Analysis of the temperate tree growth response to climate change through a modelling approach

Characterization of prediction uncertainties

PhD STUDENT: LOUIS DE WERGIFOSSE

SUPERVISOR : MATHIEU JONARD (UCL – ELIE)

CO-SUPERVISOR: HUGUES GOOSSE (UCL – ELIC)

Methods to evaluate climate change impact on forests

- Long-term monitoring of forest ecosystems
- Observational studies of species distribution according to climate
- Environment modification experiments
- Process-based modelling

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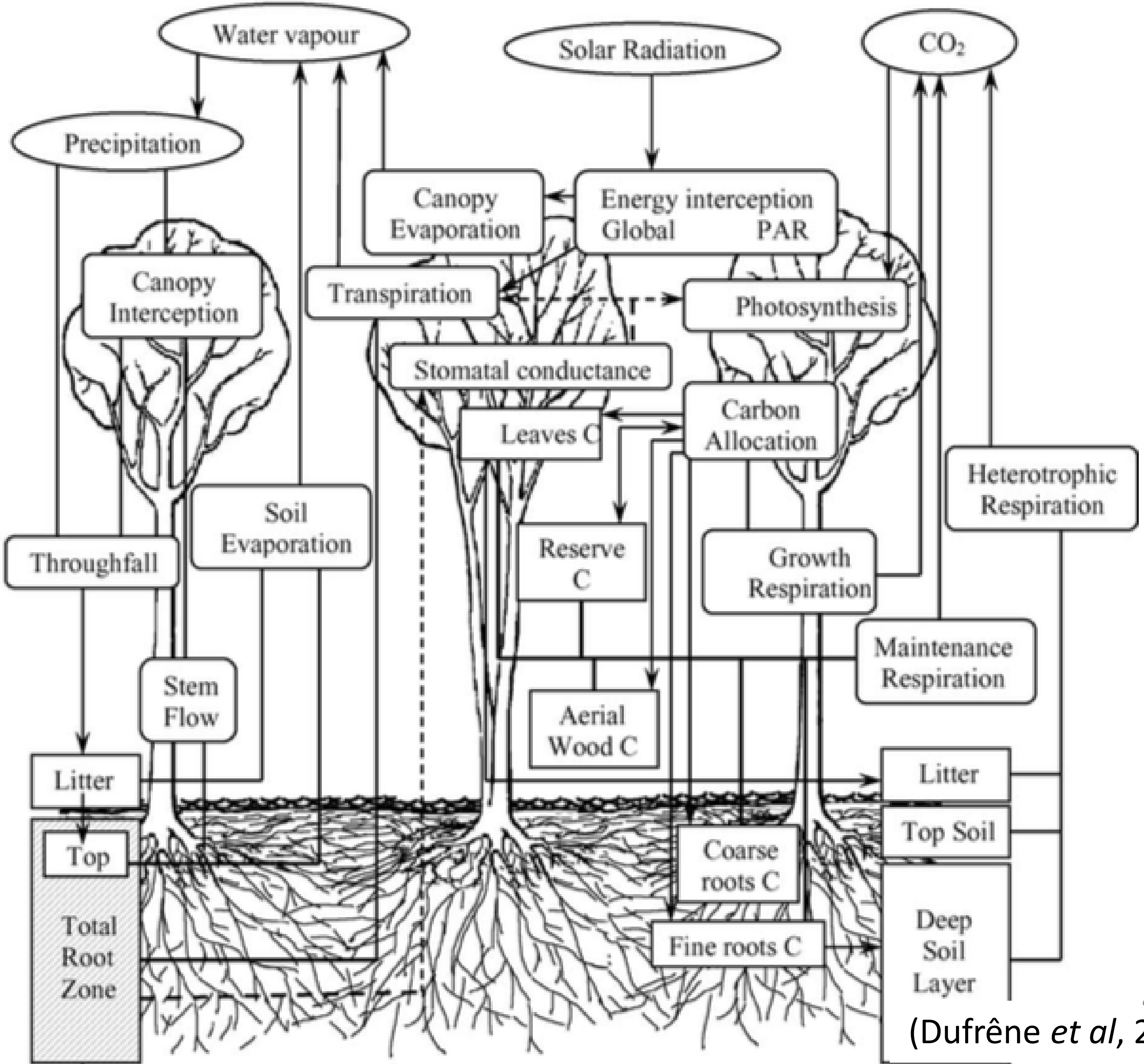
EVALUATION

KNOWLEDGE INTEGRATION

How to model the climate change impact on forests?

Complex **process-based** models at the **stand** scale



(Dufrêne *et al*, 2005)

Current approach limitations

Complex **process-based** models

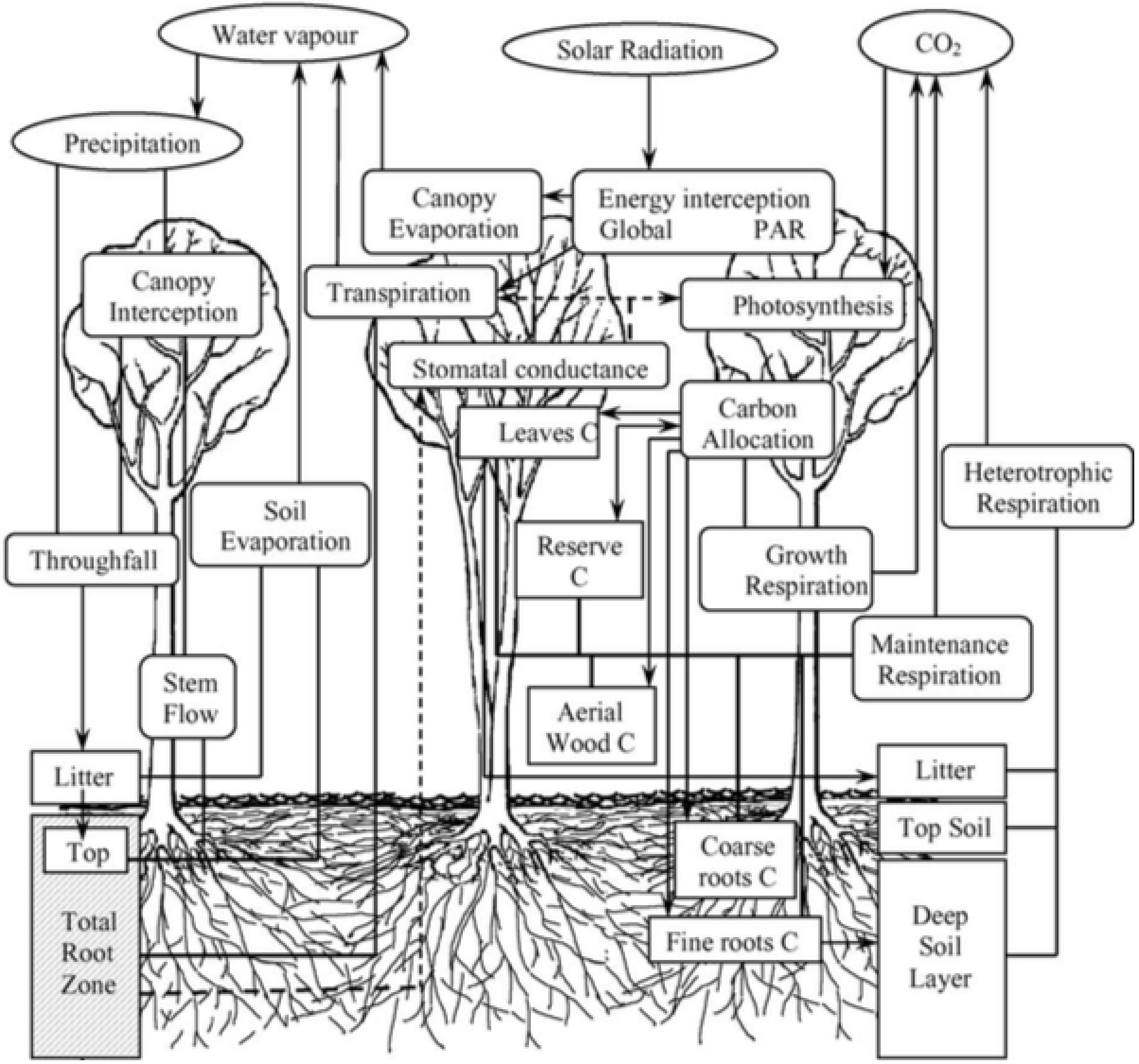
→ Hard to **calibrate** (uncertainties) and to **validate**

at the **stand** scale

→ **Management** poorly or not accounted for

→ Unadapted to **irregular and mixed stands**

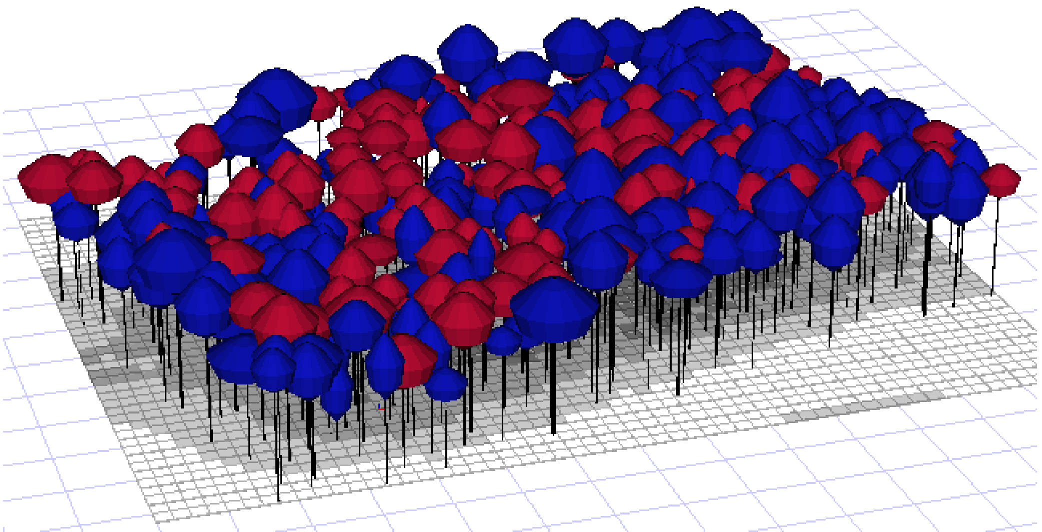
→ Hard to **compare** with retrospective individual meaurements

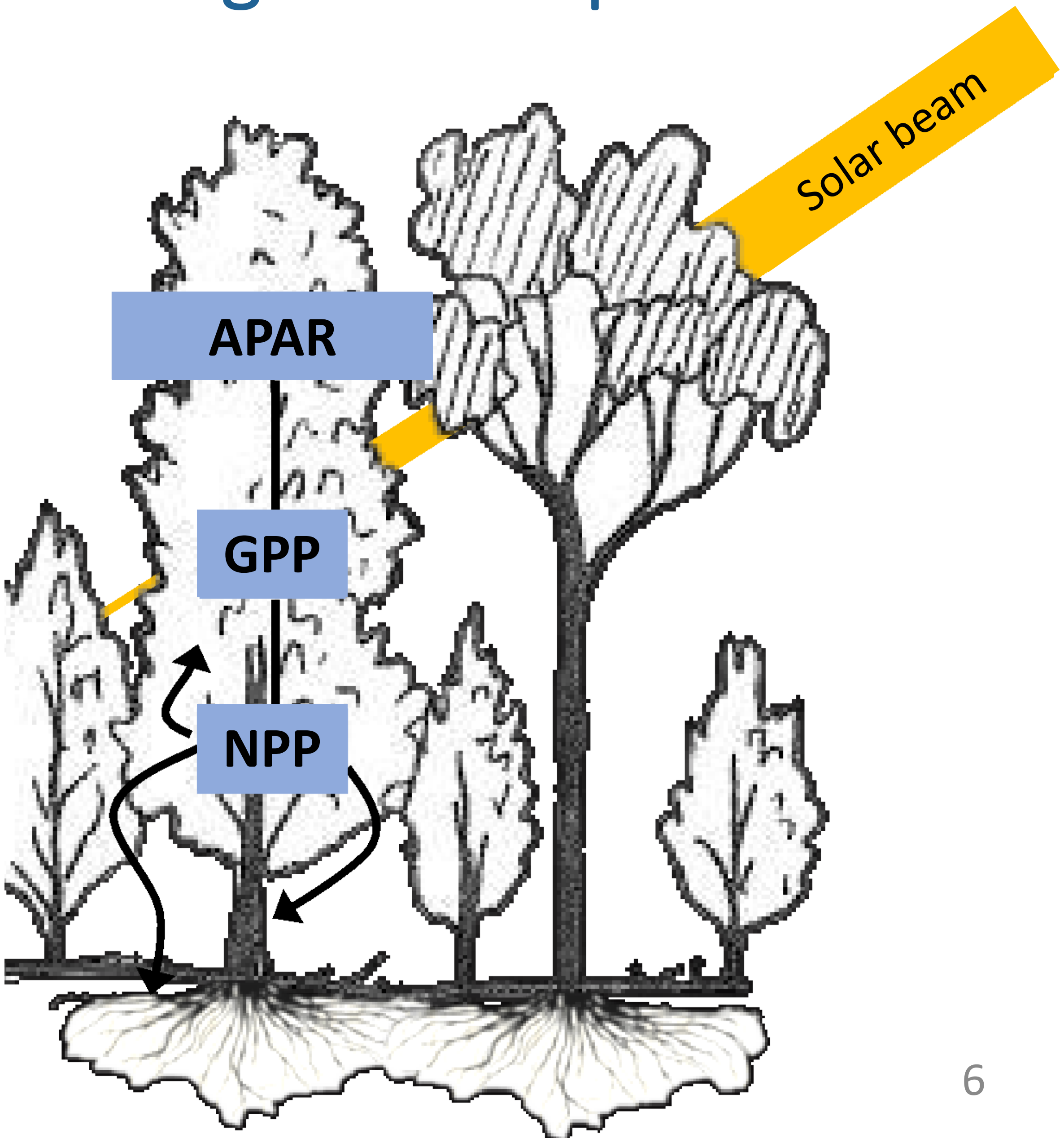


Toward a better inclusion of the management impact

Hybrid (observation and process-based), **spatially explicit** model at the **tree** level

→ **Climate sensitivity** unsatisfayingly considered



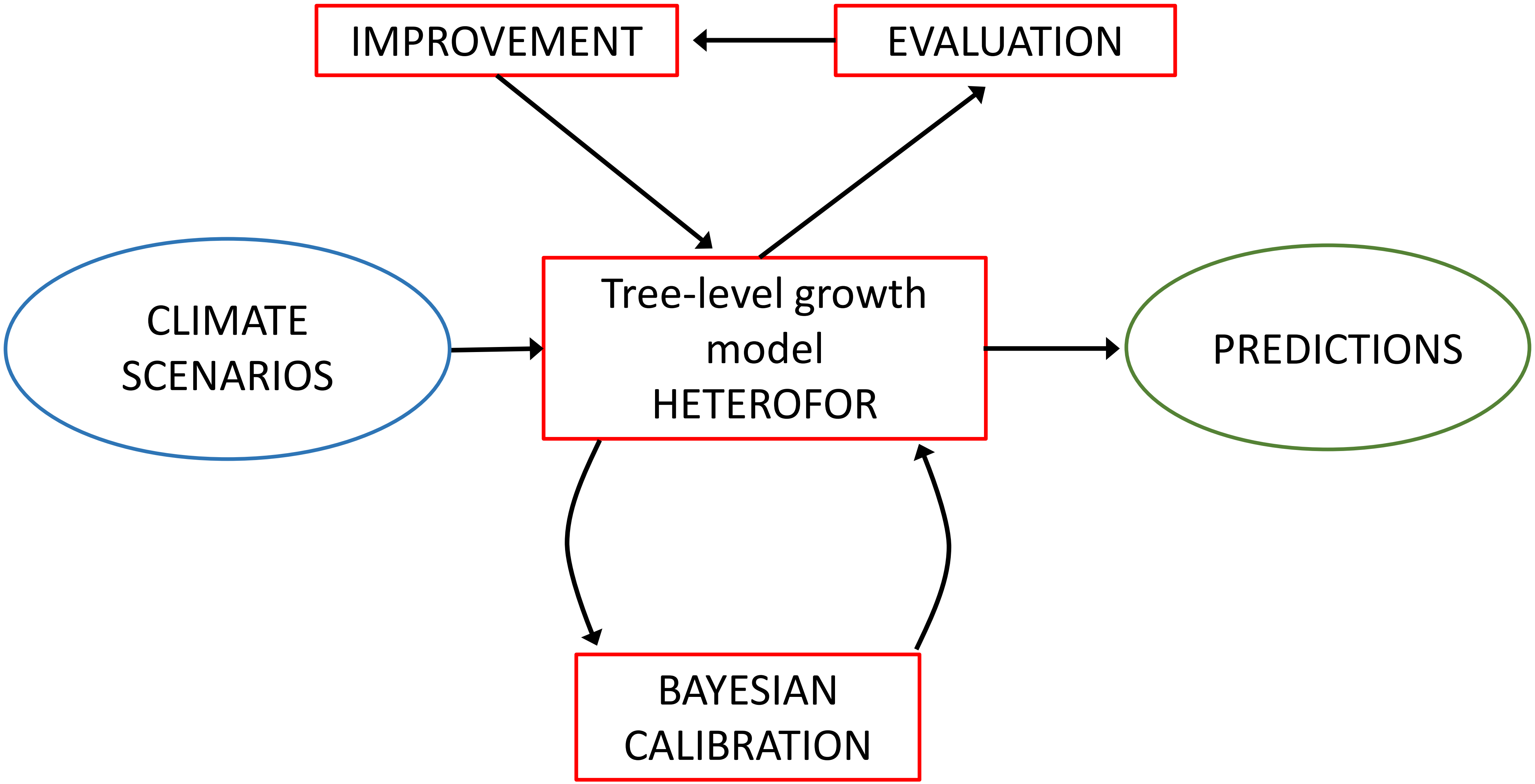


Research objectives

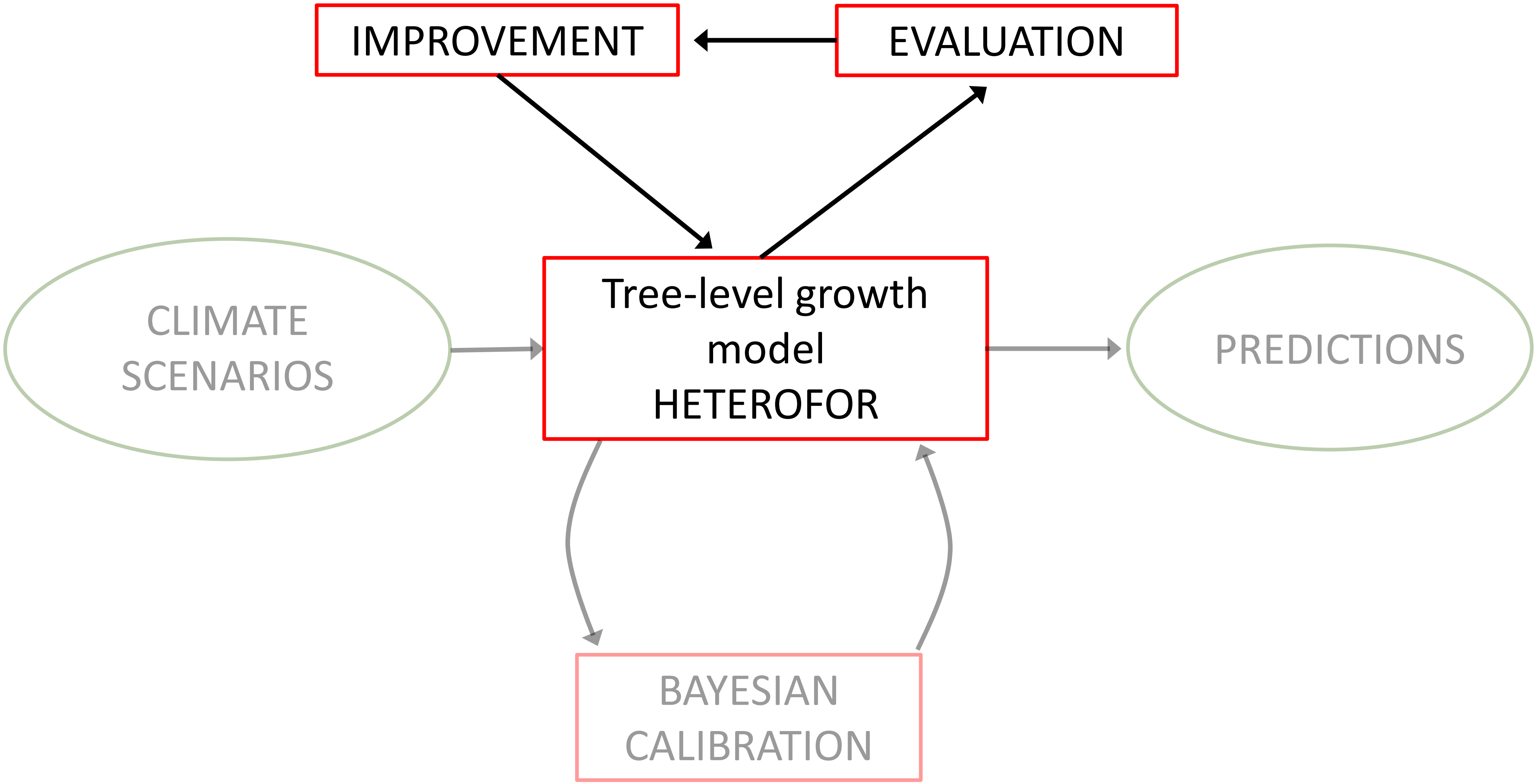
- **Simulate tree growth dynamics** according to different climate scenarios and forestry practices in different areas (Wallonia, France, Europe)
- **Develop a methodology** to evaluate climate change impact while **characterizing the uncertainties**

→ **Better understanding** of the temperate tree growth response to climate change

Research project description



1st step – Inclusion of climate sensitivity in HETEROFOR and evaluation



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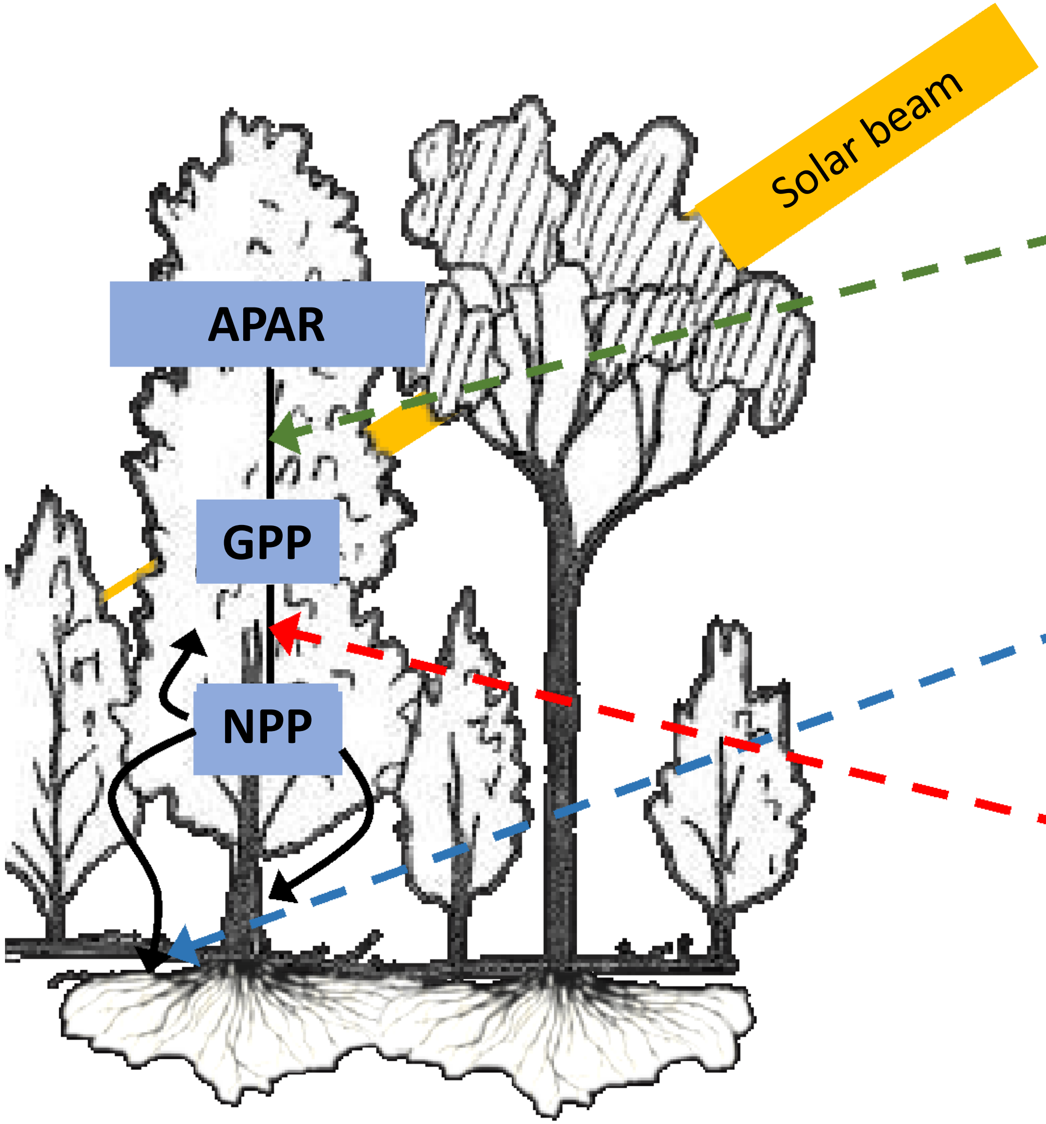


Photosynthesis

PAR used efficency → Farquhar equations

Stomatal regulation

Inclusion of a « Water balance » module

Temperature-dependant respiration

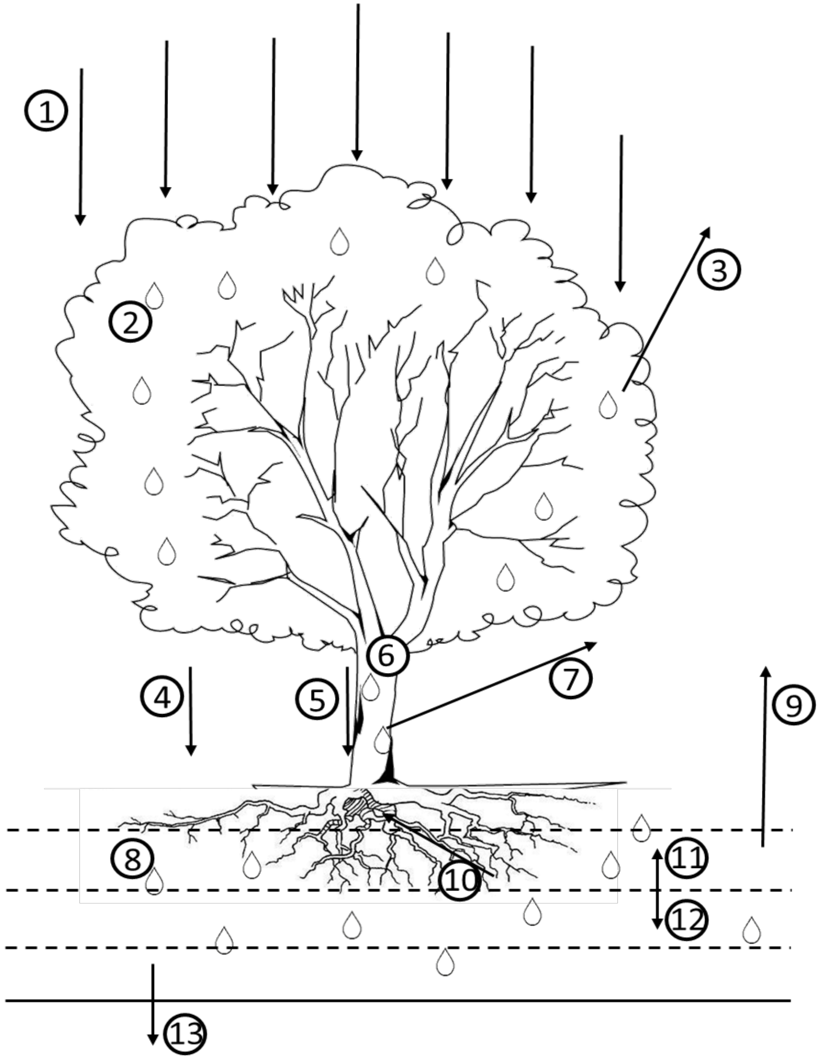
Inclusion of a phenological module

Photosynthesis module development

Use of Castanea photosynthesis module developped on CAPSIS platform by Dufrene, Davi, François, Le Maire, Le Dantec *et al* during a first time.

→ (Cfr. Dufrene *et al*, 2005 for more informations)

Water balance module development



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9. Evaporation of soil stored water (only 1st horizon)
10. Transpiration (only if roots present)
11. Capillary Rise
12. Drainage - Surplus
13. Deep percolation (only last horizon)

Water flux

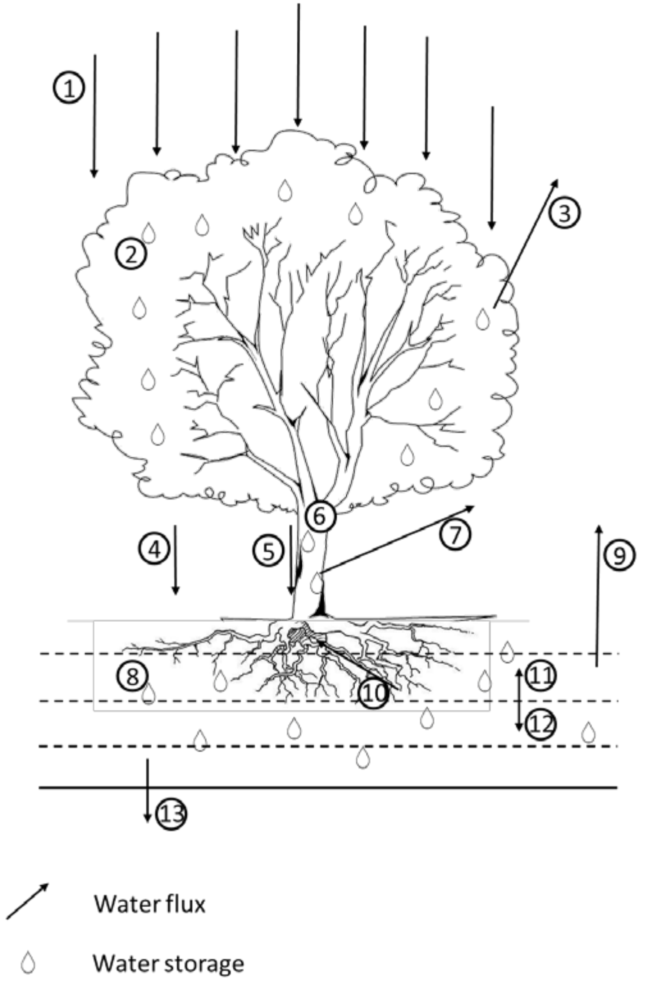
Water storage

Water balance module development

$$C_{foliage} = \sum_{sp} \left[\mathrm{Area}_{leaf\_sp} \cdot \left(c_{foliage\_sp\_min} + \left(1 - \frac{WS}{WS_{max}}\right) \cdot \left(c_{foliage\_sp\_max} - c_{foliage\_sp\_min}\right) \right) \right]$$

or

$$C_{foliage} = \sum_{sp} (Area_{leaf\_sp} \cdot c_{leaf\_sp})$$



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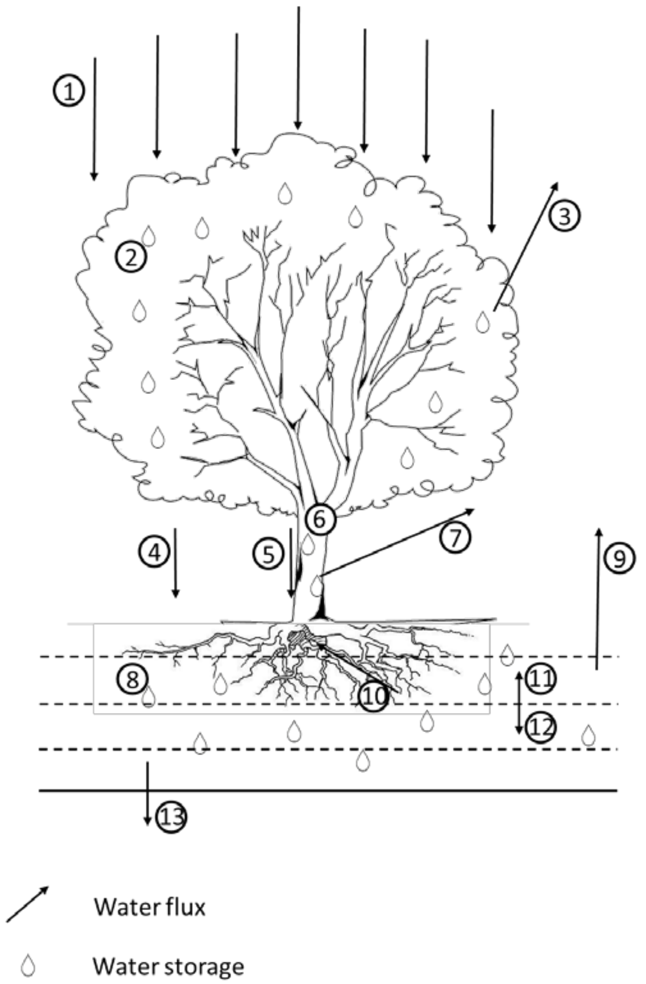
Water balance module development



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Variables calculated using empirical equation from André *et al* (2008):

$$stemflow = a + b.C130 + c.Rain + d.C130.Rain$$

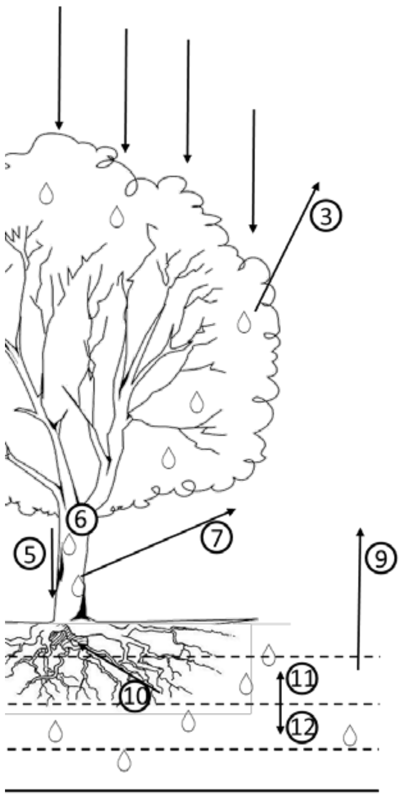
giving

$$C_{bark} = (a + b \cdot C130)$$

$$\%stemflow = \frac{(c + d \cdot C130) \cdot Rain}{Area_{stand} \cdot Rain}$$

$$\%throughfall = 1 - \%stemflow$$

Water balance module development



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Evapotranspiration calculated via Penman-Monteith equation (1965):

$$\lambda . ET = \frac{\Delta R + \frac{\rho . c_p . VPD}{r_a}}{\Delta + \gamma \left(\frac{r_a + r_s}{r_s} \right)}$$

- Foliage evaporation (eddy-covariance approach):

$$r_a = \frac{1}{g_a} = \left(0.006 \cdot \sqrt{\frac{WS}{l}} \right)^{-1}$$

$$r_s = 0$$

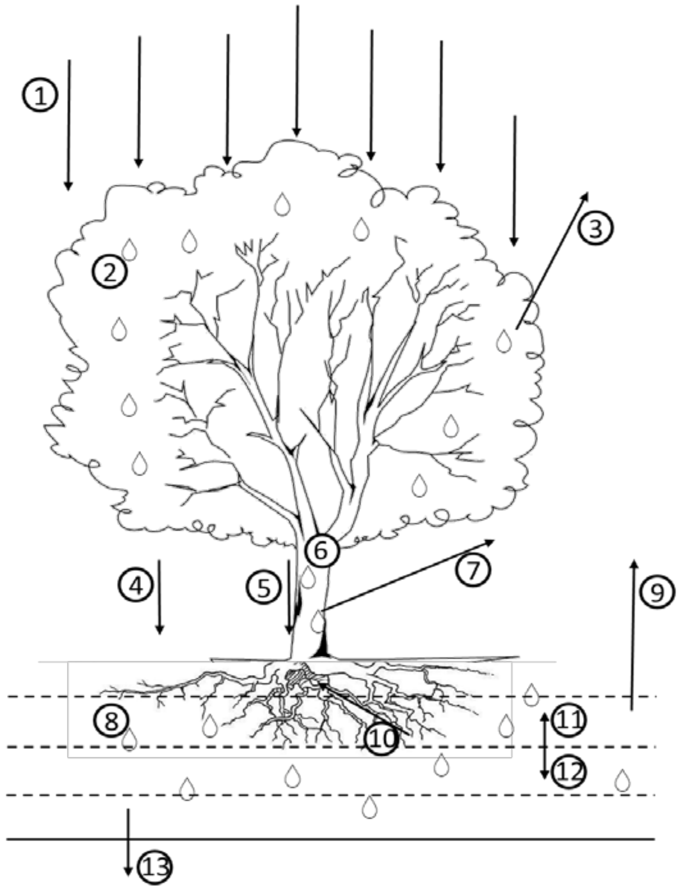
- Bark evaporation:

$$r_s = \frac{1}{g_{s\_bark}} = \left(g_{s\_bark\_min} + (g_{s\_bark\_max} - g_{s\_bark\_min}) \cdot \frac{prevS_{bark}}{C_{bark}} \right)^{-1}$$

- Soil (first horizon) evaporation:

$$r_s = \frac{1}{g_{s\_soil}} = \left(g_{s\_soil\_min} + (g_{s\_soil\_max} - g_{s\_soil\_min}) \cdot prevREW_{forest\_floor} \right)^{-1}$$

Water balance module development



Water flux

Water storage

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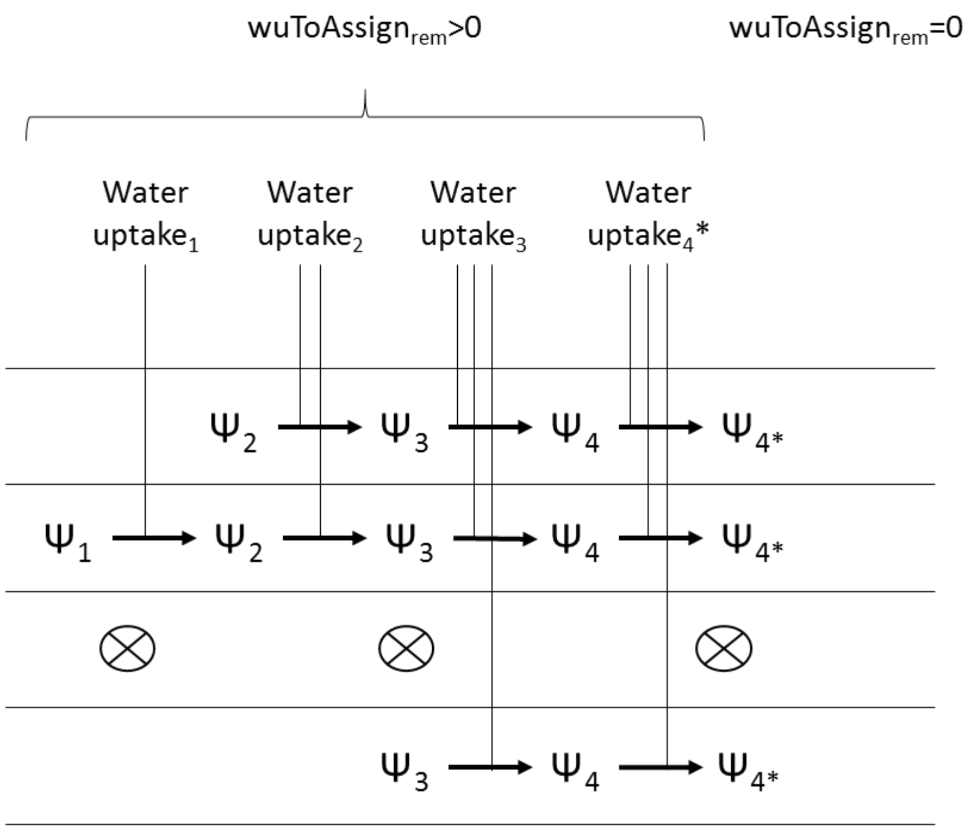
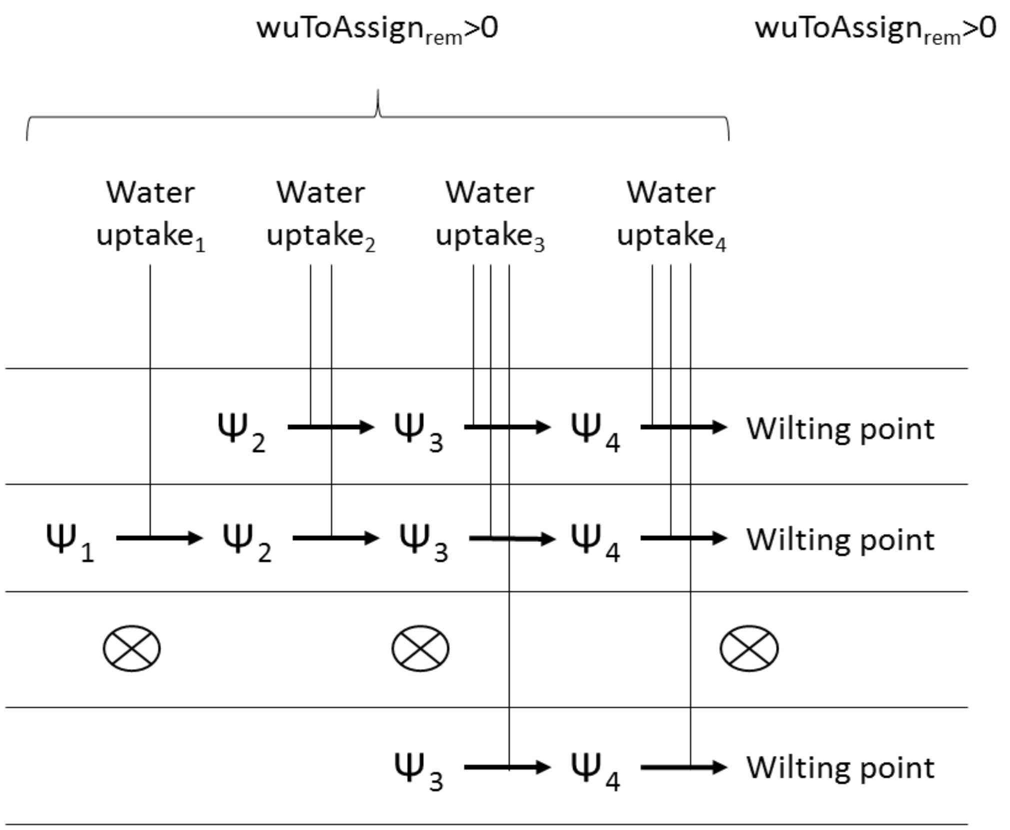
8. Horizon water content
9. Evaporation of soil stored water (only 1st horizon)
10. Water uptake by roots
11. Capillary Rise
12. Drainage - Surplus
13. Deep percolation (only last horizon)

Water balance module development



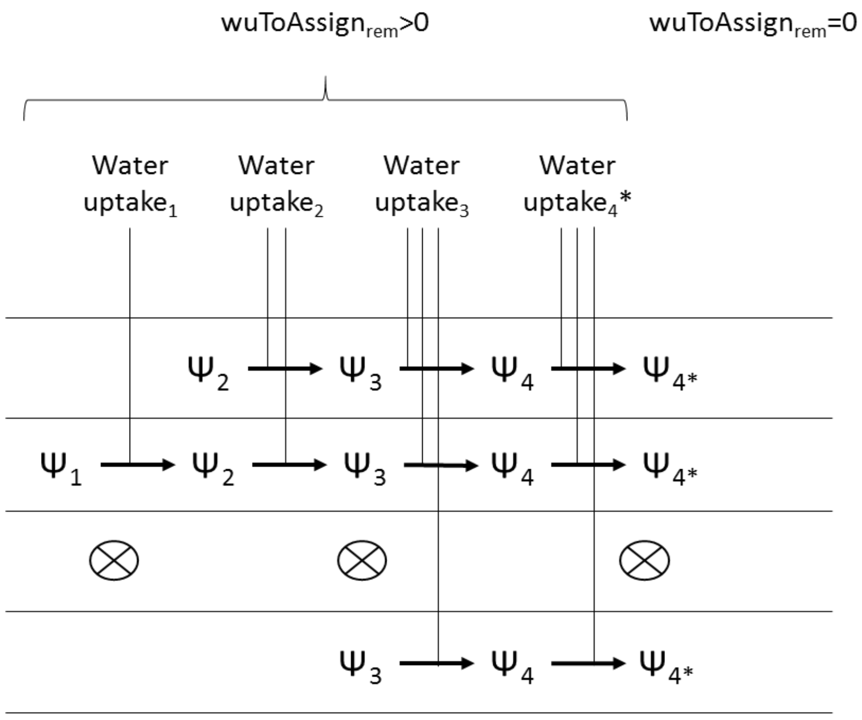


Water $uptake_4$*= $wuProportion_{next\_sum\_4}$· water $uptake_4$

⊗ no root

⊗ no root

Water balance module development



Water uptake$_4$*= wuProportion$_{next_sum_4}$· water uptake$_4$

⊗ no root

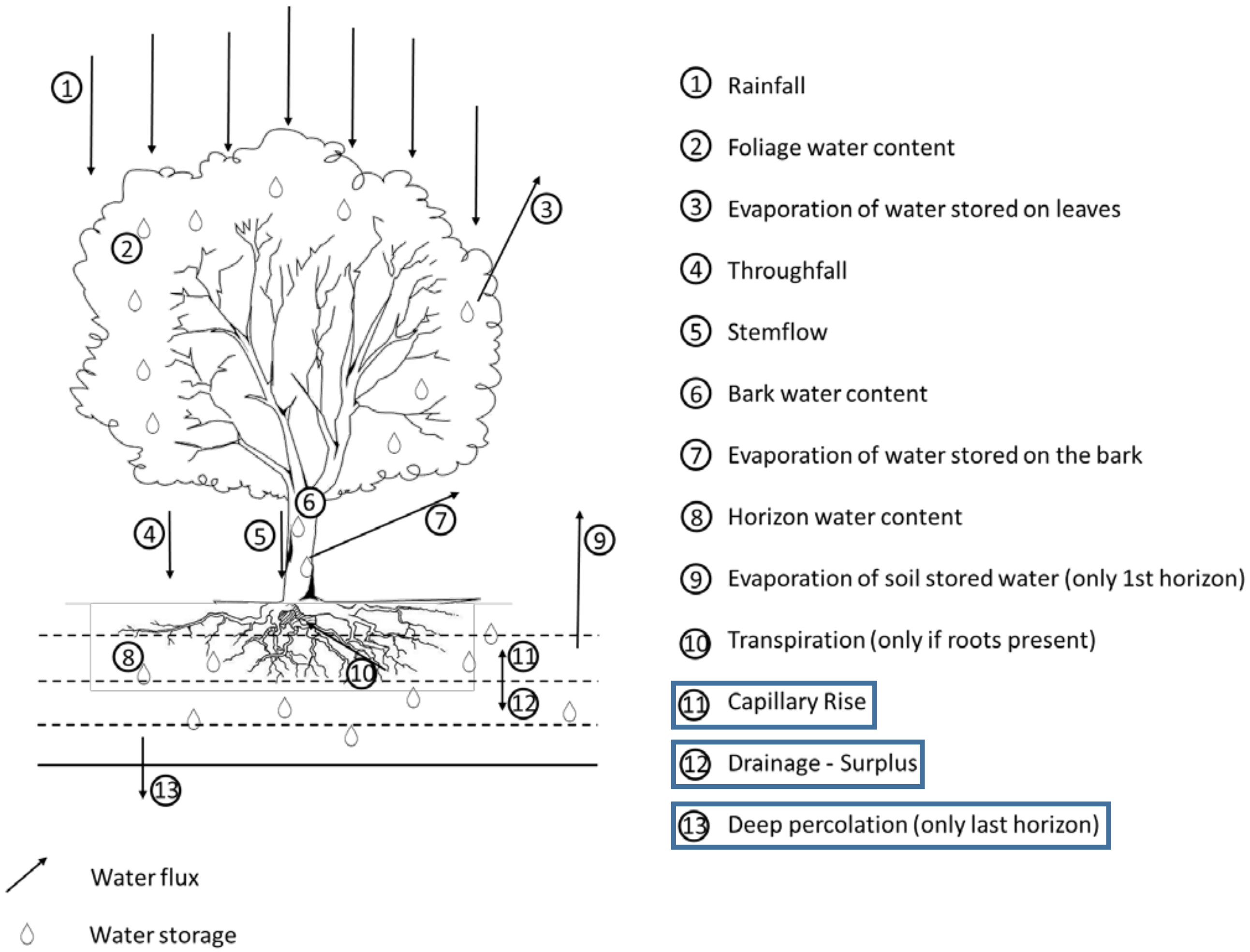
The matric potential Ψ is calculated from pressure head h determined, in turn, by van Genuchten equation (1980):

$$S = \frac{\theta - \theta_r}{\theta_s - \theta_r}$$

$$S = [1 + (\alpha|h|)^n]^{\frac{1-n}{n}}$$

Parameter values come from Vereecken pedotransfer functions (Weynants *et al*, 2009), which require information about organic, clay and sand contents and bulk density

Water balance module development



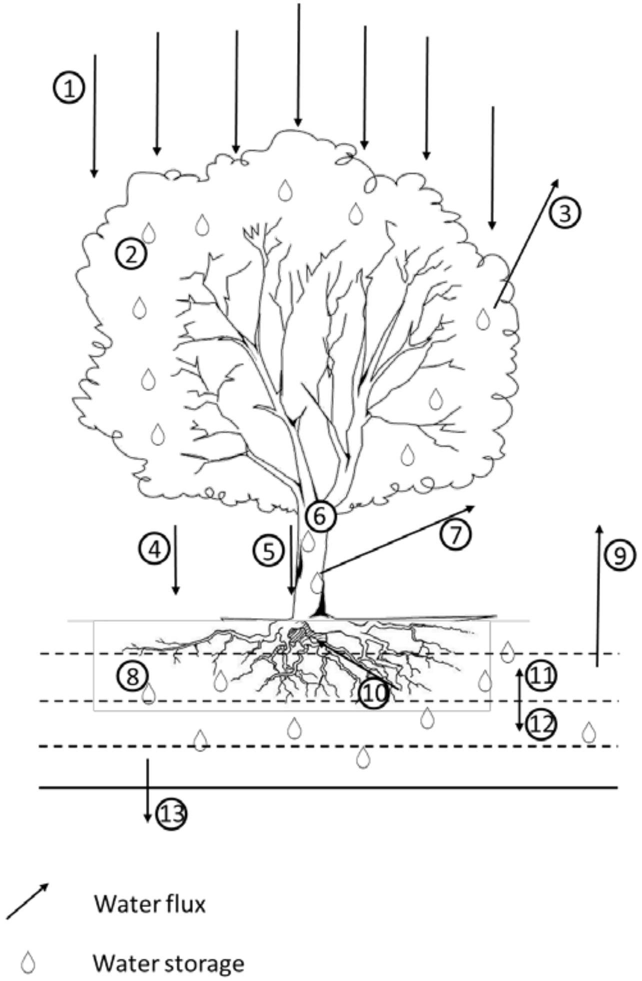
Vertical movements through horizons are regulated by soil conductivity, gravity and water potential gradient. Conductivity is obtained with Mualem - van Genuchten model equation (1980):

$$K = K_0\left(S^{\lambda}\left\{1-\left(1-S^{n/_{n-1}}\right)^{1-\frac{1}{n}}\right\}^2\right)$$

For organic horizons, parameter values from Dettmann *et al.* (2014) are used. They emanate from peat soil observations.

For mineral horizons, pedotransfer equations elaborated by Weynants et al. (2009) are used.

Water balance module development



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Surplus is currently calculated according to the assumption that once the horizon is saturated, excedent water is transferred to the next horizon. Some improvements are planned.

Drainage and capillary rise both follow the same equations:

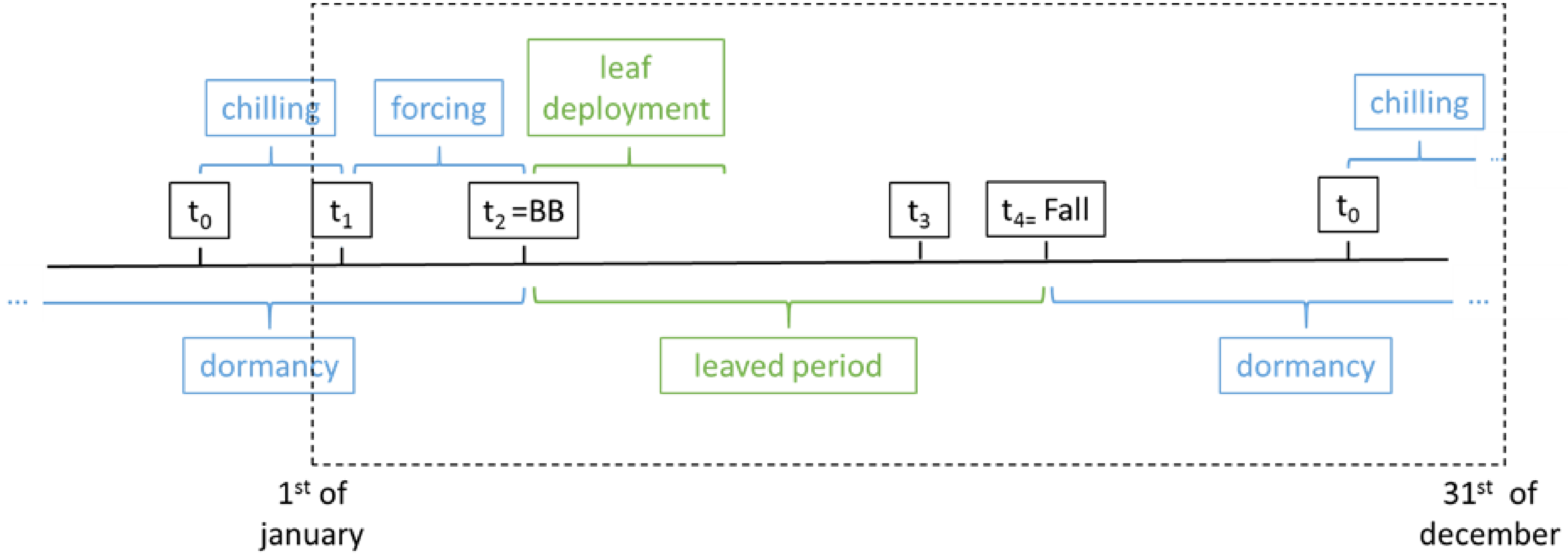
$$D = \frac{K_{hr,hr+1}}{24} \cdot \left(\frac{\delta h_m}{\delta z} + 1 \right) \cdot A_{stand} \cdot 10$$

$$K_{hr,hr+1} = \frac{(K_{hr} \cdot e_{hr} + K_{hr+1} \cdot e_{hr+1})}{(e_{hr} + e_{hr+1})}$$

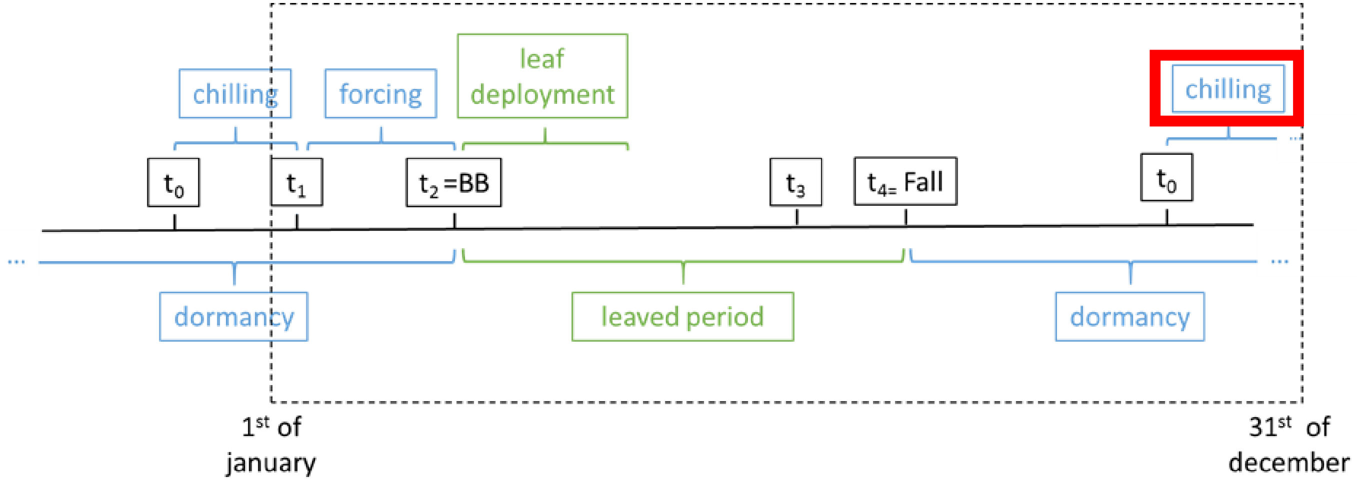
$$\frac{\delta h_m}{\delta z} = \frac{|h_{hr+1}| - |h_{hr}|}{\frac{e_{hr} + e_{hr+1}}{2} \cdot 100}$$

Comparisons between model results and data, however, show that using the minimal conductivity value gives better results than when the conductivity is averaged

Phenological module development



Phenological module development

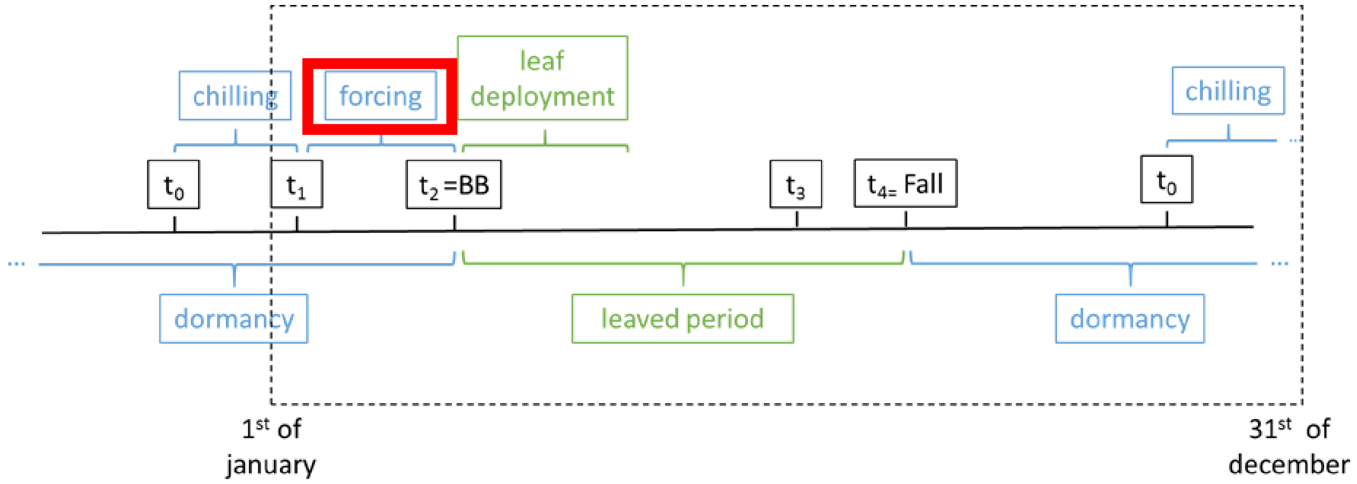


Chilling rate (Chuine, 2009):

$$R_c = \begin{cases} \frac{1}{1+e^{Ca(T-Cc)^2+Cb(T-Cc)}}, & -5 \leq T \leq 10 \\ 0, & T > 10 \; or \; T < -5 \end{cases}$$

$$S_c = \sum_{t_0}^{t} R_c(T_t), \; t = t_1 \; if \; S_c > C^*$$

Phenological module development

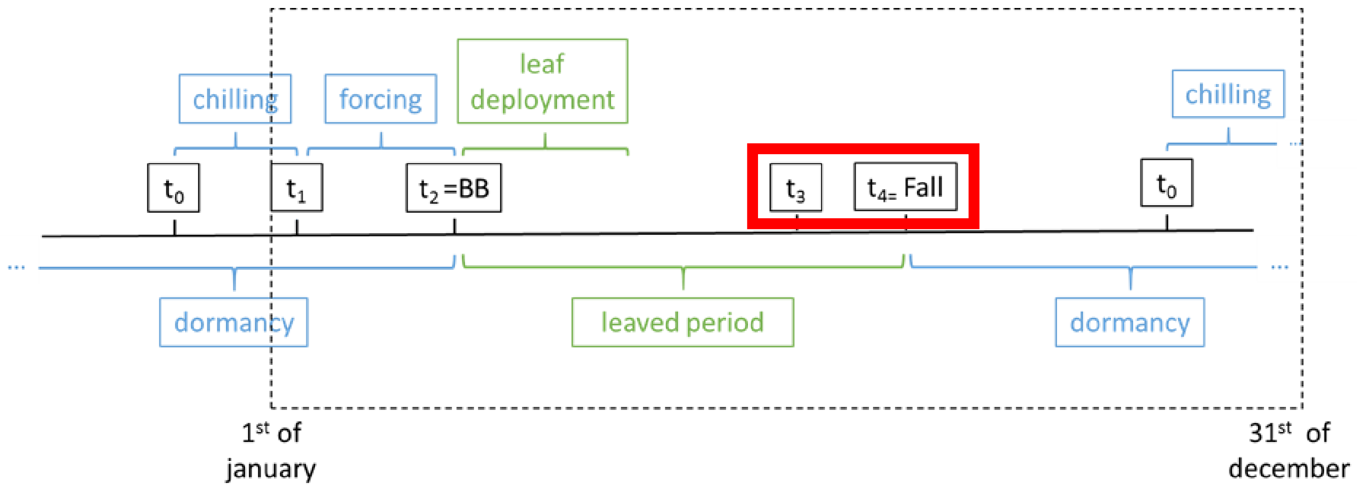


Forcing rate (Chuine, 2009):

$$R_f = \begin{cases} \frac{1}{1+e^{Fb(T-Fc)}}, & T > 0 \\ 0, & T \leq 0 \end{cases}$$

$$S_f = \sum_{t_1}^{t} R_f(T_t)\,,\ t = BB\ if\ S_f > F^*$$

Phenological module development

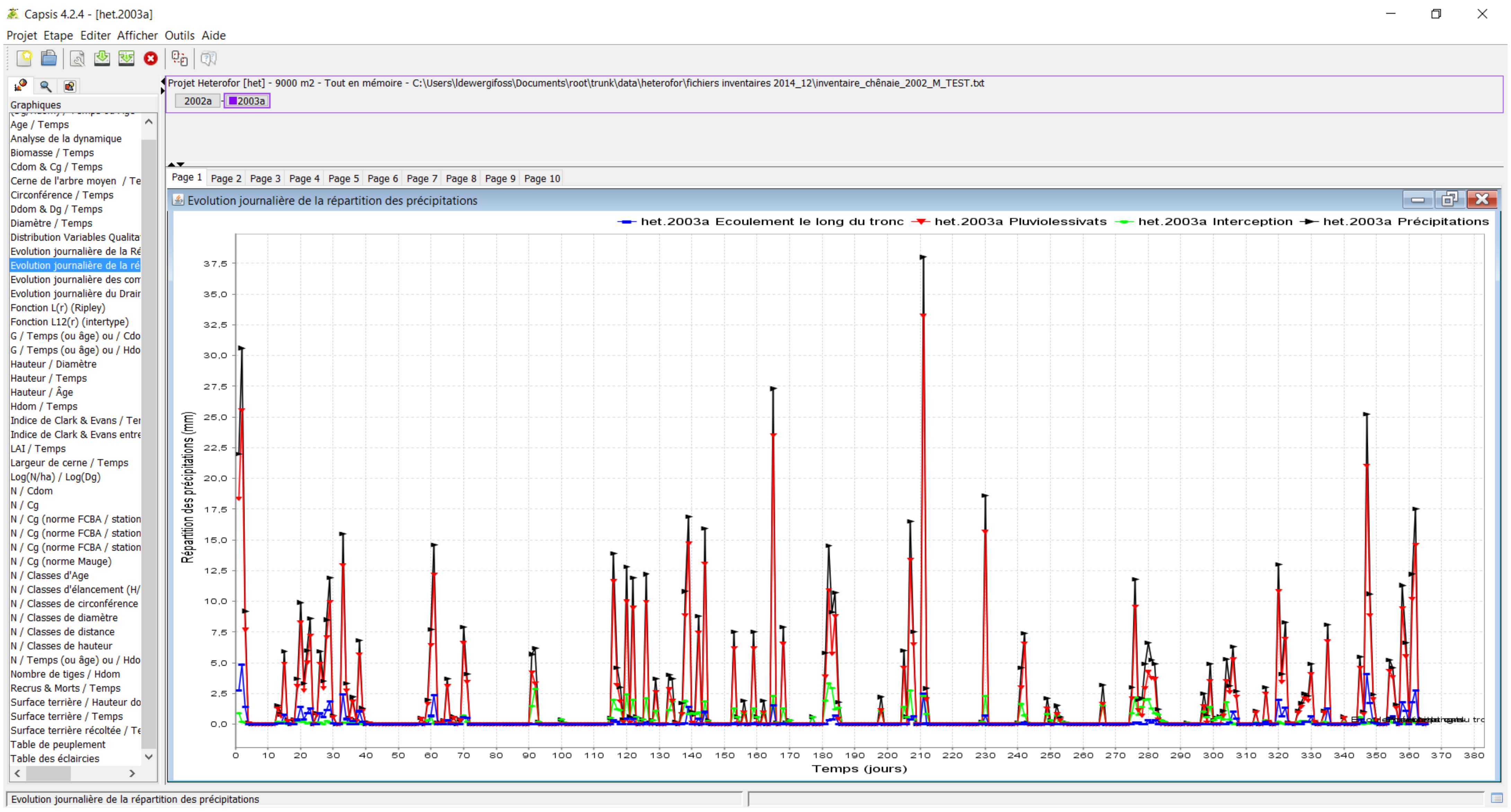


Yellowing rate (Dufrene *et al*, 2005):

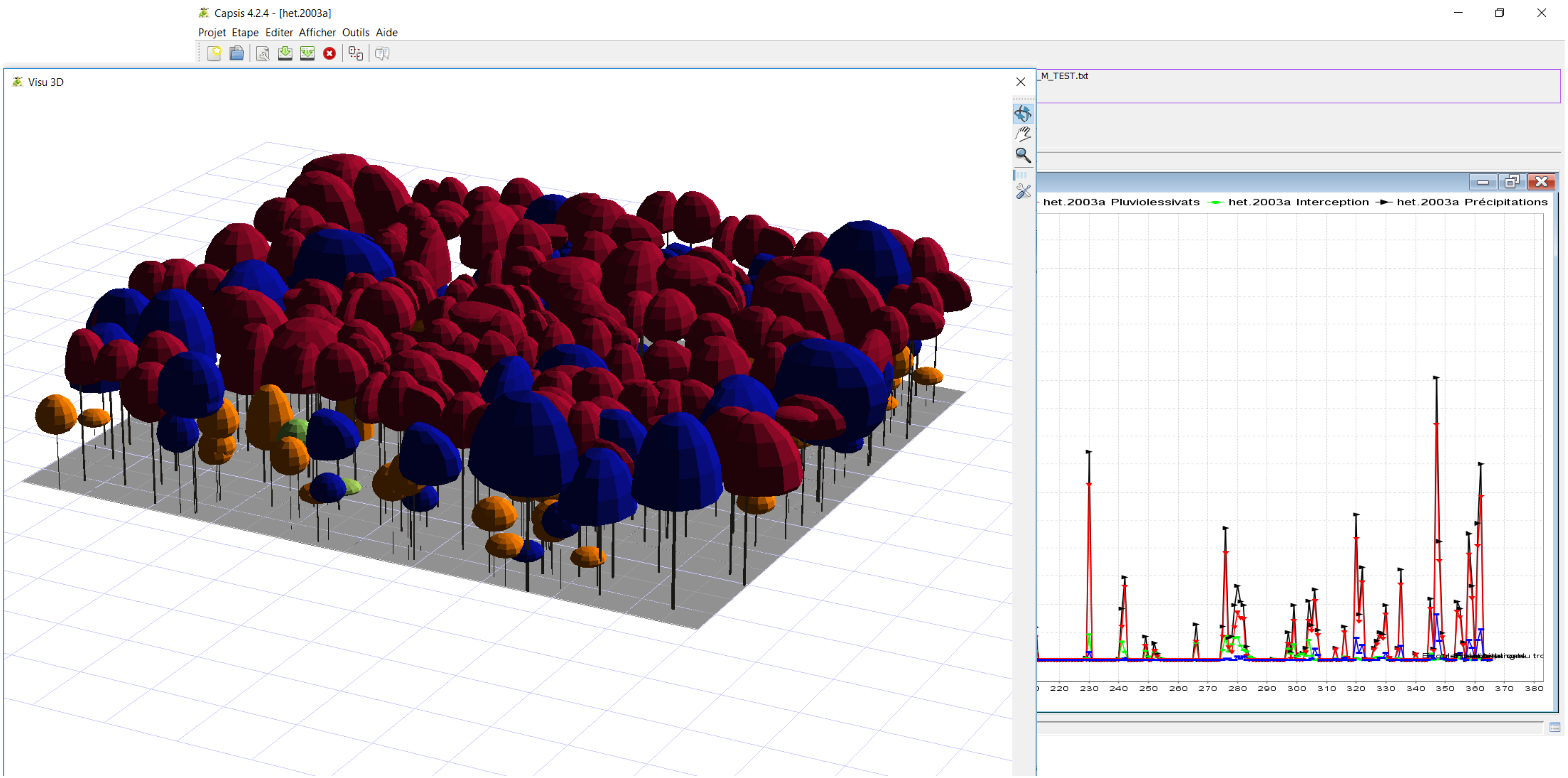
$$R_{yell} = \begin{cases} T_{b\_yell} - T, & T < T_{b\_yell} \; and \; t \geq t_3 \\ 0, & T \geq T_{b\_yell} \; or \; t < t_3 \end{cases}$$

$$S_{yell} = \sum_{t_3}^{t} R_{yell}(T_t), \quad t = Fall \; if \; S_{yell} > F^*_{yell}$$

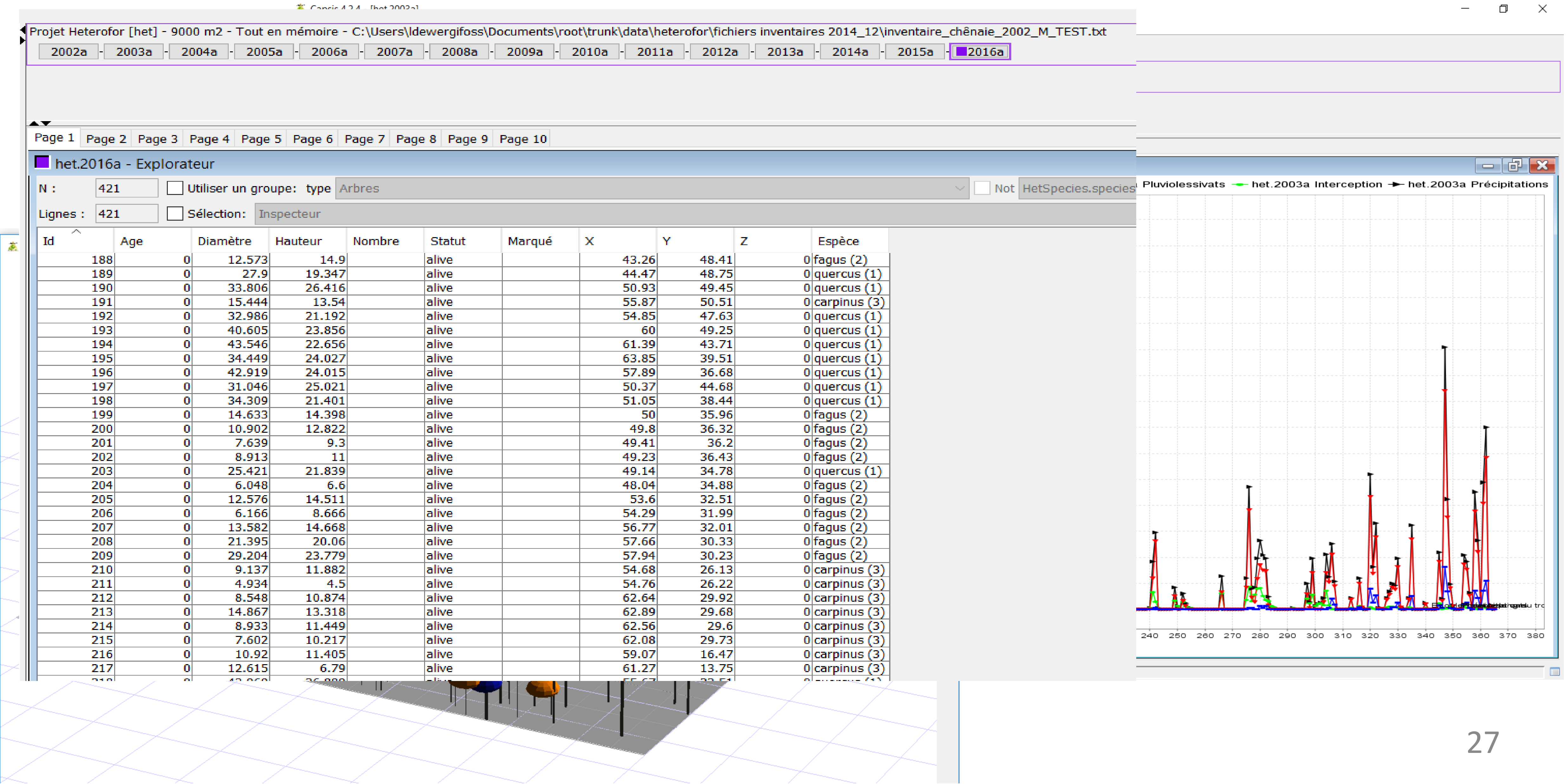
Model outputs



Model outputs

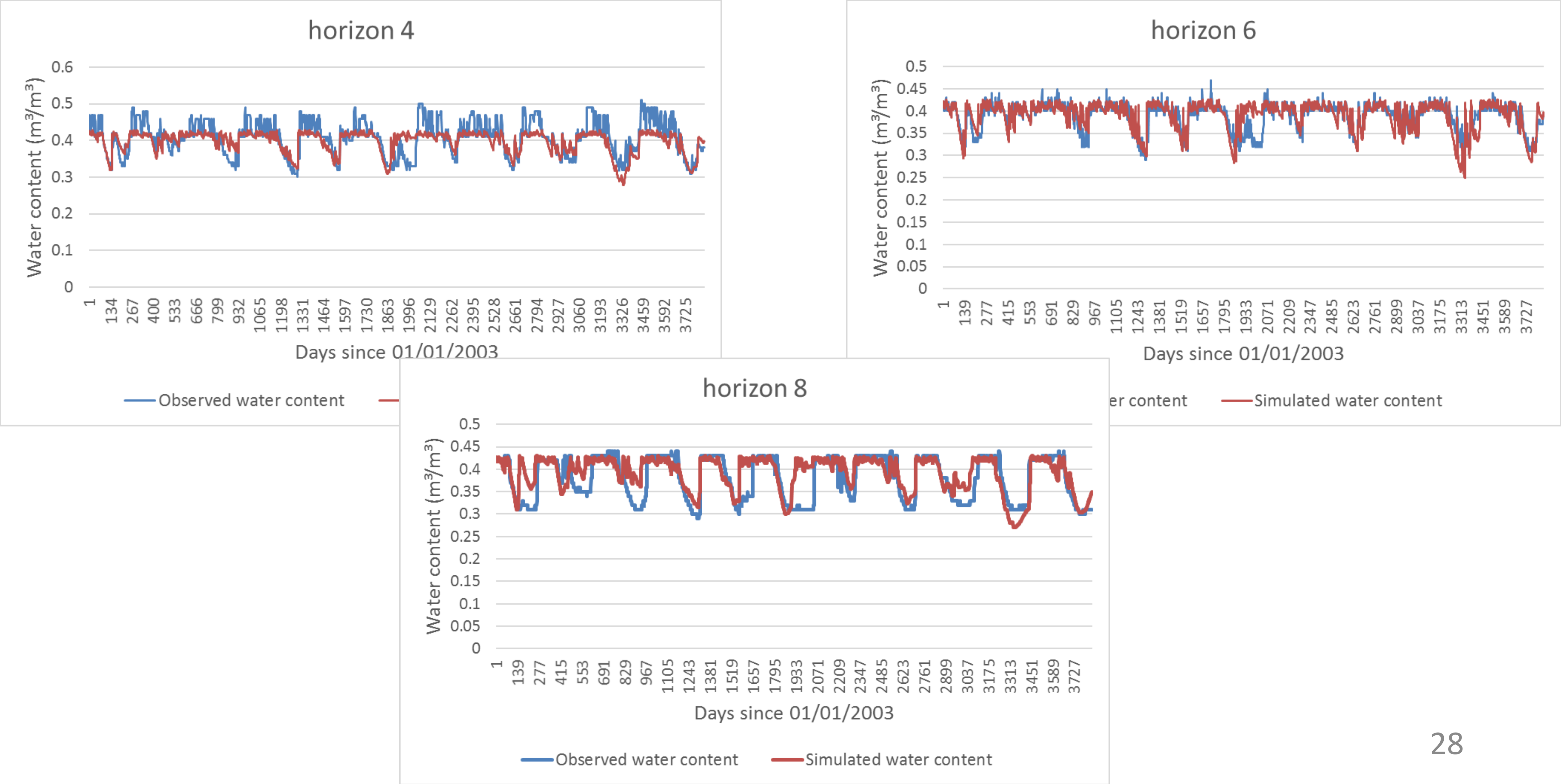


Model outputs



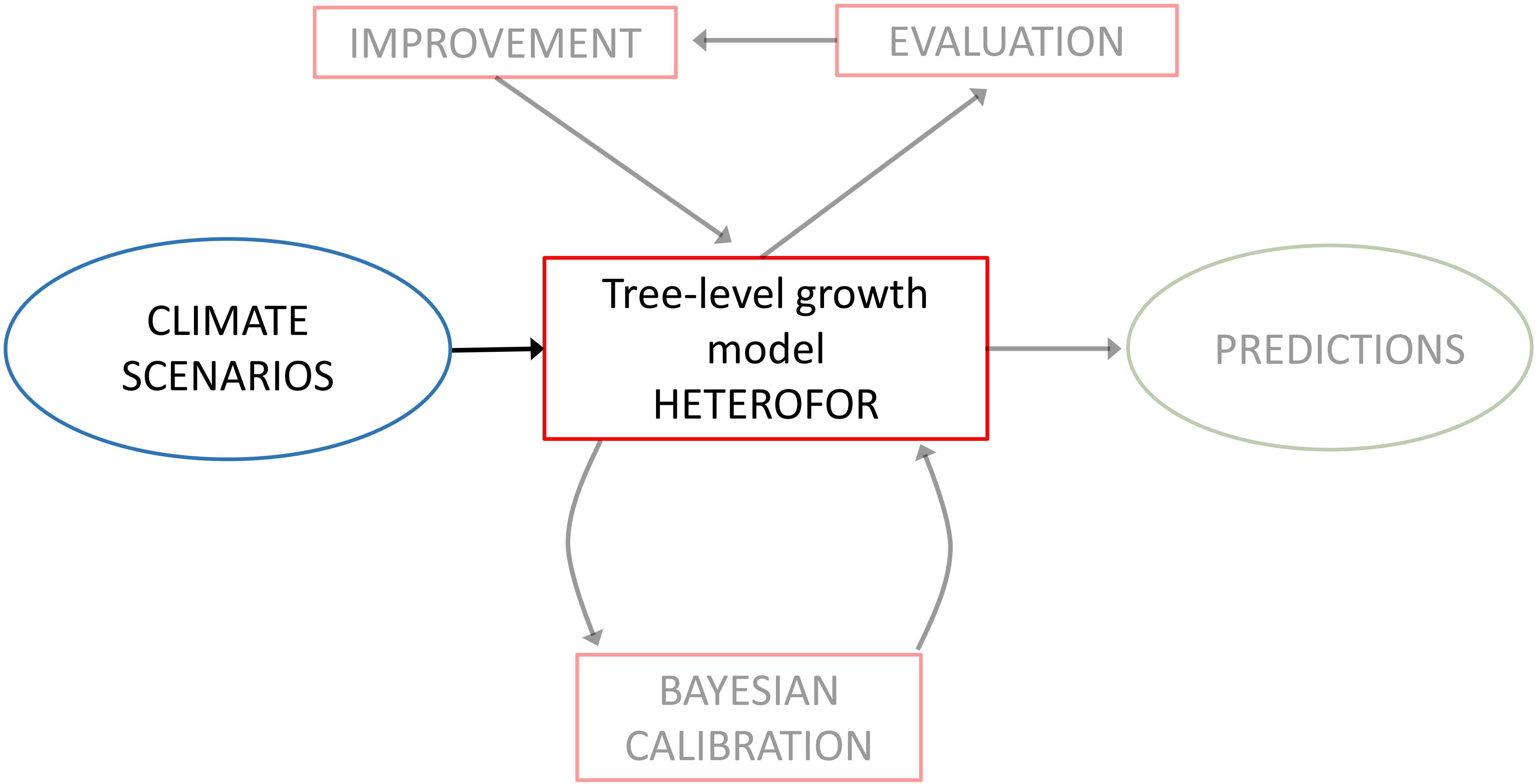
Id	Age	Diamètre	Hauteur	Nombre	Statut	Marqué	X	Y	Z	Espèce
188	0	12.573	14.9		alive		43.26	48.41	0	fagus (2)
189	0	27.9	19.347		alive		44.47	48.75	0	quercus (1)
190	0	33.806	26.416		alive		50.93	49.45	0	quercus (1)
191	0	15.444	13.54		alive		55.87	50.51	0	carpinus (3)
192	0	32.986	21.192		alive		54.85	47.63	0	quercus (1)
193	0	40.605	23.856		alive		60	49.25	0	quercus (1)
194	0	43.546	22.656		alive		61.39	43.71	0	quercus (1)
195	0	34.449	24.027		alive		63.85	39.51	0	quercus (1)
196	0	42.919	24.015		alive		57.89	36.68	0	quercus (1)
197	0	31.046	25.021		alive		50.37	44.68	0	quercus (1)
198	0	34.309	21.401		alive		51.05	38.44	0	quercus (1)
199	0	14.633	14.398		alive		50	35.96	0	fagus (2)
200	0	10.902	12.822		alive		49.8	36.32	0	fagus (2)
201	0	7.639	9.3		alive		49.41	36.2	0	fagus (2)
202	0	8.913	11		alive		49.23	36.43	0	fagus (2)
203	0	25.421	21.839		alive		49.14	34.78	0	quercus (1)
204	0	6.048	6.6		alive		48.04	34.88	0	fagus (2)
205	0	12.576	14.511		alive		53.6	32.51	0	fagus (2)
206	0	6.166	8.666		alive		54.29	31.99	0	fagus (2)
207	0	13.582	14.668		alive		56.77	32.01	0	fagus (2)
208	0	21.395	20.06		alive		57.66	30.33	0	fagus (2)
209	0	29.204	23.779		alive		57.94	30.23	0	fagus (2)
210	0	9.137	11.882		alive		54.68	26.13	0	carpinus (3)
211	0	4.934	4.5		alive		54.76	26.22	0	carpinus (3)
212	0	8.548	10.874		alive		62.64	29.92	0	carpinus (3)
213	0	14.867	13.318		alive		62.89	29.68	0	carpinus (3)
214	0	8.933	11.449		alive		62.56	29.6	0	carpinus (3)
215	0	7.602	10.217		alive		62.08	29.73	0	carpinus (3)
216	0	10.92	11.405		alive		59.07	16.47	0	carpinus (3)
217	0	12.615	6.79		alive		61.27	13.75	0	carpinus (3)

1st year – Module evaluation with data from a reference site



2nd year – Selection of PIC forest sites

3rd year – Climate scenarios constitution and integration of their different variability sources



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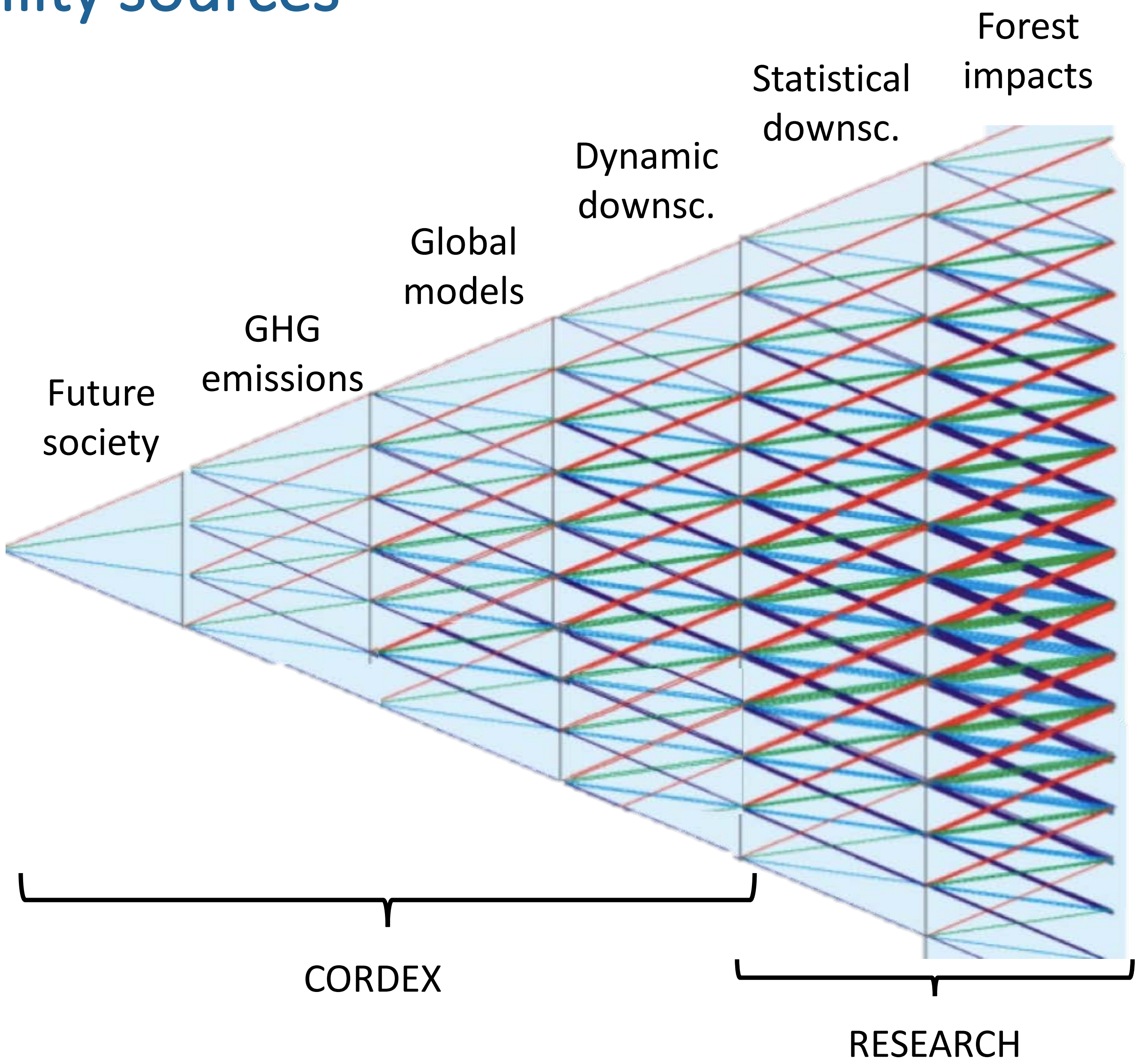
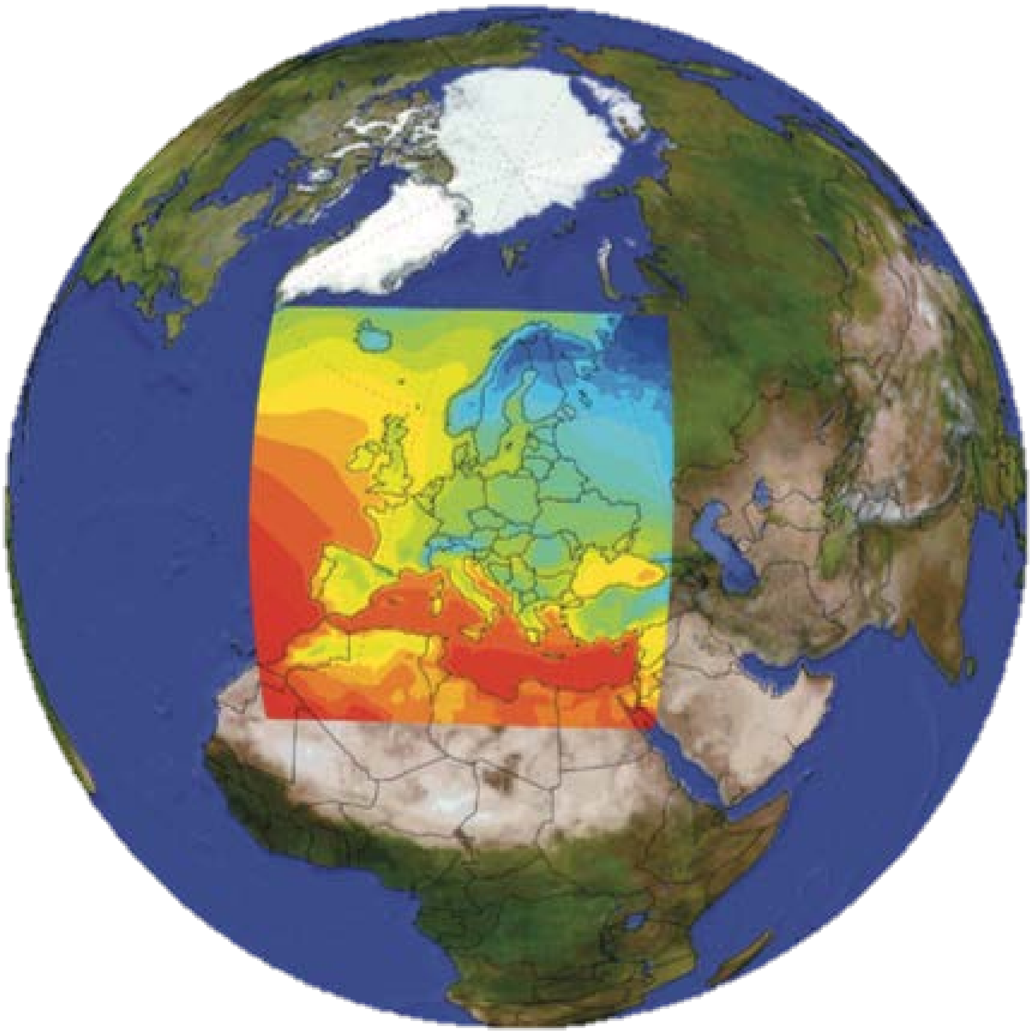


Downscaling

2 types of method:

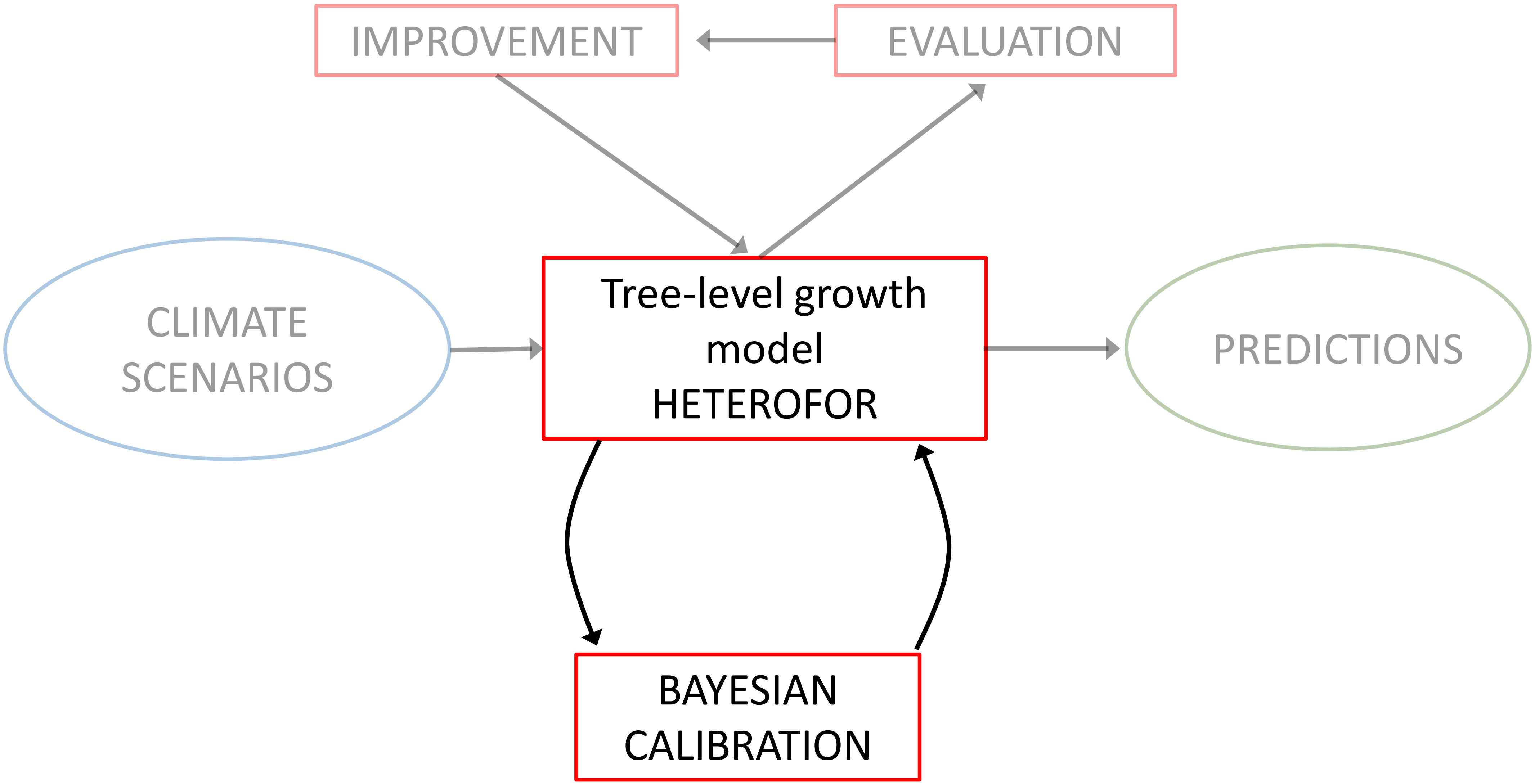
- Statistical downscaling: Use of statistical correlations between large-scale climate phenomena (values of the atmospheric pressure field) and local climate (monthly averaged temperatures) (Mearns, 2009)

- Dynamic downscaling: Use of climate models working at a finer scale and using global climate model results as boundary conditions



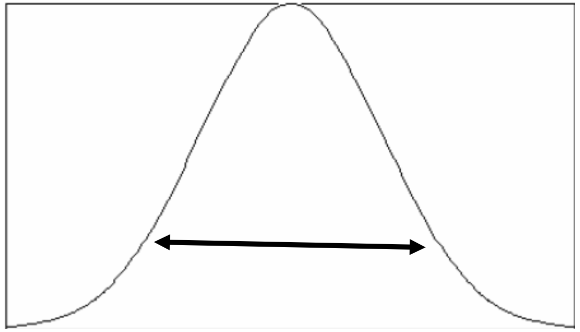
(Hoar et Nychka, 2008)

3-4th years – Inclusion of HETEROFOR uncertainties: bayesian calibration



3-4th years – Inclusion of HETEROFOR uncertainties: bayesian calibration

Prior distribution of the parameter values

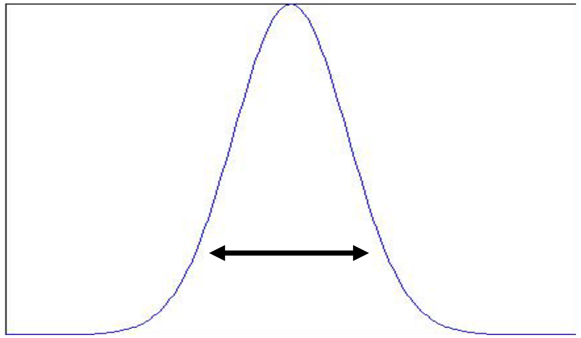


$$\frac{p(D|\Theta).p(\Theta)}{p(D)} = p(\Theta|D)$$

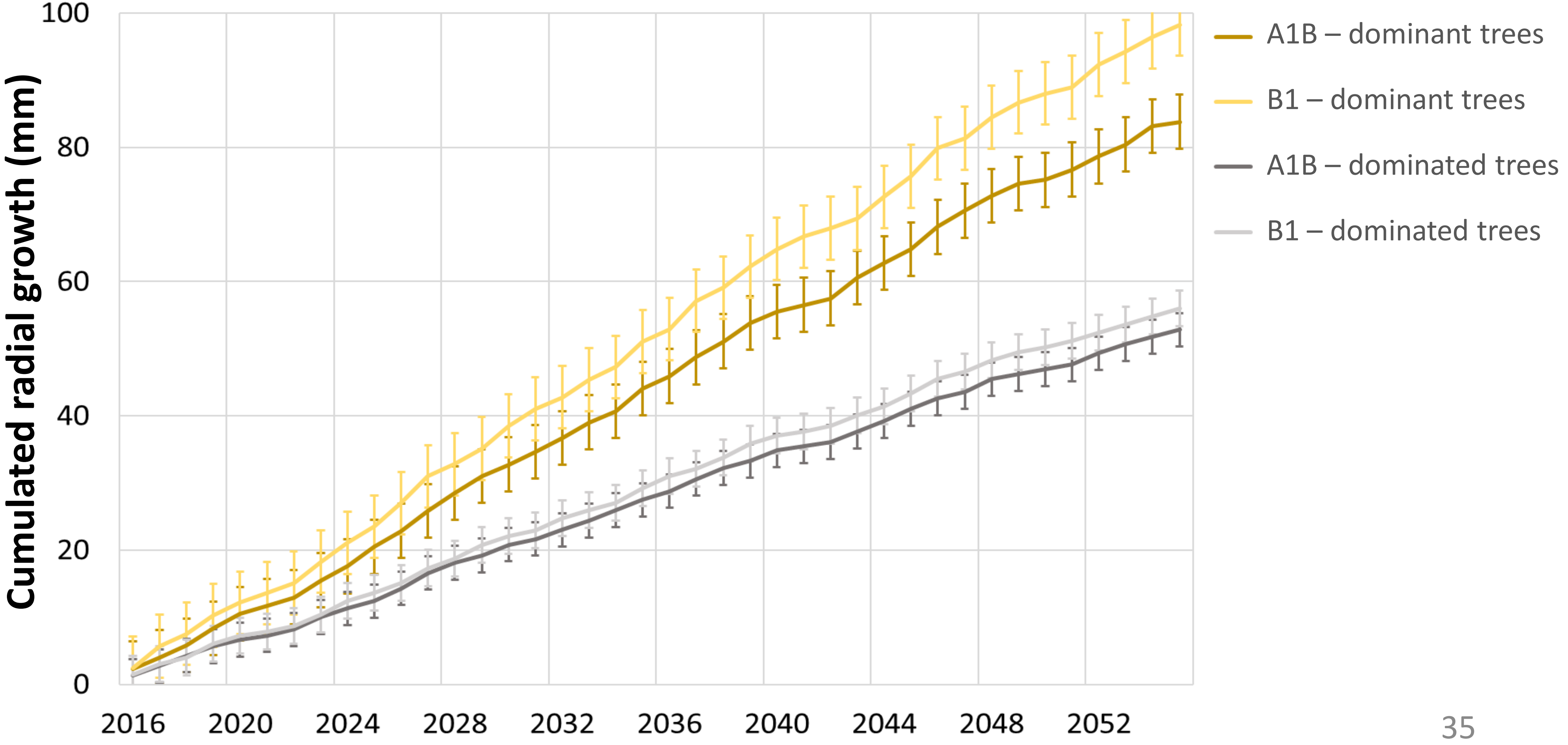
Model

Experimental data

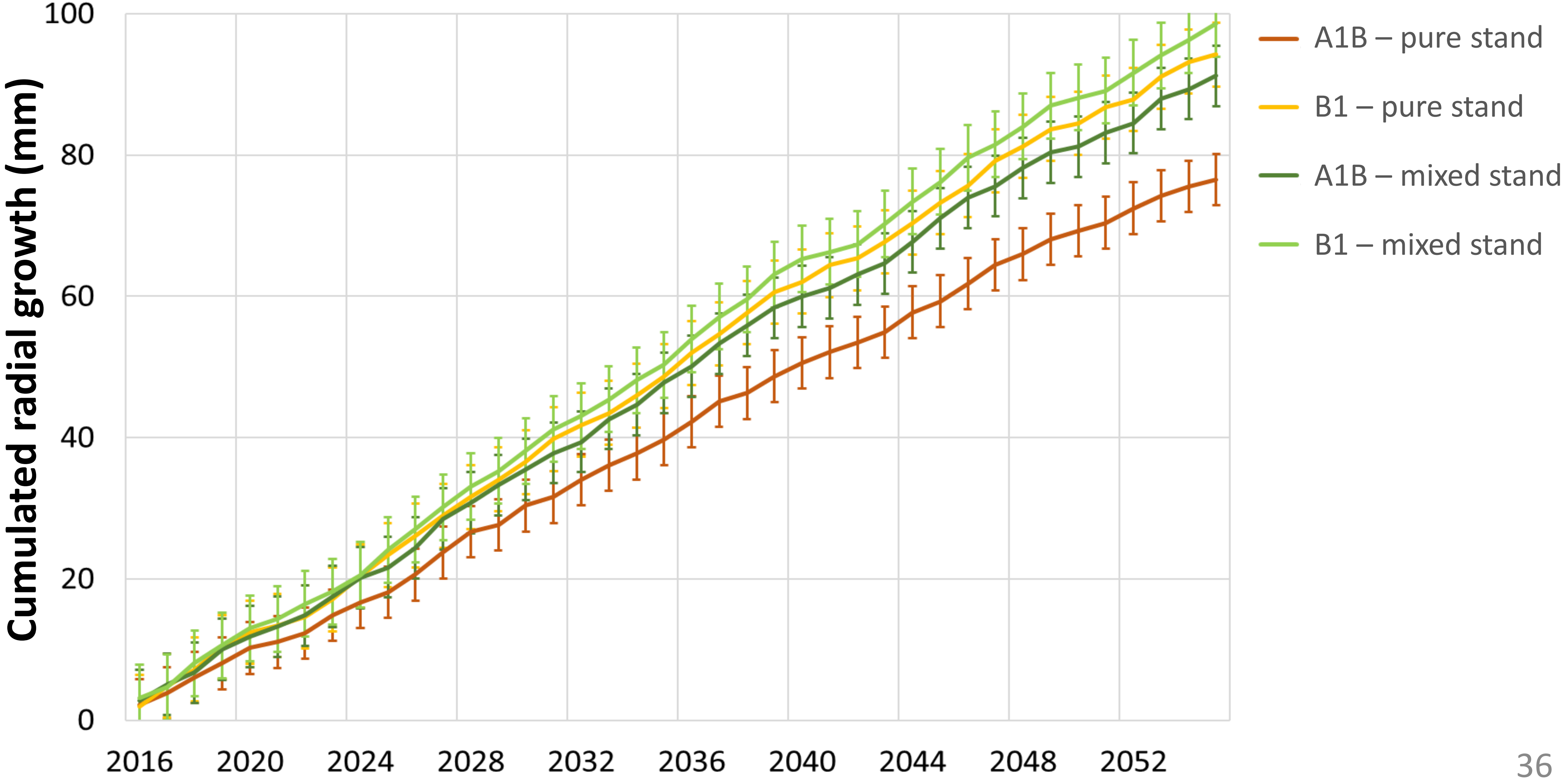
Posterior distribution of the parameter values



Expected results – Individual growth comparison climate scenario x social status



Expected results – Individual growth comparison climate scenario x stand type



Practical prospects and perspectives

Tool for helping forestry practice decisions

→ Sylvicol itineraries enhancing resilience to tackle cl. change induced risks:
- → Choice of resistant species
- → Stand types…

→ Forestry policies & land use plans

Methodology to analyse climate change impacts while characterizing uncertainties :

→ Reusable for other issues