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# Tree-Ring Widths and Snow Cover Depth in High Tauern

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**Abstract.** The aim of the study is to examine the correlation of Norway spruce tree-ring widths and the snow cover depth in the High Tauern mountains. The average standardized tree-ring widths indices for Norway spruce posted by Bednarz and Niedzwiedz (2006) were taken into account. Increment cores were collected from 39 Norway spruces growing in the High Tauern near the upper limit of the forest at altitude of 1700-1800 m, 3 km from the meteorological station at Sonnblick. Moreover, the maximum of snow cover depth in Sonnblick (3105 m a.s.l.) for each winter season in the period from 1938/39 to 1994/95 (57 winter seasons) was taken into account. The main results of the research are as follows: (1) tree-ring widths in a given year does not reveal statistically significant dependency on the maximum snow cover depth observed in the winter season, which ended this year; (2) however, the tested relationship is statistically significant in the case of correlating of the tree-ring widths in a given year with a maximum snow cover depth in a season of previous year. The correlation coefficient for the entire period of the study is not very high ( $r=0.27$ ) but shows a statistical significance at the 0.05 level; (3) the described relationship is not stable over time. 30-year moving correlations showed no significant dependencies till 1942 and after 1982 (probably due to the so-called divergence phenomenon). However, during the period of 1943-1981 the values of correlation coefficient for moving 30-year periods are statistically significant and range from 0.37 to 0.45; (4) the correlation coefficient between real and calibrated (on the base of the regression equation) values of maximum snow cover depth is statistically significant for calibration period and not significant for verification one; (5) due to a quite short period of statistically significant correlations and not very strict dependencies, the reconstruction of snow cover on Sonnblick for the period before regular measurements seems to be not reasonable.

## 1. Introduction

Dendrochronological research gave much new information about climatic conditions for the period before the beginning of instrumental meteorological measurements [1]. However, most of the studies focused on reconstruction of the air temperature [2] and precipitation [3]. Dependencies of tree-ring widths on the snow cover depth were tested so far very rare [4]. They are not so strong as in the case of the above-mentioned climate elements. The exceptions are studies of dendrochronological measurements and snow avalanches, which demonstrate significant correlations giving the ability to reconstruct the avalanche events [5].



The aim of the study is to examine the correlation of Norway spruce tree-ring widths and the snow cover depth in the High Tauern mountains. Bednarz and Niedzwiedz [6] obtained good results in investigating relationships of tree-ring widths with air temperature and precipitation on Sonnblick.

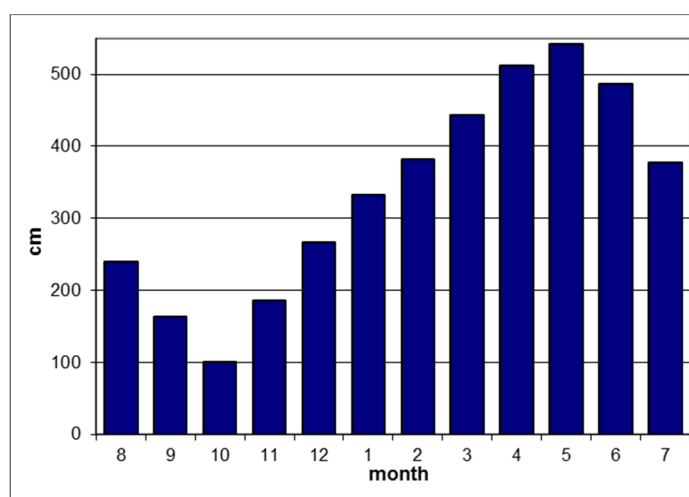
## 2. Data and method

The average standardized tree-ring widths indices for Norway spruce posted by Bednarz and Niedzwiedz [6] were taken into account. Increment cores were collected from 39 Norway spruces growing in the High Tauern near to the upper limit of the forest at altitude of 1700-1800 m, 3 km from the meteorological station at Sonnblick. Moreover, the maximum of snow cover depth in Sonnblick meteorological station (3105 m a.s.l.) for each winter season in the period from 1938/39 to 1994/95 (57 winter seasons) was pointed out from daily data snow cover series [7]. The last year of snow cover investigation period is fitted to tree-ring widths data availability.

There were investigated correlation coefficients between maximum snow cover depth and tree-ring widths (including moving correlations and time-lagged analysis) and the stability of correlation in time. The period of stable statistically significant dependencies was divided into calibration and verification period. The regression equation was constructed, the standard estimation error and the coefficient of determination were calculated. Correlations between real and calibrated snow cover data were verified. Statistical significance was always estimated for the significance level of 0.05.

## 3. Results and discussion

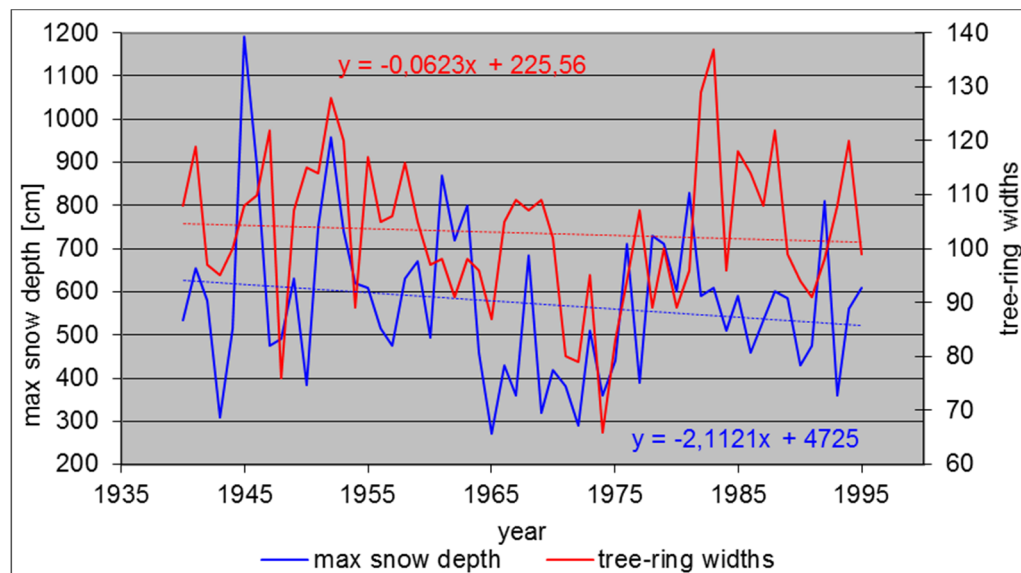
In particular years the seasonal maximum depth of snow cover on Sonnblick is observed mostly in May or in April. Mean of maximum snow cover depth for the analysed period is the lowest in October (101 cm) and increases quite rapidly to May (543 cm), when is the highest (figure 1). The largest snow depths were measured in the 1940s and 1950s [8]. The extremely high value was observed on 9 May 1944 (1190 cm) while the extremely low maximum occurred on 6 May 1964 (270 cm). Maximum depth of snow cover shows slight, statistically insignificant, negative trend of about 20 cm per 10 years in the investigated period (figure 2). Similar tendencies are observed in another areas of the central and northern Europe as well [9]. The long-term run of tree-ring widths demonstrates insignificant negative tendency in 1940-1995, while the trend is increasing in subperiod 1974-1995.



**Figure 1.** Average monthly maximum of snow cover depth at Sonnblick (period of 1939-1995)

Tree-ring widths in a given year (e.g. 1960) does not reveal statistically significant dependency on the maximum snow cover depth observed in the winter season, which ended this year (i.e. 1959/60). However, the tested relationship is statistically significant in the case of correlating of the tree-ring widths in a given year (e.g. 1960) with a maximum snow cover depth in a season of previous year (i.e.

1958/59). The correlation coefficient for the entire period of the study is not very high ( $r=0.27$ ) but shows a statistical significance at the 0.05 level. The relationship is probably associated with the reaction of the tree-ring widths to provide by underground runoff water from the slowly melting snow, infiltrating into the ground and flowing down slowly from summits to the upper limit of the forest.



**Figure 2.** Long-term run of tree-ring widths and seasonal maximum depth of snow cover in previous year (1939-1995). Regression equations were given

The above described relationship is not stable over time. Method of moving 30-year correlation showed no significant dependencies till 1942 and after 1982. However, during the period of 1943-1981 the values of correlation coefficient for moving 30-year periods are statistically significant and range from 0.37 (1944-1973) to 0.45 (1946-1975). For the whole period (39 years) the correlation is also significant (0.34). The above-mentioned extremely high snow cover value in 1944 disturbs the dependence, so the highest correlation was obtained for the period which does not include that year (figure 3, figure 4). Causes of instability relationship are not entirely clear. In the first period (1939-1942) it could contribute to the inaccurate snow cover measurements during the Second World War. After 1981 the cause of the insignificant correlation may be a quite rapid climate change resulting in an increase of temperature, which was this time more important for the tree-ring widths. This so-called divergence phenomenon [10-15] is clearly noticeable in figure 2.

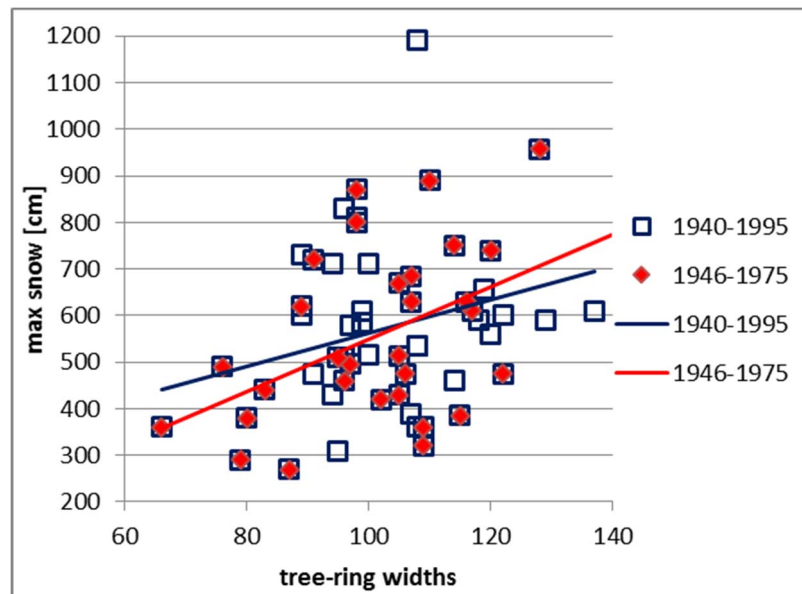
For further research only the period 1943-1981 was taken into account. It was divided into calibration period (1943-1972) and verification one (1973-1981). The relationship between maximum snow cover depth and tree-ring widths in the calibration period is expressed in a following regression equation used in figure 5:

$$\text{maximum snow cover depth} = 6.577 \text{ tree-ring widths} - 99.253 \quad (1)$$

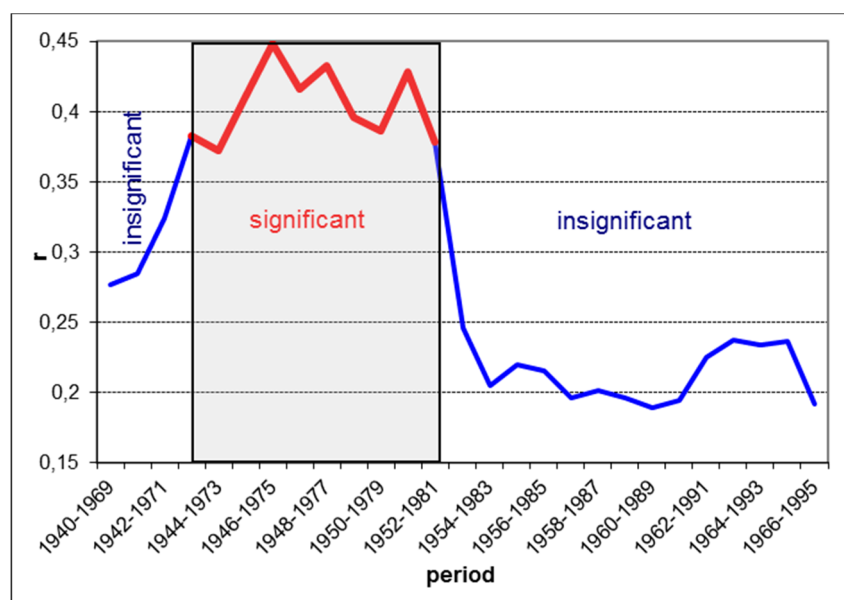
The standard estimation error is 207 cm, i.e. 36% of mean seasonal maximum value of snow cover depth for the calibration period; the correlation coefficient  $r$  is 0.38 (significant), the determination coefficient  $R^2$  is 0.147. The regression equation was the base to calibrate maximum snow cover depth for the calibration and verification periods. Standardized values of real and calibrated seasonal maximum snow depth for 1943-1981 is shown in figure 6. Both series have the decreasing trend up to the second half of seventies and slight increasing tendency after that.

In the calibration period, the values of mean maximum of snow cover depth are identical for real and calibrated data (578 cm). The correlation coefficient between real and calibrated values is statistically significant ( $r = 0.38$ ) for that period. However, in the verification period the mean

maximum of snow cover depth for real data is higher (587 cm) than that one for calibrated data (499 cm). Moreover, the correlation coefficient between real and calibrated values does not reveal statistically significance ( $r = 0.37$ ) in that period.

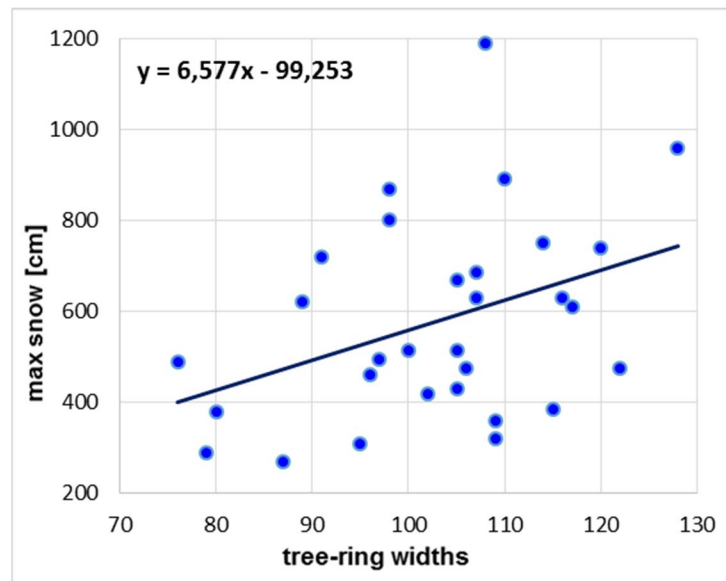


**Figure 3.** X-Y distribution of tree-ring widths (X) and seasonal maximum snow cover depth in previous year (Y) for the whole period (1940-1995) and the 30-year period of the strongest dependence (1946-1975). The correlation coefficient is statistically significant for both periods

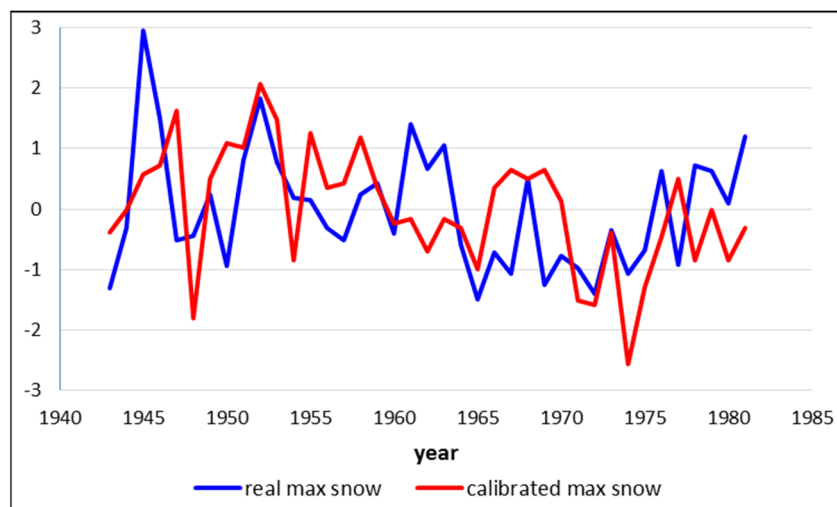


**Figure 4.** Moving 30-year correlation coefficient values for seasonal snow cover maximum depth and tree-ring widths. Periods for significant and insignificant correlations were denoted

Due to quite short period of statistically significant correlations between tree-ring widths and maximum depth of snow cover in previous year, not very strict dependencies and insignificant correlation between real and calibrated values in verification period, the attempt to reconstruct the snow cover on Sonnblick for the period before regular measurements was given up.



**Figure 5.** X-Y distribution of tree-ring widths (X) and seasonal maximum snow cover depth in previous year (Y) for the calibration period: 1943-1972. The regression equation is shown



**Figure 6.** Standardized values of real and calibrated seasonal maximum snow depth (year-1). Calibration period: 1943-1972, verification period: 1973-1981

#### 4. Conclusions

The main results of the research are as follows:

- (1) tree-ring widths in a given year does not reveal statistically significant dependency on the maximum snow cover depth observed in the winter season, which ended this year;
- (2) however, the tested relationship is statistically significant in the case of correlating of the tree-ring widths in a given year with a maximum snow cover depth in a season of the previous year. The correlation coefficient for the entire period of the study is not very high ( $r=0.27$ ) but shows a statistical significance at the 0.05 level;
- (3) the described relationship is not stable over time. 30-year moving correlations showed no significant dependencies till 1942 and after 1982 (probably due to the so-called divergence

- phenomenon). However, during the period of 1943-1981 the values of correlation coefficient for moving 30-year periods are statistically significant and range from 0.37 to 0.45;
- (4) the correlation coefficient between real and calibrated (on the base of the regression equation) values of maximum snow cover depth is statistically significant for calibration period and not significant for verification one;
- (5) due to a quite short period of statistically significant correlations and not very strict dependencies, the reconstruction of snow cover on Sonnblick for the period before regular measurements seems to be not reasonable.

The results of investigating relationship between snow cover depth in Sonnblick and tree-ring widths of Norway spruces growing near to the upper limit of the forest in the High Tauern are not fully satisfied. However, one should take into account that such research has been till now rather undeveloped and could be a starting-point for further investigation.

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