We are pleased to send you the final version of our manuscript. We have taken into account the last comments and suggestions of Referee #4 and Referee #1. Our responses are detailed below.

Response to Anonymous Referee #4

I really appreciated the careful revision of the paper made by the authors. The responses to the reviewers' comments are very complete. Substantial modifications were made to the paper that, in my opinion, improve it a lot and highlight the very interesting methodology and results about producing relevant weather data in a large mountain catchment.

We thank Referee #4 for his/her very positive feedback.

I still have some minor comments.

L 76: « low flow and flood activities »: I know that this is defined later in the text, but it would be really nice to reformulate of provide a brief definition here so the reader knows what it is about (maybe « low flow and flood occurrence » ?)

At the end of the sentence, we added the following text in brackets: « (rate of occurrence of flood/low flow discharges above/below a given threshold) »

Fig 1: Something is still not clear on the bottom map. The locations of the gauging stations / hydro network do not match with the boundaries of the subcatchments (Viège, Taninges); it makes understanding the text difficult at several places (e.g. L 205; L 219-220; L 360-366; ...)

We agree that the locations of Viège and Taninges suggest some discrepancy with the sub-basin boundaries, but both locations are well located on the hydrographic network and match with the boundaries of sub-basins 2 and 14. For reasons of clarity, we have only shown the main hydrographic network of the Rhône River and its main tributaries on the map at the bottom of Fig. 1. The complete hydrographic network is, however, visible on the map at the top of Fig. 1.

L 96-98: Do you really need to refer to French meteorological jargon « retour d'Est »; « Binn-Simplon » ? This is not used in the rest of the text, and the description of the typical precipitation patterns you provided is enough and much more understandable for an international audience.

We agree that this is likely not of capital importance to an international audience, but both situations are well known to French and Swiss scientists and operational partners. We have kept these references in brackets in the text.

L 120: Maybe you could provide a short list of the variables that can be found in the ERA-20C reanalysis (for those who are not familiar with this type of data).

We have extended the sentence to: « This reanalysis provides 6-hourly data over the 1900-2010 period at a 1.25° spatial resolution for a number of atmospheric variables (e.g. geopotential height, wind speed, temperature and humidity of air masses). »

L 145: Indicate here that the choice of Thiessen method is discussed further (section 6.4)

Thank you for this comment. We will add this sentence.

« The choice of the Thiessen's weighting method is discussed in Sect. 6.4. »

Section 4.2.2: calibration method: The authors argued that the calibration methodology presented here is original (to deal with influence obs data) and therefore should be kept in the main text of the paper. I agree, but in that case the originality of this methodology should be highlighted. Maybe not in the main objectives in the paper, but in the conclusion and abstract, as a secondary (yet very interesting) result.

Thank you for this suggestion. We slightly modified the conclusion to mention this point. It now reads as follows:

« The originality of this study is fourfold. i) We evaluated the modeling chains in contrasting and demanding hydro-meteorological configurations where the interplay between weather variables, both in space and time, is determinant. ii) The spatio-temporal relevance of the weather scenarios is assessed by their hydrological responses, simulated using an ad hoc hydrological model at several gauging stations. iii) The simulations cover the entire 20th century, a period long enough to assess the ability of the modeling chains to reproduce daily variations in observed discharges, low frequency events, and variations in low flow and flood activities. iv) For both downscaling models, we evaluated the need for additional bias correction of the weather scenarios, including that of temperature lapse rates.

This framework allowed to highlight important criteria to be met for the simulation of relevant hydrological scenarios for the Upper Rhône River catchment. The alpine configuration of the Upper Rhône River catchment (unknown effects of the large upstream dams and of the regulation of Lake Geneva, scarcity of concomitant weather/discharges observations) made the calibration of the hydrological model rather difficult. This required the development of an original multiple calibration strategy, based on both observed discharge time series and hydrological signatures.

For both modeling chains, given this difficult modeling context and the fact that the weather scenarios are only produced from large-scale atmospheric information, the simulated discharges are globally in good agreement with the reference ones. »

L 219-220 : not clear. Rephrase « the four URR sub-basins that present a natural regime »

Ok, rephrased.

« To assess this, we recalibrated the parameters of the four URR sub-basins that present a natural (or at least not significantly altered) hydrological regime, using only the hydrological signatures. »

5.3: reformulate the title to match the changes that were made to the text. e.g. « low frequency hydrological events »? + following sentence « with simulations of low frequency hydrological events, i.e. low flow sequences and annual discharge maxima used as flood proxy indicators »

Title: « Flood events and low flow sequences » was rephrased to: « Floods and low flows »

The sentence « The hydrological relevance of simulated weather scenarios is further evaluated with simulations of low flow sequences and flood events. Note that the annual discharge maxima are used as flood proxy indicators. » was changed for:

« The hydrological relevance of simulated weather scenarios is further evaluated with simulations of floods and low flows. Note that the annual daily discharge maxima are used as flood proxy indicators and that the annual monthly discharge minima are used as low flows proxy indicators ».

Figure 11. « Scatter plots of mean monthly discharges, low flows and annual discharge maxima at … » was changed for: Figure 11. « Scatter plots of mean monthly discharges, annual monthly discharge minima and annual daily discharge maxima at … »

L 455: Define of reformulate « flood and low flow activities »

The terms « flood and low flow activities » are explained in more detail a few lines later in the text (from line 465).

6.3: The discussion about Thiessen's method would match better in this section + reformulate a more general and understandable title such as « Estimation of precipitation from observations ».

Thank you for this comment. In a former version, we first presented the discussion of the Thiessen's method in this section, but this added noise to the main message we wanted to highlight (the issue of the precipitation lapse rate and its effect on simulations).

The lapse rate issue would be the same whatever the spatialisation method. On the other hand, the issue of the spatialisation method refers to the modeling problems that can be encountered in hydrological modeling. This why we have finally chosen to discuss the choice of the Thiessen's method in Sect. 6.4.

6.4: I don't understand the title. Hydrological model limitations ?

The title refers to the key message of this section. Whatever the limitations of the hydrological model, it is important to make an impact-oriented evaluation of weather scenarios. Here, the evaluation of the hydrological scenarios obtained from the generated weather scenarios allowed to highlight some important issues that we could have missed with an evaluation of weather scenarios only.

We have changed the title for:

« The hydrological model: a powerful assessment tool despite its limitations »

Response to Anonymous Referee #1

I would like to thank the authors for considering my initial comments. All my major concerns (including formulation of the novelty and process-based interpretation of results) have been adequately addressed. Finally, I have only few minor comments, which might be considered before final publication. The manuscript presents a complex and robust analysis, congratulations to it!

We thank Referee #1 for his/her very positive feedback.

Minor comments

1) Abstract: « The low frequency hydrological situations, such as low flow sequences and annual discharge maxima (used as flood proxy indicators) are reasonably well reproduced. … The results for low flow activity are less satisfactory. » This is not clear. What is the meaning of reasonably well and less satisfactory? Some quantification here will be useful. Perhaps replace also low frequency situations with extreme hydrological situations (to reduce the word low used in different contexts).

Thanks for these suggestions. We will change the text for:

« The low frequency hydrological situations, such as annual monthly discharge minima (used as low flows proxy indicators) and annual daily discharge maxima (used as flood proxy indicators) are reasonably well reproduced. The observed increase in flood activity over the last century is also rather well reproduced. The observed low flow activity is conversely overestimated, and its variations from one sub-period to another are only partially reproduced. »

2) Flood and low flow activities. The definitions of these « activities » are rather unusual, so difficult to assess their interpretations or compare it with other modeling evaluations. The word « activity » is a bit confusing in that context. What about to compare the distributions of annual Q95 (as a low flow index) and Q5 (as a high flow index)?

We agree that different definitions are possible for « flood and low flow activities ».

As mentioned in our conclusion, the follow-up to our work (see Legrand, 2024) is to force the SCAMP/GSM-SOCONT chain with a CMIP6-PMIP4 paleosimulation ensemble (Jungclaus et al., 2017; Kageyama et al., 2018) to assess the variations in hydro-meteorological regimes of the Upper Rhône River catchment over the last millenium and to confront the simulated variations in flood activity with those obtained in previous works from the sediments archives of Lake Bourget (Jenny et al., 2014; Evin et al., 2019; Wilhelm et al., 2022).

We defined « flood activity » similarly to what is often done in paleohydrology (cf. Vasskog et al., 2011; Ballesteros-Cánovas et al., 2015; Wilhelm et al., 2022), which refers to the frequency of occurrence of flood events. In most paleohydrological studies, flood events are identified from paleoenvironmental archives from tree rings, lacustrine or channel sediments. Here, floods are identified from discharges (observed or simulated) that exceed a given threshold.

For the sake of consistency, the low flow activity was defined in a symmetrical way.

3) Discussion. Please add some discussion about the impact/uncertainty of the objective function used for model calibration. Estimation of low flows and their changes (and scenarios) might be significantly impacted by the way hydrologic model is calibrated. Perhaps you learned some experience during preparation of presented results.

We added the following sentences:

The signature-based calibration of the model, used for sub-basins with altered discharge data, is also not optimal. « The objective function considered for the calibration, for instance, gives considerable weight to the statistical distribution of annual daily discharge maxima. Other results may be obtained adding criteria for low flows (e.g. distribution of annual monthly discharge minima). This will be worth further investigations. On the other hand », parameters were calibrated so that simulated signatures reproduce at best observed ones, but observed and simulated signatures come from different periods.

References

Legrand, C.: Simulation des variations de débits et de l'activité de crue du Rhône amont à partir de l'information atmosphérique de grande échelle sur le dernier siècle et le dernier millénaire, Thèse de doctorat, Université Grenoble Alpes, France, 2024.

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