Reply to RC1:

Thanks for your detailed and constructive feedback. We appreciate the time and effort you invested in reviewing our manuscript. Each of your comments and suggestions has been carefully considered, and we have carefully addressed revised the manuscript accordingly. Below is a detailed response to each point raised:

1. Line 20: the word ‘we’ is missing.

Reply: Thank you for pointing this out. The missing word "we" has been added, and the updated sentence is now reflected on Line 21.

2. Line 29: adding the range of soil depth would help strengthen this conclusion.

Reply: Thank you for your suggestion. We have added the range of soil depth to strengthen the conclusion. The revised statement is: “SOC density decreases with increasing depth, ranging from 30 Mg ha^{-1} (95% CI: 26-35) to 5 Mg ha^{-1} (95% CI: 4-7) (at depth intervals of 20-100 cm, in 20 cm increments) for cropland, from 32 Mg ha^{-1} (95% CI: 27-37) to 7 Mg ha^{-1} (95% CI: 5-9) for grassland, and from 40 Mg ha^{-1} (95% CI: 34-46) to 13 Mg ha^{-1} (95% CI: 9-17) for forestland”. The updated sentence is now reflected on Line 29-33.

3. Line 33: the word “Global” should be in lower case; Grammer error in “which providing”.

Reply: Thank you for your comments. We have corrected the word "Global" to lowercase and revised the phrase “which providing” to “providing.” The revised sentence now reads (Line 38): “This study provides information on the vertical distribution and spatial patterns of SOC density at a 10 km resolution across global ecosystems, providing a scientific basis for future studies pertaining to Earth system models.”

4. Line 41: space between gas and (GHG) is missing.

5. Line 42: a period after the citation is missing.

Reply 4 and 5: Thank you for pointing that out. We have added the missing space between "gas" and "(GHG)", and added the missing period after the citation. The updated sentence is as follows (Line 45-48): “Organic carbon in soil (SOC) plays a critical role in global C cycling, climate change mitigation, reducing greenhouse gas (GHG) emissions, and the health of ecosystems (Bradford et al., 2016; Lal et al., 2021;

Griscom et al., 2017)."

6. Line 45: grammar error in ", which contributes"

Reply: Thank you for your observation. The amended sentence now appears as (Line 50): "Worldwide, high SOC loss due to crop production and grazing significantly contributes to increasing atmospheric CO_2 levels (Beillouin et al., 2023; Lal, 2020; Qin et al., 2023)."

7. Line 108: grammar error in " from"

Reply: Thanks for your insights, The revised text now states (Line 110-112): "Profiles with more than three suitable organic carbon measurements in the first meter were included in the analysis, as they provided sufficient detail to characterize the vertical distribution of SOC."

8. The data collected from the literatures should be published as well for validation purposes and promote boarder application by other researchers.

Reply: Thank you for your insightful suggestion. We have published the data sourced from the literature, which not only facilitates validation by the research community but also encourages its broader dissemination and application in various academic activities.

9. While the authors have done a great job collecting literature data with a well global coverage. However, the density of study sites varies significantly across different regions. Please discuss the limitations of this data collection.

Reply: Thank you for your valuable feedback. We recognize that although our data covers a wide global area, the density of study sites varies significantly by region. In the new revision, we have expanded our dataset by integrating additional WoSIS profiles, including 7,636 soil profiles for cropland, 4,534 soil profiles for forestland, and 4,593 soil profiles for grassland to develop the model (Fig.1), which improve the robustness of the models. Additionally, we have added a discussion of these limitations in the revised manuscript, addressing how this variability may affect the results and suggesting directions for future research to mitigate these issues (Line 554-562).

10. Section 2.2: as the logic flows from previous section to this one, it directs reader to believe that this section explains how the authors calculated SOC density and stock

from the literature. It however seems to estimate gridded SOC stock via predicted soil β in the following section. If the latter is the main focus, consider relocating it to the right place (maybe after 2.5).

Reply: Thank you for your suggestions regarding the structural aspects of the methods section in the manuscript. We recognize that the logical flow in Section 2.2 may have led to misunderstandings, leaving readers with the impression that the section primarily focuses on calculating SOC density and stocks from the literature. In response, we have implemented necessary adjustments.

We have divided Section 2.2 into two parts: the first part concentrates on calculating the SOC density for study sites derived from the literature, which is then used to estimate soil β values for Random Forest modeling. The second part addresses how we utilize the predicted soil β values to estimate the global SOC density and stocks across various ecosystems in gridded formats (as described in Section 2.6, after Section 2.5). These revisions enhance clarity regarding data sources and promote a more coherent logical flow throughout the manuscript.

11. Section 2.3: Clarify whether the soil β values were directly obtained from the studies or calculated using Equations 3 and 4. Typically, soil β is calculated from these equations based on known SOC at different depths in the literatures, rather than the reverse. Clarification on this would be helpful.

Reply: Thank you very much for your valuable feedback. We confirm that the soil β values were calculated soil β values were derived using Equations 2 and 3, based on known SOC density data at various depths obtained from the literature. We have clarified this point in Section 2.3 to avoid any potential misunderstandings.

Additionally, we would like to note that the original Equations 3 and 4 mentioned in the initial submission have now been renumbered as Equations 2 and 3 due to a restructuring of the manuscript for better organization and readability. The methodology and calculations remain unchanged, ensuring consistency with the previous approach. We appreciate your careful review and hope the revisions enhance the clarity of this section.

12. Line 146: awkward wording.

Reply: Thank you for your feedback on the wording in Line 146. We have revised this

section to improve clarity and readability (Line 150-151).

13. Section 2.4: consider moving it after 2.5, creating a more logical sequence: extracting data from literatures -> building model to predict soil β -> preparing spatial data -> estimating SOC stock.

Reply: Thank you for your comment. The spatial data of soil and environmental variables need to be prepared (included 9 significant factors (BNPP, pH, Clay, MAT, MAP, TN, MN, MC, CN), as well as the corresponding high-spatial-resolution raster datasets) before the prediction of spatial soil β value. Therefore, the logical sequence: extracting data from literatures -> preparing spatial data -> building model to predict spatial soil β value -> estimating SOC stock.

14. For 1221 soil profiles in 161 studies, the authors could make use of the variability of SOC in each study to estimate the uncertainty range of this global SOC dataset. Given the high heterogeneity of SOC, adding uncertainty estimates could enhance the value of this dataset. This is just a suggestion for the authors' consideration.

Reply: Thank you for your valuable suggestion. We appreciate the importance of estimating the uncertainty range of this global SOC dataset, especially considering the high heterogeneity of SOC. To address this, we conducted a Monte Carlo simulation to estimate the overall uncertainty in the estimated spatial SOC density. The uncertainty primarily arises from the soil β estimation-related parameters and the Random Forest (RF) model. The input parameters in the RF model were assumed to follow independent normal distributions, with the grid value as the mean and its 5% as the standard deviation. We performed 1,000 random samplings to obtain the interval for each grid using Monte Carlo simulations. The sampled values were then used to run the RF model, predicting the grid-level soil β with 100 bootstraps. Then we use predicted grid-level soil β to recalculated the distribution of SOC density (SOCD) across different ecosystem. Finally, we calculated the mean along with the 2.5% and 97.5% percentiles to establish the 95% prediction interval of SOC density and SOC stocks. We believe this approach enhances the value of our dataset by providing uncertainty estimates.

15. The RF generally performs well across three ecosystems. However, it tends to over-estimate the lower β and under-estimate the higher β. The authors need to reset their model to improve it. If it cannot be resolved, an explanation and discussion of the

potential impacts on predicted SOC, particularly regarding spatial distribution (e.g., even lower soil β in boreal grasslands as seen in Figure 3E), should be provided.

Reply: Thank you for your valuable feedback regarding the performance of the Random Forest (RF) model across the three ecosystems. After incorporating additional the WoSIS profile data, the accuracy of the model has significantly improved, with R^2 values exceeding 0.85. The slopes for these regressions are all close to 1, indicating that the bias in the previous model was primarily due to insufficient sampling in certain regions.

16. Figure 3: clarify that the numbers in panels d-f represent predictions to avoid confusion.

Reply: Thank you for pointing this out. We have updated the caption of Figure 3 to explicitly state that the numbers in panels D-F represent predicted values to prevent any confusion.

17. Line 304-306: consider moving this explanation to the discussion section.

Reply: Thank you for your suggestion. We accept this excellent proposal and have reflected it in the main text, the updated sentence is now reflected on Line 401-404.

18. Comparing the estimated SOC stocks with other studies across different ecosystems in terms of total numbers is valuable. Additionally, including comparisons with spatial maps would provide a more comprehensive validation of the dataset.

Reply: Thank you for your suggestion. In response, we have included a discussion of the spatial variability in SOC stocks in Section 4.1 (Comparison of high-resolution SOC dynamics) to provide a more comprehensive validation of the dataset.

19. Line 414-415: awkward wording.

Reply: Thank you for your valuable comments. The updated sentence is as follows (Line 499-502): “The investigation of deep soil organic carbon is inherently complex and involves intricate and time-intensive methodologies. This complexity results in a paucity of research data, which consequently introduces considerable uncertainties into model-derived predictions.”