Journal of Environment and Earth Science www.iiste.org
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.6, No.2, 2016

Relationship Between Climate Index (WMOI, SOI) and Rainfall Variability in Azib Soltane (Sebou basin Marocco)

Zineb Zamrane[1,2*] Nour-Eddine Laftouhi[2] Gil Mahé[1] Benoit Laignel[3]
1.IRD, UMR HydroSciences, University of Montpellier, 34095 Montpellier, Cx 5, France. 6
2.Faculty of Sciences Semlalia Marrakesh, Lab. GEOHYD, BP 2390 Marrakesh 40000 Morocco
3.UMR CNRS 6143 Continental and Coastal Morphodynamics'M2C' University of Rouen, 76821 Mont-Saint-8 Aignan Cedex, France.

Abstract
The objective of this study is to understand the inter-annual variability of rainfall in the region Azib Soltane in the Sebou basin and determined the relationship with climatic fluctuations (represented by Western Mediterranean Oscillation Index [WMOI] and South Oscillation Index [SOI]). To attain this objective, the time series of precipitation at Azib Soltane is being studied by continuous wavelet analysis and wavelet coherence analysis, which are particularly adapted to the study of unstable process.The wavelet analysis of rainfall shows the existence of many groups of energy, from the annual to the inter-annual scales. These bands correspond to modes 1 year, 2-4 years, 4-8 years. The wavelet analysis of coherence shows a strong coherence between WMOI / rain, SOI/rain. The discontinuities can be observed in the late 1980s, 1995. The average contribution of climate fluctuations is about of 60%.
Keys words: Climate fluctuation, Morocco, WMOI, SOI, wavelets, and coherence.

1. Introduction

In recent studies, such as the report of the IPCC (Intergovernmental Panel on Climate Change), published in 2007, the long-term climate change refers to a change of climate parameters in time and in the space (local, regional and global), the impact may include rising sea levels, desertification (Seguin, 2010, Puigdefabregas and Mendizabal, 1997), decreasing biodiversity and freshwater resources (Middelkoop et al., 2001, Hadria et al, 2005, Green and Pershing, 2000; Parsons and Lear, 2001; Green et al., 2003; Lomas and Bates, 2004), and the accentuation of hydrological extremes (floods and drought) (Boukrim, 2011, Salama and Tahiri, 2010). Climate also varies under astronomical factors (solar radiation, atmosphere) (Christoph et al, 2004), geographical factors (topography, ocean) (Bigot et al, 2005) and meteorological factors.

Global fluctuations are generally explained by changes in climatic indices, including El Niño Southern index (ENSO), the Southern Oscillation Index (SOI) and the North Atlantic Oscillation (NAO), representing the diagnostic tools used to define the condition of a climatic system and understanding of the various climate mechanisms. This indexes were related to local hydrological changes observed in some large rivers (Labat et al, 2005b); But the interpretation of this relationship is still the subject of several discussions as indicated by Labat et al., 2005a and Legates et al., 2005.

Global fluctuations of climate change on the hydrological cycles in Africa are objet of many studies. Conway et al. (2009) studied the variability of rainfall and water resources in sub-Saharan Africa during the 20th century with nine major international river basins. They showed that sub-Saharan Africa is exposed to drought after the 1970s, marked by relative stability wet years in East Africa, the periodic behaviors are the basis of strong interannual variability in Southern Africa and modest decadal variability in Central Africa, the correlations between rainfall and streamflow for 20 years tend to be higher during periods of highest density in precipitation stations. The links between rainfall and flow data in Africa, require the integration of global climate index to improve African climate forecasts.

Numerous studies have been directed to the Sahel (Winstanley 1973 Bunting et al., 1976, Lamb 1982, Nicholson 1981 Olivry 1983, 1987, Hulme 2001, Mahé et Paturel, 2009). Some authors also compare the Sahelian rainfall with precipitations in other areas of Africa, particularly in West Africa and also in Central Africa (Sircoulon 1976 1985 Lambergeon 1977, Motha et al. 1980, Nicholson 1981, 1983, 1990, Camberlin, 2001, Hulme, 1992, Mahé et Olivry 1995). Other researchers used standardized anomalies hydrologic time series in North Africa (Taibi et al. 2013, Khomsi et al. 2013).

The Mediterranean coast receive more rainfall in winter, when extratropical synoptic disturbances through the area. Knippertz et al. (2003) explains that the rains of winter frontal regularly affect the northern and western parts of Morocco and the Algerian coast, usually fail the southern side of the Atlas Mountains. The contribution of summer rainfall is not negligible, it helps to maintain the water supply in the oases in northern Mauritania, southern Morocco and western Algeria. Hydrological variability in Africa has been studied by many authors since the beginning of the recent drought in the 1970s.

The climat of Sebou Basin is mediterranean with oceanic influence and the climate becomes more continental on the inside of basin. Two main seasons are determined by the movement in the winter of a polar air and the increasing of tropical air.

In this research, rainfall variability in Azib Soltane in the Sebou basin (Morocco) was studied between 1963 and 2006 to climate fluctuations (WMOI and SOI). The terms of this research can be divided into four parts. Following the introduction, a description of the study area and database with the study methodology are presented. Then rainfall variability is analyzed and linked to climate indices using continuous wavelet transform. The results are then discussed and concluded in the last part.

2. Study Area

The region of Azib Soltane is located in the northwest of Morocco, in the southern Mediterranean, the hydrological cycle is controlled by the Sebou basin (Figure 1), with an area about 40,000 km2, it forms a cuvette limited to the north by the Rif massif and south by the mountains of the Middle Atlas and the Meseta (Snoussi, 1988). The Sebou river rises at 600 km upstream of the basin in the Middle Atlas and it discharges into the Atlantic Ocean (Haida, et al, 1999). The Sebou basin covers in northern the southern side of the central Rif and most of the South East, the Middle Atlas in the south of the basin, culminating at 2800m, the rifaine hills and the central highlands border the alluvial plain of the Gharb.

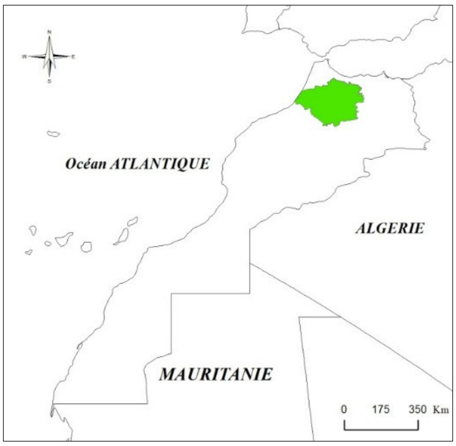

Figure 1: The Sebou watershed, Azib Soltane (Marocco).

From his position, in the West largely open to the Atlantic Ocean, in the north close to Mediterranean and southeast is dominated by an arid depression, the climate of Sebou Basin is Mediterranean with oceanic influence and the climate becomes more continental on the inside of basin. Two main seasons are determined by the movement in the winter of a polar air and the increasing of tropical air.

The northern part of the basin, occupied by the Rif Mountain, receives a high abundance of rainfall which may exceed 2000 mm / year. In the Middle Atlas, only the most elevated areas have a higher rainfall 1000 mm / year. In the Rharb plain, annual rainfall average is 600 mm / year in the coastal area and decreases to 450 mm in the southeastern part. (Haida and al.1999).

3. Data And Methodology

The data used for this study are the monthly rainfall and also the climate index WMOI (Western Atlantic Oscillation Index) and SOI (South Atlantic Oscillation). The duration of this series is 43 years. These data were obtained from the National Meteorology Direction (DMN).

The SOI gives an indication of the evolution and intensity of El Niño or La Niña in the Pacific Ocean. The SOI is calculated using the difference in pressure between Tahiti and Darwin, obtained from (http://www.ncdc.noaa.gov/teleconnections/enso/indicators/soi/).

The WMOI, is a model of low frequency atmospheric circulation variability that was first defined by Martin-Vide and Lopez-Bustins (2006). The Western Mediterranean Oscillation Index (WeMOi), defined as the difference of normalized values of the pressures at sea level between Cadiz-San Fernando (Spain) and Padua (Italy) (Martin-Vide and Lopez-Bustins 2006), was collected from (http://www.ub.edu/gc/English/wemo.htm).

The method used in our study is the continuous wavelet transform (TO), it is a mathematical technique that is very useful for numerical analysis and manipulation of multidimensional discrete signals. The TO is designed to identify and quantify each time characteristic of the main spectral components in the time series. The wavelet transform is used to follow the evolution in time of the process at different scales at the signal (Labat, 2005), used to decompose the signal to the wavelet daughters, which correspond to versions parameterized scale and translated to a reference mother wavelet.

Every wavelet has a finite length (a scale) and is highly localized in time. The mother wavelet has two settings for the time-frequency exploration: a scaling parameter a and temporal location parameter b.

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right) \quad (1)$$

ψ a, b (t): Wavelet daughter
a: parameter of scale
b: parameter of temporal localization

The parameterization of scale and wavelet daughters allows the detection of different frequency composing the signal. In addition, these frequency components can be detected and studied in time, which allows a better description of non-stationary processes (Schneider et Farge, 2006; and Torrence Compo 1998). Continuous wavelet transform of a signal S (t) produces a local wavelet spectrum, as defined below:

$$S(a,b) = \int_{-\infty}^{+\infty} s(t).\frac{1}{\sqrt{a}}.\psi\left(\frac{t-b}{a}\right).dt \quad (2)$$

The concept of coherence at the signal processing is the measurement of the correlation between the two signals or between two representations of these signals (Labat 2010). To compare the time series between them, the cross-correlation analysis is used, this method effectively gives new knowledge on the degree of correlation of the scale of dependence between two given signals (Onorato et al, 1997. Labat et al, 2002).

The coherence can be defined as the estimate of the temporal evolution of the linearity and the relationship between two signals at a given scale (Labat, 2005 Maraun, 2006). The coherence wavelet is calculated using wavelet spectrum smoothed SWXX of series (a, τ) and SWYY (a, τ) and a cross wavelet spectrum smoothed SWXY (a, τ) (Torrence and Webster, 1999):

$$WC(a,\tau) = \frac{|SW_{XY}(a,\tau)|}{\sqrt{[|SW_{XY}(a,\tau)|.|SW_{YY}(a,\tau)|]}} \quad (3)$$

The coherence is defined as the module of cross-spectrum, normalized by the same spectrum, having values between zero and one, it represents the degree of linear between two processes; a value of 1 means a linear correlation between the two signals at a time T to the scale a, a value of 0 indicates no correlation (Maraun and Kurths 2004; Maraun, 2006; Labat, 2010).

4. Results And Discussion

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 (Turki et al, 2015), Higher variation (large wavelengths) in the signal can be detected by larger daughter wavelets while smaller ones define smaller variations (short wavelengths), the TO produces time scale (which can also be represented as a time period or a time-frequency diagram) showing the distribution of the spectral content (power, z-axis) across time (x-axis) and scales (or period or the frequency, the y-axis).

Rainfall in the region of Azib Soltane, presented in Figure 2, are characterized by modes of variability, the annual scale to interannual scales, with discontinuities. We identify an annual cycle, structured and observed throughout the study series, it is strongly marked in the region. The mode 2-3 years corresponds to a small fluctuation expressed in mid-1995-1998 and the mode 4-8 years a strong fluctuations observed from 1963 to end 1970 and from 1995 to mid-2000. Discontinuities are observed in 1980 and 1995, from this discontinuities, the series is divided into three periods.

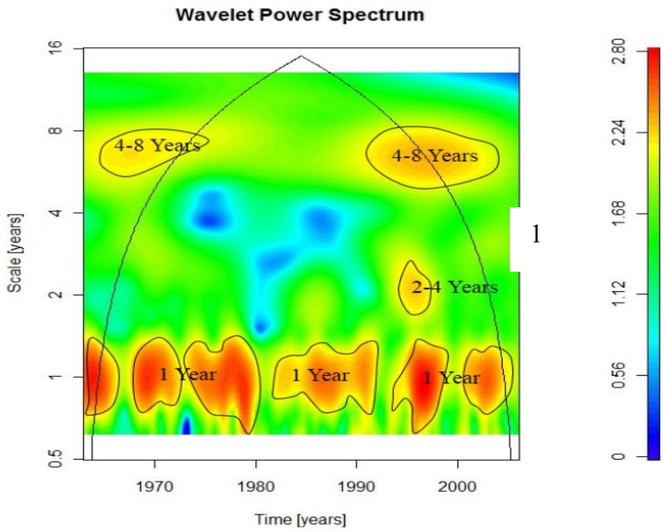

Figure 2: study the variability of rainfall in Azib Soltane by using continuous wavelet method

Interannual variability is affected by the low frequencies between 2 and 8 years, while the annual mode is associated with higher frequencies. The results show a high variability of the annual frequency during the periods 1963-1965, 1968-1980, 1983-1993, and 1995-2005. Low energy around the first discontinuity in 1980 can be observed for the low frequency modes (4-8 years). However, before the first and after the last discontinuity high power mode for 4-8 years.

The coherence between WMOI, SOI and precipitation at Azib Soltane was made using WCO. The diagram of coherence shows, according to these results, the low frequency of precipitation are highly correlated with climatic indices WMOI and SOI.

The variability of coherence, presented in Figure 3 and 4 are marked by a distribution of red (high coherence) to blue (low consistency).

WMOI shows a coherence in annual to decadal scale (Figure 3). Strong coherence is detected for time scales 16-20 years before 1990, for mode 4-8 years in 1963 and after 1985, 2-4 years of world spots were also identified in 1970 in the region of Azib Soltane, interrupted by a rupture in 1980. The annual cycle is affected between 1980 and 1990. For 2-4 years are also identified in 1970 in the region of Azib Soltane, interrupted by a rupture in 1980. The annual cycle is affected between 1980 and 1990.

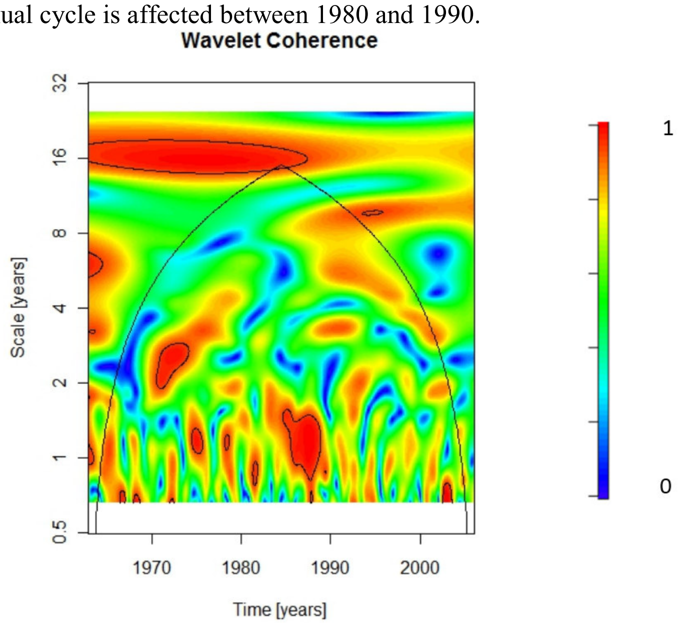

Figure 3: Spectrum wavelet coherence between rain and WMOI at Azib Soltane (Sebou basin).

The SOI show coherence (Figure 4) distributed on the decadal. For the whole period considered, the annual scales, inter-annual (2-8 years), decadal (8- 16) are affected only before the mid1970s and after the mid-1980s. The 16-20 mode is identified throughout the study period.

The series of droughts which have faced different regions of Morocco since the early 1980s were marked by Esper et al., (2007). The end of the 1980s and beginning of the 1990s are known to dry conditions over a large part of the Mediterranean basin (Kutiel et al., 1996) and according to Hurrell and Van Loon (1997), the years 1981-1995 were particularly dry in southern Europe and northern Morocco. The recurrence of dry conditions in the Mediterranean area since the early 1980s has been attributed to the persistence of the positive phase of the North Atlantic Oscillation (Lamb and Peppler, 1987; Xoplaki et al, 2004, Visbeck et al.. 2001).

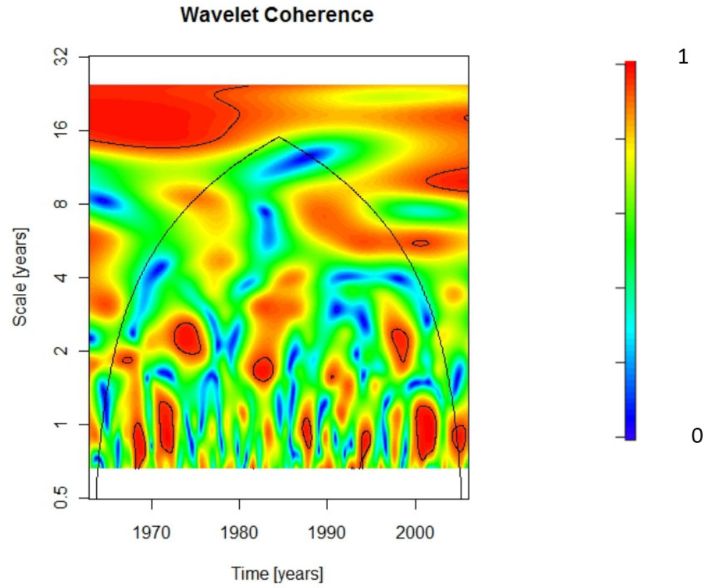

Figure 4: Spectrum wavelet coherence between rain and SOI at Azib Soltane (Sebou basin).

Using the coherence wavelet contribution weather index (WMOI and SOI) on precipitation at Aazib Sultan was quantified in time for the different modes of variability as shown in Figure 5 and 6.

The high fluctuations are between 20 and 100%, the coherence between WMOI and rain for 1year shows a short wavelength. High contribution for the annual mode can be observed between 1980 and 1990. The mode 2-4 and 4-8 years shows an average coherence of 50 %; it is higher between 1985 and 2000 for the first fluctuation (2-4 years) and between 1970 and 1980 for the second. Une forte contribution peut être observée pour le mode 8-12 ans comprise entre 60% et 80%. The total contribution of WMOI in rainfall data (1-16 years) show low vibrations with short wavelength.

The coherence between SOI and rainfall for 1y shows a short wavelength. The most important contribution of the annual mode can be observed between end 1970 and 2005. The mode 2-4 shows an average coherence of 60% identified between 1970-1980 and 1980- 1990. The mode 4-8 years shows an average coherence of 60 %; it is higher between 1985 and 2000. High contribution can be observed for the 8-16 year between 60% and 80%. The total contribution of the SOI (1-16 years old) show low oscillations with short wavelength, high contribution is identified after 1995.

The low frequency variability (> 1-2 years - 12 years) can be controlled by WMOI and SOI, then by global climatic fluctuations, while the high frequency variability (<1-2 years) is primarily controlled by local conditions so the local climate. Numerous studies have been conducted to determine the relationship between the hydrological parameters and other climate index such NAO (Massei et al. 2007, 2009, 2011, Laignel et al., 2010). The annual oscillation has been present in the series of flow rates and was affected by a power increase from 1990 in the Seine River (Massei et al., 2009).

According to the wavelet approach, rainfall variability for annual and interannual frequency can be distributed into three periods, limited by two major discontinuities in 1980 and 1995. During the first period (1963-1980), high energy was detected at frequencies of 1 year and 4-8 years. Since 1980, low energy is observed for 4-8 years, we identify energy 2-4 years between 1995 and 2005, over the same period, over the same period, the mode 4-8 years returns and the annual mode is identify between 1985 and 1995, the annual world highlighted a great energy throughout the series studied.

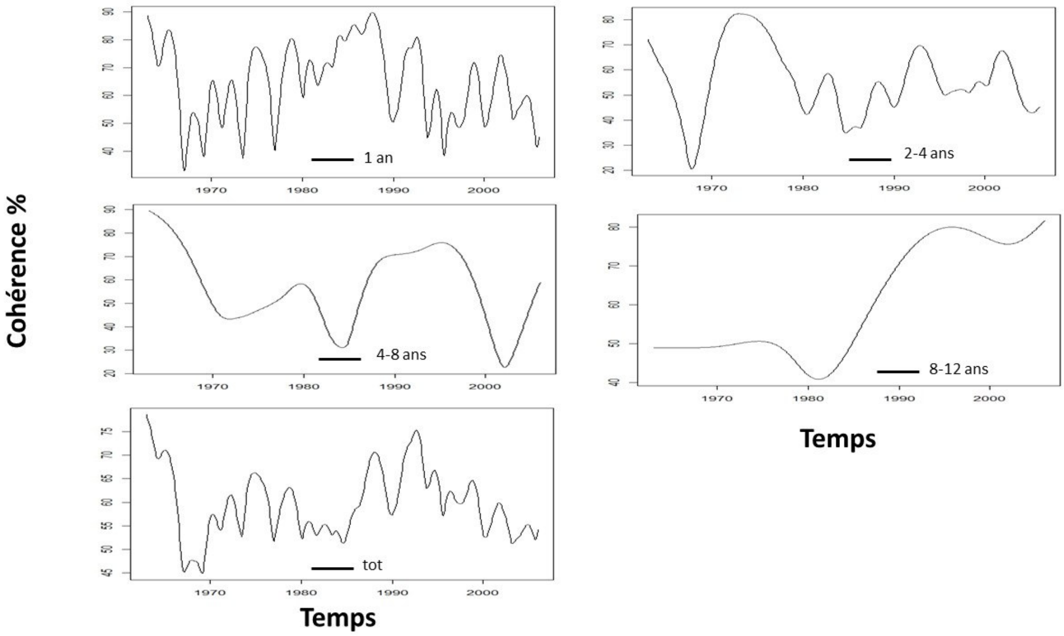

Figure 5: The contribution of WMOI in precipitation at Azib soltane for all modes of variability (1a, 2-4, 5-8, 8-12 years) and the total signal.

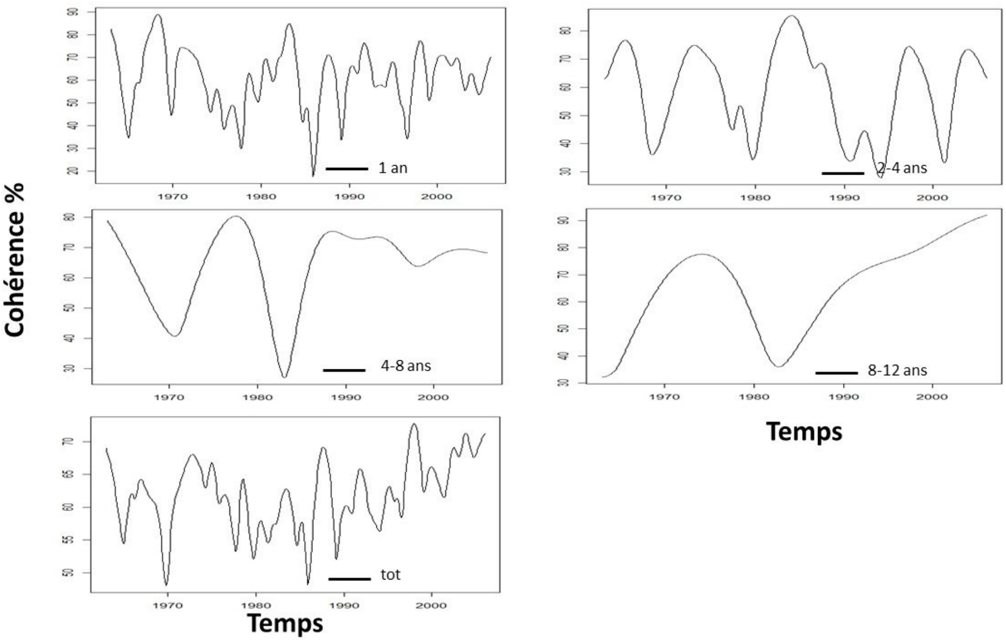

Figure 6: The contribution of SOI in precipitation at Azib soltane for all modes of variability (1a, 2-4, 5-8, 8-12 years) and the total signal.

Massei et al. (2007) showed that rainfall variability in France during the last 35 years (1970-2005) is characterized by two major discontinuities around the years 70 and 90 and identified almost biennial oscillation of precipitation in the NAO. The two discontinuities were also found in the time series of the Seine flows (northwest France) studied by Massei et al. (2009) between 1950 and 2008. The discontinuity around 1980 was not observed in their results. Fritier et al. (2009) studied the inter-annual at multi-decadal variability of rainfall in the winter on the Seine between 1951 and 2004. They showed increased variability in the last century and the discontinuity of consistency between the NAO and hydrological conditions in particular between 1910 and 1955. The coherence between WMOI and SOI and precipitation at Azib Soltane was strongly observed for all modes of variability. Laignel et al. (2008) identified two major discontinuities around 1970s and 1990s in hydrological time series and have associated this discontinuities with climate globally from various climate index such as NAO, SOI and PDO.

5. Conclusion

This research was interested to rainfall variability at Azib Soltane, one of the semi-arid south side of the Mediterranean, and its relationship with climate fluctuations (WMOI and SOI) representing major climate models. The wavelet technique aims to identify different modes of variability and their relationship with WMOI and SOI. This technique has been applied to the precipitation of Azib Soltane and showed a distribution of power following high and low frequencies. The coherence between climate indices and precipitation at Azib Soltane was defined low frequencies with a total contribution of 60%.

Studies at the East side and North East of Morocco would be necessary to study the evolution of rainfall, Studies at the East side and North East Morocco would be necessary to study the evolution of rainfall, their different modes of variability and their relationship with other climate patterns globally, being as new avenue of research.

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