Estimation of extreme flooding based on stochastic weather generators supported by a regional precipitation study and non-systematic flood data

By:

Carles Beneyto[1], José Ángel Aranda[1], Gerardo Benito[2] and Félix Francés[1]

[1]Research Group of Hydrological and Environmental Modelling (GIMHA)
Research Institute of Water and Environmental Engineering (IIAMA)
Universitat Politècnica de València, Valencia, Spain

[2]Department of Geology, National Museum of Natural Sciences, Madrid, Spain

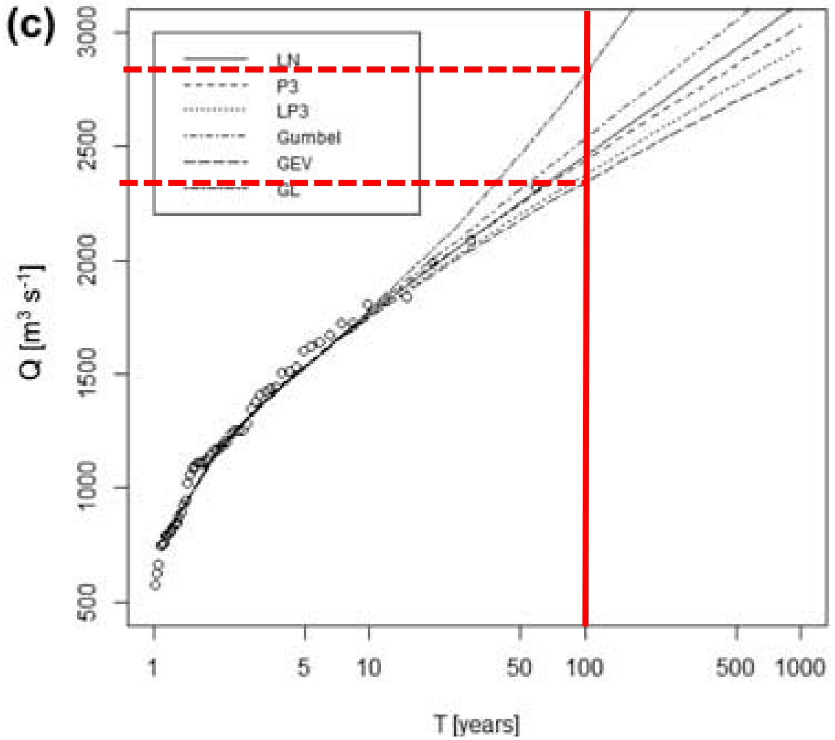
Introduction and objectives

- Importance of the study of extreme events ➡ Floods
  - Design of hydraulic infrastructures
  - Elaboration of flood maps **(Directive 2007/60 CE)**

Develop a new methodology for a better extreme flood estimation beyond the paradigm of the design storm

Introduction and objectives

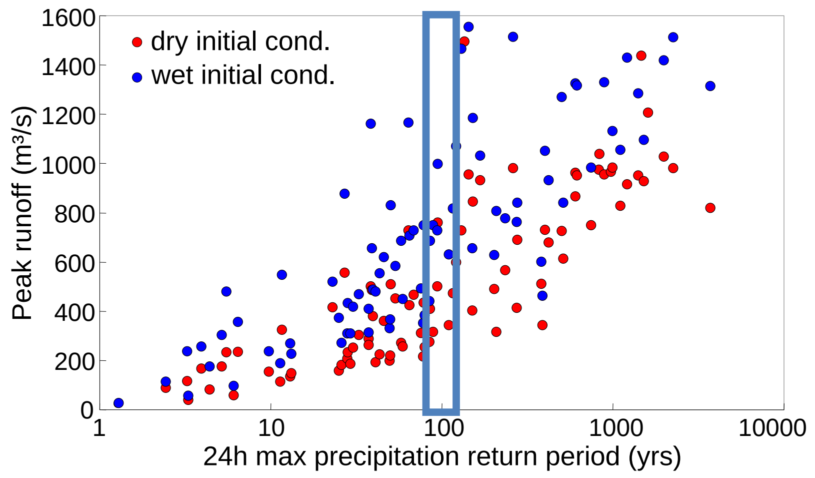
- Traditional approach: **Empirical / Statistical**



High Uncertainty
Short flow and precipitation records

Introduction and objectives

- Traditional approach: **Empirical / Statistical**
- Later: **Deterministic (Design Storm)**
  - Based on IDF curves
    - Rectangular hyetograph
    - Alternating block method, etc.
  - Based on actual precipitation records
    - Huff method
    - Stochastic storm generation
- Peak flow and hydrograph strongly dependant on
  - Initial state

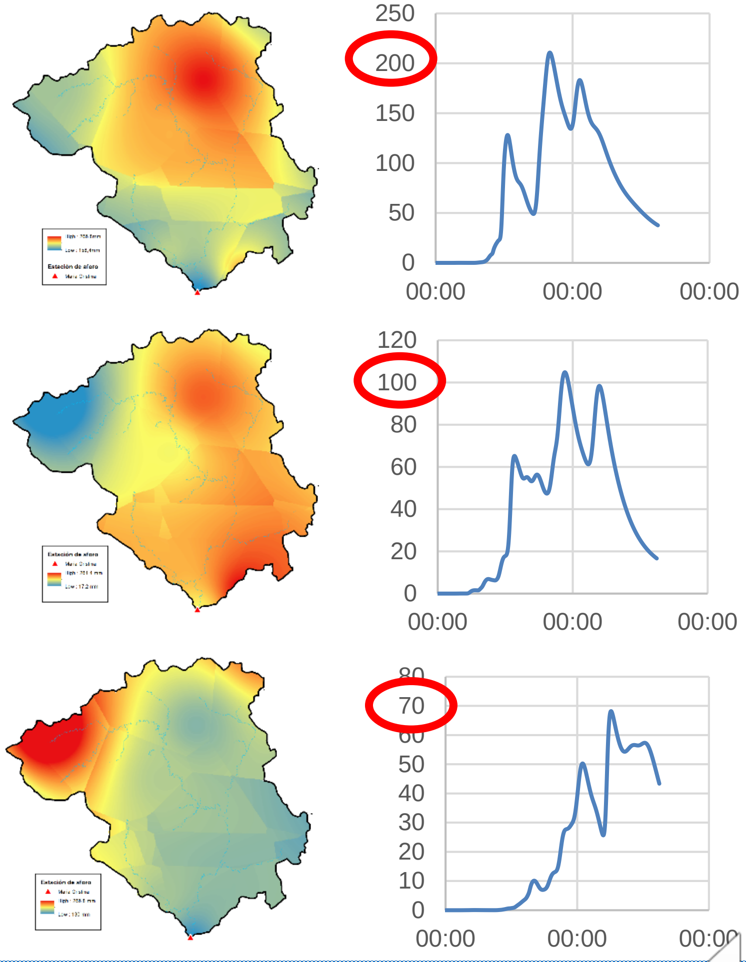


200 simulations using 100 synthetic storms and 2 initial conditions (i.e. dry-wet) in Rambla Poyo (Valencia, Spain)

Introduction and objectives

- Traditional approach: **Empirical / Statistical**
- Later: **Deterministic (Design Storm)**
  - Based on IDF curves
    - Rectangular hyetograph
    - Alternating block method, etc.
  - Based on actual precipitation records
    - Huff method
    - Stochastic storm generation
- Peak flow and hydrograph strongly dependant on:
  - Initial state
  - Spatio-temporal distribution of Precipitation

78h Event: P_m=169,2mm

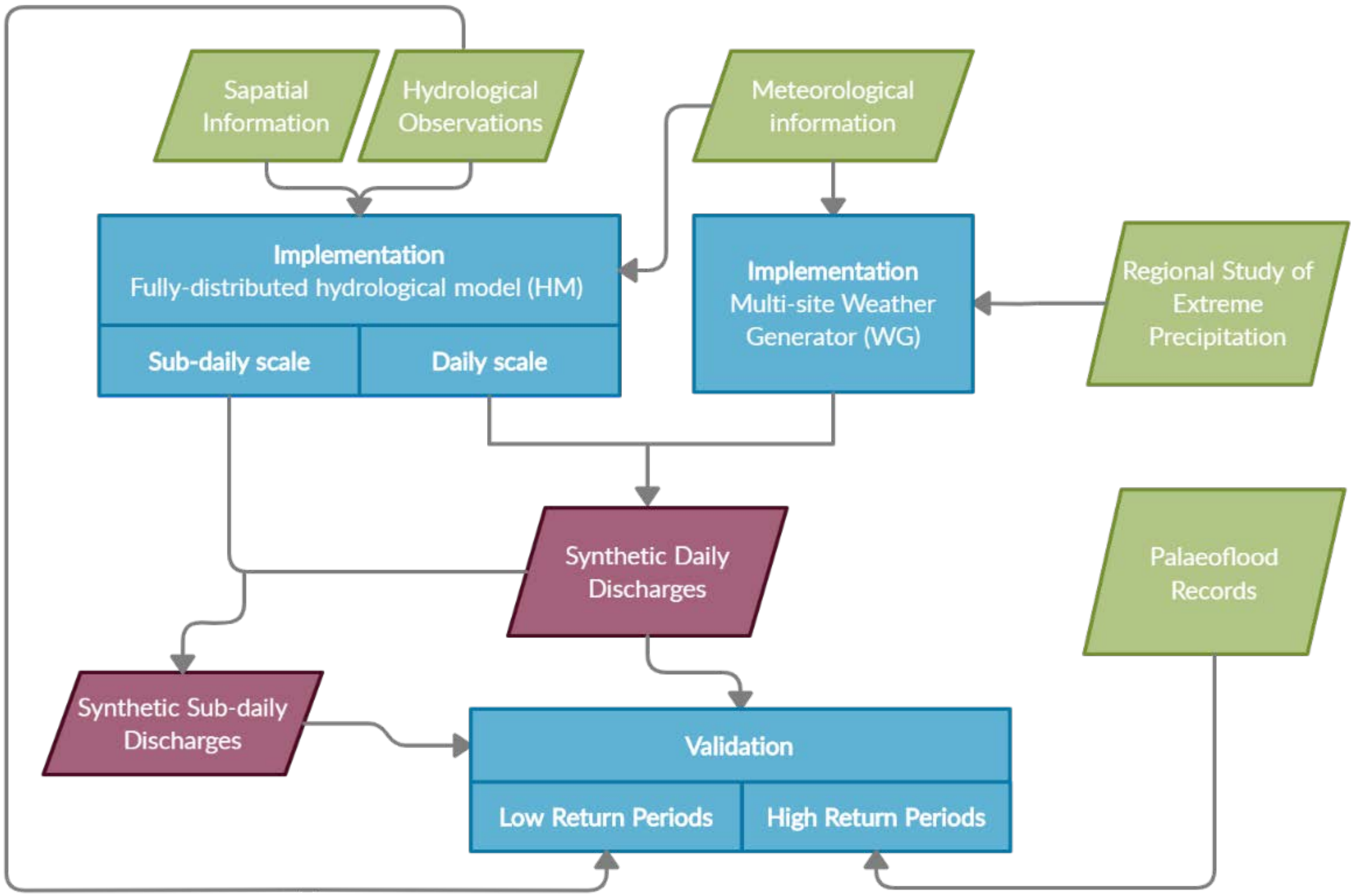


Introduction and objectives

- More recently: **Continuous Simulation**
  - Stochastic simulation + Hydrological model
    - ✓ Short input data series
    - ✓ Spatio-temporal distribution of rainfall
    - ✓ Initial state of river basin
- However:
  - Yet, stochastic weather generators need to be fed with robust input data series in order to perform adequately or;
  - Additional information must be integrated
  - Small temporal scales (i.e. < daily) are still not operative due to high computational requirements

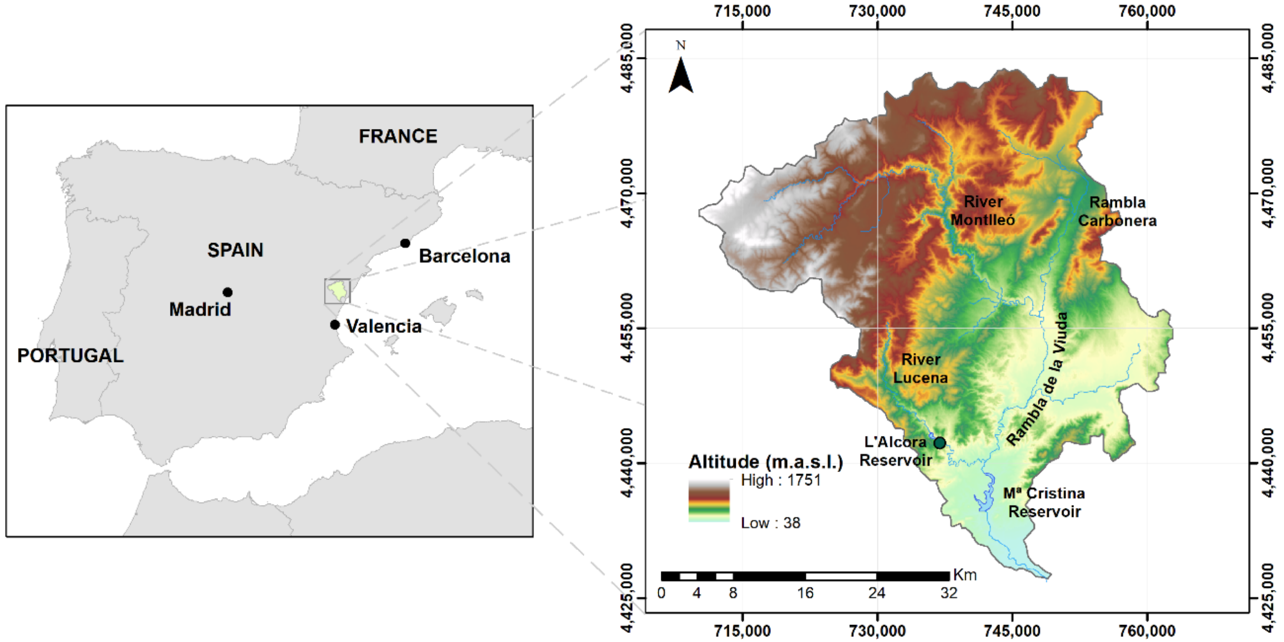
Methodology based on Stochastic Weather Generators (Weather Generator + Distributed Hydrological Model + Integration of information)

Methodology



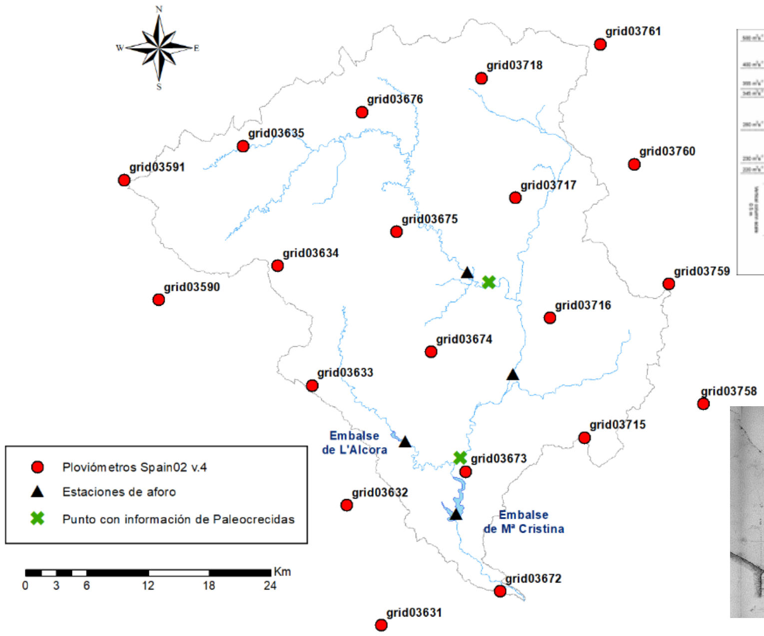
Case study: study area

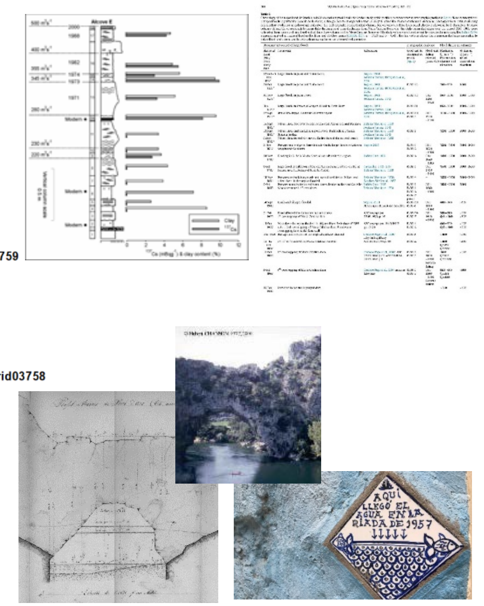
- **Rambla de la Viuda**: ephemeral river
- Approx. area: 1,500 km^2
- Semi-arid Mediterranean climate
- Annual mean precipitation: 550 mm
- High precipitation variability
- Two reservoirs (Mª Cristina y Alcora)



Case study: available information

- **Hydrometeorological information**
  - Precipitation
    - Spain02-v5 grid: 20 rain gauges + thermometers
    - Regional analysis of daily max. precipitation *(CEDEX, 1994)*
  - Flow gauges
    - SAIH Júcar
- **Historical info. and palaeofloods**
  - Two locations *(Machado et al., 2017 and Benito et al., 2020)*

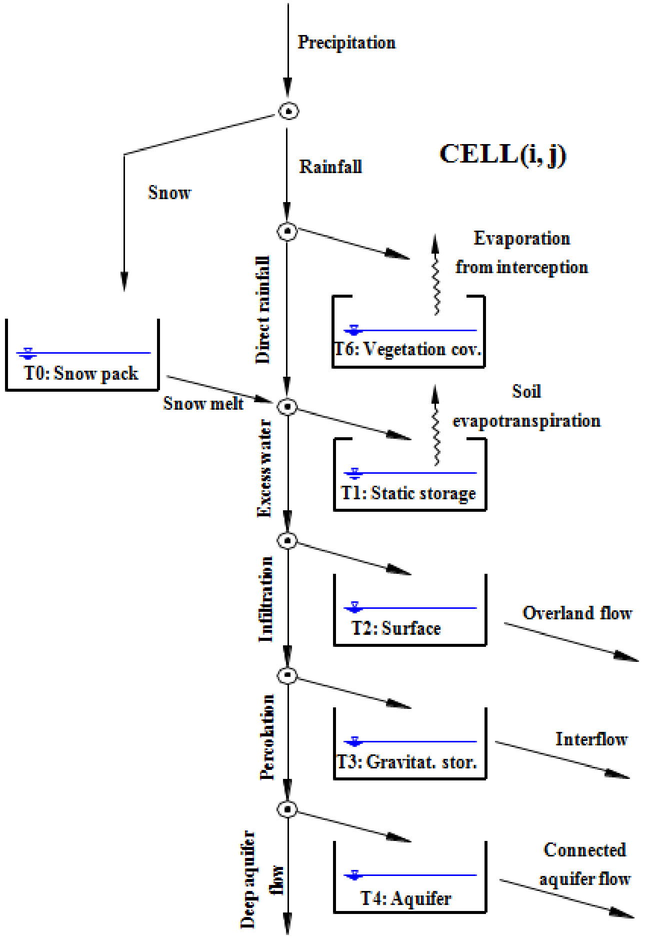




	Data series length	Period	
	(Complete years)	Start	End
Mª Cristina (Reservoir)	59	1/10/1959	17/12/2018
Alcora (Reservoir)	56	1/10/1959	30/09/2015
Vall d'Alba	15	13/05/2004	17/12/2018
Monleon	14	1/11/2005	20/12/2018

Case study: Eco-hydrological model TETIS

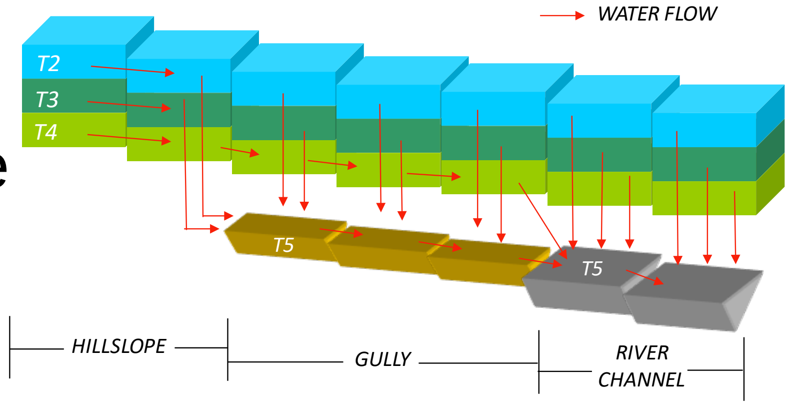
- Developed by our group since 1994 (version 9 on the web)
- Conceptual (tank structure) model, with **physically based parameters**
- **Parsimonious**: 9 parameters for hydrologic sub-model
- **Integral** model: water resources, floods, sediments, dynamic vegetation, crop production, N-C cycle, … and more to come!



Conceptual schema of the TETIS model at cell scale

Case study: Eco-hydrological model TETIS

- **Distributed** in space:
  - Reproduces the spatial variability of hydrological cycle
  - Uses all spatial information available
  - Gives results at any point



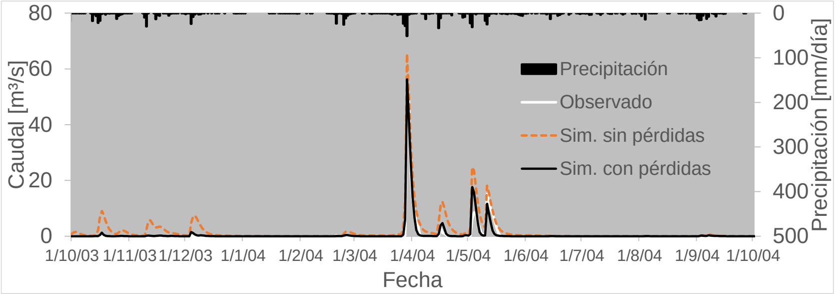
- Incorporates an **split effective parameter structure** (*Benito and Francés, 1995; Francés et al., 2007)*
  - Significant reduction of the number of variables to be calibrated => facilitates model calibration stage
  - Maintains the spatial pattern of the parameter maps
  - Powerful **automatic calibration** algorithm

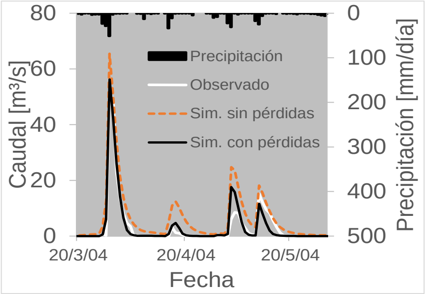
TETIS model implementation

- <u>Calibration (daily scale):</u>

  Mª Cristina (2003-2004)

  NS = 0.930

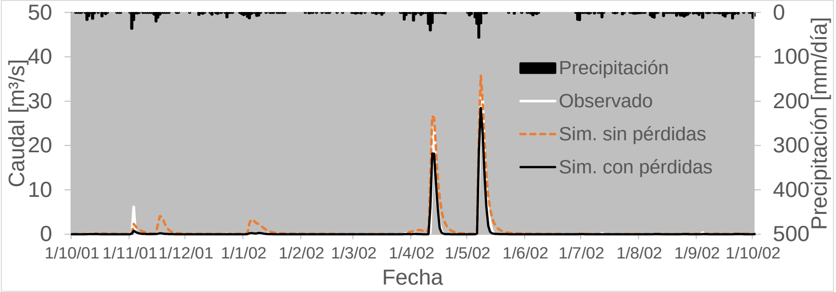


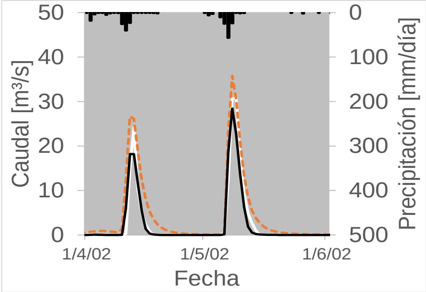


- <u>Temporal validation:</u>

  Mª Cristina (2000-2001)

  NS = 0.928

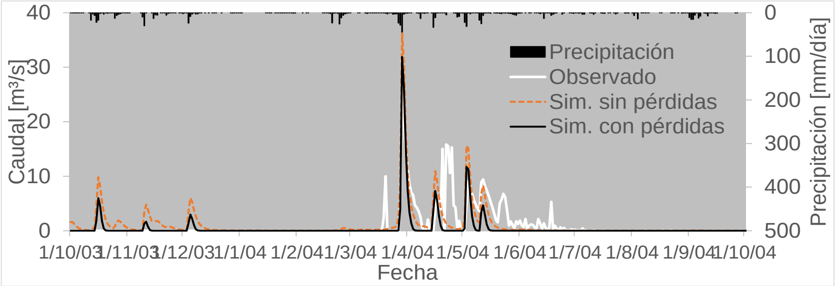


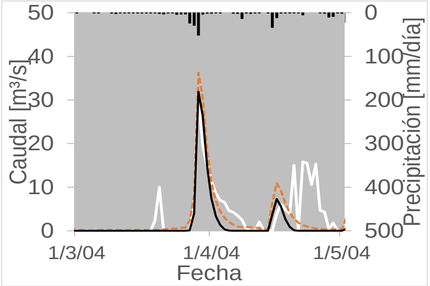


- <u>Spatial validation:</u>

  Vall d'Alba (2003-2004)

  NS = 0.428

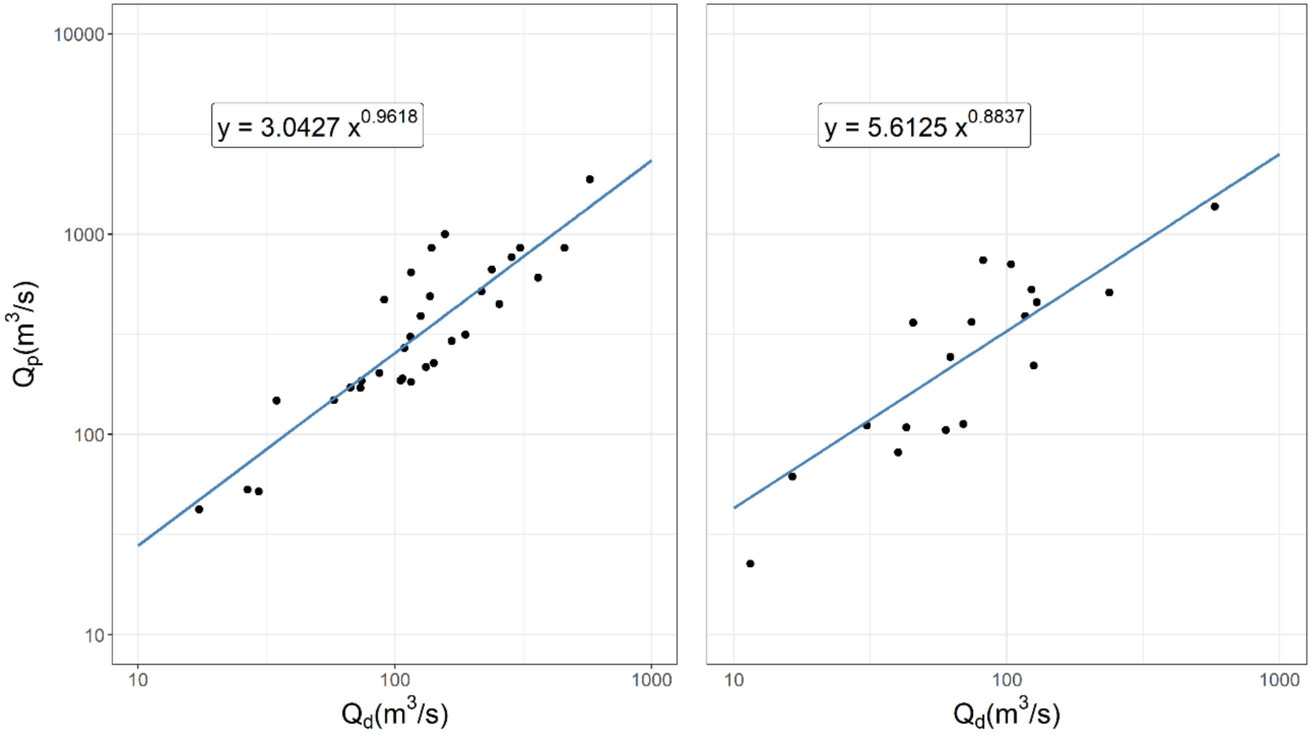




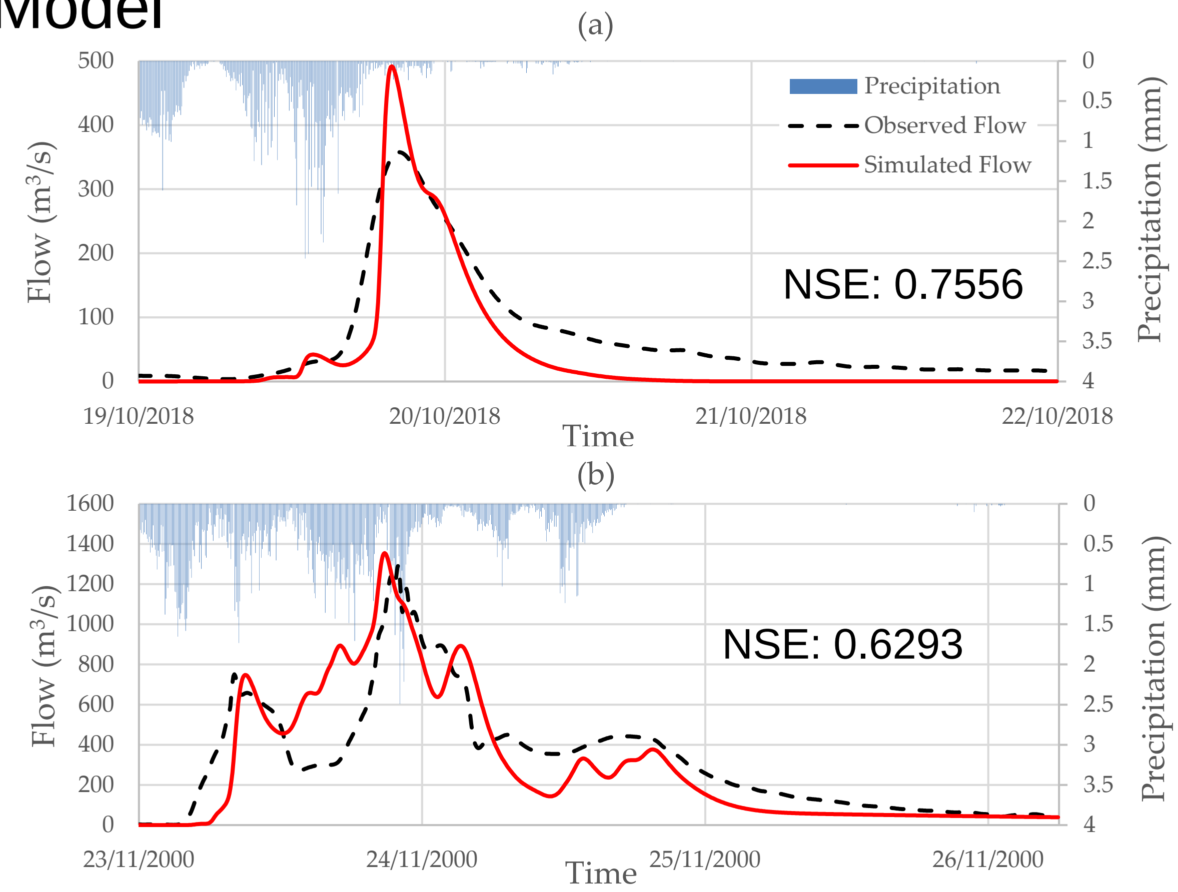
(Correcting time lag and transmission losses)

Conversion Q_{daily} => Q_{peak}

- Implementation of Sub-daily Hydrological Model



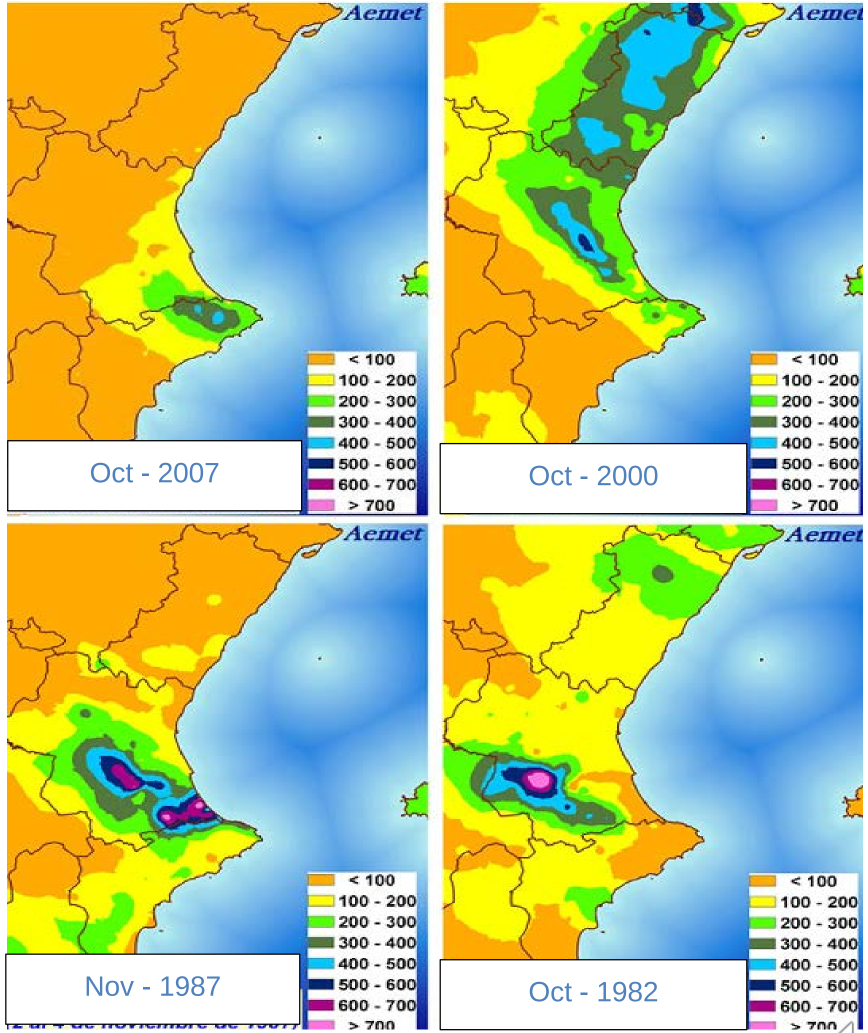
Potential regression between daily (Qd) and simulated peak discharges (Qp) at palaeoflood sites: Left, Rambla de la Viuda NS site; Right, Montlleó NS site



Observed and simulated sub-daily hydrographs for the calibration in the 2018 event (a), and temporal validation in the 2000 event (b) at Maria Cristina dam

Selection of weather generator

- Precipitation regime clearly influenced by “Gota fría” (heavy convective events)
  - Low frequency precipitation events
  - Every 7-8 years on average
  - Huge amounts of precipitation (up to 900mm in 24h)
  - Over periods of time lasting between 2-3 days
  - Autumn months (SON)
  - **COMPLEX PHENOMENA**



Selection of weather generator

- Multisite Weather Generator: **GWEX** (Evin et al., 2018)
  - At-site occurrence: *p-order* Markov chain
  - Spatial dependence of the precipitation states is modeled using an unobserved Gaussian stochastic process
  - Amounts of precipitation are modelled by using: a tail-dependent spatial distribution and an autocorrelated temporal process
  - Marginal distribution: Extended Generalized Pareto Distribution (E-GDP) -> **heavy-tailed**

$$F(x;\lambda) = \left[1 - \left(1 + \frac{\xi(x)}{\sigma}\right)_+^{-1/\xi}\right]^k, x > 0$$

    - Parameter estimation

σ, κ: From observations

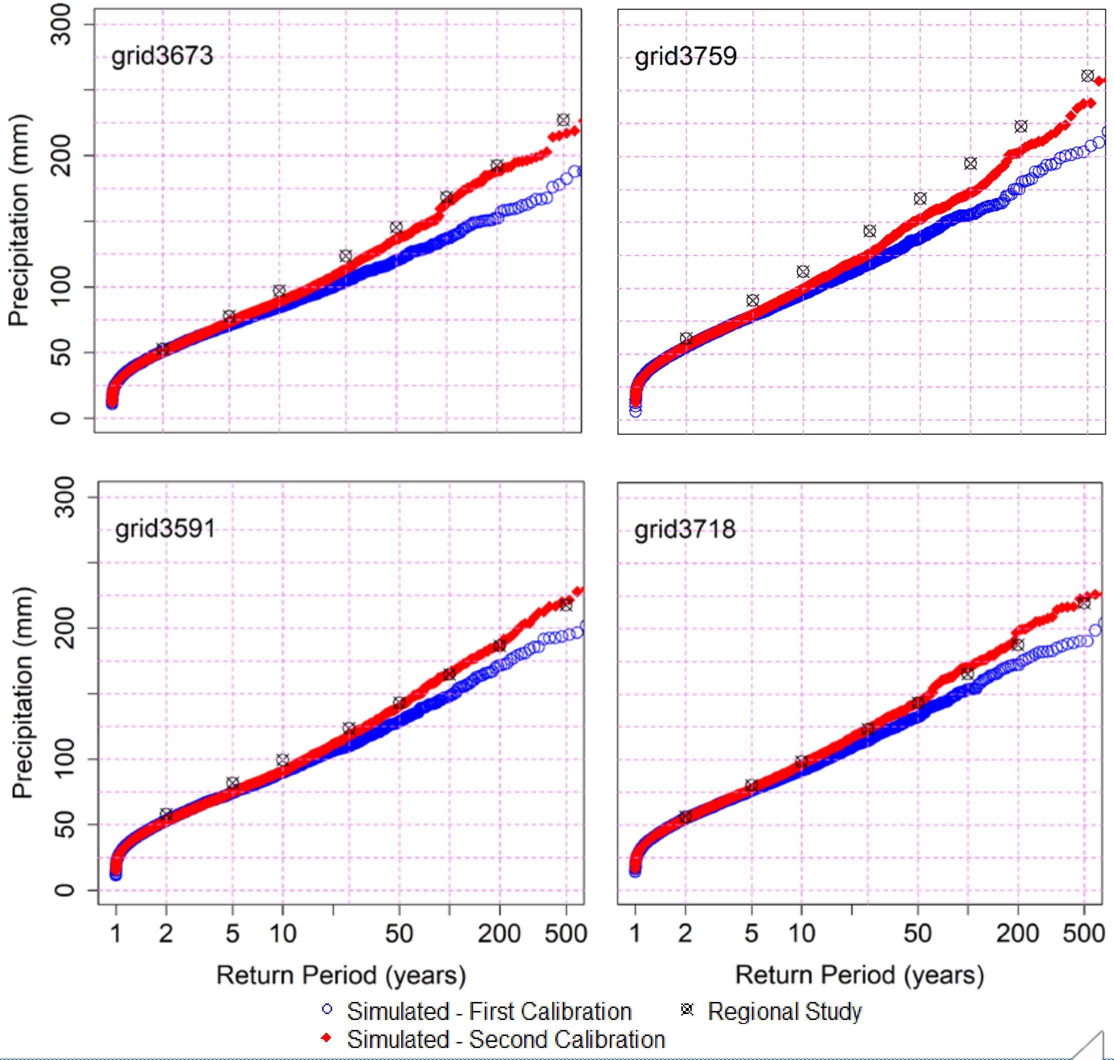
ξ: From more robust studies

(Evin et al., 2018)

  - **3-day aggregation**

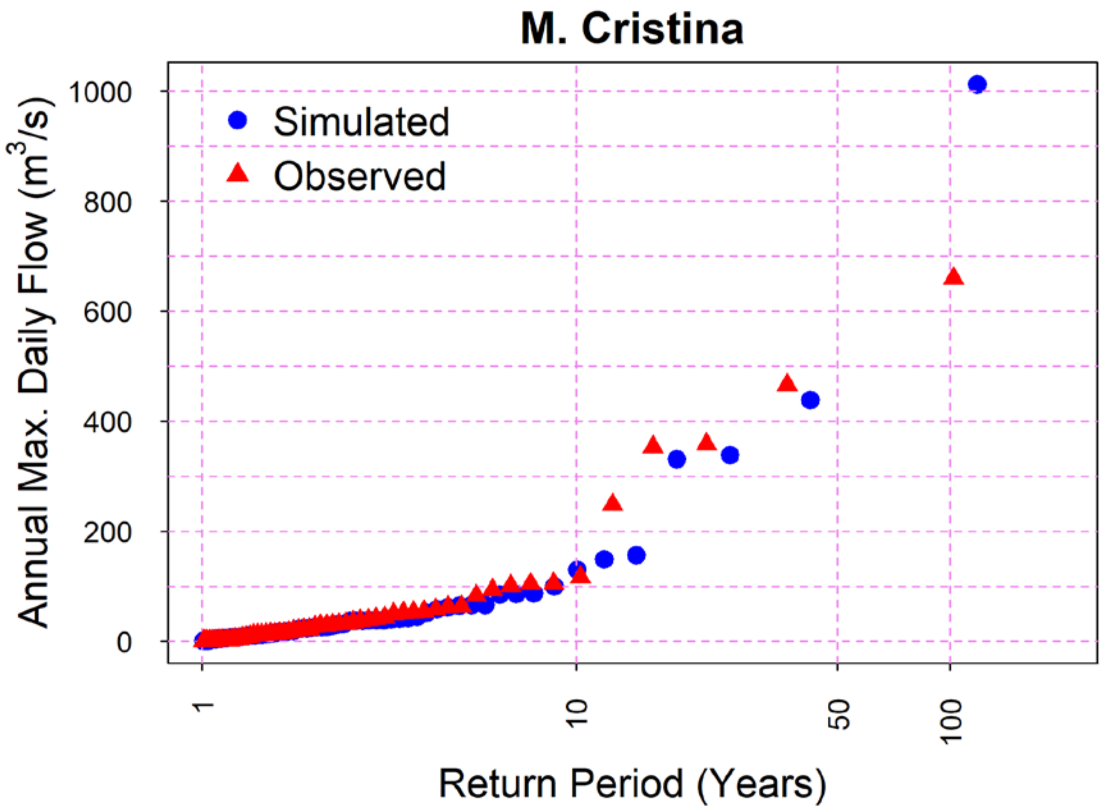
Calibration of weather generator

- First calibration=> Observed precipitation from Spain02-v5: 66 years
  - Validation with regional analysis of daily max. precipitation *(CEDEX, 1994)*
    - Updated values with Spain02-v5 observations
- Second calibration => Shape parameter ξ fit:
    - Two populations:
      - Autumn months (SON) => To calibrate (minimising RMSE)
      - Rest of months



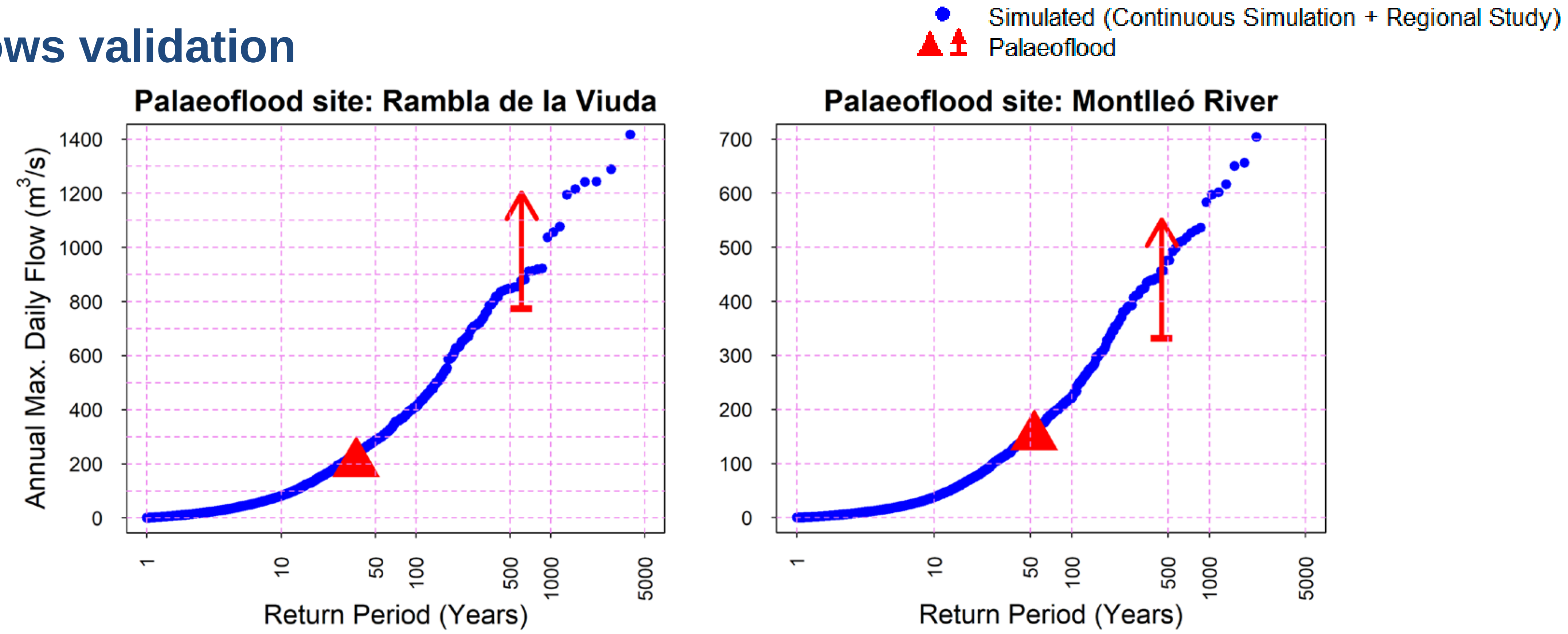
Low T Flows Validation

- Plotting positions at Maria Cristina Dam of the observed flows (SAIH) and the simulated flows with the precipitation generated by GWEX



Results

High T flows validation



Plotting positions of the simulated flows with the precipitation generated by GWEX at the locations where the historical and palaeoflood information is available

Conclusions

- The **reliability of flood estimates depends upon long and trustworthy input data series** (i.e., precipitation and/or discharges). Most **ephemeral rivers** worldwide **lack long-term and spatially fully distributed hydrometeorological information**, which leads to **inaccurate estimations of flood quantiles**, especially those associated with **high return periods**

- The use of **continuous stochastic meteorological** models coupled with a **fully distributed hydrological simulation** provide a **realistic approach**, enabling the recreation of **multiple different situations at any point within the catchment**, thus **completing** the **frequency distributions of discharges** along the whole river network

- Yet, though, **long and reliable input data series of precipitation and discharges are necessary** for the correct implementation of the WG and the HM, which in practice are **rarely available**

Conclusions

- Our results show that the **integration** of more **robust precipitation studies** for the **WG implementation** clearly **improve its performance**. In our case, the integration of an **existing regional study of annual maximum precipitation** allowed the reproduction of the high return periods precipitation quantiles, where the bias was more significant

- This **improvement** was **transferred** to the simulation of **discharge data series** with the fully distributed HM. Here, the available **palaeoflood records gave extra flood information** up to **T = 500** years as opposed to the highest quantile of T = 50 years obtained only with the systematic information

- Moreover, these **estimates** are **not limited to the sites** where **flow gauge stations are located or where the palaeoflood information is available.** The fully distributed HM **provides reliable** data on **extreme** flood **discharges at any point** of the catchment

Conclusions

- Finally, **the importance of incorporating two different sources of additional information** in the methodology when trying to estimate extreme flooding **was demonstrated**. Whilst **adding one source of additional information is essential** for a better **calibration** of the WG, adding a **second one allows for the validation of the simulated discharges**, thus improving the robustness of the methodology and providing higher confidence in the flood quantile estimates.

For more information, please see:

- Beneyto, C.; Aranda, J.Á.; Benito, G.; Francés, F. New Approach to Estimate Extreme Flooding Using Continuous Synthetic Simulation Supported by Regional Precipitation and Non-Systematic Flood Data. *Water* **2020**, *12*, 3174. https://doi.org/10.3390/w12113174

UNIVERSITAT POLITÈCNICA DE VALÈNCIA

iiama
Research Institute of Water and Environmental Engineering

Thanks for your attention!

Research Group of Hydrological and Environmental Modelling
lluvia.dihma.upv.es
Research Institute of Water and Environmental Engineering
Universitat Politècnica de València

This study has been supported by the Ministry of Science, Innovation and Universities of Spain through the Research Projects TETISCHANGE (RTI2018-093717-B-100) and EPHIMED (CGL2017-86839-C3-1-R) (cofounded with European funds FEDER).