

Review Response

HESS-egusphere-2025-3073

Reviewer #1

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: acceptable after major revision.

Theme

This paper analyses time series of monthly, seasonal, and yearly maxima of daily and hourly precipitation at observation stations in the French Alps using methods based on extreme value theory. Their purpose is twofold: firstly to provide a climatology of extremes in the region, where extremes are defined as 20-year return levels, and secondly to examine the change in these return levels between 1985 and 2022.

For the climatology of extremes, the time series are assumed to be stationary over the years, and a Generalized Extreme Value (GEV) distribution is fitted to each time series. Seasonal non-stationarity is addressed either by analysing the series month by month, or season by season. An annual analysis is also provided for comparison. They determine the circulation patterns involved in producing the largest daily precipitation events. For the trend analysis, the location or the scale parameters of the GEV, or both, are assumed to depend linearly on the year. The paper does not say which of the three models is retained at which station. A known inhomogeneity in the dataset is addressed by introducing a break in the parameters in 1985.

The results reveal a different seasonal cycle for daily and hourly extremes, and, for daily extremes, a different seasonal cycle of the relative contributions of the main circulation patterns in the north and in the south of the French Alps. Thanks to the relatively large number of stations with significant trends for daily extremes, the authors can plausibly speculate on thermodynamic or dynamic changes that might be at the origin of the trends. For hourly extremes, the arguments are more tenuous, as they sometimes depend on a large number of stations for which the trends are not significant. The reasons for the seasonal and spatial variability in significance are not discussed. The paper is well structured and well written, although it is a little tedious to flip or scroll through so many pages to compare the text with the figures. The information presented is valuable, and the interpretation of the results can invite interesting further investigation. If the comments below can be addressed, I consider the present study suitable for publication in HESS.

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

Major Comment 1

The seasonal non-stationarity of the time series is evident in Fig. 6, especially for hourly precipitation, but also for daily precipitation south of the climatological divide. In fact, the seasonal non-stationarity for hourly extremes by far exceeds the trend over the years. For daily precipitation, the assumption of seasonal stationarity is plausible in the north, but is violated in the south.

The authors painstakingly analyze the extremes month by month. I recommend that for the seasonal and yearly analyses, the return levels be numerically derived based on the monthly GEV distributions. While this represents quite an effort, I believe it would avoid introducing a bias in the results, and their subsequent interpretation would be more trustworthy.

Thank you for pointing out the relevance of comparing trends to the seasonal non-stationarity, we will include this aspect in the discussion of our results.

We agree that deriving seasonal and annual return levels numerically from monthly GEV distributions can help avoid potential inconsistencies. We will do this for the revised version of our manuscript.

Major Comment 2

For the trend analysis, I recommend that the authors do not include the stations for which the trend is not significant (neither in the maps, nor in the boxplots), as it suggests more information than there really is, and orients the discussion towards interpreting a change in the 20-year return levels at all stations. In point of fact, for 7 months of the year for daily extremes, and at least for 11 months of the year for hourly extremes, the majority of stations have no trend at all, if one believes the significance test. In my view, a balanced discussion should address the reasons for a non-change, as much as those for a change.

The number and location of significant stations varies considerably from month to month, especially for hourly precipitation. A short discussion would be welcome.

We understand your caution concerning possible overinterpretation of non-significant trends. Unfortunately, in extreme-value statistics, all results are by construction based on a very limited number of values. It is thus inherently difficult to obtain significance in trends. Additionally, the significance test applied here is quite restrictive, as we only consider a trend in 20-year return levels significant if the 5-95% range of the bootstrapped uncertainty interval does not contain

zero. Discarding non-significant trends altogether could therefore mean discarding valuable information.

Taking statistical significance as the only criterion also raises another problem: due to the neighbourhood approach we use here, some stations in the peripheral zone of the study region have much less neighbours, and thus data, than stations in the centre. As a consequence, the trend analysis for these stations is just based on very few values (one per year, so 30-60 overall). Here, the presence or absence of single events can largely affect both trend magnitude and statistical significance.

We therefore base our interpretation on both statistical significance and spatial coherence of trends: If a larger region shows a coherent pattern this is likely not due to pure chance, even if not all the trends in that region are statistically significant.

We do, however, acknowledge that it is visually difficult to tell significant and insignificant trends apart. Therefore, we will decrease the point size of non-significant trends for the revised manuscript. We will also add a table showing the relative share of stations with significant trends per month/season/year (or potentially add this information to Fig. 4). Where appropriate, we will also emphasize more which results (and their corresponding interpretation) are based on statistical significance, and which are more speculative.

Minor Comments

General

- The presentation of the datasets is both very detailed and somehow unclear and incomplete. Despite the authors' efforts, it is difficult to understand which data set is used for what, and which period they cover. A table would be most helpful. In particular, the reader would be interested in knowing which of the datasets used in the trend analysis contain known inhomogeneities. It is not clear.

Thank you for this observation. Also in response to Reviewer #2, we will completely restructure this section to make it clearer for the reader. As you also pointed out in the minor comments, there are some inconsistencies in the numbers of stations in the text and between text and figures. We will make sure to clear that up as well.

- Please consider merging Figs 5 and 8: the dominant weather patterns could be represented by northward and eastward looking arrowheads for the Mediterranean and Atlantic weather patterns. The reader wouldn't need to flip/scroll all these pages to get an idea which weather pattern led to the highest return levels, for instance.

We like the suggestion, but are a bit concerned that the figure might become too crowded. We will test it and include it in the revised version if it works.

- Fig.4 could be omitted or moved to the appendix, especially since its appearance is not commented in the text.

In our view it is important to point out that the robustness of trend estimates depends heavily on the number of neighbouring stations of which the observations are included. We will highlight this in the text, and move the figure to the appendix.

- The uncertainties are neither shown nor discussed. For the trend analysis in particular, it would be important to know if, for instance, a trend of 10mm/d/10y between 1990 and 2020, i.e. an increase 30mm/d, is within the uncertainties of the 20 year return level in 1990.

Our apologies if the following answer is not entirely exact, as we are not sure if we fully understand your comment. In the non-stationary case, uncertainty intervals are included as we use them to assess significance: a trend is considered significant if the 5-95% uncertainty interval does not contain zero. In the stationary analysis, we indeed chose to not show uncertainty intervals. We will, as a test, plot a figure showing if the trend over 30 years is in the confidence interval of the stationary estimate, and then assess if this adds enough value to our analysis to be included in a revised manuscript.

- Avoid “However” at the beginning of sentences. “Blablabla, however, blablabla”.
Thanks for the remark, we will modify some of the sentences in question.
- “timeseries” or “time series” : please choose one or the other.
We will make sure to use a coherent notation.

Line-by-line

In the following we only answer where necessary. Stylistic and grammatical corrections will be adopted as suggested or clarified where needed. We really appreciate your detailed suggestions, which will help improve the manuscript.

Line Number	Comment	Answer
12	What is meant by “partially large differences”?	Also in response to Reviewer #2, we will reformulate parts of the Introduction and clarify this as well.
23	“Also southeastern France was not spared from such events recently”. → “Even southeastern France was not spared”. Or “has not been”.	ok
25	“lead” → “led” (preterite)	ok
31	“are more exposed” → “are particularly exposed”? (exposed more than what?)	ok
36	“is not fixed between seasons and over time”. Are you talking about the location of the divide? How about “changes location over the seasons and over the years”?	We are indeed talking about the location.

38	“the Mediterranean influence on precipitation extremes is retreating in winter and spring (in favour of the Atlantic influence), but increasing in autumn” → “the Mediterranean influence on precipitation extremes retreats in winter and spring (in favour of the Atlantic influence), but increases in autumn”. Meaning: “retreats” suggests a change in location (towards the South), while “increases” only suggests a change in the strength of the Mediterranean influence. Please clarify.	Increase/decrease and advance/retreat actually go together in this case. We will clarify this in the revised manuscript.
39	Both thermodynamic and dynamic what? A word is missing.	processes
40	“thus complicating the topic of assessing possible trends.” → why “complicating”? The trends themselves are not “complicated” to assess. Do you mean “complicating the interpretation of possible trends”?	For clarification, we will change this to “complicating the big picture and the understanding of physical causes of trends.”
43	“that involved the analysis of a single aggregated time series of daily data from several stations in southern France” → “that involved the analysis of a single time series of daily data, aggregated from several stations in southern France”	ok
45	Shouldn't Clausius-Clapeyron be mentioned earlier where the authors talk about thermodynamic processes (line 38). Here it comes out of the blue. Why not simply: they found an increase of precipitation with temperature 1 to 3 times larger than the increase in maximum water content of an air parcel with temperature (equation of Clausius-Clapeyron)”.	ok
48	“onset of clear trends” → What does “clear trends” mean?	Significant trends.
48	“a consensus to significant trends” → “a consensus in the significance of trends”. I would even prefer “showed that, only in the 2000s did a consensus appear in the significance of trends in observations in southern France.”	ok

62	“globally this assumption seems to hold true” -> what does globally mean here? A spatial average? Or does it mean “in most cases”?	In most cases.
66	Super CC trends -> scaling rates or actual trends?	Scaling rates.
83	“generally agree on the big picture” seems like a strange statement, when the following sentence offers no “big picture”. Perhaps simply say that “Studies in the European Alps indicate that trends in daily heavy precipitation”?	ok
83-85	“Trends in daily heavy precipitation are different depending on the region and the period studied” → isn’t it normal that the trends should depend on the period studied, regardless of changes in processes?	True.
90	“much closer correlated” -> “much more closely correlated”	ok
111	“28 stations with more than 45 years, longest 70 years” → “the longest with 70 years”	ok
122-155	Very nice description!	Thank you!
180	“Only weekly maximum precipitation totals for 1h, 2h, 3h, 6h, 12h and 24h were archived and could be retrieved for our study” → are these gliding sums (for instance for 1h, every 6 minutes the sum over the last 10 * 6 minutes, or for 12 h every hour the sum over the last 12 hours, or for 24 h every hour the sum over the last 24)?	These are sums over fixed intervals. For hourly values that would be the sum over a full hour on the clock (from 10 to 11 am, for example). These old measurements were continuously registered on a paper roll, so not in fixed 6 minute intervals. We will clarify this.
183	“The dataset consists of quality-controlled daily and uncontrolled hourly observations for 68 stations” → The dataset consists of daily and hourly data at 68 stations, of which only the daily data is quality-controlled. “uncontrolled” sounds strange.	ok
184	“A quality control of the hourly data was thus necessary.” → Indicate here that you can use the	ok

	quality-controlled daily data to calibrate the hourly measurements.	
184	“For this purpose, we scale the hourly values, i.e. we multiply all hourly values of a given day by a uniform factor such that their 24-hour sum from 6am to 6am on the next day equals the corresponding daily value.” → a little unclear. Perhaps it would help to break it up. “The daily precipitation of a given day is the amount of precipitation that has accumulated in the 24 hours between 6am and 6am of the following day. Should the sum of the 24 hourly measurements within this time span differ from the daily sum, we scale the hourly values, day by day, i.e. multiply each hourly measurement by a uniform factor, such that their 24-hour sum from 6am to 6am on the next day equals the corresponding daily value”	ok
192	“were overlapping” → “overlapped”	ok
201	“Intensities” → are these mm/h? If not, please use “values” or “amounts” or “observations” or “accumulations”.	ok
208	“attributing weeks between two months” → “attributing weeks straddling two months”	ok
212	“contains 177 time series” → 89 MeteoFrance + 67 EDF?	Thank you for pointing this out. As said earlier in reply to your minor comment #1, there are some inconsistencies in the presentation of the dataset as well as between text and figures. We will clear this up for the revised version.
213	For the trend analysis, we only use the 67 time series including more than 30 years of non-missing data. → of EDF? This is very confusing.	See above.
222	Evolution of relative occurrence of each WP → never used again? Why bother? Especially if no explanation or comment is made?	Thank you, we will probably remove the right side of this figure.

224	“we first match” → is the “first” necessary?	Not necessary, we will remove it.
225	“of of”	ok
255	Which dataset are you using here? The 27 EDF stations with a combination of old and new?	We will reformulate this whole section to present and describe the data and the processing in a clearer way.
261	“for cases when all the density of maxima shifts in time” -> “when only the density of maxima shifts in time”?	The whole density function/curve, we will clarify this. See also Fig. 3 of Blanchet et al (2021): https://doi.org/10.1016/j.wace.2021.100356
265	“we adopt a bootstrap approach by resampling the series of maxima 100 times with replacement” → isn’t 100 a rather small sample?	Thank you for the remark. We will increase the number of resamples to 500.
277	“so these are simply discarded” → the stations?	We did this in a previous stage of the project, but noticed that it is actually not necessary. It is a mistake that the sentence is still in the manuscript, we will remove it.
297	“After some initial testing we decided against doing this, following Evin et al. (2016) (Sect. 7.2.3 therein)” → please provide a summarized reason.	We will include this.
319	“In the north Atlantic influence is dominant during the whole year” → “In the north, the Atlantic influence dominates during the whole year”	ok

320	“In the south there are clear differences between the seasons, with Mediterranean dominance extending far north in spring (April and May) and autumn (September and October), while in the other months Atlantic and Mediterranean circulations have roughly equal influence on maxima in this region” • “in this region” is confusing. It gives the impression we are maybe talking about something else than just “the south”. • “far north” is also confusing. “all the way to the climatological divide”? • “while in the other months Atlantic and Mediterranean circulations have roughly equal influence on maxima” → does not seem quite accurate, except if one looks at the seasonal summary. I would go about it differently, and say that “the influence of the Atlantic and Mediterranean circulation oscillate in opposition of phase, the Mediterranean circulation having the upper hand in spring (April and May) and autumn (September and October). When analyzed seasonally, the Atlantic and Mediterranean circulations lead roughly to the same percentage of maxima in winter and summer”.	Thank you!
327	“The stationary 20-year return levels of hourly precipitation are shown in Figs. 6 and 9.” I would suggest immediately bringing the reader’s attention to the seasonal cycle: “The stationary 20-year return levels of hourly precipitation reveal a seasonal cycle remarkably different from daily precipitation and across the north-south climatological divide (Figs. 6 and 9).”	ok

328	Evidently, hourly precipitation extremes are not stationary over the spring and autumn seasons. How does this affect your seasonal analyses?	This shows the added value of looking at the monthly level, which is not frequently done. Regarding the seasonal analyses, that means that the seasonal maxima are not representative of the whole season. We will clarify this in the Discussion.
335	“almost no EDF stations is located in the Rhône valley” → “almost no EDF stations are located in the Rhône valley”	ok
341	“Here we use the long time series (EDF stations >30 years)” → are these the 27 stations with the combination of old and new data?	This includes both the combined timeseries, but also the ‘new’ EDF timeseries which are long enough (many of them starting in the 1980s). We will clarify this..
341	“We now turn to the trends in extremes (20 year return levels).” → Please add “over the period 1985 – 2022” if that’s what it is.	ok
342	“in in”	ok
343	“are not for the exact same regions” → “are not for exactly the same regions”	ok
352	“positive trends in May” → how much of this could be attributed to a seasonal shift (maxes that normally would take place in June taking place in May)? The month of June experiences negative trends.	Thank you for this interesting remark! We will think about possible ways to test this and include the results if they are conclusive. We will also mention this in the discussion where we speculate about the shift of September from being an autumn month to a summer month (from the extreme precipitation standpoint).
372	“Annually, trends are centred around zero with comparatively large variability in the north and overall slightly positive in the south.” → Actually, if one only looks at the stations with a significant trend, there is virtually no variability in the north and it is inconclusive in the south.	Looking at significant trends only actually gives positive trends in the north, and in the south only two stations show a significant trend, one of which is quite peripheral and has little data. For a detailed reasoning on the use of statistical significance, we refer to our answer to your major comment #2.

411	“However, even though...” → it would be more elegant not to start the paragraph with “However”. “It is interesting to note that...”, perhaps?	ok
412	“This is probably due to the combination of yet relatively short timeseries” → “This is probably due to the combination of relatively short timeseries”	ok
416	“and the additional observations from Météo-France’s network starting in the 1990s starting to become long enough to be included” → “and the additional observations from Météo-France’s network starting in the 1990s soon to become long enough to be included”	ok
465	Please specify what “a drying in this region” means. Number of wet days?	Less precipitation due to less wet days, according to the reference. We will clarify this.
466– 476	Much of this discussion is based on the assumption that there is a west-east contrast in trend, when in fact, the mentioned negative trend in the western part of the domain is significant at only a few stations.	Thank you for this observation. We refer again to our answer to your major comment #2. We will also clarify in the text which part of our discussion is based on which level of confidence in the results.
477	“continuous observations by Météo-France are yet too short” → “continuous observations by Météo-France are still too short”	ok
482	“However, they also cover just a limited period of time and come with different limitations, such as masking in mountainous regions.” → and inhomogeneities in time?	That is correct, we will add this aspect.
492	“as we show for example in Fig. 11” → “as we show in Fig. 11”	ok
497	“generalised extreme value theory” → “extreme value theory”?	ok
498	“Regarding the spatial and temporal of extremes” → is there a word missing?	evolution
511	“which leads us to state that” → “state” makes it seem as if it were a fact, when it is simply an interpretation. “argue” would be better.	ok
517	“On the other side” sounds a little strange. → “In contrast”?	ok

Figures and Tables

Fig. 8	Change “light red Mediterranean” color to dark blue.	ok
Fig. 5 and 9	Add a note that within a month/season/year, the size of the dots corresponds to the amplitude of the 20-year return levels.	ok
Fig. 11	Indicate that the boxplots include both stations with significant and non-significant trends.	ok
Fig. 10 and 12	Replace stations where the trend is not significant with empty circles.	We would prefer to keep them, but decrease the size of points with non-significant trends. See our reply to major comment #2.
Fig. 10 and 12	Specify that upward triangles correspond to an increase and downward triangles correspond to a decrease in the 20-year return level.	ok