Point-to-point responses to Referee's comments

Impact of horizontal resolution and model time step on European precipitation extremes in the OpenIFS 43r3 atmosphere model

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Reviewer #1

This study focuses on the impact of horizontal resolution and model time step on extreme precipitation over Europe. The authors use AMIP-style simulations with the OpenIFS at various resolutions, covering a 25-year period (1979-2014). Results are compared with daily gridded precipitation observations data from GPCC and ERA5 reanalysis data. The authors did efforts to address some of the previous remarks/comments, adjusted parts in the revised manuscript, and provide clarification regarding the interpolation methods and impact on the results. Although I do appreciate the effort, I still have a major concern regarding the analysis conducted in section 3.2 and Figures (7,8, 11 and S5).

Specific comments:

The analysis in section 3.2 is based largely on Figures 7,8,11 and S5, S6. However, looking closer at these figures I can see that the distributions include probability densities for negative values of precipitation (both lsp and cp) as well as their ratio. To my understanding it should not be possible to have negative daily precipitation rates.

I would guess that this could be something as simple as small negative values for precipitation, which can occur due to interpolation issues. If that is the case then the analysis in section 3.2 could remain largely valid (for precipitation > 0 mm). If the issue is something else, like adding precipitation difference fields (e.g., HR - ERA5) in the computation of PDFs, instead of the actual precipitation fields, then they analysis in section 3.2 may not be valid and would need to be corrected.

Could the authors please elaborate on what has caused the issue with these Figures and if this affects the analysis in section 3.2.

Thank you for your comments. The distribution figures (Figures 7, 8, 11 and S6, S7) were done by 'seaborn.kdeplot'. Because the smoothing algorithm of 'seaborn.kdeplot' uses a Gaussian kernel, the estimated density curve can extend to values that do not make sense for a particular dataset. For example, the curve may be drawn over negative values when smoothing data that are naturally positive (https://seaborn.pydata.org/generated/seaborn.kdeplot.html). We now use parameters to truncate the curve at the data limit, so that only the exact data we have are shown in the figures. All the distributions figures are updated (Figures 7, 8, 11 and S6, S7). It does not affect the analysis in section 3.2.

Minor comments:

I would suggest to relocated the paragraph in lines 382-392 of the revised manuscript to either section 3.1 and the discuss. The insights provided here are very valuable as they highlight the impact of the interpolation from native grid to the one used for the analysis and are somewhat misplaced here in section 3.2 which focuses on relative contributions for large-scale and convective precipitation.

Thank you for your suggestions and we have moved the analysis on native grid to the discussion section (line 540-560).

Also, it may be interesting (although maybe not necessary or could be added as supplementary material) to compute the RMSE against CPCC also in the native resolution, just to see if the larger differences see in native resolution Fig 9, vs Fig 1 have any impact on the RMSE for the different percentiles.

Thank you for your advice. We cannot compute RMSE against GPCC in the native resolution for different percentiles (like we did in Fig. 5) without interpolation, because LR (192x384), MR and HR (400x800) have different resolutions with GPCC (180x360). For the 99th precipitation time series shown in Fig. 1 and Fig. 9, we can compute RMSE, because the curves have the same time dimension. We have computed the RMSE against GPCC for the time series curves in both regridded and native resolution for different percentiles (Fig. S8), and found larger RMSE values across different percentiles and larger sensitivity to horizontal resolution on native resolution (line 550-553).

I would also recommend to update the zenodo repository for this study to include the scripts used for plotting the new Figures added to this manuscript.

Thank you and we have updated the scripts on the zenodo repository (line 597).

Reviewer #2

I thank the authors for providing a succinct article investigating the sensitivity of extreme precipitation events in OpenIFS to model time step and horizontal resolution. I have tried to make some minor edits to improve the readability of your article in places but in general the quality of scientific writing and accompanying figures is very good. I have one substantive point for you to think about in relation to RMSEs at different percentile thresholds – and specifically what precipitation amounts these percentiles correspond to. I also encourage the authors to consider using "finer (or coarser) horizontal resolution" and "shorter (or longer) model time step" as it will help the readability of your article.

Substantive point

In Fig. 5 you show the RMSE for different percentiles thresholds and state the "RMSEs increase exponentially with increasing percentiles". It would be useful here to have some additional knowledge of what rainfall amount the e.g. 70th, 80th and 90th percentiles correspond to. For example, the 80th percentile may correspond to only perhaps <2mm/day, in which case would it follow that the RMSE for all resolutions (and time step lengths) would be much smaller at these lower (less extreme) percentiles? Lines 285-288 – is RMSE the best statistic to use to support this conclusion? Given the discussion above around rainfall amounts that correspond to each percentile – I'd advise calculating and/or stating the rainfall amounts that the 70th, 80th and 90th percentiles correspond to.

Thank you for your advice. We added the precipitation amounts at different percentiles to Fig. 5, and discussed the relative RMSE (RRMSE, i.e., RMSE/ (GPCC precipitation)) in the manuscript (line 321-334). Differ from the smaller RMSEs at lower percentiles, the RRMSEs are comparable at lower (70-90th) and higher percentiles (above 99th).

For the lines 285-288 (now line 300-304), we concluded that extreme precipitation is more sensitive to horizontal resolution than lower percentile precipitation. This conclusion is based on RMSE which measures the absolute magnitude of biases, but not totally applicable on RRMSE. For RRMSE, a slightly larger sensitivity to horizontal resolution at higher percentiles holds from 90th (~6 mm/d) to >99.9th (~39 mm/d), however, precipitation's sensitivity to horizontal resolution at 70-90th percentile is comparable to that above 99th percentile. We have added a paragraph about RRMSE in the manuscript (line 321-334).

Minor comments

In section 3.1 (lines 206-210) - I think it is worth starting that ERA-5 is a reanalysis product that assimilates observations of precipitation. Therefore we should expect it to e.g. do a better job of reproducing dry (1994) and wet (2010) years – than OpenIFS AMIP simulation that doesn't "see" the precipitation observations.

Thank you and we have updated this information in the manuscript (line 214-217).

Line 233 – missing word – add percentile after 99th

It is fixed now (line 244).

Lines 240-242 – also in Fig. S1 and Fig. S2 there looks to be a shift northwards of the highest orography in LR compared with MR and HR – this could be brought into this discussion.

Thank you and it is a good point. The previous Fig. S2 & S3 are for (0 – 40° E, 62° N) which is in Scandinavia. We add the surface height over Alps region (~12.6° E, 45-50° N) in current Fig. S2, and found a lower and gentle mountain in LR than MR (HR) which can help to explain the precipitation bias over Alps (line 254-258).

Line 293 – suggest reversing statement to make it clearer to the reader what you mean – i.e. shorter timestep corresponds to smaller RMSE. e.g. "The RMSEs for LR, LR30m, and LR60m are smaller when the model time step is shorter. However..."

It is fixed now (line 308).

Line 303 – I think it is more common to say "unresolved" convective motions in this context.

It is fixed now (line 339).

Line 306 – suggest to help the reader follow what you are saying here "When moving to finer (or higher) horizontal resolutions, large-scale precipitation is likely to increase"

It is fixed now (line 342).

Line 312 – mostly "consistent of" or shorten to "extreme precipitation is mostly large-scale..."

It is fixed now (line 348).

Lines 317-319 – 40N also cuts out a significant part of southern Spain, Greece and far south of Italy and Sicily. This may be intended but I suggest its worth stating explicitly that you are cutting off more than just North Africa.

It is fixed now (line 356-357).

Line 348 – Revise wording slightly for readability - "It is likely due to "the"(?) large-scale precipitation "increasing"(?) by a larger percentage...". Can you provide any evidence to support this statement? E.g. "This is due to the large-scale precipitation increasing by XX%, whereas convective precipitation only increases by YY%."

It is fixed now (389-391).

Lines 345-353 – this section needs some editing and in places is a bit weak e.g. "it is likely" – try to be more concise and provide evidence to support these statements. As is stands I'm not sure this paragraph adds to the results section.

Thank you. We have removed some information and made it concise (line 384-395).

Line 356 – consider saying a “shorter model time step” (and elsewhere in this paragraph).

I think the section detailing native grid results should be within its own sub-section under the results heading – to give clarity to the reader that you are re-producing earlier results but without the re-gridding step applied previously.

Thank you and we have changed to ‘shorter model time step’ in the manuscript. We have also moved the analysis about native resolution to the discussion section (line 540-560).

Line 395 – remove the word “and” – use a comma after (Fig. 11 a-d) instead. Line 395 – change “coarsened resolution results” to “regridded results”

It is fixed now (line 554-555).

Line 397 – as above “regridded results”. Coarsened resolution to the reader implies you are discussing the resolution of the model whereas my understanding is that here you are comparing with earlier results where you had regridded the higher-resolution data to a common 0.9 degree grid.

Thank you and we have fixed it in the manuscript.

Results and discussion section – be careful in your use of “increasing horizontal resolution” – perhaps change to “finer horizontal resolution” or similar.

Thank you and we have changed ‘increasing horizontal resolution’ to ‘higher horizontal resolution’ in the manuscript.

The final paragraph of your discussion on precipitation observational datasets is interesting. Given some of the issues that you correctly highlight I wonder whether it would be worth considering adding a line about future work that would follow-on from this study. You could compare model output to “an ensemble” of observational products – this would helpfully provide a spread of observational estimates and allow insights on whether and which model configurations sit within the observational spread.

Thank you and this is a good point. We have added this information that paragraph (line 579-583).

Minor changes to improve figures

Fig. 1 – consider removing vertical grid lines to reduce clutter on the plot. Update the figure line labels (e.g. capitalise RMSE).

It is fixed now (Fig. 1).

Fig. 3 and Fig. 4 – could you change the panel layout so that each panel is larger. I understand that you want to show differences to obs below relevant model data but its very challenging to see significance stippling at current image size

Fig. 3&4 have been updated.

Table 1- In HR column – the "native" output resolution is not 400x800 – this data has already been coarsened or regridded as stated in lines 384-385 of the manuscript. For clarity suggest you state the native resolution and in brackets add the data resolution you used for your evaluation.

It is fixed now (Table 1).