# Response to referee #2

**Referee #2:**

**Comments:**

**[Comment 1]** This study compiles a global dataset of 22,000 observations from 191 incubation experiments on soil organic carbon (SOC) mineralization to assess how temperature controls soil $CO_2$ release, a key climate–carbon feedback. The dataset, largely biased toward surface soils, short incubations, and mid-latitude regions, reveals major gaps in deep soils, extreme ecosystems, and Africa. The author suggest that Earth System Models generally misrepresent SOC temperature sensitivity, especially under warming extremes, though multi-term exponential functions perform best. Using a two-pool carbon model, the authors find that both intrinsic factors (SOC quality, microbial traits) and extrinsic constraints (oxygen, mineral protection, moisture) contribute equally to global SOC responses, but their relative importance varies by ecosystem (e.g., croplands vs. wetlands). The work highlights the urgent need for more representative experiments and improved model formulations to reduce uncertainty in carbon–climate feedback projections. Although I find the article interesting and the dataset very useful, I have a number of comments that could help improve the readability of the manuscript.

**Response:** We thank the reviewer for the positive comments and constructive suggestions. We have carefully revised the manuscript to improve its readability and clarity.

**[Comment 2]** Firstly, the mathematical approach used to distinguish between internal and external effects is rather poorly explained in section 5.4, which makes section 5.5 more difficult to understand. I suggest that the authors provide more detail in section 5.4 and perhaps simplify the vocabulary used.

**Response:** Thank the reviewer for pointing this out. We have thoroughly revised sections 5.4 and 5.5 to clarify the mathematical approach used to distinguish intrinsic from extrinsic effects (lines 276–296). We have also simplified the terminology to enhance readability and aid comprehension.

**[Comment 3]** It is noted in several places that you tested the temperature response functions of 69 ESMs. This is inaccurate, as most of the models whose temperature response functions you tested are not ESMs. This approximation should therefore be corrected throughout the manuscript.

**Response:** We thank the reviewer for highlighting this inaccuracy. We have replaced the term "ESMs" with "land surface models" throughout the manuscript.

**[Comment 4]** Table 2 also needs to be simplified because some of the information is incorrect. For example, for Jules, the centre is described as the UK, which is a country, whereas for the other models, the authors give a research group instead.

**Response:** The "Modeling centre" column has been removed from Table 2, as it contained inconsistent information and was not essential to the table's purpose.

**[Comment 5]** CENRUTY-> CENTURY

**Response:** Thank the reviewer for the careful review. Corrected.

**[Comment 6]** It is also unclear in this table what the difference is between 'land carbon' and 'land surface models'.

**Response:** Thank the reviewer for the careful review. In our study, land surface models refer to the full terrestrial components of Earth System Models that simulate energy, water, and carbon exchanges, whereas land carbon models are submodules that specifically represent terrestrial carbon cycling processes (e.g., photosynthesis, respiration, soil carbon decomposition). We have clarified this distinction in the revised table (lines 188–190).

**[Comment 7]** Figure 4 also needs improvement as it lacks clarity, particularly as M1 and M2 have not been defined.

**Response:** We thank the reviewer for this helpful comment. We have now defined M1 and M2 in the figure caption (line 251–254) and revised Figure 4 to improve clarity and readability.

**[Comment 8]** How eq. 3 affect eq. 2 in the model developed by the authors?

**Response:** In our simulations, model parameters were optimized for each incubation trial using Eq. (2) by comparing modeled and observed SOC mineralization rates across multiple incubation temperatures. Specifically, the decomposition rate constants ($k_f$ and $k_s$) and their temperature sensitivities ($Q_{10\_fast}$ and $Q_{10\_slow}$) were first optimized at the lowest incubation temperature. The corresponding $k$ values at higher temperatures were then scaled using Eq. (3) based on the optimized $Q_{10}$ values.

**[Comment 9]** Section 2 L. 78 point 2) More details are needed here, for instance do you accept when the same samples were incubated at 2 different temperatures?

**Response:** Yes, we included data from studies where the same soil samples were incubated under two or more different temperatures. This was clarified in point 2: *Each experiment must incubate the same soil at two or more temperatures.* (line 80)

**[Comment 10]** Do you use equal time or equal C (Hamdi et al., 2012)?

Hamdi, S., Moyano, F., Sall, S., Bernoux, M., Chevallier, T., 2012. Synthesis analysis of the temperature sensitivity of soil respiration from laboratory studies in relation to incubation methods and soil conditions. Soil Biol Biochem 58, 115–126. https://doi.org/10.1016/j.soilbio.2012.11.012

**Response:** In our case study, we used the equal-time method (Eq. 1) to estimate $Q_{10}$. This information has been added to the manuscript (lines 66 and 205).

**[Comment 10]** L323: "There were no significant differences of the relative importance…" how this was tested?

**Response:** We thank the reviewer for this question. We conducted pairwise significance tests using a bootstrap approach (5,000 resamples) to assess differences in the relative importance of each mechanism. Specifically, for each mechanism, we resampled the simulated relative importance values derived from independent model

runs. For each bootstrap iteration, we computed the mean difference between two ecosystems or soil depths, and generated an empirical distribution of these differences under the null hypothesis of no difference. Statistical significance ($p < 0.05$) was determined based on whether the 95% CI of the difference excluded zero. The results have been updated in the revised Fig. 5, and the statistical method has been described in the **5.2 Simulation experiments** section (lines 307-310).