LS3 2.2km Projections Report

ID	Section	Page (as per page numbering)	Line number	Comment	Category	Reviewer initials	Status	MO response	Response from authors
1	General			1.I think that the figures could do with a considerable amount of work to make them more friendly and clear for the reader. i.In general the captions on the individual panels are not helpful or clear. Each should probably be labelled (a) etc. and this label used in the legend. As an extreme case, in Fig. 3.2.1 we have a legend that says CPM STD minus CPM STD! ii.I think that the order of RCM and CPM is not consistent throughout and should be unless there is a very strong argument to the contrary. iii.The colour bars are not helpful for discriminating the features in a significant number of places and should all be looked at. E.g. Figs 3.5.1, 5 & 12; discriminate between the yellows in 4.2.1 and 4.3.1.	Typo/Format	BH	Open	We have made considerable improvements to the figures to help with clarity. This includes: (i)addition of labelling (a) etc to figures 3.2.1-3.2.4 and changes to the panel titles (for "CPM STD minus CPM STD" the title actually went onto the next line, but this title has been changed to make it clearer) (ii)reordering of panels in figures 3.2.1-3.2.4 (iii)several changes to colour bars and schemes as detailed below in response to specific comments To do: Inconsistency in the order of the RCM and CPM remains in some cases, and this is still to be addressed.	
2	General			2.Water budget, Table 4.1 i.2 decimal places are need in each element. ii.To complete the water budget, Table 4.1 needs to contain the domain (and land and ocean) average precipitation and their changes for both models. There needs to then be discussion of how close the domain averages are to 4.13 and 3.83 for the CPM and RCM, respectively and the changes to 0.79 and 0.73. If the budgets are indeed consistent there can be discussion of the source of water for the extra winter rainfall in the CPM. iii.This discussion can also use any case study information.	Scientific/technical issue	BH	Open	The table now only has elements to 2 decimal places. Precipitation results have been added, along with a second table (Table 4.2) for summer. A discussion of these results, including the extent to which there is any residual in the water budget, is now added to Section 4.2: "Tables 4.1 and 4.2 show the atmospheric water budget terms, and their future change, in winter and summer respectively. In both seasons, the mean moisture flux convergence over the CPM domain (and its future change) is very similar between the CPM and RCM, confirming that moisture entering and leaving the CPM domain is well constrained by the RCM. Over UK land points in winter, the increase in evaporation plus moisture flux convergence is larger in the CPM (0.77 mm/day) compared to the RCM (0.66 mm/day), consistent with the greater increase in winter mean precipitation (1.05 mm/day in CPM versus 0.76 mm/day in RCM). It should be noted that precipitation does not exactly equal evaporation plus moisture flux convergence (see residual in Tables 4.1 and 4.2), and this is due to numerical errors in the estimation of moisture flux convergence. In particular, although moisture conservation is enforced internally in the CPM (Section 2.3), significant errors will arise in the offline calculation of moisture convergence (which uses a finite differencing approach) due to fine-scale structures in the winds. The greater increase in winter precipitation in the CPM is coming from the greater increase in moisture flux convergence over land in the CPM (with similar changes in evaporation over land). By contrast future changes in both evaporation and moisture flux convergence over the sea are higher in the RCM than CPM in winter. Thus greater increases in moisture flux convergence over the land in winter in the CPM appear to be compensated by smaller increases in moisture flux convergence over the sea. In summer (unlike in winter) evaporation over the land dominates over moisture flux convergence over the land, with the local recycling of moisture being important (although the extent to which showers (and local moisture recycling) occur may be conditioned by the large-scale circulation patterns, e.g. fewer showers where there is more dry continental flow). This is in contrast to winter, where showers over land may be more dependent on the advected moisture from the sea. In terms of future changes in summer, however, it can be seen that these are dominated by convergence changes (with evaporation hardly changing). In particular, there is a large decrease in moisture flux convergence (over the whole domain), resulting in the UK changing from a region of small positive moisture convergence to significant moisture divergence. These mean changes in summer are captured similarly by both the CPM and RCM (see Section 5 for further discussion)."	
3	1.2 Key results from UKCP18 Land Projections report	9	33	Add a comma - "...Strands 1, 2 and 3, respectively."	Typo/Format	BH	Closed	Done	
4	1.2 Key results from UKCP18 Land Projections report	10	5	Add a comma and "respectively" - "...Strands 1, 2 and 3, respectively."	Unclear phrasing	BH	Closed	Done	
5	1.2 Key results from UKCP18 Land Projections report	10	22	Remove "of" and replace with "for" - "...shows substantial warming (of up to 9°C) ~~of~~ for cold winter days..."	Unclear phrasing	BH	Closed	Done	
6	1.3 Motivation for new 2.2km projections	11	19	Replace "can't" with "cannot"	Unclear phrasing	BH	Closed	Done	
7	1.3 Motivation for new 2.2km projections	11	24	Replace "(largely resolved)" with ", although they may not be well resolved,"	Unclear phrasing	BH	Closed	Done	
8	1.3 Motivation for new 2.2km projections	11	25	Replace "captured" with "represented"	Unclear phrasing	BH	Closed	Done	
9	1.3 Motivation for new 2.2km projections	12	11	Insert a comma after "(Kendon et al),"	Typo/Format	BH	Closed	Done	
10	1.3 Motivation for new 2.2km projections	12	32	Remove "only" - "…due to local storm feedbacks ~~only~~ captured by CPMs."	Unclear phrasing	BH	Closed	Done	
11	1.3 Motivation for new 2.2km projections	13	7	Remove "smaller" - "...their inability to fully resolve ~~smaller~~ showers…"	Unclear phrasing	BH	Closed	Done	
12	1.3 Motivation for new 2.2km projections	13	23	Insert a comma after "In particular,"	Typo/Format	BH	Closed	Done	
13	1.3 Motivation for new 2.2km projections	13	26	Insert commas "…fine-scale projections and, for the first time, an estimate of uncertainty...	Typo/Format	BH	Closed	Done	
14	1.3 Motivation for new 2.2km projections	14	13	The CPM can provide more local detail, but only to an extent that is consistent with the fields of the larger model in which it is embedded. The CPM results will reflect larger-scale errors in that atmospheric model and in the underlying ocean model.	Scientific/technical issue	BH	Open	Text has been added as follows: "In particular, the large-scale circulation in the CPM remains fairly close to that of the driving model (due to the small domain size), and local detail can be provided by the CPM only to the extent that it is consistent with this. Thus CPM results will reflect larger-scale errors in the global model."	
15	2.2 Choice of convection-permitting resolution	17	30	Insert "parameterisations" - "…when showers are large enough but activates parameterisations to represent the effects of weaker convection…"	Unclear phrasing	BH	Closed	Done	
16	2.2 Choice of convection-permitting resolution	18	23	Fig 2.2.1 Change caption to read "Probability distributions of hourly precipitation intensity…"	Typo/Format	BH	Closed	Done	
17	2.3 The 2.2km convection-permitting model	22	7	Change to "The reason for this is that the newer snow scheme…"	Typo/Format	BH	Closed	Done	
18	3.5 High impact events	52	32	Change to "…the NE-UK…"	Typo/Format	BH	Closed	Done	
19	3.5 High impact events	54	1	Change to "…observational records is 92mm~~/h~~…"	Typo/Format	BH	Closed	Done	
20	3.5 High impact events	55	1	Fig 3.5.1 The colour scale is not very helpful!	Typo/Format	BH	Closed	The colour scale has been changed.	
21	3.5 High impact events	59	1	Fig 3.5.5 Again the colour scheme is not helpful	Typo/Format	BH	Open	The colour scale has been changed, and the plots now zoom into the region of interest.	
22	3.5 High impact events	66	1	Fig 3.5.11 labels confusing in fig, or need to be mentioned in legend.	Unclear phrasing	BH	Open	Labels have been clarified in the figure caption and also the text in the figure has been enlarged to improve readability. Labels have been added to the x and y axes.	
23	3.5 High impact events	67	1	Fig 3.5.12 Is this a good choice of colour bar?	Typo/Format	BH	Closed	The colour bar has been changed.	
24	3.5 High impact events	69	7	Change to "…whilst for lying snow it is 0.78 for the CPM…"	Typo/Format	BH	Closed	Done	
25	4.1 Overview	72	4	Change to "…projected changes for the UK under the high emission scenario, RCP8.5 ~~emissions~~, comparing results…"	Unclear phrasing	BH	Closed	Done	

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26	4.1 Overview	73	15	"are represented here by showing the 2nd lowest…" - say in this para why you do not use the 1st	Unclear phrasing	BH	Open	We have added an explanation of why the 2nd lowest, central and 2nd highest member responses are chosen as follows: "These responses correspond approximately to the 10th, 50th and 90th percentiles of the ranked 12-member ensemble at each grid box (consistent with the approach used in Murphy et al, 2018)." Please note we have also added (in Appendix B) examples of the projections from individual members with the 2nd lowest, central and 2nd highest UK mean responses, and these results are discussed briefly in the context of seasonal mean changes in Section 4.2.	
27	4.2 Seasonal mean changes	74	2	Change "Wintertime" to "Winter"	Unclear phrasing	BH	Closed	Done	
28	4.2 Seasonal mean changes	74	9-10	Change to "indicating that ~~it is mainly precipitation responses over land that are greater in the CPM~~ the precipitation changes are larger over the land than the ocean."	Unclear phrasing	BH	Open	It is true that precipitation changes are larger over the land than the ocean in the CPM, but the key point here is rather that changes in precipitation over the land are larger in the CPM than RCM, but that changes over the sea are larger in the RCM (see Table 4.1). We have changed the text to clarify this point: "We note that this difference between the CPM and RCM responses is less on averaging percentage changes over all land and sea points throughout the CPM domain (central estimate of 22% increase in CPM compared to 18% in RCM), indicating that greater precipitation responses in the CPM compared to the RCM over land do not extend over the sea (c.f. Table 4.1)."	
29	4.2 Seasonal mean changes	74	10	Change to "This substantially greater increase in projections of winter precipitation…"	Unclear phrasing	BH	Closed	Done	
30	4.2 Seasonal mean changes	74	22	Change to "…the parameterised convection model, …"	Unclear phrasing	BH	Closed	Done	
31	4.2 Seasonal mean changes	75	19	"the warmer ocean" - but perhaps even warmer atmosphere, so less unstable	Scientific/technical issue	BH	Open	It is true that the atmosphere may become less unstable, and this would act to reduce the impact of the warmer ocean in triggering more convective showers. In the text we already have the caveat "(assuming convective instability remains similar)", which hopefully addresses this point.	
32	4.2 Seasonal mean changes	76	11	Table 4.1 - two decimal places needed in every element of the table	Scientific/technical issue	BH	Closed	Done	
33	4.2 Seasonal mean changes	76	11	Table 4.1 - we also need the domain average precipitation, along with the land and ocean values, and the changes in them. How close is the average precip in the 2 models to 4.13 and 3.83, and the changes to 0.79 and 0.73?	Scientific/technical issue	BH	Open	These changes have been made, and discussion of the residual added. Please see response to general comment above. Note the numbers in the table have been revised slightly, as these now correspond to the domain-average but with the rim region removed (to eliminate the effects of boundary artefacts in the water budget).	
34	4.2 Seasonal mean changes	76	13	Table 4.1 - Does this equal the convergence of moisture implied by the boundary conditions? Why one less decimal place?	Scientific/technical issue	BH	Open	Now quoted to 2 decimal places. This will slightly differ from the moisture convergence implied by the boundary conditions (as the domain considered here does not include the outer rim, as indicated in the Table 4.1 caption). However the correspondence between the CPM and RCM in the domain averaged moisture flux convergence confirms that the moisture entering and leaving the CPM domain is well constrained by the boundary conditions.	
35	4.2 Seasonal mean changes	78	1	Figure 4.2.1 - could the 2 yellow in particular and perhaps the 2 reds (around 3.5) be made more different?	Scientific/technical issue	BH	Open	The colour scheme has been changed to increase differences between yellows and reds.	
36	4.2 Seasonal mean changes	80	5	Figure 4.2.3 - "…CPM-12 aggregated (x5)…" what does this mean? Why not just change the colour bar scale if it means what I think it means?	Unclear phrasing	BH	Open	The caption has been changed to clarify that this corresponds to 5x5 smoothing: "…differences between the top row and the corresponding responses obtained when the relevant CPM-12 members are smoothed to the 12km horizontal resolution of the RCM (by averaging of data over 5x5 2.2km grid boxes)…"	
37	4.2 Seasonal mean changes	84	3	Figure 4.2.7 - again a factor of 5 used? Why does the scale go to +/-8?	Unclear phrasing	BH	Open	Please see response to previous comment in terms of 5x5 smoothing. The scale has been changed to now go to +/-2.	
38	4.3 Changes at daily time scale	87	8	"We note that a good representation of the baseline is a necessary but not sufficient condition for confidence in future projections" - not always followed in UKCP18!	Scientific/technical issue	BH	Open	We acknowledge that the discussion was framed a bit too definitely in the original text, and we have revised it to be more consistent with the approach taken in UKCP18. In particular, it is true that we still give projections even when there may not be a good representation of the baseline. For example, this is the case for winter temperature in Strand 2. However, we argue that the credibility of future changes rests upon many potential physical factors. For example, future winter warming will indeed depend on regional surface albedo feedbacks (which would be affected by a local cold bias), but also on many factors which may not be, such as global temperature changes, changes in cloud at medium and upper levels, AMOC, winter storm track etc. Therefore, credibility of future projections should not only be based on the skill of the baseline in the relevant variable, unless the biases are so large as to render the simulation clearly implausible (e.g. a complete AMOC collapse seen in present day). In the current report, we consider not only historical performance (as assessed by comparison with observations) but also our understanding of the representation of underlying processes, when assessing the reliability of future projections. This is evident from Table 5.1. Revised text: "More generally, we note that the skill of the simulated baseline, while an important consideration, is only one of (potentially) many physical factors to consider, when assessing the credibility of projected changes in a given variable. In particular, an understanding of the local and remote drivers of future change is also important. For example, we would expect both the RCM and CPM simulations to capture any future changes in wet-day frequency related to changes in the occurrence of mid-latitude weather systems inherited from the driving global simulations. However, as discussed previously in Section 4.2, a possible explanation for the differences in the downscaled responses may be more triggering of convective showers in a future warmer climate in the CPM. However, further work is needed to establish if this is the case."	
39	4.3 Changes at daily time scale	89	1	Fig 4.3.1 again yellows a problem	Scientific/technical issue	BH	Open	The colour scheme has been changed to address this.	
40	4.4 Changes in hourly precipitation	104	17	"…the number of historical events in 4 different intensity bines: 0.0-0.005…" - insert units after each	Unclear phrasing	BH	Closed	Done	
41	4.5 Changes in high impact events	112	7	"Both CPM-12 and RCPM-PPE…" extreme hourly precip	Unclear phrasing	BH	Closed	Done	
42	4.5 Changes in high impact events	117	11	Why not also cold in southern UK and warm in N	Scientific/technical issue	BH	Open	This is because spells (using the definitions in Section 3.5) are primarily occurring in the north for cold and south for warm, and analysis for additional regions is not shown to reduce the number of figures. Text has been added to justify choice: "In this section we consider changes in cold spells over the northern UK and hot spells over the southern UK, as this is where these are primarily occurring in the present-day (Section 3.5)."	
43	4.5 Changes in high impact events	117	13-14	Insert ", there being less cold spells in the CPM" after "(although larger in relative terms)"	Unclear phrasing	BH	Closed	Done	
44	4.5 Changes in high impact events	118	29	"with only a few members dropping below this threshold" - which agrees with observations better?	Unclear phrasing	BH	Open	Soil moisture in CPM-12 and RCM-PPE is now evaluated against WFDEI-JULES data, which is used a proxy for soil moisture observations. Details of the WFDEI-JULES dataset have been added to Table 3.1, and a new subsection evaluating soil moisture compared to this dataset has been added in Section 3.5. In general this shows that the CPM-12 soil moisture compares better with the proxy observations. All discussion of present-day soil moisture that was in Section 4.5 has now been moved to Section 3.5.	
45	4.5 Changes in high impact events	119	21	Rather unsatisfactory discussion as the differences in simulating today's climate dominate	Scientific/technical issue	BH	Open	Some additional text, briefly noting that the present-day differences persist and dominate over the climate change signal, has been added: "In CPM-12, β is less than 0.3 over much of south-east England, indicating a high degree of moisture restriction during the present-climate. In future, these differences between the models persist. Both models show a similar future decrease in β (increasing water stress) of 20% or more over the southern UK, but with the model differences dominating over the climate change signal. In the CPM, locally large percentage decreases occur where near-zero stress factors are seen in the present-day."	

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46	5 Interpretation and use of the projections	126		Table 5.1 - temperature - winter mean temperature - change *Understanding of CPM-RPM projection differences* column to read "Differences in N likely related to differences in snow scheme and treatment of graupel, which lead to much more lying snow in the present-day in the RCM, ..."	Unclear phrasing	BH	Closed	Done	
47	5 Interpretation and use of the projections	130	2	Table 5.1 - a very helpful table! It would be useful to sign-post the existence of this table near the beginning.	Typo/Format	BH	Open	This is now signposted at the beginning of the report (Section 1.4) and again at the beginning of Section 4 (end of 1st paragraph in Section 4.1): Section 1.4: "Section 5 provides a summary table giving an overview of present-day biases and future changes in the CPM compared to the RCM, and our understanding of any differences in terms of the key processes that are represented differently in the CPM." Section 4.1: "We note that in Section 5, a summary table is presented (c.f. Table 5.1) giving an overview of future changes in CPM-12 compared to RCM-PPE, and our understanding of any differences in terms of the key processes that are represented differently in the CPM." In addition a summary has been added at the end of Section 3 and Section 4, which includes the narrative from Table 5.1. A simplified version of this is also included in the non-technical summary at the start of the report, which again contains reference to Table 5.1.	
48	5 Interpretation and use of the projections	136	10	Change to "since this does not include either model structural uncertainties, ~~n~~or uncertainties in the CPM…"	Typo/Format	BH	Closed	Done	
49	5 Interpretation and use of the projections	139	7	Change to "…expected to be the primary source of information, ~~potentially~~ preferably supplemented by a comparison…"	Unclear phrasing	BH	Closed	Done	
50	6 Summary and forward look	141	23	Insert comma "…which like convection-parameterised models more generally, tends to underestimate…"	Typo/Format	BH	Closed	Done	
51	6 Summary and forward look	141	24	Change to "…based on convection parameterised models, as in Strands 1 and 2 and the RCM in Strand 3, may underestimate	Unclear phrasing	BH	Closed	Done	
52	6 Summary and forward look	145	18	Change to "…these results provide an ~~estimate~~ indication of uncertainties…"	Unclear phrasing	BH	Closed	Done	
53	General			The report is very thorough in its discussion of results, but for an "average" user this may well be too detailed. A very useful overview of main results and implications is given in Table 5.1. It is recommended to provide an executive summary that copies the narrative of this table. Also a summary of key findings would be welcome at the end of each of the chapters 2, 3 and 4.	Scientific/technical issue	BVDH	Open	Summaries have been added at the end of Chapter 2 (Section 2.5), Chapter 3 (Section 3.6) and Chapter 4 (Section 4.6). These include the narrative in Table 5.1. A non-technical summary has also been added at the start of the report, which presents this summary material in simplified language.	
54	General			At the end of the report (P 140, l 20) the provision of the time slice ensemble is motivated by the ability of users to create "storylines" of climate change. A guideline of how these storylines should be created is not given, and would be useful. I do assume that by "storyline" a representative evolution of the climate condition at a given spatial or temporal time scale is intended, either a climate change narratives, or even event storylines. By contrast, a few lines further down it is actually recommended to augment the limited ensemble by even more simulations. This is at odds with the ambition to create a discrete number of storylines, as this augmentation does generate even more information from which to choose a storyline. More guidance on this approach is desirable.	Scientific/technical issue	BVDH	Open	Storylines can take a number of different forms, but we have added the following guidelines in the report: "These can potentially take a number of different forms, including narratives of how impacts related to particular types of weather event might change in future (Hazeleger et al., 2015), or characterisations of simulated regional changes that promote understanding in terms of specific remote circulation drivers (Zappa and Shepherd, 2017). One specific role of Strand 3 information, for example, could be to investigate the localised consequences of future flooding events, perhaps conditioned on synoptic flow conditions similar to cases that led to costly impacts in the past (e.g. Huntingford et al., 2014). However, the Strand 3 projections do not support a probabilistic interpretation…" Regarding the subsequent text on augmentation, we take the point that the set of potential storylines should not become too large, however we don't think there is an inconsistency in the discussion. All we are saying is that adding a few additional simulations (e.g. EURO-CORDEX) would create a richer basis for the sub-selection of a small number of storylines. We have modified the text to clarify this: "For applications using Strand 3 downscaling projections, we would recommend augmenting the RCM-PPE or CPM-12 results with multi- model information. This would, for example, create a broader range of projections from which to sub-select a limited but diverse set of storylines."	
55	General			Referring to "guidelines: at P140 (L13-17) a scaling approach is suggested that is indeed a very relevant remark. But to be honest, I didn't see this suggestion coming from the text that is preceding this remark. For a user a conclusion like this does appear to be very useful, and therefore could be framed a bit more explicitly.	Scientific/technical issue	BVDH	Open	This is now discussed more explicitly in the text as follows: "… Since the representation of convective processes is very different in the explicit convection model, and this model includes local dynamical feedbacks on future changes (not included in parameterised models), it is unlikely to be possible to simply predict the CPM response from the RCM response. This can be seen from Fig 5.1, where the smallest response in winter precipitation over Scotland in the RCM is for the STD member, whereas this is not the case for the CPM. However, for temperature, a scaling approach to determine CPM changes from RCM or GCM changes (where CPM downscaling is not available) may be more valid. Fig 5.1 shows a similar relationship between the CPM and RCM response across different ensemble members, for summer and winter temperature. Thus in this case the CPM change is dominated by the large-scale warming in the driving RCM, but with some local differences. Where these local differences are due to the better representation of topography, for example, these will be similar across different CPMs and local temperature changes may be reasonably approximated by a local scaling factor applied on top of the large-scale change."	

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56	General			Figure 5.2 is an interesting evaluation of the relation between model bias and climate response, but I have a bit difficulty to understand this relationship for ensemble members of a given model. We're sampling natural variability here, which can affect both the bias and the climate response in an supposed independent way. A systematic slope when plotting model means would support a narrative that the bias generated in one model formulation affects the climate response systematically via the model formulation itself, but for the ensemble members this only applies to occasions where the response is physically constrained for a large anomaly in the baseline, such as shown for the RCM winter precipitation. The figure and its comments deserve a bit more thinking, I believe.	Scientific/technical issue	BVDH	Open	Internal variability and the effects of different representations of physical processes will both contribute to the spread of points that we see, but the latter are likely to explain any systematic relationships, because the effects of internal variability should be random. The different physics parameter settings in the GCM and RCM PPEs will lead to differences between members, which will impact the CPM members through the lateral boundary forcing. Thus a GCM-PPE member with a specific parameter setting that leads to it being dry in the present-day, for example, may also tend to favour greater decreases in precipitation in future. These biases and responses in the large-scale conditions may be expected to similarly impact the downscaling CPM. This possible explanation of the bias-response relationships seen in summer is now discussed in the text (see below). In the case of winter, the explanation is different, with a large anomaly in the baseline physically constraining the response – in particular where rainfall is very persistent in the present-day there is less scope for rainfall frequency to increase in future. Further discussion of Fig 5.2, including the points above, is now given as follows: "Figs. 5.2 and 5.3 show the relationship between present-day biases and future changes, for seasonal mean temperature and precipitation, in the Strand 2 and Strand 3 ensembles. Internal climate variability and the effects of different representations of physical processes will both contribute to the spread of points, but the latter are likely to explain any systematic relationships, because the effects of internal variability should be random. For winter precipitation there is a negative relationship between present-day biases and future changes in CPM-12 for England, and in RCM-PPE and CPM-12 for Scotland (although only the latter is significant). Thus a large wet bias is associated with a smaller future increase in mean precipitation in winter. This is consistent with the possibility mentioned in Section 4.2, that too many wet days in the present-day may limit the scope for future increases in wet day frequency. In particular, this is suggested as one of the possible contributing factors to the different responses in winter mean precipitation between the CPM and RCM. … In summer, the relationship between present-day biases and future changes is positive in the PPEs, with a very similar relationship seen in GC3.05-PPE, RCM-PPE and CPM-12 for England. Thus in this case, drier ensemble members in the present-day tend to give larger decreases in precipitation in the future. This contrast with the winter results is likely explained by differences in the driving processes between the two seasons. In winter, the atmosphere is closer to saturation (with many more wet days). In summer, showers are triggered over the land by surface heating and use the local moisture sources more directly (whereas showers in winter may be more dependent on the advected moisture from the sea). Future changes in summer are however dominated by convergence changes (with evaporation hardly changing). Specifically, over land a switch occurs from a modest net convergence of moisture during the historical time slice, to a net divergence in the future simulations, in both RCM-PPE and CPM-12 (Section 4.2). This suggests that large-scale circulation changes, and not changes in the local soil moisture state, are driving future decreases in summer rainfall. In the present-day, the extent to which showers (and local moisture recycling) occur may be conditioned by the large-scale circulation patterns (e.g. fewer showers where there is more dry continental flow). A positive relationship between biases and future changes across the ensemble, found in Figs 5.2 and 5.3, can be understood by specific parameter settings in the PPEs favouring more dry present-day circulation patterns and greater increases in these in future in some members. This large-scale circulation control of both present-day biases and future changes in summer rainfall also explains the similarity of the relationship between the GC3.05-PPE, RCM-PPE and CPM-12."	
57	2.2 Choice of convection-permitting resolution	17	28-29	You point at unrealistic very strong updrafts at 4km for winter conditions. This argument does not explain why this effect is not seen as strong in summer conditions (fig 2.2.1)	Scientific/technical issue	BVDH	Open	The overestimation of heavy intensities in the 4km model is particularly strong in summer (not winter) as shown in Fig 2.2.1. This is due to convective updraughts being too strong across a 4km grid square, and is more apparent in summer due to this being the season when convection is more prevalent. This is now stated in the text where Fig 2.2.1 is discussed: "These deficiencies are particularly apparent in summer when convection is more prevalent, and relate to the fundamental problem of updraughts being too strong across a 4km grid square."	
58	2.4 Design of 2.2km experiments	24	18-19	The lateral forcing of the CPM by the RCM is a bit unclear regarding the required prescription of vertical motions at the lateral boundaries. Is that variable available from the RCMs?	Scientific/technical issue	BVDH	Open	We explicitly state that the "three-dimensional wind components" are prescribed at the lateral boundaries, which includes vertical wind. This variable is available from the RCMs, and in the case of the 12km RCM is specifically output every 3 hours on all model vertical levels for the purpose of creating lateral boundary conditions.	
59	2.4 Design of 2.2km experiments	26	26-27	You use a mid-century time slice to be more or less representative. This argument is not used when the selection of RCP8.5 was made. So how representative is this RCP at this time horizon?	Scientific/technical issue	BVDH	Open	RCP8.5 corresponds to unmitigated emissions, with greenhouse gas emissions and concentrations increasing considerably over time leading to a radiative forcing of 8.5Wm-2 by the end of the century. For the mid-century time horizon (2020-40), greenhouse gas concentrations have not diverged strongly between the different emissions scenarios, but RCP8.5 should be considered as a high-end "business-as-usual" scenario. RCP8.5 was chosen for the CPM simulations as this has the benefit of a high signal to noise ratio, allowing changes to be identified more easily above natural variability. Changes for lower emissions scenarios can be inferred using scaling approaches. This is now stated in the text: "…For the latter two time slices, the projections correspond to the RCP8.5 scenario, which is a high emissions "business-as-usual" scenario assuming unmitigated greenhouse gas emissions. This scenario was chosen as it provides an upper estimate of expected changes, with the benefit of a high signal-to-noise ratio that is helpful in justifying use of the results to infer changes for other scenarios using scaling approaches."	
60	2.4 Design of 2.2km experiments			I have the feeling that a lot of technical descriptions are given in this section that could have been included in the methodological sections earlier in the chapter	Typo/Format	BVDH	Open	I appreciate there is a lot of technical detail here in regard to the forcing of the 2.2km model, however I feel that this is distinct from the 2.2km model physics itself (described in Section 2.3) and so it better placed in this section on experimental design. Hopefully the addition of a new summary section (Section 2.5) at the end of this chapter helps to draw out the key points.	
61	3.2 Seasonal mean performance	37	1	Fig 3.2.4: the dry western coast in the upper right panel is quite remarkable (but not commented)	Scientific/technical issue	BVDH	Open	The upper right panel (ERAI-CPM-STD bias) is now shown in panel (b) of the revised Fig 3.2.4. Further description of this figure including the dry western coast has now been added: "In summer, biases are again considerably lower in the CPM (UK-average RMS error of 25% in RCM-STD reduced to 16% in CPM-STD, Fig. 3.2.4). In particular, the wet bias in RCM-STD over the northern UK is reduced in CPM-STD, but the CPM has a tendency to be too dry in the far south. The ERAI driven simulations show a similar result, but with reduced biases in general. Although ERAI-CPM-STD gives lower biases across the UK as a whole compared to ERAI-RCM-STD, it does show a marked dry bias along western and southern coasts."	
62	3.4 Hourly precipitation variability	43	5	Figure 3.4.1: please enlarge this figure somewhat	Typo/Format	BVDH	Open	Figures 3.4.1-3.4.4 have all been enlarged.	
63	3.4 Hourly precipitation variability	48	10	Figure 3.4.6: would a log scale on the horizontal axis be more appropriate?	Typo/Format	BVDH	Open	Yes thanks for the suggestion, we now use a log scale which shows the results more clearly.	
64	3.5 High impact events			The language here (and at some other places) swaps frequently between the story told of the RCM or the CPM being the main subject of the sentence. This leads to many mind shifts of the reader, and is somewhat confusing at occasions. Please consider a consistent use of one model being the subject of the narratives (surely applies to Table 5.1, "winter mean temperature")	Unclear phrasing	BVDH	Open	We have made changes in the text in Section 3.5, to ensure the CPM is the main subject of the sentence as much as possible. The phrasing in Table 5.1 has been changed so that the CPM is the subject of the entries.	
65	3.5 High impact events	55	1	Fig 3.5.1: what is "radar-active"/"radar-former"?	Unclear phrasing	BVDH	Open	This is now clarified in the figure caption: "Also indicated in (b) are the sites of radar stations that are currently operational (radar-active) and radar sites that are in the UK network but are no longer providing data (radar-former)."	
66	3.5 High impact events	59	1	Fig 3.5.5: I can't see the pink maximum	Typo/Format	BVDH	Open	The colour scale has been changed, and the plots now zoom into the region of interest so that the pink maximum is visible.	
67	3.5 High impact events	66	1	Fig 3.5.11: please add axis titles	Typo/Format	BVDH	Closed	Done	
68	3.5 High impact events	68	10	what is the "y"?	Typo/Format	BVDH	Open	The number of stations "y"=400, but this information has now been moved to Table 3.1.	
69	3.5 High impact events	71	2	Fig 3.5.15: the downward snow trend is captured reasonably well (but not commented)	Scientific/technical iss	BVDH	Open	This is now commented (noting that Fig 3.5.15 is now 3.5.17): "A threshold of 0.02mm was used in UKCP09, and based on this choice, both the CPM and RCM substantially overestimate the number of days of lying snow and falling snow, although reasonably capture the observed downward trend in lying snow through time (Figs. 3.5.16-3.5.17)."	
70	4.1 Overview	73	20-21	the phrase "…, but not uncertainty…" is a bit confusing	Unclear phrasing	BVDH	Open	The phrase has been changed to avoid any confusion.	
71	4.2 Seasonal mean changes	73	29-30	the country mean is almost zero, a compensation takes place in SE UK (but not mentioned)	Scientific/technical iss	BVDH	Open	A comment noting this has been added: "UK-average differences between CPM-12 and RCM-PPE are almost zero because smaller increases in temperature over Scotland in the CPM are in part compensated by a tendency for larger increases in temperature in the south-east UK."	
72	4.2 Seasonal mean changes	74	2-3	Difficult to understand, with the mixed information on increases and decreases	Scientific/technical iss	BVDH	Open	The sentence has been split to improve clarity.	
73	4.2 Seasonal mean changes	74	23	Add "than in the CPM" after "higher in the RCM"	Unclear phrasing	BVDH	Closed	Done	
74	4.2 Seasonal mean changes	74	30-31	Move "in the RCM" to after "in the baseline"	Unclear phrasing	BVDH	Closed	Done	

ID	Section	Page (as per page numbering)	Line number	Comment	Category	Reviewer initials	Status	MO response	Response from authors
75	4.3 Changes at daily time scale	87	10	Replace "occurrence" by "frequency distribution"	Unclear phrasing	BVDH	Closed	Done	
76	4.3 Changes at daily time scale	87	15	Replace "this season" by "winter"	Unclear phrasing	BVDH	Closed	Done	
77	4.4 Changes in hourly precipitation	97	29	Insert "relative" between "largest" and "increases"	Unclear phrasing	BVDH	Closed	Done	
78	4.4 Changes in hourly precipitation	105	16-22	Does the limited moisture supply from the surface over dry land play a role here?	Scientific/technical iss	BVDH	Open	In winter, evaporation is not soil moisture limited (as shown in Fig 4.5.8) and as shown in Table 4.1 there are small increases in evaporation over land (of 0.20 mm/day) in both models in future. Thus the limited moisture supply from the surface over dry land does not seem to be important here for winter. Further discussion of the atmospheric water budget terms (Table 4.1 for winter and Table 4.2 for summer) is now added to Section 4.2. This supports the explanation that it is the advection of showers generated over the sea, which leads to the greater winter precipitation increase in the CPM over land. Processes in summer however are different, and in this season, local recycling of moisture is more important. In particular text has been added as follows: "Tables 4.1 and 4.2 show the atmospheric water budget terms, and their future change, in winter and summer respectively … The greater increase in winter precipitation in the CPM is coming from the greater increase in moisture flux convergence over land in the CPM (with similar changes in evaporation over land). By contrast future changes in both evaporation and moisture flux convergence over the sea are higher in the RCM than CPM in winter. Thus greater increases in moisture flux convergence over the land in winter in the CPM appear to be compensated by smaller increases in moisture flux convergence over the sea. In summer (unlike in winter) evaporation over the land dominates over moisture flux convergence over the land, with the local recycling of moisture being important (although the extent to which showers (and local moisture recycling) occur may be conditioned by the large-scale circulation patterns, e.g. fewer showers where there is more dry continental flow). This is in contrast to winter, where showers over land may be more dependent on the advected moisture from the sea …"	
79	4.5 Changes in high impact events	112	9-10	Why does SE UK show an exception here?	Scientific/technical iss	BVDH	Open	Changes in the 2 year return level reflect changes in both the intensity and frequency of rainfall. In summer the frequency of rainfall is decreasing, with the greatest decreases in the south (Fig 4.4.4). So, although the intensity of rainfall is increasing across the UK in most ensemble members (Fig 4.4.5), the frequency changes may dominate the change in the 2-year return level. This explains why the S-UK in JJA shows decreases, which is an exception compared to other regions and seasons. This is clarified in the text: "Changes in the 2-year return level reflect changes in both the intensity and frequency of precipitation, and decreases for the S-UK in summer are due to large decreases in rainfall occurrence (Fig 4.4.4), which in this case override increases in rainfall intensity."	
80	4.5 Changes in high impact events	113	6-8	Is there a good physical rationale of this seasonal shift?	Scientific/technical iss	BVDH	Open	Text has been added discussing this: "The changing seasonality of extremes may be explained by warming leading to an increase in convective activity in the autumn, and thus effectively an extension of the convective season. Hourly extremes are increasing in both seasons with increasing atmospheric moisture, however, the increases are larger in autumn than summer mainly due to the greater increases in moisture availability in autumn (UK-average ensemble-mean dew point temperature increase of 3.7K in SON compared to 3.2K in JJA). However, we do also find higher scaling of extreme precipitation increases with increased moisture in autumn (CPM-12 ensemble-mean UK-average scaling of 8.2%/K in SON compared to 7.8%/K in JJA, Section 4.4), which may be explained by differences in the atmospheric stability or nature of storms compared to summer."	
81	4.5 Changes in high impact events	118	23-25	Are the formulations of the physical relationships between soil moisture and evaporation similar in the RCM and CPM?	Scientific/technical iss	BVDH	Open	As outlined in Section 2.3 both models use JULES, and thus have the same physics formulation but there are some parameter differences that may impact the relationship. As noted in the previous paragraph (now moved to Section 3.5), a key parameter controlling the relationship between soil moisture and evaporation (the scaling factor for soil moisture, which controls the critical and saturated soil moisture thresholds) is varied across the RCM but not the CPM ensemble.	
82	4.5 Changes in high impact events	119	1-2	Bit strange formulation: the change does not occur in the CPM, but the soil limitation does	Scientific/technical iss	BVDH	Open	The text has been modified to clarify this point: "In future, there is a decrease in soil moisture during summer (Fig 4.5.8), consistent with the reduction in summer mean precipitation. In RCM-PPE, this results in the majority of members moving into a regime of evapotranspiration being soil-moisture limited over the southern-UK in summer, whilst soil moisture remains above the critical point over the northern-UK. In CPM-12, evapotranspiration becomes soil moisture limited in all members in the future over the northern-UK, as is already the case in the present-climate over the southern-UK (Section 3.5)."	
83	4.5 Changes in high impact events	120	2	Fig 4.5.6: The numbers along the axes are a bit small	Typo/Format	BVDH	Open	The font size has been increased. This Figure has now been moved to Section 3.5 (Fig 3.5.15).	
84	5 Interpretation and use of the projections	131	29	Replace "increased" by "more"	Unclear phrasing	BVDH	Closed	Done	
85	General	0		Overall: this is an extremely useful, very detailed and carefully assembled report. The analyses presented is very comprehensive and addressing most of the key issues. The authors of the report are very competent and deserve a lot of praise for their hard work, in particular given the time constraints.	Scientific/technical issue	CS	Open	Thank you very much for your positive comment.	
86	General	0		The list of references is incomplete. To make an example, p12,l13 lists Bossi et al (submitted), but there is no reference, and the paeper is not yet in any data base	Scientific/technical issue	CS	Open	The paper referred to here is now instead cited as Kirchner-Bossi et al (in prep), and is added to the reference list. To do: reference list still incomplete	
87	1.3 Motivation for new 2.2km projections	12	20-21	CPMs also have a better representation of snow cover. This is important as it introduces a systematic effect due to the improved representation of the topographic height distribution	Scientific/technical issue	CS	Open	I am not sure that CPMs always have a better representation of snow cover. They have a better representation of topographic height, and so the climate over mountainous regions as already stated in the text.	
88	1.3 Motivation for new 2.2km projections	12	30-31	Ban et al. also found substantial increases in the incidence of hourly precipitation, but the increases were actually smaller than in the 12km simulation (different to Kendeon et al 2014).	Scientific/technical issue	CS	Open	Ban et al (2015) indeed show smaller increases in the CPM compared to the 12km simulation for the 99.95th percentile of hourly precipitation, when considering all (wet and dry) hours. In this case, the metric is measuring both intensity and frequency changes combined. However, for a metric measuring extreme intensity changes, as discussed here, Ban et al (2015) show a greater increase in the CPM compared to the 12km simulation (their supplementary Fig S6 showing changes for 90th percentile of wet hours). This is now clarified in the text: "Ban et al (2015) found a similar result for the Alpine region when considering changes in an extreme intensity metric (90th percentile of wet hours, their Fig. S6), although larger increases were found in the 12km simulation compared to the CPM for extremes of all hours."	
89	1.3 Motivation for new 2.2km projections	13	2	Another study that could be mentioned here is Belusic et al. 2018: Belušić A., Telišman Prtenjak M., Güttler I., Ban N., Leutwyler D., Schär C., 2018: Near-surface wind variability over the broader Adriatic region: insights from an ensemble of regional climate models, Clim. Dyn., 50 (11-12), 4455–4480, http://dx.doi.org/10.1007/s00382-017-3885-5	Scientific/technical issue	CS	Open	Thank you that is a useful study that I was not aware of. Reference to Belusic et al 2018 has been added.	
90	1.3 Motivation for new 2.2km projections	14	1-8	You might want to mention the intercomparison of the two European-scale simulations available (i.e. Berthou et al. 2018: Pan-European climate at convection-permitting scale: a model intercomparison study. Published online, Clim. Dyn., https://doi.org/10.1007/s00382-018-4114-6	Scientific/technical issue	CS	Open	This study is now mentioned: "A first model-intercomparison study at convection-permitting scale (Berthou et al, 2018) suggested that the added value of CPMs in representing present-day precipitation is robust to CPM structural uncertainties. In particular, two CPMs, using different dynamical cores and parameterisation packages, showed qualitatively similar differences in present-day precipitation characteristics compared to 12km models."	
91	2.1 Overview	16	4-5	This is not only "the first time ... for the UK", but I believe it is the first time internationally	Scientific/technical issue	CS	Open	Thank you for pointing this out. We have made this point in the non-technical summary: "For the first time internationally, a climate model at a resolution on par with operational weather forecast models, is being used for national climate scenarios." In Section 2.1, we also now state this: "UKCP18 is the first time internationally that an ensemble of climate projections has been carried out at convection-permitting scale for use in national climate scenarios."	

ID	Section	Page (as per page numbering)	Line number	Comment	Category	Reviewer initials	Status	MO response	Response from authors
92	2.2 Choice of convection-permitting resolution	18	23	This is a "Cumulative probability distribution ...". In addition, please define the smalldiagram in the upper-right corners	Scientific/technical issue	CS	Open	The changes have been made to the caption: "Cumulative probability distribution of hourly precipitation intensity, … The insert shows a zoomed in version of the distribution for low intensities, using a linear scale on the vertical axis."	
93	2.2 Choice of convection-permitting resolution	19	4	"XX stations"	Unclear phrasing	CS	Open	The dataset is based on 1900 hourly gauges. This information has been added to Table 3.1, with reference to Table 3.1 provided in the figure caption rather than explicit reference to 1900 stations.	
94	2.2 Choice of convection-permitting resolution	19	9-12	Fig.2.2.2: It appears that there is no sign of convergence in the diurnal cycle. I think this is different to some publications (Panosetti, D., L. Schlemmer, and C. Schär, 2019: Bulk and structural convergence at convection-resolving scales in real-case simulations of summertime moist convection over land. Quart. J. Roy. Meteorol. Soc., Q. J. R. Meteorol. Soc., http://doi.org/10.1002/qj.3502)	Scientific/technical issue	CS	Open	The diurnal cycle is more similar between the 2.2km and 1.5km models, with the delay in the initiation of convection being much more pronounced in the 4km model. However the 2.2km and 1.5km models are closer in resolution than the 2.2km and 4km models, and so it is hard to assess whether there is any convergence. We feel a discussion of convergence with increasing resolution is beyond the scope of this report.	
95	2.2 Choice of convection-permitting resolution	20	17	The text mentions a time step of 60 seconds. This corresponds to a CFL number of about 3. While the model is stable (due to the use of a SISL scheme), is there an analysis of the senstitivity of the results to the time step? It appears to me that such a time step would imply large implicit diffusion, irrespective of the numerical stability of the approach.	Scientific/technical issue	CS	Open	Work has been carried out within NWP to determine the appropriate time step for convection-permitting resolution models. In particular, as long a time step as possible is used, whilst having an acceptable failure rate. 75 or 100 seconds is used operationally in NWP at 2.2km resolution. In UKCP18 we decided to reduce this to 60 sec, due to issues with numerical instability for longer time steps. We have added a note to the text: "The model time step is 60 seconds, which is shorter than that used in the NWP operational 2.2km model (75 or 100 seconds) due to improved numerical stability." We note that there is no explicit numerical diffusion applied in the model, other than damping of the vertical velocity near the lid and Davies relaxation applied near the boundary to control boundary effects. Implicit numerical diffusion however comes from: 1)Spatial damping from the interpolation used in the semi-Lagrangian scheme. This is a complicated combination of the non-integer part of the Courant number (it being maximal when the departure point is midway between grid points and zero when the departure point coincides with a grid point) and how many time steps are needed for a given integration period (i.e. how many times the interpolation is applied). So depending how those two factors play out lengthening the time step can either increase the damping or reduce it. We use various forms of cubic interpolation for all terms. For a given Courant number this is a lot less damping than the linear interpolation used in some centres. 2)Temporal damping due to off-centring of the semi-implicit scheme. With a centred scheme (off-centring weights = ½) there is no damping. As those weights are increased from ½ there is temporal damping that is a function of (weight-1/2)*dt and so this will increase with time step. We use a mild off-centring of 0.55 (comparable to that used by other semi-implicit models). Again that increase in temporal damping is balanced by the need to use fewer time steps. So overall the model has minimal damping. We feel this description is too detailed to go into the report, but many aspects (including the time stepping, and improved numerical accuracy and stability of the new dynamical formulation) are discussed in the Walters et al 2017 paper that has now been added as an additional reference in Section 2.3 where we introduce the dynamical core.	
96	2.4 Design of 2.2km experiments	24	18-19	There is some duplication in the text, the same matter is also dicussed on p.20, l.4-17, and in Fig.2.3.1. May be an improved caption of Fig.2.3.1 would help. From the current text I understand that the grid spacing is refined within the boundary zone from 4 to 2.2 km.	Scientific/technical issue	CS	Open	The variable resolution rim is described in Section 2.3 and shown in Fig 2.3.1, whilst the text in Section 2.4 describes the 24-point relaxation zone across which lateral boundary conditions (LBCs) are applied. The latter is part of the variable resolution rim (which totals 55 grid points), but is not the same thing. This difference between the variable resolution rim and the LBC relaxation zone is now clarified in the text: "These variables are introduced (from archived files) every 3 hours from the relevant Strand 3 12km RCM member, and applied to the CPM across a 24-point relaxation zone (which is the outer part of the 55-point variable resolution rim described in Section 2.3)."	
97	2.4 Design of 2.2km experiments	26	12-18	May be this can be justified by arguing that the most relevant sensitivity to the parameter choices will likely show up in large-scale circulation changes, which are represented in the current framework.	Scientific/technical issue	CS	Open	For some of the perturbed parameters, it may be true that much of the sensitivity shows up in the large-scale circulation changes. However, this is not true for all parameters. For example the soil moisture scaling parameter (which controls the critical and saturated soil moisture thresholds) is perturbed in the RCM but not the CPM, and this is likely to impact local soil moisture feedbacks. Thus the lack of parameter perturbations in the CPM in this case will result in an underestimation of uncertainties in changes at local scales. The lack of parameter perturbations in the CPM is justified by the fact that "given the structural differences between the CPM and the driving global and regional models, it was not possible to mirror the full set of RCM parameter perturbations in the CPM". It cannot be justified by arguing that much of the uncertainty is still sampled, as this is not the case. The fact that the CPM underestimates uncertainty as a consequence of this experimental choice is now emphasised here (as well as stated clearly in the non-technical summary and in several places in later sections). We additionally note here that an underestimation of uncertainty will also arise due to the fact that no information from other international climate models is included in either the CPM or RCM ensemble. These structural uncertainties may be more important than uncertainties in local processes in many cases. The text now reads: "The CPM ensemble underestimates uncertainty in changes at local scales, since parametric uncertainties in its local processes and feedbacks (e.g. uncertainty in soil moisture parameters) are not sampled. More widely, the CPM and RCM ensembles also underestimate uncertainties because they are driven exclusively by variants of the Met Office Hadley Centre model (GC3.05), and currently lack information from other international climate models. Nevertheless, the present ensemble represents a significant step forward, since previous CPM information has been limited to individual climate change simulations lacking any uncertainty context."	
98	2.4 Design of 2.2km experiments	27	26-28	Does the land-surface scheme account for changes in plant physiology related to changes in CO2 concentration?	Scientific/technical issue	CS	Open	Yes, CO2 affects how the plant stomata open and close, and this has a big impact on evaporation fluxes, which feeds back onto rainfall. Photosynthetic uptake also depends on CO2 concentration. This has been noted in the text in Section 2.3 where we introduce the land-surface model JULES: "It uses the Joint UK Land Environment Simulator (JULES, Best et al 2011) to model processes at the land surface and in the sub-surface soil. This includes the CO2 impact on plant stomata, which affects evaporation fluxes."	
99	2.4 Design of 2.2km experiments	27	28-34	The current scenarios include land-use changes. I am concerned that increasingly such changes are included (among many others), and that we do not understand whether and how they interact with the dominant effect of GHG changes. From a scientific point of view, it would be much better to restrict the simulations to the main effects, rather than adding details. This is a general comment that pertains to many studies. Simulations should be designed to understand the key issues, and not be contaminated by secondary factors.My concern is confirmed by p.28, l.2-4, which confirms that many of these additional factors are added very subjectively in different models.	Scientific/technical issue	CS	Open	It is true that the effects of future land-use change for the UK are relatively minor, compared with the main GHG-driven effects (e.g. Brovkin et al., 2013). Nevertheless, land-use was accounted for in CMIP5 simulations, and is therefore current practice in international scenario experiments run to support decision-making. This, in turn, is consistent with the "all-forcings" philosophy taken in such runs, therefore we decided to follow this approach in UKCP18. Furthermore, we considered it important to use a consistent set of forcing agents in our suite of global and downscaling projections in Strands 2 and 3, so we decided to include land-use changes in the CPM, as well as in the driving GCM and RCM. Note that we took the same approach with aerosols. It is true that, as a result, we are unable to explicitly examine the specific effects of individual forcing agents such as GHGs. However, the international community uses other approaches for this (e.g. idealised MIP studies, or single forcing simulations), rather than comprehensive scenario experiments, whose purpose is rather to study the combined effects of known (albeit uncertain) forcing agents, rather than specific agents in isolation. So we believe the approach we have taken is justifiable on this basis, and in-line with accepted understanding of the purpose of such simulations. In future, addition of further sensitivity experiments, such as parallel single-forcing simulations, is an option for consideration.	
100	3.1 Overview	32-33		Table 3.1: For all precipitation data set that are based on station data, please provide the number of stations that are included. In addition, please discuss whether these data sets include a correction for the systematic undercatch of rain gauge stations.	Scientific/technical issue	CS	Open	The number of stations is now provided, as well as additional discussion of systematic rain gauge undercatch (including reference to Kotlarski et al, 2014, Rajczak and Schar, 2017). No correction for this undercatch is applied, and this is now stated explicitly in the table.	

ID	Section	Page (as per page numbering)	Line number	Comment	Category	Reviewer initials	Status	MO response	Response from authors
101	3.2 Seasonal mean performance	General		General: Please explain why you choose different simulations for the different analyses. First of all, if you intend to validated the last model of the model chain (i.e. RCM or CPM), the analyses should use ERA-I driven simulations. Second, I did not understand why in some of the analyses you analyzed RCM-STD and CPM-STD (e.g. for mean temperatures and precipitation), while in others you use CMP-PPE and CPM-12 (for extremes). I think the same set of simulations should be evaluated in all of the analyses.	Scientific/technical issue	CS	Open	The aim of this section is to validate the performance of the RCM and CPM ensembles, in the presence of skilful but imperfect lateral boundary forcing from the global simulations. This needs to be the bottom line, as these are the simulations that will be used in applications. The ERAI-driven run is used as a key precursor to this assessment, as it establishes the credentials of the CPM as a regionalisation tool. Also of interest (in selected cases, to avoid a proliferation of plots), is to partition the total error in the GCM-driven CPM into global and regional components. This adds understanding and context to the interpretation of the total error, and is why some plots focus on this comparison for STD, which is the only ensemble member for which an ERAI-driven simulation is available. However, since the evaluation ultimately rests on the ensemble performance, we do examine present-day biases for the CPM-12 and RCM-PPE. We appreciate that biases for the latter ensembles are also affected by biases in the driving GCMs, but these effects are important to include, as explained above. Also, we are able to compare biases between the RCM and CPM, and infer for example whether the CPM is consistently wetter or drier than the RCM. However, where we show results for the CPM-12 and RCM-PPE, we now also additionally discuss biases for the ERAI-RCM-STD and ERAI-CPM-STD (although figures themselves are not shown, to keep the number of figures down). This approach is clarified at the start of Section 3.3: "We focus mainly on ensemble-averaged biases from the GCM-driven simulations, as these are the simulations that will be used in impacts applications. It is therefore appropriate to consider a measure of performance across the whole ensemble, that accounts for regional errors arising both from the global model boundary forcing, as well as from internal errors generated within the RCM and CPM domains. However, we also discuss biases from the ERA-interim driven simulations, which provide a direct validation of the RCM and CPM standard member as specific regionalisation tools, independent of biases in the driving global models." For results on biases in ERA-interim driven simulations in Section 3.3, please see response to comment below.	
102	3.2 Seasonal mean performance	General		The text should be a bit more careful about the use of the term "improvement" (of one model version versus another). Such differences might just be the result of a better compensation of errors, and not represent real improvements.	Scientific/technical issue	CS	Open	We use the term "improvement" in relation to the representation of rainfall occurrence in the CPM, which we believe is valid. In particular we now state in Section 3.3: "ERAI-driven simulations show similar results … confirming the reduced biases in CPM-12 reflect improved performance in the CPM (and not just a compensation of errors)." In Section 3.3 we also state that the CPM shows some "improvement in wet-day intensity". Again we think this is valid, as it reflects real improvements in the representation of topography for biases over mountains. Other uses of the term "improvement" or "improved" have been checked throughout Section 3, to ensure they are only used where differences represent real improvements. For example some differences in temperature biases may not reflect a real improvement, and the text has been changed accordingly.	
103	3.2 Seasonal mean performance	35	1-8	It is nice to see that overall the biases are rather small	Scientific/technical issue	CS	Open	Yes, agreed	
104	3.3 Daily variability	General		This analysis does not address the ERA-I driven simulations (see comment above), where analyses would be most significant	Scientific/technical issue	CS	Open	Please see response above in terms of clarification of the approach used. Biases from the ERA-I driven simulations are discussed in Section 3.3 as follows: For cold winter days: "The biases are also seen in the ERA-interim driven simulations (not shown), suggesting that the biases are inherent to the downscaling models." For hot summer days: "The ERA-interim driven simulations (ERAI-RCM-STD and ERAI-CPM-STD, not shown), show that the CPM gives a better representation of hot summer days over the northern UK than the RCM, but not in the south where hot summer days tend to be too hot (by up to 1.5ºC)." For precipitation frequency: "ERAI-driven simulations show similar results (with biases of 5.4% in ERAI-CPM-STD compared to 18.7% in ERAI-RCM-STD in winter, and 12.2% compared to 16.6% in summer) confirming the reduced biases in CPM-12 reflect improved performance in the CPM (and not just a compensation of errors)." For precipitation intensity: "Biases are very similar in ERA-interim driven simulations (not shown) indicating that these biases are inherent to the downscaling models." For heavy daily precipitation: "For heavy daily precipitation (99th percentile) in winter, the RCM underestimates the intensity over mountains, but typically overestimates it elsewhere. These biases are reduced in the CPM (UK RMS error is reduced from 19% in RCM-PPE to 16% in CPM-12, and similarly from 20% in ERAI-RCM-STD to 16% in ERAI-CPM-STD). In summer, biases are similar in the CPM, but with a tendency for the CPM to overestimate the intensity of heavy daily events (UK RMS error of 18% in CPM-12 compared to 16% in RCM-PPE, and similarly 17% in ERAI-CPM-STD compared to 16% in ERAI-RCM-STD). In both seasons, and in both models, wet biases in heavy precipitation are reduced in the STD member when driven by ERA-interim compared to GC3.05, suggesting wet biases are in part inherited from the driving global simulations."	
105	3.3 Daily variability	38	19-20	You need to specify whether these are all-day or wet-day percentiles (all-hour or wet-hour percentiles). This applies also to the figure captions, where percentiles should be clearly defined (e.g. Fig.3.3.2, 3.4.3	Scientific/technical issue	CS	Open	This is 99th percentile of all days. This is clarified in the text and in Fig 3.3.2 and 3.3.3 captions.	
106	3.4 Hourly precipitation variability	42	23-24	See previous comment	Scientific/technical issue	CS	Open	In Figs 3.4.3 and 3.4.4, these are percentiles of all hours. This is clarified in the text and figure captions.	
107	3.4 Hourly precipitation variability	48	10-18	This is in essence a histogram, and the fractional contribution (y-axes) will thus depend upon the bin width. I appreciate that the bins are specified in the caption, but still the display seems somewhat arbitrary to me.	Scientific/technical issue	CS	Open	We have changed the x-axis in this figure (and also similarly Fig 4.4.8) so that it has a logarithmic scale, consistent with the logarithmic intensity bins. Logarithmic bins are used so that it is possible to visualise the entire precipitation distribution and differences compared to observations easily (for both low and high intensities) on a single plot.	
108	3.5 High impact events	51	9-10	It should be mentioned that the Generalized Pareto Distribution follows from the use of the peak-over-thershold (POT) methodology.	Scientific/technical issue	CS	Closed	Done	
109	3.5 High impact events	52	29-31	It would be nice if you could state why the "growth curve" is actually important. Some readers might still conclude that CPM is actually worse.	Scientific/technical issue	CS	Open	The importance of the growth curve is now stated in the text: "The growth curve is commonly used in hydrological modelling where it is a measure of the variability in flooding, but it is also important as it is indicative of the underlying extreme rainfall processes, and the extent to which the model is able to capture the relative increase in rainfall for the rarest events."	
110	3.5 High impact events	55	1-9	Unsuitable choice of color scale in Fig.3.5.1	Unclear phrasing	CS	Open	Colour scheme has been changed.	
111	3.5 High impact events	59	1-7	Unsuitable choice of color scale in Fig.3.5.5-3.5.8	Unclear phrasing	CS	Open	The colour scale has been changed, and the plots now zoom into the region of interest.	
112	3.5 High impact events	62	5ff	This text requires revisions. It is a mixture between observations, validation and projections, and does not follow the structure of the report into sections 3 and 4	Scientific/technical issue	CS	Open	The text in Section 3.5 only relates to present-day evaluation, whilst future projections for these high impact events are discussed in Section 4.5. However, the original plots showing the frequency of cold spells over the northern UK (3.5.11) and hot spells over the southern UK (3.5.13) showed both present-day biases and future change results, which do not follow the report structure. Therefore these plots have been split. Figures 3.5.11 and 3.5.13, now only show the results relevant to the present-day evaluation, with future projected changes moved to Fig. 4.5.6 and 4.5.7. Some of the discussion of the observations has been removed from Section 3.5, and is instead covered in Table 3.1. In particular, information on snow observations is now all in Table 3.1 (rather than Section 3.5). Some discussion of the observations has been retained in Section 3.5, however, where it is important to the assessment of present-day model performance. Note soil moisture evaluation has now been added to this section, with discussion of CPM-RCM soil moisture differences in the present-day moved from Section 4.5.	
113	3.5 High impact events	68	7ff	The authors should explore the extent to which the intermediate perfromance of the snow validation relates to the underestimated temperatures (see Fig.3.2.1) in the RCM and CPM over Scotland	Scientific/technical issue	CS	Open	Some additional discussion of this has been added: "Less lying snow in the CPM is likely to be a factor leading to the CPM being warmer at the surface than the RCM over the northern UK in winter (Section 3.2), through changes in the surface energy budget. In particular a reduction in snow cover reduces the surface albedo resulting in more absorbed shortwave radiation, and allows sensible heating from the ground into the lowest atmospheric layer (since snow acts as a thermal insulator). An overestimation of lying snow in both the CPM and RCM, but with greater biases in the RCM (as the validation here suggests), is consistent with both models showing a cold bias over Scotland in winter, but with greater cold biases in the RCM."	

ID	Section	Page (as per page numbering)	Line number	Comment	Category	Reviewer initials	Status	MO response	Response from authors
114	4.2 Seasonal mean changes	74	17ff	The explanations presented are not very convincing. It would be better to shorten the text (p.74, l.19- p.75,l.33)	Scientific/technical issue	CS	Open	We appreciate that this discussion is not a full mechanistic understanding of the differences in the winter mean precipitation response between the CPM and RCM, but such an in-depth investigation was never going to be possible within the time frame for this report. In the text we acknowledge the need for further work (see added text below). Nevertheless we believe that this information as it currently stands is useful, and we understood we had broad agreement from the Peer Review Panel on this point at the virtual meeting in March. Since then we have done some further analysis of the atmospheric water budget (Tables 4.1 and 4.2 and accompanying text), which strengthens the arguments presented here, and this new information has been added later in Section 4.2. At the start of this discussion we now explicitly state that further work is needed to confirm the proposed explanations: "Instead, there are a number of possible explanations for the difference as outlined below, although further work is needed to confirm these and analyse other potential contributions to the differences."	
115	4.2 Seasonal mean changes	76	11	The table is useful but not referred to in the text. Also, this should also be shown for JJA and not only for DJF	Scientific/technical issue	CS	Open	A table has been added for summer (Table 4.2) as well as winter (Table 4.1), and these tables are now discussed in the text in Section 4.2.	
116	4.2 Seasonal mean changes	78	1-6	In this and the following figures (Fig.4.2.1-4.2.8) the display over Ireland is inconsistent. In some panels (e.g. lower panels in Fig.4.2.3) you only show the data over the UK and not in the Republic of Ireland, in others you show it throughout Ireland. Since these are simulation results that do not rely on observational data, I encourage showing the data over all land surfaces	Unclear phrasing	CS	Open	The panels now all consistently only show changes over the UK (and not the Republic of Ireland). This follows what was done in the Part 1 report (Murphy et al 2018) and previous UKCP09 reports.	
117	4.2 Seasonal mean changes	78	4	"regridded to 12 km": do you do the regridding before selecting the 2nd-largest / smallest members? Please clarify	Scientific/technical issue	CS	Open	Yes the regridding to 12km is done, before calculation of responses and selection of 2nd largest/smallest members. This is clarified in the figure caption.	
118	4.2 Seasonal mean changes	85	2-3	Is this figure (and simiilar ones) really useful? Fig.4.2.6 shows the two models, and demonstrates that they are very similar. But here (Fig.4.2.8) the small differences are blown up	Unclear phrasing	CS	Open	These figures are looking at the impact of the downscaling on the future changes, in particular they are providing information on how the CPM-RCM differences for individual members vary across the ensemble. This differs from the other figures which examine the responses and their uncertainty, independently for the CPM and RCM ensembles. In the case of winter precipitation changes (Fig 4.2.7) this provides important new information, namely that the CPM increase is greater than its parent RCM for all members. In the case of summer precipitation changes (Fig 4.2.8), the CPM decrease can either be greater or smaller than its parent RCM, depending on member. Thus there is not a systematic shift in the ensemble responses in summer. Text has been added describing the additional understanding gained from Fig 4.2.8: "Fig. 4.2.8 shows that the decrease in the CPM can either be greater or smaller than its parent RCM, depending on member. Thus there is not a systematic shift in the ensemble responses in summer (unlike winter, cf. Fig. 4.2.7)."	
119	4.3 Changes at daily time scale	96	2-3	Fig.4.3.8: the figure is using an unsuitable colorus scale, better use same scale as in Fig.4.3.5	Unclear phrasing	CS	Open	Change made	
120	4.3 Changes at daily time scale	97	23-25	It appears that this is different than in Kendon et al (2014)	Scientific/technical issue	CS	Open	Larger increases in high percentiles of summer hourly precipitation in CPM-12 compared to RCM-PPE is consistent with Kendon et al (2014). Kendon et al (2014) used different metrics of hourly precipitation to that used here. Namely, the mean of the upper 5% of wet values or frequency changes for exceeding a range of thresholds (in mm/h), as opposed to increases in the 99.95th percentile of all hours examined here. Thus it is not possible to compare the exact results. Neverthless, the discrepancy between the models in terms of summer changes is less here than in Kendon et al (2014), which suggests increases are only seen in the CPM. A note to this effect has been added: "We note that this discrepancy between the models is less than in Kendon et al (2014), which showed increases in heavy summer rainfall in the CPM only."	
121	4.3 Changes at daily time scale	97	28-32	From an impact / adaptation point of view, the most important issue are the changes in annual precipitation indices, as these are relevant for the dimensioning of water resource infrastructure. Did you compute annual indices as well? Are the changes in SON relevant to the annual changes?	Scientific/technical issue	CS	Open	Results in Sections 4.3 and 4.4 have only been computed for seasonal indices, as we want to avoid proliferation of plots, and it is useful to separate changes in summer and winter. However, we appreciate the importance of annual indices from an impact/planning perspective. Thus for hourly precipitation extremes (Section 4.5) we show changes for annual as well as seasonal extremes, and in this case annual changes look similar to autumn changes.	
122	4.4 Changes in hourly precipitation	104	2-12	Fig.4.4.8: the figure is "for wet events only". Thus this relates to conditional changes (conditional on the occrurrence of precipitation). As the precipitation frequency changes substantially, at least in JJA, the figure and the discussion might be misleading. It is not clear to what extent the intensity of heavy events actually increases. A detailed analysis of this problem is in the following paper: Schär, C., N. Ban, E.M. Fischer, J. Rajczak, J. Schmidli, C. Frei, F. Giorgi, T.R. Karl, E.J. Kendon, A.M.G. Klein Tank, P.A. O'Gorman, J. Sillmann, X. Zhang, F.W. Zwiers, 2016: Percentile indices for assessing changes in heavy precipitation events. Climatic Change, 137 (1), 201-216, http://dx.doi.org/10.1007/s10584-016-1669-2 . However, the appropriate analysis is done later in Fig.4.5.1-4.5.5. For instance, it shows that the changes projected by CPM are actually smaller than those of the RCM (with the possible exception of MAM and JJA), quite to the opposite of the indications provided by Fig.4.4.8	Scientific/technical issue	CS	Open	We appreciate that changes in wet value percentiles can differ from changes in all value percentiles, and that care needs to be taken when interpreting the results. For this reason, in Section 4.4, we start by showing changes in all value percentiles. In particular, in Figs 4.4.3, 4.4.6 and 4.4.7, we show changes for percentiles of all hours (which has now been clarified in the figure captions). These show greater increases in the 99.95th percentile of hourly precipitation in the CPM compared to the RCM in winter (22% versus 20%), summer (16% versus 12%), but not autumn (30% versus 32%). In Figure 4.4.8 we are interested in analysing the change in the shape of the precipitation intensity distribution. The changes in the fractional contribution for wet events only are shown, but since dry events (<0.1mm/h) do not contribute much precipitation, the key results are the same if changes in fractional contribution are plotted for all events (which we have done to check). In this case we find a greater intensification of precipitation in the CPM compared to the RCM in summer, which is consistent with the result above found for changes in the 99.95th percentile of all hours. Thus this analysis is not in anyway misleading. We have added notes to the text: "In this case, we are considering only wet values (>0.1mm/h), but note that the key results are the same if fractional contribution changes are plotted for all (wet and dry) values … The greatest difference in changes between the models is seen in summer, where there is a much greater increase in the fractional contribution from high intensities in the CPM (consistent with Kendon et al 2014). This is consistent with the greater increases in the 99.95th percentile (of all hours) in the CPM compared to the RCM shown in Fig 4.4.6." Figures 4.5.1-4.5.5 show changes in return levels, and so further into the extreme tail of the distribution than the analyses in Section 4.4. In this case the differences between the models are not the same as found when looking at the 99.95th percentile of hourly precipitation, not because we are now considering all hours (since both analyses do that), but because the RCM results are now influenced by large increases in the rarest events (likely due to grid point storms).	
123	4.4 Changes in hourly precipitation	103	13-14	Following up from the previous comment (Fig.4.4.8): The text states that "there is a much greater increase in the fractional contribution from high intensities". Are you sure that this is more than just a reduction of wet days?	Scientific/technical issue	CS	Open	As noted above, we still see a much greater increase in the fractional contribution from high intensities in the CPM compared to the RCM when the results are plotted for all events. Also the greater increase in the 99.95th percentile of all hours in the CPM confirms that this result is not just coming from a reduction of wet days/hours.	
124	4.5 Changes in high impact events	112	23-24	This confirms what was stated above (in the comment relating to Fig.4.4.8)	Scientific/technical issue	CS	Open	Please see response above.	
125	5 Interpretation and use of the projections	133	1-4	I agree with this statement and the report could even argue more strongly. An assessment of heavy hourly precipitation extremes based on models with parameterized projections would not be credible. You should also stress that the high-end return levels for SON and DJF can differ by more than a factor of 2 (see Fig.4.5.2). In terms of adaptation, such a difference would be of key importance		CS	Open	The fact that the CPM provides a step change in representing convective processes, and changes in heavy hourly precipitation from parameterized projections are not credible, is stated here, in Section 6 and now at the start of the report in the non-technical summary. The fact that increases in high return period events in SON and DJF can be almost a factor of 2 different is now noted where we discuss Fig 4.5.2 in Section 4.5, and is stated again here. Added text in Section 4.5: "The RCM-PPE also shows greater increases in return level with increasing return period in all seasons and regions, and most notably in the S-UK in autumn and winter. This behaviour is much less apparent in the CPM-12, so although the changes for the 2-yr return level may be comparable between RCM-PPE and CPM-12, changes for rarer extremes are typically larger in the RCM-PPE particularly in autumn and winter. In particular, increases in high return period events in autumn and winter can be almost a factor of 2 larger in the RCM than CPM for some members (Fig 4.5.2) …" Added text in Section 5: "Due to inherent limitations of the convection parameterisation scheme, RCM projections of hourly precipitation change are considered unreliable, and for high return period events may differ from CPM projections by almost a factor of 2."□	

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126	5 Interpretation and use of the projections	134	3-5	The differences between CMIP5 and the UKCP models is staggering and should be discussed more thoroughly. Much of this could be done by referencing the other UKCP18 reports. Regarding summer precipitation, however, I recommend that consideration is also given to the CORDEX models. This is important as the projected warming in the UKCP18 is almost twice as large as that from CMIP5, and one would expect that this also affects the precipitation statistics. Averages for daily precipitation over the British Isles (means and extremes) can actually be found in the Rajczak and Schär (2017, see supplemental information for the UK domain). CORDEX models project substantially smaller changes. These differences stem primarily from the driving GCMs, rather than the RCMs.		CS	Open	As yet, there are no CMIP5-driven CPM simulations available. The potential for users to consider additional RCM simulations from EURO-CORDEX is already discussed in the Part 1 report, in which Rajczak and Schär is cited. Here, we have added the following text: "… For applications specifically requiring information at fine spatial scales, Murphy et al (2018) point out that users can consider augmenting the Strand 3 RCM information with results from EURO-CORDEX simulations (Jacob et al, 2014). These include a multi-model ensemble of RCMs run at 12km resolution, and driven by a subset of CMIP5 global models using the RCP8.5 scenario. For example, three of these simulations produce small increases in average summer precipitation over the British Isles (Raczjak and Schär, 2017), in contrast to the strong drying shown in all the Strand 3 projections."	
127	6 Summary and forward look	141	General	I think it is important that the differences between CMIP5 and UKCP18 are openly discussed. Currently they are covered in Section 5, but not Section 6.		CS	Open	There is already text (in Section 6) which encourages use of other UKCP18 products as context for the CPM projections. To this general discussion, we have added: "Note, in particular, that Strands 1 and 2 reveal a wider range of potential outcomes for changes in summer, sampling changes with lower increases in average temperature, and smaller reductions, or even small increases, in summer precipitation. This is due to the inclusion of information from CMIP5 models. As discussed in Murphy et al. (2018), users wishing to explore impacts consistent with outcomes outside the envelope of Strand 3 results have a number of potential options, dependent on the requirements of specific applications. These may include direct usage of Strand 2 output (for applications in which information at space and time scales skilfully represented in global climate model output is sufficient), or use of other dynamical downscaling products such as EURO-CORDEX (e.g. Raczjak and Schär, 2017), which includes RCM projections driven by CMIP5 models using the same horizontal resolution (12km) and emissions scenario (RCP8.5) as the Strand 3 RCM simulations. Further possibilities include use of statistical tools, such as scaling or time-shifting methods (e.g. Herger et al., 2017) or weather generators (e.g. Jones et al., 2010)."	
128	General		General	In general, I think that the report reads well and that many of the previous concerns from the PRP have been addressed in a good way. It is quite clear though that it is the question of work in progress and there are quite a number of details here and there that needs to be addressed. I've tried to nail down all that I found.		EK	Open	Thank you for your positive comment. The previous issues raised by the PRP at the virtual meeting in March are listed at the end of this document, along with work that has been carried out to address these. We acknowledge that in some cases further work is still required. For example a full mechanistic understanding of the differences in the winter mean precipitation response between the CPM and RCM requires further in-depth investigation, but this is beyond the scope and time frame for this report.	
129	1 Introduction	6	3	Says "designed to replace the previous UKCP09". This report does not answer to whether this is done or not. On p143 it says that the new projections represent a significant improvement but to me it is not clear how a user, who have already made use of UKCP09, should use UKCP18. Will he/she have to redo everything? Is all previous work to be replaced? Or, in what way is UKCP18 complementing the results based on UKCP09? Possibly this comment is more for the entire UKCP18 but as it is mentioned here I think it needs addressing also in this report	Scientific/technical issue	EK	Open	We have reworded the introductory sentences to clarify "The UKCP18 land projections replace the previous UKCP09 scenarios, taking into account subsequent feedback from users and developments in modelling capability. The new projections consist of three Strands. Strand 1 provides updated probabilistic projections, which incorporate new information (notably from the latest CMIP5 generation of international climate models). These are a direct replacement for the probabilistic projections that formed the centrepiece of UKCP09. In addition, UKCP18 includes two new products (Strands 2 and 3), consisting of time series of climate model output, without the extensive statistical postprocessing required to produce Strand 1. These are provided in response to user requests for flexible datasets consisting of a wider range of climate variables with full spatial and temporal coherence, capable of supporting a range of impacts assessments. Strand 2 provides…." There is also a guidance document "UKCP18 for UKCP09 users" (Fung and Gawith, 2018) that covers this, and there are plans to update this guidance document with discussion of the CPM results, including pros and cons of using this in replacement to the UKCP09 weather generator output. This is now stated in Section 1.1: "A guidance document (Fung and Gawith, 2018) is available which provides advice on UKCP18 for UKCP09 users, including which data products have been updated and which are new. This document will be updated following release of the UKCP18 CPM results, to provide guidance on how these new results should be used alongside previous UKCP09 outputs. In particular, the pros and cons of using the CPM results as a replacement to the UKCP09 weather generator output will be outlined." Fung F and Gawith M (2018). "UKCP18 for UKCP09 Users", UKCP18 Guidance. Met Office, Hadley, Centre, Exeter https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-guidance-ukcp18-for-ukcp09-users.pdf In the non-technical summary we also state: "…Taken together the UKCP18 projections replace the previous UKCP09 scenarios. The CPM provides information at similar frequencies (daily and hourly) and spatial resolution as the UKCP09 weather generator. However, the CPM is based on a realistic physical representation of relevant climate processes, rather than relying on statistical relationships based on past observations. The UKCP18 website (https://www.metoffice.gov.uk/research/collaboration/ukcp) contains links to general advice on how to use the UKCP18 projections (Fung et al., 2018), and specific advice for previous users of UKCP09 (Fung and Gawith, 2018)."	
130	1 Introduction	6	7 and 8	Already here you could introduce (PPE), (hereafter CMIP5-13) and (hereafter GC3.05-PPE)	Typo/Format	EK	Closed	Done	
131	1 Introduction	6	9	Here it says GC3.05 instead of HadGEM3-GC3.05 on the previous line. It would be good to be consequent and to try to use short and not too complicated abbreviations if possible.	Typo/Format	EK	Open	Changed to GC3.05-PPE to be consistent with the previous sentence.	
132	1.1 Recap of UKCP09 and drivers for UKCP18	7	22	Here it says that urban effects are represented at 12 km. This is only partly true with the parameterization introduced but I would say that the real improvement for the urban scale is with the CPMs. I would suggest moving "urban effects" to line 25 (before (Kendon at al., 2014), e.g "... hourly scales representing for instance urban effects")	Scientific/technical issue	EK	Open	"urban effects" has been removed from 12km discussion and added to CPM discussion: "… the advent of very high resolution (km-scale) climate models since UKCP09 has enabled a more physically realistic representation of convection and for the first time a reliable estimate of climate change on hourly scales (Kendon et al 2014), as well as information on local scales representing for instance urban effects (Argueso et al 2014)."	

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133	1.2 Key results from UKCP18 Land Projections report	8	11 and 16	"in some members weaker than observed mid-latitude westerly winds … gives a very good simulation of the … storm track". Isn't this partly contradicting? Are these members really good at the storm tracks?	Scientific/technical issue	EK	Open	This text was a brief paraphrase from the Part 1 report. To provide more context, the comment about the mean westerlies in Part 1 was actually made in discussion of a larger ensemble of 20 global model variants, which was then reduced to the final 15 by further screening. This removed the members with the worst easterly biases. Having said that, there is still some intra-ensemble spread in the final GC3.05-PPE, with two of the 15 members showing somewhat weaker then observed large-scale westerly flow (based on 850hPa winds over the North Atlantic/Europe sector as a whole). In one of these, the number of storms over the UK is slightly too low, however in the other, the number of storms is slightly too high. This illustrates that the error in the large-scale regional mean flow is, not surprisingly, only a rough guide of local biases in the storm track over the UK, so we don't think there is any contradiction in the text. However, we have redrafted the text to avoid the risk of implying an inconsistency, and give a little more information: "For Europe, the GC3.05-PPE is found to show a significant cold bias in winter, which is considerably larger than that of CMIP5-13. These cold biases are greatest over northern Europe and much smaller (less than 2ºC) over the UK. For other seasons the two Strand 2 ensembles show similar biases. GC3.05-PPE is also too wet in winter (as is CMIP5-13) whilst showing too little precipitation over central and southern Europe in summer. In an ensemble-mean sense, the main factors driving the winter cold bias are insufficient cloud long-wave radiative effect, and a strong response to aerosol forcing. In addition to these factors, intra-ensemble variations in the cold bias are influenced by the average strength of the observed mid-latitude westerly winds, and the Atlantic Meridional Overturning Circulation (AMOC). In terms of interannual variability the Strand 2 ensembles perform comparably, and for UK precipitation variability the GC3.05-PPE members typically perform better. The GC3.05-PPE members give quite realistic simulations of the North Atlantic storm track, which is important for driving climate variability and extremes across Europe. In particular the number of storms tracking across the UK is quite well captured in GC3.05-PPE, being only slightly higher than reanalysis values in the ensemble -mean (see Fig. 3.17 of Murphy et al., 2018), with a spread of modest positive or negative biases between members. In comparison, CMIP5-13 members also give a range of biases in storm numbers over the UK, but with a larger positive bias in the ensemble-mean."	
134	1.2 Key results from UKCP18 Land Projections report	8	18	"well captured" - does this apply to all members? Compare comment above…	Scientific/technical issue	EK	Open	See response above, where we have added text briefly mentioning the performance of different members in representing the number of storms over the UK.	
135	1.2 Key results from UKCP18 Land Projections report	8	23	Should it be "GA7.05"? Missing "."	Typo/Format	EK	Open	No the name "HadREM3-GA705" is correct, with the "." not used in the name in this case.	
136	1.2 Key results from UKCP18 Land Projections report	8	23	Here you should add a sentence stating stg like "The RCM-PPE is first evaluated for the historical period (19XX-20XX)" and give the years for the comparison	Scientific/technical issue	EK	Open	Sentence added.	
137	1.2 Key results from UKCP18 Land Projections report	9	4	Here it says that daily extremes in winter are improved but not in what way. Please add a brief comment on what aspects are improved	Scientific/technical issue	EK	Open	This has been added: "with cold biases in the north and over high-elevation regions and warm biases along the south coast reduced"	
138	1.2 Key results from UKCP18 Land Projections report	9	20 to 23	Could you give the range of the different climate sensitivities here?	Scientific/technical issue	EK	Open	The idealised experiments required to estimate climate sensitivity for GC3.05-PPE have not been performed, so the information provided – namely that climate sensitivity is above 4.5C but below 6C – is all that can be said.	
139	1.2 Key results from UKCP18 Land Projections report	9	33 and 34	Please avoid using () in the sentences. Add a new sentence "Corresponding numbers for summer …". I've frequently done this myself until reading this short note https://eos.org/editors-vox/getting-your-paper-published-part-2-good-grammar-clear-figures	Unclear phrasing	EK	Open	Thank you for pointing that out. Change made.	
140	1.2 Key results from UKCP18 Land Projections report	10	4 and 16	The numbers on l 4 indicates that differences are really small between the Strands while l 16 talks about "greater reductions". Are numbers large enough for the differences to be significant?	Scientific/technical issue	EK	Open	It is true that the differences between the central estimates from Strands 1, 2 and 3 are not that large, however the differences between the ranges are considerable. For example the UK-average high-end changes are +2% (Strand 1), -6% (Strand 2) and -17% (Strand 3). Thus the differences between the Strands are significant – and this can be seen from Fig 5.1, which clearly shows the greater reductions in summer precipitation in the GC3.05 and RCM PPEs compared to CMIP5-13. The text has been modified to clarify this: "As a consequence of this difference, there is a greater tendency for summer precipitation reductions in Strand 3 (UK-average high-end changes are +2%, -6% and -17% for Strands 1, 2 and 3), since this is built entirely from a PPE that produces a consistent drying signal across its members."	
141	1.2 Key results from UKCP18 Land Projections report	10	22 and 24	Why are these expressed so differently? "up to 9C" and "large range of uncertainty"? Could l 24 also be expressed as "up to XXC"?	Scientific/technical issue	EK	Open	The text has been changed to give consistency: "For example for daily extremes, GC3.05-PPE shows substantial warming for cold winter days (1st percentile of daily mean temperature distribution) over the northern UK (of up to 9ºC in places, with high end changes exceeding 10ºC). The intensity of hot summer days (99th percentile of daily mean temperature distribution) also increases everywhere (by about 6ºC, with high end changes up to 9ºC in the south)."	
142	1.2 Key results from UKCP18 Land Projections report	10	28	"can still increase". OK, but does it? What do the results show? "general increase"? "increase at some locations? "increase in some parts of summer?"	Scientific/technical issue	EK	Open	Added text: "…daily precipitation extremes can still increase (high-end changes in summer extremes show increases across much of the UK except the far south)."	
143	1.2 Key results from UKCP18 Land Projections report	10	33 and 34	Repetition of statement on l 22. Here it could be mentioned that the reduction in RCM-PPE over the GCM is likely a feature indicating added value in a climate change sense (as the bias in the GCM is large (cf p9 l4-5) and possibly the reason for the large CC).	Scientific/technical issue	EK	Open	Text has been modified to remove repetition and add link to present-day biases: "For example, the substantial warming of cold winter days over the northern UK in GC3.05-PPE is reduced in the RCM-PPE, which may relate to reduced cold biases in the RCM."	
144	1.2 Key results from UKCP18 Land Projections report	11	5 to 11	Why only for Strand 1? Similar comparisons of Strand 2 and 3 (12 km vs 25) results between UKCP18 and 09 would be useful for some users.	Scientific/technical issue	EK	Open	A comparison between Strand 1 and UKCP09 only was provided in Lowe et al 2018, and Section 1.2 of the report here is just providing an overview of the Part 1 report. At the end of Section 1.1, however, we now note the availability of further guidance material for UKCP09 users: "A guidance document (Fung and Gawith, 2018) is available which provides advice on UKCP18 for UKCP09 users …"	
145	1.3 Motivation for new 2.2km projections	11	15	I think "40-300" is more appropriate	Scientific/technical issue	EK	Open	There are very few CMIP5 models with grid spacing below 60km. There are now some global climate models being run with higher resolutions e.g. 25km under CMIP6 HiResMIP, however this is not the "typical" grid spacing. Therefore we believe the statement "typical grid spacing of 60-300 km" is correct.	
146	1.3 Motivation for new 2.2km projections	11	21	A reference would be good here "known source of …"	Scientific/technical issue	EK	Open	References have been added: "This simplification is a known source of model error (Dai, 2016, Stephens et al 2010), that leads to deficiencies in the daily timing of convection (Brockhaus et al 2008) and an inability to represent extremes (Hanel and Buishand, 2010, Gregersen et al 2013)."	
147	1.3 Motivation for new 2.2km projections	12	29 and 30	Add also Lind et al (2016) to the Ban et al reference. Their work also relates to the Alps region with another CPM. Could end the sentence "… region with two different CPMs". 11) Lind, P., Lindstedt, D., Kjellström, E., and Jones, C., 2016: Spatial and Temporal Characteristics of Summer Precipitation over Central Europe in a Suite of High- Resolution Climate Models. J Clim, 3501-3518. doi:10.1175/JCLI-D-15-0463.1.	Scientific/technical issue	EK	Open	Lind et al (2016) does not report on climate change results and so it is not appropriate to reference here where we are talking about "future increases in the intensity of hourly summer rainfall extremes", which is now clarified in the text. Reference to Lind et al (2016) however has been added earlier in Section 1.3: "CPMs do not necessarily better represent daily mean precipitation (Chan et al 2013) but they have significantly better hourly rainfall characteristics with improved representation of the diurnal cycle of convection (Ban et al 2014), the spatial structure of rainfall and its duration-intensity characteristics (Kendon et al 2012, Lind et al 2016), and the intensity of hourly precipitation extremes (Chan et al 2014, Ban et al 2014)."	
148	1.3 Motivation for new 2.2km projections	13	10	Add "deep" before "convection"	Scientific/technical issue	EK	Closed	Done	
149	1.3 Motivation for new 2.2km projections	13	13	"uplift estimates for future rainfall intensity for sewer design". This is not easy to understand. Can you explain better what is meant?	Unclear phrasing	EK	Open	This has been clarified: "The impact of new estimates of future changes in rainfall intensity from CPMs for sewer design was demonstrated in Dale et al (2015). In particular, the CPM rainfall changes were higher than existing UK climate change allowances with implications for increased flooding."	
150	2.1 Overview	16	15	Spell out what "UKV" means	Unclear phrasing	EK	Open	"UK-Variable". Now added to text.	

ID	Section	Page (as per page numbering)	Line number	Comment	Category	Reviewer initials	Status	MO response	Response from authors
151	2.1 Overview	16	19 to 22	I think that you should address questions related to variability here. Is this "easy aerosol" applying monthly mean numbers adequate for taking into account variability on daily time scales involving polluted/clean air with implications for the state of the atmosphere? (Also p 27, l 16-18)	Scientific/technical issue	EK	Open	Discussion of Easy Aerosol is provided in Section 2.4, and a reference to this is added here. In Section 2.4, we have added a note emphasising that this approach misses any daily variability in aerosols: "In a global model, Stevens et al. (2017) showed that this ("Easy Aerosol") approach replicates quite well the aerosol forcing found in interactive simulations, and tests using GC3.05 supported this conclusion. It should be noted, however, that the use of monthly mean fields results in the smoothing out of daily variability in aerosols."	
152	2.2 Choice of convection-permitting resolution	17	6	Here you could give the factor of increase in computing power between the three configurations - I think this is likely not evident to most readers! Also, for the whole project it would be interesting to see what the corresponding numbers are for simulations in the other Strands!	Scientific/technical issue	EK	Open	Computing cost goes up with resolution as roughly the number of grid points divided by the time step. So 2.2km is 4kmx4kmx100sec/(2.2kmx2.2kmx60sec) = 5.5 times more expensive than 4.4km. Similarly 1.5km is 4kmx4kmx100sec/(1.5kmx1.5kmx50sec) = 14 times more expensive than 4.4km. This is now stated: "…weighed against the additional computational cost of higher resolution (2.2km is 5.5 times and 1.5km 14 times more expensive than 4.4km)."	
153	2.2 Choice of convection-permitting resolution	17	14	The whole chapter is difficult to follow when it comes to which specific model configuration that has been used. In this line, for instance, it Is not clear if this is the "UKV" model referred to on the previous page	Unclear phrasing	EK	Open	The UKV model is constantly being upgraded, with new versions released as Parallel Suites. The tests were actually done with UKV PS35, whilst the UKCP18 production ensemble is UKV PS38. Since the parallel suite numbers do not mean anything to anyone outside of the Met Office, it was decided not to quote them in the report. Instead we refer to the Unified Model version e.g. UM10.1. We have clarified the fact that for the test simulations we are using a version of the UKV model that was operational in 2015: "The test simulations were done with Met Office Unified Model version 10.1 (UM10.1), using the version of the NWP UKV model that was operational in 2015 (for more details see Fosser et al, submitted)." Later in Section 2.3, we again clarify that we are talking about versions of the UKV model: "In the recent operational UKV configuration (at UM10.6, from November 2016) … "	
154	2.2 Choice of convection-permitting resolution	17	16 to 17	Are these 12 km and HadGEM3 versions identical to those used for the projections in Strand 2 and 3?	Unclear phrasing	EK	Open	No, the versions are similar but not identical. The GA7 configuration was used for the 12km test simulations, whilst GA7.05 was used for the Strand 3 production simulations. We have now explicitly stated this, along with providing a reference for the GA7 configuration: "The CPMs were also assessed against a 12km RCM (a limited-area version of the Global Atmosphere GA7 configuration of the Met Office Hadley Centre Global Environmental Model HadGEM3, Walters et al 2019, which is similar to the GA7.05 configuration used for the Strand 2 and 3 projections, see Section 2.4)…" In Section 2.4, we describe the differences between GA7.05 and GA7: "The driving GCM ensemble consists of perturbed parameter variants of HadGEM3-GC3.05, which uses GA7.05 for the atmospheric model. This is close to the Global Atmosphere 7 (GA7) configuration (Walters et al 2019), but includes a number of updates (see Appendix D of Murphy et al., 2018), including the Liu et al. (2008) parameterisation of the spectral dispersion of cloud droplets, and an update to the refractive index of black carbon (Bond and Bergstrom, 2006)."	
155	2.2 Choice of convection-permitting resolution	19	4	XX	Scientific/technical issue	EK	Open	The number of stations (XX=1900) is no longer quoted in the Fig 2.2.1 caption, but rather is stated in Table 3.1, which is referred to here.	
156	2.3 The 2.2km convection-permitting model	19	15	Here, I wonder if the 2.2 km model is the same as the one used for the test simulations (p17, l 9) - this is not entirely clear from the text.	Unclear phrasing	EK	Open	Please see response to comment above which explains the versions of the UKV used for the test simulations (PS35, UM10.1) and production ensemble (PS38, UM10.6). We now clearly state: "The 2.2km model is based on a recent operational NWP configuration (that was made operational in November 2016) at UM10.6, but with the addition of various changes to support its use in climate runs. This configuration is different from the version of the UKV (at UM10.1) that was used for the test simulations in Section 2.2, with the upgraded physics shown to give improved correspondence with observations (see below) … "	
157	2.3 The 2.2km convection-permitting model	21	1 to 3	Do you keep track of how much moisture that is removed in this way? To what degree is the model "not mass-conserving"? Maybe not so relevant for this report but still interesting.	Scientific/technical issue	EK	Open	In the Unified Model we use the Semi-Lagrangian advection scheme, which is not conservative and therefore depending on the smoothness of the tracer, advection can lose or gain mass. The mass conservation scheme restores the true mass, and is applied to a number of tracers. In the case of moisture, the typical mass relative error is ~1e-5 (or 1e-3 %) and this is the error that the mass conservation scheme restores at each time step. A note has been added regarding the size of the error: "The 2.2km model includes a new mass conservation scheme (Zerroukat and Shipway 2017), which is applied to all atmospheric moisture tracers and removes the excess of moisture spuriously generated by the higher order semi-Lagrangian advection scheme (typical mass errors of ~1e-3 %)."	
158	2.3 The 2.2km convection-permitting model	21	30	Year is missing for "Van Genuchten"	Typo/Format	EK	Open	The full reference Van Genuchten (1980) has now been added.	
159	2.3 The 2.2km convection-permitting model	22	6	Reference is missing for the zero-layer snow scheme	Scientific/technical issue	EK	Open	Best et al 2011 already given is the reference both for the zero-layer and multi-layer snow scheme.	
160	2.3 The 2.2km convection-permitting model	24	3	Should it be "0.1mm/h"?	Typo/Format	EK	Open	Yes, thank you. Change made.	
161	2.3 The 2.2km convection-permitting model	24	2 to 10	Here it should be made clear in a better way that the configuration used for the CPM-12 is the _NESTED one.	Scientific/technical issue	EK	Open	Now stated: "UM10.6, with an intermediate nest, is the selected configuration for the production ensemble."	
162	2.4 Design of 2.2km experiments	25	17 to 21	Maybe not the main reason for the MetOffice but the 12km sims may be useful also to the international EURO-CORDEX community. In the long run cross evaluation with other EURO-CORDEX models may be useful also for the UKCP18 user	Scientific/technical issue	EK	Open	Yes this is now stated: "The 12km RCM projections can also be compared with EURO-CORDEX models (Jacob et al, 2014), which may be useful both to UKCP18 users as well as the international EURO-CORDEX community."	
163	2.4 Design of 2.2km experiments	25	24	What is "GA7"? Why is it interesting to mention this here? Is this the CMIP6 version? Something used for some other purposes that the UKCP18 users are aware of? Expand if important otherwise remove.	Unclear phrasing	EK	Open	GA7 = "Global Atmosphere 7". This is useful because Walters et al 2019 describes the GA7 configuration, which is a major release of the HadGEM3 model. "This is close to the Global Atmosphere 7 (GA7) configuration (Walters et al 2019), but includes a number of updates …" CMIP6 uses GA7.1, which is yet another version!	
164	2.4 Design of 2.2km experiments	26	20	Should be "21-year time slices"	Typo/Format	EK	Open	Change made.	
165	2.4 Design of 2.2km experiments	27	21	Should it really be "ITE" here?	Typo/Format	EK	Open	This has been clarified and a reference added: "Present-day land cover in the CPM is defined from the high-resolution Centre for Ecology and Hydrology land cover dataset (Fuller et al 1994), which uses Institute of Terrestrial Ecology (ITE) Landsat-derived cover types, over Great Britain …"	
166	2.4 Design of 2.2km experiments	27	29	The LUH2 … data set needs a reference	Scientific/technical issue	EK	Open	Reference Hurtt et al 2011 added.	
167	3.1 Overview	30	16	True, unless there is added value to be expected also on these larger spatial scales. (Cf. Soerland et al., 2018 ERL)	Scientific/technical issue	EK	Open	We appreciate there may be added value on scales well resolved by the driving model, as found in Soerland et al 2018 and as found here (e.g. UK-average winter mean precipitation biases are improved in the CPM compared to the RCM). However significant departures on the large-scale are inconsistent with the one-way nesting, especially where this scale is approaching that of the model domain, and any such large-scale added value is not well represented by the current approach. We do acknowledge in the text that differences in small-scale processes may feedback on the large-scale.	
168	3.1 Overview	30	20	Add "primarily" before "expect"	Scientific/technical issue	EK	Closed	Done	

ID	Section	Page (as per page numbering)	Line number	Comment	Category	Reviewer initials	Status	MO response	Response from authors
169	3.1 Overview	30	30 to the end of 3.1	I would suggest that this part is written starting with the ERA-I-runs that are used to evaluate the RCMs. Thereafter, you could say stg about RCM-PPE and CPM-12.	Scientific/technical issue	EK	Open	The aim of this section is to validate the performance of the RCM and CPM ensembles, in the presence of skilful but imperfect lateral boundary forcing from the global simulations. This needs to be the bottom line, as these are the simulations that will be used in applications. The ERAI-driven run is used as a key precursor to this assessment, as it established the credentials of the CPM as a regionalisation tool. Also of interest is to partition the total error in the GCM-driven CPM into global and regional components, which adds understanding and context to the interpretation of the total error. However, since the evaluation ultimately rests on the ensemble performance, we focus on evaluating present-day biases for the CPM-12 and RCM-PPE. We appreciate that biases for the latter ensembles are also affected by biases in the driving GCMs, but these effects are important to include. For this reason we prefer to keep CPM-12 and RCM-PPE as the main focus in Section 3.1.	
170	3.1 Overview	32		Reference is missing fot the surface air temperature	Scientific/technical issue	EK	Open	Added	
171	3.1 Overview	32		The abbreviations in the third column need to be spelled out at some place	Unclear phrasing	EK	Open	Abbreviations are now all defined.	
172	3.2 Seasonal mean performance	34	7 to 13	In this section you would need some reference(s) related to undercatch. Also, you should address the fact that undercatch is different in different seasons which may have an impact on the analysis	Scientific/technical issue	EK	Open	More details on gauge undercatch, including the size of errors, and the fact that these vary with season and are largest at high elevations, accompanied by references, have been added to Table 3.1. Some brief discussion and a reference are also added to Section 3.2: "We note that these biases are with respect to rain gauges (Table 3.1), which are known to suffer from systematic measurement under-catch (of typically about 20%, but varying between 4% and 50%, with larger errors in winter because of snow and high elevations because of wind exposition, Rajczak and Schar 2017) and sampling uncertainties (over mountains the siting of gauges mostly in valleys leads to an underestimate). These deficiencies however are not expected to (fully) account for the wet bias in the RCM, but may contribute to the greater apparent bias in winter."	
173	3.2 Seasonal mean performance	34	15	Here (and elsewhere), please point to the relevant panels to make it easier for the reader!!	Scientific/technical issue	EK	Open	Panel label has been added.	
174	3.2 Seasonal mean performance	34		Why is only STD considered ni 3.2 while the whole ensemble is addressed in 3.3?	Scientific/technical issue	EK	Open	In Section 3.2 we only consider STD, as this is the only member for which an ERAInterim driven simulation is available. This allows us to examine the extent to which biases in seasonal mean variables in the production simulations are inherited from the driving GCM or are inherent to the downscaling model. However, as noted above, the primary aim of Section 3 is to validate the performance of the RCM-PPE and CPM-12 ensembles, in the presence of lateral boundary forcing from the global simulations, as these are the simulations that will be used in applications. Therefore in Section 3.3 onwards, where we are considering metrics of daily and hourly variability, we consider the whole ensemble. However additional results from the ERAI-driven STD simulations have been added in Section 3.3 and are discussed in the text. Our rationale is now stated at the start of Section 3.3: "In this section we consider the performance of CPM-12 compared to the driving RCM-PPE in representing daily variability of temperature and precipitation. We focus mainly on ensemble-averaged biases from the GCM-driven simulations, as these are the simulations that will be used in impacts applications. It is therefore appropriate to consider a measure of performance across the whole ensemble, that accounts for regional errors arising both from the global model boundary forcing, as well as from internal errors generated within the RCM and CPM domains. However, we also discuss biases from the ERA-interim driven simulations, which provide a direct validation of the RCM and CPM standard member as specific regionalisation tools, independent of biases in the driving global models."	
175	3.2 Seasonal mean performance	35	1	In this figure and several others - why is Ireland treated differently (masked or not masked?). Also, why is the southernmost and easternmost parts of SE England masked white in the upper panels?	Scientific/technical issue	EK	Open	The masking of Ireland has now been fixed, so that we consistently only show results for the UK. Also the masking of coastal land points has been fixed.	
176	3.2 Seasonal mean performance	35	1	For this figure (and several others) I would suggest reordering the panels so that they were a) OBS, b) ERAI-STD, c) ERAI-RCM, d) aggr, e) CPM, f CPM-STD bias, g) RCM-STD bias and h) CMP-STD MINUS RCM-STD. Also, please use labels a-h and use them in the text!	Scientific/technical issue	EK	Open	Panels have been reordered and labels a-h added as suggested.	
177	3.3 Daily variability	37	14 to 19	Does this mean that the bias in the GCM in N Eur does not play a role for the British Isles in terms of cold days? In this case say so! This is also contrasting to summer when biases in the GCMs seem to play a role (p 38)	Scientific/technical issue	EK	Open	Added text: "We note the cold bias in GC3.05-PPE over northern Europe, is smaller over the UK (Section 1.2), and does not play a major role in the biases in cold winter days here."	
178	3.3 Daily variability	37	19	Why don't you show ERA-I?	Scientific/technical issue	EK	Open	Please see response above, which explains our rationale for focussing on the CPM-12 and RCM-PPE ensembles in the validation. We do discuss the ERA-I driven results, but do not show plots in all cases to avoid proliferation of plots.	
179	3.3 Daily variability	38	13	I can't see that it is "particlularly over the mountains". It is quite clear also in the SE	Unclear phrasing	EK	Open	Large absolute biases are seen over high ground in central Scotland (Cairngorms), northern England (the Pennines and the Lakes) and Wales (Snowdonia). It is true that large biases are also seen in the SE, so this has been added.	
180	3.3 Daily variability	38	13 and 14	Change "much less frequent over" to "less frequent particularly over"	Unclear phrasing	EK	Closed	Done	
181	3.3 Daily variability	38	16 to 29	Where is this shown? Give figure reference	Scientific/technical issue	EK	Open	Reference to Figs. 3.3.2-3.3.3 has been added.	
182	3.3 Daily variability	40	8	RMS is not shown in the leftmost panels	Scientific/technical issue	EK	Open	This is clarified in the figure caption: "The UK-averaged (left panels) mean value or (centre, right panels) Root Mean Square (RMS) error is indicated."	
183	3.4 Hourly precipitation variability	42	14 to 15	Remove "at the hourly timescale"	Typo/Format	EK	Closed	Done	
184	3.4 Hourly precipitation variability	42	18	Remove "slightly"	Scientific/technical issue	EK	Closed	Done	
185	3.4 Hourly precipitation variability	42	22	Replace "observational uncertainty" with "the observational uncertainty given by the difference between the two datasets used here"	Scientific/technical issue	EK	Closed	Done	
186	3.4 Hourly precipitation variability	43	2 to 4	Why, and with how much? Give reference!	Scientific/technical issue	EK	Open	Reference to Table 3.1 has been added, which gives information and references on the hourly precipitation datasets used here. This includes information on the likely errors. In particular for the gauge dataset: "As for the daily gauges, the hourly gauges are expected to underestimate the intensity of heavy events, and the same caveats as for the daily dataset apply, with even greater sampling errors due to fewer hourly gauges." We have not found any references that give an explicit quantification of the underestimation of heavy rainfall in the hourly datasets, and so have not been able to state this here.	
187	3.4 Hourly precipitation variability	48	3 to 6	This seems to be true for most ensemble members but not all	Scientific/technical issue	EK	Open	This is now noted in the text.	
188	3.4 Hourly precipitation variability	48	7	Shouldn't it be "too few wet hours"?	Typo/Format	EK	Open	No, the 12km RCM has too few dry hours (too many wet hours) i.e. it drizzles too much, which is a common problem in parameterised convection models.	
189	3.5 High impact events	52	6	Why 100? Why not 80? 120? 150? Could you give an idea to why you see this as "plausible"? You get back to this "plausible" later in the text as well	Scientific/technical issue	EK	Open	In the text that follows we explain why 100mm/h was chosen. In Table 3.1 we have now added that this corresponds to removing 0.0004% of UK radar data. We fully acknowledge however that the choice of threshold for elimination of "bad" data is not easy, and is a subjective choice balancing the removal of valid high values and contamination with remaining spurious values.	

ID	Section	Page (as per page numbering)	Line number	Comment	Category	Reviewer initials	Status	MO response	Response from authors
190	3.5 High impact events	62	15 to 17	Is this consistent with biases in cold winter days (p 37)?	Scientific/technical issue	EK	Open	Biases in the intensity of cold winter days are similar between CPM-STD and ERAI-CPM-STD (and similarly between RCM-STD and ERAI-RCM-STD), and hence in this case we concluded that the biases are largely inherent to the downscaling models. This is also the case for winter mean temperature where cold biases in the north are similar in RCM-STD and ERAI-RCM-STD (Section 3.2), and are likely due to too much lying snow in the RCM. For the frequency of cold spells (Fig 3.5.9) however we find the opposite, with biases in the GCM having a significant role in leading to too many individual cold spells of 2 days or longer (this is confirmed by comparing biases in the frequency of cold spells between CPM-STD and ERAI-CPM-STD and similarly between RCM-STD and ERAI-RCM-STD, not shown). This is explained by temporal variability and the occurrence/persistence of particular weather patterns, as well as any mean cold bias, being important for the frequency of individual cold spells. This suggests that biases in the regional models themselves relating to snow (and potentially other local processes) play a key role in controlling any overall mean bias and any biases in cold winter days – in particular the cold bias over the northern UK in winter in the RCM. However biases in large-scale variability inherited from the driving global model are important for determining biases in the number of individual cold spells of 2 days or longer. This difference explains why, despite cold winter days being too warm in the CPM, there are too many individual cold spells (+2C threshold). Biases in the number of intense cold spells (-2C threshold) are lower in the CPM than RCM, suggesting that in this case regional biases relating to snow and well as biases in large-scale variability are important. Discussion of this has been added: "We note that biases in the number of individual cold spells do not clearly correspond to biases in the intensity of cold winter days (Section 3.3). For example for the CPM, despite cold winter days being too warm, there are too many cold spells. In addition, the results above for the ERAI-driven simulations, suggest that biases in the global model have a significant role in leading to too many individual cold spells. However, biases in the regional models themselves (likely relating to snow, see below) are found to be more important for cold winter days (Section 3.3), and also any overall mean winter cold bias (Section 3.2). This difference can be explained by large-scale variability in weather patterns (inherited from the driving GCM), as well as any mean cold bias, being important for the frequency of individual cold spells. The fact that biases in the number of intense cold spells are lower in the CPM than RCM, is consistent with the CPM being warmer over the northern UK in winter than the RCM, both for the seasonal mean and cold winter days (Sections 3.2 and 3.3). In this case regional biases, as well as biases in large-scale variability are important."	
191	3.5 High impact events	66	1	Why are there so many decimals on the color bars in the middle panels?	Scientific/technical issue	EK	Open	The number of decimal places to which numbers are quoted in Figs 3.5.11 and 3.5.13 is reduced, so that we only show 2 significant figures in all cases. For the colour bars, the number of decimals shown has been reduced to 2 in all cases.	
192	3.5 High impact events	68	10	"y" stations	Scientific/technical issue	EK	Open	The number of stations (y=400) is now provided in Table 3.1, and no longer explicitly mentioned here.	
193	3.5 High impact events	68	15	Why did you use 0.02 mm here if you know it did not perform well? The fact that it was used in UKCP09 doesn't sound like a good reason…	Scientific/technical issue	EK	Open	We solicited advice from experts, but they were unable to provide a physically justifiable threshold. Therefore in the absence of other information we used the same threshold as UKCP09, but note the sensitivity of the results to using a different threshold (e.g. 0.5mm).	
194	3.5 High impact events	69	29	Here it says "in all ensemble members, Fig…" but all members are not shown in the figure	Scientific/technical issue	EK	Open	All members are not shown in the figure (now Fig 3.5.19), but all members are shown in an earlier figure (now Fig 3.5.17) which confirms this. We have clarified this in the text: "Despite there being more falling snow, there is considerably less lying snow in the CPM than RCM in the present-day (Fig. 3.5.19), which is true for all ensemble members (Fig. 3.5.17)."	
195	3.5 High impact events	70	6	Not just the albedo feedback. Also the ground heat fluxes and the isolation of the snow cover comes into play	Scientific/technical issue	EK	Open	This is now stated: "Less lying snow in the CPM is likely to be a factor leading to the CPM being warmer at the surface than the RCM over the northern UK in winter (Section 3.2), through changes in the surface energy budget. In particular a reduction in snow cover reduces the surface albedo resulting in more absorbed shortwave radiation, and allows sensible heating from the ground into the lowest atmospheric layer (since snow acts as a thermal insulator)."	
196	4.2 Seasonal mean changes	73	31	Consider changing "greater decrease" into "larger differences" or "smaller increase"	Unclear phrasing	EK	Closed	Done	
197	4.2 Seasonal mean changes	73	25 to 33	This section lacks a statement on summer	Scientific/technical issue	EK	Open	Added: "In summer, there is no consistent difference between the CPM and RCM members, and individual CPM members can give smaller or larger increases in temperature than their parent RCMs, with differences up to 0.3-0.4°C locally (Fig 4.2.4)."	
198	4.2 Seasonal mean changes	74	3	It says "up to 15%". I think the color scale says "up to 30%". Here it is talket about the RCM-PPE but also CPM shows no increase in N Scotland at the low end	Scientific/technical issue	EK	Open	This is now noted: "RCM-PPE suggests decreases of up to 15-30%, and similarly CPM-12 suggests decreases of up to 15%, are plausible (for lower estimate of change, Fig. 4.2.5)."	
199	4.2 Seasonal mean changes	75	22	Add "for the RCM as" between "and" and "an"	Scientific/technical issue	EK	Closed	Done	
200	4.2 Seasonal mean changes	77	2 to 3	Here it should be made clear how the components of the moisture budget are derived. Is the moisture convergence calculated as a residual between P and E?	Scientific/technical issue	EK	Open	Precipitation, along with a residual term, has now been added to the tables showing the atmospheric water budget in winter (Table 4.1) and summer (Table 4.2). This should hopefully make it clear that moisture flux convergence has not simply been calculated from P-E. Instead moisture flux convergence is calculated from column integrated moisture fluxes, using a finite differencing approach. This is now stated in the table caption. More discussion of the results shown in Tables 4.1 and 4.2 has been added to Section 4.2: "Tables 4.1 and 4.2 show the atmospheric water budget terms, and their future change, in winter and summer respectively. In both seasons, the mean moisture flux convergence over the CPM domain (and its future change) is very similar between the CPM and RCM, confirming that moisture entering and leaving the CPM domain is well constrained by the RCM. Over UK land points in winter, the increase in evaporation plus moisture flux convergence is larger in the CPM (0.77 mm/day) compared to the RCM (0.66 mm/day), consistent with the greater increase in winter mean precipitation (1.05 mm/day in CPM versus 0.76 mm/day in RCM). It should be noted that precipitation does not exactly equal evaporation plus moisture flux convergence (see residual in Tables 4.1 and 4.2), and this is due to numerical errors in the estimation of moisture flux convergence. In particular, although moisture conservation is enforced internally in the CPM (Section 2.3), significant errors will arise in the offline calculation of moisture convergence (which uses a finite differencing approach) due to fine-scale structures in the winds. The greater increase in winter precipitation in the CPM is coming from the greater increase in moisture flux convergence over land in the CPM (with similar changes in evaporation over land). By contrast future changes in both evaporation and moisture flux convergence over the sea are higher in the RCM than CPM in winter. Thus greater increases in moisture flux convergence over the land in winter in the CPM appear to be compensated by smaller increases in moisture flux convergence over the sea. In summer (unlike in winter) evaporation over the land dominates over moisture flux convergence over the land, with the local recycling of moisture being important (although the extent to which showers (and local moisture recycling) occur may be conditioned by the large-scale circulation patterns, e.g. fewer showers where there is more dry continental flow). This is in contrast to winter, where showers over land may be more dependent on the advected moisture from the sea. In terms of future changes in summer, however, it can be seen that these are dominated by convergence changes (with evaporation hardly changing). In particular, there is a large decrease in moisture flux convergence (over the whole domain), resulting in the UK changing from a region of small positive moisture convergence to significant moisture divergence. These mean changes in summer are captured similarly by both the CPM and RCM (see Section 5 for further discussion)."	
201	4.2 Seasonal mean changes	77	10	Consider changing "lower" to "upper"	Scientific/technical issue	EK	Open	Added "(upper estimate of the decrease)"	
202	4.3 Changes at daily time scale	86	14 and 15	Change "However, it …" into "It …" and remove "also" on l 15	Unclear phrasing	EK	Open	Sentence changed to: "It is likely that these differences between the CPM and RCM are related to differences in lying snow (Section 4.5)."	
203	4.3 Changes at daily time scale	87	25	I'm afraid I dont understand this fully. Here it is talked about differences in spread but the larger CPM spread in this respect is contrasting the argument that there is no parameter perturbation in the CPM ensemble	Scientific/technical issue	EK	Open	In fact, in this case, the ensemble spread is the same in the CPM and RCM (37.7-8.9)=(33.5-4.7)=28.8. So although the statement about no parameter perturbations potentially impacting the CPM spread is generally true, it has been removed from here and noted later in Section 4.4.	

ID	Section	Page (as per page numbering)	Line number	Comment	Category	Reviewer initials	Status	MO response	Response from authors
204	4.4 Changes in hourly precipitation	97	28 to 33	Why is it so that changes are larger for SON? Is it a result of the convectively dominated "summer" season getting longer in combination with more moisture being available. In contrast to the "real summer" (JJA) when warming in combination with relatively dry conditions isn't allowing for a strong increase??	Scientific/technical issue	EK	Open	A discussion of this changing seasonality has been added to Section 4.5, and an additional note is added here: "This change in the seasonality of heavy hourly rainfall may be explained by warming leading to an extension of the convective season and greater increases in moisture availability in autumn (c.f. Section 4.5)."	
205	4.4 Changes in hourly precipitation	111	4	Looking at the middle upper panel it is very similar to the upper right one in Fig 3.4.7 (showing biases). Is there a risk that the CPM having this systematic bias is overestimating the CC signal? I think this should be addressed in the text on p 110.	Scientific/technical issue	EK	Open	It is not clear whether this systematic bias would lead to an underestimate or overestimate of the CC signal. A brief discussion of this has been added here (with further discussion in Section 5): "It should be noted that present-day biases in the CPM in Fig 3.4.7 are similar to future changes in Fig 4.4.16. Further work is needed to assess the importance of the known tendency of the CPM to overestimate the intensity of heavy events for future projections, and in particular whether it would lead to smaller or larger increases in summer rainfall intensity. Nevertheless, the improved representation of convective processes in the CPM means it is able to provide plausible projections of changes in hourly rainfall characteristics, unlike the RCM (which shows greater biases in Fig 3.4.7)."	
206	4.5 Changes in high impact events	113	4	Compare comment p52, l6	Scientific/technical issue	EK	Open	We have added a reference back to Section 3.5, where this issue of a physically plausible threshold for hourly rainfall at the 12km scale is discussed.	
207	4.5 Changes in high impact events	118	20 to 21	Couldn't also "small P-E differences" be a reason for the similar soil moisture conditions in the ensemble members?	Scientific/technical issue	EK	Open	The evaluation of soil moisture is now added to Section 3.5, and results comparing soil moisture in the CPM and RCM for the present-day have now been moved there. The very different ensemble spread in RCM-PPE compared to CPM-12 seen for soil moisture (Fig 3.5.15) is much more pronounced than for other variables such as precipitation. Thus the fact that perturbations are applied to the soil moisture scaling factor in RCM-PPE but not CPM-12 seems the most likely explanation.	
208	4.5 Changes in high impact events	119	4 to 5	Remove "in the future"	Unclear phrasing	EK	Closed	Done	
209	5 Interpretation and use of the projections	126		For Hot Summer days I think the second column should include both a green and a red sign as the CPM is either better or worse compared to the RCM	Scientific/technical issue	EK	Closed	Done	
210	5 Interpretation and use of the projections	132	6	Not only for the CPM, the RCM ensemble is also small	Scientific/technical issue	EK	Open	This is now clarified: "Although we may have greater confidence in the central estimate of the change from the CPM-12, this is not true for the uncertainty range. The uncertainty range is likely to be underestimated in both CPM-12 and RCM-PPE due to the small ensemble size and lack of information from other international climate models, but additionally in CPM-12 due to no parameter perturbations being applied to the CPM itself."	
211	5 Interpretation and use of the projections	135	1	Most striking with these figures is the difference between the UK models and the CMIP models. I think this should be put up front.	Scientific/technical issue	EK	Open	The fact that Strands 1 and 2 explore a wider range of summer changes (due to inclusion of CMIP5 information) is discussed earlier in this section, using Fig. 5.1. This text has been augmented to point downscaling users towards potential use of EURO-CORDEX information, as a way of accessing outcomes outside the Strand 3 envelope of responses: "For applications specifically requiring information at fine spatial scales, Murphy et al (2018) point out that users can consider augmenting the Strand 3 RCM information with results from EURO-CORDEX simulations (Jacob et al, 2014). These include a multi-model ensemble of RCMs run at 12km resolution, and driven by a subset of CMIP5 global models using the RCP8.5 scenario. For example, three of these simulations produce small increases in average summer precipitation over the British Isles (Raczjak and Schär, 2017), in contrast to the strong drying shown in all the Strand 3 projections." Also interesting is the difference in the relationships between historical biases and future changes, between the PPE and multi-model products. Understanding these is for future work, however, we have added the following comment: "The different relationships seen between CPM-12 and RCM-PPE, and also the considerable scatter of points in Figs 5.2 and 5.3, show however that the present-day bias is not the only factor controlling the different future responses. This is underlined further by comparison of the relationships between historical biases and future changes in Strand 2, which reveal some substantial differences between GC3.05-PPE and CMIP5-13."	
212	5 Interpretation and use of the projections	135	26 to 28	Here, large-scale circulation differences is pointed to as a potential source of differences between the ensembles. This is of course most likely but can you exclude also other causes? For instance local/regional physics like soil moisture feedbacks beeing different in the ensembles?	Scientific/technical issue	EK	Open	This is now acknowledged: "The positive relationship in winter in CMIP5 may be explained by a wider variety of circulation changes sampled by the multi-model ensemble that dominate differences in the future precipitation response, although further work is needed to confirm this as well as investigate other potential causes."	
213	5 Interpretation and use of the projections	140	25	Here it would be appropriate with one or a few references to EURO-CORDEX and results thereof. One option is Jacob et al (2014) and/or Kjellström, E., Nikulin, G., Strandberg, G., Christensen, O. B., Jacob, D., Keuler, K., Lenderink, G., van Meijgaard, E., Schär, C., Somot, S., Sørland, S. L., Teichmann, C., and Vautard, R., 2018. European climate change at global mean temperature increases of 1.5 and 2 °C above pre-industrial conditions as simulated by the EURO-CORDEX regional climate models, Earth Syst. Dynam., 9, 459-478, https://doi.org/10.5194/esd-9-459-2018.	Scientific/technical issue	EK	Open	Both these references have been added.	
214	6 Summary and forward look	141	6	Here I think you should add "for the UK". Other countries have used different approaches, in some cases empirical statistical methods	Scientific/technical issue	EK	Open	It is not just "for the UK" but more generally. However the word "all" has been removed.	
215	6 Summary and forward look	141	18	Consider changing "improved biases" to "smaller biases"	Unclear phrasing	EK	Open	From Table 5.1 (and the number of green ticks), it is clear that the CPM gives "improved" present-day biases for almost all metrics. Therefore we do not think this should be changed to "similar biases".	
216	6 Summary and forward look	141	22	Add "other" at the end of the line	Scientific/technical issue	EK	Closed	Done	
217	6 Summary and forward look	141	30	I think you should say "likely due to" as I don't think it is shown that the snow treatment is the reason (even if it seems very plausible)	Scientific/technical issue	EK	Closed	Done	
218	6 Summary and forward look	142	6	This is indeed true for all processes in the GCM affecting the large-scales and the boundary conditions. For small-scale processes internal to the domain, this is not the case and improved features can be seen provided that these processes are treated better in the RCM.	Scientific/technical issue	EK	Open	Clarification has been added: "Note, however that the CPM shares the same caveat that applies to all climate downscaling products, that the downscaled scenarios remain subject to the effects of systematic biases, and related process errors, present in the driving global simulations that affect the large-scales (and hence impact the boundary conditions)."	
219	6 Summary and forward look	142	24	Here it says that the models may underestimate the upper-end responses but the figure (5.1) shows that this applies to summer and not winter.	Scientific/technical issue	EK	Open	It is only for winter precipitation that the CPM-12 results (in green) extend above the range sampled by all other ensembles (RCM-PPE, GC3.05-PPE and CMIP5-13) in Fig 5.1. For winter mean precipitation in England, one CPM-12 member actually samples a response above the Strand 1 5-95th percentile range.	
220	6 Summary and forward look	143	18 and 25	It is clear that the outcome of this excercise requires really skillful users and/or very good user support!	Scientific/technical issue	EK	Open	Agreed! We have added a note here about the availability of additional guidance: "see Fung et al, 2018, for further guidance" This guidance material will be updated to accompany the release of the CPM data. In the non-technical summary at the start of the report we also note the availability of additional guidance: "The UKCP18 website (https://www.metoffice.gov.uk/research/collaboration/ukcp) contains links to general advice on how to use the UKCP18 projections (Fung et al., 2018), and specific advice for previous users of UKCP09 (Fung and Gawith, 2018)."	

ID	Section	Page (as per page numbering)	Line number	Comment	Category	Reviewer initials	Status	MO response	Response from authors
221	6 Summary and forward look	144	10	Why not "CMIP5 and/or CMIP6"?	Scientific/technical issue	EK	Open	Using CMIP5 has the advantage of consistency with Strand 2.	
222	6 Summary and forward look	144	14	EURO-CORDEX	Typo/Format	EK	Closed	Done	
223	6 Summary and forward look	144	14	EURO-CORDEX projections are also available at RCP4.5 and 2.6 that would be a good complement here.	Scientific/technical issue	EK	Open	Discussions are underway regarding the possibility of providing downscaled projections for other scenarios (in addition to RCP8.5), but this is far from certain and so is not mentioned here.	
224	6 Summary and forward look	145	6 and 7	Consider changing into "… in a 12-member CPM ensemble being provided for continuous …"	Unclear phrasing	EK	Closed	Done	
225	6 Summary and forward look	145	5 and 7	These time ranges should be 1981-2000, 2021-2040 etc	Typo/Format	EK	Closed	Done	
226	6 Summary and forward look	145	12 to 15	Possibly rephrase this part depending on how much of other variables you will have time to include here	Scientific/technical issue	EK	Open	Additional variables that have now been added include cloud and lightning (in addition to soil moisture stress and snow). This is now noted: "Changes in soil moisture, snow, cloud and lightning have also been considered." Further work is still planned to assess performance for other variables, e.g. wind, and so the basic message in this paragraph is unchanged.	
227	6 Summary and forward look	145	19	Indeed the first time with dynamical downscaling, but high-resolution (1x1 km) information based on ESD downscaling of EURO-CORDEX has been provided elsewhere (e.g. Norway, https://klimaservicesenter.no/faces/desktop/scenarios.xhtml)	Scientific/technical issue	EK	Open	We now state: "In particular, for the first-time in any national climate scenarios, these results provide an indication of uncertainties in changes at kilometre and hourly scales using physical climate modelling, and plausible projections of future changes in convective extremes."	

Responses to Peer Review Panel Comments from 11 March 2019		
ID	Comment	MO response
1	Comment on how biases in cold winter days and hot summer days look for each ensemble member, as well as showing ensemble-mean biases in figure (Erik Kjellstrom).	Individual ensemble members largely show similar biases to the ensemble mean (with the exception of 1 or 2 members). Text noting this has been added to Section 3.3.
2	Change labelling on present-day precipitation variability plot (NCIC wet day frequency and UK mean is in units of frequency (not %) so remove reference to % on top left panel).	Done
3	For extreme hourly precipitation plots, extend results out to 100y return level, add ERAI-RCM-STD and ERAI-CPM-STD (to present-day evaluation plot), and add GEV uncertainty (Brian Hoskins, Christoph Schaer). This helps distinguish differences between ensemble members from uncertainty due to sampling of grid point storms.	The plots have been extended out to 100y return level and ERAI-RCM-STD and ERAI-CPM-STD have been added to the evaluation plots. It can be seen that in general the overestimation of extremes in CPM-STD is worse when driven by ERAInterim (ERAI-CPM-STD) in spring, similar in summer and slightly improved in autumn and winter. This confirms that this overestimation is largely an inherent bias in the CPM. In the case of the RCM, ERAI-RCM-STD shows a very similar result to RCM-STD (although in northern regions there is a shift to lower extremes in autumn), indicating that the tendency for the growth curve to be too steep is an inherent bias in the RCM. Uncertainty in the GPD fit has been added for the standard member only (as this is indicative of the uncertainty in the fit for all ensemble members). This shows that uncertainty in the GPD fit is generally larger than the ensemble spread, suggesting that the differences between ensemble members are due, at least in part, to uncertainty in the sampling of extremes. Uncertainty in the GPD fit in the RCM is larger than that for the CPM (increasing considerably on moving to higher return periods), consistent with this reflecting grid point storms in the RCM. These results are discussed in Section 3.5.
4	Add Clausius-Clapeyron scaling line to extreme hourly precipitation change plots (Christoph Schaer). This will help identify whether different responses across ensemble are driven by different temperature changes.	Scaling analysis has been done and results looking at the scaling between changes in the 99th percentile of wet values of daily maximum hourly precipitation and changes in mean dew point temperature have been added to Section 4.4. We find there is a range of scaling values across the CPM ensemble (of 5.4-9.3 %/K). This suggests that differences in extreme precipitation changes between members are not just explained by differences in changes in temperature or moisture availability (with the range of UK-average dew point temperature changes being 2.5-4.0K). Clearly some members have different extreme precipitation responses for a given change in moisture availability. Scaling is higher in the CPM (7.8 %/K) compared to the RCM (5.2%/K), consistent with the hypothesis that local dynamical feedbacks operating in the CPM give greater increases in extreme hourly precipitation.
5	Comment on mean precipitation changes over both land and sea, to help put winter mean precipitation changes over land into context (Brian Hoskins).	Winter mean precipitation changes averaged over the CPM model domain (including land and sea points) gives a central estimate of 22% increase in CPM-12, compared to 18% increase in RCM-PPE. Thus the difference between the responses in the CPM compared to the RCM are smaller when considering both land and sea points, but the average percentage increase is still larger in the CPM. This result is now stated in the second paragraph of Section 4.2.

ID	Comment	MO response
6	It would be good to have a synoptic feel for precipitation in winter. Is the greater increase in precipitation in the CPM really associated with showers, or with large-scale precipitation in fronts (Brian Hoskins)?	Initial work looking at the convective fraction of precipitation in winter in the RCM shows that there is a future increase in convective fraction over the sea and also over the south-east of the UK, but a decrease in convective fraction over northern and western UK regions. These results have been added in support of the discussion of winter mean precipitation changes in Section 4.2, with a new figure Fig 4.2.9. Initial analysis has also been carried out using the convective fraction of precipitation in the RCM to classify days in the CPM. In particular, days where the UK-average convective fraction in the RCM>0.3 have been selected, as indicative of days with relatively little large-scale frontal activity. Such days are not common in the present-day but increase in occurrence in future (going from 7.8 to 10.3 days per winter season on average). For these days we find a greater future increase in the contribution to total precipitation in the CPM compared to the RCM. Further work is needed to explore the sensitivity of the results to using different thresholds, but these initial results support the discussion in Section 4.2. This is now stated in the text: "This is supported by initial analysis showing that the contribution to total precipitation from days with relatively little large-scale frontal activity (diagnosed using convective fraction in the RCM) is increasing in future in the CPM, and more than in the RCM. " Further work is planned to use a spatial filter method to isolate the small scale showery component of precipitation in CPM, and thus explore the extent to which changes in winter in the CPM are associated with convective showers. The results of this analysis however will not be available in the time frame for this report.
7	Add analysis of water budget over CPM domain, to help understand different mean winter precipitation changes in CPM versus RCM (Brian Hoskins).	Table 4.1 has been added providing an initial look at the terms in the atmospheric water budget for winter, and similarly Table 4.2 for summer. These results are discussed in Section 4.2 and also Section 5. Results show that the mean moisture flux convergence over the CPM domain (and its future change) is very similar between the CPM and RCM (winter average of 1.63 mm/day in both models, see Table 4.1), confirming that moisture entering and leaving the CPM domain is well constrained by the RCM. For the present-day, there is more evaporation in the RCM compared to the CPM over both land and sea points in winter, which explains higher precipitation in the RCM within the CPM domain. Over British Isles land points, the increase in evaporation plus moisture flux convergence is larger in the CPM (0.77 mm/day) compared to the RCM (0.66 mm/day), consistent with the greater increase in winter mean precipitation. This difference is coming from the greater increase in moisture flux convergence over land in the CPM (with similar changes in evaporation over land). By contrast future changes in both evaporation and moisture flux convergence over the sea are higher in the RCM in winter. Thus greater increases in moisture flux convergence over the land in winter in the CPM, appear to be compensated by smaller increases in moisture flux convergence over the sea. In summer (unlike in winter) evaporation over the land dominates over moisture flux convergence over the land, with the local recycling of moisture being important (whereas showers in winter may be more dependent on the advected moisture from the sea). The different processes in summer compared to winter are discussed in Section 5.
8	Add plot showing how biases relate to future changes, in both summer and winter, and discuss the extent to which this supports the wet baseline in the RCM as being a factor leading to smaller future increases in mean winter precipitation (Bart van den Hurk). Comment on why it is that we only see the baseline effect in winter, whilst changes are similar between the CPM and RCM in summer.	Scatter plots have been added showing present-day biases versus future responses across all ensemble members in Strands 2 and 3, for mean precipitation and temperature, in summer and winter (Fig 5.2 and 5.3). See accompanying text in Section 5, which discusses why we only see the baseline effect in winter.