Reply to Rachel James's comment

General comments

This paper uses a new set of climate model simulations to explore climate stabilization under zero green gas emissions. This is a very welcome and novel study, which provides an insight into how climate change might evolve, and a useful comparison with many other studies which focus on much shorter simulations with rapidly increasing emissions. The paper has some important findings, for example highlighting that delaying mitigation by even 5 years could have implications for hundreds of years. The paper also illustrates how the impacts of global warming change over time and highlights the need for more research to explore the impacts of different mitigation pathways. The paper is generally fluently written with useful illustrations.

Thanks for the constructive feedback. We are confident we can address all the comments you outline below.

I have a few broader comments which might help improve the manuscript:

- I would like to see a bit more discussion of the relevance of these simulations to the real world/ climate policy. The idea that we could instantly stop greenhouse gas emissions is of course hypothetical, and in reality even very strong mitigation would be associated with a decline in emissions over time. This complicates matters as it is more likely to lead to overshoot scenarios, which could have different implications from the scenarios used here. It would be useful to add a short discussion of this.

Indeed. We agree and we will include additional text, mainly in the Summary and Conclusion section, discussing our results with idealised experiments and their relevance to more realistic emissions pathways.

- The terminology "net zero" is often used to refer to mitigation which is compliant with the Paris Agreement (i.e. 1.5ºC or 2ºC global warming), whereas in this study some of the net zero scenarios exceed 3º I found this a bit confusing, and I had to keep reminding myself that "net zero" didn't necessarily imply low emissions. I also found it a bit confusing to compare the 3ºC transient sample with the 3ºC stable samples, as I believe they have different cumulative emissions? In some cases a "reduction" (for example in heat extremes) is noted between the transient and stable cases, and it is unclear whether this is a reduction over time in the same scenario, or rather a difference between a rapidly warming 3ºC world with high emissions and stabilized world which has received fewer anthropogenic greenhouse gas emissions and more slowly reached 3ºC. I have added a few comments below that might help make the comparison between these clearer. In addition, I think it would be useful to calculate the cumulative

emissions for each GWL condition. Perhaps this could be added to Table 1? I also wonder whether it might be more straightforward to refer to the scenarios as "zero emission scenarios" rather than "net zero" since I think the scenarios imply that emissions from CO_2 sources stop, rather than there being any change in CO_2 sinks or CO_2 drawdown.

Thanks. We agree that net-zero emissions pathways are not usually discussed with respect to high global warming levels, so some additional text on this in the Data and Methods section is warranted. We will add clarifying text when discussing the GWL results. We will also add cumulative emissions levels to Table 1 as we agree that it is worth noting that they are different between the transient and stabilising GWL samples. These will be single numbers for the stabilising GWLs and a range for the transient GWLs. We propose to retain "net-zero" nomenclature as this experimental set up is consistent with net-zero carbon dioxide emissions where anthropogenic uptake and drawdown is in balance.

- The manuscript is generally very well written, but some sections of the results are a bit complicated to read. I have provided line by line comments to help improve clarity.

Thanks for these comments. We hope to make the text as clear as possible and will make these changes.

- The paper is quite long, and below you will see I have suggested adding a couple more panels to some of the figures! As a reader I didn't find it too long, but if it needs to be shortened I am not sure if Figure 5 and 6a are both needed. Also, the methods section has quite a bit of detail which I found a little hard to follow without the results, some of the explanation could come during the results figure by figure. The introduction is also quite long, although it is very clearly written and useful.

Indeed. We agree this is a long paper, but we're pleased you didn't find it too long. We will move some of the Methods description to the Results for clarity (noting the other reviewer made a similar comment). We would like to retain Figures 5 and 6a as we think they provide foundational results relevant to understanding the consequence of stabilisation relative to transient change.

Line by line comments

Line 26 – "differ greatly" – differ with reference to what? Higher greenhouse gas scenarios? Or is this about difference between regions? Please clarify.

This sentence is about difference between regions. We will clarify this.

Line 45 – "will result" – suggest to change to "would result" since it is a scenario.

We agree and will make this edit.

Line 284 – reference to Joshi et al. 2008. Please make clear how this reference supports – did they find something similar and with what kind of simulation?

Thanks- we will clarify the use of his reference. Joshi et al. (2008) use simpler GCMs run under different GCM experiments with raised temperatures and CO_2 concentrations. These are simpler experiments but they demonstrate a robust reduced land-ocean temperature contrast in equilibrium model simulations relative to transient simulations, although some contrast remains.

Line 291 – please clarify what you mean by a "fast rate".

This will be phrased and a range of warming rates will be provided.

Line 292-295 – suggest to clarify sentence – "even under the lowest global warming simulation broadly aligning with the Paris Agreement" – which simulation do you mean? And, in the latter half of the sentence I think the "beyond" could be removed? Not sure what is meant by "beyond" here.

This is for the net-zero simulation initialising in 2030 and we agree this should be clearer. We will make a suitable edit and remove the word "beyond".

Line 299-300 – "relatively small" – relative to the point of zero emissions yes, but there is a change relative to preindustrial. Please clarify.

We agree and will clarify this.

Line 303-304 – I think it would be a good idea to put this in the context of the change during the transient simulation. You could say that the models are showing strong persistence in the change in sea ice, since the decrease in sea ice extent experienced during the transient simulation is then broadly maintained (albeit with substantial variability) for 1000 years.

Yes, we can reframe this following your suggestion.

Line 305-6 – Do we know why the decline continues after emissions cessation in the Antarctic? Is it due to slower ocean changes in the Antarctic region? It would be nice to comment or perhaps give a hint that you will explore this later in the paper.

Yes, we discuss this later on, but will edit to make this clearer. We think this is related to the continued warming of the Southern Ocean (at the surface and at depth), but a fuller analysis is needed.

Line 314-315 – might be helpful to add "over time" for example "Under net-zero emissions, in the Antarctic, there is an increasing change of sea ice free events over time…"

We agree and will make such an edit.

Line 330-331 – why might it be related to Southern Ocean warming? Could you give a brief indication (quite interesting!).

Yes, on reflection this does require some further discussion. There is a suggestion by Oh et al. (2022) that changes to the interhemispheric temperature gradient under increasing and decreasing CO_2 concentrations contributes to asymmetric effects on the Indian Monsoon. The reduced interhemispheric gradient in CO2 ramp-down simulations, also seen to a lesser extent in our net-zero emissions simulations, is related to changes in water vapour transport. A brief comment will be added to explain this.

Line 345-347 – Yes, if the rate of emissions reduction is the same.

We agree a qualification on this statement is needed to make it clearer.

Line 356 – "Africa" – more helpful to say "Northern and Central Africa"

We agree and will make this edit.

Line 372 – and also dependence on the cumulative emissions? Does the SSP5-8.5 3ºC have higher cumulative emissions than the late stable 3ºC?

Yes, we can add a statement noting this difference.

Figure 8 and 9 – I wonder whether it would be useful to show and describe the warming patterns for the early stable and late stable periods as well? i.e. the warming relative to preindustrial rather than the difference between SSP5-8.5 and the stable periods? It might be nice to make the point clearly that a 3ºC "transient" world looks very different from a 3ºC "stabilized" world – i.e. (I think) – 3ºC transient has huge warming over continents and some warming over sea ice regions, 3ºC transient has more uniform warming? Are the continents showing warming similar to the global mean of 3ºC? As a reader I'd quite like to visualize this.

Yes, we agree. We can add these as additional figures to the Appendices. Adding these maps to Figures 8 and 9 would make them too crowded we think.

418-419 – "suggest very large areas of the world may exhibit some return towards pre-industrial levels of seasonal-average precipitation." – very interesting. Again, could you show this? Even as an appendix.

Yes, we agree this is an interesting implication of Figures 10-12. We can add a new Figure showing the areas of the world where precipitation reversal means changes in seasonal distributions are statistically indistinguishable from the pre-industrial period when they

were significantly different during the transient period. This could be as an addition to Figure 12 or as new Appendix Figures depending on the findings.

480 – "marked reduction" – is there a decrease over time as the climate stabilizes, or is this because a different simulation is used for the "early stable 1.5ºC" vs the "late stable 1.5ºC". If the extremes actually decrease over time, despite the cumulative emissions being the same, this is really interesting and could be highlighted more. Either way it would be nice to comment on this.

This is for a decrease in hot extremes over land areas for a given GWL between initial and later stabilisation periods. These extremes are drawn from different simulations with different cumulative emissions levels at the same GWL. We will add a statement noting this to make it clearer.

500-505 – Please could you clarify whether you expect that the stabilization scenarios show a decrease after emissions cessation? Or is the reduction between the 21st century and the net zero simulations shown in Figure 15 a result of the different emissions (where this 21st century simulation includes emissions and temperatures which exceed any of the net zero stabilization scenarios?)

Thanks. We will clarify this. We don't see significant differences in ENSO amplitude or frequency between different samples from the net-zero simulations. The difference arises between the 21st century rapid warming and stabilisation periods. We will explain this more clearly.

522 – "reduced land temperature means and extremes" – is there a reduction over time? Or is it a reduction compared to a transient world with the same GWL (and higher emissions)?

This is over time, but we will edit to clarify this.

Figure 14 caption – check references to figure letters. I think "e, f" should be "d, e"

Thanks for spotting this typo. We will make this correction.

1. Does the paper address relevant scientific questions within the scope of ESD? Yes
2. Does the paper present novel concepts, ideas, tools, or data? Yes
3. Are substantial conclusions reached? Yes
4. Are the scientific methods and assumptions valid and clearly outlined? Yes
5. Are the results sufficient to support the interpretations and conclusions? Yes

6. Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)? Yes
7. Do the authors give proper credit to related work and clearly indicate their own new/original contribution? Yes
8. Does the title clearly reflect the contents of the paper? Yes
9. Does the abstract provide a concise and complete summary? Yes
10. Is the overall presentation well structured and clear? Yes
11. Is the language fluent and precise? Yes, generally, I've made suggestions for places where it could be clearer.
12. Are mathematical formulae, symbols, abbreviations, and units correctly defined and used? Yes
13. Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated? Yes
14. Are the number and quality of references appropriate? Yes
15. Is the amount and quality of supplementary material appropriate? Yes