

Response to reviewer comment on “HETEROFOR 1.0: a spatially explicit model for exploring the response of structurally complex forests to uncertain future conditions. II. Phenology and water cycle” by Louis de Wergifosse et al.

Anonymous Referee #1

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[Author response:](#)

In addition to the previous response posted on the 20th of September, the following comments are addressed hereafter.

I understand that it is difficult to parameterize and evaluated a phenological model that differentiates for leaves in different layers in a structural forest. However, if the model is not considering these structural effects, it may be accurate but is not new and is not particular related to the specific approach of HETEROFOR. This would change if at least the option would be available (e.g. as a yet uniform parameter) to make budburst (I see you found some examples already) and leaf fall (Gressler et al. 2015) dependent on tree size or specific environmental conditions. In particular, since I assume that the model should be applied to more tree species than those presented here, which may respond differently.

[R:](#)

As suggested, we have tested the implementation of an option to make the phenology size-dependent. In the initialisation phase of the model, if the user selects the option “phenology at the tree scale”, the leaf development is first triggered in the smallest trees of each tree species and then progressively in the taller ones according to their height. Inversely, during leaf fall, the tallest trees lose their leaves before the smaller ones. At the stand scale, the option “phenology at the tree scale” provide exactly the same leaf development/fall than the default option but the difference appear at the tree scale. The default option assumes that all trees initiate budburst/leaf fall at the same time and display the same progressive leaf development/fall. The alternative option “phenology at the tree scale” supposes trees break down or lose their leaves one after the other depending on their size. These two options give the opportunity to compare two contrasted hypotheses regarding individual tree phenology and to evaluate to which extent it has an impact on tree growth. This alternative option will be described in the revised manuscript and discussed.

Regarding the question on “the benefit in comparison to cohort-based approaches” I see that you would like to differentiate between processes that you can more or less accurately determine on the individual trees (such as light availability) and those where the uncertainty is larger and that are thus treated in the same way as in cohort or even stand scale models (such as water availability). Not be able to precisely determine root competition indeed increases uncertainty. On the other hand, neglecting it makes the model inconsistent and biased towards aboveground competition process (that by the way are relying on crown form assumptions and leaf area distribution also based on rough assumptions).

[R:](#)

The default option for the water balance module in HETEROFOR considers that all trees take up water in the same soil horizons assuming that soil water is redistributed homogeneously between two hourly time steps.

Following the discussions initiated on this subject with the reviewer 1 (see previous comments and responses), we have developed a new option to perform water balance on an individual scale. With this alternative option called “Detailed spatial resolution”, all the water fluxes (throughfall, stemflow, foliage, bark and soil evaporation, transpiration, water uptake, soil water movements and drainage) are calculated at the individual level. For this option, the model distributes the total soil volume in individual soil volumes (called pedon). The pedon area (a_{pedon}) is determined proportionally to the leaf area of the associated tree (but is limited to two times its crown projection):

$$a_{pedon} = \frac{a_{leaf}}{A_{leaf}} \cdot A_{stand}$$

with a_{leaf} , the tree leaf area (m²)
 A_{leaf} , the total stand leaf area (m²)
 A_{stand} , the total stand area (m²)

In sparse stands, all the stand area is not allocated to the trees and the remaining area is considered as a pedon without any associated tree. With the detailed water balance option, the model performs a water balance for each tree pedons and also for the remaining pedon (without tree). Contrary to the default option assuming a homogeneous horizontal water redistribution, the alternative option supposes no water redistribution among pedons. These two options allow the user to test two contrasted hypotheses regarding soil water redistribution in the horizontal dimension.

This new option will be presented in the revised manuscript and evaluated against individual transpiration measurements.

Actually, this is the reasoning to apply stand-scale and cohort models which are therefore more consistent. I am even aware of an approach that recalculates individual growth from cohort-based biomass gain (Poschenrieder et al. 2013). The basic criteria, however, may be if your half-individual approach is actually performing better than a cohort-based approach. I am therefore excited to see your analysis in this behalf.

R:

As promised in our response to the comments of reviewer 1, we have realised a first sensitivity analysis of our model to evaluate how changing tree spatial distribution and restricting our individual approach into a cohort approach affect our results.

To do so, we created different stands from an existing stand. The stand we used was Baileux-mixed that is constituted from oak and beech trees in similar proportions and that was used for the evaluation of the model (cfr. manuscript). For testing the effect of the tree spatial distribution, we created two stands composed of exactly the same trees but with a contrasted spatial distribution: a patch-wise mixture in which the trees of a similar size and of the same species have a higher probability to be grouped and an intimate mixture where trees of different tree species and size are intimately mixed. In addition, to test the effect of restricting our approach to a cohort model, we distributed the trees of the intimate mixture in seven different cohorts (four beech and three oak cohorts) and replaced the dimensions of the trees by those of the corresponding cohort. The cohorts were defined according to the girth-class distribution (0-60 cm, 61-105 cm, 106-140 cm and > 140 cm) and the tree dimensions in each cohort were defined based on those of the average tree of the cohort.

In the end, we obtained one stand where all the trees are represented with their own characteristics grouped in patches according to their size and species called patch-wise mixture (tree level approach), another where all the trees are represented according to their real dimensions but where trees of

different size and species are mixed in an intimate way called intimate tree by tree mixture (tree level approach) and a last one with an intimate tree by tree mixture but where the trees of the same cohort have the same averaged dimensions. They are all represented in Fig. 1.

The evolution of the three different stands was simulated between 2001 and 2011 and they were compared based on the LAI and on the annual transpiration (Figs. 2 and 3). The differences in LAI and in annual transpiration among stands were analysed for each cohorts and for all trees together. In addition, mixed linear models were fitted to highlight the effects of the tree spatial distribution and of the clustering in cohorts taking the tree and the year into account as random factors. The cohort clustering effect was tested by comparing the intimate mixtures at the tree and cohort level while the tree spatial distribution effect was assessed by comparing the patch-wise and intimate mixture.

The tree spatial distribution effect (patch-wise vs intimate mixture) generated differences in LAI ranging from -35% to +23% depending on the year and on the cohort considered (Fig. 2). According to the linear mixed models, this effect was always significant, except for the beech > 140 cm cohort (Table 1). Regarding annual transpiration, the relative differences between the patch-wise and the intimate mixture range between -25% to +9% and the corresponding effect was significant, except for the beech 106-140 cm cohort (Table 2).

Compared to the individual approach, the clustering in cohorts induced differences from -9% to +30% for the LAI (Fig. 2) and from -10% to +6% for the annual transpiration (Fig. 3). The corresponding effect was significant, except for the oak 61-105 cm cohort concerning LAI and for the oak and beech 106-140 cm cohorts regarding annual transpiration (Tables 1 and 2).

The effects of tree spatial distribution and of clustering in cohorts are less pronounced at the stand than at the cohort level since they vary from one cohort to the other and partly offset each other at the stand level.

These first results indicate that HETEROFOR is sensitive to the tree spatial distribution and to the clustering in cohorts. To fully address this question, the analysis should be repeated on more sites with various stand types, focused on more model outputs and also tested with longer simulations. However, this is beyond the scope of this paper, which is already quite long with 5 tables and 8 figures and will be even longer with the presentation of the new options and the evaluation of tree transpiration predictions against measurements. The objectives of this paper are to describe the phenology and water balance modules of a new individual-based model that allows to account for the stand spatial and structural complexity and to evaluate its performances. We propose not to introduce this first sensitivity analysis in the article to avoid overloading it and to treat this question in another paper.

P.S. Please try to understand my remark about 'runoff is not included'. It refers to the water at the surface when the water capacity of the soil is reached. Is it nevertheless forced to percolate into or through the soil or does it pile up at the surface?

R:

The water is forced to percolate into the soil. We will insist more on that in the revised manuscript.

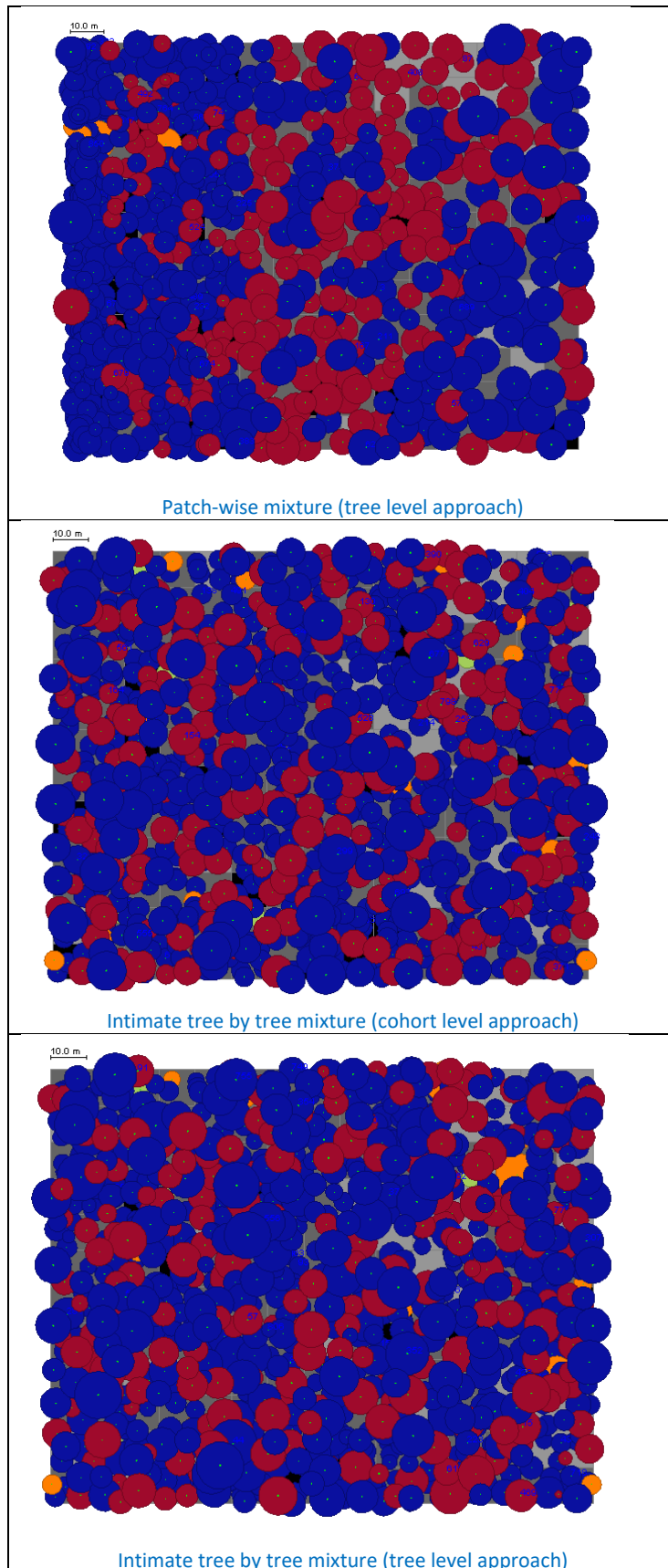


Fig. 1: Visual representation of the three stands created for analysing the model sensitivity to the tree spatial distribution and the restriction of the individual approach into a cohort approach.

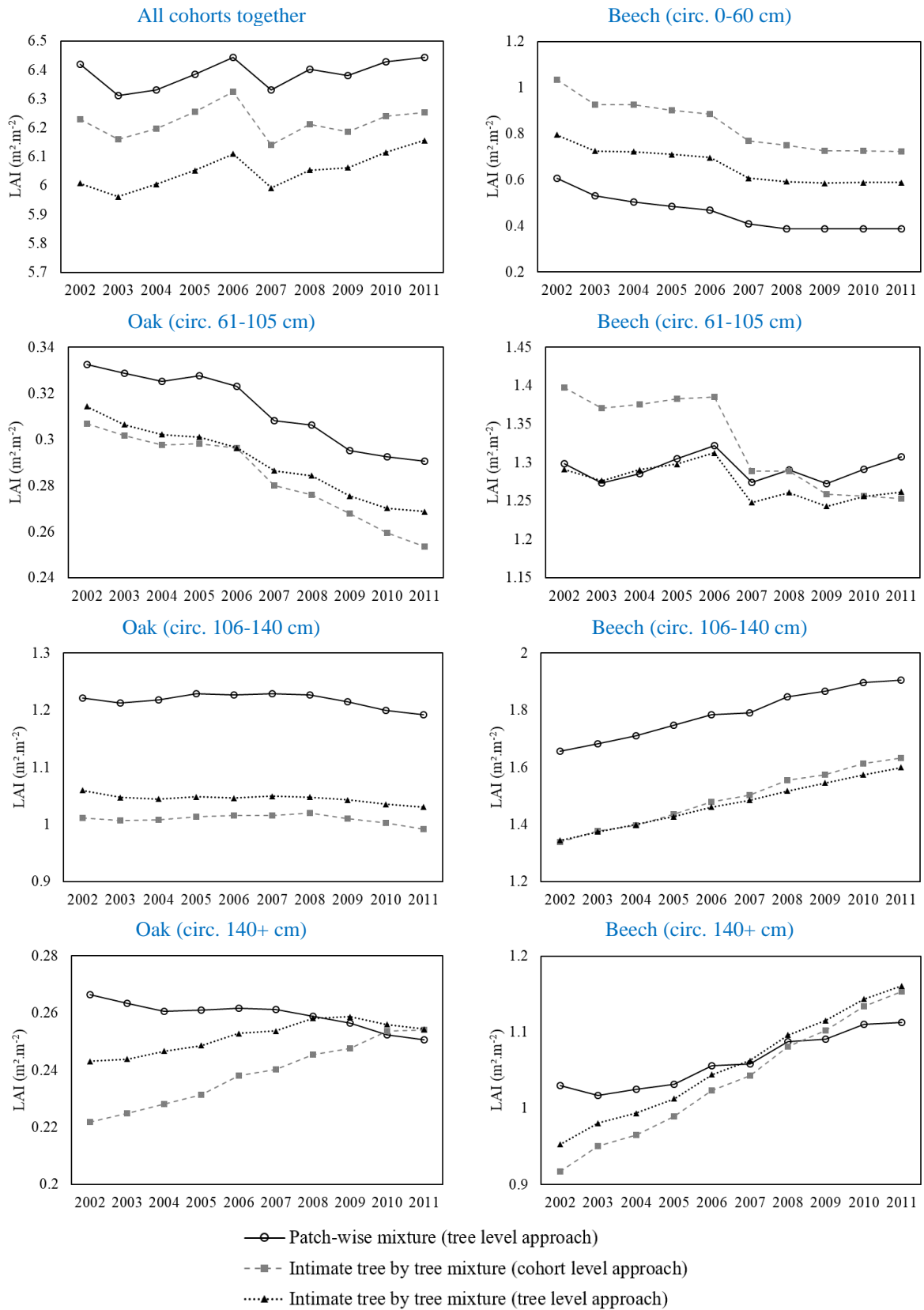


Fig.2: Temporal change in LAI (m^2/m^2) of the mixed stand in Baileux for all trees together and per cohort (four beech and three oak cohorts) according to three different stand configurations: a patch-wise mixture with a tree level approach and two intimate mixtures with a tree or a cohort level approach.

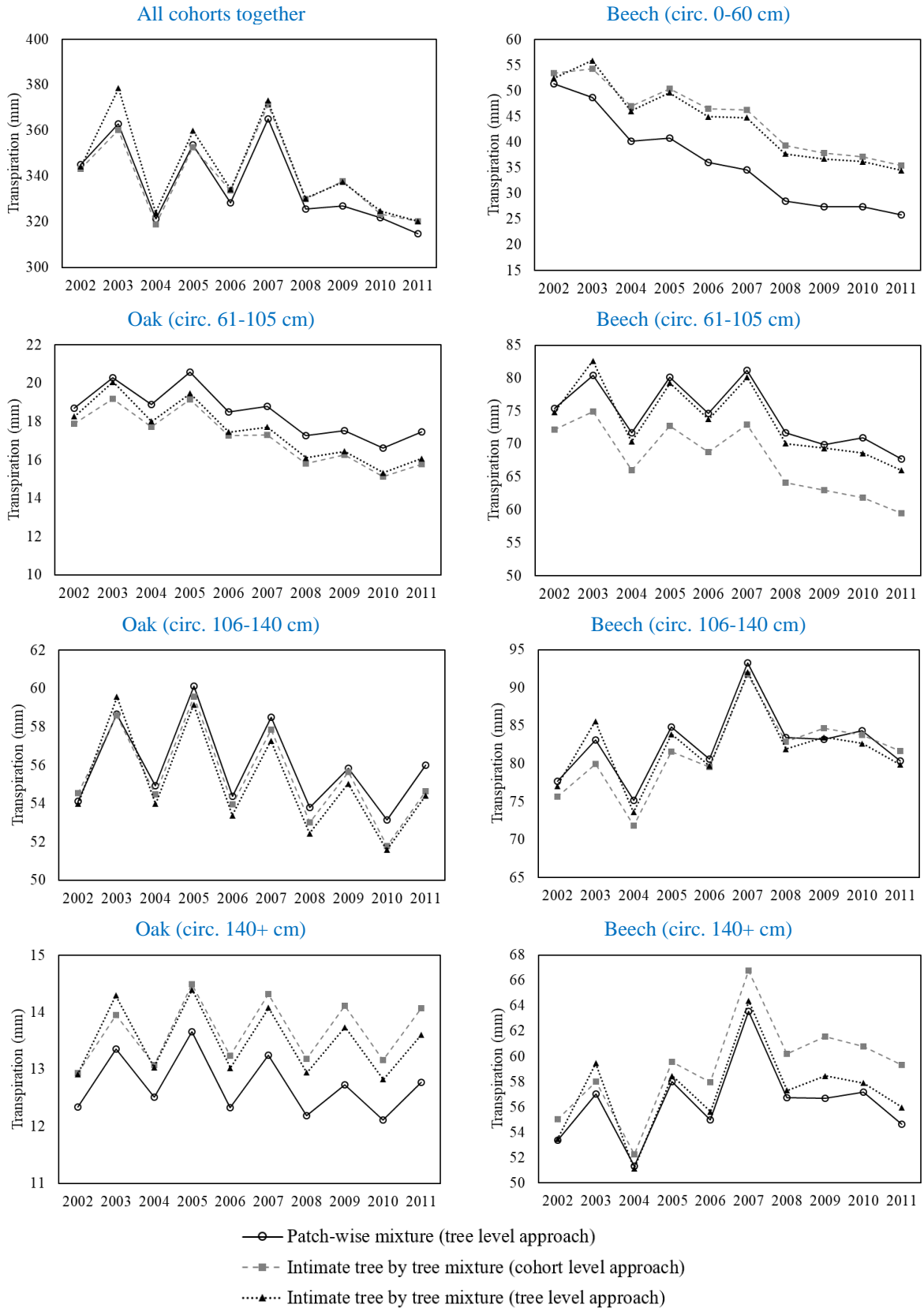


Fig. 3: Temporal change in the annual transpiration (mm) of the mixed stand in Baileux for all trees together and per cohort (four beech and three oak cohorts) according to three different stand configurations: a patch-wise mixture with a tree level approach and two intimate mixtures with a tree or a cohort level approach.

Table 1: Mixed linear model results for the different tree cohorts and for all trees to highlight the impact of tree spatial distribution (patch-wise vs intimate tree by tree mixture) and of cohort clustering (tree vs cohort approach) on LAI.

Effect	Cohort	Estimate (std dev)	p-value
Intimate vs patch mixture	Beech (circ. 0-60 cm)	-0.00032 (8.9 E ⁻⁶)	<.0001***
	Beech (circ. 61-105 cm)	5.8 E ⁻⁵ (2.7 E ⁻⁵)	0.028*
	Oak (circ. 61-105 cm)	0.00016 (2.7 E ⁻⁵)	<.0001***
	Beech (circ. 106-140 cm)	0.0018 (3.9 E ⁻⁵)	<.0001***
	Oak (circ. 106-140 cm)	0.00071 (3.6 E ⁻⁵)	<.0001***
	Beech (circ. 140+ cm)	7.6 E ⁻⁵ (0.00013)	0.56
	Oak (circ. 140+ cm)	0.00019 (8.1 E ⁻⁵)	0.018*
	All trees	0.00021 (1.3 E ⁻⁵)	<.0001***
Tree vs cohort approach	Beech (circ. 0-60 cm)	0.00027 (1.0 E ⁻⁵)	<.0001***
	Beech (circ. 61-105 cm)	0.00017 (2.8 E ⁻⁵)	<.0001***
	Oak (circ. 61-105 cm)	-4.9 E ⁻⁵ (3.3 E ⁻⁵)	0.14
	Beech (circ. 106-140 cm)	9.7 E ⁻⁵ (4.0 E ⁻⁵)	0.016*
	Oak (circ. 106-140 cm)	-0.00015 (3.4 E ⁻⁵)	<.0001***
	Beech (circ. 140+ cm)	-0.00027 (9.9 E ⁻⁵)	0.0070**
	Oak (circ. 140+ cm)	-0.00033 (8.0 E ⁻⁵)	<.0001***
	All trees	0.00010 (1.2 E ⁻⁵)	<.0001***

Table 2: Mixed linear model results for the different tree cohorts and for all trees to highlight the impact of tree spatial distribution (patch-wise vs intimate tree by tree mixture) and of cohort clustering (tree vs cohort approach) on annual transpiration.

Effect	Cohort	Estimate (std dev)	p-value
Intimate vs patch mixture	Beech (circ. 0-60 cm)	-0.012 (0.00043)	<.0001***
	Beech (circ. 61-105 cm)	0.0028 (0.00094)	0.0028***
	Oak (circ. 61-105 cm)	0.0070 (0.00087)	<.0001***
	Beech (circ. 106-140 cm)	0.0034 (0.0014)	0.016
	Oak (circ. 106-140 cm)	0.0036 (0.00089)	<.0001***
	Beech (circ. 140+ cm)	-0.011 (0.0040)	0.0049***
	Oak (circ. 140+ cm)	-0.019 (0.0018)	<.0001***
	All trees	-0.0037 (0.00043)	<.0001***
Tree vs cohort approach	Beech (circ. 0-60 cm)	0.0014 (0.00051)	0.0082**
	Beech (circ. 61-105 cm)	-0.019 (0.0014)	<.0001***
	Oak (circ. 61-105 cm)	-0.0025 (0.0011)	0.026*
	Beech (circ. 106-140 cm)	-0.0036 (0.0022)	0.11
	Oak (circ. 106-140 cm)	0.0014 (0.00092)	0.14
	Beech (circ. 140+ cm)	0.025 (0.0060)	<.0001***
	Oak (circ. 140+ cm)	0.0042 (0.0018)	0.019*
	All trees	-0.0022 (0.00057)	0.0001***

Anonymous Referee #2

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1. The authors present two modules (phenology and water budget) of a new forest growth model HETEROFOR, which is a process-based model considering spatial distribution of individual trees of mixed-species forests. This paper is the second one of the series papers (seems will be more than 2). After reading the first paper (Jonard et al., under review process in GMD) and the comprehensive comments by Referee #1 to this one, my additional comments will be given here.

2. The connection between the phenology module and the processes of photosynthesis and the allocation of NPP was not described in this paper and the first paper. The leaved period from budburst to the start point of yellowing is the period of leaf development. In the phenology module, the progress of leaf development is solely controlled by the temperature. However, the photosynthesis process modelled in HETEROFOR (as described in the first paper) has complicated controlling mechanism including other factors like PAR. The allocation of NPP to leaves and fine roots is further controlled by the nutrient status of the plant. Both the photosynthetic rate and the allocation to leaves will determine the leaf development and the further photosynthesis. Please clearly specify the relationship of photosynthesis, allocation, and leaf development.

Author response:

During the vegetation period, photosynthesis and allocation are independent since they are calculated with two different time steps. Hourly gpp is cumulated over the whole vegetation period, then converted to npp and finally allocated to tree compartments only once at the end of the year. In contrast, there is a close link between phenology and photosynthesis because phenology determines the amount of leaves that can do the photosynthesis but there is no feedback (photosynthesis has no direct impact on leaf development). This has been clarified in the revised version of the first paper (Jonard et al., accepted with major revisions).

3. For the soil water simulation, what's the domain of each individual tree? How does HETEROFOR deal with the spatial heterogeneity of soil water budget? Although the partition of rainwater to interception, throughfall, and stemflow for each tree is one dimensional in the module, the spatial distribution of the individual trees will make the soil water input different under each individual tree. As the soil water availability will have control on foliage conductance (equation 54) and thus on photosynthesis, it is necessary for a clearer description of the 3-dimensional soil water budget.

R:

The default version of HETEROFOR does not consider the spatial heterogeneity of soil water budget. Following the discussions initiated on this subject with the reviewer 1 (see previous comments and responses), we decided to implement a new option performing a water budget at the individual level. We described this new approach in response to the second paragraph of comments of the reviewer 1 (see above).

4. P3L15: I don't see any focus on climate change in this paper

R:

Indeed, a first version of the paper included some simulations considering climate change but this is not the case anymore. This will be removed.

5. P3L16: a temperature increase in which year?

R:

Between 2071 and 2100 with regards to the 1971-2000 period. This will be added in the introduction.

6. P7L10: what's the endpoint of the gradual loss of photosynthesis and transpiration of the yellowing leaves

R:

Among the different phenological parameters, the user must specify the yellowing threshold under which the green leaf proportion is set to 0 stopping therefore photosynthesis and transpiration. This will be added in the revised version of the manuscript.

7. P8L1: the average budburst date, average of what?

R:

In page 8, we explain how we integrated the within-population variability in the budburst process. As the module was calibrated based on observations carried out on trees representative of the stand, the predicted budburst starting date is expected to be that of an average tree and is consequently called average budburst date. Since, at this date, the leaf expansion of some trees has already started, the model shifts it to obtain the budburst starting date of the earliest trees.

8. P8L16: equals -> reaches

R:

Agreed, it will be changed.

9. P11L4: epsilon in equation 12 is not defined

R:

Epsilon represents the model residuals. This will be stated in the revised version.

10. P11L10: how can the threshold for stemflow appearance is tree size-independent?

R:

In André et al. (2008), from which the equations come from, it is written that "Finally, compensation between increasing stemflow rate and increasing storage capacity as C130 increases explains the non-significant influence of tree size on rainfall thresholds for stemflow."

11. P11L23: why equation 16 does not use equation 12 as the stemflow rate?

R:

Equation 16 is derived from Equation 12 and calculates stemflow proportion (stemflow rate divided by the rainfall amount) in order to partition rainfall in throughfall, stemflow and interception. The equation 12 cannot be used directly since it predicts the volume of stemflow (I) during a rainfall event and not the stemflow proportion.

12. P27L9: for the calculation of annual drainage by the chloride mass balance, a monthly calculation won't produce more reliable result?

R:

The chloride mass balance method relies on the assumption that the chloride concentration in rainfall and in the soil are in a steady-state balance. It means that chloride inputs must be equal to outputs and that there is no chloride storage change during the considered timescale. Monthly periods are too short to ensure that the input-output equilibrium assumption is respected. There is indeed a clear seasonal pattern with recharge and discharge periods. The annual timescale seems to be the good trade-off between a small temporal resolution and a perfect verification of the steady-state assumption even though some studies recommend even longer time periods (Alcala and Custodio, 2008; Alcala and Custodio, 2015; Naranjo et al., 2015).