EARLY WINTER TEMPERATURE RECONSTRUCTION OF SINAIA AREA (ROMANIA) DERIVED FROM TREE-RINGS OF SILVER FIR (ABIES ALBA MILL.)

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Abstract. The study aims at investigating the long-term evolution of the early winter temperatures in a mountainous area from the Southern Carpathians, around the town of Sinaia. The reconstruction of the temperature is based on dating tree-rings of silver fir (Abies alba Mill.), and it goes back to the 18th century. In agreement with dendrochronological principles, 20 silver fir trees were selected for sampling. The climatic data (monthly temperature and precipitation) are used as statistic predictors, and the growing indices as predicted variables. The sign and the size of the correlation coefficients are interpreted as a growth response of the tree to a specific climatic variable in a certain month. The transfer function was quantified using linear regression. The climatic dataset refers to Sinaia weather station, and it covers the interval 1961-2003. Based on the analyses of the two temporal series (tree-rings derived and weather stations data), we emphasize alternative sequences of years or decades with warm/cold early winters: the intervals 1790-1802, 1874-1888, and 1945-1956, 1980-2000 had cold winters, while the winters started with warm temperatures during the periods 1836-1846, 1860-1873, and 1934-1944. Based on this alternative of the period with warm and cold early winter we can suggest that the next decade, probably, will be warmer than the period 1980-2000.

1. INTRODUCTION

The climate change studies assume that both natural and anthropic causes have influenced the climate of the Earth in the last century. Since the instrumental data cover mainly the 20th century, and weather stations with more than 100 years data are seldom, the long-term climate variability is approached by proxy methods (e.g. dendrochronology, sediment analysis, ice-core, pollen analysis etc.). The data obtained from proxy methods support relative accurate identification of the anomalies in climate series (Grudd *et al.*, 2002). The annual tree rings provide valuable information on the interannual variability of the climate in a certain territory. The dendrochronology has a major contribution to the reconstruction of the spatial and temporal environmental dynamics (Schweingruber and Briffa, 1996). Dendroclimatology provides the possibility of the knowledge of the climate evolution at centennial and millennial scales with high resolution.

Trees can be considered as a very sensitive climatograph that can function for hundreds of years, capable to record and to store information on the environmental factors. The trees that grow close to the altitudinal or latitudinal limit of the vegetation react rapidly to the stress of thermal variations during the vegetation season (Tranquillini 1979), and dendrochronological studies have emphasized both altitudinal and latitudinal gradients (Fritts, 1965; Lara *et al*., 2001; Hofgaard *et al*., 1999).

The dendroclimatology is based on a solid statistics theory (Fritts, 1976; Cook and Kairiukstis, 1990; Schweingruber, 1985, 1996), so that significant results in reconstructing the dynamics of the climate in the last centuries and millenniums have been obtained (Eckstein and Aniol, 1981; Hughes *et al*., 1994; Briffa *et al*., 1990, 2001). Over Romanian territory paleoclimatic reconstruction has been achieved mainly on the basis of pollen analysis and made possible the reconstruction of vegetation dynamics over the Holocene (Tantau *et al*., 2006; Wohlfarth *et al*., 2001; Bjorkman *et al*., 2003; Bodnariuc *et al*., 2002). However, though, even that the forest ecosystems from Carpathians region have a high dendrochronologicalpotentia (Popa, 2003), there are still few studies about the climate-growth relationships, dendrochronological series or dendroclimatological reconstruction from Romanian territory (Popa, 2004; Schweingruber, 1985).

This paper presents preliminary results on early winter temperature regime reconstruction for Sinaia area (Romanian Southern Carpathians) using silver fir (*Abies alba*) tree-rings. Data and methods are presented in Section 2. Section 3 reveals the results and conclusions are summarized in Section 4.

2. DATA AND METHODS

The research area is located in the southern part of the Bucegi Mountains belonging to the Romanian Southern Carpathians (45°21’N, 25°32’E), in a mixed forest of spruce (*Picea abies*) and fir (*Abies alba*), at 1,050 m a.s.l., with

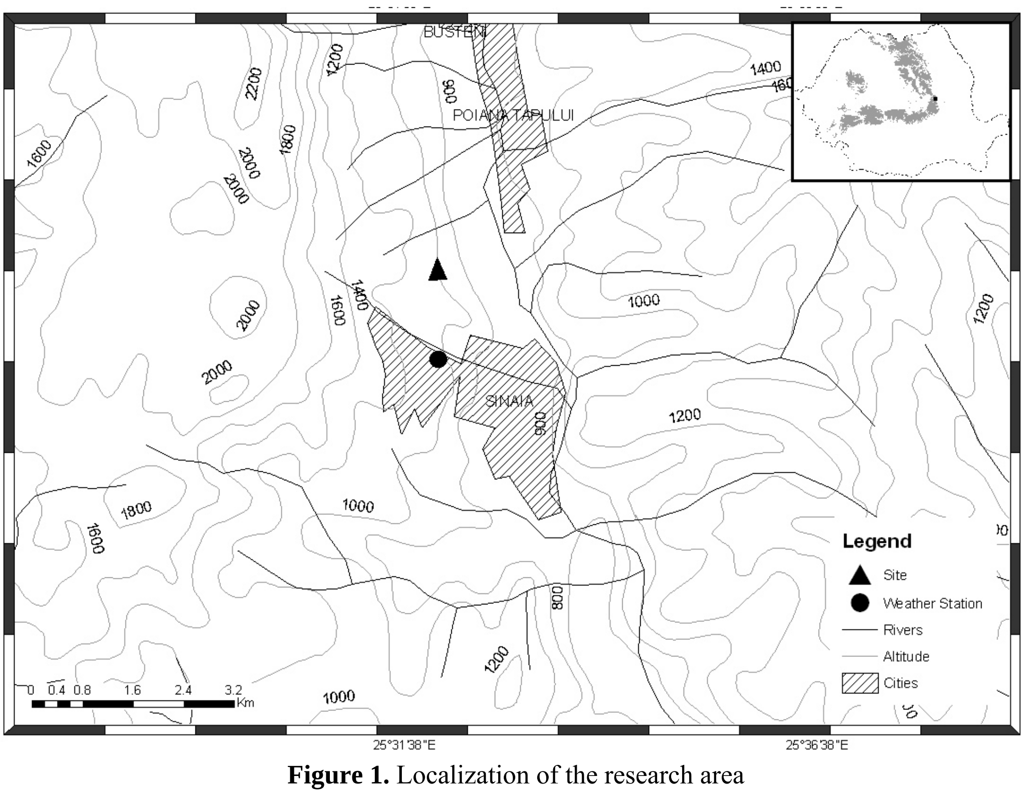

Figure 1. Localization of the research area

slopes of 25-30° (Fig. 1). In agreement with dendrochronological principles, 20 silver fir trees were selected for sampling (Fritts, 1976; Cook and Kairiukstis, 1990; Popa, 2004; Grissino-Mayer, 2003). From each of them, two cores have been sampled at a height of 1.30 m, across the line of the steepest mountain slope, in order to avoid presence of compression wood. The samples were dried out, firmly fixed, and sanded. A treatment with flax oil was applied in some cases in order to facilitate the identification of the tree rings.

The LINTAB equipment[1] and TSAP software[1] were used for measuring the annual rings with a precision of 0.01 mm, as well as for cross-dating the growth series by graphical comparison in a logarithmic scale. The results were validated using the COFECHA software (Holmes, 1983; through the analysis correlation on intercalated sub-periods (Holmes, 1983; Grissino-Mayer, 1997). After the analysis, 4 trees were excluded due to cross-dating difficulties. For each growing series the autocorrelation, sensitivity, standard deviation has been calculated. The average sensitivity (S) was used as a measure of the dendroclimatic potential of a series. It was calculated for each individual series and it can be defined as the average difference between the width of the annual growing ring and the width of the previous ring, expressed in percentage from the total number of rings (Douglas, 1941; Fritts, 1976; Popa, 2004).

$$\overline{S} = \frac{\sum_{t=1}^{t=n-1} \left| \frac{(x_{t+1} - x_t)}{\frac{x_{t+1} + x_t}{2}} \right|}{n - 1}, \text{ where}$$

S = average sensitivity for individual series

x_t, x_{t+1} = growth in the year t or, respectively, t+1

n = number of years

The growth series were standardized in order to eliminate the non-climatic signals and to maximize the climatic information from the individual data rows. We applied the method of double standardization through a negative exponential function or a linear function (to eliminate the influence of the age), followed by a cubic spline with a 50% frequency cutoff in 30 years (Cook and Kairiukstis, 1990). The ring-width index (*It*) chronologies were calculated as the ratio between the observed and estimated value using ARSTAN software (Grissino-Mayer *et al.*, 1996).

$It = Rt/Gt$, where

Rt is the measured ring width, and

Gt is the estimated ring width by a detrending function.

In order to reconstruct the historical dynamic of the climate, it is recommended to use dendrochronologic series having high sensitivity, a low autocorrelation, and a high percentage of the common signal (Fritts, 1976). The common signal is analyzed by the empirical orthogonal function (EOF) based on individual growth series. The variance explained by the first EOF pattern represents the strength of the signal.

The average population index was calculated by bi-weight robust mean method. This research is based on the residual chronology, produced by ARSTAN. The expressed population signal (EPS) (Briffa and Jones, 1990) was used to assess the theoretical number of individual series needed to acquire a

[1] http://www.rinntech.com/

robust mean chronology that represent the true population climatic signal. An EPS value of 0.85 was used as threshold for signal acceptance (Briffa and Jones, 1990) resulting from a representative period of 1774-2001 with a minimum of 5 trees.

The reaction of the trees to function was quantified using linear regression.

The climatic dataset refers to Sinaia weather station, covering the interval 1961-2003. The average annual temperature is 3.7°C and the average annual precipitation amount is 1,014 mm.

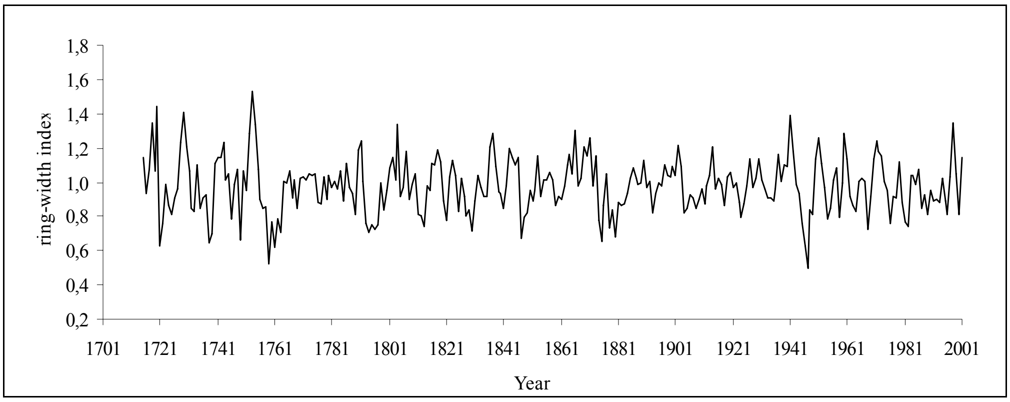

Figure 2. Dendrochronological series for silver fir from Sinaia

the climatic variation was analyzed by response functions (Fritts, 1976; Cook and Kairiukstis, 1990; Guiot, 1991), the analyses being performed by the software PRECON 5.1. The bootstrap response functions analysis has been carried out in order to identify the climatic parameters that influence significantly the growing in the area, i.e. precipitation and temperature (Fritts, 1976; Fritts and Guiot, 1990).

The climatic data (monthly temperature and precipitation) arerin used as statistic predictands, and the growing indices as predicted variables. The sign and the size of the correlation coefficients between predictor and predictand time series are interpreted as a growth response of the tree to a specific climatic variable in a certain month. The transfer

3. RESULTS AND DISCUSSIONS

The dendrochronologic series for silver fir from the Sinaia area has a length of 287 years, along 1715-2001 (Fig. 2), but the common interval with data for all series is 1866-2001, and the mean correlations were computed for this temporal window. In the silver fir chronologies studied, the average sensitivity of the individual series varied between 0.12 and 0.26. The overall average is 0.15 and it indicates a medium response to the variation of the climatic factors. The intensity of the signals between trees (the common variability) is given by the ratio between signal and noise (5.25 in the case of the residual series of growing indices), and by the variability in the first eigenvector (30.25%) (Table 1).

Table1. Statistical parameters of dendrochronological series from Sinaia

Statistical parameter	*Value*	*Mean correlation*	*Value*
Number of trees	16	Between all cores	0.264
Number of cores	32	Between trees	0.259
Average sensitivity (S)	0.15	Between cores from the same tree	0.389
Standard deviation	0.13	Individual tree seria vs. mean seria	0.529
Autocorrelation of order I	0.01	Signal / noise	5.256
Common interval analyzed	1866-2001	First EOF variance	30.25

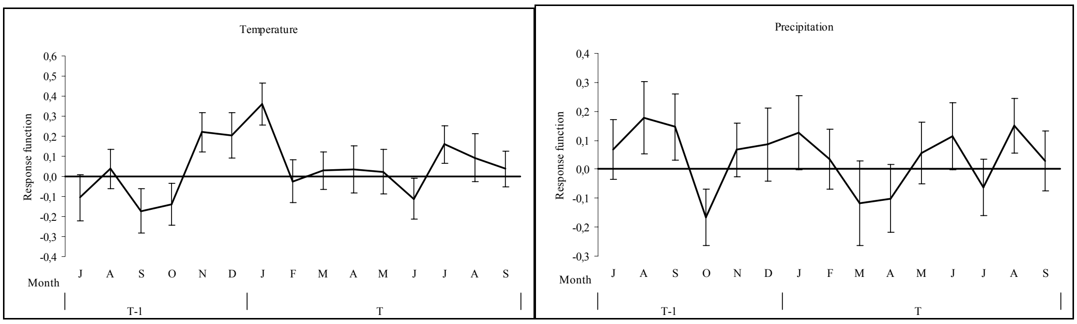

Figure 3. Response function for silver fir from Sinaia area

Many studies have agreed that the actual and the previous vegetation seasons provide enough information about the influence of the climatic factors on the growth (Schweingruber *et al*., 1991; Schweingruber, 1996; Popa, 2003). Our analysis is based on the average monthly temperature and on the monthly amount of precipitation starting from July of the year before the growing of the actual ring (t-1) to September of the year of the growing of the actual ring (t) (Fig. 3). The correlation coefficients between these time series and current growth index were computed (Fig. 3). The statistical significance was tested using t-test for a significance level of 95%.

One can notice a positive influence of the temperature regime of early winter (November-January), and in the vegetal season (July - August). A negative correlation is observed with the temperature from precedent September – October period. As regards the precipitation regime, there are significant positive influences of the current year August, and of the previous year August-September, while the influence of previous year October is significantly negative. This reaction to the climate is specific to the silver fir, and is due to the mesophyl character of the species. Similar response was observed in other sites, i.e. Eastern Carpathians, Apuseni Mountains, French Alps (Desplanque *et al*., 1998; Popa, 2003).

The response function suggests a good correlation between current growth index and the previous early winter temperature. The mean temperature of November-January has been chosen for the reconstruction based on a transfer function. In order to calibrate and to verify the statistical model, the climatic data were divided in two intervals: 1962-1981 (verification), and 1982-2001 (calibration). Using a linear regression model the transfer function was quantified: $T_{XI-I}(i)=7,769\ I_i - 10,437$, with coefficient of determination

R^2=0.629. The correlation coefficient between the real values and the ones estimated by the model, for the validation period, is 0.576, and it is statistic significant at 95% level (Fig. 4).

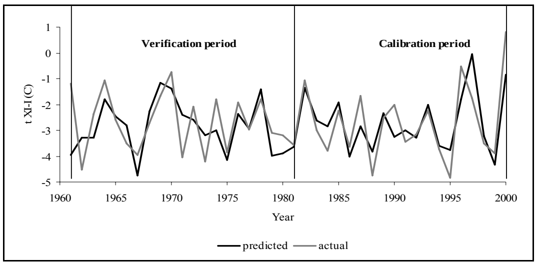

Figure 4. Comparison of the actual and predicted November – January (t XI-I) average temperature

The reconstruction of the mean temperature (November to January) at Sinaia, based on dendrochronological series for silver fir, was extended back to 1774 (Fig. 5).

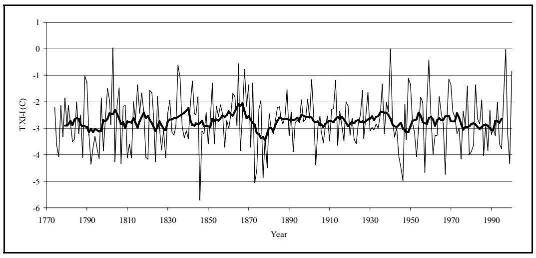

Figure 5. Early winter temperature (November – January, T XI-I) reconstructed based on the Silver fir growth index from Sinaia (smooth line), and the 11-year moving average (thick line)

While applying to temperature anomalies against the interval 1961-2000 an 11-years moving average filter, we obtained the decadal variability of the temperature from the beginning of winter in the last 230 years (Fig. 6).

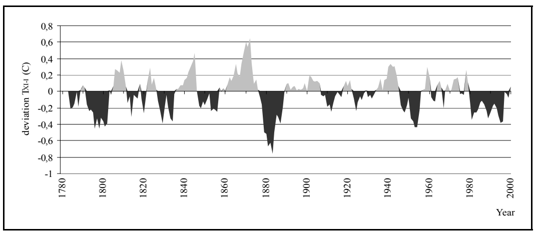

Figure. 6. Decadal variability of the deviation from mean (1961-2001) of the reconstructed temperature of the period November - January

Based on the analyses of the two temporal series, we emphasize alternative sequences of years or decades with warm/cold winters. Thus, the intervals 1790-1802, 1874-1888, 1945-1956, and 1980-2000 had cold winters, while the winters started with warm temperatures during the periods 1836-1846, 1860-1873, and 1934-1944. The transfer function explains 48% of the early winter temperature variability for the period 1961-2001.

4. CONCLUSIONS

This study is the first attempt to reconstruct the paleoclimate in the area of Sinaia (Southern Carpathians), based on the dendrocronological series for silver fir. The growing of the species is strong and positive correlate with the temperature regime from the beginning of the winter and the summer (July-August). The temperature regime that reconstructed is characterized by annual and multiannual sequences of warm and cold intervals. The statistical model presented in this study can be improved by the integration of dendrochronological series for other species from the study area (i.e. Norway spruce and beech). Similar approaches applied for precipitation would add valuable information to the climatic reconstruction.

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