Reviewer #3

Climatology and trends of observed daily and hourly extreme precipitation in the French Alps
Authors: Sebastian Berghald, Juliette Blanchet, Antoine Blanc, and David Penot
Recommendation: major revision

The study of Berghald et al. describes the development of extreme precipitation in the French Alps since 1970 based on an analysis of daily and hourly station data using extreme value statistics. A better understanding of changes in extreme precipitation worldwide is of general interest, yet current knowledge is insufficient. Therefore, this study is well suited for HESS. The study follows a well-described methodological approach and describes changes for the study area. However, I see some necessary improvements to be done before the paper can be accepted.

Thank you for your detailed comments! We greatly appreciate the time and effort you put into reviewing our paper and the constructive feedback. Please find our answers below in blue.

Major comments:

One main problem is that the analyses are not very in-depth, which gives the impression of a technical report. This is evident from the figures presented, the analyses performed and the conclusions drawn. The paper frequently points out that the results of this study are confirmed by other studies. While it is important to demonstrate agreement/disagreement, this cannot be the ultimate goal; rather, the current work must achieve new results. This should be made much clearer in the text which results go beyond those of other studies. While the authors correctly state that their study is the first on trends in extreme hourly precipitation for Alpine region, at the same time they miss to include some relevant recent papers on extreme hourly precipitation (in particular Zeder and Fischer, 2020 and Zeder and Fischer, 2024, see the list at the end of the paper) which are relevant for the study region as well.
Thank you for making us aware of these references, we will include them in the manuscript. We will also make sure to highlight the novelties of our study more.

A useful extension to the work presented could be to visualize the station time series used in the analyses (e.g. the 67 series used in the trend analysis). I fully understand the authors' motivation not to interpret individual time series, due to the risk of misinterpretation. However, visualizing the time series would give readers a better understanding of changes over time, as well as providing an impression of the length of the time series and the data gaps.
Thank you for this suggestion. Unfortunately, as the dataset provided by EDF is not publicly available, we cannot show individual time series.

Another question concerns the homogeneity of the time series used. Extreme values are particularly prone to inhomogeneity. While there are currently no usable methods for homogenising hourly values, but homogenisation methods are already available for daily values

(see e.g. Mestre et al., 2013). These methods are not without their weakness, but at least they indicate breaks that are/are not present in the series, an important information that should be possible to obtain using existing break detection methods. Even if no homogenisation has been carried out, this should be mentioned and with an explanation as to why this was not done.

Regarding homogeneity, as you say this is difficult for hourly time series, especially in the case of annual (or monthly, seasonal) maxima because of the small number of values. During preliminary analysis we did a simple test, looking at the season in which the annual maximum falls for each year, see figures below. Only one station (C2430) failed this test due to a dubiously high amount of hourly maxima falling in the winter season before 1985. We will mention this in the revised version of the manuscript.

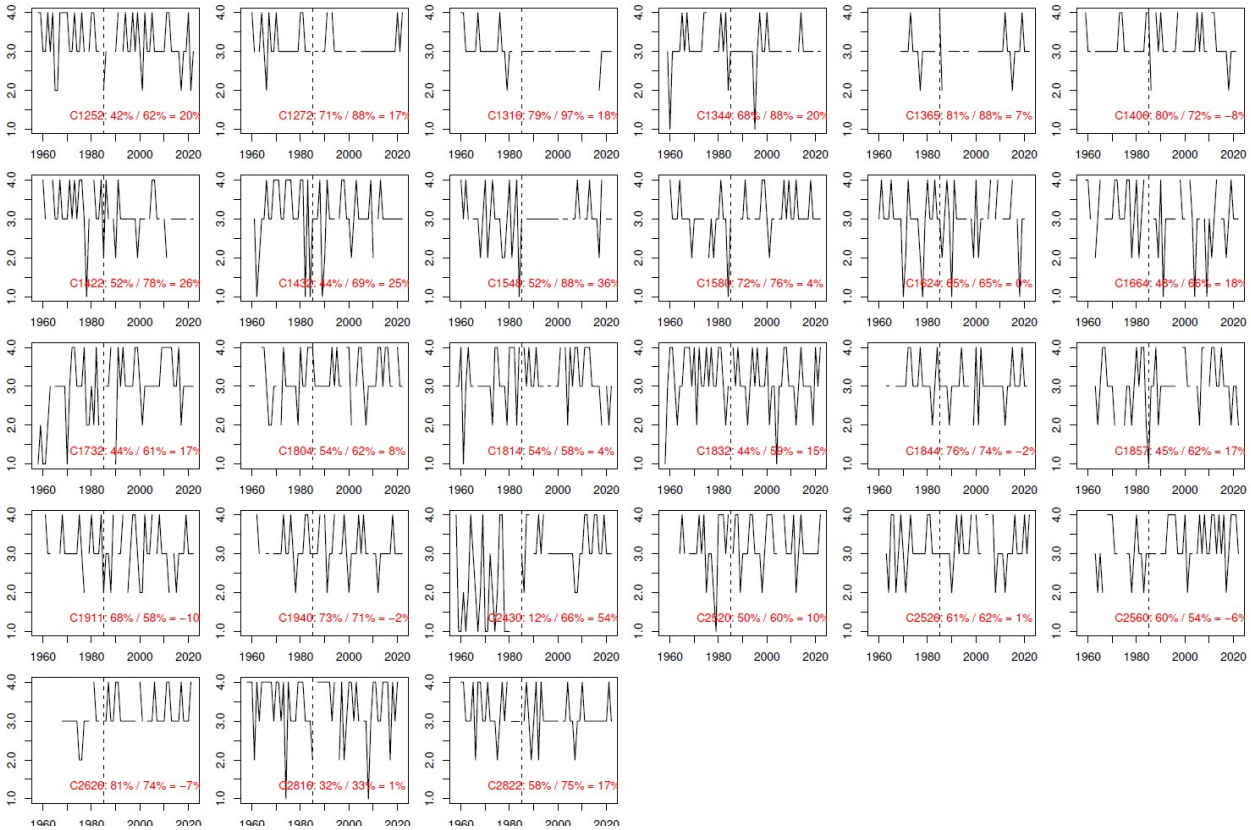
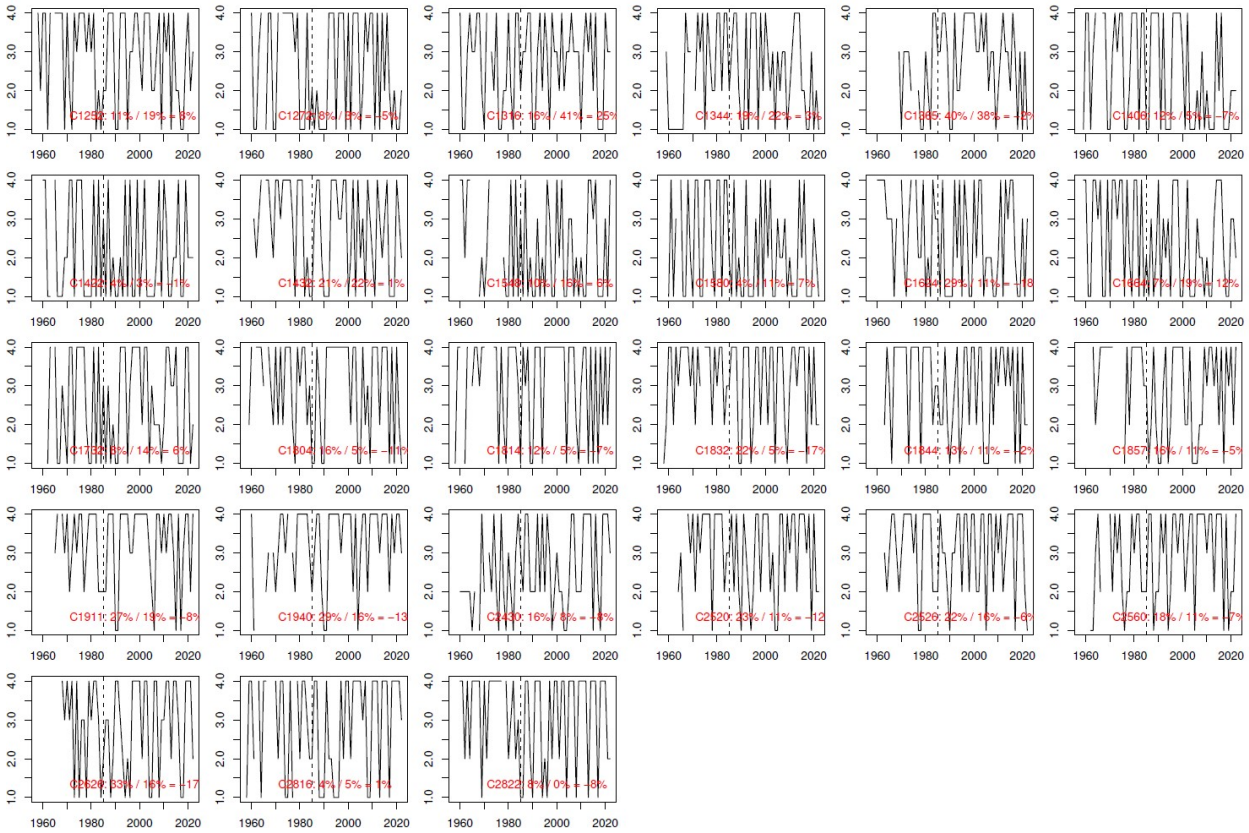


Figure showing for each year the season of the annual maximum of hourly precipitation (1=DJF, 2=MAM, 3=JJA, 4=SON). The red number gives the relative amount of maxima falling in the summer season before and after 1985 (dashed vertical line). A strong difference is found for station C2430, which lead to discard this time series.



Same as above, but for maxima of daily precipitation.

I also see potential risk of a bias being introduced by the neighbourhood approach used, as stations at the margins of the study area have fewer or no neighbours within the specified search radius. Consequently, stations in the center of the study area are therefore used much more frequently for adjusting the frequency distribution parameters.
We share the concern that as a consequence of the neighbourhood approach the results are less robust for stations at the margin of the study area. We will highlight this aspect in the manuscript to avoid possible misinterpretations.

For regionalization of subregions (North and South of Alpine main divide) the border defined in the HISTALP data set is used (which is on a much larger region). It should be discussed in the paper if such divide is really the best choice in order to show +- robust subregions with similar extreme precipitation climatology. The main divide of the Alps must not be the relevant border for precipitation extremes.
Regarding the climatological boundary, we actually use the more detailed boundary of Blanchard (1921), which coincides with roughly with the HISTALP boundary of Auer et al (2007). In our study, we use this divide purely as a guide for interpretation. In our opinion, the relevant border for precipitation extremes can best be seen by the influence of the different weather patterns (Fig. 8). While these influences change spatially over the year, the boundary between Mediterranean and Atlantic influence actually coincides quite well with the line of Blanchard (1921) and Auer (2007).

As indicated above, another shortcoming of the work is that some of the figures presented (figures 5 to 12, which are the key figures of the study) are of low quality, both in terms of content and layout (differentiation of the values shown). Probably, some of the trend/climatology figures (maps) for individual month could be moved to the appendix and only the relevant one for interpretation could be kept in the main paper and increased in size and cartographic quality (figures 5, 8,, 9, 10, 12). Figure 11 serve as the basis for relevant interpretation and discussion in the paper but miss the information on significance of shown trends. This information could be added by bars showing the number of significant/non-significant series per box-plot. Generally, all figures have rather sparse description which should be extended to full information available in order to make understanding easy for the reader.
In response also to the comments by Reviewer #1 and #2, we will make some changes to our figures:

- We will remove the differentiation between traditional (DJF, MAM…) and new (JFM, AMJ…) from the whole manuscript and use only the new seasons for both stationary and non-stationary analysis.
- In Figs. 10 and 12, we will increase the size of the triangles (significant trends) and decrease the size of the round points (non-significant trends) to better highlight visually where the trends are significant.
- In Fig. 11, we will add the information on the relative amount of stations with significant trends for the respective months.
- We will extend the figure captions to provide more information to the reader.

Minor comments:

Language: could be improved (e.g. repeating “However” etc. should be avoided), though the paper is generally very well to understand.
Title: I suggest to use a more informative title (which also would avoid the impression of technical report)
Abstract: Add some information to make the presented results of statistics data comprehensible. Otherwise the pure statistical results give impression of randomness. There is the result/indication of thermodynamic vs. weather pattern driven changes in the precipitation extremes, which could clearly go into the abstract as well. Distill your results carefully.
Thank you for your suggestions, we will reformulate the abstract and take them into account. After discussion with all co-authors, we prefer to keep the title as it is.

Introduction: (tried not to repeat comments from other reviewers)
Thank you for your detailed corrections, we will include them in our manuscript.

75: Unfortunately, there is no consensual definition of what characterises an ’extreme’.

ok.

79: More precisely, we here define extremes as 20-year return levels. Can the authors give a motivation for exactly using this definition of extreme precipitation?

As explained in the manuscript, we define an 'extreme event' as an event that occurs only rarely in a human's lifetime (as opposed to, for example, the 99th percentile which by definition occurs about three times a year). Of course, the choice of the exact return level to analyse is somewhat arbitrary but, at least in our opinion, also secondary.

85/90: large-scale circulation better to write: "weather patterns" or "synoptic patterns"

ok.

90-92: …. large-scale circulation patterns while short-duration high-intensity rainfall seems to be much closer correlated to air temperature through increased moisture holding capacity and increased energy available for convection (see also Giorgi et al., 2016). clarify by writing … much closer correlated to air temperature through dependency of moisture holding capacity and energy available for convection on air temperature.

ok.

93-95: … Barbero et al. (2017) found overall lower significance and temperature sensitivity of annual/seasonal maximum precipitation of hourly compared to daily precipitation over the contiguous United States,…. Improve (significance of what?, what is mean with "contiguous US")

Thank you, we will improve this sentence.

99-100: Only now are observational time series becoming long enough to attempt an analysis of extreme precipitation trends on an hourly timescale … this is bit misleading (if thought as general statement and not only for France) as the main challenge hasn't been series length but the data to be digitized. There are many data on precipitation at time scale of e.g. 10 minutes in data archives of weather services which are still not digitized going back to 1950 and earlier.

Thank you for this important remark, we will include this in the manuscript.

104 and throughout the ms: do not mix up rainfall and precipitation

We will replace 'rainfall' by 'precipitation' throughout the manuscript.

113-115: not really correct the study "get an overview over the weather patterns behind high-intensity precipitation in the region. " This would need much more meteorological information.

Thank you for this remark, we will replace 'overview' by 'idea'.

139-140: The Northern Alps, under Atlantic influence, are among the rainiest regions in France with a mean precipitation of 1172 mm/year …. Would be good to describe the rainiest region with highest values within the region (1172mm is not that much compared to other regions in the Alps where values above 3500mm/year have been measured).

Thank you for this remark, we will provide more detailed information.

147: can you specify the “East Return” e.g. by reference.

ok.

161: What means “large-scale automatisation”?

The replacement of human weather observers by automatic weather stations across the whole network of MétéoFrance. We will clarify this.

161-162: “continuous precipitation observation”: they are not continuous but has some sampling interval (e.g. 10 minutes), which would be interesting to know, e.g. how are hourly precipitation values derived from precipitation values of highest temporal resolution? (for both Meteo-France and EDF).

As tipping gauges are used for these measurements the observations per se are continuous down to a resolution of typically 0.2mm. The registration intervals are then sums over 6 minutes for MétéoFrance stations and sums over 1 hour for EDF stations. For MétéoFrance, the 1-hour sum is the sum over all 6-min intervals in a given hour. We will clarify this.

171: observations are not continuous for snow, runoff and precip (have some time resolution) Numbers of stations in section 2 of the paper are bit confusing. Would be very useful to get information on how precipitation were measured from the begin of the temporally high resolution measurements until today. Are always values of hourly and daily precipitation from the same sensors? (in some countries this could be different)

Thank you for this remark. To the best of our knowledge the hourly and daily values have always been measured with the same sensor for both Météo-France and EDF stations, and these are tipping gauge sensors with a resolution of typically 0.2mm. It should be kept in mind that in the case of EDF stations only the daily values are routinely controlled for spurious values, and also that the individual measurement devices have changed over time.

Data: Section: Please pProvide a table showing the data used in the study providing/summarizing some meta-information (e.g. length, missing data, relocations if known, ...) and help the reader to distinguish the different data sets used in the analyses part.

Thank you for this suggestion. In answer also to Rev1 and Rev2 we will completely restructure this part and remove known inconsistencies in the text and the figures. Following your suggestion, we will also update the table in the appendix of Berghald (2024, https://dumas.ccsd.cnrs.fr/dumas-04723319v1 and provide it as supplementary material to the manuscript.

215: Do not mix up “weather pattern” and “circulation pattern”

ok.

216: Do not use “circulation mode over the Alps”, e.g. use “flow condition/pattern over the Alps” or “weather patterns over the Alps” (dependent on what should be explained)

ok.

223: make your grouping of WPs visible in Fig. 2 from the colors used for the time series (similar colors for same group)

In response to Rev1 we will remove the right side of Fig. 2 (the timeseries). For the left side (the arrows) we will make sure to align the colours with Fig. 7 and 8.

242: I guess it is meant that “The quantiles of the distribution can now be obtained by transforming Eq. 1 or 2”

ok.

3.1.2 Non stationary GEV using a breakpoint in 1985: this is bit weak, as series could have other breakpoints as well and this was not tested in any way. So would be good to give more motivation for the selection of 1985.

In this paragraph, we provide our different reasons motivating the choice of this specific breakpoint, including the findings of previous studies (e.g. Blanchet et al., 2016), considerations regarding data availability as well as our best knowledge of changes in the instrumentation.

302: We then turn to the trends in extreme intensities. Be more precise by saying “trends in 20-years return levels”.

ok.

Throughout the paper (and particular chapter 4) authors should be precise and clear describing the synoptic drivers from weather patterns. They shouldn’t use the terms Atlantic and Mediterranean circulation, which are misleading (see also my previous comment). Use the terms from the Garavaglia (which are not very well suited as well, in my opinion, but at least published). For the paper air flow against the Alps is the key interest from the weather patterns, so focus should be given to this.

Thank you for your comment. We will make sure to talk about flow directions instead of circulations. We would, however, like to note that our study is to a large extent a follow up on previous studies by Blanchet et al (2021a, https://doi.org/10.1016/j.wace.2021.100356) and Blanchet et al (2021b, https://doi.org/10.1088/1748-9326/abb5cd) where the terms Atlantic and Mediterranean circulation have been employed.

320: “Mediterranean dominance” replace by something like “Mediterranean impact”

Ok.

322: Why is anticyclonic influence associated with convective events (which should be more related to gradient weak weather patterns)? In fact this goes already into the discussion part.

Thank you for this remark. We here mainly mean local convective events linked to the daily temperature cycle (typically highly localised thunderstorms at the end of a summer day) which occur primarily in anticyclonic conditions. We do, however, acknowledge that convective events are per se not limited to anticyclonic conditions, and will reformulate this accordingly.,

334: incomplete sentence

The sentence seems complete to us.

335-336: not clear what is meant

This refers to the comparison of results between the recent dataset (since 1980s, EDF and MétéoFrance) on the one side and the long time series only (the EDF time series we base the trend analysis on) on the other side. The EDF network is more spatially confined and does not cover the areas where the estimated 20-year return values are highest, which is in the Rhône valley and along the Mediterranean coast. We will clarify this in the manuscript.

343: … not exact the same regions … be more specific (it probably means that there are less stations per region included?)

See our comment above. We will clarify this.

387: again here, authors should be more precise in the discussion. If there results are confirmed by previous studies the question arises, what is new in the presented paper. In fact they could show confirmation of their results for the daily precipitation extremes with previous studies, but not for the hourly values (as this is new, as stated in the introduction).

For the discussion in 5.2 and 5.3 it would be useful to take into account which month of the year (in which region) are particularly relevant from stakeholder's perspective, as known to have precipitation events resulting in flood events. This could maybe show that those months with significant trends are also those known as risky from the stakeholder's perspective.

Thank you for these suggestions, we will include them in the discussion.

395-399: speculating on using temperature as estimator for parameter distribution leads to question why not giving it a try or at least showing the temperature evolution for the study region to get some feeling if it could work.
Thank you for this remark, which was also raised by Rev2. As we explain in more detail in the reply to Rev2's comment, there are homogenised time series of annual mean temperatures for some selected reference stations available online (https://meteofrance.com/climathd). While providing just anecdotal evidence, these time series show roughly linear trends since the mid-1980s (e.g. Grande-Chartreuse in Rhône-Alpes and Embrun in Provence-Alpes-Côte d'Azur). We will include a reference in our manuscript.

440: give more details on findings from Fukutome et al. (2015) here, if this could be useful for your results.

ok.

447-448: Overall, the southern part in the study region experience much stronger trends …. How does this fit to Figure 11 for hourly data?

As can be seen in Fig. 11, for most of the months and seasons, both positive and negative trends tend to be higher (in absolute terms) in the south compared to the north of the study region. We will reformulate this to make it clearer.

450: what is meant with “large scale circulations patterns”?

We will replace this by ‘weather patterns’ (the ones we use in this study).

454: We thus partly attribute this …. make clear that this is speculation, as you have no prove for really attributing it.

ok.

459: ...is never much lower than zero .. I guess it should read is close to zero

ok.

468: .. with an increase with increasing temperature …. Rephrase

ok.

474: Make clear that Georgi et al (2016) is result from model simulation and explain in more details, otherwise is hard to understand for the reader.

Thanks for this remark, we will include this.

477-479: again here (and mentioned earlier), would important to know the time resolution of precipitation sensors used by EDF and Meteo France

See our answer to your previous comment, we will also include this information here.

498: Regarding the spatial and temporal of extremes, … word is missing here.

‘evolution’, we will add it.

499-500: more precision is needed here “hourly extremes” and add the word “precipitation” to make it easier for the reader.

Thank you, we will be more precise.

501-502: I do not understand this sentence “While the general spatial and seasonal patterns confirm previous studies, our main contribution here lies in updating previous estimates of hourly extremes based on surface observations”. This is not what is described at the beginning of the paper.

Thank you for pointing this out, we will reformulate and clarify this.

501-505: this is not something for the conclusions → should be delete here

Thank you, we will remove this.

509: trend in June needs to be introduced earlier as well

We will highlight this in the results and discussion.

511: you need to explain the “decoupling”. How could/should this work in a physical sense?
Thank you for this remark, we acknowledge that there are better ways to describe this. We will follow the suggestion of Rev2 and clarify this to “An explanation of why summer daily extremes seem to become weaker while hourly ones become stronger, could be that a general drying of the region takes place in summer, limiting the overall potential for intensive precipitation over a longer time scale. At the same time, higher potential energy as a result of a temperature increase may lead to an increase in occurrence and/or intensity of short-duration convective precipitation events.”

Generally, the conclusions part is still a bit weak and should be improved. There is clear potential for doing so.

Thank you for your remark, we will reformulate the conclusions and elaborate more on the implications of our findings.

References:

Jiang, R., X. Cui, J. Lin, and J. Tian, 2023: 40-Year Statistics of Warm-Season Extreme Hourly Precipitation over Southwest China. J. Appl. Meteor. Climatol., 62, 1891–1908, https://doi.org/10.1175/JAMC-D-23-0018.1.

Zeder E. and M. Fischer. 2020. Observed extreme precipitation trends and scaling in Central Europe.Weather and Climate Extremes, Volume 29, September 2020, 100266, https://doi.org/10.1016/j.wace.2020.100266

Zeder E. and M. Fischer. 2024. Decadal to centennial extreme precipitation disaster gaps — Long-term variability and implications for extreme value modelling, Weather and Climate Extremes, Volume 29, September 2024, 100636, https://doi.org/10.1016/j.wace.2023.100636