Dear Associate Editor,

Thank you for your comment.

We have now included additional paragraphs at the end of the 'The role of false priming' section to address this. It now should be clearer that the role of false priming has *reduced the spread* in future soil carbon projections from CMIP5 to CMIP6, due to a cancellation of the increased soil carbon by NPP by the reductions due to soil carbon turnover time. On top of this result, there is now discussion on how model developments between these CMIP generations will influence the *magnitude* of soil carbon change projected.

There is discussion on how the inclusion of soil carbon pools and interactive nitrogen influences future soil carbon change in ESMs, using a couple of ESM which saw large differences in the projection of soil carbon change between CMIP5 and CMIP6 as examples. It is difficult to isolate which change had the greater impact, but hopefully now the reader will infer that multiple model developments influence future soil carbon and how. But taking away the main result of the study which is showing how false priming is limiting the spread in future soil carbon projections in CMIP6.

We hope that this has addressed the additional comment.

Best wishes,
Rebecca Varney
(On behalf of Co-authors)

Reviewer comments

Author responses (**Bold is new text in manuscript**)

RC1

Overall this paper disentangles key drivers of soil carbon dynamics in the CMIP6 model suite. This set of models is fundamental to developing the IPCC reports and thus understanding why the models return the results they do are critical to continual improvement and uncertainty quantifications for policy advising. In general, I think many of the key elements of a strong and insightful analysis are here, but need a bit more connection and stronger caveats.

We are thankful that the reviewer sees the relevance and value of the paper, we feel that including the helpful reviewer comments have now improved the paper.

I would urge the authors to spend more time in their methods section integrating the C4MIP runs with the priming hypothesis. How would we expect false-priming to show or not show up in the various runs and why?

The assertion of false priming as the sole explainer for the correlative increase in NPP and reduction in turnover time is, perhaps, a bit strong. What are alternative explanations for the observed correlations? How are climate drivers delt with in both the NPP and Rh submodels? How does the second order NEP effects integration with this false-priming framework?

Additional text is now included to integrate the false priming hypothesis with the C4MIP simulations, and how these are used with the false priming investigation.

Additional text has been added to the Introduction.
Ln 40:
"***However, the effective soil carbon turnover time can also reduce under increasing litterfall inputs (e.g., due to CO_2 fertilisation of plant growth), because the faster components of the soil increase more quickly than the slower components. The net effect of this is that a higher fraction of the soil carbon is held in the fast pools under increasing litterfall, which reduces the effective soil carbon turnover time - a transient phenomenon known as 'false priming' (Koven et al. 2015).***"
Ln 47:
"***Finally, a simple box model is used to investigate soil carbon change, along with idealised 'C4MIP' simulations which separately model the physiological and climate effects of increasing atmospheric CO_2. Our aim is to distinguish more clearly between the direct and indirect mechanisms of reduced soil carbon turnover times by isolating the effects of false priming in models.***"

Additional text has been added to the Methods.
Ln 76:
"***The use of these experiments allows for a more focused evaluation of soil carbon and related fluxes by isolating sensitivities to CO_2 and associated climate changes, as well as removing additional complications in the SSP simulations.***"

The section '***Section 3.4: Investigating the emergent relationship between $\Delta C_{s,NPP}$ and $\Delta C_{s,\tau}$***' has been split into this section plus an additional section '***Section 3.5: The role of false priming***' (which starts from Line 285). We feel this presents both the C4MIP analysis (Section 3.4) and false priming (Section 3.5) more clearly, and additional text has been added to both sections.

Additional text is added to the start of Section 3.4 to introduce the C4MIP simulations.
Ln 260:
"In this subsection, the emergent relationship between $\Delta C_{s,NPP}$ *and* $\Delta C_{s,\tau}$ *present across the CMIP6 ensemble is ~~further~~ investigated using the idealised C4MIP simulations (see Methods). T**his enables investigation of the negative correlation without additional complex processes which are included in the SSP simulations. By isolating the sensitivities to CO_2 and climate, we can more easily identify the processes which results in the apparent coupling between NPP and soil carbon turnover in CMIP6 ESMs.***"

Alternative explanations for the emergent relationship are now discussed in the text and relating to the C4MIP simulations. Additionally, a new figure is included which uses the C4MIP simulations to quantify the fraction of the total change in soil carbon turnover time which is seen in the CO2 only run (i.e. not due to reductions in soil carbon turnover time due to warming), which can be **seen below**, including the new discussion within the text.

Ln 284:
"***The correlation between $\Delta C_{s,NPP}$ and $\Delta C_{s,\tau}$, as seen in the SSP simulations (Fig. 7 and Fig. 8), is also evident in the full 1% CO_2 C4MIP simulation. This suggests the relationship is not a result of additional processes included in the SSP simulations compared to the C4MIP experiments, such as land use change (Jones et al. 2016). An additional explanation for the coupling could be similarities in the modelled sensitivities of NPP and Rh to changes in climate. For example, if NPP and specific soil respiration rate both increased with warming, a negative correlation between $\Delta C_{s,NPP}$ and $\Delta C_{s,\tau}$ would be seen. However, under these circumstances the negative correlation would not be seen in the CO_2 only C4MIP runs, as there is no global warming in these simulations (see Methods). Instead, a reduction in effective soil carbon turnover time is seen in the BGC runs (Fig. A2), which implies a non-climate response in τ_s and results in an NPP-τ_s negative correlation (Fig. 9). Fig. NEW shows that the change in the effective soil carbon turnover time in the BGC simulation accounts for at least 50% of the total change in the effective soil carbon turnover time in the full 1% simulation across CMIP6 ESMs.***"

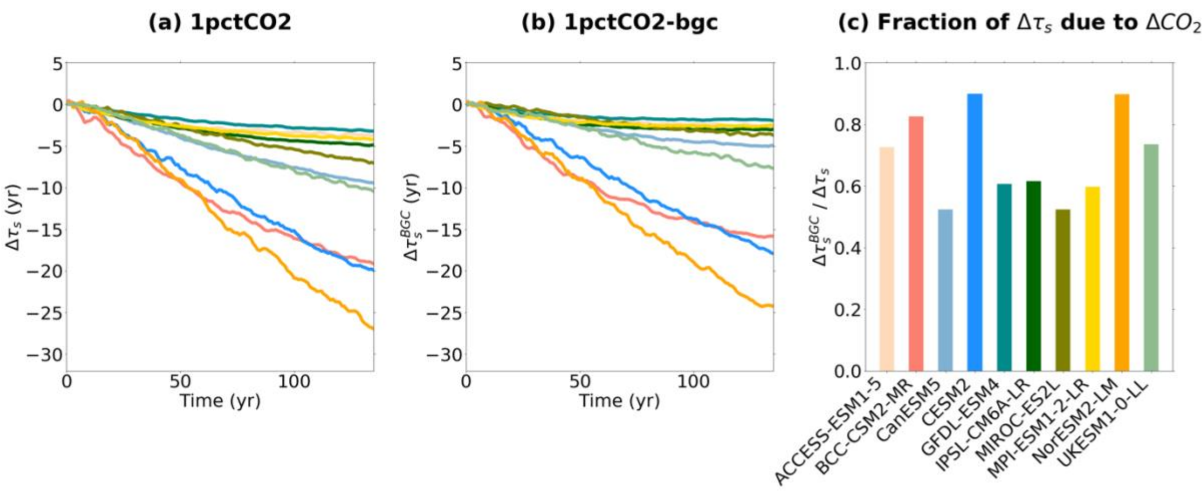

Fig NEW.: ***"Changes in soil carbon turnover ($\Delta\tau_s$) in C4MIP runs for the CMIP6 ESMs, with and without direct climate effects on τ_s. (a) timeseries of $\Delta\tau_s$ in full 1% CO2 simulation (climate and CO_2 changes), (b) timeseries of $\Delta\tau_s$ in BGC simulation (CO_2 changes only), and (c) bar chart showing the fraction of total $\Delta\tau_s$ due to the changes in CO_2 for each model.***"

New text in new false priming section clarifying the role of false priming in ESMs.
Ln 325:
"*It is noted that the influence of false priming was stronger in the full 1% CO_2 and BGC (CO_2 only) simulations, compared to the RAD (climate only) simulation* ***(Fig. 8)****. This is likely due to the RAD simulation not seeing sufficient NPP change****, and therefore sufficient input of soil carbon,*** *for the false priming* ***e****ffect to be significant (see* ***Fig. A2****). Additionally, the direct effect of temperature changes on $\boldsymbol{\tau_s}$ in the RAD simulation is likely to dampen the correlation to NPP changes, due to both direct and indirect $\Delta\boldsymbol{\tau_s}$ in this case (Varney et al. 2020).* ***False priming is dependent on the structure of the soil carbon model within the ESM. The reduced effective turnover time occurring in a transient system, without any external sensitivities on τ_s, is a consequence of varying turnover times between different soil carbon pools.***"

Additionally, false priming is now presented as a likely contributor to this correlation seen in ESMs, opposed to the sole explainer. The text has been edited throughout accordingly, such as below.

Ln 8:
"*We show* ***that the concept of 'false priming' is likely to be contributing to this emergent relationship*** ~~*this emergent relationship is the result of `false priming'*~~*, which leads to a decrease in the effective soil carbon turnover time as a direct result of NPP increase and occurs when the rate of increase of NPP is relatively fast compared to the slower timescales of a multipool soil carbon model.* ***This finding suggests that the structure of soil carbon models within ESMs in CMIP6*** ~~*The inclusion of more soil carbon models with multiple pools in CMIP6 compared to CMIP5, therefore seems to have*~~ ***has likely*** *contributed towards the reduction in the overall model spread in future soil carbon projections* ***since CMIP5****.*"

Ln 323:
"*… suggesting that* ***false priming and the structure of the soil carbon models within the ESMs is likely contributing to*** *these correlations in CMIP6 (and to a lesser extent in CMIP5).* ~~*are predominantly due to false priming.*~~"

Ln 348:
"***False priming was found to likely be contributing to the apparent emergent relationship between $\Delta C_{s,NPP}$ and $\Delta C_{s,\tau}$ in CMIP6 ESMs****, …* ~~The apparent emergent relationship between $\Delta C_{s,NPP}$ and $\Delta C_{s,\tau}$ in CMIP6 ESMs was found to be a result of false priming~~,"

The 'false priming framework' is used to explain the concept of a reduced effective turnover in a box model with multiple pools of differing turnover times. Under increasing NPP, the fast turnover pool gets a greater weighting when calculating an effective turnover of the system compared to the slow turnover pool, but the respiration values Rh do not change. Therefore, false priming is an artifact of the transient nature of the system, with NPP and Rh differing in the transient. NEP is used to define the difference between NPP and Rh (by definition). The 'NEP integration' is used to account for the subsequent change in ΔC_s due to our isolation of above and below ground soil carbon controls during a transient climate.

See line comments below:

Ln 35: Should probably mention expected limitations on the nutrient fertilization effect and colimitation of water and other factors on the turnover time.

The paragraph has been updated to include additional discussion.
Line 32:
"*This study assumes Net Primary Productivity (NPP) represents the input flux of carbon to the* ***system*** *~~soil~~ and is defined as the net rate of accumulation of carbon by vegetation arising from photosynthesis minus the loss from plant respiratory fluxes (Todd-Brown et al. 2013, 2014).* ***In the absence of nutrient and moisture limitations (Wieder et al. 2015; Green et al. 2019),*** *NPP is projected to increase under increased atmospheric CO_2 due to the CO_2 fertilisation effect, which can result in an increased soil carbon storage* ***through increased litter*** *(Schimel et al. 2015). Heterotrophic respiration (R_h) is assumed to represent the output flux of carbon from the soil and is defined as the carbon losses due to decomposition from microbes in the soil. Rh is projected to increase under global warming,* ***due to an increased rate of microbial decomposition under warming*** *(Varney et al. 2020),* ***in the absence of very significant increase in soil moisture or nutrient limitations (Sierra et al., 2015; Schmidt et al., 2011).*** *Soil carbon turnover time (τ_s) is defined as the ratio of soil carbon stocks to the output flux of carbon (Rh)* **.**~~, where~~ ***Global*** *warming alone generally reduces tau resulting in* ***carbon residing in the soil for less time and*** *a release of carbon from the soil into the atmosphere (Crowther et al. 2016).*"

1. Wieder, W. R., Cleveland, C. C., Smith, W. K., and Todd-Brown, K. (2015). Future productivity and carbon storage limited by terrestrial nutrient availability. *Nature Geoscience*, 8(6):441–444.
2. Green, J., Seneviratne, S., Berg, A., Findell, K., Hagemann, S., Lawrence, D., and Gentine, P. (2019). Large influence of soil moisture on long-term terrestrial carbon uptake. Nature, 565(7740):476–479.
3. Sierra, C. A., Trumbore, S. E., Davidson, E. A., Vicca, S., and Janssens, I. (2015). Sensitivity of decomposition rates of soil organic matter with respect to simultaneous changes in temperature and moisture. *Journal of Advances in Modeling Earth Systems*, 7(1):335–356.
4. Schmidt, M. W., Torn, M. S., Abiven, S., Dittmar, T., Guggenberger, G., Janssens, I. A., Kleber, M., Kögel-Knabner, I., Lehmann, J., Manning, D. A., et al. (2011). Persistence of soil organic matter as an ecosystem property. *Nature*, 478(7367):49–56.

Ln 60: repeat information about the ESMs as needed to understand the results of this study. Citation hunts interrupt reading of the study.

Firstly, we now have included a new table in the manuscript (which has been adapted from Tables 1 and 2 from Varney et al. 2022), which includes information on the soil carbon components of the ESMs in both CMIP5 and CMIP6. Specifically, the no. of dead soil carbon pools within the ESMs **(see below)**.

Earth System Model	Nitrogen cycle	No. of live carbon pools	No. of dead carbon pools	References
BNU-ESM	No	-	-	Ji et al. (2014); Dai et al. (2003)
CanESM2	No	3	2	Arora et al. (2009); Arora and Boer (2010)
GFDL-ESM2G	No	8	2	Dunne et al. (2012, 2013); Shevliakova et al. (2009)
GISS-E2-R	No	7	5	Schmidt et al. (2014); Yue and Unger (2015)
HadGEM2-ES	No	3	4	Jones et al. (2011); Best et al. (2011): Clark et al. (2011)
IPSL-CM5A-LR	No	-	7	Dufresne et al. (2013); Krinner et al. (2005)
MIROC-ESM	No	4	2	Watanabe et al. (2011); Ito and Oikawa (2002); Sato et al. (2007)
MPI-ESM-LR	No	4	2	Raddatz et al. (2007); Knorr (2000)
NorESM1-M	Yes	13	7	Bentsen et al. (2013); Iversen et al. (2013); Lawrence et al. (2011)
ACCESS-ESM1.5	Yes	3	6	Ziehn et al. (2020); Haverd et al. (2018);
BCC-CSM2-MR	No	3	8	Wu et al. (2019); Ji et al. (2008)
CanESM5	No	3	2	Swart et al. (2019); Melton et al. (2020); Seiler et al. (2021)
CESM2	Yes	22	7	Danabasoglu et al. (2020); Lawrence et al. (2019)
CNRM-ESM2-1	No	6	7	Séférian et al. (2019); Delire et al. (2020)
GFDL-ESM4	No	6	4	Dunne et al. (2020); Zhao et al. (2018)
IPSL-CM6A-LR	No	8	3	Boucher et al. (2020); Cheruy et al. (2020); Guimberteau et al. (2018)
MIROC-ES2L	Yes	3	6	Hajima et al. (2020); Ito and Oikawa (2002)
MPI-ESM1.2-LR	Yes	3	18	Mauritsen et al. (2019); Goll et al. (2017); Goll et al. (2015)
NorESM2-LM	Yes	22	7	Seland et al. (2020); Lawrence et al. (2019)
UKESM1-0-LL	Yes	3	4	Sellar et al. (2020); Wiltshire et al. (2021)

Table NEW: "***The CMIP5 and CMIP6 Earth system models included in this study and the relevant features of associated land carbon cycle components: simulation of interactive nitrogen, number of live carbon pools and the number of dead soil carbon pools (Varney et. al 2022; Arora et al. 2013; 2020).***"

Secondly, we have included extra text in the Methods.

Ln 57:
"~~Specific soil carbon related updates within ESMs from CMIP5 to CMIP6 are included in Varney et al. 2022 within the 'Earth system models' section of the Methods, and more general model updates are presented within the 'Model descriptions' section of the Arora et al. 2020 Appendix.~~
The use of CMIP allows for comparison between ESMs in the different ensemble generations. Table 1 presents key soil carbon ESM information from both CMIP6 and CMIP5 (adapted from Tables 1 and 2 in Varney et al. 2022). The Table can be used to identify key ESM updates between CMIP6 and CMIP5, such as: the simulation of interactive nitrogen in CMIP6 (ACCESS-ESM1.5, CESM2, MIROC-ES2L, MPI-ESM1.2-LR, NorESM2-LM and UKESM1-0-LL) compared to CMIP5 (NorESM1-M) and the number of soil carbon pools (dead carbon pools). The ESMs where both CMIP5 and CMIP6 generations are included in our analysis are: CanESM2 and CanESM5, GFDL-ESM2G and GDFL-ESM4, IPSL-CM5A-LR and IPSL-CM6A-LR, MIROC-ESM and MIROC-ES2L, MPI-ESM-LR and MPI-ESM1.2-LR, NorESM1-M and NorESM2-LM, and HadGEM2-ES and UKESM1-0-LL, respectively, where direct comparisons can be made. It is noted that some Land Surface Models within ESMs

share similarities (e.g. CESM2 and NorESM2-LM both use the Community Land Model version 5; Arora et al. 2020)."

Ln 125: Can you pull these ratios from the model to justify this assumption?

The common mathematical assumption (products of deltas are negligible, $\Delta * \Delta \approx 0$) is not made here as we include the $\Delta\Delta$ terms in our analysis. The sentence has therefore been changed to make this clearer.
Ln 124:
"*Equation 7 is exact for given time-varying values of NPP, NEP and τ_{s}. ~~but in this form it does not cleanly separate into contributions due to changes in each of these factors. A linear approximation is therefore made (assuming $\Delta \rm{NPP}/\rm{NPP} << 1$ and $\Delta \tau_{s}/\tau_{s} <<1$), which allows for the cross-terms to be neglected ($\Delta \rm{NPP} \Delta \tau_{s}$ and $\Delta \rm{NEP} \Delta \tau_{s}$).~~ The ~~resultant~~* ***individual*** *terms in Equation 8*

Ln 241: If this term was non-negligible then I would suggest dropping this framing from the introduction and maybe including a comment like "We thought this would be negatable but were surprised to find it was not."

Similarly (**see above**), the text has been changed as follows.
Ln 241:
"*~~The non-linear $\Delta \rm{NPP} \Delta \tau_{s}$ term having non-negligible contributions to future ΔC_{s} means the initial $\Delta \rm{NPP}/\rm{NPP} << 1$ and $\Delta \tau_{s}/\tau_{s} <<1$ assumptions were not valid in this case.~~* ***A linear assumption is commonly used which would allow these cross-terms to be neglected (****$\Delta \rm{NPP}/\rm{NPP} << 1$ and $\Delta \tau_{s}/\tau_{s} <<1$****; Koven et al. 2015). However, the*** *ESM projected … "*

How are the different model runs going to be used in the analysis? How would you expect each scenario to behave given their driving conditions within the framework developed in Eqn 8? I suspect that key to the argument that this is a false-priming effect is going to be the C4MIP runs. Setting this up explicating in the methods section makes a lot of sense.

As above, see main comments 1 and 2. Additional text has been added to explain why each model run is used and explaining false priming in the context of the C4MIP runs.

This false priming analysis feels very tacked on and needs to be introduced before the discussion section more clearly. How was this three box model parameterized? It appears that you are claiming that because you see similar patterns in this 3 pool model that you confirm that this is what is happening in the CMIP models. Maybe but there are other alternatives.

False priming is now introduced within the Introduction (**see response given to comment 1 on Ln. 40**).

A new section '***Section 3.5: The role of false priming***' has been added to present false priming more clearly. It comes at the end because it is used to explain results which were found during the analysis. The 3-box model was taken from Koven et al. 2015 and the same parametrisation was followed. The presence of false priming will not be dependent on the parameterisation assuming the 3-box model has carbon pools with a fast, medium and slow turnover time, and carbon is able to flow between the carbon pools. This has been made clearer in the text (including the additional detail that the carbon pools are initialised at 0).

As above, false priming is now presented as a likely contributor to this correlation due to the structure of the soil carbon models within ESMs producing the same relationship. We feel the additional information on possible alternatives and more details on false priming in the different C4MIP runs will have improved this point.

1. Koven, C. D., Chambers, J. Q., Georgiou, K., Knox, R., Negron-Juarez, R., Riley, W. J., Arora, V. K., Brovkin, V., Friedlingstein, P., and Jones, C. D.: Controls on terrestrial carbon feedbacks by productivity versus turnover in the CMIP5 Earth System Models, Biogeosciences, 12, 5211–5228, https://doi.org/10.5194/bg-12-5211-2015, 2015.

Reviewer comments

Author responses (**Bold is new text in manuscript**)

<u>RC2</u>

Varney et al. present results on soil carbon changes in CMIP5 and CMIP6 models under different levels of climate change, and quantify the contribution of productivity and turnover controls on these changes in soil carbon. They find that the spread in soil carbon responses across CMIP6 models was less than that across CMIP5 models, suggesting a potential reduction of uncertainty in 21st century soil carbon projections. The study shows that there are still differences in the relative contributions of controls (e.g., NPP and tau) on soil carbon changes across the models. They also illustrate a linear relationship between the change in carbon from NPP and turnover time, which they connect to the concept of false priming and demonstrate that this relationship is tighter across the CMIP6 models. In all, this is an interesting study with nicely summarized figures. Some findings could be discussed in greater detail with appropriate caveats, and I include specific comments below.

We are thankful to the reviewer for the helpful comments which we feel have now improved the paper.

Main comments:

It is an important result that the study finds such differences across the two CMIP generations, and I think more discussion on this point could be helpful. Could the authors provide further details on a few of the soil C models that showed large differences between the CMIP generations? How did these soil C model representations change?

We agree that the comparison between two CMIP generations is useful to try and interrupt new additions within ESMs. The response to this comment has been incorporated into related responses below (see ***Comments 2*** and ***Comments 4***).

In particular, did the soil C models change with regards to the number of pools from CMIP5 to CMIP6? I was under the impression that most were based on the the Century or DayCent models, which were developed decades ago. It'd be great if the authors could provide more details on the models here. Otherwise, the last sentence of the abstract about the "inclusion of more soil carbon models with multiple pools in CMIP6" does not have sufficient support currently.

We have included a new table in the manuscript (which has been adapted from Tables 1 and 2 from Varney et al. 2022), which includes information on the related soil carbon components of the ESMs in both CMIP5 and CMIP6. Specifically, the no. of dead soil carbon pools within the ESMs **(see below)**.

Earth System Model	Nitrogen cycle	No. of live carbon pools	No. of dead carbon pools	References
BNU-ESM	No	-	-	Ji et al. (2014); Dai et al. (2003)
CanESM2	No	3	2	Arora et al. (2009); Arora and Boer (2010)
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CNRM-ESM2-1	No	6	7	Séférian et al. (2019); Delire et al. (2020)
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MIROC-ES2L	Yes	3	6	Hajima et al. (2020); Ito and Oikawa (2002)
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UKESM1-0-LL	Yes	3	4	Sellar et al. (2020); Wiltshire et al. (2021)

Table NEW: "***The CMIP5 and CMIP6 Earth system models included in this study and the relevant features of associated land carbon cycle components: simulation of interactive nitrogen, number of live carbon pools and the number of dead soil carbon pools (Varney et. al 2022; Arora et al. 2013; 2020).***"

Secondly, we have included extra text in the Methods describing the key differences between the CMIP5 and CMIP6 generations.

Ln 57:
"~~Specific soil carbon related updates within ESMs from CMIP5 to CMIP6 are included in Varney et al. 2022 within the 'Earth system models' section of the Methods, and more general model updates are presented within the 'Model descriptions' section of the Arora et al. 2020 Appendix.~~
The use of CMIP allows for comparison between ESMs in the different ensemble generations. Table 1 presents key soil carbon related information from the ESMs for both CMIP6 and CMIP5 (adapted from Tables 1 and 2 in Varney et al. 2022). The Table can be used to identify key ESM updates between CMIP5 and CMIP6, such as: the simulation of interactive nitrogen in CMIP6 (ACCESS-ESM1.5, CESM2, MIROC-ES2L, MPI-ESM1.2-LR, NorESM2-LM and UKESM1-0-LL) compared to CMIP5 (NorESM1-M) and the number of soil carbon pools (dead carbon pools). The ESMs where CMIP5 and CMIP6 generations are included in our analysis are: CanESM2 and CanESM5, GFDL-ESM2G and GDFL-ESM4, IPSL-CM5A-LR and IPSL-CM6A-LR, MIROC-ESM and MIROC-ES2L, MPI-ESM-LR and MPI-ESM1.2-LR, NorESM1-M and NorESM2-LM, and HadGEM2-ES and UKESM1-0-LL, respectively, where in these cases direct comparisons can be made. It is noted that some Land Surface Models

within ESMs share similarities (e.g. CESM2 and NorESM2-LM both use the Community Land Model version 5; Arora et al. 2020)."

Ln 60:

"***Within ESMs, specific soil carbon processes are modelled using soil biogeochemical models which are used to simulate the flow and storage of carbon within the soil. Since early models, both the litter and soil are simulated using separate carbon pools, which are used to represent differing sensitivities of carbon to decomposition and allocation into pools is often dependent on the molecular structure of the litter and the long-term stability (Exbrayat et al., 2013). Early examples of soil carbon models are the grass and agroecosystems dynamic model (CENTURY; Parton et al. (1988)) and the Rothamsted carbon model (ROTH-C; Jenkinson et al. (1991)). Updated variants of these models are still widely used to represent soil carbon decomposition in modern ESMs within CMIP (Arora et al., 2020; Todd-Brown et al., 2018). Table 1 presents the number of soil carbon pools (dead carbon pools) within both CMIP5 and CMIP6 ESMs, which can be used to compare between the ESMs.***"

1. Exbrayat, J.-F., Pitman, A., Zhang, Q., Abramowitz, G., and Wang, Y.-P. (2013). Examining soil carbon uncertainty in a global model: response of microbial de- composition to temperature, moisture and nutrient limitation. *Biogeosciences*, 10(11):7095–7108.
2. Parton, W. J., Stewart, J. W., and Cole, C. V. (1988). Dynamics of c, n, p and s in grassland soils: a model. *Biogeochemistry*, 5(1):109–131.
3. Jenkinson, D. S., Adams, D., and Wild, A. (1991). Model estimates of co2 emissions from soil in response to global warming. *Nature*, 351(6324):304.
4. Todd-Brown, K., Zheng, B., and Crowther, T. W. (2018). Field-warmed soil carbon changes imply high 21st-century modelling uncertainty. *Biogeosciences*, 15(12):3659–3671.

The abstract has changed to be more appropriate for the findings of the study, then more specific details included in Discussion.

Ln 8:

"*We show* ***that the concept of 'false priming' is likely to be contributing to this emergent relationship*** ~~*this emergent relationship is the result of `false priming'*~~*, which leads to a decrease in the effective soil carbon turnover time as a direct result of NPP increase and occurs when the rate of increase of NPP is relatively fast compared to the slower timescales of a multipool soil carbon model.* ***This finding suggests that the structure of soil carbon models within ESMs in CMIP6*** ~~*The inclusion of more soil carbon models with multiple pools in CMIP6 compared to CMIP5, therefore*~~ ~~*seems to have*~~ ***has likely*** *contributed towards the reduction in the overall model spread in future soil carbon projections* ***since CMIP5***."

How were the particular ESMs included in the analysis chosen? Line 55 says that this was due to data availability, but it is surprising that certain of the CMIP6 models (e.g., CESM2) did not have the necessary data for CMIP5 as well. Either way, it seems that 5-6 models (CanESM, IPSL, MIROC, MPI, NorESM, and HadGEM/UKESM) are included for both the CMIP6 and CMIP5 model output. These models would be good candidates to explore the earlier point above, regarding changes to the soil C modules and the number of pools in the CMIP5 and CMIP6 representations.

The study used all ESMs which had data available for all required variables (cSoil, cLitter, NPP, Rh) on the ESGF website (https://esgf-node.llnl.gov/projects/cmip6/, where all nodes where checked). We have checked the data source again and additional data is still not available. We agree that the ESMs with CMIP5 and CMIP6 model generations provide good candidates to explore common model updates. As above, the study now includes details regarding changes in the number of C pools between CMIP5 and CMIP6 generations.

How many of the models did not report a separate litter carbon pool? (These could be briefly listed on line 88.) It seems that the analysis could be more consistent by using only the soil carbon pool across the models. If not, additional rationale can be provided.

Most ESMs do include a separate litter carbon pool variable. Those that do not in this analysis is only UKESM1-0-LL in CMIP6, plus HadGEM2-ES and GISS-E2-R in CMIP5. The use of combining soil and litter carbon pools to consider 'total soil carbon' in ESMs is a common method used within literature (Todd-Brown et al. 2013, 2014; Koven et al. 2015; Varney et al. 2022). The models which do not report the litter pool do have the representation of litter within the model, but not report a separate variable in the CMIP simulations. The sentence has been updated as suggested.
Ln 88:
"*For models that do not report a separate litter carbon pool (cLitter), soil carbon is taken to be simply the cSoil variable* ***(UKESM1-0-LL in CMIP6, GISS-E2-R and HadGEM2-ES in CMIP5)***."

1. Todd-Brown, K. E. O., Randerson, J. T., Post, W. M., Hoffman, F. M., Tarnocai, C., Schuur, E. A. G., and Allison, S. D.: Causes of variation in soil carbon simulations from CMIP5 Earth system models and comparison with observations, Biogeosciences, 10, 1717–1736, https://doi.org/10.5194/bg-10-1717-2013, 2013.
2. Todd-Brown, K. E. O., Randerson, J. T., Hopkins, F., Arora, V., Hajima, T., Jones, C., Shevliakova, E., Tjiputra, J., Volodin, E., Wu, T., Zhang, Q., and Allison, S. D.: Changes in soil organic carbon storage predicted by Earth system models during the 21st century, Biogeosciences, 11, 2341–2356, https://doi.org/10.5194/bg-11-2341-2014, 2014.
3. Koven, C. D., Chambers, J. Q., Georgiou, K., Knox, R., Negron-Juarez, R., Riley, W. J., Arora, V. K., Brovkin, V., Friedlingstein, P., and Jones, C. D.: Controls on terrestrial carbon feedbacks by productivity versus turnover in the CMIP5 Earth System Models, Biogeosciences, 12, 5211–5228, https://doi.org/10.5194/bg-12-5211-2015, 2015.
4. Varney, R. M., Chadburn, S. E., Burke, E. J., and Cox, P. M.: Evaluation of soil carbon simulation in CMIP6 Earth system models, Biogeosciences, 19, 4671–4704, https://doi.org/10.5194/bg-19-4671-2022, 2022.

The finding of a turning point from increasing to decreasing soil carbon in Fig. 2 (lines 155-165) is really interesting, and the authors mention that this suggests a potential limit to the Cs increase. Why do you think this could be? And why does this turning point appear later or not at all in some models? Do any geographic regions contribute more to this turning point? Some more discussion here would be great, as this is an interesting finding.

The result of a turning point in future soil carbon simulations has been expanded upon and extra discussion has been included.
Ln 163:
"~~*This finding suggests a potential limit to* ΔC_s *increase and a reduced likelihood of a carbon sink under more extreme levels of climate change.*~~
Generationally related ESMs between CMIP5 and CMIP6 allow us to highlight some key changes between the CMIP generations and to suggest potential model updates which may have contributed to the change. For example, within CMIP5 the models HadGEM2-ES and MPI-ESM-LR predicted the greatest increases in soil carbon within the ensemble. Conversely, within CMIP6 the updated versions UKESM1-0-LL and MPI-ESM1-2-LR predict reduced increases (Fig. 1). This is likely

due to the inclusion of interactive nitrogen within simulations, which could limit carbon sequestration through limiting the magnitude of CO_2 fertilisation (Wiltshire et al. 2021). The projected 'turning point' seen in UKESM1-0-LL within CMIP6, suggests a saturation of the CO_2 fertilisation effect, compared with no saturation of increased respiration with warming. This is again most likely due to the more widespread inclusion of nutrient limitations on CO_2 fertilisation in CMIP6. This finding suggests a potential limit to ΔC_s increase and a reduced likelihood of a carbon sink under more extreme levels of climate change."

1. Wiltshire, A. J., Burke, E. J., Chadburn, S. E., Jones, C. D., Cox, P. M., Davies- Barnard, T., Friedlingstein, P., Harper, A. B., Liddicoat, S., Sitch, S., et al. (2021). Jules-cn: a coupled terrestrial carbon–nitrogen scheme (jules vn5. 1). *Geoscientific Model Development*, 14(4):2161–2186.

The immediate response in respiration in Fig 10b looks surprising, especially the abruptness and shape of the tau curve. I guess this may be because the Cs1 and Cs2 pools both equilibrate almost instantaneously, with intrinsic turnover times of 1 and 10 years. However, it is difficult to see any of these details associated with the short-term response, because the x-axis spans 500 years. It would be helpful to focus on the first 100 or so years following the perturbation, as in Fig. 10a.

Figure 10b demonstrates how the 3-box model responds to a step change of NPP increase. The aim here is to demonstrate the subsequent effects of soil carbon, Rh and turnover changes clearly as a response to the increased input and allowing an equilibrium to be reached. Fig. 10b is a complementary figure to Fig. 10a, which shows the short-term transient response in the same 3-box model. More discussion has been added to the text discussing the figure.
Ln 314:
*"Fig. 10(b) demonstrates that false priming is a transient effect associated with ~~a disequilibrium in~~ the distribution of soil carbon between the 3 pools****, which emerges from the differences in the mass-weighted and flux-weighted responses****. **The fast soil carbon pool reaches equilibrium before the slower soil carbon pool resulting in** the* ***… (Fig. 10(b)).***"

The authors could consider adding some discussion/conclusions on how their results on effective turnover times may connect with radiocarbon-based insights from soil carbon ages (e.g., He et al. Science 2016; Shi et al. Nat Geosci 2020) in data and ESMs.

Discussion connecting with these stated studies has now been included.
Ln 329:
"***A more apparent false priming affect within CMIP6 could suggest an improved representation of the slower components of soil carbon since CMIP5, commonly by including more dead carbon pools within the ESM (Table 1). Based on observational radiocarbon estimates it has been found that CMIP5 ESMs underestimate carbon age within the soil (He at al. 2016; Shi et al. 2020), suggesting that ESMs underestimate the amount of carbon in the slow carbon pools. It has been shown that representing soil carbon ages more in line with radiocarbon estimates leads to a reduced potential for soil carbon sequestration in the future (He et. al 2016), which agrees qualitatively with the projected 21st century soil carbon changes as predicted by CMIP6 compared to CMIP5 found in this study.***"

1. He, Y., Trumbore, S. E., Torn, M. S., Harden, J. W., Vaughn, L. J., Allison, S. D., & Randerson, J. T. Radiocarbon constraints imply reduced carbon uptake by soils during the 21st century. *Science*, *353*(6306), 1419-1424 (2016).

2. Shi, Z., Allison, S.D., He, Y. *et al.* The age distribution of global soil carbon inferred from radiocarbon measurements. *Nat. Geosci.* **13**, 555–559 (2020).

The last point in the conclusions (#6) reads as if false priming itself is a mechanism that affects soil carbon storage. However, it is in fact an effective bulk quantity that results from differences in mass-weighted and flux-weighted responses when there are multiple soil components with different residence times (as is the case in most models and in soil itself). It can thus be a useful quantity to further probe and diagnose model responses in response to perturbations. The authors may want to clarify and refine this last point.

This last point has been changed.
Line 352:
"~~It is recommended that the full extent of false priming on future soil carbon is understood, where if increased carbon inputs to soil carbon pools preferentially enters fast soil carbon pools, this could limit the maximum increase in soil carbon storage in the future.~~"
"***Our study highlights the significant role that false priming can play under transient changes in atmospheric CO_2 and climate. We advise caution in the interpretation of changes in the effective soil carbon turnover time in terms of climate affects alone. Idealised C4MIP simulations, which can be used to separate the effects of CO_2 and climate on the effective soil carbon turnover time, are very useful to assess the role of false priming in models. Understanding these factors will be key to predicting soil carbon changes over the next 100 years.***"

Minor comments:

Lines 18-24: This background jumps around a bit, giving a case study for warming and then saying 'therefore' with a statement about elevated CO2 importance. Consider reorganizing this intro paragraph. Also, there could be a discussion somewhere here regarding the uncertainty resulting from underestimation of soil C ages in most ESMs (e.g., He et al. Science 2016). This is particularly relevant for the discussion of uncertainties resulting from increasing NPP and elevated CO2.

The paragraph has been edited to be clearer.
Ln 18:
"*However, the long-term response of soil carbon is uncertain due to large stocks which are known to be particularly sensitive to changes in CO_2 and the subsequent global warming (Cox et al. 2000). For example, permafrost thaw under climate change has the potential to release significant amounts of carbon into the atmosphere over a short period of time with increased warming, representing a significant feedback within the climate system (Schuur et al. 2022; Hugelius et al. 2020; Burke et al. 2017). Therefore, quantifying the future response of soil carbon* ***under future changes to climate*** ~~*to increased CO2*~~ *is vital in determining the long-term potential land carbon storage.*"

Line 30: There is only reference to Crowther et al. 2016 here, but just a note that there was conflicting evidence in a follow-up to that paper by van Gestel et al. 2018.

Follow up paper is noted and included. The Crowther et al. 2016 study was used as they attempted to quantify the carbon loss from global soils under global warming. However, we note here that Van Gestel et al. (2018) stated a limiting factor of this study is the number of field experiments within northern latitude regions, potentially leading to an underestimation of soil carbon loss. Additional citations have been added here ***(van Gestel et al. 2018)***.

1. van Gestel, N., Shi, Z., van Groenigen, K. *et al.* Predicting soil carbon loss with warming.*Nature* **554**, E4–E5 (2018).

Line 70: ‘subtracted’ instead of ‘taken away’

Sentence changed.

Line 120: can ‘be’ expanded

Sentence changed.

Line 314: Can you elaborate on what you mean by “offsets about 40% of the increase in soil carbon that would arise from the NPP increase alone” here?

This sentence has been removed to avoid confusion as is not vital to the presentation and understanding of false priming.
Ln 314:
“***.*** *~~and for this set of parameters offsets about 40% of the increase in soil carbon that would arise from the NPP increase alone~~.*”

Line 315: I’m not sure that it is a ‘disequilibrium’ per se, but rather an apparent quantity that emerges from differences in mass-weighted and flux-weighted responses.

This sentence has been changed as suggested.
Ln 315:
“*Fig. 10(b) demonstrates that false priming is a transient effect associated with ~~a disequilibrium in~~ the distribution of soil carbon between the 3 pools****, which emerges from the differences in the mass-weighted and flux-weighted responses****.*”