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Interactive comment on "The importance of model resolution on simulated precipitation in Europe – from global to regional model" *by* Gustav Strandberg and Petter Lind

Anonymous Referee #1

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This study analyses precipitation characteristics over Europe from a wide range of model ensembles, including Global Climate Models (CMIP5, CMIP6, PRIMAVERA) and Regional Climate Models (CORDEX). The precipitation characteristics include daily precipitation distributions based on the ASoP diagnostics developed by Klingaman et al (2017), as well as statistical metrics such as number of wet days, number of heavy precipitation days, intensity of wet days, intensity of heaviest precipitation day. The aim of this study is three-fold: 1) investigate differences between model ensembles, and between models within each ensemble, by using a wide range of ensembles from CMIP5, CMIP6, PRIMAVERA and CORDEX; 2) evaluate model performance against observations, using E-OBS data; 3) investigate the role of resolution in precip-

itation characteristics over Europe, by selecting only models available at both low and high resolution versions.

I have several comments regarding this study, as described below. Some of them would require more analyses and restructuring of the paper, but I think it would also greatly improve it.

1) The authors have made an impressive work by analysing such a huge amount of simulations. This is very complementary to the work by Demory et al (2020), which have analysed daily precipitation over Europe in CMIP5, PRIMAVERA (high-resolution) and CORDEX (low and high resolutions) compared to high-quality observational datasets over Europe. This work has now been revised by focusing more on EUR-11 (which is a newer ensemble than EUR-44), and by including also spatial distribution of precipitation and Taylor diagrams, which confirm the results shown by the precipitation distribution. The paper is now accepted and should appear soon. I suggest to refer to this study already in the introduction. Iles et al (2020) could also be referred to in the introduction as another study evaluating a range of GCMs and RCMs at various resolutions, considering the atmosphere-only UPSCALE simulations. The fact that this study and Demory et al find similar results, despite using slightly different methods, give strength to these two studies and should be discussed further.

2) The authors have managed to combine their results into well-designed figures. However, I feel the 3 goals should not be addressed with the same method. The authors have indeed decided to perform the analyses on the model native grids. This is a good choice for showing what each ensemble is able to simulate at its own resolution, and could be used for addressing aim 1) written above, as long as the models are not compared to each other. A clean comparison could only be done on a common coarser grid, as emphasised by Klingaman et al, 2017. Evaluating results on native grid not only shows the potential of the model physics but also includes the technical aspect of doing analyses on a finer grid. This technical aspect can be evaluated by regridding the data on a coarser grid and see how the results are affected by such a regridding.

Evaluating results on common grids would show the impact of the model physics, its internal resolution solely (Na et al, 2020), and allows a direct assessment and inter-comparison of the results across resolutions (Demory et al, 2020; Iles et al, 2020; see also Torma et al, 2015 (their Fig 3-6)). I would therefore suggest to redo analyses on a common coarser grid to verify the results shown on native grid. I believe this would strengthen the results. One way to answer all 3 aims of the study could be to split it into two parts: the first part would address 1) and 2) on native grids, considering observations available at various resolutions (such as low-resolution satellite data on grids similar to CMIP); the second part would evaluate the impact of resolution by regridding all data on a common coarser grid.

3) The models are evaluated against E-OBS. E-OBS is a good product that tries to gather the highest number of stations currently available. This is particularly the case over Scandinavian regions, or Germany. However, there are still many regions where the station density is low (e.g. France, Italy, Spain, Switzerland, Austria). Over these regions, it would be better to use national gridded datasets, available at much higher resolution (see Demory et al, 2020 for details). I understand the authors may not want to go in that direction, as it adds a lot of processing time and the definitions of the regions would be slightly different than in the current study. I would therefore suggest to include a discussion on this (and eventually an intercomparison with observational results of Demory et al if feasible). Moreover, for aim 1) of the study, I would suggest the authors to use another lower resolution dataset, such as satellite observations, using a resolution closer to CMIP models. This would give an additional range of observational uncertainty.

4) Please verify the use of model resolution when you actually refer to model horizontal grid spacing. The model effective resolution is typically 4 to 8 times the model horizontal grid spacing (Skamarock, 2004; Klaver et al, 2019).

5) Most analyses have been performed annually. It would be good to show them seasonally as well (at least DJF and JJA), as the processes driving precipitation are differ-

ent and RCMs depend more on GCMs in DJF than JJA (e.g. Hall, 2014; Prein et al, 2016; Fernandez et al, 2019).

6) The abstract needs to be revised. It writes very general conclusions as it stands. See detailed suggestions below. This is true as well for the entire text. Some sentences are a bit hard to read, and in many places, it reads like general statements or approximative sentences. I provided some suggestions for some of them below, but a careful review of the language would clarify the text and be beneficial to the final paper.

7) For reproducibility of the results, it appears important to list the models that were considered for the study.

Detailed comments:

Title: the importance of model 'horizontal' resolution... from global to regional 'models'

L. 10: model 'horizontal' resolution

L. 17-18: I find this conclusion too general. This depends on seasons, and most of the analyses have been performed annually.

L. 20: I don't agree with this. The authors have shown here that the improvement is systematic across models but that there is a large inter-model variability.

L. 21: I agree with this, but I think it cannot be generalised for all resolutions. The authors have shown here that the averaged resolution of CMIP5 and CMIP6 anyway is too low to capture the characteristics of precipitation, at least against E-OBS and other higher resolution ensembles.

L. 22: again, this depends on the season and the authors have mostly worked with annual means.

L. 23: different RCMs driven by the same GCM give different results, but the same RCM driven by different GCMs also give different results (e.g. Vautard et al, 2020).

L. 24-25: Given the complementarity to Demory et al (2020), this sentence needs to be rewritten.

L. 28: delete 'precipitation extremes' in 'precipitation extremes (heavy precipitation events)' -> heavy precipitation events

L. 34: see also Ban et al, 2015

L. 38-39: could the authors add references to support this sentence?

L. 40: 'statistically': remove

L. 40: 'decreasing' -> 'refining'

L. 45: these papers are among many others (e.g. Delworth et al, 2012; Kinter et al, 2013; Roberts et al, 2018 and references therein)

L. 47: please also refer to more recent studies

L. 53-54: Please be careful not to suggest that climate change response in RCM versus GCM may be solely due to resolution. They also depend on the forcings. For example, Boe et al, 2020 and Gutierrez et al, 2020 show the impact of different aerosol treatments between GCM and RCM that may explain part of the different climate change response.

L. 61: please add a reference

L. 62: check the study by Vergara-Temprado et al, 2019. They show that it is possible to turn off convection scheme at such resolution and get appropriate results.

L. 63: 'certain': which ones?

L. 66: 'giving' -> 'simulating'

L. 68: that is true for models with parametrised convection, please also refer to Vergara et al, 2019 (also in L. 71).

L. 77-78: 12km is not high resolution for RCMs, it is its new standard resolution within CORDEX

L. 79: spell out HighResMIP

L. 95: high-resolution PRIMAVERA models are available at higher resolution than 40km at mid-latitude (with is the common referenced latitude), or please specify at which latitude this refers to. I would suggest to use the mid-latitude grid spacing (at 50 degree N), as it is the mid latitude of the European domain (so comparable to EURO-CORDEX grid spacings). It would be clearer to use the term horizontal grid spacing here.

L. 95-97 & Table 1: why not considering the full ensembles? How were the models selected? Why are there 5 PRIMAVERA LR and 4 HR?

Figures 2-3-5: I refer to the revised figures. What does 'act' mean? Please clarify the x-axis 'precipitation bins' and y-axis 'precipitation contribution' labels.

Figures 2-3: specify in the caption that the thick lines are for ensemble means, and that the bottom panels are differences with E-OBS.

Figures 2-3-4: E-OBS is written in Table 1 to be available at 2 resolutions. Which is shown on these figures?

Figures 6-7-8-9-10: I guess E-OBS is shown here at its 2 available resolutions, which one is which?

L. 150: bottom left panel for the Alps. Also, CMIP6 upper end seems to be around 50 mm/day and CORDEX HR over 100mm/day.

Figure 3: The spread is much larger in CORDEX than CMIP6 in JJA. It shows that CORDEX is not so sensitive to the GCM boundary conditions but to different parametrisation schemes in JJA. The spread is determined by the min and max values for both EUR-11 and EUR-44. So are these min and max values only represented by 1 RCM, or 1 RCM-GCM simulation? If the spread is represented by min and max values, wouldn't

it be better to plot the median instead of the mean?

Figure 4: It seems biased to consider EUR-11 as the reference and compare observations to that reference, possibly because, although EUR-11 has a higher resolution, their mean climate seems too wet against high density observations as shown by Demory et al (2020), although I agree observations have undercatch errors. If E-OBS are considered too low resolution and not trustable, considering datasets with higher density stations as the reference would be necessary here. Moreover, the ensembles are clearly compared to each other in this figure, with respect to EUR-11. It would be good to see this analysis performed on a common grid to evaluate how it affects the conclusions. It could be done both at 50km for EUR-11, EUR-44 and PRIMAVERA, and then redone for all datasets at 150 (or even 300km), as done in Torma et al, 2015. Why writing the E-OBS total annual mean in the box if EUR-11 is used as a reference?

L. 181: more strongly biased lower -> more negatively biased: I suggest not to use the word 'bias' when compared to an ensemble, which is itself biased.

L. 193-194: Observations have uncertainties but EUR-11 could also rain too much along coastlines and over topography.

L. 211-212: Fig. 5 shows results for the annual mean, so this conclusion may be different at seasonal means (at least between DJF and JJA), so I would suggest to show these seasonally as well. Moreover, the delta in grid spacing between CORDEX LR (50km) and HR (12.5km) is similar for all models (delta=4), so the impact of resolution is potentially more similar (although it depends on models). This is more complex for the PRIMAVERA models that have various deltas between the LR and HR versions. I counted that deltas vary between 2 for most models, 3 for a couple and 5.4 for the HadGEM3 model (https://www.primavera-h2020.eu/modelling/our-models/). Moreover, note that PRIMAVERA HR uses exactly the same tuning parameters as their LR version, so the effect of resolution solely is seen here (this is not the case for the CORDEX ensembles that may use different model versions). Something that could be interesting

to show here is whether, depending on their delta in grid spacing, some PRIMAVERA models show larger differences than some others. But I would not generalise, based on ensemble means, that resolution in CORDEX has more effect than resolution in PRIMAVERA. It would be good to see the spread of the ensembles on figure 5.

L. 216-218: I agree with this hypothesis, and yet you found greater differences in CORDEX (driven by same low-resolution GCMs) than in PRIMAVERA (L. 211-212). I think this highlights the need for analyses on a common grid, based on seasonal means, and taking into account the fact that CORDEX and PRIMAVERA have different deltas in grid spacing.

L. 226-227: this is not a sentence/question: please rephrase.

Figures 6-9: I considered the revised figures. I still do not understand why some values are not shown. For example: Fig. 6 top left: For one of the CMIP5, only the 10th and 90th percentiles are shown, nothing else it seems. For some other CMIP5 and CMIP6 models, the boxes are drawn but not the whiskers.

Figures 6-7: it seems that CMIP5, CORDEX LR and HR have a larger variability, so is the variability of CORDEX driven by the variability of CMIP5? This could be answered by looking at the seasonal means (DJF and JJA).

L. 227-246: Again for these analyses, the metrics can be analysed for each ensemble on their native resolution, but if the ensembles are compared to each other, as written in the text, then the analyses need to be redone on a common grid.

L. 232-233: Would it be possible to show this with seasonal means?

L. 245: isn't it 20 mm/day instead of 10?

L. 271: rephrase 'negative for some models and positive for some' as it reads too vague

Figure 10: This intercomparison needs to be performed on a common grid

L. 281: left -> right

L. 283: right -> left

L. 283-284: Note that ECMWF HR is 25km grid spacing output at 50km, and LR is 50km output at 100km grid spacing. The delta in grid spacing is therefore 2, and the output are regridded to coarser resolution. This may impact the results.

L. 300-301: Demory et al have revised the manuscript with a focus on EUR-11.

L. 306: give extremes that are heavier and more frequent -> simulate more intense and more frequent heavy precipitation. I would avoid the term 'extremes' with such low-resolution models, and refer instead to 'heavy' or 'intense'.

L. 308: overestimation compared to E-OBS

L. 315: CMIP6 and CMIP5

L. 318-319: this is probably particularly the case for JJA (as shown in fig 3), but for this conclusion it would be good to see DJF and JJA for fig 6-9.

L. 320: not only. E-OBS is not based on the full network of rain gauges over some other countries, such as France.

L. 332: scale -> grid

L. 336: will have -> has

L. 340-341: yes but PRIMAVERA tends to be drier than CORDEX in all seasons.

L. 343: to -> too

L. 344: agree -> agrees

L. 345: the quantification can be done if performed on common grids

L. 348-349: this can depend on seasons

L. 350-351: this needs to be rephrased, as Demory et al have evaluated CMIP5, CORDEX LR/HR and PRIMAVERA HR

Proper acknowledgement needs to be given to the PRIMAVERA, CORDEX, and CMIP modelling groups

There are several typos in the text, please check carefully (e.g. L.8: effects -> affects; L. 20: in depending -> depends; L. 180: region -> regional (and remove comma afterwards); L. 218: were -> where; many others) L. 139 and 141: below/above c: are these typos?

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