Author Response to Referee Comment Set #1:

General comments:

The manuscript tests and compares various empirical correction functions (β) of stomatal closure under soil-moisture limitations to more advanced plant hydraulics models. The authors explain the source of the differences between the β and mechanistic plant hydraulics approaches, leading to the development of a new dynamic β model that compares well to mechanistic plant hydraulic schemes, but with half the parameters. The authors are clearly well aware of the issues within terrestrial biosphere models. This is a nice manuscript. The supplementary information is particularly clear and thorough.

Major comments:

(1) A key strength of the manuscript is that it proposes a new dynamic β scheme which has half the parameters as the full plant hydraulics scheme. This is mentioned in the main text beginning at line 306 and more fully discussed in the SI (lines 40-44). The simplicity of the parameterization should be more fully discussed in the main text, considering its importance and since it seems to have at least partially motivated the study (as discussed in introduction; lines 49-54). The parametric benefits of the new scheme should be brought out more in the title (which is appropriate, but does not reflect this strength– if anything, the current title evokes an obvious statement), the abstract (which mentions the scheme being generally parsimonious but without being exact), and the end the introduction (near lines 58-59).

BPS: Thank you for the comment. We are currently working on a follow-up manuscript to validate the simple parametrization for the dynamic β and to relate the parameters to measurable hydraulic traits. The main focus of the current paper was to identify the spectrum of transport-limitation, recognizing that the coupling of soil water supply to atmospheric moisture demand through leaf water potential is why β and PHMs differ. The dynamic β emerged as a by-product of this theoretical understanding. Therefore, we are still working through whether we can generalize this for all transport-limited sites consisting of various soil and plant hydraulic properties, and reserve additional analysis on the dynamic β model for future work.

Nevertheless, we will emphasize in the updated manuscript that the dynamic β is a potentially more parsimonious alternative to PHMs and highlight the current benefit of reduced computational cost as well as the future work needed to generalize to all transport-limited sites. In addition to being placed in the abstract and the introduction, these updates will also occur in the last paragraph of Section 3.3 and the last paragraph of Sect. 4 to clarify the current state of the dynamic β.

(2) It should be made clear that the results and their interpretation reflect β functions when formulated as a function of soil water potential (or soil moisture content by extension). The choice of soil water potential as the explaining variable is explained in lines 158-164, but should be discussed elsewhere for emphasis. It is not clear if the manuscript's conclusions would be the same had the authors formulated β as a function of leaf water potential, which is recognized as an alternative model

scheme in line 159. I expect that the conclusions would be different had β been defined as a function of leaf water potential, considering that the finite plant conductance is explained here as a controlling variable for the response (lines 211, 252-257, 290), and the conductance would be reflected in the resulting leaf water potential. Whether or not the conclusions would be different for a leaf potential formulation, at the very least, these concepts should be explained in the text. Nonetheless, regardless of the alternative formulations for β and their implications, the study is still highly meaningful to terrestrial biosphere models, considering most terrestrial biosphere models apply β as a function of soil water potential or moisture – another point that can be further brought out in the text (or a Table could summarize existing schemes in terrestrial biosphere models).

BPS: Thank you for the comment. Based on your comment, we realize now that saying β is formulated as a function of leaf water potential is not quite correct. Originally, we referenced Jarvis (1976) for this point as he does use an empirical downregulation term as a function of leaf water potential. However, he provided a simple PHM to calculate leaf water potential from soil water potential. The older TBMs that had used the Jarvis formulation (mainly SiB2) effectively transformed soil moisture to leaf water potential. Therefore, in the updated manuscript, we will remove the mention of β formulations as a function of leaf water potential.

Additionally, we plan to update Sect. 2.5 to clarify that β is typically defined in terms of soil moisture (using either soil water potential or soil water content), which avoids calculating leaf water potential (and implementing PHMs). We will direct the reader to Trugman et al. (2018), where there is a nice summary table of typical β formulations in TBMs (as functions of soil water potential and soil water content) in lieu of creating our own table.

Your comment also brings up another important point worth clarifying: do our results extend to β functions using soil water content instead of soil water potential? We selected β in terms of soil water potential for a few reasons. Primarily, soil water potential provides more consistent comparison with PHMs as water transport follows a water potential gradient and not a water content gradient. Additionally, Egea and Verhoef (2011) found β using soil water content struggled to match empirical data, unless a more complex functional form was used---likely accounting for the nonlinear mapping between soil water content and soil water potential. We will update Sect. 2.5 to justify our use of soil water potential and clarify the conditions under which our results apply to β using soil water content.

Minor comments:

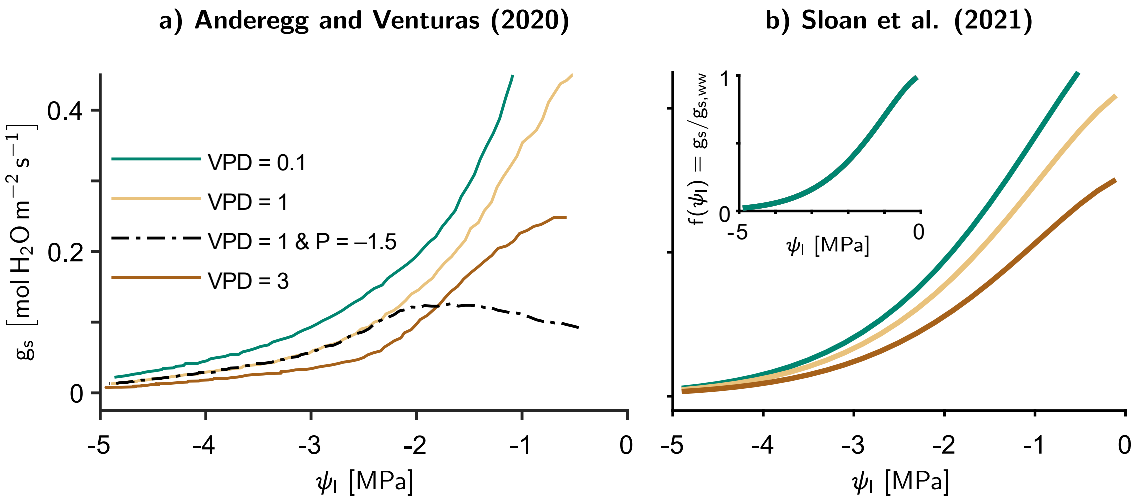
(1) Line 17: "water use" is a broad term that can mean many things besides transpiration. To be more exact, change "water use" to "transpiration."

BPS: Agreed, we will address in the updated manuscript.

(2) Eq. 3 + 8: These formulations are reasonable enough for the purposes of the study; however, limitations of these formulations should be explained. Eq. 3 is flawed in the sense that there is no unique stomatal conductance response for a given leaf water potential (recently discussed by Anderegg & Ventuas, 2020; "*Plant hydraulics play a critical role in Earth system fluxes*"). Similar logic applies to Eq. 8. The formulation for stomatal conductance as calculated by Eq. 8-9 is a little funny, considering at least two things. First, Eq. 8-9 causes the minimum stomatal conductance to decline

with leaf water potentials. And second, g_1 in Eq. 9 is considered a constant, even though it reflects the marginal water use efficiency (which is recognized by the authors in the SI; lines 325-326), which can be further considered a function of leaf water potential (e.g. Manzoni et al., 2011; "*Optimizing stomatal conductance for maximum carbon …*"; Wolf et al., 2016; "*Optimal stomatal behavior with competition for water and risk of hydraulic impairment*"). I do not expect these equations to change with revision, but the formulations should be justified in the text or SI.

BPS: This is a very interesting issue that we will clarify in the updated manuscript. Figure 2 in Anderegg & Venturas (2020) illustrates the non-unique response of stomatal conductance to leaf water potential (shown below in Fig. RC1a). Our formulations of stomatal downregulation in response to water potential, f(ψ_l), exhibit similar non-uniqueness. This is because Eq. 3 (and Eq. 8) does not relate actual stomatal conductance to leaf water potential, but rather relates actual stomatal conductance <u>normalized by the well-watered value</u> to leaf water potential (shown in Fig. RC1b inset for Eq. 8). So even with this simple formulation, the relationship between stomatal conductance and leaf water potential varies with VPD (Fig. RC1b) because the well-watered stomatal conductance value (determined by the Medlyn equation) changes with environmental forcings. To illustrate this, we quickly ran our LSM with PHM downregulation scheme for parameters and environmental conditions similar to those in Venturas et al. (2018). Fig. RC1b illustrates that our simple Jarvis-like term can produce similar results to those in Anderegg and Venturas (2020), though we do agree there are benefits to the Venturas et al (2018) formulation in terms of not having to determine parameters for f(ψ_l). However, for the purpose of this work, our assumptions should be sufficient. In the updated manuscript, we will emphasize the importance of this non-unique g_s- ψ_l relationship.


a) Anderegg and Venturas (2020)

b) Sloan et al. (2021)

Figure RC1: a) Figure 2b taken (and modified) from Anderegg and Venturas (2020) illustrating the non-unique relationship between stomatal conductance (g_s) and leaf water potential (ψ_l). b) Results for our PHM transpiration downregulation scheme using similar parameters and environmental forcings to Fig. 2a. We obtained relevant parameters from Venturas et al. (2018) for Aspen, and made educated guesses on others that were not explicitly in the formulation Venturas et al. (2018) (e.g., Medlyn's g_1). The point of the figure was not to match exactly Anderegg and Venturas (2020), but rather to show our model creates the non-unique g_s- ψ_l behavior and could match the Fig. 2a behavior with tuning (except the dashed line representing no xylem refilling). Our scheme utilizes a normalized curve (inset) of g_s to its well-watered value ($g_{s,ww}$) to represent stomatal closure, rather than this relationship being an emergent property of plant hydraulic properties and an optimality hypothesis as in Venturas et al. (2018).

In response to the comments on Eqs. 8-9, we selected this Jarvis-like approach because it allows for simple comparison between the minimalist and complex PHM formulations as well as β. As you have pointed out, this approach is similar, but not identical to the approaches of Manzoni et al. (2011) and Wolf et al. (2016). In the updated manuscript, we will revise Sect. 2.1-2.2 to clarify that our Jarvis-like approach is a simplification that facilitates our model comparisons. Furthermore, we will direct the readers to other established approaches for altering g_1 with water potential. We will make the argument that our main conclusions on the differences between PHMs and β will not change with different stomatal downregulation formulations, as long as the downregulation factors from each model are applied consistently.

(3) Lines 154-156: This sentence is vague, and the intent is unclear. In particular, "tested against the selection of different soil moisture depths to represent plant water availability" suggests to me something about parameterized rooting depths and/or soil properties, but again, it is unclear. If it concerns rooting depth, refer to the SI (either generally to section S6.5.3 or specifically to Eq. 84). However, the rooting depth appears to have been set as a constant based on literature review (Table S7) and not a calibrated value. As a side note, the rooting depth of 0.1 m seems very shallow for an 18 m tall pine tree.

BPS: Thank you for pointing this out. We will update Sect. 2.4 based on this comment and a comment from Reviewer 2 by adding more details from Sect. S4 justifying our use of soil moisture measurements at 50 cm to force the model. We selected this depth based on analyzing GPP deviations from the mean as a function of dryness (Fig. S5).

Thank you for catching the typo for rooting depth. The rooting depth should have a value of 1.1 m based on a previous modeling study at US-Me2 from Schwarz et al. (2004). We will update the supplemental materials.

(4) Line 169: Refer to Figure S2 here. Figure S2 helps explain the linear functions used by the dynamic β scheme.

BPS: We will add a reference to Fig. S2

References for Response to Reviewer 1

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Jarvis, P. G. (1976). *The interpretation of the variations in leaf water potential and stomatal conductance found in canopies in the field. Trans. R. Soc. Lond. B* (Vol. 273).

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