Initial Author Response for "Snow thermal conductivity controls future winter carbon emissions in shrub-tundra", Rutherford *et al*.

The authors would like to thank the editor and reviewers for taking the time to read and review the manuscript and for the suggested improvements. The reviewer comments are included here in black and our initial responses are in green. Where we refer to line numbers in our response, this relates to the original submitted document.

Reply to comments from Reviewer 2:

Rutherford and others study the consequences of using more realistic snow thermal parameters and biogeochemical temperature sensitivities for future carbon dioxide and methane release in a tundra ecosystem. The results make some interesting points but I was unsure why the particular site was chosen if no data are being compared against model results, especially as the earlier simulation period overlaps with the present day. As such it is unclear if the base model is realistic in the first place, which is critical for defensible future scenarios. I recommend trying to use existing observations, especially for things like snow duration and soil temperature that are measurable, for ensuring that model results are realistic before moving on to the important topic of making the model more realistic.

The authors would like to thank the reviewer for their interest in our manuscript and for highlighting the importance of model validation. Our choice of Trail Valley Creek (TVC) is grounded in its extensive observational dataset beginning in the early 1990s, which has made it the focus of many measurement and modelling studies. Notably, Dutch et al. (2023), focusses on CLM5.0 simulations at TVC and show that implementing the Sturm et al. (1997) K_{eff} parameterisation alleviates cold soil biases in CLM5.0 simulations when compared with field measurements. Further, use of the Sturm et al. (1997) parameterisation brings NEE simulations more closely in line with field measurements. In our manuscript we use the work by Dutch et al. (2023) to provide the essential scientific foundations the reviewer requests, which shows CLM5.0 configurations to be realistic. The process of showing the model is realistic is a paper in itself, i.e. Dutch et al. (2023). Here we leverage these realistic parameterisations to provide more robust projections of soil and carbon.

To address this, we have added the following text to the introduction to reinforce the performance of the model against field observations of soil temperature and net ecosystem exchange (NEE) as outlined in Dutch et al. (2023):

We add the following text to the introduction:

"Implementing the Sturm et al. (1997) parameterisation reduces the cold bias in simulated soil temperatures by two-thirds. Further, while default CLM5.0 produces negligible winter NEE, combining the Sturm et al. (1997) parameterisation with a mid-range value for Ψ_{min} (-20) produces winter NEE values consistent with field observations (Dutch et al. 2023, Figure 5)"

We add the following text to the discussion:

"The CLM5.0 parameterisations for Keff, Q10 and Ψmin explored by Dutch et al. (2023) were found to be highly suitable for representing winter soil temperatures and carbon fluxes under present day conditions. This alignment between observations and simulations provides confidence in the model's ability to simulate future Arctic soil processes through to 2100."

86: what does 'not appropriate' mean in this context? Why is it not appropriate?

To better clarify this, we revise this text as follows:

“Further, the CLM5.0 default soil moisture threshold for decomposition (Ψ_{min} = -2) is too high to permit sub-zero degree soil respiration and this has been identified as a limitation in winter simulations (Tao et al., 2021, Dutch et al., 2023). Similarly, CLM5.0 default settings of Q10 (1.5) and Q10ch4 (1.3) which dictate respiratory responses to changes in temperature are too low for Arctic tundra environments (Dutch et al., 2023, Müller et al., 2015). These parameters Ψ_{min}, Q10 and Q10ch4, alongside K_{eff}, require adjustment to realistically simulate soil respiration (SR) and methane flux (FCH4) under cold season conditions. Implementing the Sturm et al. (1997) parameterisation reduces the cold bias in simulated soil temperatures by two-thirds. Further, while default CLM5.0 produces negligible winter NEE, combining the Sturm et al. (1997) parameterisation with a mid-range value for Ψ_{min} (-20) produces winter NEE values consistent with field observations (Dutch et al. 2023, Figure 5). Our study builds on the findings of Dutch et al. (2023) by investigating the influence of the Sturm et al. (1997) parameterisation on future projections of soil temperature and associated carbon emissions.”

161: note the spread of Q values…these are related to the chemical composition of the respired material and can change quite a lot, especially with respect to more labile carbon inputs that are easier to decompose.

We agree that Q10 is an important and complex variable in controlling soil decomposition which is greatly influenced by the composition of respired material. To capture this variability we implement a wide range of Q10 and Q10ch4 values ranging from 1.3 to 7.5 to reflect temperature sensitivities of both labile and recalcitrant carbon stocks (Fierer et al., 2005, Yan et al., 2017).

To reflect this, we add the following to the Methodology:

“We implemented a broad range of Q10 and q10ch4 (1.5 – 7.5) to capture variability in the temperature sensitivity of soil respiration associated with differences in carbon pool lability (Fierer et al., 2005, Yan et al., 2017).”

222: note reference formatting error

This error has been corrected in the revised manuscript.

The analysis in Figure 3 is interesting but for the particular site is there a measured data record to compare against, especially because the 2016-2046 averaging period includes the present day? It’s critical to understand how well modeled values match measurements to help instill confidence in the future projections.

We agree that grounding projections in observational data is essential. As mentioned in response to a previous comment, Dutch et al. (2023) conducted a thorough comparison between CLM5.0 simulations and field measurements from TVC including snow depth, soil temperature and Net Ecosystem Exchange (NEE) measurements. Their study shows that incorporating the Sturm et al. (1997) K_{eff} parameterisation improves model performance in winter, alleviating soil temperature biases.

References

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