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Applications of Dendrochronology:

from tree rings to beyond

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CELLULAR CHARACTERISTICS OF CONIFERS AND THEIR USE IN DENDROECOLOGY

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Cellular characteristics of tree-ring is one of key elements in dendrochronology.Particular attention is given to coniferous plant species, since they are widespread in areas of cold and temperate climate, are durable and have well discernible tree-rings and responsive to changing of external conditions.

Often the formation of tree rings is defined as a linear function oflocal or regional precipitation and temperature with a set of coefficients that are temporally invariant. However, various researchershave stressed that tree-ring records are the result of multivariate, often nonlinear biological and physical processes. For example,tree-ring records may reflect nonclimatic influences, includingage-dependent effects, specific local environmental conditions,fire disturbances, and insect outbreaks[1, 2, 3]. One of solutions in non-leaner approach is process-based models. In this study was used VS-Oscilloscope. The aim of study is solving fundamental problems of examing reaction of woody plants to changing environmental conditions.

The tasks are:

1) Study of the structure of tree-rings as indicator of environmental changes.
2) Modeling of structure growth rings on the basis of external (climatic) factors.
3) Separation of the influence of external factors on the structure of tree-rings based on the Vaganov-Shashkin simulation model.

This model developed for simulation of tree-ring chronologies using visual manipulation of the values of the main parameters of the VS - model, allowing to obtain the best approximation of the simulated curve of growth. VS-oscilloscope allows to simulate a nonlinear response of tree growth to climate change, assessing the contribution of each climate variable to the variability of the seasonal dynamics of the formation of annual rings of woody plants.

The ability of theVaganov-Shashkin model to successfully simulate interannual to decadal scale variations in the observed tree-ringchronologiessupportstheiruseaspaleoclimaticindicatorsonthese timescales in multivariate climate field reconstructionefforts. The model may be suitable for estimating tree-ringwidth chronology uncertainty, especially on decadal time-scales, constraining paleoclimatic field reconstructions, andassessing the effects of anthropogenic climate change onaspects of the growth of temperate conifer forests [4][5].

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TIMING OF TRACHEID PRODUCTION DURING SEASONAL TREE-RING GROWTH IN SIBERIA

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It is well known that one of the principal indicators of the tree ring structure is the distribution of radial cell sizes during growing season. The internal factors of cell growth and maturation in combination with external conditions are recognized in the tree-ring structure of conifers. The main anatomical characteristics, e.g. number of cells, radial cell size and cell walls thickness, are closely related to the kinetic characteristics of seasonal tree-ring formation, especially with the kinetics of cell production [1].

In the works of the 60-70es and recent studies the seasonal growth dynamic was analyzed by direct and indirect methods [2, 3, 4]. Due to specificity of these processes and complexity of labor-intensive experimental methods mathematical modeling can be considered as an one of possible approaches to simulate cell production by cambium and differentiation of cambial derivatives, which requires to develop adequate mathematical methods and corresponded software components. To describe development of tree-ring formation and to predict the wood characteristics, a process-based modeling of wood formation can be very useful in that case [5, 6].

In this work the process-based tree-ring VS-model was used to resolve the critical processes linking climate variables to tree-ring formation. This model computes daily tree-ring growth by using daily data of temperature, precipitation and solar irradiance at the site (for example of model applications see [7, 8, 9]). The daily growth rate is estimated as a percentage of the maximal possible growth (i.e., in absence of any limitations). This is obtained by computing the growth *Gr* at the day *t* of year as:

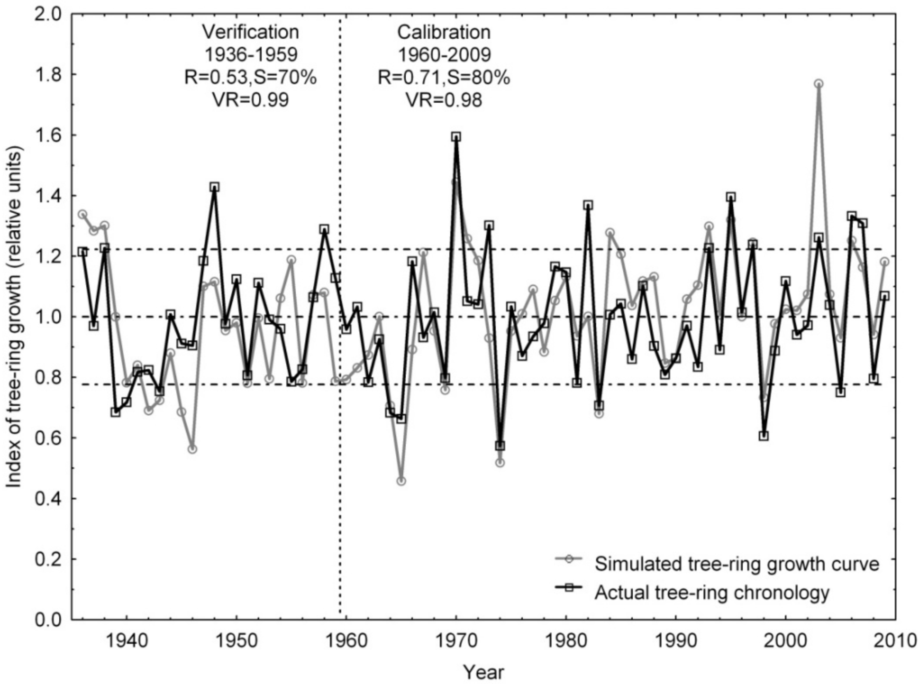
$$Gr(t) = Gr_E(t) * \min\{Gr_T(t), Gr_W(t)\} \tag{1}$$

where Gr_E, Gr_T, and Gr_W are dependences determining the percentage of possible growth as a function of solar irradiance (E), temperature (T) and soil moisture (W), respectively.

This study is based on tree-ring data from “Malaya Minusa” (53°43′ N, 91°47′ E, 251 m a.s.l.), a foothill forested site located in the Altai–Sayan region of Khakassia (Russia). The site is at 251 m a.s.l. and is covered by a mixed forest of birch (*Betula pendula*) and pine (*Pinus sylvestris*).

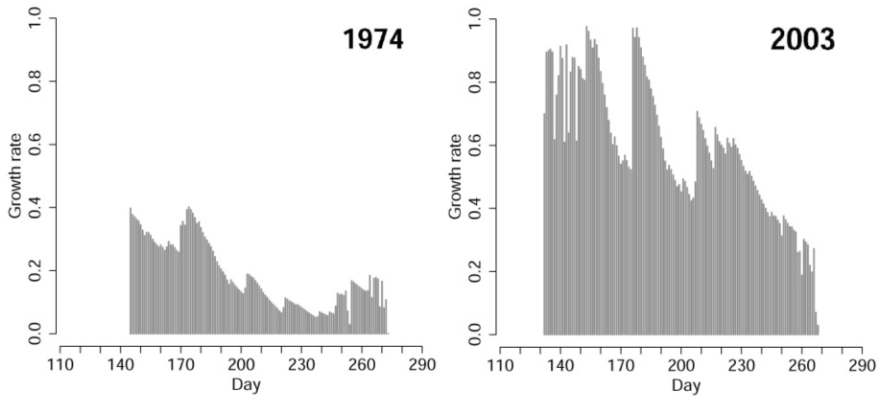
To calibrate the model we first fixed the site and species specific coefficients according to site observations and current knowledge of the species. Subsequently, we calibrated the most sensitive 18 model coefficients [10], i.e. the coefficients that mainly define Gr_T and Gr_W using the VS-oscilloscope [9]. This tool is designed to uses daily climatic data to allow the user to interactively adjust the parameter's coefficients to quickly generate comparisons between the observed and the simulated indexed tree-ring width chronologies [9]. To validate the model the period of direct climate observations (A.D. 1934-2009) was divided on two independent parts: calibration (A.D. 1960-2009) and verification (A.D. 1934-1959) periods. The calibrated model provided an simulated chronology matching the actual tree-ring chronology with a Pearson's correlation R = 0.65 and coefficient of synchronicity S = 75% ($p < 0.001$; n = 76 years, Fig. 1) [10].

Figure 1 – Actual tree-ring residual chronology (black line) and simulated tree-growth curve (grey line) for period 1936–2009 for Minusinsk site



The modeling is extremely important step here because the simulated daily tree-ring growth rate *Gr(t)* is a basis to evaluate intra-seasonal variation of cambial production [1] (Fig. 2).

Figure 2 – The integral growth rates from VS modeling for selected years: 1974 –narrow ring; 2003 – wide ring.



A new procedure of timing cell production during the season based on the obtained simulations for Southern Siberia (the Republic of Khakassia) is suggested in this work. It should be considered a comparative analysis of the evaluation of growth rates for radial cell size as one of the principal anatomical characteristics of the tree-ring structure of conifers. For this purpose a method to identify the formation time of new cell in the enlargement zone of tree ring is developed. We used the cell measurements obtained for Scots pine (*Pinus sylvestris L.*) over the 1964-2009 to develop and to validate a new procedure of cell timing.

An integral growth rate *Gr* (Fig. 2) is estimated for each day of the growing season $[\mathrm{DOY_{bg}}, \mathrm{DOY_{eg}}]$, where $\mathrm{DOY_{bg}}$ – the start date of growing season (Day of Year, DoY), $\mathrm{DOY_{eg}}$ – the end date of growing season . Since the sum of all daily *Gr* within a given year is proportional to the indexed tree-ring width, we assigned the corresponding *Gr* of each tracheid in the tracheidogram by considering its position and size. We note that reconstruction of the seasonal tree-ring growth kinetics is a reconstructed dependence between number of cells in tree ring and their size with corresponded timing. Based on the number of cells in tree ring (*N*) we assume that $[\mathrm{DOY_{bg}}, \mathrm{DOY_{eg}}]$ is a time period of *N*-cells formation. The average production (average rate) (s_i) of each *i*-cell in tree ring can be estimated as:

$$s_i = \frac{\sum Gr}{N}, \tag{2}$$

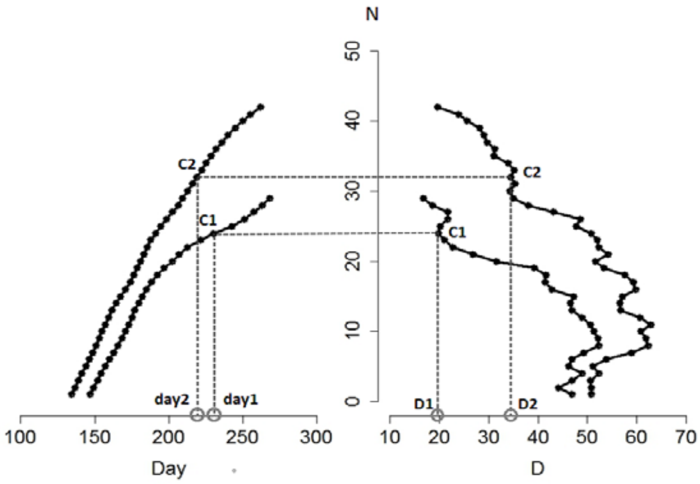
where an amount is taken over the number of days in the growing season $[\mathrm{DOY_{bg}}, \mathrm{DOY_{eg}}]$.

From the start of growing season for the first cell it is necessary to summarize the daily integral growth rates until the average production s_i will be reached:

$$Gr_1 + Gr_2 + \ldots \leq s_i \tag{3}$$

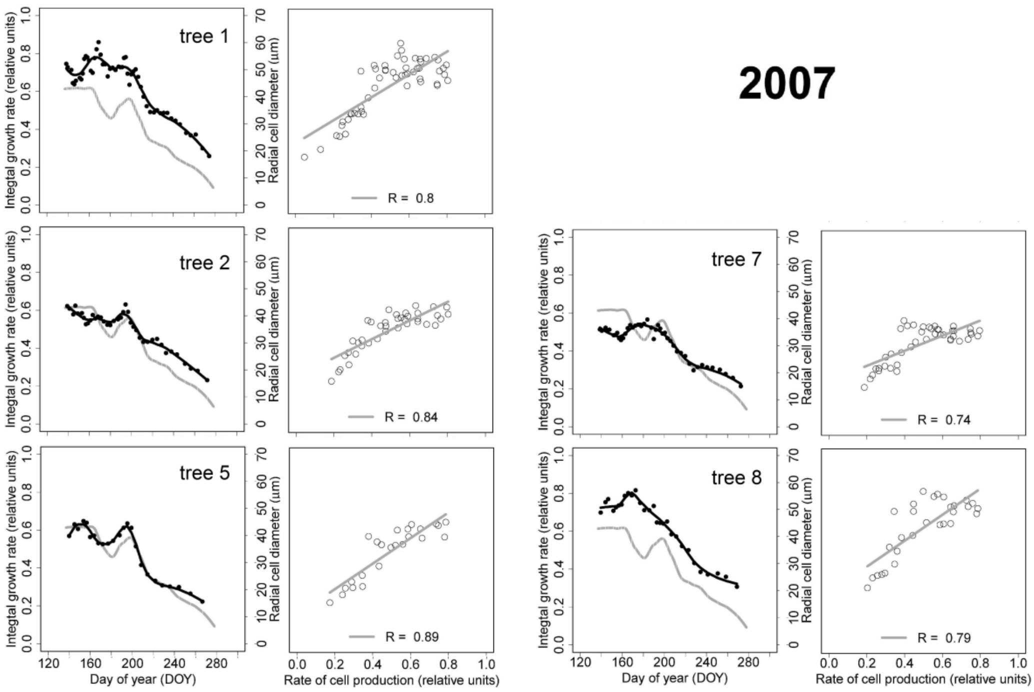
Further, we estimate a production time moment of each cell by the summing of relevant days. Therefore, each cell is assigned a value of time i-cell formation $(\mathrm{DOY_{bg}} + d_i)$ and growth rate - the daily integral growth rate in the last day of cells formation (Fig. 3). The code used for these calculations has been developed in R [11].

Figure 3 – Illustration of timing procedure: for cells within tree ring (position C1 and C2). Estimation a temporal moment of the cell production (day 1 and day2) corresponds to the cell size in the same time scale (D1 and D2).



The estimated growth rate for a particular year can be applied to each ring despite of the number of cells produced in different trees in every particular year. This similarity in curves (Fig. 4) is presumably associated to a linear relationship between average daily *Gr* (vi) and cell size (RD).

Figure 4 – Combined growth rates and the radial cell size during growth season are associated with linear relationship between these characteristics



In the study, at first time we demonstrate the approach which allows to detect the precise time moment to form each cell in the cell profile based on VS-simulation. Based on the approach the size of each cell in cell profile can be coincided with simulated daily growth rate at the same time scale. Based on the obtained results we could suggest that there is presumably non-linear relationship between the growth rate and cell size but more research is needed.

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PROCESS-BASED MODELING OF TREE-RING GROWTH IN SIBERIA

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One of the main tasks of dendrochronology is the study of the variability of the qualitative and quantitative characteristics of the layers of wood growth and the identification of environmental factors that determine this variability [1].

Due growth of dendrochronological information, there is a constant need to develop methods and programs, or to upgrade established methods, for identifying and processing various environmental information from the structure of tree-rings, as well as a comparative analysis of the results. And here lies main problem - choice of study methods.

Generally formation of tree-ring proxies defined as linear function of environmental conditions. However, it is not correct to use linear function alone to prove a physical or biological mechanism. For example, tree-ring records may reflect nonclimatic influences, including tree biology, size, age-depending effects and the effects of localized forest dynamics (fire disturbances, insect outbreaks etc.) [2, 3, 4]. Also changes in climate can cause temporal nonstationarity in the biological response of trees to local climate changes [1].

The process-based tree-ring VS-model describing tree-ring growth rate as the result of nonlinear function of climate variables: daily temperature, precipitation, solar irradiance [1].

It is been well documented, VS-Model shown itself as useful and accurate tool at simulation growth curve based on variety of climatic conditions and various species.

VS-Model was used to simulate tree-ring growth over large scale territories [5,6]. However, the study areas retained common features throughout their whole length (high temperatures and arid territories, or study areas located in mountains).

The main goal of this study is to apply VS-Model on large scale territory Yenisey-Lena transect, aimed at a retrospective assessment and short-term forecast variability and productivity of woody plants of the main tree species of northern taiga of Siberia under the influence of major climate (temperature and precipitation) and non-climatic (fires, floods, outbreaks of mass reproduction of insects, etc.) factors.

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