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Geoscientific Model Development Discussions

Interactive comment on "Data-mining analysis of factors affecting the global distribution of soil carbon in observational databases and Earth system models" *by* Shoji Hashimoto et al.

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Dear Dr. Todd-Brown,

We greatly appreciate your constructive comments and suggestions. We have revised the manuscript on the basis of your comments, and the responses to the Major and Specific comments are found below. According to the editorial instructions, our response is structured as follows: (1) comments from Referees; (2) author's response; and (3) author's changes to the manuscript. Thank you very much.

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General comments:

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Discussion paper

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Comment 1: Need for considering model structures

Response: We have added information about model structure to Table 2 in the revised manuscript. As reported in previous studies, we did not see clear influences of model structure on our results. We have also added a discussion.

Changes to the manuscript: (Page 6, line 4– 21) “Analyses of the ESM outputs showed large variability, but the influential factors were predominantly similar among the ESMs (Fig. 5). This similarity most probably indicates that the structures of the models that describe SOC dynamics in the ESMs are similar. One reason for the similarity is probably because some ESMs share common code (Alexander and Easterbrook, 2015). Another reason may be rooted in the basic structure of the soil carbon model: SOC is calculated as the balance between dead organic matter input to soil and carbon emissions from the decomposition of organic matter in soil, and these processes are influenced by temperature and water conditions. The SOC pool is characterized by its turnover time (decomposition constant). In general, decomposition exhibits an exponential response to temperature, which is more severe than its response to water. As a result, modelled SOC is strongly influenced by NPP (litter input), temperature, and turnover time, which have been demonstrated by previous studies (Exbrayat et al., 2014; Todd-Brown et al., 2013) and were also confirmed in our analyses. As shown in Table 2, SOC submodels in ESMs differ in the number of SOC pools and function types of temperature and moisture. Todd-Brown et al. (2013) have reported the absence of any pattern of agreement between ESM outputs and observational SOC databases with soil carbon pools, temperature and moisture sensitivity functions, and Exbrayat et al. (2014) have found that turnover times of SOC in ESM outputs are not affected by the number of SOC pools. Our analyses also indicated that a match or mismatch of major contributing factor between ESM outputs and observational databases are not strongly related to these properties of SOC submodels. Thus, it is likely that the spatial pattern of SOC from ESMS are more strongly affected by the basic structure, driving variables (NPP and temperature) and parameterisations (turnover time and influential parameters of temperature and moisture sensitivity) than by the number of pools and the function types of temperature and moisture sensitivity."

Please see Table 2 in the revised manuscript.

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Comment 2: Lack of other studies included in detail.

Response: We have added more detail regarding citation of other studies. Please see the specific response to comment 4.

Changes to the manuscript: (Page 2, line 14– 21) "Todd-Brown et al. (2013) have analysed soil carbon outputs from 11 ESMs from the fifth phase of the Coupled Model Intercomparison Project (CMIP5) and data from HWSD, and have found that the spatial variation of SOC from ESMs can be explained by net primary productivity (NPP) and temperature but that the spatial variation in HWSD cannot be explained by NPP and temperature. They have also found that the differences in SOC from ESMs are driven by differences in the simulated NPP and the parameterisation of soil heterotrophic respiration, not by differences in soil model structure in ESMs. The important influence of parameterisation of soil heterotrophic respiration (e.g., turnover time) on SOC in CMIP5 ESMs has also been suggested by Exbrayat et al. (2013)." (Page 6, line 9– 16) "The SOC pool is characterized by its turnover time (decomposition constant). In general, decomposition exhibits an exponential response to temperature, which is more severe than its response to water. As a result, modelled SOC is strongly influenced by NPP (litter input), temperature, and turnover time, which have been demonstrated by previous studies (Exbrayat et al., 2014; Todd-Brown et al., 2013) and were also confirmed in our analyses. As shown in Table 2, SOC submodels in ESMs differ in the number of SOC pools and function types of temperature and moisture. Todd-Brown et al. (2013) have reported the absence of any pattern of agreement between ESM outputs and observational SOC databases with soil carbon pools, temperature and moisture sensitivity functions, and Exbrayat et al. (2014) have found that turnover times of SOC in ESM outputs are not affected by the number of SOC pools."

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Specific comments

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Comment 1: Please make it clearer that the ESMs are regressed against data products not other ESM output. While the modern ESM NPP and temperature distributions match better with current data products. There are some notable differences in modeled NPP in particular in the CMIP5 models and this could be a source of bias in the analysis.

Response: In this study, we downloaded the SOC output of ESMs from CMIP5 and examined the relationships between many variables in various data products listed in Table 1. We have revised the sentences to make this clearer. Furthermore, we have added the code to the manuscript Supplement, which should be helpful for understanding what we did. We have stated the cause for the variation in global SOC as the variation of modelled NPP.

Changes to the manuscript: (Page 2, line 28– 30) "We combined the potentially influential variables from many data products and SOC data from both observational databases with those by ESMs, and we examined the factors influencing the distribution of SOC and the relationships between these factors and SOC stocks.", (Page 7, line 20– 21) "Todd-Brown et al. (2013) have found that one of the major causes of variations in SOC among ESMs is differences in simulated NPP and that the strong control by NPP is not present in HWSD."

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Comment 2: P1L23-24 C:N ratio and clay content are in most ESMs in the allocation scheme. While it is intractable to investigate each modeling code directly, much of the documentation for these ESMs includes Lignin:N ratio (similar to C:N ratios) and clay content mediating decomposition. CENTURY Parton et al 1988 use Lignin:N ratio and clay content for allocation parameters (IPSL-CM5 Krinner etal 2005 cite CENTURY: Parton et al 1988)

Response: As you noted, it is intractable to investigate each modelling code directly, and hence we believe that collecting and investigating each model code here is beyond the scope of this study. We have modified the sentences in the abstract and discussion.

However, we fully agree with the importance of investigating each model code, and we are very curious about how many processes in site-scale process-based models are incorporated in land ecosystem models in ESMs. For instance, the CENTURY model simulates C and N, and the dynamics of C and N influence each other. Hence, the CENTURY model SOC submodels without N do not fully capture the processes in the CENTURY model (for example, please see Figure S12 in Åd'upek et al. 2016 Biogeosciences). These detailed comparisons should be required to identify the source of variation of SOC dynamics by ESMs in the future. To do so, full descriptions of the model structure and parameters are needed.

Changes to the manuscript: (Page 6, line 28– 35) "The SOC increased with increasing CN ratio in the observational databases (Fig. 4c), whereas the outputs of the ESM were insensitive to the CN ratio. Our results support the importance of properly incorporating the N cycle (e.g., control over decomposition, soil fertility, nutrient availability, and plant litter quality) into SOC models (Berg et al., 2001; Cotrufo et al., 2013; Fernández-Martínez et al., 2014; Liski et al., 2005; Tuomi et al., 2009; Åd'upek et al., 2016). All of the ESMs, except for the CESM1 and NorESM in CMIP5, do not include terrestrial nitrogen processes (Todd-Brown et al., 2013). Including the nitrogen process has been suggested as an important improvement for the next model intercomparison (CMIP6) (Hajima et al., 2014; Zaehle et al., 2015). The results derived from our analysis support the importance of the appropriate inclusion of the N cycle in ESM models." (Page 6, line 36– Page 7, line 2) "Clay content is also often used as a regulator of the decomposability of organic matter in the soil (e.g., CENTURY and RothC). Generally, high clay content inhibits organic matter decomposition in the soil. Furthermore, high clay content often results in low drainage and anaerobic soil conditions, which also inhibit organic matter decomposition. For IGBP-DIS, the clay content had as high a contribution as the CN ratio. The control of decomposability by clay content has been previously incorporated in site-scale process-based models (Parton et al., 1987) and may be incorporated in some ESMs, because soil carbon submodels in some ESMs are based on the CENTURY model (see the soil model history reported in Todd-Brown et al., 2014). However, regardless of incorporation of the control in decomposability by clay, our results suggest that the influence of clay on the carbon cycle is not well captured in present ESMs."

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Comment 3: P2L4-8 Should there be a citation here?

Response: This is Todd-Brown et al. 2013. We have added "(Todd-Brown et al., 2013)".

Changes to the manuscript: (Page 2, line7– 8) "a recent study (Todd-Brown et al., 2013) has found that. . ."

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Comment 4: P2 L8-11 A more in depth treatment of past attempts to disentangle drivers of data- model differences is called for here. Please expand on each of these treatments with particular attention to the ones that looked at the same models and data products the authors are using in this study. In addition, add something to the discussion to contrast your results with these studies.

Response: We have expanded the description of previous studies, added sentences and also omitted some sentences to contrast our results with previous work.

Changes to the manuscript: Please see the response to the General comment 1 and 2.

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Comment 5: Section 2.1 There needs to be some discussion about model structure in the ESM vs data products. These data products are typically constructed using correlation to the local environment (climate + land cover + geology) where the pedon was collected.

Response: We have included more sentences about the difference in the Introduction.

Changes to the manuscript: (Page 1, line 38– Page 2, line5) "These databases incorporate observed data points with global coverage, although there are biases in the spatial distribution or densities of the data points. In these databases, gridded SOC have been generated on the basis of inter-extrapolation of model outputs derived from analysis of observed SOC data points. Earth system models (ESMs), which have been developed to understand the current climate and to provide future climate projections, incorporate the terrestrial carbon cycle, including SOC. In ecosystem carbon cycle models of ESMs, SOC is calculated as the balance between dead organic matter input into soil and carbon emission from the decomposition of organic matter in soil, and these processes are influenced by temperature and water conditions. Compared with the observational estimation of SOC, the SOC distribution in ESMs involves more process-oriented simulations."

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Comment 6: Section 2.1: Please summarize the methods used for each specific data product. For ESMs a discussion of their sensitivity functions and pool structure is appropriate (note that BCC was incorrectly stated to have their N-cycle turned on for CMIP5 in Todd-Brown et al 2013).

Response: We summarized the methods used for observational SOC databases. "BCC" was omitted from the list of ESMs with an N cycle. We have added a discussion about the model structure.

Changes to the manuscript: (Page 2, line 35–Page 3, line 9) “We used SOC data from two global and one northern observational database. The first global database was the HWSD (FAO/IIASA/ISRIC/ISSCAS/JRC, 2012). The HWSD is a global database of soil physiochemical properties that has been developed by the International Institute for Applied Systems Analysis (IIASA) and the Food and Agriculture Organization of the United Nations (FAO) in collaboration with the International Soil Reference and Information Centre (ISRIC) -World Soil Information, the European Commission Joint Research Centre (JRC), and the Institute of Soil Science, Chinese Academy of Sciences (ISSCAS). The database was constructed by compiling the European Soil Database (ESDB), a 1:1 million soil map of China, various regional SOTER databases (SOTWIS Database), and a soil map of the world from the FAO. We used an SOC stock database obtained with HWSD from the Joint Research Centre (JRC) (Hiederer and Köchy, 2011) (Fig. 1a). The second database included global gridded surfaces of selected soil characteristics (IGBP-DIS) (Global Soil Data Task Group, 2000) (Fig. 1b), which contains gridded soil physiochemical properties. The database has been developed by the Global Soil Data Task Group of the international Geosphere Biosphere Programme's (IGBP) Data and Information System (DIS), and the database was generated by linking the pedon records in the Global Pedon Database to the FAO/UNESCO digital soil map of the world. The third database was the Northern Circumpolar Soil Carbon Database, version 2 (NCSCD) (Hugelius et al., 2013; Tarnocai et al., 2009) (Fig. 1c). This database is a spatial database of SOC stock of the northern circumpolar permafrost region. The soil map data were obtained from different regions/countries (e.g., USA, Canada, Russia etc.) and were harmonized. The NCSCD were based on 1778 pedon data points.”

Please see the Table 2.

(Page 6, line 4– 21)“Analyses of the ESM outputs showed large variability, but the influential factors were predominantly similar among the ESMs (Fig. 5). This similarity most probably indicates that the structures of the models that describe SOC dynamics in the ESMs are similar. One reason for the similarity is probably because some ESMs share common code (Alexander and Easterbrook, 2015). Another reason may be rooted in the basic structure of the soil carbon model: SOC is calculated as the balance between dead organic matter input to soil and carbon emissions from the decomposition of organic matter in soil, and these processes are influenced by temperature and water conditions. The SOC pool is characterized by its turnover time (decomposition constant). In general, decomposition exhibits an exponential response to temperature, which is more severe than its response to water. As a result, modelled SOC is strongly influenced by NPP (litter input), temperature, and turnover time, which have been demonstrated by previous studies (Exbrayat et al., 2014; Todd-Brown et al., 2013) and were also confirmed in our analyses. As shown in Table 2, SOC submodels in ESMs differ in the number of SOC pools and function types of temperature and moisture. Todd-Brown et al. (2013) have reported the absence of any pattern of agreement between ESM outputs and observational SOC databases with soil carbon pools, temperature and moisture sensitivity functions, and Exbrayat et al. (2014) have found that turnover times of SOC in ESM outputs are not affected by the number of SOC pools. Our analyses also indicated that a match or mismatch of major contributing factor between ESM outputs and observational databases are not strongly related to these properties of SOC submodels. Thus, it is likely that the spatial pattern of SOC from ESMS are more strongly affected by the basic structure, driving variables (NPP and temperature) and parameterisations (turnover time and influential parameters of temperature and moisture sensitivity) than by the number of pools and the function types of temperature and moisture sensitivity."

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Comment 7: P2 L33-35 Be more convincing about averaging models from the same center, there is some clustering analysis that is in the Supplemental of Todd-Brown et al 2013 that could support this.

Response: We have cited Todd-Brown et al. 2013, who have found that ESMs from the same climate centre generate very similar distributions of SOC.

Changes to the manuscript: (Page 3, line 17–18) ": Todd-Brown et al. (2013) showed through a hierarchical cluster analysis that SOC distributions were very similar among ESMs from the same climate centre."

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Comment 8: P2 L34-35 Todd-Brown et al 2013 averaged all ensembles that were available at the time, this statement is incorrect. Please either provide a different justification for only considering one ensemble or, preferably, go back and re-analyze the data with the multi-ensemble mean (even better if you can incorporate the modeled uncertainty).

Response: We apologize for the incorrect description and have corrected it. We have cited other references that use only r1i1p1; most ESMs have this ensemble member output (Dirmeyer et al. Journal of Hydrometeorology 2013.; Chang et al. Journal of Geophysical Research 2012; Kumar et al. Climate Dynamics 2014; Jiang et al. Journal of Climate 2015).

Changes to the manuscript: (Page 3, line 19–21) "The notation "r1i1p1" is an identifier of the model simulation and is an ensemble member that is often used for analyses (Chang et al., 2012; Dirmeyer et al., 2013; Jiang et al., 2015; Kumar et al., 2014)."

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Comment 9: Section 2.4 What regridding algorithm did you use? There are several options in CDO, not all are appropriate for soil data, temperature and NPP. Please discussion which algorithm was used and why.

Response: We used "remapbil" (a bilinear interpolation) in CDO for the soil data. We used this algorithm simply because this is one of the most widely used algorithms for regridding. This study focuses only on the spatial pattern of SOC, and the total amounts of SOC were beyond the scope of this study. We believe that the difference in regridding algorithms would not affect the conclusions of this study, but we will willingly conduct a recalculation if you strongly recommend a specific algorithm.

Changes to the manuscript: (Page 4, line 1– 2) “A bilinear interpolation, which is one of the most widely used algorithms, was used (remapbil in CDO).”

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Comment 10: P5 L1 Describe the results here in addition to referencing the figure.

Response: The description of the results was after the sentence P5 L1 in the former manuscript. We agree with your comment that this sentence was unnecessary. We have modified this paragraph by inserting figure numbers after descriptions.

Changes to the manuscript: (Page 5, line 24– 30) “The relationships between SOC and certain variables substantially varied among the ESM databases (Fig. 6a–e), particularly in the mean annual temperature (Fig. 6a). The SOC decreased with increasing mean annual temperature (Fig. 6a) but increased with increasing precipitation (Fig. 6b) and NPP (Fig. 6e). The mean of the relationship with mean annual temperature for ESMs was highly consistent with that in the HWSD and IGBP-DIS databases of the temperature range -5–15 °C (Fig. 6a). The increasing trend with increasing NPP in ESMs was consistent with that of the HWSD, particularly below approximately 500 g C m$-$2 of NPP (Fig. 6e). Although the wetland ratio did not contribute to the ESMs (Fig. 6a) with respect to land cover, permanent wetlands had higher SOC (Fig. 6d).”

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Comment 11: P7 L15 A BRT tutorial is not appropriate to cite under ‘Code availability’. Please either link or reference as SI to the actual code used in this analysis (preferred) or remove this section.

Response: We have added the codes and data for the observational databases to the Supplement.

Changes to the manuscript: (Page 8, line 18– 20) “The R code, with a tutorial for BRT, is available in the supplementary material of Elith et al. (2008) (http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2656.2008.01390.x/full). The codes and data for the observational databases are available in the Supplement."

Please see the Supplement.

Please also note the supplement to this comment:
http://www.geosci-model-dev-discuss.net/gmd-2016-138/gmd-2016-138-AC2-supplement.zip

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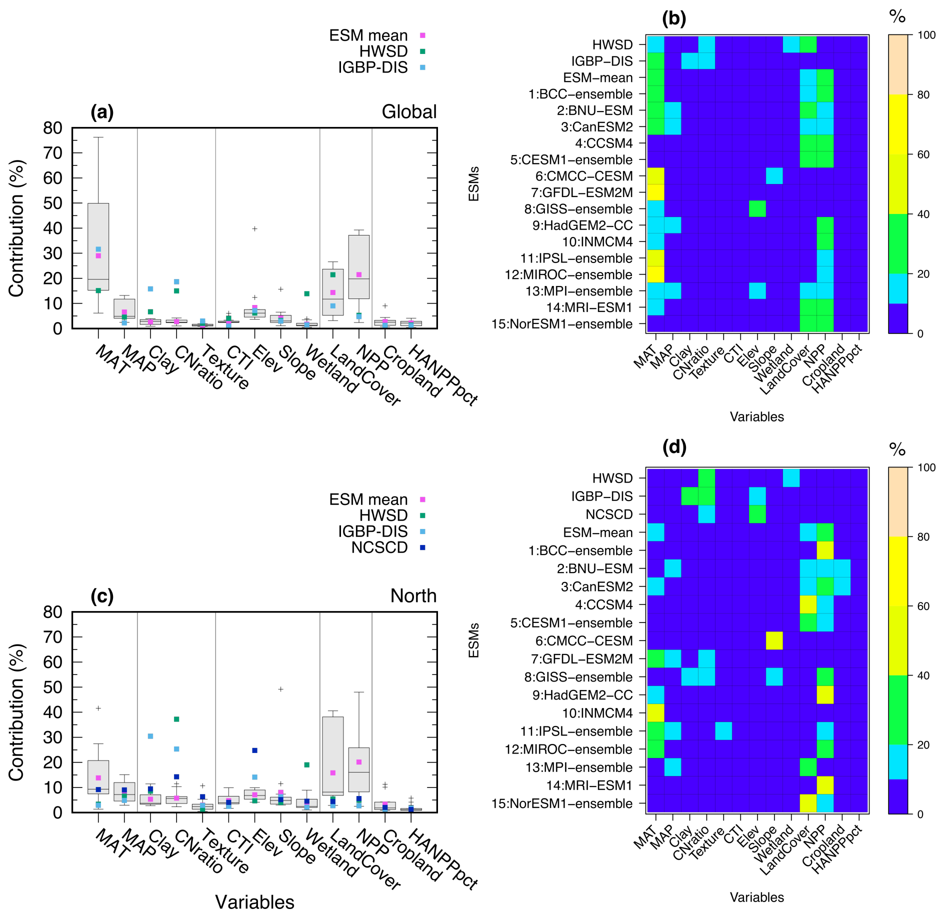

Fig. 1. New Fig. 6 (Fig. 5 in the revised manuscript)

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Discussion paper