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VS-oscilloscope: A new tool to parameterize tree radial growth based on climate conditions☆

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ABSTRACT

It is generally assumed in dendroecological studies that annual tree-ring growth is adequately determined by a linear function of local or regional precipitation and temperature with a set of coefficients that are temporally invariant. However, various researchers have maintained that tree-ring records are the result of multivariate, often nonlinear biological and physical processes. To describe critical processes linking climate variables with tree-ring formation, the process-based tree-ring Vaganov–Shashkin model (VS-model) was successfully used. However, the VS-model is a complex tool requiring a considerable number of model parameters that should be re-estimated for each forest stand. Here we present a new visual approach of process-based tree-ring model parameterization (the so-called VS-oscilloscope) which allows the simulation of tree-ring growth and can be easily used by researchers and students. The VS-oscilloscope was tested on tree-ring data for two species (*Larix gmelinii*and *Picea obovata*) growing in the permafrost zone of Central Siberia. The parameterization of the VS-model provided highly significant positive correlations ($p < 0.0001$) between simulated growth curves and original tree-ring chronologies for the period 1950–2009. The model outputs have shown differences in seasonal tree-ring growth between species that were well supported by the field observations. To better understand seasonal tree-ring growth and to verify the VS-model findings, a multi-year natural field study is needed, including seasonal observation of the thermo-hydrological regime of the soil, duration and rate of tracheid development, as well as measurements of their anatomical features.

1. Introduction

Tree-ring growth and wood formation are strongly affected by climatic variations in boreal zones of the Northern Hemisphere. Often the formation of tree rings is defined as a linear function of local or regional precipitation and temperature with a set of coefficients that are temporally invariant. However, various researchers have 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, including age-dependent effects, specific local environmental conditions, fire disturbances, and insect outbreaks (Fritts, 1976; Cook and Kairiukstis, 1990; Dale et al., 2001; D'Arrigo et al., 2001; Kirdyanov et al., 2012, 2013; Shishov, 2000; Shishov et al., 2002; Touchan et al., 2014; Varga et al., 2005). The temporal nonstationarity of biological tree-ring response to climate may also be connected with local climatic variation itself (Fritts et al., 1991; Fritts and Shashkin, 1995; Aykroyd et al., 2001; Briffa et al., 2008; Bunn et al., 2013; Evans et al., 2013; Schweingruber, 1996; Shishov and Vaganov, 2010; Vaganov et al., 2006; Touchan et al., 2012). The process-based tree-ring Vaganov–Shashkin model (VS-model) can be used to describe critical processes linking climate variables with tree-ring formation (Vaganov et al., 2006).

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 (Vaganov et al., 2006).

Several publications have described the use of the model in different environmental conditions and various conifer species. For example, the potential of the VS-model was used to simulate tree-ring growth of conifers in North America (Evans et al., 2006). A

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total of 190 tree-ring chronologies were adequately simulated in different parts of the United States in this first broad-scale application of the VS-model for simulating tree-ring width data used for statistical paleoclimatology. The obtained results showed that the analyzed broad-scale network of tree-ring chronologies can be used primarily as climate proxies for their further use in statistical paleoclimatic reconstructions. Furthermore, Anchukaitis et al. (2006) used the VS-model in a case study for the southeastern United States region to understand if tree-ring chronologies across the warm, mesic climate conditions could be simulated as a function of climate alone. They showed that there is a significant correlation between simulated and observed tree-ring width data (Anchukaitis et al., 2006). Moreover, application of the process-based model in the Mediterranean region demonstrates the ability to explain observed patterns of tree-growth variation in the past and to simulate tree-ring growth in extreme drought conditions (Touchan et al., 2012).

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

The model requires 42 input parameters, which should be reasonably estimated for different forest stands (Vaganov et al., 2006). Twenty-seven parameters are used to estimate an integral tree-ring growth rate, or growth rate $Gr(t)$ (Vaganov et al., 2006; Evans et al., 2006; Touchan et al., 2012). Another 15 parameters are needed to calculate cell production and cell sizes based on simulated values of seasonal integral growth rates (Vaganov et al., 2006). It is noteworthy that the model is sensitive to changes of some VS-parameters, and even small changes of these values significantly affect the simulated tree-ring growth. Thus, for the northern timberline these parameters are directly connected with local temperature conditions (Vaganov et al., 2006). For the Mediterranean area, up to 60% of tree-ring variation can be explained by the soil moisture regime, which is simulated by observed precipitation and particular VS-parameters (Touchan et al., 2012). Such a large number of parameters makes the VS-model difficult to operate, and for practical use the model needs to be simplified.

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

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

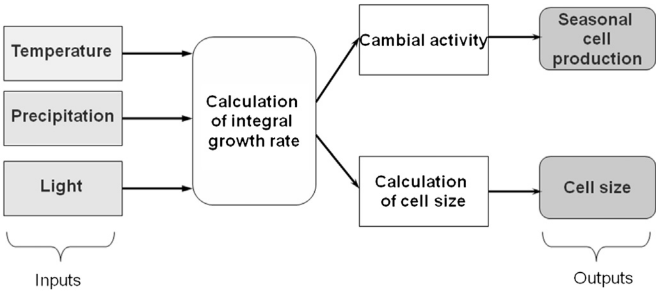

Fig. 1. Process-based VS-model of tree-ring growth simulation and its basic blocks.

2. Material and methods

2.1. Study area

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

Wood samples (cores and/or disks) of larch (*Larix gmelinii* (Rupr.) Rupr.) up to 471-years old and spruce trees (*Picea obovata* Ledeb.) up to 276-years old were taken for the analysis in a spruce-larch mixed stand with an admixture of birch (*Betula pubescens*). The ground vegetation mainly consists of ledum (*Ledum palustre* L.), mosses (*Pleurozium schreberi* (Brid.) Mit., *Aulocomnium palustre* (Hedw.) Schwaegr.) and lichens (*Cladina* spp., *Cetraria* spp.).

2.2. Wood sampling, tree-ring width measurements and climatic data

Wood sampling was performed during the autumn of 2009 on about 25 trees per species. Annual tree-ring width (TRW) was measured using a LINTAB measuring table with 0.01 mm precision combined with the program TSAP (Rinntech, Heidelberg, Germany). The resulting time-series were visually cross-dated and the dating quality verified using the program COFECHA (Holmes, 2001). To avoid the influence of non-climatic factors (age-depending trends, abrupt changes (fires, insects), etc.) on tree-ring growth a 50%-variance cubic smoothing spline with 2/3 cut-off length of time series was used as the detrending method (Cook, 1985). Along with standard tree-ring chronologies, residual chronologies (PlatLG—*L. gmelinii* and PlatPO—*P. obovata*) were used for tree-ring growth simulation.

Daily mean temperature and precipitation amount data (A.D. 1950–2009) were used from the Tura weather station (64.27° N; 100.23° E, 188 m a.s.l.)

3. Model description

3.1. Brief description of basic VS-algorithm

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

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

$$Gr(t) = Gr_E(t) \times \min\{Gr_T(t), \mathrm{Gr}_W(t)\},$$

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

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

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

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

3.2. *VS-oscilloscope: conception and realization*

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

By definition, an oscilloscope (also known as a scope, CRO, DSO or an O-scope) is a type of electronic test instrument which allows observation and analysis of constantly varying signal voltages as a two-dimensional graph of one or more electrical potential differences using the *Y*-axis, plotted as a function of time on the *X*-axis. The oscilloscope is used to observe the change of an electrical signal over time, so that voltage and time describe a shape which is continuously graphed against a calibrated scale (Kularatna, 2003). Simple manipulation of amplitude, frequency, phase and other values allows simulation of an electrical signal of any complexity.

Potentially any tree-ring chronology can be considered as an analogue of "electrical signal," in which case parameters of the VS-model play the role of manipulators that modify the "signal". By interactively changing the parameter values, we can observe the variation of climatic signal in a tree-ring chronology. Moreover, we can correct the selected values of parameters according to the direct observations and knowledge. Therefore, we named this new parameterization approach "VS-oscilloscope".

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

The VS-oscilloscope contains two different window sheets: (1) The "Open Data" sheet, where users should upload the files of initial parameter values (*.par), climatic data (*.cli), tree-ring chronology (*.crn), latitude value for the site of interest, and the final value of the year before the start of calculation (Fig. 2A)[2]; and (2) The "Model parameterization" sheet, which contains scroll-bars for most parameters of the model, such as minimum temperature for tree growth, critical growth rate, etc. (Fig. 2B). Values of the parameters can be changed manually in the Model Parameterization sheet. By moving scroll-bars along value scale to the left (or right), we can decrease (or increase) values of the parameters. Other parameters not presented in the sheet can be changed in the file of parameters directly before running the program.

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

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

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

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

3.3. *Differences between software versions*

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

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

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

where E—the extraterrestrial daily irradiance received on a horizontal surface, Btu/Day-sq ft; I_{sc}—the solar constant; r—the ratio of solar radiance intensity at normal incidence outside of Earth's atmosphere to solar constant, dimensionless, L—latitude, degrees; δ—solar declination angle, degrees; ω—sunset hour angle, radians.

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

$$Gr_W(t)\_corr = Gr_W(t) \times dep(t)/Lr,$$

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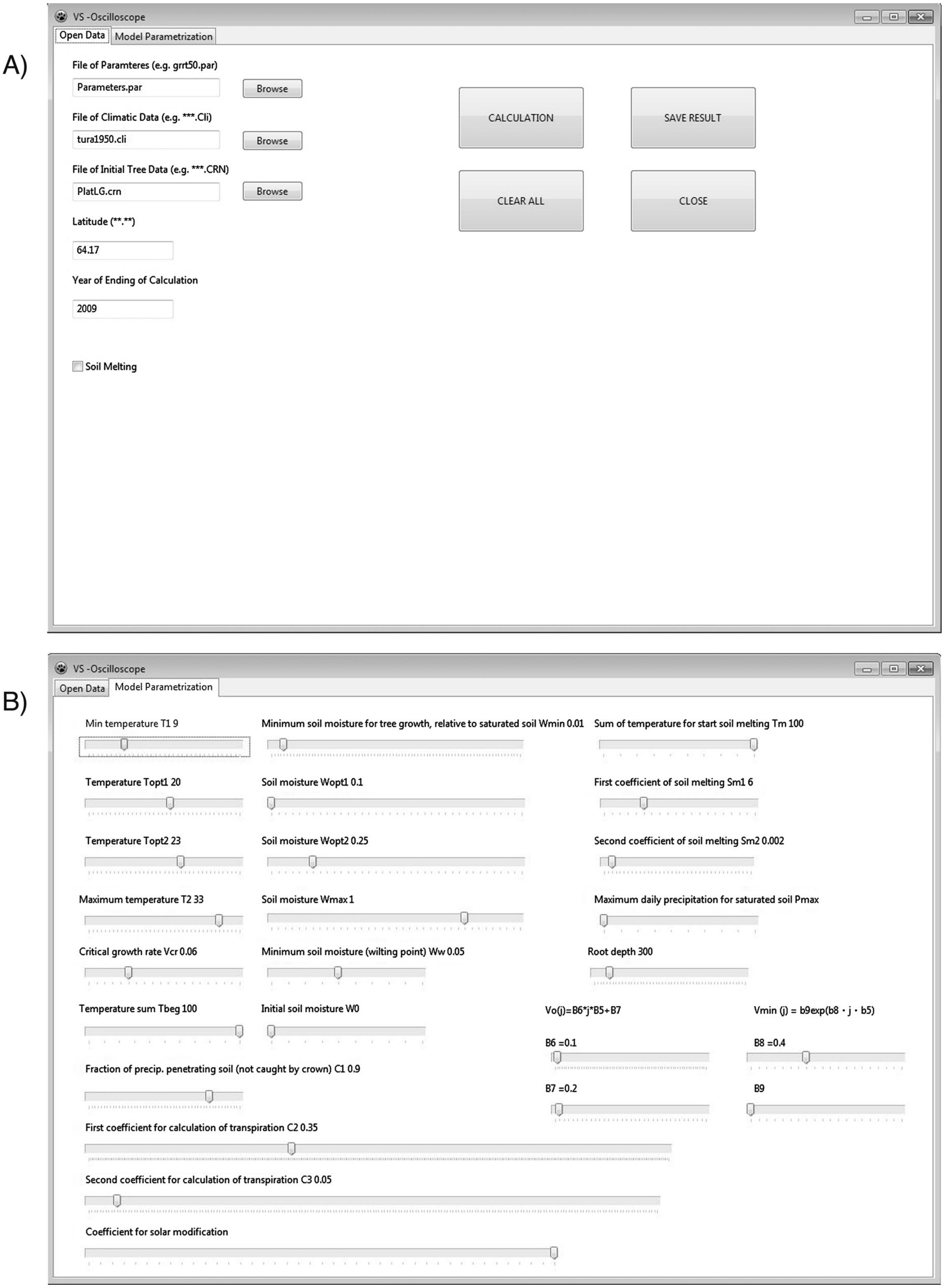
[1] The Lazarus Code of the VS-oscilloscope and distributive package (free using license) can be downloaded from the http://vs-genn.ru/downloads/. Technical questions can be addressed to Mr. Ivan Tychkov: ivan.tychkov@gmail.com.

[2] See a detailed description of file formats in Supplementary material.



File of Paramteres (e.g. grrt50.par)
Parameters.par
File of Climatic Data (e.g. ***.Cli)
tura1950.cli
File of Initial Tree Data (e.g. ***.CRN)
PlatLG.crn
Latitude (**.**)
64.17
Year of Ending of Calculation
2009
☐ Soil Melting

Min temperature T1 9
Temperature Topt1 20
Temperature Topt2 23
Maximum temperature T2 33
Critical growth rate Vcr 0.06
Temperature sum Tbeg 100
Fraction of precip. penetrating soil (not caught by crown) C1 0.9
First coefficient for calculation of transpiration C2 0.35
Second coefficient for calculation of transpiration C3 0.05
Coefficient for solar modification
Minimum soil moisture for tree growth, relative to saturated soil Wmin 0.01
Soil moisture Wopt1 0.1
Soil moisture Wopt2 0.25
Soil moisture Wmax 1
Minimum soil moisture (wilting point) Ww 0.05
Initial soil moisture W0
Sum of temperature for start soil melting Tm 100
First coefficient of soil melting Sm1 6
Second coefficient of soil melting Sm2 0.002
Maximum daily precipitation for saturated soil Pmax
Root depth 300
Vo(j)=B6*j*B5+B7
B6 =0.1
B7 =0.2
Vmin (j) = b9exp(b8 • j • b5)
B8 =0.4
B9

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

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

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

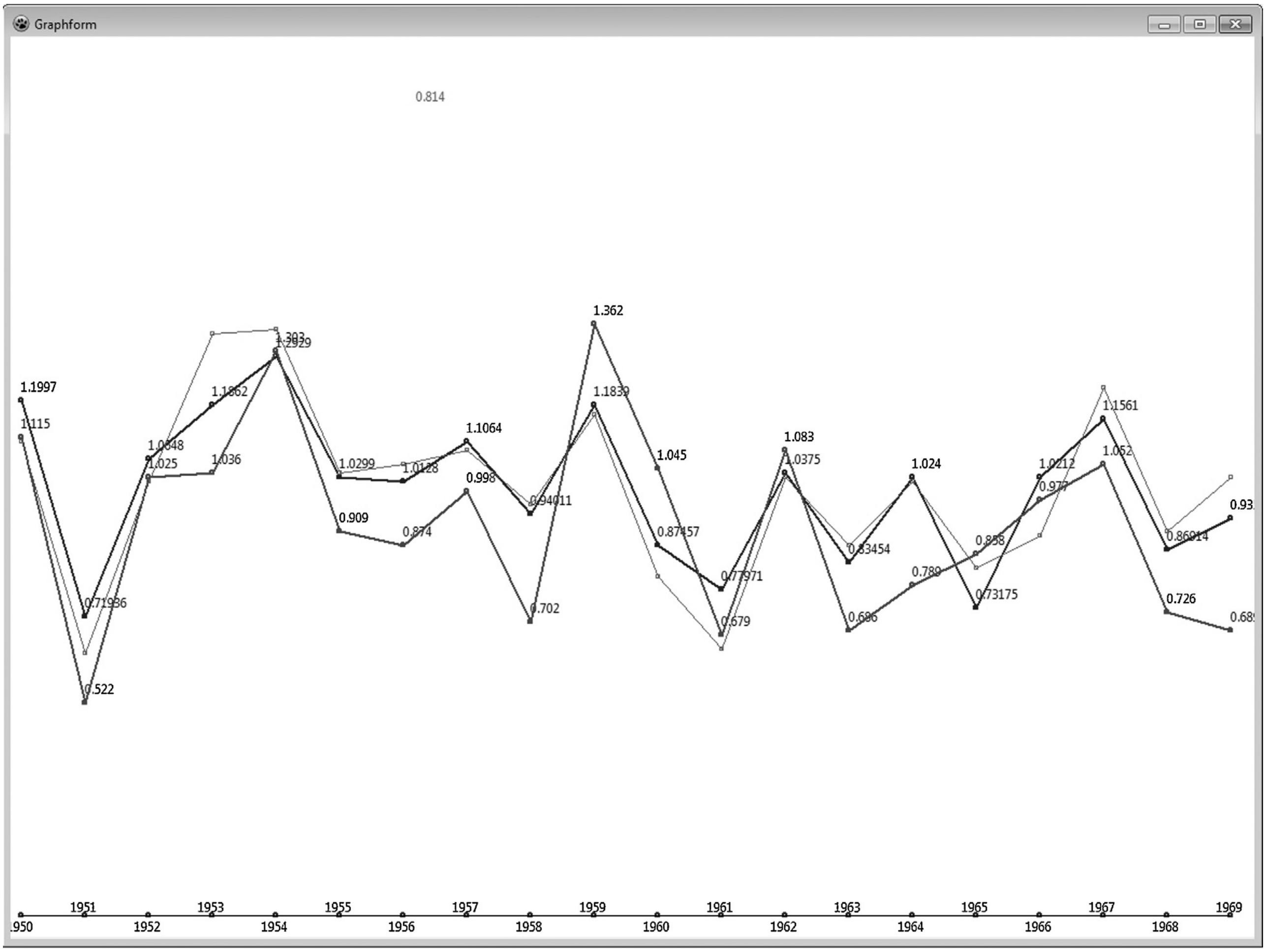


Fig. 3. Virtual display of the VS-oscilloscope, showing initial tree-ring chronologies (red curve), simulated chronologies with recent values of parameters (blue curve) and modeling growth time series with previous set of parameters (green curve). The number in the center of the display is the correlation between red and blue curves. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

4. Results and discussion

With the estimated VS-parameters by the VS-oscilloscope (see Table 1) we obtained highly significant positive correlation between the initial tree-ring chronologies and estimated growth curves (PlatLG: $R = 0.70$, $p < 0.0001$; PlatPO: $R = 0.65$, $p < 0.0001$; $n = 40$ years) for the calibration period 1970–2009 (Fig. 4A and B correspondingly). In fact, climate variability explains 42–49% of tree-ring growth variation in these particular cases.

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

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

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

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

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

The start dates of growing seasons vary from the end of May to the start of June for both species (Fig. 5), which is in accordance with the direct observations (Rinne et al., 2015). The simulated average duration of the growing season is approximately the same for both species (PlatLG: 75 (±15) days; PlatPO: 80 (±15) days) (Fig. 5). Comparison of these results for larch with xylogenesis observations (Bryukhanova et al., 2013) reveals up to three weeks' differences in the duration of the growing season, which can be related to the difference in site locations: the studied site is 450 m above the one reported in Bryukhanova et al. (2013). The difference in duration of tree-ring development also may be due to difference in

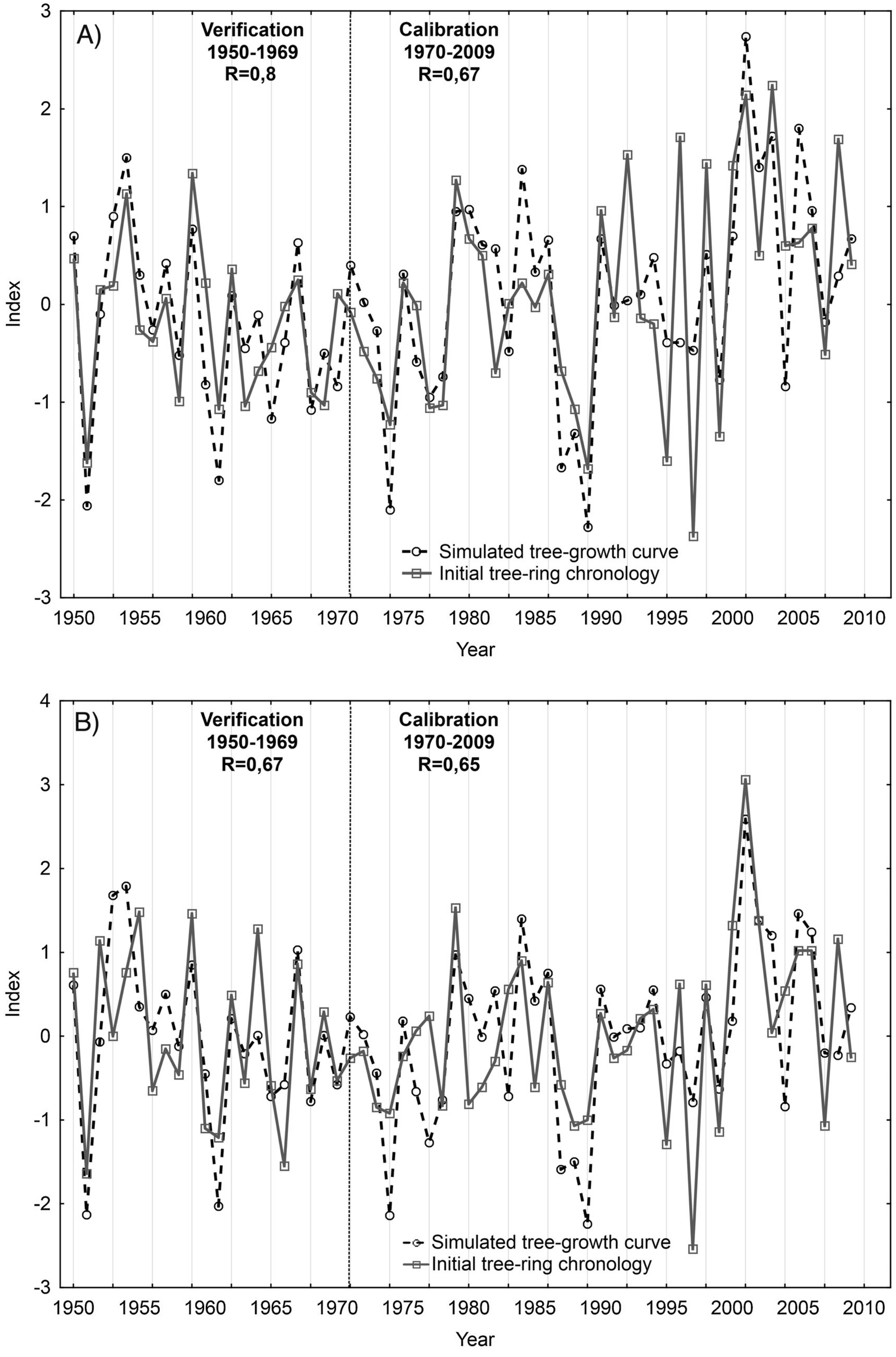


Fig. 4. Variations of initial tree-ring residual chronology (solid grey line) and simulated tree-growth curve (dashed black line) for calibration period (1970–2009) and verification period (1950–1969) for PlatLG (A) and PlatPO (B) sites.

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*.

Parameter	Description (units) value	PlatLG	PlatPO
T_{min}	Minimum temperature for tree growth (°C)	9	9
T_{opt1}	Lower end of range of optimal temperatures (°C)	22	24
T_{opt2}	Upper end of range of optimal temperatures (°C)	27	29
T_{max}	Maximum temperature for tree growth (°C)	31	34
W_{min}	Minimum soil moisture for tree growth, relative to saturated soil (v/vs)	0.02	0.06
W_{opt1}	Lower end of range of optimal soil moistures (v/vs)	0.17	0.125
W_{opt2}	Upper end of range of optimal soil moistures (v/vs)	0.475	0.275
W_{max}	Maximum soil moisture for tree growth (v/vs)	0.625	0.55
W_0	Initial soil moisture (v/vs)	0.05	0.05
W_w	Minimum soil moisture (wilting point)	0.1	0.1
T_{beg}	Temperature sum for initiation of growth (°C)	100	100
t_{beg}	Time period for temperature sum (days)	10	10
Ir	Depth of root system (mm)	500	500
P_{max}	Maximum daily precipitation for saturated soil (mm/day)	40	40
C_1	Fraction of precip. penetrating soil (not caught by crown) (rel. unit)	0.71	0.54
C_2	First coefficient for calculation of transpiration (mm/day)	0.53	0.3575
C_3	Second coefficient for calculation of transpiration (mm/day)	0.265	0.355
Λ	Coefficient for water drainage from soil (rel. unit)	0.005	0.005
Tc	Cambial model time step (days)	1.00	1.00
V_{cr}	Minimum cambial cell growth rate (no units)	0.02	0.01
D_0	Initial cambial cell size (μm)	4.000	4.000
D_{cr}	Cell size at which mitotic cycle begins (μm)	8.000	8.000
V_m	Growth rate during mitotic cycle (μm/day)	1.000	1.000
D_m	Cambial cell size at which mitosis occurs (μm)	10.00	10.00

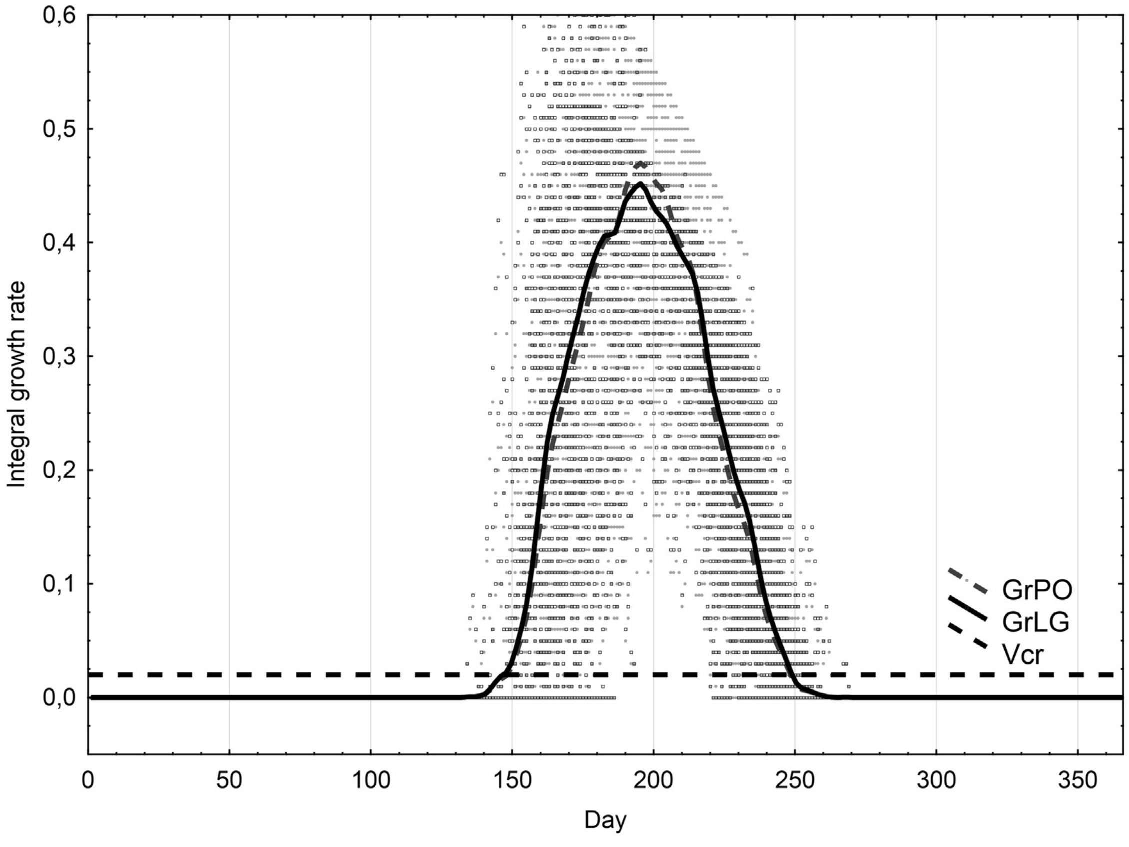


Fig. 5. Average integral growth rate Gr(t) for the period (1950–2009) fitted by negative exponentially-weighted smoothing (Mclain, 1974) for PlatLG (solid black line) and PlatPO (dashed grey line). The dashed black line corresponds to the critical growth rate when cell division is stopped.

approaches used. Thus, secondary cell wall development observed in Bryukhanova et al. (2013) may take several weeks at the end of the growing season, but does not influence the final tree-ring width simulated here.

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

The applied parameterization approach reveals a significant difference in seasonal tree-ring responses to climatic variations between species. Thus, at the start of the growing seasonal larch growth (PlatLG) is limited by temperature (lower values of $Gr_T(t)$

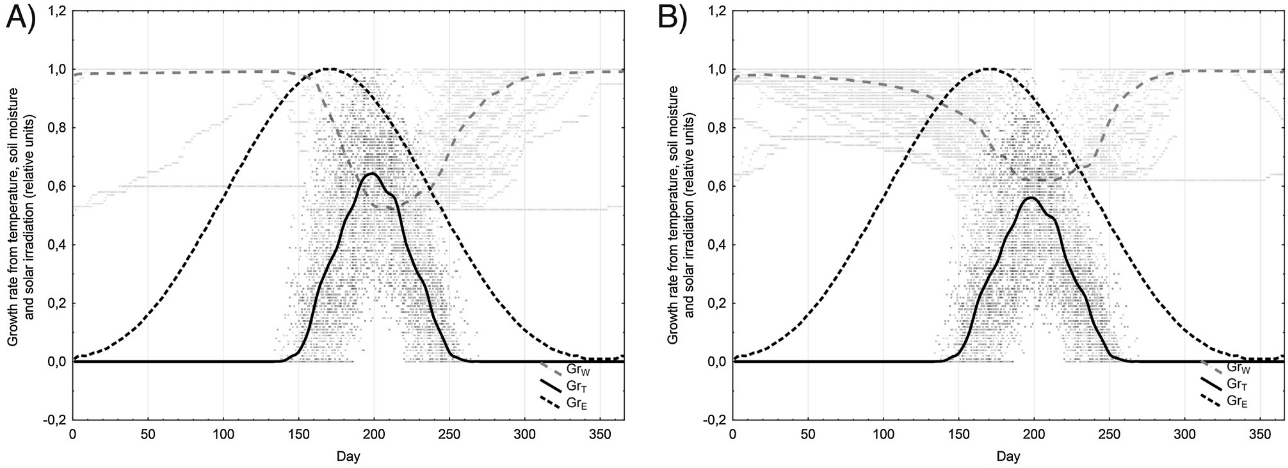


Fig. 6. Partial growth rates for (A) PlatLG and (B) PlatPO depending on solar irradiance $Gr_E(t)$ (black dots), soil moisture $Gr_W(t)$ (gray dash line) and temperature $Gr_T(t)$ (black solid line) for 1950–2009, fitted by a negative exponentially-weighted smoothing (Mclain, 1974). Black and grey dots on the graph are daily values of simulated partial growth rates superimposed on each other for all growing seasons.

in comparison with $Gr_W(t)$) (Fig. 6A). In the middle of the season there is a change of limiting factor (lower values of $Gr_W(t)$). Soil moisture starts to play a key role in tree-ring formation until the end of the growing season, when again temperature becomes the principal factor limiting tree-ring growth (Fig. 6A). Such temperature-precipitation effects were shown by previous studies of larch trees at some sites in the studied region (Kirdyanov et al., 2013; Kujansuu et al., 2007)

In comparison, spruce is less sensitive to seasonal soil moisture changes (Fig. 6B). During the growing season, the tree-ring growth of spruce is limited by temperature changes (Fig. 6B). This quite surprising result can be explained by the fact that spruce trees prefer and grow in moister habitats, which are formed in local depressions and associated with troughs. However, the VS-parameterization indirectly explains this result: minimum soil moisture for larch growth is three times less than for spruce (W_{min} is 0.02 for PlatLG and 0.06 for PlatPO) (Table 1).

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

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

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

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

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

Although tree-ring growth is influenced by permafrost conditions in the region (Kirdyanov et al., 2013), we excluded a soil melting estimation because the particular block of the VS-model needs to be improved using data from long-term experiments of soil observation (soil melting and soil moisture content) in different environments.

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

5. Conclusions

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

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

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

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.dendro.2015.10.001.

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