Sönke Zaehle
Editor, Biogeosciences

Dear Dr. Zaehle,

Our sincere thanks for allowing us to respond to the reviewer's comments and revise the manuscript. We found the reviewer's comments helpful in revising our manuscript, and that responding to them improved the text by clarifying the methods we used and including a separate paragraph to discuss the limitations of this study. We adopted all the specific changes recommended by the reviewers in the revised manuscript.

We made a strong effort to address the specific reviewer concern that we investigate the use of soil texture in scaling of SOC stocks. The soil properties at a particular location were predicted using soil forming factors (P1724, L1-4) (Jenny et al., 1941; McBratney et al., 2003). In practice, ancillary information of soil forming factors that are extensively available over the study area was used for spatial prediction of different soil properties. Soil texture does impact the SOC stock at a location. However, to our knowledge, soil texture information at fine resolution representative of natural landscapes does not exist. We used the soil texture data that is currently used in CLM 4.5 (Bonan et al., 2002), which was available at ~8 km (7559.1m) spatial resolution across Alaska. However, these data show one soil texture value for each ecoregions of Alaska (see figures below). This implies that although the data has a spatial resolution of ~ 8 km, it this must have been derived from a source with a much coarser spatial resolution (International Geosphere-Biosphere Programme soil dataset that had 4931 soil mapping units globally; CLM 4.5 Technical notes). Because of this limitation, we were unable to include soil texture in the current scaling study. However, if soil texture information becomes available at fine resolution in the future, this information could be readily integrated using the methods we describe here. We have modified the text in the Discussion section to address this issue (P20L4-13).

We further modified the text to include all the suggestions provided by both reviewers. Please find below a detailed description of our response to reviewer's comments and changes made in the manuscript.

Sincerely,

Umakant Mishra
Environmental Science Division
Argonne National Laboratory

<u>Referee # 1</u>

This work builds on a previous study published by the authors in 2012 by investigating spatial scaling controls on soil carbon stock estimates. The authors use a suite of databases with spatial resolutions ranging from approximately 100m to 10km, including National Land Cover Database, USGS databases, and DEMs (convolved to 100m). The authors successively increased the spatial scale of environmental variables, using both observational data and geospatial approaches, to predict soil carbon stocks at different spatial scales. Their principal finding was

that the strength of controls of environmental factors on soil carbon stocks generally decreased as spatial scale increased (which makes sense), with the effects of temperature exerting the strongest controls across scales. At finer scales, the controls of topographic attributes were more prominent while at larger scales temperature and elevation were more significant. While these findings are perhaps not surprising, and are consistent with other reports, the implications are of broad significance with respect to interpretation of earth system models. The main take home message of this important work is that current modelling efforts operating at coarse spatial scales (> 100 km) are likely unable to utilize certain environmental data in estimating soil organic carbon stocks. The manuscript is generally well written, well researched, and clearly presented. I feel this should be appropriate for the readership of Biogeosciences and offer minor comments by line number, below.
Response – We thank the reviewer for summarizing our study and indicating its implications. We have adopted all the changes recommended by the reviewer in the revised manuscript.

1724, L3: If citing Jenny, it would be appropriate to also mention the significance of time as a soil forming factor. The authors mention this on page 1734, line 7, but it's worth mentioning here.
Response – We thank the reviewer for this suggestion. The text has been modified in the revised manuscript to include Time as a soil forming factor (P4L6).

1725, L9: I think it would be helpful to succinctly state what the authors mean by "model benchmarking".
Response – Thanks for this suggestion. By the term "model benchmarking", we mean using observation based scaling relationships to test the land biogeochemical representations in earth system models. The text has been modified to define the term "model benchmarking" (P5L18-20).

1727, L9: Would it be possible to provide a citation or reference for the UAF Northern Soils Research Program?
Response – Thanks for this suggestion. We provided a citation for the Northern latitudes soils program (P7-8L23-1).

1729, L14: Perhaps this is described in detail in Mishra and Riley, 2012, but there are no descriptions of soil depths in this study. Could it be clarified that pedons described here are to 1m?
Response – On page 1727 line 12, we provided the sampling depths of the pedon data we used in this study. The sampled depths ranged from 0.05 – 4.5 meters. We added a sentence in the modified manuscript to describe the depth distribution of sampled pedons (P8L6-8).

1732, L20-25: Could it be clarified how the relationship between scrub vegetation and SOC stocks changes (positive or negative relationship)?
Response – Thanks for this suggestion. The control (median geographically weighted regression coefficient across Alaska) of scrub vegetation on SOC stocks decreased linearly (from 0.3 to 0.13) with increasing scale. At finer scales, scrub vegetation showed higher control on SOC stocks, which decreased by about 57% as the scale increased up to 10 km. Despite the observed decrease in control of scrub vegetation on SOC stocks due to scaling, the relationship between

scrub vegetation and SOC stocks remained positive (more positive to less positive). We modified the text in revised manuscript to describe the change in control of scrub vegetation on SOC stocks (P14L10-14).

1734, L20: Another good discussion of soil forming factors at multiple scales affecting SOC stocks: Torn MS, Swanston CW, Castanha C, Trumbore SE. 2009. Storage and Turnover of Organic Matter in Soil, in Biophysico-Chemical Processes Inolving Natural Nonliving Organic Matter in Environmental Systems; edited by Senesi N, Xing B, Huang PM. John Wiley and Sons, Jew Jersey, USA. pp. 219-272.
Response – Thanks for this suggestion. We have cited appropriately the recommended reference (P4L19).

<u>Referee # 2</u>

Using observational data and geostatistics approaches, this study discussed about environmental controls on soil organic carbon (SOC) stocks and spatial heterogeneity of SOC stocks at different spatial (sample) scale. The authors shows that 1) different environmental predictors of soil organic carbon (SOC) stocks at different spatial scales; and 2) the variance of predicted SOC stocks decreased with spatial scale over the range of 50 to ~500 m, and remained constant beyond 500 m scale. The conclusions make sense and are expected. The manuscript is well organized and well written. But before its publication in Biogeosciences, several concerns should be addressed.
Response – We thank the reviewer for summarizing our results and indicating limitations of our study. In the revised manuscript, we have adopted all the changes recommended by the reviewer and used the last paragraph of the discussions section to discuss limitations of our study as suggested by the reviewer.

1. This study only used data from Alaska, if using observational data from larger spatial range such as boreal to tropical (as normal scale ESMs works), the dominant predictors of SOC may be different as the results from Alaska even at the same scale such as 50 m. In the discussion, the authors should leave some space for larger scale. For example, if more samples were taken from whole USA, applying the same methods used in this study, the conclusions in this study are still the same?
Response – Thanks for this suggestion. We agree with the reviewer, that the results might differ in absolute magnitude of the regression coefficients of environmental factors if a global or continental scale study would have been conducted, as both the spatial heterogeneity and environmental controls of SOC stocks are determined by the variability of soil-forming factors. We believe that the overall scaling impacts on environmental controllers and spatial heterogeneity might remain the same. However, conducting such a large scale study at high spatial resolution as in this study is not within the scope of our current efforts. And as suggested by the reviewer, we have added text in the discussion section to add limitations of our study (P19L19-23).

2. Page 1730, line 7, how about the auto-correlation between independent variables for predicting SOC stocks? Does the auto-correlation impact the coefficients (beta) for each predictor (as shown in Figure 3)?

Response – We thank the reviewer for this question. We paid careful attention about auto-correlation between independent variables (multicollinearity) while selecting log linear model predictors (Mishra and Riley, 2012; 2014). During the selection of environmental predictors we chose uncorrelated environmental variables (P1730L2-3). This was done by calculating the variance influence factors (VIFs) for each of the selected variables. The VIFs for all the variables included in models selected at different spatial resolutions were <5. High levels of multicollinearity (VIF > 10) can falsely inflate the least squares estimates (Kutner et al., 2004; O'Brien R., 2007; Gomez et al., 2013); therefore only variables with lower VIF values were used in our study. Therefore, multicollinearity between selected environmental variables was not a problem in the selected models at different spatial resolutions. We added text to further clarify our method of model selection (P11L8-12).

3. Page 1733, Line 6-13, it seems arbitrary to set the 25% as criteria of spatial dependency. It is really large difference between 27% at 50 m and 100 m scales and ~20% at other scales?

Response –We agree with the reviewer that the difference between 27% and ~20% is not large. However, we did not set this criterion of spatial dependency, but have used a criterion that is well documented and well cited in literature (Cambardella et al., 1994; Karvchenko, 2003; Sun et al., 2003; Mora-Vallejo et al., 2008) to characterize and describe the spatial dependency of soil properties including SOC stocks. This criteria basically relies on the geostatistical theory which assumes that as the nugget increases the spatial structure of an environmental variable decreases.

4. Page 1734, Line 22-26, how about soil texture controls on SOC in this study? Is it possible to show whether silt/clay fraction is a significant predictor on SOC, and at which scale?

Response – We made a strong effort to address the specific reviewer concern that we investigate the use of soil texture in scaling of SOC stocks. The soil properties at a particular location were predicted using soil forming factors (P1724, L1-4) (Jenny et al., 1941; McBratney et al., 2003). In practice, ancillary information of soil forming factors that are extensively available over the study area was used for spatial prediction of different soil properties. Soil texture does impact the SOC stock at a location. However, to our knowledge, soil texture information at fine resolution representative of natural landscapes does not exist. We used the soil texture data that is currently used in CLM 4.5 (Bonan et al., 2002), which was available at ~8 km (7559.1m) spatial resolution across Alaska. However, these data show one soil texture value for each ecoregions of Alaska (see figures below). This implies that although the data has a spatial resolution of ~ 8 km, it this must have been derived from a source with a much coarser spatial resolution (International Geosphere-Biosphere Programme soil dataset that had 4931 soil mapping units globally; CLM 4.5 Technical notes). Because of this limitation, we were unable to include soil texture in the current scaling study. However, if soil texture information becomes available at fine resolution in the future, this information could be readily integrated using the methods we describe here. We have modified the text in the Discussion section to address this issue (P20L4-13).

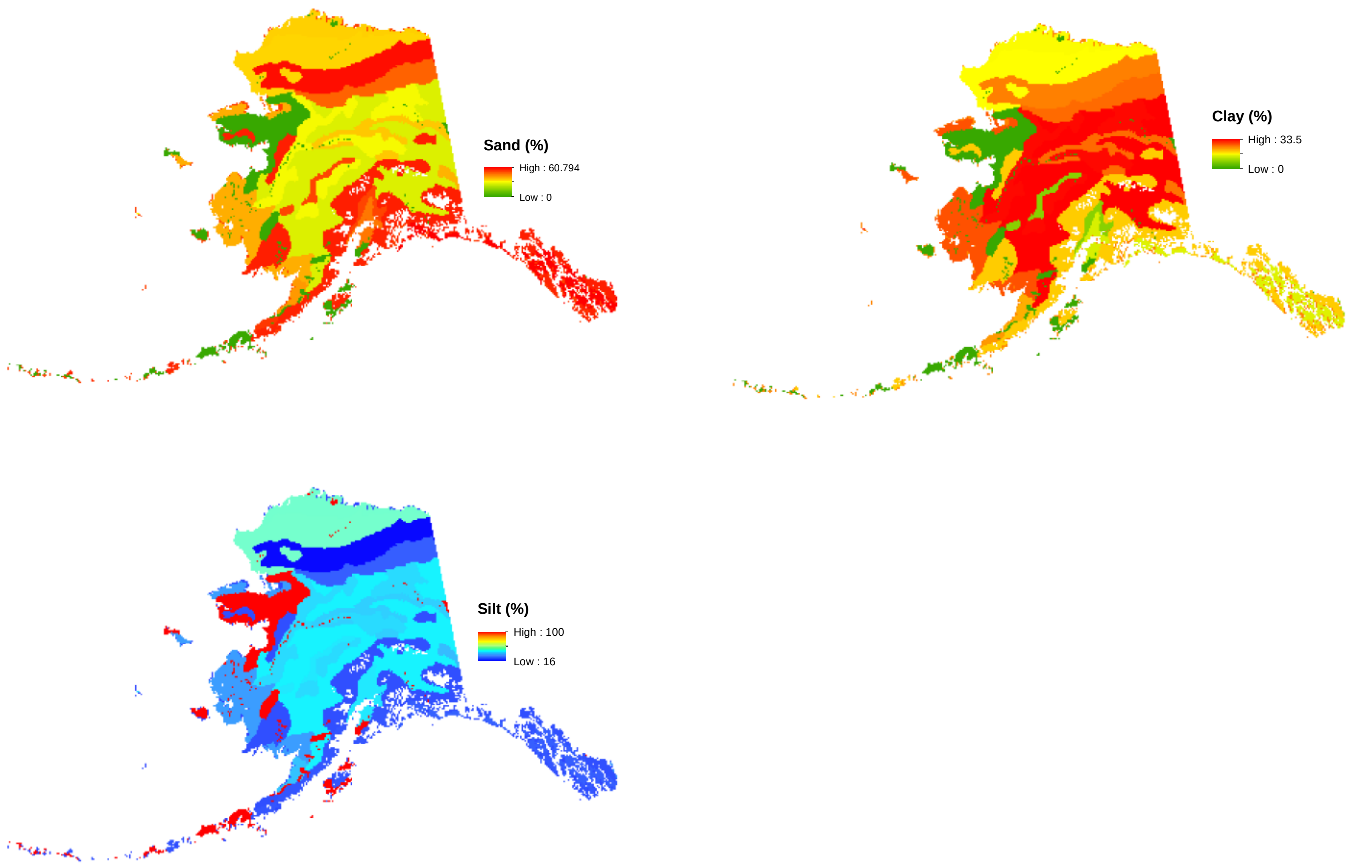

Figure: Soil texture data currently available for State of Alaska in CLM4.5 (Bonan et al., 2002)

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