

Point-by-point reply for the manuscript „Interactions between atmospheric composition and climate change - Progress in understanding and future opportunities from AerChemMIP, PDRMIP, and RFMIP“ by Fiedler et al.

Dear Sophie Valcke,

Thank you very much for the appraisal of our manuscript. We appreciate the time for the review and the support for further improving the clarity of the text. Below are our replies in blue to your suggestions in black.

L. 57-61: “The climate modeling community creates multi-model ensembles of a common set of ESM experiments with the same perturbations applied. The simulated climate responses can differ across a multi-model ensemble. This diversity in responses may for instance be due to differences in process complexity and interactions within the respective ESMs. Experimental protocols are used to create multi-model ensemble simulations for specific ESM experimental setups. These aim to better understand the reasons for the diversity in climate responses and feedback and to create future climate projections.” : First and before last sentences are redundant; I suggest: “The climate modeling community creates experimental protocols to set up multi-model ensembles of a common set of ESM experiments. The simulated climate responses can differ across the multi-model ensemble members in response, for instance, to differences in process complexity and interactions within the respective ESMs. The aim is to better understand the reasons for the diversity in climate responses and feedback.”

Changed as suggested.

L.87: “... consider structural differences concerning the design and the level of complexity between ESMs.” => “... consider structural differences in the design and complexity of the different ESMs.”

Changed to : “considered structural differences in the design and complexity of the different ESMs“.

L. 90: “... radiative forcing diversity to anthropogenic perturbations ...” => “radiative forcing linked to anthropogenic perturbations ...”

Changed as suggested.

L. 173: “The RFMIP protocol included experiments to diagnose radiative forcing for greenhouse gases and aerosols as bulk quantities with setups parallel to the CMIP6 experiments for the "Diagnostic, Evaluation, and Characterization of Klima" (DECK)” => “The RFMIP protocol included experiments to diagnose radiative forcing from greenhouse gases and aerosols as bulk quantities with setups common to CMIP6 "Diagnostic, Evaluation, and Characterization of Klima" (DECK) experiments.”

Changed to: „The RFMIP protocol included experiments to diagnose radiative forcing from greenhouse gases and aerosols as bulk quantities.“

L. 216-220: “A major challenge to further advancing the understanding of climate change with ESMs is that differences in their results for individual segments of the perturbation-response paradigm are not independent of other segments. Specifically, a model-to-model difference in a climate response might be caused by various segments in the paradigm. For instance, the same emissions can lead to different ERFs, the same ERF can induce different climate responses and the same response can trigger different feedbacks across multi-model ensembles. In multi-model studies, one therefore sees inter-model spreads in forcing for the same change in atmospheric

composition and model-dependent climate responses to the same forcing involving different types and magnitudes of feedbacks.” The text you added makes the paragraph even more fuzzy from my point of view. In the first sentence, you discuss dependence of what you call the “segments of the perturbation-response paradigm”. In the second sentence, you discuss the fact that differences may be linked to more than one segments; I am not sure then why the second sentence starts with “Specifically”. Then, if I understand well, in the 3rd sentence, you give an example of different responses in different segments. Please simplify. Consider removing the second sentence. In all cases, remove “across multi-model ensembles” in “different feedbacks across multi-model ensembles” as I think you mean that the difference in the feedbacks are differences across the ensemble members (but this is confusing as one may understand that the feedbacks themselves occur between the ensemble members).

We removed the second sentence and “across multi-model ensembles” to simplify this part as suggestion.

L.226: “for a better understanding of reasons for model differences” => “for a better understanding of model differences”

Changed to: „for a better understanding of model diversity“.

L 249: “newly requested diagnostic output that is not yet available in the standard variable list of ESMs, e.g., for RFMIP-IRF” => remove “that is not yet available in the standard variable list of ESMs”

Removed.

L.252-255: “In this case, it takes longer to finish the experiments and to do the associated scientific exploitation, e.g., in the case of RFMIP-SpAer several years after the work began (Fiedler et al., 2023), which is long compared to easy experiments that modelers can quickly set up via a simple change in a setting for performing an experiment, e.g., for RFMIP-ERF, thanks to prior work on the development and testing of models.” This is a way too long and over convoluted sentence and does not bring much to the previous sentence. I suggest removing it and just modifying the end of the previous sentence as “...to carry out the work including coding, testing, performing the experiments and associated scientific exploitation.”

Changed as suggested.

We also shortened text in the following paragraph: „In preparation for the next phase of AerChemMIP and RFMIP, the type and number of experiments in the experimental protocol will therefore be revised based on a refined set of research questions and the desire to reduce the computational burden for modeling centers as much as possible. In this process, AerChemMIP activities will be closely coordinated with other community MIPs with common or similar interests.“, to make the text more coherent with the experiment review in the following paragraph.

L.265: “we reviewed the current status of the experiments” => “we reviewed the status of the experiments”

Changed as suggested.

L.287: “They contribute to the decision for which community-driven MIP experiments with the ESM will be conducted, e.g., through granting computational resources and prioritizing experiments to be completed.” => “They contribute to the decision as to which MIPs will be conducted with which priority, e.g., through granting computational resources.”

Removed this paragraph as suggested in next comment.

L.288-290: “Additional decisions for the experiments are made by the scientists interested in the MIP. There is some room to make their own choices since not all experimental settings are explicitly defined by the MIP’s experiment protocols, e.g., they may use a coarser spatial resolution and to some degree less model complexity to reduce the computational burden.” Another example of the same idea expressed twice. Simply remove this paragraph as the same ideas are expressed with slightly different word in the paragraph just after.

Removed as suggested.

L.291: “There are inevitable tradeoffs in the final experimental designs for individual MIPs. Such choices can be categorized along the three axes of (1) model complexity addressing how many process interactions ESMs allow or how much fidelity processes have, (2) model resolution referring to the grid spacing of the model, and (3) simulation length covering the length and number of simulations in an ensemble of different experimental setups per ESM.” => “There are inevitable tradeoffs in the final experimental choices that can be categorized along the three axes of (1) model complexity addressing how many process interactions ESMs allow or how much fidelity processes have, (2) model resolution referring to the grid spacing, and (3) simulation length covering the length and number of members in ensemble simulations. “

Changed to: „There are inevitable tradeoffs in the final experimental choices that can be categorized along the three axes of (1) *model complexity* addressing the number of process interactions represented in ESMs and the fidelity of the processes simulations, (2) *model resolution* referring to the grid spacing, and (3) *simulation length* covering the length and number of members in ensemble simulations. “

L.339: remove “of the experiments” in “the ensemble sizes and simulation lengths of the experiments”

Removed as suggested.

L.445-455 (L. 427-434 in version 2) : Referee #2 wrote that these sentence are “vague, not nice” but you did not change anything. Please rephrase, clarify, simplify.

The paragraph has now been removed and relevant information integrated in the previous section on natural processes: „ESMs differently simulate desert-dust aerosols (e.g. Evan et al., 2014; Checa-Garcia et al., 2021; Zhao et al., 2022) and do not reproduce the magnitude of the reconstructed dust increase from the pre-industrial to the present-day (Kok et al., 2023). (...) Skillful simulations of winds (e.g., Bony et al., 2015) and rain (e.g., Fiedler et al., 2020) are challenges for ESMs, which in turn introduce uncertainty in simulated dust trends.“

L.528-530 : “Much finer spatial resolutions with horizontal grid spacings of a few kilometers hold the potential to overcome some of the long-standing challenges concerning the representation of clouds, precipitation, and circulation in global climate simulations, which would require a step change in collaboration between climate science and high-performance computing (Slingo et al., 2022).” is another example of a too long sentence; please cut in two parts, end first sentence after “global climate simulations”; in the second part, it is not clear what “which” refer to, please rephrase.

We shortened it to: “Much finer spatial resolutions with horizontal grid spacings of a few kilometers hold the potential to overcome some of the long-standing challenges concerning the representation of clouds, precipitation, and circulation in global climate simulations.“. We removed the subordinate clause here and include the information in the following paragraph for better readability: „Global kilometer-scale simulations for climate change assessments would require a step change in collaboration between climate science and high-performance computing (Slingo et al., 2022).“

L.531 : Change “in coarse resolution models of several tens to hundreds of kilometers of grid spacings” for “in models with resolution of several tens to hundreds of kilometers”.

Changed as suggested.

L. 560-561: “especially in the context of a MIP since fully coupled ESMs with interactive aerosols and chemistry at a resolution of 1 km fast enough to perform multi-decadal simulations are unlikely to be ready in the time of CMIP7”: please rephrase for something like “since fully coupled kilometer-scale ESMs with interactive aerosols and chemistry fast enough to perform multi-decadal simulations are unlikely to be ready in the time of CMIP7”

Changed to: “(...) since several fully coupled kilometer-scale ESMs with interactive aerosols and chemistry fast enough to perform multi-decadal simulations are unlikely to be ready in the time of CMIP7.”

L. 564-566: “This approach is suitable to answer some but not all research questions in our community. For instance, the response of dust emission fluxes to changes in winds and moisture can be addressed with offline modeling and allows to identify underlying reasons for changes and model differences in the dust response (Fiedler et al., 2016), but the implication of such dust emission changes for air quality and climate responses can not be quantified with such an approach.” ; please simplify for something like “This approach is suitable to answer some but not all research questions in our community, for instance, the response of dust emission fluxes to changes in winds and moisture (Fiedler et al., 2016), but not the implication of such dust emission changes for air quality and climate responses.”

Changed as suggested.

L. 691: “sufficiently long experiments or sufficiently many ensemble members” is not grammatically correct; I suggest “sufficiently long experiments or enough ensemble members”

Changed as suggested.

L 692: “to better distinguish climate and air quality responses to atmospheric composition changes from” is another example of useless words in a sentence; it should simply be “to better distinguish climate and air quality responses to atmospheric composition from”

Changed as suggested.

L.711: “multi-purpose experiments can be useful and less burdensome in terms of human and computational resources” => “multi-purpose experiments can be useful and associated to less burden in terms of human and computational resources“

Changed to: „multi-purpose experiments can be useful and contribute to reducing the use of human and computational resources“

L.712: “as long as they facilitate answering the science questions laid out by the MIPs” is one example of an obvious sentence that does not bring much to the text

Removed.

Figure 1 captions: “are simulated with a model configuration coupled to an ocean model.” => “can be simulated with a model configuration including coupling to an ocean model.”

Changed as suggested.

Additional comments and propositions of modifications

L.62-64: “Results from multi-model intercomparison projects (MIPs) are widely used to advance scientific understanding and inform stakeholders on climate change. The most prominent

example is the Coupled Model Intercomparison Project (CMIP, Meehl et al., 2000) that has contributed ...”: I don’t agree that CMIP is an example of a MIP; instead, CMIP is composed of several MIPS, please rephrase.

Now: „The Coupled Model Intercomparison Project (CMIP, Meehl et al., 2000) has contributed through multiple phases to the assessment reports of the Intergovernmental Panel on Climate Change (IPCC, Meehl et al., 2023), e.g., the sixth phase of CMIP (CMIP6, Eyring et al., 2016) created experiments that were also used in the sixth IPCC assessment report (IPCC-AR6)“

L.85-100: Some lines use the past tense and other the present tense, please standardise .
Thanks, it is written in past tense now.

L.88: “for the answer to the MIP’s question” => “in the answer to the MIP’s question “
Changed as suggested.

L.115: “and refers to the same term as short-lived climate forcings (SLCFs) used by Collins et al.”
=> “and refers to the same concept than short-lived climate forcings (SLCFs) used by Collins et al.”
Changed to: „NTCF is used by Collins et al. (2017) and is the same as short-lived climate forcings (SLCFs) used in IPCC-AR6.“

L 155: I don’t understand what “quantify radiative forcing within and outside of the three MIPS” means, please clarify.

We mean that the concept of forcing calculation is also followed by others that are not participating in the MIPS. We removed it, now: „(...) consistent methodology to quantify radiative forcing, which facilitated easier comparisons across CMIP6.“

L.268: Change “out of the” for “of the” in “Available model output to assess differences in forcing and response was, however, limited, e.g., output for the mid-visible aerosol optical depth is available only for 45 out of the 67 models providing historical experiments.”
Changed as suggested.

L.345: “and also pose challenges for reducing model-based uncertainty” => “but pose challenges in reducing model-based uncertainty”
Changed as suggested.

L.365: remove “in” in “do not prescribe the level of process complexity in a ...”
Changed as suggested.

L.545: “globally for restricted time periods of a few weeks to years” : be more specific on the number of years so to be coherent with the first part of the sentence.
Revised to: „Kilometer-scale experiments with horizontal grid spacings finer than 10 km are presently only possible for climate studies on limited area domains or globally for restricted time periods of a few weeks to single years.“

L.569: make a new paragraph before “We perceive dynamical downscaling ...”
Done.

L.645: As suggested by referee #2: “There is the opportunity” => “There is an opportunity” (you did not make the change).
Thanks for spotting it, it is now changed as suggested.

L.710: “is smaller for the separate MIPS” => “than what it would be for one converged MIP”

Added as suggested.

Table 1: The additions made in the legend are not self-coherent. For example “hist-X” does not appear as is in the column (does it refer to “hist” and/or “hist-piAer” ?) while “histSST-X”, “piClim-X” and “piClim- 2xX” do appear as is. Also “piControl” and all “ssp370...” are not described; please change.

Thanks, we now simplified the entries in the experiment column for a better coherence and introduce all experiment abbreviations in the caption: „Key results from the three MIPs for their research topics. Listed experiments are fully coupled atmosphere-ocean experiments for the historical time period (*hist-X*), experiments with prescribed transient changes in sea-surface temperatures and sea-ice for the historical time period (*histSST-X*), experiments with prescribed sea-surface temperatures and sea-ice at pre-industrial level (*piClim-X*), fully coupled atmosphere-ocean experiments for future projections using scenario SSP3-7.0 (*ssp370-X*), experiments for future scenarios with prescribed sea-surface temperatures and sea-ice (*ssp370SST-X*), where *X* refers to single or several climate forcings. Experiments with prescribed doubled emission fluxes are listed as *piClim-2xX*, pre-industrial control experiments as *piControl*, and experiments with abruptly quadrupled CO₂ concentrations as *Abrupt-4xCO2*.“

Finally, I see that Table 4 has thoroughly changed without justification; can you make some comments on why you made all those changes?

These changes were part of improving the readability and clarity that was requested. In Table 4, we alphabetically sorted the rows and adjusted words of the entries.