Chapter 9
Low Frequency Winter Rainfall Variability in the North West of Morocco

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Abstract The main characteristic of the rainfall climate in the North West of Morocco is its strong interannual variability which is due to its eccentric latitudinal position on the fringe of the North Atlantic mid-latitude baroclinic region. Linked to the North Atlantic large scale circulation variation and winter extra-tropical disturbance, the rainfall events in our region are closely connected to the NAO regime as the dominant winter mode of low-frequency variability over the North Atlantic sector. The swings between one phase to another of this regime produce large changes in storminess and precipitation over our region. The temporal rainfall evolution over the last 60 years shows two characteristic sub–periods: the first one is dominated by more rainy winters from 1950–1951 to 1978–1979, and the second one has frequently experienced more dry winters, particularly between 1979–19 80 and 2008–2009 usually with many persistent and severe long drought episodes. Both sub–periods exist in a causal relationship with one of the two phases of the NAO. In the first sub-period, under the effect of a negative phase of this pattern, a southward shift in the storm–track is produced, which can easily reach our latitude and give rise to rainier winters. The second sub–period is subject to an increase in frequent persistent and intensive positive phase events, which generate enhance a northward shift of the mid-latitude storm–track and deficiency conditions, and which can affect our region substantially.

Keywords North West Morocco • Winter rainfall variability • North Atlantic Oscillation • Intense irregularity

9.1 Introduction

The Moroccan rainfall climate is characterized by a rather erratic intra and inter-annual variation that is quite evident; this refers to the overall variability of rainfall events whose frequency and intensity are very much dependent on the state of the general circulation and its changes in our latitudes. The general trend which has

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been present over the last six decades reflects a net decrease in annual rainfall quantities with a rather mixed seasonal distribution. The analysis of the overall variability of rainfall and its intra – annual irregularity in the literature uses various methods while overall giving a prominent place to the relations with some major modes of atmospheric circulation (Hurrell 1995).

Many studies have already shown the more or less marked influence of the evolution of atmospheric conditions on the overall variability of climate elements (Goodess and Jones 2002; Herrera et al. 2003; Kucharski and Molteri 2003; Trigo et al. 2002; Quadrelli et al. 2001; Martin-Vide and Lopez-Bustins 2006; Haylock and Goodess 2004; Lorenzo et al. 2008; Ortizbevia et al. 2011; Knippertz 2004; Hurrell and Deser 2009). Thus, taking account of a more structured approach, a certain number of major circulation patterns with repeated occurrence contributes to a better understanding of the evolution of the average isobaric situation patterns which as a consequence shapes the basic features of the climate and its character.

The notion of weather regime (*weather régime*) seems to sum up perfectly the evolution of general circulation in the North Atlantic and Western Mediterranean. The concept itself as it is introduced in the specialized literature by synopticians since the early 1950s, is based on the idea of atmospheric circulation evolving between a limited number of atmospheric states (Plaut and Simonnet 2001; Michelangeli et al. 1995).

These weather patterns and their temporal succession are now regarded as the main factors underlying much of the variability of weather and climate in their area of influence (Hurrell and Deser 2009). The geographical position of Morocco in the area of influence of the Azores anticyclone, one of the main structural poles of these major patterns of movement, place it in the context of the atmospheric dynamic that is strongly marked by fluctuations in space and in time, the famous "depression or storm track". This governs most of the rainfall conditions of the middle and subtropical latitudes (Kvamto et al. 2008).

Four weather regimes define the main configurations of the general circulation of the North Atlantic, as identified by Vautard (1990), Michelangeli et al. (1995), Cassou et al. (2004), and Cassou (2008): The Blocking regime, the Atlantic Ridge, and both the positive and negative phases of the North Atlantic Oscillation (NAO).

Of these four régimes, only the latter two are considered to be those that mark the most deeply in terms of intensity and orientation the disturbed mid-latitude flows and therefore the overall variability of precipitation in this area of the North Atlantic (Barnston and Livezey 1987; Hurrell and Deser 2009; Shabbar et al. 2001; Trigo et al. 2002; Rodriguez Fonseca et al. 2006). In other words, it is the alternating passage from one situation to another including intermediate or transitional situations, which determine most of the general variation in rainfall climate of our region. The relatively eccentric position of our latitudes in particular, and of the Mediterranean in general, that influences our weather regime possesses a special character to the extent that the alternation of two phases of the NAO undeniably brand and roughly determines the length of the rainy season in the winter months. The highly variable trajectories of depressions here more than anywhere else, give the rainfall in our region its character at times random and certainly very irregular.

9.2 The Data

The data used for this study are first monthly precipitation amounts from the Global Precipitation Climatology Centre (GPCC) (GPCC Full Data Reanalysis Version 5) and spatilized by grid points, covering the north western area of Morocco. We selected seven grid points with a resolution of 2.5° × 2.5 ° (P1: 35°N 7.5°W; P2: 35°N 5°W; P3: 32.5°N 10°W; P4: 32.5°N 7.5°W; P5: 32.5°N 5°W; P6: 30° N 7.5°W; P7: 30°N 5°W) (Fig. 9.1). Data were used with a geopotential of 500 hPa from NCEP/NCAR, of 5° × 5° extending from latitude 25 to 60° North and 60°W to 40°East, or about 168 grid points. The values of the NAO index are based on the pressure difference between the ground stations of Gibraltar and Akureyri (Iceland). All these data were recalculated to transform them into a seasonal winter series (December, January, February) over the period 1950–51 to 2008–09.

9.3 An Intensely Variable and Very Erratic Rainfall

Winter precipitation averaged about 40–45 % of annual totals recorded in our region, which gives them a dominant role as the main component of rainfall. The contribution of these winter rains is essential in defining and determining the

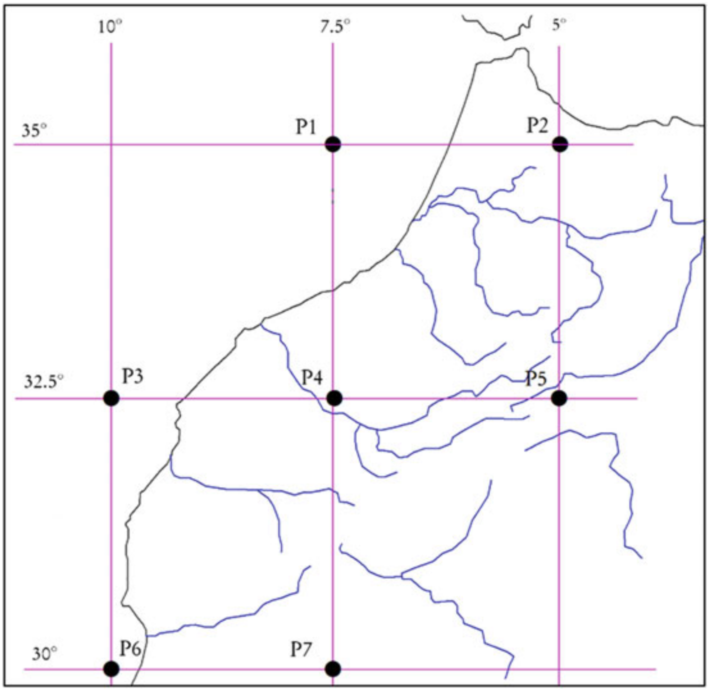


Fig. 9.1 Sketch of the locations of the grid points used

average rainfall profile, and their fluctuations directly affect the agricultural and water potential of the wettest part of the country.

The rainfall during this season generally follows two gradients more or less characteristic, first and most importantly from north to south and secondly, of lesser importance, from west to east. If the northern part of the country is favoured mainly because of its latitudinal position that makes it more subject to the different trajectories of perturbations and therefore is thus the wettest, the southern part is less so, due to the low frequency on average of disturbances. On average (normal for winter 1960–1961/1989–1990): 229.27 mm (35°N 7.5°W), 152.34 mm (35°N 5°W), while further south these averages remain below 41.68 mm and 25.90 mm respectively for the grid points (30°N 10°W and 30°N 7.5°W).

The rains of this season increase steadily towards the interior under the effect of the altitude on the western slopes of the Rif mountains in the north and of the Middle Atlas in the centre, before declining significantly further east on the eastern slopes of these mountains. This is even more evident in the central part of our region, the winter normal of which is just slightly over 100 mm: 118.52 mm and 110.71 mm respectively for the grid points 32.5° 10°W and 32.5°N 7.5°W. On the same latitude but located much further to the east, the grid point 32.5°N 5°W only receives on average 26.30 mm.

9.3.1 *Temporal Evolution of Two Contrasting Sub-Periods*

Changes in seasonal winter heights over the last 60 years from 1950–1951 to 2008–2009 show a distribution dominated by a relatively high variability which is essentially characterized by being relatively higher in the wetter north with more rainfall than the southern sector, and in coastal areas more than in the interior (Fig. 9.2). One observes as well an irregularity that is much stronger in the north than in the south.

The temporal distribution of the heights of winter precipitation during the study period generally shows a succession of quite variable and contrasted periods of rainfall that denotes generally a highly volatile and highly irregular character.

A sensitive wetness characterizes the winters of the 1950s, 1960s and 1970s, which stand out in terms of the volume of rainfall that generally exceeds the seasonal norm, sometimes with maximum concentrations as was the case in 1955–1956 which sometimes had a cumulative total of +3 σ +5 σ in the center and south of the region. In contrast, the winter of 1958–1959 experienced a significant deficit for the country as a whole with volumes that occurred below −1σ and −1.7σ in the north and centre. During the 1960s, the winters of 1962–1963, 1963–1964 and also that of 1964–1965 which posted the second largest volumes of rainfall exceeding +1 σ +2σ everywhere. The two successive winters of 1965–1966 and 1966–1967 showed on the other hand very low rainfall amounts of about −0.6 σ and −1.5σ.

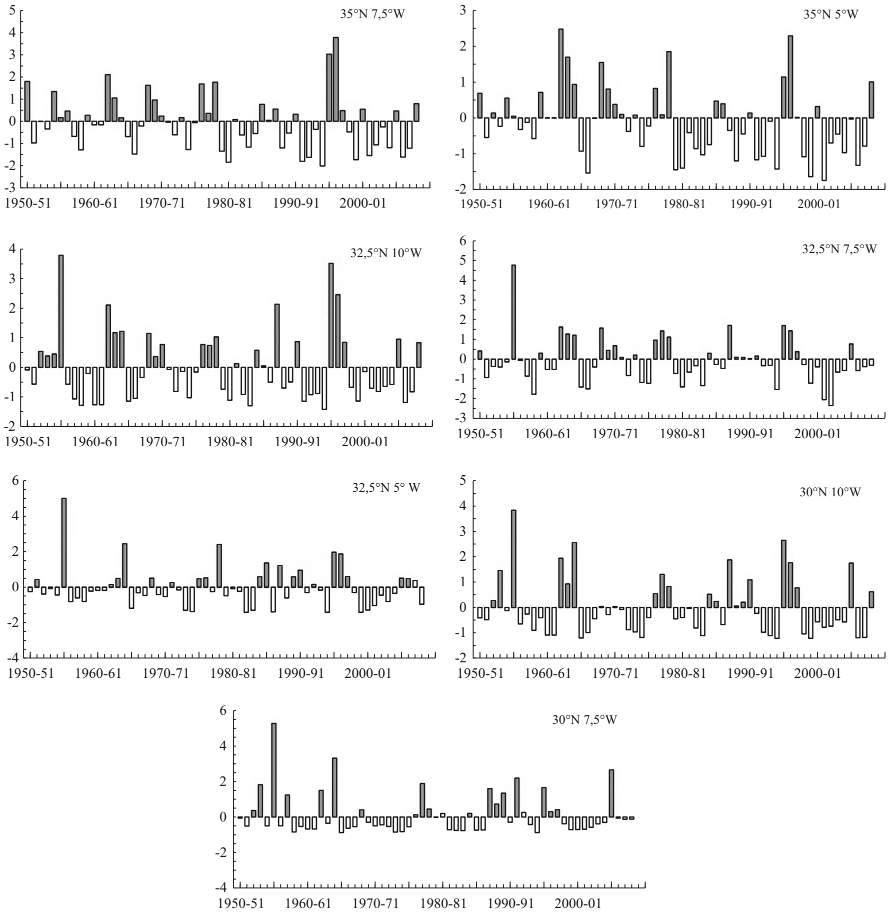


Fig. 9.2 Temporal evolution of deviations from the normal (1961–1962 to 1990–1991) of the winter totals from 1950 to 1951/2008 to 2009 of the different grid points selected

The 1970s saw overall a very average rainfall with volumes around $\pm$ 1σ, but with a significant winter 1974–1975 deficit everywhere, with quite low volumes showing differences in the order of $-0.7\ \sigma$ to -1σ. The winters of 1977–1978 and 1978–1979 marked a short period of significantly high rainfall where almost everywhere one notes excess values and relative concentration of rainfall around +1σ to 1.5σ in the north and centre, particularly during the 1978–1979 season.

The year 1979–1980 marks the beginning of a period of recurrent rainfall deficit especially in the winter, which significantly differentiated it from the average rainfall profile over the previous three decades. General weakness and predominant rainfall of this period contrasted remarkably with the first period of the study which identified an increased frequency of years with very few rainy winters and with deviations from the normal dropping significantly each time below -1σ. This is thus a period that saw widespread and recurrent droughts, notably in1979–1980/1983–1984, 1991–1992/1994–1995, 1998–1999/1999–2000, 2001–2002/2002–2003 and 2006–2007/2007–2008. The generalized deficit which hit the country over the past three decades has been of an unparalleled intensity and persistence so far. Some years in this period were illustrated by the strong deficit of their winters such as those of 1979–1980 and 1980–1981 with some gaps that were around -2σ in the north and centre of the country. During the winter of 1983–1984, the winter drought extended throughout the country and the total rainfall remained well below -1σ. On the other hand, the 1987–1988 year was the only year when winter rains showed a surplus of about +1 to + 2σ, mainly in the centre and south of the country.

The 1990s saw the phenomenon being further amplified and generalized, with the rainfall deficit affecting first the north of the country from 1991–1992 to 1992–1993 with anomalies of from -1σ to -1.6σ. The year 1994–1995 was one of the most severely dry years both in duration and scope, since it had not rained enough in any season and especially during the winter everywhere, and the rainfall deficit varied throughout the country from -0.87σ to -1.97σ. The next 2 years 1995–1996 and 1996–1997 experienced, however, extremely wet winters with high rainfall concentrations with volumes showing surpluses of $+1\sigma$ to $+3.5\sigma$ and $+1.4\sigma$ to $+3.7\sigma$ respectively. The very rapid pace of change reflects the highly irregular nature of the rainfall climate, and highlights the propensity to observe amplified interactions with extreme events. Two years later, the winter of 1999–2000 showed another negative anomaly of about -0.71σ to $-1.69\ \sigma$ across the country. The winters of 2000–2001 and 2001–2002 also show a generalized deficit of -0.42σ to $-.5\sigma$, but which reached almost -2σ in the centre.

Winter precipitation was fairly small during the period 2003–2004 to 2007–2008 with deviations from the normal generally around $-0.5\ \sigma$, with the exception of the winter of 2005–2006, which was relatively wet, especially in the south where it reached surplus of $+1.8\sigma$ to $+2.6\sigma$. The following years saw their winters accumulate very insufficient amounts of rainfall of the order of -0.5σ and -1.57σ, particularly in the north and south, while the winter of 2008–2009 was characterized by fairly average volumes especially in the north.

The comparison between the two sub-periods (Table 9.1) shows that the proportion of volumes larger than 1 standard deviation has a relatively higher frequency in the first compared to the second period. In contrast, the frequency of volumes less than 1 standard deviation is generally more important in the second period. In other words, it rained more heavily during the first period than in the second half which experienced more occurrences of average to modest cumulative averages, or even insignificant accumulations. The contrast between the two sub-periods is even more intense in the extreme north of the country which was significantly wetter. The incidence of low volumes shown here in the second sub-period increased by almost three to five times compared to the first sub-period, while relatively large quantities declined by two to three times during the second period.

Table 9.1 Percentage frequency of winter cumulative rainfall anomalies less or greater than one standard deviation for the two sub-periods (1950–1951/1978–1979) and (1979–1980/2008–2009)

	1950–1951/1979–1980		1980–1981/2008–2009	
	≥1σ (%)	≤1σ (%)	≥1σ (%)	≤1σ (%)
35°N 7.5°W	13.3	23.3	41.4	6.9
35° N 5° W	6.7	13.3	34.5	6.9
32.5° N 10° W	20	16.7	20.7	10.3
32.5° N 7.5° W	16.7	23.3	10.3	13.8
32.5°N 5° W	10	10	24.1	13.8
30°N 10° W	16.7	16.7	27.6	17.2
30° N 7.5° W	0	20	0	17.2

9.3.2 *Increasingly Deficit Prone Winters in the North and Centre*

Our latitudinal rainfall climate falls in the southern margin of the temperate and Mediterranean reference area accounts for its intensely variable and quite irregular climate conditions. The irregularity of the Mediterranean climate appears to be (according to Garcia-Barron et al. 2011) a key feature that emphasizes even more the reality of the non stationarity of the climate, specifically with regard to its latitudinal position.

The graphic display of Fig. 9.3 which shows the cumulative deviations from the average (normal) values reveals very clearly the dominant evolutionary trend on our rainfall data series. Thus, one can distinguish a first period characterized by the winters of 1950–1951 to 1978–1979 that is more or less humid, and whose rainfall levels often show deviations from the normal that overall are positive. The second period is characterized by a decreasing trend of the curve, which occurs in a two-time grouping first of the winters from 1979–1980 to 1994–1995, with a net decrease of rainfall during this season especially in the north (35°N). This decrease appears to be easing a bit in the centre of the country (32.5°N), and the intensity of this decrease is here more pronounced particularly along the coast. The advent of two exceptional years 1995–1996 and 1996–1997, and the maximum concentration of winter rainfall levels during these years have contributed significantly to cushion the sharp drop in levels after that date, while afterwards during the early 2000s there was a continuation of considerably greater negative deviations. However, the overall deficit that seems to characterize the latter period in the north and centre of the country appears to give rise to relatively differential intensities. In the north, this decrease appears to be common to both the coastal areas and inland initially and then becomes lower on the coast during the 2000s. In contrast, in the centre this general decrease in rainfall is more pronounced on the coast than in the interior although the differences become noticeably less as we reach the mountainous terrain of the Atlas Mountains to the east.

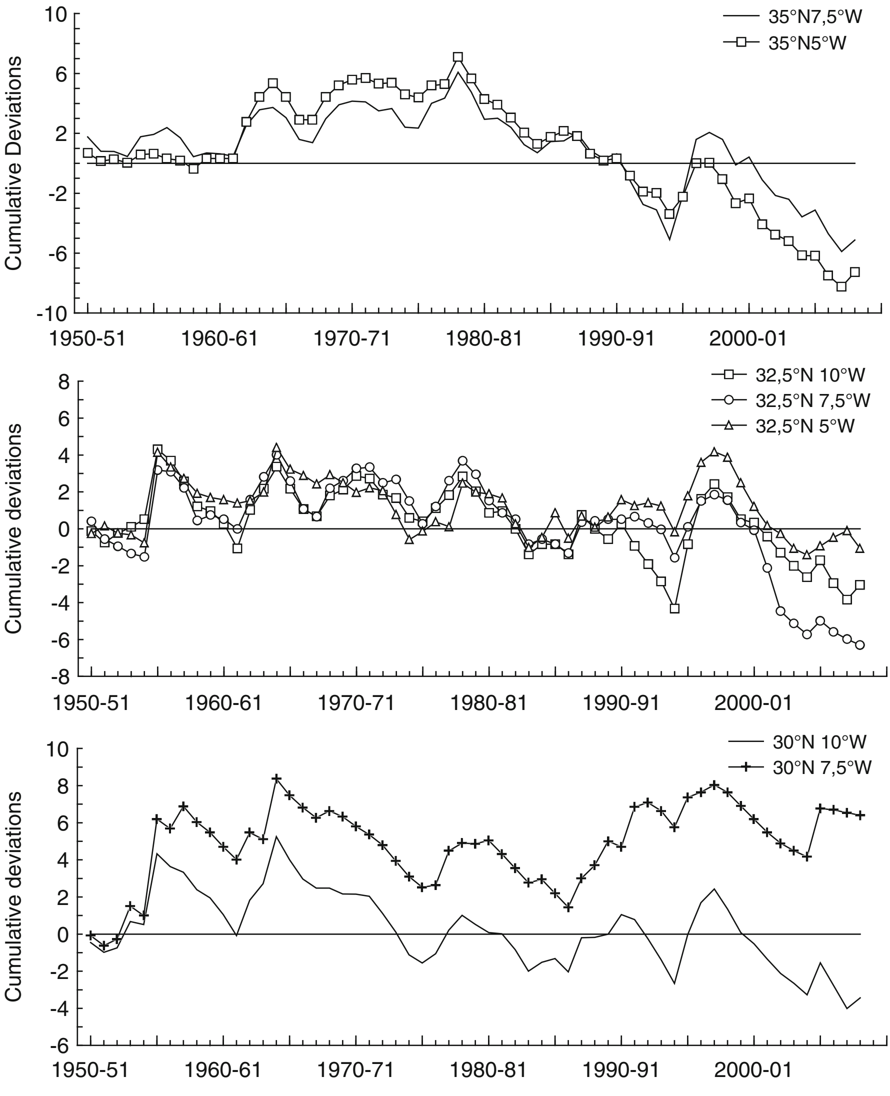


Fig. 9.3 Cumulative deviations of winter rainfall 1950–1951/2008–2009

Apart from the north and the center of our study area, where the evolution of winter precipitation shows a clear downward trend in winter rains, the south region (Fig. 9.3c) shows that this trend is less pronounced especially in the interior (30°N 7.5°W) which shows instead a succession of quite wet winters throughout the whole period. On the coast in contrast (30 ° N 10 ° W), we can see the slow decline of

Table 9.2 Average deviations from the normal of seasonal totals for the first and second sub-periods

	1950–1950/1978–1979 (%)	1979–1980/2008–2009 (%)
35°N 7.5°W	3.	−11.17
35°N 5°W	9.05	−22.67
32.5°N 10°W	2.87	−9.65
32.5°N 7.5°W	3.35	−13.11
32.5°N 5°W	1.93	−9.92
30°N 10°W	1.28	−19.48
30°N 7.5°W	2.89	−3.82

winter rains since the mid-1960s, which then gradually becomes more accentuated relatively and again from the 1980s as well. The comparison between these two periods clearly denotes in terms of rainfall the markedly deficient character of the last three decades (Table 9.2). The great weakness of the totals recorded during these winters converges significantly with those of the first period. Over the entire study period, the winter rainfall of the region decreased by an average of −7.73 % in the north, −4 % in the centre and −3.6 % in the south.

9.4 Weakly Developed Trends

In order to understand the nature of temporal discontinuities that mark our long rainfall data series, a nonparametric test (Mann-Kendall) is used as a tool of statistical validation of these discontinuities (Sneyers 1975, 1990).

$$t = \sum_{i=1}^{n} ni$$

$$E = \frac{n(n-1)}{4}$$

$$Var = \frac{n(n-1)(2n+5)}{72}$$

$$u(t) = \frac{(t-E)}{\sqrt{Var(t)}}$$

This frequently used test especially in the context of global change is considered the most appropriate method to detect any prevailing trends in climate data series (Goossens and Berger 1986). The use of this test by Rodrigo et al. (2000) distinguishes three types of changes in a series. A "tendency" refers not only to a linear change, but also a change with a maximum and a minimum at the end of the series. There is an "abrupt change" when the pattern is present with an inflection which divides the series into two series, while a "fluctuation" is generally characterized as a temporal in which a non linear temporal evolution of increasing trends and decreasing trends.

We applied this test to our data series in order to detect possible ruptures in stationarity. Thus, the sequential evolution of the Mann-Kendall test appears on Fig. 9.4 suggesting that the assumption of the existence of a dominant trend in the evolution of winter precipitation only appears to be demonstrated for the extreme north of the country. Changes in seasonal winter totals in this part denotes a decreasing trend in rainfall from the winter of 1979–1980 onwards and becomes statistically significant at the 95 % level from 1992–1993 to more in the interior areas (35°N 05°W) (Fig. 9.4b) than for the coastal areas (Fig. 9.4a). As for the rest of the grid points, both direct and retrograde curves intertwine continuously thereby demonstrating the absence of any significant trend.

This appears to be partly in agreement with the study of Norrant and Douguédroit (2006) who found no trend for monthly, seasonal and annual precipitation in the Mediterranean during the period 1950–2000. Moberg et al. (2006) spoke of an increase in winter precipitation for the period 1901–2000 in Central and Western Europe, while the trend was not significant for the same period in the Iberian Peninsula. A similar observation was noted by Gonzalez-Hidalgo et al. (2009).

The significant decrease in the cumulative seasonal winter (revealed here especially in the far north of the country) from 1979 to 1980, does, however, highlight one of the signs marking the change that has occurred within the Moroccan rainfall climate, with the introduction of seasonal episodes of recurrent droughts. The appearance from that date of some major attributes that redefined the specific features of this climate, notably the establishment of persistent deficit seasonal periods of several consecutive years during the last three decades that had never seen before. This is particularly the case in the first half of the 1980s, 1990 and 1998–1999/1999–2000, in 2001–2002, 2002–2003 and 2007–2008. The intensity of the deficit sometimes has taken on an almost exceptional and widespread character in some years, as was the case in 1982–1983 and 1994–1995.

9.5 Mode of Variability and Asymmetric Persistence of Abnormal Circulation

The variability of the large-scale atmospheric circulation is described today as an alternating sequence of movement of types or weather patterns (Casado et al. 2009). In other words, the repeated occurrence of a number of well-defined circulation patterns determines overall the general conditions in intensity and frequency of rainfall events. Atmospheric circulation in the mid-latitudes is mainly characterized by its sequence of depressions, a real pivot of atmospheric dynamics at these latitudes. The constant interaction between the synoptic wave height and surface

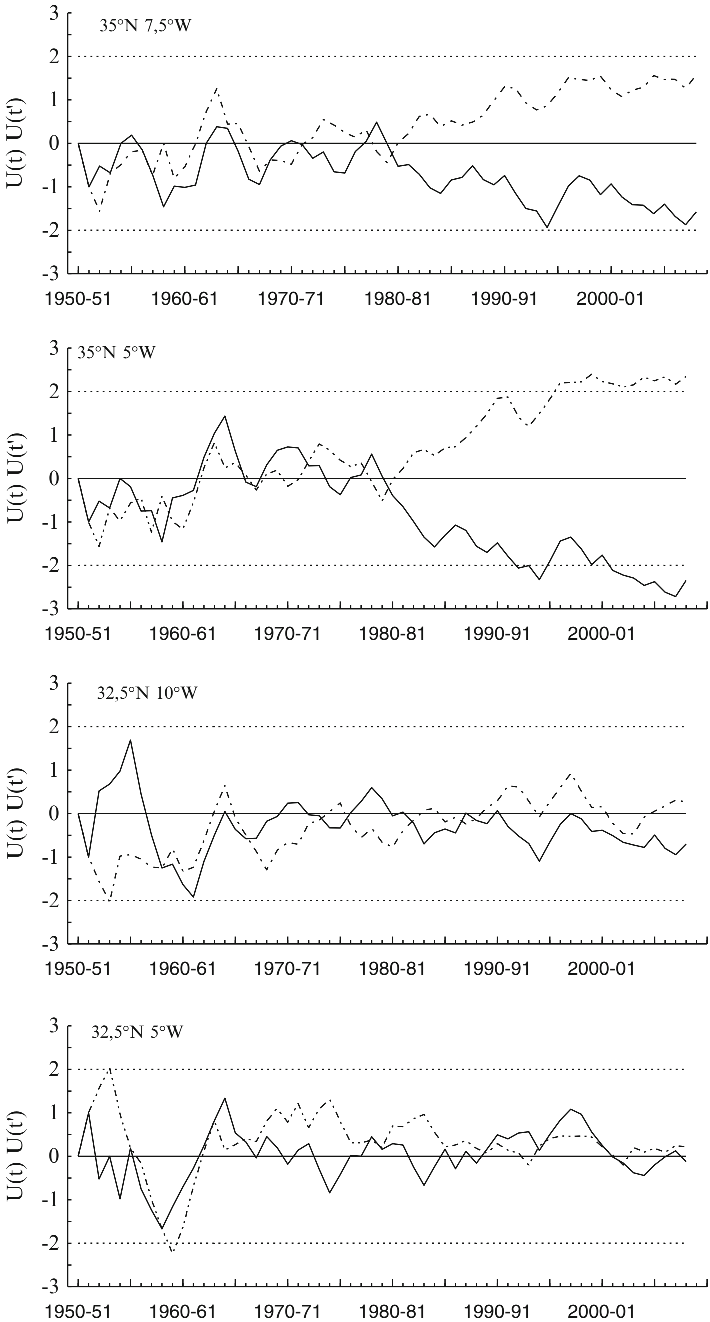
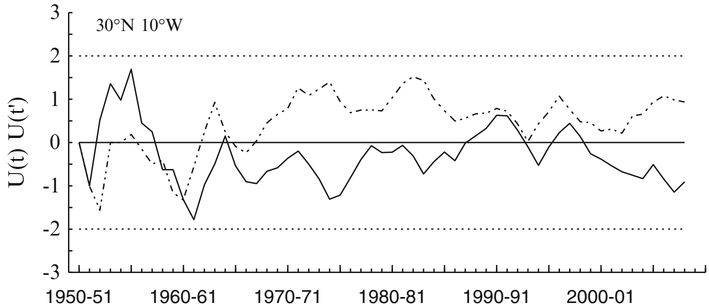


Fig. 9.4 The sequential evolution of the Mann-Kendall test 1950–1951/2008–2009



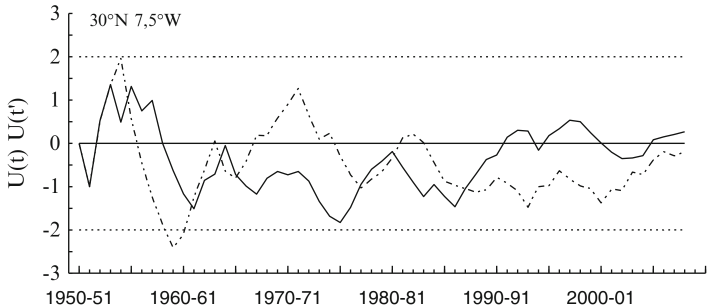


Fig. 9.4 (continued)

depressions configures overall the state and intensity of the low variability of the climate of these latitudes. This low variability often encountered in the North Atlantic is dominated by the presence of two alternating phases of the North Atlantic Oscillation, which alone explain about 40 % of the variance of the mean isobaric field of the North Atlantic (Pinto and Raible 2012). The North Atlantic Oscillation (NAO) dominates here because of its bipolar structure and spatial configuration close to our region as the most likely circulation pattern to affect the general conditions of these rainfall events and their variability in our region.

The linkages between the state of the atmospheric circulation and precipitation in the middle latitudes and the Mediterranean is now well established (Bartoly et al. 2009; Knippertz 2004; Costa et al. 2012; Lorenzo et al. 2008; Quadrelli et al. 2001; Herrera et al. 2003).

Recent studies on this type of circulation and on the predominant evolutionary trend point out an asymmetry in the persistence of these phases. Barnes and Hartman (2010) point to the fact that the NAO is linearly associated with latitudinal tilting southward and northward in the jet stream. And they stress that when the latter displays a southward movement, the circulation has more of a zonal orientation (positive phase of the NAO), and tends to stay longer than when the jet stream is moving northwards (negative phase of the NAO). The track of the depressions then follows an episodic depression according to one of the two phases of the rather zonal trajectories, and then our region is on the margins of the disturbed flow and thus suffers less favorable rainfall conditions. Otherwise, during the negative phases with rather meridian or sub-meridian pathways, more favorable conditions are felt by the receiving country which had experienced repeated frontal discontinuities of the perturbations. According to several studies of the temporal evolution of the NAO, notably Yin (2005) and McCabe et al. (2001) it was indicated that the general trend was rather to let appear a predominance of its positive phase, characterized by a northward shift of the general westerly flow and a significant reduction in the number of depressions. Another feature that also seems to be confirmed concerns the shift in its bipolar structure in recent decades (Jung et al. 2003). Thus, the two phases of the NAO have dominated asymmetrically the mid-latitude circulation conditions with a predominance of the negative phase in the 1950s and 1960s, and a predominance of the positive phase since the late 1970s and which has increased during the 1980s, 1990s and the year 2000.

It is obvious that the fluctuating variation of this major mode of circulation between the positive and negative phase is accompanied by changes in the activity of atmospheric depressions in temperate latitudes in general and the Mediterranean area in particular. The intensity, frequency and position of the track of depressions must be associated with the variation of the large-scale circulation under the influence of both internal and external forcing.

Several studies have focused on the role of the NAO in the overall variability of precipitation in the western Mediterranean in particular, including Goodess and Jones (2002), Herrera et al. (2003), Dunkheloh and Jacobeit (2003), Gonzalez Hidalgo et al. (2009), Vicente-Serrano et al. (2011), Quadrelli et al. (2001), Andrade et al. (2011), Lorenzo et al. (2008), and OrtizBevia et al. (2011).

The overall variability of precipitation according to Rodrigo and Trigo (2007) in the west part of the Mediterranean is often caused by the change in the frequency of rainfall events, or of their intensity, or a combination of both. These rainfall events are controlled by the atmospheric circulation that determines the frequency, intensity and the different orientations of the unsettled flows, which is dependent in the extra-tropical latitudes on one phase of the NAO (Santos et al. 2009).

The statistically significant relationship between Moroccan precipitation and the North Atlantic Oscillation has been highlighted by several authors including Lamb and Peppler (1987), Knippertz (2004), and Knippertz et al. (2003). They demonstrated that it is the repeated occurrence in number and intensity of the southern trajectories of low pressure systems from the Atlantic, which usually characterize the rainy winters in the north-west of Morocco. This part of Morocco is often subject to significant rainfall, when there is often a widening of the upper trough axis offshore to the coastline Ibero-Moroccan (Jacobeit 1987).

It is the study of Lamb and Peppler (1987) that was able to demonstrate the existence of a statistically significant relationship between the Moroccan precipitation for the winter period (November-April) and ONA, through the Rogers index (1984), based on the pressure difference at ground level between Ponta Delgada (Azores) and Akureyri (Iceland). The correlation coefficient describing this relationship is −0.64 for the northern part of the Atlantic coast of Morocco, and −0.57

for the southern part of the coast, explaining respectively about 41 and 32 % of the variation in rainfall in these two sectors for the period 1933–1983.

Winter precipitations are negatively correlated with the seasonal index of the NAO as shown in Table 9.3. In other words, the negative phase of this régime and the general orientation of the southern westerly flow associated with it, allows for discontinuities to reach our latitudes more easily. The correlations are much higher in the north than the south, and they are even less so towards the interior. However, the statistical link to this weather régime explains a sizeable proportion of the variation in seasonal winter totals, mainly in the north, hence the interest to see in the synoptic aspect of this relationship, the means of explaining the overall variability of our winter rainfall.

The temporal evolution of this seasonal winter NAO index (Fig. 9.5) shows almost the same two major trends identified using our rainfall data series. The period of rainy winters of 1950–1970 here coincides with the occurrence of significant negative indices, while from the 1980s and its winters with recurring deficits correspond to the predominance of positive indices.

The extreme deficit that each time has accompanied the episodes of drought which prevailed for years highlights the high variability of the climate and increases its spatio-temporal irregularity. After several decades of more or less normal rainfall during the 1950s–1970s, we have moved on to a period of uncertain and

Table 9.3 Correlations between the NAO index and winter precipitation

	NAO (djf)	% de variance
35°N07.5°W	−0.60	36.2
35°N05°W	−0.63	39.7
32.5°N10°W	−0.52	27.6
32.5°N07.5°W	−0.44	19.6
32.5°N05°W	−0.31	9.9
30°N 10°W	−0.42	17.4

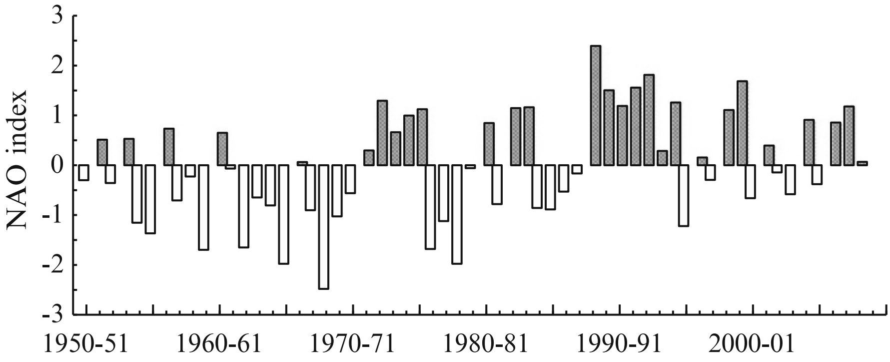


Fig. 9.5 Evolution of the winter NAO index

erratic rainfall from the 1980s. Obviously, the succession of these two periods can only be explained by the fact that they are the consequence of the strong large-scale variation of the general atmospheric circulation, which can significantly alter the precipitation conditions in our latitudes.

The occurrence of rainfall events in our region is thus dependent before anything else on the state of the atmospheric dynamics of our latitude is expressed via permanent fluctuations in the position of the high level jet stream (*eddy drive*), by which the different trajectories of the ground level perturbations (Bader and Latif 2011) with a more southerly orientation of this high level circulation that characcterizes the positioning of the negative regime of the NAO. Woollings et al. (2010) identify obviously a descent in latitude of the frontal discontinuities of the Atlantic depressions.

From a synoptic view, atmospheric conditions over the last few decades have changed remarkably as shown in the maps in Fig. 9.6 on average 500 hPa of geopotential in the first period (1950–1951/1978–1979) and during the second period (1979–1980/2008–2009).

As can be seen in Fig. 9.6a, b, the axis of the altitude ridge appears to shift slightly to the east in the middle of the second period compared to the first period. Similarly we observe a relative displacement of contours to the north during the second period. The difference between the two average situations (Fig. 9.6c shows a large zone ranging roughly from the extreme South-East of Canada to Scandinavia,

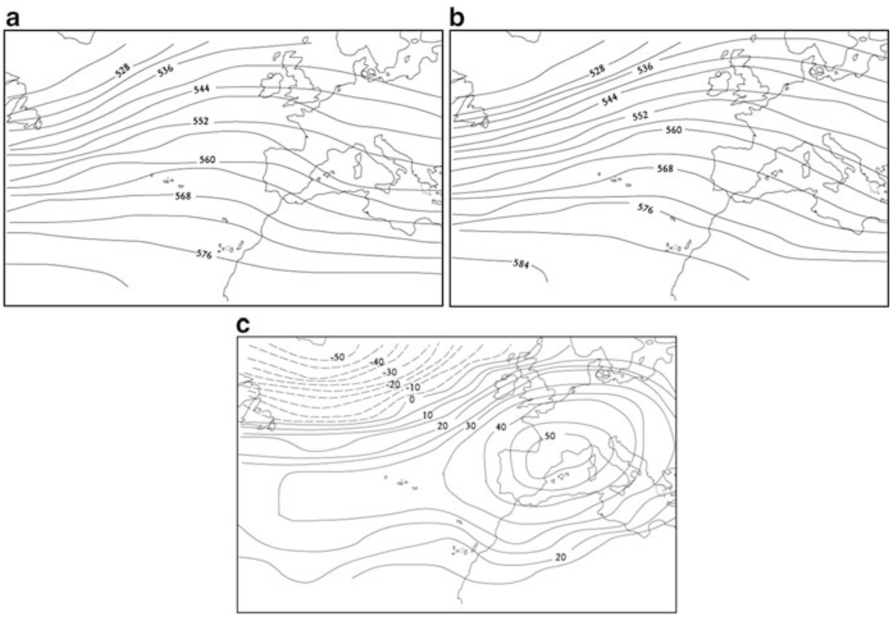


Fig. 9.6 Map of the average position of 500 hPa geopotential during the winters. (**a**) 1950–1951/1978–1979, (**b**) 1979–1980/2008–2009 and (**c**) difference (**b**) – (**a**)

where there is a level of 500 hPa geopotential during the second period, particularly in the south, which strengthens European average anticyclonic conditions.

In contrast, the contours of this level show an opposite trend to the north-west quarter of the map, which shows the widening of cyclonic conditions during the second period. Here we find again the bipolarity of the classic configuration of the NAO, with the establishment of a strong sub-meridian gradient and the relative movement of the whole structure to the north-east. This is a feature emphasized by many authors quite correctly, including Jung et al. (2003), Cassou et al. (2004), and Luo et al. (2012), as a increasingly important trend regarding the spatial configuration of the NAO, following its change of sign (Peterson et al. 2003).

Thus, the reinforcement of the global peak in Western Europe during the second sub-period of the study reached here + 50 hPa in terms of difference which explained the shifting circulation of depressions beyond the British Isles. Maintaining the trajectories of atmospheric disturbances quite some distance from our latitudes due to the repeated occurrence of the positive phases of the NAO, has led to a reduction in the number and intensity of disturbed systems following more southerly axis systems, as highlighted by Dong et al. (2011), thus giving rise to strong asymmetric and persistent anticyclonic conditions in our region.

9.6 Conclusion and Discussion

The rainfall climate of north-western Morocco on the whole is characterized by a relatively high variability, which gives it both its rather eccentric latitudinal position in relation to the general westerly flow, and its involvement in the fluctuations of large scale circulations at mid-latitudes. The very irregular rainfall of this season is then a function of the frequency of rainfall events, the degree of instability of disturbed systems and their potential rainfall.

Thus, the distribution of cumulative inter- and intra-seasonal rainfall therefore depends on the occurrence and the general orientation of the circulation depressions that primarily determine the different circulation patterns – the most predominant type in winter is the North Atlantic Oscillation.

The temporal evolution of winter accumulations gives rise to two sub-periods with contrasting rainfall. The accumulations during this season often exceeded the normal volumes in the 1950s, 1960s and 1970s, which gave its prominent character par excellence, notably its contribution to the average rainfall profile with a contribution of about 40–45 % of the annual average accumulation. The repeated occurrence of generally deficit conditions during the last three decades and a significant decrease in rainfall events during this season, has remarkably contributed to the dysfunctional character of the rainfall regime across the region. Long episodes of persistent and widespread drought in the 1980s, 1990s and 2000 were generally even more intense during the winter of those years. The accumulated volumes of winter rainfall thus decreased accordingly, mostly from 15 to 32 % compared to the first period.

The very strong variability was also reflected in an increase in extreme events that accentuates once more the strong irregularity of the rainfall climate. The year 1994–1995 for example, were extremely dry, the winter rains showed a deficit ranging across the entire region from −62.14 to −79.74 % in the north and from −100 % in the south. National cereal production has never reached the level of this year: 17,489 million quintals (CIHEAM 2006), which led the government to declare for the first time this year as "a year of national disaster". For the following year 1995–1996, the winter season was extremely wet, with the difference from the normal reaching values everywhere ranging from +56.33 to +120 % in the north and from +68.64 to +187.4 % in the centre and around 200 % in the south. Domestic production of grain during that year recorded a record of more than 99,822 million quintals (CIHEAM 2006).

The decreasing contribution of winter precipitation directly affects the water balance and worsens the situation of water availability, making it more difficult to engage work proactively in a process of sustainable development. The effort required for adaptation must confront continually towards constructing a permanent equilibrium between managing scarcity, environmental conservation, and development imperatives. Persistent drought over several years in a row remains a major constraint with multiple agricultural, hydrological and socio-economic consequences.

The trend observed in the rainfall climate of the region is linked to changing weather conditions on a large scale that have occurred since the 1980s in extra-tropical space of the North Atlantic. On the one hand, the predominant occurrence of a high NAO index has had an effect on the maintenance of circulation depressions further north. Interaction with the ENSO phenomenon has been recognized as the cause of global climate variability (Sterl et al. 2007; Trenberth et al. 1998) and the increased frequency and intensity of recent decades are considered potentially attributable to global warming (L'heureux et al. 2013), and these on the other hand are factors forcing atmospheric dynamics that may give rise to very intense and persistent climate anomalies.

According to the latest IPCC report of 2007 and based on the different model projections of low resolution (Solomon et al. 2007), Morocco would experience a significant reduction in rainfall by the end of the century. This decrease is due in large part, according to the report, of the inreasing frequency also of positive phases of the NAO among other factors, which is associated with the increase in latitude of the trajectories of disturbances on the polar front, and the sustained persistence of strong anticyclonic anomalies on our country.

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