

Review Response HESS-egusphere-2025-3073

We would like to thank all reviewers for their constructive comments which helped to significantly improve our manuscript. Please find our detailed reply to Reviewer #1's concerns below. We also have to apologise for some minor errors we discovered during revision. We address these at the end of this reply.

Rev #1's recommendations (see Rev #1's report for their detailed comments):

- Estimate seasonal return levels assuming that the seasonal maxima follow a GEV (as already done in the manuscript).
- Estimate yearly return levels from seasonal GEV distributions, both in the (long-term) stationary analysis, and year by year in the (long-term) non-stationary analysis as a basis for the estimation of trends.
- Add a paragraph in the Method description.
- Discuss briefly the ability of weather types to indicate differences in processes, and eventually justify the grouping of the months into seasons.

First we want to thank you for the time and effort you put into reviewing our manuscript and for your detailed explanation and suggestions. This is very much appreciated. On purely theoretical grounds, we also agree with your considerations. We have now done the analysis as suggested also for the nonstationary case, and find that the results are, while of course not the same, comparable. However, the extent to which we can verify which method is actually performing better is very limited, and within these limitations we do not find any reason to give more credit to either method. In our opinion, there is also still a high risk of error propagation even when deriving annual from seasonal estimates. Also, the computational effort of deriving seasonal/annual return levels from monthly/seasonal fits is multiple times higher than the direct fit on seasonal / annual maxima. We have thus decided to keep the original methodology, and have extended the discussion significantly to address the alternative method. We further believe that we can use the relative influence of the different weather patterns to justify the assumption that not only do the seasonal maxima come from a (reasonably) homogenous distribution, as you have pointed out in your comments, but that this can actually be assumed for annual maxima, too.

Please find our detailed reply including figures below.

We start by comparing the results of both methods for estimating annual 20-year return levels for the 'recent' period (EDF and Météo-France stations between 1980 and 2023 as in the manuscript). As Figure 1 and Figure 2 show, both methods give very similar results for both daily ($R=0.98$) and hourly ($R=0.95$) extremes in the stationary analysis. The

estimates differ more in the trend estimates for the long EDF time series covering 1952-2022 (Figure 3), but remain well correlated ($R=0.88$ for daily, $R=0.72$ for hourly trends). However, the number of stations with a significant trend is different, especially in the southern part of the study area, as Figure 4 shows.

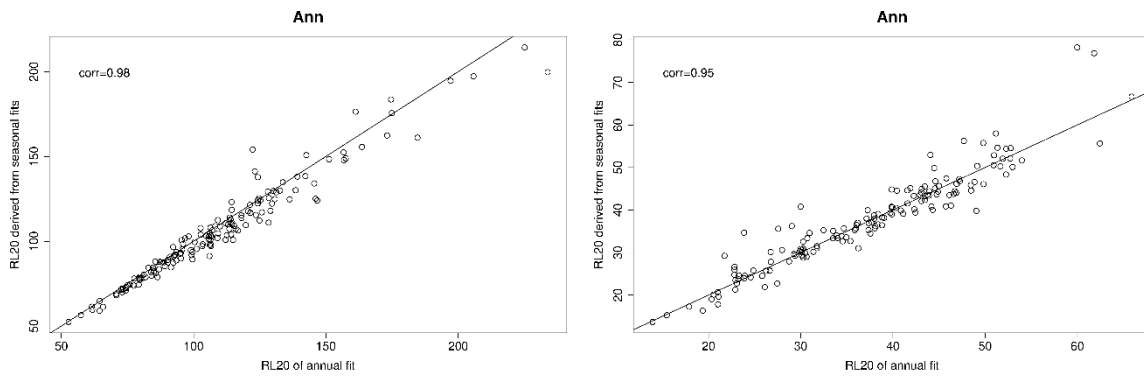


Figure 1: Comparison of the two methods for daily (left, in mm/d) and hourly (right, in mm/h) estimates of annual 20-year return levels in the stationary analysis between 1980 and 2023.

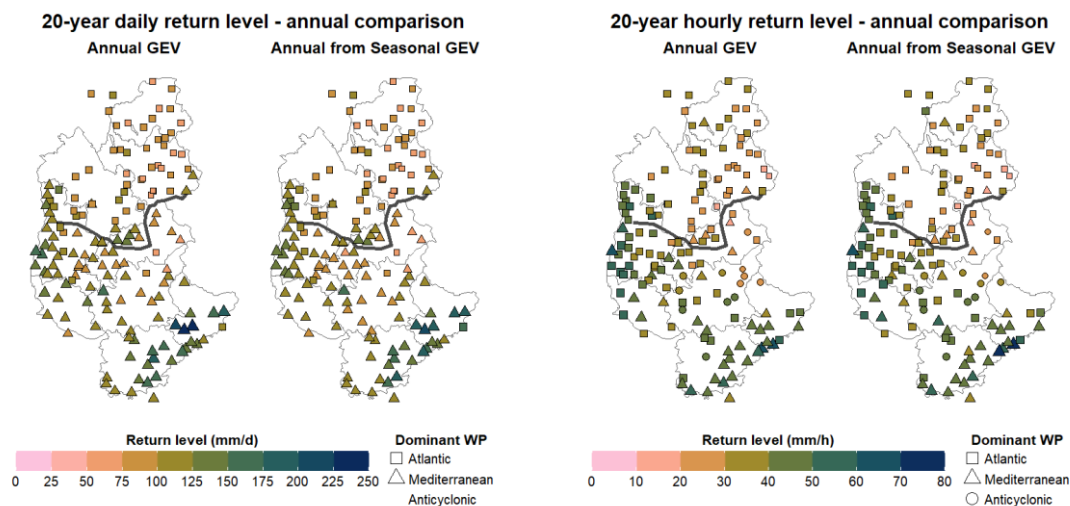


Figure 2: Same as Figure 1, but shown on maps. The symbols show the dominant weather pattern for annual maxima at each station.

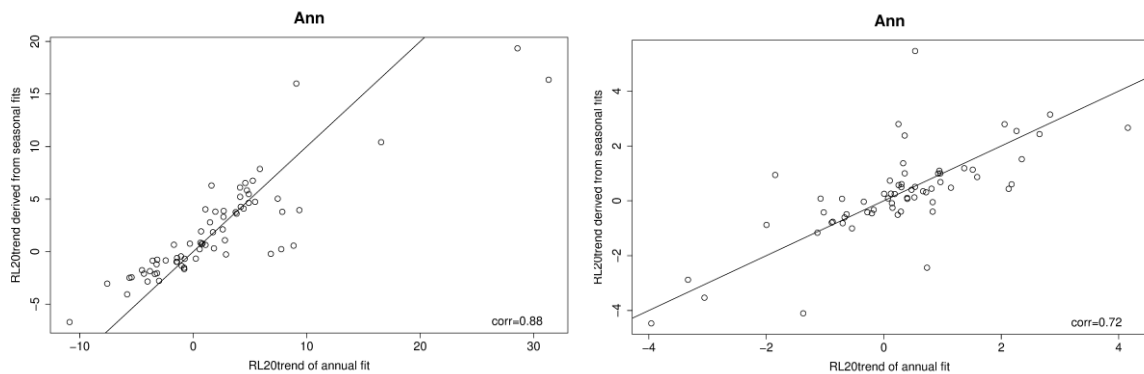


Figure 3: Comparison of the two methods for daily (left) and hourly (right) estimates of trends in annual 20-year return levels (between 1985 and 2022, in mm/d/10y and mm/h/10y, respectively) in the non-stationary analysis.

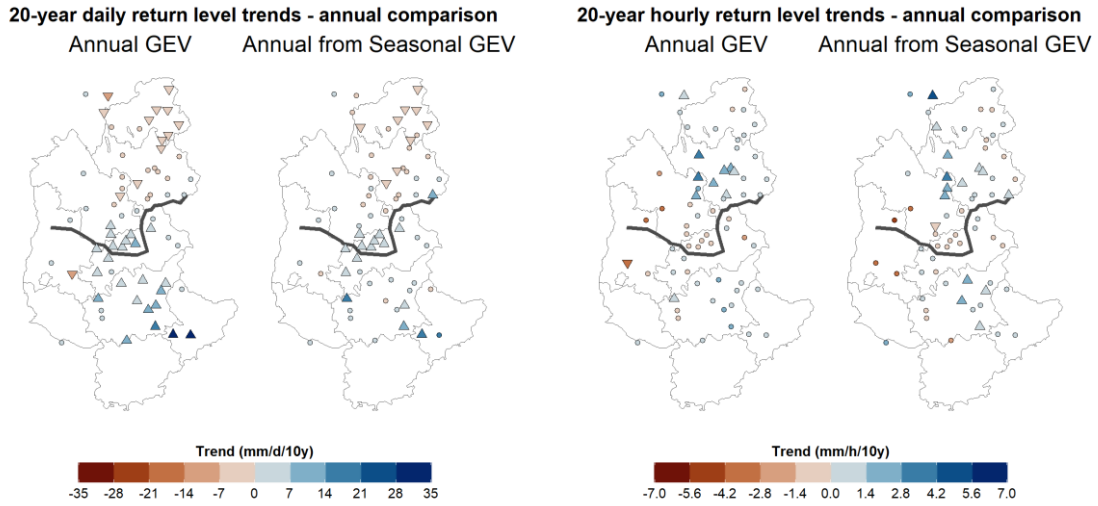


Figure 4: Same as Figure 3, but shown on maps.

For the sake of completeness, we also show the scatterplots for seasonal and annual trends derived from the monthly GEVs (Figure 5 and Figure 6). Due to error propagation, the correlation between the two methods drops strongly, which confirms our reply to the previous round of review.

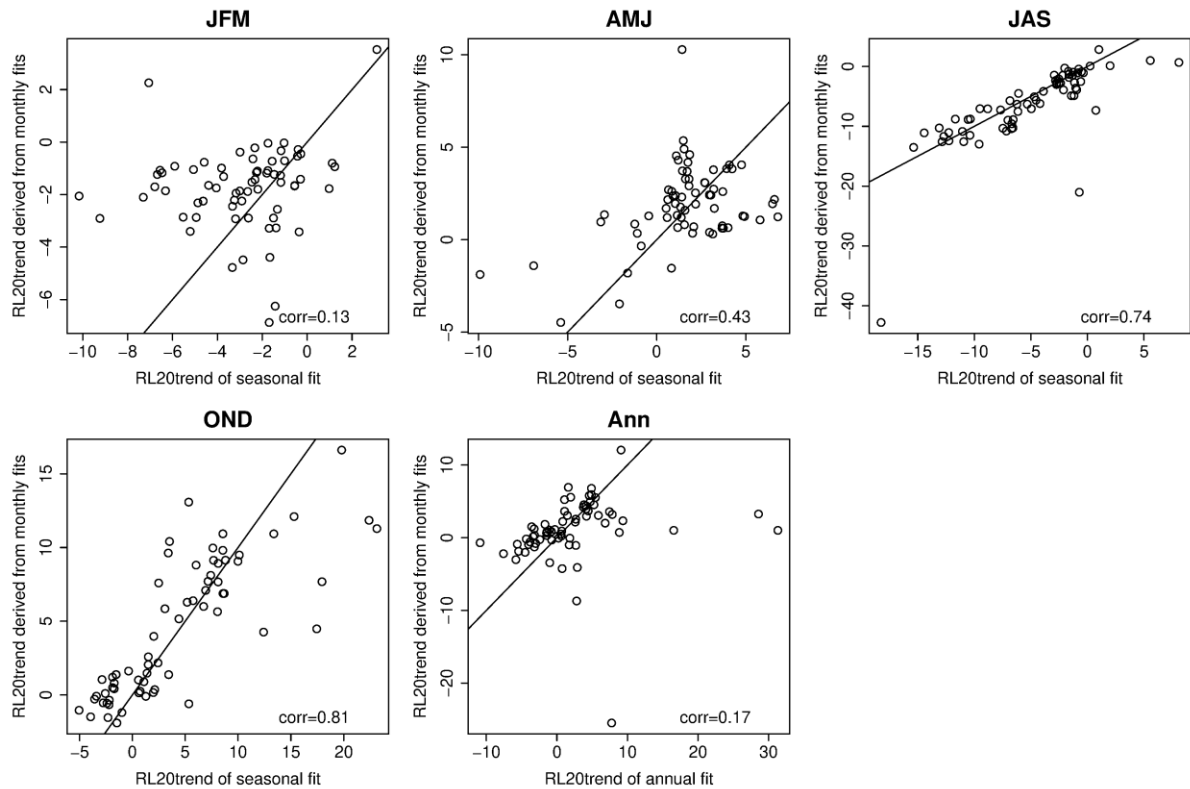


Figure 5: Comparison of the two methods for daily estimates of trends in seasonal and annual 20-year return levels (between 1990 and 2020, in mm/d/10y) in the non-stationary analysis, here derived from monthly GEV fits.

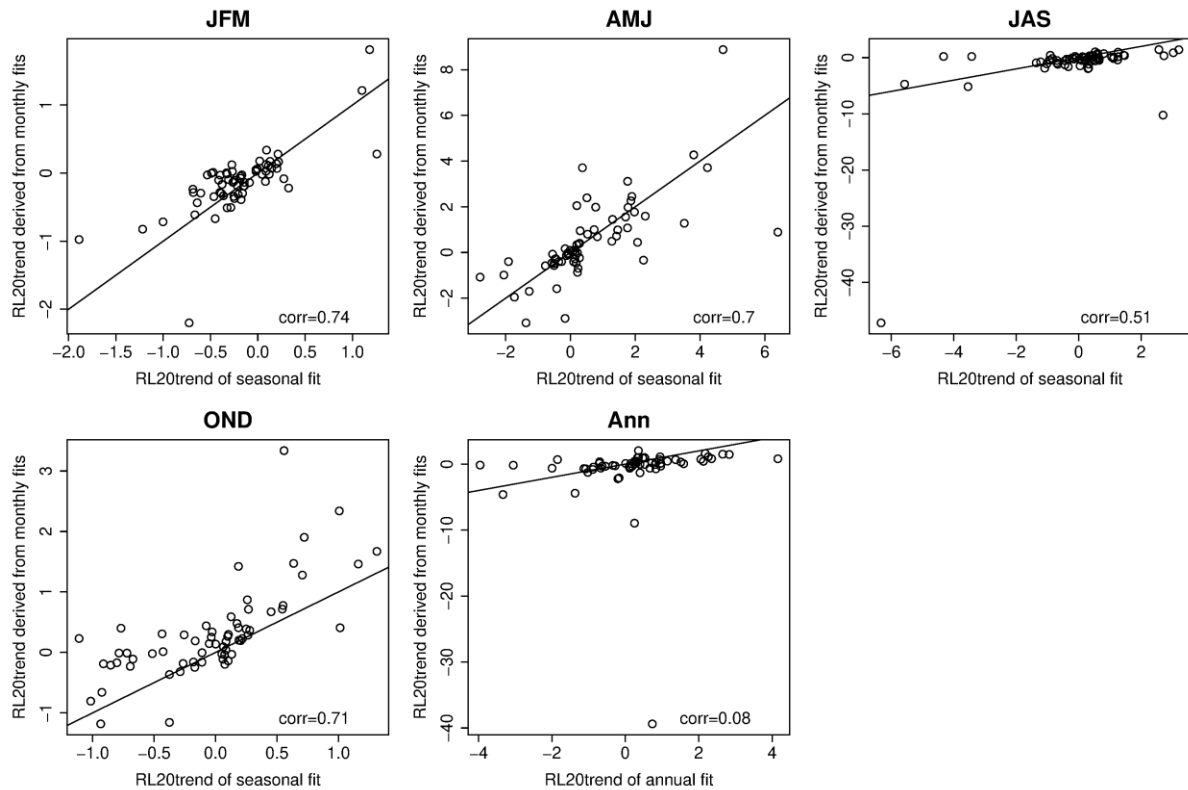


Figure 6: Same as Figure 5, but for hourly RL20.

So we turn back to the suggestion to derive only annual return levels from the seasonal GEV fit, but we are still left with the question if this would represent a significant improvement. Unfortunately, unlike the stationary case where we can have reasonable empirical estimates of 20-year return levels, we cannot have empirical estimates of 20-year return level trends as we do not have sufficient data. However, we know that the 2-year return level corresponds to the median of the annual maxima, thus we can at least compare the trend in the 2-year return level to the trend in the median obtained by quantile regression (qreg). Figure 7 shows the comparison of the two methods for the 2-year return levels. The correlations are a bit higher than for the 20-year return level, which is expected.

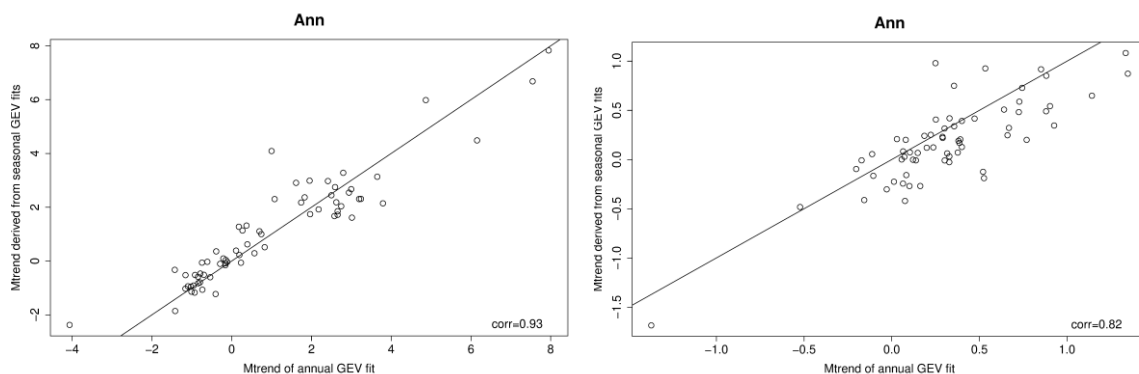


Figure 7: Same as Figure 3, but for 2-year return levels

In Figure 8 we now compare the trends in the 2-year return level estimated by the two different methods to the trend in the median for daily intensities obtained by qreg. Both methods show high correlation with the median trend, with the trends derived from the seasonal GEVs showing slightly higher correlations than the values derived from the annual fit (0.9 vs 0.87).

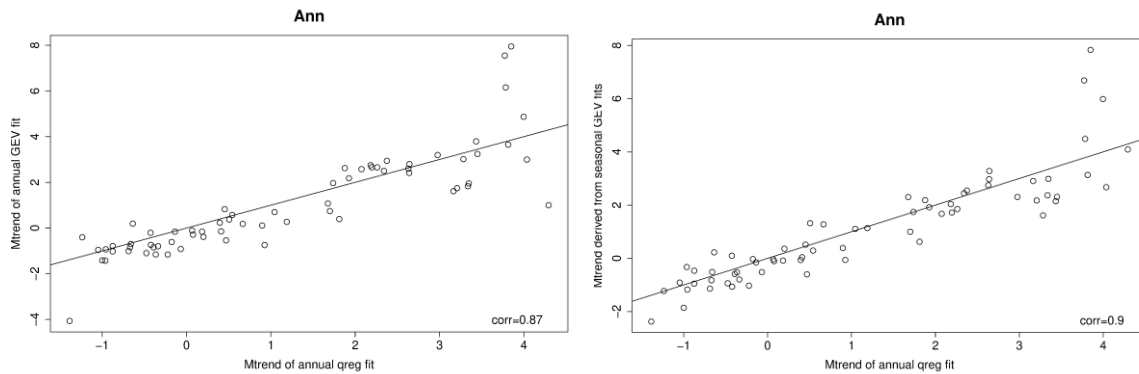


Figure 8: Comparison of the trend in daily 2-year return level (between 1990 and 2020, in mm/d/10y) derived from annual maxima (left) and from the seasonal GEVs (right) with the quantile regression on the median.

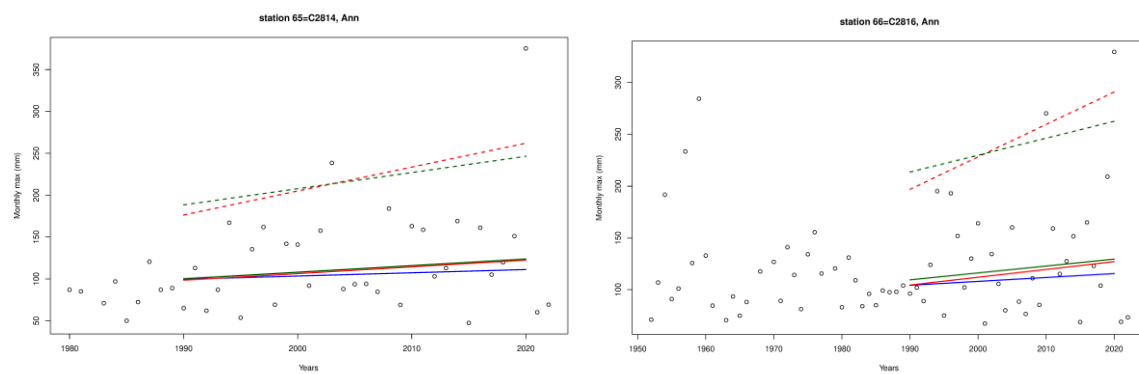


Figure 9: Comparison of the median regression (blue), and the 2-year return level estimated by the two different methods (red: GEV on annual maxima, blue: return levels derived from seasonal GEVs, both in mm/d/10y). The two stations shown are the ones showing the highest difference with the median trend in Figure 8. The linear trends are shown for 1990-2020, which corresponds to the trends shown in the manuscripts and the previous figures. The GEV is fitted on the whole dataset (see Sec. 3.1.2 in the manuscript)

Some stations show high differences in 2-year return level trends between the estimates obtained by qreg and the trend in RL2 for both methods, however, the differences actually don't seem very important given the scale of the absolute values (Figure 9).

For hourly timesteps, the overall picture is very similar. The correlations are a bit worse, and in this case the direct estimate based on annual maxima is a bit better than the estimate based on seasonal GEVs (0.68 vs 0.64, Figure 10)

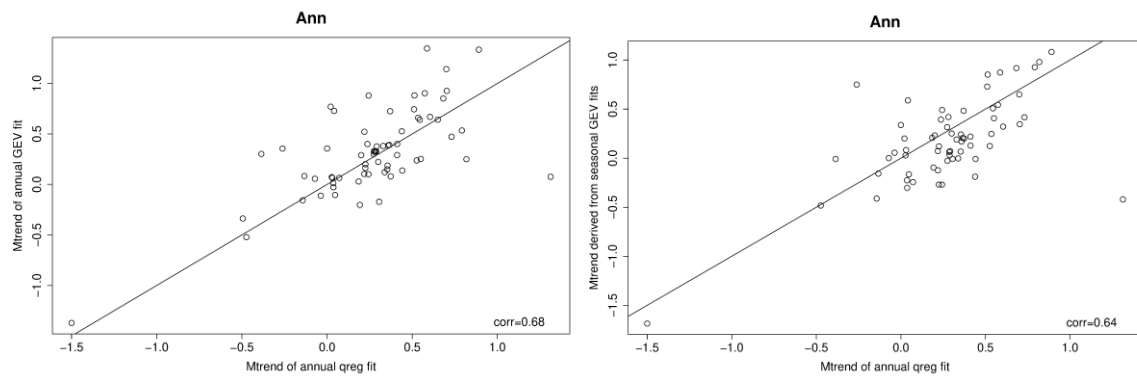


Figure 10: Comparison of the hourly 2-year return level derived from annual maxima (left) and from the seasonal GEVs (right) with the linear trend of the annual maxima.

Looking again at a station with a comparatively high difference in Figure 10, we see that also here the difference seems small compared to the absolute values (Figure 11).

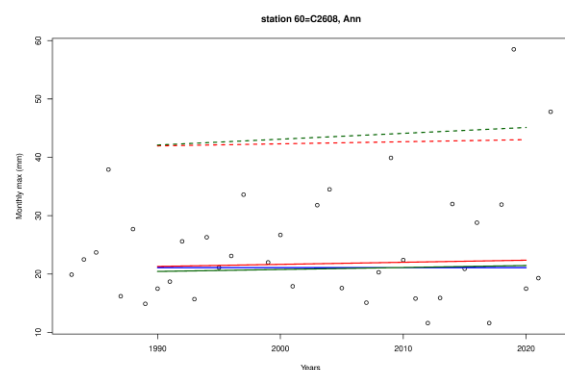


Figure 11: Comparison of the median regression (blue), and the 2-year return level estimated by the two different methods (red: GEV on annual maxima, blue: return levels derived from seasonal GEVs) – shown is the station with the biggest error in Figure 10.

Given these considerations, we prefer to keep the original method, i.e., to estimate annual return levels based on annual maxima. This can actually also be justified given the relative influence of the weather patterns, as for daily intensities this looks very similar for both annual and autumnal maxima (OND, manuscript Fig. 6). For hourly intensities on the other hand it is the spring and summer seasons that closely resemble the annual distribution of WPs (AMJ, JAS, Figure 12, also as Fig. S2 in the supplement). As also the stationary patterns look very similar between the annual 20-year return levels and those for the respective seasons mentioned above, we have good reason to assume that these actually come from a similar distribution (or in other words, that annual maxima are dominated by specific seasons, which in itself have a homogenous distribution).

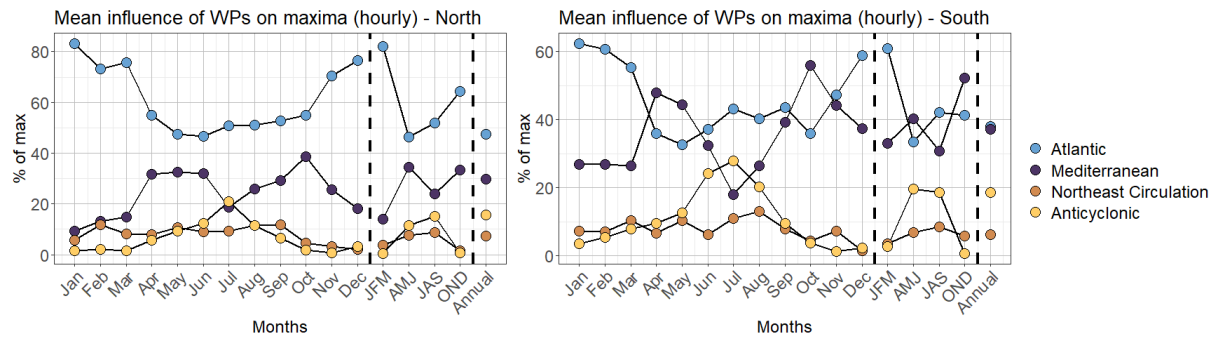


Figure 12: Relative influence of the four weather patterns on monthly/seasonal/annual maxima of hourly precipitation intensity in the study region, grouped by stations north (left) and south (right) of the climatological divide.

We have thus modified the manuscript as follows:

- We modified and extended the Discussion, specifically the part on methodological limitations. It now includes a brief summary of the suggested alternative method and the limitations we identified (Section 5.1.3).
- In support of this, we added Figure 2 and Figure 4 to the supplementary material (as Figures S6 and S7), and reference it in the text.
- We also included a brief discussion on the ability of the weather patterns to justify the grouping of months into seasons, and especially to justify our choice regarding the estimation of annual return levels, as discussed above.
- As the Discussion increased in length, we added subsections for better structure.
- Since we do not show the results of the suggested alternative method in the manuscript, we did not add anything to the Methods description.

Further notes

During revision we noticed a few minor errors and inconsistencies, which we have also corrected now (see below). We want to apologise for these oversights on our side.

- We found some inconsistencies between the manuscript and our codes concerning the periods covered by the different datasets. Actually, the number of observational time series that pass all quality control procedures and minimal length requirements for hourly data is 154 (instead of 161) for the stationary, and 66 (instead of 65) for the nonstationary analysis. For daily data the numbers are 156 and 67, respectively. We have now corrected this and also simplified which datasets are used for stationary and non-stationary analysis, respectively (changes in Section 2.2 and throughout the Results).
 - For stationary analysis we use all available time series with at least 25 years of observations between 1980 and 2023. This introduces some potential minor inhomogeneities in the 1980s, however, we consider these negligible.

- For non-stationary analysis all EDF time series covering between 34 and 71 years in the period 1952 and 2022 are used as before.
- We updated the table in the supplement (station metadata) with first and last years of available daily and hourly observations separately.
- We have also changed the method for parameter estimation in the stationary case and now use generalized maximum likelihood estimation instead of L-BFGS-B. This is slightly more robust and reduces the amount of outliers in Figs. 4,5, and 7 (changes in Section 3.2.1)
- Further, we have clarified that we use the neighbourhood approach only for non-stationary analysis (Section 3.2.2).
- We also noticed an error in our code leading to a mismatch between results and coordinates in Figs. 8-10, S3 and S4, meaning that not all trends were plotted at the correct locations in the trend figures. We corrected this now. We note that in the corrected figures the trends are spatially better organised (which seems reasonable given the regional approach we used to estimate trends), however, the overall conclusions remain the same. We scanned the manuscript for mismatches between figures and their interpretation and corrected these as necessary.

Overall, these improvements do not change the main patterns and conclusions, but increase the robustness of the methodology and lead to spatially more coherent patterns.