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Spatial Analysis of Extreme Hourly and Daily Precipitation Return Levels

Borrowing Information over Space in Complex Topography

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Objectives

- Estimate **extreme precipitation return levels** on a grid over complex terrain (Switzerland).
- Device a model of spatial EVA to integrate data simultaneously from many stations, i.e. **borrowing information over space**.
- Compare results for daily and hourly precipitation to gain insight on the **potential** of and the **obstacles** for effective information transfer in complex terrain.
- Share experience that effective information transfer depends as much on the **analyst's rigor in working out the climatological peculiarities**, than on fancy methodology.

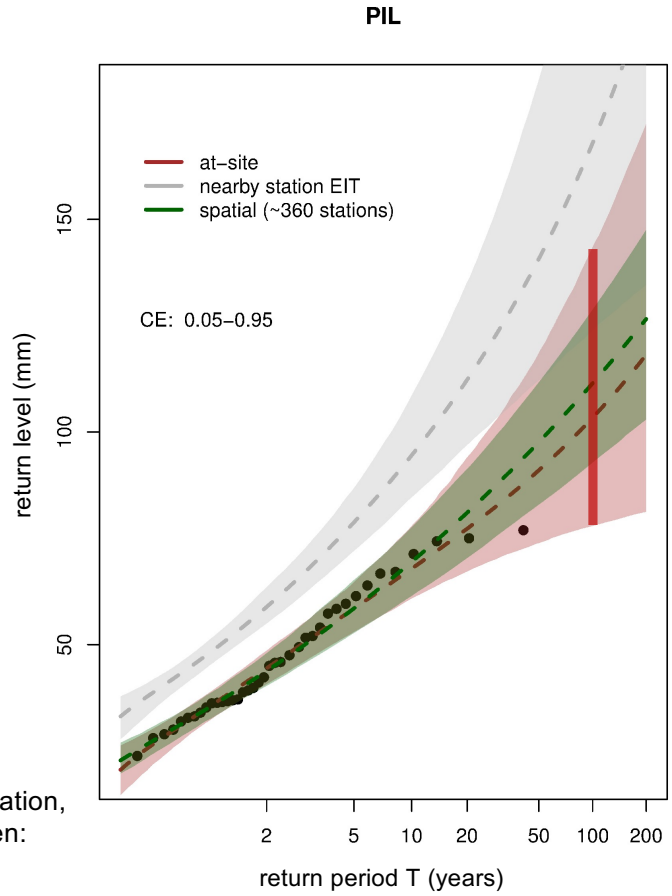
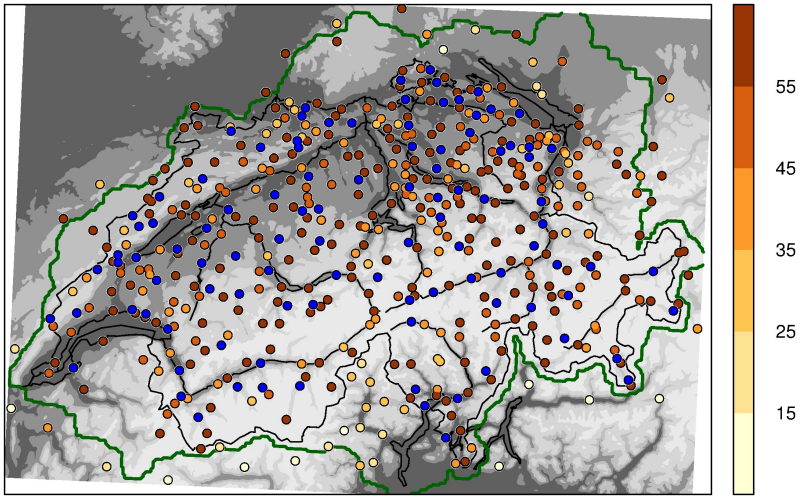


Figure: Challenge and potential of information transfer in complex terrain.
Return-level plot of daily precipitation for a selected station in Switzerland. Shaded areas depict 90% credible intervals. Red: estimate from data at station only, large uncertainty (vertical red bar shows uncertainty for 100-year level). Grey: result at nearest neighbor station, has different climatic conditions from target station (challenge with complex terrain). Green: estimate based on data from the whole station network (using spatial EVA), showing remarkably reduced uncertainty.

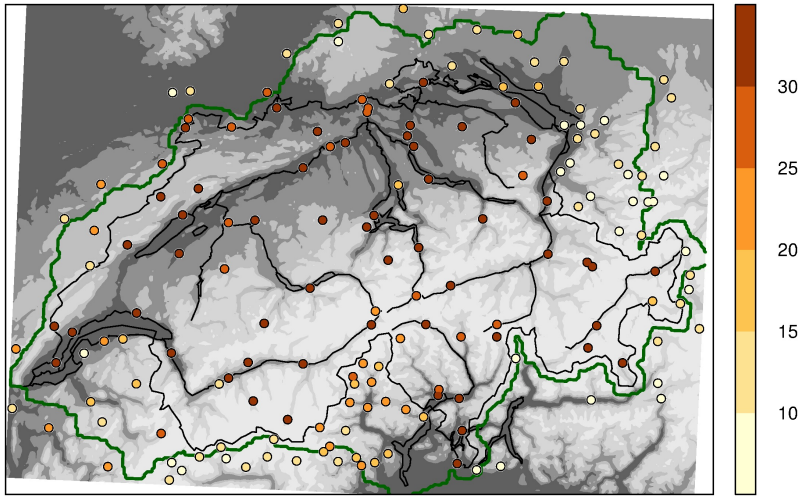
Data

Daily precipitation



395 stations for calibration
101 stations for evaluation (blue, left out)
1961-2020
Series length varies betw. 10 – 60 years (color)

Hourly precipitation



168 stations for calibration
Evaluation by leave-one-out (Swiss stations only)
1981-2020
Series length varies betw. 10 – 40 years (color)

Model and Inference

- Hierarchical Model
  - GEV for observed block maxima (1)
  - GRF for latent GEV parameters (2)
  - e.g. Cooley et al. 2007; Dyrrdal et al. 2014; Bracken et al. 2016
- Spatial information transfer via …
  - spatial covariates (climatological patterns) ★
  - residual dependence (“close locations are similar”) ★
- Bayesian inference using MCMC (Gibbs- and Metropolis-Hastings Sampling)
- Account for conditional dependence (e.g. Ribatet et al. 2012, Sharkey and Winter 2019)
- Seasonally stratified results combined to statistics for annual extremes

$Y_i(t)$ observed max at station i, year t

$$Y_i(t) \sim GEV(\mu_i, \sigma_i, \xi_i) \quad (1)$$

$$\mu_i = \mu(x_i), \quad \text{ditto for } \sigma_i \text{ and } \xi_i$$

$$\mu(\boldsymbol{x}) \sim MVN\left(\varepsilon_\mu(\boldsymbol{x}), \Sigma^\mu\right) \quad (2)$$

$$\varepsilon_\mu(\boldsymbol{x}) = \sum_k \beta_k^\mu \cdot z_k(\boldsymbol{x}) \text{ ★}$$

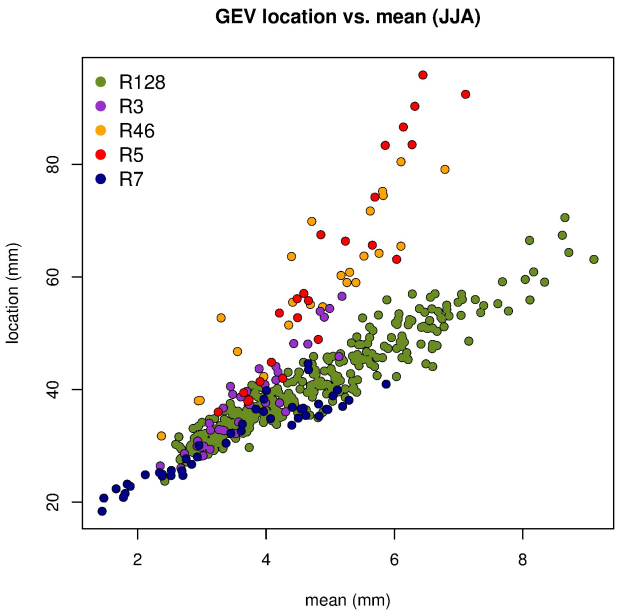
$$\Sigma_{i,j}^\mu = f(h, \phi^\mu),\ h = \left\|\boldsymbol{x}_i - \boldsymbol{x}_j\right\| \text{ ★}$$

ditto for $\sigma(x)$ and $\xi(x)$

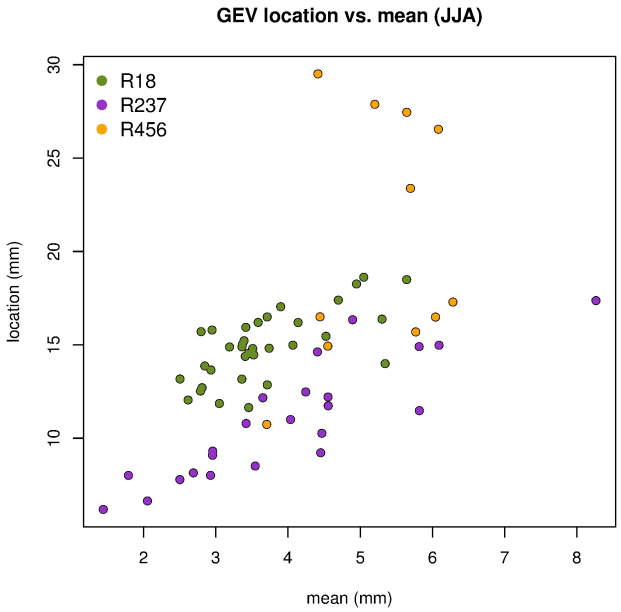
analyst’s leverage

Choice of Covariates

Daily precipitation



Hourly precipitation



Messages:

There is scope for "borrowing information", also in complex terrain.

Climatological knowledge can guide us to model configurations that are crucial to facilitate spatial information transfer.

Figure: Exploratory climatological analysis to guide covariate choice.
Panels show relationship between GEV location parameter at stations (y-axis) and mean seasonal precip (x-axis). For *daily* (left), the relationship is strong, but it varies between regions (color), and there is nonlinearity. Both are relevant for configuring a good covariate set. For hourly (right), the relationship is less well constrained, leaving ambiguity about proper model configuration and limited scope for effective information transfer.

Experiments (Covariate Models)

- PLAIN: No Covariate
  - Information transfer via spatial dependence only (i.e. close stations only)
- SIMPLE: Mean Precipitation
  - One covariate only plus intercept
  - Limited account of complex climatological features (see exploratory analysis for daily)
- RADAR: Radar (hourly only)
  - 99% quantile of hourly precipitation observed by radar
  - One covariate only plus intercept
- ELABORATE: Mean, Mean^2, Height, Regions
  - Interaction terms, many (20) predictors
  - Extended information on climate features from exploratory analysis (daily)
  - Risk of overfitting with small station network (hourly)

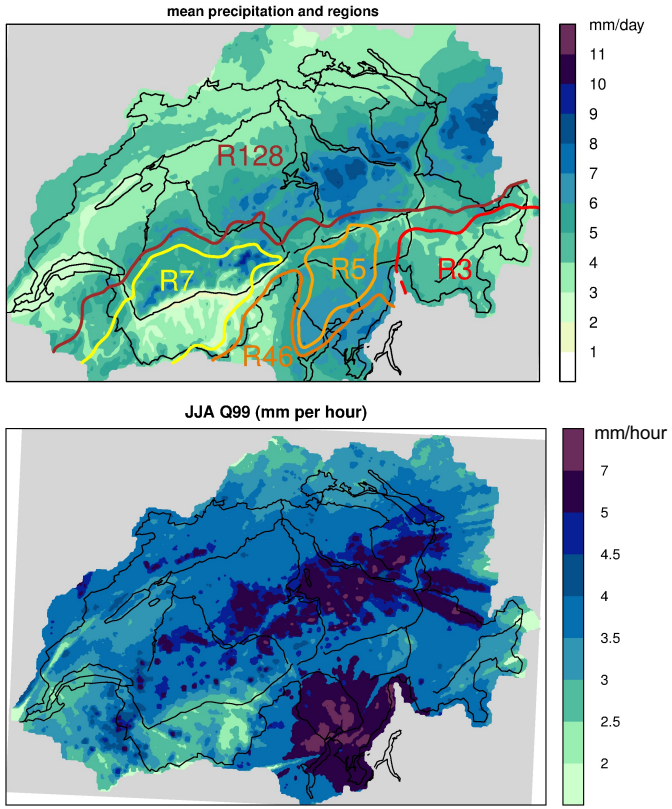


Figure: Covariates used in the mean process for μ. Mean precipitation and subregions (top panel), 99% quantile of radar observed hourly precipitation (bottom panel).

Comparison of Experiments (Daily)

Message:
Climatologically more informed experiments yield spatially more detailed analyses, less conditional bias, and smaller uncertainty between stations, suggesting improved spatial information transfer.

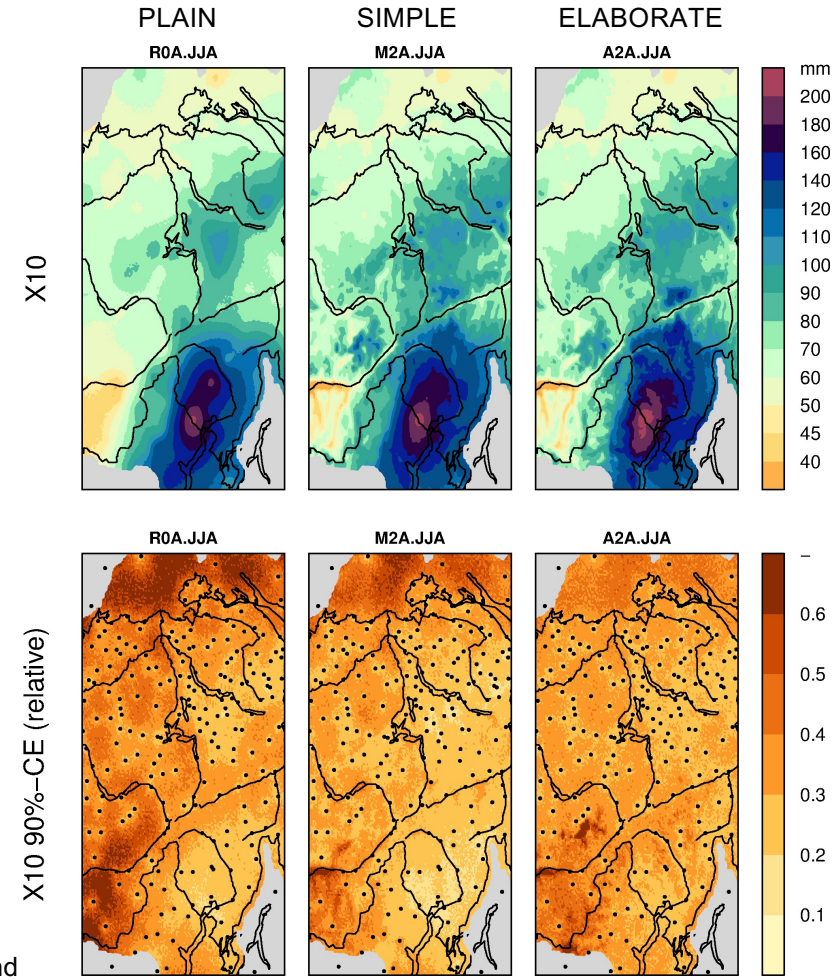
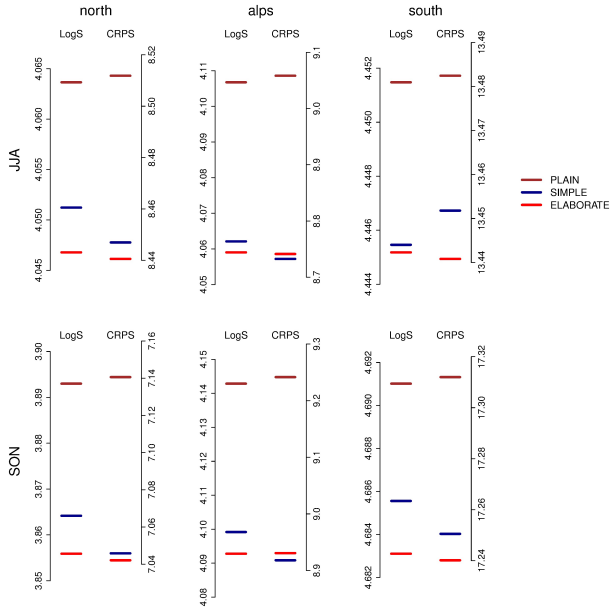


Figure: Return level and uncertainty (daily only).
Upper panels show 10-year return level for daily precipitation (mm per day), as estimated by experiments PLAIN (left), SIMPLE (middle) and ELABORATE (right). Bottom panels depict 90% credible intervals for the return level, expressed as ratio between credible range and median (Q95-Q05)/Q50 of the posterior distribution.

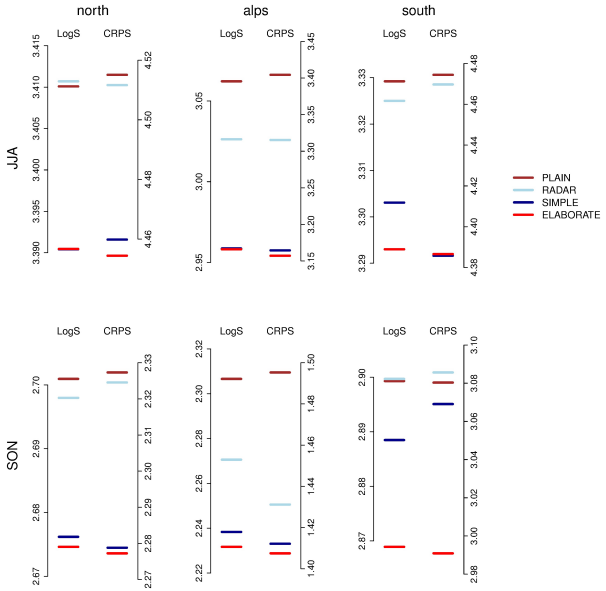
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Comparison of Experiments (Daily)

Daily precipitation



Hourly precipitation



Messages:

Climatologically more informed experiments yield more skilful analyses (daily), provided there is enough data for robust estimation of the (more) parameters.

Analysts climatological input may not materialize if data is insufficient to feed a complex model configuration.

Figure: Quantitative *assessment of experiments (i.e. different choices of covariate model).*
Evaluation scores of experiments using independent data (daily) or cross-validation (hourly). LogS and CRPS are scoring rules for assessing distribution predictions against data (see Gneiting & Raftery 2007). The smaller the better, absolute values have no meaning here. Results displayed for three subdomains and two seasons. For *daily*, ELABORATE excels PLAIN by far and SIMPLE clearly. For hourly, SIMPLE improves over PLAIN and RADAR, but is only insignificantly topped by ELABORATE.

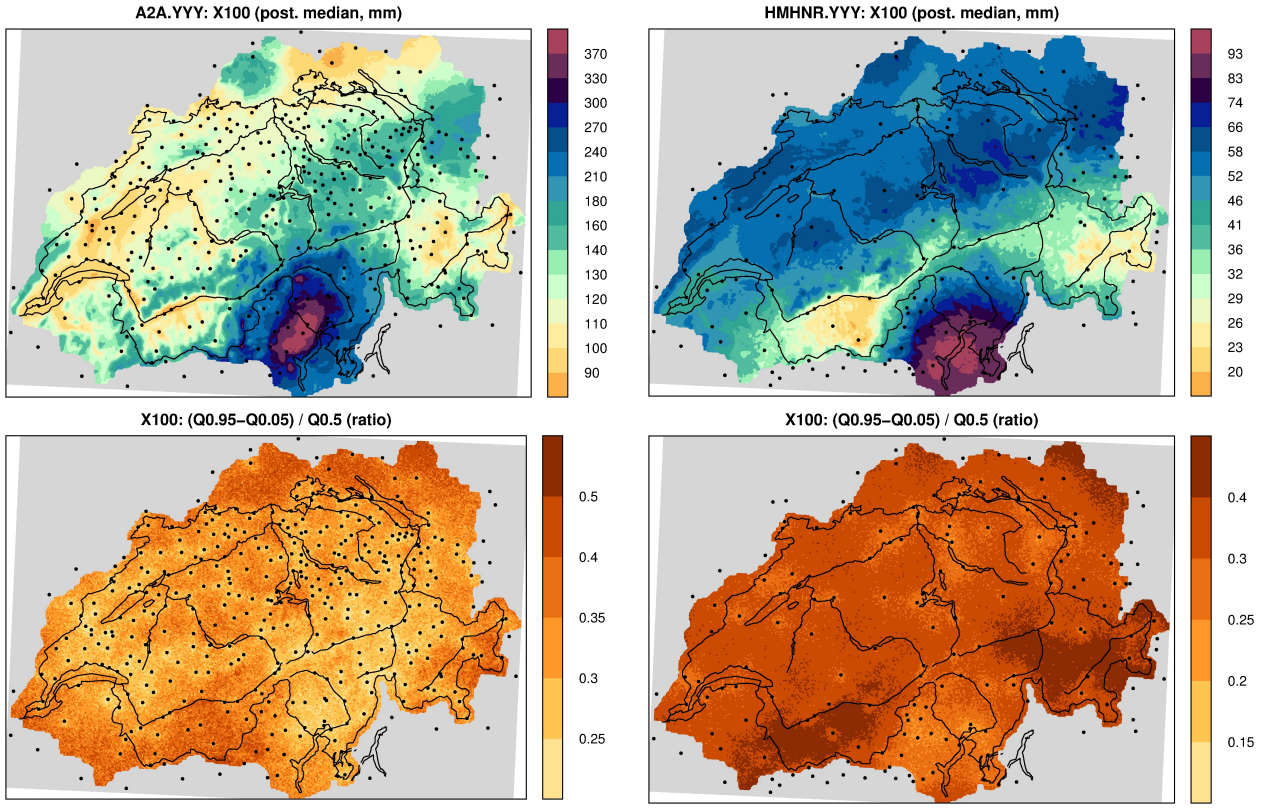
Return Level and Uncertainty

Daily precipitation

Hourly precipitation

X100

90% CE



Message:
Uncertainty in a spatial EVA depends on data amount (density / length of series), and the possibility to facilitate spatial information transfer with elaborate covariates and model configuration.

Figure: Return level and uncertainty. Upper panels show 100-year return level for daily (left, mm per day) and hourly (right, mm per hour) precipitation, as estimated from the covariate models suggested from the comparative assessment (daily: ELABORATE, hourly: SIMPLE). Bottom panels depict relative 90% credible intervals (uncertainty) of return level. Uncertainty is substantially larger for hourly return level.

Conclusions

- Spatial EVA can **facilitate information transfer** across a station network, which is key to **reducing uncertainty** on extremes.
- Our application **for daily extremes** demonstrates that effective information transfer can be achieved **also in complex terrain**.
- A fancy method does not warrant for efficient information transfer. Incorporating **climatological knowledge** (gained from exploratory analysis) in the method's configuration (e.g. the covariates) is crucial.
- Our application (for hourly extremes) illustrates that limited data may impede a climatologically elaborate model configuration. **Information transfer depends on but does not replace data**.

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Take Home Message

- The covariate model and method configuration are important leverages in spatial climate analysis. This is where topical knowledge and exploratory discoveries can make a big difference.
- But we observe a certain ignorance on this important modelling element. Maybe this is because …
  - … one is tempted to trust in the promise of fancy methods,
  - … one prefers to “press a button” rather than to work out the climatological peculiarities in exploratory analyses.
- By this, there is a risk to not adequately exploit the information contained in data.

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