Joint effects of rain-gauge density and data resolution on estimates of extreme precipitation over short durations

Point precipitation measured at rain gauges is widely used to estimate the quantiles of extreme rainfall, using frequency analyses, thus obtaining Depth (or intensity) - Duration - Frequency (DDF) values. Due to the mostly convective nature of extreme precipitation over short durations, many such events are limited to a small geographical area. This, in combination with their rarity, results in these extreme events having small probabilities of being captured or detected by rain gauge stations, which are typically few and far between, at least in the United States. We propose that this must result in crucial effects of the density of the rain gauge network on our estimates of extreme precipitation. Moreover, the rather low 15-min time resolution at most US stations introduces a negative bias for the shorter durations, as the clock-time (fixed-time window) data are not able to capture the true sliding-window values when extracting the maxima.

Germany has 182 main meteorological stations and 1925 voluntary weather stations for precipitation, with long time series of observations; of these, about 900 rainfall stations provide at least 10 concurrent years of data at 1-minute resolution. The spatial density of rain gauges is thus at least one order of magnitude higher than in the US, where the typical time resolution of rainfall data is of only 15 minutes. In this study, we use this German data at a much higher spatial and temporal resolution to better understand how the density of a rain gauge network and the temporal resolution of the rain gauges jointly affect the estimation of extreme precipitation. In other, more general words, we aim at understanding how different would the information about DDF values be in Germany, both in central tendency and variability, if they had the same type of rainfall data that we typically have in the US, with lower gauge density and temporal resolution.

These possible effects are explored in two different ways. In a simpler framework, we will generate DDF values at every single station, independently, for durations D =10 min, 15 min, 20 min, 30 min, 45 min, 60 min, 90 min, and120 min, and relatively frequent average return intervals ($\leq$ 10 years), using partial duration (PD) analyses. Cunnane (1973) demonstrated that PD series are more efficient than Annual maxima(AM) series when the average number of yearly occurrences is greater than 1.6. Also, selecting higher values for average yearly occurrence may introduce dependence on both time and magnitude of an extreme event. Therefore, our PD series will contain 2 occurrences per year on average. We will use the same, short period of record for all stations, thus minimizing the effects of non-stationarity. To study the effect of the temporal resolution of the data, all analyses will be conducted both for maxima extracted using clock data, as well as for true maxima from sliding time windows. The available data at a 1-minute temporal resolution will be aggregated to clock (fixed-time) data at a 15-minute temporal resolution, thus mimicking the temporal resolution available at US stations. The fixed-time, 15-min records will be obtained in 15 different ways at each station, by resampling the 1-min data (i.e., shifting the starting by 1 min, and then by 2 min, and so on), giving us insight into the at-a-station variability. We will then randomly subsample stations from the complete German network of rain gauges, randomly choosing one of the 15 possible 15-min records at each station, thus generating a large number of possible realizations of lower-density networks with 15-min data. From the complete (full density) rain gauge network, using the 1-min data, we will create a spatial map of the “true” DDF values using the sliding time-window maxima. On the other hand, from the multiple realizations of the lower-density networks, using the 15-min totalized data, we will create spatial maps for the DDF values (including both central tendency and variability) that will mimick the gauge density and type of data, as well as the procedures typically used in the US. These DDF values at each grid point obtained from the different spatiotemporal realizations of 15-minute precipitation records will follow a certain distribution around the “true” DDF values. For each return period and rainfall duration, we will create a map of the bias and uncertainty in DDF values, using the aforementioned distribution parameters, which will summarize the joint effects of lower rain gauge density and temporal resolution of data on DDF values.

In a second, more complex approach, we will simulate the regionalization procedure followed in NOAA’s Atlas 14, i.e., we will use L-moments (Hoskin and Wallis, 1997) of partial duration series (PDS). The regional shape parameter will be used to compute the DDF values for each grid point inside a region. The comparisons between the DDF values obtained from the regional frequency analysis and the earlier method will allow us to explain and attribute the estimation biases due to station density and temporal resolution of the data, as well as those introduced by using a typical regionalization procedure.