VS-OSCILLOCSOPE ONLIE: WEB-APPLICATION OF PROCESS-BASED VAGANOV-SHASKIN MODEL FOR TREE-RING GROWTH

Pavel Peresunko[1]

Margarita Popkova[2]

Artem Sazonov[1]

Viktor Ilin[2]

Ivan Tychkov[2]

[1] Institute of Space and Information Technologies, Siberian Federal University, **Russia**

[2] Math Methods and IT Department, Siberian Federal University, **Russia**

ABSTRACT

The efficiency of the process-based Vaganov-Shashkin model for tree-ring growth simulation has been tested previously on extensive dendrochronological material from the Northern Hemisphere in USA, China, Russia, Tunisia, Spain and France. But using the model is not a trivial task, taking into account a number of the model parameters that should be adjusted for the certain environmental conditions based on parameterization approach.

Here we present a new web tool of the VS-model parameterization, i.e. VS-Oscilloscope online, which can be used any computer platform due to the universal internet technologies. The software was tested on different datasets, and results of the web simulation were identical to the modeling based on previous version of parameterization – VS-Oscilloscope as a benchmark. It provides researchers an opportunity to use the complex model for visual simulation, reconstruction and forecast realistic tree-ring growth based on daily climatic conditions.

Keywords: *VS*-Oscilloscope online, Process-based modeling, Tree-ring growth, Climate signal, Node.Js

INTRODUCTION

Trees growth response on ongoing climate change is actively studied for different terrestrial ecosystems [1], [2], [3]. Connection between tree-ring formation and environmental conditions is a significant part of this research [4]. Often researchers use statistical approaches to link environmental data and tree-ring growth, but statistical methods ignore non-linear interconnections between tree growth and climate impact [5]. This issue can be resolved by using process-based simulations [6]. For example, the MAIDEN model correctly simulate measurements of bud-burst date, soil water content, transpiration and ring-width series [7]. The MAIDENiso, an extension of the MAIDEN, has isotopic modules to simulate stable oxygen and carbon isotopes in tree-ring cellulose [8]. The CAMBIUM can predict wood density, fiber and vessel anatomical

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properties at a daily time step [9]. The Vaganov-Shaskin tree-ring model (VS-model) explains how climate effects on tree-ring formation as function of three principal factors limiting tree-ring growth: daily temperature, precipitation and day length [6]. Results of VS-simulation include estimations of tree-ring width, dates of onset and end of cambium activity, precise timing of new cell production, daily tree-ring growth limited factor in different habitats. Moreover, it can be applied to predict a xylogenesis of conifer species in short- and long-term time scales [2], [3], [10].

In most cases application of any model mentioned above is a real challenge for experts due to the complexity of internal algorithms and as a rule a large amount of the model parameters. Consequently, even the first run of any model with the realistic interpretation of simulations is not a trivial issue.

One of the possible way to deal with this complexity is to parameterize the multi-dimensional model, i.e. to estimate values of the model parameters that guarantee a realistic simulation of tree-ring growth [11], [12].

In this work we present a new tool of the VS-model parameterization, i.e. VS-Oscilloscope online which can be used any computer platform. It gives to researchers an opportunity to use the complex model for visual simulation of real tree-ring growth.

WEB –APPLICATION DEVELOPMENT: CHOSEN IT

The VS-Oscilloscope online (VS-osci online) has the client-server design. This application can be used with any web-browser. Structure of the developed online system is presented by three interconnected sections: Web-interface, Server and Basic algorithm of the VS-model (Fig.1).

The main reasons to choose this type of structure are:

1. A selection criteria is an ease of development and independence of each part of the application, i.e. changes in one part of the program do not affect the working stability of other one.
2. The web application is an environment for the VS-model which is able to process input and output data of the modeling.

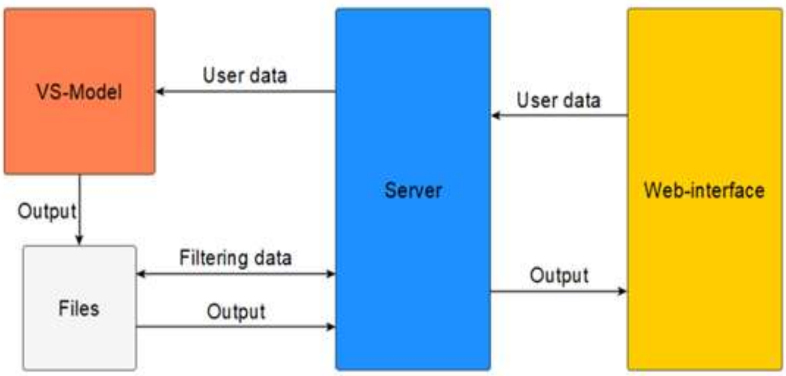

Fig. 1. The VS-Oscilloscope online structure.

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The R programming platform was chosen to implement a basic algorithm of the VS-model [13]. This program language perfectly suits for mathematical software programming because of a powerful library of built-in mathematical functions and procedures. Besides of it, R language allows to create and distribute packages, which help to researchers share their results.

Web-interface was designed with a JavaScript. Server was developed with Node.js technology (library). Each user of the VS-Oscilloscope online goes through an identification to create a unique folder where the input and output data of the model as well as specific additional files for server will be stored.

The server runs the VS-model package upon user request with user's files as arguments. After the VS-model processes all files, the server sends model output files to the client part, where user is able to access them manually.

The VS-Oscilloscope online has the customizable graphics. Such approach draws the model's output data and allows user to tune it. As a result, user can draw graphs without third-party applications. Whereas browser can “hang” due to the visualization of huge graphic data (50 000 and more points), Dygraph.js library is used to avoid this problem [14].

BRIEF DESCRIPTION OF VS-OSCILLOSCOPE ONLINE RUNNING

The web-application “VS-Oscilloscope online” - is available on http://vs-genn.ru/vs-oscilloscope-online/.

To use the VS-Oscilloscope online user needs the Internet connection and basic skills of working with a web browser.

The web-application consists of two linking web-pages: (1) Load data page (Fig. 2) and (2) Processing page - VS-Oscilloscope online parameterization (Fig.3).

User can upload thedata to run the VS-model (Fig. 2). It needs to upload the following: (1) file with the VS-parameters (*.par or *.parn); (2) climatic files (*.cli files), (3) file with initial tree-ring chronologies (*.crn), (4) site latitude and longitude and (5) trees species.

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Fig. 2. Load-data Web-page. It needs to upload the following: (1) file with the VS-parameters (*.par or *.parn); (2) climatic files (*.cli files) and (3) file with initial tree-ring chronologies (*.crn)

The format of the input files is described in [11] (Supplementary Materials)

Using second page (Fig.3) user can:

1. Adjust the VS-model parameters;
2. Re-run the VS-simulation;
3. Visualize output simulation data of the model;
4. Download output files in different formats, e.g. ASCII (*.dat), Excel (*.csv or *.xlsx).

The Web-application keeps values of VS-parameters that provide the best fitting tree-ring chronology and simulated growth curve, which is estimated by the Spearmen and Kendall rank correlation, and synchronicity coefficient.

After using the “Calculation” button server runs the VS-model (Fig. 2).

Processing page of VS-Oscilloscope online parameterization contains two blocks (Fig. 3): Stick bars (left panel) of the values of parameters in an interactive mode, (2) Graphic chart (right panel) reflecting observed tree-ring chronology and simulated growth curve. User has an opportunity to change values of VS-model parameters by the sliders (left panel) and numeric input field as well (Fig. 3). After each shift of the parameter values, the server re-runs the model with updated set of the parameters. The result of every new simulation reflects immediately on the Graphic chart (Fig. 3).

User can also use the customizable graphic to plot the VS-model outputs (Fig. 4). There is an ability to select a specific simulation data to be shown, type and color of lines. The customizable graph draws an integral tree-ring growth rate, partial growth rates dependent on daily temperature, soil moisture and solar irradiation as a default option (Fig. 4).

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Fig. 3 Processing page of VS-Oscilloscope online parameterization: (1) Left panel - Stick bars of the parameter values in an interactive mode, (2) Right panel -Graph chart reflecting observed tree-ring chronology (red curve) and simulated growth curve (blue curve).

Fig. 4. Customizable graphics with the integral growth rate (black curve), partial growth rates dependent on: daily temperature (pink curve), soil moisture (gray curve) and solar irradiation (red curve)

SOFTWARE TESTING

For testing the VS-Oscilloscope online we compared the simulated results obtained by the new web-application and the previous version of the VS-Oscilloscope as a benchmark for the same dataset [11].

We used the data from the dendrochronological site "MIN" (53°43’ N latitude, 91°50’ E longitude, 325 m a.s.l.) near Minusinsk. The samples of 67 Scots pine trees (*Pinus sylvestris* L.) were collected to obtain a tree-ring chronology [15]. The study area is a part of the Altai-Sayan region in temperate climate zone with moderate cold continental climate. Daily precipitation (P) and temperature (T) were obtained from the Minusinsk meteorological station (Khakassian Centre of Hydrometeorology and Environmental Monitoring). The available climate data cover the period of 1936–2009.

The whole period of direct climate observation was divided by two sub-periods: (1) calibration (1960-2009) to estimate values of “optimal” parameters provided the best fit between simulated and actual chronologies; (2) verification (1936-1959) to check an ability of the model to simulate the actual growth of trees based on the parameter values estimated on the calibration period.

Based on the previous version of VS-Oscilloscope we adjusted values of the model parameters to obtain significant results ($R = 0.71$, S=80% ($p < 0.0001$, $n = 50$ years for calibration; $R = 0.53$, S=70% $p < 0.0001$, $n = 24$ years for verification) (Fig. 5) with using the current version of VS-model [2], [11].

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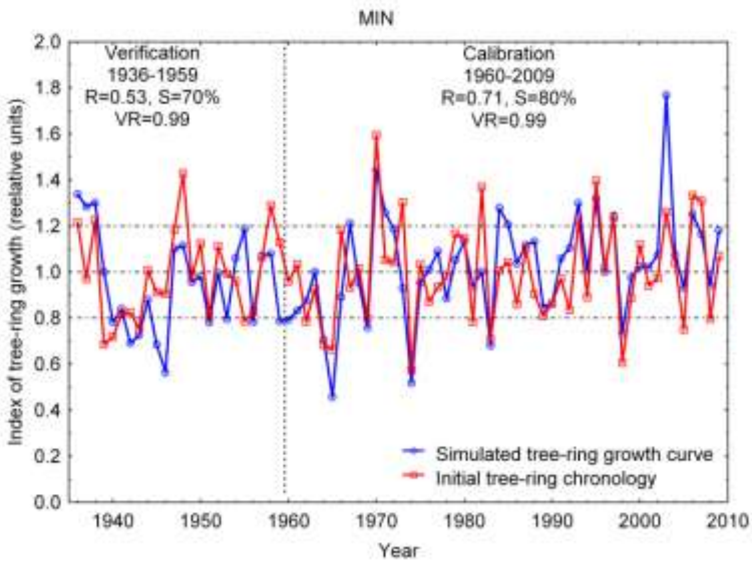

Fig. 5. Actual tree-ring chronology (solid blue line) and simulated tree-ring growth chronology (solid red line). Dashed horizontal lines are an average index of tree-ring growth ± standard deviation.

Table 1. Tree-ring growth values obtained by VS-Oscilloscope (as a benchmark), VS-osci online and indexes of actual chronology

Year	VS-Oscilloscope	VS-osci Online	Actual chronology
1936	1.3382	1.34	1.215
1937	1.284	1.28	0.97
1938	1.3011	1.3	1.227
1943	0.7248	0.72	0.754
…	**….**	**….**	**….**
2006	1.2513	1.25	1.333
2007	1.1638	1.16	1.309
2008	0.9418	0.94	0.796
2009	1.1817	1.18	1.069

We applied the obtained parameters with the same dendroclimaticdataset to the online version and compared the simulation results of both models. The simulations were identical for the calibration well as the verification periods (Table 1). Mean absolute

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error (MAE) between the simulated tree-ring chronologies for both versions was less than 0.003 and was statistically equal to zero (p-value << 0.001).

CONCLUSION

The efficiency of the VS-model has been tested previously using extensive dendrochronological material from the Northern Hemisphere in USA, China, Russia, Tunisia, Spain and France. Model parameters estimation is not a trivial task taking into account a number of the variables that should be adjusted for the certain environmental conditions based on parameterization approach. In the previous studies we have shown the VS-model is a powerful tool to explain the reliable relationships between direct climate daily observations, tree-ring growth and wood formation over long-term periods [2], [3], [10], [11], [12].

We especially note here that the VS-model parameterization can provide an important reliable phenological information, e.g., the onsets and terminations of the growing seasons over several decades, based on available daily climatic observations in a long-term historical context [1], [3]. In practice to obtain such information even for few years is a time-consuming and complex procedure.

We have developed a new web tool of the VS-model parameterization, i.e. VS-Oscilloscope online, which can be used any computer platform due to the universal internet technologies. The new software was tested on different datasets and results of simulation were identical with the modeling based on previous version of parameterization – VS-Oscilloscope – used as a benchmark.

It provides researchers an opportunity to use the complex model for visual simulation, reconstruction and forecast of realistic tree-ring growth based on climatic conditions.

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