

Author response to Referee 2

We thank the referee for the careful, critical, and constructive review. We appreciate the recognition of the practical motivation of the study, notably the need to efficiently exploit existing EURO-CORDEX simulations and to facilitate the use of large CMIP ensembles for climate services and impact applications. We also acknowledge the referee's concerns regarding the underlying assumptions of the proposed method, in particular those related to differences between CMIP5- and CMIP6-based forcings, model characteristics, and physical consistency. We agree that these assumptions require clearer justification and a more explicit discussion of their implications and limitations. Below, we respond point by point to all general and specific comments and outline how they will be addressed in a revised version of the manuscript.

Response to general comments

Referee comment:

This paper presents a method to adjust CMIP5-based RCM simulations to better align with CMIP6 GCM simulations. I perfectly see the value in combining or merging scenario generations, I also see the need of speeding up the process of downscaling CMIP ensembles with CORDEX RCMs. The number of people struggling with these issues is quite large.

As I see it this study builds on a premise that is, if not false, at least not proven. You assume that CMIP5-based RCM simulations can be related to CMIP6 GCMs in a consistent way. There are a few problems with this, however. 1) The CMIP5 and the CMIP6 models are not the same, and they have different climate sensitivity. You state this yourself in the paper. 2) RCP8.5 and SSP5-8.5 do not prescribe the same GHG concentrations (Wyser et al., 2020). 3) In the reference period you use, 1991-2020, the scenario period starts 2006 in RCP8.5 and 2016 in SSP5-8.5, thus the proportion of observed and assumed emissions is different.

Taken together, this raises a few questions. If the forcing is different and the models are different, why should we expect the results to be the same, and why is it motivated to adjust CMIP5-based RCMs to better fit CMIP6 GCMs? It can be suggested that the CMIP6 scenarios are better because they are newer, but when you decouple GHG forcing and climate response, as I see that you do with the RCM simulations, the physical consistency breaks down.

I might have missed something, but for this paper to be published I think these questions need to be properly explained.

Author response:

We acknowledge that this is a central point that needs to be more clearly explained in the manuscript. The proposed method does not assume that CMIP5-based RCM simulations and CMIP6 GCM simulations are physically equivalent or interchangeable. It rather represents a pragmatic approach in which existing high-resolution RCM simulations are adjusted to enable a

consistent chain from emission scenario to global and regional warming (CMIP6) to the grid-cell scale (RCM).

We fully agree that CMIP5 and CMIP6 differ in climate sensitivity, forcing trajectories, and model formulation, and that RCP8.5 and SSP5-8.5 do not prescribe identical greenhouse gas concentrations. The method does not attempt to reconcile these differences at the level of radiative forcing or climate sensitivity. Instead, it uses global mean temperature as a common reference variable to align the long-term regional temperature evolution across simulations.

This decoupling is standard practice in the warming-level framework widely adopted in AR6(IPCC 2021; Arias et al., 2021) and in climate services. In this context, the proposed adjustment should be seen as a practical tool to exploit existing RCM simulations under a CMIP6-consistent global warming framework, rather than as an attempt to restore full physical consistency between forcing and regional climate response. The limitations associated with this assumption will be stated more explicitly in the revised manuscript.

Reference:

Chapter 4: Future Global Climate: Scenario-Based Projections and Near-Term Information.

In: *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

Arias, P. A., Bellouin, N., Coppola, E., Jones, R. G., Krinner, G., Marotzke, J., Naik, V., Palmer, M. D., Plattner, G.-K., Rogelj, J., Rojas, M., Sillmann, J., Storelvmo, T., Thorne, P. W., Trewin, B., AchutaRao, K., Adhikary, B., Allan, R. P., Armour, K. C., Bala, G., et al., Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 553–672.
<https://doi.org/10.1017/9781009157896.006>

Specific comments

L10

RC: *“physical coherence” I don’t see how this is achieved. See general comments above.*

Author response:

The wording will be clarified. The term “physical coherence” refers here to the preservation of spatial patterns and inter-variable relationships within each selected annual RCM field, not to full forcing–response consistency across model generations. This distinction will be made explicit.

L31–33

RC: *It would be good to specify that this statement applies to Europe (specifically west central Europe). The aerosol forcing problem is not a problem in northern Europe. I don’t know how it is in the rest of the world.*

Author response:

The geographic scope will be specified more clearly. The statement will be revised to explicitly refer to Europe, and where relevant to west-central Europe.

L41 and related occurrences

RC: Please specify that you are talking about CMIP5-based RCM (and not GCM) simulations here, because it explains some of the differences to CMIP6 GCMs.

Author response:

The text will be revised to consistently specify “CMIP5-based RCM simulations” where appropriate, in order to avoid confusion with CMIP5 GCMs or not yet published CMIP6-based RCM simulations.

L44–46

RC: Another reason for this could be that RCMs better resolve some processes, and that the results from RCMs actually are better. Are all differences between CMIP5-based RCMs and CMIP6 GCMs a proof that the GCMs are better?

Author response:

This point will be addressed more explicitly. The revised manuscript will clarify that differences between CMIP5-based RCM simulations and CMIP6 GCM simulations do not necessarily imply superior realism of the GCMs. In particular, we will acknowledge that RCMs can better represent certain regional processes and extremes due to their higher spatial resolution and more detailed process representation. The intent of the method is therefore not to rank model generations, but to retain the strengths of existing high-resolution RCM simulations while expressing their long-term evolution within an updated, CMIP6-consistent global warming framework.

L63

RC: Again, CMIP5-based EURO-CORDEX simulations.

Author response:

This will be applied for consistency.

L64–66

RC: I find this sentence a bit awkward, unnecessarily long. Consider rephrasing to something like: “CMIP5-based EURO-CORDEX simulations as 0.11 degree horizontal resolution, the best available”.

Author response:

The sentence will be simplified along the lines suggested by the referee.

L71–77

RC: *See general comments. I would argue that there are reasons for at least some of these differences, and that this not necessarily mean that one ensemble is wrong. It's just that they are based on different data and different models.*

Author response:

The text will be revised to better reflect that differences between ensembles arise from different models and forcing assumptions, and do not imply that one ensemble is intrinsically incorrect.

Figure 1a

RC: *"CMIP6-CORDEX" could mean CMIP6-based RCM simulations. Consider using "CMIP6 GCMs – CMIP5 RCMs" or something like that.*

Author response:

The label will be revised to avoid ambiguity, for example by explicitly referring to "CMIP6 GCMs" and "CMIP5-based RCMs" and changing the combined names along the lines suggested by the referee.

Figure 1b

RC: *C6" -> "CMIP6"*

Author response:

This will be corrected.

Figure 1c.3 (axis increments)

RC: *It would be helpful if the increments are the same on the x-axis and the y-axis.*

Author response:

The figure will be revised accordingly.

Figure 1c.3 (grey dots)

RC: *The text mentions "grey dots". The grey dots I see are the vertical lines, which I don't think are referred to. I think the text refers to the grey dots that look like a line. Consider using different colours.*

Author response:

The figure and caption will be revised to clarify which elements are referred to, and colours will be adjusted to improve readability.

Figure 1c.4

RC: What is the blue line, and the thin orange line? Add to legend.

Author response:

These elements will be added to the legend and explained in the caption. They show the same information in the same color as in 1c.1.

L151

RC: Does this approach assume a constant relationship between global and local warming? It's not clear to me.

Author response:

This point will be clarified. The revised manuscript will explain that the method relies on a monotonic, but not necessarily strictly linear, relationship between global and regional warming over the selected windows.

Section 2.4 and figure order

RC: Considering the lengthy description of Fig 3 here, should the ordering of the figures be changed so that Fig 3 comes before Fig 2? That seem logical to me. Fig 2 is only briefly mentioned before this.

Author response:

The ordering of figures and sections will be reconsidered to improve logical flow.

L162

RC: Please explain the "IPCC GMT trajectories" more. Where do they come from, and what are they based on? How is it different from the CMIP6 GCM ensemble?

Author response:

The origin and meaning of the IPCC global-mean temperature trajectories will be explained more explicitly, including how they differ from raw CMIP6 ensemble trajectories. We will clarify that the "IPCC GMT trajectories" are smoothed, scenario-based global-mean temperature pathways used in the IPCC AR6 Working Group I assessment. They are derived from observations and climate model responses to represent central, scenario-consistent estimates

of global warming, in contrast to raw CMIP6 GCM outputs, which include model-specific variability and internal climate fluctuations.

For reproducibility, these trajectories can be accessed via the IPCC Data Distribution Centre and the World Data Center for Climate (WDCC). The assessed global surface air temperature (GSAT) projections are archived in the dataset *IPCC-DDC_AR6_Sup_GSATPr* (DOI: 10.26050/WDCC/AR6.IPCC-DDC_AR6_Sup_GSATPr), which includes metadata and NetCDF files. Broader IPCC data, including scenario inputs and CMIP6 model outputs, are available at <https://www.ipcc-data.org>.

L164

RC: “chatateristics” -> “characteristics”?

Author response:

This will be corrected.

L165

RC: “trajectoeies” -> “trajectories”?

Author response:

This will be corrected.

L192

RC: “intermediate behaviour” feels like an awkward formulations. Consider rephrasing.

Author response:

This wording will be revised.

L194

RC: *I don't agree with the use of “modifications” here. Modifications are something you do, not a result of your method, nor a part of the climate system.*

Author response:

The terminology will be revised to avoid confusion between methodological adjustments and physical processes.

L201–211

RC: These paragraphs seem a bit redundant. Was this not explained already in sec 2.4? I don't see any real results here. Consider to move to, and merge with, 2.4.

Author response:

The structure will be revised to reduce redundancy, potentially by merging these paragraphs with Section 2.4.

L223

RC: I don't fully understand how you did the adjustment of TXx. Is the adjustment made on TXx? I thought that only annual Tm was adjusted, and don't see how TXx could be derived from that.

Author response:

We will clarify that TXx is warming-adjusted following the same procedure as for mean temperature. The reassembling table created for the mean-temperature adjustment provides the year mapping, which can be applied to compute TXx from the warming-adjusted annual data in a consistent way.

Figure 3b

RC: It would be more logical to put IPCC range and IPCC mean together in the legend.

Author response:

The legend will be revised accordingly.

Figure 3c

RC: Consider using colours that are more different and to use dashes and dots.

Author response:

The figure will be revised to improve visual clarity.

Figure 4a and 4b

RC: Could be more clear that "IPCC" in the title and legend actually means RCM simulations.

Author response:

The titles and legends will be revised to remove ambiguity.

Figure 4 caption

RC: “*responsetatasets*” -> “*response data sets*”?

Author response:

This will be corrected.

L240

RC: *What are modifications if not adjustments? I don't think that you need to demonstrate this, I think you should demonstrate how your modifications effect the climate change signal.*

Author response:

The terminology will be simplified, and the focus will be placed on how the adjustments affect the climate change signal.

L243

RC: *Again, it sounds a bit strange to say that adjustments led to modifications. They are the same to me. I see what you want to say. Isn't it enough to just say: "The adjustments produce shifts ..."?*

Author response:

The sentence will be rephrased as suggested.

L244

RC: *"These outcomes reflect an additional information layer ..." I don't understand this sentence.*

Author response:

This sentence will be clarified or reformulated.

L246

RC: *"These findings underscore..." Do they? In what way? I thought they showed the importance of adjustments.*

Author response:

The conclusion drawn from these findings will be stated more explicitly. Specifically, they show that unadjusted model outputs can misrepresent the magnitude and timing of extreme temperature changes, and that using warming-adjusted data ensures consistency with

scenario-based global warming targets. We will rephrase the sentence to explicitly reflect this interpretation rather than making a broader claim.

L250–251

RC: *How useful for adaptation planning and impact modelling are the new annual ensemble means over large areas that you produce here? They usually require higher spatial and temporal resolutions.*

Author response:

We will clarify that the annual ensemble means are intended to provide regional-scale information on trends and variability. While they are less suitable for detailed local impact modelling due to their spatial and temporal resolution, they can still support broader adaptation planning and serve as a reference for downscaling approaches.

L255

RC: “replace CMIP6-CORDEX” Isn’t the question rather whether they should replace CMIP5-CORDEX RCMs?

Author response:

This wording will be corrected.

Figure A1 caption

RC: *like Fig, 1a. (b) Like (a), but for” is a bit difficult to understand. Please rephrase.*

Author response:

The caption will be rewritten for clarity.