

Review 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.

The authors have taken into account many of the comments in the first round of the review. They have considerably improved the description of the data, although it is still a little confusing, and have increased the bootstrap sample size to 500. While they disagreed with the idea of removing non significant stations from their analysis, they modified Fig. 9 in such a way that the percentage of significant stations is available to the reader. Unfortunately, they do not seriously use this information in the discussion. Comments regarding this issue can be found under “Minor Comments”.

Major comment 1 of the first review round is neither addressed nor discussed in the new manuscript. I reiterate this comment under “Major Comment” below, and recommend this paper for publication if this comment is addressed.

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

Major Comment

Since the authors have estimated the GEV parameters for each month of the year (be it in the stationary or the non-stationary case), the seasonal and yearly return levels must be derived numerically, using the equation (here for the yearly return level)

$$G(z) = \prod_{j=1}^{12} G_j(z) = 1 - \frac{1}{T}$$

where G is the unknown yearly distribution, G_j is the GEV distribution for the j -th month, z is the return level, and T is the return period.

If heavy precipitation has a seasonal cycle, as Fig. 5 suggests, the numerically derived return level will differ from the one estimated with a seasonal or yearly maximum. If the return level in itself is our ultimate interest, it may matter less, especially if the confidence intervals are large.

The purpose here, however, is to determine the trend in return levels over the period of observation. Since the trend differs from month to month (e.g. Fig.9), it is likely that the discrepancy between the numerically derived return levels and those estimated from seasonal or yearly maxima will differ from year to year. Thus, I expect the seasonal and yearly trends to be sensitive to the way the seasonal and yearly return levels were determined, and therefore do not regard the seasonal and yearly trends estimated in the present manuscript as trustworthy.

I recommend that the seasonal and yearly return levels be derived from the monthly GEV distribution both in the stationary analysis and the trend analysis. In my view, it will be well worth the effort.

Thank you for your comment. Although we understand your point about numerically deriving the CDF of seasonal maxima from the monthly maxima by multiplying the CDFs, unfortunately we do not agree with the statement saying the two methods - fitting the GEV to seasonal maxima (method 1) vs. fitting the GEV to monthly maxima and deriving from them the CDF of the seasonal maxima (method 2) - should give different return levels due to the seasonal cycle. On the contrary, theoretically, the two methods should actually give exactly the same CDF since

$$P(\max_i(X_{1,i}, X_{2,i}, X_{3,i}) \leq x) \quad (1)$$

$$= P(\max_i(X_{1,i}) \leq x \text{ and } \max_i(X_{2,i}) \leq x \text{ and } \max_i(X_{3,i}) \leq x) \quad (2)$$

$$= P(\max_i(X_{1,i}) \leq x)P(\max_i(X_{2,i}) \leq x)P(\max_i(X_{3,i}) \leq x) \quad (3)$$

(assuming X_1, X_2, X_3 independent, which is reasonable in our case if, e.g., $X_{1,i}$ = January daily or hourly precipitation, X_2 =February, X_3 =March). So, if the monthly CDFs are exact, fitting the CDF of January maxima (i.e. to $\max_i(X_{1,i})$), February maxima ($\max_i(X_{2,i})$) and March maxima ($\max_i(X_{3,i})$), then multiplying the CDFs as in (3) should give theoretically *exactly* the same CDF as fitting the CDF to the seasonal maxima ($\max_i(X_{1,i}, X_{2,i}, X_{3,i})$) as in (1). This is valid even if there is a seasonal cycle, i.e. valid even if X_1, X_2 , and X_3 have different distributions. Equations 1 to 3 are valid whatever the underlying distributions (GEV or not). Finally this is also valid in a non-stationary framework and even if the trends in X_1, X_2, X_3 are not the same. In the equalities above, there is actually no assumption but the independence of X_1, X_2 , and X_3 .

Thus fitting seasonal maxima (method 1) or deriving the seasonal CDF from the monthly fits (method 2) are theoretically equivalent. It could be claimed that method 2 is expected to be more robust as it uses 3 times more data, but at the same time it has 3 times more free parameters (three GEVs) so the uncertainty is actually expected to be similar.

However, as we already discussed in our reply on the similar comment in the first revision round, using method 2 (deriving seasonal CDFs from monthly CDFs) sometimes fails due to error propagation, which leads us to not use it in our study. In details, in our previous reply:

- We compared the return level of the two methods at seasonal and annual scales and showed large discrepancies for some stations.
- We illustrated some issues with method 2 on a given station (C2814 in JFM at daily scale) where the 10-year return level was clearly overestimated, whereas it was reasonable with method 1.

Our conclusion was that discrepancies between the two methods were due to error propagation since for station C2814, the GEV fit for the month of March was biased, giving thus biased seasonal return levels when combining the monthly distributions of January, February and March with method 2.

It seems like you were not satisfied with our answer. The reason may be that our illustration on a single station was not convincing enough. Thus, in order to expand our comparison and, we hope, convince you, we performed a more systematic evaluation taking as reference the empirical estimates of return levels. Given N seasonal maxima, sorted in ascending order, the empirical return levels associated to these values are given by $RL=1/(1-p)$ where p is the empirical non-exceeding probability, which can be given by Hase plotting positions. Whatever the chosen model, a good fit should give return level estimates close to the empirical ones.

Thus we compare below:

- The return levels of methods 1 and 2 with the empirical return levels (for 20 and 50 years), calculating the bias between fitted and observed (empirical) return levels (Figure 1).
- The % of time the empirical return levels are outside the estimated 90% confidence intervals (obtained with a bootstrap method with 500 replicates) (Figure 2).

We also illustrate the fits for several stations (including C2814) but this time showing the two return level curves on a single plot for better comparison (Figure 3).

Figure 1 shows that with method 1 biases in hourly return levels are reasonably centered around 0 (gray) whereas method 2 (cyan) tends to have systematic negative biases particularly at annual scale. Some stations with method 2 show very large bias above 0.4 (corresponding to more than 40% overestimation of the empirical return level). This is even more pronounced at daily scale and in particular for the 50-year return level.

Figure 2 shows that, although the 90% confidence interval of the return levels contain almost always the empirical values with method 1 (gray), many confidence intervals of method 2 lie outside the empirical return levels.

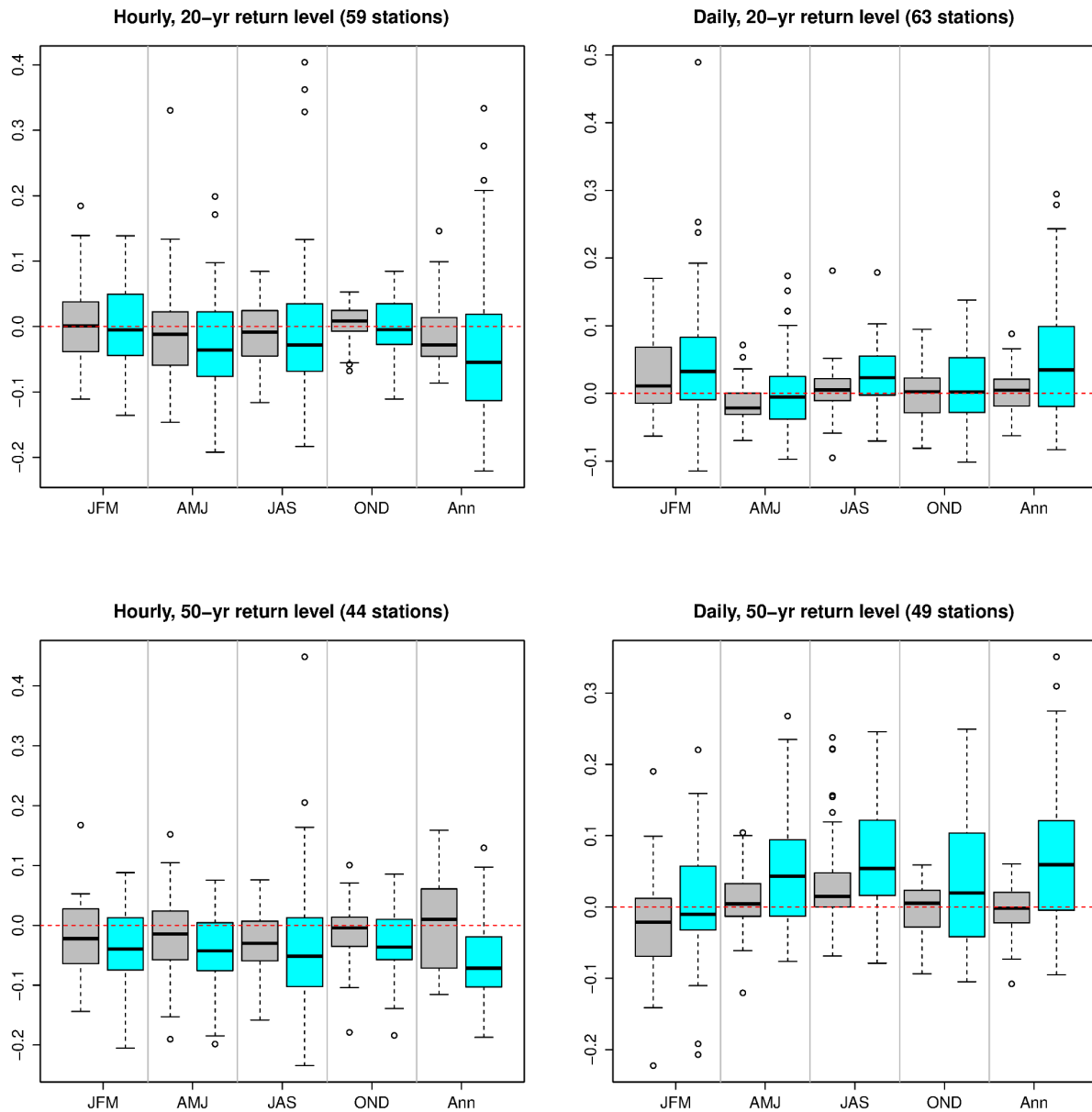


Fig. 1: Bias in return levels ($(\text{modeled}-\text{empirical})/\text{empirical}$) the N -year return level (top: $N=20$, bottom: $N=50$) at hourly (left) and daily (right) scale. Gray: method 1. Cyan: method 2. In each case ($n=20$ or $N=50$), only the stations whose neighborhood samples contain at least $3 \cdot N$ years are considered, in order to get reliable estimates of empirical return levels.

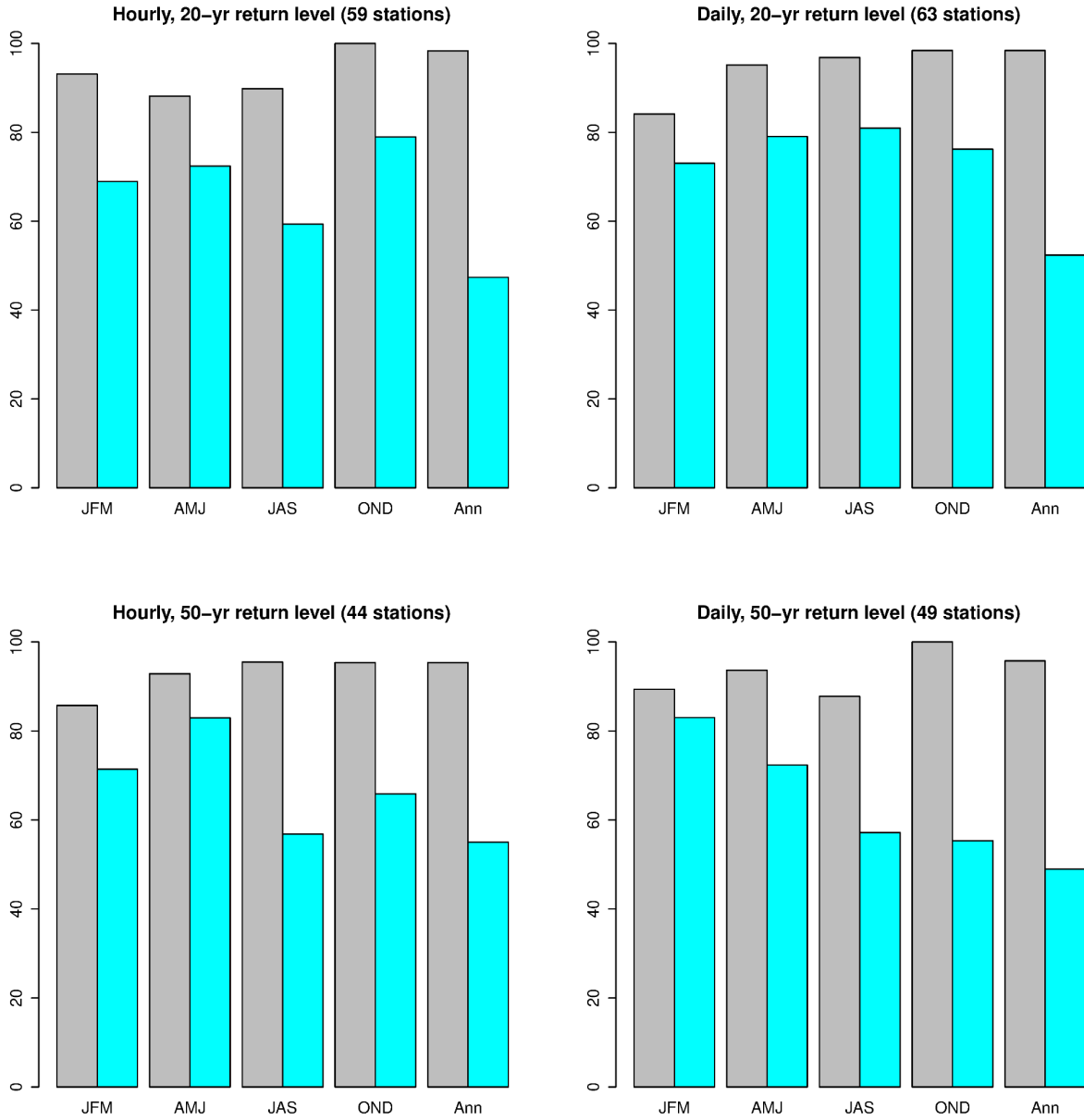


Fig. 2: % of stations where the N -year return level (top: $N=20$, bottom: $N=50$) is within the 90% confidence interval of the estimated CDF, at hourly (left) and daily (right) scale. Gray: method 1. Cyan: method 2. In each case ($n=20$ or $N=50$), only the stations whose neighborhood samples contain at least $3 \times N$ years are considered, in order to get reliable estimates of empirical return levels.

Figure 3 illustrates discrepancies with method 2 for the station C2814 at daily scale. In this case, discrepancies are particularly strong for JFM and, by further error propagation, for annual return levels. Bias with method 2 are actually inherited from bias at monthly scale since Figure 4 shows that the monthly fits for some months (particularly March) are not good. To further show that this is really an issue of error propagation, Figures 5 and 6 show the reverse case: the case of a

station (C1252) where all monthly fits are good (Figure 5), leading to similarly good fits at both seasonal and annual scales (Figure 6) (despite slight discrepancies in JAS with method 2).

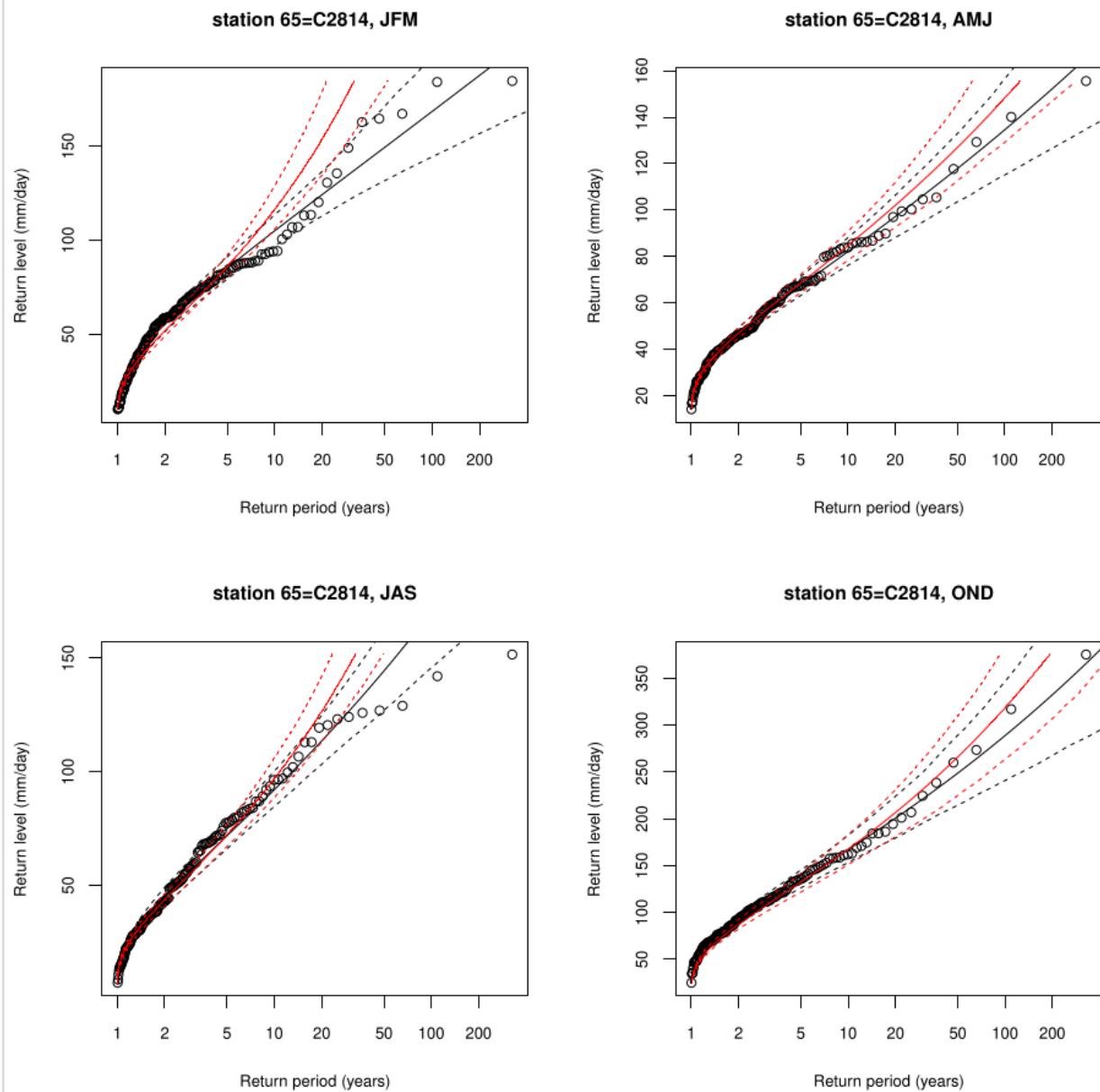


Fig. 3: Daily return level plots for station C2814 with method 1 (black) and method 2 (red) with 90% confidence intervals, together with the empirical return levels (black points).

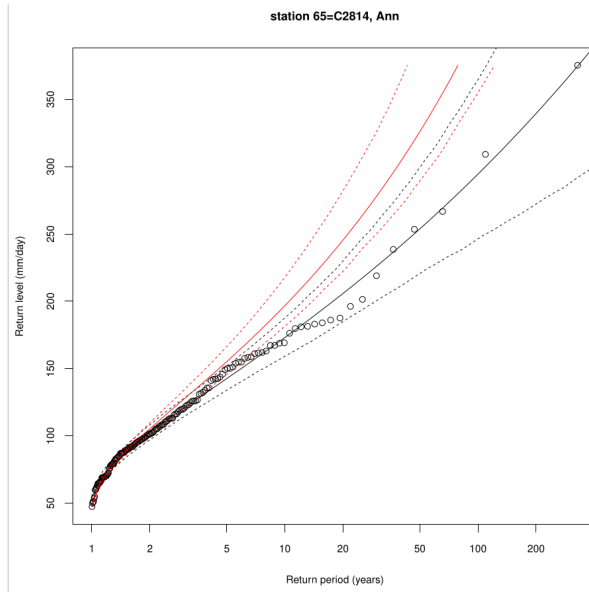


Fig. 3 continued

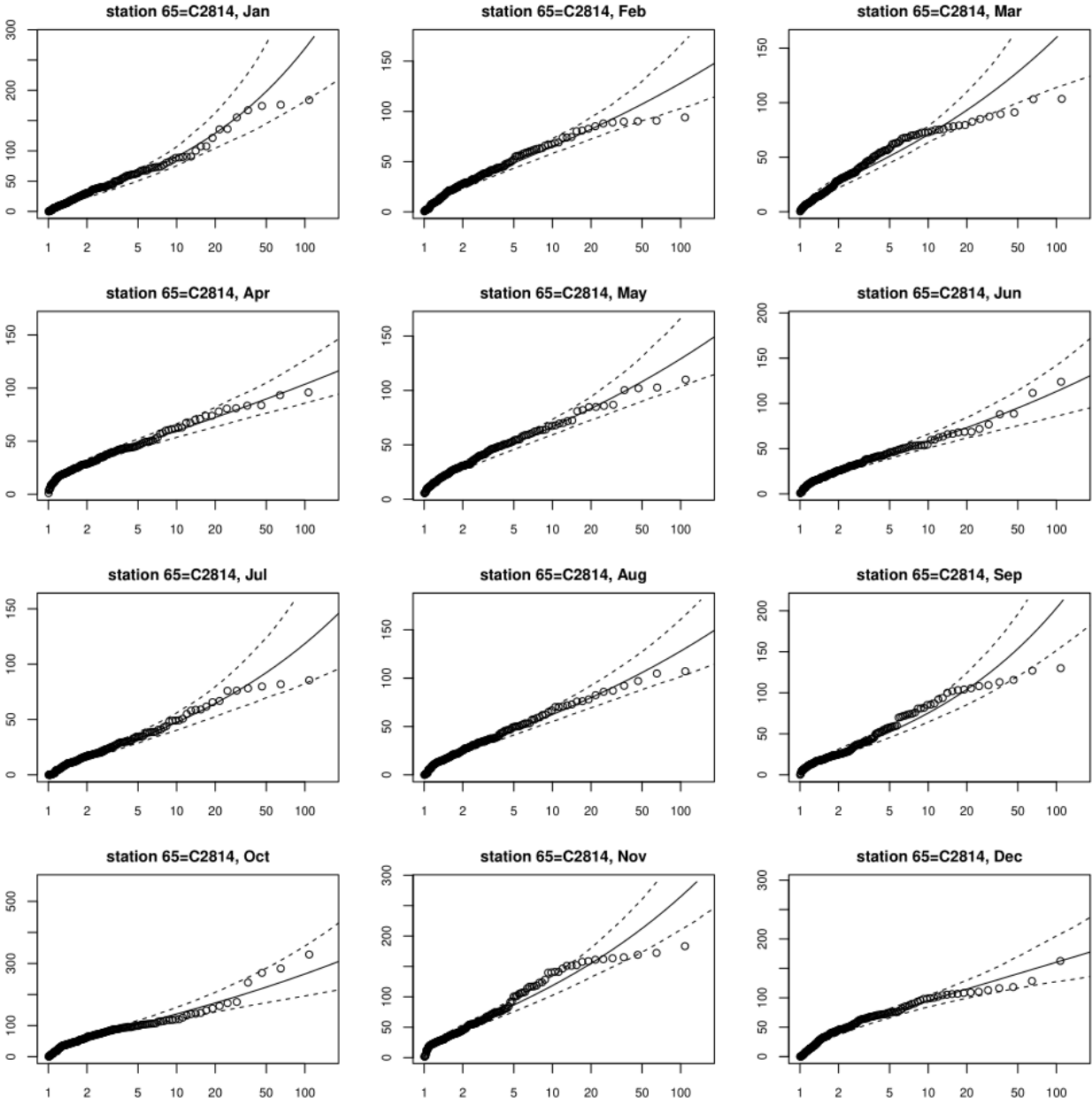


Fig.4: daily return level plots (return level in mm against return period in years) obtained from monthly GEV fits for station C2814

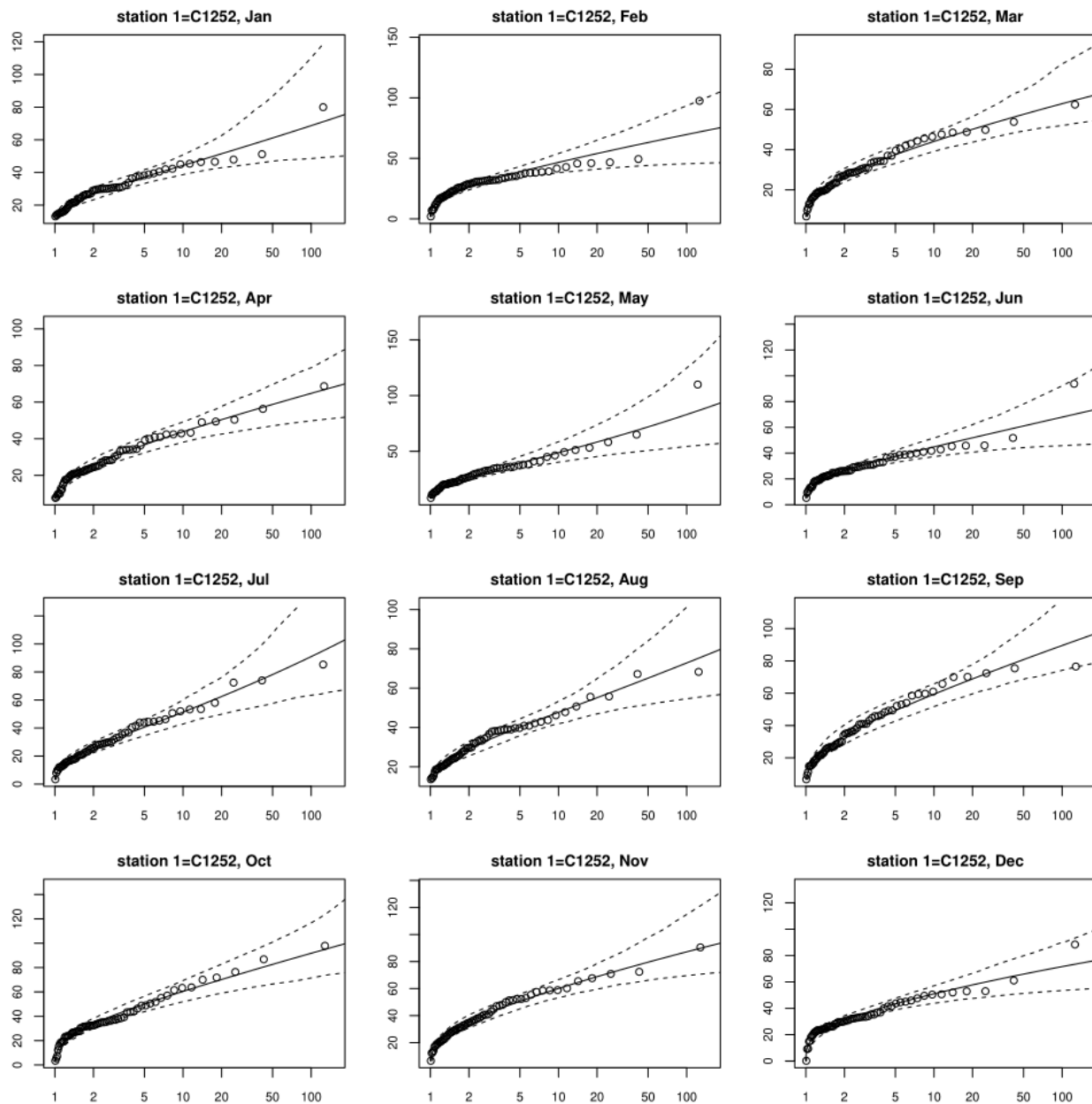


Fig. 5: daily return level plots (return level in mm against return period in years) obtained from monthly GEV fits for station C1252

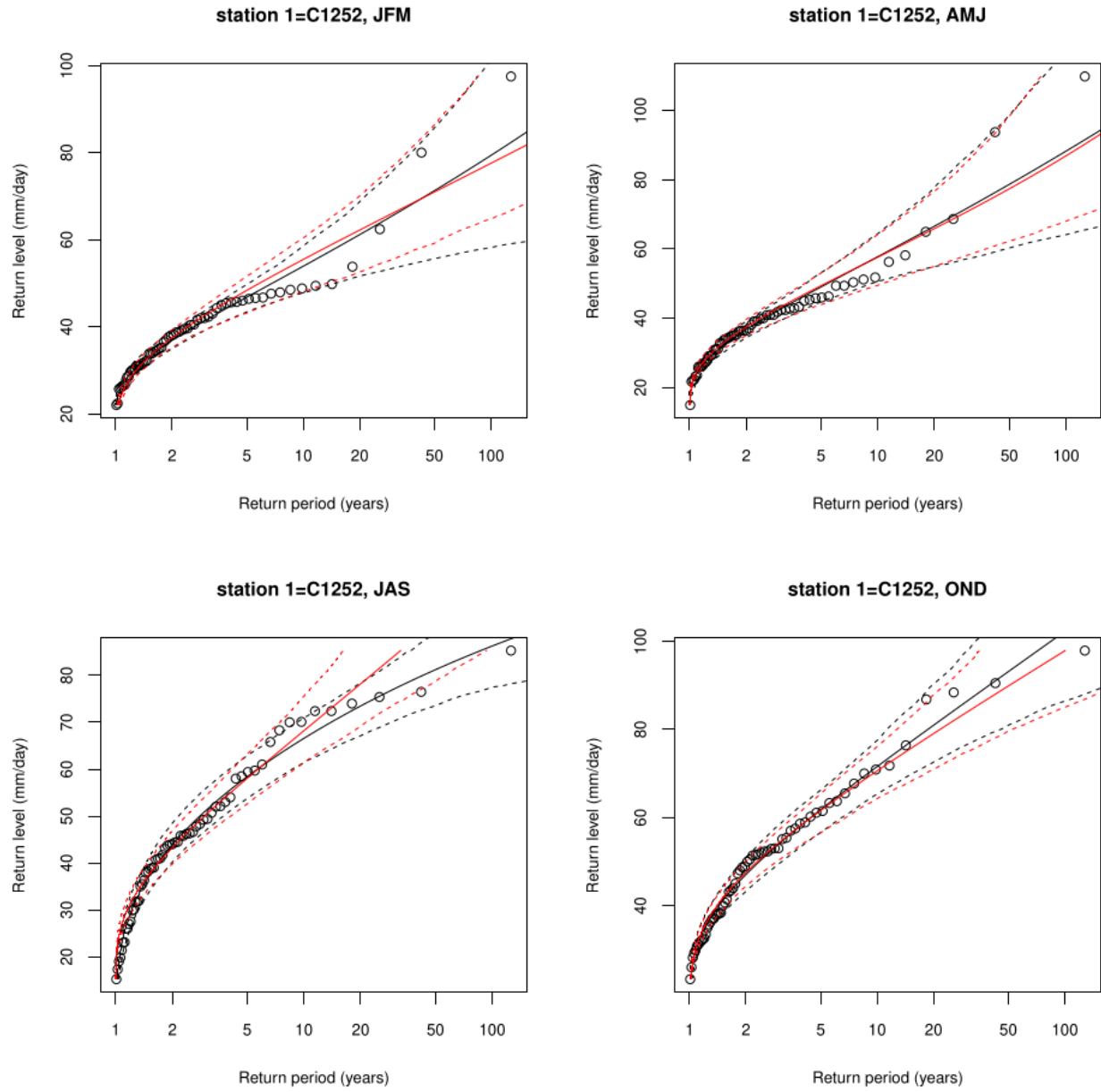


Fig. 6: daily return level plots for station C1252 with method 1 (black) and method 2 (red) with 90% confidence intervals, together with the empirical return levels (black points).

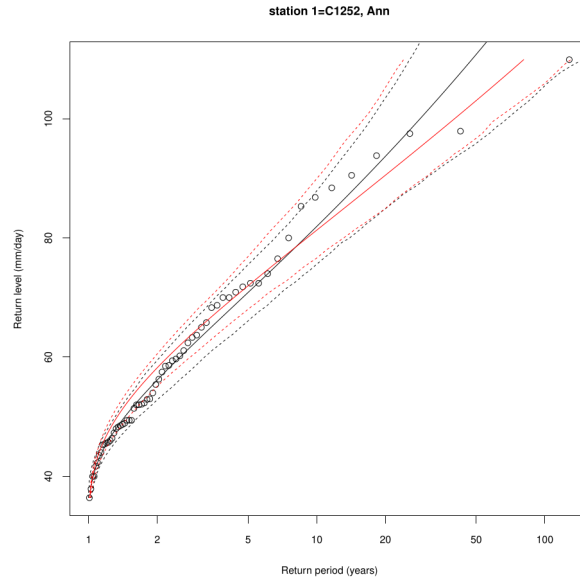


Fig. 6 continued

In conclusion, we claim that for this data, method 2, where seasonal and annual CDFs are derived from monthly fits, is not an appropriate method due to error propagation. However, we understand the comment made by the reviewer and acknowledge that some readers could have the same concern. Thus we have added a paragraph in Section 5.1 discussing this point, together with the above Figure 2 in the supplement (Fig. S5). The stationary return level plots of all stations at monthly, seasonal and annual scales with method 1 can be found here: <https://cloud.univ-grenoble-alpes.fr/s/z4gb4NnczasKj>

Minor Comments

General

- The description of the datasets is still a little confusing. See comments below. Wouldn't it be clearer to give each EDF dataset a name, EDFold and EDFrec for instance?
[Thank you for your suggestions, we have included them and agree that this helps with clarity.](#)
- Not enough effort is made to avoid misleading the reader with non-significant results. In fig. 9, the authors have paired the boxplots describing long-term trends in the north and south of the domain with a plot showing the corresponding percentage of significant stations. They do not mention these percentages when discussing the results in paragraph 486-491 (see comments below). In particular, the number of significant stations leading to the interpretation of the results should be mentioned when this number is small. Indeed, Fig. 9 should be modified to include this information (see comment below). Being straightforward about the number of significant stations, whether they are scattered, contradictory in trend, or deliver a concentrated signal, increases credibility and, in this case, does not even affect the interpretation.

Thank you for your suggestions, we improved the relevant sections following your comments.

- The discussion of the trends sometimes does not correspond to the evidence presented. See the comments below.

Thank you, we refer to our replies to individual comments.

- Is Inner-Alpine the same as Intra-Alpine? If so, please use only one term. Otherwise, define both.

Changed “intra” to “inner”

- Because of the switch to the seasonal stratification JFM-AMJ-JAS-OND, expressions such as “in early summer” become confusing. Is it July? Please clarify which series of 3 months correspond to the use of “spring”, “summer”, “autumn”, “winter”, and ensure that this convention is used in a consistent manner throughout the paper.

This became indeed a bit confusing. We now consistently add the abbreviations (JFM etc.) whenever a season is mentioned to improve clarity.

Line-by-Line Comments

Thank you for your detailed suggestions! We included them unless stated otherwise.

36	“While this divide can be quite sharply defined from differences in topography, vegetation, and mean climatic influences, this does not necessarily imply that the same features apply to influences in extreme precipitation intensities. Eventually replace with: → “While differences in topography, vegetation, and mean climatic influences can sharply define this divide, this may not be the case for extreme precipitation intensities”	ok
111	This possibility has been exploited in a series of doctoral theses at the time Either → This possibility was exploited in a series of doctoral theses at the time Or → This possibility has been exploited in a series of doctoral theses	ok
123	we build on and expand the work of Garavaglia et al. (2010); Blanchet et al. (2016, 2021a) to get an idea of the weather patterns behind high-intensity precipitation in the region → we build on and expand the work of Garavaglia et al. (2010) and Blanchet et al. (2016, 2021a) to get an idea of the weather patterns behind high intensity precipitation in the region	ok
168	The datasets of EDF and Meteo-France combined we have time series for a total of 163 stations → The datasets of EDF and Meteo-France combined have time	ok

	series for a total of 163 stations	
171	but registration of precipitation at high temporal resolution (6 minute intervals) was first introduced within the Meteo-France network in the 1990s (data availability, see also Guillou, 2018). What is meant by “(data availability, see also Guillou, 2018)”?	The available data reaches back to the 1990s, which indicates the start of digital registrations. For improved clarity we remove the first part, and cite only Guillou, 2018.
189	“squared points in Fig. 1” → “squares in Fig. 1”	ok
192	We complete this ‘recent’ dataset with digitalised observations covering the period from the late 1950s to the early 1980s (Garcon, 1993; Saidi-Bououdina, 1996; Kieffer-Weisse, 1998). → We complete this ‘recent’ dataset with an ‘old dataset’ of digitalised observations covering the period from the late 1950s to the early 1980s (Garcon, 1993; Saidi-Bououdina, 1996; Kieffer-Weisse, 1998), and comprising 65 stations.	ok
195	Of this dataset → Of this ‘old dataset’	ok
197	At the end of the paragraph, it would help to say something like: “In summary, we have 30 EDF stations with weekly maxima for 1h...24h approximately covering the period 1955 – 2022. (squares with colors purple to yellow in Fig.1)”	We changed the end of the paragraph to: “Of this old dataset, we use only observations for the 30 stations which are also included in the ‘recent’ dataset. In summary, we have 30 EDF stations with weekly maxima for 1h...24h approximately covering the period 1955-2022 (squares with colours orange to red in Fig. 1) and another 37 stations covering approximately covering the period 1980-2022 (squares with colours yellow to orange). “
185 vs 200	daily observations at 6am as the sum over the preceding 24 hours precipitation that has accumulated in the 24 hours between 6am and 6am of the following day → which of the two is it? Please specify.	It is indeed the second definition, and we now changed the first occurrence to “daily observations as the sum from 6am until 6am on the following day”.
212	→ For the stationary analysis: all 96 Meteo-France stations and the ‘recent’ data from the 67 EDF stations (i.e. 162 time series of both hourly and daily data, and 1	Thank you for this suggestion. Actually, since 1 station was removed following 2.2.3, there

	time series of daily data), covering between 25 and 42 years of observation. While there are differences in instrumentation between EDF and Meteo-France, we assume each individual time series to be homogeneous in time.	is 1 less EDF station. We included this now as well.
215	→ For the trend analysis: all 67 EDF stations (i.e. 66 time series of both hourly and daily data, and 1 time series of daily data only), covering between 33 and 71 years of observations. At 30 of the stations, time series from different data sources are combined and thus contain known inhomogeneities from both changes in instrumentation and different quality control procedures before and after the 1980s.	Same as above
219	During initial analysis → During the initial analysis	ok
245	“if it has generated the maximum of season or month m in every respective year t, and 0 otherwise” → If it has generated the maximum of season or month m in year t, and 0 otherwise [“every respective” is confusing]	ok
247	“We call the weather pattern showing the relatively highest contribution the dominant influence for seasonal maxima at a given station” [It seems to me that “relatively highest” doesn’t mean anything. Either it’s the highest, or it isn’t. And “highest”, in itself, already implies that it is higher than something else. Perhaps it would be clearer to simply say “We call dominant with respect to a given season (month) the weather pattern that is associated with the largest number of seasonal (monthly) maxima over the complete time series at a given station.”]	ok
250	French Alps;. → French Alps.	ok
253	“For the estimation of return periods” → “For the estimation of return levels”	ok
285	“red solid line in Fig. 3” → Isn’t it Fig. 3A? / “return level is arbitrary, it aims” → return level is arbitrary; it aims	Indeed.
286	“Patterns” → spatial patterns?	yes.
309	“for a point j in the neighbourhood of i, N_i ” → What is N_i ?	The neighbourhood. Changed to “the neighborhood of i, denoted N_i ,”
329	between non-declusterised old and declusterised recent data → between non-declustered old and declustered recent data	ok
365	“This did not result in significantly different spatial	It indeed means “very”.

	patterns” Does significantly mean “very”, here? Or has the degree of difference been quantified?	Changed.
368	“applying it for hourly maxima is less robust” → What does “robust” really mean here? Please be more precise.	The weather patterns are identified based on large scale circulation patterns over Western Europe centered on Southern France, at the daily timescales (see Figure 3 of Garavaglia et al., 2010, https://doi.org/10.5194/hess-14-951-2010). Since high daily amounts of precipitation are usually associated with large-scale circulation patterns (Atlantic or Mediterranean circulation for our region of interest), it is relevant to compare WP and daily maxima. Hourly heavy rainfall both depends on the large-scale signature and on local atmospheric conditions which drive convective processes. In that sense, the comparison of WPs to hourly maxima is less robust. Sentence changed to “Since hourly heavy rainfall depends on both the large-scale atmospheric circulation patterns and on local atmospheric conditions which drive convective processes, the analysis of the weather patterns by Garavaglia (2010) is less robust for hourly than for daily maxima.”
369	The main patterns resemble the daily patterns, but with a higher influence of Anticyclonic conditions between June and September (Fig. A2). • In what way does Fig. A2 help understand this statement? • “The main patterns” → Please be more precise: “the spatial distribution of the dominant weather patterns”	Thank you, this was indeed a wrong cross-reference. We reference to Fig. 7 now (where we added the information on the dominant WPs), and also added the equivalent of Fig. 6 for hourly data to the supplementary material (Fig. S2).
384	“small positive trends in May are followed by...” This is not very convincing (only 7 stations are significant). Why not skip May, and talk only about August to December	Changed to “In the south of the domain, significant negative trends in August and

	where you seem to have a signal worth mentioning?	September are followed by significant positive trends in October to December.”
392	“and also overall less significant” → “Overall, the trend is significant at much fewer stations than for daily precipitation, and the number and location of such stations varies considerably from month to month and season to season.”	ok
393	“with the highest range of values” → “with the widest range of values”	ok
398	“with highest variability in spring and summer “ → “with the largest variability in spring and summer”	ok
401	although most annual trends are statistically not significant. → “although the annual trends are statistically significant at only 2 of the stations, and are of opposite sign.”	ok
488	“Between June and December, the southern part of the study region experiences much stronger trends, both positive and negative, for both hourly and daily extremes» → “Between June and December, the southern part of the study region experiences much stronger trends, both positive and negative, for both hourly and daily extremes. Note that for hourly extremes, the trends in the south only affect more than half the southern stations in November and December...”	We added “Note that for hourly extremes, trends are never statistically significant at more than half of the stations, with the exception of November.”, as this is true for both south and north.
492	“Especially the autumn period (October to December) deserves attention” → The evidence points to this sentence being about the South. Please specify.	Changed to: “Still looking at the south, especially the autumn period...”
499	“and for which the mean trend over all stations in the south is always close to zero” → do you mean in the north? In Fig. 9, in the north, the mean is close to zero in all months but September.	This part of the sentence does indeed not help with the understanding. We removed it altogether, the sentence now reads: “...the clear negative trends in summer shown for daily extremes are much weaker or absent in the hourly values.”
501	“Daily trends in the same period are overall negative” → “Daily trends in the same period are overall negative, except for June” Are the authors still talking about the South here?	Yes. Changed to “Daily trends in the same period and region are overall negative.”
501	“To a lesser extent (in June and September) this is also true in the north, showing that during this time of the year hourly and daily extremes are not experiencing the same	Indeed, thank you.

	trends.” For September this is not true.	
507	“Trends of hourly extremes in the same season show both negative and positive trends” How do the authors come to this conclusion?	We rephrased the sentence and hope this improves clarity, it now reads: “The strong negative trends of daily precipitation in summer are likely to be a direct consequence of generally less precipitation in this region (Menegoz, 2020), which is already characterised by low precipitation totals (Joly, 2010). Trends in hourly extremes in the same season show both negative and positive trends, with significant positive trends especially at several stations in the northeastern part of the region, where the mountains are highest.”
508	“with significant positive trends especially in the eastern part of the region, where the mountains are highest” Positive trends only at very few stations; please rephrase.	See above.
512	“We further hypothesize that the drying effect might dominate in the pre-Alps ...” Comment about pre-Alps vs interior Alps; seems inconsistent with Fig. 10.	We acknowledge that this argument is indeed standing on very thin legs based on our results alone and think we have been sufficiently careful in our formulation. We agree that there is no strong contrast between pre-Alps and interior Alps. However, we still see at least a southwest-northeast gradient from negative/nonsignificant trends to significantly positive trends for JAS and Annual (Fig. 10). We changed ‘western’ to ‘southwestern’ and ‘eastern’ to ‘northeastern’.
550	“At the hourly timescale, trends are more spatially variable, with a tendency towards positive trends prevalent in the high Alps and negative trends in the pre-Alps.” Same issue as above.	We changed this to “with a tendency towards positive trends prevalent in the high mountain ranges in the northern parts of the study domain.”
558	“could be a potential change” → “could be a change” or	ok

	"could potentially be a change"	
561	"and in early summer as well as autumn for hourly extremes." Does "early summer" refer to July or June?	June. Changed to "and in June as well as November for hourly extremes."
562	"showing partially strong increases in the south (daily)" What does "partially strong" mean?	Changed to: "showing increases in the south of up to 24 mm/d/10y for daily, and increases in the inner Alps of up to 4 mm/h/10y for hourly extremes"

Figures

Fig. 1	Description: "Stations maintained by Meteo-France are shown as circles, these are used for stationary analysis only due to the comparatively short period they have been operating for." → "Stations maintained by Meteo-France are shown as circles, and are used for stationary analysis only, due to the comparatively short period they have been operating for." "Stations maintained by EDF are shown as squares, these are used for both the stationary and the trend analysis" → "Stations maintained by EDF are shown as squares, and are used for both the stationary and the trend analysis" Legend: For the first 2 squares (26-30years, 30-40 years) the color cannot be distinguished. Could you please choose a lighter color?	ok. We changed the colour ramp of the figure. However, due to the large range of values (26-71 years), neighbouring values remain difficult to distinguish. Following the HESS guidelines we want to keep our figures accessible to people with colour vision deficiencies, therefore multi-colour colourmaps such as jet are unfortunately not an option in this case.
Fig. 9	Please add the number of stations that are significant for each month, season, or for the year. In the legend, please remind the reader of the total number of stations.	Thank you for this suggestion, we now added the numbers to the bars and the total numbers to subplot titles and caption.
Fig. A2	"Note that the colorbar is different from 7." → What is 7?	"Fig." was missing.

Reviewer #2

Thank you again for your detailed comments! Please find our answers below in blue.

Major:

As the authors state in their rebuttal letter, the data from EDF is not publicly available. This just something to be checked how this fits with the journal data policy. Probably this is already clarified.

We are aware that this is not ideal, but the datasets are owned by EDF and they don't want them to be publicly available. However, as we state in the data availability statement, data can be requested for research purposes by contacting hydro-dtg-demande-donnees@edf.fr. Moreover, we note that several articles published in HESS have used restricted EDF datasets before (e.g. Dura et al, 2024; Blanchet et al, 2019; Ménégoz et al, 2020).

Figure 9: It is not clear from the text and figure caption whether the box-plots in the first and third row show only significant trends (which they should) or all trends, including the insignificant ones.

While we understand your concerns, we prefer to show all trends (not just the significant ones) in the boxplots. This (a) because of the difficulties associated with obtaining statistical significance in extreme value analysis due to data shortness and variability, and (b) because in our opinion it would also be misleading to show distributions based on a different subset of stations from one month/season to the next. Furthermore, we included the sentence “Both statistically significant and non-significant trends are included.” in the caption.

Moreover, the type of trend estimation used is not described and how trend strength is computed.

Unfortunately, we are not sure if we understand your comment. We describe our methodology in detail in section 3, including an explanation of the non-stationary GEV analysis in 3.1.2 and of parameter estimation in 3.2.

Minor comments:

7: statistically confirmed based on what? Observations? Model simulations?

Added “based on observations”.

8: would not term it “long-term” in-situ observations

Changed to “long time series of in situ observations”, as (digitalised) observations for similar or longer time periods are very rare, especially in such spatial density.

13 “which do not increase uniformly across the region” implies the authors would expect that increase should uniformly, which is probably not the expectation of authors.

We replaced the sentence in the abstract by “We focus on 20-year return levels to analyse rare, potentially high-impact events and show that precipitation extremes exhibit distinct spatial patterns with marked differences between daily and hourly timescales.” We also modified a similar sentence in the conclusion accordingly.

18-19: “for daily extremes, we observe ...” specify which indicators of extreme precipitation
Added “for extremes of daily precipitation intensity...”

11-13: Why is the trend for hourly extremes (-> explain which one) influenced by thermodynamic effects with different trends in high Alps and pre-Alps. Isn't the temperature trend the same for high-Alps and pre-Alps? This needs to be explained.

Changed to: “The spatial patterns for hourly extremes show more spatially variable trends, and seem to be primarily influenced by local thermodynamic effects potentially linked to e.g. changing moisture availability or changes in surface albedo due to shorter snow cover persistence.”

14-16: Don't say “the study is important for stakeholders etc.” instead explain what is the relevant result for stakeholders

Changed to: “This detailed analysis provides important insights for stakeholders who are working on prevention and protection from precipitation-related hazards, underscoring the need for adaptive strategies in response to changing precipitation patterns. It also highlights the importance of region-specific and timescale-specific approaches in future studies of precipitation extremes.”

37: locally exceeding 120mm/h of precipitation)
ok.

47-48: While this divide can be quite sharply defined from differences in topography, vegetation and mean climate, this does not imply that the same divide apply to spatial patterns in extreme precipitation intensities.

Following Rev1's suggestion, we changed this sentence to: “While differences in topography, vegetation, and mean climatic influences can sharply define this divide, this may not be the case for extreme precipitation intensities.”

50- 52: make clear if changing Mediterranean/Atlantic influence changes in space between seasons or only from relative share

See below.

52-53: Associated with this change Rephrase the sentence, it is not really clear what you mean

Both relative share and spatial extent are linked. We now rephrased these sentences using “weaken” and “strengthen”: “For example, a study by Blanchet et al (2021) showed that the Mediterranean influence on precipitation extremes is weakening in winter and spring (in favour of the Atlantic influence), but strengthening in autumn.”

62: increase in maximum moisture content of air with temperature ...
ok.

63: that this trend in annual daily precipitation maxima was —> which trend?
increasing/decreasing?
increasing.

63: 20 to 40% since then —> give time reference for trend
From the 1990s until 2015. Added.

66: ... only in the 2000s did a consensus appear in the significance of trends in observations ...
—> do not understand this statement: All series show the same significance level?
Changed to “only in the 2000s did a coherent spatial pattern appear in sign and significance of trends in observations”.

70: .. and protection from such events ... —> which events?

Changed to: “precipitation-related hazards”

73: .. no studies have been conducted on this topic yet... —> which topic?

Changed to “possible sub-daily precipitation extremes in the French Alps”

106-107: Nevertheless, the European Alps as a whole show significantly positive trends. —> positive trends for which quantity?

Changed to “Nevertheless, the European Alps as a whole show significantly positive trends in daily heavy precipitation (Menegoz, 2020). On sub-daily time scales, trends are generally positive and follow more closely the 7%/K relation expected from the Clausius-Clapeyron relationship ...”

120: ... which is mostly due to the limited temporal depth ... —> would mention data quality as well

ok.

121: Many mechanical registrations of precipitation ...

ok.

253: We therefore decided to use this definition throughout the study

ok.

279-284: this already method and could go there

We don't think we understand?

323-324: Why would patterns of 10-years and 50-years return levels show similar patterns as 20-years return levels?

Assuming you mean I. 286f: We replaced "would show similar patterns" by "are not shown but have similar patterns".

341: Neighborhood Approach: —> it is still unclear how the selected number of neighbors could be verified. Is the selection just decision based on “feelings”? Couldn't be the number of neighbors quite different dependent on the precipitation event?

Unfortunately, there is no objective criterion for this (yet), see also Carreau et al (2013), and Evin et al (2016). The radius of 0.3 degrees (~30km) we use here is similar to values chosen in previous studies: Carreau et al (2013) used 5-50km, Evin et al (2016) used 5-100km, and Blanchet et al (2021) 20km. There is a tradeoff between obtaining robust estimations by including a sufficient number of stations on the one hand and avoiding to mix different climatologies on the other hand. The radius could indeed theoretically be different depending on the type of precipitation events (e.g. large-scale stratiform vs small-scale convective), but how to distinguish the two based on point-observations at the surface alone? And what of events that are both small- and larger-scale such as squall lines? Solving these questions is out of the scope of this paper, although the whole author team would be very interested in a definitive answer.

373: We then turn the trends in extreme 20-year return levels.

Changed to “We then turn to the trends in 20-year return levels.”, if this is what is meant.

373: We don't try and interpret ...

We don't think we understand?

Figure 4 and 7: Suggest to improve the color coding of return levels

We acknowledge that 'batlow' is not the most intuitive colourmap for precipitation, but unfortunately there are not many colour maps that use several colours (needed because of the

large range of values) while at the same time being accessible for people with colour vision deficiencies.

In the first draft we used 'vik' (white-blue-black), but in our opinion 'batlow' makes it easier to differentiate also small differences. This improved clarity is even more important as after the first round of review we added the information on dominant weather patterns as symbols into these figures as well.

Discussion and Conclusions:

There should be discussion on how the temperature scaling based on air temperature changes could be used to explain trends in hourly precipitation extremes (return level trends). As temperature change is rather homogenous in space one would expect similar pattern in hourly extreme precipitation. So would be good to say something about temperature change in the study region and how this links to changes in precipitation extremes. Is temperature change really homogenous in space and how relevant is mean temperature for the temperature scaling? Clearly, there could be other reasons for spatial patterns of extreme precipitation trends, but the role of temperature scaling could be discussed in more detail.

Indeed, as we also describe in the Introduction (l.63-79, 91-101) it is generally expected that hourly extremes should scale more similarly to temperature changes than daily extremes.

Unfortunately, computing trends of air temperature ourselves is out of the scope of this paper as it is already quite long. Note also that most EDF stations only measure precipitation, thus a direct station-based comparison is not possible.

However, the study by Beaumet et al (2021) can give us some hints in this regard, although they studied a different (but overlapping) period. In their Fig. 5 they show modelled temperature trends in the French Alps for the period (1959-2010) for traditional seasons (DJF, MAM etc.). If we assume that hourly extremes should scale most closely to JJA temperature trends, we can see that the region with the highest trends (the northeast) very roughly coincides with the region of the highest temperature trends of Beaumet et al.

We added these elements to our manuscript. A more detailed analysis, comparing the trends we find to, e.g. temperature or dewpoint temperature at different levels, unfortunately has to remain to future work.

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