

Author's Response to the Reviewer #2 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 regular text refers to our response to the comments.

This paper describes the implementation of a hydraulics scheme into the land surface model ORCHIDEE and its evaluation against the Caxiuana drought experiment. In general, this is a nice piece of work, but the presentation could be quite significantly improved.

One important point is the need to show how the model simulations have changed since the new routines were added. The figures only show output from the new version of the model. To assess the value of the added subroutines, the paper needs to show output from previous versions of the model for comparison. There is some in the supplementary, but there is insufficient quantitative assessment of how each version of the model performs. The R values for sap flow are lower in the new model version than the previous one, suggesting a degradation of model performance. The comparison of GPP with previous models is qualitative only. It would be valuable to add some statistics to compare performance of different model versions.

[Response] Thanks for the comments. We add comparison of transpiration as well as biomass loss with ORCHIDEE-CAN and ORCHIDEE-CAN-RS. We do not put water potential here as the other two model versions do not have such outputs. Here we show the updated results after increasing interception reservoir (following later comment from the Reviewer). We do not aim to let the model outputs perfectly match the observation in order to avoid the overfit issue. We add below evaluation of model performance in supplementary.

In terms of comparison on transpiration (Table R1), under CTL, the correlation coefficient with the observation is similar among three model versions (0.71-0.76) although there is indeed a bit increase in other error metrics in ORCHIDEE-CAN-NHA like root mean square error (RMSE) and mean absolute percentage error (MAPE). ORCHIDEE-CAN-NHA performs better in water stress condition (under TFE) in aspects of error metrics but shows a bit lower correlation with observation than other two versions.

As SPA-GPP is also based on model simulation, here we compare the seasonal magnitude of GPP among different model versions more specifically (Table R2), without using correlation and other errors metrics. During 2001-2003, under CTL, SPA-GPP shows very little difference between wet and dry season, while GPP from ORCHIDEE-CAN-NHA presents $1.1 \text{ gC m}^{-2} \text{ day}^{-1}$ difference, which is similar with two previous versions. Under TFE, SPA-GPP drops from wet to dry season, while ORCHIDEE-CAN-NHA shows small GPP increase in dry season as water stress effects tend to occur later in dry season, rather than the beginning of dry season like SPA. Dry season GPP increase is also found in other two model versions in spite of a bit difference in the magnitude.

With regard to the biomass loss, only ORCHIDEE-CAN-NHA can produce a comparable amount of biomass loss under TFE by the end of 2008 (Table R3).

Table R1 Model performance of transpiration evaluated by R, RMSE (unit: mm d^{-1}), and MAPE

against observed transpiration.

	TFE			CTL		
	R	RMSE	MAPE	R	RMSE	MAPE
ORCHIDEE-CAN	0.60	0.95	0.46	0.75	0.49	0.14
ORCHIDEE-CAN-RS	0.49	0.90	0.44	0.71	0.54	0.16
ORCHIDEE-CAN-NHA	0.48	0.74	0.35	0.76	0.79	0.24

Table R2 Comparison of modelled GPP from 2001 to 2003. Since SPA-GPP is based on model simulation as well, here we just compare the magnitude of GPP, without using correlation and other errors metrics. Unit : $\text{gC m}^{-2} \text{ day}^{-1}$.

Unit: $\text{gC m}^{-2} \text{ day}^{-1}$	CTL		TFE	
	Wet	Dry	Wet	Dry
SPA	8.1	8.0	7.8	7.0
ORCHIDEE-CAN	7.6	9.4	6.9	7.3
ORCHIDEE-CAN-RS	8.0	9.3	7.5	7.5
ORCHIDEE-CAN-NHA	6.2	7.3	6.0	6.3

Table R3 Model performance in simulation of biomass loss. Here the values in the table refer to relative change to the beginning of the experiment (2001).

	CTL	TFE
Observation	+1%	-12.1%
ORCHIDEE-CAN	+0.6%	-1.1%
ORCHIDEE-CAN-RS	+0.6%	-0.8%
ORCHIDEE-CAN-NHA	-0.7%	-19%

There were quite a few questions about the model description. It would be of great value to go through the symbols used and try to make them consistent, instead of using a mixture of abbreviations and symbols. It is confusing to have WD the wood density, rho-root the root density, WC the amount of water per unit volume of sapwood, and rootwc the amount of water per gram root biomass. Try to come up with a more systematic set of symbols. In particular, avoid abbreviations instead of symbols (e.g. use D rather than dbh) and avoid using variable names from code such as circ_class_mor or counterPLC50. Give these symbols. Also use capitals consistently, e.g. Cleaf, Cstem and Croot should all have capital "C"

[Response] Thanks for the comments. We revised the model description part by using symbols especially those variables whose previous name is its abbreviation.

Specific leaf area: S, Leaf dry matter content: L, mass of water per unit of sapwood volume: γ , wood density: δ , root shoot ratio: θ , root water content: ε

Ensure to give all units clearly in text and ensure they are consistent. For example, is

capacitance in units of mmol (line 203) or mmol m⁻² MPa⁻¹ (line 207) or in kg m⁻³ MPa⁻¹ (Table A1)? I suggest checking over all of the equations thoroughly to ensure units are correct throughout the text.

[Response] Thanks for the reminder. The unit mentioned in line 203 is the unit of water storage. To avoid ambiguity, I specify the unit more clearly. The unit of stem and root capacitance is written as kg m⁻³ MPa⁻¹. In the model, we also did a unit transform from kg to mmol. I specify it in the description of model formula.

Eqn 4: $m_{sap,max} = V_{stem} * WC$

V_{stem} is the volume of a cylinder of diameter DBH and height h (eqn 6) so overestimates volume of a stem. How is the stem form factor corrected for? How is this then converted to sapwood?

[Response] We acknowledge that using cylinder as approximation for the tree volume will cause overestimation. The amount of water per unit stem volume is from Suzuki (1999), which is defined as $\frac{\text{fresh weight} - \text{overdried weight}}{\text{fresh volume}}$.

WC is defined as the mass of water per unit sapwood volume in mol m⁻³. It should be defined as the maximum mass of water, or the mass of water when water potential = 0. Clarify, is this per unit sapwood volume or per unit stem volume?

[Response] WC is from Suzuki (1999), which is defined as $\frac{\text{fresh weight} - \text{overdried weight}}{\text{fresh volume}}$. We correct that WC (now symbol γ) corresponds to the maximum mass of water per stem volume.

Figure 2 does not seem important or relevant enough to include as a main figure. It just shows the form of the sigmoidal relationship for different parameter values. The different values are not used in the paper, however, so it's not clear why this wide range of parameter values are shown.

[Response] We aim to give an illustration of the sigmoidal relationship between hydraulic conductance and water potential as well as how this relationship varies with shape parameter and Ψ_{50} . We moved Figure 2 to SI.

What happens when the canopy is wet? I note that in Figure 4, the canopy evaporation is a tiny fraction of ET, which seems very unlikely for this wet, high-LAI forest. These numbers need a reality check

[Response] When the canopy is wet, there are both leaf-level transpiration and canopy evaporation (from intercepted leaf water or dew re-evaporation – the model produces dew under certain conditions when the air is more humid than the surface from night to predawn). In our model, the potential fraction of rain that can be intercepted by the canopy is set to 30% for tropical evergreen forest. The interception is also regulated by the amount of interception reservoir, which is related to LAI and a coefficient λ (transforming LAI into size of interception reservoir, (Carlyle-Moses and Gash, 2011)). We find that in previous setup, the low canopy evaporation is mainly due to a very small interception reservoir (small λ). Measurement at Manaus site showed the interception loss is about 8.9% of annual rainfall (Lloyd et al., 1988). As we do not find other evidence at Caxiupana site, we use this Manaus value as reference. Here we increase the interception reservoir and now interception is about ~8% of annual rainfall (Figure R1). All the results are updated correspondingly.

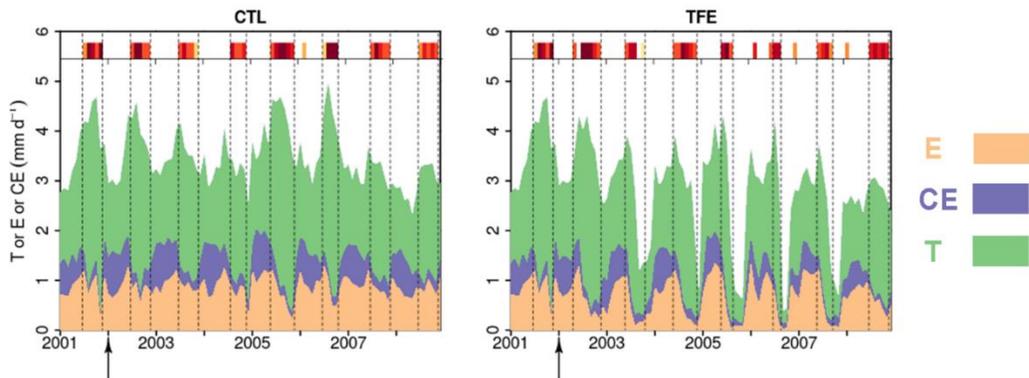


Figure R1 Modeled (ORCHIDEE-CAN-NHA) daily soil evaporation (E), canopy evaporation (CE) and transpiration (T) during 2001-2008. The arrows point to the start of TFE in the beginning of 2002.

I found the representation of T_{demand} (eqn 23) to be remarkably simple – one would normally expect a land surface model such as Orchidee to have a more complex representation of T, including a boundary layer conductance and some scaling of g_s to the canopy. Is the canopy transpiration the same as T_{demand} ?

[Response] Canopy transpiration is not equal to T_{demand} (potential transpiration demand, we rename this variable as PT_{demand} later for clarity) in our model. PT_{demand} acts as a constraint for the transpiration in water demand aspect. Regarding the transpiration, in ORCHIDEE, it is related to canopy surface resistance, vegetation structural resistance, air density, aerodynamic conductance and relative air humidity, thus state of the art parameterizations.

Does this value of g_s affect assimilation? How has the assimilation (and GPP) calculation changed?

[Response] This g_s value (varying with leaf water potential) does not affect assimilation directly but relates to the water supply for transpiration. Normally, when there is no water limitation, GPP is calculated by FvCB model that is the minimum of the Rubisco-limited rate of CO_2 assimilation and the electron transport-limited rate of CO_2 assimilation (Yin and Struik, 2009). If the water supply cannot meet the transpiration demand, then the transpiration would be re-calculated to match the water supply part. The canopy resistance is also re-calculated and so does the GPP.

Be more specific about how water potentials are found.

[Response] Water potentials are solved to let the water supply equal to water demand at each organ. In the model, HYBRD1 function from Minpack package in Fortran is used, which seeks a zero of N nonlinear equations in N variables. The evaluated function is the difference between water supply and water demand at each organ level. This function iteratively minimizes the absolute value of the evaluated function. The initial estimate of the solution vector is quite important and comes from the water potential at last time step. For example, the initial estimate for leaf water potential at time step t that will be used in the formula is the stem water potential at time step t-1.

Line 270: we decrease leaf water potential until the difference between leaf water supply and demand is “close to zero” – How does this algorithm work? How close is tolerable?

[Response] Leaf water potential is solved using HYBRD1 function (see above response). The tolerance is 0.00001MPa. When the relative error between two consecutive iterates is below the tolerance, the calculation routine is terminated.

Line 294 and line 304: we “try to solve” Why only “try” ? How is the water potential found, and what happens if one can’t be found?

[Response] ‘try’ is removed from this sentence to avoid ambiguity. The water potential is solved using HYBRD1 routine that finds the solution for a series of non-linear equation. If no solution can meet current requirement and the number of iterations reaches the limit, water potential at final calculation step would be used.

Give some indication of how parameter values are chosen. The table does list references, but it is not clear how values are chosen from the references.

[Response] We did some sensitivity tests by attempting different values combination of parameters within range of records in literatures, like degree of vulnerability, Ψ_{50} , and degree of sensitivity, a (shape parameter). Parameters set that can better capture the observed variation of drought-induced tree mortality (especially the higher tree mortality rate in larger cohorts) were chosen. Figure R2 shows that when Ψ_{gs50} equals -1.2 MPa, the annual mortality rate would be more comparable with the observation. We do not aim for a perfect match between model output and observation to avoid the overfit issue during the generalization of the model.

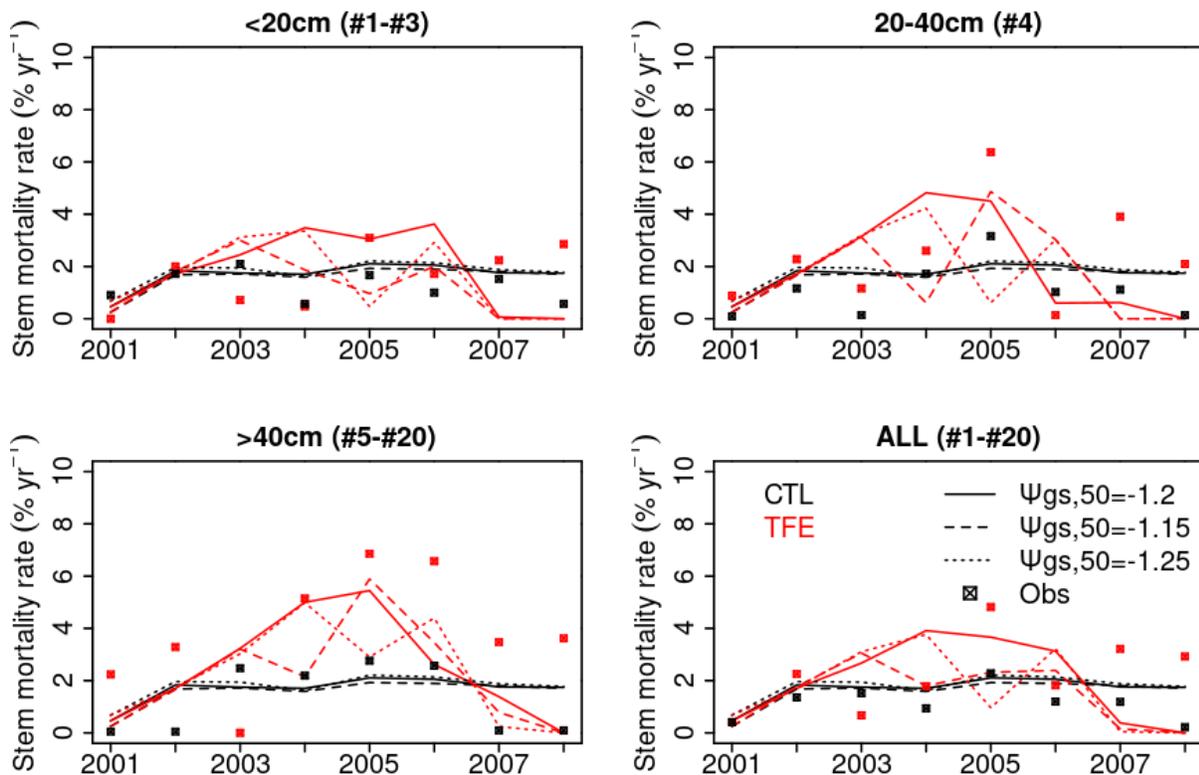


Figure R2 Modeled tree mortality rate varies with different parameters setup (Ψ_{gs50} was taken as example here).

It’s unfortunately not acceptable to refer to other papers that are still in review. The Joetzjer

et al. (in review) paper was not accepted in Biogeosciences in 2018.

The fact it has not yet appeared raises some questions. This paper does rely quite heavily on that one, so it seems essential that that paper be accepted before this one can be. There may of course be some extenuating circumstances.

[Response] Joetzjer et al (2022) has been published by *Ecological Modelling* at doi: 10.1016/j.ecolmodel.2022.109969.

Section 2.1.6 is quite disconnected from the rest of the model implementation and it is not clear what has changed here from previous versions of the model.

[Response] This section describes the related carbon fluxes we used later in model-observation comparison. This calculation process is the same among different model versions and we put it in a separated section 2.2 now.

It would be valuable to add more interpretation of the outputs of the model in terms of underlying assumptions. For example, it's noted that leaf water potentials are lower in the taller trees. The effect of height should be about -0.1MPa / 10m. Once this is accounted for there are similar LWPs across cohorts, which is somewhat surprising given that cohorts have different rooting depth and see different soil moisture. There also doesn't appear to be a lot of difference in the PLC by cohort (Figure 9). The discussion later talks about the larger mortality rates in large trees, but it's not clear how this arises from the model structure. It would be useful to talk through how this works in the text.

[Response] We assume that smaller cohorts can only access to shallower water table whereas larger cohorts can absorb soil water from the deeper soil layer. Soil water potential in root zone ($\Psi_{\text{soil-root}}$) is weighted by the amount of water that can be absorbed from each soil layer (η). η is determined by soil water potential and also the soil-root resistance. $\Psi_{\text{soil-root}}$ did not show too much variation among different cohorts (Figure R3). Then the leaf water potential difference among cohorts is mainly contributed by the height effect.

With regard to the tree mortality sub-model, we assume when the cumulated drought exposure reaches our specified threshold (15 continuous days with PLC above 50%), then there would be one mortality event. Such requirement is further relaxed by allowing 5 days wet break during a water stress condition, which would not impede the accumulation of the drought exposure. Figure R4 and R5 show that smaller cohort (#5 here) shows a bit larger variation in water potential dynamics and corresponding PLC, which indicates that an adequate cumulated drought exposure occurs less frequently than that of larger cohorts (#20 here). Thus the higher annual tree mortality rate is found in larger cohorts.

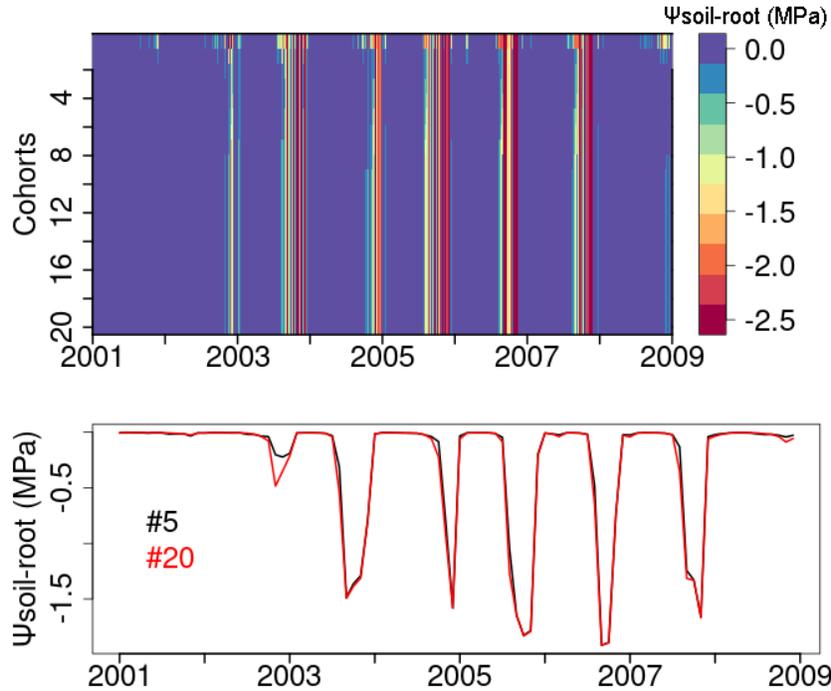


Figure R3 Soil water potential in root zone ($\Psi_{\text{soil-root}}$). The top panel shows the temporal distribution of $\Psi_{\text{soil-root}}$ at daily time scale. The bottom one shows monthly $\Psi_{\text{soil-root}}$ in cohort #5 and #20 for better comparison of their dynamics.

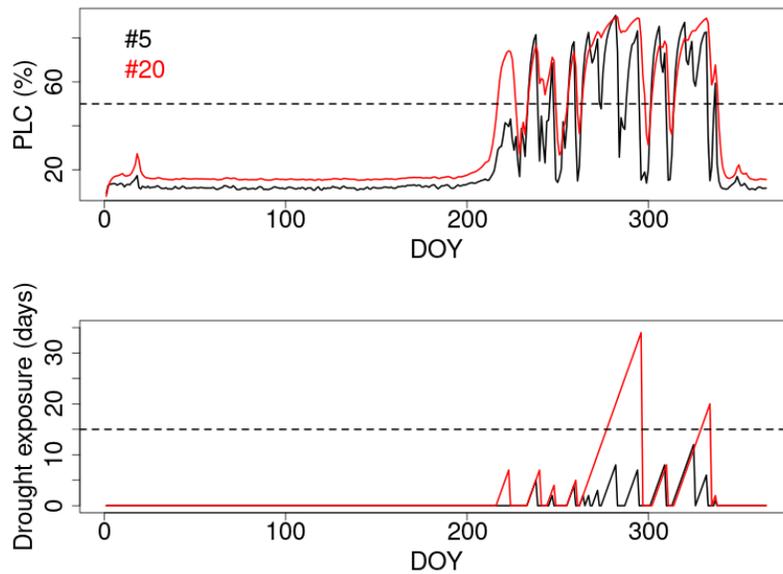


Figure R4 Percentage of loss in stem hydraulic conductance (at daily time scale) and drought exposure in year 2005. Cohort #5 and # 20 are shown.

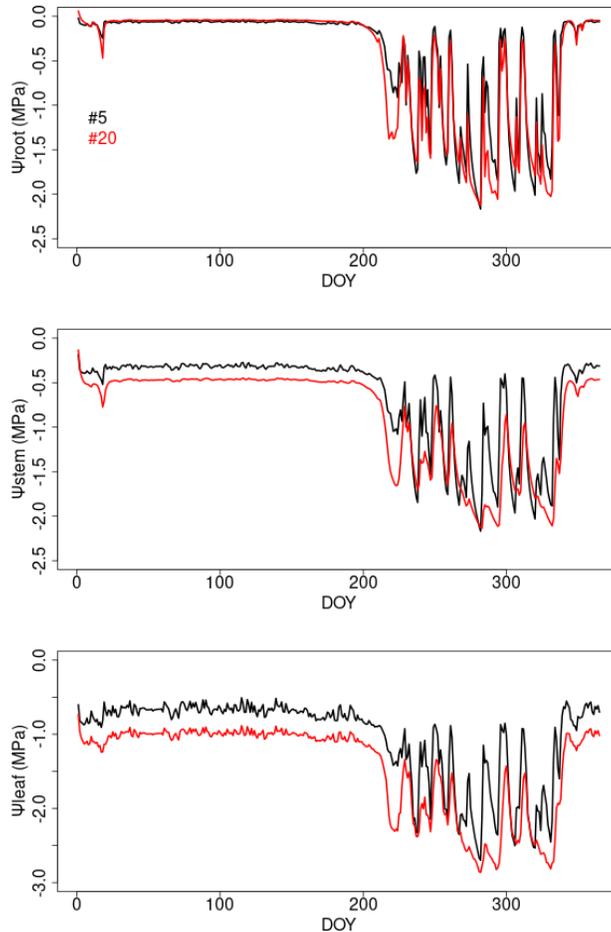


Figure R5 The temporal dynamics of Ψ_{leaf} , Ψ_{stem} and Ψ_{root} in year 2005. Cohort #5 and #20 are shown.

It does also seem odd that the lower soil layers dry out much more than the upper soil layers. It seems that the plants are preferentially using water from lower in the soil profile. Again, it would be useful to talk through what the model is doing in terms of water uptake.

[Response] The soil moisture content (SMC) at each layer is influenced by infiltration, evaporation, transpiration and drainage. The amount of water that can be absorbed from each layer (η) is determined by its water potential and also soil-root resistance. Soil water potential decreases with soil depth while soil-root resistance becomes much smaller with soil depth as well. Therefore, η does not change monotonically with soil depth. For example, in wet season in 2005 under TFE, η in deeper soil layer is higher than that in top layer. While in dry season, η in deeper soil layer can decrease to almost 0, when the water supply mainly comes from the shallower layer. In year 2004, even in dry season, lower soil layers can contribute a lot to water uptake (Figure R6). Soil water potential in root zone ($\Psi_{\text{soil-root}}$) is weighted sum of soil water potential in each layer and η in each layer.

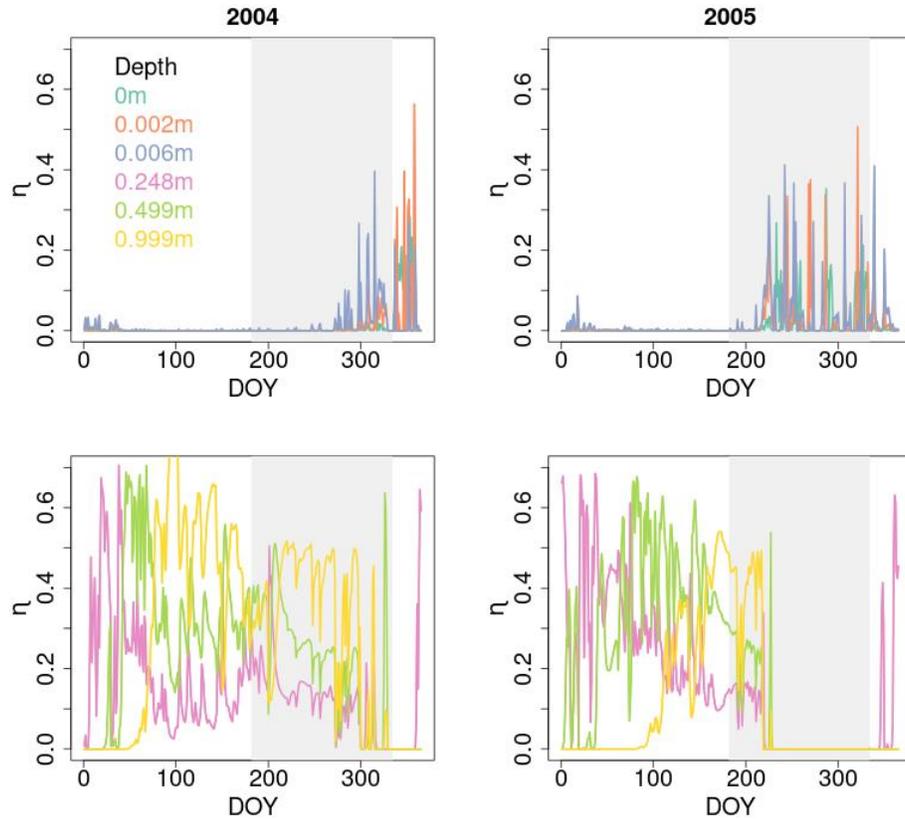


Figure R6 Distribution of η in each soil layer (year 2004 and 2005 are taken as examples here). Top panels show η in top three layers (0m, 0.002m, 0.006m), and bottom panels show η in lower layers (0.248m, 0.499m, 0.999m). The period with shading corresponds to the dry season from July to November.

Smaller points:

Line 200 mentions “the first time-step” but is that just the very first half hour of a ten year simulation or is it every day? If water potentials are assumed the same in the first time step, what value do they take?

[Response] “the first time-step” points to the very first half-hour of the simulation. At first time-step, the initial value of Ψ_{leaf} , Ψ_{stem} , and Ψ_{root} all equal to $\Psi_{soil-root}$, which is the weighted sum of soil water potential.

Please justify eqns 14 and 15.

$$k_{upper,t} = \frac{1}{\frac{1}{k_{leaf,t}} + \frac{1}{2k_{stem,t}}} \quad (14)$$

$$k_{trunk,t} = \frac{1}{\frac{1}{2k_{root,t}} + \frac{1}{2k_{stem,t}}} \quad (15)$$

[Response] The value 2 in front of $k_{stem,t}$ in each equation denotes that only half of stem is accounted for in upper part (water flow from middle of the stem to leaves) and trunk part separately (water flow from middle of the root to middle of the stem). Half of root length is considered in trunk part as well. The water transport process is assumed to be similar to electric current, of which

the resistance (the reciprocal of hydraulic conductance) should be added up along the water transport path.

Line 246: Please give correct units for J. (mmol m⁻² s⁻¹ ?)

[Response] We add the unit for J. The unit of J is mmol.

Please include values and units for the parameters in eqn 24.

[Response] The values and units for the parameters in eqn24 are shown in Table A2.

Line 349, “morality” should be “mortality”

[Response] Thanks.

Figure 3, how is sapflow extracted from the model? Is it the same as “T” in Figure 4 and “Tsupply” in Figure S4, or are these different outputs?

[Response] Here sap flow is treated as transpiration. The sap flow in Figure 3 is the same as ‘T’ in Figure 4. T_{supply} is transpiration supply, which is larger than transpiration when there is no water stress.

Please give full figure captions for the supplementary material. What is shown in Figure S1, exactly? What do the grey bands represent? Are the values given on a half-hourly or daily basis, and if daily, how are they averaged? Do the g_s values differ by cohort?

[Response] We revise the figure captions in supplementary information. Here this g_s value differs by cohort as it is also regulated by the leaf water potential per cohort. I chose cohort #10 as an example here. The value is averaged to daily mean directly. The gray bands indicate dry season from July to November.

What are the values shown in Figure S2? Were the data from Lin et al. filtered to show just high-PAR values? Are the observational values in fact comparable with the modelled values?

[Response] Figure S2 shows the g_s data from observation and our model output. The g_s data collected in Lin et al (2015) only provides the records during the time period we show here rather than the whole-year records. Lin et al (2015) did not mention the filtering work. Admittedly, there is model-observation mismatch in term of the magnitude of intra-annual variation but the magnitude of modelled values falls in the range reported from observation.

What are the measured and modelled values shown in Figure S8? How are the modelled values averaged over the cohorts? Where are the obs measured, and what is the uncertainty?

[Response] Figure S8 shows the leaf water potential values at Caxiuana site, which were monitored by a digital pressure bomb (Fisher et al., 2006). The measurement uncertainty can be due to limited sampling of leaves. The modelled value is an example from cohort#10. We did not average the value over all cohorts.

I did go looking at the code repository but it’s very large and not clear where the new code resides. It would be useful to indicate which subroutines were modified / added in this version of the code

[Response] I add description mentioning the modification in this new model version. Please see the ‘details of model improvement’ section in below link:

https://forge.ipsl.jussieu.fr/orchidee/wiki/GroupActivities/CodeAvailabilityPublication/ORCHID_EE_CAN_NHA

Details of model improvement:

The improvement of the new version mainly focuses on the simulation of dynamic water potential profile, hydraulic conductance, water storage dynamics regulated by capacitance, and drought-induced tree mortality in aspects of tree density and biomass.

Transpiration supply is updated in `./src_sechiba/sechiba_hydrol_arch.f90`. Dynamic water potential profile and percentage loss of stem hydraulic conductance (PLC) are also solved in this script. Subroutine `hydrol_arch` is modified. Then PLC is transferred to `./src_stomate/stomate_mark_kill.f90`, where the number of continuous days with PLC above 50% is calculated as drought exposure. Then the amount of trees that would be killed is derived. The update of tree density and transfer of live biomass to litter are solved in `./src_stomate/stomate_kill.f90`.

References

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