How does the CMIP6 ensemble change the picture for European climate projections?

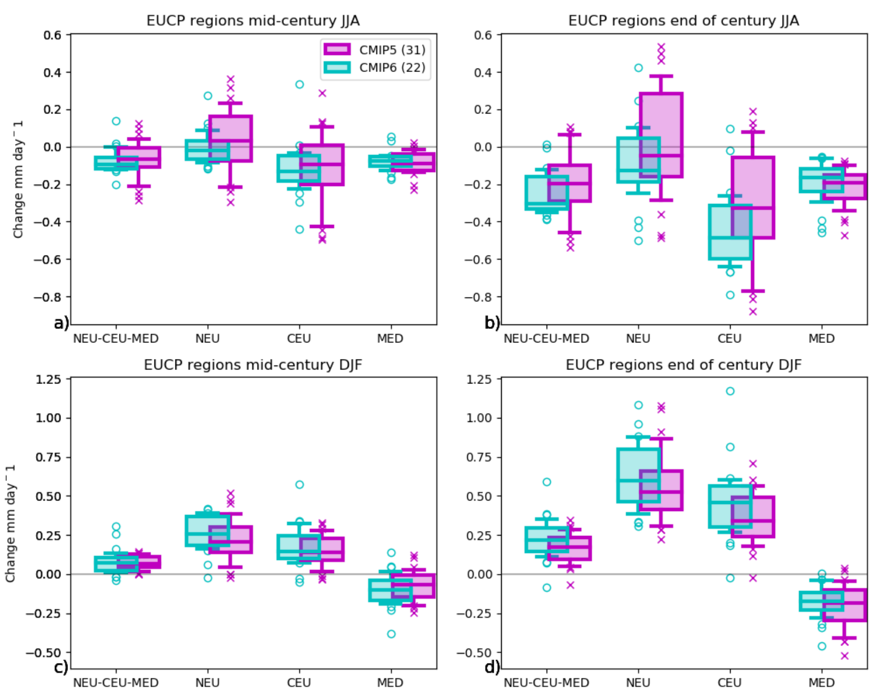
Tamzin Emily Palmer[1], Ben Booth[1], and Carol Frances McSweeney[2]

[1]Met Office
[2]Met Office Hadley Centre

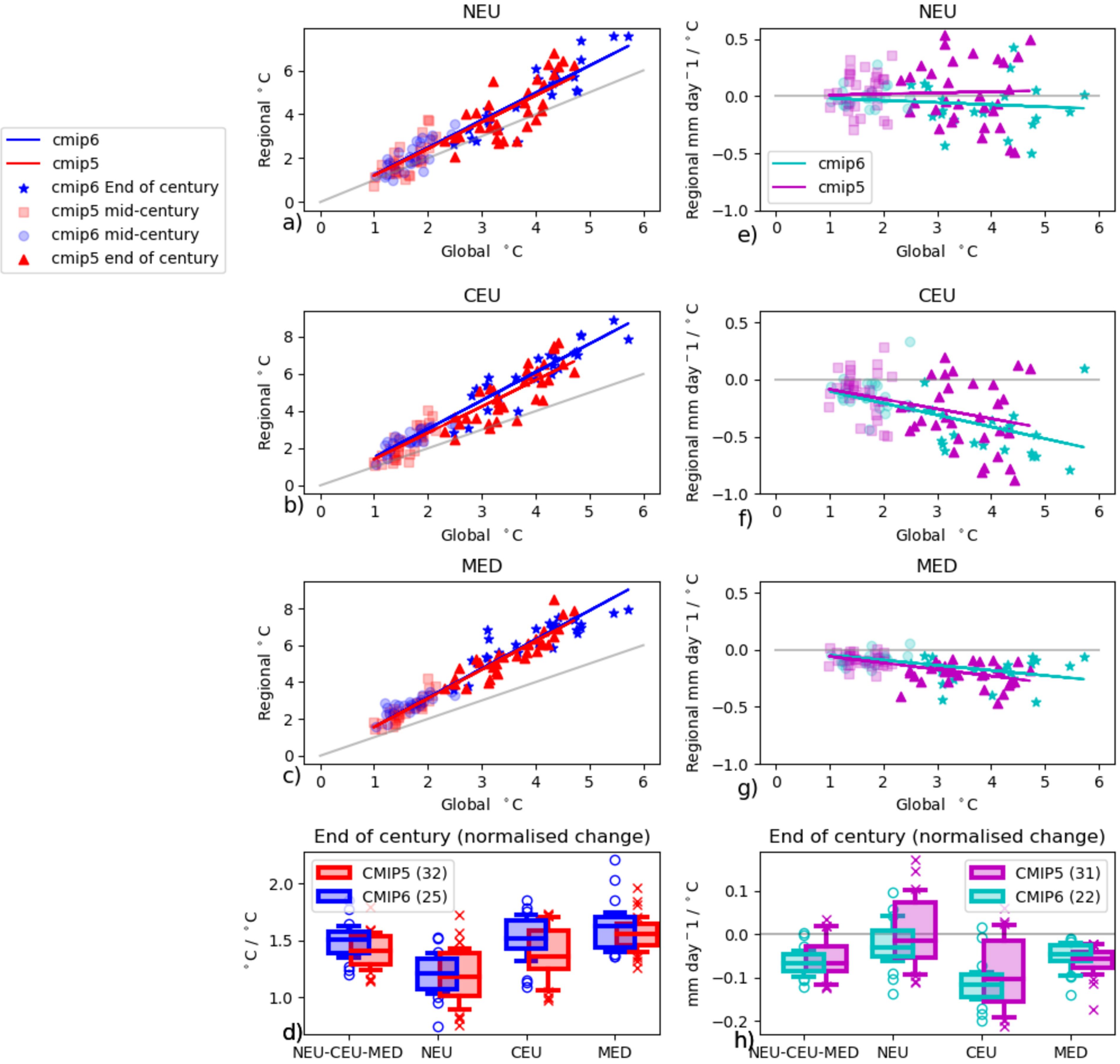
November 26, 2022

Abstract

Reliable climate projections are essential for adaptation and mitigation planning. We compare CMIP6 projections for temperature and precipitation to CMIP5 for northern Europe, central Europe and the Mediterranean. The CMIP6 ensemble shows an increased projected summer warming compared to CMIP5. Central Europe was also found to have a stronger drying trend in the summer months in CMIP6. We show that warmer projected summer temperatures are largely driven by CMIP6 sampling higher global climate sensitivities, with broadly similar regional responses to these. For those interested in central estimates of European changes, CMIP6 does not change the existing CMIP5 picture but better samples higher end change for more risk adverse users. However, regional sensitivity is important in central Europe where it accounts for roughly 40$\%$ of the differences between ensembles in projected regional temperature. This analysis raises an important question about whether CMIP6 can be considered to supersede CMIP5, or supplement it

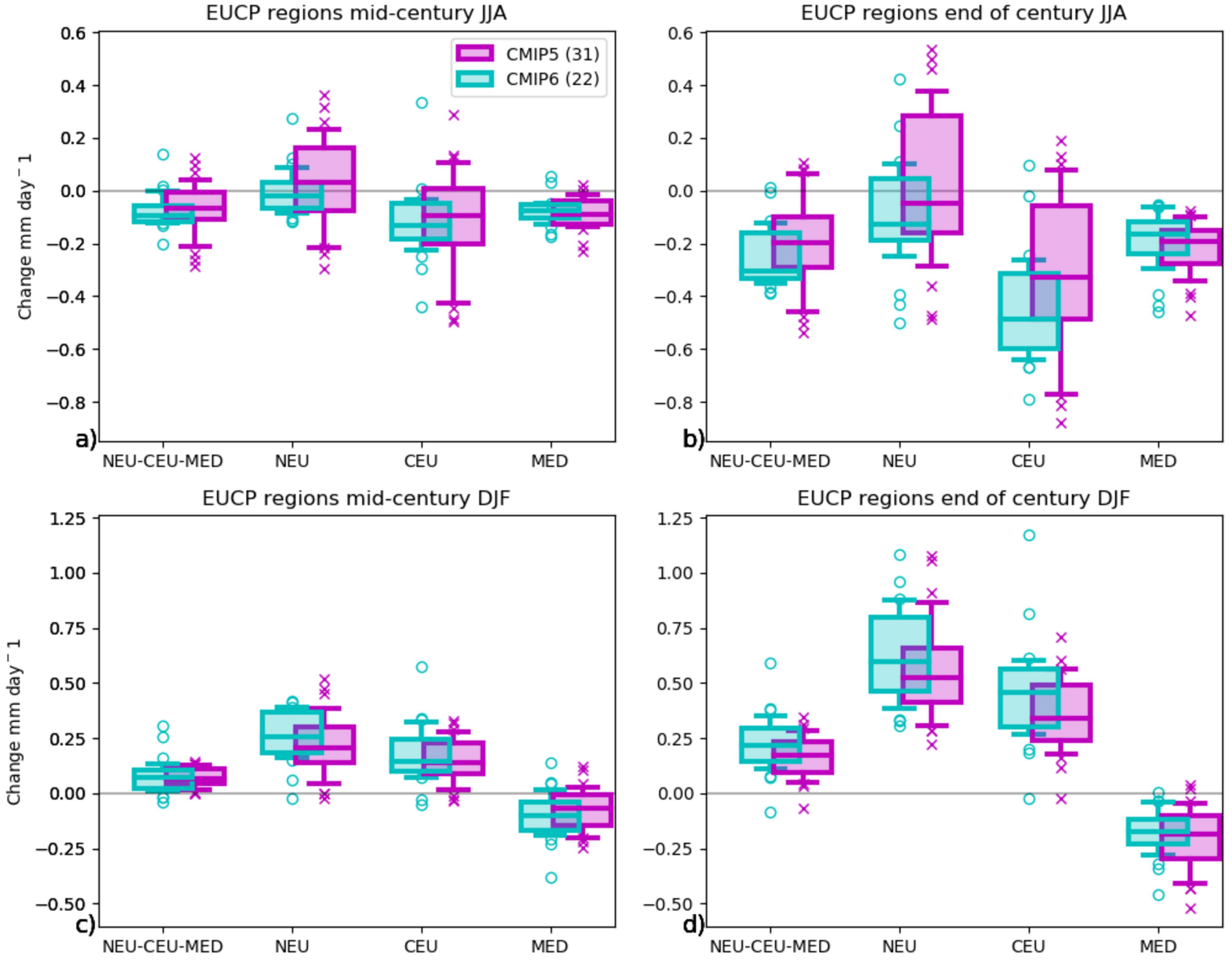


combined_fig.png. combined_fig.png



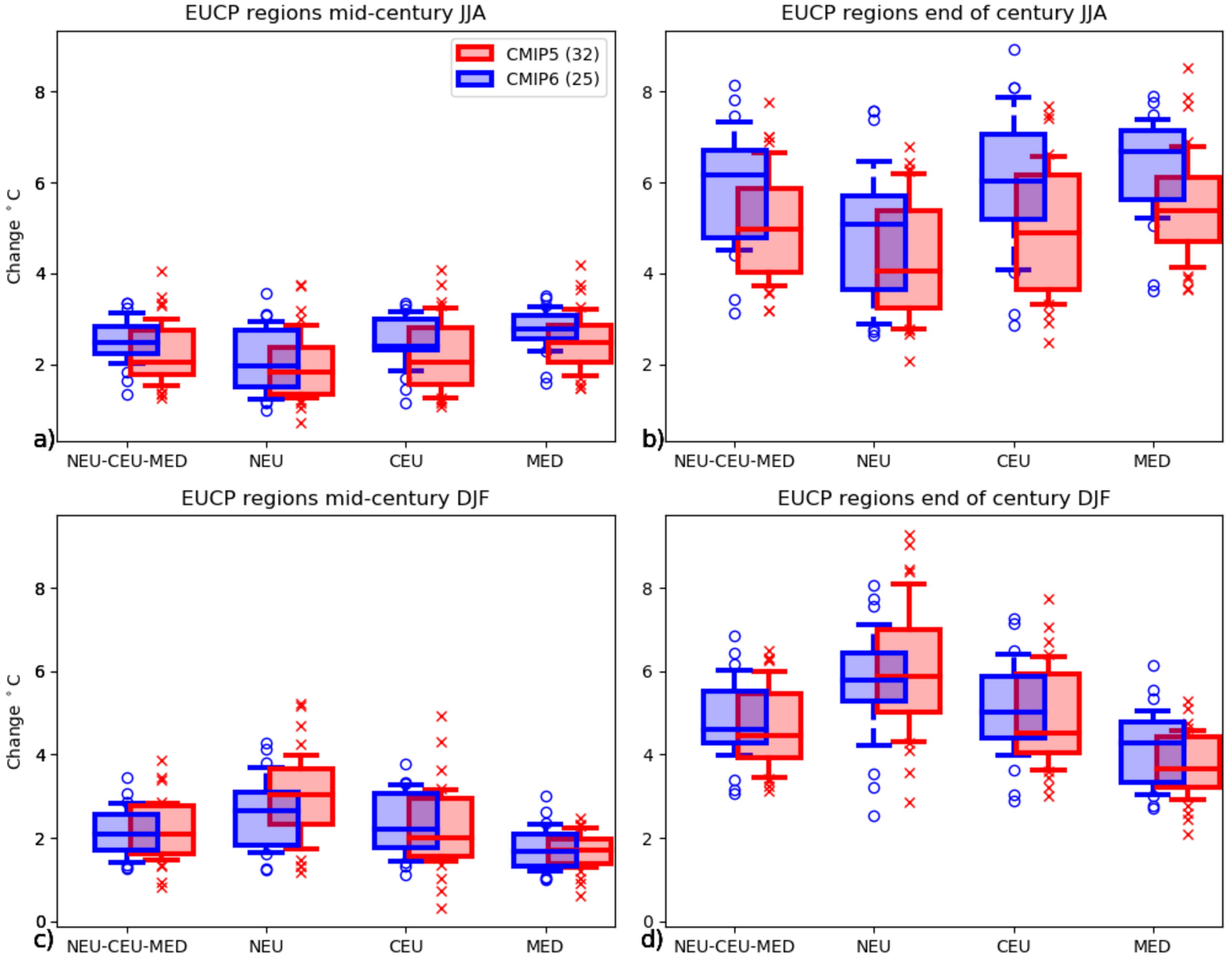
NEU
CEU
MED
End of century (normalised change)
cmip6
cmip5
cmip6 End of century
cmip5 mid-century
cmip6 mid-century
cmip5 end of century
Regional °C
Global °C
Regional mm day⁻1 / °C
°C / °C
mm day⁻1 / °C
CMIP5 (32)
CMIP6 (25)
CMIP5 (31)
CMIP6 (22)
NEU-CEU-MED
a)
b)
c)
d)
e)
f)
g)
h)

Figure 2.



EUCP regions mid-century JJA
EUCP regions end of century JJA
EUCP regions mid-century DJF
EUCP regions end of century DJF
CMIP5 (31)
CMIP6 (22)
Change mm day^{-1}
NEU-CEU-MED
NEU
CEU
MED
a)
b)
c)
d)

Figure 1.


EUCP regions mid-century JJA
EUCP regions end of century JJA
EUCP regions mid-century DJF
EUCP regions end of century DJF
CMIP5 (32)
CMIP6 (25)
Change ° C
NEU-CEU-MED
NEU
CEU
MED
a)
b)
c)
d)

How does the CMIP6 ensemble change the picture for European climate projections?

T.E. Palmer[1],B.B. Booth[1], C.F. McSweeney[1]

[1]Met Office, Exeter, EX1 3PB, UK

Key Points:

- The CMIP6 ensemble projects greater warming in the summer for all European regions than CMIP5.
- CMIP6 shows a clearer and more consistent increased summer drying trend in central Europe with increasing global temperatures.
- Our results suggest that using a combination of CMIP5 and CMIP6 in assessing the risks posed by global warming to European regions may provide a more complete picture.

Corresponding author: Tamzin Palmer, `tamzin.palmer@metoffice.gov.uk`

Abstract

Reliable climate projections are essential for adaptation and mitigation planning. We compare CMIP6 projections for temperature and precipitation to CMIP5 for northern Europe, central Europe and the Mediterranean. The CMIP6 ensemble shows an increased projected summer warming compared to CMIP5. Central Europe was also found to have a stronger drying trend in the summer months in CMIP6.

We show that warmer projected summer temperatures are largely driven by CMIP6 sampling higher global climate sensitivities, with broadly similar regional responses to these. For those interested in central estimates of European changes, CMIP6 does not change the existing CMIP5 picture but better samples higher end change for more risk adverse users. However, regional sensitivity is important in central Europe where it accounts for roughly 40% of the differences between ensembles in projected regional temperature. This analysis raises an important question about whether CMIP6 can be considered to supersede CMIP5, or supplement it

Plain Language Summary

It is important to have reliable projections of the future climate for both mid-century and the end of century to allow countries to adapt to climate change. Ensembles of climate models are used to construct projections of future climate and to quantify how confident scientists are about what they can tell us.

New data from a new ensemble of climate models called CMIP6 has been released. We find that the CMIP6 projections compared to the previous ensemble (CMIP5) predict higher summer temperatures Europe. The trend of drier summers (decreased amounts of precipitation) in central Europe is also slightly stronger in CMIP6 than CMIP5. Many of the CMIP6 models have a higher sensitivity to changes in greenhouse gases in the atmosphere, causing them to project greater global warming. We find that while this increase in global warming accounts for much of the increased summer temperatures in Europe for CMIP6, differences in the regional sensitivity of the models accounts for about 40% of the increased warming in central Europe. These new projections from CMIP6 show that higher summer temperatures may occur in Europe due to global warming than previously considered likely, which will need to be taken into account for planning adaptation.

1 Introduction

1.1 Rationale and Motivation

Robust climate projections are needed for strategic adaptation and mitigation planning at the global, regional and national level. Inferences about robustness are heavily influenced by what is learnt about future climate change from multi-model ensembles, which can be used to sample the known uncertainties in climate change responses due to intrinsic variability, structural differences in the models and different socio-economic pathways.

A new generation of climate models provides an opportunity to assess if the new developments in the latest Coupled Model Intercomparison Project (CMIP) ensemble (CMIP6), changes the picture regarding what is know about climate projections for Europe. Previous generations of ensembles such as CMIP3 and CMIP5 have not lead to much change in the overall projections (Kumar et al., 2014; Knutti & Sedláček, 2013), despite improvements in the model science and better integrated earth systems models. Early indications are that CMIP6 may be different in this regard with a number of models showing much higher climate sensitivity e.g. (Forster et al., 2020). These new models may have a large impact on projected climate responses for European regions and it is unknown to what extent our picture of the known risks of global warming may be changed in regions already considered climate change 'hot spots' such as the the Mediterranean (Lionello & Scarascia, 2018; Giorgi, 2006).

The analysis presented here was carried out as part of the European Climate Prediction Project (EUCP), which has an overarching objective to develop a European regional ensemble prediction system that is designed to support practical and strategic climate adaption and mitigation on a range of scales from local to global. This study contributes to the the aims of the EUCP project by investigating how the CMIP6 ensemble impacts on the European projection range and the uncertainties in climate response in the main project regions, compared to CMIP5.

A further question that has yet to be answered regarding the CMIP6 ensemble is how this data set should be viewed in relation to CMIP5 for Europe? If the CMIP6 model represents a step change in our understanding of the physical processes that drive climate change responses, should the projections from this new ensemble replace CMIP5 or should our understanding of uncertainty in the future climate response be sampled from a combination of CMIP5 and CMIP6?

1.2 Regional and Global CMIP6 Projections

While there is a large body of literature comparing previous CMIP ensembles, studies for CMIP5 and CMIP6 are only recently beginning to emerge. There are many differences in the CMIP6 model processes, in particular the representation of clouds, in the model physics (Zelinka et al., 2020). There is however considerable debate in the climate modelling community about the greater surface warming from these models and the plausibility of the model projections from the models with an ECS higher the IPCC AR5 likely range (66 % probability) (IPCC, 2013). These studies so far suggest that while the higher warming predicted by the CMIP6 ensemble may be considered unlikely it should not be discounted and projections at the regional scale need to be investigated further. In this study we address the impacts on the picture at the regional scale in Europe. Questions regarding the likelihood or plausibility of some of the CMIP6 models are beyond the scope of this study.

2 Materials and Methods

The models from CMIP6 and CMIP5 that are included can be viewed in the supplementary material. The experiments in CMIP archives represent a core strand of evidence that informs adaptation (and mitigation) planning. The CMIP5 and CMIP6 scenarios are based on Representative Concentration Pathways (RCPs) (van Vuuren et al., 2011). In this study we focus on the highest emission scenario (RCP8.5/SSP5-8.5), from which we expect to see the strongest climate signal and therefore the clearest basis for comparison. We note that although the RCPs and SSPs scenarios have nominally equivalent forcing level in 2100, the actual forcing levels are shown by (Ribes et al., n.d.) to be somewhat higher in SSPs. This discrepancy between the two scenarios can be expected to contribute to differences between the overall global warming level, in addition to any differences that occur due to differences in model sensitivities between the two ensembles.

We use a baseline period of 1995-2014 and two future periods: 2041-60 (mid century) and 2081-2100 (end of century. These time periods have been selected for consistency with IPCC analyses (IPCC, 2012) and existing EUCP analyses (e.g. (Brunner et al., 2020)). We focus on season averages for JJA and DJF.

The regions we use in this study refer to SREX regions (IPCC, 2012), (Brunner et al., 2020)) for northern Europe (North Europe), central Europe (central Europe) and

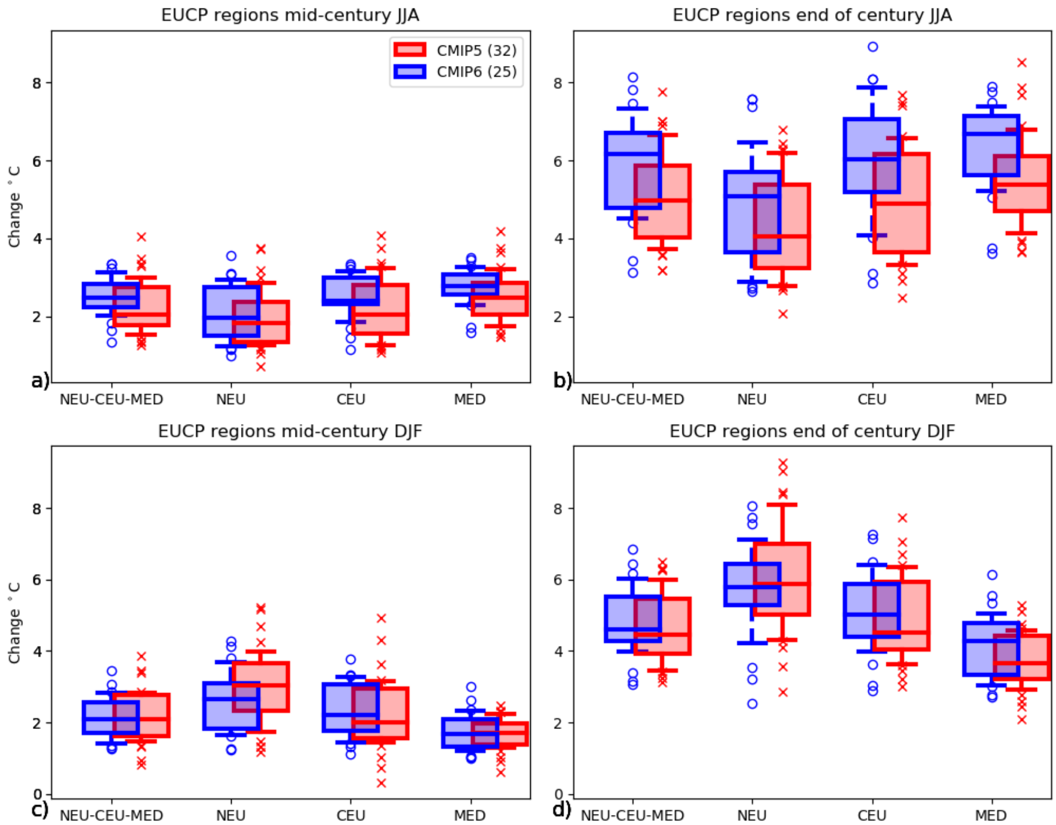


Figure 1. Projections of average summer (JJA) and winter (DJF) temperature change for CMIP5 and CMIP6 ensembles. Baseline: 1995-2014. Mid-century: 2041-2060. End of century:2081-2100. Boxes show the interquartile range and whiskers are at 10th and 90th percentiles.

the Mediterranean, with a focus on summer (JJA) and winter (DJF). The model data was regridded onto a 2.5° x 2.5° grid and land-sea mask applied as used in (Brunner et al., 2020), using a standard nearest neighbour interpolation

We used the Kolmogorov-Smirnov two sample, two sided test (KS two-sample test) to determine whether the difference between the CMIP5 and CMIP6 projections are considered significant at 95% confidence. This test has been applied with the caveat that the individual model projections in each sample cannot be considered to be truly independent due significant amounts of shared code between the models (Sanderson et al., 2015a),(Sanderson et al., 2015b).

3 Results

3.1 Near surface temperature

In the winter the differences between the CMIP5 and CMIP6 projections at the regional scale are small for all European regions. In the summer the CMIP6 ensemble projects a warmer range of temperatures than the CMIP5 ensemble in all regions. The change in projected temperature for the CMIP6 ensemble (compared to CMIP5) for summer is statistically significant ($P < or = 0.05$, see table for KS tests in supplementary material) in the central Europe and the Mediterranean regions by mid-century (see fig-

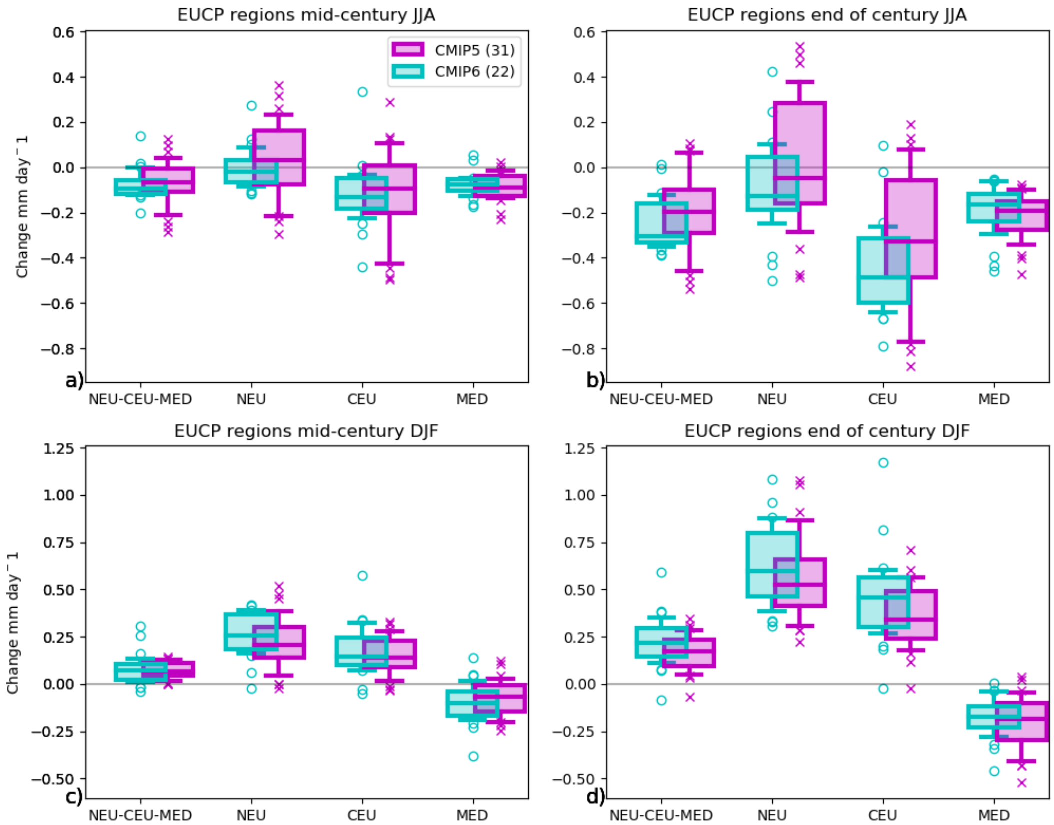


Figure 2. Projections of average summer (JJA) and winter (DJF) precipitation change for CMIP5 and CMIP6 ensembles. Baseline: 1995-2014. Mid-century: 2041-2060. End of century:2081-2100. Boxes show the interquartile range, whiskers are at the 10th and 90th percentile.

ure 1 a)) and this difference has increased by the end of century (figure 1 b)). Projected temperature differences between MIPs in the northern Europe region are smaller for summer than the other two regions and were not found to be statistically significant. End of century projections for the central Europe and the Mediterranean regions show an increased interquartile range for both ensembles compared to mid-century (Figure 1 a) and b)).

In the winter, central Europe and the Mediterranean do see higher median temperatures projected in CMIP6 (figure 1 c) and d)), but these changes are smaller than in the summer (with the Mediterranean showing the largest increase in mean of approximately 0.5 degrees, compared to about 1.5 degrees in JJA) by end of century. The overall projected range for the Mediterranean and central Europe areas are almost unchanged. No statistically significant differences were found between the ensembles for winter temperature projections in for mid-century or end of century.

Overall the difference between the MIPs are clearer by the end of century due to a stronger climate signal and larger signal to noise. Where there are differences between the MIPs these are usually already apparent by mid-century however.

3.2 Precipitation

Precipitation changes are important for central Europe and the Mediterranean regions, where further drying may have significant impacts on agriculture. In previous studies higher temperature projections for central Europe and the Mediterranean are also linked to greater drying in these regions ((Lionello et al., 2012; Lionello & Scarascia, 2018) (IPCC, 2013)). We show here that there is a large reduction in the projected range of precipitation change in the summer CMIP6 ensemble for northern Europe and central Europe regions (figure 2a) and b)), which is projected for both mid-century and end of century. For winter the difference in all regions between CMIP5 and CMIP6 is small, for mid-century and whilst there is a suggestion that CMIP6 projects wetter conditions in northern and central Europe by the end of the century, neither can be excluded as being statistically different (see table for KS tests in the supplementary material) from the earlier CMIP5 responses by the end of century (figure 2 c) and d)).

CMIP6 suggests a clearer shift to drier conditions in northern Europe in summer, however, these differences can not be said to be statistically different from the prior CMIP5 distribution. The difference between MIPs is only statistically significant by the end of century for the combined regions. The reduced range of predictions for northern Europe in the summer is not significant. While the difference for northern Europe is not found to be significant it does also indicate more of a trend in the northern Europe of a neutral or slight drying response to regional warming in the CMIP6 projections.

3.3 Global change vs regional changes

Where CMIP6 projections diverge from the existing CMIP5, it is helpful to understand whether the differences arise mainly due to differences in the global mean response of the models between the two ensembles, or differences in regional responses. In Figure 3 we show scatter plots of the relationship between the regional temperature and precipitation response to global mean warming in each ensemble (for both mid and end of century responses). These plots help identify where the differences arise due to different global warming responses (indicated by differences along the x-axis) or the regional sensitivity to the global warming (indicated by the slope and spread of responses for a given warming. etc).The bottom two plots of Figure 3 (d) and h)), show the normalised projected changes in summer temperature and precipitation for end of century (regional change per global °C),these plots further help to identify where regional changes occur in addition to those caused by the global temperature increase.

For summer temperature (left panels a) to c), 3) the regional temperature response is largely a function of the global warming change, in both ensembles. The small vertical spread, for a given global temperature change, is indicative of this. For summer temperature,the warmer shift towards higher regional responses in CMIP6 relative to CMIP5 appears to be driven largely by the large global warming responses. The similar slopes and widths of the relationships in figure 3 (left panels a) to c)) suggest that the relationship between regional and global responses remain similar between the two ensembles for NEU and MED. A small difference in the linear regression slope for CEU indicates a slightly higher regional warming response relative to the global in CMIP6 than in CMIP5. the warmer projected regional temperatures in northern and central Europe can be linked to these larger global warming responses in CMIP6.

Whilst individual quantiles visually differ for temperature in Figure 3d), for most regions there is no consistent shift between the two ensembles, across the quantiles. Central Europe, however, shows consistently larger normalised temperature response across all the quantiles, highlighting a change in the regional sensitivity consistent with the differences in slope identified in Figure 3b). These normalised differences between MIPs were statistically significant in central Europe, by mid-century and have increased by end of century (mid-century $P = 0.05$ and end of century $P = 0.03$). What is apparent

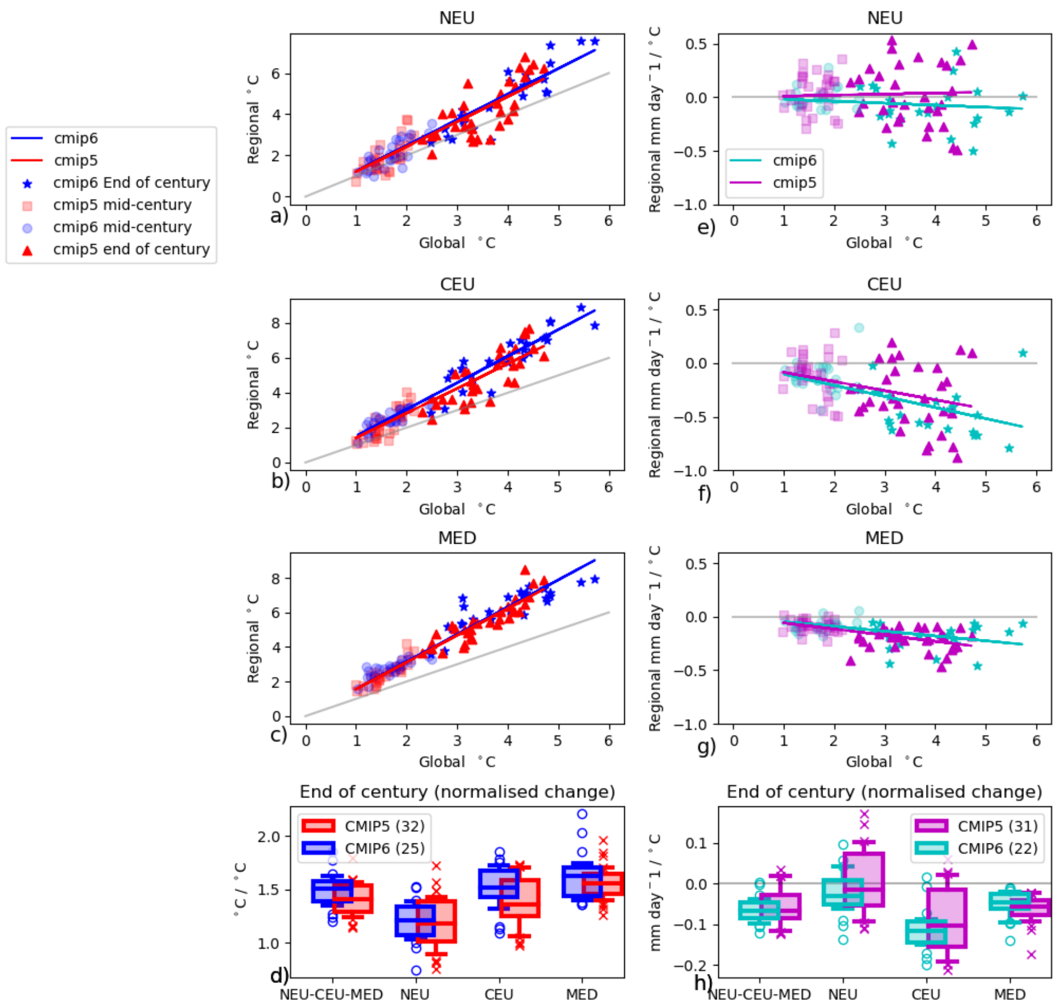


Figure 3. Left panel a)-c): Regional seasonal (summer) temperature change by Mid-century and End of century(2080-2100) with annual global temperature change. Left panel d): Projections of average seasonal (summer and winter) normalised temperature change (change per ∘C) for CMIP5 and CMIP6 ensembles. Baseline: 1995-2014. Mid-century: 2041-2060. End of century:2081-2100. Boxes show the interquartile range, whiskers are at 10th and 90th percentiles Right panel e)-g):Regional seasonal (summer) precipitation change by End of century(2080-2100) with annual global temperature change. Right panel h): Projections of average seasonal (summer and winter) normalised precipitation change (change per ∘C) for CMIP5 and CMIP6 ensembles.

Table 1. Simple statistics values for temperature and precipitation for simple model, shown as percentage of Y (total mean regional change) from the Slope (S) and mean global change (X). Tables showing all values are in the supplementary material.

	Temperature (tas)		Precipitation	
Region	Slope %	Global %	Slope %	Global %
NEU	21	79	98	2
CEU	42	58	71	29
MED	7	93	67	33

(from all panels, 3) is that CMIP6 explores a number of larger global warming responses compared to CMIP5, particularly at end of century.

There is more scatter in the relationship in the right panels showing the regional precipitation response to global temperature (figure 3e) - g)). Both ensembles show a similar overall response, with summer precipitation decreasing in response to increasing global mean temperatures. The difference in slope between the two ensembles is visibly greater than for temperature indicating that there is a larger difference between MIPs in their regional responses.

The summer precipitation change per °C global warming (Figure 3 h)), has similar median values for CMIP5 and CMIP6 for most regions and timescales. CMIP6 projections are largely consistent with CMIP5 in terms of central estimates of the projected changes. The most evident difference between the two ensembles is the narrow spread of the projected range for northern and central Europe in CMIP6. This smaller range of projected changes is an interesting result, as it suggests a more confident picture of future precipitation change in both regions. The differences between the two normalised ensembles in nearly all cases are not significant.

To attempt to quantify the contribution of the regional sensitivity, compared to that of the global temperature change, to the total regional projected summer temperature change, we applied a simple statistical model to the end of century projections. This model is based on equation 1.

$$Y \approx XS \tag{1}$$

Where Y is the mean regional change, X is the mean global change and S is the slope of the linear regression line shown in figure 3 (which was forced through the origin). The slope is taken to represent the contribution of the regional sensitivity to the overall regional change.This simple statistical model is able to capture the differences in regional mean responses, within both MIPs, to the first order (see tables in the supplementary material).

We can now assess the relative importance of either differences in the global response (represented by global mean temperature differences) or the regional sensitivity (captured by the Figure 3 regression slope) in explaining the CMIP6/CMIP5 differences in the mean regional response, by substituting alternatively one or either of these terms. S was substituted (CMIP5 slope for CMIP6) and the difference between Y for the two ensembles was calculated. This was then repeated substituting X (the mean global temperature change). The estimated contribution to the total change for each region from the regional sensitivity (slope) and global mean changed is shown in table 1.

The results for temperature in table 1 confirm and help quantify what is seen visually in Figure 3. For the Mediterranean the higher global sensitivity of the CMIP6 models accounts for nearly all of the increase in projected temperature for this region. There is some regional sensitivity in northern Europe, but most of the change is due to the annual global temperature increase. In central Europe a significant percentage of the total mean regional temperature anomaly is due to the regional sensitivity and this result warrants further investigation.

The same model was applied to the precipitation results where equation 1 was found to be a good model of mean regional precipitation response in both ensembles (see supplementary material). The results in this case showed a considerably larger difference in S (regional sensitivity) than in X (global mean temperature change), these are summarised in table 1. The regional precipitation sensitivity to global temperature change has a larger degree of uncertainty than regional temperature as can be seen in the scatter and the projected ranges in in Figure 3.

4 Discussion

The differences between the CMIP5 and CMIP6 projections for the European regions are small for winter in all three regions, for both temperature and precipitation. In the summer, however higher temperatures are projected in all European regions, with the largest differences in central Europe and the Mediterranean; interquartile range and ensemble median is shifted towards greater projected warning in the central Europe and the Mediterranean by the end of century for CMIP6 and these differences are found to be statistically significant.

For precipitation the projected range for summer precipitation is narrower in CMIP6 than in CMIP5 . This is particularly the case for the northern Europe region where the upper quantile is reduced in CMIP6 by the end of century. The entire summer range of precipitation projections is also reduced in central Europe. CMIP5 and CMIP6 both show a overall trend for drying in summer for central and northern Europe with increasing global temperatures, this drying trend appears to be stronger in the CMIP6 ensemble for central Europe. There is a large degree of disagreement between individual models in both ensembles in the northern and central Europe regions in response to global temperature, where there is also disagreement on the sign of the change. The reduced ranges for CMIP6 in central Europe and northern Europe may indicate a reduction in the uncertainty for precipitation projections.

Our results show that regional increases in summer temperature projections for CMIP6 are largely due to increases in the global mean warming response. The exception was in central Europe where the regional sensitivity was found to contribute approximately 40% to the difference between MIP's central estimates. In contrast the differences in precipitation projections were found to be due largely to the regional responses and processes that drive precipitation at a regional scale.

Senerviratne and Hauser (2020) examined extreme regional temperature and precipitation projections as a function of the global warming and they concluded that there was a quasi-linear response at a regional level for CMIP5 and CMIP6. In general the regional sensitivity was found to be very similar in CMIP5 and CMIP6 (as opposed to the Global sensitivity). Although we focus on mean temperature responses here our results are largely consistent with Seneviratne ans Hauser (2020) for Europe. In central Europe where other process changes such as soil moisture and atmospheric feedbacks in the CMIP6 models may affect projections they also found some differences in regional sensitivity.

Regional precipitation projections have always been more uncertain than temperature, due to differences in model representation of the local thermodynamic and dynamic drivers of rainfall. In northern and central Europe in particular, model differences in the regional rainfall responses to global warming explain a larger fraction of the spread in future projections, in both ensembles. In northern Europe, reductions in the upper quantile of projected changes in CMIP6, suggests that the possibility of summer increases in rainfall is less likely. CMIP6 suggests that net summer rainfall in northern Europe is less likely to diverge from what has been historically observed, however it is not clear why. This could be due to improved model physics and representation of precipitation patterns, which may lead to greater confidence in these predictions but further investigation is needed. CMIP6 suggests both a stronger but also a tighter range of projections for precipitation response in central Europe, pointing to a clearer shift to drier conditions than found in CMIP5.

These results have a number of implications for assessing the risks and potential impacts of climate change. Whilst there are differences between CMIP5's and CMIP6's RCP8.5 emissions, which explain part of this increased warming (Ribes et al., n.d.), a substantial factor is thought to be differences in the climate sensitivity between the ensembles. The global climate sensitivity is an emergent property of simulation of the underlying climate feedback processes (e.g. cloud, water vapour, albedo feedbacks). Emergence of larger climate sensitivities in CMIP6 compared to CMIP5 is unlikely to have arisen by chance sampling of the same underlying distribution (Flynn & Mauritsen, 2020) but is being linked to further development of the underlying cloud processes (Zelinka et al., 2020; Meehl et al., 2020), and aerosol-cloud interactions (Bodas-Salcedo et al., 2019; Meehl et al., 2020; Wyser et al., 2020).

For the regions and seasons where any differences between MIPs have been found to be largely driven by global temperature response, there may be no need to change the projection advice in light of new CMIP6 projections. Risk adverse users, however may want to sample simulations from the high CMIP6 end, as whilst these simulations can be considered less likely (in terms of their global climate sensitivity) they remain plausible samples (Meehl et al., 2020) of potential high end change.

For other variables, where we have shown differences in regional sensitivity between CMIP5 and CMIP6, then users of climate projection data may want to take account of new information within CMIP6. The central Europe region is an example of this, showing changes in the MIP differences are regional sensitivity for both temperature (approximately 40% of the increase is due to regional processes) and precipitation (two thirds of the summer drying shift is due to regional processes)

When using projections for variables/regions where CMIP6 identifies changes in the regional sensitivity, then there are questions about whether CMIP6 simulations should supersede CMIP5 or supplement it. The answer to this question is important, as it will strongly influence projected range of future climate, particularly in central Europe. We find that in many cases the regional responses in the two MIPs are similar and the differences in temperature are largely driven by an increase in global temperature in CMIP6. Where this is the case it may be reasonable to consider the two ensembles as from the same population (with a slightly larger magnitude of change in CMIP6). In some cases however the regional responses differ significantly which suggests a change in the way that regional processes are represented and the two ensembles should be treated separately.

5 Conclusions

The CMIP6 projections differ from CMIP5 in the summer, with warmer projections (all regions) and narrower ranges of rainfall projections in northern and central Europe. The magnitude of existing temperature changes indicate an increase in the severity of the impact of global warming on the central Europe and the Mediterranean regions. This increase in projected warming is largely attributed to increased global sensitivity in some of the CMIP6 models, in these cases the overall picture for European projections is largely the same with the upper end of the projections becoming more frequently sampled in CMIP6. However, in some cases a significant difference in the regional responses was found and in these cases the picture could be said to have changed. In our cases central Europe was found to show a significant increase in temperature projections for CMIP6 and a higher degree of regional sensitivity. It is not clear why this is the case, but the impact of improved understanding of physical processes in these models on projections at the regional scale should not be ruled out at this stage and warrants further investigation.

A consideration for projections in Europe (and for other regional projections) is whether the CMIP5 and CMIP6 ensembles should be considered as separate ensembles or if they can be combined as a single set of projections? Due to differences in the forcing for the two ensembles this may not always be an appropriate approach; however our results provide pointers to how combinations of the two ensembles can be used in assessing the risks posed by global warming.

Acknowledgments

The EUCP project is funded by the European Commission through the Horizon 2020 Programme for Research and Innovation: Grant Agreement 776613.

We acknowledge the World Climate Research Programme, which, through its Working Group on Coupled Modelling, coordinated and promoted CMIP5 and CMIP6. We thank the climate modeling groups (particularly those listed in tables S1 and S2) for producing and making available their model output, the Earth System Grid Federation (ESGF) for archiving the data and providing access, and the multiple funding agencies who support CMIP, CMIP6 and ESGF. Terms of use and further instructions can be found at https://pcmdi.llnl.gov/. The is data is available through the ESGF data portal at https://esgf-node.llnl.gov/projects/esgf-llnl/.

The authors would also like to thank Jamie Kettleborough, Emma Hibling and James Bedwell from the Met Office for there work on software tools that were used to manage and analyse the CMIP data.

References

Bodas-Salcedo, A., Mulcahy, J. P., Andrews, T., Williams, K. D., Ringer, M. A., Field, P. R., & Elsaesser, G. S. (2019). Strong dependence of atmospheric feedbacks on mixed-phase microphysics and aerosol-cloud interactions in HadGEM3. *Journal of Advances in Modeling Earth Systems*, *11*(6), 1735–1758.

Brunner, L., McSweeney, C., Ballinger, A. P., Hegerl, G. C., Befort, D. J., O'Reilly, C., ... Undorf, S. (2020). Comparing methods to constrain future European climate projections using a consistent framework. *Journal of Climate*, 1–62. doi: 10.1175/jcli-d-19-0953.1

Flynn, C. M., & Mauritsen, T. (2020). On the climate sensitivity and historical warming evolution in recent coupled model ensembles. *Atmospheric Chemistry and Physics*, *20*(13), 7829–7842.

Forster, P. M., Maycock, A. C., McKenna, C. M., & Smith, C. J. (2020). Latest climate models confirm need for urgent mitigation. *Nature Climate Change*, *10*(1), 7–10. Retrieved from `https://doi.org/10.1038/s41558-019-0660-0` doi: 10.1038/s41558-019-0660-0

Giorgi, F. (2006). Climate change hot-spots. *Geophysical Research Letters*, *33*(8). Retrieved from `https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/2006GL025734` doi: 10.1029/2006GL025734

IPCC. (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* (Tech. Rep.). Cambridge, United Kingdom and New York, NY, USA.

IPCC. (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (T. F. Stocker et al., Eds.). Cambridge, UK and New York, NY, USA: Cambridge University Press. Retrieved from `https://www.ipcc.ch/report/ar5/wg1/`

Knutti, R., & Sedláček, J. (2013). Robustness and uncertainties in the new CMIP5 climate model projections. *Nature Climate Change*, *3*(4), 369–373. doi: 10.1038/nclimate1716

Kumar, D., Kodra, E., & Ganguly, A. R. (2014). Regional and seasonal intercomparison of CMIP3 and CMIP5 climate model ensembles for temperature and precipitation. *Climate dynamics*, *43*(9-10), 2491–2518.

Lionello, P., Abrantes, F., Congedi, L., Dulac, F., Gacic, M., Gomis, D., ... Xoplaki, E. (2012). Introduction: Mediterranean ClimateBackground Information. In P. B. T. T. C. o. t. M. R. Lionello (Ed.), (pp. xxxv–xc). Oxford: Elsevier. Retrieved from `http://www.sciencedirect.com/science/article/pii/B9780124160422000124` doi: https://doi.org/10.1016/B978-0-12-416042-2.00012-4

Lionello, P., & Scarascia, L. (2018). The relation between climate change in the Mediterranean region and global warming. *Regional Environmental Change*, *18*(5), 1481–1493. Retrieved from `https://doi.org/10.1007/s10113-018-1290-1` doi: 10.1007/s10113-018-1290-1

Meehl, G. A., Senior, C. A., Eyring, V., Flato, G., Lamarque, J.-F., Stouffer, R. J., ... Schlund, M. (2020). Context for interpreting equilibrium climate sensitivity and transient climate response from the CMIP6 Earth system models. *Science Advances*, *6*(26), eaba1981.

Ribes, A., Quasmi, S., & Gillett, N. (n.d.). Making climate projections conditional on historical observations. *Submitted*.

Sanderson, B. M., Knutti, R., & Caldwell, P. (2015a). Addressing interdependency in a multimodel ensemble by interpolation of model properties. *Journal of Climate*, *28*(13), 5150–5170.

Sanderson, B. M., Knutti, R., & Caldwell, P. (2015b). A representative democracy to reduce interdependency in a multimodel ensemble. *Journal of Climate*, *28*(13), 5171–5194.

van Vuuren, D. P., Edmonds, J. A., Kainuma, M., Riahi, K., & Weyant, J. (2011). A special issue on the RCPs. *Climatic Change*, *109*(1), 1. Retrieved from `https://doi.org/10.1007/s10584-011-0157-y` doi: 10.1007/s10584-011-0157-y

Wyser, K., van Noije, T., Yang, S., von Hardenberg, J., O'Donnell, D., & Döscher, R. (2020). On the increased climate sensitivity in the EC-Earth model from CMIP5 to CMIP6. *Geoscientific Model Development*, *13*(8), 3465–3474.

Zelinka, M. D., Myers, T. A., McCoy, D. T., Po-Chedley, S., Caldwell, P. M., Ceppi, P., ... Taylor, K. E. (2020, jan). Causes of Higher Climate Sensitivity in CMIP6 Models. *Geophysical Research Letters*, *47*(1), e2019GL085782. Retrieved from `https://doi.org/10.1029/2019GL085782` doi: 10.1029/2019GL085782