TIME IDENTIFICATION OF TREE RINGS CELL PRODUCTION DUE TO CLIMATE FACTORS IN SIBERIA

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ABSTRACT

It is well known that tree-ring formation mechanism is influenced by the number of climate and non-climate factors. An analysis of simulated and observed cell production of tree rings allows to separate the climate signal from other local effects (e.g., fire or insects), which can be fixed in the tree ring profile. One of principal indicators in tree ring structure is a distribution of radial cell sizes during growing season. In this work the process-based tree-ring VS-model was used to resolve the critical processes linking climate variables to tree-ring formation.

A new block of the model allows to estimate a cell production in tree rings and transfer it into time scale based on simulated integral growth rates of the model. The obtained detailed approach with a calculation of time moment of each cell formation improves significantly the date accuracy of new cell formation in growing season. In the developed algorithm we used integral growth rates simulated by the VS-model for each growing season.

The approach was applied and tested for the cell measurements obtained for Scots pine (*Pinus sylvestris L.*) over the 1964-2009 in the middle stream flow of Malaya Minusa river (Khakassia, Southern Siberia).

Keywords: ring, cell chronologies, process-based model, cambial activity, cell size

INTRODUCTION

Tree ring width, cell profile, cell diameter and cell wall thickness are the main anatomical characteristics of tree rings described by the climatic signal [13]. It well known that seasonal dynamics of the tree growth explained by the several components: a real tree-ring growth, an individual characteristics of tree and external climatic conditions. To describe and understand development of tree-ring formation and predict the wood characteristics, a process-based modeling of wood formation can be very useful in this case.

Recently, there was a sufficient number of works that reveal the processes of differentiation of cells [3, 4, 5, 15]. However, due to a specificity of these processes and a complexity of experimental methods a mathematical modeling can be considered as one of possible tools to simulate cell growth and division, which requires developing mathematical methods and corresponded software components.

In the work we used the Vaganov-Shashkin simulation model to analyze the relationship between the tree-ring growth rate and cell size [13]. Estimation of radial cell size variations was based on wood anatomy and on the simulated curves of integral growth rates [7]. We obtained simulations for southern Siberia, the Republic of Khakassia. This region is relatively well studied in term of dendroecology [1, 2, 6, 8].

This paper presents a new procedure for time scaling cells in radial rows. The obtained detailed approach improves significantly the date accuracy of new cells formation in growing season.

MATERIALS AND METHODS

Study area, climatic data and cell measurements

Wood samples of Scots pine *(Pinus sylvestris* L.) were collected in Minusinsk pine forests at a distance of 25 km from the meteorological station "Minusinsk" (South Siberia, 53°41' N, 91°40' E). This is the area of the Altai-Sayan region climate. According to the meteorological data, the average annual temperature is around 1°C and precipitation is 330 mm. Up to 91% of precipitation is observed in the warm season (in the end of April – till the beginning of October), with a maximum in July, whereas minimum precipitation is observed in February – March. Tree-ring growing season (with average daily temperature over 5°C) starts in the last decade of April. The period with a temperature above 10°C is 110-120 days. Measurements of the number of cells, the thickness of two adjacent cell walls and radial size of the lumen were obtained for 5 rows of cells in each annual tree ring and then were normalized to the average number of cells [14]. Finally radial cell sizes were obtained for the last 50 years of tree growth (1964-2013).

Statistical evaluation of the variability, average tracheidogram and its normalization

Rows of tracheids in a single tree ring and also in different trees contain different numbers of cells. Therefore there is a problem in the comparative analysis of micro-anatomical features, which can be solved by means of normalization (standardization) of the number of cells to some standard number (for narrow rings - 15 cells, for wide rings – 30 cells) [4, 14]. This procedure allows to obtain the same numbers of cells in cell profiles without changing shape of it.

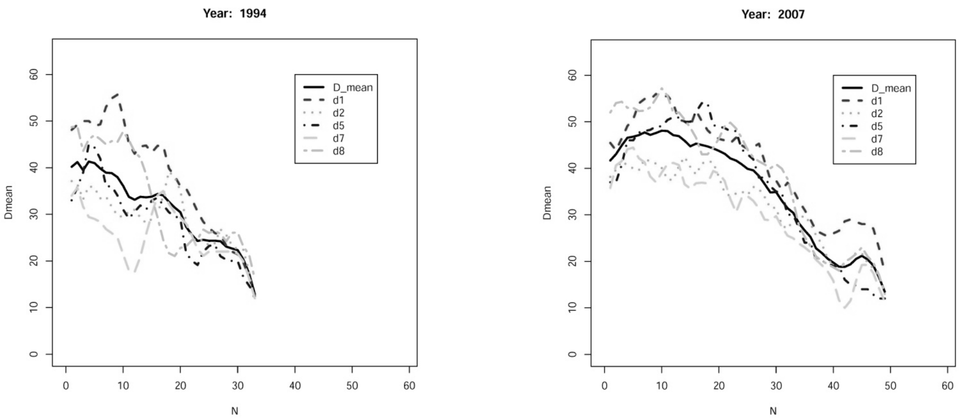

Fig 1. Tracheidograms of five trees with the average curve (dashed line) in the years with low (left) and high (right) number of cells.

As a result of tracheidograms normalization several rows of measured cells can be averaged to produce a mean tracheidogram (Fig.1). This normalization also allows a structural comparison of rings with different numbers of cells.

VS-MODEL AND ITS PARAMETERIZATION. ANALYSIS INITIAL AND SIMULATED DATA

The VS model is a nonlinear functional operator of daily temperature, precipitation and solar irradiance, which transforms a climatic signal to tree-ring growth rate, which is connected closely with seasonal cambial activity and cellular production of tree rings [10, 13].

We used the VS-oscilloscope to obtain a best simulation fit of initial tree-ring chronology based on daily climatic data [9, 11, 12]. To use the simulation model in a particular environment, it is necessary to define the values of model parameters which allow to provide a maximum synchrony in variation of the initial tree-ring chronology and simulated curve. Therefore, these values provide highly significant positive correlation between the initial data and modeling results. For the selected site we obtained highly significant correlation between the initial tree-ring chronology and estimated growth curve ($R = 0.65$, $p < 0.00001$; $n = 74$ years) for the period 1936–2009.

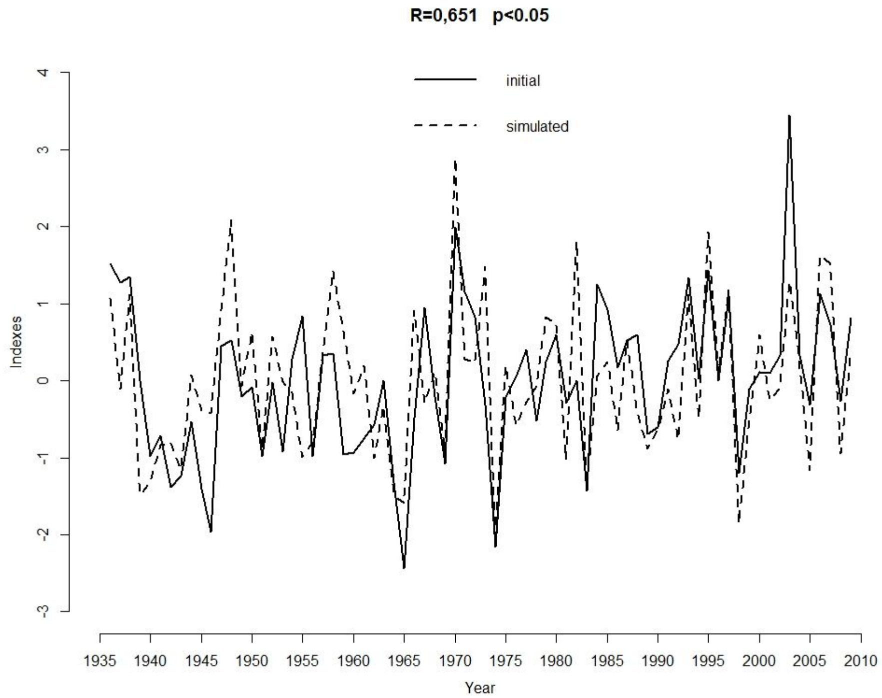

Fig 2. Initial tree-ring residual chronology (solid line) and simulated tree-growth curve (dashed line) for period 1936–2009.

Simulated integral tree-ring growth rate *Gr(t)* is a basis to estimate seasonal cell production, so these data are used as input for the next step [9].

TIME IDENTIFICATION OF TREE RINGS CELL PRODUCTION

The growth of a tree ring is a result of cell divisions in cambial zone and of their differentiation. The growth rate depends on the number of cells in the cambial zone and their rate of division. In coniferous species, the growth of a tree ring during a season is always accompanied by a change in the number of cambial cells, which has specific dynamics which is in general the same for all species [15].

In the algorithm of time identification for cell production we used an integral growth rate *Gr* simulated by the VS-model for each growing season (Fig.2). The integral growth rate can be estimated for each day of the growing season $[D_1, D_2]$, where D_1 – the date of growing season start, D_2 – the date of growing season finish. Based on the number of cells in tree ring (*N*) we assume that $[D_1, D_2]$ is the period of *N*-cells formation. An average production (average rate) of each cell in tree ring (s_i) can be estimated as:

$$s_i = \frac{\sum Gr}{N}$$

where an amount is taken over the number of days in the growing season $[D_1, D_2]$. Further, we estimate the production time moment of each cell summarizing sequentially integer (d_{int}) and fractional (d_{frac}) part of the day:

$$d_{\text{int}} + d_{frac} = d_i \text{, where } d_i \text{ is the time of i-cell formation.}$$

From the beginning of growing season (day D_1), it is necessary to summarize the daily integral growth rates until the value of the average cell production for the current year:

$$Gr_1 + Gr_2 + \ldots \leq s_i$$

The number of whole days during summarizing period is an integer day part d_{int}. Next step is to estimate the fractional day part. In the algorithm d_{frac} is equal to the share size of the daily integral growth rate, which is necessary to reach the certain threshold value - s_i. Therefore, each cell is assigned a value of time *i*-cell formation $(D_1 + d_i)$ and growth rate v_i - the daily integral growth rate in the last (fractional) day of cells formation.

As a result of the developed algorithm, for each cell *i* in the tree-ring we estimate the temporal moment of the cell production corresponded to the seasonal growth rate in the same time scale (Fig.3). The algorithm code was developed in R environment.

Interrelation between the kinetics of tracheid development, tree-ring structure, growth rate and climate conditions are shown in Figure 3:

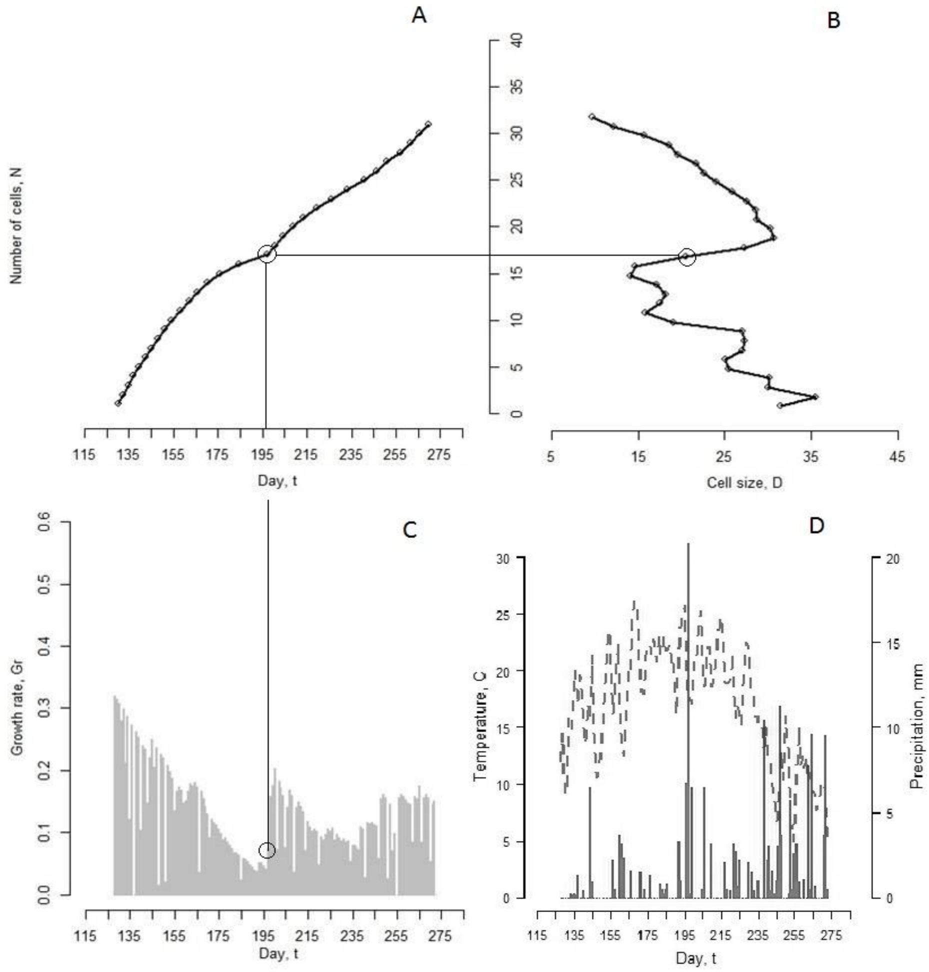

Fig 3. Seasonal growth curve (A), tracheidogram (B), integral growth rate graph (C) and climograma (D) for one typical year (1965)

CONCLUSION

In this study, we demonstrated the time scaling of tree rings cell production based on VS-modelling. As a result for each cell in the tree-ring we estimate the temporal moment of the cell production corresponded to the seasonal growth rate in the same time scale.

This approach was applied and tested for the cell measurements obtained for Scots pine (*Pinus sylvestris L.*) for the period 1964-2009 in Malaya Minusa river (Khakassia, South Siberia). The results represent a unique procedure describing the formation of tree rings of coniferous trees during the growing season for southern part of Siberia. This approach can also be used for regions with different climatic conditions. In addition these results can be used to better understand the observed processes during formation of cell seasonal profiles.

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