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TREE-RINGS AND CLIMATE IN MOROCCO

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ABSTRACT

Two sites located near Ketama in the Morocco Rif have been selected, on the basis of limiting climatic factors, in order to study the relationship between tree rings and climate. After the trend associated with biological factors related to increasing age has been removed and all variables have been standardized, some statistical parameters have been computed and a variance analysis has been performed. After the persistence has been eliminated, an original technique of multiple regression on the principal components and of selection of the most significant variables has been built. Twenty-four climatic variables have been used.

The principal aim of this paper is to describe this original statistical technique of data analysis and to illustrate its power with dendroclimatological data in Morocco.

For the temperate site located in low altitude (1280 m), among the most important variables, we have retained total monthly precipitation for August, mean temperature of January, April, and May of the current year and mean temperature of October of the previous year. For the cold site (2100 m), total monthly precipitation for September and temperatures of January and May of the current year and precipitation for October of the previous year definitely influence the growth rate of cedars.

Deux sites du Rif Marocain près de Ketama ont été sélectionnés sur base de facteurs climatiques limitants pour étudier la relation entre les cernes annuels et le climat. Après avoir éliminé la tendance dans la courbe d'évolution des cernes et avoir standardisé toutes les variables, quelques paramètres statistiques ainsi qu'une analyse de la variance ont été calculés. Après enlèvement de la persistance, une technique originale de régression multivariée sur composantes principales, avec rejet conditionné de variables, a ensuite été mise au point. Vingt-quatre variables climatiques ont été utilisées.

L'objet principal de cet article est précisément de décrire cette méthode originale d'analyse statistique et d'illustrer sa puissance à partir de données dendroclimatiques du Rif marocain.

Pour le site tempéré, situé à basse altitude (1280 m), parmi les variables les plus importantes, nous avons retenu les précipitations d'août et les températures de janvier, avril et mai de l'année de la croissance ainsi que les températures d'octobre de l'année précédente. Pour le site froid (2100 m), sont favorables tout particulièrement à une bonne croissance du cèdre, les précipitations de septembre et les températures de janvier et mai de l'année de croissance ainsi que les précipitations d'octobre de l'année précédente.

Bei Ketama im marokkanischen Rifgebirge wurden zwei Baumstandorte im Hinblick auf begrenzende Klimafaktoren ausgewählt, um die Beziehungen zwischen Jahrringbildung und Klima zu analysieren. Nachdem der Alterstrend der Jahrringfolgen eliminiert und alle Variablen standardisiert worden waren, wurden einige statistische Parameter berechnet und eine Varianzanalyse durchgeführt. Nach Ausschaltung der Erhaltungstendenz in den Jahrringfolgen wurden ein multiples Regressionsverfahren für die Hauptkomponenten und ein Verfahren zur Auswahl der signifikantesten Variablen entwickelt. Dabei wurden 24 Klimavariable benutzt.

Im vorliegenden Beitrag werden dieses statistische Verfahren beschrieben und seine Möglichkeiten anhand dendroklimatologischer Daten von Marokko dargestellt.

Für den gemäßigten Standort in 1280 m Höhe erweisen sich die Augustniederschläge sowie die Durchschnittstemperaturen im Januar, April und Mai des laufenden Jahres und im Oktober des Vorjahres als einflußreich. An dem kalten Standort in 2100 m Höhe wirken sich die Niederschläge im September und die Temperatur im Januar und Mai des laufenden Jahres sowie die Niederschläge im Oktober des Vorjahres günstig auf den Zuwachs der Zedern aus.

INTRODUCTION

Recent studies (Fritts 1976) have clearly demonstrated that multivariate analysis techniques based on annual tree-ring data are able to provide reliable information on the relationship between tree rings and climate (response function) and on the nature of the climate itself and its variations in time (transfer functions). Indeed, if the dendroclimatological network is sufficiently dense in a given region, a climatic reconstruction can be made over the lifetime of the trees. These reconstructions thus require the existence of annual tree rings, limiting climatic factors, and long-live trees.

Northern Africa seems to be a good area to do such research. From a climatological point of view, this region is situated under Atlantic, Mediterranean, and Saharian influences. It is also a region where the horizontal gradients of the climatic variables are large, due to topography. Moroccan mountains are oriented along two axes: east-west (Rif) and northeast-southwest (Middle and High Atlas) with an maximum altitude of respectively 2,448 and 4,165 m.

Preliminary studies started in 1974 have shown that of the available genera (cedar, fir, cypress, juniper, pine), cedar *(Cedrus Atlantica Men.)* is particularly sensitive to climate and thus favorable in dendroclimatology. Large cedar forests covering around 140,000 ha still exist over a range of temperature and humidity conditions and on several substratums (schist, lime, basalt, . . .). Finally, numerous stands still have cedars some centuries old; some even between 500 and 1,000 years old.

In fact, research in dendroclimatology can provide information on the climatic variability in a region where sparse rain affects any agricultural or industrial development, but it also allows climatic reconstruction over a long period of time.

SITES AND DATA

Among some 40 sites under study, two were selected from the western part of Rif near Ketama (Figure 1). Site 301 is one of the lowest cedar forests in Morocco, while site 302 is located near the top of Djebel Tidighin, the Rif culminating point (2,448 m).

1. Site 301: Tleta de Ketama (1,280 m).

Ten trees were sampled in this cedar forest located near Tleta de Ketama. The soil, slightly inclined to the south, is deep and comes from the decomposition of the schist (pH 6.5). All trees are almost the same age, their mean height is around 50 m and their circumference is frequently more than 5 m. The tree density is high, this site being undisturbed by man. The mean precipitation in Ketama (1,520 m) is 1,570 mm/year and the mean temperature is around 10.7°C.

2. Site 302: Djebel Tidighin (2,100 m)

Eleven cedars were selected on the western slope of Mont Tidighin where the slope is 30 °. The substratum is schistous and a humid mountainous soil is being developed (pH 6.5). The mean height of the trees is 17 m, the mean circumference is 2 m. No meteorological data are available for the site itself, but the rainfall can be estimated to range between 1,400 and 2,000 mm/year, a large part of the humidity transported by the west maritime atmospheric currents being intercepted by Mont Tidighin. The mean annual temperature is around 4 °C.

CHRONOLOGY STATISTICS

Ring widths for all cores were plotted. After crossdating the curves, indices and statistics were computed for each core, each tree, and for the master chronology which summarizes all cores in all trees. These statistics, based upon tree-ring indices (ring width divided by trend), are the mean ring width and index, the mean sensitivity and the serial correlation coefficient, as generally used (Fritts 1976). Variance analysis has also been performed, using 10 trees and two cores per tree, usually one upslope and one downslope. All the results are summarized in Table 1.

Mean ring widths indicate that the limiting factors act more strongly in site 302 than in site 301. The annual variability defined by mean sensitivity is almost the same in both sites, although it is significantly less for the master chronology of site 302 than of site 301. From experience gained in many other dendrochronological studies, one can suggest a middle to low variability of the limiting factors. The serial correlation coefficient is very large for site 302 as compared to 301, indicating a strong persistence from one year to the other. This result was more or less expected because large serial correlation is consistently associated with low mean sensitivity. From the variance analysis, irregularity of the growth within the trees for both sites may be deduced. For the site 301, the climate has less influence than other external factors. However, as it will be shown in the following sections, both sites are suitable for establishing response functions.

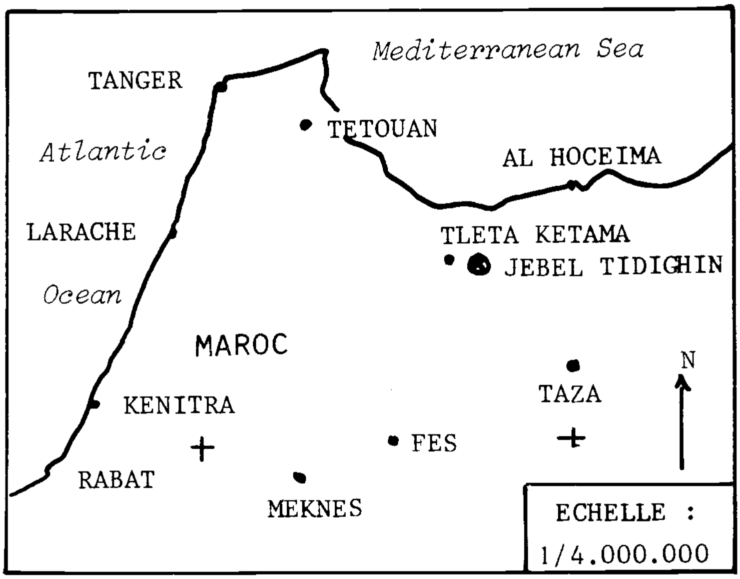


Figure 1. Location of dendrochronological sites in the Rif Mountain region near Ketama.

Table 1. Statistics for the Moroccan sites.

		SITE 301	SITE 302
Total Period	interval	1790-1975	1754-1975
	number of trees	10	11
	number of cores	29	34
	missing rings	0.2%	0.33%
	mean ring	2.1 mm	1.4 mm
	mean index	0.99	0.99
	std. dev.	0.22	0.26
	serial R.	0.28	0.83
	mean sensitivity	0.18	0.15
ANOVA Period	interval	1871-1970	1901-1970
	number of trees	10	10
	number of cores	20	20
	missing rings	0%	0.64%
	mean ring	1.5 mm	1.0 mm
	mean index	0.99	1.0
Variance Analysis			
	variance components (%)		
	cores	75	47
	trees	0	1
	chronology	25	52

METEOROLOGICAL DATA

Climatological data are taken from the Tetouan Airport station and extend from 1941 to 1971. The following 24 variables have been selected on the basis of the growth season of cedar trees (around April to September): monthly mean temperature and total monthly precipitation for October of the year prior to growth till September of the current year. As compared with the classical Fritts 14-month interval (June of the previous year till July of the current year, Fritts et al. 1971), this 12-month interval has been chosen to clarify the interpretation of the model's results. On the other hand, it must also be stressed that the number of variables that can be taken into account is limited by the number of observations (30 years). More details are given in Guiot et al. (1979).

These meteorological data are represented on Figure 2 and the means and standard deviations in Table 2. The indices of site 301 and site 302 are represented on Figure 3. It can be seen that the driest months are July and August and the wettest months are December to February. For site 301, the indices of years 1963, 1969, 1970, 1971 are the largest. During these years, April and May are relatively cold. The indices of years 1945, 1949, 1953 are the smallest, which corresponds to warm April or May.

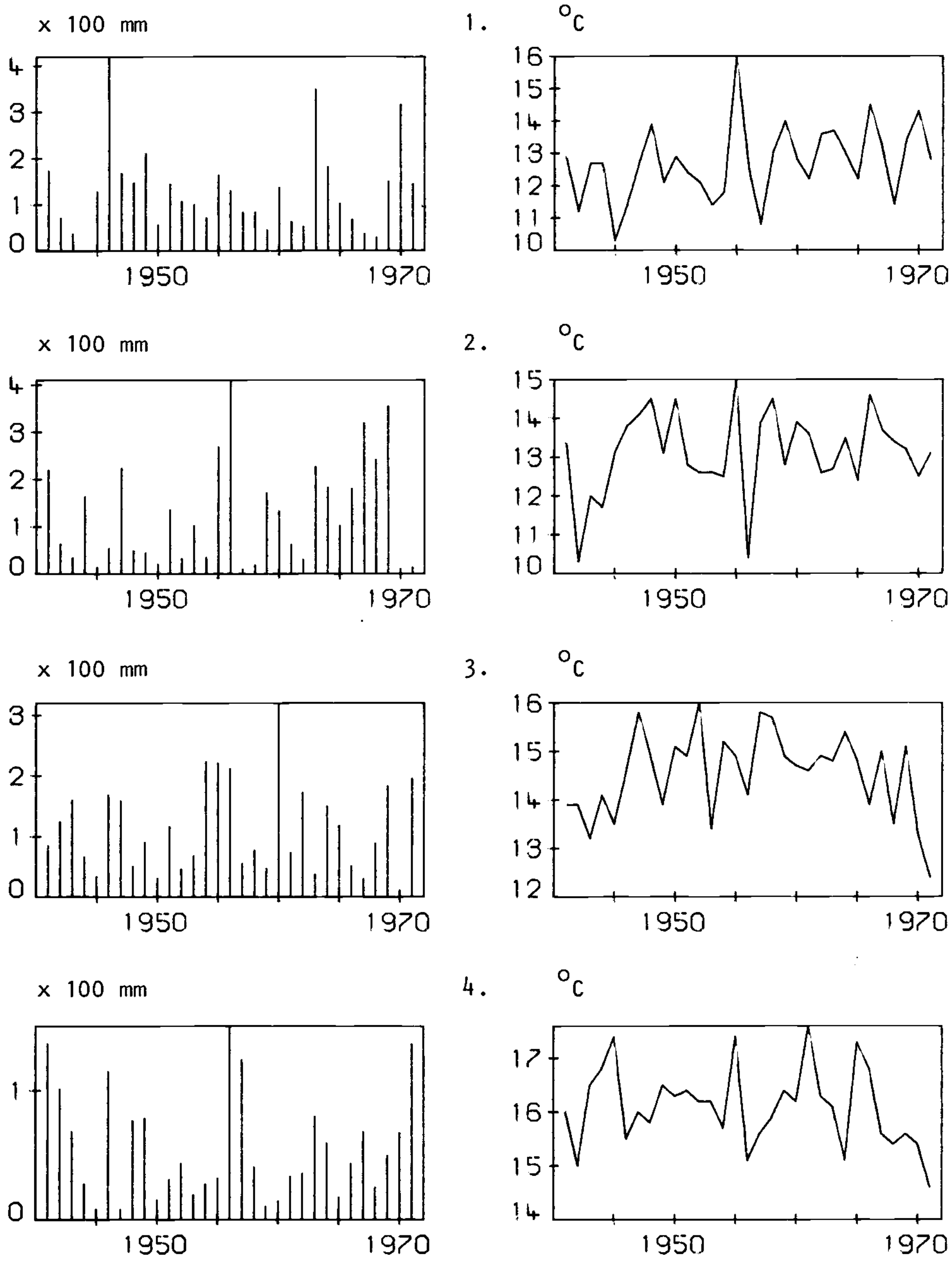


Figure 2. Meteorological data for Tetouan Airport from January (1) through December (12). Precipitation on the left, temperature on the right. Scales vary.

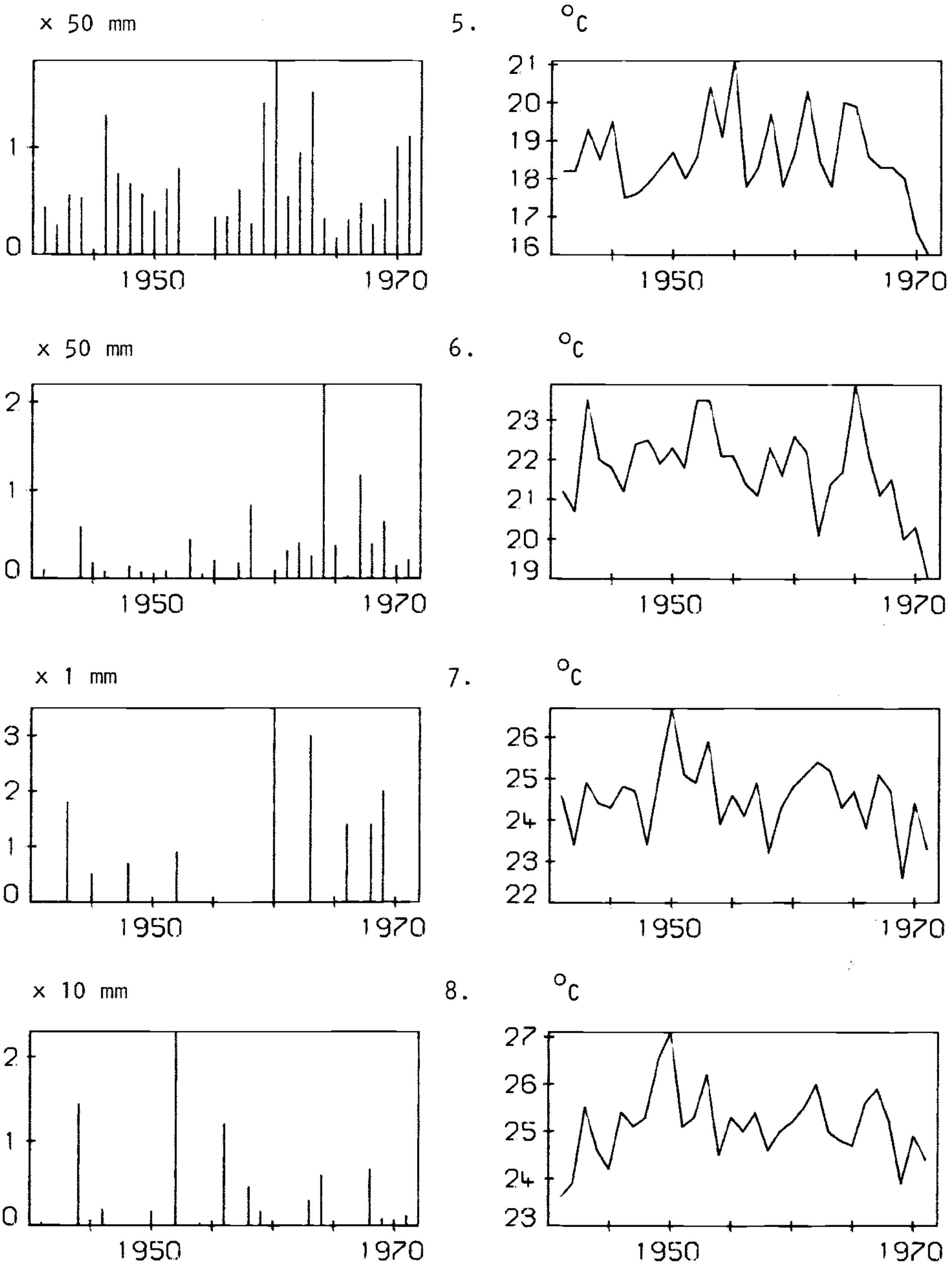
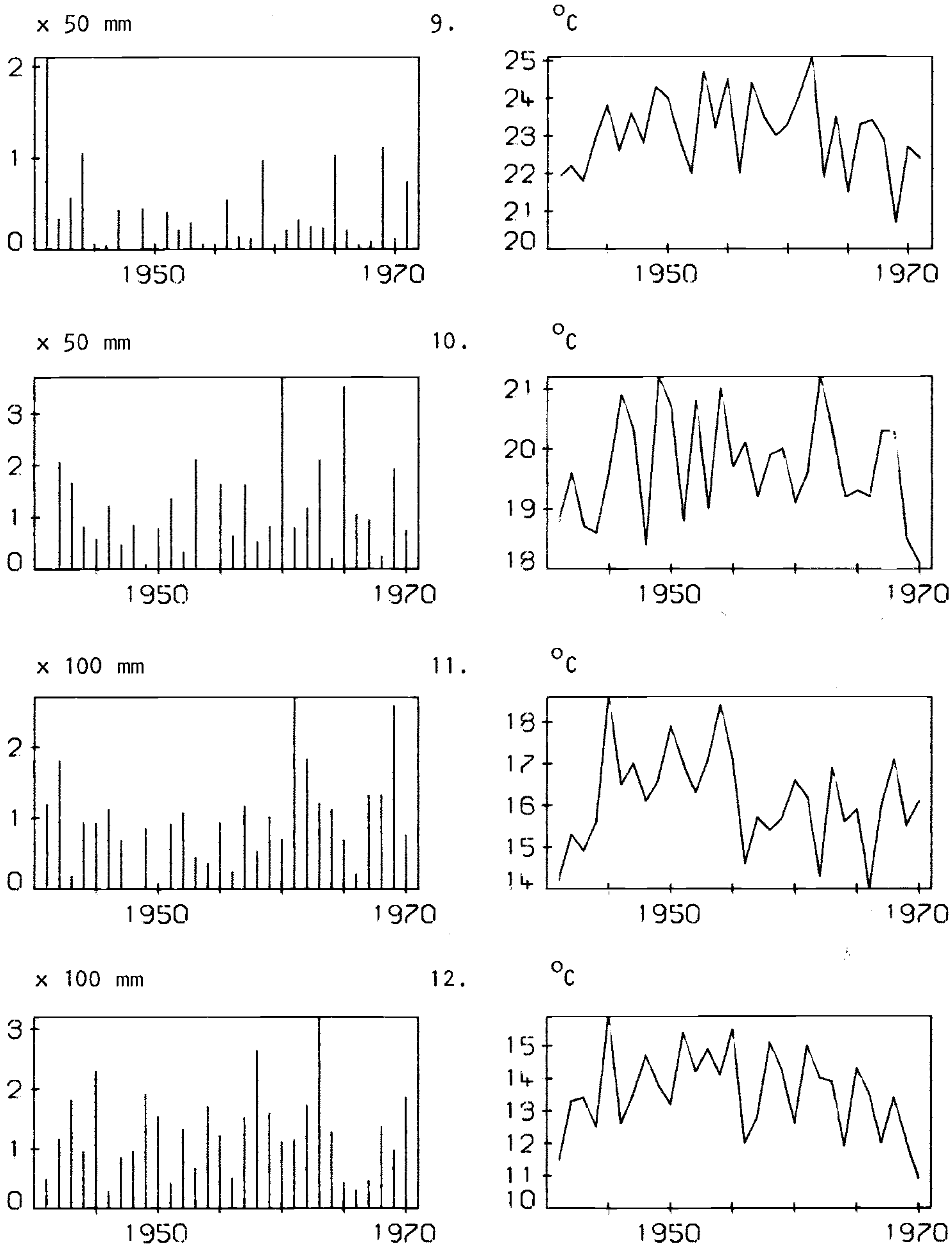


Figure 2, continued



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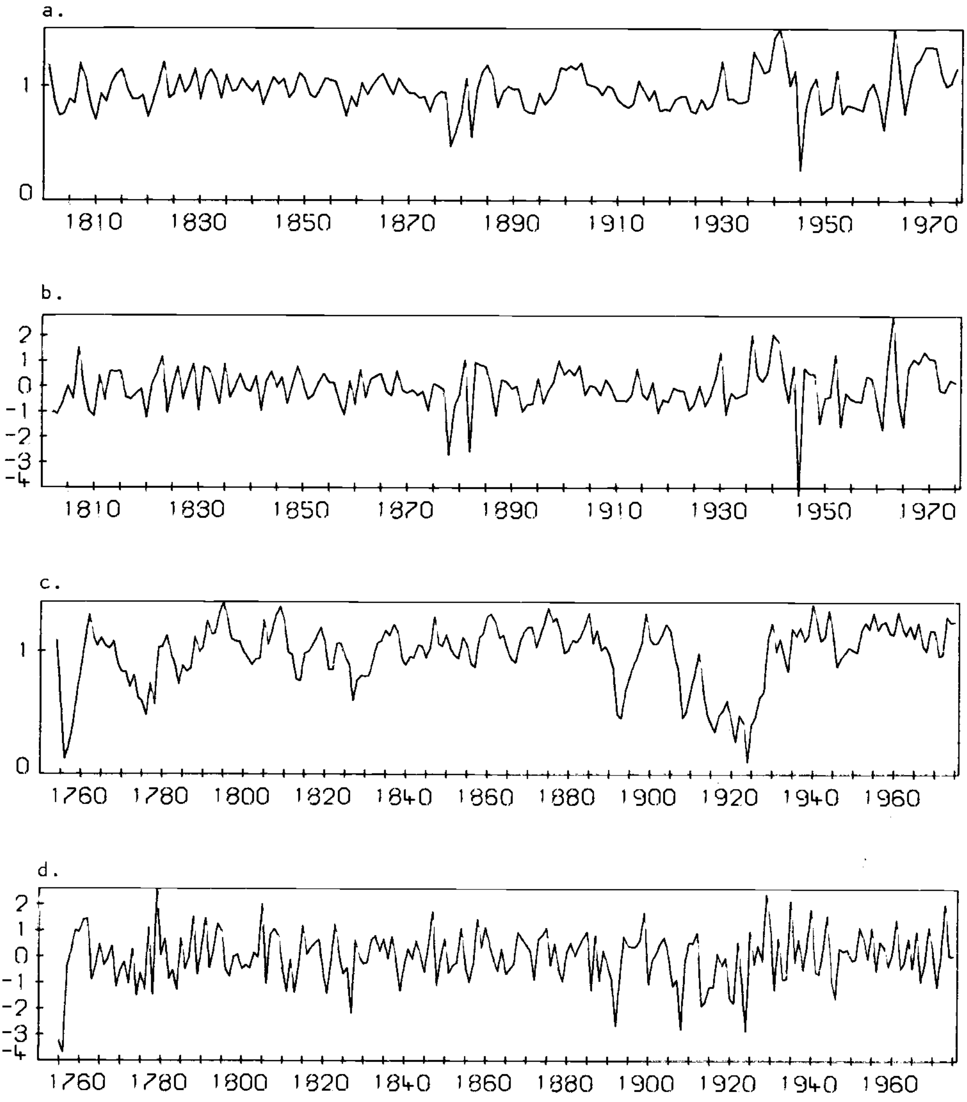

Figure 3. Moroccan chronologies: *a,* site 301; *b,* site 301 with persistence removed; *c,* site 302; *d,* site 302 with persistence removed.

Table 2. Statistics of climate for Tetouan Arport, A.D. 1942-1971.

	Variable	mean	standard deviation
Precipitation (mm)	January	129.0	97.1
	February	125.1	114.3
	March	112.8	75.4
	April	55.2	40.7
	May	31.9	23.5
	June	15.5	23.1
	July	0.5	1.0
	August	2.6	5.3
	September	17.3	17.4
	October	57.4	46.6
	November	98.2	65.7
	December	127.7	71.7
Temperature (°C)	January	12.7	1.2
	February	13.1	1.1
	March	14.5	0.9
	April	16.1	0.8
	May	18.6	1.1
	June	21.8	1.1
	July	24.5	0.8
	August	25.2	0.7
	September	23.1	1.0
	October	19.7	0.9
	November	16.1	1.1
	December	13.5	1.3

For site 302, it is remarkable that the curve of May temperature follows quite well the curve of indices.

RESPONSE FUNCTIONS

This section will provide a relationship between standardized tree-ring indices (^tC) and standardized climatic variables (X_j). It is based upon statistical data analysis techniques which differ from the usual Fritts et al. (1971) method in the following way.

1) The persistence in the tree-ring chronology (i.e. the autocorrelation at lag 1 or more in the series) is extracted before starting to compute the response functions (The procedure is even different from the procedure in Munaut et al. 1978). This leads to a chronology directly related to the climate. For the response function and for the reconstruction of the climate (the next step), tree rings of the previous years are no longer entered. 2) The regression is performed after extracting the principal components, but the principal components are introduced with a probabilistic criteria.

Table 3. Serial correlation and significance of chronologies before (t_C) and after $t_C{}^*$) removal of persistence.

		Site 301	**Site 302**
t_C	serial correlation	0.452	0.819
	significant level	0.9999	0.9999
$t_C{}^*$	serial correlation	-0.005	0.048
	significant level	0.51	0.78

3) The variables that are less important for tree growth are rejected in a stepwise fashion and, finally, only a very limited number of climatological parameters are selected.

Elimination of the persistence in the index series

A chronology of 222 years for the site 302 (1754-1975) and a chronology of 175 years for the site 301 (1800-1974) are available. These series are detrended, because they are autocorrelated (Table 3). Their serial correlation coefficient at lag 1 is significant at the 95% level for both sites. Thus a regression has to be performed between ${}^{t}C$ and ${}^{t-1}C$. At the following steps, the serial correlation of the residuals are computed. As they are not significant at the 95% level (Table 3), it will not be necessary to introduce indices ${}^{t-2}C$, ${}^{t-3}C$ . . . in the regression (this test on serial correlation is explained in Sneyers 1978).

A regression is thus performed between ${}^{t}C$ and ${}^{t-1}C$ only. This leads to uncorrelated residuals which are considered as indices ${}^{t}C^{x}$ where persistence is left out, the regression equations being:

$$\text{site 301:} \quad {}^{t}C^* = {}^{t}C - 0.447\,{}^{t-1}C - 0.553$$

$$\text{site 302:} \quad {}^{t}C^* = {}^{t}C - 0.820\,{}^{t-1}C - 0.179$$

This 1-year persistence explains 20% of the total variance in the series from site 301 and 67% from site 302. This is closely related to the comments already made about some values given in Table 1.

Regression after extracting the principal components

The predictor variables of this regression are the 24 climatic parameters, monthly precipitation and temperature for October of the year prior to growth till September of the current year. They are standardized. These variables being not independent, principal components must be extracted to provide 24 orthogonal variables (Table 4). Because the least important components (those that account for a portion of the data variance not significantly different from zero) will contribute to the inaccuracy of the regression coefficients (Richard 1977), only the most important eigenvectors are retained. Table 4 shows that the eigenvalues product becomes clearly less than one after the 18th eigenvalue. This eigenvalues product is in fact the determinant of the correlation matrix of the climatic data and if we keep all the principal components, this determinant appears to be much less than one. As a determinant of a correlation matrix of orthogonal variables is equal to one, only around 18 principal components

Table 4. Results of principal component analysis (* indicates components used in regression).

principal component	variance explained (%)	eigenvalues product	weight on 301 coeff.	weight on 301 signif.	weight on 302 coeff.	weight on 302 signif.
1	17.9	4.292	0.21	0.98*	-0.18	0.91*
2	12.4	12.773	0.25	0.98*	-0.04	0.24
3	9.8	30.029	0.02	0.18	-0.28	0.95*
4	7.7	55.824	-0.09	0.57*	-0.08	0.39
5	7.2	96.018	-0.04	0.25	-0.07	0.35
6	6.0	137.882	-0.34	0.98*	-0.19	0.72*
7	5.8	191.518	-0.03	0.21	0.17	0.67*
8	5.5	254.144	0.22	0.89*	-0.00	0.01
9	4.9	298.366	-0.19	0.80*	-0.15	0.56*
10	4.5	320.743	-0.03	0.18	0.02	0.06
11	3.5	268.782	-0.05	0.23	-0.04	0.15
12	3.2	208.844	-0.28	0.88*	-0.04	0.14
13	2.2	110.479	0.17	0.56*	0.15	0.39
14	2.0	52.146	-0.13	0.44	-0.07	0.18
15	1.9	24.456	-0.05	0.20	0.15	0.38
16	1.5	8.682	-0.01	0.02	-0.34	0.67*
17	1.3	2.804	-0.02	0.06	-0.00	0.01
18	1.0	0.701	-0.07	0.19	0.38	0.64*
19	0.7	0.112				
20	0.04	0.010				
21	0.03	7.10^{-4}				
22	0.02	2.10^{-5}				
23	0.01	6.10^{-7}				
24	0.00	3.10^{-9}				

are allowed to be kept to provide a resulting determinant nearly equal to one. It must be noticed that each of the first 18 principal components explain more than 1% of the data variance (Table 4). Moreover, applying the test of Lawley (Kshirsagar 1972), it can be seen that the last six principal components are not significantly different from zero. These three remarks amply justify our selection.

However, some components in this selection have a zero weight on the dependent variables in such a way that we are also going to reject such components that have a zero weight on $^{t}C^{*}$ with a probability greater than 0.50. This level was chosen after several experiments. When the number of observations is small as in our case (30), this level is more justified than higher one like 0.90 or even 0.95. Comparison between all these procedures are described in Guiot et al. (1979).

Thus eight principal components for the site 301 and seven for the site 302 have finally been kept.

Then a multiple regression analysis has been performed between tree-ring indices from which persistence (lag 1) has been eliminated, $^{t}C^{*}$, and the amplitudes of the selected components (principal components in the observation-space, Guiot et al. 1978). This leads respectively to two sets of eight and seven regression coefficients. These coefficients are then converted into a new set of coefficients, T_i $(1<i<24)$, expressing the same relationship but in terms of the 24 original amplitudes (Figure 4):

$$^{t}C^{*} = \sum_{i=1}^{24} T_i \quad X_i$$

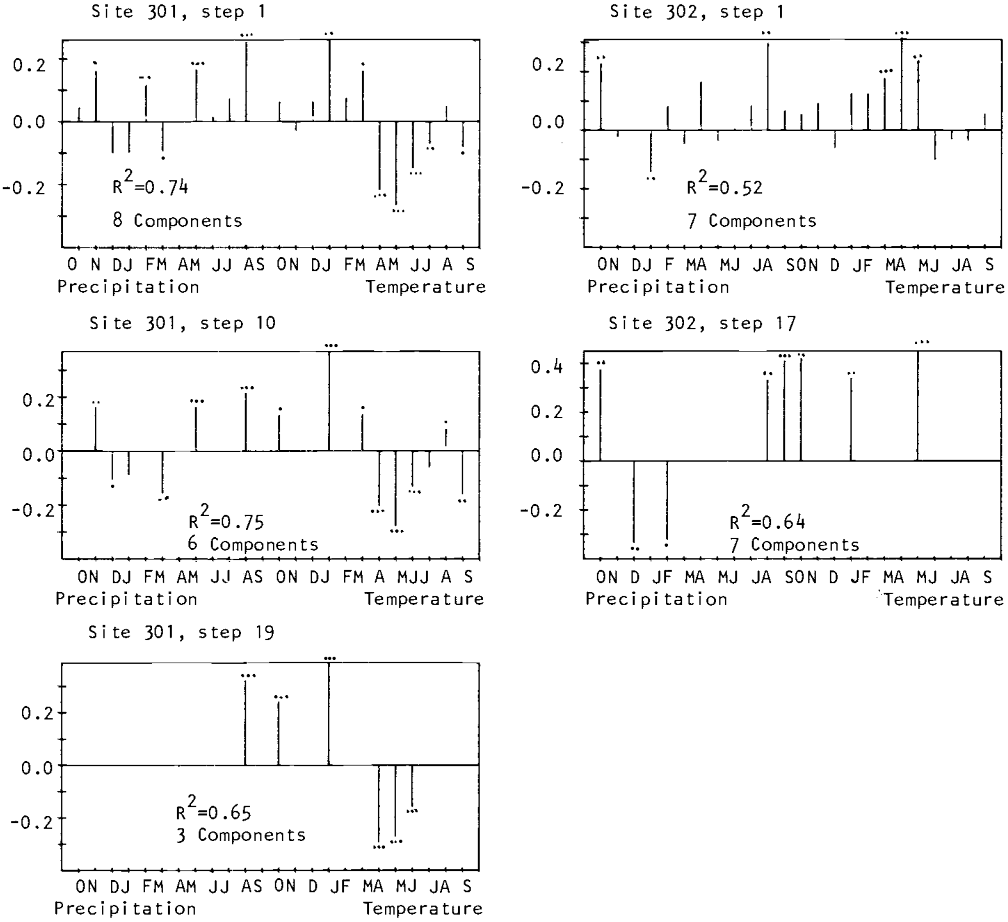

Figure 4. Response functions. Vertical bars represent the regression coefficients of the 24 standardized variables. One, two, or three dots mark significance of 90, 95, and 99% respectively. Using all principal components, R^2 of site 301 is .95 and of site 302 is .88.

Table 5. Serial correlation of chronologies for total length and for period of instrumented climate.

	Site 301	Site 302
whole period	0.452	0.819
30-year period	0.439	0.281

Selection of the most significant variables

The regression coefficients (T_i) of the response functions for both sites are given in Figure 4, where it can be seen that some of them are not significantly different from zero at the 95% level. As a consequence, the T_i with the smallest value of the Student's *t*-statistic is deleted and the whole procedure is started again in a stepwise fashion. However, some of the variables could never be rejected. Indeed, it is possible that, when dealing with a large number of variables, some of them become significant only after other competitive variables have been eliminated. Thus other criteria for the selection have to be defined. At the same time as the procedure of rejecting the less significant variables, we select, in the set of climatic variables, the variables which individually explain a part significant at more than 95% of the variance of ${}^tC^*$. This gives a final selection of variables which may not be deleted, and the final selection will at least contain these variables and, as a consequence, in the stepwise fashion, the least significant climatic parameters are deleted one by one beyond this minimal selection. The program provides these different steps till the minimal selection remains. So we can extract from these different steps, the step which explains the maximum of ${}^tC^*$ variation but where the coefficients are "sufficiently" significant. More details on this method and comparisons with others are given in Guiot (1979).

In this study, for the site 301, 15 climatic parameters have been selected and their influence on the indices ${}^tC^*$ have been represented by six principal components ($R^2 = 0.75$). The coefficients, except one, are significant at the 90% level. For the site 302, we have selected eight climatic parameters which the influence on the indices ${}^tC^*$ may be represented by seven principal components ($R^2 = 0.64$). All the coefficients are significant at the 90% level. Figure 4 provides, for both sites, the response function related to the variables remaining in the final regression equations.

Study of the 30-year period

These response functions are established for the indices from which persistence has been taken out on the basis of the whole chronology (222 years for the site 302 and 175 years for the site 301). These functions are mainly useful for the reconstruction of the climate; but if we want to study the relationship of cedar to climate, we have to eliminate the persistence on the 30-year period basis only (1942-1971). For the site 302, the serial correlation appears to be larger over the whole chronology ($\rho = 0.82$) than over the partial chronology ($\rho = 0.28$) (Table 5), which means that persistence was more important in the first part of the tree's life than now. However, for the site 301 persistence has not changed.

Considering only this 30-year period, the relations between the tree-rings and the most important climatic parameters for both sites can now be written as:

site 301

$$ {}^{t}C = 0.448\,{}^{t-1}C + {}^{t}C^{*} $$

$$ {}^{t}C^{*} = 0.283\,P_{Aug} + 0.192\,{}^{t-1}T_{Oct} + 0.438\,{}^{t}T_{Jan} - 0.336\,{}^{t}T_{Ap} - 0.353\,T_{May} + \in $$

$$ R^{2} = 0.660 $$

site 302

$$ {}^{t}C = 0.420\,{}^{t-1}C + {}^{t}C^{*} $$

$$ {}^{t}C^{*} = 0.388\,P_{Oct} + 0.317\,{}^{t}P_{Sept} + 0.247\,{}^{t}T_{Jan}\ {}^{\wedge}\ 0.471\,{}^{t}T_{May} + \in $$

$$ R^{2} = 0.516 $$

where all the variables are standardized. As these relations are computed only over the 30-year period, they describe the real behavior of the tree during this period.

INTERPRETATION

Site 301

Using 24 or 15 variables, it appears that the monthly precipitation of November, May, and August has a positive effect on growth. On the other hand, winter and early spring precipitation seems to be unfavorable. This effect is explainable in a mediterranean cold climate when it is snowing during winter. An accumulation of snow in the forest can delay the tree growth by maintaining a cold microclimate. This unfavorable effect of cold winter and spring is clearly illustrated by the positive effect of the temperature during the same period. On the other hand, at middle altitude, high temperature during April, May, June, and July, are the cause of an intense evapotranspiration which reduces drastically the water resource in the soil and the subsequent growth. The five variables still giving a high R^2 summarize obviously this interpretation emphasizing the positive effect of high precipitation in summer and high temperatures during fall and winter, while high spring temperature, lengthening the summer dryness, reduces the yearly growth.

Site 302

Compared with the response function of site 301, this one shows some interesting analogies but also dissimilarities. The positive effect of precipitation during fall and summer and the negative one in winter may be explained in the same way as for site 301. It is especially obvious that in a fairly wet environment (maybe more than 1 m/year) *Cedrus* takes advantage of summer rains. Concerning the temperature, warm

October and January are also favorable, but this effect is the same for February, March, April, and May. Indeed at high altitude, during springtime, the water supply is still sufficient, but if the temperature is too low the growth is reduced.

CONCLUSION

In conclusion, this preliminary study shows that the dendrochronological analysis of two adjacent forests of *Cedrus atlantica* located at the upper and at the lower limits of this species in the Rif mountains, gives two response functions of the same type. In fairly wet and cold mediterranean climate, precipitation is of great influence on the yearly growth, except in winter when a snowy cover delays the spring growth. Temperature acts favorably at both sites during winter, and also during spring at high elevation where there is no fear of strong evapotranspiration.

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