VS-LITE

Jan Tumajer

Charles University, Prague
Czech Republic
tumajerj@natur.cuni.cz

UNTERSTÜTZT VON / SUPPORTED BY
Alexander von HUMBOLDT STIFTUNG

VS-LITE

Low-complexity non-linear sink-oriented process-based model of wood formation

Tolwinski-Ward, S.E., Evans, M.N., Hughes, M.K., Anchukaitis, K.J., 2011. An efficient forward model of the climate controls on interannual variation in tree-ring width. Clim. Dyn. 36, 2419–2439. https://doi.org/10.1007/s00382-010-0945-5

HOW TO QUANTIFY CLIMATE-GROWTH RESPONSES?

1. Statistical approaches

- Statistical function (e.g., linear regression) → statistical parameter(s) (e.g., correlation)

  \+ Easy to implement (mathematical definitions)

  \- Statistical assumptions (≠ ecological reality)

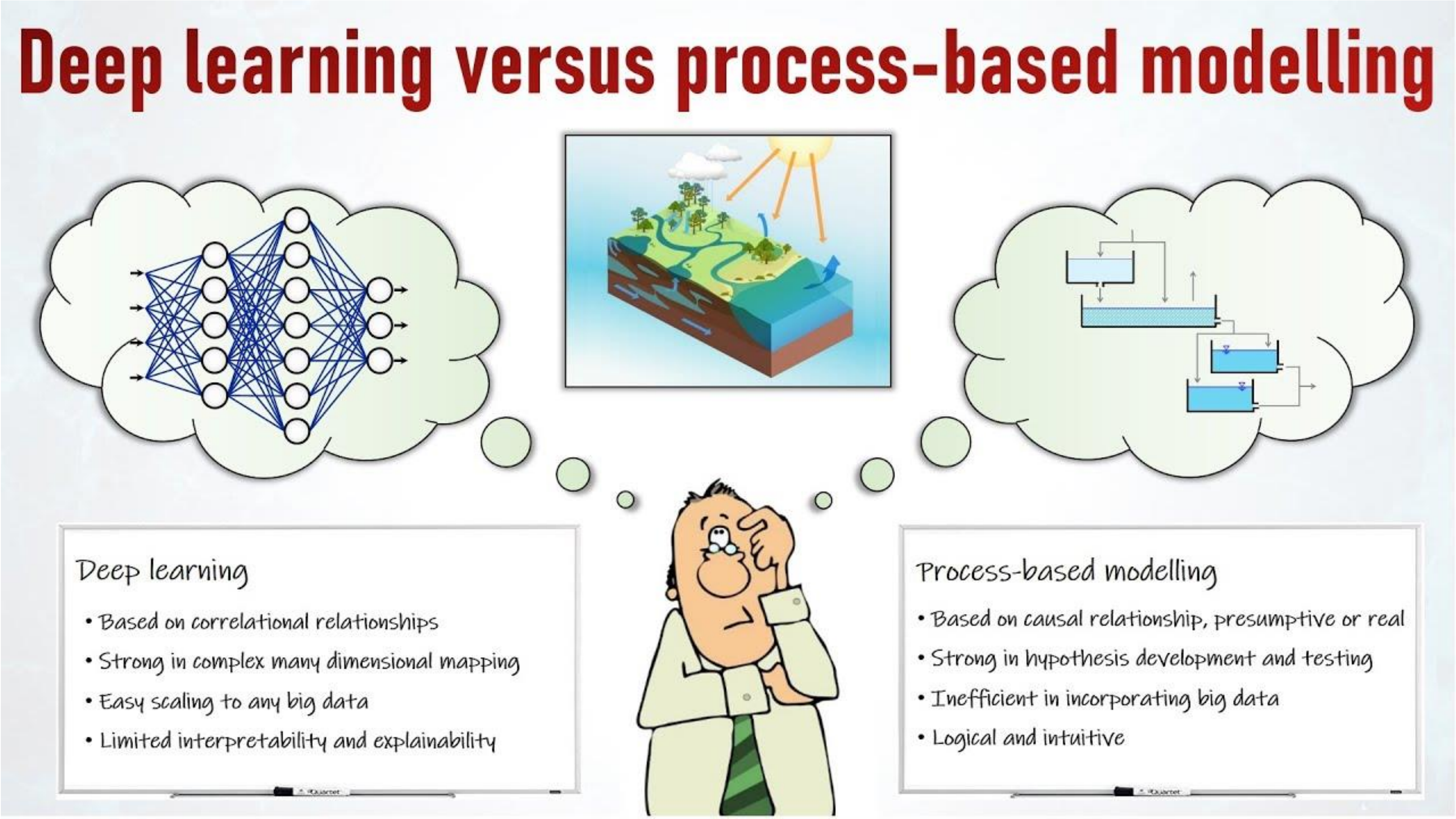
2. (Climate-driven) process-based models of tree-ring formation

- Set of equations implementing current state of knowledge about climatic effects on kinetics and phenology

  \- Complexity, input requirements

  \+ Realistic implementation of ecological principles

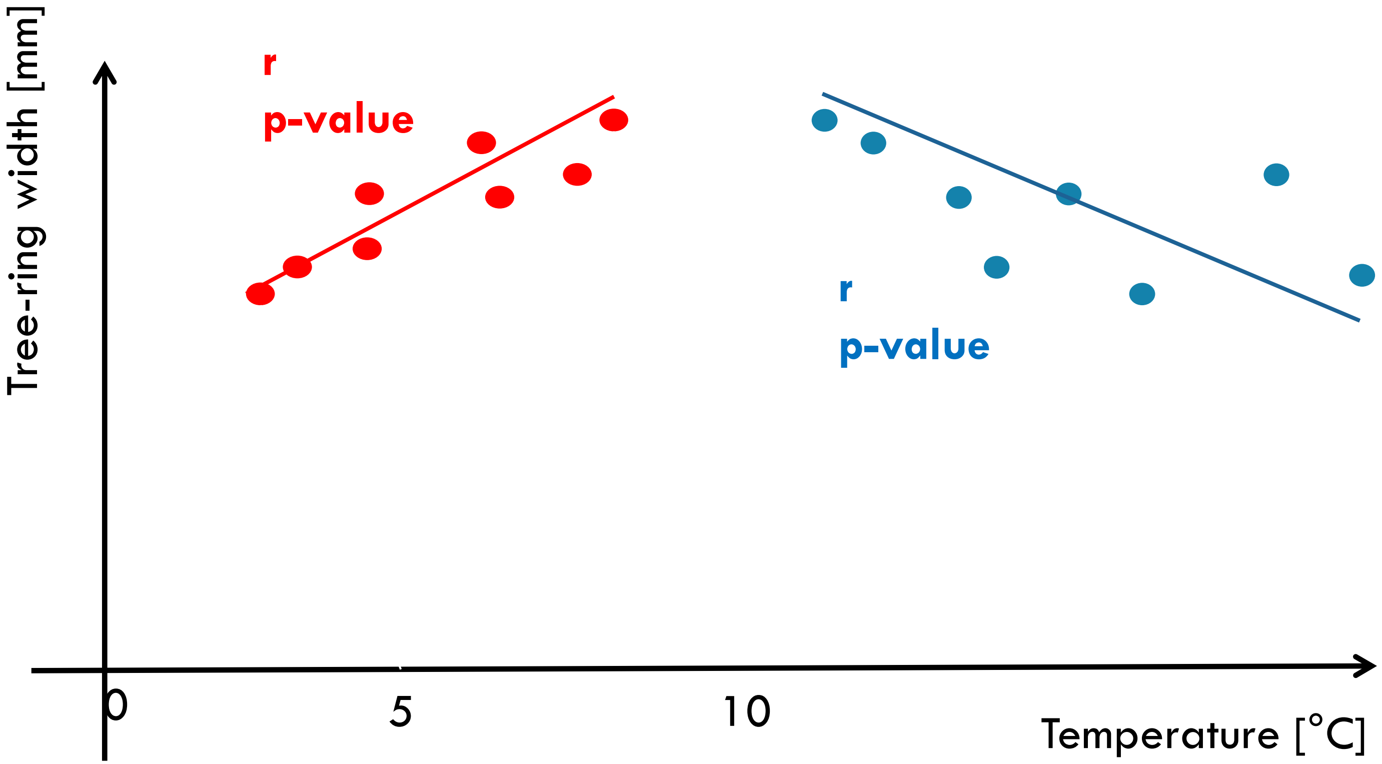
HOW TO QUANTIFY CLIMATE-GROWTH RESPONSES?



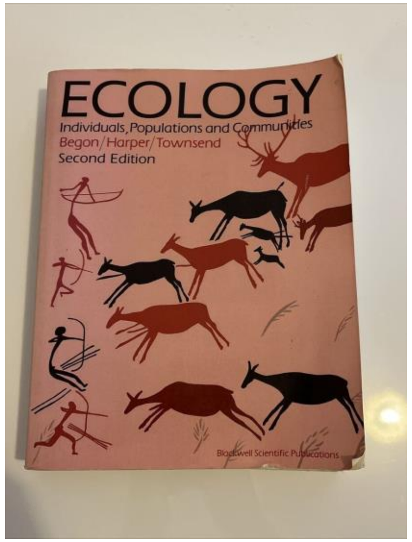
WHAT ARE KEY LIMITATIONS OF CLIMATE-GROWTH CORRELATIONS?

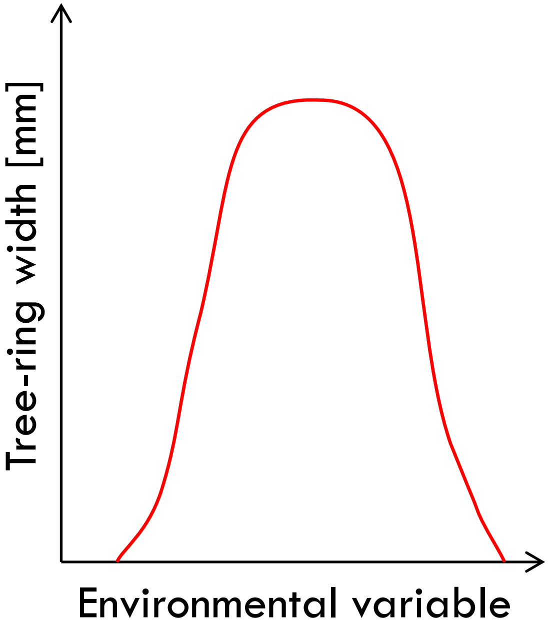
Linearity assumption

Interpretability („black box“)

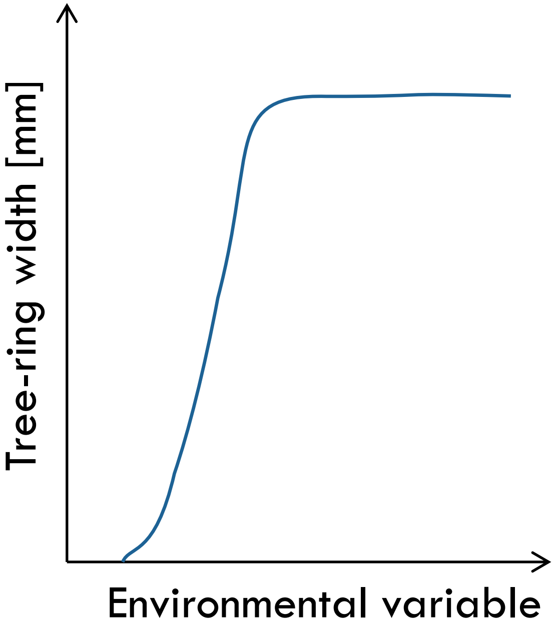


LINEAR OR NON-LINEAR RESPONSE IN ECOLOGY?

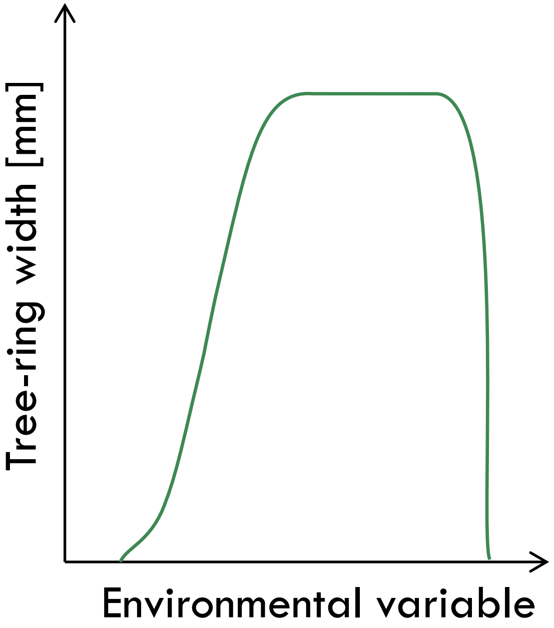




Temperature

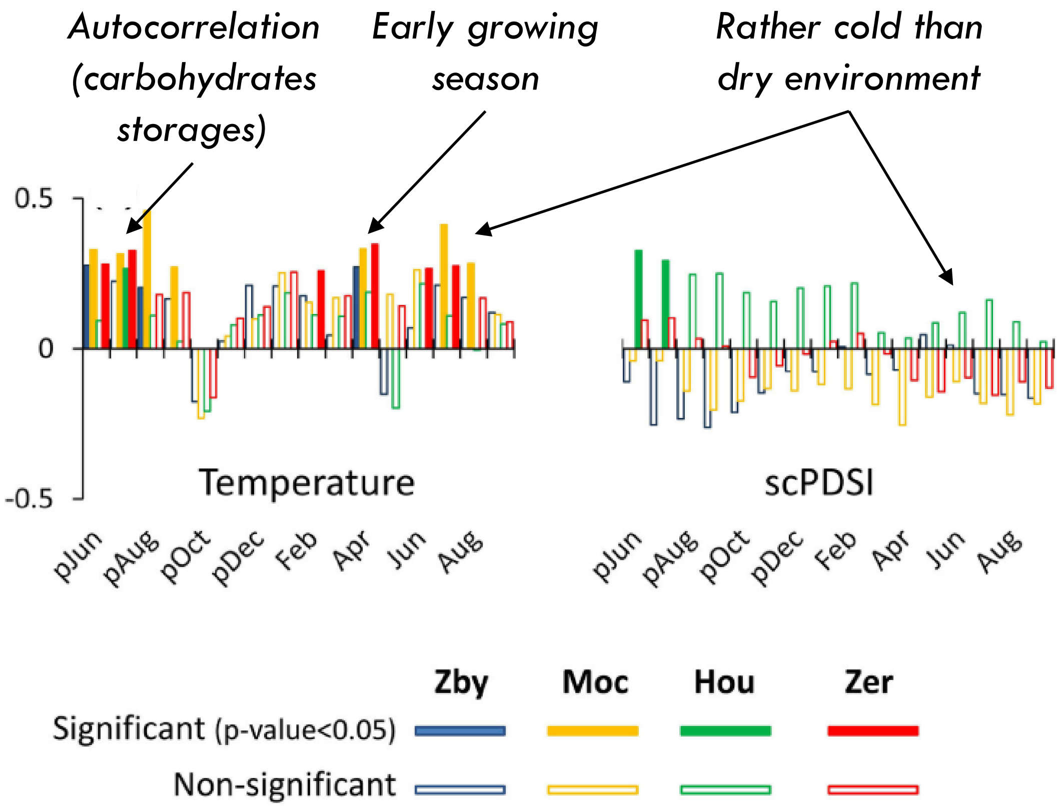


CO_2 concetration (greenhouse)



N concentration in soil

INTERPRETATION OF CORRELATIONS



(Tumajer and Treml 2017: Trees-Structure and Function)

… but climate-growth correlations <u>cannot</u> answer following questions:

- How trees grew during 1976 extreme year?
- What shapes the growth in May?
- Was the climatic response stable over the calibration period?
- …

PROCESS-BASED MODELS OF WOOD FORMATION

= sets of numerical equations that implement current state of knowledge about mechanisms of environmental control of <u>tree-ring formation</u>, QWA, photosynthesis, isotopic composition of lignin, hormonal dynamics, …

- Sink X Source models

Eckes-Shephard et al. (2022): Frontiers in Plant Science

Guiot et al. (2014): Frontiers in Ecology and Evolution

Table 1 | Rough classification of the models cited according to the main processes included.

Model	Water cycle	Carbon cycle	Tree compartments	Wood structure	Isotopes
Biome3 (Rathgeber et al., 2000a)	x	x			
VS-light (Tolwinski-Ward et al., 2011)	x				
- (LeBlanc and Terrell, 2001)	x				
StandLEAP (Girardin et al., 2008)		x	x		
SIMFORG+SICA (Berninger and Nikinmaa, 1997)	x	x	x		
MAIDEN (Misson, 2004)	x	x	x		
CASTANEA (Dufrene et al., 2005)	x	x	x		
VS (Fritts et al., 1991)	x	x	x	x	
ECOPHYS (Rauscher et al., 1990)		x	x		
-(Ogee et al., 2009)	x	x	x		x
- (Hölttä et al., 2010)			x	x	
CAMBIUM (Drew et al., 2010)	x	x	x	x	
MAIDENiso (Danis et al., 2012)	x	x	x		x
ISOCASTANEA (Eglin et al., 2010)	x	x	x		x

VS-LITE

Low-complexity climate-driven …

- *Considers climatic limitation of the growth (temperature, soil moisture)*
- *Works with monthly resolution*
- *+ Can be applied almost everywhere (you only need monthly temperature, precipitation and site chronology)*
- *- Less detailed outputs of simulations compared to other models*

… non-linear …

- *Climate-growth response functions are non-linear*

… sink-oriented …

- *Considers direct effects of climate on cambium, ignores everything related to photosynthesis*

… process-based model of wood formation

TRACH, VAGANOV-SHASHKIN, VS-LITE

TRACH (Fritts et al. 1991)

- Original ancestor

Vaganov-Shashkin model (Vaganov et al. 2006)

- Daily resolution
- Three serialy-linked modules
  - Environmental module – calculation of dimensionless relative daily growth rates GrINT (VS-Oscilloscope – Shishov et al. 2016: Dendrochronologia)
  - Xylogenesis module – conversion of GrINT into daily cell numbers inside cambial zone and kinetics of their radial growth and division (Anchukaitis et al. 2021: Dendrochronologia; Tumajer et al. 2021: Frontiers in Plant Science)
  - QWA module – calculating LA and CWT for each developing tracheid each day (Popkova et al. 2023: Dendrochronologia)

VS-Lite (Tolwinski-Ward et al. 2011)

- Adopting environmental module of the Vaganov-Shashkin model for monthly resolution

VS-LITE – WORKFLOW (1)

Calculating environmental variables that (according to the model) affect tree growth

- Mean monthly air temperature T[°C]
  - Provided by the user as an input
- Mean monthly volumetric soil moisture M[v/v]
  - Provided by the user as an input OR …
  - … calculated from temperature and precipitation (input) by inbuild soil moisture model (Huang et al. 1996: Journal of Climate)
- Mean monthly daylength E[h]
  - Calculated automatically from site latitude

VS-LITE – WORKFLOW (2)

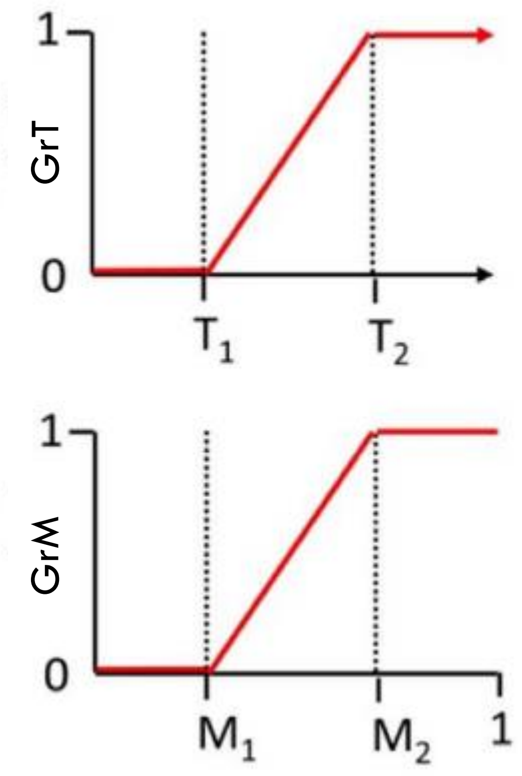
Converting environmental variables into monthly **partial growth rates**

= relative variable describing the capacity of a tree to produce wood under given temperature OR soil moisture OR daylength

= how fast would a tree grow in case its growth would be fully controlled by temperature OR soil moisture OR daylength

- 0 = no growth, dormancy; 1 = optimum, full growth capacity

- Partial growth rate to temperature (GrT) and partial growth rate to soil moisture (GrM)
  - Determined from climatic variables by means of non-linear response functions



VS-LITE – WORKFLOW (3)

Converting environmental variables into monthly **partial growth rates**

= <u>relative</u> variable describing the capacity of a tree to form wood under given temperature OR soil moisture OR daylength

- 0 = no growth, dormancy; 1 = optimum, full capacity to growth

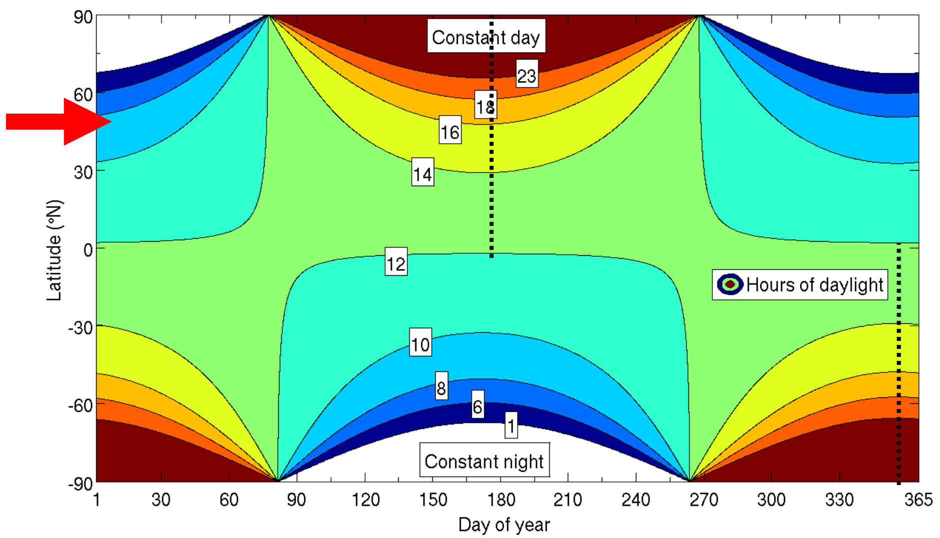
- T_1, T_2, M_1 and M_2 are usually calibrated inside „reasonable ranges“
  - Subjectivity

$$\mathrm{GrT} = \begin{cases} 0 & if\ T \leq T_1 \\ (T - T_1)/(T_2 - T_1) & if\ T_1 < T < T_2 \\ 1 & if\ T_2 \leq T \end{cases}$$

$$\mathrm{GrM} = \begin{cases} 0 & if\ M \leq M_1 \\ (M - M_1)/(M_2 - M_1) & if\ M_1 < M < M_2 \\ 1 & if\ M_2 \leq M \end{cases}$$

VS-LITE – WORKFLOW (4)

Converting environmental variables into monthly **partial growth rates**



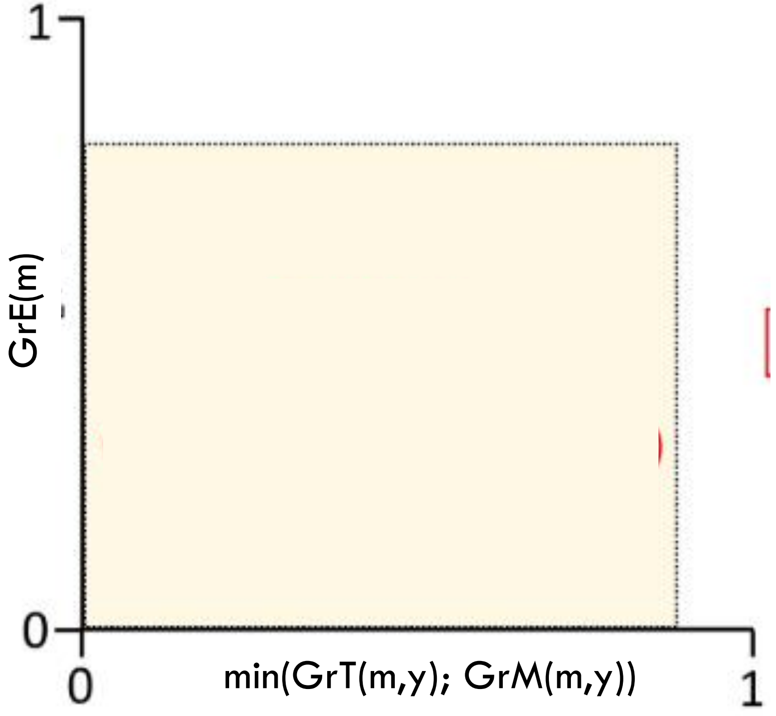
- Partial growth rate to daylength (GrE)
  - GrE(d) = daylength of day d / daylength of summer solstice
  - Calculated automatically

VS-LITE – WORKFLOW (5)

Integration of partial growth rates into **integral growth rates (GrINT)**

- Dimensionless proxy of monthly growth rate
- Liebig's law of minimum – the more limiting climatic variable (temperature, soil moisture matters) determines GrINT

$$GrINT(m,y) = GrE(m) * min\big(GrT(m,y)\,; GrM(m,y)\big)$$

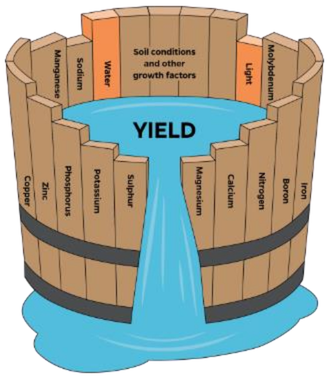


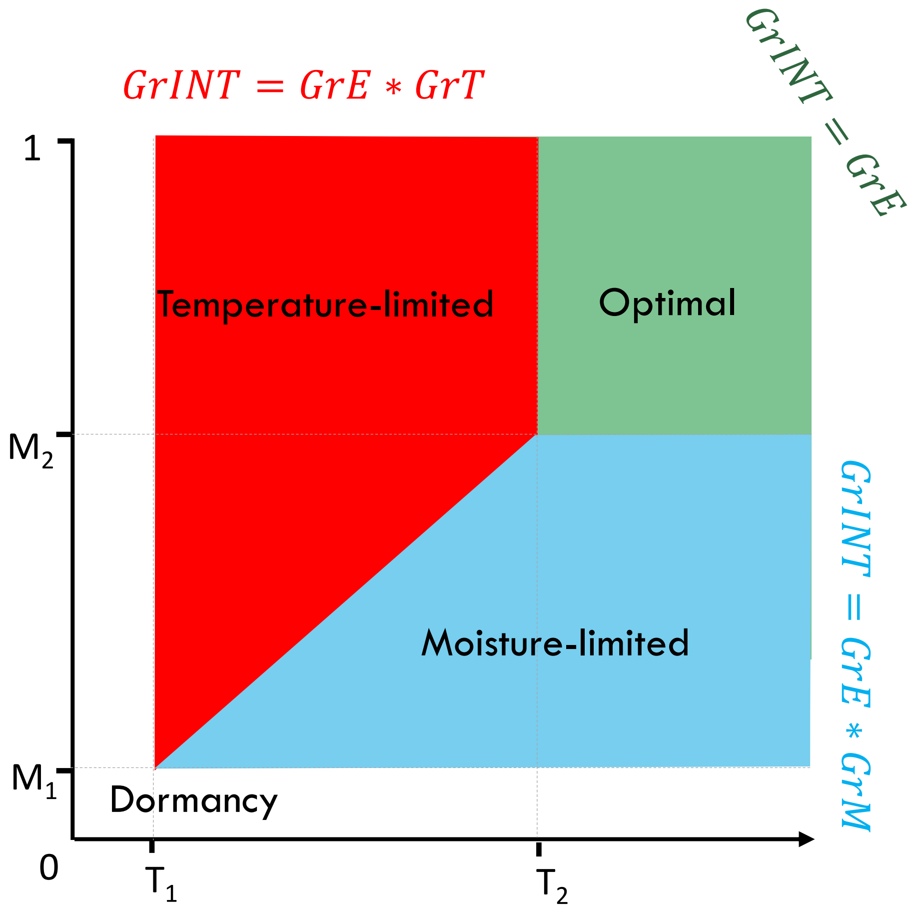
VS-LITE – WORKFLOW (6)

Identification of dominant climatic limiting factor of growth for each month

- GrINT follows the lower of GrT and GrM

- 0 < GrT < GrM … temperature-limited
- 0 < GrM < GrT … moisture-limited
- GrT = GrM = 1 … optimal growth
- GrINT = 0 … dormancy



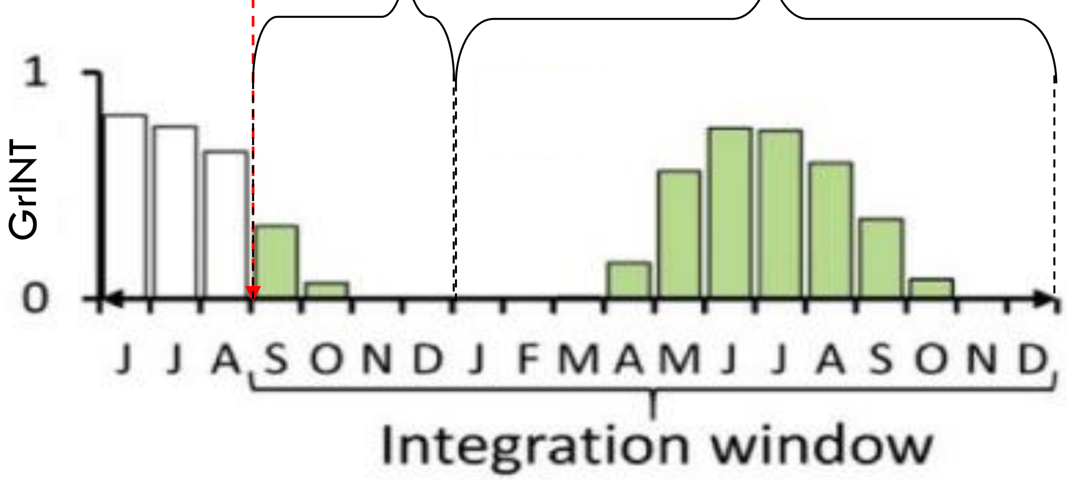


VS-LITE – WORKFLOW (7)

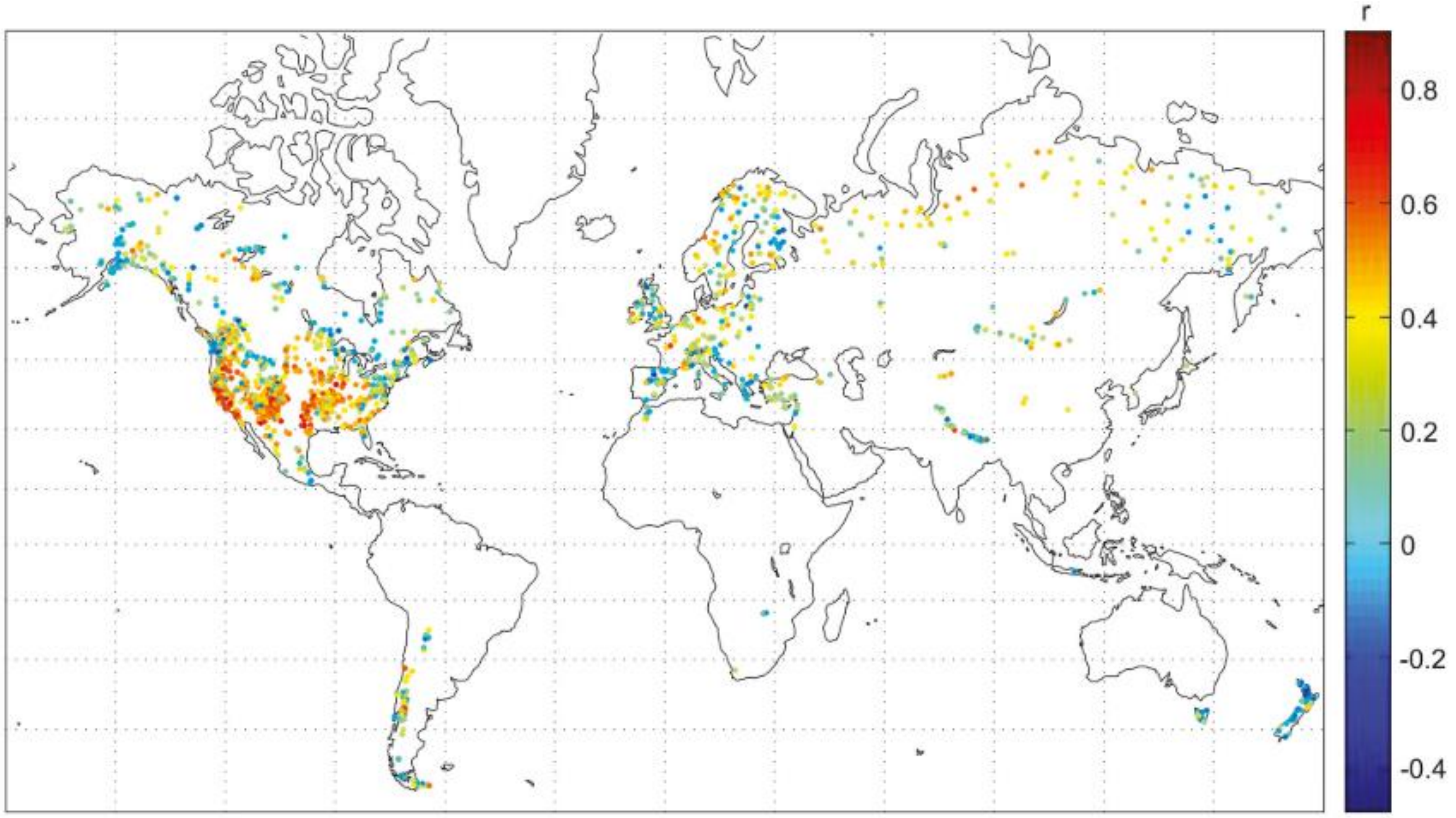
Calculating simulated annual tree-ring width chronology

≈ sum of GrINT during the given year + (optionally) part of GrINT from the previous year * (optionally) weight

$$TRW(y) \approx \sum_{I\_0}^{Dec} GrINT(m, y-1) + \sum_{Jan}^{Dec} GrINT(m, y)$$



GLOBAL APPLICATION OF THE VS-LITE



Breitenmoser et al (2014): Climate of the Past

MODEL DEVELOPMENT

Dendrochronologia 49 (2018) 77–88

Contents lists available at ScienceDirect

Dendrochronologia

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

Original Article

The facultative bimodal growth pattern in *Quercus ilex* – A simple model to predict sub-seasonal and inter-annual growth

Filipe Campelo[a,*], Emilia Gutiérrez[b], Montserrat Ribas[b], Raúl Sánchez-Salguero[c,d], Cristina Nabais[a], J. Julio Camarero[c]

Agricultural and Forest Meteorology 247 (2017) 56–64

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

Research paper

Increasing moisture limitation of Norway spruce in Central Europe revealed by forward modelling of tree growth in tree-ring network

Jan Tumajer[a,b,*], Jan Altman[c], Petr Štěpánek[d], Václav Treml[b], Jiří Doležal[c], Emil Cienciala[a]

Science of the Total Environment 905 (2023) 167153

Contents lists available at ScienceDirect

Science of the Total Environment

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

Linkage between growth phenology and climate-growth responses along landscape gradients in boreal forests

Jan Tumajer[a,*], Jan Altman[b,c], Jiří Lehejček[d,e]

Agricultural and Forest Meteorology 221 (2016) 13–33

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

Forward modeling of tree-ring width improves simulation of forest growth responses to drought

Marco Mina*, Dario Martin-Benito, Harald Bugmann, Maxime Cailleret

RESEARCH PAPERS

WILEY Global Ecology and Biogeography

The climatic drivers of normalized difference vegetation index and tree-ring-based estimates of forest productivity are spatially coherent but temporally decoupled in Northern Hemispheric forests

Kristina Seftigen[1,2] | David C. Frank[3,4] | Jesper Björklund[3,5] | Flurin Babst[3,6] | Benjamin Poulter[7]

Agricultural and Forest Meteorology 327 (2022) 109196

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

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

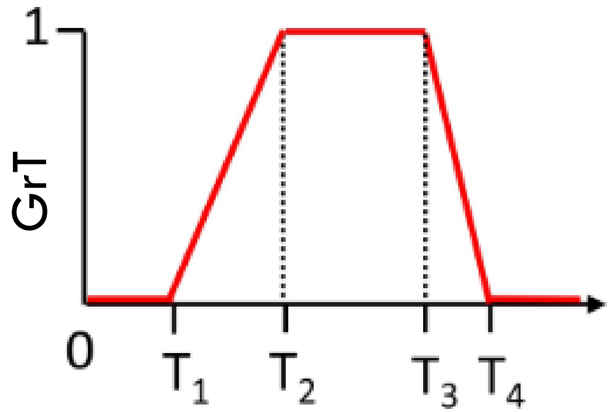
Process representation of conifer tree-ring growth is improved by incorporation of climate memory effects

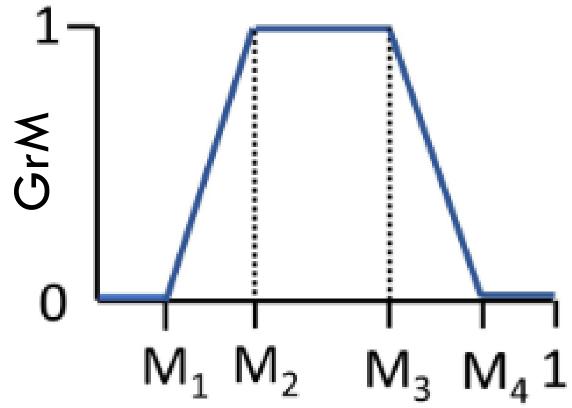
Xiaomin ZENG[a,*], Michael N. EVANS[b], Xiaohong LIU[a,c,*], Drew M.P. PELTIER[d], Simin ZHAN[e], Ping NI[a], Yao LI[a], Lingnan ZHANG[a], Bao YANG[f]

MODEL MODIFICATIONS (1)

More complexity in response functions

- Declining partial growth rates for too high temperatures and too high soil moisture
- New parameters T_3, T_4, M_3, M_4
- New types of limitation
  - Low temperature – **High temperature**
  - Drought – **Soil water oversaturation** (wetlands!!!)





$$GrT = \begin{cases} 0 & if\ T \le T_1 \\ (T - T_1)/(T_2 - T_1) & if\ T_1 < T \le T_2 \\ 1 & if\ T_2 < T \le T_3 \\ (T_4 - T)/(T_4 - T_3) & if\ T_3 < T \le T_4 \\ 0 & if\ T_4 \le T \end{cases}$$

MODEL MODIFICATIONS (2)

Integration based on interaction of temperature and soil moisture instead of Liebig's law

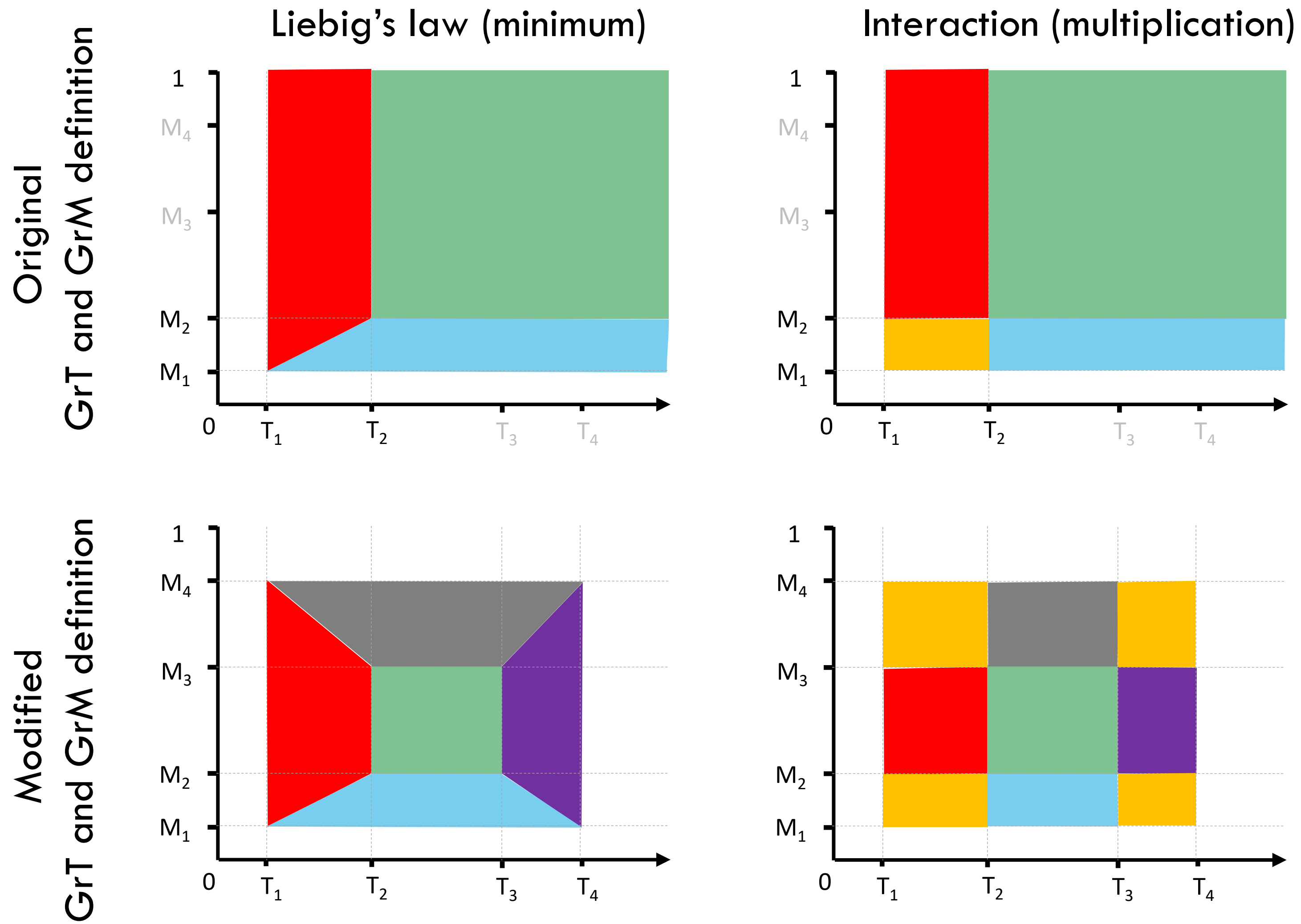
Original VS-Lite: $GrINT(m,y) = GrE(m) * \boldsymbol{min}\big(GrT(m,y)\,; GrM(m,y)\big)$

Modified VS-Lite: $GrINT(m,y) = GrE(m) * GrT(m,y) \ * GrM(m,y)$

New type of limitation

- **Mixed**

MODEL MODIFICATIONS (3)



Limitations:

Cold

Warm

Dry

Wet

Mixed

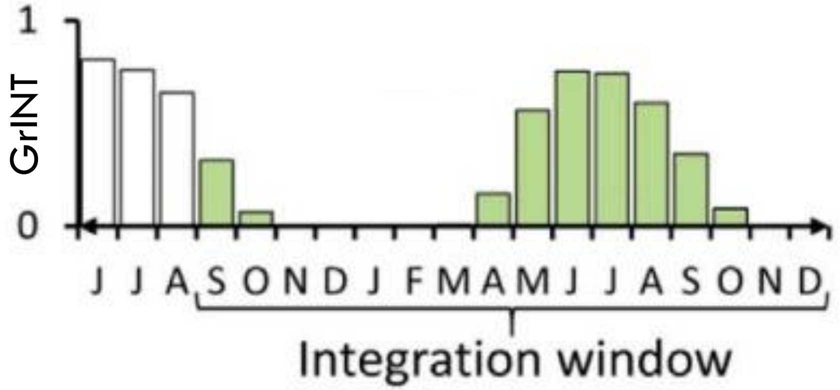
Optimal growth

MODEL MODIFICATIONS (4)

Weighting previous year integral growth rates in proxy of annual tree-ring width

Original: $TRW(y) \approx \sum_{Jan}^{Dec} GrINT(m,y) + \mathbf{1} * \sum_{I\_0}^{Dec} GrINT(m,y-1)$

Modified: $TRW(y) \approx \sum_{Jan}^{Dec} GrINT(m,y) + \boldsymbol{Acor} * \sum_{I\_0}^{Dec} GrINT(m,y-1)$



MODEL PARAMETERS – HOW TO DETERMINE THEM?

Parameters of response fuctions

- T1, T2, (T3), (T4)
- M1, M2, (M3), (M4)

Parameters related to autocorrelation component

- I_0, Acor

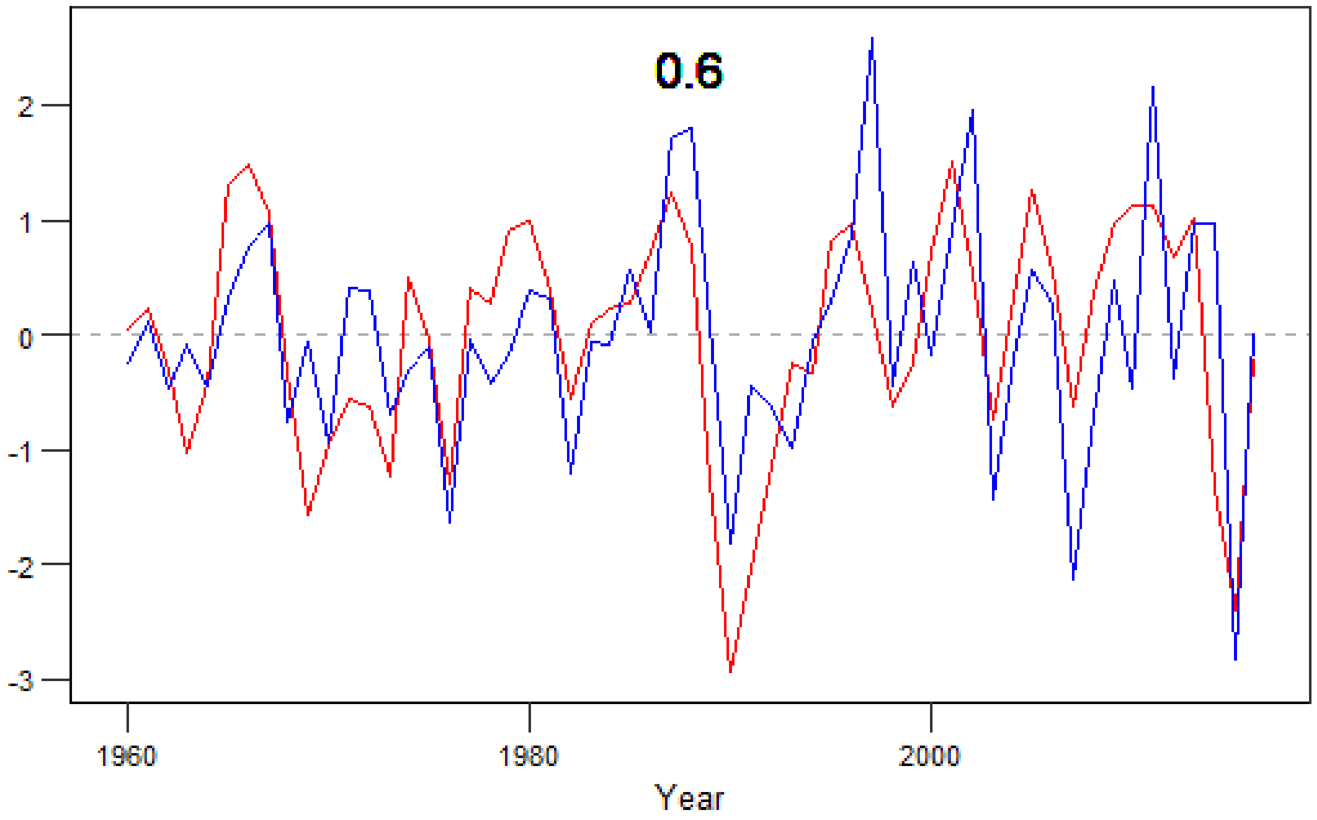
Parameters of soil moisture model

1. Fixed value - estimate
2. Calibration against site chronology and, if possible …

- Dendrometers, xylogenesis, (NDVI)
- Soil moisture level
- …

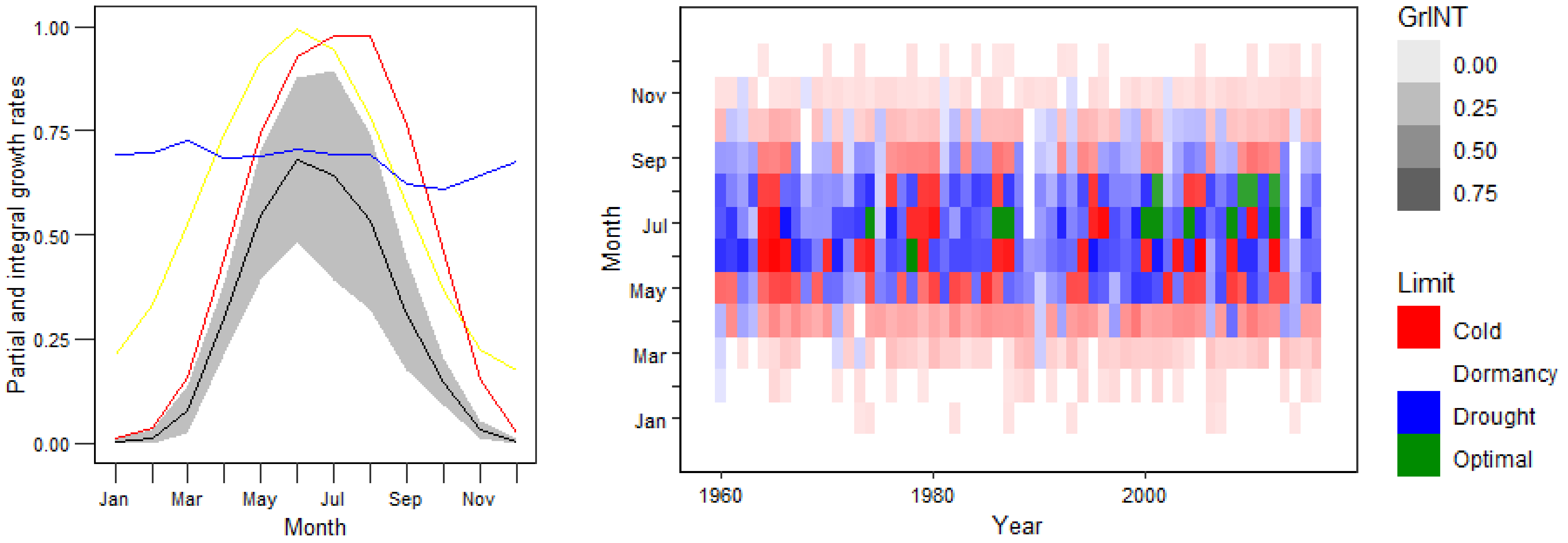
RESULTS (1)

Simulated and observed chronologies



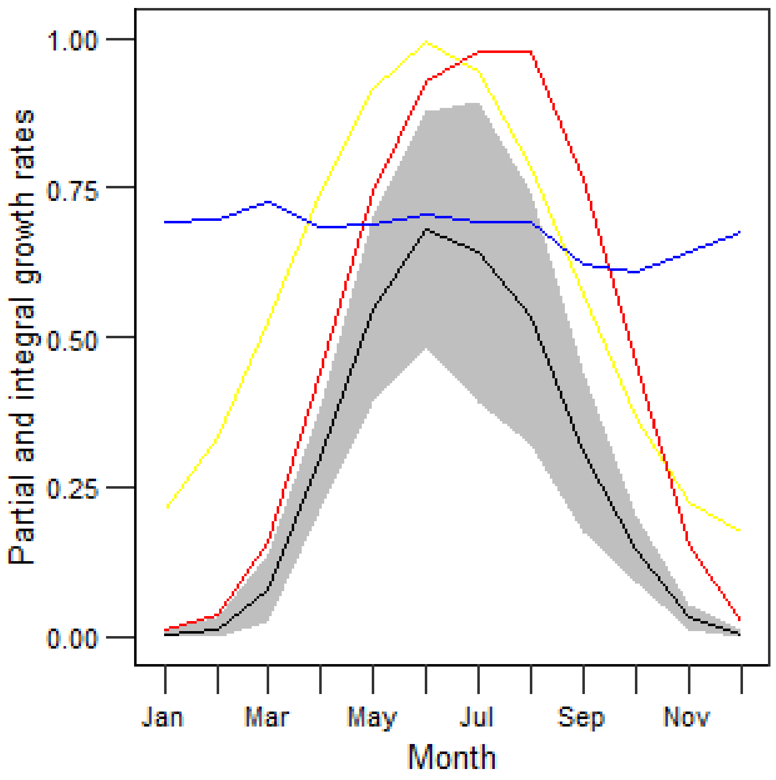
RESULTS (2)

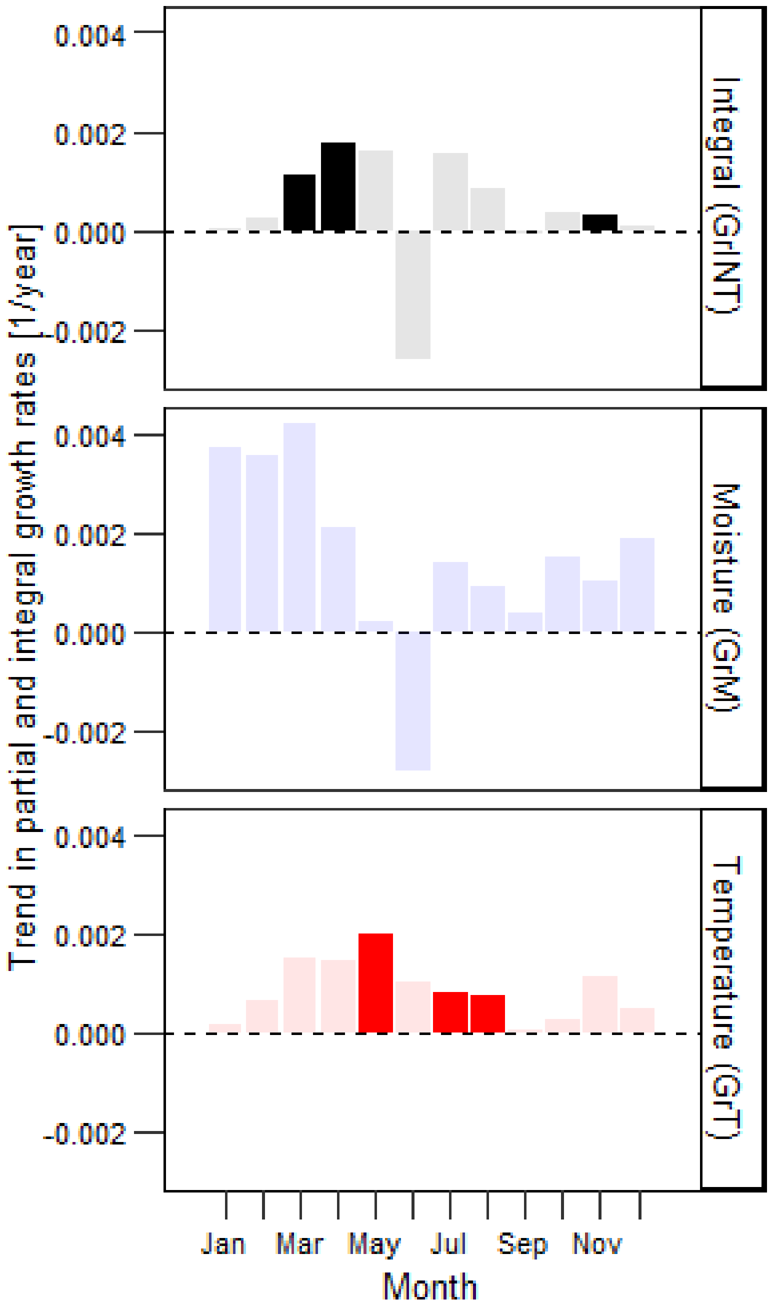
Intra/inter-annual variation of partial and integral growth rates



RESULTS (3)

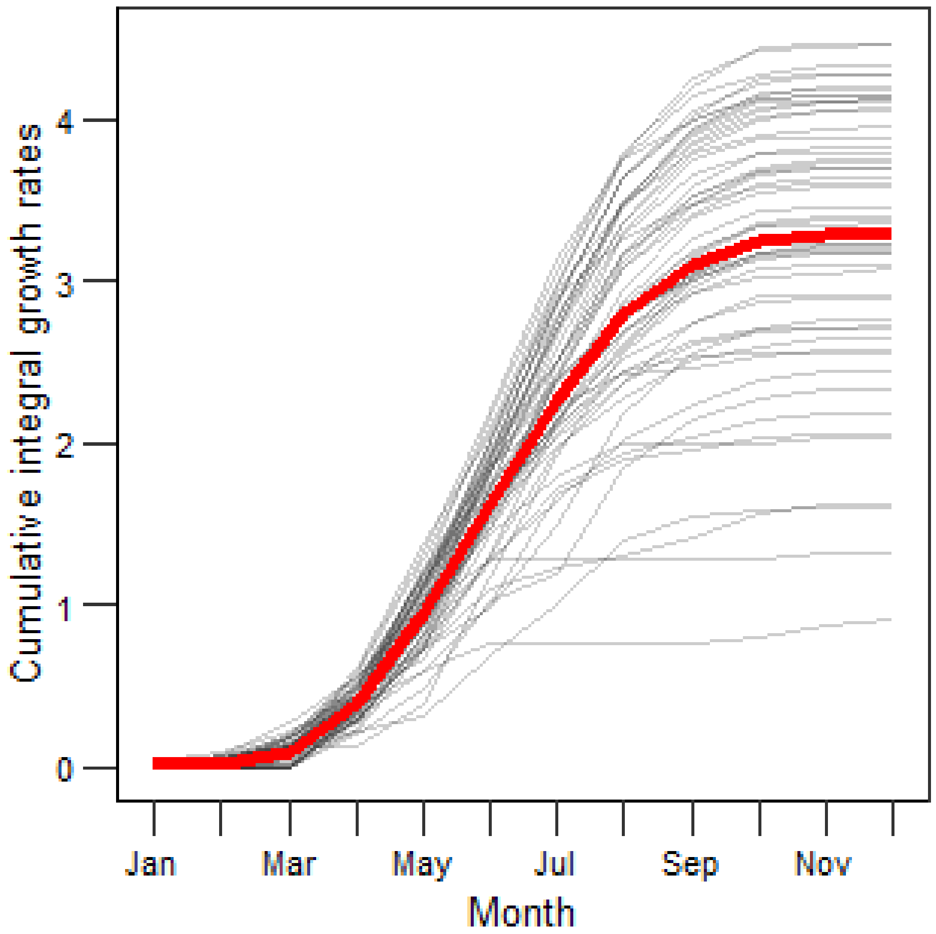
Temporal changes of partial and integral growth rates





RESULTS (4)

Phenology



Thank you for your attention

tumajerj@natur.cuni.cz

web.natur.cuni.cz/physgeo/dendro/

www.github.com/jantumajer

www.twitter.com/JTumajer