Reply to comments of Reviewer 1

In ***"blue"*** we copied the comments of the reviewer, in **black** our reply, in **green** new additions that will be included in the manuscript, and in **red** the deletions to the manuscript. We also indicated within square brackets the line number when we refer to specific points or sections of the manuscript "[Line]". The numbering of figures and tables of this reply are preceded by R aiming to differentiate them from the original figures and tables of the manuscript.

*"**Summary:***

The authors manipulate existing CLM 5 soil texture and depth to bedrock (DTB) parameters to account for plant-accessible moisture stored in fractured bedrock beneath soils. They compare simulated to actual transpiration across four sites in Europe with different climate conditions and find that the two simulated bedrock scenarios (one with 1.5 m of simulated "bedrock" and another with additional "fracturing") better match observed transpiration during the summer for the sites with a pronounced dry season.

This work motivates further exploration of how bedrock water is accessed by plants and how this process is represented in hydrologic and ecophysiological models. The manuscript is exceptionally well motivated and contextualized, and was easy to follow. The conclusions are well reasoned and of interest to a number of communities engaged in biogeosciences research. Comments are shared to increase clarity."

1. Reply:

We would like to thank the reviewer's for the positive comments and constructive feedback. Hereafter, we provide a separate response to each comment to clarify the points raised by the reviewer and improving the manuscript.

Comments and questions for the authors:

Why are the rooting profiles illustrated as linear but described as exponential?

2. Reply:

The rooting profiles showed in Figure 1 provide a visual representation of the roots distribution and were not intended to provide a mathematical representation of the exponential rooting profile. However, to prevent any misinterpretation for the readers, we improved the graphics of this figure and changed it from linear to an exponential representation (Figure R1). Consequently, Figure R1 will replace Figure 1 in the manuscript keeping the caption unchanged.

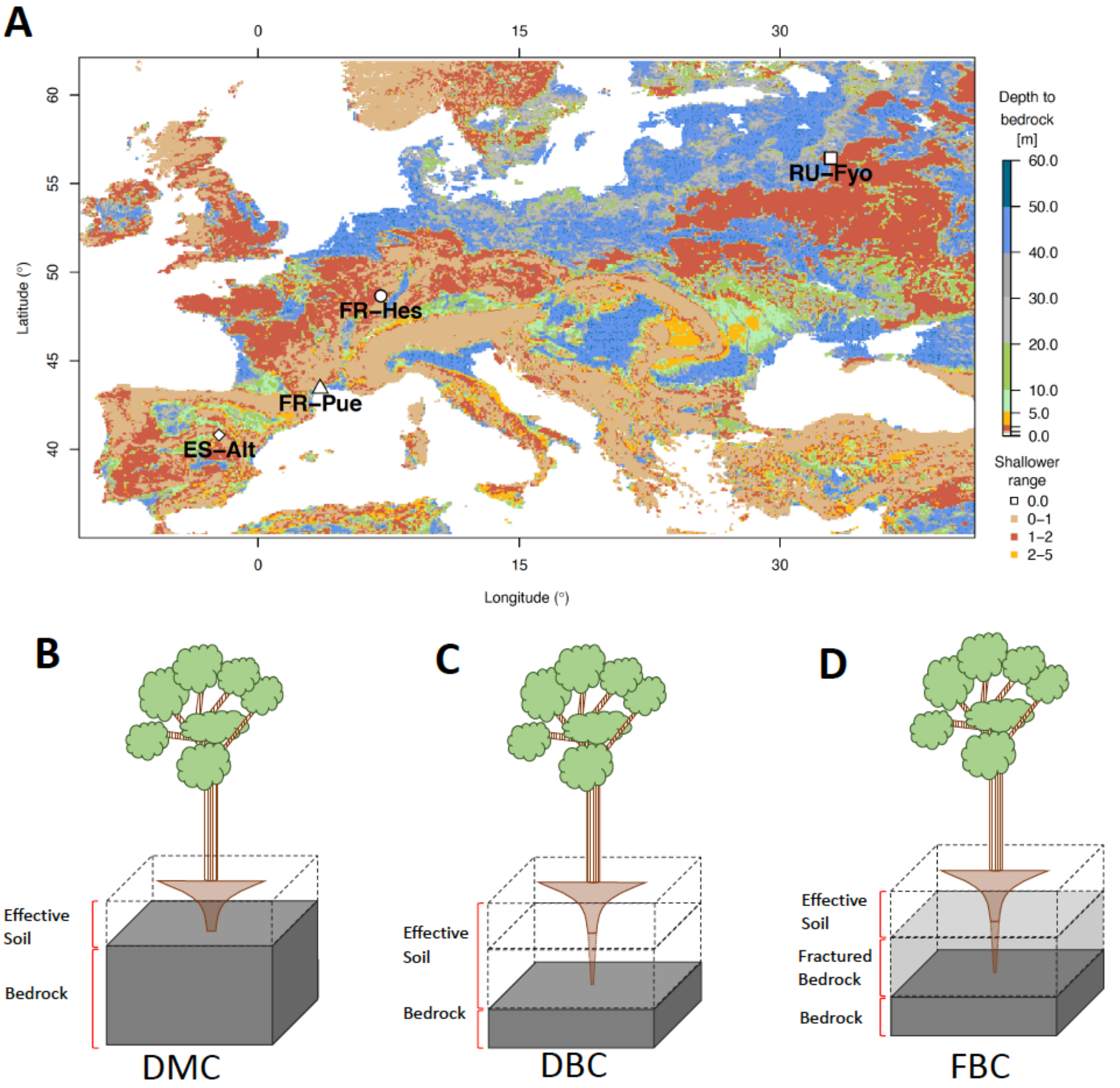

Figure R1. Modified version of the vertical distribution profile of roots according to the exponential function used by CLM 5. This figure will replace Figure 1 of the manuscript.

Is there an expectation that model agreement should be improved during energy limited periods or in energy limited sites (e.g. line 303, 405). Limitations outside of water availability could be better quantified and described in the results and discussion.

3. Reply:

Yes, the expectation is that any of the model configurations should agree with the observed transpiration under energy-limited conditions. Nonetheless, under these conditions, we expect that the modeled vegetation does not deplete the soil water reservoir, which is the case in these sites. Due to the lack of plant water stress, the model configurations can transpire at maximum capacity during winter (for the evergreen sites), spring, and autumn [Lines 323-324]. This response during unstressed periods happens because the precipitation water is enough to replenish the transpired water [Lines 376-

377, 420-421] as it happens in FR-Hes during summertime. In this regard, water availability (surplus and deficit) is the main driving factor for the differences among model configurations that only include the changes to subsurface conditions.

The manuscript mentioned that atmospheric forcing [Lines 223-226] and plant physiological parameters [Lines 144-145] do not change among models. Also, we discussed the role of plant hydraulics on the water movement within the plant [Lines 417-420, 442-447]. However, we cannot discard the possibility that the increased water stress in summertime could result from an over-estimation of water use during the early season that depletes the water reservoirs. Under these conditions, the overestimation could be linked to a lack of water use strategy or additional stressors not accounted for in the model formulation.

Consequently, we propose to add:

In [Line 428]:

"… stems and leaves (Fig 5.). Also, the increased water stress in summertime could result from an over-estimation of water use during the early season that depletes the water reservoirs. Under these conditions, the overestimation indicates a lack of water use strategy or additional stressors not accounted for in the default model parameterization."

Are the default parameters reported in line 145 site specific and if so, are they reported?

4. Reply:

No. None of the default parameters for root distribution and plant hydraulics were adjusted to site conditions. Also, the parameters are available in Table 1.

A statement on the rationale behind the specific three model configurations would benefit the reader. Why these three and not other possibilities? Additionally, in line 167, how does the 90% sand and 10% clay mimic fractured bedrock? Justification is needed here.

5. Reply:

We agreed with the reviewer's comment that additional information will benefit the readers. The selection of these model configurations was done aiming to provide a straight evaluation of the impact of changing the depth to bedrock and soil properties. In this manuscript, we used the measured transpiration as benchmark to compare the model transpiration, however, the Default Model Configuration (DMC) was used as a baseline to compare the effects in the simulated percent loss of conductivity (PLC).

The Deeper Bedrock Configuration (DBC) shifts the DTB adding a predetermined profile of 1.5 m below the DTB in the DMC. This depth was defined as a fixed parameter across all sites because the heterogeneous nature of weathered bedrock depends on the interaction between climate, vegetation, and rock type (Pawlik *et al.* 2016).

Moving the bedrock deeper implies solving the issue of how to parameterize this newly created water storage. “Section 3.2 Bedrock Configuration” [Line: 154] describes the selected approach which relies on two main assumptions: a fractured bedrock will have a high-water conductivity and low water holding capacity. This approach is based on the recent studies at regional and continental scales stressing the importance of the accumulated sediments in weathered bedrock fractures that enhances the water holding capacity beneath the soil (Jian *et al.* 2020), allowing the woody ecosystems to use the rock moisture at regional scales (McCormick *et al.* 2021). The soil texture selection that mimics a fractured bedrock is supported by the similarities in saturated hydraulic conductivity (K_s) that both, sandy soils (Miyazaki, 1996; Pachepsky and Park, 2015) and weathered granite rocks have (Rouxel et al., 2010; Katsura et al., 2009) [Lines: 396-400]. As the sandy soil texture classification can be described by any soil with a combination of more than 85% of sand and less than 10% of clay, we decided to choose the combination of soil fractions that provides a sandy soil texture with a maximum water holding capacity for this textural class.

Consequently, we propose to add:

In [Line 163]:

> “… each location, using this model configuration as a baseline for comparison across the manuscript. The second …”

In [Line 164]:

> “… texture classification. This depth was defined as a fixed parameter across all sites because the thickness and degree of bedrock weathering are difficult to characterize over broad scales (Holbrook et al. 2014), where the interaction between climate, vegetation, and rock type determines the extent and properties of the weathered bedrock (Pawlik et al. 2016). The third configuration …”

In [Line 166]:

> “… clay (Table 1). This approach aims to mimic the hydrological behavior of a fractured bedrock based on two main assumptions: a fractured bedrock should have a high-water conductivity and low water holding capacity. As the sandy soil texture classification can be described by any soil with a combination of more than 85% of sand and less than 10% of clay, we decided to choose the combination of soil fractions that provides a sandy soil texture with a maximum water holding capacity for this textural class. The high sand percentage will mimic the fast water movement through the primary and secondary porosity of the fractured bedrock. At the same time, the low clay content allows having a low water holding capacity for plant water uptake compared with the above soil layers.”

The Pelletier et al 2016 dataset is a model output and not reflective of local site conditions per se. As far as I understand, it is only validated for depth to bedrock in the US using groundwater well data (which is rarely available in uplands areas like the sites in this study.) The language around use of the dataset should be couched to reflect that the dataset does not provide DTB at the four sites.

6. Reply:

Yes, the data set from Pelletier et al (2016) was validated for US and then applied to estimate the depth to bedrock (DTB) globally. However, the differences between the DTB used in the model and that reported for the experimental sites does not show differences larger than 50 cm for FR-Pue and FR-Hes, and in ES-Alt it is within the reported field data (Table R1). In RU-Fyo the first 50 cm are reported as peat, lying above glacial deposits (Table R2).

Table R1. Differences between the soil depths ingested in the model and the soil depths reported for the sites.

	Experimental Sites			
	ES-Alt	FR-Pue	FR-Hes	RU-Fyo
Input for the Model [cm]	82 cm	95 cm	101 cm	132 cm
Reported Field Data [cm]	20-100cm	50 cm	145 cm	50 cm (peat)
References	Grossiord et al. (2015) Martin-Duque et al. (2008) Penuelas et al. (2003)	Pita et al. (2013)	Granier et al. (2000b)	Arneth et al. (2002) Kurbatova et al. (2002) Schulze et al. (2002) Vigodskaya et al. (2002)

Following the reviewer's recommendation, we will add the following:

In [Line 149]:

> "… summary information. Although this data set does not reflect the exact site conditions, the depth to bedrock is closer to measurements reported in previous studies at the experimental sites. The simulations were …"

Also, we will add Table R2 as an appendix describing the reported data for each experimental site.

Table R2. Summary of the main sub-surface characteristics of each experimental site.

Main Site Characteristics	**ES-Alt**	**FR-Pue**	**FR-Hes**	**RU-Fyo**
Rooting Depth (m)	8.0	4.5	> 1.5	0.2
Peat Layer Depth (cm)	None	None	None	50
Soil Depth (cm)	20-40 | 100	50	145	N.A.
Soil Texture: % Clay	25.9	39	25	N.A.
Soil Texture: % Sand	57.3	26	N.A.	N.A.
Soil Texture: % Silt	16.8	35	N.A.	N.A.

Soil Type	Sandy Clay Loam	Silty Clay Loam	Clay Loam	Loam
Soil Permeability	N.A.	High	N.A.	N.A.
Superficial Stone Fraction	N.A.	0.75 (0-50cm)	N.A.	N.A.
Deep Stone Fraction	N.A.	0.90 (>50 cm)	N.A.	N.A.
Bedrock Type	Cretaceous carbonate	Jurassic Limestone	Sandstone	Glacial deposits
Water Table Depth	Deep	Deep	Deep	Superficial
Plant Water	Soil Water, Weathered Bedrock, Groundwater	Soil Water, Weathered Bedrock, Groundwater	Soil Water	Non-Saturated Substratum
Hydraulic Lift	Present	N.A.	Present	N.A.
References	Carcavilla et al. (2008) Forner et al. (2018) Grossiord et al. (2015) Martin-Duque et al. (2008) Penuelas et al. (2003)	Allard et al. (2008) Limousin et al. (2009) Pita et al. (2013)	Betsch et al. (2011) Granier et al. (2007) Granier et al. (2000a) Granier et al. (2000b) Le Goff et al. (2001) Zapater et al. (2012)	Arneth et al. (2002) Kurbatova et al. (2002) Milyukova et al. (2002) Novenko et al. (2010) Schulze et al. (2002) Vigodskaya et al. (2002)

In line 80, what does "fully developed" mean in this context?

7. Reply:

The term "fully developed" was intended to convey the description of a canopy showing the maximum leaf area index (LAI) during the growing season. However, we see that this may misguide the reader. Consequently, we propose to change it as follows [Line 80]:

"… It is expected that during summer, the vegetation has a fully developed canopy exhibiting a peak in leaf area index, extracting soil water at the maximum rate, and relying on deeper soil water pools during extended dry periods."

In line 75, an additional possibility is that belowground biomass distributions may change over time in response to water stress (e.g. Liu et al, 2019).

8. Reply:

Good point, thank you. Following this recommendation, we will add the following in [Line 74]:

> "… This latter approach emphasizes the key role played by soil texture and rock fragments in regulating the response of root growth (Hu *et al.*, 2021, Li et al., 2019) and plant hydraulics to soil drying …"

Is there site specific subsurface information (from e.g. the papers cited in the site descriptions) that could be added to contextualize the DTB increase needed to improve model performance?

9. Reply:

Yes, there is available information in Table R2 that will be added as an appendix (see reply 6). Also, we propose to add the following lines to improve the site descriptions:

In [Line: 95]:

"… and lowlands (RU-Fyo). All the sites lack detailed information concerning the physical properties of the weathered bedrock, such as hydraulic conductivity, water holding capacity, or percentage of fractures. The sites are distributed across an environmental …"

For ES-Alt [Line: 101]:

"… et al. 2017). The soils are formed from Cretaceous carbonate rocks settled on top of sandy sediments (Carcavilla et al. 2008), showing a poor development (Granda et al. 2012) with maximum soil thickness varying between 25 cm at the top of the slopes, and more than 1.0 m at the bottom (Martín-Moreno et al. 2014). The climate …"

[Line: 108]:

"… et al. 2014). Quercus ilex trees at this site have the capacity to allocate structural and fine roots down to 8.0 m depth (Penuelas et al. 2003). The plant …"

For FR-Pue [Line: 112]:

"… et al. 2002). The superficial soil layers have a high soil permeability thanks to the elevated stone fraction of 0.75. On the other hand, soil layers beneath 50 cm have a larger clay content (> 30%) and a stone fraction of more than 0.9 (Limousin et al. 2009, Pita et al. 2013). This location …"

[Line: 115]:

"… 2008). This forest stand allocates most of the fine root biomass in the top 50 cm of the soil profile with a small fraction of roots reaching depths down to 4.5 m (Allard et al. 2008). Similarly, to …"

For FR-Hes [Line: 112]:

"… 2007). It is a clear transition between the eluviated horizon and the horizon with high clay accumulation at 50 cm depth (Zapater et al. 2012), leading to a low clay content in the upper soil layers (Granier et al. 2000 a). It has … "

[Line: 124]:

“… 2001). Fagus sylvatica trees allocate most of the fine roots in the upper 40 cm of soil with some fine roots reaching depths down to 1.5 m (Granier et al. 2000a, Granier et al. 2000b, Zapater et al. 2012, Bestch et al. 2011). The dominant …”

For RU-Fyo [Line: 131]:

“… and still present. The peat layer at this site has an average depth of 50 cm (Schulze et al. 2002, Vygoskaya et al. 2002, Arneth et al. 2002, Kurbatova et al. 2002), and the glacial deposits result in a loamy texture of the soil beneath it (Novenko et al. 2010, Schulze et al. 2002). The water table at this site is shallow, forcing the trees to allocate most of the fine roots in the top 20 cm of the soil (Milyukova et al. Schulze et al. 2002, Vygodskaya et al. 2002). The climate …”

The overprediction of transpiration during spring and rapid drying of the root zone is a very interesting result that models representing deeper water stores will have to grapple with. The discussion of plant hydraulics in L420-440 is thorough and very well done, but are there perhaps other additional factors that could be considered as well? For example, dynamic belowground biomass, fungi, or the role of multi-porosity systems (e.g. Schwinning, 2020).

10. Reply:

The additional factors mentioned by the reviewer may help to explain the measured transpiration during the dry season at sites such as ES-Alt and FR-Pue, where the precipitation is reduced, and plants must access any source of water available belowground to survive during this period. In this context, the four potential pathways proposed by Schwinning (2020) could play an important role for this vegetation.

We propose to add the following in [Line 436]:

> “… vegetation types. Also, plants depending on rock moisture had developed special water access strategies such as dynamic root systems or mycorrhizae growing along the rock cracks and accessing water stored in or dripping from the bedrock (Schwinning 2020). Experimental evidence …”

Is it necessary to have well developed soil to access groundwater (Line 355)?

11. Reply:

No, it is not necessary to have well developed soil to access groundwater. Nonetheless, to improve the idea we want to convey, we will add the following lines:

In [Line 354]:

> “… If geological conditions allow the formation of deep soils (e.g., Amazon Basin, Loess Plateau), the roots will access deep groundwater that will become very

> important for surviving extended dry periods (Chitra-Tarak et al., 2021; Tao et al., 2021). On the other hand, when soils are shallow and less developed, the trees must thrive by accessing additional water pockets in the weathered bedrock. The heterogeneous nature of weathered bedrock depends on the interaction between climate, vegetation, and rock type (Pawlik et al. 2016). These interactions allow the increment of the water-holding capacity of weathered bedrock by increasing the porosity and mineral surface area (Navarre-Sitchler et al. 2015). This water holding capacity is considered negligible (Novák & Šurda, 2010), but the vertical extent of this layer makes the water reservoir large enough to support deep rooting vegetation during dry spells (Graham et al. 2010, Jones & Graham 1993). As an example, Mediterranean trees are able to uptake water from the deep vadose zone …"

The definition of bedrock within the paper is a bit inconsistent, specifically in the caption of Figure 1. For example, bedrock in CLM5 is considered impermeable but bedrock is represented as a combination of sand and clay. Clarification is needed here.

12. Reply:

It is true that in CLM 5 the bedrock is described as an impermeable layer and the paper also states that in [Line 158]. Also, in Figures 1B, 1C, and 1D the impermeable bedrock layer is represented by a solid block. The term "Fractured Bedrock Configuration" that is in the caption of Figure 1 is explained in the methodology [Lines 164-167] and the description is extended with the proposed addition in reply 5. To improve clarity further, we will change the caption text to:

> "Figure 1. Geographical location of the experimental sites and spatial distribution of the depth to bedrock across Europe (A) based on Pelletier et al. (2016). The graphics below the map are the schematic of the three model configurations used in this work: default model configuration, DMC (B); deeper bedrock configuration, DBC (C); and fractured bedrock configuration, FBC (D). The block with dashed lines represents the soil profile, the solid grey block represents the impermeable bedrock layer as it is assumed by CLM 5, and the translucid grey block represents the mimicked fractured bedrock layer."

Some comments about figures:

Figure A1: Is this a boxplot? It seems like a timeseries. A description of the points vs. lines is needed in the caption.

13. Reply:

Yes, those are boxplots showing the multiannual variability per day of the year. The points are the outliers for each boxplot when present. We will improve the figure caption as follows:

> "Figure A1. Multi-annual daily boxplots for potential evaporation (E_o), stand transpiration (E_T), and vapor pressure deficit (Λ) of the selected experimental sites across Europe. The boxplot represents the data contained between the first and third quartiles, the central line is the median, the whiskers represent a predefined distance from the median (1.5 x inter-quartile range), and the dots are the outliers."

Figure 2: Is there a legend label missing (corresponding to pink or orange)?

14. Reply:

There is actually not a missing label but the bars with a pink looking color are translucid red representing E_o that it is solid red in the legend. We will improve the figure as follows:

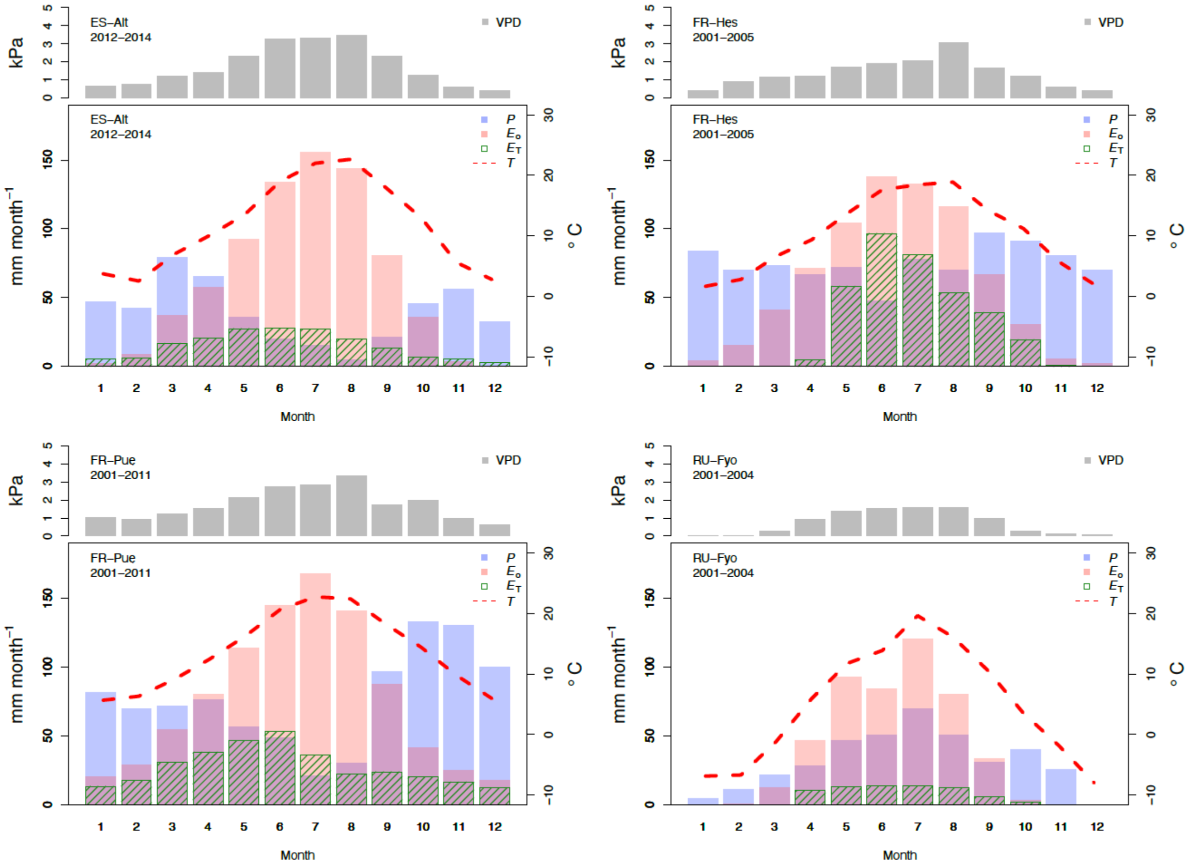

Figure R2. Updated version of Figure 2 to be replaced in the manuscript.

Figure 3: This is the most impactful figure but it is very difficult to tell the different model configurations apart. The caption says boxes but there don't seem to be boxes in the figure.

15. Reply:

Thanks for the heads-up on this. This plot shows only the boxplot (inter-quartile range), but it is difficult to distinguish between model configurations. Consequently, we will replace Figure 3 and caption as follows:

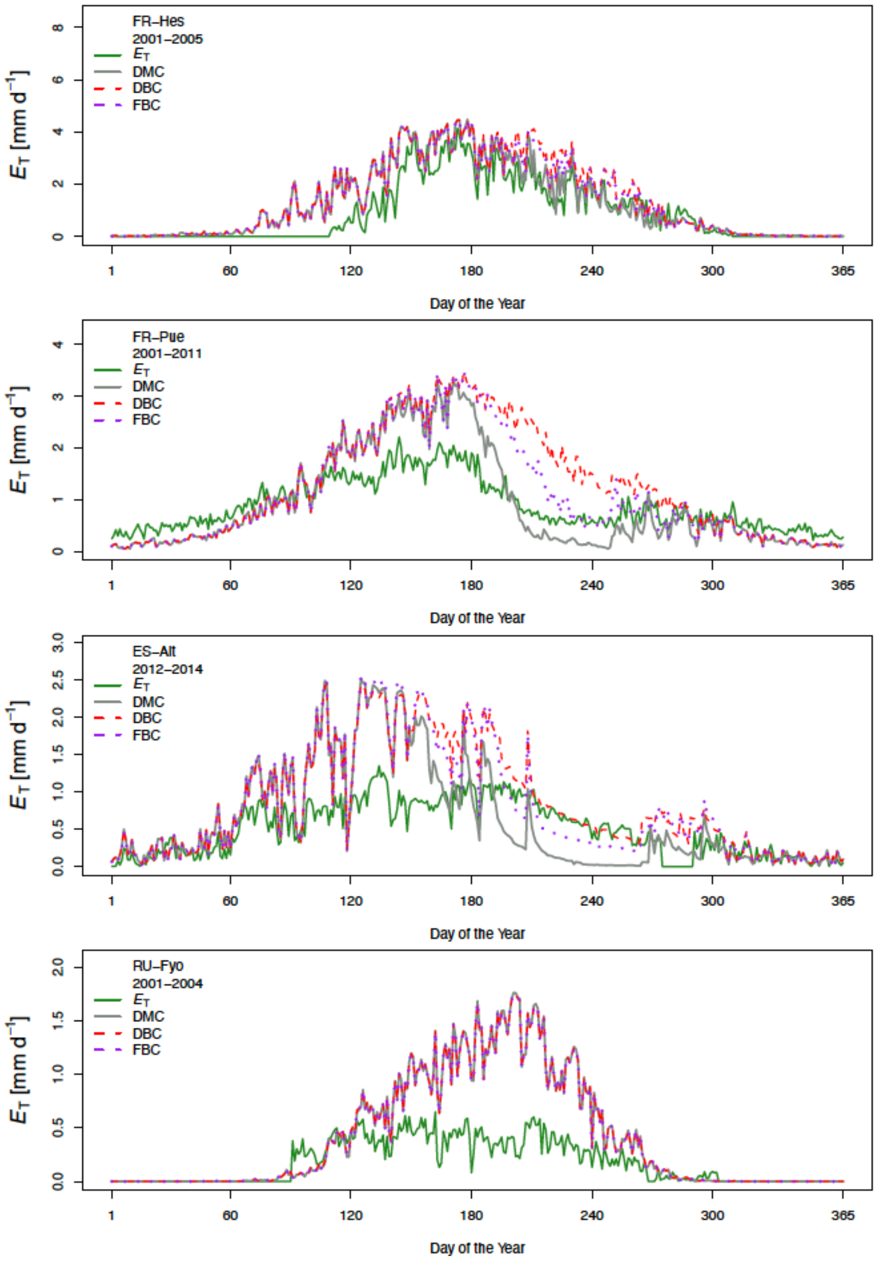

Figure R3. Median of the measured and modeled daily transpiration rates for the different model configurations at each experimental site.

Figure 4: Some of the concepts in this figure could potentially be better represented by scatterplots for specific times or model configurations that are most significant to the results. Including a simple illustration of how model-data agreement is improved with bedrock water storage under specific conditions could make the paper potentially more impactful and approachable to non-CLM experts. "

16. Reply:

Thanks for the recommendation, the simpler the better. We decided to change this figure into an annual time series (Figure R2) that will replace Figure 4 of the manuscript. This figure change will require to modify the manuscript as follows:

Deleting [Lines: 268-277]:

"… experimental sites. In the graphical scheme adopted in this figure … proportionally to the α value (e.g., ES-Alt.DMC.March)."

Replacing Figure 4 with Figure R2 and updating the figure's caption as follows:

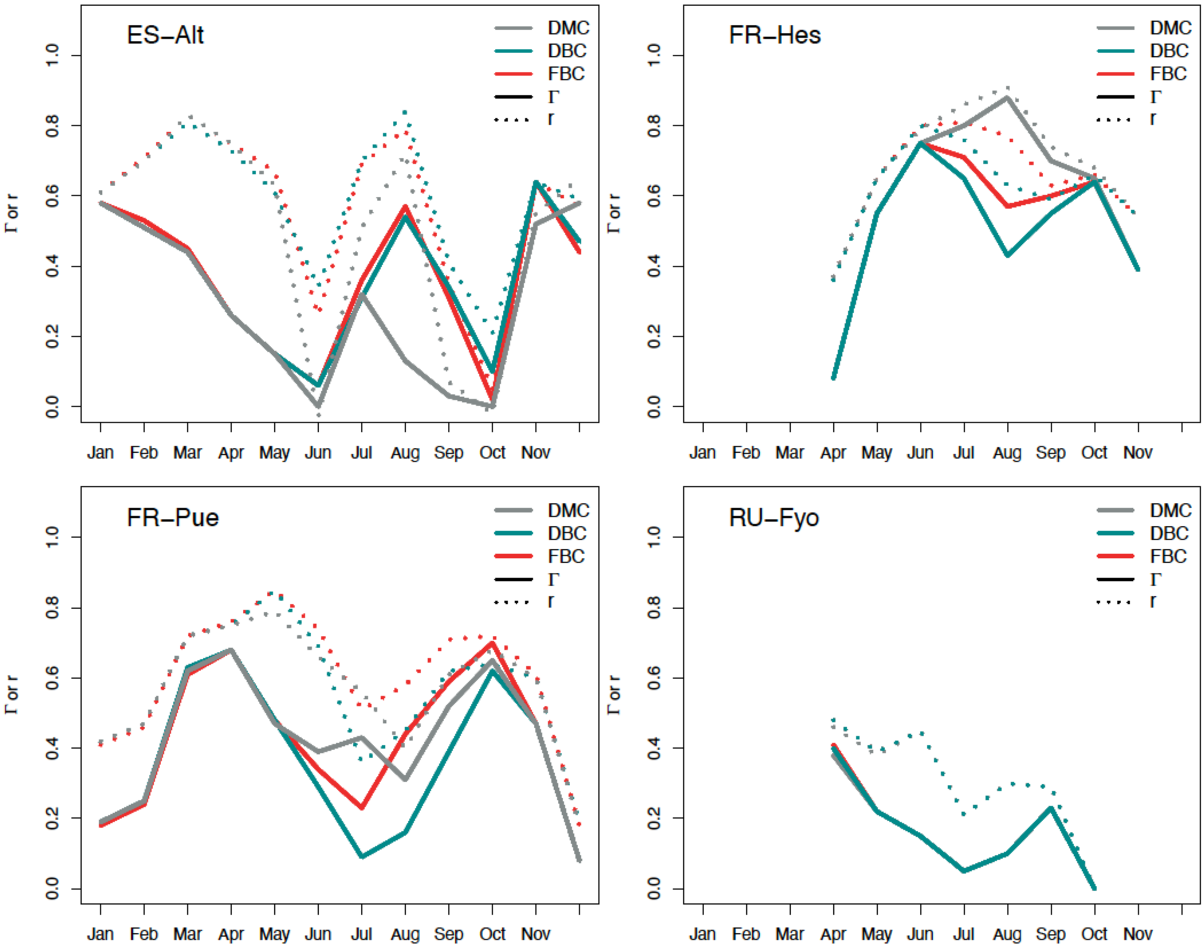

Figure R4. Multi-annual monthly variation of the Pearson correlation coefficient (r) and the index of agreement (Γ) for the default model configuration (DMC), deeper bedrock configuration (DBC), and fractured bedrock configuration (FBC).

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