Source: Gärtner H, Esper J, Schleser G (eds.) (2005) TRACE - Tree Rings in Archaeology, Climatology and Ecology, Vol. 3: Proceedings of the DENDROSYMPOSIUM 2004, April 22nd – 24th 2004, Birmensdorf, Switzerland. Schriften des Forschungszentrums Jülich, Reihe Umwelt Vol. 53, p. 159 – 166.

New multivariate cross-correlation analysis

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Introduction

In various archaeological excavations small wooden samples were found. For the dating of wooden samples univariate standard methods are available until now. Often this method can not be applied, because the samples do not include the necessary number of 50 or more tree-rings to achieve a high statistical confidence of the dating result. The following paper gives information about a new approach using a multivariate cross-correlation analysis. The method based on data obtained from x-ray images made from the wood samples.

The cell wall thickness of xylem cells is typical and representative of the climatic conditions during the vegetation periods (cf. Larson 1994). Such time specific tissues are able to be described by “Tracheidograms” (Terskov et al. 1981). The idea was to improve the cross dating effectively by measuring and using more than the total ring width parameter and hence increasing the degrees of freedom. The dating of small Spruce (*Picea abies* [L.] Karst.) wood samples is as a result now possible.

Material and methods

Development of a regional multivariate chronology (master-chronology)

Xylem structures of Spruce are more regionally pronounced than such e.g. of Fir (*Abies alba*). That’s why regional standards are necessary for dating. Recent samples were collected on 20 different sites in Saxony (Fig.1) at altitudes ranging from 260 to 1070 m a.s.l. (cf. Neumann 2001). Four radii from each of 123 recent Spruce logs were investigated to develop site-specific standard-chronologies by averaging. In addition 45 older samples (mostly cores) from historical buildings in Saxony were researched to compile, among others, a multivariate standard-chronology with 438 included years.

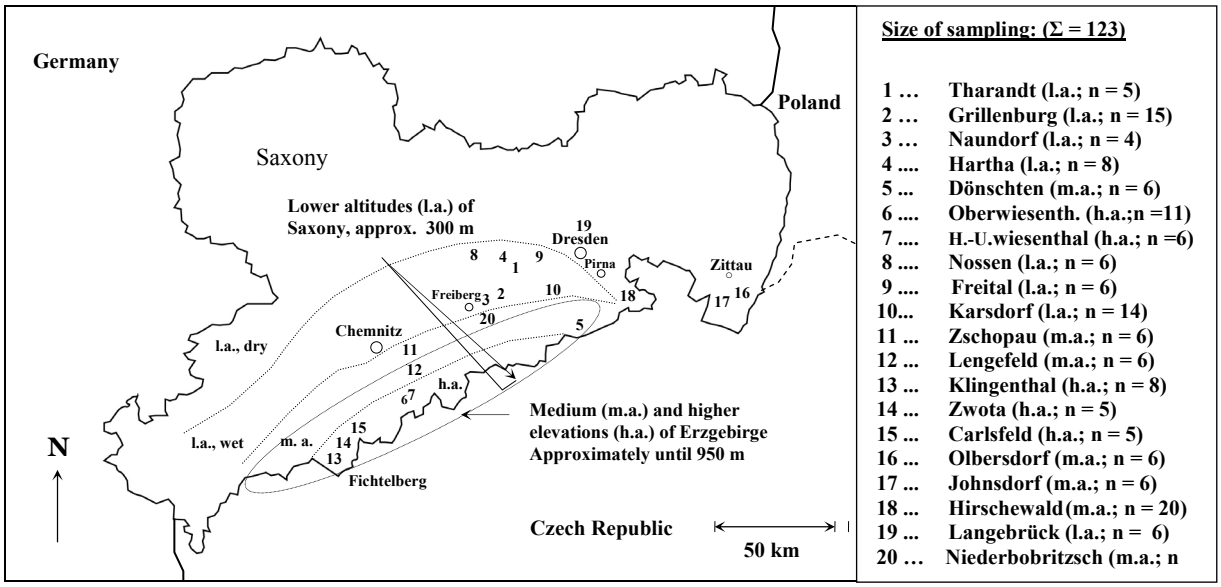

Figure 1: Map of sampling on sites of different altitudes in Saxony with indication of the number of investigated samples.

After air conditioning the extracted cross-cut samples were exposed over x-ray films (AGFA-Microvision Ci) and x-rayed under controlled conditions, using the facility “BALTOGRAPHE”. The quantifications of year-specific grey values on the developed x-ray films by the tree-ring structure were done with the optometric unit "DENDRO 2003" (Walesch-Elektronic). The basic principles of the x-ray densitometry are explained in detail in Polge (1970b) and Cook & Kairiukstis (1990).

Quantification of late wood portion

The early wood/late wood percentage in a tree ring is an important parameter for the interpretation of climatic influences on the tree growth (Schweingruber 1980). To elaborate and quantify the late wood percentage in every single tree ring, the tracheid cell wall thickness was measured for 303 prepared tree-rings for 19,214 single tracheids on certain radii according to Mork´s definition (1928). For x-ray densitometry data the early wood/late wood boundary was defined by mean wood density within each single tree-ring (mean value between minimum and maximum density). Both results were compared with each other.

Selection of tree-ring variables suitable for multivariate cross-correlation method

There is no variation in the real sense in case of time series by extreme values. But rather such extreme values (e.g. minima and maxima of late wood density) are indicators for late frost periods or extreme dry summers. The dispersion of values was adjusted by using statistical methods (e.g. low-pass filter). Some of these densitometrical tree-ring parameters are highly correlated (e.g. tree-ring width and early wood percentage). That’s why the set of available parameters was reduced via principal component analysis to a set of independent

variables. Type and number of selected variables are dependent on the aim of the investigation.

Development of novel computer program

Univariate cross-correlations are calculable by the well known TSAP-program (RINN 1996, 2003). To realize the multivariate cross-correlations a novel software program (TreeRing-Analyser - TRA) was developed. The multivariate crossdating analysis of time series complexes can now be performed on the base of 10 independent variables (respectively of representatives) and several statistical indices used by program.

Final crossdating and verification of the new method

Finally the possibility and efficiency of dating shorter time series (with less than 50 tree-rings) were examined with a generated master-chronology (1566-2004).

Results and interpretation

Quantification of late wood portion

The histological investigations of microscopic cross-cuts by microtome, associated with x-ray analysis led to a practicable possibility of determining late wood cells. The annual tree-ring profiles showed that late wood cells are detectable by densitometry. The variation between both methods (MORK vs. x-ray densitometry) amounts to approximately ±1%.

Selection of tree-ring variables suitable for multivariate cross-correlation method

Twenty tree-ring features were measured by x-ray densitometry. The investigated tree-ring features are:

- Maximum late wood density
- Mean late wood density
- Minimal early wood density
- Mean early wood density
- Wood density contrast
- Early wood percentage
- Late wood percentage
- Tree-ring width
- Early wood mass equivalent
- Late wood mass equivalent
- and the according ratios of measured data and the following value of the tree-ring parameter in the time series

The absolute values of tree-ring width of one stand varied up to 17%, but the comparability of several time series was maintained. Some of these parameters are highly correlated (e.g. mean and minimum early wood density; r = 0.91).

The principal component analysis was used to reduce the number of generated time series to some independent variables (e.g. maximal late wood density, wood density contrast, early wood percentage, mean early wood density, wood mass equivalent and total tree-ring width). Thereby the negative influences by multicollinearity were minimised. The investigations showed that type and number of variables are dependent on the target of the investigation and the region of origin of samples. Ten independent variables were extracted, which are able to include 97% of the input information. These variables were allocated to the sample and standard-complexes. On this basis the multivariate dendrochronological investigations for dating were possible by the bivariate cross-correlation.

Final crossdating and verification of the new method

The interactive early and late wood determination and the generation of several ring specific time series including dating itself are possible with the developed software. Extracted and synchronised time series of tree-ring features for the sample and standard complexes were used. The multivariate cross-correlation and dating can be controlled on the basis of calculation tables and interactive diagrams. The internal structure of the standard-chronologies is documented year after year with the number and direction vector of included values (corresponding with the “Gleichläufigkeit”). The degrees of freedom increase by measuring more than one tree-ring parameter using the extracted variables for crossdating. That’s why the statistical confidence of cross dated true positions increases as well. The program works with dendrochronological statistics such as t-values, “Gleichläufigkeit” and a newly developed multivariate dating index (MDI). The MDI is a cumulative sum of similarity values of all cross dated variables.

Figure 2 illustrates the principle of multivariate cross-correlation with three selected tree-ring parameters (early wood mass equivalent, maximal late wood density and total tree-ring width).

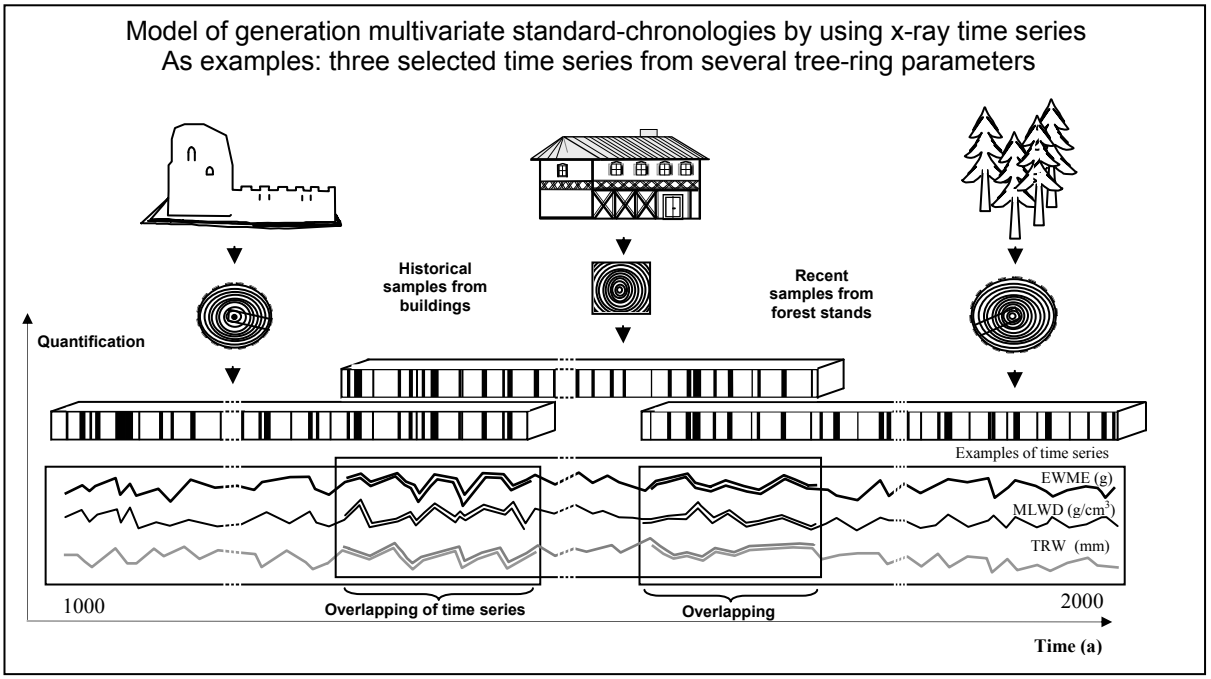

Figure 2: Principle of multivariate cross-correlation on the basis of several ring features, e. g. early wood mass equivalent (EWME), maximal late wood density (MLWD) and tree-ring width (TRW) – as a selection. Generation of regional standard-chronologies on the basis of analysing recent and historical material (cf. Schweingruber 1988).

The generation of multivariate standard-chronologies (e.g. 1566 - 2004, *Picea abies*, Tharandt, Saxony) is based on the synchronisation of single time series. Furthermore 20 site-specific standard-chronologies were generated by averaging the values of tree-ring parameters. The dating referred to generated site-specific regional standards of Spruce regarding the lower, medium and higher elevations in Erzgebirge Mountains.

As a final step the possibility of dating shorter time series with less than 50 tree-rings was proved. The cross-correlation analysis on the basis of generated multivariate standard-chronologies for the different regions in Saxony allowed for calculating the efficiency of dating. Step by step a given time series complex (e.g. a sample from forestry district: Altenberg / Dönschten, section: 758b^2, 600m o.s.l., Fig.3) was curtailed concerning shortened tree-ring sequences from the direction of the cambium layer. This was done in each case to include the more problematic tree-rings with more density fluctuations in the centre of the cross-section.

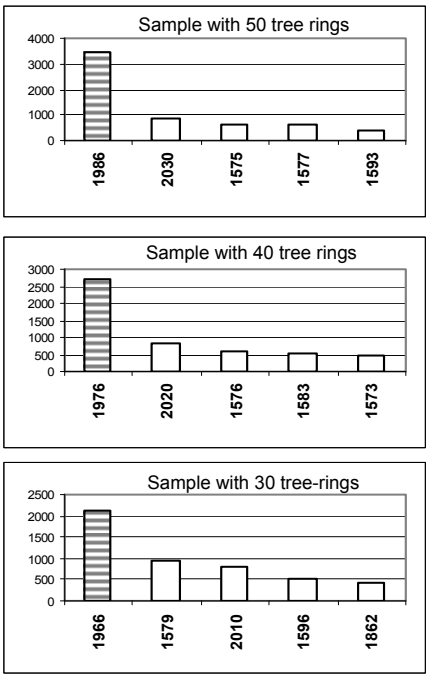

Figure 3: Results of statistical qualification (displacement) during cross-dating analysis, true solution (left) differs from four wrong solutions (right).

During the investigations the true results were well qualifiable as against the next wrong solution with positive differences of the MDI-values in dependence on the altitude of sites. Time series with 40 till 30 tree-rings were datable over a master-chronology of 438 years with a high statistical confidence level on the basis of the MDI-values. The difference between the true solution and the next wrong solution was quantified with approx. +40%. In case of dating by tree-ring width, the difference was 60% lower than with the multivariate method. Hence, the density features contributed considerably to the cross-correlation analysis (with 49 % at higher mountainous elevations). Samples from such higher (more temperature influenced) elevation with approximately 20 tree-rings were datable during the investigations (Fig.4). Samples from the lower sites with 30 tree-rings showed the comparable results and were datable, even though they show a higher variability of the tree-ring parameter values.

Such differences of MDI-values are indications of a higher quality of dating with increased statistical confidence by using the multivariate method. The acceptance of wrong solutions during the multivariate dating process of Spruce samples will become more improbable.

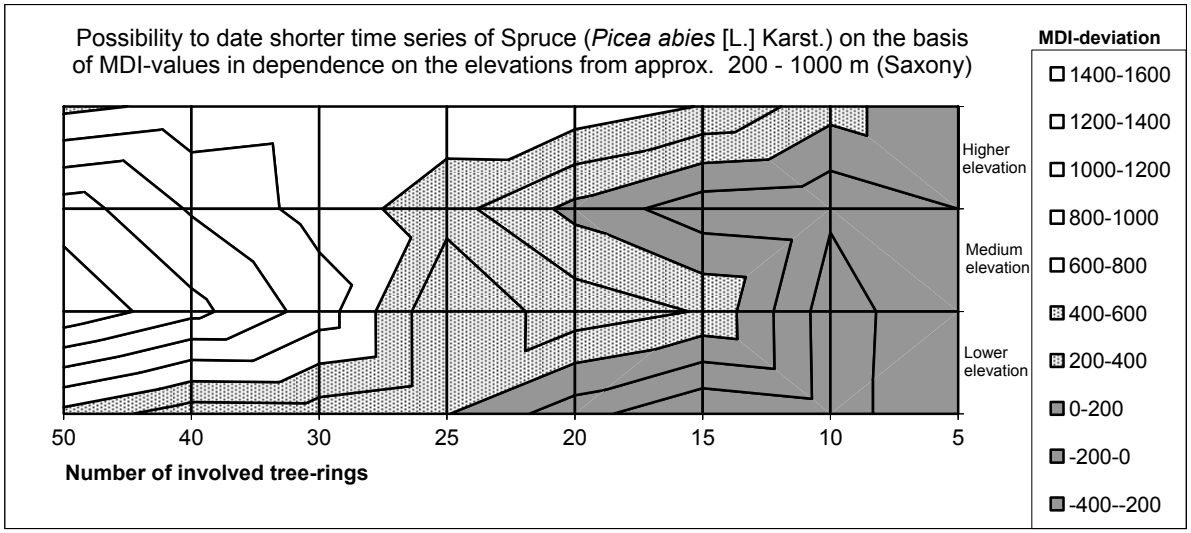

Figure 4: Differences between the true solution and wrong solutions of dating on the basis of distinction of the MDI-values: MDI-deviation from 1600-600 (white) and 600-200 (light grey): the true solution is significant qualifiable; 200 until -400 (dark grey): the qualification of the true solution under the wrong correlations is not significant in dependence from the elevation (lower elevations: from 200 m; medium: approx. 500-700 m; higher elevations: approx. 1000m).

Discussion and conclusion

Dendrochronological dating of softwoods is possible by using univariate and multivariate methods. On the one hand, the acceptance of wrong correlations may happen during the univariate cross-correlation on the basis of only one tree-ring feature (e.g. tree-ring width). On the other hand, the multivariate cross-correlation leads to a higher value of efficiency during the dating of Spruce samples by a more detailed characterisation of xylem. X-ray densitometry produces several tree-ring parameters for crossdating. Features of ring widths, wood densities and wood mass equivalents were involved during the investigations. Smaller Spruce samples are dateable with the developed multivariate analysing procedure by using the software “TRA”. The target of the investigations, to develop a multivariate dating method for smaller Spruce samples with less than 50 tree-rings, was achieved.

An improved qualification of the true solution and wrong solutions by objective calculated numbers become possible by the explained procedure. Samples from higher elevations in the Erzgebirge Mountains (with stronger temperature influence) were more successfully cross dated than samples from the surrounding low-lying areas (with stronger precipitation influence). Not datable samples with abnormalities in the xylem structure will appear also regarding the multivariate method. The samples have to meet the demands of dendrochronological dating. The xylem structures have to be physically stable and regularly grown. Samples with secondary damage need special accuracy during the treatment.

Outlook

The developed multivariate analysis method is an innovative completion in comparison with the actual software for dendrochronological analysis. This method is applicable especially to complex problems. The multivariate analysis method seems to be useful for the cross-correlation of problematic time series (e.g. softwood structures with very uniform and smaller tree-rings from Scandinavia). A discussion based on wide interests is desired. The target for the near future is the adaptation of the method to the demands of analysing European (Richter *et al*. 2004) and tropical hardwoods. In doing so, the information content of the input variables should be retained basically during the selection of main factors. Sometimes weakly correlated variables were also used together in several investigations. For instance the height/diameter ratio (h/d) is used for the characterisation of specific tree growth features in the silviculture science. Using of special time series in the complex matters is beneficial for specific investigations. For instance the time series of early and late wood mass are useable for calculations of seasonal yield in forest stands.

References

Cook, E.R., Kairiukstis, L.A. (1990): Methods of Dendrochronology. Applications in the environmental Science. Kluver. Dordrecht, Bosten, London: 55-63.

Larson, P.R. (1994): The Vascular Cambium. Springer-Verlag Berlin: 630 p.

Mork, E. (1928): Die Qualität des Fichtenholzes. Papierfabrikant. Bd. 26 (48): 741-747.

Neumann, U. (2001): Zusammenhang von Witterungsgeschehen und Zuwachsverläufen in Fichtenbeständen des Osterzgebirges. Diss. Contributions to For. Sc. Tharandt 11: 38 p.

Polge, H. (1970b): The use of X-ray densitometric methods in Dendrochronology. Tree-Ring Bulletin 30: 1-10.

Richter, C., König, J., Bues, C.T. (2004): Baumarchäomorphologische Untersuchungen an einer Eichenholztruhe. Sächsische Heimatblätter. Bd. 2: 120-126.

Rinn, F. (1996): TSAP-Time Series Analysis and Presentation. Manual. Heidelberg: 185 p.

Rinn, F. (2003): TSAP-Win Professional 0.23. Vers. 5.1. Manual. Heidelberg. Software-Service-Pack 1.

Schweingruber, F.H. (1980): Dichteschwankungen in Jahrringen von Nadelhölzern in Beziehung zu klimatischökologischen Faktoren. Eidg. Anstalt f. Forst. Vers., Birmensdorf, Ber.213: 35.

Schweingruber, F.H. (1988): Tree-Rings. Basics and Application of Dendrochronology. Reidel Publishing Company. Dordrecht, Boston, Lancaster, Tokyo: 51.

Terskov, I.A., Vaganov, E.A., Sviderskaya, I.V. (1981): Tree-ring Tracheidogram as a Characteristic of Seasonal Growth Rate of a Tree. Izv. SO AN SSSR 10: 22-29.