Response to Reviewers' Comments on egusphere-2022-215

Changgui Lin[1,2], **Erik Kjellström**[1,3], **Renate Anna Irma Wilcke**[1], **and Deliang Chen**[2]

[1]Rossby Centre, Swedish Meteorological and Hydrological Institute, Norrköping, Sweden
[2]Regional Climate Group, Department of Earth Sciences, University of Gothenburg, Gothenburg, Sweden
[3]Department of Meteorology and the Bolin Centre for Climate Research, Stockholm University, Stockholm, Sweden

Correspondence: Changgui Lin (mapulynn@gmail.com)

We thank the reviewers for their positive evaluation on the first round of revision. We also appreciate the detailed and helpful comments raised by Reviewer #2, which we feel, again, will considerably improve the manuscript. Please see our detailed responses below.

1 Reviewer #2

General remarks:

Comment 1.1: It remains still unclear to me how the model ensemble was chosen. When considering Vautard et al. (2020), also MPI would have simulations for all 4 RCMs selected. Why is thus, e.g., the MPI model not included? If only a subset of available models is selected for a study, a thorough justification is needed to guarantee that not only models that support some results are chosen, while excluding others that would yield contradict these results. I thus strongly encourage the authors to clearly explain and justify the selection of models in the manuscript.

Reply: We understand the reviewer's concern for the influence of selecting models on the results. As we stated in the Subsection 2.2 (Climate model simulations and other data), the main requirement is that the GCM-RCM combinations should be a full matrix without gaps. The selected GCM-RCM combinations represented such a matrix with the largest size at the time we conducted the analysis. The following justification was added during this round of revision (L97–100):

> *It is worth noting that "GCM" here represents GCM data rather than GCM itself, since we are concerned about the role of driving data in influencing RCM simulation results; i.e., different ensemble members from one GCM model (e.g., EC-ERATH_r12i1p1 and EC-EARTH_r1i1p1) were not treated as the same "GCM". Likewise, "RCM" here means no differences in dynamic core and physics parameterizations.*

That means REMO2009 and REMO2015 were not treated as the same "RCM" in the study. MPI, opposite to other GCMs, has simulations for REMO2009 but not for REMO2015. So, it is not true that "MPI has simulations for all 4 RCMs selected".

Regarding the potential uncertainty subject to the selection of GCM-RCM combinations, we already have the following text within Discussion (L378–380):

> *In fact, we conducted the same analyses upon another GCM-RCM simulation matrix (GCMs: EC-EARTH, HadGEM2-ES, and MPI-ESM-LR; RCMs: CCLM4-8-17, HIRHAM, RACMO22E, and RCA4) and derived similar results (not shown), which can alternatively support the conclusions herein.*

Comment 1.2: I appreciate the efforts that the authors made to relate the observed changes in HWMId to drying trends, but I think that the discussion of this remains too short. Currently, it is basically summarized in only one sentence "The r values in Fig. S9–S11 read that the general warming, compared to drying, plays a small role in regulating the spatial pattern of HWMId in GCM simulations, different from the case of the RCMs."

I would thus ask the authors to expand the discussion about the influence of dryness on HWMId. In particular, I think that the varying importance of drying in the south and north (strong influence in southern Europe but rather unimportant in Northern Europe) deserves some more discussion.

Reply: First we would like to make a clarification that it is the projected future changes within the simulations we focused in this part of discussion. Second, following the reviewer's suggestion, we have added some text (L355–360; right after the sentenced mentioned) expanding the discussion about the influence of dryness on HWMId, as follows:

> *This echoes the varying importance of drying in influencing ΔHWMId in northern Europe for GCM and RCM simulations; i.e., the wetting trend in northern Europe, projected by both the GCM and RCM simulations (Fig. S10 and S11), seems to dampen the local ΔHWMId within the GCM simulations, but has little impact on the local ΔHWMId within the RCM simulations. It is interesting and deserves further study which factors cause the varying importance of drying in influencing heat wave magnitudes and how differently GCMs and RCMs represent these factors.*

Comment 1.3: Furthermore, the manuscript should be thoroughly scrutinized regarding grammar, orthography, and sentence structure. Although I acknowledge that the text has improved and is well understandable in general, it lacks clarity in some instances, which I think can mostly be resolved by improving the language.

Reply: We have followed the suggestion by going through the manuscript several times and rephrasing some sentences when needed.

Specific remarks (all line numbers refer to the manuscript version with tracked changes):

Comment 1.4: Line 5: Add "observation-based estimates" and/or shortly explain what E-OBS is.

Reply: We have added "(observation-based estimates)" as a short explanation.

Comment 1.5: Line 9: It is unclear what "west-east gradient" refers to, as this has not been introduced before and it is also unclear to which dataset "reproducing" refers to.

Reply: The corresponding text has been rephrased as "(e.g., by reproducing the general pattern revealed by E-OBS with high values at western coastal regions and low values at the eastern part)"

Comment 1.6: Line 44: I would rather use "regional climate models" instead of "a regional climate model" to highlight that there are several RCMs available (and not just one)

Reply: We have followed the suggestion.

Comment 1.7: Line 67: "the EURO-CORDEX collection": This sentence implies that GCM-RCM combinations of the whole collection are used, but afterwards only a subset is applied. I would suggest making clear from the beginning that only a subset is used (see also my general comment above)

Reply: We have added "a subset of " before "the EURO-CORDEX collection".

Comment 1.8: Line 75: Add "maximum temperature (Tmax)", otherwise it remains unclear what Tmax is.

Reply: We have followed the suggestion.

Comment 1.9: Line 84: Add "the calculation of Tmax,ref,25p and Tmax,ref,75p. . . "

Reply: We have followed the suggestion.

Comment 1.10: Line 86: "and somehow makes calculation more stable." In my eyes, this statement does not create trust in the results. What exactly does it mean? Or can it be removed? I think that it should also be noted here whether any tests have been performed to check that the results are in fact similar when using the two different approaches to calculate Tmax,ref.

Reply: We removed "and somehow makes calculation more stable." and have added "as we see similar spatial patterns of HWMId in E-OBS for the extreme years (Fig. S4–S7) compared to those presented in Russo et al. (2015, Fig. 2 therein)".

Comment 1.11: Lines 97-99: see my general remark about justification of the selected model ensemble.

Reply: Please see our reply to Comment 1.1.

Comment 1.12: Lines 99-100: This sentence should be revised, as it contains duplicate statements.

Reply: The sentence has been revised as:

> *The driving GCM simulations, from CMIP5, include runs with historical forcing (to 2005) and projection runs (since 2006) forced with representative concentration pathways (RCPs).*

Comment 1.13: Lines 115-117: The text should shortly explain why the different reference periods are necessary. And I think it would be good to also highlight that the reference period for ERA-Interim-driven runs is 20 years, while it is 30 years for the

GCM-driven runs.

Reply: Following the suggestion the corresponding text has been revised as:

> *When RCMs are driven by ERA- Interim the reference period for HWMId is 20-year period 1989–2008 as limited by the short evaluation runs, and when driven by GCMs it is 30-year period 1981–2010 following Russo et al. (2015).*

Comment 1.14: Line 124-125: What does "As a background of warming" mean?

Reply: The corresponding sentence has been revised as:

> *The simulated climate change signals in annual mean T_{max} were also examined, showing the direct impact of warming.*

Comment 1.15: Line 194: Replace "in no way" by "not well", otherwise it sounds exaggerated.

Reply: We have followed the suggestion.

Comment 1.16: Line 233: Here, it should be highlighted that RCP8.5 was used.

Reply: We have followed the suggestion.

Comment 1.17: Line 234: I can still see some differences in the maps, and thus I would suggest replacing this sentence by something like: "The HWMId patterns do generally stay similar within the two observed time periods, according to the spatial r."

Reply: We have followed the suggestion.

Comment 1.18: Line 240-241: I would suggest changing "compared to the driving HadGEM2-ES and NorESM1-M" to "than two out of the three driving models (i.e., HadGEM2-ES, NorESM1-M)"

Reply: We have followed the suggestion.

Comment 1.19: Line 257: I would again highlight that this is only true for RCP8.5, thus add "under the high emissions scenario RCP8.5" at the end of the sentence

Reply: We have followed the suggestion.

Comment 1.20: Line 272: Again, I would change: "become more common" to "would become more common under the high emissions scenario RCP8.5"

Reply: We have followed the suggestion.

Comment 1.21: Line 287: I would add "RCM" before "runs"

Reply: We have followed the suggestion.

Comment 1.22: Lines 317-319: I think, "information" is not the right term, as it is much more than just "information" that is added. Maybe "details" or "additional processes"? Or maybe you have a better idea?

Reply: We have replaced "information" by "details".

Comment 1.23: Line 319-320: I think, this statement needs a reference.

Reply: We have followed the suggestion.

Comment 1.24: Line 324: I don't think that one study is enough to "reject" this hypothesis in general. Maybe better use "questioning"?

Reply: We have used "questioning" instead.

Comment 1.25: Lines 328-330: But isn't that the most known and most prominent added value of RCMs? I would not see this as a new finding.

Reply: We agree. The corresponding sentences have been revised as:

> *Some spatial features of HWMId showing orographic traces, thereby considered to be related to orographic effects, can be seen as one aspect of the added value of RCMs as GCMs cannot represent such features due to too coarse spatial resolution. An interesting finding of this study is that the orographic effects are however represented differently across the RCMs (i.e., the large ensemble spread along the RCM dimension; Fig. 4), suggesting that the representation of orographic effects, possibly related to dynamical/thermodynamical interaction with parameterizations, is meanwhile one of the major sources of uncertainty.*

Comment 1.26: Line 337: "The exponential increase is patent": This sound rather exaggerating to me, better find a more neutral formulation.

Reply: Following the suggestion, the corresponding sentence has been revised as:

> *The RCMs, as well as the driving GCMs, project a rise in HWMId values at an exponential rate under RCP8.5 on the European continent, as we can observe the linear shape of time series when plotting on a logarithmic scale (Fig. S8).*

Comment 1.27: Line 343: Replace "this scenario" by "RCP8.5"

Reply: We have followed the suggestion.

Comment 1.28: Line 409: Which are the GCMs and RCMs that have additionally been analysed? These should be indicated in any case, as otherwise the statement cannot be tested or reproduced.

Reply: We have added the information of GCM and RCM members: "(GCMs: EC-EARTH, HadGEM2-ES, and MPI-ESM-LR; RCMs: CCLM4-8-17, HIRHAM, RACMO22E, and RCA4)"

Comment 1.29: Lines 413-415: Check sentence structure

Reply: The sentence has been revised as:

> *As another example, Apparent Heat Wave Index (AHWI, Russo et al., 2017), is the HWMId applied to daily apparent temperature, which considers also the impact of air humidity on human beings. Such variants of HWMId are being considered for future studies.*

Comment 1.30: Line 421: I cannot fully support this statement. If one considers, e.g., the summer of 2003, it is obvious that RCMs do not fully replicate the observed HWMId patterns (Figure S5).

Reply: The statement has been revised as:

> *It shows that the RCMs generally capture most spatial and temporal features of the observed HWMId when considering climatological mean and regional mean, respectively.*

Comment 1.31: Line 429: Add "of heatwaves" at the end of sentence.

Reply: We have followed the suggestion.

Comment 1.32: Table 1: I think it would be good to indicate the resolution in degree latitude and degree longitude as well. I personally cannot directly translate T159L62 or N96L38 into a grid resolution in lat/lon.

Reply: Following the suggestion we have added the resolution in lat/lon.

Comment 1.33: Figure 3: red rectangle -> blue rectangle (in caption)

Reply: Corrected.

Comment 1.34: Figure 4: 2020 -> 2010 (in caption)

Reply: The recent past climate is defined as the 40-year period 1981–2020, whereas The 1981–2010 is the reference period for HWMId calculation. Therefore, no change is needed here.