Author's Response to the Reviewer # 1 Comments

We appreciate the time and efforts by the editor and Reviewers in reviewing this manuscript and the valuable suggestions offered. We have attempted to address all issues raised by the Reviewers and hope that the revised manuscript can satisfy the Reviewer's comments and journal's requirements. The **bold** text indicates the comments proposed by Reviewers and the black text refers to our response to the comments.

In this paper, Yao et al. developed and implemented a new plant hydraulic architecture module "NHA" into ORCHIDEE-CAN based on soil-root-stem-leaf water transport continuum and the relationship between PLC and tree mortality. They compared the model performance of NHA model with two previous versions of the model to prove the efficacy of the new model in capturing the change of sap flow, soil moisture content, and GPP under drought events. They also evaluated model results against field measurements of leaf water potentials, biomass and mortality rates from a tropical lowland rainforest in eastern Amazonia. Their results show great potential of the NHA model to capture the drought-related tree biomass loss and mortality for tropical forests. The new model represents the state-of-the-art development of plant hydraulic model and will be of interest to the research community and readers of GMD. This paper is well written, and the results are nicely presented. I have some general comments as below.

For improvement, first, they should fit their new model into a broader field of mechanistic plant hydraulic models. They mentioned some previous work such as SPA model and Xu et al. (2016) but it's still not very clear how they were motivated, how the new model was built on, and what are the strengths and weaknesses of their new model compared with other similar plant hydraulic models. They had some discussion starting from Line 547, but adding more details would be great.

[Response] Thanks for your suggestions. Our new model mainly focus on the extension of plant hydraulics to the hydraulic failure induced tree mortality. We add comparison with other plant hydraulic models in format of table as Table A1. Our model solves a complete water potential profile including nodes of soil, soil in root zone, root, stem and leaf as well as the hydraulic conductance dynamics. One of our strong strength is the extension of plant hydraulic structure to the modeling of drought-induced tree mortality using continuous higher loss of stem conductance as the indicator of occurrence of tree mortality event. Admittedly, weakness does exist in our model, for example, parameter retrieval can be further realized through data assimilation that uses more benchmark. More optimization paradigm can be integrated into our model, which would benefit the parameterization process. Please see line 613-618 in the revised main text.

Table A1 Plant hydraulics in major vegetation models. The column of validation indicates how the model performance be validated against observation.

Model	Framework for modeling hydrodynamics	Validation	Reference
CLM v5	Stomata optimization and supply-demand theory	Caxiuana site	Kennedy et al. (2019)
JULES-SOX	Optimization of stomatal conductance by maximizing the product of leaf photosynthesis and xylem hydraulic conductance	70 global eddy flux sites	Eller et al. (2020)

CliMA	Optimization-based stomatal model by maximizing the difference between leaf level carbon gain and risk	Two flux sites in US	Wang et al. (2021)
CABLE	Supply-demand theory	Garden dry-down experiment across south-east Australia	De Kauwe et al. (2020)
ORCHIDEE-CAN	Water supply via Darcy's law without dynamics in stem water potential	Europe	Naudts et al. (2015)
Ecosystem Demography Model 2	Stomata optimization and supply-demand theory	Costa Rican field	Xu et al. (2016)
TRIPLEX	Loss of stem conductivity is related to soil water potential	Canada boreal forests	Liu et al. (2021a)
SPAC	Stomata optimization and supply-demand theory	13 temperate and tropical forest biomes across the globe	Liu et al. (2017)
One hydraulic module	Two parameters: isohydricity factor and well-watered forcing pressure	Leaf- and soil water potentials of 66 species under drought and non-drought conditions	Papastefanou et al. (2020)
SurEau	Water mass conservation law	One forest site in east France	Cochard et al. (2021)
TFS v.1-Hydro	Continuous porous approach with pressure-volume formula	Caxiuana site	Christoffersen et al. (2016)
SPA	Stomata optimization and supply-demand theory	Caxiuana site	Fisher et al. (2007)

Second, one of the key limitations of the usage of such plant hydraulic models is numerous parameters, as shown in Table 1 in this paper. The authors focused on one site simulation with well-recorded plants' traits. However some topics such as how sensitive and uncertain these parameters are, and how to parameterize the model at the regional and global scales might be interesting to add to the discussion. The authors may find this paper relevant to their discussion:

Liu, Y., Kumar, M., Katul, G. G., Feng, X., & Konings, A. G. (2020). Plant hydraulics accentuates the effect of atmospheric moisture stress on transpiration. Nature Climate Change, 10(7), 691-695.

[Response] We acknowledge that the parameters corresponding to one site simulation are subject to large uncertainty to some extent. Parameters like Ψ_{50} reflects the vulnerability of tree species, with less negative value meaning higher vulnerability to water stress. We made sensitivity test by varying degree of vulnerability (e.g. Ψgs_{50}). Figure R1 shows that when Ψgs_{50} equals -1.2 MPa, the annual mortality rate would be more comparable with the observation.

We also add discussion regarding the parameterization of model at the regional and global scales. Generally, three means can be resorted to benefit such realizations. The first one can be embedding the plant trait database like TRY (Kattge et al., 2020) into our process-based model although the records are still limited in aspect of hydraulic traits. The second solution can be the optimization of hydraulic parameters using e.g. Monte Carlo Markov Chain with measurements or remote sensing products as constraints like traits retrieval in Liu et al. (2021b) or other data-assimilation system like ORCHIDAS. The third method can be building simple regression formula between plant traits and the climatology where the plants reside in. In next step, these solutions will be attempted to test the generalization of process-based model performance at large scale. Please see line 683-690 in the revised main text.

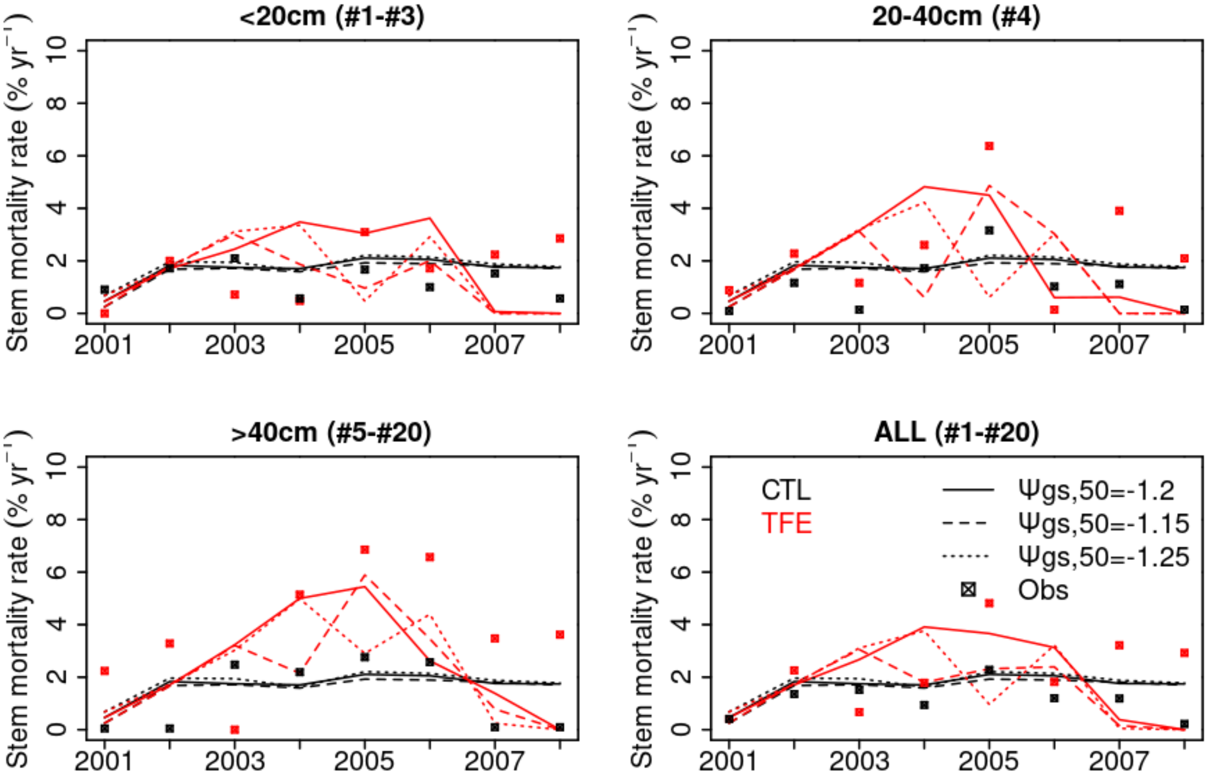

Figure R1 Modeled stem mortality rate with regard to different $\Psi gs_{,50}$ values. when Ψgs_{50} equals -1.2 MPa, the annual mortality rate would be more comparable with the observation.

Third, some references when the authors described the equations in Methods are missing.

[Response] We check the equations carefully and add the necessary references.

More information about throughfall exclusion experiment and model simulation set up is needed as well. Below, I provide more specific comments:

[Response] We add description for throughfall exclusion experiment and model simulation setup.

-Line 225: Any references for the sigmoidal relationship? How about other relationships such as linear, logistic, or exponential?

[Response] We add reference for the sigmoidal relationship (Pammenter and Van der Willigen, 1998). Linear may be not appropriate as we need impose segmentation on top of linear type to avoid the unrealistic values. Exponential and logistic functions can also be alternative since they can correspond to quick loss of conductance after reaching a critical threshold as well.

-Line 275: Please provide reference and a simple description for the gs model. L is not defined

either.

[Response] The aim of this g_s model is to let g_s vary following dynamics of leaf water potential in sigmoidal function then g_s can be coupled into the plant water transport system via the transpiration supply. Meanwhile, the g_s is assured to close to 0 in the night, mediated by the radiation-related variable ($\frac{\mathrm{L\times Rad}}{\mathrm{L\times Rad+L_k}}$).

$$g_s = \frac{g_{max}\frac{L\times Rad}{L\times Rad+L_k}}{1+e^{a_{gs}(\psi_{leaf,t}-\psi_{50,gs})}} + g_{min}$$

g_s, g_{max} and g_{min} are in unit of mmol m^{-2} s^{-1}. $\frac{L\times Rad}{L\times Rad+L_k}$ is the function of short-wave radiation (*Rad*), which is used to ensure that g_s at night is very low. L and L_k are parameters specifying the strength of short-wave radiation limitation on stomatal conductance.

-Line 280: What's the gs model in the SPA model, is that the same one used in this study?

[Response] The g_s model in the SPA model is different from what we used in this study. In SPA model, g_s in each canopy layer is obtained by maximizing the marginal carbon gain of stomatal openness, that is the optimization of intrinsic water use efficiency. Specifically, g_s in SPA increases iteratively until there is only negligible increase in assimilation or the leaf water potential is below a minimum threshold (Williams et al., 1996). We briefly mention the gs in SPA model in line 299-300 in the revised main text.

-Line 332: How is LAI modeled in this study?

[Response] LAI is determined by leaf mass, which is regulated by the leaf growth, leaf turnover and leaf loss due to drought-induced tree mortality. Please see new line 355-356 in the revised main text.

-Line 346: More information such as the plot size and duration of the experiment about the TFE site could be added here so readers don't need to read the cited papers.

[Response] We add more description for the experiment. There are two experiments, which were carried out since the beginning of 2001. A throughfall exclusion experiment (TFE) started in the end of dry season in 2001, where 50% of canopy throughfall is excluded by plastic roof at the height of 1-2m above the ground. It is of 1-ha size. Another 1-ha control plot is also set without any manipulation. Here the observation data we used extends to 2008 at most due to data access issue, but these experiments are still running.

-Line 353: What are the similarities and differences between SPA model and your model?

[Response] The similarities lie in the framework of hydrodynamic simulation, in which both models follow supply-demand theory. Specifically, the transpiration is limited by water supply derived from plant hydraulics. FvCB model is used for photosynthesis calculation in both models. The difference mainly relates to the computation of stomatal conductance (g_s) and water potential. SPA model represents g_s using optimization theory, while ORCHIDEE-CAN-NHA lets g_s vary with leaf water potential. The SPA model did not realize more explicit hydraulic segmentation, like root water potential was not modeled yet. As ORCHIDEE is a complex land surface model, including carbon allocation, phenology, turnover, tree mortality, SPA model did not resolve these processes yet.

-Line 360: What meteorological forcing was used to drive the model, at what temporal

resolution? Were the simulations coupled with a climate model or offline?

[Response] The meteorological forcing is of half-hourly time step. The half-hourly meteorological data are measured using an automatic weather station located at the top (51.5 m) of a tower 1 km from the experimental plot. The simulation was ran offline without coupling with a climate model.

How was the TFE simulation carried out? Was the precipitation be reduced to 50% of CTL level at each model time step?

[Response] Yes. In model simulation, for TFE setup, we modify the precipitation forcing by cutting 50% of precipitation at each half-hourly time step while keeping temperature and down-ward short-wave radiation unchanged.

Is the model also initialized with real forest inventory data? How do 20 circumference classes correspond to the real-world situation?

[Response] The model was not initialized with real forest inventory data. In model routine, the tree density in each size class is firstly prescribed as a function related to PFT-related maximum tree height and initial number of trees. Then the tree density in each class changes with carbon allocation during tree growth, i.e., trees would move from current class to the next one. These 20 circumference classes constitute the demographic structure, spanning from smaller trees to bigger one. As the existing studies at Caxiuana site did not report its demographic structure, we retrieve the observed tree density distribution from annual mortality rate in each size group and total annual mortality rate. We assume here F (fraction of each size group) did not show inter-annual variation. This is an approximate estimation, from which the sum of F1 to F3 could not equal 1 due to the above assumption.

$F_1m_{11}+F_2m_{21}+F_3m_{31}=T_1$
$F_1m_{12}+F_2m_{22}+F_3m_{32}=T_2$
$F_1m_{13}+F_2m_{23}+F_3m_{33}=T_3$
F_j is the fraction of group j (j=1,2,3). T_i is annual tree mortality rate in year i. Three groups correspond to class with DBH < 20cm, class with DBH between 20cm and 40cm, and class with DBH above 40cm.
a_{ji} is the annual mortality rate of group j in year i (i=1,2,3). Here we choose mortality rate in three years to solve F_1, F_2, and F_3 as only square matrix (here 3 rows and 3 columns) has the inverse matrix.

$$[F_1 \quad F_2 \quad F_3] * \begin{bmatrix} m_{1,1} & m_{1,2} & m_{1,3} \\ m_{2,1} & m_{2,2} & m_{2,3} \\ m_{3,1} & m_{3,2} & m_{3,3} \end{bmatrix} = [T_1 \quad T_2 \quad T_3]$$

$$F = [F_1 \quad F_2 \quad F_3]$$

$$M = \begin{bmatrix} m_{1,1} & m_{1,2} & m_{1,3} \\ m_{2,1} & m_{2,2} & m_{2,3} \\ m_{3,1} & m_{3,2} & m_{3,3} \end{bmatrix}$$

$$T = [T_1 \quad T_2 \quad T_3]$$

$$F * M = T$$

$$F = T * M^{-1}$$

F could vary according to different T as we can choose three-year data. Generally, F_1 is the highest and F_3 is the lowest. For example, when we choose year 2002 to 2004, the fraction of first group is 62% ($F_1 = 0.62$, $F_2 = 0.25$, $F_3 = 0.07$). In model output, the group with DBH less than 20cm accounts for almost 70% of all tree individuals, which is similar to the real situation at Caxiuana site. Modeled fraction of each size group also decreases with tree size (Figure R2).

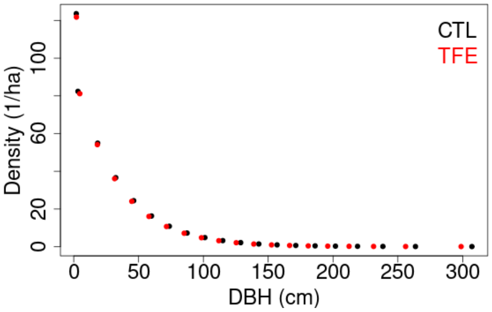

Figure R2 Tree density distribution of 20 circumference classes.

-Line 365: Past tense for "run", and "compare" in line 367.
[Response] They have been revised. Thanks.

-Line 384: Could the authors discuss why their new model underestimated sap flow in the dry season but overestimated it under TFE conditions?
[Response] The simulated transpiration could be limited by water supply (water limitation) or water demand (energy limitation). Under CTL, there is almost no water limitation even in dry season. The underestimated sap flow can be due to that model tends to underestimate the sensitivity to VPD increase in dry season. Under TFE, there is water supply limitation. The possible reasons for such overestimation under TFE can be that the sensitivity of water supply to drop in soil moisture is underestimated or the too slow soil water drainage in our model setup relative to that in reality (Kennedy et al., 2019). Please see line 420-425 in the revised main text.

-Line 421: What mechanism leads to the larger seasonal amplitude of modeled GPP compared with SPA model?
[Response] In SPA model, GPP is simulated using FvCB model regulated by optimization of intrinsic water use efficiency, in which the optimization target is $\frac{\partial A}{\partial g_s}$ (A is assimilation, g_s is stomatal conductance), not accounting for VPD. So the magnitude of GPP variation would not be too high. In ORCHIDEE-CAN-NHA that we used here, larger seasonal amplitude of modeled GPP especially the low GPP in dry season under TFE is due to higher water limitation arised from our hydraulic architecture. Please see the explanation in line 475-479 in the revised main text.

-Line 550: What's the leaf-level demand of Xu et al. (2016)?
[Response] Leaf-level demand of Xu et al (2016) is transpiration. It is calculated as the product of total conductance for water vapor, total leaf area per cohort and the gradient of water vapor concentration between leaf intercellular space and leaf boundary layer.

-Figure 2: Color for $\Psi 50 = -1.6$ is too weak to be seen.
[Response] We revise the Figure 2 to let each line be clear now. We also move Figure 2 to SI following reviewer 2's comment.

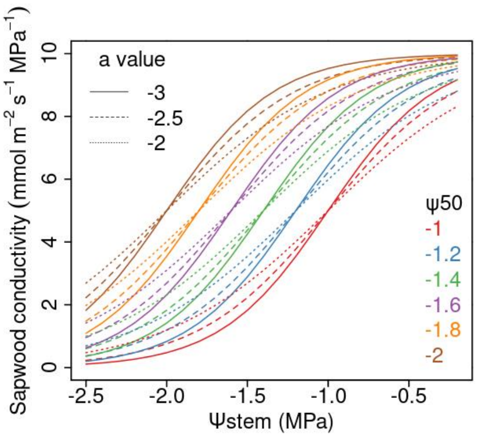

Figure R3 Sigmoidal relationship between stem sapwood conductance (normalized by total leaf area) and stem water potential. Line colors correspond to different Ψ_{50} values. The line types (continuous, dashed and dotted line) denote different curvature parameters (a_{stem}).

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