

# 1 VS-oscilloscope: a new tool to parameterize tree radial growth based on 2 climate conditions

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12

## 13 **Abstract**

14 It is generally assumed in dendroecological studies that annual tree-ring growth is adequately  
15 determined by a linear function of local or regional precipitation and temperature with a set of  
16 coefficients that are temporally invariant. However, various researchers have maintained that  
17 tree-ring records are the result of multivariate, often nonlinear biological and physical processes.  
18 To describe critical processes linking climate variables with tree-ring formation, the process-  
19 based tree-ring Vaganov-Shashkin model (VS-model) was successfully used. However, the VS-  
20 model is a complex tool requiring a considerable number of model parameters that should be re-  
21 estimated for each forest stand. Here we present a new visual approach of process-based tree-  
22 ring model parameterization (the so-called VS-oscilloscope) which allows the simulation of tree-  
23 ring growth and can be easily used by researchers and students. The VS-oscilloscope was tested  
24 on tree-ring data for two species (*Larix gmelinii* and *Picea obovata*) growing in the permafrost  
25 zone of Central Siberia. The parameterization of the VS-model provided highly significant  
26 positive correlations ( $p < 0.0001$ ) between simulated growth curves and original tree-ring

27 chronologies for the period 1950-2009. The model outputs have shown differences in seasonal  
28 tree-ring growth between species that were well supported by the field observations. To better  
29 understand seasonal tree-ring growth and to verify the VS-model findings, a multi-year natural  
30 field study is needed, including seasonal observation of the thermo-hydrological regime of the  
31 soil, duration and rate of tracheid development, as well as measurements of their anatomical  
32 features.

33

34 **Keywords:** VS-model; Parameterization; VS-oscilloscope; Central Siberia; Permafrost; Tree-  
35 ring width; Tree-ring growth; Climate signal; Non-linear response; Tree-ring growth rates;  
36 Larch; Spruce.

37

## 39 **Introduction**

40 Tree-ring growth and wood formation are strongly affected by climatic variations in boreal zones  
41 of the Northern Hemisphere. Often the formation of tree rings is defined as a linear function of  
42 local or regional precipitation and temperature with a set of coefficients that are temporally  
43 invariant. However, various researchers have stressed that tree-ring records are the result of  
44 multivariate, often nonlinear biological and physical processes. For example, tree-ring records  
45 may reflect nonclimatic influences, including age-dependent effects, specific local environmental  
46 conditions, fire disturbances, and insect outbreaks (Fritts, 1976; Cook and Kairiukstis, 1990;  
47 Dale et al., 2001; D'Arrigo et al., 2001; Kirilyanov et al., 2012; 2013; Shishov, 2000; Shishov et  
48 al., 2002; Touchan et al., 2014; Varga et al., 2005). The temporal nonstationarity of biological  
49 tree-ring response to climate may also be connected with local climatic variation itself (Fritts et  
50 al., 1991; 1995; Aykroyd et al., 2001; Briffa et al., 2008; Bunn et al., 2013; Schweingruber,  
51 1996; Shishov, Vaganov, 2010; Vaganov et al., 2006; Touchan et al., 2012). The process-based  
52 tree-ring Vaganov-Shashkin model (VS-model) can be used to describe critical processes linking  
53 climate variables with tree-ring formation (Vaganov et al., 2006).

54 The VS-model is a nonlinear functional operator of daily temperature, precipitation and solar  
55 irradiance, which transforms a climatic signal to tree-ring growth rate, which is connected  
56 closely with seasonal cambial activity and cellular production of tree rings (Vaganov et al.,  
57 2006).

58 Several publications have described the use of the model in different environmental conditions  
59 and various conifer species. For example, the potential of the VS-model was used to simulate  
60 tree-ring growth of conifers in North America (Evans et al., 2006). A total of 190 tree-ring  
61 chronologies were adequately simulated in different parts of the United States in this first broad-  
62 scale application of the VS-model for simulating tree-ring width data used for statistical  
63 paleoclimatology. The obtained results showed that the analyzed broad-scale network of tree-

64 ring chronologies can be used primarily as climate proxies for their further use in statistical  
65 paleoclimatic reconstructions. Furthermore, Anchukaitis and others (2006) used the VS-model in  
66 a case study for the southeastern United States region to understand if tree-ring chronologies  
67 across the warm, mesic climate conditions could be simulated as a function of climate alone.  
68 They showed that there is a significant correlation between simulated and observed tree-ring  
69 width data (Anchukaitis et al., 2006). Moreover, application of the process-based model in the  
70 Mediterranean region demonstrates the ability to explain observed patterns of tree-growth  
71 variation in the past and to simulate tree-ring growth in extreme drought conditions (Touchan et  
72 al., 2012).

73 These results illustrate how nonlinear multivariate functions can provide realistic results, but the  
74 various authors noted that the same default sets of the model's parameters for different regions  
75 were used. Similarly equally artificial results would be obtained if the process model's  
76 parameters were adjusted to obtain the best fit for each modeled tree-ring width chronology  
77 (Evans et al., 2006; Ivanovsky, Shishov, 2010). It means that the "optimal" values of model  
78 parameters could conflict with field observations of tree-ring growth due to unreal ecological  
79 interpretation of that values and natural observed process. Therefore, to parameterize the VS-  
80 model — estimation of the model's parameters to provide the best fit of initial tree-ring  
81 chronologies and a reasonable description of interaction between climate and tree-ring formation  
82 — is a real challenge for researchers.

83 The model requires 42 input parameters, which should be reasonably estimated for different  
84 forest stands (Vaganov et al., 2006). Twenty-seven parameters are used to estimate an integral  
85 tree-ring growth rate, or growth rate  $Gr(t)$  (Vaganov et al., 2006; Evans et al., 2006; Touchan et  
86 al., 2012). Another 15 parameters are needed to calculate cell production and cell sizes based on  
87 simulated values of seasonal integral growth rates (Vaganov et al., 2006). It is noteworthy that  
88 the model is sensitive to changes of some VS-parameters, and even small changes of these  
89 values significantly affect the simulated tree-ring growth. Thus, for the northern timberline these

90 parameters are directly connected with local temperature conditions (Vaganov et al., 2006). For  
91 the Mediterranean area, up to 60% of tree-ring variation can be explained by the soil moisture  
92 regime, which is simulated by observed precipitation and particular VS-parameters (Touchan et  
93 al., 2012). Such a large number of parameters makes the VS-model difficult to operate, and for  
94 practical use the model needs to be simplified.

95 A good example of VS-model simplification is a deterministic VS-Lite Model (VSLM), which  
96 uses monthly temperature and precipitation as input data (Tolwinski-Ward et al., 2011a,b, 2013).  
97 The transformation from daily to monthly resolution reduced significantly the number of  
98 parameters needed. However, such simplification of the model resulted in the loss of ability to  
99 estimate seasonal cell production and cell sizes.

100 Here we present a new visual approach of process-based tree-ring model parameterization (the  
101 so-called VS-oscilloscope), which allows simulation of tree-ring growth by selection of  
102 parameter values in an interactive mode. This approach provides solutions to equations from the  
103 model, which should be verified, where possible, by direct comparison with natural field  
104 observations (i.e. seasonal soil moisture, soil thawing, cell division, cell enlargement, etc.). The  
105 approach was applied to dendrochronological data from Central Siberia.

106

## 107 **Material and Methods**

### 108 **1. Study area**

109 The study area is located in the northern part of Central Siberia, close to the settlement of Tura  
110 (Evenkia, 64°17' N, 100°13' E, 610 m a.s.l.), within the continuous permafrost zone. The climate  
111 is continental, characterized by long and very cold winters and short and cool to mild summers.  
112 The mean annual air temperature is -9 °C and the annual precipitation is 370 mm, based on data  
113 from the Tura meteorological station for the period 1936-2009.

114 Wood samples (cores and/or disks) of larch (*Larix gmelinii* (Rupr.) Rupr.) up to 471-years old  
115 and spruce trees (*Picea obovata* Ledeb.) up to 276-years old were taken for the analysis in a

116 spruce-larch mixed stand with an admixture of birch (*Betula pubescens*). The ground vegetation  
117 mainly consists of ledum (*Ledum palustre* L.), mosses (*Pleurozium schreberi* (Brid.) Mit.,  
118 *Aulacomnium palustre* (Hedw.) Schwaegr.) and lichens (*Cladina* spp., *Cetraria* spp.).

119

## 120 **2. Wood sampling, tree-ring width measurements and climatic data**

121 Wood sampling was performed during the autumn of 2009 on about 25 trees per species. The  
122 cores were collected perpendicular to the stem axial axis. Annual tree-ring width (TRW) was  
123 measured using a LINTAB measuring table with 0.01 mm precision combined with the program  
124 TSAP (Rinntech, Heidelberg, Germany). The resulting time-series were visually cross-dated and  
125 the dating quality verified using the program COFECHA (Holmes, 2001). To avoid the influence  
126 of non-climatic factors (age-depending trends, abrupt changes (fires, insects), etc.) on tree-ring  
127 growth a 50%-variance cubic smoothing spline with 2/3 cut-off length of time series was used as  
128 the detrending method. Along with standard tree-ring chronologies, residual chronologies  
129 (PlatLG – *Larix gmelinii* and PlatPO – *Picea obovata*) were used for tree-ring growth simulation.  
130 Daily mean temperature and precipitation amount data (A.D. 1950-2009) were used from the  
131 Tura weather station (64.27° N; 100.23° E, 188 m a.s.l.)

132

## 133 **3. Model description**

### 134 **3.1. Brief description of basic VS-algorithm**

135 The basic algorithm of the model can be divided into four blocks (Fig. 1) (see Vaganov et al.,  
136 2006 for details):

- 137 - The Data input block, in which observed temperature, precipitation and estimated solar  
138 irradiance are used as input data;
- 139 - The Basic block, in which an integral tree-ring growth rate  $Gr(t)$  is estimated based on  
140 the following equation:

$$141 \quad Gr(t) = Gr_E(t) * \min\{Gr_T(t), Gr_W(t)\},$$

142 where  $Gr(t)$  is an integral tree-ring growth rate,  $Gr_E(t)$ ,  $Gr_T(t)$ ,  $Gr_W(t)$  are partial growth rates  
143 dependent on daily solar irradiation E, temperature T and soil moisture W, respectively;

- 144 - The Cambium block, where seasonal number of cells and cell sizes are estimated;
- 145 - The Data output block which provides seasonal cell profiles.

146 The model estimates a daily water balance based on accumulated precipitation into the soil  
147 (taking into account snow melting if needed), transpiration (dependent on temperature) and  
148 drainage (Thorntwaite, Mather, 1955). Daily solar irradiation from the upper atmosphere is  
149 determined by latitude, solar declination and day of the year (Gates 1980).

150 Rate of cambial activity depends on the number of cells in the cambial zone and rate of their  
151 divisions, which linearly depends on the integral tree-ring growth rate in the model. Moreover,  
152 the integral tree-ring growth rate is used to estimate actual cell sizes during the enlargement  
153 stage and the phase of maturation (Vaganov et al., 2006). It was shown that the simulated  
154 integral growth rate can be transformed to tree-ring indices by specific procedures used in the  
155 Fortran code of the VS-model (Vaganov et al., 2006; Tychkov et al., 2012; Touchan et al., 2012).  
156

### 157 **3.2. VS-oscilloscope: conception and realization**

158 The principal goal of parameterization of the model is to obtain a best fit of the simulated tree-  
159 ring curves to the observed tree-ring chronologies by selection of certain parameter values of the  
160 model. At the same time the selected values should not conflict with the biological principles of  
161 growth and field parameters, obtained for the different ecological conditions of analyzed forest  
162 stands. The solution of this task by direct mathematical optimization of multi-dimensional  
163 parameter space is problematic, taking into account a high probability to reach local optimum  
164 generating artificial decisions (Evans et al., 2006; Ivanovsky, Shishov, 2010; Tolwinski-Ward,  
165 2013). It is necessary to develop a parameterization tool, which allows the correct selection of  
166 parameter values in an interactive mode in complete accordance with the expert knowledge.

167 By definition, an oscilloscope (also known as a scope, CRO, DSO or an O-scope) is a type of  
168 electronic test instrument which allows observation and analysis of constantly varying signal  
169 voltages as a two-dimensional graph of one or more electrical potential differences using the Y-  
170 axis, plotted as a function of time on the X-axis. The oscilloscope is used to observe the change  
171 of an electrical signal over time, so that voltage and time describe a shape which is continuously  
172 graphed against a calibrated scale (Kularatna, 2003). Simple manipulation of amplitude,  
173 frequency, phase and other values allows simulation of an electrical signal of any complexity.  
174 Potentially any tree-ring chronology can be considered as an analogue of “electrical signal,” in  
175 which case parameters of the VS-model play the role of manipulators that modify the “signal”.  
176 By interactively changing the parameter values, we can observe the variation of climatic signal  
177 in a tree-ring chronology. Moreover, we can correct the selected values of parameters according  
178 to the direct observations and knowledge. Therefore, we named this new parameterization  
179 approach “VS-oscilloscope”.

180

181 The VS-oscilloscope is a computer program with a graphical interface developed by the cross-  
182 platform integrated development environment - Lazarus – using the Free Pascal Compiler<sup>1</sup>. The  
183 Fortran realization of the VS-model was used as a test version of the model (Vaganov et al.,  
184 2006).

185 The VS-Oscilloscope contains two different window sheets: 1) The “Open Data” sheet, where  
186 users should upload the files of initial parameter values (\*.par), climatic data (\*.cli), tree-ring  
187 chronology (\*.crn), latitude value for the site of interest, and the final value of the year before the  
188 start of calculation (Fig. 2A)<sup>2</sup>; and 2) The “Model parameterization” sheet, which contains scroll-  
189 bars for most parameters of the model, such as minimum temperature for tree growth, critical  
190 growth rate, etc. (Fig. 2B). Values of the parameters can be changed manually in the Model

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<sup>1</sup> The Lazarus Code of the VS-Oscilloscope and distributive package (free using license) can be downloaded from the <http://vs-genn.ru/downloads/>. Technical questions can be addressed to Mr. Ivan Tychkov: [ivan.tychkov@gmail.com](mailto:ivan.tychkov@gmail.com)

<sup>2</sup> See a detailed description of file formats in Supplementary material.



191 Parameterization sheet. By moving scroll-bars along value scale to the left (or right), we can  
192 decrease (or increase) values of the parameters. Other parameters not presented in the sheet can  
193 be changed in the file of parameters directly before running the program.

194 Before starting parameterization users should upload all needed files (see Supplementary  
195 material).

196 After the start of calculation (initiated by pushing the button “Calculation”) a new window will  
197 be opened (Fig. 3). It is a virtual display of the VS-Oscilloscope, which contains three graphs:  
198 the initial tree-ring chronology (red curve), simulated growing time series with recent values of  
199 parameters (blue curve) and the chronology modeled with the previous set of parameters (green  
200 curve). The number in the center of the display indicates correlation between the red and blue  
201 curves (Fig. 3). If the correlation between original and simulated curves is increased (decreased)  
202 after changing the parameter’s value, it will change the color to green (red) correspondingly.

203 Note that initially all scroll-bar positions correspond to the value of parameters from the input-  
204 file (grrt50.par). For example, if the minimum temperature for tree growth is equal to 5° C then  
205 the scroll-bar will be moved to the position corresponding to 5 on the scale. Any changes in the  
206 scroll-bar positions will lead to a recalculation of the simulation using the new values of the data.  
207 In this case, the visual display automatically redraws the new simulated growth curve in blue  
208 color, while the previous version is displayed in green.

209 After obtaining the satisfactory simulated results, these will be saved in a subfolder “Results”  
210 which is opened automatically (see Supplementary material).

211

### 212 **3.3. Differences between software versions**

213 Due to differences between the Fortran and Lazarus programming platforms and their compilers  
214 there are changes in VS-Oscilloscope code that can affect the final results of simulations.

215 Particularly in the Fortran version, the partial growth rate  $G_E(t)$ , which depends on solar  
216 irradiance, is calculated correctly only for middle latitudes. The VS-Oscilloscope calculates the  
217 rate based on the following formula (Liu, Jordan 1960):

$$218 \quad E = I_{sc} * (\cos L * \cos \delta * \sin \omega + \omega * \sin L * \sin \delta) * r * 24/\pi,$$

219 where  $E$ - the extraterrestrial daily irradiance received on a horizontal surface, Btu/Day-sq ft;

220  $I_{sc}$  – the solar constant;

221  $r$  – the ratio of solar radiance intensity at normal incidence outside of Earth’s atmosphere to solar  
222 constant, dimensionless,

223  $L$ - latitude, degrees;

224  $\delta$  - solar declination angle, degrees;

225  $\omega$  - sunset hour angle, radians.

226 If the permafrost soil melting block is activated then the partial growth rate  $Gr_W(t)$  depending on  
227 soil moisture should be modified in the VS-Oscilloscope algorithm by the following formula:

$$228 \quad Gr_W(t)_{corr} = Gr_W(t) * dep(t) / Lr,$$

229 where  $Lr$  - depth of roots,  $dep(t)$  - depth of the thawed soil layer for the Julian day  $t$  (Vaganov et  
230 al., 2006). We note that the modification is in correspondence with the description of the basic  
231 algorithm of the model (equation# 7.6, p. 213, Vaganov et al., 2006)

232 In our study the soil melting block was deactivated because additional information of soil  
233 properties (i.e. thermal conductivity, water content, snow depth, etc.) was not available to  
234 simulate the melting process adequately.

235

## 236 **Results and Discussion**

237 With the estimated VS-parameters by the VS-Oscilloscope (see Table 1) we obtained highly  
238 significant positive correlation between the initial tree-ring chronologies and estimated growth  
239 curves (PlatLG:  $R = 0.70$ ,  $p < 0.0001$ ; PlatPO:  $R=0.65$ ,  $p<0.0001$ ;  $n = 40$  years) for the

240 calibration period 1970–2009 (Fig. 4 A and B correspondingly). In fact, climate variability  
241 explains 42-49% of tree-ring growth variation in these particular cases.

242 When the VS-model with the obtained parameters was applied to simulate chronologies for the  
243 verification period (1950–1969), agreement of the observed chronologies with the simulated  
244 curves was also highly significant (PlatLG:  $R = 0.81$ ,  $p < 0.0001$ ; PlatPO:  $R = 0.59$ ,  $p < 0.01$ ;  $n=20$   
245 years, Fig. 4 A and B correspondingly).

246 The parameterization of the VS-model provided highly significant positive correlations (PlatLG:  
247  $R = 0.70$ ,  $p < 0.00001$ ; PlatPO:  $R = 0.62$ ,  $p < 0.00001$ ,  $n=60$ ) between simulated growth curves and  
248 initial tree-ring chronologies for the common period 1950-2009.

249 Although highly significant positive correlation between the measured tree-ring chronology and  
250 the simulated growth curve is obtained by the parameterization procedure, there is no guarantee  
251 that the parameter values are suitable and can be explained ecologically (Evans et al., 2006;  
252 Ivanovsky, Shishov, 2010). Hence, it is necessary to check parameters of the model and compare  
253 them with direct field observations and/or earlier published results.

254 According to our simulation, tree-ring growth of both studied species starts at a minimum  
255 temperature  $T_{\min}$  ( $9\text{ }^{\circ}\text{C}$ ), which is close to observed mean stem temperature for conifer species  
256 when xylogenesis starts (Rossi et al., 2007) (Tab. 1). Due to the altitude difference between sites  
257 and the Tura weather station (more than 400 meters) the actual daily temperature directly  
258 observed on sites was less than  $1.5\text{ }^{\circ}\text{C}$  in comparison with the weather station data (Rinne et al.,  
259 2015). This means that the estimated minimum temperature  $T_{\min}$  can be modified to an actual  
260 value of  $7.5\text{ }^{\circ}\text{C}$ .

261 Differences between the range of the optimal temperature ( $T_{\text{opt1}}$ ) and  $T_{\min}$  show that the growth  
262 rate of larch at the beginning of the growing season is higher than that of spruce. This result  
263 confirms that larch trees are more sensitive to temperature changes, particularly at the beginning  
264 of the growing season (Kujansuu et al., 2007).

265 The start dates of growing seasons vary from the end of May to the start of June for both species  
266 (Fig.5), which is in accordance with the direct observations (Rinne et al., 2015). The simulated  
267 average duration of the growing season is approximately the same for both species (PlatLG: 75  
268 ( $\pm 15$ ) days; PlatPO: 80 ( $\pm 15$ ) days) (Fig.5). Comparison of these results for larch with  
269 xylogenesis observations (Bryukhanova et al. 2013) reveals up to three weeks' differences in the  
270 duration of the growing season, which can be related to the difference in site locations: the  
271 studied site is 450 m above the one reported in Bryukhanova et al. (2013). The difference in  
272 duration of tree-ring development also may be due to difference in approaches used. Thus,  
273 secondary cell wall development observed in Bryukhanova et al. (2013) may take several weeks  
274 at the end of the growing season, but does not influence the final tree-ring width simulated here.

275 During the growing season an average integral growth rate for spruce trees (Fig. 5 B) is not  
276 significantly higher than for larch (Fig. 5 A). This can be explained by the larger leaf area and  
277 higher photosynthesis rate in spruce.

278 The applied parameterization approach reveals a significant difference in seasonal tree-ring  
279 responses to climatic variations between species. Thus, at the start of the growing seasonal larch  
280 growth (PlatLG) is limited by temperature (lower values of  $Gr_T(t)$  in comparison with  $Gr_w(t)$ )  
281 (Fig.6 A). In the middle of the season there is a change of limiting factor (lower values of  
282  $Gr_w(t)$ ). Soil moisture starts to play a key role in tree-ring formation until the end of the growing  
283 season, when again temperature becomes the principal factor limiting tree-ring growth (Fig.6 A).  
284 Such temperature-precipitation effects were shown by previous studies of larch trees at some  
285 sites in the studied region (Kirilyanov et al., 2013, Kujansuu et al., 2007)

286 In comparison, spruce is less sensitive to seasonal soil moisture changes (Fig. 6 B). During the  
287 growing season, the tree-ring growth of spruce is limited by temperature changes (Fig. 6 B). This  
288 quite surprising result can be explained by the fact that spruce trees prefer and grow in moister  
289 habitats, which are formed in local depressions and associated with troughs. However, the VS-

290 parameterization indirectly explains this result: minimum soil moisture for larch growth is three  
291 times less than for spruce ( $W_{\min}$  is 0.02 for PlatLG and 0.06 for PlatPO) (Tab.1).

292 The VS-oscilloscope approach also shows that tree crowns can play a different role for different  
293 species; thus, spruce can capture 17% more precipitation in the crown (see values of parameter  
294  $C_1$  in the table 1). So the fraction of precipitation amount which is not stopped by the crown is  
295 0.71 for PlatLG and 0.54 for PlatPO correspondingly. It means that 29% of daily precipitation is  
296 caught by larch crowns and 46% by spruce trees. This result agrees well with the lower water-  
297 conducting ability of spruce crowns in comparison with larch trees.

298 The VS-parameterization shows that spruce tree transpiration is higher compared to larch trees,  
299 because the exponential coefficient  $C_3$  (0.355) for spruce is significantly larger than for larch  $C_3$   
300 (0.265) (see Table 1). The reason for such differences can be explained by the larger leaf area of  
301 spruce trees.

302 We used the VS-oscilloscope to get a best fit of initial tree-ring chronology based on daily  
303 climatic data. The results and their interpretation concerning tree-ring growth for two conifer  
304 species are realistic and show a significant agreement with direct field observations.

305 Potentially the VS-Oscilloscope can be used without much dendrochronological experience. For  
306 non-expert users, it is possible to obtain primary qualitative information about growth processes  
307 and environmental conditions of forest stands, based on daily temperature and precipitation from  
308 the nearest weather station, particularly to identify species-specific features in reaction to  
309 changing environmental conditions, to find phenological characteristics of tree-ring growth, to  
310 assess the impact of local habitat conditions, etc.

311 In this study, we did not consider a simulation of seasonal cell profiles because the cambial block  
312 of the model was deeply upgraded and is currently tested on cell measurements obtained for  
313 eastern and southern parts of Siberia.

314 Although tree-ring growth is influenced by permafrost conditions in the region (Kirilyanov et al.,  
315 2013), we excluded a soil melting estimation because the particular block of the VS-model needs

316 to be improved using data from long-term experiments of soil observation (soil melting and soil  
317 moisture content) in different environments.

318 Nonetheless, these two modules of the VS-Oscilloscope can be implemented as soon as an  
319 improved version in the VS-model is available.

320

## 321 **Conclusions**

322 The efficiency of the VS-model has been tested previously using extensive dendrochronological  
323 material from the Northern Hemisphere (e.g., Evans et al., 2006; Anchukaitis et al., 2006;  
324 Touchan et al., 2012), but the parameterization of the model was not applied, i.e. the set of VS-  
325 parameters with the same values was used for the entire tree-ring dataset. A new visual  
326 parameterization approach has shown that fine-tuning of the model provides qualitatively new  
327 results that can be used to better understand various processes of tree-ring formation.

328 To better understand seasonal tree-ring growth and to verify VS-model findings, either suitable  
329 experimental data are needed or a field study for several years needs to be done, including  
330 seasonal observation of the thermo-hydrological regime of the soil, duration and rate of tracheid  
331 development, as well as measurements of their anatomical features. Such improvements should  
332 help improve understanding of the mechanisms of tree-ring formation inferred by climatic  
333 variability.

334 The application of the VS-oscilloscope for tree radial growth parametrization under different  
335 environmental conditions is a prerequisite to support the development of a VS-Growth Evolution  
336 Neural Network (fully automatic parameterization algorithm based on a specific evolution IT-  
337 approach) for the Northern Hemisphere.

338

## 339 **Acknowledgements**

340 We thank Dr. Rolf T. W. Siegwolf, Dr. Thomas M. Melvin and Prof. Kathleen A. Campbell for  
341 their valuable constructive comments and suggestions during preparation of the manuscript.

342 We also are very grateful to both reviewers for their valuable comments which improved the  
343 paper.

344 This work was supported by the Russian Scientific Foundation (project #14-14-00219).

345

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## Captions to Tables

**Table 1.** Estimated model parameters by the VS-Oscilloscope that guarantee highly significant correlations between initial tree-ring chronologies and estimated growth curve results. PlatLG – *Larix gmelinii*, PlatPO – *Picea obovate*.

## Captions to Figures

**Figure 1.** Process-based VS-model of tree-ring growth simulation and its basic blocks.

**Figure 2.** Main window of the VS-oscilloscope including two application sheets: Open Data (A) and Model Parameterization (B)

**Figure 3.** Virtual display of the VS-Oscilloscope, showing initial tree-ring chronologies (red curve), simulated chronologies with recent values of parameters (blue curve) and modeling growth time series with previous set of parameters (green curve). The number in the center of the display is the correlation between red and blue curves.

**Figure 4.** Variations of initial tree-ring residual chronology (solid grey line) and simulated tree-growth curve (dashed black line) for calibration period (1970–2009) and verification period (1950–1969) for PlatLG (A) and PlatPO (B) sites.

**Figure 5.** Average integral growth rate  $Gr(t)$  for the period (1950-2009) fitted by negative exponentially-weighted smoothing (Mclain 1974) for PlatLG (solid black line) and PlatPO (dashed grey line). The dashed black line corresponds to the critical growth rate when cell division is stopped.

**Figure 6.** Partial growth rates for a) PlatLG and b) PlatPO depending on solar irradiance  $G_{rE}(t)$  (black dots), soil moisture  $G_{rW}(t)$  (gray dash line) and temperature  $G_{rT}(t)$  (black solid line) for 1950-2009, fitted by a negative exponentially-weighted smoothing (McLain, 1974). Black and grey dots on the graph are daily values of simulated partial growth rates superimposed on each other for all growing seasons.

# Supplementary Material

## File Formats

All input and output files should be presented as ASCII files.

### Input files:

- *File of Default Parameters Values*

Filename extension is \*.par. Decimal mark is “.”, e.g. 0.01. Filename extension is \*.par.

An example:

Grrt50.par

*blank line*

*A - filter for moving average*

| Parameter value | # | Parameter       | Description  |
|-----------------|---|-----------------|--|
| 12              | 1 | T1              | Minimum temperature for tree growth                          |
| 19              | 2 | T2              | Lower end of range of optimal temperatures                   |
| 28              | 3 | T3              | Upper end of range of optimal temperatures                   |
| 33              | 4 | T4              | Maximum temperature for tree growth                          |
| 0.7             | 5 | Wmax            | Maximum soil moisture for tree growth                        |
| 0               | 6 |                 | Coefficient of temperature modulation T+b6                   |
| 100             | 7 | Tm              | Sum of temperature for start soil melting                    |
| 6               | 8 | sm <sub>1</sub> | First coefficient of soil melting                            |
| 0.002           | 9 | sm <sub>2</sub> | Second coefficient of soil melting                           |
|                 | 1 |                 |  |
| 0.05            | 0 | W <sub>0</sub>  | Initial soil moisture  |
|                 | 1 |                 |  |
| 40              | 1 | Pmax            | Maximum daily precipitation for saturated soil               |
|                 | 1 |                 |  |
| 0.09            | 2 | Wmin            | Minimum soil moisture (wilting point)                        |
|                 | 1 |                 |  |
| 400             | 3 | lr              | Depth of root system (mm)                                    |
|                 | 1 |                 |  |
| 0.1675          | 4 | C2              | First coefficient for calculation of transpiration           |
|                 | 1 |                 |  |
| 0.385           | 5 | C3              | Second coefficient for calculation of transpiration          |
|                 | 1 |                 | Fraction of precip. penetrating soil (not caught by crown)   |
| 0.91            | 6 | C1              | (rel. unit)  |
|                 | 1 |                 | Minimum soil moisture for tree growth, relative to saturated |
| 0.02            | 7 | W1              | soil (v/vs)  |
|                 | 1 |                 | Lower end of range of optimal soil moistures (v/vs)          |
| 0.2             | 8 | W2              |  |
|                 | 1 |                 | Upper end of range of optimal soil moistures (v/vs)          |
| 0.5             | 9 | W3              |  |
| 0.09            | 2 | W4              | Maximum soil moisture for tree growth (v/vs)                 |

|     |   |     |   |
|-----|---|-----|---|
|     | 0 |     |   |
|     | 2 |     |   |
| 0   | 1 | Cd  | Coefficient for water drainage from soil (rel. unit)      |
|     | 2 |     |   |
| 100 | 2 | Tg  | Sum of temperature to start growth                        |
|     | 2 |     |   |
| 7.9 | 3 | Sno | Initial snowpack  |
|     | 2 |     |   |
| 1   | 4 |     | Rate of snow melting                                      |
|     | 2 |     |   |
| 2   | 5 |     | Minimum temperature snow melting                          |
|     | 2 |     |   |
| 1   | 6 |     | Temperature correction on elevation                       |
|     | 2 |     |   |
| 0   | 7 |     | This parameter is changed by program                      |
|     | 2 |     |   |
| 1   | 8 |     | Coefficient of precipitation modification                 |
|     | 2 |     |   |
| 0   | 9 |     | This parameter is changed by program                      |
|     | 3 |     |   |
| 0.5 | 0 |     | Delta for parameter                                       |
|     | 3 |     |   |
| 1   | 1 |     | Coefficient of solar modification                         |
|     |   |     |   |
| 0   | 1 |     | Soil melting if 1, no soil melting if 0                   |
| 1   | 2 |     | This parameter is changed by program                      |
| 1   | 3 |     | Estimation with pause for each 5 years if 1, without if 0 |
| 0   | 4 |     | Snow melting if 1, no 0                                   |
| 0   | 5 |     | This parameter is changed by program                      |
| 1   | 6 |     | This parameter is changed by program                      |
| 125 | 7 |     | This parameter is changed by program                      |
| 50  | 8 |     | Maximum duration (days) of latewood formation             |
| 10  | 9 |     | Period of sum temp. to start growth                       |
|     | 1 |     |   |
| 10  | 0 |     | Period of sum temp. to start soil melting                 |
|     | 1 |     |   |
| 153 | 1 |     | This parameter is changed by program                      |
|     | 1 |     |   |
| 272 | 2 |     | This parameter is changed by program                      |
|     | 1 |     |   |
| 0   | 3 |     | Options for procedure CSCALC 0-4, no calculation if 5     |
|     | 1 |     |   |
| 0   | 4 |     | This parameter is changed by program                      |
|     | 1 |     |   |
| 0   | 5 |     | Period of cell enlargement after last division            |
|     | 1 |     |   |
| 0   | 6 |     | This parameter is changed by program                      |
|     | 1 |     |   |
| 0   | 7 |     | This parameter is changed by program                      |
|     | 1 |     |   |
| 1   | 8 |     | Number of parameter which is changed                      |
| 1   | 1 |     | Number of iterations                                      |

9  
2  
50 0 Skale win 5

*Parameters for calculation cambial activity (type of parameters - integer)*

0 1 The testing growth rate 1 or const=b3, 2  
To open output file of cellular parameters (precipitation) - 1,  
no - 0  
1 2  
0 3 To open output file of cellular divisions - 1, no - 0  
0 4 This parameter is changed by program  
30 5 Vp  
2 6 Vp  
0 7 Vp  
30 8 This parameter is changed by program  
0 9 This parameter is changed by program  
1  
0 0 This parameter is changed by program

*Parameters for calculation cambial activity (type of parameters - real)*

0.07 1 V<sub>cr</sub> Critical growth rate  
0 2 This parameter is changed by program  
0 3 If k1=2 Growth rate Gr=const=b3  
0.8 4 Correction of growth rate (Gr\*b4)  
1 5 Correction of Vo(j\*b5) and Vmin(j\*b5)  
0.1 6 B6 Vo(j)=B6\*j+B7  
0.2 7 B7 B7 and B6 determinate the fuction Vo(j)  
0.4 8 B8 Vmin(j)=B9\*EXP(j\*B8\*B5)  
0.04 9 B8 B8 and B9 determinate the fuction Vmin(j)  
1  
1 0 V<sub>o</sub> Growth rate in S,G2 & M phases  
1  
8 1 D<sub>G1</sub> Max size in G1-phase  
1  
9 2 D<sub>s</sub> Max size in S-phase  
1  
9.5 3 D<sub>G2</sub> Max size in G2-phase  
1  
10 4 D<sub>m</sub> Max size in M-phase  
1  
1 5 is the time step in cambium model  
1  
30 6 This parameter is changed by program  
1  
0 7 This parameter is changed by program  
1  
0 8 This parameter is changed by program  
1  
85 9 Maximum period without division to enter into dormancy  
2  
20 0 Number cells in the ring (for graphic output)

*Parameters for calculation number of cells and cell size (type of parameters - real)*



|      |   |                                      |
|------|---|--------------------------------------|
| 3    | 1 | P1+P2*LOG(N/P3)                      |
| 1.56 | 2 | This parameter is changed by program |
| 3    | 3 | This parameter is changed by program |
| 0    | 4 | This parameter is changed by program |
| 40   | 5 | This parameter is changed by program |
| 0.25 | 6 | CWT=P6* D                            |
| 40   | 7 | Average cell size                    |
| 0    | 8 | This parameter is changed by program |
| 4    | 9 | This parameter is changed by program |
|      | 1 |                                      |
| 1    | 0 | This parameter is changed by program |

*Parameters for calculation number of cells and cell size (type of parameters - integer)*

|    |                                      |
|----|--------------------------------------|
| 10 | This parameter is changed by program |
| 0  | This parameter is changed by program |
| 0  | This parameter is changed by program |
| 0  | This parameter is changed by program |
| 0  | This parameter is changed by program |
| 0  | This parameter is changed by program |
| 0  | This parameter is changed by program |
| 0  | This parameter is changed by program |
| 0  | This parameter is changed by program |
| 0  | This parameter is changed by program |
| 0  | This parameter is changed by program |

*Files of climatic data.*

Each file contains daily climatic data (temperature, precipitation) for the certain year. Therefore, a number of climatic files is equal to number of observed years.

Filename extension is \*.cli.

Day (DA), Month (MO), Year (YE), Daily precipitation (mm\*10), Daily temperature (<sup>0</sup>C\*10).

Blank data should be filled as 0 for precipitation, -9999 for temperature. Filename extension is \*.cli.

An example:

Tura1950.cli

|   |   |      |    |      |
|---|---|------|----|------|
| 1 | 1 | 1950 | 0  | -476 |
| 2 | 1 | 1950 | 14 | -409 |
| 3 | 1 | 1950 | 0  | -305 |
| 4 | 1 | 1950 | 1  | -425 |
| 5 | 1 | 1950 | 0  | -477 |
| 6 | 1 | 1950 | 3  | -438 |
| 7 | 1 | 1950 | 0  | -456 |
| 8 | 1 | 1950 | 0  | -450 |
| 9 | 1 | 1950 | 3  | -410 |

|    |    |      |    |      |
|----|----|------|----|------|
| 10 | 1  | 1950 | 14 | -365 |
| 11 | 1  | 1950 | 12 | -353 |
| 12 | 1  | 1950 | 11 | -344 |
| 13 | 1  | 1950 | 2  | -437 |
| 14 | 1  | 1950 | 2  | -479 |
| 15 | 1  | 1950 | 0  | -526 |
|    |    | ...  |    |      |
| 15 | 12 | 1950 | 2  | -360 |
| 16 | 12 | 1950 | 0  | -269 |
| 17 | 12 | 1950 | 0  | -208 |
| 18 | 12 | 1950 | 0  | -273 |
| 19 | 12 | 1950 | 4  | -384 |
| 20 | 12 | 1950 | 2  | -425 |
| 21 | 12 | 1950 | 0  | -468 |
| 22 | 12 | 1950 | 5  | -368 |
| 23 | 12 | 1950 | 0  | -384 |
| 24 | 12 | 1950 | 0  | -532 |
| 25 | 12 | 1950 | 0  | -568 |
| 26 | 12 | 1950 | 0  | -577 |
| 27 | 12 | 1950 | 0  | -562 |
| 28 | 12 | 1950 | 0  | -562 |
| 29 | 12 | 1950 | 0  | -561 |
| 30 | 12 | 1950 | 0  | -547 |
| 31 | 12 | 1950 | 0  | -535 |

*File of tree-ring chronologies*

Filename extension is \*.crn.

The file of tree-ring chronologies should contain three columns of values: Year, Index. Decimal mark is “.”, e.g. 1.115.

An example:

```

PlatLG.crn
1950  1.115
1951  0.522
1952  1.025
1953  1.036
1954  1.303
1955  0.909

2000  1.385
2001  1.587
2002  1.122
2003  1.615
2004  1.152
2005  1.161
2006  1.203

```

|      |       |
|------|-------|
| 2007 | 0.836 |
| 2008 | 1.461 |
| 2009 | 1.097 |

*Latitude* of dendrochronological site should be in the next format “degrees.digital degree”. For example 64.17° N (latitude of meteorological station) should be written as 64.17 in the VS-Oscilloscope application.

*Year of Ending of Calculation*, e.g. if the observation period is 1975-1989, the first file of climatic data should be 1975.cli, and 1989 can be used as the Year of Ending of Calculation.

### Output files

File of chronologies.

Filename extension is \*.dat, e.g. Tura1970-1974.dat.

The file contains the next columns of values: simulated growth index (indc); initial tree-ring chronology (crn); start date of growing season (BG1); end date of growing season (EG1); start and end date of growing season (BG2 and EG2, correspondently) in case of bimodal growing season.

An example:

Tura1970-1974.dat

| year | indc | crn  | NMOD  | NCRN  | BG1 | EG1 | BG2 | EG2 |
|------|------|------|-------|-------|-----|-----|-----|-----|
| 1970 | 1,04 | 1,01 | 0,12  | 0     | 170 | 220 | 0   | 0   |
| 1971 | 0,67 | 0,96 | -0,99 | -0,17 | 194 | 233 | 0   | 0   |
| 1972 | 1,19 | 0,85 | 0,59  | -0,54 | 164 | 225 | 0   | 0   |
| 1973 | 0,58 | 0,77 | -1,29 | -0,79 | 197 | 228 | 0   | 0   |
| 1974 | 0,1  | 0,63 | -2,74 | -1,22 | 180 | 199 | 0   | 0   |

File of rates.

Filename extension is \*.dat, e.g. Tura rate 1975-1989.dat.

The file contains the next columns of values: Year, Date t, Temperature Tem (°C), precipitation Prec (mm), soil moisture SM, depth of thawed soil Dep (mm), integral growth rate Gr daily

based, partial rate depended on soil moisture Grw, temperature Grt, solar radiation Solar daily based and cumulative growth rate Cumul.

An example:

Tura rate 1987-1987.dat

| year | t   | Tem    | Prec | sm    | Dep | Gr   | Grw  | GrT  | Solar | Cumul |
|------|-----|--------|------|-------|-----|------|------|------|-------|-------|
| 1987 | 1   | -50,84 | 0,2  | 0,338 | 400 | 0    | 1    | 0    | 0,01  | 0     |
| 1987 | 2   | -50,56 | 0,2  | 0,338 | 400 | 0    | 1    | 0    | 0,01  | 0     |
| 1987 | 3   | -50,85 | 0    | 0,339 | 400 | 0    | 1    | 0    | 0,02  | 0     |
| 1987 | 4   | -51,26 | 0    | 0,339 | 400 | 0    | 1    | 0    | 0,02  | 0     |
| 1987 | 5   | -51,61 | 0    | 0,339 | 400 | 0    | 1    | 0    | 0,02  | 0     |
| 1987 | 6   | -51,83 | 0    | 0,339 | 400 | 0    | 1    | 0    | 0,02  | 0     |
| ...  | ... | ...    | ...  | ...   | ... | ...  | ...  | ...  | ...   | ...   |
| 1987 | 182 | 12,69  | 0    | 0,554 | 400 | 0,1  | 0,27 | 0,1  | 0,98  | 0,1   |
| 1987 | 183 | 12,79  | 7,6  | 0,549 | 400 | 0,11 | 0,24 | 0,11 | 0,98  | 0,21  |
| 1987 | 184 | 13,25  | 6,7  | 0,56  | 400 | 0,17 | 0,3  | 0,18 | 0,98  | 0,38  |
| 1987 | 185 | 13,86  | 8,1  | 0,563 | 400 | 0,26 | 0,31 | 0,27 | 0,97  | 0,64  |
| 1987 | 186 | 14,32  | 0    | 0,559 | 400 | 0,29 | 0,29 | 0,33 | 0,97  | 0,92  |
| 1987 | 187 | 14,78  | 0    | 0,529 | 400 | 0,14 | 0,15 | 0,4  | 0,97  | 1,07  |
| 1987 | 188 | 15,26  | 0    | 0,512 | 400 | 0,06 | 0,06 | 0,47 | 0,96  | 1,12  |
| 1987 | 189 | 16,45  | 0    | 0,503 | 400 | 0,02 | 0,02 | 0,64 | 0,96  | 1,14  |
| 1987 | 190 | 18,35  | 0    | 0,5   | 400 | 0,86 | 1    | 0,91 | 0,95  | 2     |