VS-OSCILLOSCOPE: SIMULATION OF TREE-RING IN SIBERIA

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ABSTRACT

Tree-ring records are annually resolved, well replicated, and can be calibrated and validated against the instrumental record. We analyze relationships between climate and tree-ring data using the VS-Oscilloscope (parameterization software of process-based tree-ring Vaganov-Shashkin model). The obtained approach can provide useful data to better understand how tree growth there is controlled by climate conditions.

Scots Pine (Pinus sylvestris) was selected as a tree species in the work. Wood samples were collected at the site in 25 km distance from meteorological station "Minusinsk", southern Siberia.

The key goals of the study are: to assess a performance of the VS-Oscilloscope on semi-arid territories; to obtain “optimal” tree-ring growth parameters during the calibration time interval and check them for the verification period; and to understand how climate principal factors can affect on ring formation, to evaluate differences in climate forcing on tree-ring growth between growing seasons when wide and narrow rings were formed.

Simulated tree-ring growth indexes significantly correlate to initial tree-ring chronology. Outputs of the modeling demonstrates that start and end of growth season are influenced by temperature, while rest period of growth is limited by precipitation. That fact confirmed by natural field observations.

Moreover the analysis of specific growing seasons when wide and narrow rings were formed show us how daily rainfall and temperature affect on tree-ring growth rate for particular years.

The Lazarus Code of the VS-oscilloscope and distributive package (free usinglicense) can be downloaded from the http://vs-genn.ru/downloads/. Technical questions can be addressed to Ivan Tychkov: ivan.tychkov@gmail.com.

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Keywords: Process-based model, Parameterization, VS-oscilloscope, Tree-ring width, Tree-ring growth

INTRODUCTION

Climatic variations strongly affect tree-ring growth and wood formation [2,3,4,11,12,13,15].

Often for analysis and interpretation of tree-ring growth or climate reconstruction linear on nonlinear functions of environmental conditions are used [2,7,10]. Unfortunately linear function is not accurate enough to represent precisely physical or biological mechanisms. For example, tree-ring records may reflect nonclimatic influences, including tree biology, size, age and the effects of localized forest dynamics, or temporal nonstationarity in the biological response of trees to climate might be a function of changes in climate itself [2,15]. It may lead to estimation misleading or even unrealistic results.

Sufficient amount of studies to develop the observational and conceptual basis for modeling of conifer cambial processes were published as a direct but nonlinear and multivariate response to external environmental conditions [6,9].

The process-based tree ring VS-model is one of such models, representing tree-ring growth as the result of multivariate nonlinear interaction between biological and physical processes [15].

VS-Oscilloscope is a parameterization approach to describe critical process linking climate variables with tree-ring formation, based on Vaganov-Shashkin model algorithm [11].

In this paper we analyze: (1) VS-Oscilloscope using in semi-arid area, (2) possibility to obtain model parameter values representing growth-climate relationship, (3) how climate factors affect tree-ring formation and tree-ring width.

MATERIALS AND METHODS

STUDY SITES

Materials for tree-ring chronologies of Scot pine (*Pinus sylvestris*) were collected from site “Min” located in the middle stream flow of Malay Minusa river and from site “Tar” site near river “Bidzha”. This sites were chosen due close distance to each other, similar environment and same climate. Site “Min” is part to the Altai-Sayan region of temperate climate zones with moderate cold continental climate [5]. According data from the climatic station average annual temperature is about 1°C. Start of vegetation period (daily temperature over 5°C) is in the last ten days of April. Length of period with temperature higher than 10°C, or potential length of growing season, is about 110-120 days.

"Tar" site is located in Ust-Abakan region, 2 km south of village Vershino-Bidzha (54°00’ N, 91°01’ E, altitude 660 m). Vegetation at the site represented by larch, pine, birch with grass-forb plant community. In this region of human impact on the forest stand slightly.

Monthly and daily mean temperature and precipitation amount data for growth simulation chronologies form “Min” site were used from the "Minusinsk" weather station (N 53°41' E 91°40', 320 m a.s.l.), data from the "Abakan" weather station (N 53°43' E 91°25', 245 m a.s.l.) were used for "Tar" site.

FORWARD TREE-RING BASED MODELING

The VS-Model is forward model of tree-ring growth which operates on next principles [14,15].

The main factors influencing tree-ring growth are climate data. Based on input data the model estimates partial daily growth rates on solar irradiation $Gr_E(t)$, temperature $Gr_T(t)$ and soil moisture $Gr_W(t)$.

Daily growth rate Gr(t) is estimated on the principle of limiting factor, as minimum between $Gr_T(t)$ and $Gr_W(t)$, modulated by $Gr_E(t)$.

The simulation of variations in growth rate and tree-ring structure depends on the current climatic changes (within the season).

Those principles can be presenting as an equation:

$Gr(t) = Gr_E(t) \cdot \min(Gr_T(t), Gr_W(t))$, where t - number of days.

The model requires more than 30 input parameters, which should be reasonably estimated for different forest stands. Value of integral growth rate and partial growth rates can be adjust by changing values of each parameter. To simplify procedure of simulation VS-oscilloscope was developed. VS-oscilloscope is a computer program with a graphical interface developed by using the Free Pascal Compiler, which allows simulation of tree-ring growth by selection of parameter values in an interactive mode [11].

MODEL PARAMETERIZATION AND VERIFICATION

To simulate ring width formation of Scots pine (Pinus sylvestrys) VS-Oscilloscope was calibrated for each site by optimizing the set of parameters to obtain a best fit of the simulated tree-ring curves to the observed tree-ring chronologies, and maximize the correlation coefficient between chronologies.

For site "Min" were used daily temperature and precipitation were used form "Minusinsk' station during 1973 - 2008. The initial and simulated annual tree-ring chronologies significantly correlate with each other. Pearson correlation coefficient R is 0.63 ($p<0.001$, $n=36$), and coefficient of synchronicity S is 83% (Fig. 1).

To assessment model estimation, verification was done on data from "Tar" site. Parameters estimated for "Min" were applied to independent chronology and climatic data from station near Abakan, city closer to site than Minusinsk. With obtained climatic data for period 1973-2008, correlation R between model growth and chronology is 0.65 ($p<0.001$, $n=36$) and coefficient of synchronicity S is 72% (Fig. 1B). Therefore, obtained parameterization can be used for the research region.
Average length of growing season, according the model, is 131 day (± 11 days), from middle of May to end of September. During all growth season partial integral growth rate form temperature Gr_T was higher than partial growth rate from soil moisture Gr_W,

that means annual growth of trees limited by soil moisture in semi-arid region (Fig. 2.). That fact is confirmed by experimental observations published earlier [1].

To study impact of climatic factors on ring formation we analyzed a difference in climate factors and tree ring growth for years when were formed wide and narrow rings (maximum and minimum values of the growth indexes, respectively) were formed. We define wide (narrow) tree-ring as mean number of cells plus (minus) standard deviation. According this definition, wide rings during selected period were formed in 1973, 1982, 1993, 1995, 1997, 2003, 2006, 2007, while narrow rings were formed in 1974, 1981, 1983, 1998, 2005.

Analysis of climatic factors for both groups shows significant differences of partial growth rates during period when growth limited by soil moisture. For years with wide rings the initial soil moisture was significantly high than for narrow rings (Fig. 3A), and partial growth rate depended on soil moisture reaches maximum value at the end of June, while for narrow rings – in the middle of May (Fig. 3B).

During period of formation wide rings total amount of monthly precipitation was significantly higher than for narrow rings period that affected in result integral growth rate. (Fig. 4).

Identification of limiting factor during growth season of wide and narrow rings allows understanding how daily precipitation and temperature affect rate of tree-ring growth and as a result, tree-ring width.

Same procedure was applied to estimated simulated chronology for "Tar" site. The initial and simulated annual tree-ring chronologies correlating with each other, Pearson coefficient R is 0.67 ($p<0.001$, $n=36$), and coefficient of synchronicity S is 72% (Fig. 5A).

Average length of growing season, according the model, is 131 day (± 12 days), from middle of May to end of September. Wide rings during selected period were formed in 1982,1985, 1993, 1995,2003,2006, while narrow rings were formed in 1974, 1977, 1987, 1998, 1999, 2005, 2008.

Due to common climate conditions with "Min" site tree-ring growth form "Tar" site was limited by soil moisture (Fig. 5B). But despised similarity in climate, for period formation of narrow rings mean temperature during summer months was higher. (Fig. 4 D) Higher temperature causes a higher rate of evapotranspiration (in VS-model evapotranspiration depends exponentially on the daily temperature), that can be a reason of soil moisture reduction and therefore, formation of a narrow rings (Fig. 6). It shows how VS-Oscilloscope is sensitive to climate variations of sites.

Analysis of the Table 1 shows an interesting result. Modeling results indicate that no significant differences in the length of the growing season in the formation of wide and narrow rings is obtained, i.e. the width of the annual rings is not determined by the duration of the growing season. It can be depended on variation of temperature and soil moisture during the growing season.

CONCLUSION

We used the forward modeling approach of ring-width, which already shown potentials to relate tree-ring growth by climate signal, using model parameterization (VS-Oscilloscope).

The high sensitivity of model's parameters reflects the ability of VS-Oscilloscope to simulate tree-ring growth in specific environment. Further using of the VS-Oscilloscope for other sites with different climatic conditions will help to understand how tree-ring growth process is affected by different amount climatic conditions. At same time it will help to make the model more adoptable for potential users.

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Tables

Table 1. Estimated mean numbers of the beginning of the growing season for period 1973-2008 (Date1), for years of formation wide rings (Date3) and narrow rings (Date5), the end of the growing season for period 1973-2008 (Date2), for years of formation wide rings (Date4) and narrow rings(Date6), the length of the growing season of period 1973-2008 (Date2-Date1), for wide rings (Date4-Date3) and narrow rings (Date6-Date5), with standard deviations for each value.

Site	Date1	Date2	Date3	Date4	Date5	Date6	Date2-Date1	Date4-Date3	Date6-Date5
Min	137±9	269±7	137±9	271±4	136±9	271±6	132±11	134±9	135±11
Tar	137±9	268±9	138±7	270±7	137±8	265±10	131±11	132±9	128±11

Figures and images

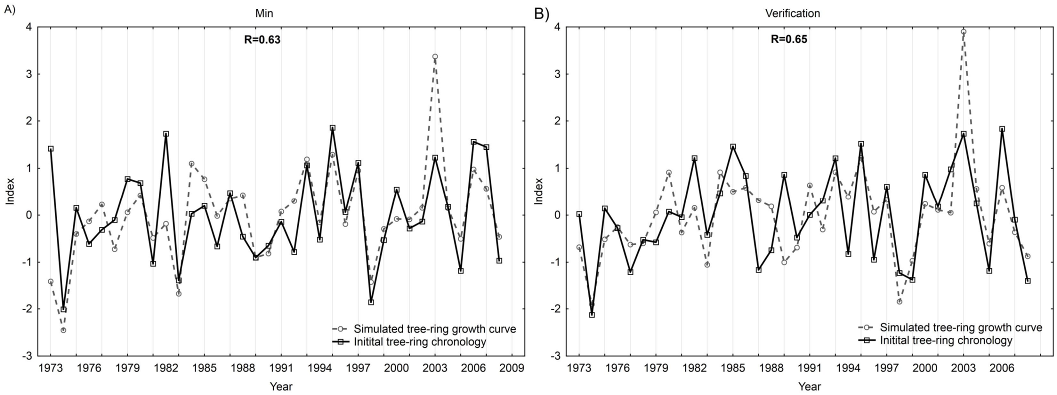

Fig. 1. A) Variations of simulated tree-growth curve (dashed black line) and initial tree-ring residual chronology (solid grey line) from "Min" site; B) tree-ring residual chronology (solid grey line) form "Tar" site, over 1973-2009, estimated with optimal parameters.

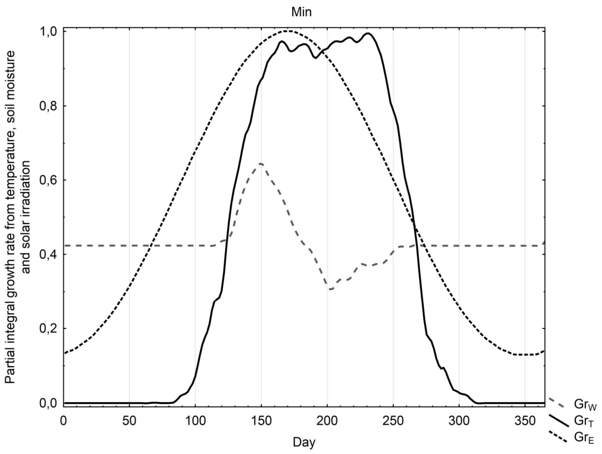

Fig. 2. Partial growth rates depending on solar irradiance GrE(t) (black dots), soil moisture GrW(t) (gray dash line) and temperature GrT(t) (black solid line) for 1950–2009, fitted by a negative exponentially-weighted smoothing [8].

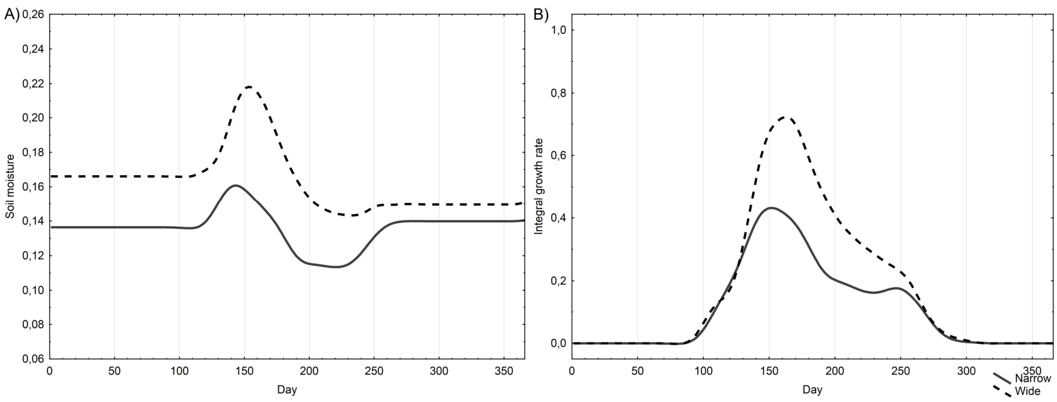

Fig. 3 A) Mean soil moisture for years with wide rings (black dashed line) and years with narrow rings (solid gray line). B) Mean integral growth rate for years with wide rings (black dashed line) and years with narrow rings (solid gray line).

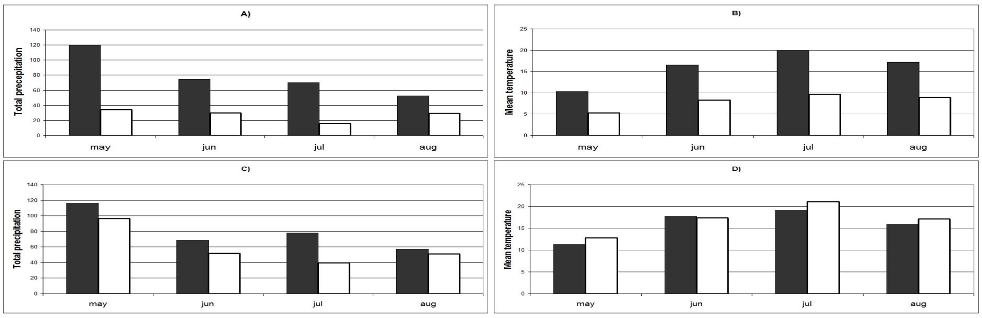

Fig. 4 A) Total precipitation and B) mean temperature from site "Min", and C) total precipitation and d) mean temperature from site "Tar" for the period from May to August for the years of wide rings (black shaded bars) and narrow rings (blank columns).

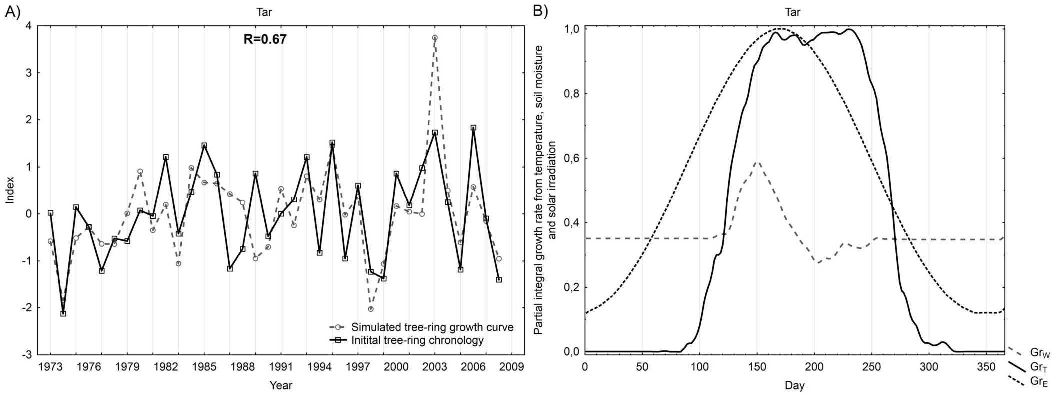

Fig. 5. A) Variations of simulated tree-growth curve (dashed black line) and initial tree-ring residual chronology (solid grey line) from "Tar" site over 1973-2009, estimated with optimal parameters. B) Partial growth rates for "Tar" site depending on solar irradiance GrE(t) (black dots), soil moisture GrW(t) (gray dash line) and temperature GrT(t) (black solid line) for 1950–2009, fitted by a negative exponentially-weighted smoothing [8].

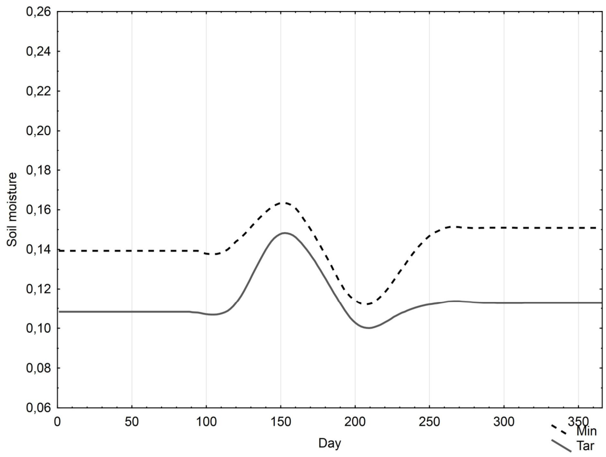

Fig. 6. Mean soil moisture for years with narrow rings from site "Min"(black dashed line) and from site "Tar" (solid gray line).