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ORIGINAL PAPER

Trends in indices of daily temperature and precipitations extremes in Morocco

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Abstract The purpose of this paper is to provide a summary of Morocco's climate extreme trends during the last four decades. Indices were computed based on a daily temperature and precipitation using a consistent approach recommended by the ETCCDI. Trends in these indices were calculated at 20 stations from 1970 to 2012. Twelve indices were considered to detect trends in temperature. A large number of stations have significant trends and confirm an increase in temperature, showing increased warming during spring and summer seasons. The results also show a decrease in the number of cold days and nights and an increase in the number of warm days and nights. Increasing trends have also been found in the absolute warmest and coldest temperatures of the year. A clear increase is detected for warm nights and diurnal temperature range. Eight indices for precipitation were also analyzed, but the trends for these precipitation indices are much less significant than for temperature indices and show more mixed spatial patterns of change. Heavy precipitation events do not exhibit significant trends except at a few locations, in the north and central parts of Morocco, with a general tendency towards drier conditions. The correlation between these climate indices and the large-scale atmospheric circulations indices such as the NAO, MO, and WEMO were also analyzed. Results show a stronger relationship with these climatic indices for the precipitation indices compared to the temperature indices. The correlations are more significant in the Atlantic regions, but they remain moderate at the whole country scale.

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1 Introduction

Morocco is located between the arid regions of the Western Sahara and the Mediterranean and Atlantic regions (Born et al. 2008). The climate of Morocco is mostly semiarid with warm to hot, dry summers, occasional droughts, and mild, relatively wet winters (Critchfield 1983; Touchan et al. 2010). Due to a large variety of climates ranging from moderate humid and subhumid climates at the northern slope of the High Atlas to semiarid and arid climates south of the Atlas, agricultural production and local economy depend very much on water availability. Any changes in the frequency or severity of extreme weather and climate events could have significant impacts on nature and society. It is therefore very important to analyze extreme events. Indices that characterize aspects of the tails of the distribution tend to be more relevant to society and natural systems than indices that characterize aspects of the distribution that occur more frequently. This is because the more extreme an event is, the most likely it will cause social or environmental damage (Zhang et al. 2011).

Temperature is associated with several extremes weather events such as heat waves and cold spells which impacts human health, the physical environment, ecosystems, and energy consumption. The IPCC report lists the regional observed changes in temperature and precipitation extremes since 1950 (IPCC 2012) and, in general, analyses of temperature extremes show changes consistent with warming climate. A number of recent studies have shown that European summer temperatures are sensitive to global warming. For example, Dobrovolny et al. (2010) concluded that the last 20 years (since 1988) stand out as very likely the warmest 20-year period for Central Europe, Rebetez et al. (2008) studied heat wave in Europe in 2003 and 2006, respectively, and concluded that the mean monthly temperature were very high in June and July. Summer 2007 was exceptionally hot for many parts of southeastern Europe, the Balkans, and particularly Greece (Founda and Giannakopoulos 2009). Also, the summer of 2010 was exceptionally warm in Eastern Europe and large parts of Russia (Barriopedro et al. 2011), and a regional study for annual extremes on the eastern Mediterranean region shows an increase in the warm days and nights (Kuglitsch et al. 2010). For the countries located in the northern and eastern parts of Mediterranean region, several studies observed increasing trends in temperature (Brunet et al. 2007; Hertig et al. 2010; Lelieveld et al. 2012; Donat et al. 2013).

Similarly, there is a strong association between precipitation and droughts or floods. Several studies indicate a possible increase in the number of heavy precipitations events in many Mediterranean regions, even in those where there had been a reduction in total precipitation amount (Gao et al. 2006; Giorgi and Lionello 2008). This could lead to an increased probability of occurrence of extreme weather inducing floods, flash floods, and droughts (Gao et al. 2006; Trenberth et al. 2007). Decreasing trends in precipitation have been found in some regions such as northern Italy (Pavan et al. 2008) and some Mediterranean coastal sites including North Africa (Toreti et al. 2010; Giorgi 2002; Donat et al. 2013; Tramblay et al. 2013). There are also some studies on the change and trends using discharge data for rivers in the western Mediterranean such as in France (Renard et al. 2008) and in Spain (Benito et al. 2005); however, such exhaustive discharge datasets are lacking in North Africa to conduct similar studies on flood or hydrological drought occurrence.

Floods and droughts are perhaps the major issues associated with climate change in this region. Adaptation to these hazards requires changes in both infrastructures and strategies (Hitz 2004). Several events causing human losses and economic damages have been reported in the late decades, such as in 1995 (Ourika valley), 2002 (Mohammadia, El Jadida, Taza, Tétouan, Settat, Berrechid), and 2009 (Rabat, Tanger, Nador, Casablanca, Khenifra, Tetouan, Agadir, Essaouira) (Bouaicha and Benabdelfadel 2010; Tramblay et al. 2012). In the same way, Morocco has suffered from a series of dry years: 1944–1945, 1982–1983, 1994–1995, 1998–2000, and 2006–2007 (Bouaicha and Benabdelfadel 2010).

Recent studies have revealed that the vulnerability of the populations to extreme hydrological events is high in Morocco (Douglas et al. 2008; Di Baldassarre et al. 2010). Driouech et al. (2013) and Tramblay et al. (2013) observed a decrease in precipitation in the north of Morocco, and Sebbar et al. (2011) studied the recent evolution in the precipitation regime and estimated its impact on spatiotemporal extension of the drought in northern Morocco. Moreover, various parts of North Africa have suffered devastating drought in the last 30 years (Nicholson and Wigley 1984; Swearingen 1992; Hoerling and Kumar 2003; Esper et al. 2007).

The aim of this paper is to evaluate if the frequency and severity of extreme weather and climate events have changed in recent decades in Morocco, using climate indices of temperature and precipitation computed from the meteorological synoptic network of stations of Maroc-Météo. The Expert Team on Climate Change Detection and Indices (ETCCDI) has attempted to facilitate the analysis of such extremes over the last decade by defining a set of climate indices that provide a comprehensive overview of temperature and precipitation statistics focusing particularly on extreme aspects (Karl and Easterling 1999; Klein Tank et al. 2009; Sillmann et al. 2013). The indices of temperature and precipitation extremes considered in the present study were selected from the list of indices for surface data recommended by the joint working group on climate change detection of the World Meteorological Organization–Commission for Climatology (WMO–CCL) and the Research Program on Climate Variability and Predictability (Peterson et al. 2012), therefore allowing a direct comparison with different studies performed in other regions (Klein Tank et al. 2009).

The rest of the paper is structured as follows: In Section 2, we describe the analyzed data, the criteria for the station selection. The methodology used to compute the extremes in observed data is presented in Section 3. In Section 4, we include the discussion of results relating to the selected trends for temperature and precipitation, and we investigate the temporal variability of the different climate indices related to the relationship with large-scale atmospheric pattern. The summary and conclusion is presented in Section 5.

2 Data

2.1 Data source

In order to study the climate and its variability, the first thing to do is the acquisition of observational information in the region of interest. In Morocco, the density and quality of observations are better than in most other parts of Africa (Born et al. 2008). Due to the spatial heterogeneity of climates in this region, we need a high density of station to adequately capture spatial variability. Our source of information is SYNOP weather stations (Direction de la Météorologie Nationale), which contribute to the WMO network and deliver data of a relatively high-quality standards for several decades. The observed data consists of daily station data of differing lengths and completeness of record. The first stations in Morocco

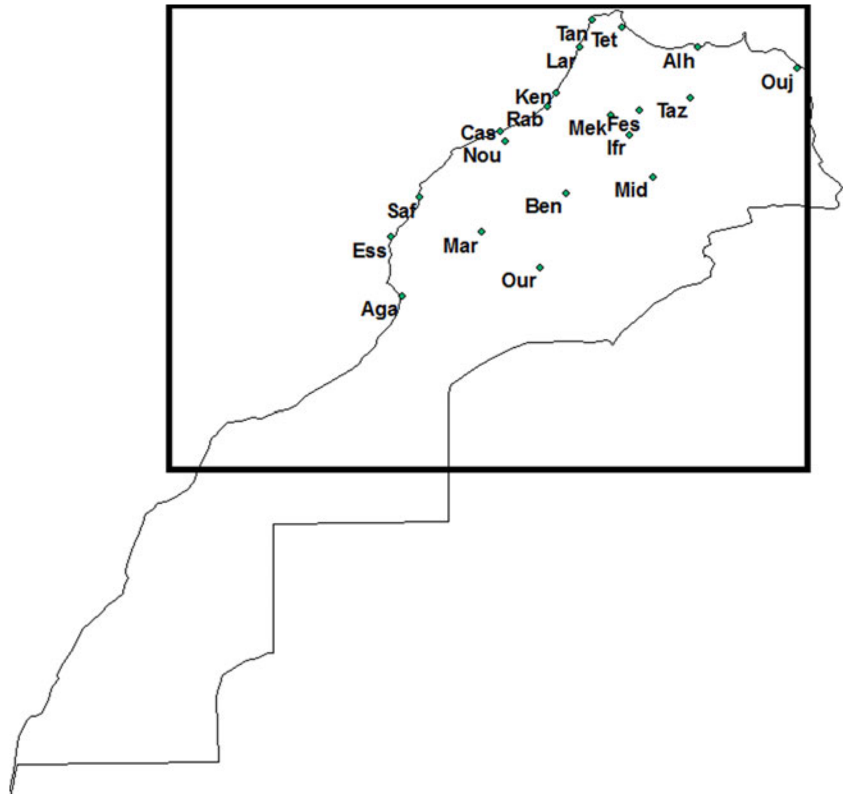

Fig. 1 Map indicates the study area and the geographical locations of the 20 SYNOP weather stations used in this study

were set up between 1910s and 1920s, and most of them between 1970s and 1980s. In order to identify trends in each variable, it is necessary to use data records of sufficient length, typically a minimum of 30 years in climate analyses.

The reference period for the selected stations is 1970–2012 which was chosen to maximize the number of stations with data available for calculation of indices. With this choice of maximization of the record length, only 20 of the 43 original stations had long enough homogeneous periods to be included in the analysis. The geographical locations of these stations are shown in Fig. 1, and their details are listed in Table 1. The data cover the following meteorological variables: daily minimum and maximum near surface temperature (TN and TX, respectively) and also daily precipitation. Most of the selected stations are located in the northern part of Morocco where the population density is the highest.

2.2 Quality control

Daily minimum and maximum near surface temperature (TN and TX, respectively) and daily precipitation accumulation were used. A quality control of the station-based daily datasets was performed following numerical and visual checks in order to identify errors caused by data processing. For each

Table 1 Geographical description of the synoptic stations used in this study

Station	Station name	Lat	Lon	Altitude
Aga	AGADIR	30.38	−9.56	23
Cas	CASABLANCA	33.56	−7.66	57
Tan	TANGER	35.71	−5.9	15
Rab	RABAT	34.05	−6.76	84
Alh	ALHOUCEIMA	35.18	−3.85	27
Ben	BENI MELLAL	32.36	−6.4	472
Ouj	OUJDA	34.78	−1.93	465
Mek	MEKNES	33.88	−5.53	548
Fes	FES	33.96	−4.98	571
Mid	MIDELT	32.68	−4.73	1508
Ess	ESSAOUIRA	31.51	−9.78	8
Ifr	IFRANE	33.5	−5.16	1664
Taz	TAZA	34.21	−4	510
Mar	MARRAKECH	31.61	−8.03	463
Ken	KENITRA	34.3	−6.6	12
Lar	LARACHE	35.18	−6.13	49
Saf	SAFI	32.28	−9.23	34
Tet	TETOUAN	35.58	−5.33	10
Nou	NOUACEUR	33.36	−7.56	200
Oua	OUARZAZATE	30.93	−6.9	1136

climatological mean value of the daily temperature variable, it was checked whether it falls within the range of ±4 standard deviations, following Zhang et al. (2005). Checks controls were also applied to identify the negative precipitations values. For the records of sufficient lengths and completeness, it was then necessary to assess their homogeneity to ensure that any variations in the records are the result of changes in climate rather than changes in the station location, instrument, or data collection. The homogeneity of the records was assessed using the RHtestV4 software available at the ETCC DI web site (http://etccdi.pacificclimate.org/software.shtml), which analyzes monthly or daily data and identifies step changes in the record (Wang 2003, 2008). No step changes or homogeneity breaks were found in the studies dataset.

3 Methods

3.1 Climate indices and trend analysis

A set of 27 indices proposed by the ETCCDI were calculated using RClimDex and R-based software package developed at the Climate Research Branch of Meteorological Service of Canada on behalf of the ETCCDMI (Zhang et al. 2005). The indices are primarily based on station level thresholds calculated over a base period, such as the 90th percentile of minimum temperature. For detailed descriptions of the indices and the exact formula for calculating them, please see the ETCC DMI web page. The indices find multiple applications in climate research and related fields due to their robustness and

Table 2 Core set of 27 extremes indices recommended by the ETCCDI

Label	Index name	Index definition	Units
TN10p	Cold nights	Percentage of days when TN<10th percentile	%
TX10p	Cold days	Percentage of days when TX<10th percentile	%
TN90p	Warm nights	Percentage of days when TN>90th percentile	%
TX90p	Warm days	Percentage of days when TX>90th percentile	%
WSDI	Warm spell duration	Annual count of days with at least six consecutive days when TX>90th percentile	days
CSDI	Cold spell duration	Annual count of days with at least six consecutive days when TN<10th percentile	days
TXx	Max TX	Warmest daily maximum temperature	°C
TXn	Min TX	Coldest daily maximum temperature	°C
TNx	Max TN	Warmest daily minimum temperature	°C
TNn	Min TN	Coldest daily minimum temperature	°C
FD	Frost days	Annual number of days when Tmin<0 °C	days
ID	Ice days	Annual number of days when Tmax<0 °C	days
SU	Summer days	Annual number of days when Tmax>25 °C	days
TR	Tropical nights	Annual number of days when Tmin>20 °C	days
GSL	Growing season length	Annual count between first span of at least 6 days with mean temperature (TG) >5 °C and first span after July 1 of 6 days with TG<5 °C	days
DTR	Diurnal temp range	Monthly mean difference between TX and TN	°C
RX1day	Max 1-day precipitation	Monthly maximum 1-day precipitation total	mm
RX5day	Max 5-day precipitation	Monthly maximum 5-day precipitation total	mm
SDII	Simple daily intensity	The ratio of annual total precipitation to the number of wet days	mm
R10mm	Number of wet days	Annual number of days when precipitation ≥10 mm	days
R20mm	Heavy precipitation days	Annual number of days when precipitation ≥20 mm	days
R25mm	Very heavy precipitation	Annual number of days when precipitation ≥25 mm	days
CDD	Consecutive dry days	Maximum annual number of consecutive dry days	days
CWD	Consecutive wet days	Maximum annual number of consecutive wet days with precipitation <1 mm	days
R95p	Very wet days	Annual sum of daily precipitation >95th percentile	mm
R99p	Extremely wet days	Annual sum of daily precipitation >99th percentile	mm
PRCPTOT	Total wet-day precipitation	Annual sum of daily precipitation ≥1 mm	mm

fairly straightforward calculation and interpretation (Min et al. 2010; Morak et al. 2011; Sillmann et al. 2013). Some advantages of using predefined indices are that they allow some comparability across modeling and observational studies and across regions (IPCC 2012).

Table 2 lists names and the definitions of the indices computed in this study, with a base period from 1970 to 2012. Most of the definitions for the indices were presented in the work of Peterson et al. (2001). Analysis of the times series of the computed indices was undertaken using the Mann-Kendall test for trend and Sen'S slope estimates. The software combines two steps, the first is a nonparametric Sen's method for identifying the magnitude of any trend (Sen 1968), and the second is a nonparametric Mann-Kendall's tau test to identify the significance of any trend. The Man-Kendall test does not assume any specific distribution for the datasets (Kendall 1975), a modified version, taking into account the possible presence of autocorrelation in the time series (Gilbert 1987), is considered here.

3.2 Relationship with atmospheric circulation indices

In this work, we study the correlation between the indices of the daily temperature and precipitations extremes and the large-scale atmospheric circulation indices describing the Mediterranean Oscillation (MO), the West Mediterranean Oscillation (WEMO), and the North Atlantic Oscillation (NAO). We used the nonparametric Spearman's (1904) test to compute the annual correlations. The null hypothesis for the test is there is no correlation in between the two variables.

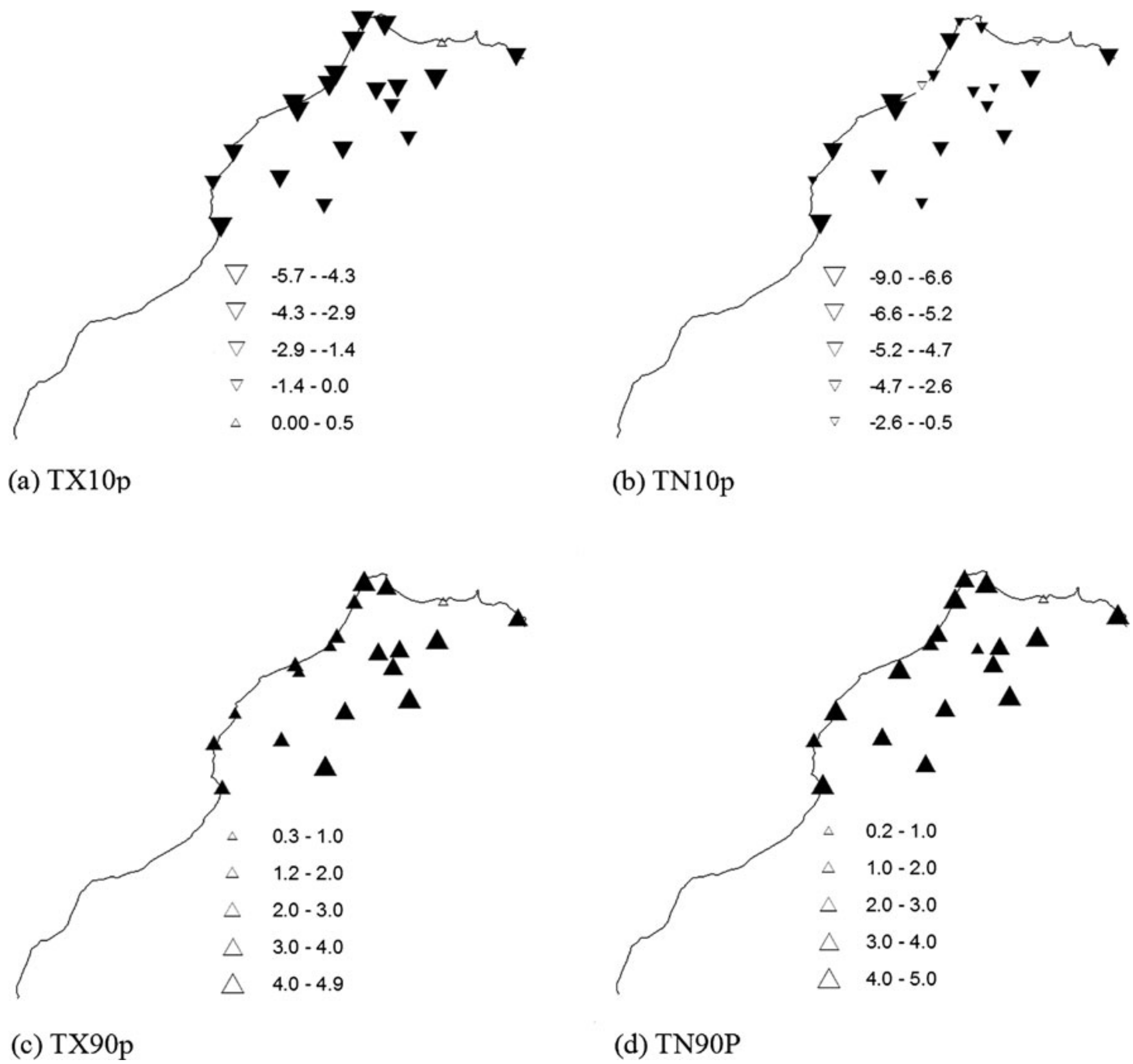

Fig. 2 Spatial distributions of the trends in the annual series of **a** TX10p, **b** TN10p, **c** TX90p, and **d** TN90p from 1970 to 2012. *Upward triangles* present increasing trends; *downward triangles* present decreasing trends. The size of the triangles shows the range associated with the magnitude of the 10-year trend. *Solid triangles* represent statistically significant trends at 5 % level

4 Results and discussion

4.1 Trends in temperature indices

4.1.1 Percentile-based temperature indices: TX10p, TN10p, TX90p, and TN90p

Figure 2a shows the spatial distribution of trends in the annual series of TX10p. The observed downward trends suggest a decrease in the number of cold days. The largest decrease can be found at Casablanca, Agadir, and Kenitra with changes equivalent to −5.7 % per decade. Trends are significant in all stations except for Alhoceima. Also, a decreasing trend is observed in the annual series of percentage of TN10p as showed in Fig. 2b. This trend suggests a decrease in the number of cool nights. The largest decrease was found at Agadir with values of −7.0 % per decade. The trends are significant in all stations except for Alhoceima and Rabat.

The spatial distribution of trends in the annual series of warm days is showed in Fig. 2c. The trends are generally of opposite signs compared to TX10p and also significant for all stations except for Alhoceima. The maximum value is observed at Ouarzazate with an increase of 4.8 % per decade. These values are indicative of a trend towards warmer days.

The trend in the annual series of percentage of days when daily minimum temperature is above its 90th percentile (TN90p) is shown in Fig. 2d. The trends are significant for all stations except for Alhoceima, and they have the opposite signs compared to the trends detected for TN10p. The maximum value is observed for Nouaceur with a 4.8 % increase per decade. These values indicate an increase in the number of warmer nights.

Table 3 displays the seasonal trend of TX10p, TX90p, TN10p, and TN90p. The seasonal trends for the 90th percentile of maximum temperature are highest in magnitude in spring and summer (>4 % per decade on average), but during the spring season (noted MAM), more stations have statistically significant trends than compared with other seasons. Similarly, the seasonal trends in the 90th percentile of minimum temperature are highest in spring and summer (>5 % per decade) as compared with other seasons. The increasing trends are observed in all stations except for Alhoceima in DJF and SON and for Meknes in DJF. The seasonal trends in the TX10p and TN10p indices are similar to those in seasonal trends of TX90p and TN90p but in opposite direction. The decreasing seasonal trends in TX10p and TN10p are observed, in general, in all stations. The decrease or increase in the seasonal data is generally similar to those observed in the

Table 3 Seasonal trends of TX10p, X90p, TN10p, and Tn90p. Data are shown for all seasons. Unit is percent per decade

	Tx10p				Tx90p				Tn10p				Tn90p			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
Alh	1.2	−0.8	0.7	*2.5*	−0.1	0.6	*1.8*	−1.4	1.7	−1.2	−1.7	0.5	−1.5	0.1	0.8	−0.3
Ben	−1.6	*−4.3*	*−5.1*	−0.6	1.9	*4.6*	*4.2*	*2.2*	−1.9	*−5.8*	*−5.7*	*−3.7*	0.6	*4.6*	*6*	*3.1*
Cas	*−3.4*	*−5.6*	*−5.3*	*−3.4*	1.6	*4.5*	1.5	1.3	*−5.7*	*−9.9*	*−8*	*−6.8*	*3.1*	*6.7*	*5.6*	*5.5*
Ess	−0.9	*−1.8*	*−2.4*	*−3.1*	1.9	*3.7*	*4.2*	0.02	0	*−3.2*	*−2.2*	*−2.8*	0.85	*3.6*	*4*	1.1
Fes	−1.8	*−5.3*	*−4.5*	−0.5	1.7	*4.2*	*4.1*	1.3	−0.3	*−1.2*	*−3.6*	*−3.5*	1.2	*3.9*	*3.9*	*2.8*
Ifr	−1.4	*−3.9*	*−3.7*	0.2	1	*4.4*	*6.6*	1.9	−0.6	*−3.4*	*−3.6*	*−2.4*	1	*4.2*	*4.6*	*2.5*
Aga	*−4*	*−5.1*	*−6.2*	*−6*	*3.1*	*2.7*	*4.3*	0.2	*−3.5*	*−7.8*	*−7.9*	*−5.5*	1.4	*5.5*	*6.1*	2.8
Ken	*−3.7*	*−1.1*	*−6.2*	*−2.9*	1.9	*4.9*	*2.5*	−0.4	−2.3	*−3.9*	*−3.3*	*−3.6*	0.2	*5.3*	*4.8*	*2.6*
Lar	−1.1	*−5.3*	*−5.1*	*−3.8*	1	*4.5*	*3.4*	0.4	*−3.6*	*−4*	*−5.9*	*−4.5*	0.4	*5.4*	*5.9*	*3*
Mar	*−2.2*	*−3.9*	*−4.7*	−2.1	*2.8*	*3.4*	*2.7*	1.2	−0.9	*−5.9*	*−6.1*	*−3.1*	1.5	*4.5*	*3*	2.1
Mek	−1.6	*−5.1*	*−5.3*	−0.6	1.6	*4.1*	*4.2*	1.8	−0.1	*−2.7*	*−1.4*	*−3.4*	−0.8	*3*	*2.4*	1.7
Mid	−1.1	*−3.6*	*−3.6*	0	1.5	*3.9*	*7.1*	4.6	*−2.8*	*−4.7*	*−6.4*	*−3.5*	*2.8*	*4.5*	*5.7*	*4.6*
Nou	*−3.3*	*−5.2*	*−5.7*	−1.8	1.2	*3.9*	*2.2*	−0.04	*−4.5*	*−6.8*	*−6.3*	*−6.1*	2.2	*5.5*	*6.3*	*4.9*
Ouj	*−2*	*−5.9*	*−5.3*	*−1.9*	2	*4.3*	*4.2*	1.6	*−3.5*	*−5.2*	*−6.5*	*−4.7*	1.5	*5.7*	*6.4*	*4.6*
Our	*−2.2*	*−2.9*	*−2.0*	−1.3	1.8	*3.5*	*5.5*	*4.6*	*−2.3*	*−5.4*	*−6.3*	−1.7	0.6	*4.5*	*4.9*	*3*
Rab	*−1.8*	*−6.2*	*−5.3*	*−2.4*	0.8	*3.6*	2.2	−0.3	1	−0.5	−1.1	−0.9	0.03	*4.9*	*4.6*	1
Saf	−1.3	*−4.6*	*−5.4*	*−2.3*	*2.1*	*2.6*	0.4	−0.1	−1.9	*−5.1*	*−5.5*	*−5.1*	1.2	*6*	*5.6*	*3.2*
Tan	*−2.2*	*−6.2*	*−6.9*	*−3*	*3.2*	*5.2*	*4.1*	2	1.4	−0.9	*−4.1*	−2	1.1	*5.1*	*4.9*	*5*
Taz	*−3.3*	*−5.4*	*−5.3*	*−1.5*	*3.2*	*5*	*6*	*2.7*	*−3*	*−5.8*	*−4.7*	*−5*	1.4	*5.6*	*6.4*	*4.1*
Tet	*−2.8*	*−5.6*	*−5.4*	*−3.3*	*2.9*	*3.4*	*4.5*	*2.4*	*−2.4*	*−3.7*	*−5*	*−3.1*	2.1	*5.9*	*5.2*	*2.3*

The numbers set in italics represent trends significant at 95 % CL annual data. In addition, more stations show significant trends from Mars to August, when more than 90 % of stations showed a statistically significant trend, compared to 50 % for the other half of the year.

4.1.2 Annual maximum and minimum value of daily annual temperature

The trends in absolute warmest and coldest temperatures of the year referred to as TNx (a), TNn (b), TXx (c), and TXn (d), respectively, are displayed in Fig. 3. The maximum of TX and TN shows a largest number of significant and positive trends compared to the minimum of TX and TN. Areas with positive trends are much larger than those with negative trends; only a few stations observe negative trends especially in the annual minimum values of daily minimum (Fig. 3b) and maximum (Fig. 3d) temperature, but these trends are not statistically significant. The warmest daily maximum temperature TXx has significant positive trends in all inland stations (more than 0.5 °C per decade).

Table 4 displays the seasonal trend of TXn, TXx, TNn, and TNx. The spatial patterns of trends differ from season to another. We observe the difference in both terms of magnitude and significance for the trends. Among the four seasons, spring and summer shows, in general, the greatest warming. The TXx index has statistically significant trends during MAM at all station except at Safi and at 12 stations on JJA. The maximum increase is 1.9 °C per decade, observed at Meknes followed by 1.6 °C at Kenitra on MAM. The trend was, in general, positive in all seasons, and this is consistent with annual trend. TNx index has statistically significant trends during MAM and JJA in all stations except at Alhoceima; the maximum increase is around 1 °C at Casablanca in MAM. The same for TNn, the maximum increase was observed at Casablanca, while for TXn, the maximum was observed at Ifrane in summer. From these results, it

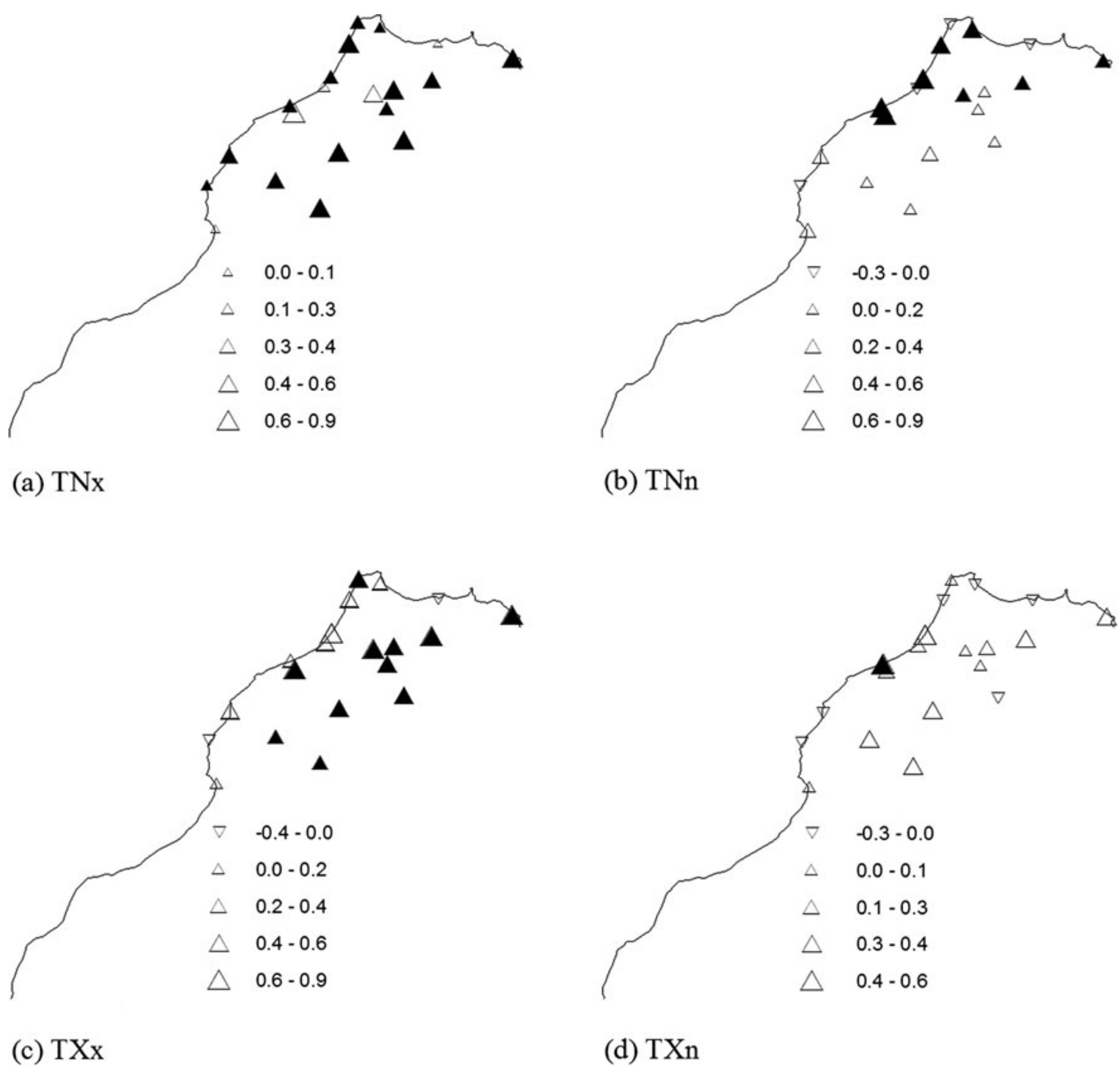

Fig. 3 Same as Fig. 3, but trends for **a** TNx, **b** TNn, **c** TXx, and **d** TXn

Table 4 Seasonal trends of TXn, TXx, TNn, and TNx. Data are shown for all seasons. Unit is °C

	TXn				TXx				TNn				TNx			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
Alh	−0.2	0.1	−0.03	*−0.3*	−0.3	*0.6*	0	−0.4	−0.2	−0.02	0.1	0.02	−0.3	0.1	0	0
Ben	*0.4*	*1*	*1*	−0.1	0.1	*1.1*	*0.7*	0.3	0.2	*0.7*	*0.7*	*0.5*	0	*0.6*	*0.7*	*0.4*
Cas	*0.4*	*0.4*	*0.4*	*0.3*	0.1	*1.3*	0.2	−0.2	*0.8*	*1.2*	*1.2*	*1*	*0.6*	*0.9*	*0.7*	*0.6*
Ess	0.04	0.1	*0.3*	0.3	0.4	*1.1*	0.4	−0.4	0.1	0.2	*0.2*	0.07	0.1	*0.5*	*0.4*	0.1
Fes	*0.4*	*0.8*	*0.9*	−0.1	0.1	*1.2*	*0.6*	0.3	0.1	*0.4*	*0.6*	*0.5*	0.2	*0.7*	*0.9*	*0.5*
Ifr	0.3	*0.8*	*1.2*	−0.3	0.2	*0.8*	*0.5*	0.2	0.3	*0.5*	*0.6*	*0.4*	0.1	*0.8*	*0.6*	*0.4*
Aga	*0.3*	*0.3*	*0.4*	*0.5*	0.2	*0.9*	0	0	*0.5*	*0.9*	*0.9*	*0.7*	0.3	*0.7*	*0.5*	0.1
Ken	*0.3*	*0.6*	*0.6*	0.2	0.2	*1.6*	0.8	0.6	0.3	*0.5*	*0.4*	*0.5*	0.1	*0.6*	*0.5*	*0.2*
Lar	0.2	*0.5*	*0.7*	0.1	0.2	*1.2*	*1.0*	0.5	*0.5*	*0.6*	*0.6*	*0.6*	0.03	*0.9*	*0.9*	*0.5*
Mar	*0.5*	*0.6*	*0.9*	0.1	0.04	*0.8*	*0.4*	0.2	0.1	*0.6*	*0.6*	*0.3*	0.2	*0.8*	*0.7*	0.4
Mek	0.2	*0.8*	*0.9*	−0.02	0	*1.9*	*0.9*	0.4	0.03	0.3	*0.3*	*0.4*	0.1	*0.5*	*0.5*	0.2
Mid	0.1	*0.7*	*0.9*	0.2	0.4	*0.7*	*0.6*	0.3	0.3	*0.5*	*0.8*	*0.4*	0.2	*0.7*	*0.7*	*0.6*
Nou	*0.3*	*0.7*	*0.6*	0.2	0	*1.4*	*0.6*	0.4	*0.5*	*0.9*	*1*	*1.1*	0.3	*0.7*	*0.8*	*0.5*
Ouj	0.4	*0.7*	*0.9*	0.3	0.2	*1.3*	*0.9*	0.4	*0.4*	*0.6*	*1*	*0.8*	*0.4*	*0.8*	*0.8*	*0.7*
Our	*0.5*	*0.7*	0.2	0.4	−0.2	*0.5*	*0.3*	*0.3*	0.1	*0.9*	*0.9*	0.3	0.1	*0.8*	*0.7*	*0.6*
Rab	0.7	*0.5*	*0.4*	0.2	−0.1	*1.4*	0.6	0.1	−0.1	−0.01	*−0.01*	0.04	0.1	*0.6*	*0.4*	0.1
Saf	*0.3*	*0.3*	*0.4*	*0.3*	−0.1	0.7	0.5	−0.1	0.3	*0.6*	*0.7*	*0.6*	0.3	*0.7*	*0.6*	*0.4*
Tan	0.1	*0.6*	*0.6*	0.1	*0.4*	*1.1*	*0.6*	0.5	−0.2	−0.1	*0.3*	0.3	0.03	*0.5*	*0.5*	0.3
Taz	*0.3*	*1*	*1.2*	0.1	0.5	*1.4*	*0.6*	*0.7*	*0.4*	*0.6*	*0.7*	*0.6*	0.1	*0.7*	*0.8*	*0.4*
Tet	0.1	*0.6*	*0.7*	0.2	0.4	*0.7*	*0.3*	0.5	*0.4*	*0.5*	*0.8*	*0.5*	*0.2*	*0.4*	*0.3*	*0.3*

The numbers set in italics represent trends significant at 95 % CL

is apparent that warming in spring and summer maximum temperature contributes the most to the warming in the annual maximum value of daily maximum temperature.

4.1.3 Fixed threshold-based indices

The annual fixed threshold-based indices are computed for the 20 Moroccan stations. Figure 4 shows the spatial distribution of SU25 (Fig. 4a), TR20 (Fig. 4b), WSDI (Fig. 4c), and DTR (Fig. 4d). There is a clear increase in the number of nights and day for both indices SU25 and TR20; only Alhoceima shows a decrease but not significant, and there is no trend observed at Essaouira in SU25. The largest increases are observed at Agadir and Kenitra with 16 days per decade (Taza with 12.5 days per decadale) for SU25 (TR20), respectively. Most stations show statistically significant trends, except at Alhoceima and Essaouira (Alhoceima and Meknes) for SU25 (TR20), respectively.

Figure 4c shows the spatial distribution of the WSDI index; no trends are found for 14 stations. The 6 other stations show an upward statistically significant trend, and the maximum is observed at Ouarzazate with 3.75 % days per decade. DTR (Fig. 4d) represents the monthly mean difference between TX and TN. Eight stations have statistically significant trends. The increasing trends are much stronger than the decreasing trends, and it is largely due to the maximum temperature having increased more than minimum temperature.

4.2 Trends in precipitation indices

For RX1day and RX5D, only a few significant trends are detected (Fig. 5a, b) at 4 and 2 locations, respectively (Agadir, Essaouira, Tetouan, Al Hoceima) indicating a possible increase in wet days. For maximum 1-day precipitation (RX1day), the dominance of positive trends is clear with a maximum at Agadir (+6.7 mm per decade). At four stations, the trends are statistically significant compared to two stations for RX5day (Fig. 5b). These indices are the indicator of wet day events that can produce flood events. Similarly, five statistically significant trends are observed for the percentile-based indices quantifying very wet days, R95p (Fig. 5c); the maximum trend is observed at Tetouan with 35 mm per decade. Figure 5d shows the simple daily intensity index (SDII), defined as the mean daily intensity for events greater than or equal to 1 mm per day. Trends at six coastal stations were found to be statistically significant; all of them are positive. The largest increase is computed at Essaouira with 0.9 mm per

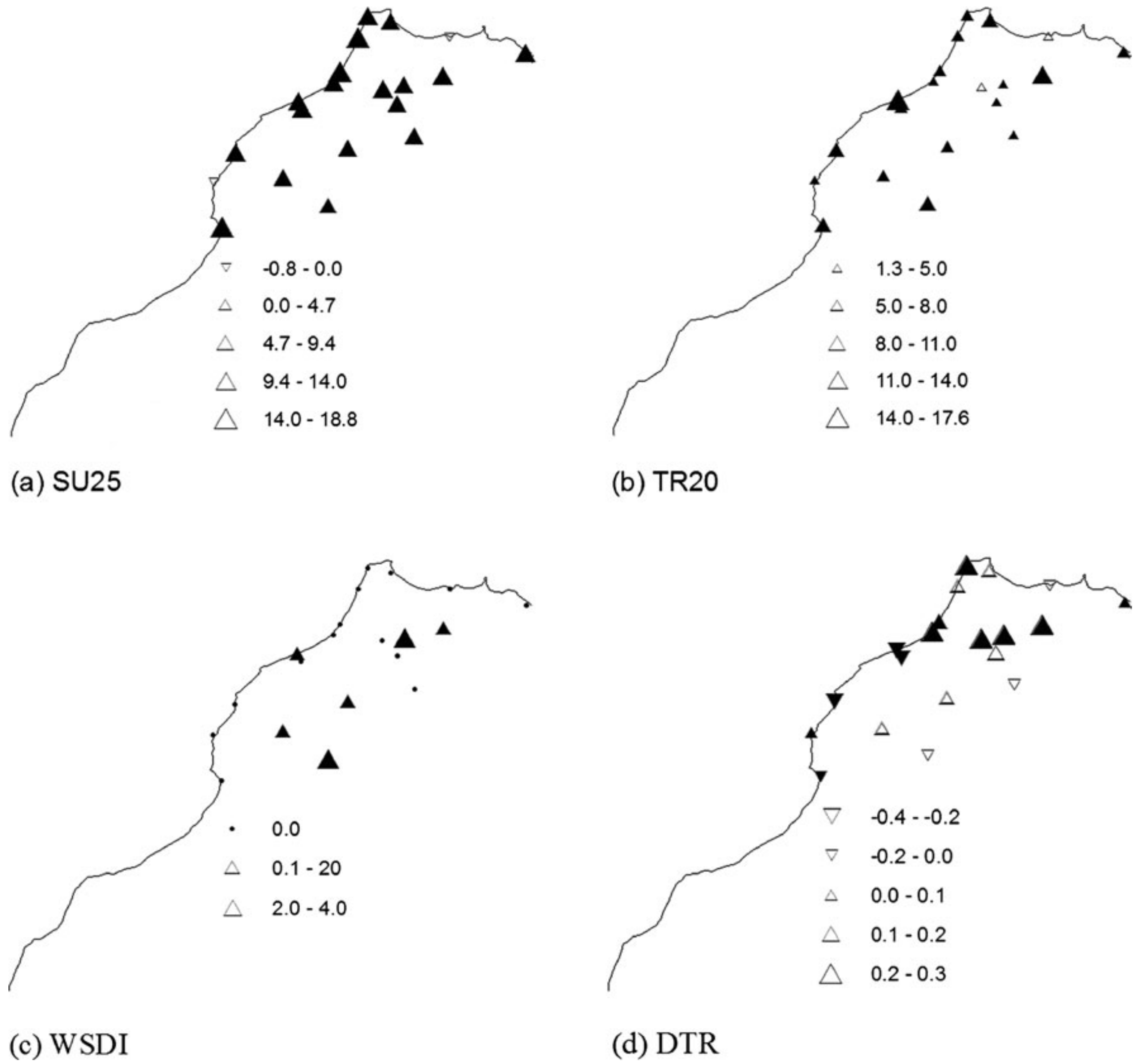

Fig. 4 Same as Fig. 3, but trends for **a** SU25, **b** TR20, **c** DTR, and **d** WSDI

decade. Overall, very mixed spatial patterns are observed with upward or downward trends even in neighboring stations.

For PRCPTOT (Fig. 6a), decreasing trends are detected for the majority of stations, yet these trends are only significant at a few stations. This result is consistent with those of Tramblay et al. (2013) or Donat et al. (2013) obtained with different sets of stations over North Africa. In particular, it must be noted that the decreasing trends are observed in the Northwestern region or Morocco (Meknes, Fes, Ifrane, Taza, Rabat.), where most of the largest dam reservoirs are located (Sebou, Loukkos, Bouregreg basins) indicating an increase of the stress for water resources. The maximum trend is observed in Tetouan (55 mm per decade), while the minimum trends is observed in Taza and Meknes (−49 mm per decade). The number of heavy precipitation days shows the annual count of days when precipitation is greater than 10, 20, and 25 mm noted, respectively, R10 (Fig. 6b), R20 (Fig. 6c), and R25mm (Fig. 6d). Much less changes are detected for these indices, with respectively five statistically significant trends for R10 and four statistically significant trends for both R20 and R25, with mixed patterns of positive and negative trends. There are much more significant positive trends than significant negatives trends; all of R25 significant trends are indicating an upward trend. Overall, this study over Morocco shows that the trends in precipitation indices are much less spatially coherent and less significant compared to temperatures extremes. Indeed, in semiarid areas, precipitation exhibits a strong spatial and temporal variability, as previously observed by Tramblay et al. (2013) in the Maghreb region.

4.3 The effect of NAO, MO, and WEMO

We investigated the relationships between the large-scale atmospheric circulation over the North Atlantic-European-Mediterranean area, represented by the NOA, MO, and

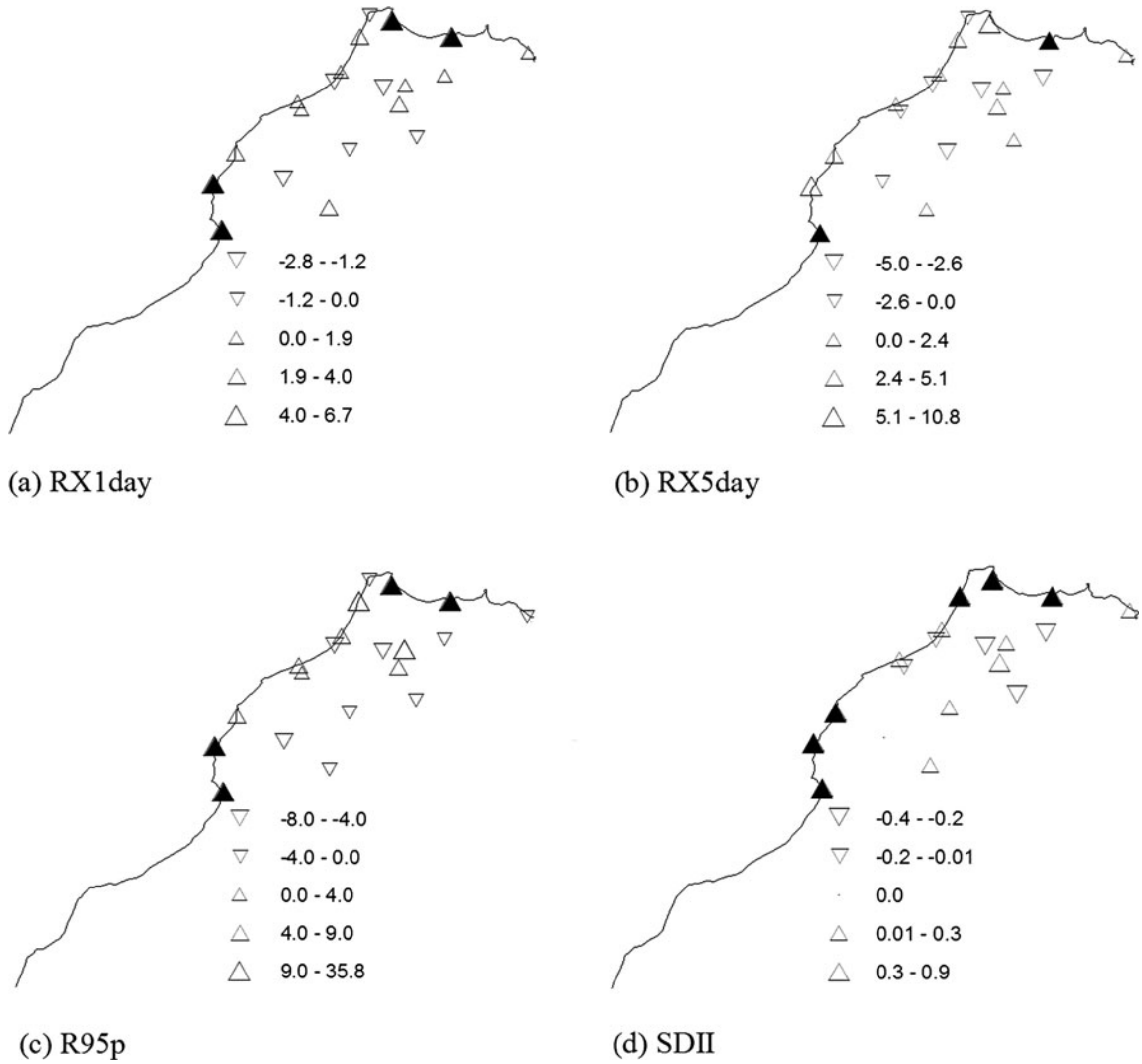

Fig. 5 Same as Fig. 3, but trends for **a** RX1day, **b** RX5day, **c** R95p, and **d** SDII

WEMO indices and the extreme climate indices. In this study, we used the annual correlation between the two sets of indices in an attempt to possibly explain the observed trends by large-scale influences. Generally, we observe a stronger teleconnection for the precipitation indices than for the temperature indices, and a larger number of correlations with MO or WEMO indices than with the NAO. From 12 indices based on maximum and minimum temperature, only two (DTR and TN10p) among them have significant correlations with MOi and WEMOi (Fig. 7). A large number of significant correlations are obtained with the eight indices based on precipitation. The PRCPTOT, R25mm, R20mm, and R10mm indices show the largest number of significant correlations with MO and WEMO indices. Figure 8 shows the spatial distributions of the correlations found for the PRCPTOT and R10mm indices with the MOi. We observe that the correlations are significant in several stations mainly located on the Atlantic coast. For non-coastal stations, only Midelt and Ourzazate show significant correlations between PRCPTOT and R10mm and MOi. It must be noted that the correlations are not very strong, the maximum Spearman correlation coefficients are −0.5 at Safi for PRCPTOT and −0.4 for R10mm observed at Essaouira, Kenitra, and Tetouan. This means there is not a strong correlation between the extreme climate indices calculated in this study and the large-scale circulations indices of NAO, MO, and WEMO, as previously noted for the NAO index in Morocco by El Hamly et al. (1988) The relationships found between NAO and climate extreme indices are weaker compared to the relationships observed with MO and WEMO indices. Some other teleconnection patterns are known to influence precipitation in the Mediterranean region to a lesser extend, such as the East Atlantic or the Scandinavian patterns, but they are not considered in the present study since their influence is mainly noticeable in the northern part of the Mediterranean basin (Lionello 2012).

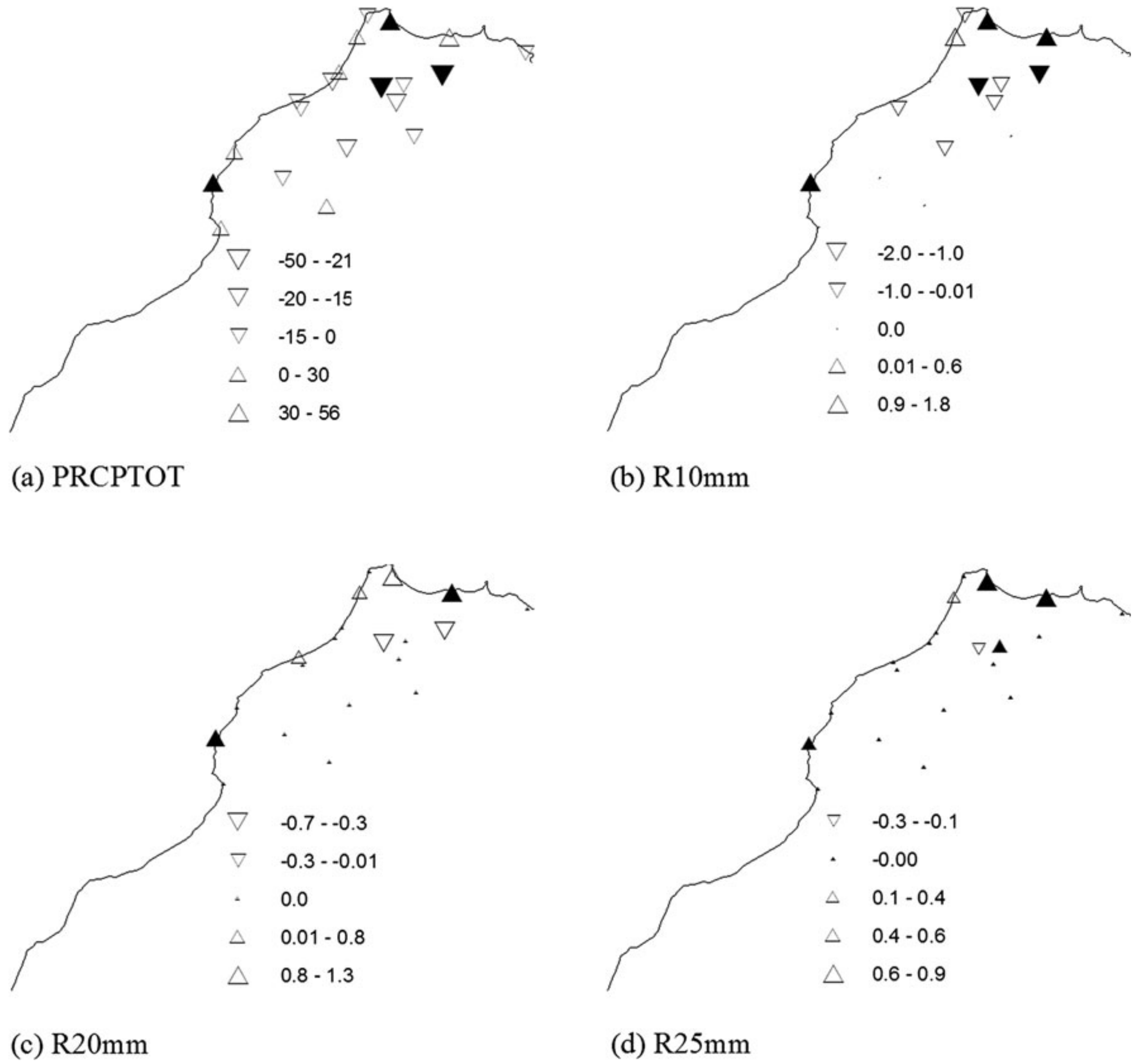

Fig. 6 Same as Fig. 3, but trends for **a** PRCPTOT, **b** R10mm, **c** R20mm, and **d** R25mm

5 Summary and conclusions

This study provides an assessment of trends in temperatures and precipitation indices in Morocco, using the national network of synoptic meteorological stations managed by Maroc-Météo. Most of the stations of this network are located in the northern part of Morocco, covering the most important agricultural zones and also the rainiest regions that are contributing for most of the country's water resources. The set of 27 indices recommended from the ETCCDI expert team to ensure international comparisons between studies has been computed for 20 stations having long data records of daily temperature and precipitation. Daily data of 43 years from 1970 to 2012 have been processed in the study to assess the long-term interannual variability of different temperature and precipitation characteristics.

The trend analysis results indicate more statistically significant trends for temperature than for precipitations indices. The indices based on temperatures over the past 4 decades shows an increase in the number of warm days and nights, and a decrease in the number of cold days and nights, identified in all indices: percentile-based temperature indices, annual maximum and minimum value of the daily annual temperature and also fixed threshold-based indices. These results are similar to those obtained by Brunet et al. (2007) or Hertig et al. (2010), indicating that these changes are regional since they affect the western part of the Mediterranean basin.

For precipitation, much less little significant trends have been found compared to temperature trends and these trends are mostly significant for the coastal sites. Precipitation indices show a tendency towards wetter conditions for a few locations in the extreme north of Morocco, compared to the drier conditions in the south. There is a possible increase in the frequency of heavy precipitation events (i.e., R20mm and R20mm) only at two stations located in the Mediterranean region, together with an overall decrease of precipitation

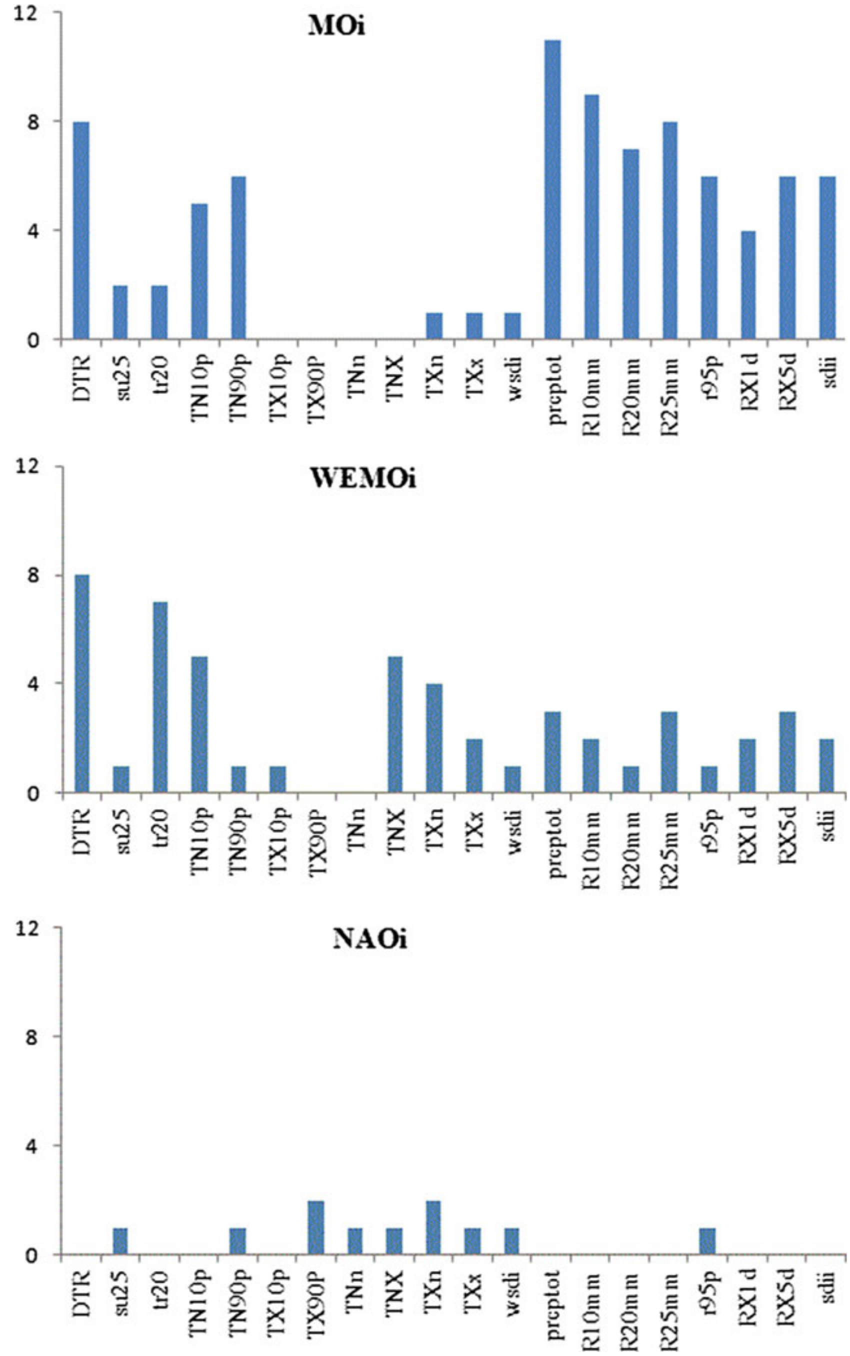

Fig. 7 Number of stations with significant correlations with Moi, WEMOi, and NAOi at the 5 % significance level

totals. These results are in agreement with Räisänen et al. (2004) or Tramblay et al. (2013) who observed that average precipitation reduction in North Africa may be associated with a reduced number of precipitation days.

We also investigated the annual teleconnection between climate extremes and large-scale atmospheric circulation patterns, described by the NAO, MO, and WEMO indices. The relationship between MO, WEMO, and the climate extreme indices considered in our study is stronger compared to the relationships found with NAO. There is a significant correlation at different locations between precipitation totals, heavy and very heavy precipitation events with the MO and WEMO indices mostly. The largest numbers of significant correlations with large-scale patterns are found for the costal stations but the correlation coefficients remain low and do not exceed 0.5. Therefore, we can conclude that for the extreme climate indices considered in the present study, there is not a strong correlation with large-scale circulation indices such as the NAO, MO, and WEMO. These indices are not sufficient alone to explain the variability and the trends observed for the temperature and precipitation indices considered in the present study. It means that the local factors, such as the orography and the

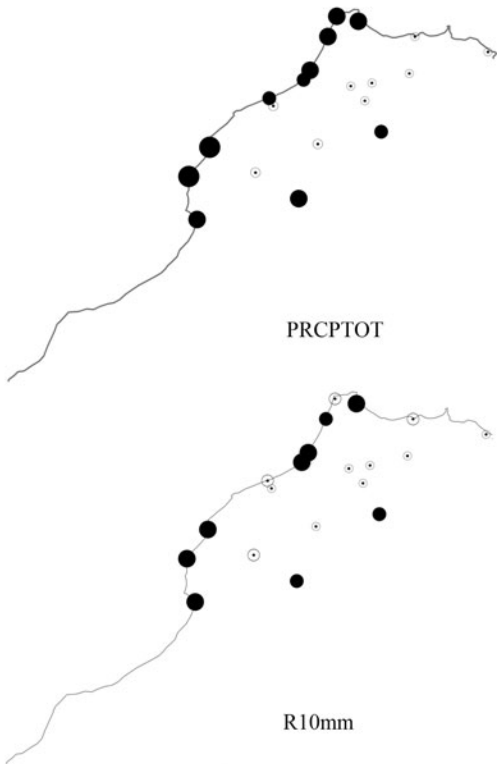

Fig. 8 Correlation between PRCPTOT and R10mm and the MOi indices at the different stations. The size of the circles is proportional to the Spearman correlation coefficients. The *circles filled with black* are the stations where the correlation is significant at the 5 %

local climate characteristics may have a similar, or even a greater, impact than large-scale circulation changes on the observed trends. Indeed, Morocco's climate is semiarid and influenced by a wide range of regional and topographic effects. Its climate is cooled by sea breezes originating from the Atlantic Ocean and the Mediterranean Sea. In the interior of the country, due to the high mountain areas in the Atlas and Rif regions (reaching up to 4000 m for the High Atlas, 2000 m for the Rif Mountains), Fohen winds, and orographic effects can raise the temperatures and dry the wind blowing down the opposite slopes of the mountains. Also, convection near the humid regions (Mountain ranges) gives heavy local precipitations events during summer. In addition, continental hot and dry easterly or southeasterly wind from Sahara named Chergui blows on the most part of Morocco mainly during summer.

Further research in Morocco should now focus on producing regional scenarios of possible climate change impacts, in order to improve the mitigation strategies. The present study is a first step aiming to validate, or refute, the stationarity hypothesis for several climate characteristics of Morocco, since this stationary hypothesis underlays several downscaling methods. Different studies have shown that the projected changes by climate models over the Mediterranean domain indicate a warming that could reach up to +3 °C for temperature and −30 % in precipitation over Morocco (Hertig et al. 2010; Schilling et al. 2012; Driouech et al. 2013). However, there is a need to develop specific approaches tailored for Moroccan climate conditions, using either high resolution regional climate models (Driouech et al. 2009) or statistical downscaling methods (Jacobeit et al. 2014) validated against observed temperature and precipitation.

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