A DENDROCLIMATIC RECONSTRUCTION OF APRIL-JULY MEAN TEMPERATURE VARIATION IN THE MIDDLE ATLAS,MOROCCO, SINCE 1776 AD

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DOI No. – **08.2020-25662434**

Abstract

In Morocco, high-resolution tree-ring records covering the last hundreds years are very scarce, yet essential for understanding the process and pattern of climate change and designing climate model. In this paper, an Atlas Cedar (Cedrus atlantica M.) ring- width chronology spanning 1796-2011 AD and 1776-2011 AD was developed using standard dendroclimatological methods in two forest sites designed Tafechna and Ouiouane, respectively, at the Middle Atlas Mountains located in Khenifra province, Morocco. Trees in the second site are the oldest and strongly negative relationships were detected between the ring-width chronology and the monthly mean temperatures from June during the previous season to September during the growing season in this site. Based on correlation analysis, the mean temperature from April to July was reconstructed back to 1776 AD using a regression linear model. Therefore, 34% of the variance in temperature is reconstructed by this model. The reconstructed climate records show several alternating periods of high and low temperatures. Many of these hot years have been recorded to coincide with most of the known principal drought years of Morocco. The analysis of spatial correlation with the overall climate data, and comparisons with other temperature reconstructions based on tree rings surrounding areas, revealed that our reconstruction represented a regional variation on a larger scale temperature in the Middle Atlas region. Significant correlation between tree ring and climate is implying the possible influence of North Atlantic Oscillation (NAO) on the local climate. Considering the strong and negative between tree growth and temperature relationship, future warming will likely cause drought which will influence negatively the growth of trees as seen during the recent climate change experienced by Morocco since 1979. However, due to the limit of cedar age, the reconstruction couldn't save the changes to the millennial scale which requires the development in the future of long time series of tree rings in Morocco

Keywords: *Climate change, Cedrus atlantica M., ring width chronology, temperature reconstruction, Morocco.*

INTRODUCTION

Dendroclimatology is the discipline that looks for the relationship between tree trunk growth ring characteristics and climatic factors [1]. In Morocco, the first dendrochronological studies date is from 1974 to 1979, when a group of Belgian researchers undertook a sampling campaign covering the entire natural area of the Atlas cedar. Their collection includes 5 sites of Morocana Abies (Sapin du Maroc), 6 sites of *Cupressus atlantica* (Cyprès de l'Atlas), and 75 sites of *Cedrus atlantica* M. (Cèdre de l'Atlas) [2].

Following the years 1979-1984 drought and as part of a project to reconstruct past droughts, 13 cedar plantation sites were sampled and used and 7 sites were dated [3]. Between 1980 and 1990 a study of the dendroclimatology of Quercus canariensis W. was conducted in the Western Rif and the Middle Atlas [4]. In addition, the research dendrochronological on the Atlas cedar has been carried out in several Moroccan forest sites as part of a doctoral thesis[5].This work was supplemented and updated by a sampling of marginal sites where the oldest cedar groves in Morocco are located [6].

Since 2006, the "Tree Ring Research Laboratory" at the University of Arizona has undertaken more additional research focused on the dendroclimatology of cedar and pine in the Rif, Middle Atlas, High Atlas and Oriental regions. Currently, cedar forests are subject to a phenomenon of dieback, which seems to be the result of biotic and abiotic factors that could be a strong indicator of climate change. The retrospective study of radial growth versus the cedar stand decline allowed to analyzing the spatial and the temporal dynamics of cedar stand loss and their relationship to the ecological and physiological factors [7]. Other studies on the structure and dynamics of the cedar in the Middle Atlas have also been conducted [8]. Several previous research works are devoted to other species with dendroclimatological potential but less long-lived than cedar, thus the dendroecology, productivity and radial growth dynamics of maritime pine (Pinus pinaster var. maghrebiana) have been studied in Morocco [9]. Also a contribution to the study of the dendroecology of Juniperus thurifera L. of the high Mediterranean mountains (High Atlas, Morocco) has been realized [10]. Generally, dendrochronological research is rare in Morocco compared to other Mediterranean countries such as Turkey, Algeria and Lebanon.

Our knowledge, the Atlas cedar has rarely been the subject of a dendroclimatological reconstruction study over several centuries. At the present time, this species has taken a considerable importance in the forest world of the Mediterranean rim. Therefore, it appeared interesting to initiate a climatic study, whose importance, in Morocco, is shown by choice of the place which was granted to it in the National strategy in terms of reaforestation and reforestation. Indeed, Morocco is the country that holds the largest area occupied by this species estimated at 125,000 ha in the Middle Atlas and the Eastern High Atlas, between 1500 and 2800 m altitude, and at 15.000 ha in the Rif [11]. These statistics do not take into account recent reforestation, especially in the Rif. In the context of current climate change, the knowledge of the relationships between climate and tree growth is essential to understand the evolution of forest ecosystems and to develop mathematical growth-climate models. The present study aims to identify the relationships between climate and tree growth in the Moroccan Middle Atlas Mountains. A dendroclimatic reconstruction will be carried out based on the ring thicknesses of the cedar cores. This will improve the understanding of climate variability in Morocco. Thus, the results of this study will be of particular interest in the context of current climate change, whose effects will probably be strong in the Mediterranean region.

MATERIALS AND METHODS

The forest area of the province of Khenifra occupies a choice place both by its size and by the socio-economic, recreative and tourist roles that it plays. It is characterized by the diversity and the quality of the species that it includes, in particular, the Atlas cedar which represents 12% of the forest estate of the province and about 50% of the cedar forests of Morocco [12]. The cedar is par excellence the noble species of North Africa and the East, by the presence of its port, its longevity and the historical memories which are attached to it.

Dendrochronological material

At each sample site, at least two cores were taken parallel to the contour lines at a height of 1.3 m from dominant or co-dominant trees using a Pressler auger. According to [13], the number of trees to be tested should vary from at least 12 to 20. This rule was followed when coring trees in Ouiouane and Tafechna. Table 1 presents a description of the two sites.

Development of the tree ring chronology

The widths of the rings were measured to an accuracy of 0.01 mm using the Lintab table at the "Laboratoire de Technologie du Bois" at the Nationale School of Forestry Engineers (N.S.F.E.) in Salé, then the cores were visually and statistically dated with the TSAPwin software (version 0.53) [14]. Each ring has been assigned a specific training date that will be verified through the use of the COFECHA program, which detects potential errors that may occur during interdating [15]. In order to identify interannual variations in the dendrochronological signal, the individual series were standardized by ARSTAN software; the raw ring width data were first fitted by a negative exponential curve in order to remove all ages not related to non-climatic trends [16]. This adjustment will remove long-term variance, but may conserve variance over periods up to a century using these trees. Then, the raw thicknesses were divided by the cambial age-adjusted curve values to derive the indexed width series.

Table 1: Geography, ecology, dendrometry and climate of the dendrochronological sites studied

Description	**Tafechna**	**Ouiouane**
Latitude (N)	32°56′664"	33°08′877"
Longitude (W)	5°28′565"	5°20′426"
Elevation (m)	1519	1722
Slope (°)	26	25
Exhibition	South West	South East
Average tree diameter (cm)	351	316
Average tree height (m)	24,15	24,7
Tree stratum	*Cedrus atlantica* M.	*Cedrus atlantica* M.
Shrubby and herbaceous strata	*Lingula elongata*	*Hedera helix*
Substrate	Calcareous	Calcaro-dolomitic
Depth of soil (m)	Shallow soil	Medium deep soil (litter)
Bioclimat	Subhumid to humid	Subhumid to humid

The two indexed chronologies made from the raw tree ring thicknesses are shown in Figure 1. The duration of the chronologies varies from 216 years (Tafechna: 1796-2011) to 236 years (Ouiouane: 1776-2011). The curves for both populations clearly show the age trend, i.e., a decrease in ring thickness as the trees age and the trunk circumference increases (Figure 1).

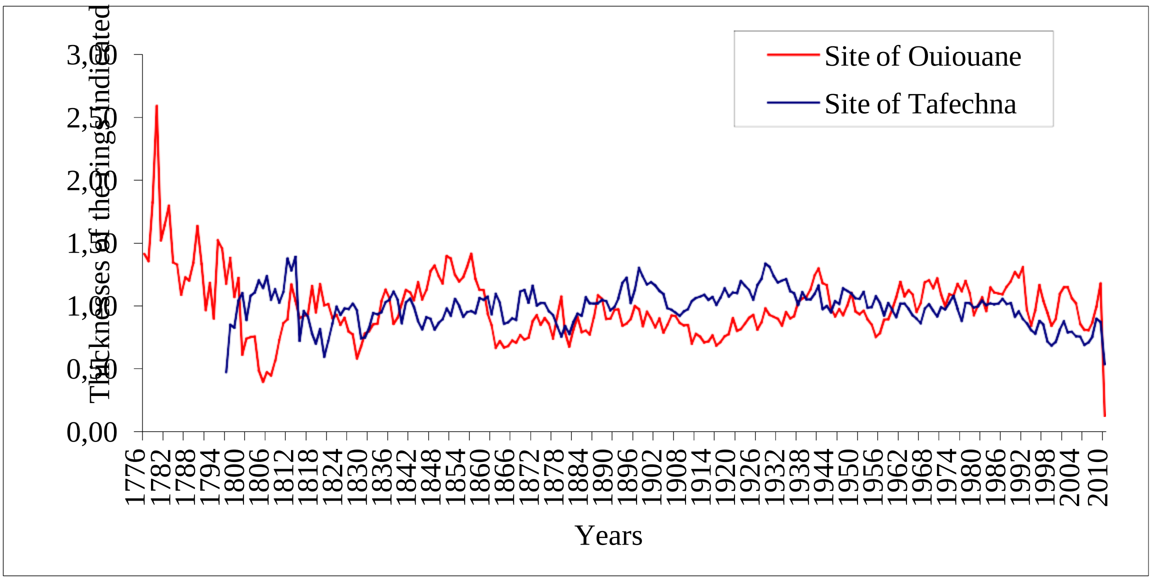

Figure 1: Master chronologies indexed in the two dendrochronological sites.

The Comparison of interannual variations on the two curves (Figure 1) show good synchronism of master chronologies between the two sites. Growth ring chronologies are often less reliable when we go further back in time, as the oldest trees are fewer.

Acquisition of climatic data

The average monthly temperature and the average monthly precipitation (1958-2008) of the Ouiouane meteorological station were used in the analysis of the growth-climate relationship. This station is the closest geographically to the sampling site and it has similar altitude to the sampled populations. If we assume that the climatic variations are homogeneous in the study area [17], it seems possible to work with weather stations far enough away from the selected subject study [18]. Given the location of the studied stands, these meteorological data provide the best compromise for the calibration of the response functions. The maximum monthly precipitation occurs in December (3202.8 mm) and the minimum precipitation occurs in July (159.5 mm) during the common period 1958-2008. The precipitation falling between December and April represents a significant part (48%) of the annual precipitation. Monthly temperatures vary in synchronization with precipitation; winters are marked by cold temperatures and increasing precipitation, and summers are very hot with low precipitation.

Tree ring-climate relation

The response function is an orthogonalized linear regression [19] in which the explicative variables are the climatic data and the variables to be explained are the tree ring widths. The climatic data used are the 16 monthly temperature and precipitation variables from June of year t-1 to September of year t, corresponding to the biological year of the species and extended to the previous summer, whose climatic conditions may influence the growth of year t. Thus, Pearson correlation coefficients are calculated over the full period selected.

Processing and Analysis and Statistics

Statistical variables such as mean climate sensitivity (MS), Standard deviation (SD) which measures the variability of measurements at all ring widths were calculated. Also, the population signal (PSE) which represents the quality of an average chronology [20] is estimated by the following formula:

$$EPS = \frac{n * R}{n * R + (1 - R)} \qquad (4)$$

Where : R= Average correlation between all series
n= Number of dated series.

In dendroclimatic research, a threshold value of PSE>0.85 is generally used to determine which part of the chronology are mean reliable and locally-representative [21]. The Signal to Noise Ratio (S/N ratio), which measures the statistical value of the common variance between trees at the same site, was calculated. In addition, the average inter-tree correlation (R) was calculated for our site chronologies to check the inter-datum and robustness of the climate signal carried for each individual chronology.

To test the validity of the reconstruction and the reproducibility of the results of a model, a calibration of any statistical model is necessary and always requires the use of a large volume of data.

In order to evaluate the quality of the linear model for climate reconstruction, the period of climate data records between 1958-2008 was split into two long periods: calibration (1978-2008) and verification (1958-1977). The efficiency and quality of the model predictions were checked using the Reduced Error (RE) which is a very rigorous test to pass if there are significant differences between the means of the two periods, the theoretical limits for the RE values range from a maximum of +1 to infinity, but a value > 0 should be considered as a positive power. The Coefficient of Effectiveness (CE) which allows us to verify if our reconstructions were statistically significant [22] was also calculated.

In addition, SPSS software (version 20) was used to estimate statistical quality control parameters like Pearson's correlation coefficient (R) which used to evaluate the degree of the relation between the annual growth of Cedrus atlantica and climate. The square of the correlation coefficient (R^2) shows the proportion of variance explained in each time period which called coefficient of determination. The Significance Test is also used to evaluate the ability of the model to follow the interannual variability in the climate data [23] and for extensive comparisons between real and estimated values.

Based on the results of the tree growth-climate analyses, the linear regression was used to select the best combination of tree rings as independent variables and climate conditions as dependent variables in order to develop a model for reconstruction development.

RESULTS AND DISCUSSIONS

Development of the chronology

The values of the different statistics of the chronologies after autoregression (standard version) are represented in Table 2. The value of PSE is > 0.75 from the beginning of the 1870s, signifying that we have approximately 75% of signal and 25% of noise. By the 1904s, the index increases to 0.91. In addition, the fact that the Tafechna (site I) and Ouiouane (site II) sites are so similar (their average correlation is high) proves that the two chronologies have a strong common regional signal. The differences are due to local dissimilarities associated to the layout of the sites (slope, streams, forest fires) or to disturbance effects.

Table 2: Calculated statistics of the chronology of the cedar rings in Tafechna (site I) and Ouiouane (site II).

Characteristics	**Site I**	**Site II**
Length of the master chronology	1796-2011 (216 years)	1776-2011 (236 years)
Number of dated series	40	22
Average thickness (mm)	0,981	0,967
Average correlation between all cores (Rbar)	0,345	0,363
Medium sensitivity	0,285	0,304
Autocorrelation	0,824	0,877
Standard deviation	0,118	0,189
average segment length over the years	145,2	175
Average inter-tree correlation	0,434	0,534
Variance due to autoregression (%)	58,9	73,5
Signal to Noise Ratio (SNR)	8,099	9,435
Concordance with the chronology of the population	0,483	0,527
Signal Expressed by the Population	0,968	0 ,962
Variance explained (VFE) in %.	48	56,45

The high autocorrelation value > 0.80 noted in the full cedar series suggests that growth in previous years has a strong influence on growth in future years. This parameter is important because it affects the reconstruction of the low frequencies [24]. Since the trees in Site I are younger than those in Site II, the cores from Site II were used to develop a dendroclimatological reconstruction for the Moroccan Middle Atlas.

Analysis of the climatic response

During the present study, we first need to establish the season in which trees are most responsive to climate change, in other words, over which time period the climate variables have a better correlation with annual ring widths. The ring-climate correlation analysis is carried out with average monthly temperatures (T) and cumulative monthly precipitation (P) for the 16 months of the biological year, i.e. from June of the previous year (year t-1); [(P) means prior to ring formation] to September of the current year (year t of ring formation). The Table 3 summarizes the degree of importance of the different climate variables for growth and the type of ring-climate correlation (positive or negative).

The monthly distribution of correlation coefficients is presented in Figure 2. The Pearson coefficient is considered statistically significant at ($p<0.01$ and $p<0.05$). The Ring widths are positively correlated with rainfall in the current growing season from May to July with a significant correlation in June (Figure 2). This coefficient also shows a strong negative growth in response to summer temperatures (May to August). This is mainly because the water deficit at the beginning of the growing season suppressed the rapid expansion of tracheids and cell division in the cambium of the trees and also, evaporation increased with the progression of temperature in June-September, which accelerated the already existing water stress. Trees produce narrow tracheids if water is low and tracheid diameter contributes to density variations. This result suggested that precipitation is less influential on tree growth compared to temperature. Even though precipitation plays an important role in cedar growth, average summer temperature is the main limiting factor for tree growth. Previous studies in the Mediterranean region have also demonstrated that radial growth is much more correlated with temperature than with precipitation at similar altitudes [25].

The end of winter temperatures (January and February) determines the beginning of cambial activity [26]. The severe frosts of February explain the very low productivity of 2006 and 2008 but also of the following years because the cambium seems to have been deteriorated. Precipitation in May and sometimes June regulated the cambial activity in relation to soil water availability. A significant water deficit at this time can stall growth for the summer. Rainfall in August and September in relation to August temperatures determines the recovery of photosynthetic activity in the autumn.

The histograms show the values of Pearson's coefficients between the dendrochronological series of cedar and climate variables over a 16 month period.

Table 3: Pearson correlation between tree-ring thickness and 16-month (June-September) climate data from 1958 to 2008

	PJune	**PJuly**	**PAug**	**PSep**	**POct**	**PNov**	**PDec**
T	-0,228	-0,247	-0,204	-0,069	-0,025	-0,111	0,097
P	-0,038	-0,200	-0,042	-0,025	-0,095	0,281	0,025

	Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**
T	-0,060	0,141	-0,131	-0,262	-0,406*	-0,477*	-0,355*	-0,178	0,105
P	0,126	0,196	0,277	0,106	0,281	0,345*	0,211	0,199	0,012

** Statistically significant correlation coefficients at (p)<0,05 (95%)*

The Cedar populations indicate a strong rainfall dependency especially for the month of June, probably related to Mediterranean influences, with a positive relationship to high winter precipitation and disrupted growth in case of very dry and extremely cold winter [27]. But in our study, a more detailed analysis of the results where the global responses are significant (p> 0.01) has shown that the climatic parameters that occur significantly more often are: the monthly temperature parameters, always more significant than rainfall whatever the couple of months examined. On these, the strongest relationship was observed between tree growth and temperature (May-July), therefore the climatic variable "temperature" was selected for a demonstration of the climatic reconstruction at the studied site.

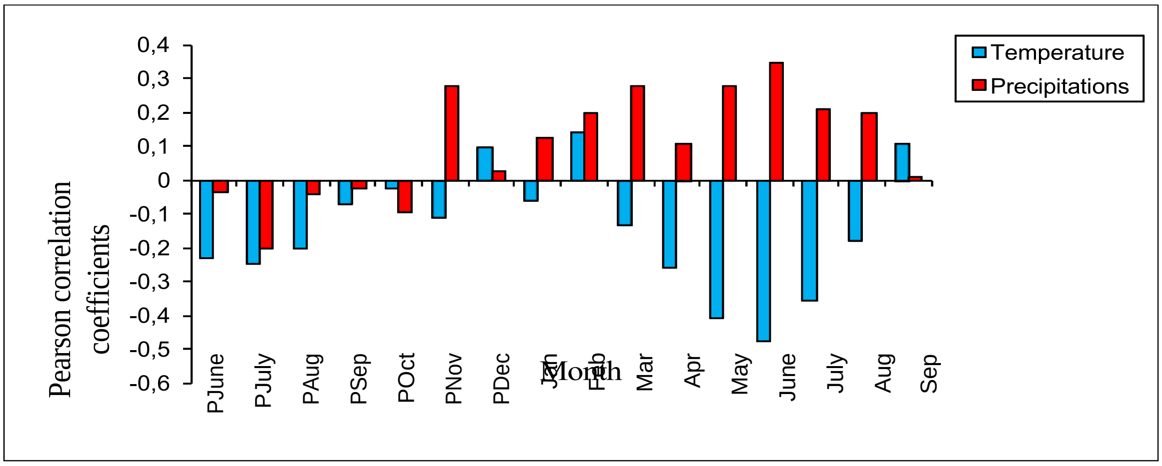

Figure 2: Cedar climate response function.

Temperature reconstruction (April-July)

The mean temperature of the growing season from April to July was reconstructed over the period (1776-2008), 233 years. All statistical properties of the 2 calibration (1958- 1977) and verification (1978-2008) periods are high and significant. The two periods provide approximately 34% of the variance in the temperature data. Also, the analysis of the reconstruction showed that the temperatures during the last decades have largely exceeded the mean values reaching (14.30 °C). The statistical parameters of the chronology (Table 4) indicate that the cedar in this site has moderate values of auto-correlation, mean sensitivity, joint variance and SNR, which proves the relevance of the chronology for a good climate reconstruction. Thus, a linear regression model between cedar growth and mean temperature (April-July) was developed as follows:

$$\boxed{T_{average}\text{ (April-July)} = -18{,}666-(2{,}291\times \text{ Growth of rings})}$$

The value of ER which measures the variance between the observed and reconstructed climate data indicates a positive potency (greater than 0). This parameter indicates a high predictive capacity of the selected model which also gives good results as it explains 34% of the temperature variance over the full set of observations; this demonstrates the robustness of our climate reconstruction which will be further detailed in the next section.

Table 4: Statistics of calibration and verification test results for the common period (1958-2008)

Period	r	R^2	F	DW	Period	Sign. Test	Pmt	RE	CE
1958-1977	-0,55**	R^2C (0,30)	13,66	1,219	1978-2008	+21/-3**	2,69**	0,29	0,38
1978-2008	-0,57**	R^2V (0,32)	11,03	1,211	1958-1977	+20/-6**	2,76**	0,67	0,54
1958-2008	-0,58**	0,34	9,62	1,123					

***: signification at p<0,01*

With:
r : the multiple correlation coefficient
F : Fisher test
DW: Durbin-Watson statistic (d)
Pmt : Product mean test

Robustness of the reconstruction

The calibration (R^2C) and verification (R^2V) statistics reach 0.30 and 0.32 respectively. These highly significant coefficients confirm the reliability of the model. This is usually tested by verifying the regression. The CE value in both periods is also positive. The test of significance (Sign Test) which describes how well the predicted value follows the direction of the actual data exceeds the 99% confidence level. Also, the R^2 value is almost the same throughout the climate reconstruction. Therefore, the temporal stability of the model which implied that the combination of tree-ring widths with one or more climate parameters, which occurred in the past, will continue to apply. However, the main shortcoming of our model is to underestimate very high growths and to a lesser extent to overestimate very low growths; this is normal to some extent as only part of the variance is explained.

During the 1958-1877 verification periods, the climate-cerne relationship was strongly supported with a high Pmt value of 2.69 found to be significant at the 0.01 level. The linear regression model performs marginally better during verification but moderately worse during calibration. These tests indicate that the model to be used in the climate reconstruction has passed the critical tests.

The Mean temperature (April-July) has a significant negative effect on tree growth. However, this negative influence is more likely to be indirect, rather than direct, because temperature in mountainous sites cannot negatively influence tree growth. These results strongly support the validity of the temperature reconstruction, which allows it to be used to evaluate the occurrence of climatic phenomena in Morocco.

Evaluation of the reconstruction

The observed and reconstructed temperatures from April to July showed high similarity, except during the coldest and warmest periods of the 20th century (1966-1979, 1987-1994) and (1998-2001) when the reconstructed temperature based on the cedar chronology was significantly higher and respectively lower than the recorded temperatures. To exclude the possibility that the good relation between temperature and cedar chronology was dependent on the slopes between the measured cores, the correlation coefficient (r) between the observed and reconstructed first-order series was also calculated. The high r value (0.404, $p < 0.01$) suggests a good existing relation between the two series in high frequency. The comparison of the observed and reconstructed temperatures shows that the high and medium frequency variations are reproduced by the model. However, a clear drop appears for the years 1986, 87, 94, 99, 2000, 2001, 2003 and 2005 in the populations where the reconstruction is poor. In these years, the observed temperature is very high while the model predicts a low temperature. The final temperature reconstruction, which explains 34% of the variance and extends from 1776 to 2008, is plotted in Figure 3. It covers a period of 233 years with a mean temperature 0.5°C lower than the observed reference period. The average error is estimated to be ± 1.33°C.

The present work of reconstructing the climate of the past (over 2 centuries) extends the mean temperature to the year 1776. Thus, the mean reconstruction temperature was 14.30 °C; the standard deviation (σ) was 1.45 °C. High temperature is defined as> mean +1σ (15.75 °C) and low temperature as < mean-1σ (12.85 °C). The number of high temperature years (10 years) was lower than the number of low temperature years (31 years), it represented, respectively, 4.29% and 13.3% in the whole reconstruction. From 1776 to 2008, the continuous period of high temperature above 2 years was 1804-1807, 1862-1869, 2006- 2008 with 1804-1807 having the highest temperature in the reconstruction. However, the continuous episode of low temperature above 2 years was 1776-1790 and 1846-1855. The 233-year temperature reconstruction revealed both annual and interannual variation. In general, low temperatures and high precipitation during the early part of the growing season (late January-early April) appeared to lead to increased ring width.

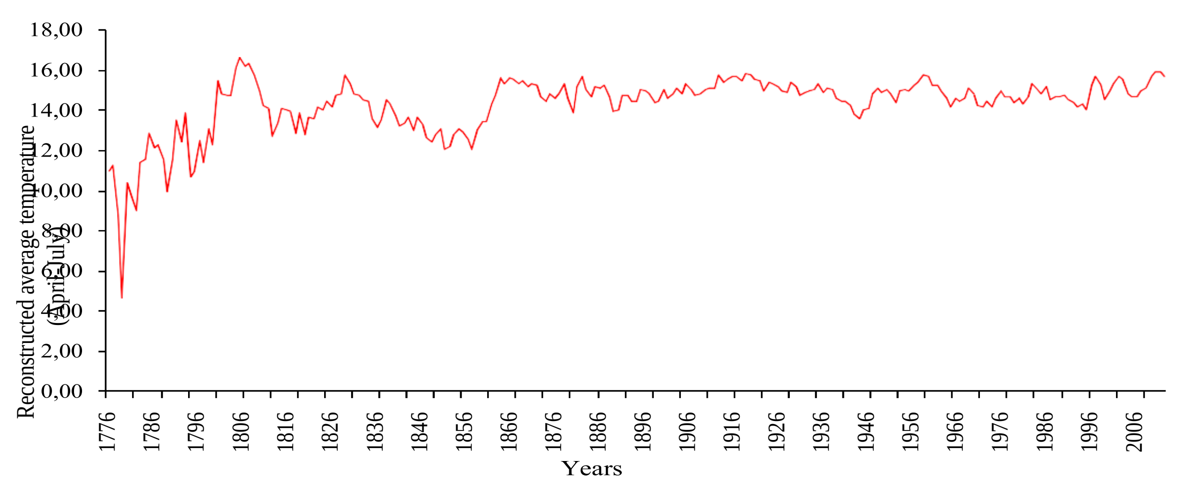

Figure 3: Reconstruction of the average temperature from April to July on (1776-2008 AD).

Growth-climate relations

Previous studies have revealed that the critical periods for radial growth of Cedrus atlantica M. in the Mediterranean region are mainly from May to August, based both on anatomical analysis of tree rings [28,29] and dendroclimatological investigations [30]. This result is in perfect agreement with our modeling results which show that the impact of temperatures from June to July is decisive on the degree of ring growth. With the rapid increase in air temperature from spring to summer, the emergence of foliage leads to the consumption of large volumes of water, at the same time, the high temperature causes water stress accentuated by soil evaporation and tree transpiration, which may lead to a negative relation between tree rings and temperature. This response to climate could be due to the decrease in net photosynthetic rate, probably due to the increase in evapotranspiration.

In particular, during the summer months, rainfall is lower, but the temperature is at its maximum in the Middle Atlas region. On the other ways, the temperature in March has shown its significant effect on cedar growth, because it promotes the opening of dormant leaf buds and also the initiation of cambial activity. In semi-arid regions, trees are generally sensitive to humidity, especially before and during the growing season [31]. Although a slight increase in precipitation could be particularly beneficial to later photosynthetic production and cambial growth, the positive correlation between ring thicknesses and precipitation is statistically significant for the month of June. The present study showed the effect of climatic conditions in the season prior to cedar ring growth, this is similar to other research results highlighting the importance of environmental factors in the year prior to thickness increase [32,33].

Furthermore, the positive influence of autumn precipitation, which preceded annual growth (Table 3), can be explained by the important role of autumn waterfalls in reconstituting the water stock in the soil. These can also have an influence on the restoration of the root system and, as a result, participate in the increase of the absorption potential allowing a good storage of nutritive substances until the triggering of cambial activity.

The results of the calibration and verification statistics for Cedrus atlantica M. (r=0.34) are comparable (higher) to those found by [34] in Western Quebec. The soil of the Ouiouane dendrochrnological site is calcaro-dolomitic. In this type of soil, drainage and aeration are high, which is essential for good root growth. Aeration helps soil organisms to survive. These organisms often contribute by making nutrients available to plants. This data set shows the greatest potential of this site for the development of a reconstruction by using an average temperature from April to July.

The negative influence of the average temperature studied previously on the growth of Cedrus atlantica M. is reasonable in the area where the summer temperature exceeds 20°C, for example, in the Mediterranean area, especially at medium high altitudes, where our site is located (1722 m). The existing positive relation between tree growth and precipitation from November of the previous year to September of the current year suggests that precipitation plays a key role in cedar growth.

In the study area, during the months of December and January, low precipitation could favor respiration during photosynthesis considering that the trees stay leafless and photosynthesis is almost zero at that time, this could be the cause of low tree growth. The inverse relation with June precipitation could be due to the decrease in net photosynthetic rate, which could have resulted from higher evapotranspiration levels.

In the last 100 years, the earth's temperature has shown two important warm periods in 1910 and 1945 [35]. In the studied site, the average temperature (April-July) in these two periods showed a high value that coincided with observed in the rest of the world. From the year 1910 to 1919 and (2004- 2008), the ring thicknesses start to become increasingly smaller, which may be due to a response to extreme cold or dry conditions due to sea ice anomalies related to the positive influence of the North Atlantic Oscillation (NAO) index. However, the trend in radial growth of cedar in the selected site is nearly stable during the period 1906-1922 despite the observed increase in temperature of about 1.11 °C above the mean. This trend has also been noted in other studies [36]. The climatic sensitivity of Ouiouane cedar (0.304) is specific to this site and indicates a strong dependence on proximity to the Atlantic Sea. However, some years reported as hot and dry in the literature such as 1781 [37] appear cold in our reconstruction with an average of 9.79 °C. The climatic mildness of the end of the 18th century seems to be specific to the cedar forests of the Moroccan Middle Atlas and more generally in Morocco. It is also reconstructed in the Pyrenees [38] and on the whole western Mediterranean area [39]. The results of our study showed the importance of spring and summer temperatures on the radial growth of cedar in the Ouiouane.

CONCLUSION

Many studies have been devoted to follow-up the impact of climate on natural ecosystems, particularly forests in Africa and the Maghreb. However, few are sufficiently interested in studying the usefulness of tree rings in reconstructing the climate of the recent past. In Morocco, in general, there is very little data available on the dendroclimatology of natural forest species such as the Atlas cedar.

Consequently, it seemed necessary to conduct a dendroclimatic study in the cedar forests of the Khenifra province in the Moroccan Middle Atlas. The present work aims to highlight the dendroclimatological potential of cedars in two forest sites Tafechna and Ouiouane. Both areas present a good climatic signal proved by their high average sensitivity. However, since the trees of Ouiouane have the longest chronologies, they were used for the reconstruction of 233 years of average temperature (April-July) since 1776, based on a linear regression model. The calibration and verification processes confirm the stability and reliability of the model used.

The results obtained show that the reconstruction explained 34% of temperature (April-July) during the period 1776-2008. We also find that the reconstruction of temperature in the Middle Atlas Mountains can represent a regional variability of climate, so we indicate a longer cold period (1776-1790 AD), another period moderately cold (1846-1855 AD) and three hot periods (1804-1807 AD., 1862-1869 AD and 2006-2008 AD). A comparison with previous works allowed us to note a strong resemblance between our results and those obtained in some regions of the world in particular in those of the Mediterranean region.

Data from tree-ring chronologies dating back to 1776 AD are insufficient for a long climate reconstruction. In contrast, future intensive sampling of aged cedar trees in the field and their analysis can extend said chronologies. This will provide a better understanding of drought and rainfall variability in and around Morocco.

REFERENCES

1. Kaennel M., Schweingruber F.H. Multilingual glossary of Dendrochronology: Terms and definitions in English, German,French, Spanish, Italian, Portuguese and Russian. Paul Haupt Publishers, (1995) 467 p.
2. Munaut A.V., Serre-Bachet F. The mediterranean area in «Climate from tree rings». Proceedings of the Second International Workshop on global dendroclimatology, Norwich, Cambridge University Press, London, (1982) 151.
3. Stockton C.W. Current research progress towards understanding drought. Proceeding of Drought, water management and food production, Agadir, Morocco, (1988) 21-35.
4. Raouane M. Étude dendroclimatologique du chêne zéen (Q. canariensis Willd) du Rif Occidental et du Moyen-Atlas au Maroc. Thèse de doctorat de troisième cycle, Faculté de Saint-Jérôme, Marseille, (1985) 125 p.
5. Till C. Recherches dendrochronologiques sur le Cèdre de l'Atlas (Cedrus atlantica M.) au Maroc. Thèse de doctorat, Université Catholique de Louvain, Louvain-la-Neuve, (1985) 170

p.
6. Chbouki N. Spatio-temporal characteristics of drought as inferred from tree ring data in Morocco. PhD Thesis, University of Arizona, Tucson (1992) 243 p.
7. Mokrim A. Ann. Rech. For. Maroc 41 (2009) 48-68.
8. Bohórquez J. Estructura y dinámica de masas de Cedrus atlantica M. en el Medio Atlas (Ifrane, Marruecos), (2010) 61 p.
9. Nefaoui M. Dendroécologie, productivité et dynamique de la croissance radiale du pin maritime naturel au Maroc. Thèse de doctorat, Université de Aix-Marseille III, (1996) 299 p.
10. Bertaudière V. Dendroécologie du Genévrier thurifère (*Juniperus thurifera* L.) dans la haute montagne méditerranéenne (Haut Atlas, Maroc) et dans une station xérothermique des Pyrénées centrales (France). Thèse de doctorat, Université Paul Sabatier, Toulouse, (1999) 234 p.
11. Benabid A., *Ann. Rech. For. Maroc* T (27) (1994) 61-76.
12. MATEE, Quatrième Rapport National sur la Biodiversité. Département de l'Environnement au Maroc (2009) 112 p.
13. Merian P. Variations spatio-temporelles de la réponse au climat des essences forestières tempérées : Quantification du phénomène par approche dendroécologique et influence de la stratégie d'échantillonnage, Thèse de doctorat, Institut des Sciences et Industries du Vivant et de l'Environnement (AgroParisTech), (2012) 454 p.
14. RINNTECH, User reference TSAP-Win : Time Series Analysis and Presentation for Dendrochronology and Related Applications, (2003) 99 p.
15. Grissino-Mayer H.D., *Tree-ring Research* 57(2) (2001) 205-221.
16. Cook E.R., Holmes, R.L. Program ARSTAN User's Manual. Laboratory of Tree-Ring Research, University of Arizona, Tucson (1986) 51 p.
17. Tessier L. *New Phytologist* 111(3) (1989) 517-529.
18. Belingard C. Étude dendroécologique de la limite supérieure de la forêt dans les Alpes du sud en relation avec les facteurs climatiques et anthropiques. Thèse de doctorat, Université Aix-Marseille III, (1996) 103 p.
19. Fritts H.C. Tree rings and climate. London, New-York, San Francisco, Eds Academic Press, (1976) 567 p.
20. Briffa K., Jones P. Basic chronology statistics and assessment: *Methods of Dendrochronology : Applications in theEnvironmental Sciences,* Kluwer Academic, Dordrecht, (1990) 137-152.
21. Wigley T.M.L., Briffa K.R., Jones P.D., *Journal of Climate and Applied Meteorology* 23 (1984) 201-213.
22. Cook E.R., Meko D.M., Stahle D.W., Cleaveland M.K., *J. Climate,* 12 (1999) 1145-1162.
23. Fritts H.C., Reconstructing Large-Scale Climate Patterns from Tree-Ring Data, University of Arizona Press, (1991) 286 p.
24. Cook E.R., Briffa K.R., Meko D.M., Graybill D.A., Funkhouser G., *The Holocene* 5(2) (1995) 229-237.
25. Liu X., Qin D., Shao X., Chen T., Ren J., *Science in China Series D: Earth Sciences* 48 (2005) 521-529.
26. Poirier M. Etude écophysiologique de l'endurcissement au gel des arbres : Impact des conditions estivales de croissance sur la résistance au gel des arbres, Thèse doctorat, Université Blaise Pascal, (2008) 316 p.

27. Chbouki N., Stockton C.W., Myers D. E., *International Journal of Climatology* 15 (1995) 187-205.
28. Guan W., Xiong W., Wang Y.H., Yu P.T., He C.Q., Du A.P., Liu H.L., *Scientia Silvae Sinica* 43 (9) (2007) 1-6.
29. Liang J., Yang S., Hu Z.Z., Huang B., Kumar A., Zhang Z., *Climate Dynamics* 32 (2009) 989-1001.
30. Cai Q.F., Liu Y., Bao G., Lei Y., Sun B., *Chinese Science Bulletin* 55(26) (2010) 3008-3014.
31. Cai Q.F., Liu Y., *Journal of Geographical Sciences* 17(3) (2007) 293-303.
32. Oberhuber W., Kofler W., Pfeifer K., Seeber A., Gruber A., *Trees* 22 (2008) 31-40.
33. Pfeifer K., Kofler W., Oberhuber W., *Veg Hist Archaeobot* 14 (2005) 211-220.
34. Tardif J., Brisson J., Bergeron Y., *Canadian Journal of Forest Research* 31(2001) 1491-1501.
35. Walther G.R., Post E., Convey P., Menzel A., Parmesan C., Beebee T.J.C., Fromentin J.M., Hoegh-Guldberg O., Bairlein F., *Nature* 416 (2002) 389-395.
36. Briffa K.R., Schweingruber F.H., Jones P.D., Osborn T.J., Shiyatov S.G., Vaganov E.A., *Nature* 391(1998) 678-682.
37. Casty C., Handorf D., Sempf M., *Geophys. Res. Lett* 32 (2005) L13801.
38. Büntgen U., Frank D.C., Grudd H., Esper J., *Climate Dynamics* 31 (2008) 615-631.
39. Nicault A., Alleaume S., Carrer M., Nola P., *Climate dynamics* 31 (2008) 227-245.