The Cryosphere Discuss.,
https://doi.org/10.5194/tc-2020-76-AC3, 2020

The Cryosphere Discussions

Interactive comment on "The ERA5-Land Soil-Temperature Bias in Permafrost Regions" *by* Bin Cao et al.

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Received and published: 12 June 2020

Responses of Anonymous Referee #3

The authors would like to thank the reviewer for the constructive feedback, and the thorough assessment of the manuscript. Below we provide a point-to-point response to each comment, reviewer comments are given in black, responses are given in blue. Additionally, we have included details of how we intend to address these changes in a revised submission.

This paper assesses the utility of ERA5L soil temperature products for permafrost

studies by using a wide range of global station data from both permafrost and non permafrost regions as well as detailed simulation experiments at a specific site. The authors find that ERA5L has large biases making the product problematic for permafrost studies. This study is a valuable contribution as we increasingly use reanalysis products for land surface modeling studies, especially at regional or global scales and insights into performance of these products are useful. Additionally, such studies may help to guide future developments in land surface schemes used in reanalyses. I recommend publishing after considering my (mainly minor) comments.
(in grammatical comments changes are CAPITALIZED)
The manuscript will be carefully edited by native speaker with strong permafrost background in order to improve the language.

1. l.3 "is predicted TO BE too warm...."
2. l.19 "Reanalysis, ASSIMILATES"
9. l.74 "These INCLUDE"
13. l129 "A linear model..."
16. l.147 "While ERA5L does not have DATA allowing deep ALT values to be computed"
26, l.232. use of "low" here is confusing. you are biased to low densities, you do not have a low bias. I would say "a low-density bias" to make it clear.
Will be edited by native speaker

3. l.28 what is ERA5-Interim/Land? Seems a confusion of the products
It was a typo, should be ERA-Interim/Land.

4. l.29 "consistently cold BIASED."
Will be revised to *"..,and generally the soil temperature from different reanalyses (i.e. ERA5-Interim/Land, MERRA-2, and CFSR)* ***shows consistently cold bias."***

5. l.54 I think the HTESSEL ref could do with a publication citation.
The latest ERA5 paper, Hersbach et al., (2020), that describes HTESSEL is added here.

6. l.57 now available from 1981.
In the revision, we'll add *"Note that, during writing only ERA5L data after 2001 are released andhence this evaluation is conducted for data between 2001–2018."*.

7. Section 2.2.1 what do B1 and B2 refer to?
Will be revised to *"Appendix B1"* and *"Appendix B2"* to clarify.

8. l.71 is the node really at the lower boundary (0.07) in soil layer 1?
Reviewer #2 also mentioned this issue. We copied the responses here.

Based on the Table 8.7 in IFS Documentation CY45R1 (https://www.ecmwf.int/en/elibrary/18714-part-iv-physical-processes), the lower boundary is 0.07 m, although this is different from the description in ERA5L document website). We also contacted the scientist from ECMWF, and I simply copied the reply below.

"The soil temperature of a given layer is an averaged value over of the thickness of that layer and assigned to the middle of the layer. From the modeling point of view this temperature is a valid temperature for any point in the layer, whereas in reality it'll be different depending on the depth. This is one of the limitations when the soil is discretised in a finite number of layers."

For this reason, we followed the depth in model document as described in L70–71: *"The soil column of ERA5L is discretized into four layers with node depths (layer boundaries) of 0.07 (0–0.07), 0.21 (0.07–0.28), 0.72 (0.28–1.00), and 1.89 (1.00–2.89) m."*

10. Section 2.3 and Table 1 are all stations boreholes? If so perhaps explicitly state that.
No, some sites are from boreholes, e.g., GTN-P, but sites like CMA, HiWATER, are from soil temperature sensor of meteorological stations. In Section 2.3, we'll change the first sentence to *"Soil temperatures from 639 borehole sites or meteorological stations located in permafrost regions are used"* to clarify.

11. l.90-91 and driven by ERA-Interim air temperature.
The TTOP map compiled by Obu et al., (2019) was driven mainly by MODIS LST, but the data gaps due to cloud cover was filled by downscaled ERA-Interim air temperature. Please see Section 2.2 and Figure 1 from Obu et al., (2019). In the revision, we'll change the sentence to
"...(3) the 1-km Northern Hemisphere permafrost map Obu et al., (2019) based on the semi-physical Temperature at the Top Of the Permafrost table (TTOP) model (TTOP map) driven by Moderate Resolution Imaging Spectroradiometers (MODIS) land surface temperature that filled by downscaled ERA-Interim air temperature;" to clarify.

12. l111-114: I don't quite understand the motivation for the two definitions of near surface permafrost I think a sentence explaining why you do this would be helpful for the reader.

The two algorithms are defined here to derived ERA5L soil temperature-based permafrost area. In the revision, this sentence will be changed to *"To evaluate the ERA5L near-surface permafrost area, permafrost is diagnosed from ERA5L soil temperature in two ways..."*

14. l.137 What depth are these MAGT's? Averaged across time or space? Please provide a bit more detail here.
Reviewer #1 also had similar comment. We copied the response here as well.

In Section 3.1, we'll add *"The TTOP and CP map are derived using equilibrium model, and MAGT is given as an average of the entire period (MAGTavg), i.e. 2002–2014 for the CP map and 2002–2016 for the TTOP map, without uniform/specific soil depth. For better evaluation purpose, we aggregate all available observed MAGTs during the period by averaging, and then compared against the MAGTavg of these two maps. Note that the performance of CP and TTOP maps may be lower here than reported in the original publications due to differing observations (depths, periods and proportion of sites in mountains) used."* to clarify

15. l.143 more prevalent snow and soil freezing in the model or in reality? Please clarify. If in reality, then permafrost regions do not necessarily have more prevalent snow than non-permafrost regions.
This is in the HTESSEL model or ERA5L based on the bias comparison of in permafrost and non-permafrost regions(Table 2; Figure 1). We will revise this part to *"In addition to the worse performance of MAAT in these regions, the result suggests that more prevalent snow and soil freezing may reduce the suitability of HTESSEL for soil temperature simulation."*

17. l.153 "(annually)" is it an annual average? Please clarify.
Yes, it will be revised to *"Near-surface permafrost area of ERA5L as defined in this study decreased with a rate of -0.11 (-0.08) $\times 10^6$ km^2 $year^{-1}$ based on hourly (annually) mean soil temperature (Figure 6)." to clarify.*

18 Figure 3 Interesting latitudinal trend in c,d. Can you shed more light on this in the discussion? I guess densification processes at high latitudes (badly represented wind?) What is driving the cold bias at low latitudes?
As Reviewer #1 mentioned, HTESSEL does not have a representation of wind effects on snow densification. In this case, blowing snow. Both Figure 1 and the linear model (Eq. 1) indicated that the cold bias at low latitudes is largely due to the MAAT bias. In Section 5.1, we will add
"Our results indicate that the cold bias of ERA5L in mid-low latitudes is highly aligned with the MAAT bias (Figure 1), and this could also be reflected by the linear model (Eq. 2)."

19. Figure 4 perhaps add the mean value that you cite in the text here.
Will be revised as attached.

20. l.170 "shows REMARKABLY"
Will be revised.

21. l.194 "Even for A"
Will be revised.

22. l.198 "This issue is KNOWN"
Will be revised.

23. l.208 "as AN exponential..."
Will be revised.

24. l.226 soil temperatureS MATCH..."
Will be revised as suggested.

25. l.230 But what about the cold bias you see? the bias appears to evenly spread (figure3) why does this not give a similar spread in ALT estimates (Figure 4) and a related underestimation of ALT?
This is because the shallow ALT sites ($<$ 1.89 m) are mainly in high latitudes (Figrue 5), and in high latitudes the soil temperature was found too warm. This is aligned with Figure 3. In the revision, we'll change the caption of Figure 4 to *"The observed sites are mainly located in high latitudes, and the distribution is present in Figure 5." to clarify.*

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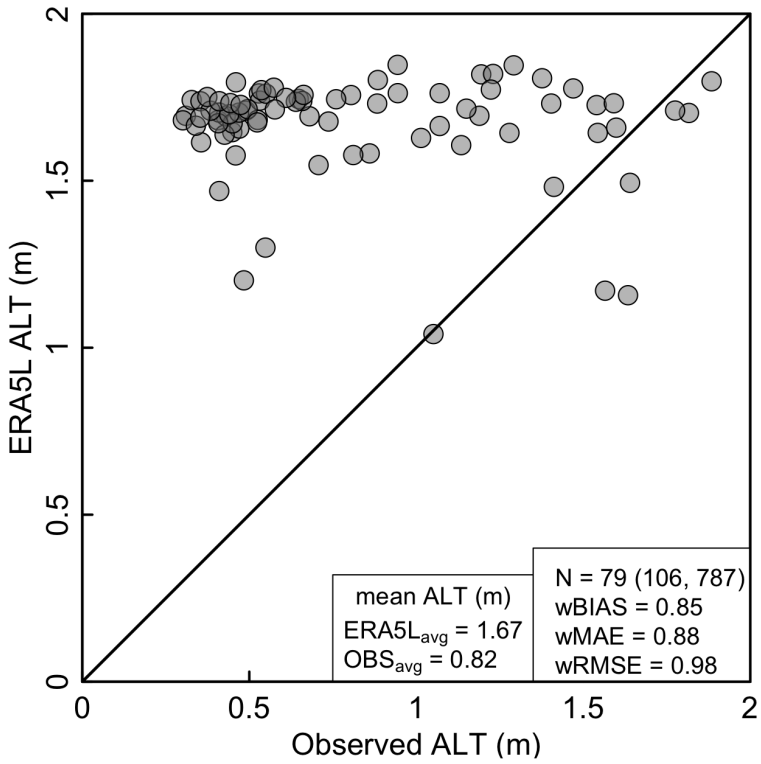
ERA5L ALT (m)
Observed ALT (m)
0
0.5
1
1.5
2
mean ALT (m)
ERA5L$_{avg}$ = 1.67
OBS$_{avg}$ = 0.82
N = 79 (106, 787)
wBIAS = 0.85
wMAE = 0.88
wRMSE = 0.98

Fig. 1.