NHESS manuscript : NHESS-2023-82

Does a convection-permitting regional climate model bring new perspectives on the projection of Mediterranean floods?

We would like to thank the reviewers for the time and efforts they have dedicated to review our manuscript and for their useful and relevant comments. We believe that the comments truly helped to improve the manuscript. You can find below the responses to the requests and suggestions.

Reviewer 2

This paper evaluates the skill of the CNRM-AROME Convection-Permitting regional climate Model (CPM) in projecting floods, using the Gardon at Anduze catchment in southern France as a case study. The CPM demonstrates superior accuracy in reproducing extreme hourly rainfall events compared to traditional models. The study underscores the potential of CPMs in future flood predictions in a warming climate.

The manuscript is interesting and generally well written, although some important aspects must be addressed before being suitable for publication in NHESS:

We thank reviewer #2 for reviewing the manuscript. The answers to all the comments are indicated below.

MAJOR COMMENT

The focus of the paper is not clear to me. I understand there has been a great effort to run two different hydrological model approaches, with two climate projection standards CPM vs high resolution but non-CPM models. The results and conclusions are too much focused on describing the experiments output with barely no interpretation. Indeed the results sections consist of what should be a caption inserted in the text and a description of the figure. What is the research question attempted to be responded by this study? The outlook for future flood scenarios is clearly not an objective as no attention to uncertainties is put.

Thank you for this important comment, we will improve the description of the results.

To clarify, the main objective of the study consist to assess the differences between using a CPM and a RCM to simulate extreme precipitation and projecting mediterranean floods. We agree that some more in-depth discussions are warranted to clarify this point, so we will add the following sentences..

For the description of figures (minor comments below):

- l643-645 : “We now analyze the flood distributions from the hydrological models forced with the AROME and ALADIN climate simulations under the historical and the future RCP 8.5 scenario (Figure 7).”

- l744-745 : “Then, we analyzed the flood and associated rainfall events characteristics (figure 8) simulated by historical and future bias-corrected climate simulations”.

For the interpretation of climate models flood projections :

- after line 783 : “ However, the trend over this catchment should be interpreted with caution as it comes from a single pair of RCM and CPM. With these preliminary results, the impacts of climate change on flood characteristics highlight the fine scale benefits of CPM in simulating underlying hydrological processes in such modeling chains. However, The robustness of this These new perspectives on the climate change impact on flash flood need to be confirmed with a comprehensive study that includes an uncertainty assessment.”

MINOR COMMENTS

The title is too ambitious provided the type and robustness of the conclusions reached in the manuscript. The conclusions do not offer “new perspectives”.

Given that the title is a question and not a statement that we try to answer, it seems hard to say that it is too ambitious. However, the following lines will be added to highlight what we call “new perspectives” and guide future work on this topic :

after line 783 : “However, the trend over this catchment should be interpreted with caution as it comes from a single pair of RCM and CPM. With these preliminary results, the impacts of climate change on flood characteristics highlight the fine scale benefits of CPM in simulating underlying hydrological processes in such modeling chains. However, The robustness of this These new perspectives on the climate change impact on flash flood need to be confirmed with a comprehensive study that includes an uncertainty assessment.”

On Figure 7, the future flood signals between the two types of climate models are significantly different. This major difference is potentially linked to a better simulation of rainfall event shape (convective peak) with the CPM. The attenuation of the RCM drizzle effect with the CPM yields a reduced bias in the soil moisture. For all these reasons, we think CPM can effectively bring new perspectives in projecting Mediterranean floods. This study is the first to use this modeling chain over a Mediterranean catchment. It would be interesting to extend such a study using a multi-basins and multi-CPM approach to assess further if the findings are robust..

1. **, 56 “all floods are projected to increase… the moderate floods are expected to decrease.” More precision in the language is required. Are these sentences referring to the frequency of floods? the magnitude? the flashiness?**

These sentences refer to the flood magnitude. We will rephrase it in “With the CNRM-ALADIN RCM, the magnitude of all floods is projected to increase. A threshold effect is found for simulations driven by the CNRM-AROME CPM, where the magnitude of the largest floods is expected to intensify while the magnitude of the less severe floods is expected to decrease.”

2. **“Thober et al. (2018) showed a decrease of high flows and flood magnitudes for different levels of future global warming.” Where?**

This change was stated for the Mediterranean region. After a closer look at the French Mediterranean region, we will change this statement to “Thober et al. (2018) showed no clear signal for high flows and flood magnitudes in the French Mediterranean.”

122-127 The argument presented in these lines seems vague and unfounded. Can you identify studies that directly attributes the contradictory results to the underrepresentation of sub-daily extremes?

Even if hydrological processes are complex and non linear, in the Mediterranean region, the strongest floods are caused by the heavy precipitation events (HPE). It can be assumed that a poor simulation of these extreme rainfall events yields poor simulations of the most intense Mediterranean floods. Furthermore, most of the RCMs do not simulate precipitation at an hourly timestep but every 3h or 6h, leading to biases in the simulation of flashy and sub-daily floods.

The contradictory results on the French Mediterranean region are stated from lines 109 to 116. To our knowledge, no study has ever made a review on flood projections specifically on this region.

1. **The resolution required to explicitly simulate convective processes is not necessarily determined at 4km. This statement is too absolute.**

Indeed, this statement is too strict. The resolution of a CPM can reach up to 4.5km and it is still unclear if the deep convection parameterization schemes can be removed for resolutions between 5 and 10km (Vergara-Temprado et al., 2020).

2. **“get rid of” seems too colloquial.**

Changed to “dispense with”.

167/176 and 168. floods→ flood and emission→emissions

Done.

1. **“Evaluate the added value of the CPM on extreme rainfall”, you mean “the simulation of”? “the prediction of”**

We mean “the simulation of”.

2. **The COMEPHORE is a high quality dataset but is not an "observation". As the text already states, it is a high resolution analysis gridded field of precipitation. This should be corrected throughout the manuscript.**

We agree with the reviewer and we will change this fact when possible. In a figure, we will change "observation" by "COMEPHORE" and we will better define this product in the description of the datasets.

242 and 243. Can you find alternative expressions to refer to the radars used that avoid the relative reference as "foreign" of the Swiss and Jersey Islands radars. They are not "foreign" to some readers.

"Foreign" is to be placed in the context of "French radar network". We can change this sentence to "In 2019, COMEPHORE was built using data from 29 radars comprising the French radar network (ARAMIS), in addition to radars from the Swiss network and another one on Jersey Island".

243-245. Are there any references that support this statement. "is still considered" should be backed by a referenced source.

This sentence will be changed in "COMEPHORE can be considered as the best national precipitation product for studying hourly rainfall at high spatial and temporal resolutions". No paper has ever compared all the French precipitation datasets, but Fumière et al. (2020) compared it to another dataset called SAFRAN and Caillaud et al. (2021) used COMEPHORE as a reference dataset for the study of Heavy Precipitation Events.

1. **I think the change of subject towards temperature use for PET must imply a new line/paragraph.**

Changed.

2. **Can you find a more rigorous description of the differences between the two hydrological models than "physical concepts"?**

Our aim here was to provide a general overview of the different concepts between the two models. The differences are better explained in the two following paragraphs describing each hydrological model.

3. **Describing the use of a hydrological model as a system that "transforms" precipitation into discharge sounds naïve.**

This statement will be improved as follows : "this model uses catchment-aggregated hourly precipitation and potential evapotranspiration data to simulate hourly discharge"

296-297. What is the calibration set of flood cases used? Are these extreme floods? How does this affect the application of the model for extreme events in the experiments?

Both hydrological models have been calibrated over the complete 2002-2018 period. This period contains several floods (see figure 5, black curve) and especially the major 2002 flood. However, we want to stress that since these hydrological models are run in a continuous way, agreement with the best practice in hydrological modeling, the entirety of the full time series (i.e. also including non-flood time steps) has been used.

The Nash and Sutcliffe Efficiency (NSE) criterion used for the calibration gives more weight to the simulation of high flows compared to low flows. These observed extreme floods are therefore well considered during the calibration.

344-345. The presence of biases in climate simulations hampers their use in virtually all impact studies, not only in hydrological applications.

Yes, that is true. We will replace “using hydrological models” by “such as for hydrological impact modeling”

359-362. How do calibrated precipitation maps look like? Is the spatial correlation of the original pcp fields lost?

The spatial correlation is little affected by the bias correction. Figure 1 presents a few rainfall maps of three heavy rainfall events. Raw data is on the left and bias corrected data on the right. From these pictures, we can notice that the precipitation patterns are roughly the same. We will add a sentence in the paper to specify this aspect.

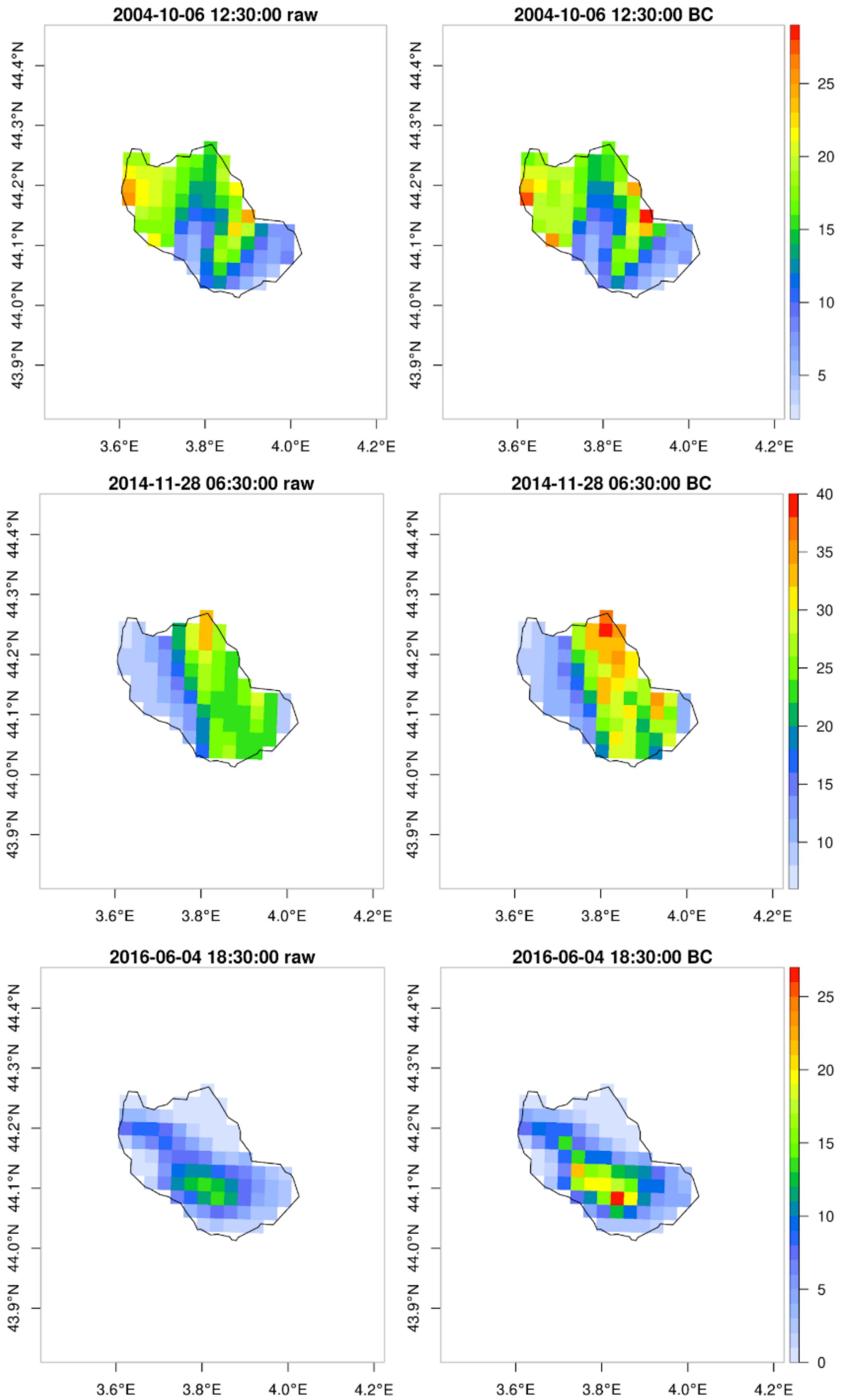

Figure 1 Hourly simulated rainfall before (raw) and after (BC) bias correction for some events

1. **Add "…periods of the same…"**

Sorry but we cannot find where in the text this comment comes from.

405-406. "The rainfall thresholds are related to our knowledge of the river basin dynamics and hydrological expertise." Can you provide any hint or supporting evidence?

We based this assessment on the analysis of flood hydrographs and associated rainfall events. We compared different thresholds to extract the flood events and different parameters to delimitate related rainfall events. Figure 2 is an example of an event. The yellow array represents the barycenter of the rainfall event computed over the 24h (window) before the flood peak. Given the relatively small sample size (one catchment only), it is more efficient to validate manually this threshold rather than using an automatic algorithm.

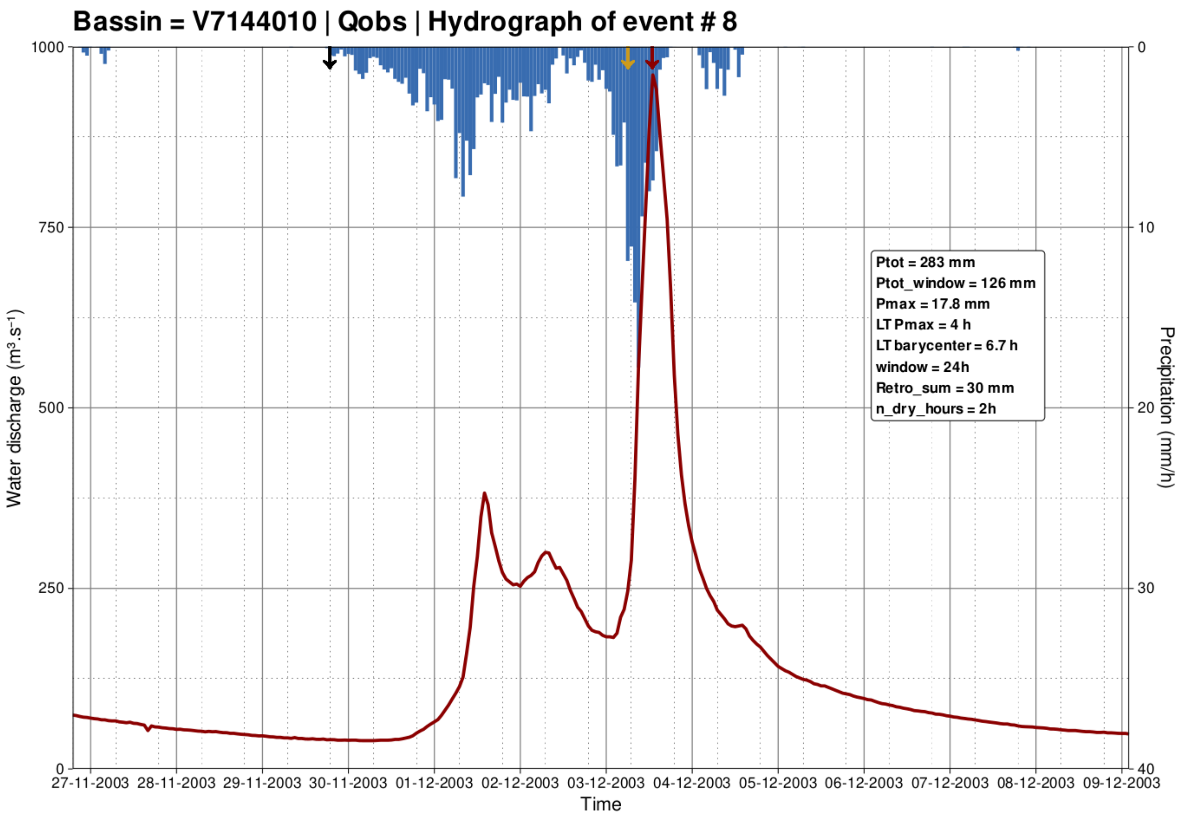

Figure 2 : Example of a hyetograph and hydrograph for an event

459-461. Is this spring-autumn connection possible provided the intense hydric deficit that characterizes Mediterranean climate, that acts as a drying reset to the hydric cycle in most surface basins in the region?

Thank you for this relevant comment. This statement is an hypothesis. It is true that the summer months are really dry over this basin leading to a strong hydric deficit, even after a wet spring. The water stored after wet springs in ALADIN could potentially go through the summer months depending on the representation of hydrological processes and soil storage inertia in the models and depending on the presence of drizzle effect during the early summer. To illustrate that, we performed two simulations of the GR5H model on catchment Y4615020 for the period March to December 2006. The two simulations consist of the same model with different initial states as of 1st March 2006: one with average amount of water in the model storages, one with high levels of water in the initial storages, to illustrate a wet bias during spring. Figure 3 presents the simulated discharge over March to December 2006. Logically, the model with high storage levels for the initial state presents higher simulated flows for the first time steps. However, what is interesting is that even after the dry summer period, where simulated discharges are very close for both models, we see that during the first autumn floods the model with the high storage levels on 1st March still presents higher simulated discharges. This is well visible on Figure 4. Although presented here as a fictive case, this illustrates that summer, even in the Mediterranean area, does not necessarily reset the hydric states in the model. It therefore makes our hypothesis plausible.

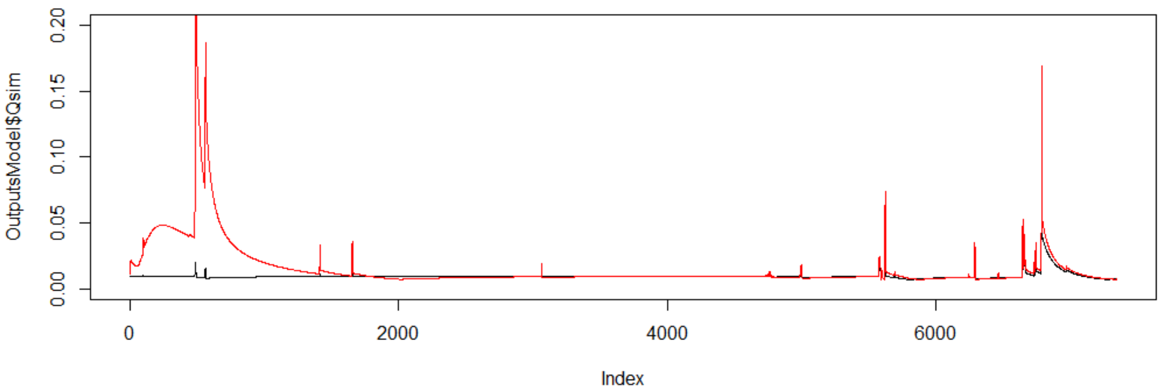

Figure 3: Simulated discharge for the same model with high (red) or normal (black) initial states as of 1st March 2006 (first time step of the model).

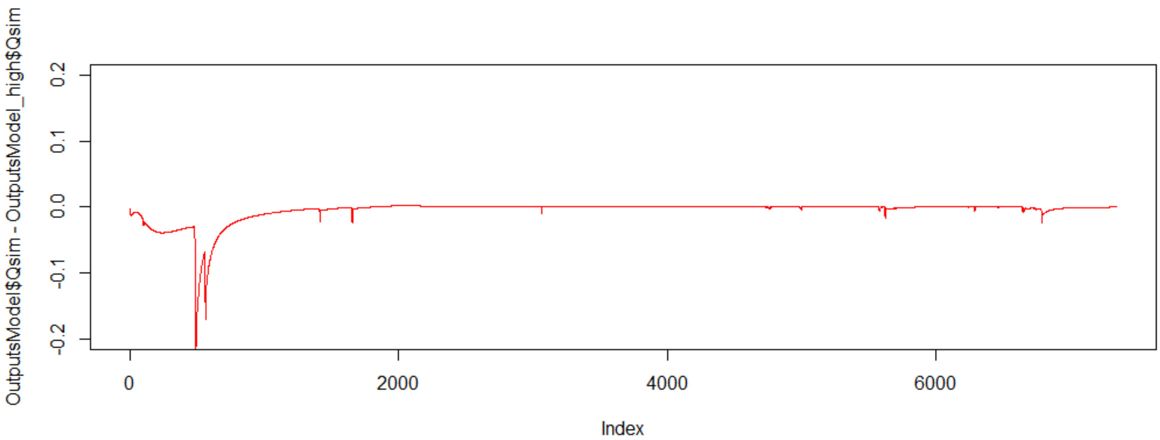

Figure 4 : Difference between the simulated discharge of the normally initialised model and the highly initialised model

Figure 3. Being COMEPHORE an analysis, it very likely underestimates actual precipitation peaks. Despite that, none of the two models reach its extremes. Can you comment on that and the implications for the projected scenarios and the derived hydrological conclusions?

Indeed, the first paper (Tabary et al., 2012) describing COMEPHORE concluded that COMEPHORE has a tendency of underestimating some extreme values. However, the river basin is located in a region with many radars and weather stations and that COMEPHORE has been improved over time (Caillaud et al., 2021). Extreme events are by definition rare and it is possible that for the short simulated periods, the CPM and RCM cannot reproduce the most extreme observed events, even though the observed extreme are likely underestimated. It is also known that despite the added value of CPM in simulating precipitation extremes, such models still underestimate the most extreme events. We will clarify these aspects in the revised manuscript. Concerning hydrological implications, it is not as straightforward. Observed discharges could be biased too, especially during the highest floods, because of gauging difficulties and uncertainties related to the rating curve. We cannot quantify the importance of the COMEPHORE biases for future flood projections, but they are very likely to be minor compared to the biases of the river discharge that are partly compensated through the calibration of the hydrological model parameters.

555-558 After asking the reader to keep in mind an aspect, the authors are expected to make an important statement that requires to keep that in mind. What is it here?

This aspect is recalled in the following lines: “some of the parameters of CREST are fixed and the ones of GR5H are free”.

Figure 6. The bias corrected results show that AROME underestimates Flood Peak Discharges more than ALADIN. Doesn’t that tell opposite messages than the main point of the paper?

On Figure 6 of the manuscript, the reference dataset is not the observation, but the green curve where the different hydrological models have been forced by COMEPHORE. A sentence will be added to explain that l598 : “The green line on the figure represents the hydrological simulations forced by the COMEPHORE observed precipitation dataset that has been used for the calibration and could be considered as the reference simulation”.

For GR5H, after correction, both distributions are quite similar even if the shape of the AROME CDF(red one) is closer to to the green one (less concave).

For CREST, the ALADIN curve tends to overestimate a bit between quantiles 0.6 to 0.8 and the AROME curve tends to underestimate the same quantiles.

Furthermore, the main point of the paper is the comparison between AROME and ALADIN under future projections.

1. **Can you provide a better section title?**

We can propose : “Hydrological models evaluation”

2. **“determine how the flood distribution will evolve in the future” This statement is way too pretentious. I don’t think we currently have tools that can do that. At most, current tools generate projection, but not outputs that “will” occur.**

We agree with the reviewer. We will rephrase it to: “This section aims to provide an overview of the flood signal suggested by future climate projections and whether this projected evolution…”

643-645. This is a caption for Figure 7. Avoid using this type of sentence in the argumentation text throughout the results section.

Indeed, it will be changed to “We now analyze the flood distributions coming only from the hydrological models forced with the AROME and ALADIN climate simulations under the historical and the future RCP 8.5 scenario (Figure 7).”

744-745. Idem.

Ok. Changed to : “Then, we analyzed the flood and associated rainfall events characteristics (figure 8) simulated by historical and future bias-corrected climate simulations”.

795 if→ whether

Ok.

797-801 These two sentences seem to state contradictory messages. “Until now” “regional models … cannot” and “In the last 10 years …CPM”. Are regional models that now allow (…) or CPMs?

CPM are a type of Regional Climate Models, we can specify it in the sentence.

- **Despite the last paragraph of the conclusions section mentions the lack of attention to uncertainties, previous parts of the text attributes predictive capacity to the set of experiments done. For instance, the 3rd paragraph of the conclusions present results of the experiments with 2080-2099 data as “future” predictions.**
- **The use of the label “future” to describe results is excessive, provided the lack of robustness of the single projection used. I recommend using “projection” and avoid presenting the scenarios calculated as an interesting outcome of the work, provided that not uncertainty analysis is done.**

Thank you for your comment. We will remove the label “future” to make these statements less predictive.

Comment to the reviewers and editor

Since the submission of the paper, a problem has been identified in the AROME future simulations. As mentioned by Caillaud et al. (2023) : “For CNRM-AROME41t1, a bug was recently found in the GHG concentrations : they evolve, but do not completely follow the RCP8.5 scenario.”
The impact on temperature change has been tested and is marginal since the RCM emissions and temperature are correct and the lateral boundaries forcing takes over from internal CPM forcing.
This issue will be revealed in a coming note.

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