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The Cryosphere Discussions

Interactive comment on "Evaluating permafrost physics in the CMIP6 models and their sensitivity to climate change" *by* Eleanor J. Burke et al.

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Many thanks to the reviewers for their detailed set of comments. We have responded below.

Main suggestion 'the authors should put more effort into connecting modelling outcomes with real world consequences' – We initially included in this paper a rough calculation of the potential impact of permafrost thaw on sea level rise and permafrost carbon. We have been asked by the editor (sea level rise) and the other reviewer (permafrost carbon) to remove these. They suggested that our analysis was too rough and required a much more extensive analysis which would be beyond the scope of the paper.

We have reworded the section in the middle of the discussion to expand the discussion on missing processes affecting the hydrology of the permafrost region. This now reads - 'In particular, excess ground ice which exists as ice lenses or wedges in permafrost soils is a key process that is not included in the current generation of CMIP models. Thawing of ice-rich permafrost ground will lead to landscape changes including subsidence, thaw slumps and active layer detachments and large-scale modification of the hydrological cycle \citep{liljedahl2016pan}. These ice-rich thermokarst landscapes are susceptible to abrupt changes and cover about 20 \% of the northern permafrost region \citep{olefeldt2016circumpolar}. Recent observations suggest that even very cold permafrost with near surface excess ice is highly vulnerable to rapid thermokarst development and degradation \citep{farquharson2019climate}. The inclusion of these processes within the CMIP6 models will further perturb the hydrologcial cycle and result in additional permafrost degradation not yet quantified by current generation of climate models.'

19-21 – This section has been expanded to 'This unprecedented change will have consequences for northern hydrological and biogeochemical cycles. For example, it will result in CO$_2$ and CH$_4$ emissions which will have a positive feedback on the global climate \citep{burke2017quantifying}. The ecology of thaw-impacted lakes and streams is also likely to change with microbiological communities adapting to changes in sediment, dissolved organic matter, and nutrient presence \citep{vonk2015reviews}. Conditions are likely to be more conducive to fire with earlier snow melt and drier ground in spring \citep{wotton2017potential}. Furthermore subsidence from thawing permafrost will cause damage to manmade infrastructures \citep{melvin2017climate, hjort2018degrading}; leading to issues with the overall sustainability of northern communities \citep{larsen2014polar}.'

33 – changed

43 – deleted

35 – changed as suggested

27 - deleted

53-54 rephrased to: Gradual thaw will occur as the global temperature increases leading to an increase in both the ALT and the time over which the near surface soil is thawed.

56-57 now reads - Abrupt thaw processes caused by the melting of excess ground ice will also occur with the landscape destabilising and collapsing \citep{turetsky2020carbon}. These thermokarst processes are not currently represented in Earth System Models and are not assessed here.

63-64 – sentence removed

74-75 - SSP5 is a world of rapid and unconstrained growth in economic output and energy use (SSP5), with a radiative forcing of 8.5 W m-2 by 2100. The description of SSP5-8.5 is changed to: 'high end of the range of future pathways with fossil fuel development and updating RCP8.5'

105- MAGT is always defined at the top of the permafrost and is shown in Figure 1. This is added to the text in a couple of places to clarify.

115-117 – This now reads: 'Using the \cite{chadburn2017observation} relationship, we reconstructed a permafrost probability map from the WFDEI estimates of $MAAT$. In addition, we applied the \cite{chadburn2017observation} relationship to the $MAAT$ for each model to estimate a benchmark permafrost distribution specific to each model ($PF_{benchmark}$)'

117 – 118 – This sentence now reads - 'This model-specific $PF_{benchmark}$ can be used to evaluate the land surface module independently of any climate biases in $MAAT$.'

138 – MAGST is now defined

156 – Agreed should be 0.25 m.

164 – agreed and included earlier as well.

175 – Slater and Lawrence did not provide a probability of permafrost being present if the deepest soil temperature was less than 0 – they just assumed permafrost.

218-220 – A figure has been added showing this observed relationship and more detail discussing its derivation has been added to the paragraph.

223 – is changed to are

233-252 – this paragraph is divided up and clarified.

279-280 – This now reads 'This spread was calculated independently for each model by binning the $MAAT$ into 0.5°C bins and calculating the median value of each offset for each bin'

284 – to changed to too

285 – first 'between models' is removed.

292 - 'to be able' deleted.

294-296 – this now reads 'The offsets are a function of both $MAAT$ (not shown) and $S_{depth,eff}$. A low $MAAT$ and a high $S_{depth,eff}$ gives a bigger offset (see also \cite{wang2016evaluation}).'

328 – this sentence has been reworded in response to reviewer 2.

409 - 'at the lowest model level or D_{zaa}' has been added.

458-459 – this now says 'Over the past few years there have been a lot of model developments improving the representation of northern high latitude processes in land surface models (e.g. \cite{chadburn2015impact, porada2016effects, guimberteau2018orchidee, cuntz2018physically, burke2017vertical, hagemann2016soil, lee2014effects}). \cite{chadburn2015impact, porada2016effects} developed a dy-

namic moss parameterisation which enables the insulation effect of the moss on the permafrost to be simulated. \cite{burke2017vertical} added a vertically resolved soil carbon model to enable the permafrost carbon to be identified and traced through the soil. \cite{lee2014effects} included a representation of excess ice within the soil which will melt in response to climate change. Many of these processes are yet to be included within the climate models.'

Figure 3 – the resolution was not the same for the two orange lines- this has been changed.

Figure 5 – only the observed surface offset was available and was not separated into summer and winter, but the surface offset is dominated by the winter snow. We wanted to include the summer offset to show its relative size compared to the winter offset.

Figure 6 – Not all models reported snow depth in the CMIP archives. We will add that note in the caption.âĂČ

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