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Reply on RC1

Kajsa Maria Parding et al.

Author comment on "A principal component based strategy for regionalisation of precipitation intensity-duration-frequency (IDF) statistics" by Kajsa Maria Parding et al., Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2022-233-AC1, 2022

General Comments:

This manuscript is well-written with a good structure, and the proposed methodology is mathematically sound and well-established, which provides a good contribution in statistical inference methods of the IDF curves. Having said that, there are several issues needed to be addressed to better discuss the uncertainty and to enhance the applicability of the method.

- The nature and probabilistic behaviour of extreme climate phenomena is known to be influenced by anthropogenic climate change over time, which challenges the fundamental stationary risk concepts in calculating the IDF curves. As a result, the static stationary-based IDF curves may underestimate the occurrence probability of extreme precipitation. I wonder how the proposed methodology address the non-stationary issue (e.g. historical trends in the probability of heavy rainfall) and incorporate the influence of non-stationary conditions on IDF curves?

The proposed methodology does not address the non-stationarity issue. Both the IDFs (estimated from sub-daily precipitation data) and the climatological information (from daily climate data) that were used in the study are based on data from stations that meet some requirements of data availability, but not necessarily from the exact same period. Requiring a common period would have reduced the number of stations as well as the sample size for the stations that were included, which would also have reduced the representativeness.

A common way to take climate change into consideration in IDF statistics is to simply multiply the return values by a climate change factor that is derived from climate modeling. Another way to achieve this would be to use a statistical inference method like the one described in this study and apply it to downscaled climatological data for the future. Such an approach may add value to the IDF estimates by being site specific and scaling differently to different durations and return periods. (But as noted by both reviewers, we have not applied our method to downscaled climate data for the future yet, so this is hypothetical.)

- The Benestad et al, (2021) simple approximate formula that used to compare and assess the proposed methodology in this study is only one of many approaches in estimating the return values and predicting the IDF curves, and it is based on some assumptions (e.g. deliberate choice of using L=24) and is calibrated only from Oslo and validated at some independent sites in Norway. The formula has not been, to my knowledge, vigorously tested worldwide, and thus, remains regional specific. To ensure the robustness of the proposed methodology and increase its applicability, I suggest the authors evaluate the proposed methodology with several more commonly used statistical inference methods (e.g. parametric formulation of IDF relationships based on Koutsoyiannis et al. (1998) framework, distribution fitting using L-moments/probability weighted moments estimation, and regionalization methods such as the Index Flood method). In this way, the readers will have better ideas on how the proposed methodology performs against those widely used methods.

- Koutsoyiannis, D., Kozonis, D., & Manetas, A. (1998). A mathematical framework for studying rainfall intensity-duration-frequency relationships. Journal of Hydrology, 206(1-2), 118-135. https://doi.org/10.1016/S0022-1694(98)00097-3.

We compare our results to two other sets of return values, the ones calculated using the Lutz et al. 2020 method, which are the IDF statistics that we use as a sort of "truth" when calculating the RMSE, and the simple relationship developed by Benestad et al. (2021). The Benestad method has not been extensively tested and we think that's a good reason to include it here, not as a gold standard but as another regionalization method that also needs to be evaluated. It would be interesting to compare with other methods as well, but we consider it beyond the scope of this paper.

- As the authors correctly stated, the accuracy of IDF curves depends on the quality of input data and the statistical inference methods. While this study focuses on the latter, the former should not be neglected and a better discussion in this regard could be done. Since considerable amount of research (e.g. Eldardiry et al., 2015; Marra et al., 2017; Degaetano & Castellano, 2017) have been done on investigating the use of alternative sources of rainfall measurements (e.g. radar, satellite-based precipitation, downscaled global/regional climate models' precipitation simulations, and reanalysis products) in constructing the IDF curves, I wonder how these alternative sources of information could potentially be used and supplement with the ground stations in the study region?

- Eldardiry, H., Habib, E., & Zhang, Y. (2015). On the use of radar-based quantitative precipitation estimates for precipitation frequency analysis. Journal of Hydrology,531, 441–453. https://doi.org/10.1016/j.jhydrol.2015.05.016.
- Marra, F., Morin, E., Peleg, N., Mei, Y., & Anagnostou, E. N.: Intensity–duration–frequency curves from remote sensing rainfall estimates: comparing satellite and weather radar over the eastern Mediterranean, Hydrol. Earth Syst. Sci., 21, 2389–2404, https://doi.org/10.5194/hess-21-2389-2017, 2017.
- DeGaetano, A. T., & Castellano, C. M. (2017). Future projections of extreme precipitation intensity-duration-frequency curves for climate adaptation planning in New York State.Climate Services,5,23–35. https://doi.org/10.1016/j.cliser.2017.03.003.

That's an interesting idea. Other sources of information could be a useful complement to the surface based observations. While daily temperature and precipitation observations are more widely available than sub-daily data, there are issues with missing data in many regions. Gridded products have their limitations when it comes to representing extreme precipitation, as there is an inherent difference between point observations and the spatial average of a grid point. This is especially notable in a country such as Norway with dramatic topography and large climatological variations on small scales (high peaks, deep *valleys and fjords), where precipitation may differ considerably within a grid cell. Nevertheless, data from remote sensing could serve as an additional source of information.*

Specific Comments:

- L34-35: Certainly building the relationship between IDF curves and some climatological and geographical factors is one way to regionalize the IDF curves, but there are also other ways to estimate the IDF curves such as using radar and remote sensing data (e.g. Eldardiry et al., 2015; Marra et al., 2017; Ombadi et al., 2018; Sun et al., 2019). It would be appreciated if the authors could add some discussions in this regard.

- Ombadi, M., Nguyen, P., Sorooshian, S., & Hsu, K. L. (2018). Developing intensity-duration-frequency (IDF) curves from satellite-based precipitation: Methodology and evaluation. Water Resources Research, 54(10), 7752-7766. https://doi.org/10.1029/2018WR022929.
- Sun, Y., Wendi, D., Kim, D. E., & Liong, S. Y. (2019). Deriving intensity–duration–frequency (IDF) curves using downscaled in situ rainfall assimilated with remote sensing data. Geoscience Letters, 6(1), 1-12. https://doi.org/10.1186/s40562-019-0147-x.

A discussion about and references to studies of IDF regionalization using remote sensing data have been added to the manuscript.

- L40-41: It is not clear that why calculating IDF curves for each grid is impractical and computationally expensive as research has been done at the global scale, i.e. Courty et al., 2019. Please clarify.

- Courty, L. G., Wilby, R. L., Hillier, J. K., & Slater, L. J. (2019). Intensity-duration-frequency curves at the global scale. Environmental Research Letters, 14(8), 084045.

Calculating IDF curves for each point in a grid tends to be more computationally expensive than doing the same for a set of stations, simply because it involves more data. Of course, it is not so impractical and expensive that it cannot be done and it can definitely be worth doing to get a more complete spatial coverage. However, for Norway and other mountainous and coastal regions, the resolution of the grid would have to be very high. One example is the regionalization done by Dyrrdal et al. (2015) who estimated IDF curves for Norway based on the seNorge data set which has a 1x1 km resolution.

The sentence has been changed to clarify this.

Dyrrdal, A., Skaugen, T., Stordal, F. & Førland, Eirik. (2014). Estimating extreme areal precipitation in Norway from a gridded dataset. Hydrological Sciences Journal. 61. 141217125340005. 10.1080/02626667.2014.947289.

- L73-74: It seems to me that there are no analysis done on using the proposed statistical modelling in combination with future projections of meteorological quantities. I could have missed the material, please correct me if I am wrong. If not, please show the results or the objective is over-stated otherwise.

No, you are right, this has not been done yet. We have adjusted the text to clarify that this is a plan for the future rather than an analysis that has been performed.

- L88-90: Can the authors comment on the quality of the data (e.g. % of missing values) please?

For the IDF curves that were calculated and provided by Dr. Julia Lutz, the stations that were included had to have at least 80% data availability per April - October season and a minimum of 10 seasons that met this requirement. For the daily temperature and precipitation data used in this study, we had a similar requirement of data availability (10 years of available data). The observational data, both sub-daily and daily precipitation and temperature, has also undergone a quality assessment before being made publicly available by the Norwegian Meteorological Institute.

We added an investigation of the data availability of daily precipitation and temperature data at the stations that were included in the study in the supplementary material (Figure S23). Temperature and precipitation data are available for different periods at different locations, and in some instances with no overlap in time. Few stations have long complete observational records of both temperature and precipitation. For example, only four of the selected stations have a data availability of at least 70% in the period 1970-2020 for both temperature and precipitation. Since we do not have any restrictions on the specific period for which observations should be available and have no information about the precise period of the data that went into the IDF computations, there is no guarantee that the IDF curves and the climatological data that were used to tune the regionalization models represent the same period. This is a weakness of the study, and an unfortunate result of the sparseness of historical observations. Other sources of information, such as the gridded seNorge data set, could be used to alleviate this problem. A discussion of the data availability and quality has been added to the manuscript.

- L90-92: Is it possible to have the same station with temperature data assigned to two different IDF stations, given the sparse spatial coverage of the network?

Yes, it is possible and it happens. Out of the 74 stations considered in this study, 26 are assigned to multiple stations and 48 are associated with only one precipitation station. The multiple assignment occurs primarily in the more densely populated parts of the country where there are several precipitation stations in a relatively small area (around Stavanger, Trondheim and Oslo). Since the temperature is rather spatially homogeneous, this is likely not a very large issue when looking at climatological values. However, it would be interesting to look further into this, as a part of a larger investigation into the influence of data quality and availability on the estimated IDF curves.

- L196-205: The sensitivity of the IDF curves on the predictors were examined by holding one variable constant at a time. I wonder how the combined effect of the predictors influences on the shape and level of the IDF curves? It would be appreciated if the authors could do a more in-depth analysis here.

We did some investigations of how changing combinations of parameters influence the shape of the IDFs, and while they did not reveal anything unexpected, the new figure was helpful in showing how the various parameters can interact. For example, it clearly showed how the wet-day mean precipitation in the warm season (April - September) had a more dominant influence on the estimated IDFs than the wet-day mean in the cold season (October - March). The new plot is included in the Supplementary material as Figure S13.

Remarks:

- Figure 2: the IDF curves for all return periods for eight stations (Figure S4) could be shown here alongside with the geographical locations of the stations, i.e. combining Figure S4 and Figure 2.

That’s a good idea. We have combined the two figures and replaced Figure 2 with the new and improved version.