Report on the Extreme Rainfall Event 14.07.2021 Rainfall Intensity-Duration-Frequency Analysis

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1 Aim

We intend to estimate the annual exceedance probabilities (or average return periods) of the mean precipitation intensities over different time intervals that occurred during the event. For this purpose, we employ a duration-dependent generalized extreme value (d-GEV) distribution, to model the distribution of annual precipitation intensity maxima for different accumulation durations. Since in a previous study we have already applied these methods to the Wupper Catchment, which was affected by the event, we initially focus on this area in this report. However, the methods used can be extended to a larger area. We estimate the Intensity-Duration-Frequency (IDF) relationships for different stations in the study area using both a station-based and a spatial model. From this, we can subsequently classify the recorded precipitation intensities in the event. We aim to answer the following question: Based on the previous analyses, what are the estimated annual exceedance probabilities of the maximum precipitation intensities during the event?

2 Data and Methods

2.1 Station-Based Precipitation Data

Recent rainfall data for this event and historical data was obtained from the German Meteorological Service (DWD) and is publicly available [DWD, 2021]. More historical data has been provided by Wupperverband. Annual maxima of rainfall from both sources can be found online [Fauer et al., 2021]. Table 1 lists all stations and their DWD ID considered in this analysis. Recorded daily sums are the aggregated maximum 24-hour duration rainfall values between 13-16.07.2021. In some cases rainfall measurements were interrupted and the records can show values smaller than the actual precipitation amount. Maps of the RADOLAN recorded rainfall [Weigl and Winterrath, 2009] are shown in Fig. 1 as well as accumulated daily sums and positions of measurement stations. The station with highest daily rainfall sum is Koeln-Stammheim at the south-west edge of the considered region. The accumulated sums show that most of the total rainfall occurred on Wednesday (14.07.2021). A wider time range from 13th to 16th July is necessary to obtain accumulated maxima for durations of up to 72 hours.

2.2 Duration-Dependent GEV

Extreme precipitation values can be defined by their exceeding probability. An annual non-exceeding-probability of p=0.99 can be interpreted as an event, that occurs on average every 100 years (return period). The concept of return periods however should be treated carefully because it is not to be confused with a fixed frequency.

The probability of an event can be evaluated by fitting a duration-dependent Generalized Extreme Value (d-GEV) distribution to annual maxima of the recorded data. We use a 5-parameter [Koutsoyiannis et al., 1998] maximum likelihood model as in Ulrich et al. [2020] to derive non-exceedance probabilites (average return periods) for the event at 14.07.2021.

The model can be trained for each station individually (station-based) or for all stations at once in a spatial setting with latitude and longitude as covariates for the five d-GEV parameters. The spatial model enables a spatial interpolation and decreases uncertainty, because more information can be used for quantile estimation. On the other hand, the station-based model estimates quantiles better [see Ulrich et al., 2020] and is more flexible regarding new station data,

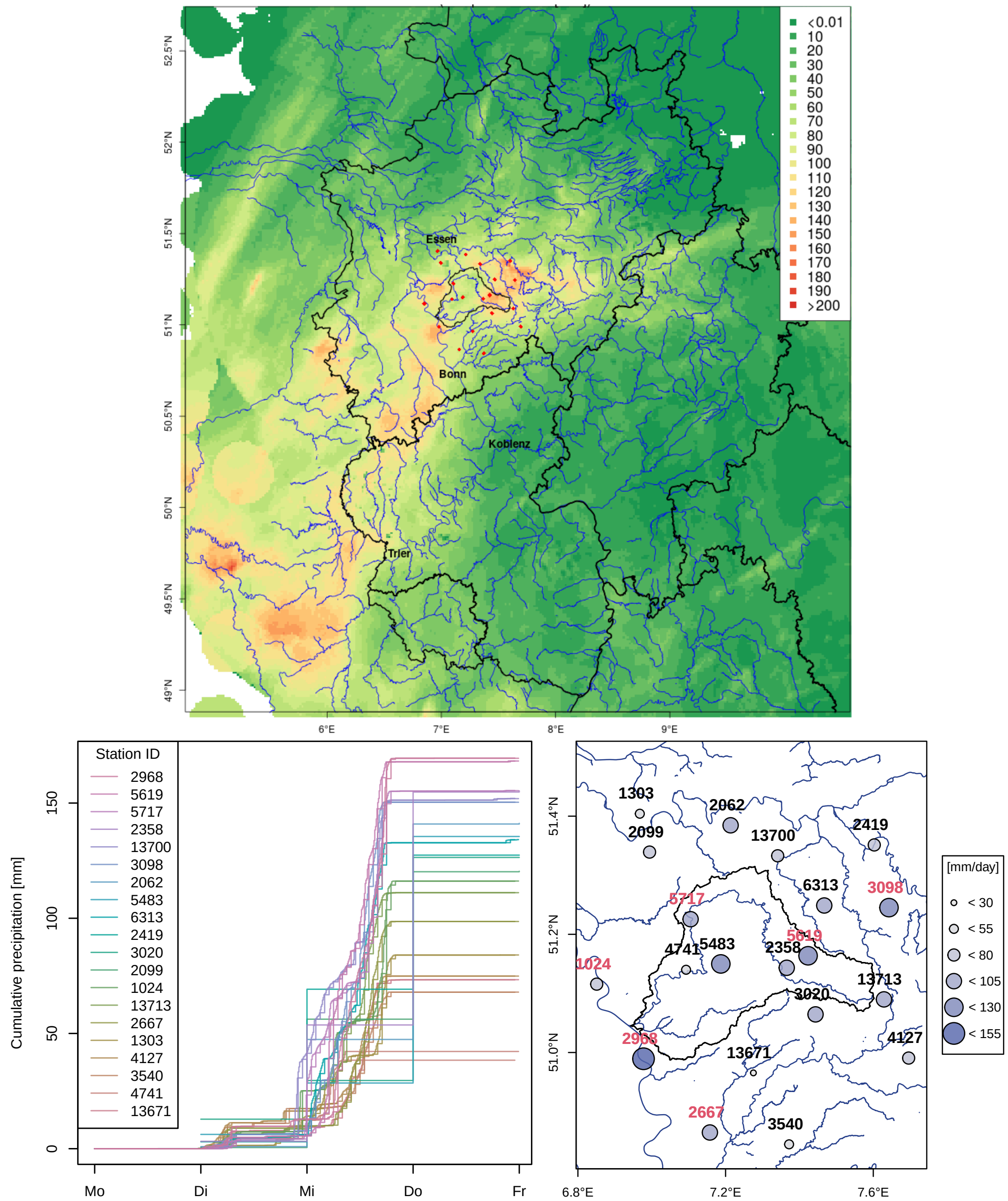


Figure 1: **Top**: RADOLAN Radar 24-hour rainfall sum (mm) from 13-16.07.2021 over North Rhine Westphalia and Rhineland Palatinate. Red dots indicate the positions of the avalaible rain gauges for the Wupper Catchment. **Bottom left**: Station-based accumulated precipitation sum. **Bottom right**: Maximum daily precipitation sum in and around the Wupper Catchment (thick black line). IDF curves will be presented in this report for stations labelled in red.

Table 1: List of DWD stations with recent data from 13-16.07.2021. Temporal Resolution refers to the available measurement frequency. *****: For these stations IDF curves are presented in this report.

Station	ID	Temp. Resolution	daily sum (mm)
***Dormagen-Zons**	01024	10min	79.70
Essen-Bredeney	01303	10min	53.70
Hattingen-Holthausen	02062	day	93.50
Heiligenhaus-Abtskueche	02099	day	64.00
Hueckeswagen (Bevertalsperre)	02358	day	101.10
Iserlohn-Letmathe	02419	day	66.20
***Koeln-Bonn**	02667	10min	88.40
***Koeln-Stammheim**	02968	10min	153.50
Lindlar-Oberlichtinghagen	03020	day	96.80
***Luedenscheid**	03098	10min	114.40
Neunkirchen-Seelscheid	03540	10min	49.90
Reichshof-Eckenhagen	04127	10min	55.30
Solingen-Hohenscheid	04741	10min	30.50
Wermelskirchen	05483	day	107.00
***Wipperfuerth-Gardeweg**	05619	10min	111.80
***Wuppertal-Buchenhofen**	05717	10min	90.80
Breckerfeld-Wengeberg	06313	10min	91.00
Overath-Boeke	13671	10min	6.70
Gevelsberg-Oberbroeking	13700	10min	78.90
Meinerzhagen-Redlendorf	13713	10min	82.10

because no model selection is needed. Both the spatial and the station-based model are used here.

3 Results

Intensity-Duration-Frequency (IDF) curves are a powerful tool to show the probability (frequency) of an event with a certain intensity for different durations (time scales). Figure 2 shows IDF curves and average return periods of the event at 14.07.2021 for 6 selected stations (* in Tab. 1). Since most of the selected stations are located at the edge of the considered region, the spatial model might find worse estimates than the station-based model, however with smaller uncertainty because more data has been taken into account. Especially for Dormagen-Zons (1024), average return periods differ from $>$1000 years (spatial model) to 200 years (station-based model). At the other stations, average return periods are similar in both models with $\sim$300 years only for Koeln-Bonn and $>$1000 years elsewhere. Highest non-exceedance probabilites (longest average return periods) are found at most stations for a duration of 24 hours or slightly less. These very high and possibly unrealistic return periods could point to a limitation of the model which assumes a stationary climate. Since it is expected that extreme rainfall will occur more often in a changing climate, future models should adapt to this phenomenon.

4 Outlook

This report shows preliminary results of IDF curves and return periods for this extreme rainfall event. We plan to improve the methodology for more accurate results. One approach is to expand the considered region with more stations. The spatial model might profit from that, since interesting stations are at the edge of the region, where polynomials for the spatial covariates are harder to fit. Furthermore, we want to address the question how estimates change when data from different time periods is considered. This might help understanding the limits of the concept of return periods in a changing climate. Non-stationarity can also be included in the model with selected large-scale covariates. This is planned for future studies.

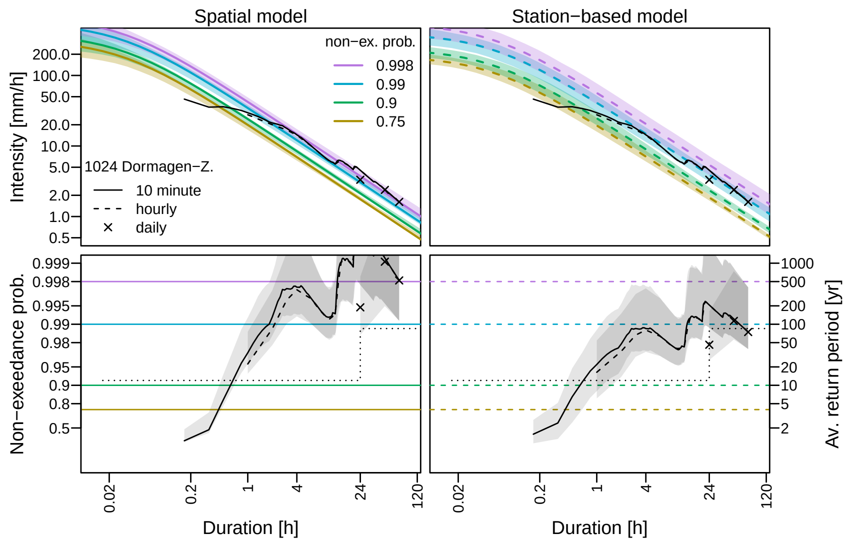
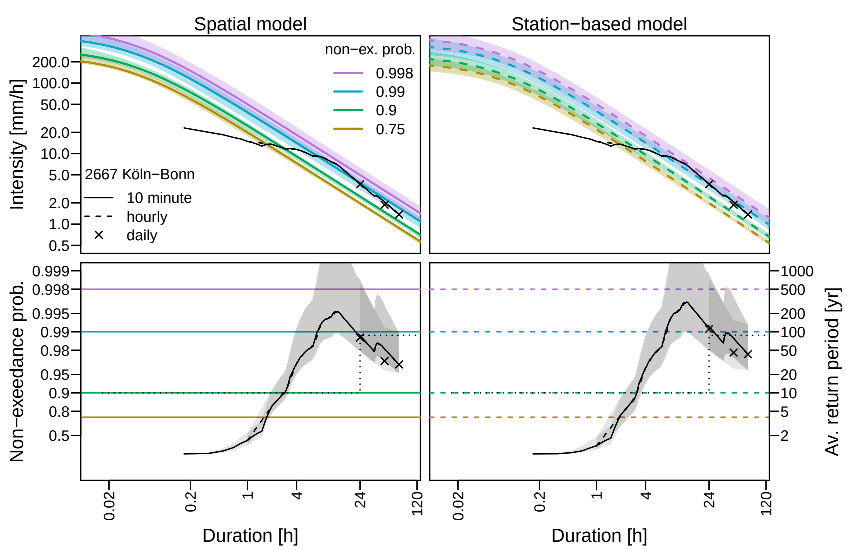
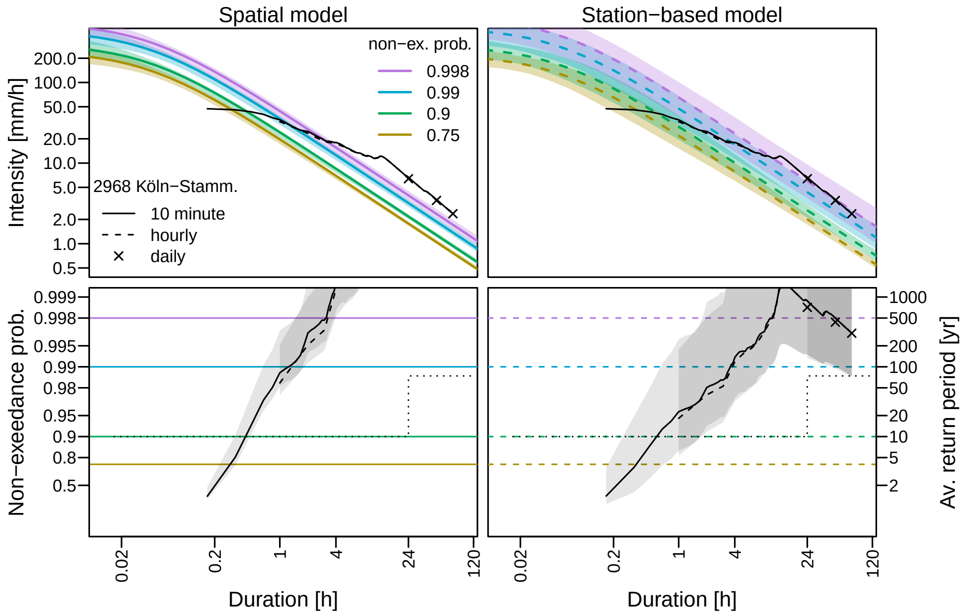


Figure 2: **Top:** IDF curves. Colored lines indicate the modelled intensities for chosen probabilities. Black lines show the intensity of the event at 14.07.2021 for three different measurement resolutions. **Bottom:** Average return periods / non-exceedance probabilities. The dotted line indicates the number of years in the historic record for the respective accumulation duration. **Left:** Spatial model. **Right:** Station-based model.





Spatial model
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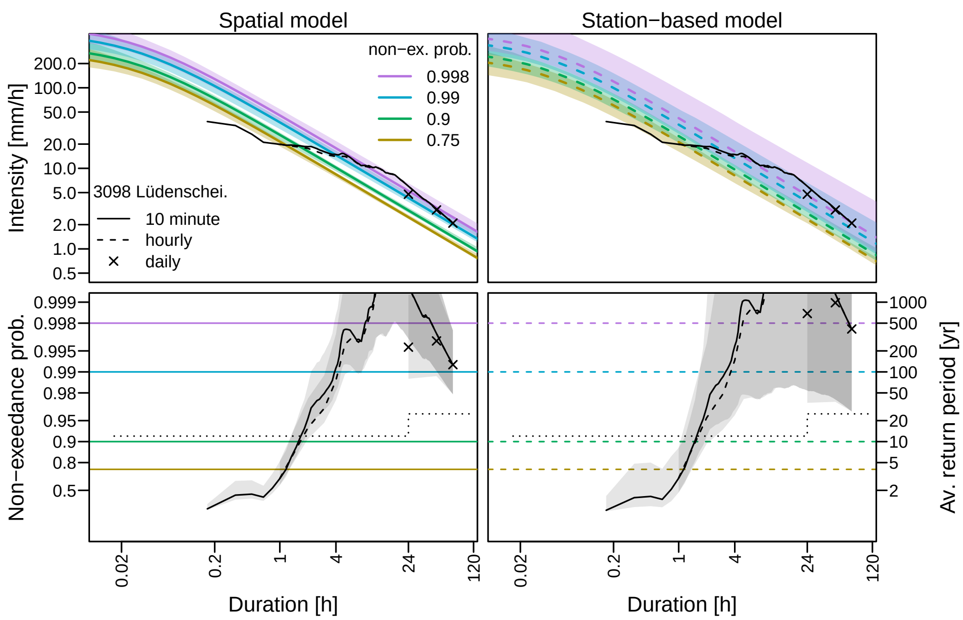
Av. return period [yr]
Duration [h]



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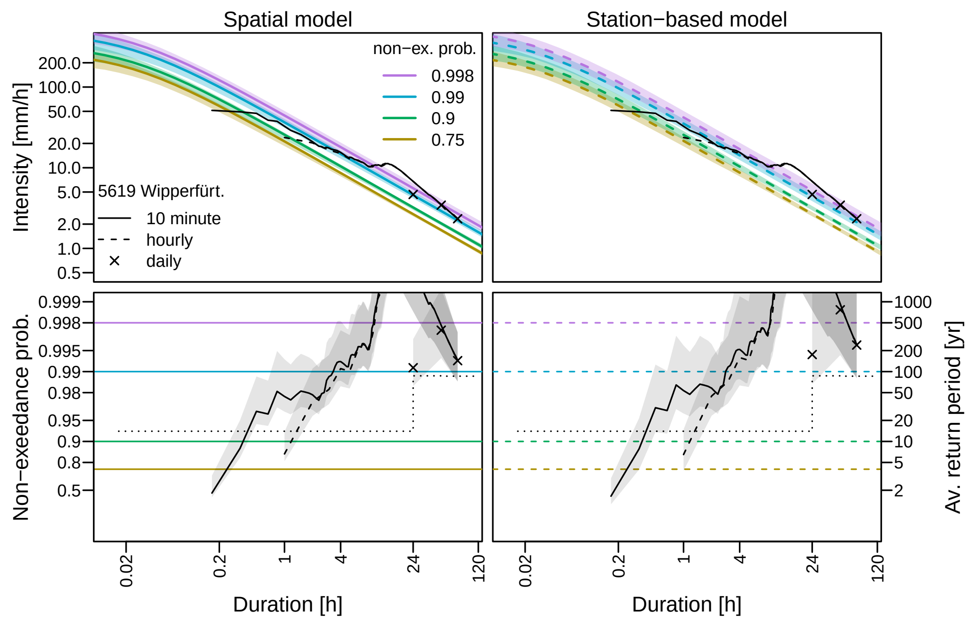
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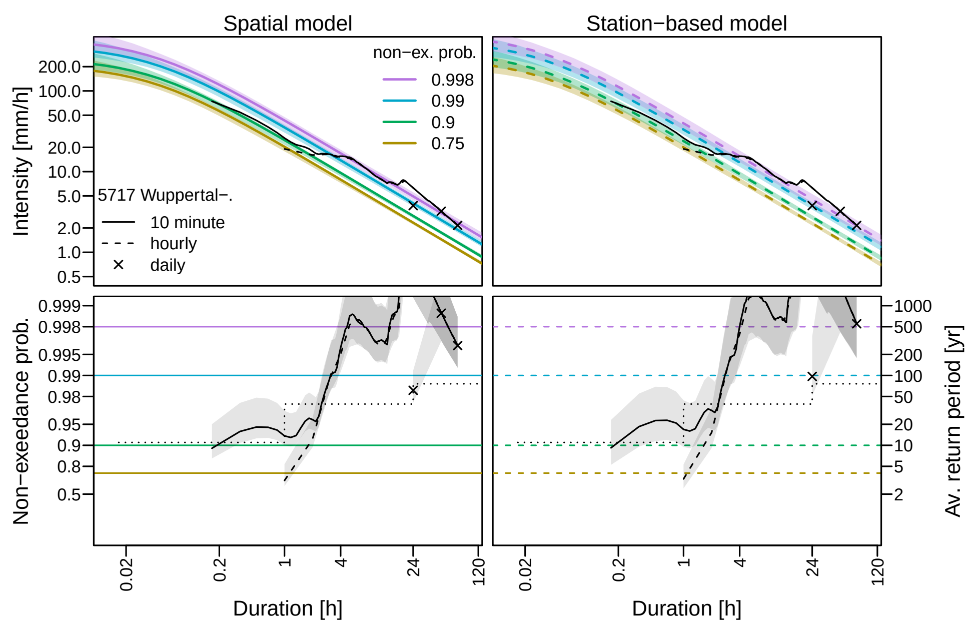
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Non−exeedance prob.
Av. return period [yr]
Duration [h]

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