XIth Scientific Assembly of the International Association of Hydrological Sciences (IAHS 2022)
Extremes in hydroclimatic systems

Investigating the clustering mechanisms of hydroclimatic extremes: from identification to modelling strategies

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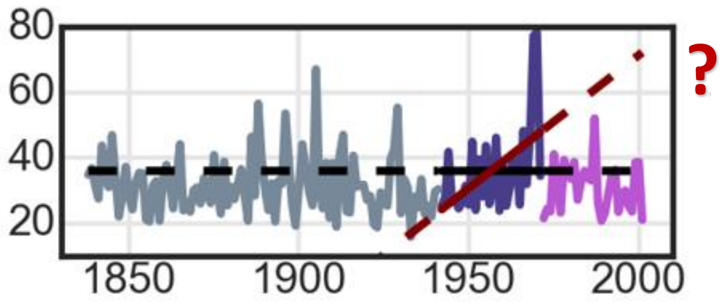
Importance of temporal clustering of hydrological extremes

Temporal properties of extreme events are less understood compared to marginal distribution properties.

❑ **Temporal dependence properties of hydrological extremes** affect:

Small to large scales

- Duration of flood and extreme rainfall events
- Failures due to ‘medium-magnitude’ yet prolonged/consecutive events, e.g. bridge scour, dam failures, landslides
- Droughts
- Insurance and re-insurance strategies
- Climatic simulations & projections
- Risk perception & communication



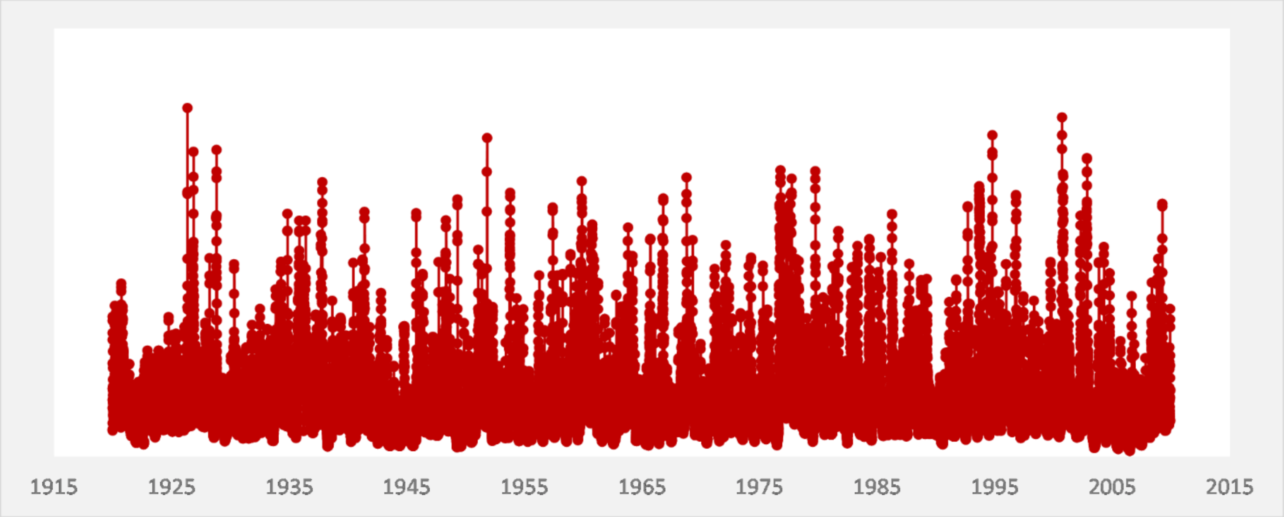
❑ As continue-time simulation is progressively adopted in hazard models, the need to identify and reproduce dependence of hydroclimatic extremes becomes more relevant.

Temporal clustering of extremes: a 'reverse' stochastic approach

- How can we **identify** and characterize **multi-scale clustering** of extremes?
  - **Seasonal**, i.e. multitude of days to multitude of months
  - **Annual and multi-annual**, i.e. ~365 days to multitude of years
  - **Climatic**, i.e. 30 years

- What is a parsimonious approach for modelling multi-scale clustering?

We study clustering of extremes through the study of the parent process' properties.
- The two are typically decoupled in the literature under asymptotic assumptions.
- Extremes are treated as independent and clustering is studied either under a multi-variate perspective or via non-stationary reasoning.



Stochastic properties of the parent process

- Scaling of the second-order properties in long-time horizons
  - was first observed in the water level data of the Nile River by **Hurst** (1951)
  - was first mathematically described by **Kolmogorov** (1940)
  - is a ubiquitous behaviour known as long-range dependence/persistence/Hurst phenomenon/Hurst-Kolmogorov (HK) dynamics associated with increased long-term variability (Koutsoyiannis, 2010).

Climacogram (Koutsoyiannis, 2010) variance of the averaged process as a function of the timescale of averaging:

$\gamma(k) := \mathrm{var}\left[\frac{\underline{X}(k)}{k}\right]$ where $\underline{X}(k) := \int_0^k \underline{x}(t)\,\mathrm{d}t$ aggregated process at timescale k

Climacogram with asymptotic scaling at $t \to \infty$ defines an HK process in continuous-time (Koutsoyiannis, 2021):

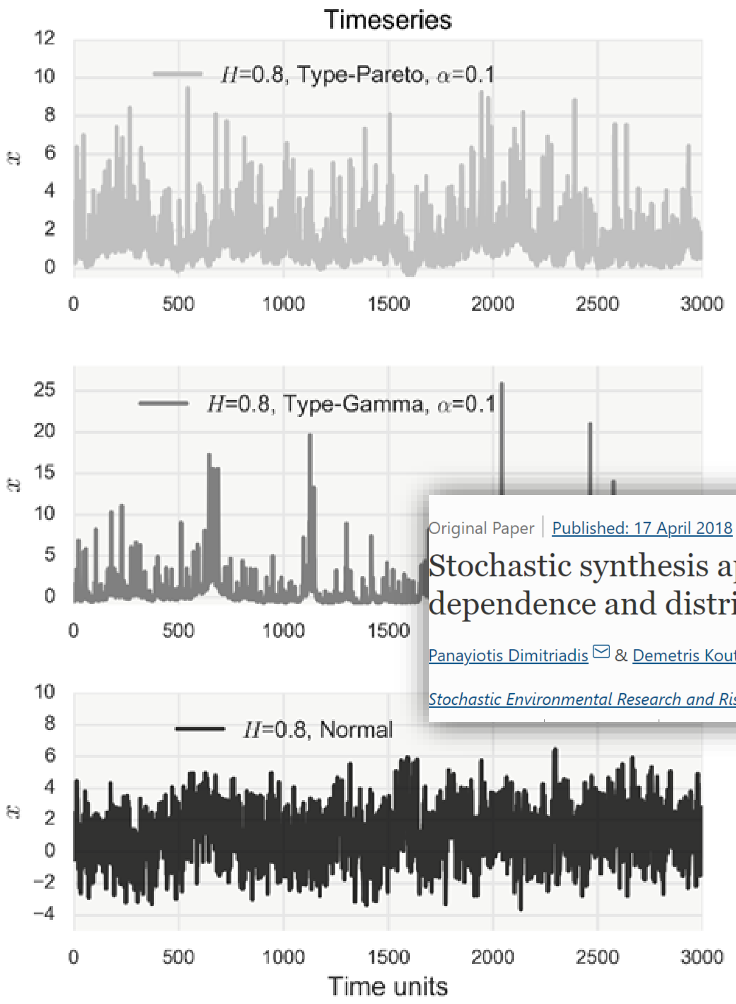
$$\gamma(k) := \lambda \left(\frac{a}{k}\right)^{2-2H}$$

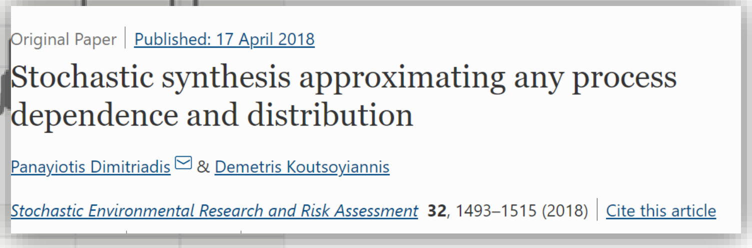
where α and λ are scale parameters, with dimensions $[t]$ and $[x^2]$ while H is the so-called Hurst parameter ranging in the interval (0,1).

- $H = 0.5$ yields a White-Noise process,
- $H > 0.5$ indicates enhanced change/clustering/variability at large-scales.

Simulation of synthetic timeseries reproducing HK dynamics

- ✓ Stochastic synthesis of timeseries preserving the **second-order scaling** and the first **4 moments** of the process.
- ✓ Extended frameworks also **preserving time irreversibility** and **higher-order moments.**

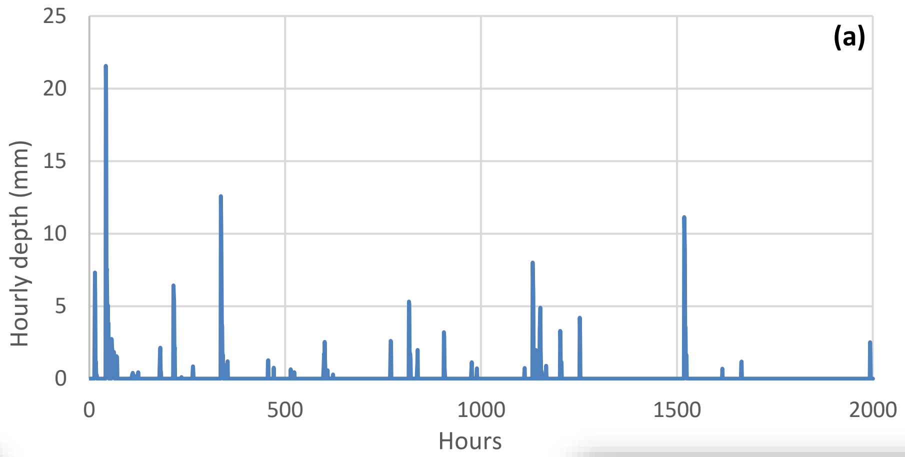


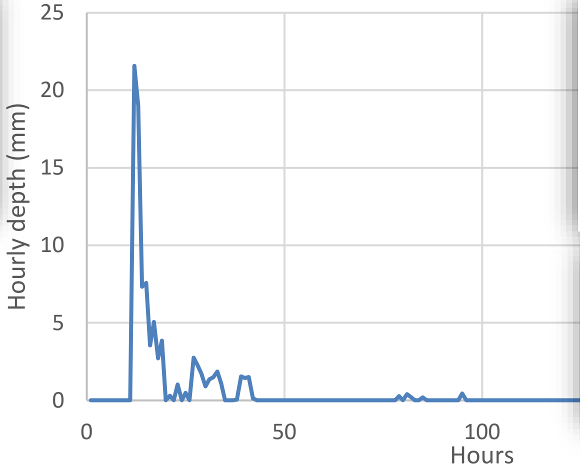

Original Paper | Published: 17 April 2018

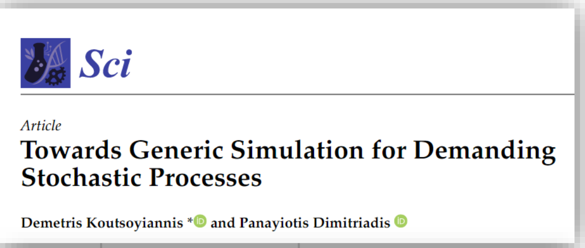
Stochastic synthesis approximating any process dependence and distribution

Panayiotis Dimitriadis & Demetris Koutsoyiannis

Stochastic Environmental Research and Risk Assessment **32**, 1493–1515 (2018) | Cite this article






Sci

Article

Towards Generic Simulation for Demanding Stochastic Processes

Demetris Koutsoyiannis * and Panayiotis Dimitriadis


hydrology

Article

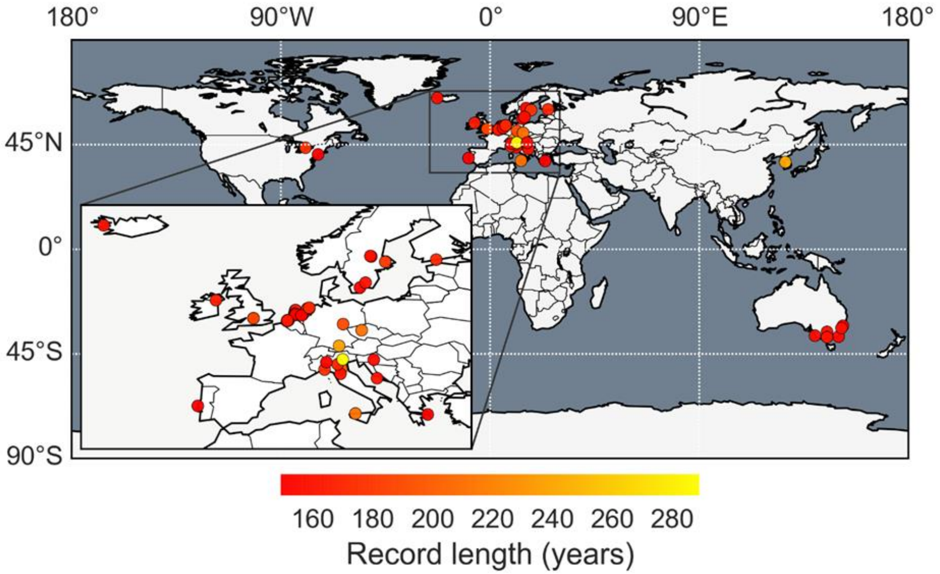
Multiscale Temporal Irreversibility of Streamflow and Its Stochastic Modelling

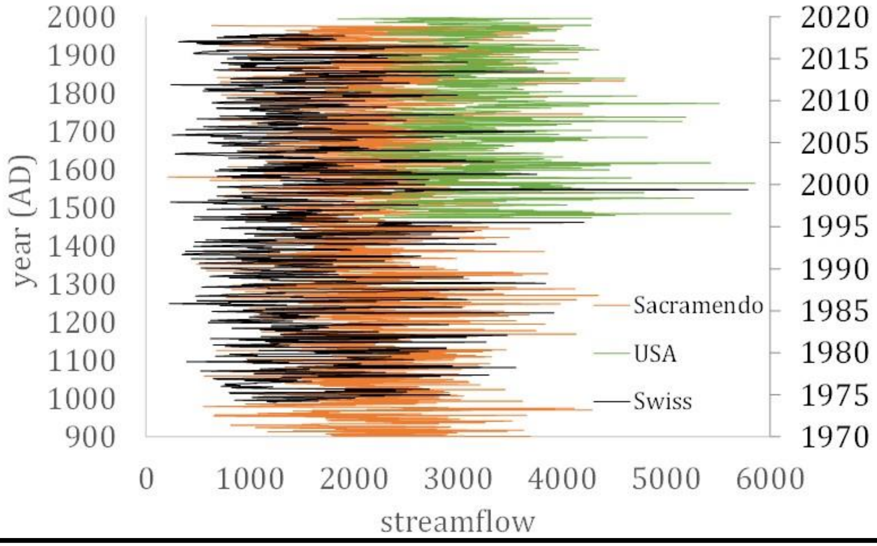
Stelios Vavoulogiannis *, Theano Iliopoulou, Panayiotis Dimitriadis and Demetris Koutsoyiannis

Dimitriadis and Koutsoyiannis (2018), Koutsoyiannis and Dimitriadis, (2020), Vavoulogiannis et al. (2021)

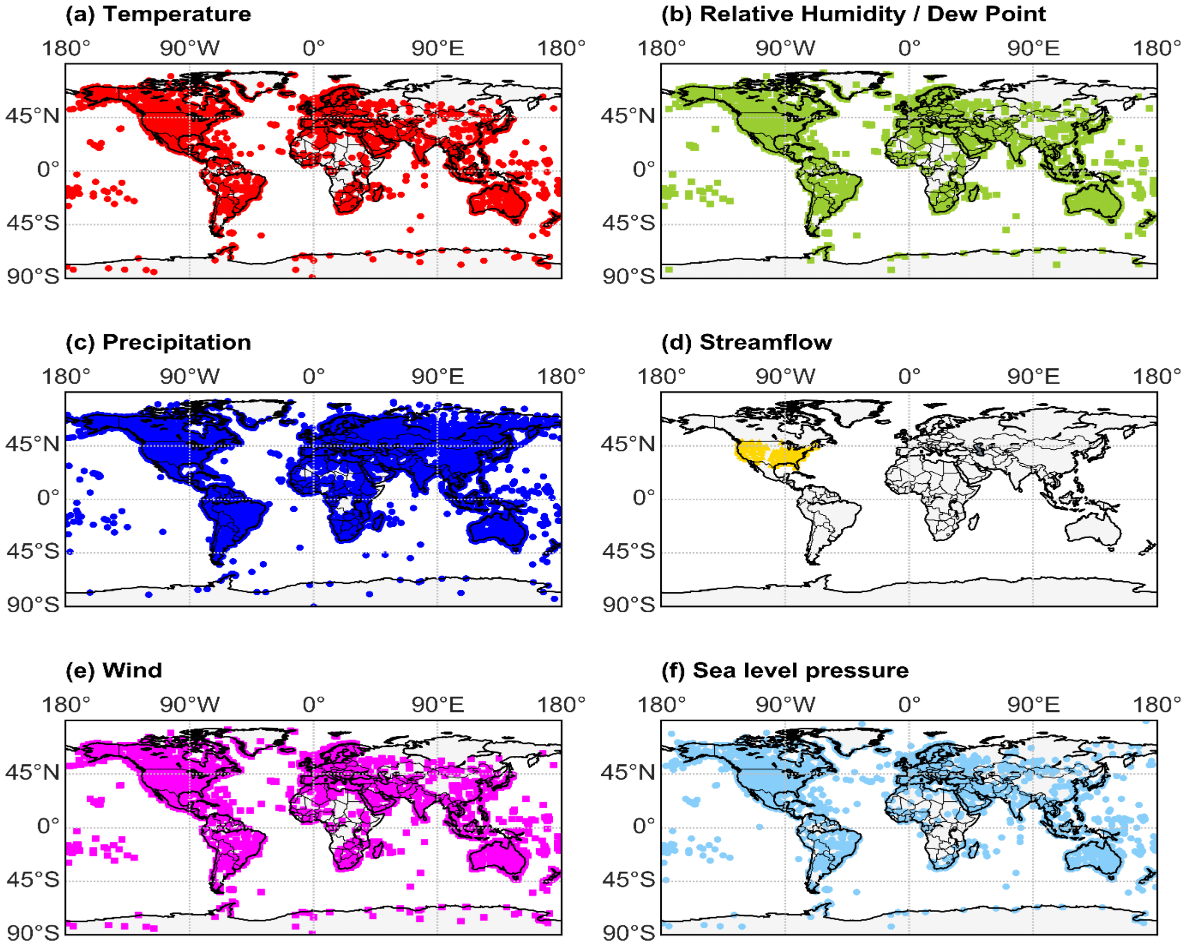
Long-term records and global-scale analysis

- **Investigation of long-term rainfall and streamflow records**





- **Investigation of hydroclimatic records at a global-scale**

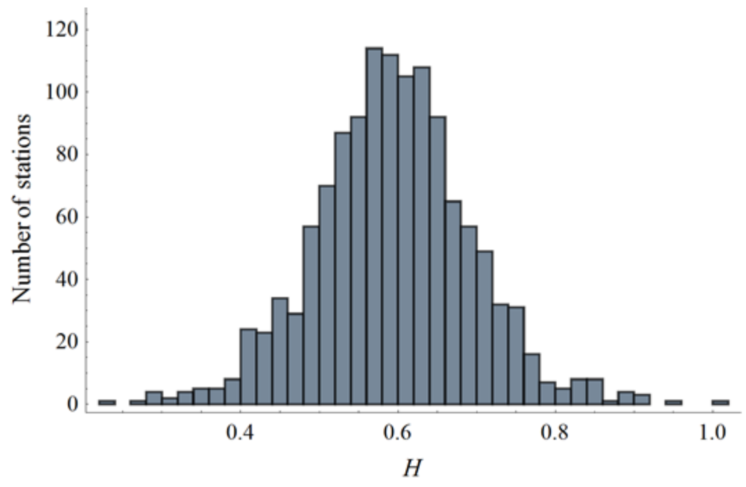


Iliopoulou and Koutsoyiannis (2019), Dimitriadis et al. (2021), Pizarro et al. (2022, in review)

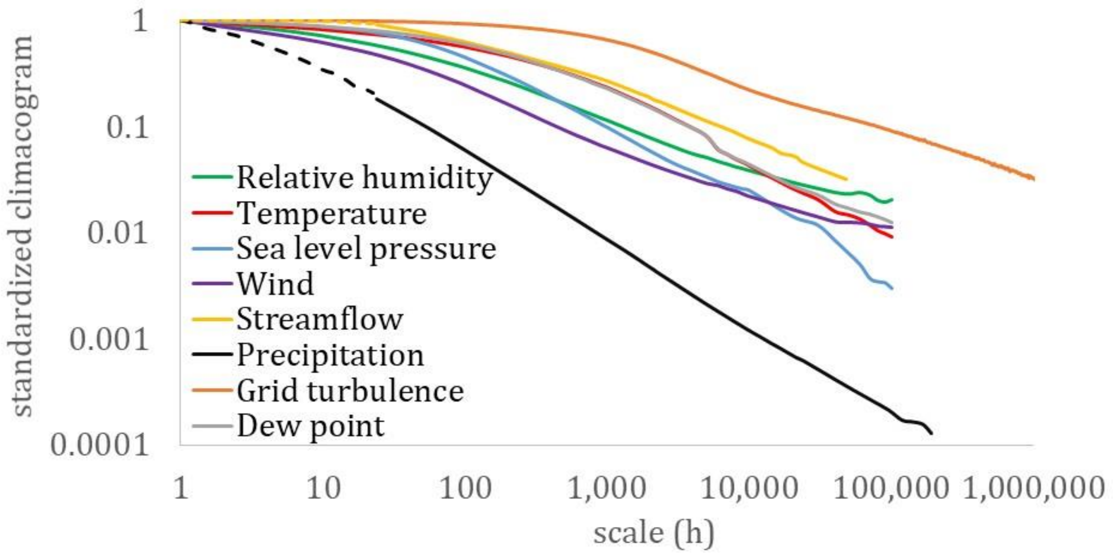
Persistence in the parent hydroclimatic process

Precipitation:

- A common $H \approx 0.6$ is representative for the majority of the records above 100 years;
- 50% of the records $H \geq 0.59$
- 2.5% of the records $H \geq 0.8$
- 15% no evidence of persistence.



Other hydroclimatic processes:

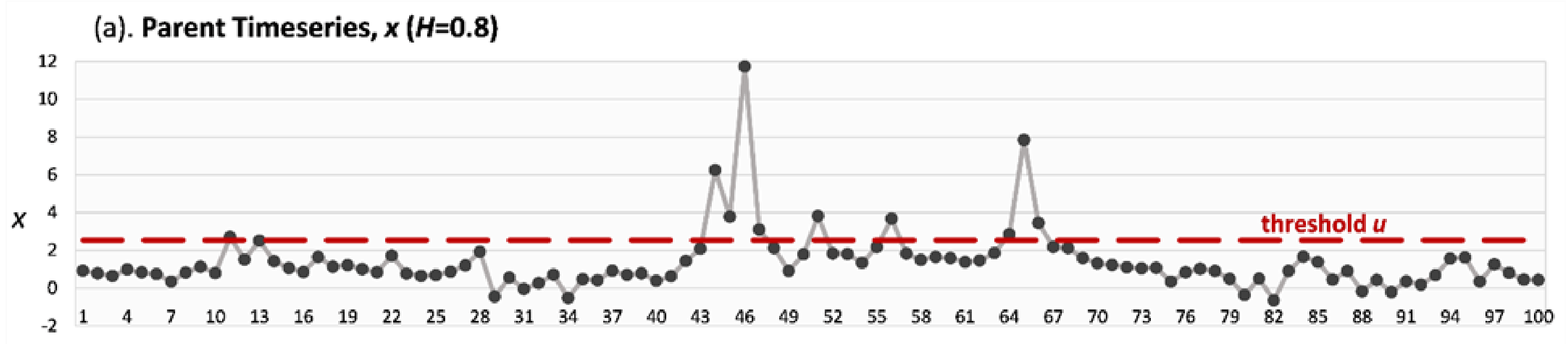


	Average H parameter
Near-surface temperature	**0.81**
Relative humidity	**0.83**
Dew point	**0.77**
Sea level pressure	**0.7**
Wind speed	**0.85**
Streamflow	**0.78**
Precipitation	**0.61**

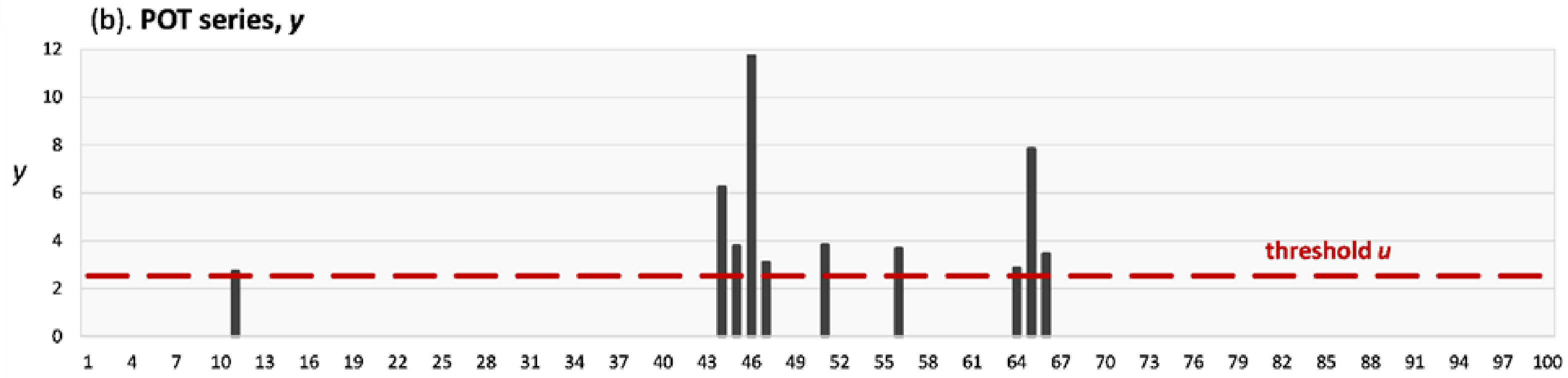
Iliopoulou et al. (2018), Dimitriadis et al. (2021), Pizarro et al. (2022, in review)

Does persistence **propagate** to the extremes?

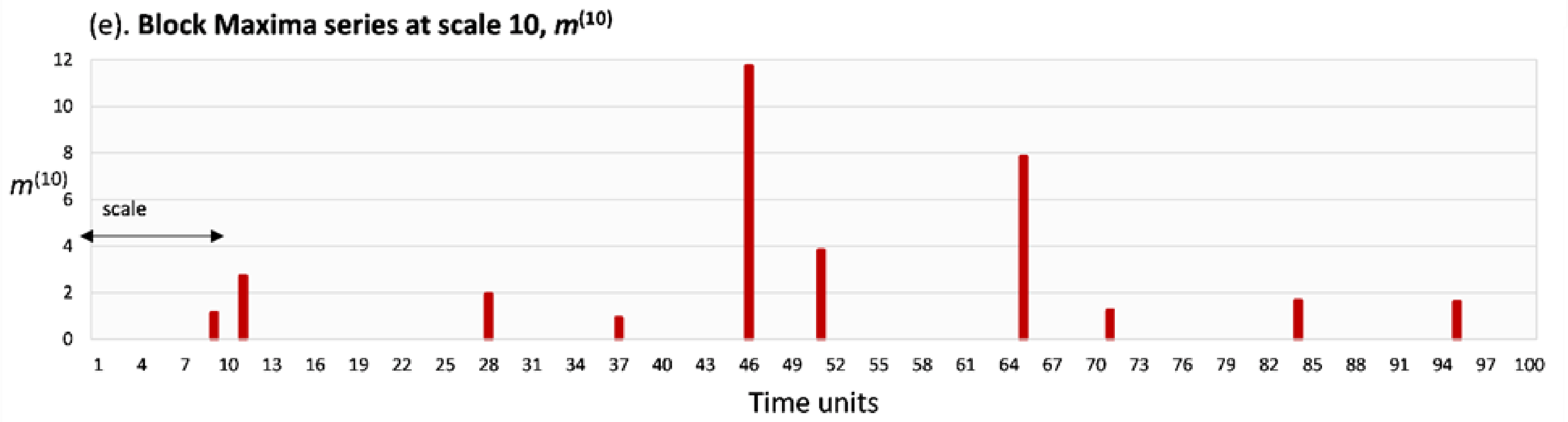
Parent timeseries



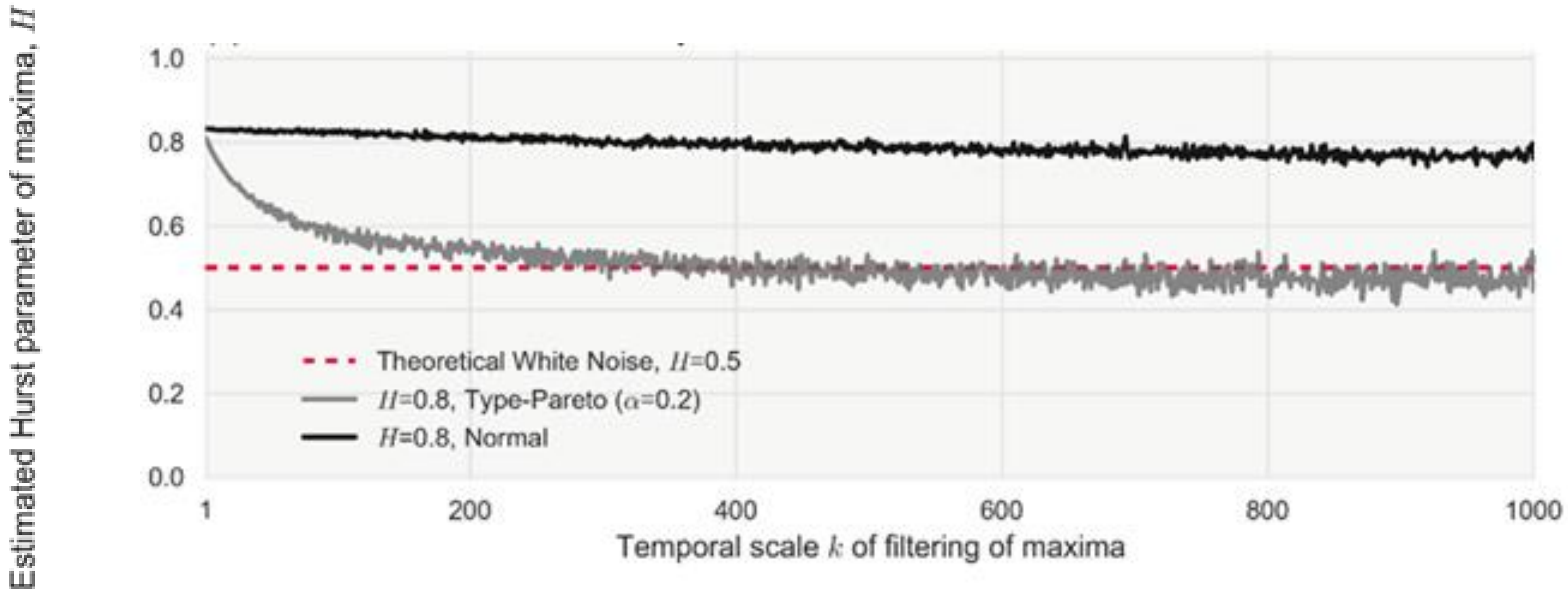
Peaks Over Threshold (POT)



Block Maxima



Can we use the Hurst parameter for block maxima?



- The climacogram estimator **falsely indicates independence after a few scales of filtering** of extremes from non-Gaussian processes. Similar results are obtained from the dispersion index.

Second-order characterizations are not suited for identification of clustering of non-Gaussian extremes, but may be effective for near-Gaussian processes (e.g. air temperature, see Glynis et al. 2021).

Iliopoulou and Koutsoyiannis (2019)

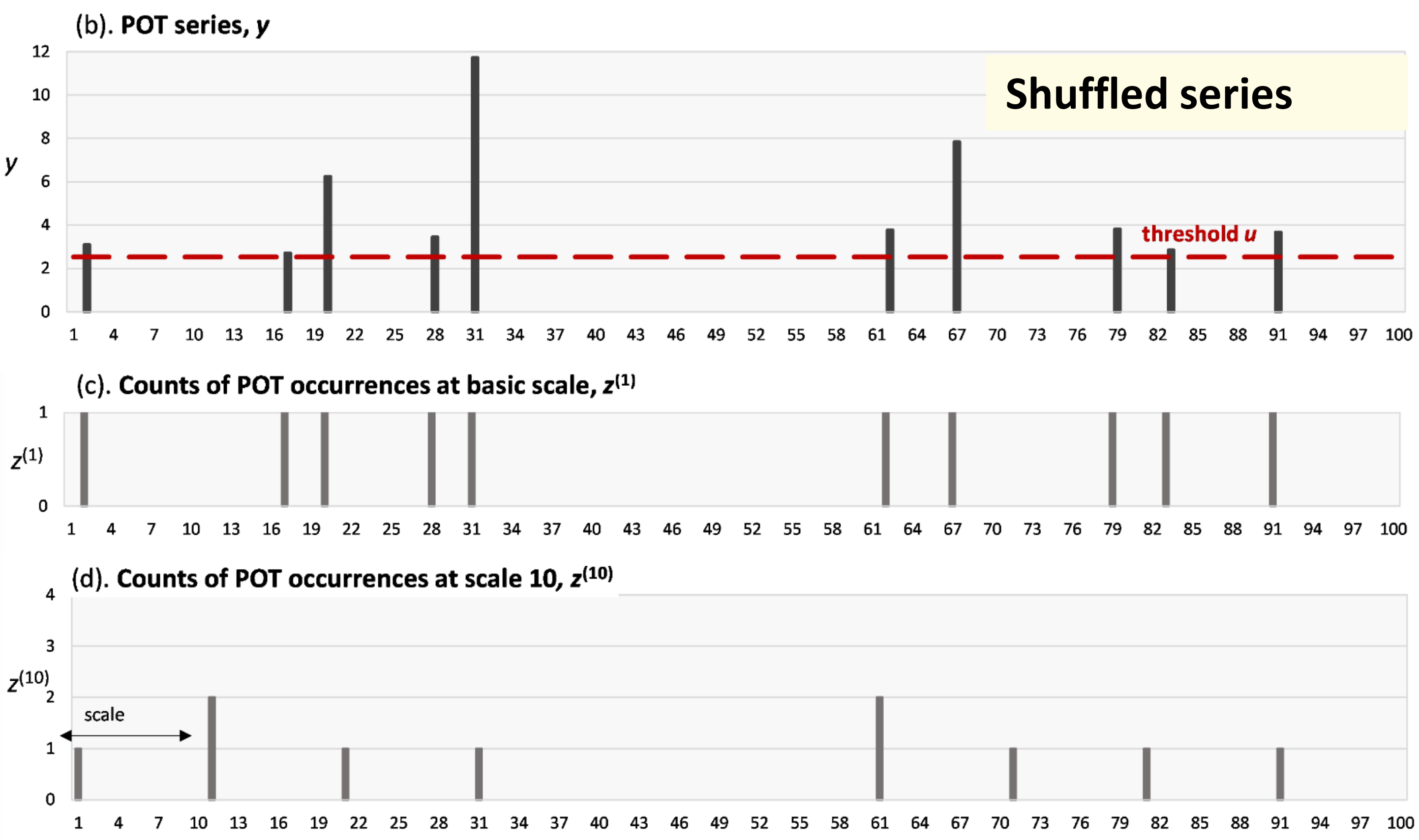
A new probabilistic **multi-scale** clustering index

1 **POT series:**

$$\underline{y}_i := \begin{cases} \underline{x}_i, & \underline{x}_i > u \\ 0, & \underline{x}_i \leq u \end{cases}$$

2 **Counts of POT occurrences at timescale k:**

$$\underline{z}_q^{(k)} := \underline{N}(qk) - \underline{N}((q-1)k)$$



3 **Indicator function of $\underline{z}$:**

$$\underline{r}_q^{(k)} := \begin{cases} 1, & \underline{z}_q^{(k)} > 0 \\ 0, & \underline{z}_q^{(k)} = 0 \end{cases}$$

4 **Probability of exceedance of the threshold for timescale k:**

$$\bar{p}^{(k)} = \frac{\sum_1^{\lfloor n/k \rfloor} \underline{r}_q^{(k)}}{\lfloor n/k \rfloor}$$

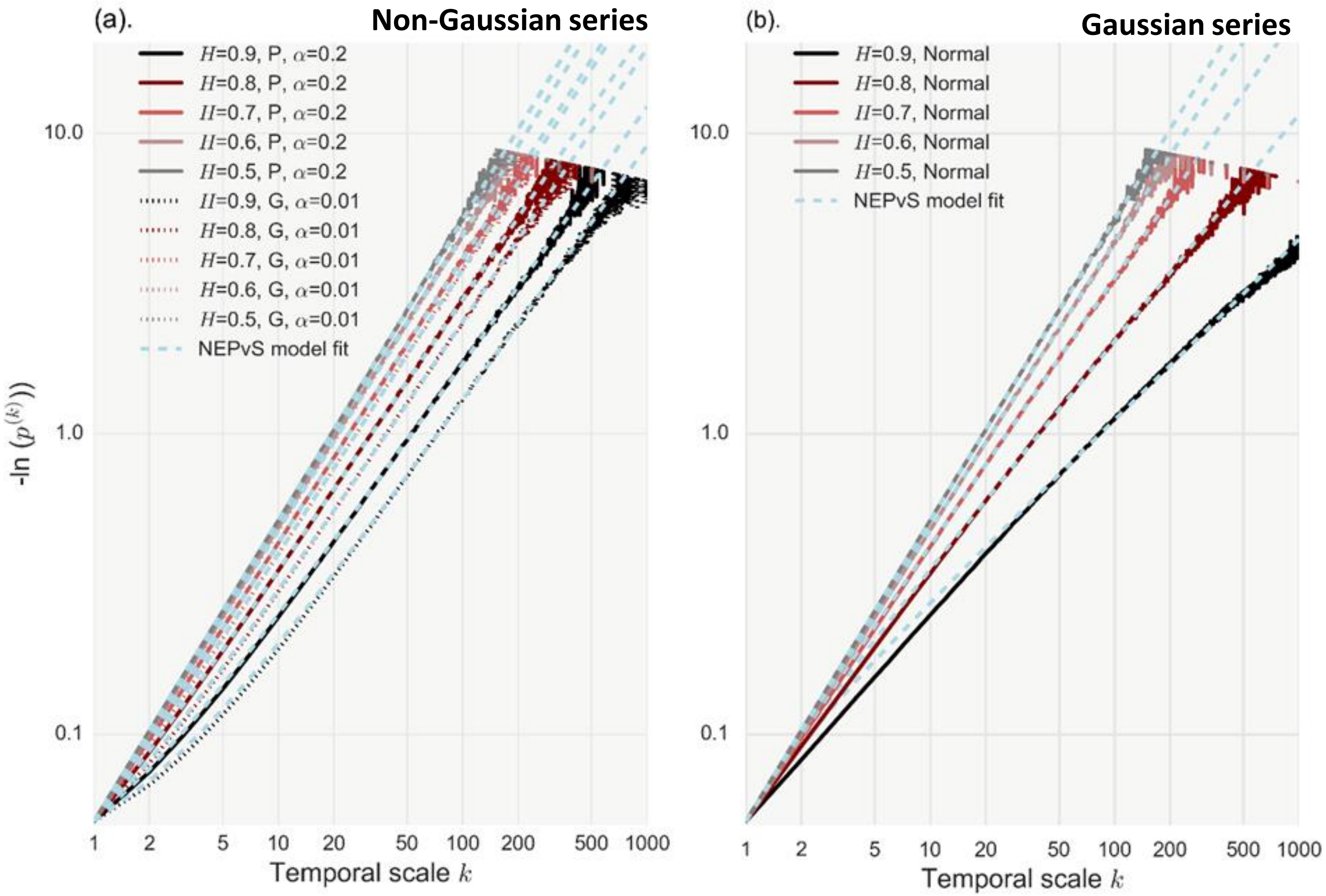
5 **Non-exceedance probability versus scale (NEPvS):**

$$p^{(k)} = 1 - \bar{p}^{(k)}$$

Iliopoulou and Koutsoyiannis (2019)

Multi-scale clustering of extremes under persistence

Persistence increases the probability of non-occurrence of extremes at multiple scales, i.e. **prolonged periods of absence of extreme events are more probable than in an IID process.**



- For a White-Noise process

$$p^{(k)} = p^k$$

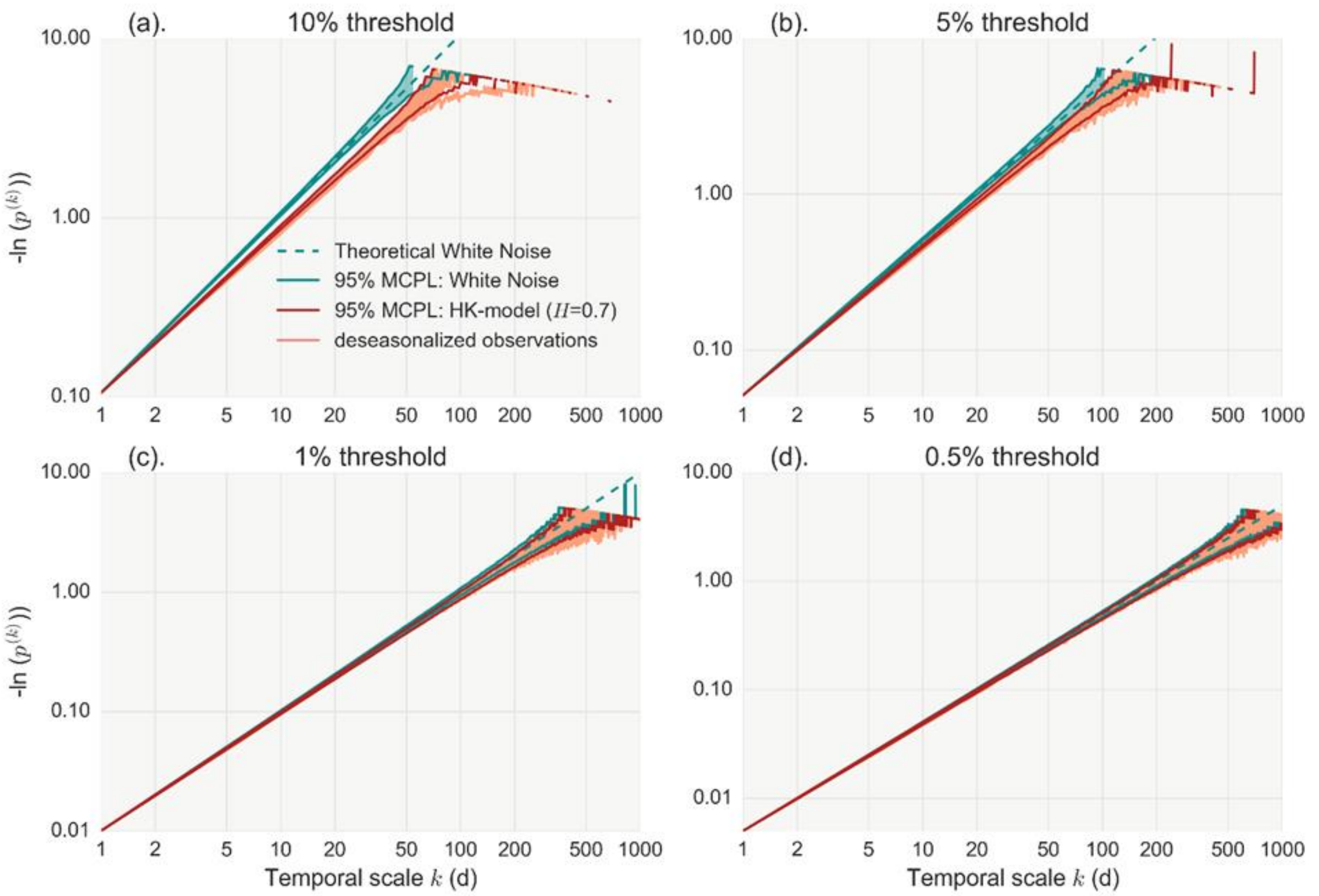
- Two-parameter model

$$p^{(k)} = p^{(1+(\xi^{-1/\eta}-1)(k-1))^{\eta}}$$ (adapted from Koutsoyiannis, 2006)

- For η = 1 and ξ = 0.5, the model describes Poisson occurrences.
- For η < 1 and ξ > 0.5 clustering emerges.

Iliopoulou and Koutsoyiannis (2019)

Clustering of rainfall POT occurrences in the Netherlands

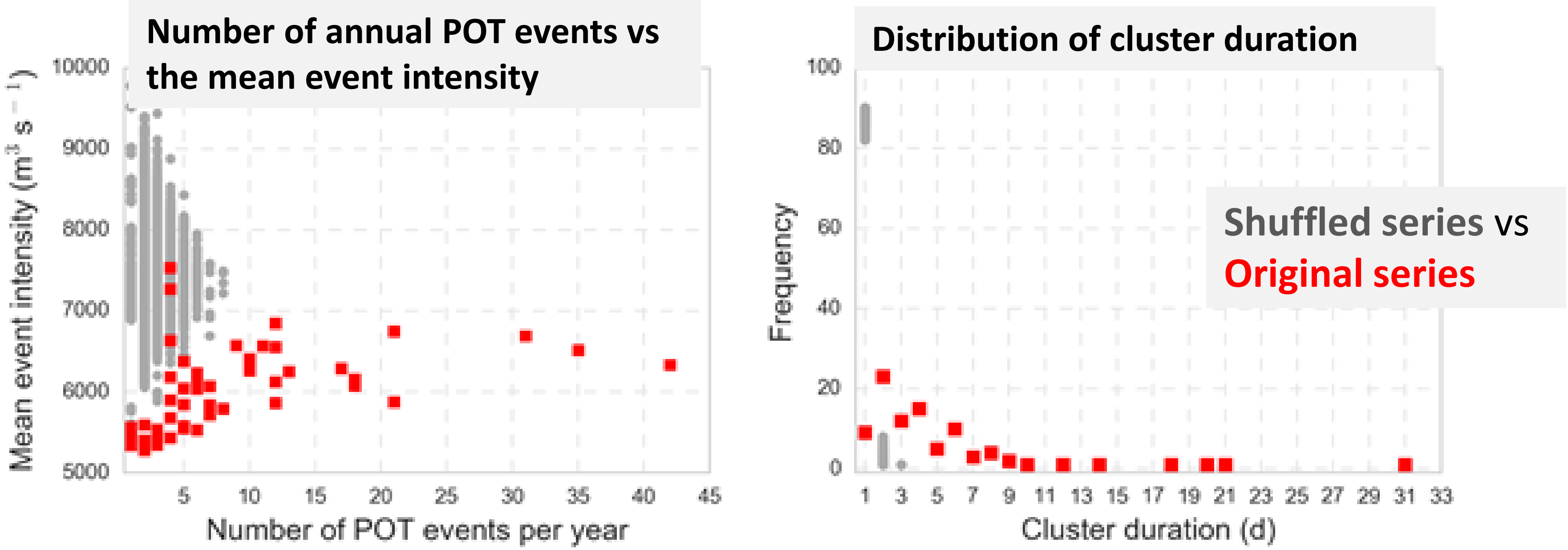


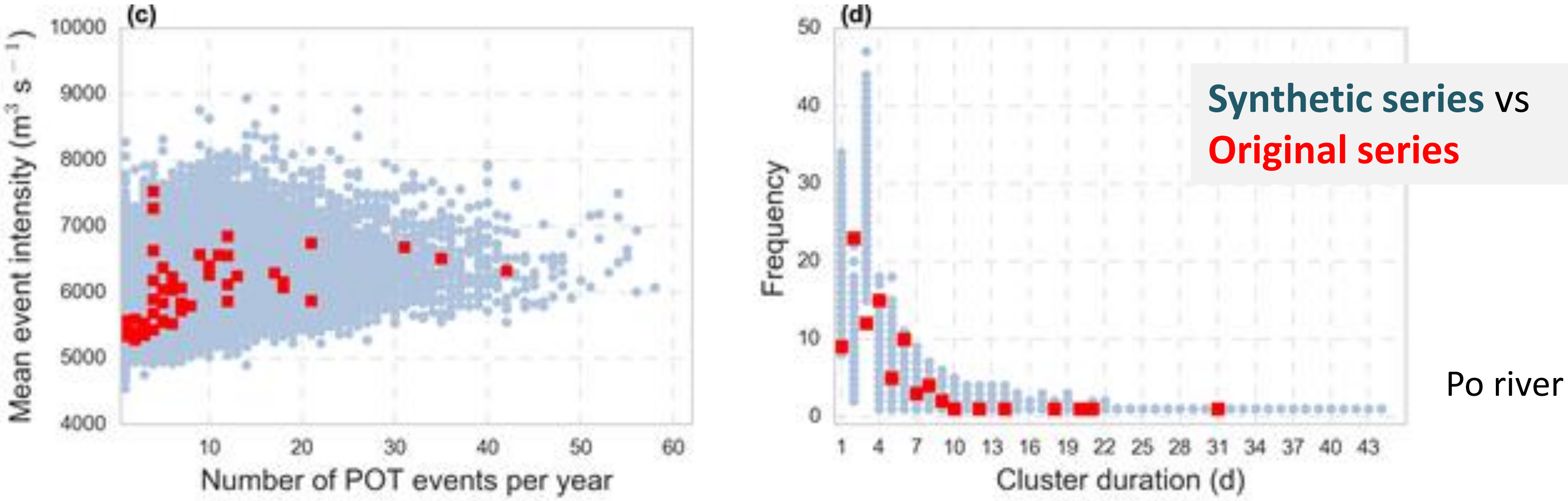
10^3 Monte Carlo simulations from an HK-model preserving the empirical H parameter and first four moments compared to the 28 deseasonalized records.

- HK model is consistent with the majority of the records; a few stations exhibiting even stronger clustering outside of the 95% region of the model.
- **As the threshold increases the probabilistic behaviour of POT occurrences resembles a purely random one.**

Iliopoulou and Koutsoyiannis (2019)

Clustering properties of daily POT streamflow **at the annual scale**



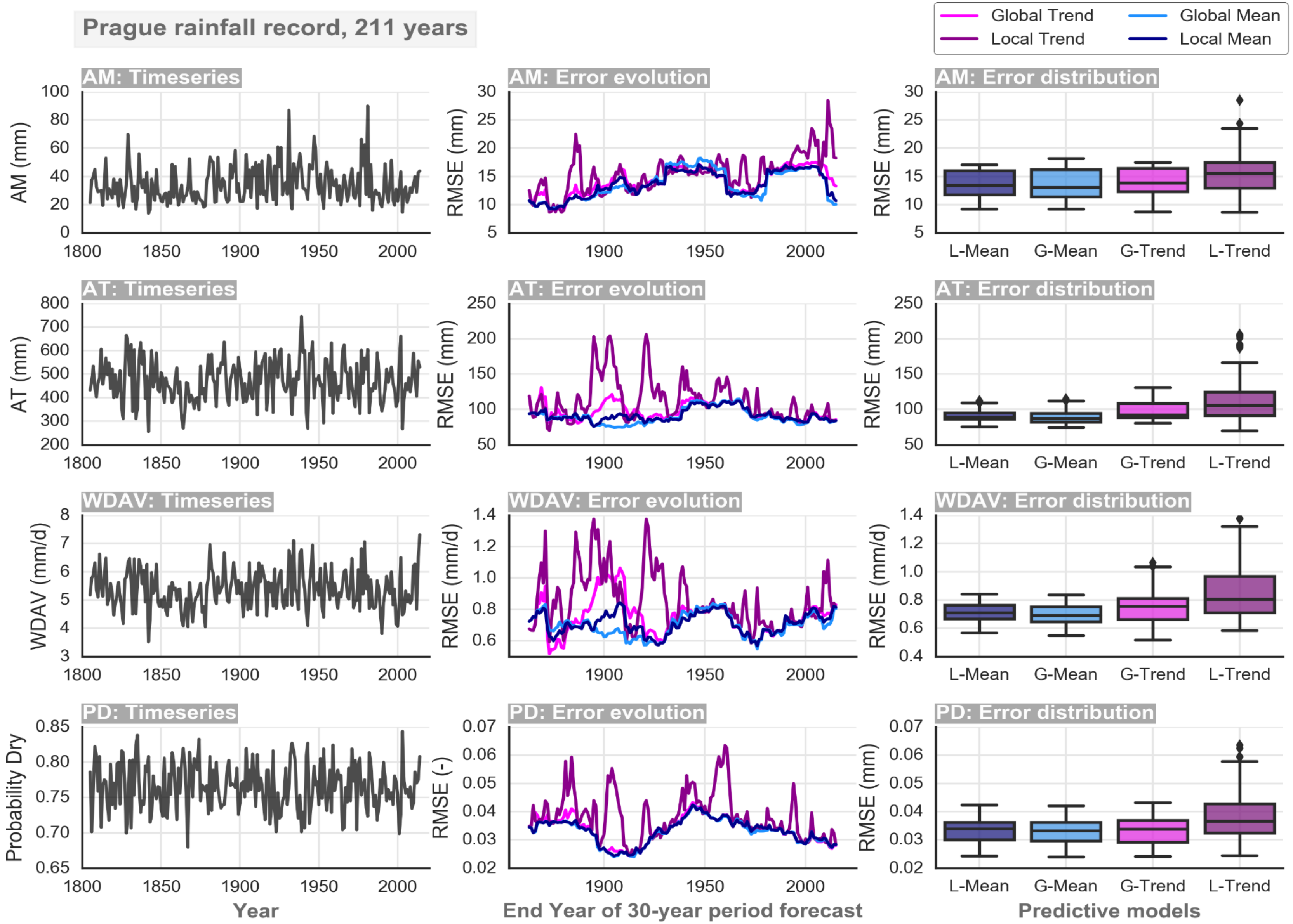


Dependence of POT events at the annual scale is manifested by:

- positive association between **the mean intensity and the intensity and the number of POT events per year.**
- **longer cluster duration** compared to the IID case

Po river daily streamflow series (90 years)

Climatic-scale rainfall clustering – Are trends an effective descriptor?



We assess the 'trends' effectiveness in long-term projections via a **prediction-oriented evaluation framework.**

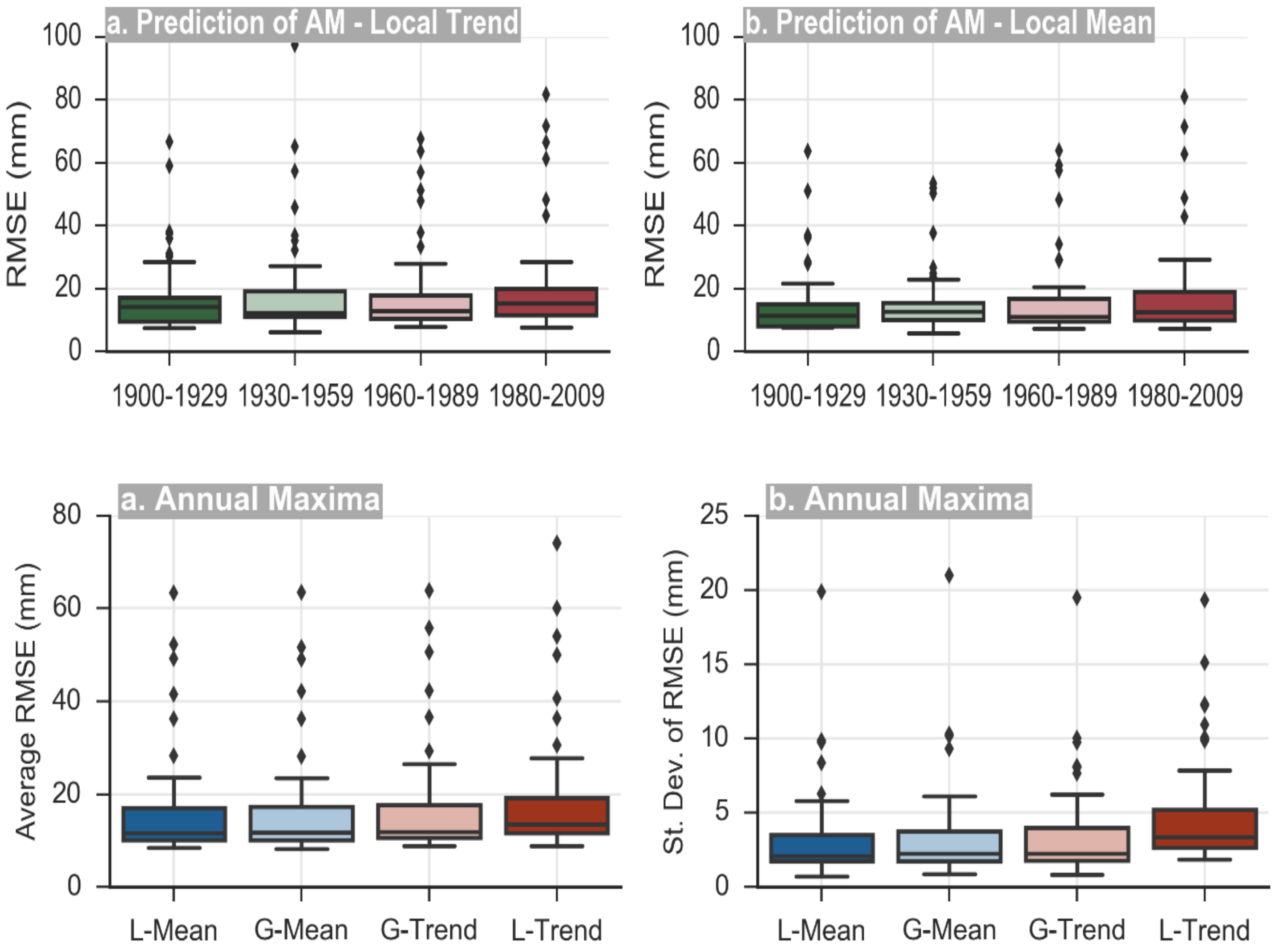
We compare the predictive performance of **global and local trend models** over climatic periods (30 years) to the one obtained by **global and local mean models**.

Iliopoulou and Koutsoyiannis (2020)

Extreme rainfall projections – Local mean models prevail

Fixed periods

Moving-window periods



The models' predictive performance **ranks from best to worse** as follows:

1. L-Mean
2. G-Mean
3. G-Trend
4. L-Trend

In persistent process, where clustering arises, local information is likely to be more relevant for prediction.

Iliopoulou and Koutsoyiannis (2020)

Conclusions

- Linking clustering of extremes to the stochastic properties of the parent process offering probabilistic insights otherwise difficult to obtain.

- Extremes from skewed processes tend to ‘hide’ the persistence of the parent process, often falsely signalling independence. **Identifiability of persistence weakens as the threshold increases**.

- A **new probabilistic index** (NEPvS) is proposed to represent clustering based on the multi-scale probability of non-exceedance of a given threshold.

- POT events from persistent processes have a bilateral character compared to IID processes:
  - absence of POT events in a scale is more likely; persistence increases the multi-scale probability of non-occurrence of extremes.
  - yet if occurrence of extremes is triggered, a higher cluster duration and greater mean and aggregate intensity thereof should be expected.

- Deviations from IID behaviour are prominent in observational records of extremes.

- Understanding and modelling the temporal properties of the parent process is a parsimonious way to reproduce observed temporal clustering under a univariate stochastic approach.

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Thank you!

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