Areal Reduction Factors from COSMO-REA6 Reanalysis

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Background and Motivation

Design rainfall is typically expressed as Intensity–Frequency–Duration (IFD) data at point locations. However, for hydrological applications—particularly in larger catchments—point rainfall does not adequately represent the areal average rainfall. The ratio between areal and point design rainfall values for the same duration defines the *Areal Reduction Factor (ARF)*.

In this study, ARFs are derived from the COSMO-REA6 gridded reanalysis dataset (6 km spatial resolution, 1-hour temporal resolution) for a group of catchments in Slovakia covering areas up to 10 000 km^2. Areal rainfall series are constructed directly from grid-cell precipitation, and annual maxima are analyzed for durations of 1, 3, 6, and 24 hours.

Uncertainty in ARF estimation is quantified using non-parametric bootstrapping, and seasonal differences are explicitly considered to capture variability in precipitation-producing processes and their spatial extent across the year. The resulting ARF relationships provide regionally consistent estimates that enhance the translation of point-based IFD data into hydrologically relevant design rainfall for catchments of varying sizes.

Derivation of Annual and Seasonal Areal Reduction Factors (ARF)

Data and temporal aggregation. Hourly COSMO-REA6 precipitation fields were processed sequentially. Each file contributes one hour of rainfall to rolling D-hour totals ($D = 1$–24 h):

$$R_D(t) = \sum_{i=0}^{D-1} R_{1\mathrm{h}}(t-i),$$

yielding continuous D-hour rainfall time series over the model grid.

Spatial aggregation per catchment. For each catchment polygon with N grid cells, the rainfall fields were converted to time series of catchment-mean and point-maximum rainfall:

$$R_{\mathrm{area},D}(t) = \frac{1}{N}\sum_{j=1}^{N} R_D(t,j), \qquad R_{\mathrm{point},D}(t) = \max_{1\le j\le N} R_D(t,j).$$

This converts gridded fields into representative catchment values.

Annual and seasonal maxima. For each hydrological year y and season s (DJF–MAM–JJA–SON), the script maintains running maxima of both quantities. Whenever a new point maximum occurs, the corresponding areal mean is recorded:

$$R^{\max}_{\mathrm{area},D,y} = \max_t R_{\mathrm{area},D}(t),$$
$$R^{\max}_{\mathrm{point},D,y} = \max_t R_{\mathrm{point},D}(t),$$
$$\overline{R}_{\mathrm{at\,max},D,y} = R_{\mathrm{area},D}(t^*), \quad t^* = \arg\max_t R_{\mathrm{point},D}(t).$$

An analogous procedure is applied seasonally. Here t^* denotes the time of the maximum point rainfall (Eulerian definition).

Areal reduction factor.

$$\boxed{\mathrm{ARF}_{D,y} = \frac{\overline{R}_{\mathrm{at\,max},D,y}}{R^{\max}_{\mathrm{point},D,y}}.}$$

Both quantities correspond to the same event (t^*), ensuring $\mathrm{ARF} \le 1$ and a physically consistent comparison of spatially averaged versus local peak intensity.

ARF Model Fitting and Bootstrap Uncertainty

Purpose. To quantify how ARF decreases with increasing catchment area, median-binned observations from sub-catchments were fitted with a normalized exponential–power model.

Model formulation. For each duration D and catchment:

$$\widehat{\mathrm{ARF}}(A) = \frac{\exp[-(kA)^n]}{\exp[-(kA_0)^n]}, \qquad A_0 = 1\ \mathrm{km}^2.$$

The scale parameter k controls spatial decay, and the shape parameter n governs curvature. Normalization ensures $\widehat{\mathrm{ARF}}(1) = 1$.

Parameter estimation. Initial guesses derive from the linearized form $\ln[-\ln R(A)] = n\ln A + n\ln k$. Final estimates use robust nonlinear least squares with:

$$(k,n) = \arg\min_{k,n} \sum_i \rho_{\mathrm{soft\text{-}L1}}\left[R_i - \frac{\exp[-(kA_i)^n]}{\exp[-(kA_0)^n]}\right],$$

with bounds $10^{-8} < k < 1$, $10^{-3} < n < 5$.

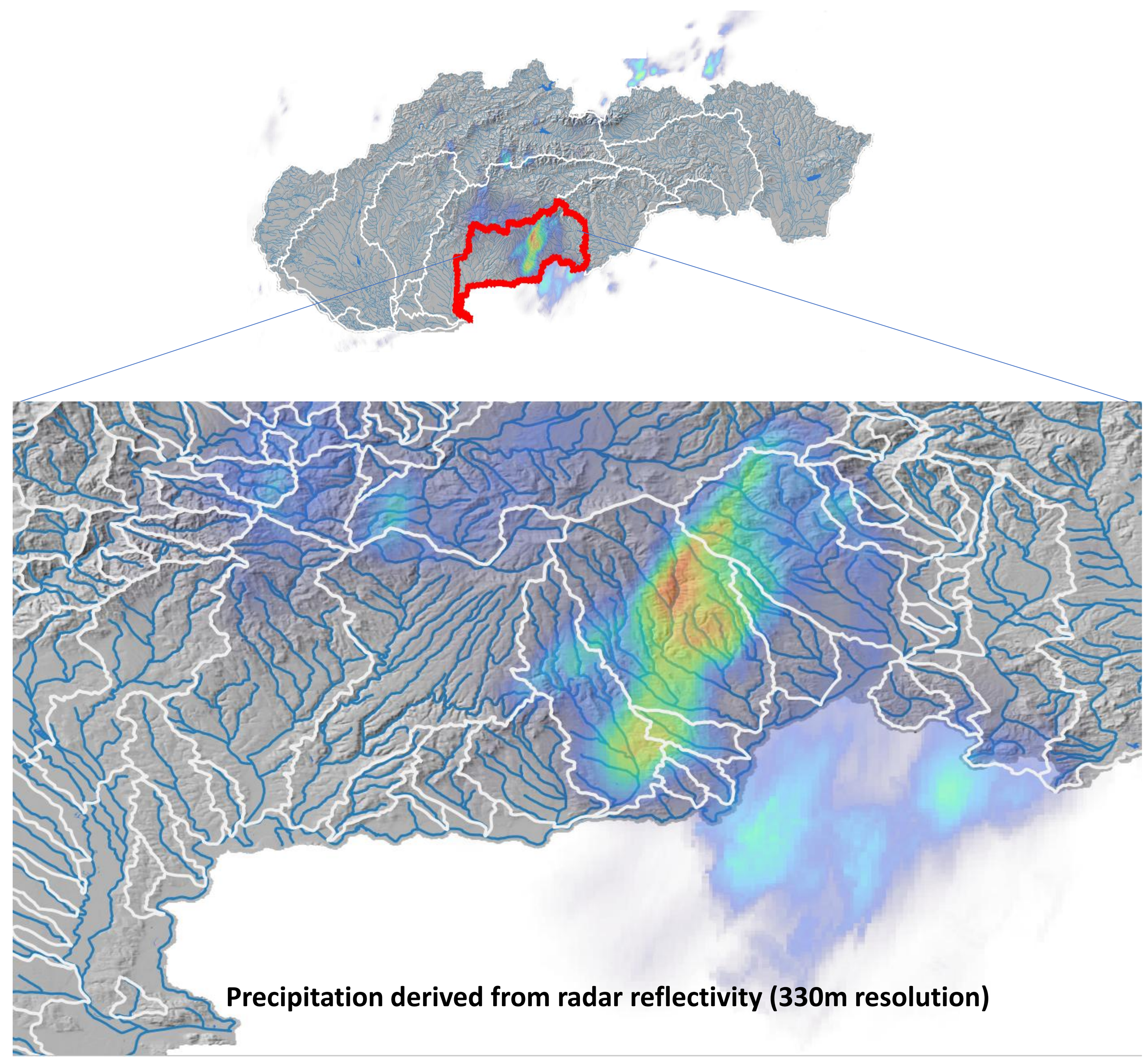
Bootstrap uncertainty. Parameter uncertainty is evaluated using non-parametric bootstrap resampling ($B = 200$):

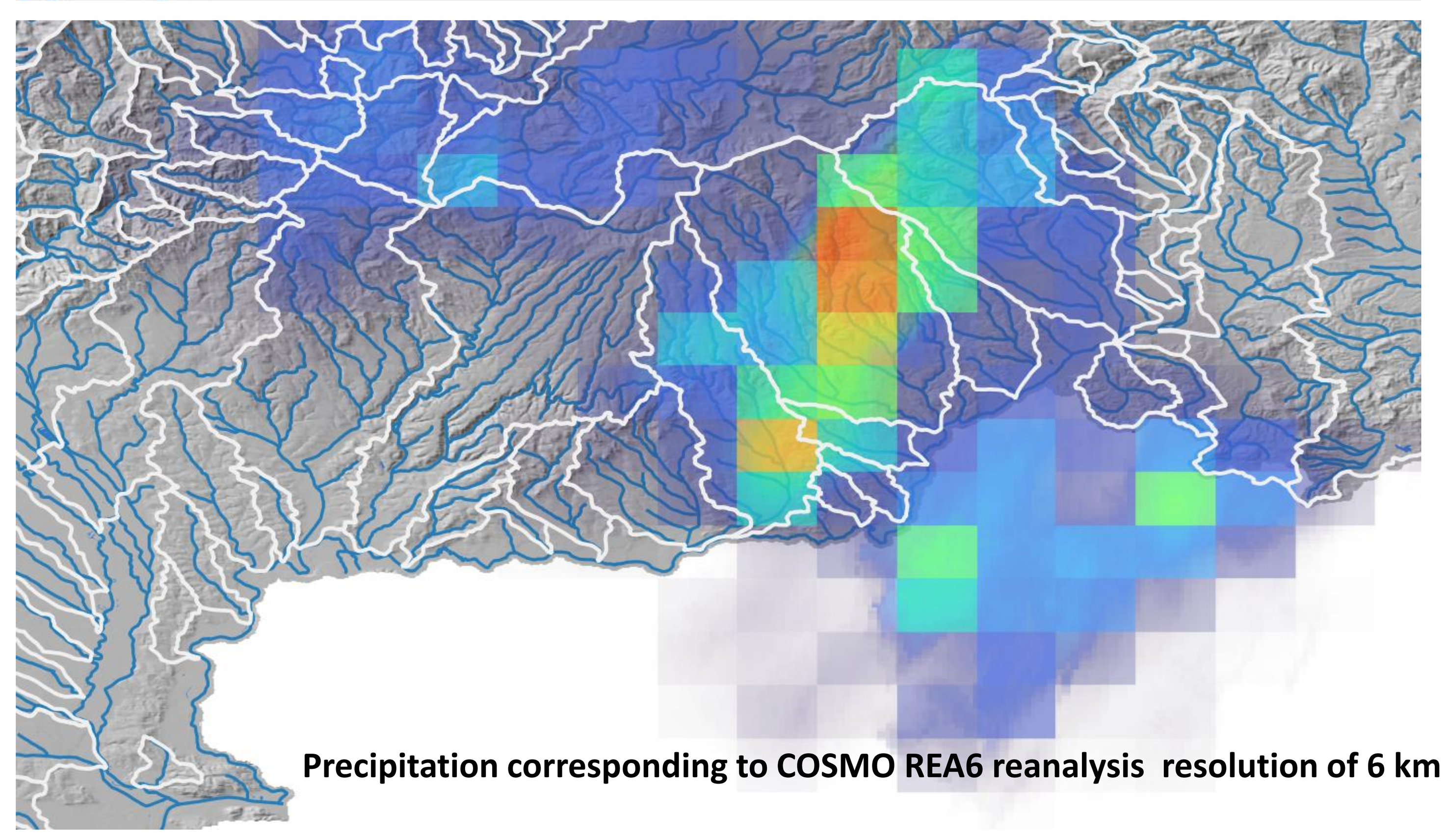
$$\widehat{\mathrm{ARF}}^{(b)}(A) = \frac{\exp[-(k^{(b)}A)^{n^{(b)}}]}{\exp[-(k^{(b)}A_0)^{n^{(b)}}]}, \quad b = 1,\ldots,B.$$

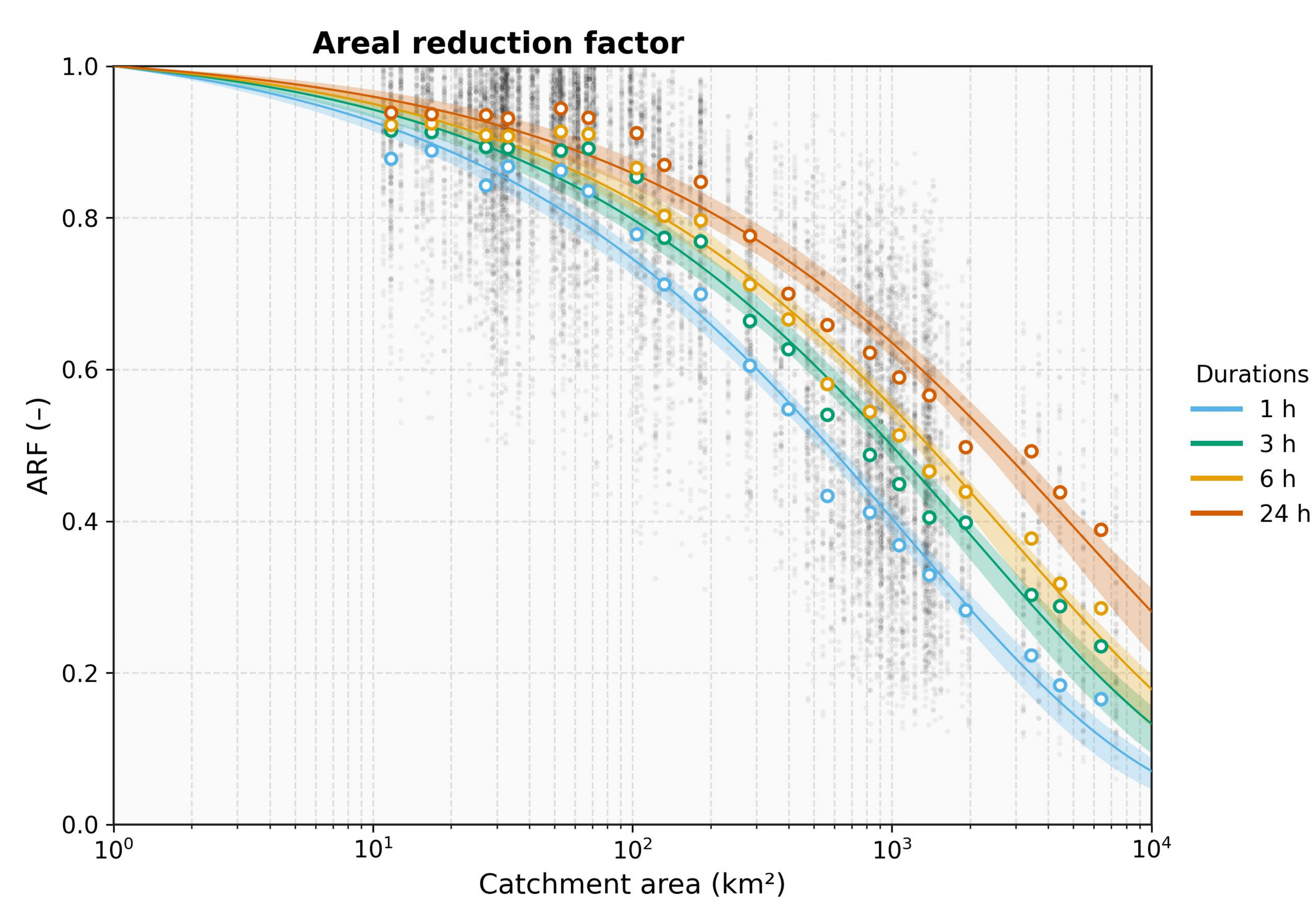
At each area A, the 5th and 95th percentiles of $\widehat{\mathrm{ARF}}^{(b)}(A)$ define the confidence envelope:

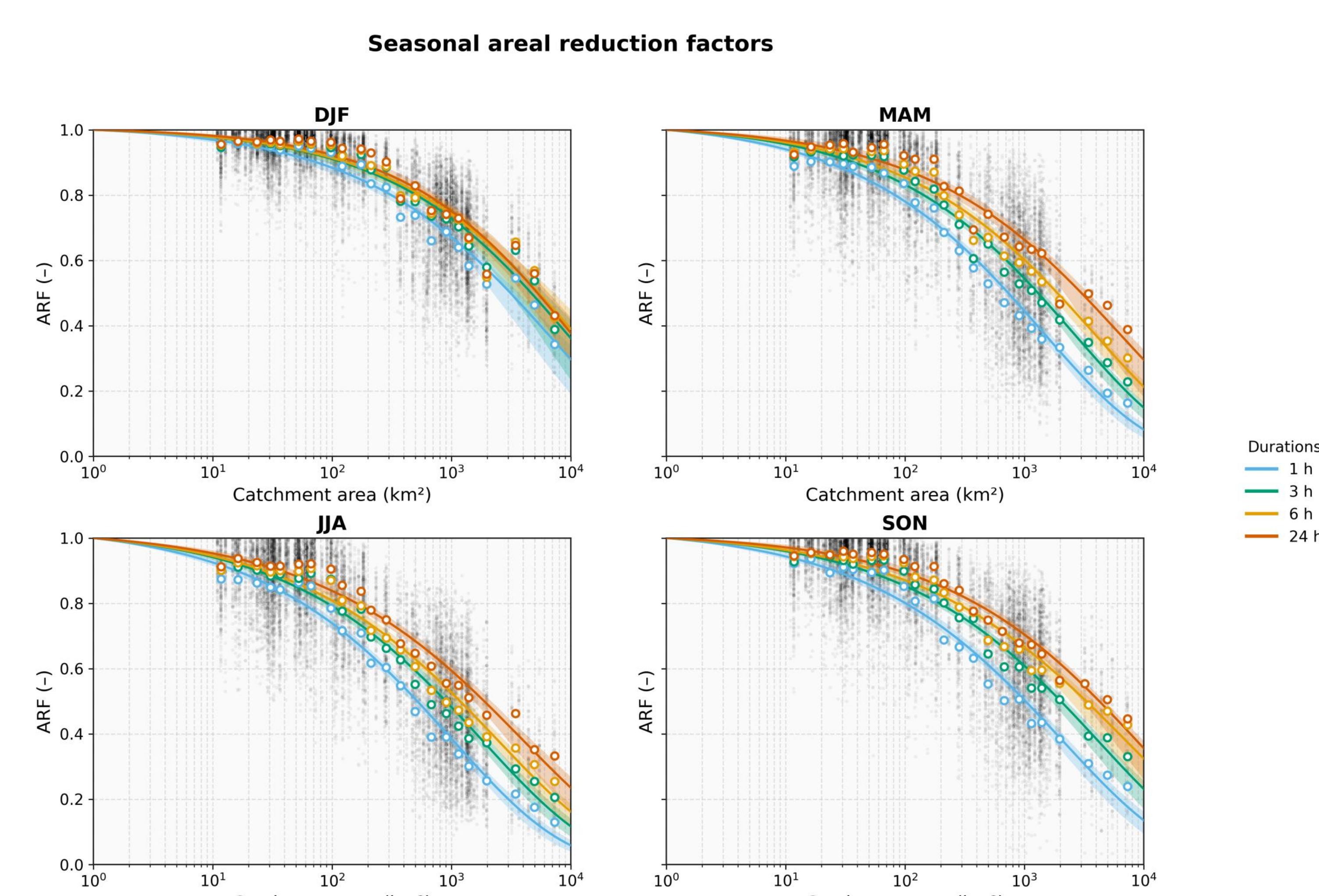
$$\mathrm{ARF}_{5\%}(A), \qquad \mathrm{ARF}_{95\%}(A).$$

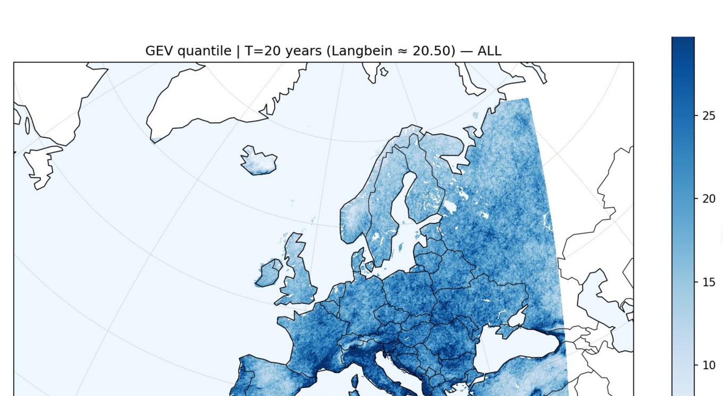
Outputs. For each catchment and duration, the fitted parameters (k,n) and percentile envelopes were stored and visualized. Colored curves represent fitted models; shaded bands show bootstrap uncertainty ranges.



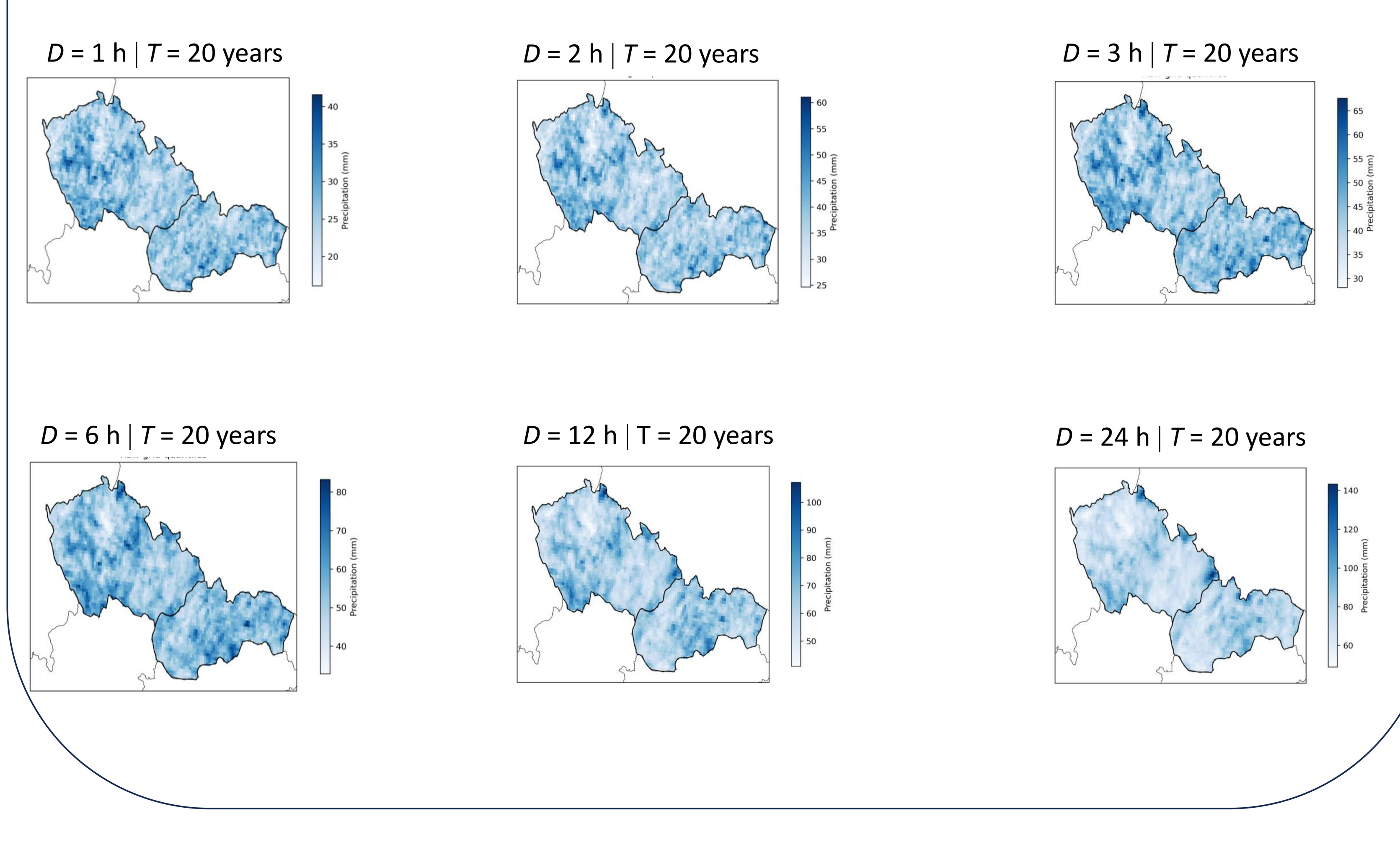








20-year quantile of precipitation over the entire COSMO REA6 domain (1995 – 2017)



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