then rose substantially over the last 30 years in France (Ribes *et al.* 2010) and Lebanon (Ramadan *et al.* 2013). It increased significantly from 1990 in Greece (Nastos *et al.* 2011) and Turkey (Türkeş *et al.* 2002). Other than the Mediterranean basin, this significant increase has also been observed in western North Carolina since the late 1970s (Laseter *et al.* 2012) and elsewhere in the world (Solomon *et al.* 2007).

   The Lombard method analysis revealed that most breaks in mean values of temperature series are gradual, although these breaks are not synchronous for maximum and minimum temperatures. These gradual breaks suggest that the increase in temperature was likely slow due to the dampening influence of the Mediterranean Sea on strong temperature fluctuations.
2. As far as rainfall is concerned, no significant change in the long-term trend and mean values of the series is observed

Table 5 | Results of the analysis of the relationship between climate variables and climate indices using CC analysis for the 1970–2013 time period

	Annual			Winter			Summer		
	r	F	*p*-values	r	F	*p*-values	r	F	*p*-values
CC1	**0.458**	7.71	<0.0001	**0.442**	6.58	<0.0001	**0.475**	8.61	<0.0001
CC2	**0.346**	5.54	<0.0001	**0.294**	4.27	<0.0001	**0.362**	6.34	<0.0001
CC3	**0.196**	2.90	0.0215	**0.194**	2.89	0.0218	**0.218**	3.71	0.0055
CC4	0.026	0.19	0.6597	0.036	0.38	0.5358	0.046	0.62	0.4299

The values of the CC coefficients.
Statistically significant values of *r* are shown in bold.

Table 6 | Results of the analysis of the relationship between climate variables and climate indices using CC analysis for the 1970–2013 time period

Variables	V1	V2	V3	V4	W1	W2	W3	W4
T_{max}	**0.649**	0.105	−0.034	− **0.814**				
T_{min}	**0.657**	0.105	0.569	−0.494				
T_{mean}	0.571	−0.516	−0.107	−0.540				
Rainfall	0.469	0.204	−0.524	**0.682**				
MOI					−0.242	0.232	**0.938**	−0.092
WEMOI					− **0.898**	0.348	−0.212	−0.161
NAO					−0.607	−0.483	0.465	0.425
SOI					0.338	0.575	−0.103	**0.738**
EV (%)	34.9	0.82	15.3	41.6	33.7	18.5	28.8	19

Structure coefficients at the annual scale.
Values statistically significant of structure coefficients appear in bold.

Table 7 | Results of the analysis of the relationship between climate variables and climate indices using CC analysis for the 1970–2013 time period

Variables	V1	V2	V3	V4	W1	W2	W3	W4
T_{max}	−0.585	**0.787**	−0.144	−0.132				
T_{min}	− **0.925**	0.178	0.248	−0.225				
T_{mean}	− **0.794**	0.437	−0.282	−0.315				
Rainfall	−0.212	−0.487	−0.075	**0.844**				
MOI					**0.751**	0.469	0.403	−0.232
WEMOI					**0.602**	−0.353	− **0.652**	−0.297
NAO					0.556	−0.301	**0.773**	−0.045
SOI					0.261	0.132	−0.190	**0.937**
EV (%)	46.8	27	4.2	22	32.6	11.3	30.6	25.6

Structure coefficients in winter.
Values statistically significant of structure coefficients appear in bold.

over the period analyzed. Moreover, as discussed below, the temporal variability of temperature and rainfall is not correlated with the same climate indices. These findings are consistent with studies in the literature of precipitation trends during the 20th century in the Mediterranean basin, that yield different, in some cases opposite, results from one area to the next and from one period to the next because of the effect of the spatial and temporal peculiarities of each area on the results. For instance, Giorgi (2002) and Norrant & Douguédroit (2005) found

Table 8 | Results of the analysis of the relationship between climate variables and climate indices using CC analysis for the 1970–2013 time period

Variables	V1	V2	V3	V4	W1	W2	W3	W4
T_{max}	**0.640**	−0.508	−0.546	0.261				
T_{min}	**0.666**	− **0.671**	−0.408	−0.407				
T_{mean}	**0.689**	−0.399	0.157	0.285				
Rainfall	0.285	**0.826**	0.482	−0.068				
MOI					0.391	−0.082	− **0.740**	0.541
WEMOI					− **0.757**	0.353	−0.473	0.281
NAO					−0.349	−0.045	0.530	0.771
SOI					0.423	**0.849**	0.250	−0.193
EV (%)	35.2	38.7	18	8	25.7	21.4	27.9	25.1

Structure coefficients in summer.
Values statistically significant of structure coefficients appear in bold.

negative trends of winter precipitation in the Mediterranean basin for the 20th century, whereas Xoplaki *et al.* (2004) showed that trends in many regions are not statistically significant due to considerable variability at the regional scale. Furthermore, significant positive changes in total winter precipitation and the absence of significant change at the annual scale were noted in several studies, including Ribes *et al.* (2010) in France, Brunetti *et al.* (2006) in Italy, Karabulut *et al.* (2008) in Turkey, and Gonzalez-Hidalgo *et al.* (2009) in the Iberian Peninsula (Spain) in the period from 1951 to 2000.

3. Finally, as far as the relationship between climate indices and climate variables is concerned, results show a better negative correlation between temperatures and the WeMOI index. As mentioned above, this climate index is a measure of meridian (North–South) variations in pressure in the western part of the Mediterranean basin, reflecting the meridian movement of tropical (Azores anticyclone) and temperate (Central European anticyclone) air masses in this part of the basin. For Northern Algeria, the negative correlation found between WeMOI and temperatures implies that the positive phase of this climate index corresponds with relatively high temperatures in the area, likely due to the predominance of warm tropical air associated with the Azores anticyclone, as shown by Martin-Vide & Lopez-Bustins (2006). Incidentally, this index is positively correlated with mean temperatures in winter in Serbia (Berdon 2013). Martín *et al.* (2011) observed that the positive phase of WeMOI is significantly correlated with minimum sea-surface temperature, and its negative phase is significantly correlated with maximum sea-surface temperature in the northwestern Mediterranean. Rainfall, for its part, is positively correlated with SOI, and this correlation was highlighted in other parts of Algeria (e.g. Meddi *et al.* 2010). Similarly, Mariotti *et al.* (2002) found that fall mean precipitation is positively correlated with ENSO in the Western Mediterranean and is positively correlated with this index in some regions of Spain and in Morocco. Nicholson & Kim (1997) and Ward *et al.* (1999) showed that ENSO has a significant influence (decrease in precipitation) in Northwestern Africa and Southern Europe in the spring. In addition, an ENSO influence was identified in the European North Atlantic region mainly in winter during extreme events (Pozo-Vázquez *et al.* 2001; Brönnimann *et al.* 2007).

This study highlights the fact that temperatures show a better correlation with the two local indices that characterize atmospheric circulation over the Mediterranean basin, while rainfall is better correlated with SOI, which affects climate at the global scale. It follows that the temporal variability of temperatures is much more strongly affected by local general circulation patterns, a finding that may account for the cooling trend observed at the Tenes station, whereas the temporal variability of total rainfall is much more strongly affected by global scale circulation mechanisms (i.e. SOI).

CONCLUSIONS

It is a well-established fact that temperature has been steadily increasing worldwide and, in particular, in the Mediterranean basin since the end of the 1970s. This study aimed to analyze the stationarity of (maximum, mean and minimum) temperature and rainfall at the annual and seasonal scale, measured at seven weather stations distributed throughout coastal Algeria, over the period 1970–2013, and their relationship with four climate indices. The MK (analysis of long-term trends) and Lombard (analysis of breaks in mean values) methods revealed that temperature series generally show an increasing long-term trend with gradual breaks in mean values that reflect a slow increase in temperature since the 1970s. Rainfall, on the other hand, does not show a significant long-term trend. CC analysis revealed that temperatures show a stronger correlation with the WeMOI climate index that characterizes atmospheric circulation over the Mediterranean basin, while rainfall is most strongly correlated with a large-scale atmospheric index such as SOI. Given the major economic activities that depend on water and the high population density in this coastal region, the reported increase in temperature, although moderate, must be taken into account in water resource management planning for this region.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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First received 30 November 2015; accepted in revised form 29 April 2016. Available online 27 May 2016