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Reconstructing Temperature from Tree Rings of Pacific Silver Fir in Coastal British Columbia

Abstract

We used ring-width (RW) and maximum latewood density (MLD) chronologies for high-elevation Pacific silver fir (*Abies amabilis* Dougl. *ex* Forbes) from the Coastal Western Hemlock zone near Vancouver, British Columbia to reconstruct April to September mean temperatures for the 1770 - 1990 period. The reconstruction was based on a calibration and verification procedure. The best reconstruction result was achieved when both RW and MLD chronologies were utilized. The reconstruction agreed with that produced for interior British Columbia from densitometric data. We suggest that rings of Pacific silver fir, growing under the influence of a perhumid maritime cool mesothermal and subalpine boreal climates in the Pacific Northwest, can serve as proxy-climate indicators.

Introduction

In regions with discrete growing seasons, annual growth rings of trees can serve as unique proxy-climate indicators providing year-to-year climatic variations are great enough to affect growth and be reflected in the characteristics of rings (Fritts 1970; Briffa et al. 1988). Tree ring analysis of high-elevation species, in particular, can yield information on past temperature fluctuations because at high-elevations growing season temperature can be the factor most limiting cambial activity and ring formation (Fritts 1970, Graumlich and Brubaker 1986, Luckman 1997).

The methodology of climate reconstruction from tree-ring data and the problems encountered were discussed by Fritts (1976. 1991), Lofgren and Hunt (1982), Gordon (1982), Pittock (1982), and Meko et al. (1980). In the Pacific Northwest, several temperature reconstruction were made with varying degree of success. For example, Graumlich and Brubaker (1986) reconstructed annual temperature from tree rings trees at timberline in the Cascade Range of Washington; however, Briffa et al. (1992) was only partly successful when reconstructing summer temperature patterns for northern Alaska and northwestern Canada because of uncertainties in the extreme northern portion of their grid.

Most of the tree ring studies in the Pacific Northwest, however, were conducted outside the coastal region in more continental climates. The data that do not capture unique features of rings of the trees that have grown under the influence of maritime climate may result in faulty climatic reconstruction for the coastal region (Fritts 1991). This study represents the first attempt in the coastal region of British Columbia to reconstruct growing-season temperature using ring-width and maximum latewood density chronologies of Pacific silver fir.

Although the conifers of this maritime region show complacent growth patterns with weak climatic signals, common signals (marker rings) have been found in several tree species, such as Pacific silver fir and western redcedar [*Thuja plicata* (Donn *ex* D. Don) Lamb.] (Dobrý et al. 1996). Of the species investigated, the ring-width and maximum-latewood-density chronologies for Pacific silver fir from montane and subalpine sites in the North Shore Mountains (near Vancouver, B.C.) had the strongest climate signals as determined by response functions. This finding suggests that these chronologies might have potential as proxy-climate data. Thus the objectives of the present study were (1) to determine the utility of Pacific silver tree-rings for a local climatic reconstruction and (2) to make comparison with other temperature reconstructions done for the Pacific Northwest (e.g., Graumlich and Brubaker 1986, Schweingruber et al. (1991).

Materials and Methods

As proxy-climate data, we used ring widths (RW) and maximum latewood densities (MLD) chronologies that were developed for Pacific silver fir from trees growing on a high-elevation site in the transition between the Coastal Western and Mountain Hemlock biogeoclimatic zones (Klinka et al. 1991) within the Greater Vancouver Watershed District (Dobrý 1994, Dobrý et al. 1996). Both zones are influenced by a very wet, maritime climate; the Coastal Western Hemlock zone by a cool mesothermal climate, and the Mountain Hemlock zone by a subalpine boreal climate (Klinka et al. 1991). The study site was situated in Eastcap Creek, Capilano Watershed (1000 m asl, 49° 31' N, 123° 04' W).

RW and MLD measurement series were crossdated by the COFECHA program and only the best inter-correlated series were selected for developing chronologies using the ARSTAN standardization program (Grissino-Mayer et al. 1994). Standard chronologies were developed using default detrending option (negative exponential curve or linear regression and cubic smoothing spline). RW and MLD indices were computed by division and subtraction, respectively.

Residual chronologies were modeled by autoregression to remove most of the low-frequency trend and to emphasize the common high-frequency variation in the chronologies. The RW chronology (coded CA1; 16 trees, 32 cores) spanned the period of 307 years, and the MLD chronology (coded CA2; 7 trees, 7 cores) 238 years. However, for reconstruction we utilized only the 1769–1990 and 1770–1991 period in the RW and MLD chronologies, respectively, so that density series from at least 5 trees could be included into the MLD chronology in any particular year of the period used for reconstruction.

The climatic data for reconstruction came from the Agassiz station, located approximately 100 km east of Vancouver (49° 15' N, 121° 46' W, 15 m asl.). This station provided the longest continuous climatic data for the study area. A few missing records in the data were computed by linear regressions using the data from the neighboring Chilliwack station.

Simple correlations and response functions for RW and MLD chronologies were computed by the PRECON program (Fritts 1994) to determine which of the 34 available climatic parameters (monthly temperature and precipitation from the previous May through September of the current year) were to be selected and tested in transfer functions. The results of simple correlations and response functions were integrated in one figure (see Figure 1). For temperature reconstruction we selected that chronology from among standard and residual RW and MLD chronologies that had the strongest correlation with climatic data. Linear regression was used to quantify climate – growth relationships.

We used transfer functions (Fritts 1976) to describe the relationship between climate and tree-ring data. To select the most suitable climatic parameter for a transfer function, we matched both chronologies and corresponding climatic data for a calibration period following the methodology described in Fritts (1976), Lofgren and Hunt (1982), and Conkey (1986). A two-step process was applied for developing transfer functions. In the first step we developed transfer functions for each RW and MLD chronology. When using the RW chronology, we examined relations of ring-width indices in the current year to the mean monthly temperature in (a) July, (b) July and August, and (c) June through August of the previous year. When using the MLD chronology, we examined current year temperature data for each individual month from March through September, and for the period of April through September as it was done by Schweingruber et al. (1991). In the second step, we developed the transfer functions based on both the RW and the MLD chronologies.

In developing transfer functions, we followed the 2-step calibration-verification scheme applied by Briffa et al. (1988, 1992). In the first step, for the first calibration period of 1892–1941 (early calibration), the late period from 1942 to 1990 was used for verification, and inversely, for the second calibration period of 1942–1990 (late calibration), the early period of 1982 to 1941 was used for verification. In the second step, we examined the stability of the developed linear regression model using the procedure of Graumlich (1985) and used five additional randomly selected data sets, each with 50 years for the first part and 49 years for the second part.

We used several tests to verify the reliability of reconstruction (Gordon and LeDuc 1981; Fritts et al. 1990; Fritts 1991). The tests were computed using the 'verify' routine (VFY) of the Dendrochronology Program Library (DPL) software (Holmes 1994). From all the tests done, we selected only those used by Grissino-Mayer (1996) for presentation: (1) correlation coefficient, (2) reduction of error (RE), (3) products-means test, and (4) sign-products test.

Correlation coefficient reflects the entire spectrum of variation that is common between two data sets. RE statistics provides a sensitive measure of reliability because it estimates fairly accurately the explained variance. The products-means test calculates the products of the deviations and collects the positive and negative products in two separate groups based on their signs. The values of the products in each group are summed, the means are computed, and the difference between the absolute values of the two means is tested for significance. The sign-products test is a less sensitive measure of reliability; it enumerates the frequency of agreements and disagreements of the signs of departures from the sample means. If the test is successful, it can be concluded that the sign of the estimate is more often correct than would be expected from random numbers.

We tested for the normality of differences between actual and reconstructed temperatures using the Kolmogorov-Smirnov goodness of fit (Zar 1984). Following the verification of the transfer functions developed following the calibration-verification procedure (i.e., the early and late calibration-verification), we used the entire 1892–1990 period of climatic and tree-ring data to develop a new transfer function for temperature reconstruction.

Temporal patterns of actual and reconstructed temperatures in the 20th century were examined by polynomial regression (Luckman 1997). Comparison between our reconstructed temperatures and those reported by Schweingruber et al. (1991) was done using a sign-products test (with normal approximation) that compared the agreement between the positive and negative departures of the reconstructed values from the mean values.

Results

Response functions for the residual RW- and the standard MLD chronologies showed which climatic parameters were suitable for developing transfer functions. In both correlations and response functions, there was a significant response of RW to July temperature of the previous year and a significant response of MLD to March, April, May, and August temperature of the current year. The response profiles for precipitation showed (i) significant positive responses of RW to August precipitation of the previous year and to May precipitation of the current year, (ii) a negative response to July precipitation of the current year, and (iii) significant negative responses of MLD to November precipitation of the previous year and to September precipitation of the current year (Figure 1).

The correlation coefficients between mean July–August temperature of the previous year and the RW chronology index in the current year were $r = -0.33$ and $r = -0.44$ for the standard and residual chronologies, respectively. The transfer function model based on residual chronology ($T_{t-1} = 19.597 - 1.712(RW_t)$; $n = 99$; $R^2 = 0.19$; $p < 0.001$) passed 83% of the verification tests using the following criteria: correlation coefficient, reduction of error, T-value of products-means test, and sign-products test (including additional five randomly selected data sets, i.e., twelve tests for one criterion).

We used the standard MLD chronology for temperature reconstruction because it was better correlated with the mean growing-season temperature in the current year than residual MLD chronology (mean sensitivity = 0.06, and the first order autocorrelation = 0.15). Following Schweingruber et al. (1991), we examined the current year temperature data for each individual month from March through September, and for the period of April through September. Since the April through September period gave the strongest correlation ($r = 0.57$), it was used in the MLD transfer function model ($T_t = 8.316 + 6.561(MLD_t)$; $n = 99$; $R^2 = 0.32$; $p < 0.001$). Similar to the RW model, the MLD model passed all verification tests except for one of the twelve sign-products tests. The calibration and verification statistics indicated a considerably stronger climate-growth relationship for the MLD than RW chronology.

In the second step, we developed the transfer functions based on both the RW and the MLD chronologies. Correlation between these chronologies was not significant ($r = -0.21$; $p = 0.40$), indicating independence of predictor variables. In consequence, we used multiple linear regression to analyze climate - growth relationship and both chronologies to estimate the mean April – September temperature. Verification tests showed an improvement in the performance of the climate – growth model as a result of combining the chro-

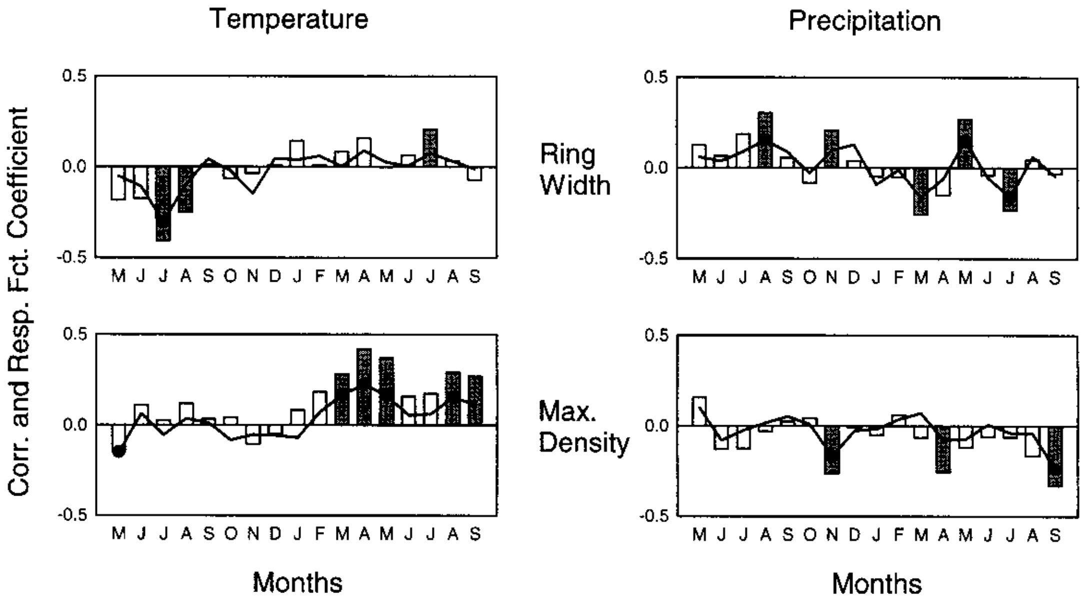

Figure 1. Correlations (bars) and response functions (lines) for indices of ring width and maximum late wood density *Abies amabilis* chronologies on mean monthly precipitation and temperature (May of the previous year to September of the current year) for the period of 99 years. Months with significant positive or negative relations between climate and RW or MLD indices are indicated by filled bars or circles, respectively .

TABLE 1. Calibration and verification statistics for the April-September mean temperature reconstruction based on the ring-width and standard maximum latewood chronologies. Part A: 1—verification (1942-1990) for the early calibration (1892-1941), and 2 through 6—verification for five randomly selected data sets of 49/50 years; part B: 1—verification (1892-1941) for the late calibration (1942-1990), and 2 through 6—verification for five randomly selected data sets of 50/49 years. Values significant at the 95% confidence level are marked with an asterisk. Any positive RE value can be considered significant.

Criterion	Part	Data set						Mean
		1	2	3	4	5	6	
Correlation coefficient								
	A	.60 *	.66 *	.67 *	.58 *	.55 *	.51 *	.60
	B	.64 *	.59 *	.55 *	.66 *	.66*	.69 *	.63
Reduction of error (RE)								
	A	.30	.38	.45	.36	.22	.23	.32
	B	.38	.28	.30	.46	.38	.45	.38
T-value of Products-means test								
	A	3.23 *	3.47 *	3.42 *	3.70 *	3.12 *	2.73 *	3.28
	B	3.40 *	3.65 *	3.73 *	3.56 *	3.77 *	4.68 *	3.80
Sign-products test								
	A	13 *	11 *	14 *	13 *	19	16 *	14
	B	17 *	18 *	21	16 *	13 *	17 *	17

nologies (Table 1). Normality of differences between actual and estimated values was significant at the 95% confidence level. The final transfer function was recalibrated as follows:

[1] $T_{t-1} = 9.697 + 5.922(MLD_{t-1}) - 0.742(RW_t)$
Adjusted $R^2 = 0.37 \quad p < 0.001 \quad n = 99$

where T_{t-1} is the predicted mean April–September temperature of the previous year, MLD_{t-1} is the maximum latewood density in the previous year, and RW_t is the ring-width index in the current year.

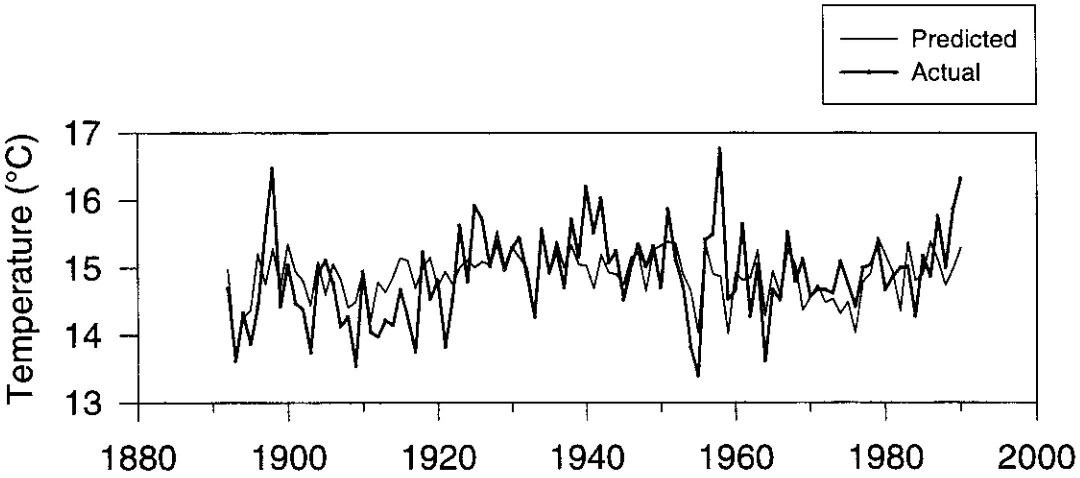

Figure 2. Comparison between actual April - September mean temperatures and the values predicted by the RW and MLD chronologies over the 1892-1990 period.

The actual and predicted April–September mean temperatures for the 1892-1990 period are plotted in Figure 2. Correlation between the actual and predicted temperatures was moderately strong (r = 0.57). 'Extreme' years were more poorly predicted than 'moderate' years. For high-pass filtered actual and predicted temperatures, the short-term variation of these two time series was well correlated (r = 0.68). The low-frequency component of the reconstructed temperatures for the 1770–1990 period had the same mean and the same low-frequency variation as the original data, and showed alternating periods with predominantly higher or lower reconstructed temperatures, respectively (Figure 3). The sign-products test (148 agreements, 62 disagreements, p < 0.001) showed agreement between reconstructed temperatures in this study and Schweingruber et al. (1991).

Discussion

The significant negative correlation between July - August temperature of the previous year with RW of the current year was consistent with the results of Ettl and Peterson (1995) and Garfinkel and Brubaker (1980) who also suggested a significant negative correlation of ring-width with July temperature of the previous year. A possible explanation for the significance of the previous late summer temperature is that it reduces foliage loss during a late summer moisture stress and allocate stored assimilates for the use in the next growing thus positively affecting ring width in the next growing season (cf. Larsen and MacDonald, 1995).

Better correlation of standard than residual MLD chronologies with the temperature data

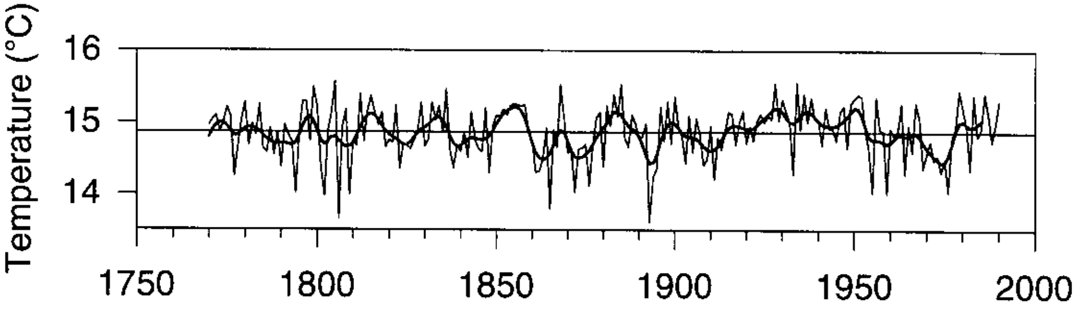

Figure 3. Reconstruction of April - September mean temperatures over the 1770-1990 period for Vancouver, British Columbia. The smoothed line is for the same data passed through a 13-yr low-pass filter.

appears to reflect some lower frequency temperature variations as suggested by D'Arrigo et al. (1992). The verification of transfer functions indicated that the model based on the MLD chronology was superior than that based on the RW chronology. Using both RW and MLD chronologies as combined proxy-climate data resulted in a further improvement of the model. The stability of the model was confirmed by verification tests that gave very similar results when using different data sets.

A year-by-year comparison of reconstructed temperatures in this study agreed with the temperature isolines maps for western North America by Schweingruber et al. (1991), despite the fact that they used tree-ring density data from more continental inland sites of British Columbia. There was no significant relationship between our reconstruction and that of Fritts (1991, and personal communication) who also used ring-width chronologies from inland sites, such as from the Kamloops region.

Some of the differences between these reconstructions might be a result of the differences in the strength of temperature signals between maximum latewood densities and ring-widths or the differences in climatic patterns between more maritime and continental sites. The reconstructed April through September mean temperature in this study had some very similar features to the reconstructed mean annual temperature for Longmire, Washington (Graumlich and Brubaker 1986). In both reconstructions, there was a greater variation of reconstructed temperatures in the first decade of the 19th century. The cool episodes in 1860s, 1870s and 1890s in our reconstruction for the coastal region correspond with the cool episodes from 1860 to 1890 for Longmire. Furthermore, the rise of temperature in the first half of the 20th century detected in this study corresponds to that reported for Longmire.

When comparing temporal patterns between actual and reconstructed temperatures in this study for the 20th century by polynomial regression, the fitted lines of the third order regression ($p < 0.001$) had the same shape. This indicates a general conformity between tree-ring characteristics and a warming trend in the 20th century. The curves were similar to polynomial regressions used by Luckman (1997) to characterize long-term trends in the records of mean annual temperature of one station in the Canadian Rocky Mountains. He differentiated two general patterns in the polynomial curve shape and suggested that they may reflect some influence of maritime and continental climates on the climate of the area. The shape of our fitted polynomial lines had the position in between these two patterns.

Our reconstruction also agreed with that developed for the Pacific Northwest by Briffa et al. (1992). All of their negative (1810, 1876, 1880, 1899) and positive (1772, 1776 1796, 1915) extreme years corresponded in the direction of their departure from the mean value with our data. The long-term variation in our reconstructed temperatures in both studies showed several periods with similar positive or negative departures in the smoothed data from the mean values: warmer periods in 1790s, 1850s, and during 1920-1950, and a cool episode in 1890s. The longest warm period in our reconstruction, which is outside the climatic record, occurred from 1848 to 1858 AD (Figure 3).

We concluded that the tree-rings of Pacific silver fir growing in the montane and subalpine coastal forests of British Columbia under a strong influence of a perhumid maritime cool mesothermal or subalpine boreal climate have a promising potential as local proxy-climate indicators.

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