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Interactive comment on "Improved estimates show large circumpolar stocks of permafrost carbon while quantifying substantial uncertainty ranges and identifying remaining data gaps" *by* G. Hugelius et al.

Anonymous Referee #1

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Hugelius et al. use the Northern Circumpolar Soil Carbon Database (NCSCD) with additional data to improve estimates of Soil Organic Carbon (SOC) in permafrost soils. Improved SOC estimates are always welcome, but the unique aspect of this paper and its biggest scientific achievement is the estimate of uncertainties associated with the SOC estimates. Uncertainty estimates for this kind of statistical upscaling are rare indeed and on behalf of all potential users of this data I applaud them for their boldness and creativity. However, the authors need to correct several errors, inconsistencies, and omissions in how they estimate and combine the uncertainties before the paper

will be ready for publication. The paper will be suitable for publication after major revisions. Major comments related to uncertainty estimation: Pg. 4781 L22-4: The authors should consistently define all uncertainties in the same way for all estimates so that we know they all mean the same thing. The authors use three different definitions: 95% CI, 99% CI, and 16th and 84th percentiles, but should use the same definition for all uncertainties. Throughout the manuscript and in the tables the authors list both the 95% and 99% CI, but this is confusing to the readers who in the end must choose one of the values for their own uses. In Figures 2 and 3, the authors show standard deviation to represent uncertainty rather than a 95% or 99% CI, creating additional confusion. I recommend the authors use the 95% CI as the uncertainty everywhere, which is very common in the literature. Pg. 4781 L26: The authors are not combining the uncertainties correctly. The Roddick [1987] formulation is standard Gaussian error propagation. In Gaussian error propagation, the correct correlation to use is the correlation between uncertainties, not the correlation between variables. If the correlation between uncertainties is not known, as is often the case, it is typically approximated by the correlation between variables. Roddick [1987] clearly assumes the correlation between uncertainties is not known and uses the correlation between variables. However, in Hugelius et al. the correlations between uncertainties ARE known because of the way the authors scaled up the NCSCD by soil order. SOC for all histels, for example, are all based on the exact same data and thus the uncertainties for all histel soils are perfectly correlated (rhoij = 1.0 in the Roddick [1987] formulation). The uncertainties across soil orders, histels and turbels for example, are perfectly uncorrelated (rhoij = 0.0) because they are derived from independent data. The two methods the authors use are actually two cases derived from Roddick [1987] assuming either correlated or uncorrelated uncertainties. The first method, addCI, assumes perfectly correlated uncertainties and can only be used to add SOC within a soil order. The second method, covCI, is correct only if you assume perfectly uncorrelated uncertainties and can only be used to add uncertainties across soil orders. The authors state that thy prefer addCI (P4789 L20-23), but this is incorrect because when to apply addCI or covCI is very

strictly controlled by the rules of Gaussian error propagation. I did the derivations from Roddick [1987] and it boils down to adding uncertainties linearly within a soil order and in quadrature across soil orders. The authors need to add to the supplementary material the derivations of the two forms they use to combine uncertainties starting from the original Roddick [1987] formulation. The authors need to explain exactly when to apply each of the two formulations in the main text and the supplementary material (addCI within a soil order and covCI across soil orders). Lastly, they need to construct the appropriate error covariance matrix when summing the SOC regionally or globally and recalculate the uncertainties for the sums. P4795 L10-11: The authors need to include representation error as part of their overall uncertainty estimation. In this application, the representation error is how well the mean of a small sample size represents the true mean of all soils of that type. By definition, uncertainty is the measure of robustness of our observations. By stating that they cannot get robust estimates, what the authors mean is that estimated uncertainties do not include key factors required to estimate the true uncertainty. The authors know that there far fewer samples of thin overburden compared to thick overburden, so the uncertainties for thin overburden should be higher. However, the thin and thick overburden soils have roughly the same estimated uncertainties in Table 2 and Figure 2, indicating they need to include representation error in the total error estimates. Estimating representation error is not as hard as one might initially think. There are several ways to do it, but essentially, you estimate the difference in the mean value of a small sample size compared to the mean of the full sample size. Let us say that you have 100 samples for thick overburden and 10 samples for thin overburden. If you sub-sample all possible combinations of 10 samples from the full 100 samples you get a distribution mean values. The 95% CI of this distribution is an estimate of the representation error. Representation error uncertainty should be applied only within a soil order and, because it is independent, should be combined in quadrature with the uncertainties already estimated by the authors. Minor and editorial comments: Pg. 4773 L11: delete second Comma. Pg. 4773 L15-25: The authors need to rewrite these sentences to correct a large number of improper

uses of algebraic symbols which make the text almost unreadable. The authors should replace algebraic symbols with appropriate text because they should be used only in full equations: '> 3 m' should read 'greater than 3 m,' '>3m to <60m depth' should read 'depths between 3 and 60 m,' and so forth. The division symbol should be completely eliminated: '178+140/−146 Pg' should read '178 Pg with an uncertainty range of 32 to 318 Pg.' I identified these changes for the abstract, but really the authors should go through the entire manuscript and get rid of all the algebraic symbols. Pg. 4773 L23: The authors should delete the abbreviation for 'circa' because the term should be used only for a single value rather than a range of values. Because circa is primarily used in reference to dates, the authors should consider replacing it throughout the text with the approximate symbol ($\sim$). Pg. 4773 L23-4: I cannot relate the mean value to the uncertainty range. Normally, a mean refers to a single number with an uncertainty bar or range, but here the authors report a range of mean values. Also, the authors need to specify that this is frozen carbon and thus does not include carbon in the active layer (at least I presume this is the case). Pg. 4773 L25-7: The last two sentences of the abstract are out of place and should be moved to after 'region deposits' on line 12. Identifying problems or future work is always a weak way to end an abstract, so the last sentence should be your most important result: the total amount of frozen carbon. Pg. 4774 L5: The authors should specify that the carbon is protected because it is frozen. There are several mechanisms that protect organic matter in soil from decay. Pg. 4774 L15-20: The authors should specify that these deposits are frozen. Pg. 4782 L10-16: These numerical values should be in a table. Long lists of numerical values in the text are very hard to read. I glossed over these values without reading them at all. Pg. 4782 L17: 'Samples' appears twice. Pg. 4782 L17: The presentation of the results from both the v1 and v2 datasets is confusing. If I were to use the data in Figures 2 and 3, which one should I use, v1 or v2? How does this relate to the map in Figure 4a, which shows only one number? For Figures 2 and 3, I recommend the authors replace the v1 and v2 data with whatever they used to get Figure 4a. I recommend the comparison of v1 and v2 be moved to supplemental material or to the discussion.

Figure 2, 3, and 4: The authors should include the numbers for 0 to 0.3 m depth. These numbers are mentioned in the text and appear in the tables, so they should also appear here. P4782 L14-6: These numbers for the high Arctic regions should appear in the figures and tables. P4783 L9: Why did the authors choose the v2 dataset? As stated, this sounds a bit arbitrary, although I suspect it is not. Also, this choice should appear in the methods section. P4783 L18-23: The methods section should describe the statistical significance test they used to evaluate differences and here they should simple state that the differences are statistically significant. It looks like they used a 2-tailed, student t-test at 95% significance. All of Section 3: Much of the text simply repeats what can be seen in the figures or read from the tables. I recommend the authors eliminate most of this text and keep only text that explains how to use the tables or interprets the results. P4784 L15-20: These numbers for the high arctic region should appear in the tables and figures. P4785 L28: The authors need to explain where they got the 89% and why they talk about variance instead of uncertainty. The authors should be talking about contribution to total uncertainty, not total variance. They define uncertainty as the 95% CI, which is not variance. Also, there are several, equally valid ways to estimate contributions to total uncertainty and the authors need to explain in the methods section which method they used. P4786 L1, L5: The authors are using variance and uncertainty interchangeably, which is incorrect. The authors defined uncertainty based on CIs, so the two terms are not interchangeable. P4786 L21: This section needs to include an explanation of Table 5. I could not figure out the meaning of several columns, such as % in permafrost. P4787 L11-2: The authors should pick one CI for uncertainty and stick with it. Showing two values just confuses the reader about which to choose. P4788 L2-9: Most of this text repeats what was stated in the introduction and can be deleted. P4788 L10: Change 'estimate' to 'estimated.' P4788 L22-3: The numbers in Tables 2 and 3 do not add up to these two numbers and are not consistent with table 4. This is the first mention of this difference, but no explanation is given. The authors should identify and explain this difference in Section 3 when the tables are introduced. Section 4.1: Reading this would be much easier if

the authors would simply put the Tarnocai et al. [2009] and these values in a table. P4789 L21-2: The rules for determining how to combine uncertainties in the sums are very specific and defined by the rules of Gaussian error propagation. Therefore it is incorrect to choose a specific way to combine errors based on expected 'realism' (see my main comment above). P4789 L25: Here and throughout the manuscript, the '1303 +362/−368 Pg' notation is very difficult to understand. After seeing the notation several times and thinking about it for 10 minutes or so I now understand that the last two numbers represent the CI intervals. I do not know if they are 95% CI or 99% CI (see my comment on consistent definitions above). The numbers are not identical, indicating a slight asymmetry in the distribution, but I would argue that this difference is so small as to be meaningless. Throughout the manuscript, I suggest the authors switch to a uniform plus and minus representation of uncertainty: '1303±365 Pg.' P4792 L13-7: The authors should explain why thin overburden histosols have higher SOC. This is the second mention of this with no explanation. P4793 L20-3: This repeats previous text and can be deleted. P4794 L1: Why are there two values shown for total SOC in permafrost? How is the reader to choose which one to use? The authors should pick one and use that. P4794 L6-20: The authors need to clarify this paragraph because I just do not follow the subtle differences in upscaling. Also this should be explained in the methods section rather than here. P4794 L27: The authors use the same terminology everywhere for uncertainty. Variance and CIs are not the same thing, but are used interchangeably here. P4803 L16: The uncertainties described here are roughly 25%, which actually are not bad considering this is the first solid estimates of uncertainty. I urge the authors not to use subjective terms like 'wide' because the uncertainties are neither good nor bad, they simply state how much we believe in the data. I suggest the authors start this paragraph with 'we can reduce uncertainties by ...' Table 2 and 3: I did not understand the two numbers in each column. Figure 4: The authors need to add a map of uncertainties for each map in Figure 4. Nearly all of this paper is devoted to uncertainty, so maps of uncertainty are essential.