RC2: 'Comment on gmd-2022-136', Anonymous Referee #2, 23 Oct 2022

In this manuscript, the authors attempted to incorporate the effect of cold hardening on the hydrological and physiological processes of trees into the CLM5.0-FATES-Hydro. The scheme of cold hardening consists of the hardening scheme (Rammig et al., 2010; some modifications) and the physiological scheme (maximum conductance, parameters for stomatal conductance, hydraulic failure mortality, pressure-volume curve, and carbon starvation mortality). They showed that the inclusions of cold hardening schemes are vital for reproducing the biomass of two boreal forests in Farstanas and Spasskaya Pad. Otherwise, the trees die due to hydraulic failure during the winter, caused by the low water potential of frozen soil and the resulting dehydration of the trees. Therefore, I think their schemes are successfully developed and valuable for many readers who want to model the processes in boreal forests.

Authors response: *We would like to thank the reviewer for this positive feedback on the manuscript. Please see our responses in blue texts under each comment.*

I recommend this article be accepted after the revisions listed below.

On the modifications to the scheme by Rammig et al. (2010)

For example, the authors modified the maximum hardiness level (H_MAX) from a constant (i.e., -30 deg C) by Rammig et al.(2010) to the variable changing with the running mean of the annual minimum air temperature of the past 5 years. This may result in a big difference in the simulations, particularly in Spasskaya Pad, but such a result is not shown in the present manuscript. I'd suggest showing the results when the original schemes by Rammig et al. (2010) are adopted so that the importance of the modifications in this study will be emphasized

Authors response: *Thank you for this suggestion. In principal it would make sense to test the scheme from Rammig et al. (2010) at Spasskaya Pad, but that scheme was only tested and parameterized for a location in Sweden, and not generalized to the rest of the world like our implementation. Due to the large climatic differences between Sweden and East Siberia, it is unlikely that the original scheme from Rammig et al. will perform well at Spasskaya Pad making it less valuable to compare to. This is especially true since the variables modified downstream of the hardening scheme (K_{MAX}, g0, g1 and HFM) have been adjusted based on H_{MAX} and hence on the climate of a location. Still, the results from the test you suggested are partly represented by the sensitivity experiments on, for example, H_{MAX}. When we reduce T5 (the 5 year running mean of the minimum daily temperature) by 15°C instead of 10°C to define H_{MAX}, we end up with a reduced (less negative) hardiness level, which results in more dehydration but also more carbon uptake. In addition, we also compare the FATES model in its current state (default) with the FATES model containing the hydro-hardening scheme to show the importance of our model improvement. We have added more explanation to emphasize the necessity of the modifications in this study in the revised version of the manuscript: "Due to the large climatic differences between Sweden and East Siberia, it is unlikely that the original scheme from Rammig et al. will perform well at Spasskaya Pad. To deal with this, in our adaptation of the hardening model, H_{MAX} becomes site- and time- dependent (to function globally and to account for evolution associated to changes in climate), and varies with the 5 year running mean of the annual minimum of daily mean air temperature at 2m height (T5)."*

Citations of equations

Throughout the manuscript, the citations of equations look strange and probably do not fit the style of GMD. In the case of this manuscript, all the "Eq. XX" should be put in parentheses. For example, in L182, "TH Eq. (1), HR Eq. (2) and DR Eq.(3)" should be "TH (Eq. (1)), HR (Eq. (2)), and DR (Eq.(3))". Please revise all of them.

Authors response: *Thank you for pointing this out. We have changed this for all equations based on some published papers in GMD where they do it like this: "(Eq. 1)". We also changed "Eq." to" Eqs." when appropriate.*

Symbols in equations

Throughout the manuscript, the symbols differ between the text and the equations. For example, H_MIN and H_MAX in the text are presented as M_min and H_max, respectively, in equations (1), (2), and (3). Please maintain the integrity of symbols.

Authors response: *Thank you for noticing this mismatch. H_{MAX} and H_{MIN} are now only mentioned this way.*

Section 2.2

I strongly suggest the authors provide the model description of HD (i.e., L191-202) in advance of those of TH, HR, and DR for better readability.

Authors response: *We agree that this improves readability, and we moved the text describing HD to L172 in the revised version of the manuscript, in advance of those of TH, HR, and DR:*

Once a value has been assigned to TH, HR and DR, depending on the daily mean 2m air temperature, the model operates as follows: if TH is lower than the hardiness of the previous day (HDP), then HR is removed from HDP. By contrast, if TH is higher than HDP, DR is added to HDP (Eq. 1).

$$HD = \begin{cases} HDP - HR, if HDP > TH \\ HDP + DR, if HDP \leq TH \end{cases}$$

Besides, the description L191-202 seems not sufficient. For example, HD takes the maximum value H_MIN in summer, but it is not explained. This corresponds to equations (1) and (3) of Rammig et al (2010). Here, Rammig et al. (2010) adopted aggd5 (the accumulated growing degree days), but the authors did not mention it in the manuscript. Is that OK?

Authors response: *We agree that the hardening scheme could be better explained and the differences with the Rammig scheme made clearer. Some changes were made in the manuscript and are described in the next response.*

Since this hardening scheme is the core of this study, the authors should describe it entirely, even if it is nearly the same as Rammig et al. (2010). Otherwise, the reader would have to refer to Rammig et al. (2010) when reading this paper.

Authors response: *Thank you for pointing this out. We have added 3 changes listed below in the revised version of the manuscript. We hope that this section is now less confusing and that all the modifications made to the scheme are better explained.*

Added L1996: "In Rammig et al. (2010), the hardening period is prevented until the 210th Julian day and a growing degree day threshold is reached."

Added at L201: "In our version of the hardening scheme, if the requirements of Eq. (6) are met, the value given to HD in Eq. (1) will be overwritten."

Added at L205: "At the end of the time-step, values of HD outside of the range H_{MIN} to H_{MAX} will be redefined within these extremes according to Eq. (7).

$$HD = \begin{cases} H_{MIN}, if HD > H_{MIN} \\ H_{MAX}, if HD < H_{MAX} \end{cases}$$

(7)"

In addition, according to equations (4) to (6), HD is determined depending on the interrelations between HDP and TH. I'd suggest showing the example of the temporal variation of HD and TH to show how these variables are interrelated.

Authors response: *According to the reviewer's comment, we have added Figure S14 in the Supplement to illustrate the evolution of TH and HD during two random years. Please also see the modification at L174 in the revised version of the manuscript: To illustrate Eq. (1) and the interrelation between HDP and HD, Figure S14 shows the temporal evolution of TH and HD during two random years.*

Figures

As reviewer 1 pointed out, most of the figures are difficult to distinguish between lines, and the legend obstructed the figure. Please try to make it easy to see, and put the legend outside the plot.

Authors response: *To make the figures clearer, the lines were made thicker on almost all graphs and large legends are placed outside of the graphs. The font size was also adjusted on most graphs.*

L61: It is unclear what "it" stands for here. Is it "plant hydraulics"? If so, I suggest rewriting this sentence as follows. "Plant hydraulics, apart from its critical role in the survival of plants during droughts, is also a major driver of species distribution."

Authors response: *Thank you for the suggestion. We have modified the sentence, please see L61 in the revised version of the manuscript. It now reads: "Plant hydraulics, apart from its critical role in the survival of plants during droughts, is also a major driver of species distribution."*

L110-111: Lawrence et al. (2019) --> (Lawrence et al., 2019)

Authors response: *Change made*

L178 and the caption of Table 1: Does "the minimum 2m daily temperature" mean the "annual minimum of daily mean air temperature at 2m height"? Describe it clearly.

Authors response: *"the minimum 2m daily temperature" was replaced by "the annual minimum of daily mean air temperature at 2m height"*

L192: "the hardiness of the previous day (HDP)" --> "the hardiness level of the previous day (HDP)" or "the HD of the previous day (HDP)"

Authors response: *"the hardiness of the previous day (HDP)" was replaced by "the HD of the previous day (HDP)"*

L245 (Eq. 12): The variables "HFMortScalar" and "percentage" appear here for the first time without any explanation. What are these?

Authors response: *Thank you for pointing this out. The variable "HFMortScalar" was replaced by "MortScalar" in (Eq. 12), and "percentage/100" was replaced by "50%". These changes should make the paragraph clearer and make the reader understand what we actually do to reduce the hydraulic failure mortality. We also added the two following sentences at L242 in the revised version of the manuscript: "In the control hardening simulation we reduced HFM by up to 50% at HD equal* H_{MAX} *(see Eq. 12). In the two sensitivity experiments conducted on HFM, we modified the occurrences of 50% in Eq. (12) to obtain a reduction reaching 100% and 0% respectively (Table 1)."*

L262: Hd --> HD (italic)

Authors response: *Thank you for pointing this out. Change made.*

L342: 0.55% --> 55%

Authors response: *Thank you for the correction. Corrected to* 55 %

L342: (Fig. 8b and c) --> (Fig. 8a and b) Note that Fig. 8c shows the CSM, not HFM.

Authors response*: Thank you for pointing this out. "(Fig. 8b and c)" was replaced by (Fig. 8a and b) as suggested.*

L356: Insert "(Eq. (10))" to read "since HFM is a function of flc (Eq. (10))".

Authors response: *This was changed accordingly and "(Eq. 10)" was added at L360 in the revised version of the manuscript.*

L359-360: I could not get the meaning of this sentence. Does it mean "The contribution of the changes in K_MAX, g0, and g1 to the reduction of HFM can be seen by comparing Fig. 8b and Fig. S12."?

Authors response: *We have replaced "The contribution of the changes to* K_{MAX}*, g0 and g1, and the reduction of HFM, can be seen by comparing Fig. 8b and Fig. S12." with "The contribution of hardiness to the reduction of* K_{MAX}*, g0 and g1, and HFM, can be seen by comparing Fig. 8b and Fig. S12." in the revised version of the manuscript.*

L439: green --> red

Authors response: *Thank you. It's corrected.*

L439: brown --> green

Authors response: *Thank you. It's corrected.*

L440: dark green --> (light) blue

Authors response: *Corrected.*

Figures 8a and b, S5a and b, S12a and b, S13a and b: "Hydraulic mortality" in the vertical axis should be "Hydraulic failure mortality" to maintain the integrity of the terms.

Authors response: *Thank you. We have replaced "Hydraulic mortality" with "Hydraulic failure mortality" in Figures 8a and b, S5a and b, S12a and b, S13a and b.*