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ASSESSING TEMPERATURE SIGNAL IN X-RAY DENSITOMETRIC DATA OF NORWAY SPRUCE AND THE EARLIEST INSTRUMENTAL RECORD FROM THE SOUTHERN CARPATHIANS

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Abstract

Radiodensity data derived from Norway spruce were studied from a southern Carpathian site. Maximum density record showed significant positive relationship (r=0.59) with the growing season (April-September) air temperature and minimum density (MND) record showed clear and significant negative response (r=-0.41) to June-July mean air temperature. This significant MND response to climate is a novel result as traditionally this densitometric parameter was regarded not to carry any meaningful climatic signal. Derived temperature sensitive proxy records were compared to instrumental data of Sibiu (Nagyszeben/Hermannstadt) the oldest available regional station. Results of the running window correlation analysis pointed out notable inhomogeneities in the instrumental data before 1906. The Sibiu temperature series should be subjected to scrutiny revision to clean it from inhomogeneities.

Key words: maximum latewood density, minimum earlywood density, Picea abies, inhomogeneous instrumental temperature, dendroclimatology, Romania

INTRODUCTION

Norway spruce (*Picea abies* (L.) Karst.) is the main species of the Carpathian coniferous belt. Its longevity is documented to reach 576 years (Schweingruber F. H. – Wirth C. 2009). Norway spruce deserves special attention in the regional tree-ring research due to its importance from viewpoints of silviculture, dendroclimatology and dendroarchaeology. Several studies have been already conducted to decipher climatic information preserved in ring width variability of spruce in the Carpathians (e.g. Bednarz Z. et al. 1998-99, Szychowska-Krapiec E. 1998, Popa I. 2003, 2004, 2005, Savva Y. et al. 2006, Kaczka R. – Büntgen U. 2007, Kern Z. – Popa I. 2007, Popa I. – Kern Z. 2007, Bouriaud O. – Popa I. 2009), while other parameters were analysed solely in the Tatras (Büntgen U. et al, 2007). However, wood density data from spruce are also available from three eastern and the southern Carpathian sites. These sites were sampled in the frame of a global dendrochronological sampling campaign. These southern Carpathian stands were used to assess spatial teleconnections in the network (Schweingruber F. H. 1985) and in a broad scale dendroclimatological comparison (Schweingruber F. H. et al. 1987). Nevertheless, the climatic signal preserved in the radiodensity data has never ever been explored separately. The fact that Schweingruber F. H. (1985) defined an individual densitometric zone in the European coniferous belt centred on the southern Carpathians gives even further interest for the climatic interpretation of the southern Carpathian archive wood density data.

An additional motivation of this study was to test the earliest instrumental temperature record of the region (Ro-Sibiu/H-Nagyszeben/G-Hermannstadt) in order to see if its known inhomogeneities might be tracked comparing with climate sensitive proxy records. Curiosity emerged as proxy/data comparisons suggested biased early instrumental data for many sites in Europe (e.g. Moberg A. et al. 2003, Frank D. et al. 2007a, Winkler P. 2009), and corrections were recommended for some temperature data even before the 1900s.

MATERIAL AND METHODS

Radiodensity data

Wood density data originated from ITRDB database (Schweingruber F. H. 2000, NOAA 2009), from which database a southern Carpathian timberline site (45.30N, 23.67E, 1650 m a.s.l.) near Novaci in the Parang Mts (*Fig. 1*) was selected for this study. Sampled species was Norway spruce. The archive dataset contains 30 series of maximum and minimum density from 15 trees (each tree represented by two series). The wood density data were developed by the X-ray densitometric technique (Polge H. 1970, Schweingruber F. H. et al. 1978) in the framework of a global dendrochronological sampling network of conifers (Schweingruber F. H. 1985). Maximum and minimum density values are the characteristic parameters of the radial wood density structure. In a given tree ring the density maximum is linked to latewood and minimum is linked to earlywood (Schweingruber F. H. et al. 1978).

The Novaci dataset covers a 178-years long period, 1804-1981 AD, so despite its almost tridecadal antiquity it

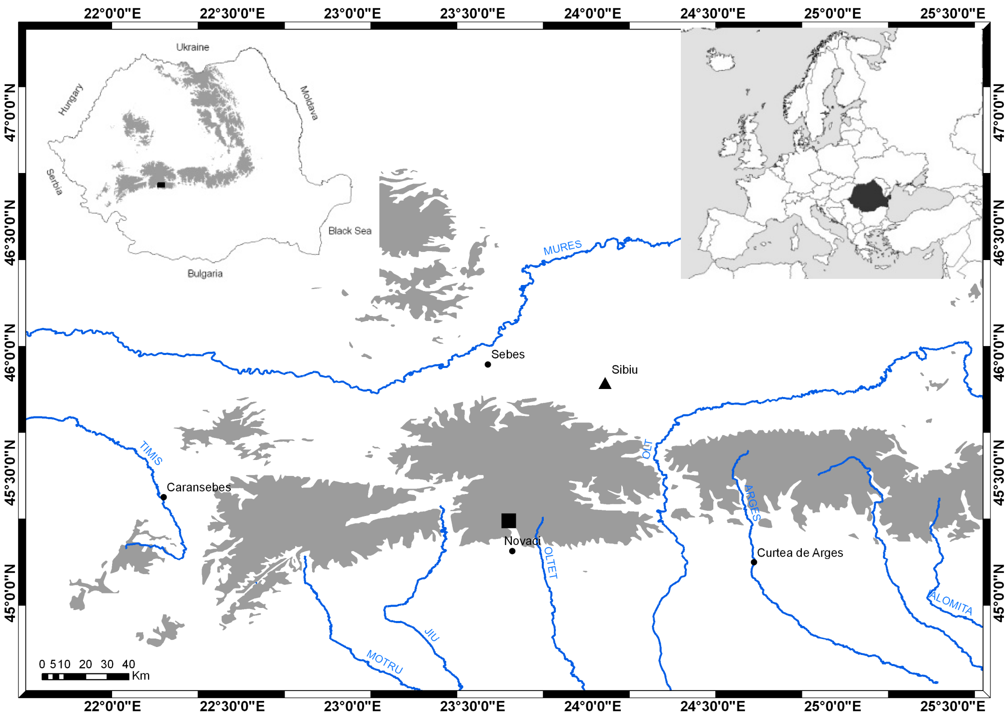

Fig. 1 Location of the sample site (filled square) and Sibiu (filled triangle) the earliest meteorological station of the region of southern Carpathians. Right corner: Location of Romania shown by black shading. Left corner: Black rectangle shows the location of the site in the southern Carpathians

is still the longest wood densitometric record from the entire eastern and southern Carpathian domain. Mean tree age is 88 years and ranges from 35 to 178 years. Replication decays before AD 1944 down to 4 at AD 1827 (*Fig. 2*). A sole series dates before AD 1821. Average maximum and minimum density of the population is 0.769 and 0.256 g/cm^3, respectively. Average maximum density value fits nicely in the range found for Norway spruce in the Tatras (Büntgen U. et al. 2007), but lower than the value reported from a Slovenian alpine spruce stand (Levanič T. et al. 2009). Average minimum density fits similarly well in the range presented for spruce in the Alps (Schweingruber F. H. et al. 1978).

Standardization, Index calculation

Raw density data were subjected to standardization procedure to eliminate non-climatic trends and emphasize climatic signal (Cook E. R. et al. 1990). A relatively stiff cubic spline function (50% frequency cut-off at 300yrs) was fitted to each individual series (Cook E. R. – Peters K. 1981). Raw density data were converted into index values as ratio between measured and modelled values. Final population indices for maximum density (MXD) and minimum density (MND) were computed as biweigth robust mean (Cook E. R. 1985). Variance of derived MXD and MND chronologies was adjusted to minimize bias due to changing sample replication (Osborn T. J. et al. 1997, Frank D. et al. 2007b). Stability of climate related signal preserved in the index series was controlled by the Expressed Population Signal (EPS) statistics applying the standard acceptance threshold of 0.85 (Wigley T. et al. 1984). Mean interseries correlation (Rbar) and EPS were calculated for 40 yrs moving window with 20 yrs steps. Standardization and index calculation procedure was carried out using the ARSTAN software (Cook E. R. – Krusic K. J. 2006).

Instrumental data

For climate response analysis monthly temperature means of grid-box enclosing the Novaci tree-ring site (*Fig. 1*) were extracted from the CRU TS2.1 database (Mitchell T. D. – Jones P. D. 2005) from 1901 to 1981.

The longest instrumental temperature record of the southern Carpathian region originates from Sibiu a prominent town of Transylvanian Saxons (*Fig. 1*). Observations at Sibiu began in 1851. Monthly mean temperature data since 1851 are available via the Climate Explorer (van Oldenborg G. J. et al. 2005). Sibiu is regarded as the most precise and most reliable temperature record in the region (Ţîştea D. at al. 1966). However, location of observation as well as termini and calculation method of daily mean temperature had changed a couple

Table 1 Recorded changes of observation conditions of the Sibiu/Nagyszeben/Hermanstadt station (source: Ţîştea D. et al. 1966). Row-head codes: A: date of change; B: location of observation; C: Termini (time of regular thermometer readings) and calculation method of daily mean temperature. Note the width of cell is not proportional with the duration of the represented period!

<table>
<tr><td>A</td><td>1851
January</td><td>1861</td><td>1880</td><td>1887
May</td><td>1897
August</td><td>1900
July</td><td>1905
October</td><td>1921</td><td>1940
September</td><td>1947
August</td></tr>
<tr><td>B</td><td>Weinanger platz 14</td><td>Sag-gasse 15</td><td>Elisabeth-gasse 9</td><td>Schiff-bäumel 3</td><td>Lang-gasse 5</td><td>Reisbach-gasse 9</td><td colspan="2">Weber-gasse 6</td><td>Strada Riului 5</td><td>Dimitri Anghel 3</td></tr>
<tr><td>C</td><td colspan="2">6-14-22
arithmetic mean</td><td colspan="5">7-14-21
arithmetic mean</td><td colspan="2">7-14-2*21
Kaemtz-method</td><td>8-14-20
Köppen-formula</td></tr>
</table>

of times during the station's history (*Table 1*). For instance, daily and inherently monthly mean temperatures are positively biased by the (T7+T14+T21)/3 calculation method compared to (T7+T14+2*T21)/4, the so-called Kaemtz-method (see Dall'Amico M. – Hornsteiner M. 2006). Nevertheless mean temperatures are obviously suffering negative bias due to the earlier morning (6 vs. 7 a.m.) and the later evening (22 vs. 21 p.m.) readings before 1880.

Climatic signal analysis

Pearson's correlation coefficients have been computed between MXD, MND and gridded monthly mean air temperature to assess the temperature effect of each month on the annual radiodensitometric characteristics of spruce. Months from the June of the previous year to October of current year of tree-ring formation were involved in the analysis. After the first trial, bimonthly means of August-September (AS) for MXD and June-July (JJ) for MND were also invoked. In addition, the April-September (AMJJAS) mean temperature was also included into the MXD comparison. Correlation coefficients were compared to 95% significance level derived from Student's t-test to evaluate their importance. Investigation was restricted to the period after 1906, because the first five years were designated as biased instrumental data (see later).

Temporal stability of relation between MXD/MND and Sibiu record was investigated by running correlation computed in 21-year moving windows. Moving window correlation technique is a standard tool to trace temporal stability in proxy-climate correlations (Aykroyd R. G. et al. 2001). The choice of any window width is somewhat arbitrary but the applied 21-year window over the screened 130-year long period is an acceptable compromise between a very narrow window (with a higher sampling error) and boarder window (which approximate the behaviour of the full dataset) (Aykroyd R. G. et al. 2001) and it is in conformity with choice of similar dendroecological studies (e.g. Carrer M. et al. 2007, Friedrichs D. A. et al. 2009). Timing of detected unusual shifts was compared to events in station history.

RESULTS AND DISCUSSION

Novaci spruce MXD and MND record

Both density indices (*Fig. 2a*) preserve quite strong common signal as evidenced by the high and stable signal strength statistics. Mean Rbar (EPS) is 0.44 (0.95) and 0.27 (0.91) for MXD and MND, respectively. Same statistics calculated in moving windows (*Fig. 2b,c*) showed exceptional signal stability and present that the relatively higher values found in mean values for MXD is permanently valid through the entire studied period. EPS values exceed the 0.85 threshold level suggesting robust chronology for both radiodensitometric parameters. The correlation between MXD and MND is 0.02, indicating that independent environmental information is preserved in the proxies. Wimmer R. and Grabner M. (2000) also found that in a spruce stand the density measured in earlywood (e.g. MND) were widely independent from latewood, suggesting that they are not under the same control.

Relationship between temperature and maximum/minimum density of spruce wood

In the case of MXD, August and September yielded the largest coefficients among monthly means 0.56 and 0.39, respectively (*Fig. 3a*). These findings broadly agree with the previous observations carried out at various sites in the Carpathians (Schweingruber F. H. et al. 1987). However, comparison with April, May and June showed also significant positive coefficients. The coefficient of July has not reached the 95% significance level but still positive and exceeds the other monthly responses. Regarding AS bimonthly mean temperature the coefficient slightly improved, and the multi-monthly AMJJAS presented even bit higher coefficient (0.59). The latter one was found as the optimal target season corresponding to the climate information of spruce MXD in the Tatras (Büntgen U. et al. 2007) and in the Alps (Frank D. – Esper J. 2005). The weakened mid-summer temperature response seems to be a characteristic pattern of the spruce MXD response. Both for the Alps and Tatras June coefficient dropped below 95% significance level (Frank D. – Esper J. 2005, Büntgen U. et al. 2007). In the case of the southern Carpathian spruce MXD chronology a bit different pattern was found. June coefficient is significant while for July it showed low values.

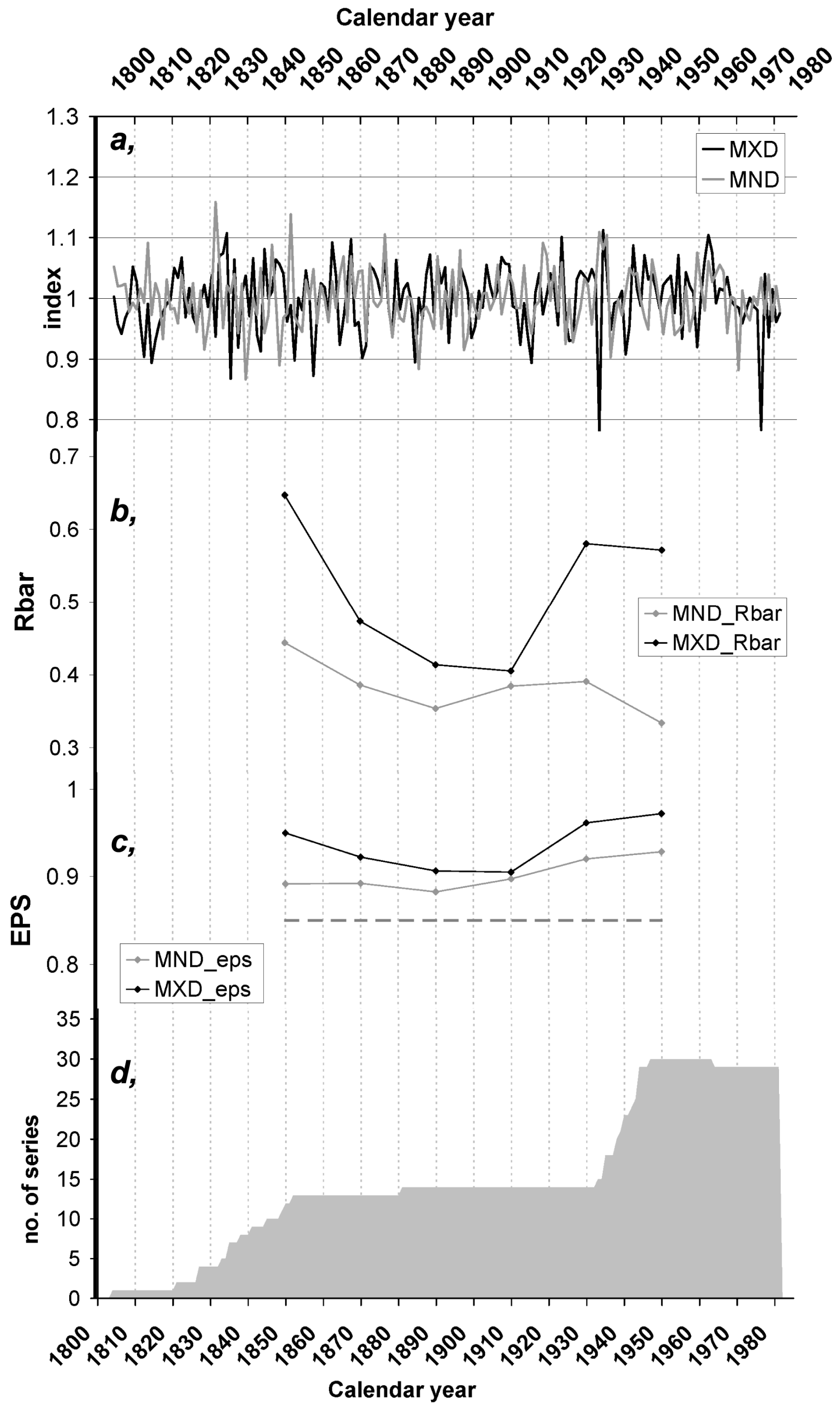

Fig. 2 Radiodensitometric chronologies of spruce from Novaci and graphical illustration of signal strength statistics calculated for 40 yrs moving window with 20 yrs steps, where black (grey) curves and symbols show MXD (MND) records. a: indices of maximum (MXD) and minimum (MND) density;. b: interseries correlation (Rbar); c: expressed population signal (EPS). Dashed horizontal line denotes the 0.85 threshold level; d: sample depth

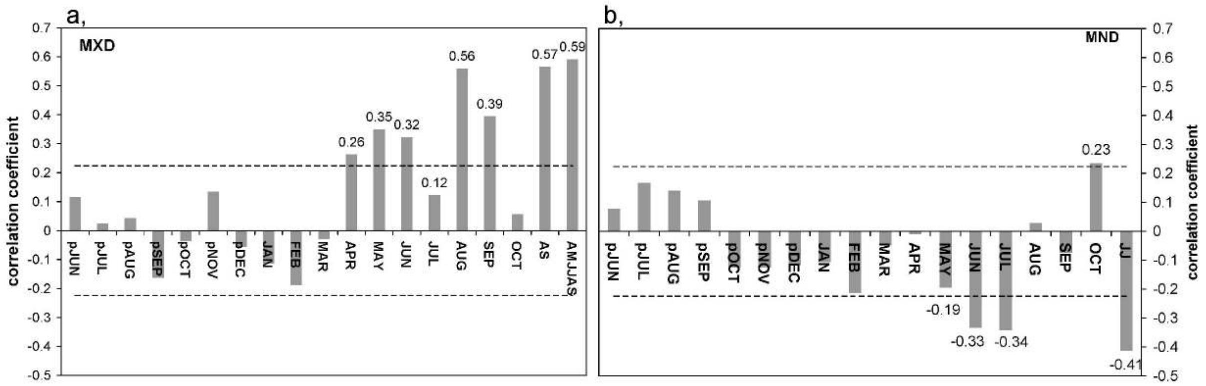

Fig. 3 Columns indicate the Pearson's correlation coefficients computed between monthly and multi-monthly mean air temperatures and maximum (a) and minimum (b) density indices over the 1906-1981 interval. Few coefficients are given near to the corresponding column. Horizontal dashed lines denote the 95% significance level

Interesting to note that in a recent study on two Slovenian spruce stands reported September mean temperature as the main climatic driver of cell wall thickening (Levanič T. et al. 2009). This discrepancy between the Slovenian and south Carpathian spruce MXD responses, however, can be easily explained as the growing season at the more temperate Slovenian sites is longer compared to the more continental southern Carpathian timberline. The shorter vegetation period means earlier cell maturation as well.

None months from the year before tree-ring growth showed significant effect on cell wall thickening during the subsequent year. This lack of responses from the year preceding the growth is normal for the MXD (Schweingruber F. H. et al. 1987).

In the case of MND June and July showed the strongest results -0.33 and -0.34, respectively (*Fig. 3b*). Regarding JJ bimonthly mean temperature the correlation further improved (-0.41). May mean temperature yielded similarly negative coefficient albeit it slightly lags behind the 95% significance level. This response is especially exciting as the pioneer milestone study of radiodensitometric dendroclimatology conducted in the Alps (Schweingruber F. H. et al. 1978) experienced no any clear relationship between this densitometric parameter of spruce and climate variables, consequently MND was usually neglected in later researches. A sole exception is the study of Wimmer R. and Grabner M. (2000) from the following 30 years. They analysed 16 anatomical variables (including also MND and MXD) averaged from 20 Norway spruce trees over a relatively short, 40-year long, tree-ring sequence. They found poor climatic response in MND.

However the neglected potential of MND as climate archive can be emphasized referring to a very recent study. Grabner M. et al. (2009) investigated MND record

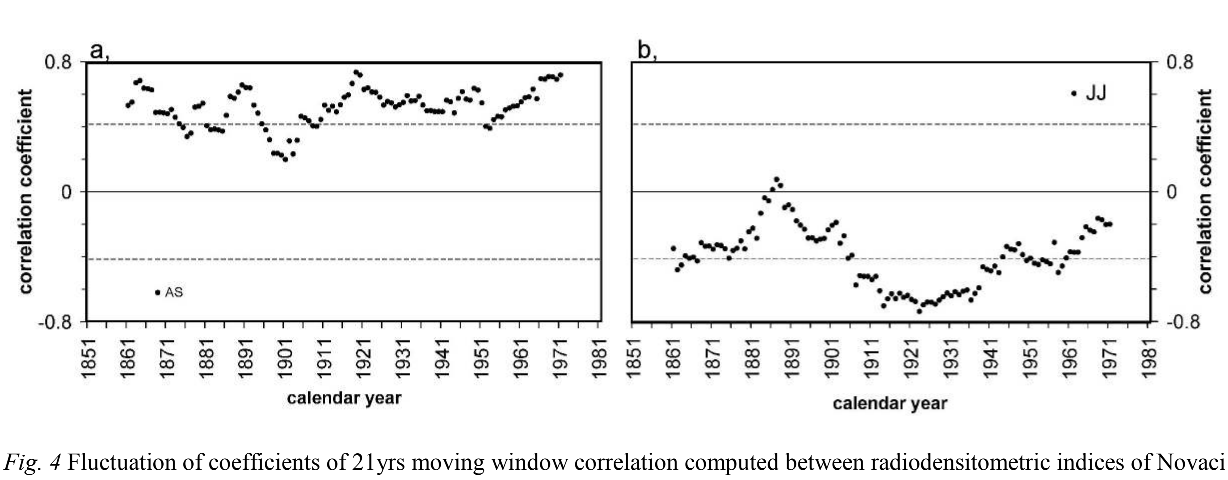

Fig. 4 Fluctuation of coefficients of 21yrs moving window correlation computed between radiodensitometric indices of Novaci spruce samples and their optimal bimonthly temperature target from the Sibiu record. a: maximum density vs. AS, b: minimum density vs. JJ. Dashed horizontal lines denote the 95% significance levels

in a dataset of juvenile spruce stands. Surprisingly they found stronger correlation between MND and climate variables than with MXD.

Statistical results suggest that dominantly June-July thermal conditions determine the minimum earlywood density of spruce tree ring in the southern Carpathians. Higher June-July air temperature seems to retain cell wall thickening and/or to produce larger lumen diameter in the earlywood. May also has some minor role in this process. We propose that only the late half of May preceding June affects the process, and the corresponding coefficient become non-significant as the monthly means integrates also the daily temperatures from the early half of the month.

The relatively high positive coefficient of October lacks explanation as cell maturation in the earlywood section is probably ceased for mid-autumn. Even more, it might be a fake response due to biased instrumental reference (see later).

Comparison with the earliest local instrumental temperature record

For the sake of brevity out of the many prepared moving window correlation (hereafter MWC) analyses only a few arbitrary selected graphs are presented. They were chosen to best illustrate our conclusion.

Fig. 4 shows the temporal fluctuation of the correlation coefficient calculated with the optimal bimonthly mean temperature target of both radiodensitometric parameters (i.e. AS vs. MXD; JJ vs. MND). Although MND lost significance in the last decade, coefficients generally exceed the significance levels over the last seven decades. In contrast, coefficients of both densitometric parameters drop below significance level at 1905-1906. The coefficients reach significance level again before 1896 and 1880 for MXD and MND, respectively. Each date can be found in the station movement history. This suggests that between 1880 and 1905, when the location of observation frequently changed settling in one place, as short as 3 to 9 years homogeneity of observation conditions were failed to maintain. As gridded temperature data largely relies on Sibiu record before 1920 in the region, this is the reason why the proxy/climate relationship was finally analysed on the truncated record from 1906.

Coefficients of MWC calculated between MXD and April monthly mean temperature are presented in *Fig. 5a*. Coefficients are well above significance level during the early decades, they start to decline from 1880, and sink permanently below significance level from 1886. They fluctuate around zero level over few decades, afterwards abruptly increase from 1922, and exceed the significance level from 1924. The period of weakened even more non-significant coefficients coincide with the era of T07-T12-T21 readings, but also include the hectic station movements. The date of sudden recovery of positive correlation relationship coincides with the introduction of Kaemtz-method. The last sudden drop from 1943 to 1944 is a sole event which is not mirrored in station history. However, its time is equally near to a station movement (i.e. 1940) and a methodological change (introduction of Köppen-formula) which was accompanied with station movement, as well.

MWCs calculated between MND and May and October monthly mean temperatures are presented in *Fig. 5b*. Temporal evolution of MWC coefficients show strange shifts again. May coefficients fluctuate slightly below the 95% significance level through the main part of the studied period. Some decline can be seen during the last decade but a very unusual drift appears at the earliest time. Coefficients steadily increase before 1883,

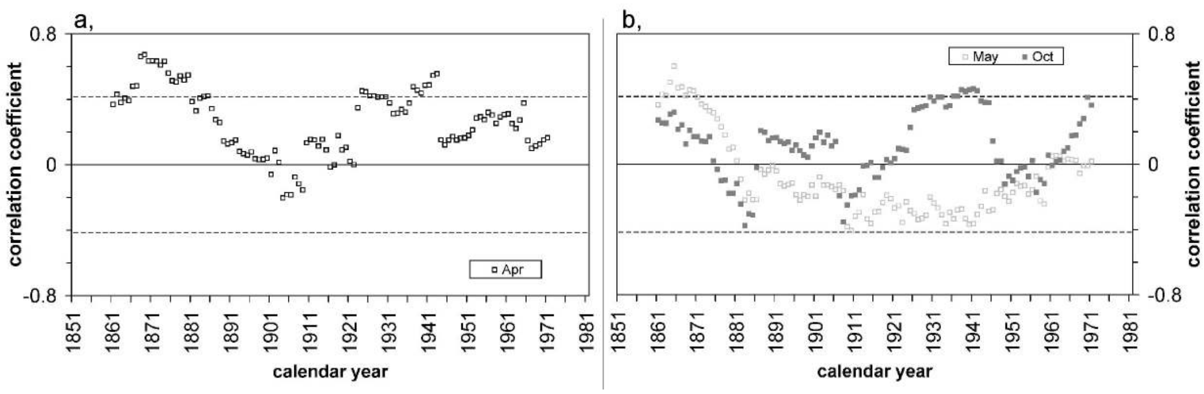

Fig. 5 Fluctuation of coefficients of 21yrs moving window correlation computed between radiodensitometric indices of Novaci spruce samples, and a few arbitrary chosen monthly mean temperature targets from the Sibiu record. a: maximum density vs. April, b: minimum density vs. May (open squares) and October (filled squares). Dashed horizontal lines denote the 95% significance levels

change sign at 1881, and become significant before 1878. The period of unusual positive coefficients broadly coincides with the era of T06-T12-T22 readings. October coefficients show more sudden changes. The first from 1886 to 1887 when coefficients change from negative to positive, and the second after 1906 when swap sign again. Both date link to station movement. The coefficients are close to zero for a decade, then start a gradually rise from 1921, and abruptly jump to significance level after 1925. Coefficients fluctuate around significance level until 1946, after drop suddenly to zero level. The period of positive, occasionally even significant, MWC coefficients of October coincides with the utilization of the aforementioned Kaemtz-method. We suspect that the found positive response to October mean temperature might be the effect of the Kaemtz-method.

CONCLUSIONS

Climatic information was evaluated for archive Norway spruce maximum and minimum radiodensity data from a southern Carpathian location. Spruce MXD record showed significant positive relationship with the growing season (May-September) air temperature. Similar response was found for the same species in the Tatras and the Alps. However, some characteristic discrepancy was also experienced (i.e. July vs. June signal weakening). The southern Carpathian MXD response showed distinct difference compared to the Slovenian one, too (i.e. strongest reaction for August vs. September). These small differences compared to surrounding areas could plausibly explain the existence of the individual densitometric provenance defined by Schweingruber F. H. (1985) for the southern Carpathians.

Spruce MND record showed clear and significant negative response to June-July mean air temperature. This is a novel result as traditionally this densitometric parameter was regarded not to carry any meaningful temperature signal.

Hitherto dendroclimatological research focused exclusively on radial growth properties in the southern Carpathians (e.g. Soran V. et al. 1981, Popa I. – Cheval S. 2007, Kaczka R. – Büntgen U. 2007). In the present study, however, we point out that densitometric properties have also great potential both in ecological and palaeoclimate reconstructions, and future researches are recommended in this field.

Derived temperature sensitive proxy records were compared to instrumental data of the oldest available regional station. Results of the moving window correlation analysis showed strange shifts coinciding with changes in station history. Considerable inhomogeneities can be suspected in the instrumental data before 1906. The Sibiu temperature record would have eminent importance in the regional historical climatology due to its completeness and exceptional length. Nevertheless, this prominent secular record is hardly usable as temperature target in regional proxy paleoclimatological research until a scrutiny revision is done.

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