CLIMATIC CHANGES IN THE MAGHREB REGION: THE EVOLUTION OF THE PLUVIOMETRIC PARAMETERS IN THE MIDDLE ATLAS AND AT ITS MARGINS (MOROCCO) AND ITS RELATION TO THE NORTH ATLANTIC OSCILLATION

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Abstract: Climatic changes in the Maghreb Region: the evolution of the pluviometric parameters in the Middle Atlas and at its margins (Morocco) and its relation to the North Atlantic Oscillation. In order to characterize the climatic changes observed on a regional and local scale, an analysis of the pluviometric parameters has been proposed. It relies on the calculation of the centered index decreased and the quintile method to characterize their long-term evolution. This investigation allows for an explanation for the extreme rain variability. It also shows the severe and durable character of the climatic drought noticed in this region beginning with the 1970s and the shy return towards a possible humid phase observed beginning with 2008. At the same time, the analysis of the evolution of the extreme rains has highlighted a relevant relation with the North Atlantic Oscillation (NAO). This relation is in reversed phase with the humid periods (negative NAO index and high frequency of the extreme rains from the humid categories) and in phase with the dry periods (positive NAO index and high frequencies of the extreme rains from the dry categories).

Keywords: precipitations tendency, North Atlantic Oscillation, Middle Atlas.

1. INTRODUCTION

The results of different studies referring to the evolution of the precipitations show that, on a global average, the climatic change appears as an intensification of precipitations and a recurrence of extreme events (more noticeable during the last decennia) (New & al., 2001, Planton & al., 2005). These studies also bring to light that changes will occur mostly as far as precipitation repartition worldwide is concerned, resulting in an increase in precipitations in the equatorial areas and at the Poles, at the expense of the Mediterranean and of the dry and temperate tropical areas.

The Mediterranean area, acknowledged as one of the hot spots of the climate change, should undergo – until 2100 – an average temperature increase of 3 to 4 °C, a decrease in precipitations and an intensification of the extreme events (GIEC, 2007). The combined effect of the climatic change and of the anthropic impact should trigger a lack of water for about 290 million people.

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The study undertaken on about 80 (eighty) years of measurements recorded at the meteorological stations from the Middle Atlas (Morocco) and its margins, aims to highlight that after many years of drought, one can note a return towards more humid weather conditions. The signs of change are very significant in the recent years. Described as exceptional and historical, these rains have filled the dams to their maximal capacity (the Al Wahda dam, the largest of the kingdom, situated on the Ouergha oued (wadi) rose to about 90 % in 2010 and reached 98.5% in February 2009 ; by comparison, the average of the previous years was 70%). This new tendency observed throughout the country is nevertheless accompanied by intense and stormy events. During each such episode, enormous water quantities are poured down in a matter of a few days, and sometimes even in just a few hours (Ourika in 1994, El Hajeb in 1997, El Jadida in 1996, Taza in 1995, 1997, 2000, 2002, Mohamedia in 2002, Demnate in 2005, Casablanca in 2010, 2012). These rains also seem to be the norm nowadays for the whole of the Maghreb region (Hlaoui & al, 2008). This return of the rains, if confirmed, could mark the end of several decennia of recurrent droughts (Amyay & al., 2012), and could announce a possible durable return to “normal” weather. This hypothesis is supported by the highlighted impact of the different world climate oscillations (North-Atlantique-Oscillation; El Nino Southern Oscillation) on the whole of the continents and especially on the African continent (Saadaoui & al., 2007, Sebbar & al., 2011). These cyclic oscillations whose significance is still the object of many debates could explain the variability of the precipitations in Morocco, and could support the hypothesis of a return of the rains, marking the end of the years of droughts. The forecasts vary from one model to the next, but an increase in precipitations and a multiplication of the extreme climatic events could find its place in this global dynamics of climate change (GIEC, 2007).

2. SITUATION OF THE AREA UNDER ANALYSIS, DATA AND METHODS

The area under analysis corresponds to an average mountain of Morocco, the northern Middle Atlas and its northern neighborhood, the Sais, which it dominates by several hundreds meters. The hydrological and hydrogeological junctions between these two entities impose their association in this investigation despite certain dissimilarities. These entities are part of the Sebou hydrographic basin, one of the most important basins of Morocco. The Middle Atlas corresponds to an average mountain standing up in the middle of Morocco, with altitudes varying between 800 and more than 3000 meters. Two morphostructural units: the Folded Midle Atlas and the Tabular Middle Atlas, separated by the northern Middle Atlasic accident, make up this geographic entity.

The Sais corresponds to a depression dominated by the reliefs of the southern Middle Atlas and the Rif entities in the north. The altitudes oscillate there between 500 and 750 m, with very gentle slopes. These dominant reliefs largely exposed to the western atmospheric fronts filled with humidity benefit of a climate with a well delineated rainy season. The humid and gentle winters alternate with dry and hot summers. The precipitations, which cover a period of several months, a part of them falling as snow over 1500 m, assure abundant water resources. This seasonal distribution varies widely from one year to the next.

The analysis of the pluviometric parameters has been carried out on the basis of data from four measurement stations. The stations from Ifrane and Sefrou are situated in the Middle Atlas, the first one at 1640 m and the second at 930 m. The other two are situated in the corridor of Fès-Taza, at an altitude of respectively 569 and 510 m (Figure 1). The average precipitations calculated for the different observation points vary between a little less than 510 and 985 mm (Table 1). The highest values have been recorded on the mountaintops of the Middle Atlas.

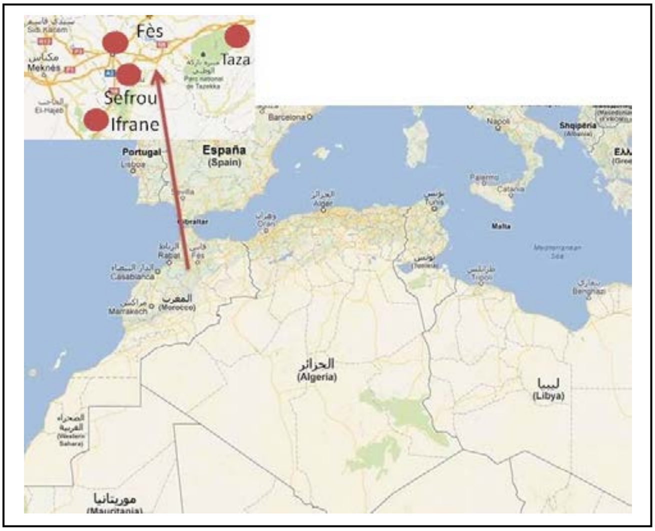

Fig 1. ***Location map of the Middle Atlas and its margins***

Table 1. ***Features of the stations used for this study***

Station name	Ifrane	Taza	Fès	Sefrou
Altitude	1640 m	510 m	569 m	930 m
Average precipitation	984.8	581.9	505	573.2
Standard deviation	277.2	179.0	145.3	160.7
Period	(1935-2010)	(1935-2010)	(1935-2010)	(1935-2010)

In order to determine the general evolution of the climatic parameters, two indexes have been used:

- the centered indexes reduced, calculated based on the average yearly values of the rains.

- the mobile average over five years to level out the series.

In order to determine the pluviometric tendency at the different stations, a graphic chronologial data processing method of the “Matrice Bertin” type has been applied to the annual data (Nouaceur, 2009, 2010).

This method consists in making - during a first step - a classification per year and per station related to the limit values (Q1, Q2, Q3 and Q4) calculated for all the stations and for all the series (Table 2).

Table 2. ***The quintiles and the average calculated at Fès, Sefrou, Ifrane and Taza for the pluviometric parameters (period: 1935 - 2010).***

Dispersion parameter	Fès	Sefrou	Ifrane	Taza
Q1	377.6	422.6	739.4	426.5
Q2	471.8	538.1	862.6	512.47
Q3	513.5	600.8	1001.6	621.4
Q4	621.1	703.1	1161	713.7
Me (Average precipitations)	494.7	565.5	933.3	552.9
Min (Minimal precipitations)	206.9	227.4905	583.2	328.2
Max (Maximal precipitations)	1025.5	921.68235	1865.7	1203.3

The years of the first quintile (Q1) with their limit value are considered very deficient (in point of rain). The years situated between the first and the second quintile (Q2) are considered deficient. The years whose pluviometric height is comprised between the second quintile and the average are normal, with a dry or humid tendency. In-between the median interval and the third quintile (Q3), the years are normal, with a rainy tendancy. The interval from the third to the fourth quintile (Q4) comprises years with a rainy tendancy. Finally, all the years whose pluviometric total is above that of the fourth quintile are considered excessively rainy.

During a second step, the projection of the results obtained after the first data processing on a colored graph (the color varying according to the position of the annual pluviometric accumulation in relation to the limit values) allows for the visualization of the evolution of the climatic parameter according to two dimensions (time and space). In order to determine the gaps and the characteristic periods, a number varying between 1 (very dry year) and 5 (very humid year) has been attributed to each year, according to the already determined characteristic features. The sum of the numbers of all the stations for each year is centered and reduced, which allows for the obtaining of an index varying from + 1.72 for a very humid year to – 1.72 for a very dry year.

2.1. Regional pluviometric parameters marked by extreme oscillations.

The application of the graphic chronological data processing method to the pluviometric data recorded in the Middle Atlas and at its margins, allows us to see on figure 2 the different periods characterizing the rains fallen in an interval of about 80 years. The graph clearly highlights the succession of the dry and the humid periods. So, during this long period, one can note a succession of three humid and two dry stages. At the beginning of this series, between 1936 and 1942, the yearly rains are marked by a humid character, as the indexes for this first period are all positive with four years going over the value of + 1.

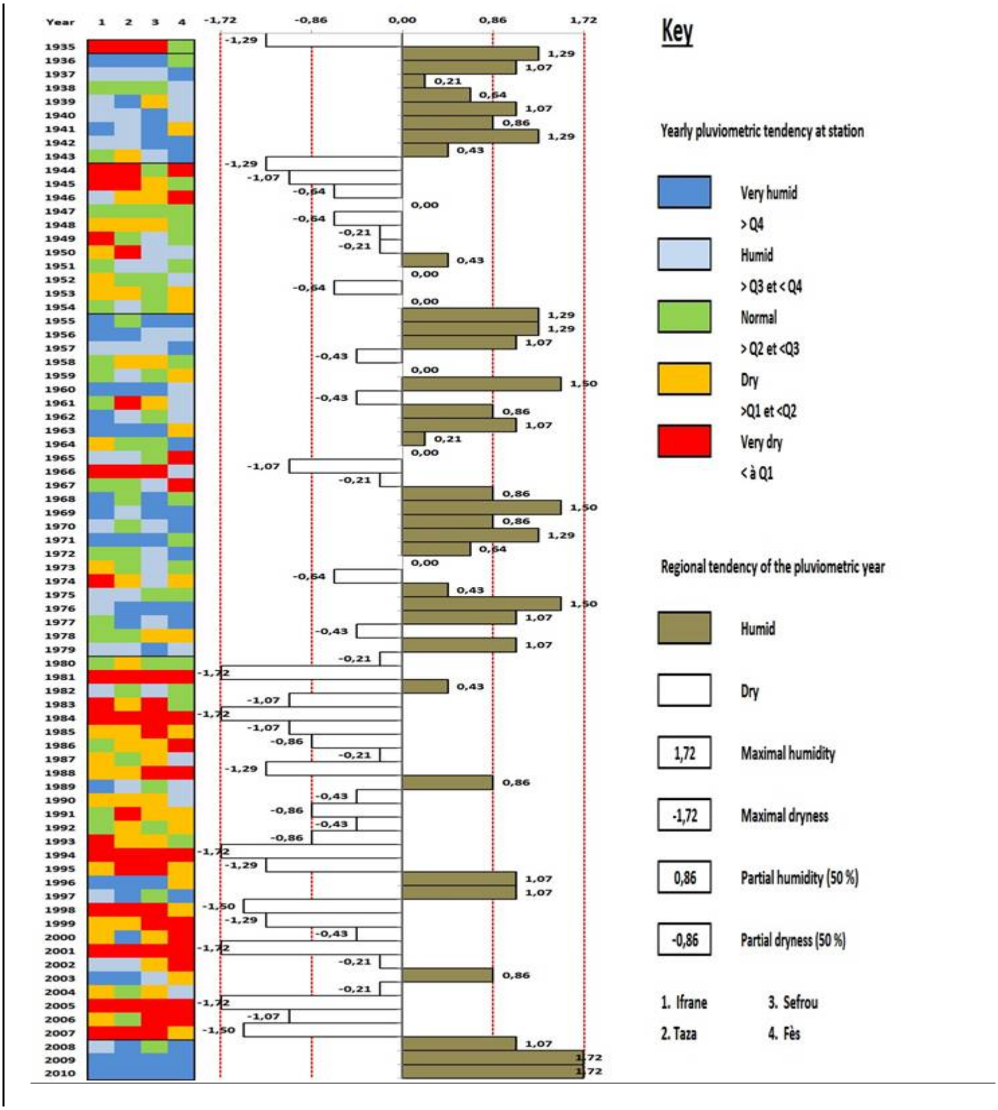

Fig 2: ***Classification of annual precipitation according to quintiles Q1, Q2, Q3, Q4 and Q5 (measurement period from 1935 to 2010).***

Beginning with 1944, a dry tendency is confirmed and only the year 1951 registers a positive index (+ 0.43). The years 1947 and 1952 are marked by indexes equal to 0, characteristic for a normal year. Beginning with 1955, the region enters a favorable period, which lasts until the year 1979. The positive years are more numerous than the negative ones, therefore indicating a humid stage. Sixteen years are characterized by values over 0 and a decennium by values over + 1. Only the year 1966 marks a gap in this succession as three stations (Ifrane, Taza and Sefrou) register a pluviometric record corresponding to the "very dry" category.

Beginning with the year 1980, a long dry period lasting for 27 years marks this territory. The centered reduced deviations show negative values over – 1 for 13 years between 1980 and 2007. Finally, out of the 27 years of this period, only five belong to the humid category (1982, 1989, 1996, 1997 and 2003). The final stage (2007 – 2010) is a breakup compared to the dry conditions observed until then. We find again humid conditions with indexes going over + 1. One can also notice that the two last years are characterized by "very humid" pluviometric parameters at all the stations.

The study of the annual evolution of the rains since 1935 has shown the very irregular character (specific for the Mediterranean climate) of the pluviometric parameters in this pre-Rif region. The periods of dryness are more homogenous and are marked by an almost uninterrupted succession of years of deficit (dry stages: 1944-1954 and 1980- 2007).

The humid periods are often sprinkled with dry years which can sometimes be very severe (such is the case of the years 1935 and 1966). Finally, the last stage in the series clearly stands out with its record indexes, which may indicate the beginning of a new tendency (2008, 2009 and 2010).

2.2. A close relation with the North Atlantic Oscilation

In order to determine to what extent the NAO influences the pluviometric parameters observed in the Middle Atlas and at its margins, we have used the evolution of the frequency of the extreme years (the class of values higher than the fourth quintile or lower than the first quintile). So, for each year we have evaluated the number of stations that meet these conditions. This number is then turned into a ratio in relation to the total number of the stations. The projection of these results on a graph thanks to two curves of evolution has allowed us to obtain the regional variation of the extreme pluviometric accumulations. The figure 3 obtained using this work method allows for an identification of the main phases of the extreme pluviometry of this Morrocan region and permits a comparison with the evolution of the Atlantic Oscillation substantiated by the NAO index.

The four stages already identified on the matrix in Figure 2 are well highlighted by the gaps in the two curves of the dry and humid years. The first humid period (1936 – 1943) is in reversed phase with NAO (negative index of the North Atlantic Oscilation and high frequencies of the humid years). Under these circumstances, the pressure associated to the Azores Anticyclone (or Azores High) is lower than its normal value and, at the same time, the Icelandic Low is hardly a bit lower. According to this type of circulation, the rail of these lows moves more to the south and touches in this way the regions of the southern border of the Mediterranean Sea, which will be watered more. This relation is resumed for the second humid stage, which is very obvious between 1954 and 1979, despite a change in the sign of the NAO index between 1971 and 1975.

When the NAO index becomes positive (reinforcement of the Azores Anticyclone and descent of the Icelandic Low), the rail of the lows moves towards the northern latitudes, which allows a dry and gentle weather to settle in on the surroundings of the Mediterranean basin and in the regions of Maghreb. So, we find a very strong connection between the increase of the frequencies of the dry years and the positive NAO indexes. Consequently, the great drought which began in 1980 and ended in 2007 corresponds to a period of reinforcement of the pressure gradient on the North Atlantic. Actually, during this period one can observe the highest NAO indexes (higher than + 1).

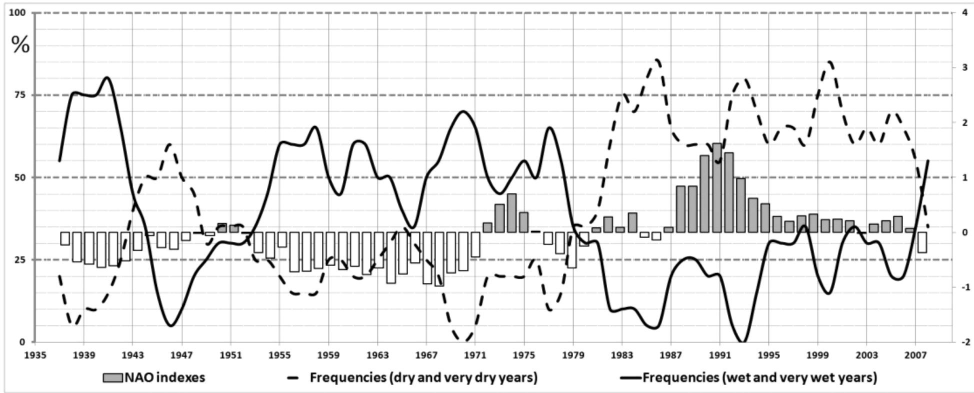

Fig. 3. ***Mobile averages for the frequencies of the stations which recorded humid and very humid and dry and very dry years and NAO index for the measurement period 1935-2010.***

The correlation between the short dry period from 1944 to 1954 and the NAO indexes is less obvious on the graph. Yet, in detail, this relationship exists and is translated by a dwindling of the NAO index compared to the previous years and a sign reversal in 1950 and 1951 (with respectively + 0.15 and + 0.27). Finally, the last humid stage, which concerns the last years of the series (2008 – 2010), is translated again by a significant sign change (- 0.37 in 2008) and a reversed crossing between two frequency curves operated in 2007, which marks the passage to a possible humid tendancy, to be confirmed by the pluviometric accumulations (2011 and 2012).

3. CONCLUSION

The analysis of the pluviometric data recorded in the Middle Atlas of Morocco and at its margins has shown the importance of the variability of this climatic parameter. The specific character of the Mediterranean climate situates this “hot spot” of the global climate change in a vulnerable position. This investigation has also allowed to highlight the seriousness of the great period of drought which hit the region between 1980 and 2007. During this period of lack of water, the pluviometric accumulations have reached their lowest level. Beginning with 1996, a few humid years have spotted this long series (1996, 1997, 2003). More recently, a succession of three humid years (towards the end of the series) has been noticed (2008, 2009 and 2010). Could these new dispositions announce a new, gentler climatic tendency? Today, it is very difficult to give an answer to this question, but the last pieces of information gathered so far allow one to note a quantity over the average for the crops of 2010/2011 and 2011/2012 (Direction des études et des prévisions financières, DEPF / The Direction for Financial Studies and Forecasts, 2012) and so to confirm the beginning of a new stage. The study of the influence of the North Atlantic Oscillation on the pluviometry of this region has allowed us to bring to light a close relationship between the fluctuations of the extreme rains and the NAO indexes. When the NAO index is positive, a series of dry years is recorded. During a negative stage, the humid periods prevail.

The Middle Atlas is the most important hydrological province in the area of Morrocco. Together with the Sais, it constitutes the most important underground water reservoirs in the Sebou basin. These resources go today through a significant pressure, on the one hand as a consequence of a very intense and long-lasting climatic drought, and on the other hand because of an intense anthropic action on the water stocks (increase of the intensive cultures), which strongly diminishes the level of the underground waters. In order to preserve this potential, it is necessary to think about a sustainable management of this naturel environment, which remains the only solution for the preservation of the water resources, which are today strongly menaced.

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