Reply on RC3

Jana Ulrich, Felix S. Fauer and Henning W. Rust

August 26, 2021

Dear Reviewer,

Thank you very much for your detailed and constructive comments. We address them point by point below.

Main comments

1.

While the results are informative and supported by extensive analysis, the motivation for this very detailed investigation was not clear from the introduction. IDF curves are typically used for design of long-lived infrastructure systems where monthly variations are essentially irrelevant. The authors discuss a few reasons that monthly IDF curves could be valuable, including to support agricultural or water resources stakeholders. However, these stakeholders typically care about monthly average rainfall, and there is no reasoning in the paper that supports why they would be interested in extremes. Could the authors elaborate and/or find a reference that supports this?

Answer: Thank you for pointing out that the motivation might not be clearly stated. We will revise the introduction to communicate this more clearly.

In addition to the availability of more data and the resulting reduction in uncertainty when estimating annual IDF curves, there are three further aspects that suggest that studying intra-annual variations in the IDF relationship is relevant.

- For stakeholders who use IDF curves for water management rather than planning of infrastructure, the additional information on intra-annual variations may be beneficial. An important example is the recent extreme precipitation event in the states of North Rhine-Westphalia and Rhineland-Palatinate in western Germany. The event also affected the Bever dam, where the example station Bever-Talsperre of this study is located. The intense long-lasting rainfall on 7/14/2021 caused the Bever dam to spill in a controlled manner. There was concern that the resulting higher water level in the Beverteich lake below could cause the dam there to breach, with serious consequences for the downstream villages. As a result, the residents were evacuated. We therefore think that both the information about the time scale and the seasonality of extreme precipitation is of importance for stakeholders who, for example, manage the water level of reservoirs.
- The study of seasonal variations allows drawing new conclusions about the underlying processes, since the use of annual maxima of different durations does not take into account that these may originate from different seasons.
- Changes in the frequency and intensity of extreme precipitation in Europe have been found to differ between different seasons (e.g. Moberg and Jones, 2005; Łupikasza, 2017). Modeling the seasonal variations of extreme precipitation on different time scales is a first important step to detect and interpret the changes in seasonality in a consistent way.

References

- Moberg, A. and Jones, P. D.: Trends in indices for extremes in daily temperature and precipitation in central and western Europe, 1901–99, Int. J. Climatol., 25, 1149–1171, https://doi.org/10.1002/joc.1163, 2005.
- Łupikasza, E. B.: Seasonal patterns and consistency of extreme precipitation trends in Europe, December 1950 to February 2008, Clim. Res., 72, 217–237, https://doi.org/10.3354/cr01467, 2017.

2.

It seems instead that the motivation for the paper is to "increase understanding" of monthly extremes and examine "underlying mechanisms." If so, then what new information do monthly IDF curves bring? Is this simply a convenient way to evaluate monthly extremes and also account for storm duration? Or could monthly IDF curves bring added value to engineering analyses?

Answer: Two major new insights we found using monthly IDF curves are:

- It could be incorrect to assume a simple scaling of intensity with duration for durations $\geq 1\,\mathrm{h}$, especially at stations with a prominent shift in seasonality from short to long durations. We could show that such a shift can lead to a decreased slope of the IDF curves for long durations $\geq 24\,\mathrm{h}$. While it is also possible to model this deviation by adjusting the IDF model for annual maxima, this would not enable us to understand its cause.
- Due to the large uncertainties associated with the estimation of the shape parameter ξ, it has so far not been possible to derive an empirical relationship between ξ and duration. We were able to show that a more reliable estimate of this parameter is possible when seasonal variations are incorporated. On average, ξ decreases with duration across all investigated stations. This interesting result should be investigated in more detail in future studies.

3.

The introduction does mention that monthly IDF curves could bring added value compared to annual block maxima by including more data in the analysis. However, there is an existing technique, called "peaks over threshold" (POT), that evaluates all storms in a year over a certain threshold. It is unclear whether the monthly maximum technique brings added value compared to the POT method, but it is clear that the monthly maxima method is not the only way to include more data in the analysis. There are drawbacks to POT, of course, including that the annual return period is no longer directly interpretable since more than one storm per year can be included in the extreme event series. But the POT technique should be mentioned in the introduction as an alternative way to include more data. A comparison of the monthly maximum technique to POT should also be mentioned in the conclusions/future work section.

Answer: We agree that the POT approach is an alternative method for modeling precipitation extremes. We will mention this in the introduction. However, the POT approach alone does not allow to study seasonal variations within the IDF relationship. To do so, one would need a seasonally varying threshold. Within a duration-dependent distribution, the threshold would additionally depend on the duration. We consider this approach to be much more complex for the problem at hand and consider the d-GEV approach as a more suitable choice in this context. We this motivation for our choice to the introduction.

4.

Based on these points, a distinct motivation for the creating of monthly IDF curves seems to be missing. After reading the results, it seems that monthly IDF curves could bring some added value in terms of uncertainty evaluation and potentially even for parameter fitting. This is of interest to an engineering audience who are developing and using IDF curves. Suggest restructuring the introduction to ensure the typical IDF curve audience understands this before reading the entire, very detailed study.

Answer: Thank you for pointing this out. We will change the introduction to more clearly communicate the benefits mentioned above.

5.

The motivation or added value for creating monthly IDF curves could also be discussed further (in results or discussion section). Is it worth it to use monthly maximum instead of annual maxima? If so, in which cases: for annual IDF curves in general, or only when we are interested in monthly extremes? Why?

Answer: The advantages of modeling monthly maxima are:

- reduced uncertainties in parameter and quantile estimation due to more available data points
- seasonal information
- better understanding of the processes/ duration dependence of the parameters.

They come at the cost of a more complex model. It is therefore suitable to use the monthly maxima when there are large differences in the seasonality of extreme events on different time scales, such as at the station Bever-talsperre, or for stations where only short observation time series are available. However, it must be considered that a misspecification of the seasonal variations of the parameters can lead to poor results. Future studies should therefore investigate whether the assumptions made for the intra-annual variations of the d-GEV parameters can be relaxed further. Moreover, modeling monthly precipitation maxima with the GEV may not be possible in regions with very small precipitation amounts during some months of the year. Therefore, the applicability of the model to the data should always be verified.

We will add this information to the discussion.

6.

The discussion section, which repeats a lot of the results, could be condensed, or merged with the results section.

Answer: We agree and will combine the discussion section with the results section.

Specific comments

Line 25 and line 32

Similar to general comment. Why it is "critical" to provide information about extremes on a monthly basis?

Answer: See above.

Line 47 – 52

This is a common problem, not just in Germany. Many places (like the US, NOAA NCDC) have 50 years or more of daily data, with data at sub-hourly resolutions only available in the past decade or so. I suggest making this statement more generalizable, and say this is also the case for Germany, the focus of this study. Many others will also be interested in using the available data more efficiently through pooling information.

Answer: We will change this accordingly.

Line 59 – 64

Yes, block maxima typically are only used for annual maximum because other methods like peaks over threshold (see Coles) are used if you want to capture more data and extremes within a year. Why not use the peaks over threshold method instead of monthly block sizes? If monthly variation is relevant, why are periodic functions needed as covariates (instead of a GEV distribution dependent on duration and month)? It seems that later on you clarify this – parameters can be reduced. Suggest clarifying this in the introduction as well and that you will compare the two techniques later on.

Answer: We will mention in the introduction, that the POT approach is an alternative method for modeling precipitation extremes, which can make more use of the available data than the block-maxima approach. We consider it more complex, however, to include seasonal variations into a duration-dependent GPD distribution.

We will also mention that smooth periodic functions as covariates are used to reduce the number of parameters which need to be estimated in the introduction.

Line 65

Did Fischer et al compare this method to peaks over threshold? More precise quantile estimates compared to what?

Answer: Fischer et al. (2018) compared the annual return levels of 24 h precipitation sums estimated from a GEV using annual maxima to those estimated when modeling monthly maxima using a GEV with smooth periodic functions as covariates.

Line 74, research question 3

this question is unclear and should be briefly introduced in the introduction.

Answer: Thank you for pointing this out, we will add an explanation in the introduction.

Line 137 – 138

unclear what is meant by "identically distributed precipitation cannot be motivated if an annual cycle exists. . . " Please clarify. Is it an interannual cycle or intra-annual? Also, do you mean independent identically distributed?

Anwer: A basic assumption of the Fisher-Tippett-Gnedenko theorem is that the random variables within each block are independent and identically distributed (iid). However, we can see that there is a clear intra-annual cycle for the precipitation intensity and this assumption is therefore violated when modeling annual maxima. We will reword this sentence to make it more clear.

Line 139

what is meant by "sufficient"? Meaning it can be used? It is a compromise? Also, this sentence is repeated from the introduction. Suggest rewording, shortening, or removing.

Answer: We will reword this sentence. Briefly, sufficient in this context means that the GEV distribution is well suited for the description of the monthly maxima, despite the smaller block size. For a more detailed explanation, please see our response to Reviewer Comment 1 https://hess.copernicus.org/preprints/hess-2021-336/hess-2021-336-AC1-supplement.pdf.

Line 215

choice to keep the shape and theta parameters constant is justified. How so? It seems these parameters are varying in the same fashion as mu, the modified location parameter? A bit more explanation here would be useful.

Answer: The choice to keep the shape parameter ξ and the duration offset parameter θ constant is discussed in the manuscript in lines 187-197. We agree that we have not sufficiently discussed our choice of a varying modified location parameter $\tilde{\mu}$. We will add our reasoning to the manuscript.

The modified location parameter is defined as

$$\tilde{\mu} = \mu(d)/\sigma(d).$$

Therefore setting $\tilde{\mu}(\text{doy}) = \text{const.}$ would enforce the annual cycle of the location parameter μ and the scale parameter σ to be in phase for any fixed duration d. Maraun et al. (2009) investigated this relationship for daily precipitation sums in the UK and found that this assumption is not justified, because the annual cycles of these two parameters are slightly out of phase. We investigated this in an explorative analysis by modeling the individual durations. For this purpose, we modeled the monthly maxima of each duration using a GEV with monthly covariates. Figure 1 shows the resultig parameter estimates μ and σ for some durations at station Bever-Talsperre in the first two columns as lines. For comparison, the estimates resulting from separately modeling the maxima of each duration and month with a GEV are shown as dots. The right column presents the resulting estimates for μ/σ for each duration. Since μ/σ shows a clear variation for each duration, it can be concluded that the assumption of phase equality of μ and σ for each duration may be too restrictive. Based on this exploratory analysis, we decided to adopt a varying parameter $\tilde{\mu}$ throughout the year.

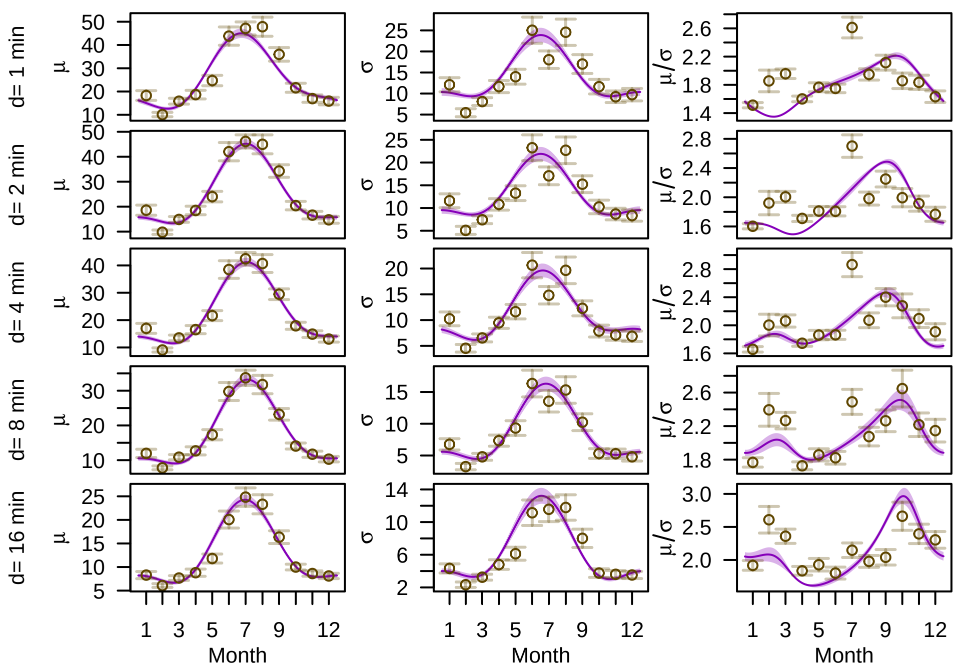

Figure 1: Parameter estimates for fixed durations modeling monthly maxima using (1) a GEV with monthly covariates (purple lines) and (2) a separate GEV model for each month (dots). The error bars and shaded areas show the 95% confidence intervals obtained via the estimated Fisher information matrix.

We suggest to add the additional information about the exploratory analysis to the appendix.

Reference

- Maraun, D., Rust, H. W., and Osborn, T. J.: The annual cycle of heavy precipitation across the United Kingdom: a model based on extreme value statistics, Int. J. of Climatol., 29, 1731–1744, https://doi.org/10.1002/joc.1811, 2009.

Line 350

could you comment on what this implies for IDF created with annual block sizes? Does it matter?

Answer: It does not seem to affect the quantiles estimated from the annual maxima, at least at stations where the annual maxima of different durations are from approximately the same seasons, such as stations (3)-(6) in Figure 4 in the manuscript. When a stronger shift in seasonality between short and long durations exists, as at station (1) and (2), the IDF model as defined in equations (4)-(7) in the manuscript is not able to reproduce this shift. This can be observed in Figures 6 (left) and B1 in the manuscript. The annual maxima of the individual durations originate from different seasons or distributions and therefore do not follow a simple power-law for longer durations. However, this could be resolved by adjusting the annual IDF model.

Lines 352 – 354

The authors state that the annual maxima originate from effective blocks of different sizes, seasons, etc. Could you comment more on why this is a problem when annual block sizes are used? Wouldn't the annual maxima still be captured? Does it matter when it occurred?

Answer: It does not matter as long as the effects caused by a shift in seasonality in the annual maxima of different durations are accounted for in the annual IDF model. To accomplish this, these effects must first be understood. Therefore modeling of the seasonality is a crucial step.