NORTH ATLANTIC OSCILLATION AND RAINFALL VARIABILITY ON THE SOUTHERN COAST OF THE MEDITERRANEAN

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ABSTRACT. **North Atlantic Oscillation and rainfall variability on the Southern coast of the Mediterranean**. Regions of the south-western Mediterranean basin were the focus of many studies since they have experienced a series of climate changes. The contribution of the North Atlantic Oscillation in precipitations is required to be analyzed with the aim to understand the possible hydrological changes. In this way, an analysis of precipitations along the coast of central Maghreb (Morocco, Algeria and Tunisia) was carried. The present analysis was performed using (1) The graphical method of information processing and (2) wavelet transform technique. Results can be summarized as the following. Results show a high drought observed in all studied regions since the med-eighties and a return of the wet period since year 2003. Moreover, we demonstrate significant links of precipitations with the North Atlantic Oscillation

Keywords: climate change, Mediterranean basin, precipitation variability, NAO, wavelet transform

1. INTRODUCTION

Regarding the challenge of climate change, the increasing temperatures observed at most of world weather stations suggests the global warming effect. According to the WMO (World Meteorological Organization (http://www.wmo.int), 2010 is considered the warmest year, higher than the hottest year in 2005 and 1998 Decadal average temperature between 2001 and 2010 is th hottest decenie since the first recordings of meteorological instruments. The results of various studies on the evolution of rainfall across the globe show that climate change results in increased precipitation and recurrence of extreme events (more noticeable over the last decades) (Christensen et al, 2007). These studies also highlight that there will essentially changes in the global distribution of

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precipitation, with an increase in the equatorial and poles regions, and a decrease in the Mediterranean, dry tropical and temperate zones. Climate change is considered as the greatest challenge for ecosystems (Scavia et al., 2002; Hammer, 1999), forestry and many social and economic sectors such as agriculture and coastal zones (Nicholls et al., 2005).

Recent researches have made significant progress in investigating the time variation of ecological systems (Parsons and Lear 2001, Lomas and Bates, 2004), water resources and hydrological processes (Labat et al., 2005; Legates et al., 2005) in response to climate change. As stated by the Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the global warming would be responsible for changes in the hydrological cycle with major alterations in the timing of wet and dry seasons (IPCC, 2007) and then the increasing in both floods and droughts.

Most researches were interested in the link between NAO and precipitations (Bojariu and Reverdin, 2002, Lopez et al., 2011, Querad et al., 2011) and river streamflows (Mares et al., 2002; Keim et al., 2004). (Sebbar et al., 2011) have described the NAO intra-Moroccan variation in the correlation patterns with rainfall. Over the last few years, many works have focused on the non-stationary evolution of climate indices (Appenzeller et al., 1998; Higuchi et al., 1999). A continuous wavelets transform has been used to analyze the non-stationary climate features from mean annual streamflows provided by 79 rivers of the Canadian Reference Hydrometric Basin Network (Coulibaly and Burn, 2004). This technique was also used by Massei et al. (2007) to investigate the relation between Seine precipitation (north-western France) and NAO. They have showed a quasi-biennal oscillation (QBO) which shifted since 90s. Study of long term variability of hydrological conditions in Atlantic Ocean (NW France, N Africa, USA) and their relation with climatic fluctuations of NAO and SOI were carried out by Laignel et al. (2010). Here, both discontinuities of 70s and 90s were identified and related to the global scale. Conway et al. (2009) research was based on nine major international river basins to study the variability of rainfall and water resources in sub-Saharan Africa during the 20th century. They have shown that the sub-Saharan Africa exhibits drying across the Sahel after the early 1970s while relative stability can be punctuated by extreme wet years in East Africa.

The variability of global climate in the short term is generally associated with phases of coupling of Oceanic and atmospheric phenomena including El Niño (ENSO) and the North Atlantic Oscillation (NAO). This last cyclical oscillation whose scope is still debate could explain the variability of precipitation in much of the Mediterranean area, and supports the hypothesis of a return of the rains marking the end of the years of drought in the Mediterranean areas (Lopez et al, 2011 Querad, 2011).

The objective of this contribution is to improve our understanding of the teleconnections between the global climatic patterns and rainfall variability in the North Africa (Marocco, Algeria and Tunisia). This contribution can be divided into four parts: first, data are described; second, the methodology is presented. Then, results are analyzed and then discussed respectively in the fourth part.

2. DATA AND METHODS

In order to determine to what extent the NAO influences the rainfall, we have used two methods describe below:

- the evolution of the frequency of the extreme years (the class of values higher than the fourth quintile or lower than the first quintile, Nouaceur et al, 2013). 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 continuous wavelets transform (CWT) is an alternative option to define an eventual relation between both patterns. This method was used by some authors (Torrence and Compo, 1998; Higuchi et al., 1999) to identify the non-stationary behaviour of NAO evolution. The method of CWT is defined as the Gaussian derivative (DOG). This function is obtained by including a Heaviside step function *H(w)* in the frequency domain (*H(w) = 0* for $w < 0$, *H(w) = 1* for $w = 0$). DOG_{14} wavelet, derivates 14 times, is able to provide 14 oscillations as its frequency resolution. The signal is correlated with a set of 'daughter wavelets' which consists of a scaled version of the reference 'Mother wavelets' with the same shape and different sizes. Higher variation (large wavelengths) in the signal can be detected by larger daughter wavelets while smaller ones define smaller variations (short wavelengths).

In this research, CWT was performed on monthly dataset aiming to identify the spectral components of the signals which can be assigned to different modes of variability characterizing the geophysical signal and, eventually, the time scales involved. The convolution of the filtered monthly signal ($\hat{P}_m$, $\hat{Q}_m$ and $\hat{N}_m$) by a non-orthogonal wavelet basis was applied to define the continuous wavelet time-scale spectrum which is able to identify the spectral components assigned to the dominant mode of variability of the total signal.

The data used for this study concerns three countries of central Maghreb (Morocco, Algeria, Tunisia - Fig. 1). For Morocco, the chosen area is the Middle Atlas. In Algeria, six coastal stations have been retained. In Tunisia, we selected 7 stations of the Bizerte region – Ichkeul. The choice of the selected stations is performed according to the availability of data (Table 1).

3. LINK BETWEEN THE NAO AND THE RAINFALL

The connection between the rainfall and the North Atlantic Oscillation will be tested initially by using the analysis of the evolution of extreme years: wet and very humid and dry and very dry years.

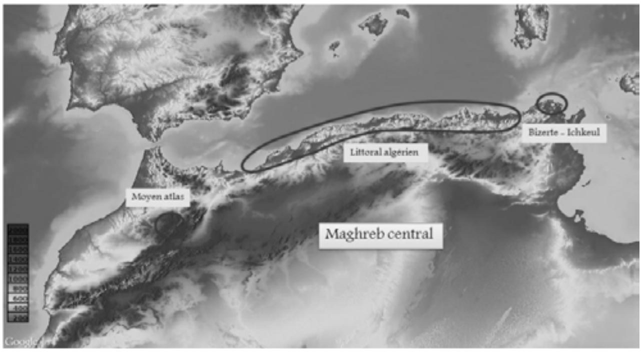

Fig. 1. Geographical localization of the different zones under study

Table 1. Features of the stations used for this study

Stations	Average precipitation	Standard deviation	Altitude	Country
Sejenane Délégation	832,73	216,73	135	Tunisia
Ras El Ain	518,97	145,75	10	Tunisia
Djebel Essama	711,86	193,33	210	Tunisia
Chaab Eddoud	611,54	142,69	20	Tunisia
Koussat El Bey	452,99	138,48	70	Tunisia
Tinja Her	595,89	146,27	8	Tunisia
Sidi Salem	668,96	154,71	28	Tunisia
Oran	**349,30**	**93,22**	90	Algeria
Dar le Beida	**637,79**	**185,95**	25	Algeria
Annaba	**653,88**	**152,82**	8	Algeria
Skikda	**737,17**	**157,69**	1,3	Algeria
Béjaïa	**784,08**	**187,20**	1,74	Algeria
Echlef	**373,42**	**89,42**	143	Algeria
Ifrane	**948,00**	**277,20**	**1640**	Morocco
Taza	**581,90**	**179,00**	**510**	Morocco
Fès	**505,00**	**145,30**	**569**	Morocco
Sefrou	**573,20**	**160,70**	**930**	Morocco

3.1. Results of extreme analysis

In Morocco: It is very difficult to exactly identify the influence of "NAO" on the evolution of the rains in the Moroccan Middle Atlas: probably due to the particular geographic site of this study area which is an area of average mountain in high rainfall variability. However, detailed analyses of the different curves in Fig. 2 highlight a probative association with periods of drought (corresponding to the extreme dry and very dry years). We can that a strong positive NAO index is much more favourable to the establishment of more arid conditions on the western part of the central Maghreb: these drastic conditions have been observed at the Morocco over a very long period of more than 27 years. At the same time there field observations show a return of the rain in recent years in this part of North Africa. These new climatic conditions correspond to the preponderance of a negative NAO index (new terms from the 2010s).

In Algeria: In the case of Algeria (Fig. 2), the situation seems comparable to that which we have already referred to the Morocco. Dry and very dry years are consistent with a positive NAO index.Three periods are made obvious by the curves representing the years wet and very wet.

- the first period located between 1970 and 1986, is in phase with a 'NAO' index that is characterized by a very low intensity > + or - 0.5;
- the second phase, ranging between 1995 and 2010, presents a more pronounced interannual variability and low NAO index;
- finally, the period of 1987-1994 is characterisedby the strongest clues and reduced variability.Thus coastal Algerian stations show a greater fit with the influence of the NAO.

In Tunisia: The situation appears similar to that observed for Morocco. We find a similar pattern for large climatic periods:

The great drought that stretches over a long period between 1982 and 2001 seems consistent with a period when the positive NAO indices are more frequent

3.2 Results of wavelets transform

The coherence between NAO and rainfall was performed in studied stations: Algeria, Morocco and Tunisia (Fig. 3).

In Algeria, the coherence is manifested in three main bands of energy: 2-4y band where the contribution of NAO is observed during 1970-1980 and 1995-2005. The NAO contribution is also shown from 1970 to 2005 for 4-8y band. On the other hand, the NAO is limited during 1980-2000 for the 8-12y band.

In Morocco, the coherence is observed between 1975 and 1995 for 2-4y band. During this period, a low of energy is shown for 4-8y band and increases in 1970-1975 and 1995-2010. For the last band of 8-12y, the contribution of NAO is displayed during the full period of study.

The **Tunisian** rainfall conditions are correlated to NAO for three bands of energy. For 2-4y band, the coherence is observed during 1975-2005 with an interruption in 1995-1998. For the 4-8 y energy band, the link between the NAO and Rainfall is strong. Similar to Morocco, the NAO contribution is observed from 1970 to 2010 for the low frequency of 8-12y band.

The two discontinuities of NAO in 1975 and 1990 seems to be reproduced by rainfall conditions as seen in Fig. 5 in Morocco and Tunisia which is not the case in Algeria where the NAO discontinuities are not clearly observed (Fig. 5, Algeria).

The low energy of coherence in Morocco between 1975 and 2007 can be explained by the long dry period characterizing this country. The return of wet conditions since 2007 is related to NAO variability which shows a high energy bands. The dry period in Tunisia is shorter than Morocco one, which is clearly observed from the coherence with NAO. The dry period in Algeria was occurred between 1980 and 1998 which is explained by NAO coherence, observed for 4y band.

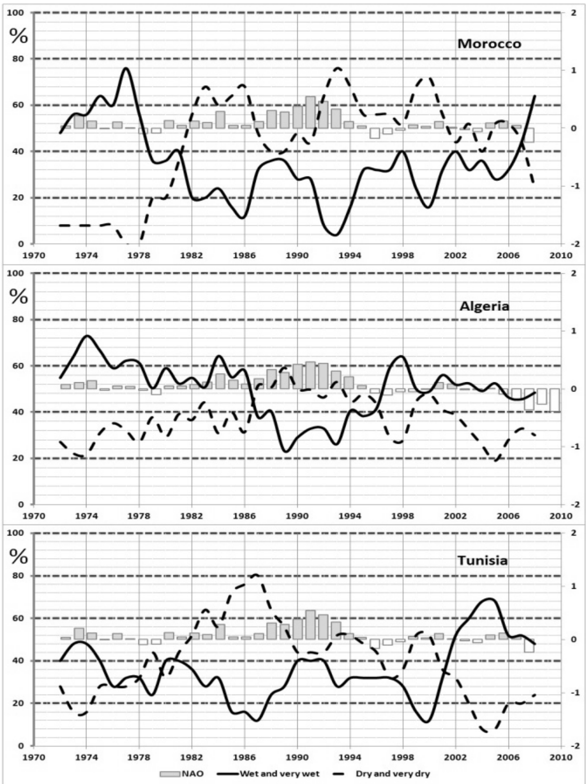

Fig. 2. Mobile averages for the frequencies of the stations which recorded humid and very humid and dry and very dry years (%) and NAO index (September to February) for the measurement period from 1970 – 2010

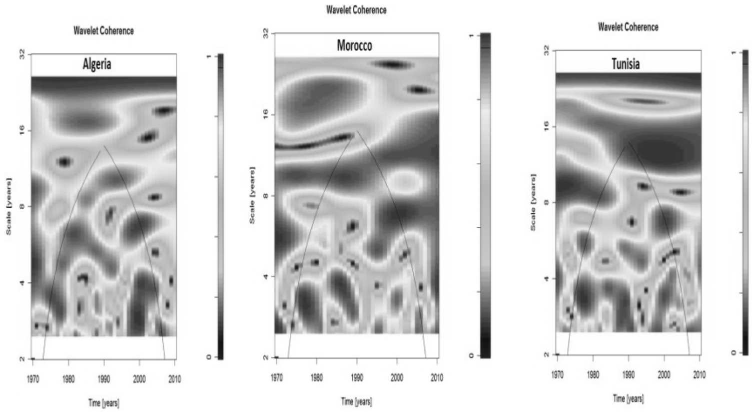

Fig. 3. Wavelet coherence of NAO and rainfall in the three regions

4. CONCLUSION

In this study, we show that a positive NAO index is consistent with dry rainfall conditions. Thus, the detailed analysis (extreme and wavelets) of the response of the rainfall to the North Atlantic Oscillation shows that the drought period seems more correlated with the positive indices of high intensity, reflecting a greater strengthening of the anticyclone of the Azores and a digging depression of Iceland. Under these conditions, the depressions rail withdraws to northern latitudes, which promotes the establishment of a time dry and soft around Mediterranean basin and Maghreb regions.

For the studied regions, the last years of the time series are characterized by an increase of the wet years. These are observed in Algeria from 1996 and in Tunisia from 2001. For Morocco, we find this phenomenon from 2007. This new more rainy period continues in this area of the North Africa for the years 2011, 2012 and 2013 (according to the meteorological, hydrological and agricultural observations obtainable in these different countries) and coincides with a phase negative NAO index. When the NAO index is negative, the pressure associated with the Azores is lower than its normal value. In the same time, the Iceland depresssion is barely shallower. According to this mode of movement, the depressions rail is offset to the south. In this position, it affects the southern part of the Mediterranean basin and led to more rainfall in these regions

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