Dendrochronologia 39 (2016) 42–50

Contents lists available at ScienceDirect

Dendrochronologia

journal homepage: www.elsevier.com/locate/dendro

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

Vladimir V. Shishov[a,*], Ivan I. Tychkov[a], Margarita I. Popkova[a], Victor A. Ilyin[a], Marina V. Bryukhanova[b], Alexander V. Kirdyanov[a,b]

[a] Siberian Federal University, Math Methods and IT Department, 660075 Krasnoyarsk, Russia
[b] V.N Sukachev Institute of Forest SB RAS, Laboratory of Tree-Ring Structure, 660036 Krasnoyarsk, Russia

ARTICLE INFO

Article history:
Received 16 June 2015
Received in revised form
23 September 2015
Accepted 6 October 2015
Available online 20 October 2015

Keywords:
VS-model
Parameterization
VS-oscilloscope
Central Siberia
Permafrost
Tree-ring width
Tree-ring growth
Climate signal
Non-linear response
Tree-ring growth rates
Larch
Spruce

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

☆ This article is part of a special issue entitled "Russian tree-ring research".
* Corresponding author.
E-mail address: vlad.shishov@gmail.com (V.V. Shishov).

http://dx.doi.org/10.1016/j.dendro.2015.10.001

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.

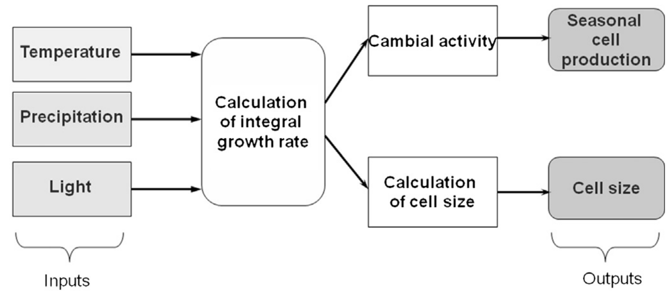

Fig. 1. Process-based VS-model of tree-ring growth simulation and its basic blocks.

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:

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