

The Cryosphere Discuss., author comment AC1
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Reply on RC1

Tyler C. Herrington et al.

Author comment on "Validation of pan-Arctic soil temperatures in modern reanalysis and data assimilation systems" by Tyler C. Herrington et al., The Cryosphere Discuss.,
<https://doi.org/10.5194/tc-2022-5-AC1>, 2022

The authors would like to thank Referee 1 for their helpful comments. We are planning a substantial restructuring of the Results (Sections 4 and 5) and the Discussion/Conclusion (Section 6) to shorten its length and remove superficial discussion material. We are also planning to rework Section 5 to instead investigate trends in the ensemble mean soil temperature against a subset of stations with longer temperature records.

Major Comments

- Reformulate and shorten the manuscript (maybe as a brief communication) with a very specific focus on soil temperature validation

The authors are not aware of an option for a brief communication style manuscript in The Cryosphere. Instead, the revised manuscript will be substantially rewritten in response to the reviewer comments. We are shortening Section 4 (Results) by removing discussion material and moving it to Section 6 (Discussion/Conclusion). Section 5 will be revised, with focus on comparing soil temperature trends in the ensemble mean soil temperature product against a subset of stations with longer soil temperature records. Section 6 will be shortened, by including only the most relevant details that describe uncertainties in the analysis related to instrumental uncertainty, modeling uncertainty, and sampling uncertainty.

- In Sec. 4 & 5, the authors present the evaluation results together with a large part of the discussion, and additional discussions are given in Sec. 6. This makes the manuscript very unclear and difficult to follow.

We will separate the discussion material in Section 4 and 5 and move it instead to Section 6. Within Section 6 we plan to more concisely describe how model uncertainty, instrumental uncertainty and sampling uncertainty could impact our results (see our response above and for Major Comment #3 for further information).

- The discussion in Sec 6 is very general and superficial, and is not tightly connected to previous sections. For instance, the gap of site-scale observation and model grid (about 10–100 km), or so-called scale effects, is widely reported. P23, L392–398, this part is

very confusing. Does the misclassification of permafrost affect the results? Please make sure only to present the most relevant parts here to avoid diluting your real contributions.

We thank the reviewer for their helpful suggestions on Section 6. Our plan is to move pertinent discussion material from Sections 4 and 5 to Section 6. By doing so, we believe that the discussion will more directly tie-in with the results. In addition, we are planning to show how our estimate of instrumental uncertainty is qualitatively similar to the findings of studies exploring scale effects in frozen soils (e.g. Gubler et al., 2011; Morse et al., 2012; Gislén 2014; Cao et al., 2019) (see our response to Minor Comment #5 for more details).

As the number of validation grid cells in the discontinuous permafrost zone is substantially smaller than those in the continuous permafrost zone (particularly so when we use the Obu et al. (2019) permafrost zonation), the authors do not believe that any potential misclassification of permafrost in this region would fundamentally alter the conclusions of the study. We will be sure to shorten this section, and point out that the results appear not to be impacted by any potential misclassifications of permafrost in the discontinuous permafrost region.

- The authors presented and discussed the reanalysis soil temperature deviation. I am wondering why this is important here and how this could be used for validation purposes? The strong variation of soil temperature in the cold season could be expected due to the presence of a snow layer, see Figure 6 from Burke et al., (2020).

The authors thank the reviewer for bringing this figure to our attention. We use the normalized standard deviation as a measure of the temporal variance of soil temperatures across the grid cells. Doing allows us to assess the range of simulated soil temperatures at each grid cell for a particular product, to see if it can capture a similar seasonal cycle of temperatures to that of the observations.

When we describe soil temperature variability in the cold season we are referring to two main features – first that the individual products themselves show a larger variance in soil temperatures than they do during the warm season. Second, we are also describing the spread in soil temperature variance between products. Figure 6 in Burke et al. (2020) clearly shows how differences in snow insulation between products could contribute for the spread in soil temperatures over the winter, and we will include a reference to Burke et al. (2020) in our discussion section describing this.

While snow cover could very well account for the larger variance in soil temperatures within a product over the cold season – Figure 6 in the Burke et al. (2020) paper is unable to fully explain why an individual product's cold season soil temperature variance is often substantially larger than its warm season variance. We are planning to explore the impact of snow cover on soil temperatures in reanalysis products in a follow up paper.

- The climatology based on the ensemble results is somehow unfocused. The purpose of this study is "validation of pan-Arctic (and Boreal) soil temperatures from eight reanalyses and land data assimilation system (LDAS) products." (see P2, L53–54), rather than analyzing the climatology. To be more focused, authors could compare and evaluate the trend of ensemble results with site-scale observations.

We agree that a focused evaluation of the trends against a subset of the stations with longer timeseries would be of value, and will restructure Section 5 to instead validate the trends in the ensemble mean soil temperature against station observations.

- P8, L180: Then why not directly use the IPA map? You could also find the global permafrost zonation index map from Gruber et al., (2012).

The authors thank the reviewer for this suggestion. We have incorporated the Obu et al. (2019) permafrost zonation index map into our analysis. Figure R1 compares permafrost zonation using the Smith and Riseborough (2002) air temperature method and the Obu et al. (2019) index. The Smith and Riseborough (2002) method appears to overestimate the number of permafrost grid cells relative to Obu et al. (2019), however this difference does not fundamentally alter the conclusions of our study.

Minor Comments

- P2, L24: Permafrost carbon and climate warming loop are complex, and thus ...could act as a "possibly/potentially" positive...

We will revise this statement to read as: "Continued warming, and thawing of permafrost soils, and related decomposition of carbon could act as a **potential** positive feedback on warming."

- P2, L31: Qinghai-Tibetan Plateau

Corrected.

- P2, L45–49: Ensemble simulation has also been used for permafrost simulation, for instance, Cao et al., (2019), although these studies do not directly use the soil temperature

We have added a reference to Cao et al. (2019) in our introduction where we describe the use of ensemble mean datasets in the literature.

- P4, L122: The variation of soil temperature is complex and typically depends on surface condition (i.e., snow layer, vegetation), soil properties (i.e., soil organic content), and soil depth. It could vary very large at the hourly and daily scales.

The authors thank the reviewer for this helpful comment. As we are using soil temperatures averaged between 0cm and 30cm in the near surface, and between 30cm and 300cm at depth, we had presumed that the soil temperatures should show reduced variation on daily and hourly timescales. We will revise this sentence to read "Many of the in situ (station) sites reported measurements at hourly or daily frequency, however we chose to perform the analysis at monthly time scales, in order to focus on processes controlling the seasonal cycle of soil temperatures."

- P6, L135: How much the difference could be? Could you please write it down?

The authors presume that the reviewer is asking by how much the soil temperatures may vary between stations within a grid cell. Panel B of Figure 1 gives an estimate of the variability of soil temperatures within a grid cell – most stations have a median spatial standard deviation of $\sim 2^{\circ}\text{C}$, however soil temperatures may vary by as much as 7°C in some cases. The variability is of a similar magnitude to previous studies exploring sub-grid scale variability in cryospheric soil temperatures (e.g. Gubler et al., 2011; Morse et al., 2012; Gislås 2014; Cao et al., 2019).

- P6, L141: ...2 to 12..

We chose to write 2 as "two", since style conventions in The Cryosphere specify that all single digit numbers (unless they are followed by units) should be written as a word.

- P6, L142: The so-called "scale effects" has been widely reported, see Gubler et al., (2011) for the Alps and Cao et al., (2019) for high latitudes. Please cite relevant references.

We thank the reviewer for pointing out several relevant references on scale effects. In our revisions, we plan to link our estimates of scale effects with those in the literature, and show that our results qualitatively agree with those exploring scale effects in seasonally frozen and permafrost soils (e.g. Gubler et al., 2011; Morse et al., 2012; Gignès 2014; Cao et al., 2019) – see our response to Minor Comment # 5 for more details.

- P8, L172: you have two "also" here

Corrected.

- P9, L192: "more" □ greater/larger

Revised.

- P14, L250: Qinghai-Tibetan Plateau

Corrected.

- P16, L256: Zero curtain period is heavily dependent on the soil moisture rather than the active layer thickness

The authors thank the reviewer for this helpful comment. We will remove the following sentence here: "In regions where the active layer is deep (such as over the discontinuous permafrost zone), the zero curtain period is often longer and more pronounced (Chen et al., 2021) than it is over the continuous permafrost zone or regions with seasonally frozen soil."

The section will now read: "Thirdly, latent heat interactions in the active layer during spring can lead to long periods of time where the soil remains at or close to freezing - the zero-curtain period. Many of the processes that control the zero-curtain effect, such as freeze-thaw parameterizations are relatively simplistic in many land models (Cao et al., 2020; Chen et al., 2015), and their coarse resolution would fail to capture local scale variations in the zero-curtain period."

- P22, L357: Remove the redundant ')''

We will remove the extra bracket here.

- Table 1: Could you please also add the soil discretization information here, such as depth for each layer and the total soil column depth? Please double-check the spatial resolution of all the reanalyses, ERA5 should be 0.25°, ERA-Interim is 0.75°, and MERRA-2 is 0.5°×0.625°. Depending on the datasets you used, JRA-55 is 1.25° for the reanalysis level and 0.56° for the model level

We will fix the spatial resolutions in the table for ERA5, ERA-Interim and MERRA2. For JRA55, we used data at the model resolution of 0.56°. We will also add another column to the table to include information about the soil depths included.

- Figure 4: Do you really need so many sub-plots? The inter-comparisons among different reanalyses are shown here but not discussed in the main text. Did I miss something important? Please also add the 1:1 line, so that readers could clearly see the cold/warm bias

The most important comparisons to be made here are the performances of the individual products against the station – the outer margins of Figure 4 in the paper – which is the focus of the text. We also used the histograms of the warm/cold season to look at the variability of soil temperatures in the warm and cold season. We will include a paired down figure in the revisions - similar to the one below (Figure R2).

- Figure S3: Could you please improve the resolution of Figure S3?

We will make sure to improve the resolution of Figure S3 in the revisions.

References:

Cao, B., Quan, X., Brown, N., Stewart-Jones, E., and Gruber, S.: GlobSim (v1.0): deriving meteorological time series for point locations from multiple global reanalyses, *Geosci. Model Dev.*, 12, 4661–4679, <https://doi.org/10.5194/gmd-12-4661-2019>, 2019.

Gisnås, K., Westermann, S., Schuler, T. V., Litherland, T., Isaksen, K., Boike, J., and Etzelmüller, B.: A statistical approach to represent small-scale variability of permafrost temperatures due to snow cover, *The Cryosphere*, 8, 2063–2074, <https://doi.org/10.5194/tc-8-2063-2014>, 2014.

Gubler, S., Fiddes, J., Keller, M., and Gruber, S.: Scale-dependent measurement and analysis of ground surface temperature variability in alpine terrain, *The Cryosphere*, 5, 431–443, <https://doi.org/10.5194/tc-5-431-2011>, 2011.

Morse, P. D., Burn, C. R., and Kokelj, S. V.: Influence of snow on near-surface ground temperatures in upland and alluvial environments of the outer Mackenzie Delta, Northwest Territories., *Can. J. Earth Sci.*, 49, 895–913, <https://doi.org/10.1139/e2012-012>, 2012.

Please also note the supplement to this comment:

<https://tc.copernicus.org/preprints/tc-2022-5/tc-2022-5-AC1-supplement.pdf>