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Modeling Daily Rainfall Occurrence and Amount Conditional on Atmospheric Predictors

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A Pressing Problem for Hydrologists…

⇨ ***Hydrologic impact assessment in a changing climate*** ⇨ { *Accurate* estimates of *precipitation* at a river basin level and at temporal scales suitable to run hydrologic models (i.e. daily).

- ***Quality and availability of water resources***
- ***Flood risk***

× ***Precipitation is the less well reproduced variable by GCMs and LAMs…*** ⇨ {

- *low spatial resolution (≈ 22km)*
- *complex hydrological processes*
- *derivative product* (related to fluxes of energy)

➢ ***Statistical rainfall downscaling*** ⇨ {

(<u>or more accurately:</u> Rainfall simulation conditional on atmospheric predictors)

- *atmospheric variables* (*GH*, *RV*, *div.*, *geostrophic winds* etc.) are more accurately reproduced by GCMs and LAMs *than rainfall*.
- use a *statistical scheme* to relate large-scale *atmospheric predictors* (*GH*, *RV*, *div.*, *geostrophic winds* etc.) to *rainfall* measurements at ground level.
- use the *calibrated scheme* to simulate *synthetic rainfall* conditioned on atmospheric predictors from climate models.

Available Downscaling Schemes

- ***Transfer functions:*** functional relationships between *atmospheric variables* and certain *rainfall statistics* ⇨ *limited number of atmospheric predictors can be linked to rainfall*

- ***Weather generators:*** *broad classes of storms + rainfall statistics linked to storm categories* ⇨ *dependencies of rainfall statistics on refined weather characteristics fade out*

- ***Scaling or non scaling representations of rainfall:*** *not necessarily suited for conditional rainfall simulation* ⇨ *perturbation of model parameters may lead to unanticipated outcomes* (effects on inter-annual variability, rainfall seasonality, extremes…)

What we are after ⇨

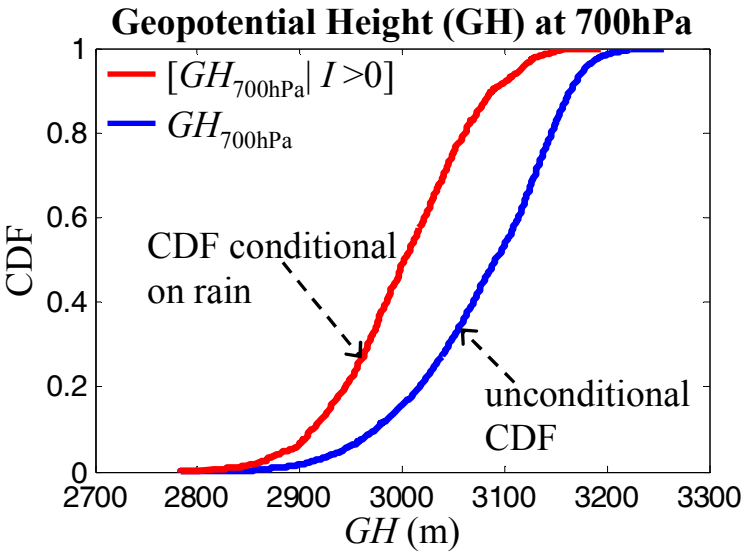
- ✓*A simple scheme…* ✓*No grouping of storms into categories*
- ✓*No limitations in the number of atmospheric predictors*
- ✓***Accurate reproduction of rainfall statistics***

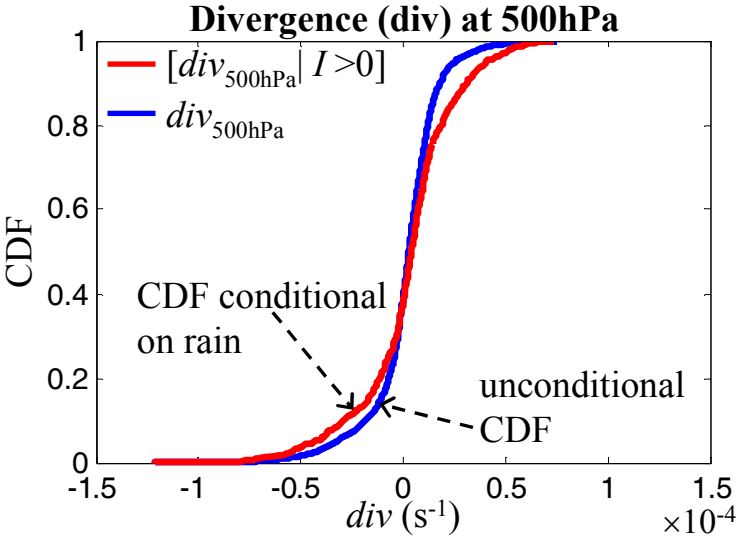
- ***Seasonal character*** *of precipitation occurrence and amount*
- *Alternation of wet and dry intervals* (i.e. $P_{1|0}$, $P_{1|1}$, …) ⇨ ***rainfall intermittency***
- *Distributions of the durations of dry & wet spells* ⇨ ***rainfall clustering***
- *Dependence of rainfall statistics on the observation scale* ⇨ ***rainfall scaling***
- *Distribution of* ***extremes***
- *Long-term* ***climatic features*** *of rainfall* ⇨ *CC impact studies*

Theoretical Framework (1)

➢ ***Select atmospheric predictors*** *and their corresponding* ***pressure levels*** *based on their effect on ground level rainfall* ⇨ ***Concepts from probability theory…***

X: atm. predictor
j: pressure level





➢ *Dimensionless measure $M(X_j)$*

- **Transform** the marginal and conditional-on-rain distributions to a standard distribution space
- **Calculate** measure M as the sum of the squared differences of certain quantiles (e.g. 5%, 25%, …)

Pressure level j (hPa)	$M(GH_j)$	$M(RV_j)$	$M(U_j)$	$M(V_j)$	$M(div_j)$	$M(U_j) + M(V_j)$
300	4.248	1.077	0.744	0.430	0.361	1.174
400	4.481	1.358	0.726	0.532	0.398	1.258
500	4.692	**1.679**	0.673	0.526	0.263	1.199
600	4.905	1.548	0.638	0.611	0.218	1.248
700	**4.964**	1.009	0.747	**0.668**	0.438	1.415
800	4.619	0.560	**0.836**	0.584	**0.559**	**1.419**
900	3.258	0.280	0.754	0.563	0.510	1.317

- **Atmospheric data** from ERA-Interim (1979-1993).
- **Point rainfall** measurements from Glafkos catchment in western Greece (1979-1993).

Variable	$M(X_j)$	%
GH_{700hPa}	4.964	57.58%
RV_{500hPa}	1.679	19.48%
U_{800hPa}	0.836	9.69%
V_{800hPa}	0.584	6.77%
~~div_{800hPa}~~	~~0.559~~	~~6.48%~~
Sum	8.621	100.00%

Theoretical Framework (2)

➢ ***Stochastic model for continuous rainfall simulation conditional on large-scale atmospheric forcing:***

Atmospheric predictors ⇨ $\mathbf{X} = [GH_{700\text{hPa}}, RV_{500\text{hPa}}, U_{800\text{hPa}}, V_{800\text{hPa}}]$ ***…more can be included***

Probabilistic model for rainfall occurrences ⇨

(CPT) $$P[I > 0 | \mathbf{X} = \mathbf{x}] = \frac{f_{\mathbf{X}|I>0}(\mathbf{x})}{f_{\mathbf{X}}(\mathbf{x})} P[I > 0]$$

Prob. it rains on a certain day

joint density of **X** *cond. on wet*

joint density of **X**

yearly fraction of wet days (constant)

➢ *Approximate the ratio:* $R(\mathbf{x}) = \dfrac{f_{\mathbf{X}|I>0}(\mathbf{x})}{f_{\mathbf{X}}(\mathbf{x})}$

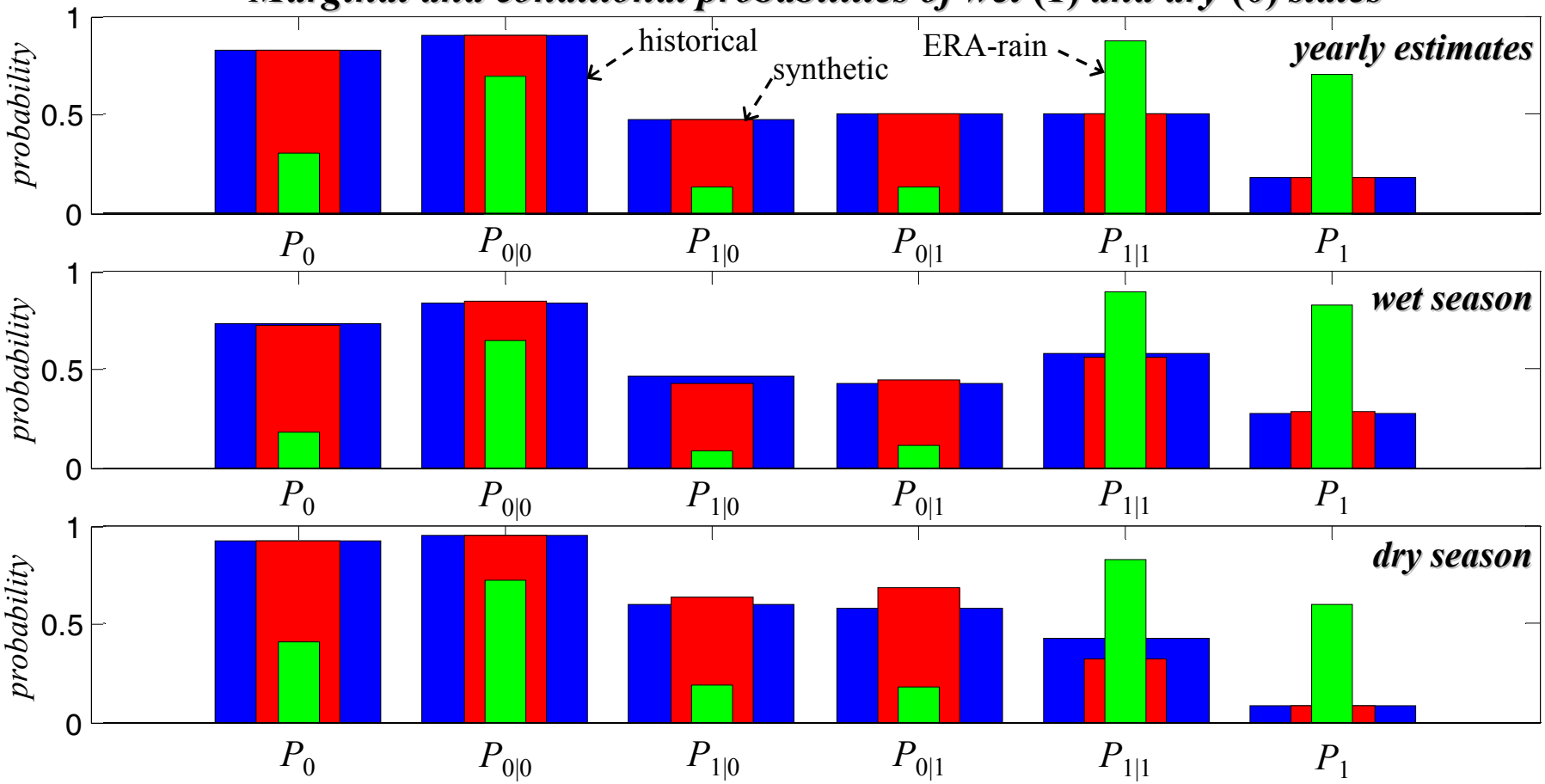
✓ use simple transformations of the associated distributions to avoid detailed conditional distribution analysis

Probabilistic model for daily rainfalls ⇨

- Use a *lognormal distribution* for *daily rainfall* intensities (other distribution models are also applicable)
- *Distribution parameters* are estimated *conditional on* **X** using CSM

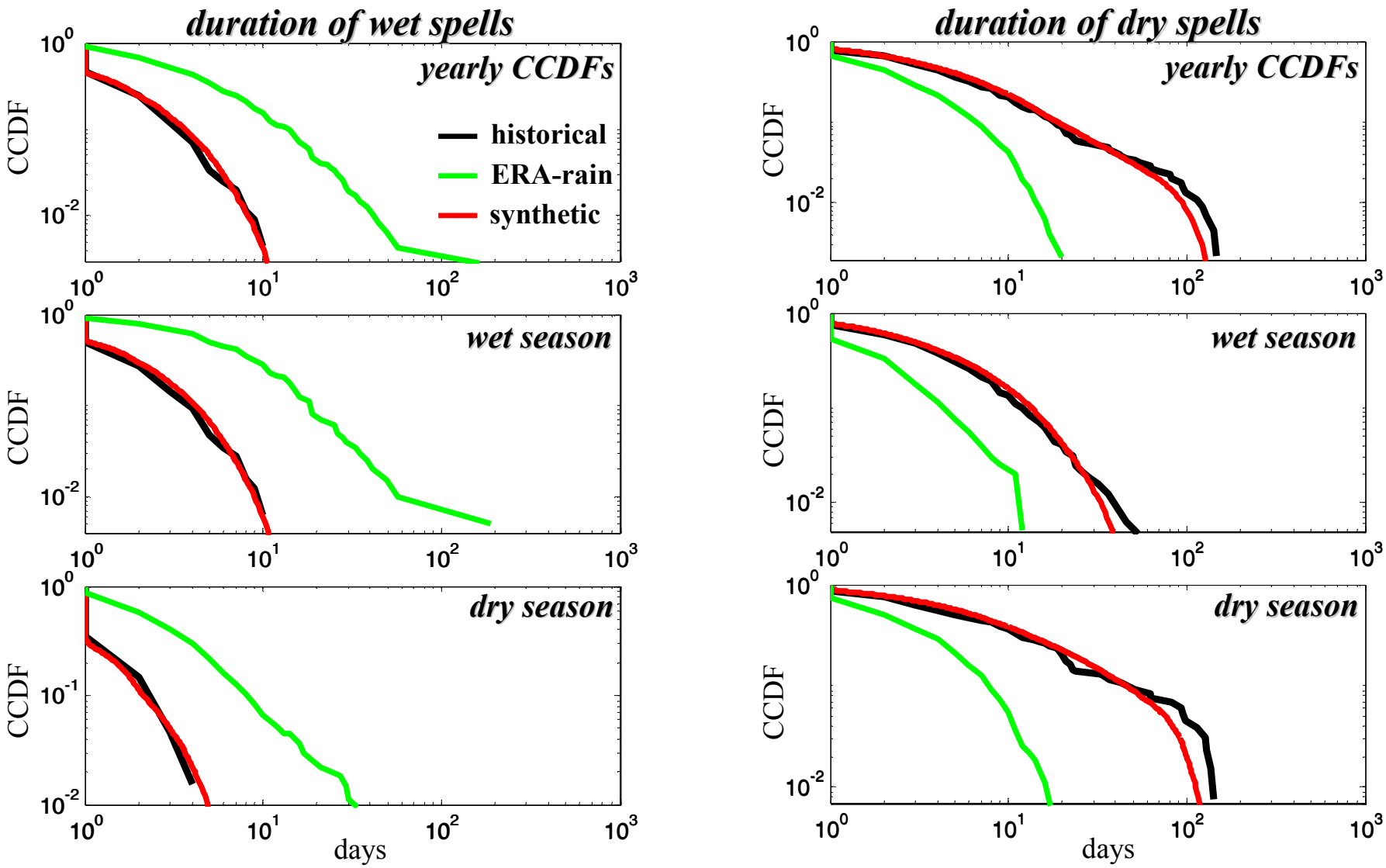
Model Application (1)

Marginal and conditional probabilities of wet (1) and dry (0) states

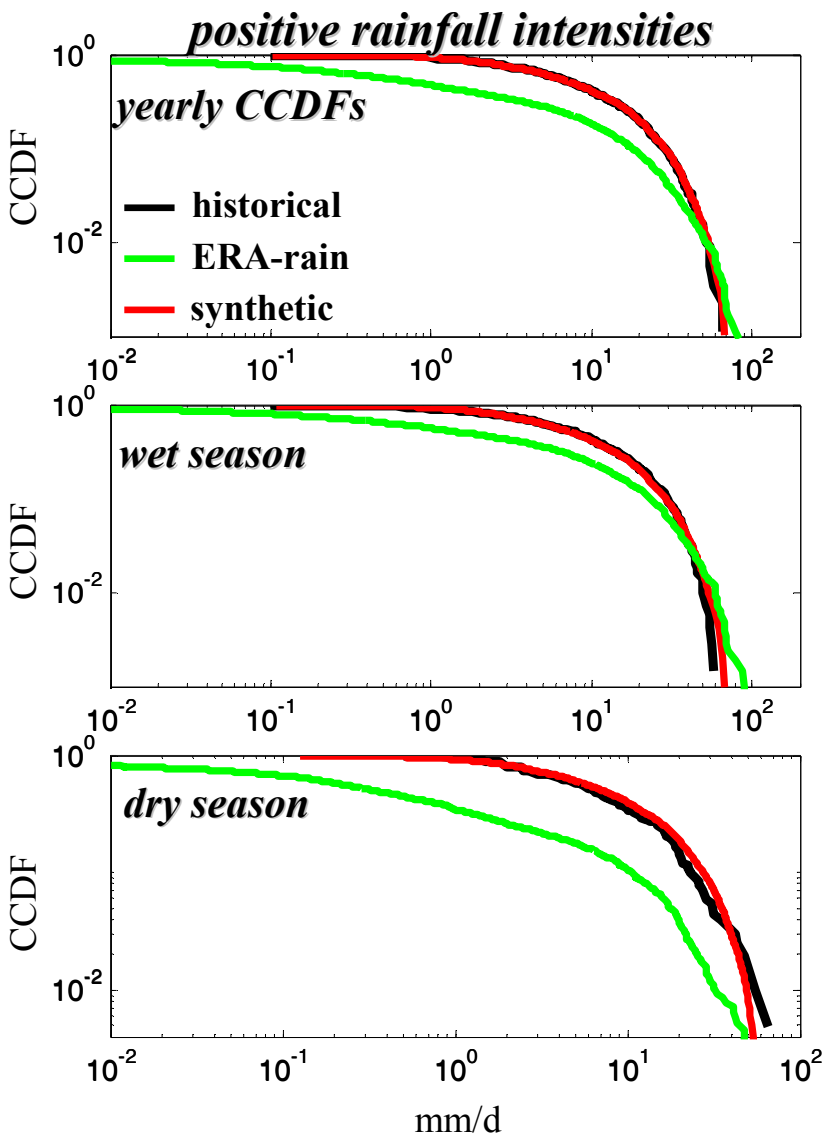


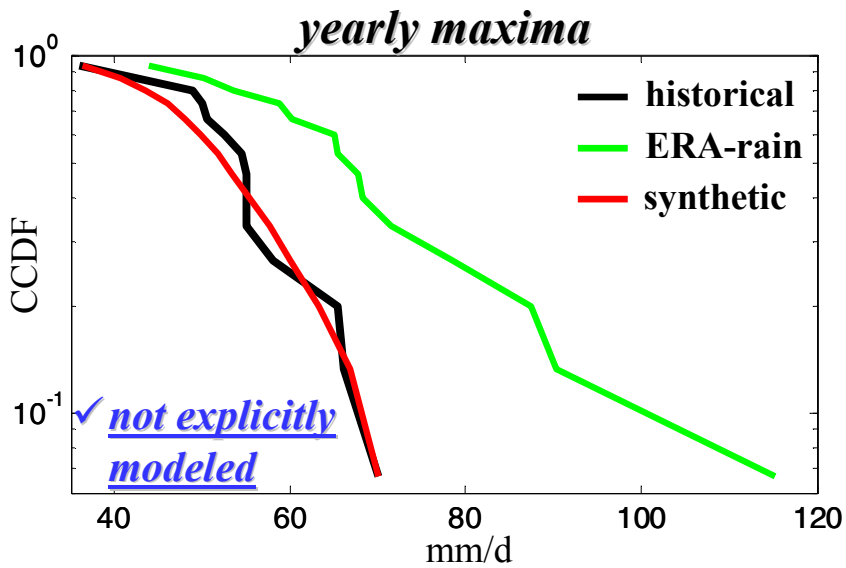
✓ ***<u>No seasonal analysis</u>*** ⇨ ***model parameters are yearly constant***

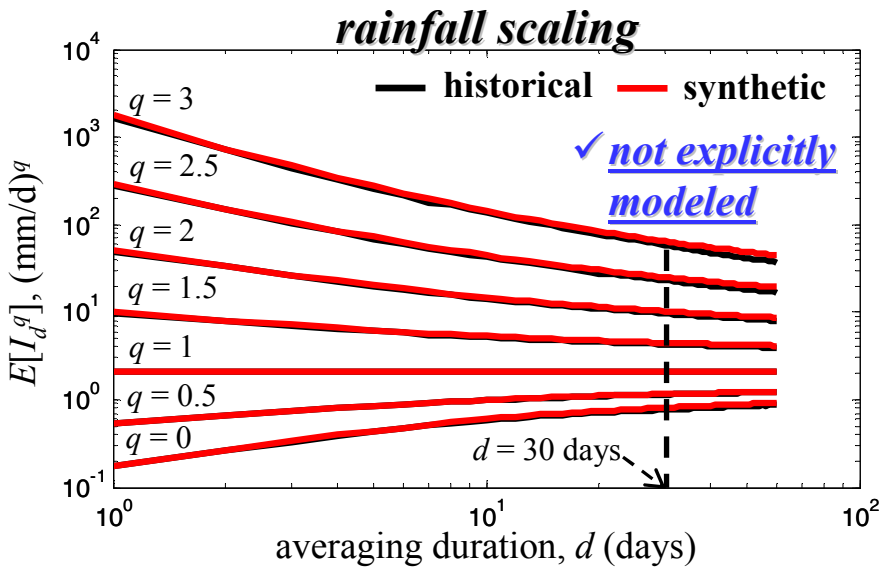
Model Application (2)



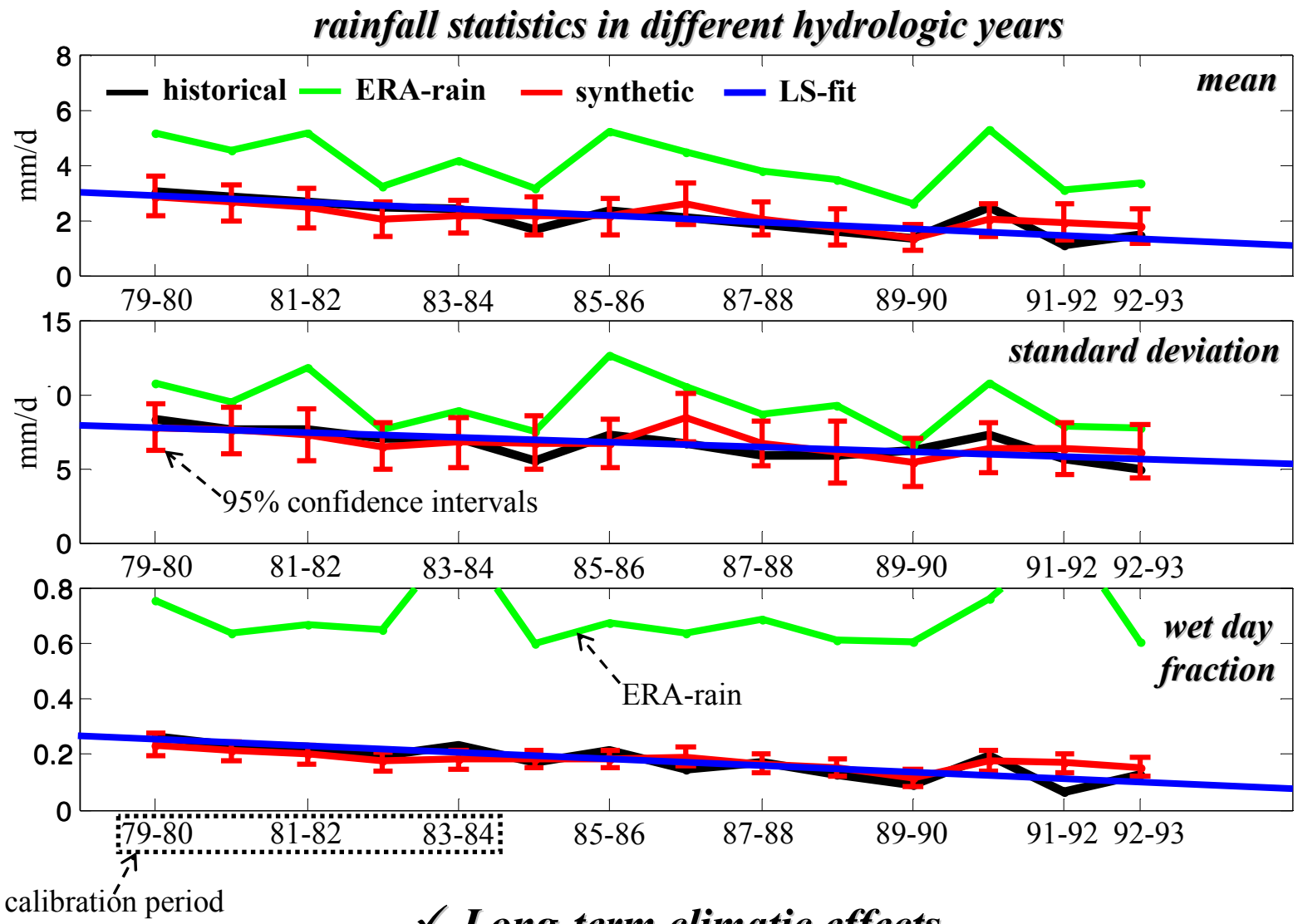
Model Application (3)







Model Application (4)



✓ ***Long-term climatic effects***

Summary and Conclusions

➢**We developed a stochastic scheme for rainfall simulation conditional on atmospheric predictors, capable of reproducing**:

✓*The seasonal character of precipitation, without any type of seasonal analysis or modeling*
⇨ the duration of seasons varies in a changing climate

✓*The alternation of* ***wet and dry intervals*** (rainfall intermittency)

✓*The distribution of* ***dry and wet spell lengths*** (rainfall clustering)

✓*The distribution of* ***rainfall intensities*** *in wet days*

✓*The distribution of* ***rainfall maxima***

✓*The dependence of rainfall* ***statistics on scale*** (rainfall scaling)

✓*Long-term* ***climatic features*** *of rainfall*

⇨***Solely from atmospheric forcing***

Future work ⇨

- ***Calibrate*** the developed scheme using ***atmospheric forcing*** from climate models & ground-level ***rainfall measurements***
- Simulate ***synthetic rainfall*** series.

Skip using rainfall products form GCMs and LAMS

➢***Use the simulated rainfall series to run hydrologic models, and assess the effects of climate change on river basin hydrology.***

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