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Space-time characteristics of areal reduction factors and precipitation mechanisms

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Space–Time Characteristics of Areal Reduction Factors and Rainfall Processes

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ABSTRACT

We estimate areal reduction factors (ARFs; the ratio of catchment rainfall and point rainfall) varying in space and time using a fixed-area method for Austria and link them to the dominating rainfall processes in the region. We particularly focus on two subregions in the west and east of the country, where stratiform and convective rainfall processes dominate, respectively. ARFs are estimated using a rainfall dataset of 306 rain gauges with hourly resolution for five durations between 1 h and 1 day. Results indicate that the ARFs decay faster with area in regions of increased convective activity than in regions dominated by stratiform processes. Low ARF values occur where and when lightning activity (as a proxy for convective activity) is high, but some areas with reduced lightning activity exhibit also rather low ARFs as, in summer, convective rainfall can occur in any part of the country. ARFs tend to decrease with increasing return period, possibly because the contribution of convective rainfall is higher. The results of this study are consistent with similar studies in humid climates and provide new insights regarding the relationship of ARFs and dominating rainfall processes.

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Overview

- We **estimate areal reduction factors** (ARFs; the ratio of catchment rainfall and point rainfall) varying in space and time for Austria **and link them to the dominating precipitation mechanisms**
- ARFs are estimated using a **rainfall dataset of 306 rain gauges** at different durations
- We used **lightning data** as **proxy for convective activity** and examined the **ARFs in space and time by mapping**
- To examine the **relationship between rainfall extremes and lighting information**, we use a high resolution **gridded precipitation dataset**
- We apply a **novel efficient method of estimating ARFs** based on block kriging

Motivation

Understanding of the hydrometeorology (i.e. precipitation mechanisms) **helps assess the plausibility of the ARFs** estimated

ARFs contribute to a better understanding of the hydrometeorology as they are a **fingerprint** of the spatial statistical behavior **of extreme precipitation**

Study area and data

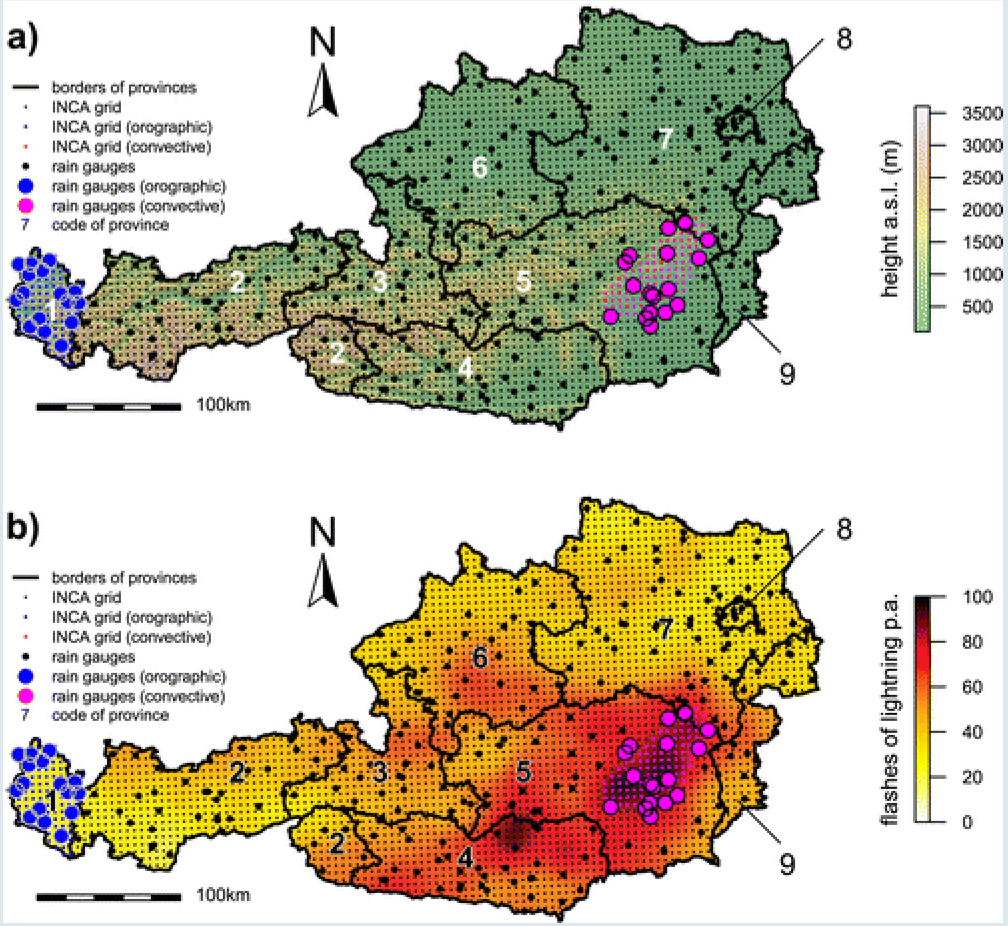


Fig. 1. (a) Distribution of the rain gauges and INCA grid across Austria including the two areas in focus (blue and magenta colors) and the province borders. Numbers refer to the provinces (1 = Vorarlberg, 2 = Tyrol, 3 = Salzburg, 4 = Carinthia, 5 = Styria, 6 = upper Austria, 7 = lower Austria, 8 = Vienna, and 9 = Burgenland. **(b)** Average annual number of flashes of lightning per square kilometer according to the Austrian Lightning Detection and Information System (ALDIS) for the period 1992–2018 (www.aldis.at) including information on rain gauges and the INCA grid.

- **Predominately mountainous** country in central Europe with an area of about 84 000 km^2
- **306 rain gauges** (1995–2014)
- **3354 grid points** of gridded rainfall dataset “**INCA**” (Integrated Nowcasting through Comprehensive Analysis) (2003-2018) (Haiden et al. 2011)
- INCA is based on rain gauge and radar data
- **Lightning information** from the Austrian Lightning Detection and Information System (**ALDIS**; Schulz et al. 2005)
- **Particular focus** on one region dominated by **convective precipitation** (**magenta**) and one region dominated by **stratiform precipitation** (**blue**)

Methodology

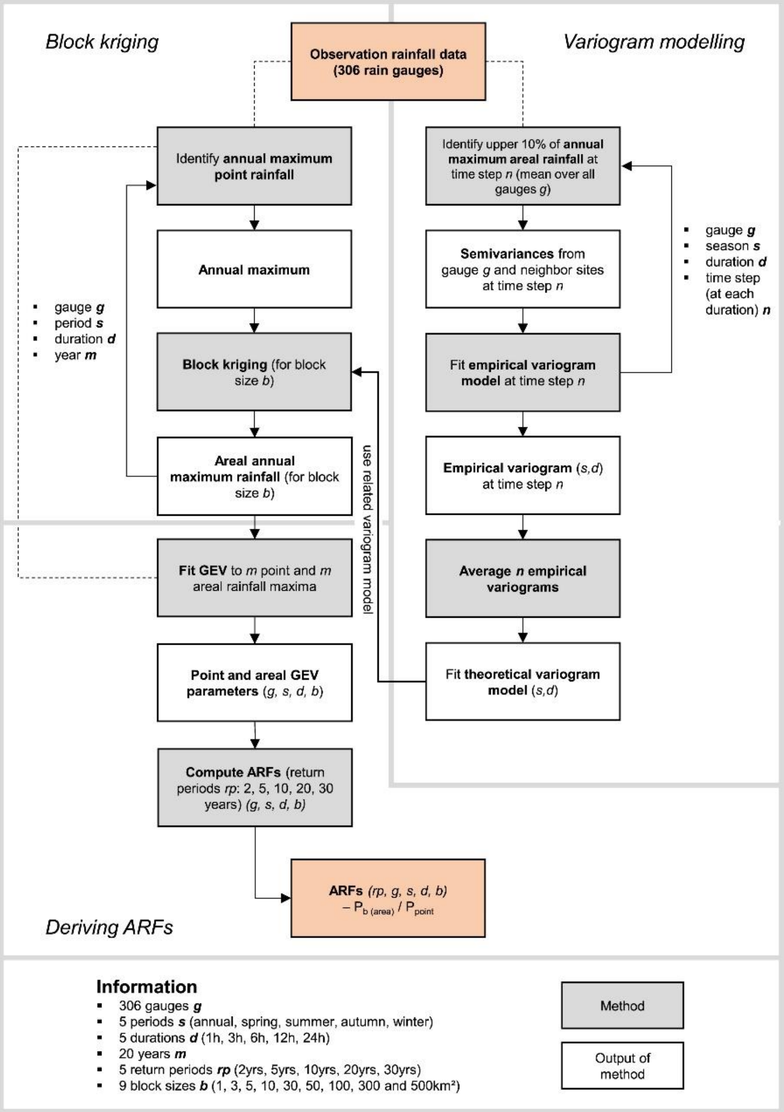


Fig. 2. Schematics of the framework for estimating the areal reduction factors (ARFs), split into (i) the block kriging methodology, (ii) variogram modeling, and (iii) the estimation of the final ARFs.

Variogram modelling

- Variogram models fitted for all of Austria, i.e. all 306 gauge locations

Block kriging

- Annual maximum point rainfall estimated at each rain gauge location, in each period, for each duration, and for each year
- Areal annual maximum rainfall for each rain gauge location *g*, each period *s*, each dration *d*, and for each year *m* estimated by block kriging for different square block sizes (block kriging does not require interpolation over a grid and is thus much more efficient)
- The annual maxima for the point and areal rainfall were estimated independently

Estimating ARFs

- To both the point and areal rainfall maxima we fitted a GEV distribution using the method of maximum likelihood
- With the GEV parameters we computed point and areal rainfall for five different return periods (RP; 2, 5, 10, 20, and 30 years)
- The final ARFs for each return period RP, rain gauge location, each season, each duration, and each area (i.e., block) size were computed by P_{areal}/P_{point}.

Results – IDF statistics

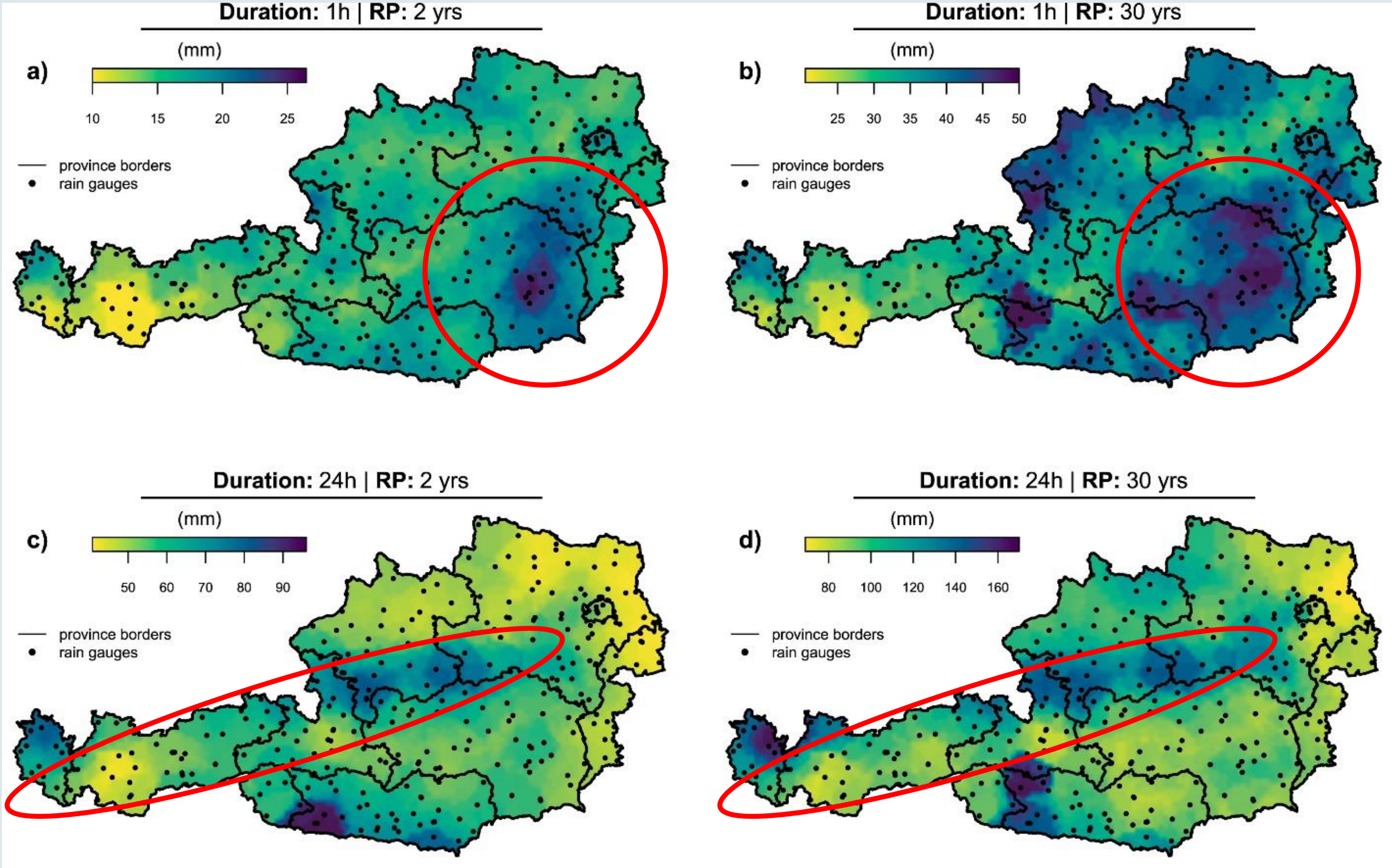


Fig. 3. IDF estimates for different durations (1 and 24 h) and frequencies (2- and 30-yr return periods) across Austria, estimated from the entire time series (i.e., entire year) of the rain gauge data.

- High **short-duration rainfall** intensities in eastern Austria (Figs. 3a,b) are in line with high lightning activity (Fig. 1b) → **convective rainfall**
- Spatial distribution of the **24-h rainfall** (Figs. 3c,d) can be related to the dominant circulation patterns → mainly **synoptic systems and stratiform rainfall**
- Stratiform orographic rainfall comes from air masses from predominantly northwest directions (Hofstätter et. al.)

Results – IDF statistics

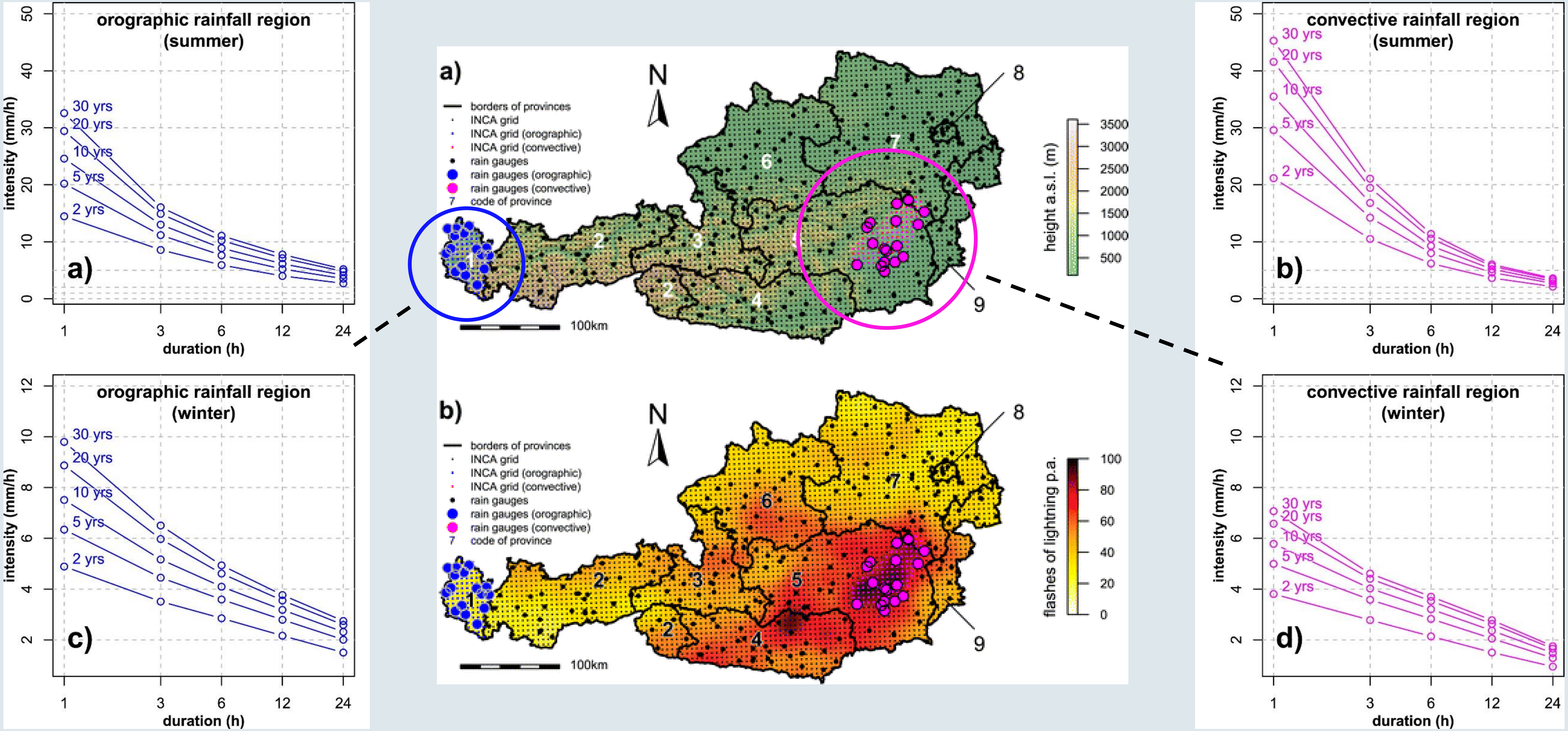
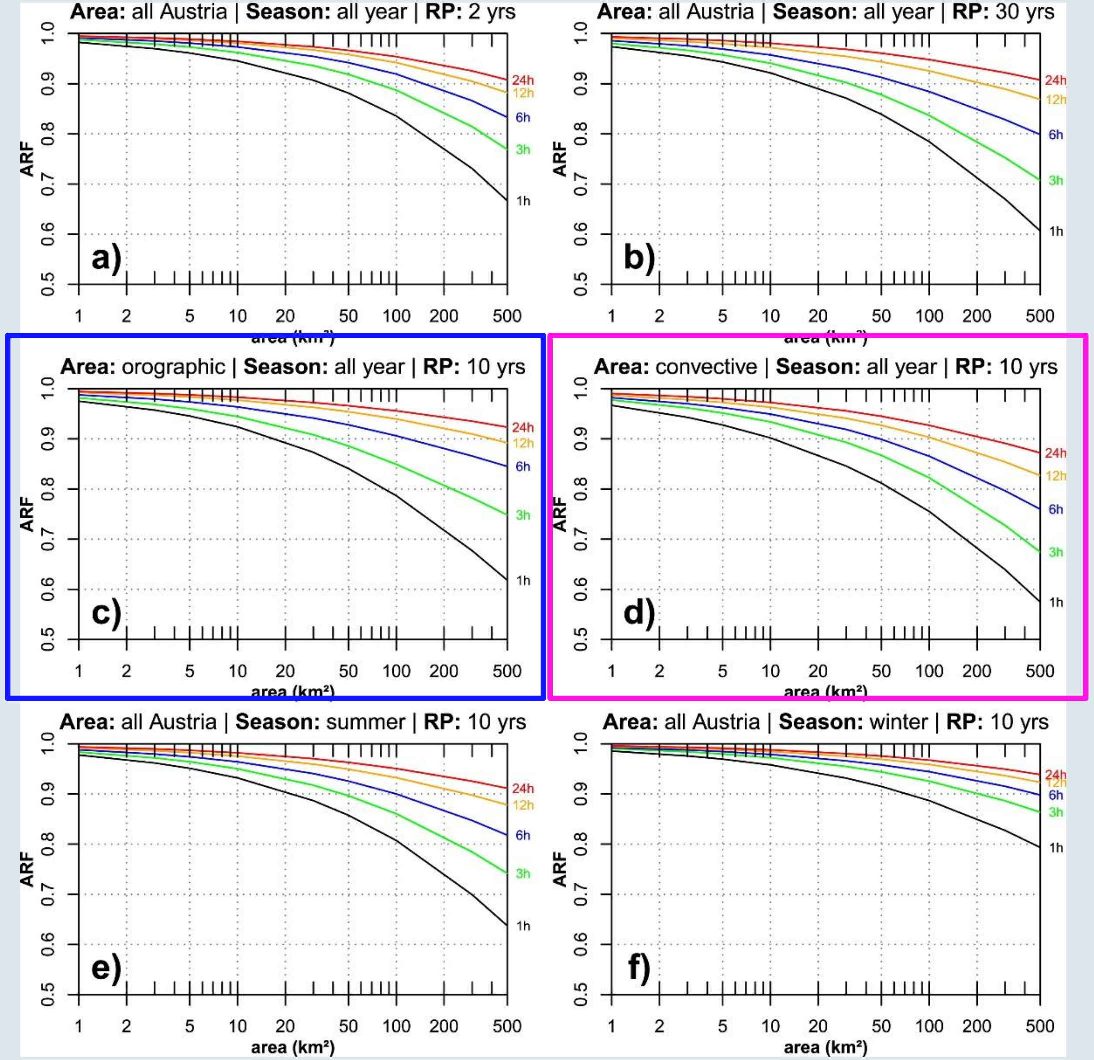


Fig. 4. IDF curves for the (left) orographic and (right) convective rainfall region (right) (see Fig. 1 for regions) in (a),(b) summer and (c),(d) winter. IDF curves are the averages of all rain gauges of the rain gauge data.

Results – ARFs



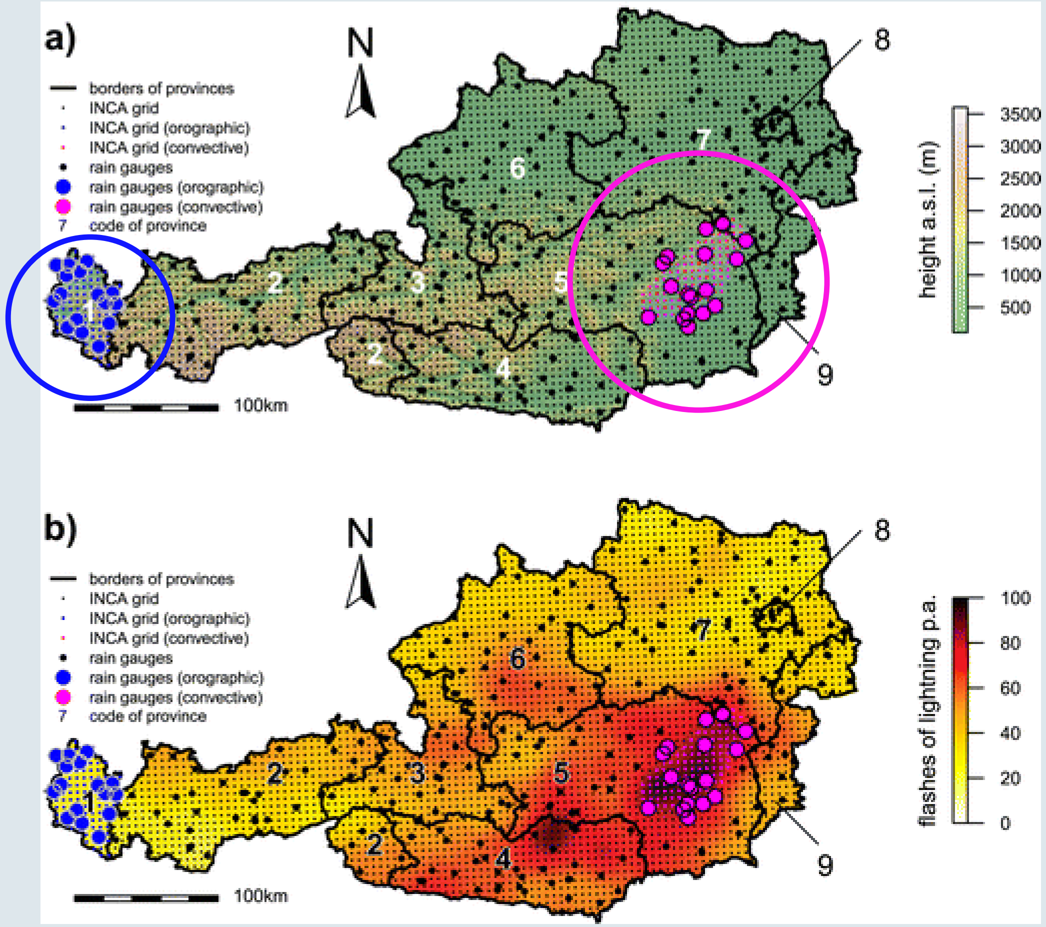


Fig. 5. Areal reduction factors (ARFs) for different return periods, seasons, for all of Austria and the two study regions based on the rain gauge data. Comparisons are shown for (a),(b) two return periods, (c),(d) two regions, and (e),(f) summer and winter.

Results – ARFs

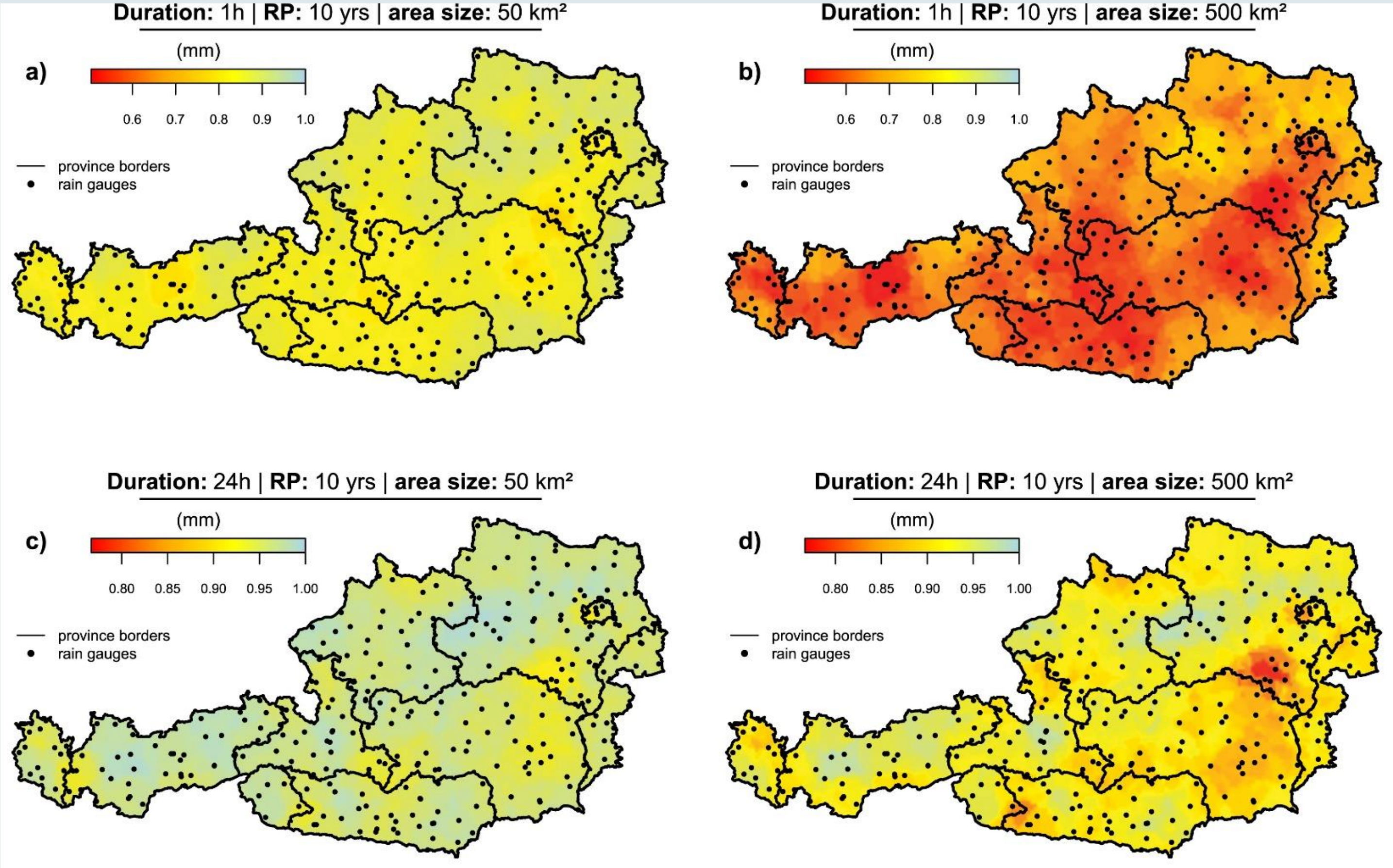


Fig. 6. ARFs for a return period of 10 years, two durations (1 and 24 h) and two catchment sizes (50 and 500 km^2), estimated from the rain gauge dataset.

- For **short durations** (Fig 6a, b), pattern shows similarities with the distribution of the lightning frequency as an indicator of convective activity with smaller ARFs in regions of higher lightning frequency

- For **longer durations** (Fig 6c, d), the region of Styria gives particularly low ARFs, which is likely related to the dominance of convective rainfall

- The relative spatial differences in ARFs are lower for 24h than for 1h, which suggests that, **at 1h duration, convective events dominate**, while at **24h duration synoptic weather systems and stratiform rainfall** are more important

Results – ARFs and lightning data

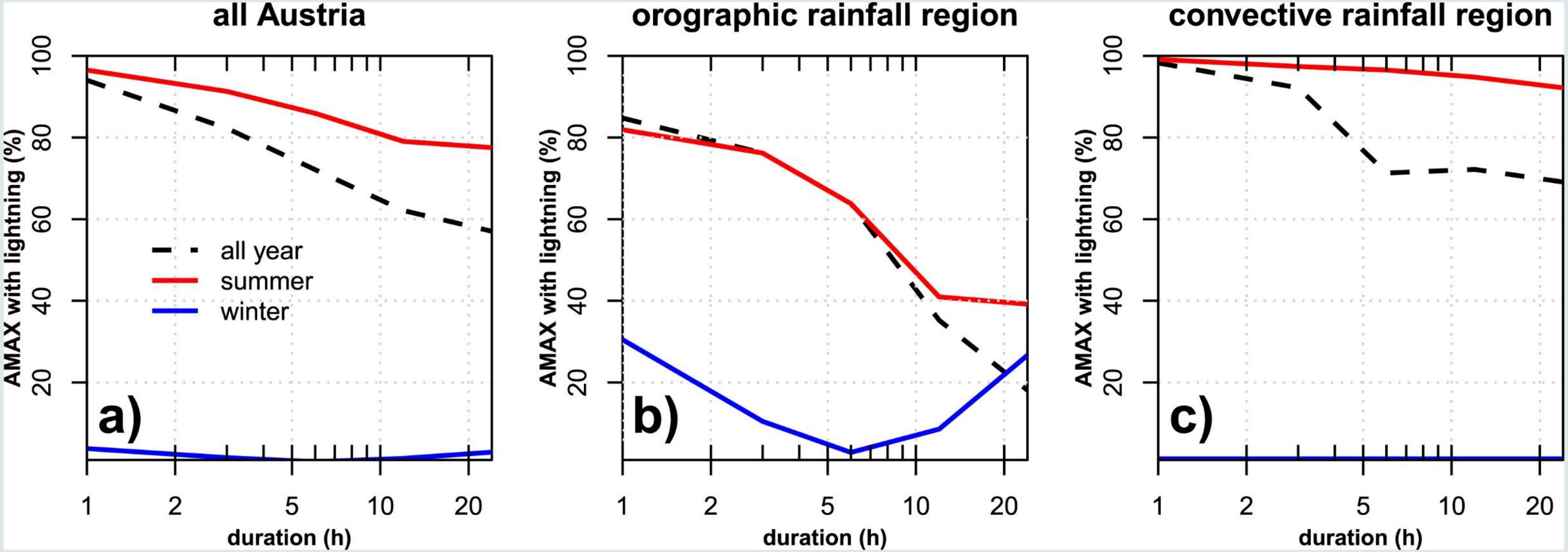


Fig. 7. Percentage of AMAX with different durations associated with lightning for (a) Austria, (b) the orographic rainfall region, and (c) the convective rainfall region, for the entire year, summer, and winter. The lightning statistics are estimated from the ALDIS dataset for the year 2012.

- Lightning activity decreases with increasing duration, indicating a **change in rainfall processes**
- Overall, the **lightning activity is higher in the convective rainfall region** compared to the orographic rainfall region

Conclusions

- We developed a **new method of estimating ARFs** based on block kriging, which is computationally more efficient than interpolating each duration time step and each area size of the entire time series across the domain at high resolution to estimate the ARFs
- **ARFs tend to decay faster in areas with dominant convective activity** than in areas with dominating stratiform rainfall, visible in both classic (regional) IDF curves and in space (maps)
- **Lightning information can be a useful proxy for convective activity** and thus the magnitude of areal reduction factors in space and time
- **The (countrywide) magnitudes of the ARFs** estimated in Austria **are similar to those from other studies** conducted in humid climates using fixed area methods (e.g.,Myers and Zehr 1980; NERC 1975; U.S. Weather Bureau 1957, 1958; Verworn 2008)
- **ARFs decrease with the return period**, which matches findings of other authors (e.g., Allen and DeGaetano 2005a; Asquith and Famiglietti 2000; Le et al. 2018; Mailhot et al. 2012; Sivapalan and Blöschl 1998). This decrease is most pronounced for durations shorter than 24 h, possibly due to a higher contribution of convective rainfall

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