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Climatology and trends of observed daily and hourly extreme precipitation in the French Alps

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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.

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.

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.

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.
- 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.

- Fig.4 could be omitted or moved to the appendix, especially since its appearance is not commented in the text.
- 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.
- Avoid "However" at the beginning of sentences. "Blablabla, however, blablabla".
- "timeseries" or "time series" : please choose one or the other.

Line-by-line

12	What is meant by "partially large differences"?
23	"Also southeastern France was not spared from such events recently". → "Even southeastern France was not spared". Or "has not been".
25	"lead" → "led" (preterite)
31	"are more exposed" → "are particularly exposed"? (exposed more than what?)
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"?
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.
39	Both thermodynamic and dynamic what? A word is missing.
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"?
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"
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)".
48	"onset of clear trends" → What does "clear trends" mean?
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."
62	"globally this assumption seems to hold true" -> what does globally mean here? A spatial average? Or does it mean "in most cases"?
66	Super CC trends -> scaling rates or actual trends?
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 …."?
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?
90	"much closer correlated" -> "much more closely correlated"
111	"28 stations with more than 45 years, longest 70 years" → "the longest with 70 years"
122-155	Very nice description!
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)?
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.
184	"A quality control of the hourly data was thus necessary." → Indicate here that you can use the 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"

192	“were overlapping” → “overlapped”
201	“Intensities” → are these mm/h? If not, please use “values” or “amounts” or “observations” or “accumulations”.
208	“attributing weeks between two months” → “attributing weeks straddling two months”
212	“contains 177 time series” → 89 MeteoFrance + 67 EDF?
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.
222	Evolution of relative occurrence of each WP → never used again? Why bother? Especially if no explanation or comment is made?
224	“we first match” → is the “first” necessary?
225	“of of”
255	Which dataset are you using here? The 27 EDF stations with a combination of old and new?
261	“for cases when all the density of maxima shifts in time” -> “when *only* the density of maxima shifts in time”?
265	“we adopt a bootstrap approach by resampling the series of maxima 100 times with replacement” → isn’t 100 a rather small sample?
277	“so these are simply discarded” → the stations?
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.
319	“In the north Atlantic influence is dominant during the whole year” → “In the north, the Atlantic influence dominates during the whole year”
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“.
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).”
328	Evidently, hourly precipitation extremes are not stationary over the spring and autumn seasons. How does this affect your seasonal analyses?
335	“almost no EDF stations is located in the Rhône valley” → “almost no EDF stations are located in the Rhône valley”
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?
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.
342	“in in”
343	“are not for the exact same regions” → “are not for exactly the same regions”
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.
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.
411	“However, even though…” → it would be more elegant not to start the paragraph with “However”. “It is interesting to note that…”, perhaps?
412	“This is probably due to the combination of yet relatively short timeseries” → “This is probably due to the combination of relatively short timeseries”
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”
465	Please specify what “a drying in this region” means. Number of wet days?
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.
477	“continuous observations by Météo-France are yet too short” → “continuous observations by Météo-France are still too short”
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?
492	"as we show for example in Fig. 11” → "as we show in Fig. 11”
497	“generalised extreme value theory” → “extreme value theory”?
498	“Regarding the spatial and temporal of extremes” → is there a word missing?
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.

517	“On the other side” sounds a little strange. → “In contrast”?

Figures and Tables

Fig.8	“light red Mediterranean” → dark blue?
Fig.5 and 9	Please mention that within a month/season/the year, the size of the dots corresponds to the amplitude of the 20-year return levels.
Fig.11	Please indicate that the boxplots include stations for which trends are significant and non-significant.
Fig. 10 and 12	Please replace stations for which the trend is not significant with empty circles. Please indicate that the upward (downward) triangles correspond to an increase (decrease) in the 20-year return level.