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Inter-annual variability of precipitation in the Souss Massa region and linkage of the North Atlantic Oscillation.

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Abstract

The analysis of the spatial and temporal inter-annual variability of Souss-Massa precipitation is the main objective of this work. The spatial distribution of precipitation in the region during 1980-2010 shows that rainfall follows a gradient from the North to the South and from the West to the East. We study the influence of altitude and distance to the Atlantic Ocean on annual precipitation using the Principal Component Analysis. The regional precipitation increases with high altitude and decrease with low distances to the sea. We distinguish three clusters of stations with the same rainfall behaviour, stations located in the plains, in the mountains and the most distant stations from the Atlantic Ocean. The evolution of the standardized precipitation index during 1980-2010 shows that the wet years represent 16% and the dry years represent 35% of the studied period. No statistically significant trend is detected during 1980-2010 for all the stations according to the results of the Mann-Kendall test. Change-points analyses show no statistically significant change-point according to Buishand test, Pettitt test and the Hubert segmentation. The results of continuous wavelet analysis show multiple significant high energy bands (p=0.05) for the periods of 1 year, (2-4) years, (3-5) years and (5-10) years in most stations, with the persistence of continuous high energy bands of 8 to 9 years around the period 1990-2002. The wavelet coherency analysis indicates a significant anti-phase between the NAO and the regional SPI during 1980-2010.

1. Introduction

The geographical context places the Souss-Massa region between four major geographical structures, Atlantic Ocean to the west, High-Atlas Mountains to the north, Anti-Atlas Mountains to the east and Sahara to the south. Cold fronts are blocked north of the study area by the High Atlas, while maritime breeze allows the coastal zone to have a relatively mild and regular climate [1]. Also, the Saharan borders influence areas Southeast Souss-Massa. These regional specificities could be at the origin of the rainfall regime, as other components could contribute in it is explanation.

Semi-arid regions, particularly the South and the East of Morocco face high inter-annual precipitation variability increasing their sensitivity to climate change [2,3,4]. Rainfall contributions are decreasing in Mediterranean regions since the 1970s. By studying the periods 1931-1960 and 1960-1990, an increase in the relative variability of annual precipitation is indicated south of the Atlas Mountains by [5]. Concerning Morocco, pronounced dry conditions are experienced since the 1980s [6]. More global models show a trend towards reduced rainfall [7,8].

Climate conditions of these arid areas influence the availability of natural resources. In addition to wet season precipitations, the analysis of the origin of water resources in Souss Massa region show a considerable contribution from High Atlas Mountains snow melt [9]. The vulnerability of Souss Massa Basin to climate change effects has been confirmed by earlier published studies [10, 11]. Another equally alarming is the decrease of groundwater levels related to arid climate conditions and agricultural exploitation [10,12]. Water resources in the Souss-Massa region are beneath pressures caused by a growing demand since the second half of this century, mainly for the sectors of agriculture and tourism.

Positioned between different geographical structures, the climate of the study area is influenced by a combination of local and regional factors. The characterization of the local rainfall regime is important to better understand the dynamic of the hydrological regime in Souss Massa which strongly influences the local economy. The study of the relationship between local precipitation and global climate variables improve the acknowledge of regional characteristics. The works of [36,37] were the first to investigate the influence of extra-tropical circulation patterns on Moroccan rainfall.

The purpose of this work is to analyse the spatial and temporal variability of rainfall in the Souss-Massa region. Also, we are interested by the relationship between the standardized precipitation index of Souss-Massa rainfall and the North Atlantic oscillation (NAO). We use a dataset of monthly precipitation data from 11 meteorological stations in the Souss-Massa region during the period of 1980-2010 provided by the Agency of Hydraulic Agency of Souss-Massa Basin (ABHSM) (Figure 1).

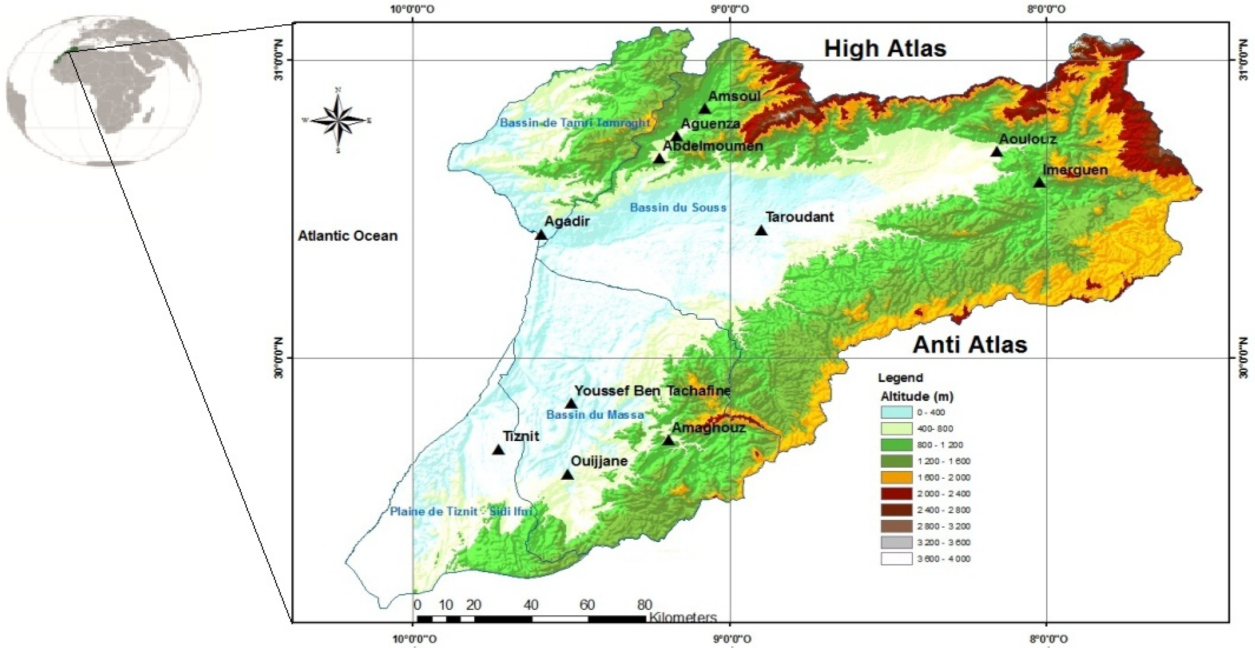

Figure 1: Topography (altitude in meters) and locations of the stations.

2. Data and Methods

2.1. Data

The data used in this study are from the regional network of meteorological stations under the authority of public organisations, provided by the Hydraulic Agency of Souss-Massa-Draa Basin (ABHSMD). The data consist of observed monthly precipitation data from 11 stations in the Souss-Massa region. These stations were chosen for their quality (limit of 10% of missing data) during the period 1980-2010 and for their coherent spatial coverage of the study area. Their geographical descriptions and their organisms are showed in Table 1, (ABHSMD) and High Commission for Waters and Forests and the Fight against Desertification (HCEFLCD).

2.2 Statistical analyses

The coefficient of variation is calculated in order to show the variability of cumulative rainfall for each station. It consists of a measure of the relative dispersion of the standard deviation from the mean. Principal component analysis (PCA) [13,14] and Hierarchical clustering [15] are also performed to study the spatial distribution of rainfall in Souss Massa region during 1980-2010. Furthermore, the standardized precipitation index (SPI), developed by [16] is used to distinguish wet years from dry years. Values less than -0.5 are considered as dry years and greater than 0.5 are wet years. Continuous wavelet transforms and wavelet coherency were calculated to detect significant periodicities of precipitation from 1980 to 2010 [17, 18, 19]. In order to highlight possible trends in the data series we applied the non-parametric test of Mann-Kendall [20, 21] which has been shown to be effective for analyzing hydrological data trends [21,22]. The U statistics of Buishand [23,24] is a parametric Bayesian approach and derives from an original formulation given by[25]. The non-parametric test of Pettitt

[26, 27, 28, 29] is applied, the null hypothesis is of "non-break". The segmentation procedure of hydrometeorological series is also applied to detect breaks [30, 31, 32]. This method is adapted to the search for multiple changes of mean in the series.

Table1: Geographical description of the data, percentage of missing data and organisations.

Stations	Latitude	Longitude	Z	Missing data (%)	Organisations
Agadir (AGA)	30°25'57,69"N	9° 5'53,73"O	32	0	ABHSMD
Taroudant (TAR)	30°25'52,52"N	8°53'52,21"O	206	0	ABHSMD
Aoulouz (AOL)	30°41'37,19"N	8° 9'19,13"O	698	0,54	HCEFLCD
Amsoul (AMS)	30°50'15,64"N	9° 4'33,17"O	852	1,88	ABHSMD
Ouijjane (OUJ)	29°36'51,31"N	9°30'32,20"O	283	2,68	ABHSMD
Imerguen (IMG)	30°35'27,43"N	8° 1'12,78"O	901	6,43	ABHSMD
Tiznit (TIZ)	29°41'45,96"N	9°43'40,77"O	241	7,77	HCEFLCD
Youssef ben Tachafine (YBT)	29°51'2,73"N	9°29'48,00"O	114	4,83	ABHSMD
Aguenza (AGZ)	30°44'47,08"N	9° 9'52,30"O	740	9,38	ABHSMD
Abdelmoumen (ABD)	30°40'16,59"N	9°13'10,88"O	692	9,92	ABHSMD
Amaghouz (AMA)	29°43'35,46"N	9°11'25,64"O	634	1,34	ABHSMD

3. Results and discussion

3.1 Spatial variability of regional inter-annual precipitation

The duration of the rainy season presents slight spatial differences from north to south of the country. In order to identify the seasonal variation of precipitation in the Souss Massa region, the mean precipitation is calculated for each month of the year for all the stations. The dry months are defined as months with precipitation below 20 mm and the wet months are those that exceed of 20 mm. Therefore, two rainfall structures were distinguished: a rainy season from October to April, during which the depressions and perturbations from the West plays an essential role in the explanation of the rains and a dry season from May to September during which the precipitation are very weak and often stormy, under the influence of the anticyclone of the Azores [33].

The analysis of the inter-annual evolution of precipitation was based on the rainfall totals calculated from October to September of the following year. The rainfall records during 1980-2010 show an inter-annual mean of 234 mm. This average varies between 154.2 mm in Ouijjane station located in the Massa basin at 283 m.a.s.l and 371.2 mm in the dam of Abdelmoumen located in the High Atlas Mountains 692 m.a.s.l. (Figure 2). We observe that it rains more in the Souss basin than in the Massa basin and in Tiznit plain. The coastal station of Agadir is recording the higher average during 1980-2010 among stations located in the plains. The distribution of annual precipitation mean during 1980-2010 shows that it rains remarkably more from the North to the South and from the West to the East in the Souss Massa Region.

Furthermore, the contributions of rainy and dry seasons to the amounts of annual rainfall were analyzed. The station of Agadir and Abdelmoumen show the highest contribution during the rainy season with respectively 96.4 and 96.3 % and the stations of Imerguen, Aoulouz, Amsoul and Amaghouz show the highest contributions during the dry season compared to all stations with values between 11.3 and 8.1 %. The latter stations are located in the High-Atlas and the Anti-atlas Mountains. The dry season precipitation in stations located in high altitude suggests convective rainfall events contributing to annual amounts in the Western High-Atlas and Anti-Atlas Mountains.

The coefficients of variation of Souss Massa precipitation between 80% and 45% respectively in Abdelmoumen and Imerguen stations located Northwest and East of the study area. The distribution of the coefficients of variation, which can be arranged according to three levels of variability, are shown in Figure 3. The stations of Agadir, Ouijjane and Taroudant located at about 200 m.a.s.l. and stations of Imerguen, Aoulouz, Amaghouz and

Amsoul located over 500 m.a.s.l. vary between 45 and 55%. The stations of Tiznit and Youssef Ben Tachafine dam vary between 60 and 65%. The stations of Aguenza and Abdelmoumen located in the Argana corridor, for which the coefficient of variation is greater than 65%.

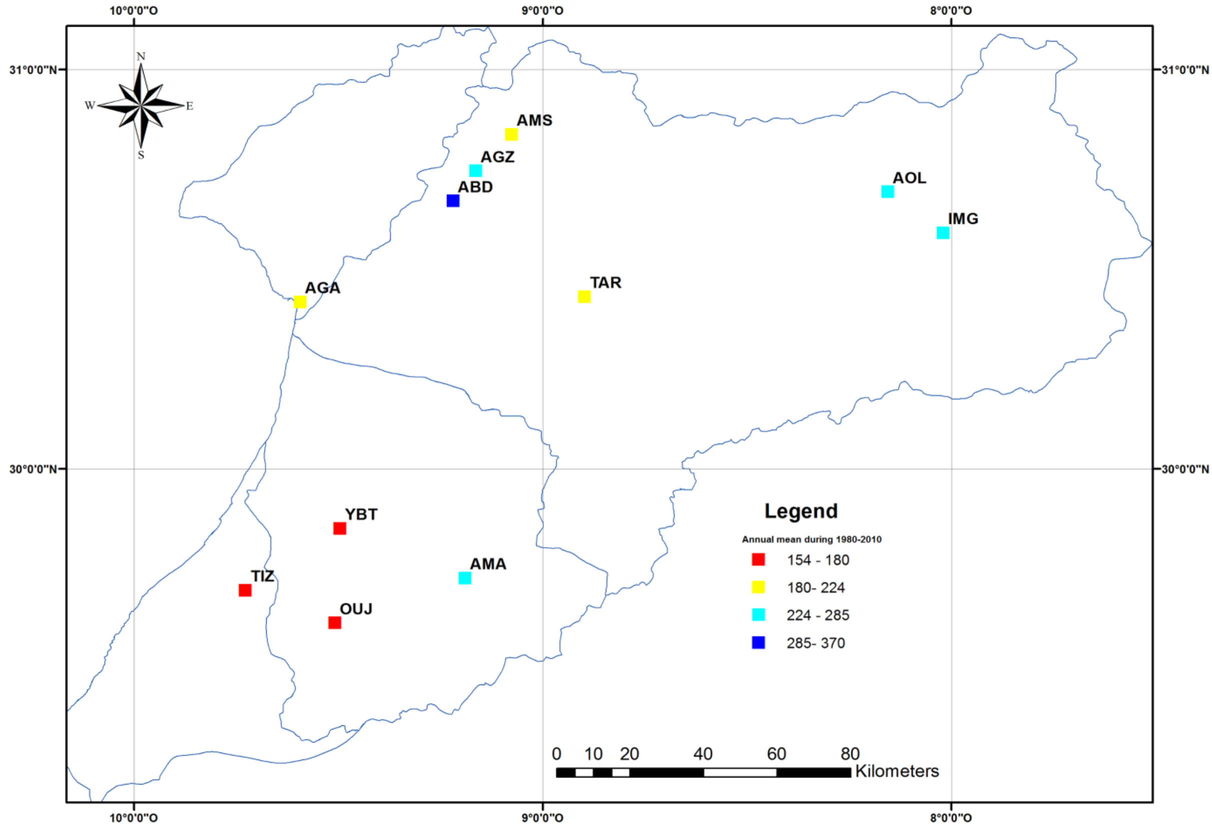

Figure 2: Spatial distribution of annual mean precipitation during 1980-2010.

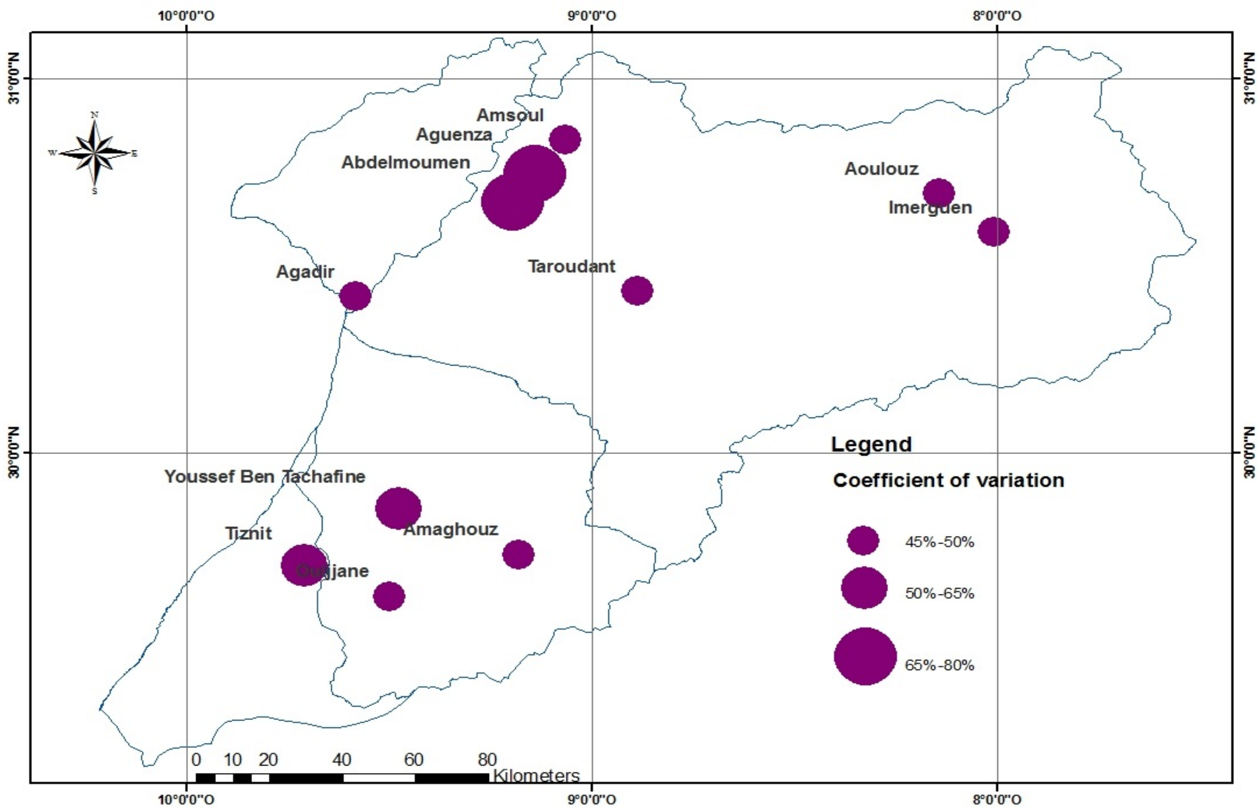

Figure 3: Spatial distribution of coefficient of variation during 1980-2010.

Previous works on the variability of Moroccan precipitation, which have often been limited to the city of Agadir, stipulates that the variation in precipitation increases in general towards the South and that this variation is of about 40% in Agadir [34] and of 70% Southern Morocco [2,35]. The order of magnitude and the direction of this variation observed in previous studies are not confirmed for studied stations. The limited number of stations used in this work, in time and in space is restricting the analyses.

In order to show the influence of local factors on the inter-annual precipitation in each of the studied stations, PCA analysis was performed. The individuals of the PCA are the stations, while variables consist of the inter-annual mean precipitation, altitude, distance to the Atlantic Ocean, latitude and longitude. Calculation of the correlation coefficients between inter-annual mean precipitation and local factors shows a significant positive correlation with altitude ($r = 0.63$, $p = 0.05\%$) but less significant with latitude ($r = 0.51$) and distance to the Atlantic Ocean ($r = 0.4$) and allowed to eliminate the latitude and longitude because of their redundancy. The PCA results show that the first axis represents 67.6% of the variance, followed by the second axis with 16.7% and the third axis with 10%. Altitude and distance to the sea contribute the most to the construction of the first axis with very close values ranking between 22.96% and 23.46%. While latitude and average precipitation contribute less with values around 15%. The stations that contribute least to the construction of the first axis are the stations of Taroudant, Amaghouz and Amsoul. The quality of their representation is rather low (the square cosines are around 0.01 for the Amaghouz station and around 0.2 for the other two stations). The stations of Abdelmoumen and Imerguen contribute more than the rest of the stations to the construction of this axis. For the second axis, the variable that contributes most to the construction are the distance to the sea. From Figure 4, it is apparent that annual mean precipitation increases with high altitude and decreases with low distances to the Atlantic Ocean. As per the second axis, it summarizes 16.7% of information and contrasts altitude and precipitation with distance to the sea. It shows that it often rains closer to the sea.

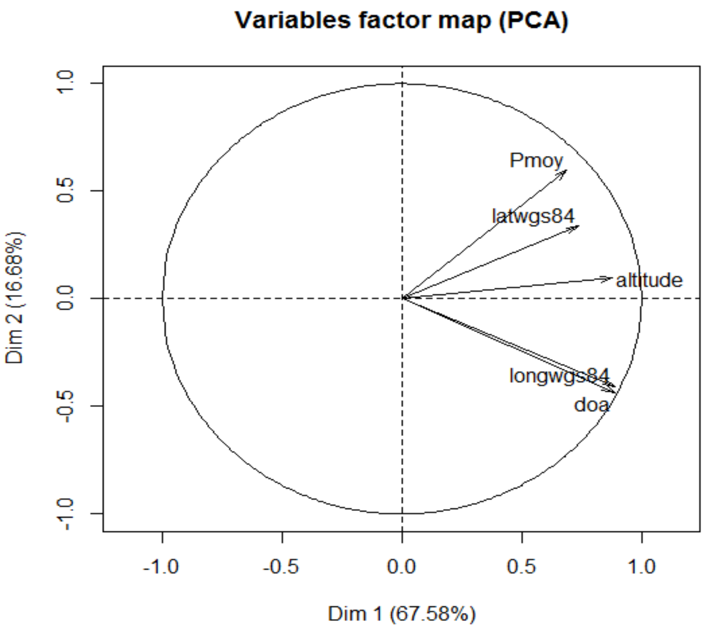

Figure 4: Factor map of Principal Component Analysis (PCA).

The hierarchical clustering is applied on the PCA, results allowed the distinction of homogenous clusters of stations presenting the same rainfall behaviour. The results show three clusters of stations: stations located in the plains, in the mountains and the most distant stations from the Atlantic Ocean (Figure 5). The first cluster is characterized with low precipitation and low altitude. The stations of Ouijjane, Youssef ben Tachafine and Tiznit are located in the plain of Massa and are receiving the same amounts of precipitation comparing to the stations of Agadir and Taroudant. The last two stations are located in the Souss plain and are receiving the same amounts of precipitation. However, their positions on the factors map are distant. This might be related to the location of the station of Taroudant of about 70 km away from the coastal station of Agadir. The highest rainfall stations are grouped in the second cluster. These stations are located in high altitudes varying from 630 to 850 m.a.s.l. The stations of Abdelmoumen, Aguenza and Amsoul are located in the Western High Atlas Mountains, while the station of amaghouz is located in the Anti-Atlas Mountains. The stations of Imerguen and Aoulouz are the most distant stations from the Atlantic Ocean with about 160 km, located respectively in 900 and 700 m.a.s.l and are receiving the same amounts of precipitation.

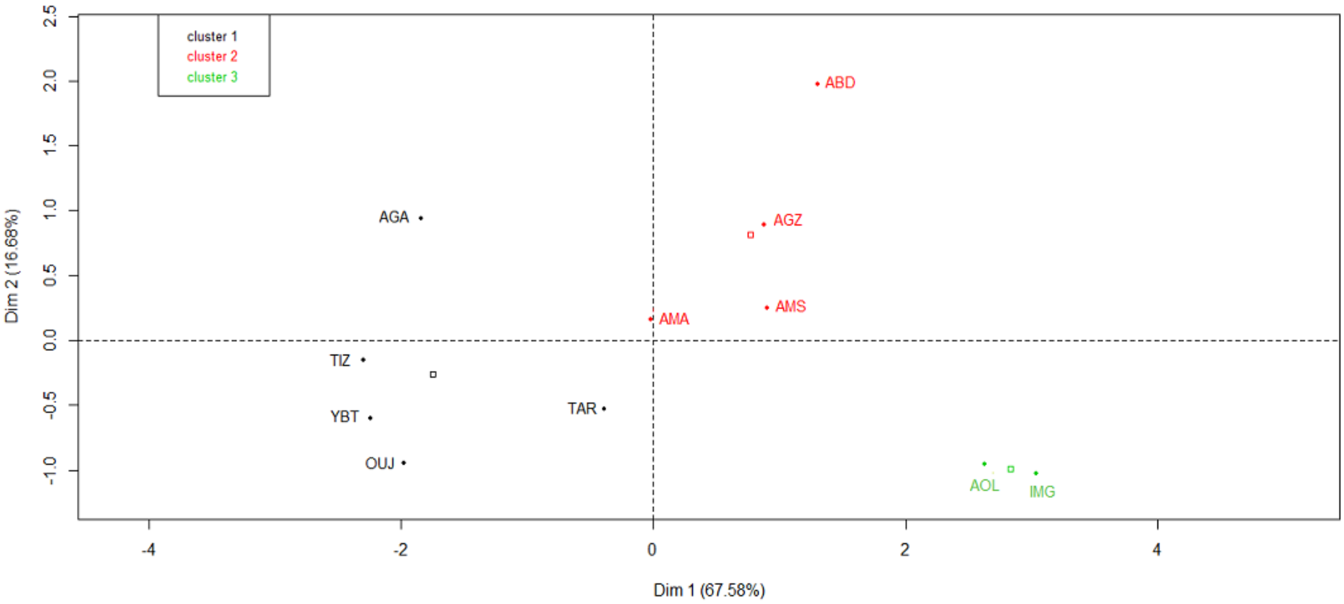

Figure 5: Clusters of stations.

3.2 Trend and change-points analyses

The Mann-Kendall test shows no statistically significant trend during 1980-2010 since the computed values are higher than the critical values for all the stations. Change-points analyses show no statistically significant change-point according to Buishand and Pettitt test. The Hubert segmentation is identifying the year 2009 as a break in five stations, however it is not considered as change-point as the position of this year in the end of the time-series.

3.3 Temporal variability of regional inter-annual precipitation

The standardized precipitation index is used to distinguish wet from dry years (Figure 6). The results show that the years 1988, 1996 and 2010 are distinguished by their high rainfall amounts, the years 1989 and 1997 which are the only other wet years, succeed them with less amounts of precipitation. We note that the driest year during 1980-2010 is the year 1993 with (SPI = -1.09). The succession of dry years 1992-1993, 2007-2008 and 1999-2001 as well as the succession of wet years 1988-1989 and 1996-1997 are also shown. The SPI evolution analysis shows that the wet years represent 16% of the total years and the dry years represent 35%. Hence, it is deduced that the Souss Massa region experienced more dry years than wet years from 1980 to 2010.

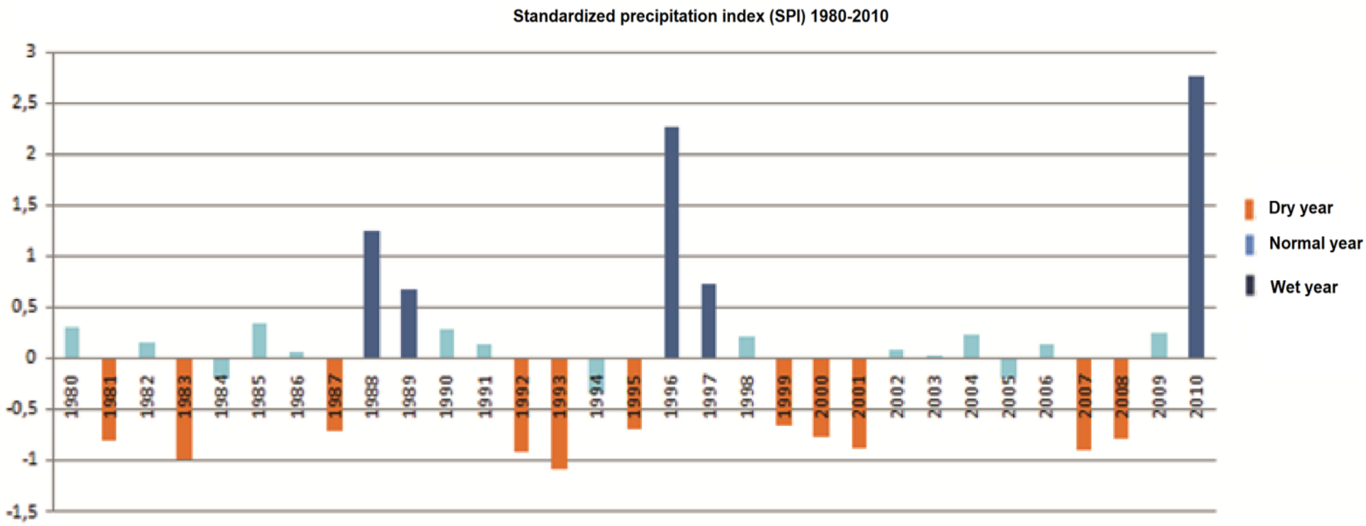

Figure 6: Evolution of the standardized precipitation index (SPI) during 1980-2010.

To analyse periodicities of annual regional precipitation during the period 1980-2010, the continuous wavelet analysis is applied to the stations (Figure 7). The results show multiple significant (p=0.05) high energy bands: 1

year, (2-4) years, (3-5) years and (5-10) years, expect for the Youssef Ben Tachafine. We observe the persistence of continuous high energy bands of 8 to 9 years around the period 1990-2002 in the eleven stations.

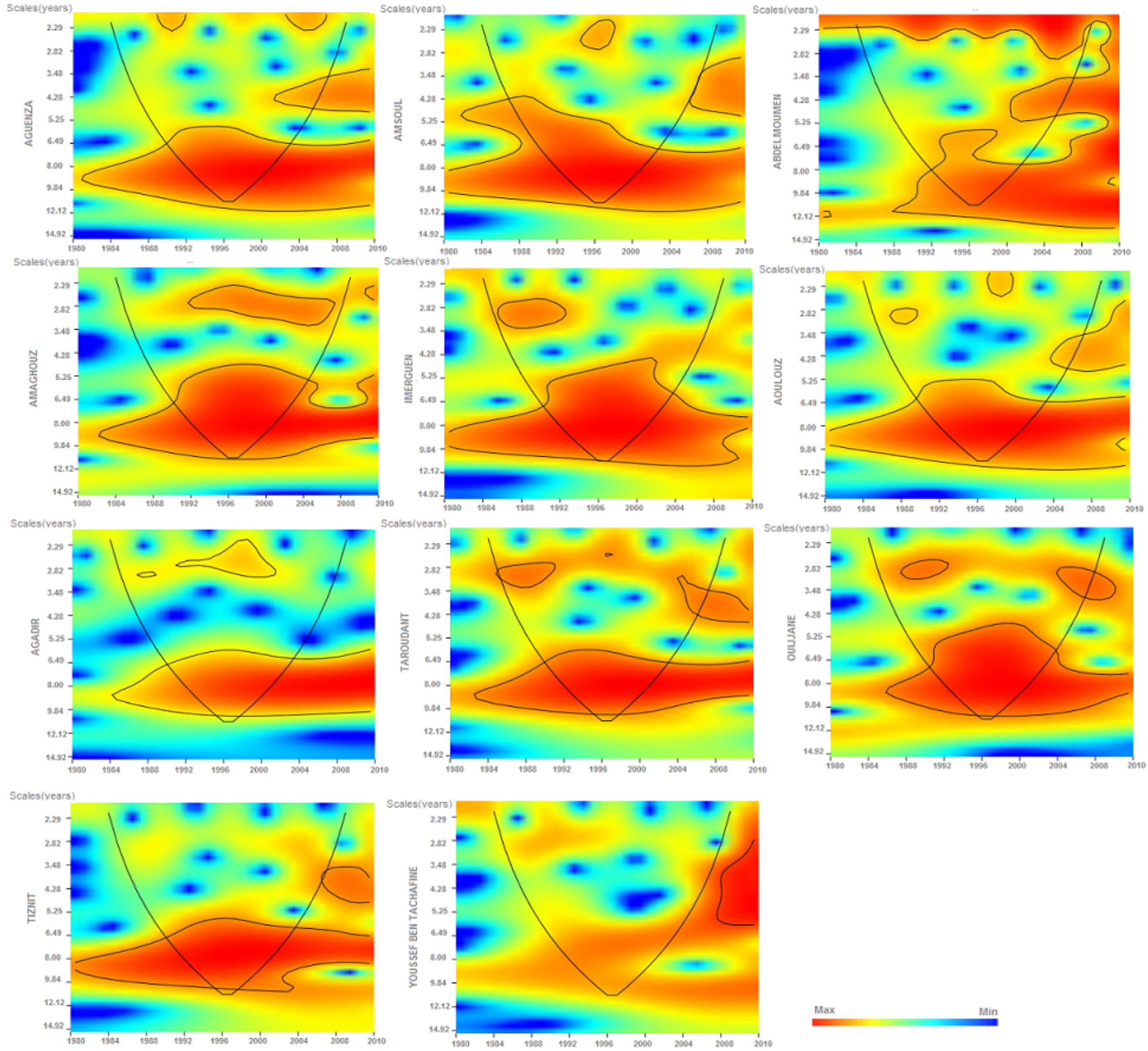

Figure 7: Continuous wavelet transform of annual precipitation during 1980-2010.

3.4 Linkage between regional precipitation and North Atlantic Oscillation:

Recent works confirmed linkage between the North Atlantic oscillation (NAO) [38,39]. In this section, we are interested by the relationship between the standardized precipitation index of Souss-Massa rainfall and the North Atlantic oscillation (NAO). The Nao index then indicates two phases: one is positive and the other negative. The positive phase of the NAO corresponds to a deepening of the Icelandic depression and an intensification of the anticyclone of the Azores, which intensify the western circulation on the northeast Atlantic and the European continent. The disturbances that form over the Atlantic are deviated to the north-west of Europe, which in this case benefits from wet conditions, whereas in southern Europe and Morocco precipitation is reduced [40,41]. The negative phase of the Nao corresponds to a decrease in the southern pressure gradient in the North Atlantic and thereafter to a decrease in the intensity of the western winds, which allows the passage to the south of Europe of The Mediterranean basin of Atlantic perturbations. Precipitation in this case is favorised in Morocco and northwest Africa [42, 43, 2].

The detected periodicities of annual precipitation in the Souss-Massa region are consistent with the North Atlantic Oscillation (NAO) periodicities as shown in the previous section. The influence of NAO on Souss-Massa precipitation is studied by analyzing wavelet coherency between the regional SPI during 1980-2010 and the NAO index. The result show a significant anti-phase for the periods of 4 and 8 years between the two signals with (p=0.05) (Figure 8).

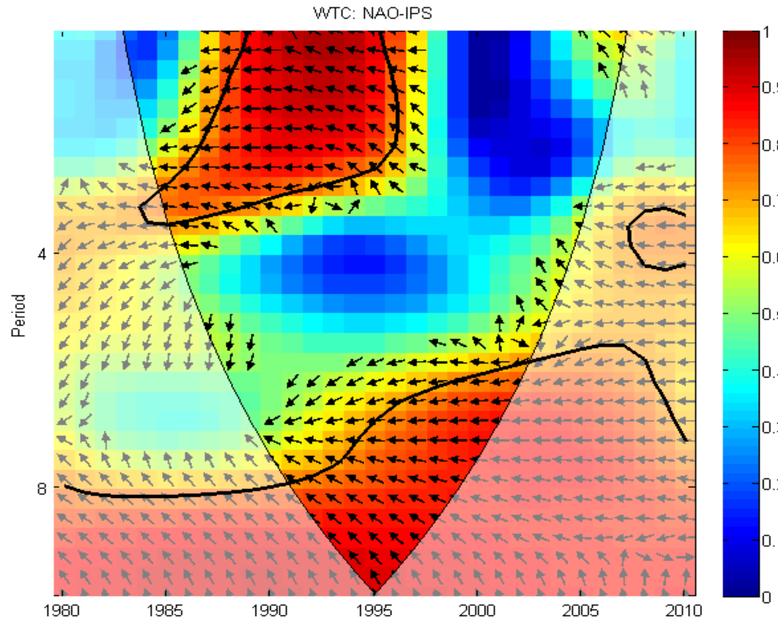

Figure 8: Wavelet coherency between the NAO and SPI of Souss-Massa region during 1980-2010.

Conclusion

The analysis of spatial distribution of precipitation in the region during 1980-2010 shows that rainfall follows a gradient from the North to the South and from the West to the East. It rains more in the Souss basin than in the Massa basin and in the plain of Tiznit, while Western High-Atlas Mountains receives more rainfall than the Anti-Atlas Mountains. The contribution of rainy and dry seasons to the amounts of annual rainfall varies spatially. The stations of Agadir and Abdelmoumen show the highest contribution of the rainy season. The stations of Imerguen, Aoulouz, Amsoul and Amaghouz, located in the Mountains show the highest contribution of dry season. The dry season precipitation of stations located in high altitude suggests that convective rainfall events contribute to annual amounts in the Western High-Atlas and Anti-Atlas Mountains.

The coefficients of variation of Souss Massa precipitation during 1980-2010 varies between 80% and 45%. The stations of Aguenza and Abdelmoumen located in the Argana corridor reveals highest coefficients greater than 65%.

The standardized precipitation index is used to distinguish wet from dry years (Figure 4). We note that the driest year during 1980-2010 is the year 1993 with (SPI = -1.09). The succession of dry years 1992-1993, 2007-2008 and 1999-2001 as well as the succession of wet years 1988-1989 and 1996-1997 are also shown. The analysis of the evolution of the SPI shows that the wet years represent 16% of the studied years and the dry years represent 35%. The region of Souss Massa experienced more dry years than wet years from 1980 to 2010.The heavy rainfall of 2010 confirms the upward trend of the rainy year amplitudes from 1980 to 2010.

The PCA is applied to analyse the effect of the altitude and distance to the Atlantic Ocean on annual precipitation. It's apparent from the result that annual mean precipitation increases with high altitude and decrease with low distances to Atlantic Ocean. The hierarchical clustering allowed to distinguish homogenous clusters of stations presenting the same rainfall behaviour. The result shows three clusters of stations located in the plains, in the mountains and the most distant stations from the Atlantic Ocean.

No statistically significant trend is detected during 1980-2010 for all the stations according to the results of the Mann-Kendall test. Change-points analyses show no statistically significant change-point according to Buishand test, Pettitt test and the Hubert segmentation.

The continuous wavelet analysis is applied to detect periodicities during the period 1980-2010. The results show multiple significant high energy bands (p=0.05). We detect the periods of 1 year, (2-4) years, (3-5) years and (5-10) years, expect for the Youssef Ben Tachafine. We observe the persistence of continuous high energy bands of 8 to 9 years around the period 1990-2002 in the eleven stations. The wavelet coherency analysis indicates a significant anti-phase between the NAO and the regional SPI during 1980-2010. The results of this work are a contribution to the understanding of the Souss-Massa rainfall regime.

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