Estimation of extreme flooding based on stochastic weather generators supported by the use of non-systematic flood data

By:
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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

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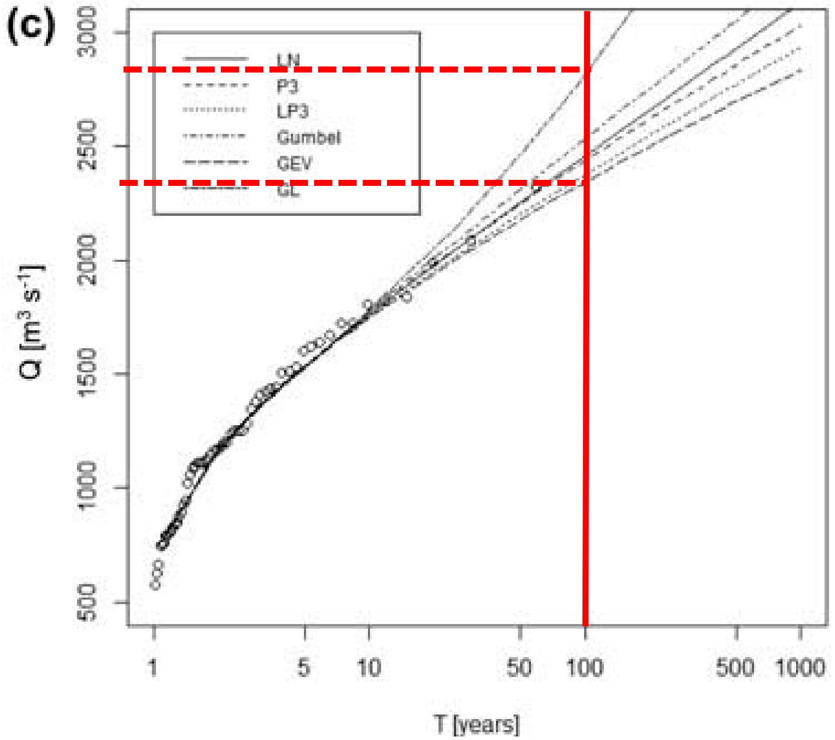
Introduction and objectives

- Traditional approach: **Empirical / Statistical**



High Uncertainty
Short flow and precipitation records

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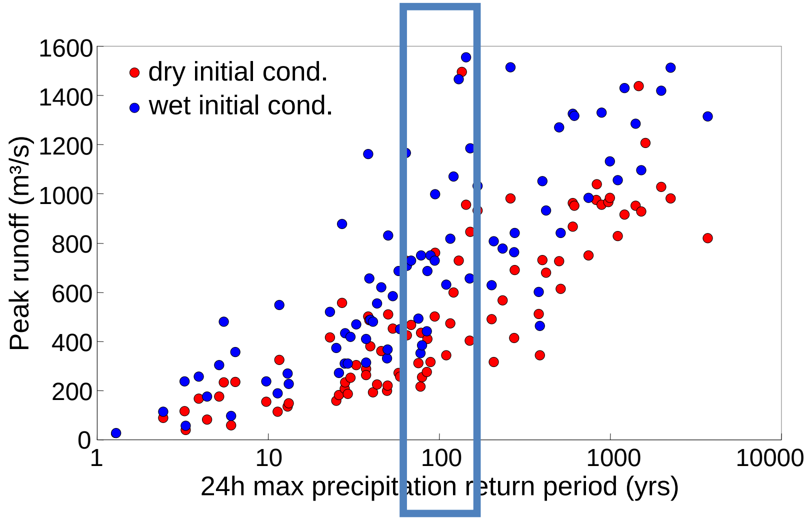
Introduction and objectives

- 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)

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Introduction and objectives

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- Later: **Deterministic (Design Storm)**
  - Based on IDF curves
    - Rectangular hyetograph
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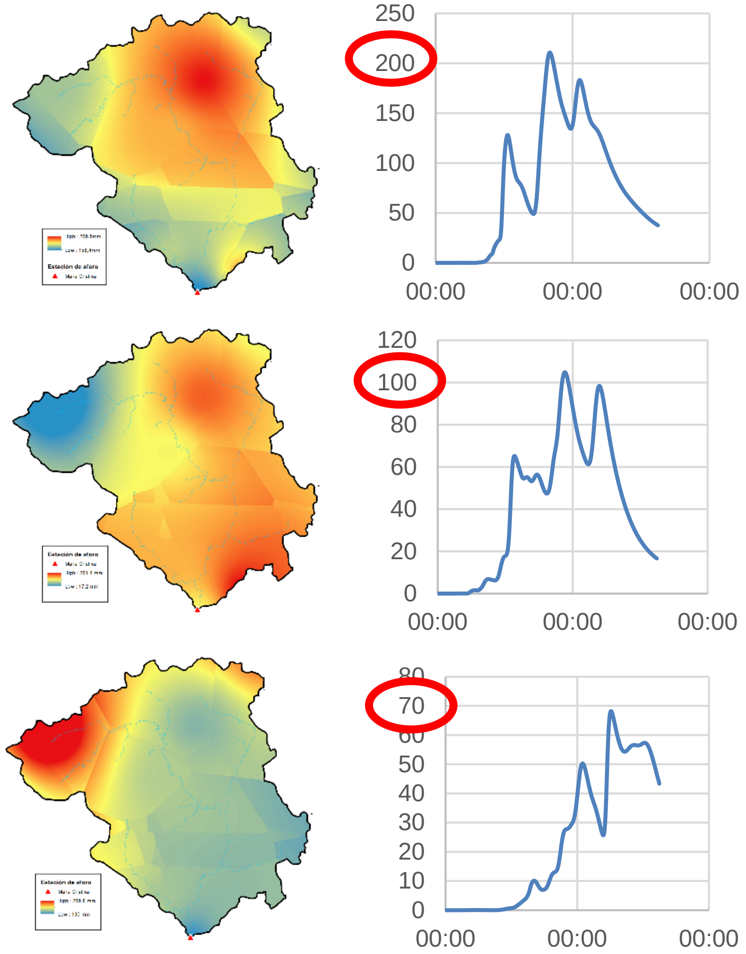
  - Based on actual precipitation records
    - Huff method
    - Stochastic storm generation
- Peak flow and hydrograph strongly dependant on:
  - Initial state
  - Spatio-temporal distribution of Precipitation

78h Event: P_m=169,2mm



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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)

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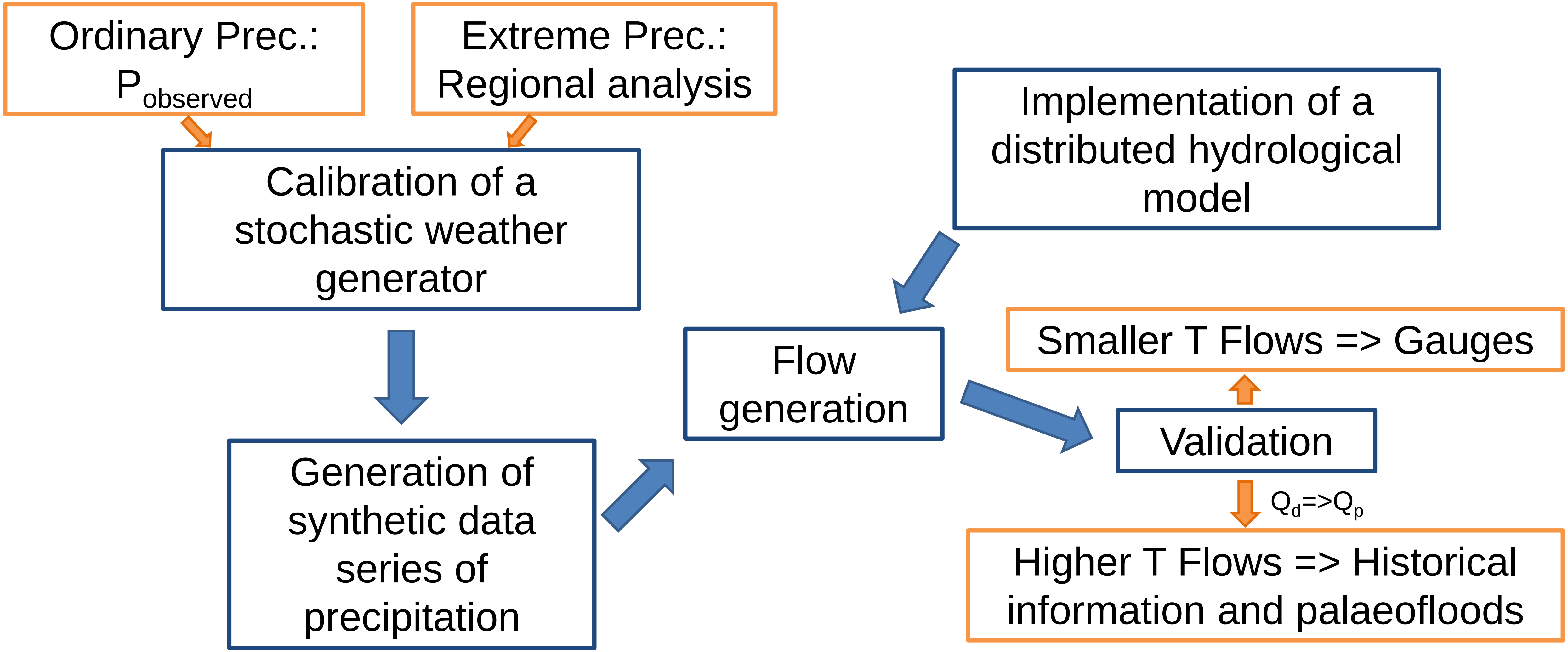
Methodology



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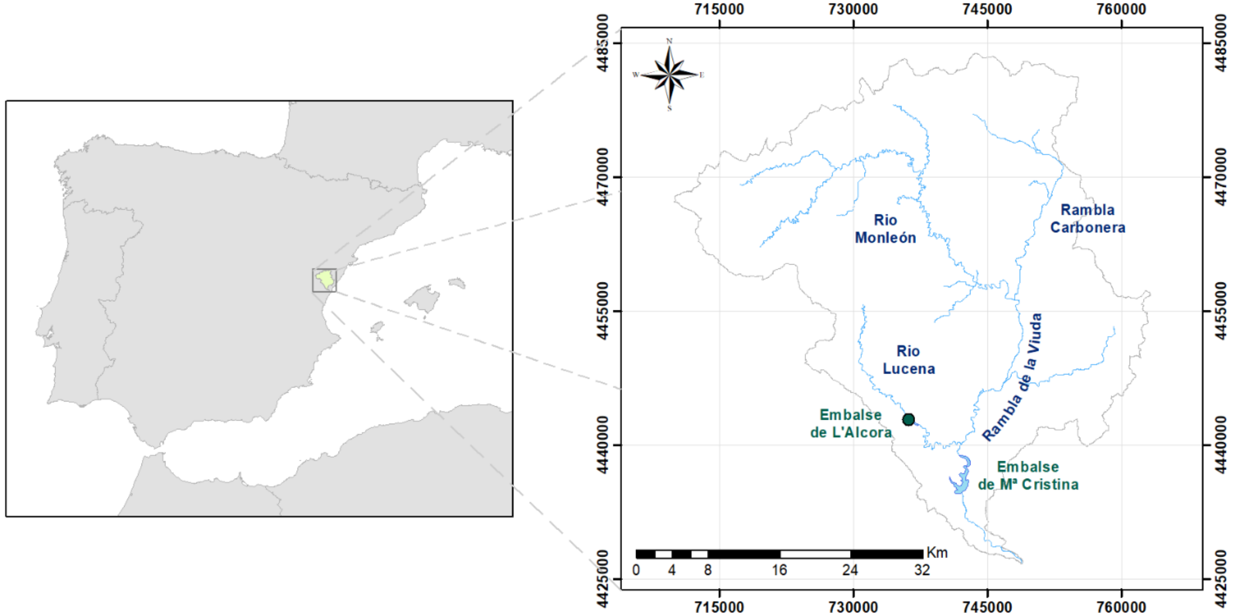
Case study: study area

- **Rambla de la Viuda**: ephemeral river
- Approx. area: 1,500 km^2
- Semi-arid Mediterranean climate
- Annual mean precipitation: 615 mm
- High precipitation variability
- Two reservoirs (Mª Cristina y Alcora)



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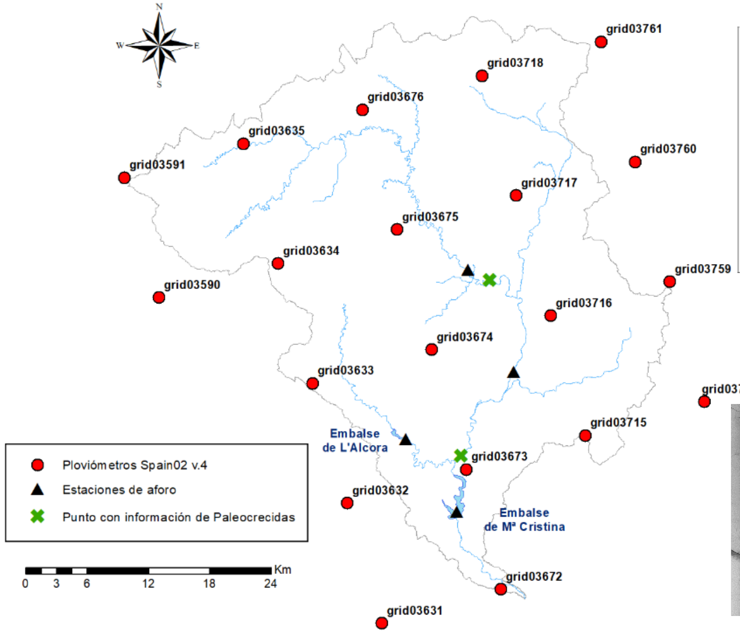
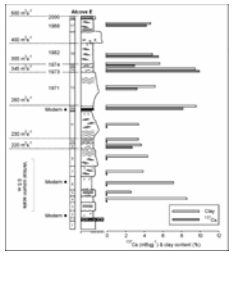
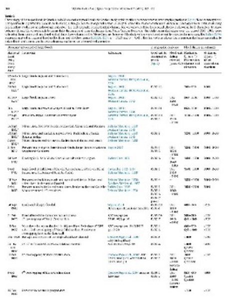
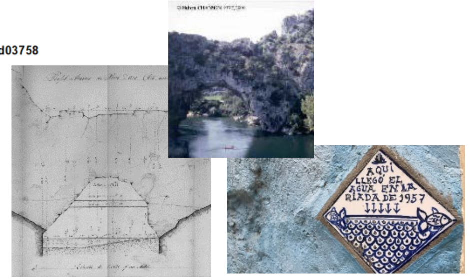
Case study: available information

- **Hydrometeorological information**
  - Precipitation
    - Spain02-v4 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

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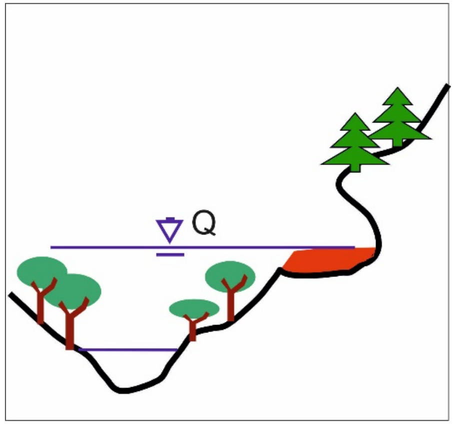
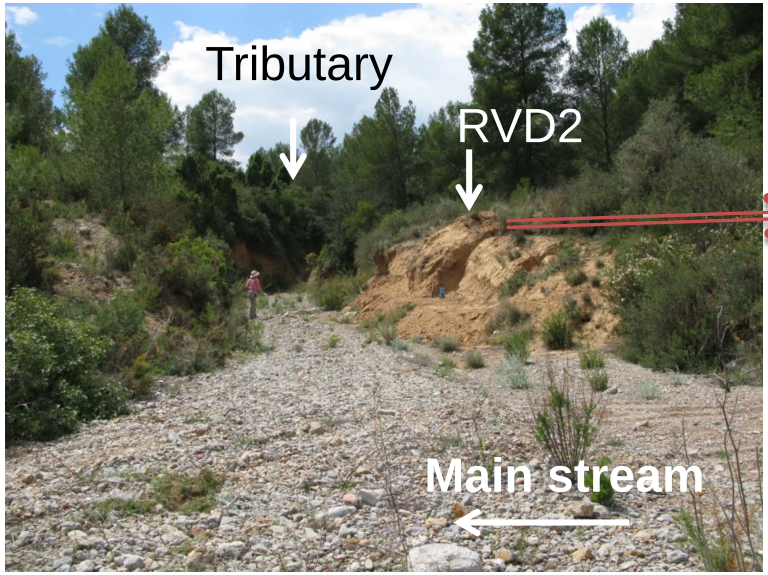
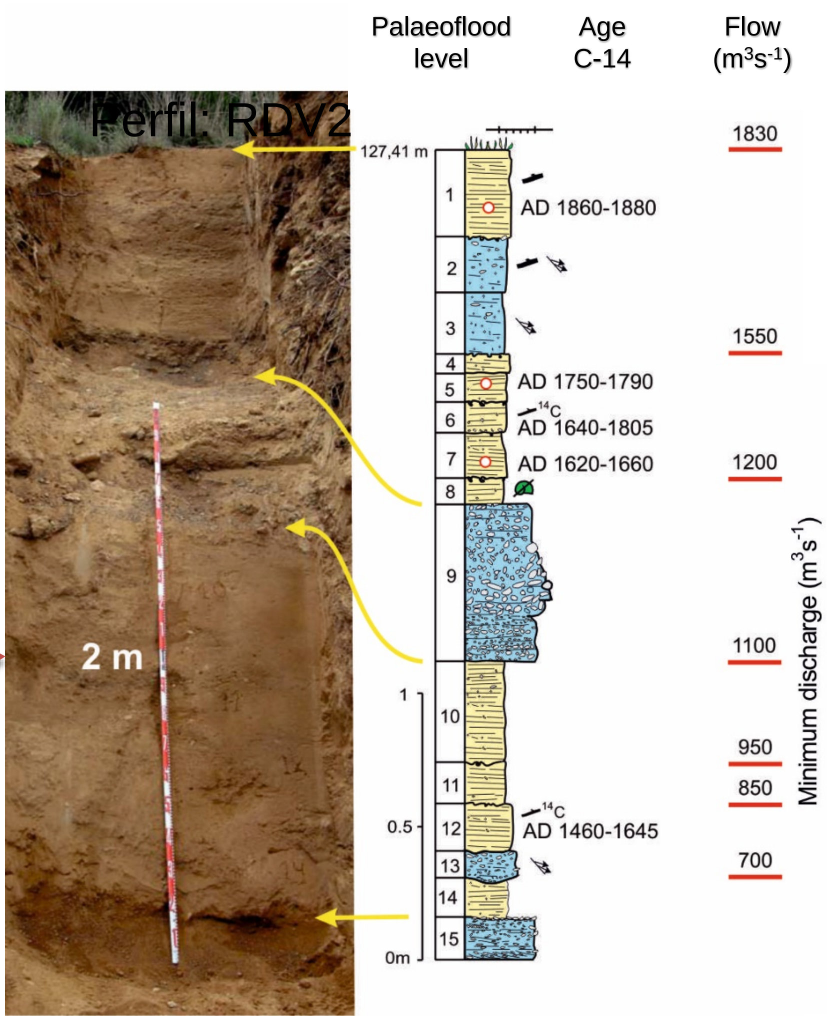
Case study: available information (palaeofloods)



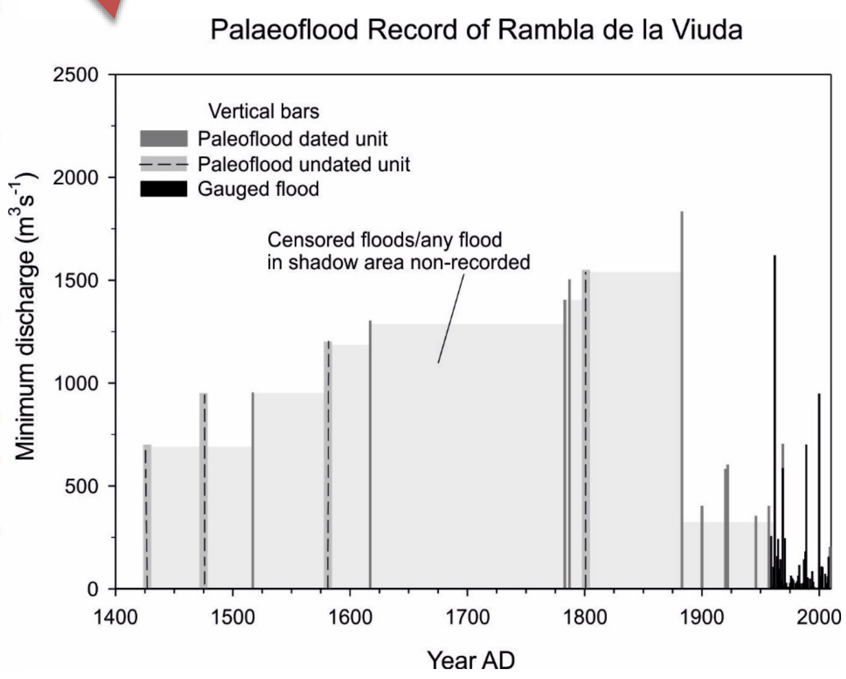
Flow calculated from the sediment depth





PALAEOFLOODS: Extreme flood flow records from the recent past

R. Viuda: 500 years on record



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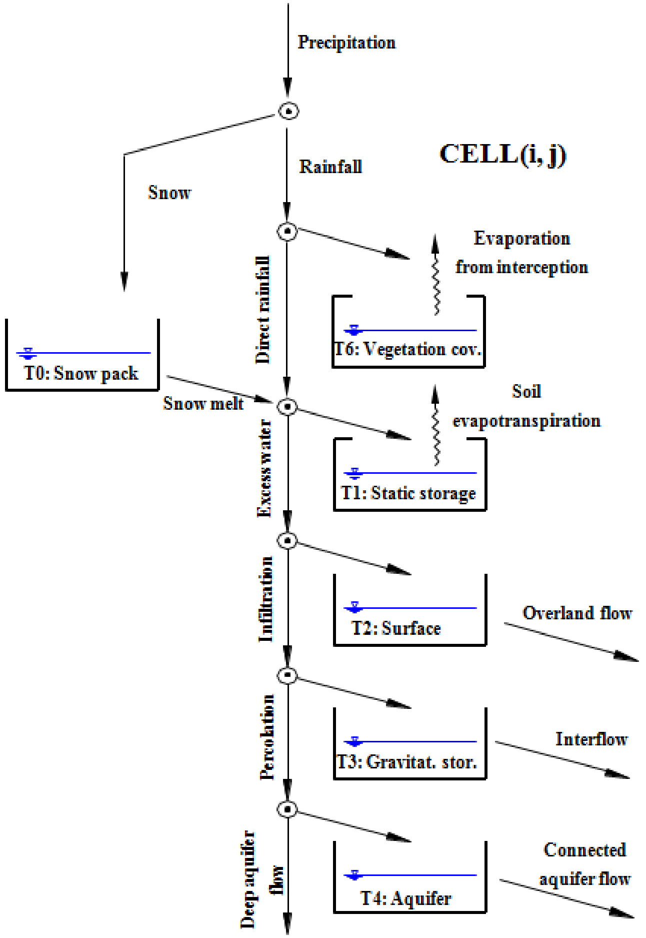
Case study: Eco-hydrological model TETIS

- 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

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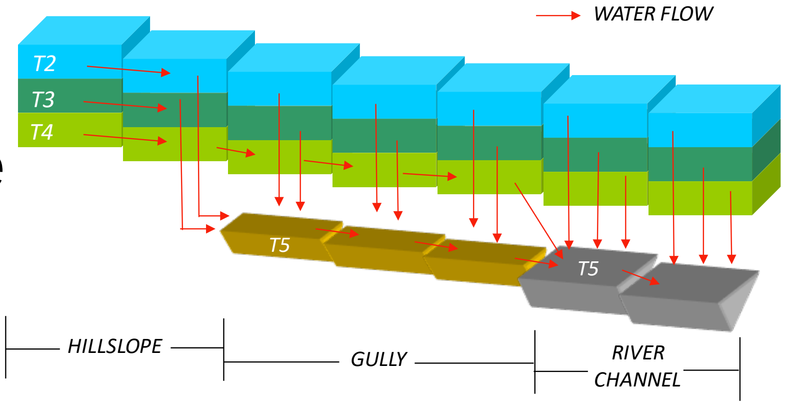
Case study: Eco-hydrological model TETIS



- **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

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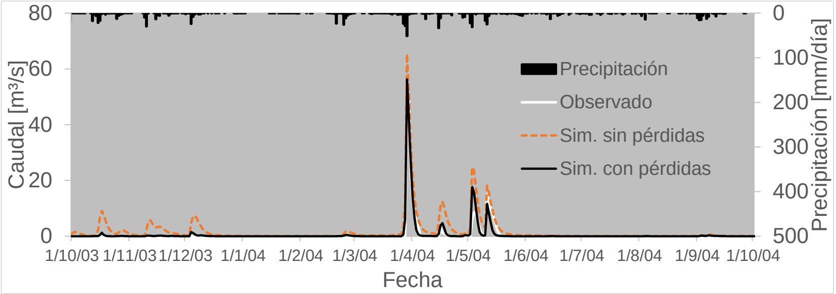
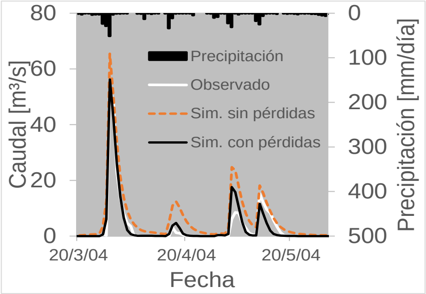
TETIS model implementation

- **Calibration (daily scale):**

  Mª Cristina (2003-2004)

  NS = 0.930

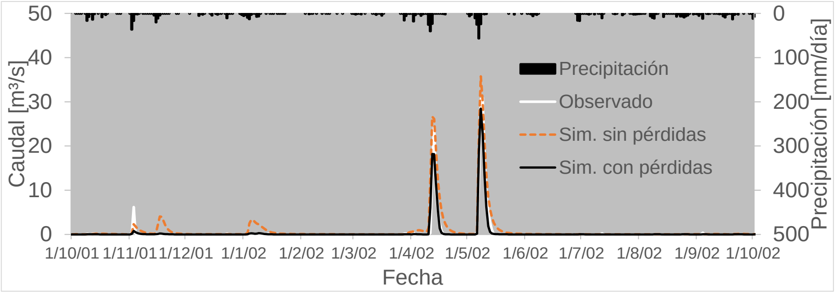


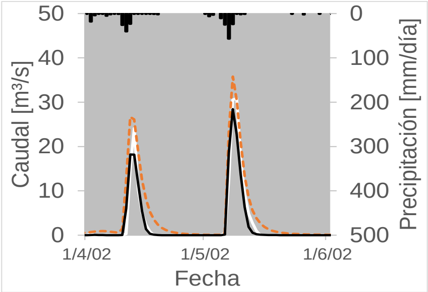


- **Temporal validation:**

  Mª Cristina (2000-2001)

  NS = 0.928

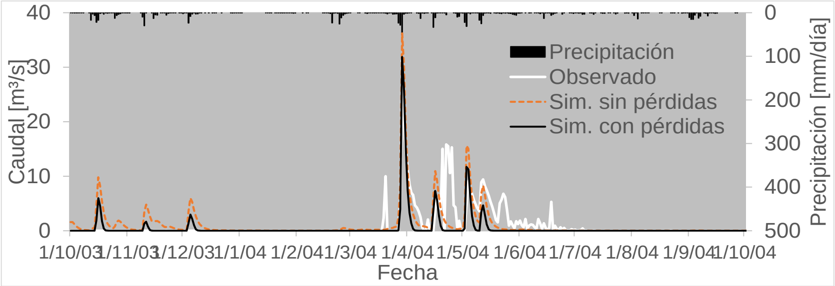


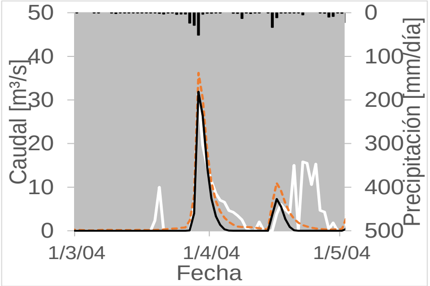


- **Spatial validation:**

  Vall d'Alba (2003-2004)

  NS = 0.428





(Correcting time lag and y transmission losses)

Conversion Q_{daily} => Q_{peak}

- Conversion of daily flows into peak flows
  - Fuller formula *(1914)*

$$Q_i = \left(1 + \frac{a}{A^b}\right) Q_d$$

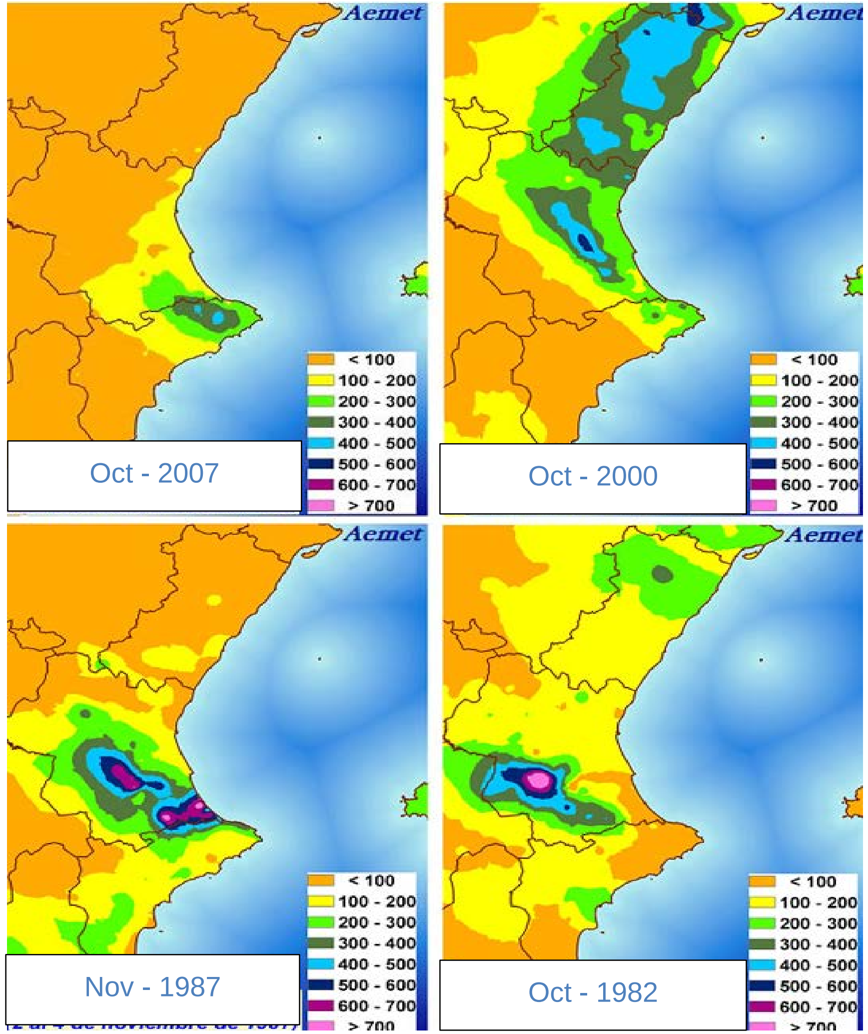
    - Where:
      - *A* is the catchment area in Km^2
      - *a*, *b* are dimensionless parameters
  - Initial parameter estimation: Study from *CEDEX (2011)*
  - Parameter *b* was set and parameter *a* was calibrated for the available events (a=82.86, b=0.51)

REGIÓN	a	b
Miño-Sil + Galicia Costa	1.81	0.23
Cantábrico + C.I. País Vasco	3.1	0.26
Duero	1.78	0.29
Tajo	5.01	0.38
Guadiana + Guadalquivir		
- Zona 1	35.89	0.72
- Zona 2	112.82	0.7
- Zona 3	11.56	0.42
Júcar	20.87	0.51
Segura	145.85	0.75
Ebro		
- Zona 1	2.49	0.36
- Zona 2	3.39	0.29
- Zona 3	37.73	0.55

Sub-daily hydrological model

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



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Selection of weather generator

- State of the art review: MulGETS and GWEX

MulGETS
(*Chen et al., 2014*)

- Parametric models
- Wilks approach
(Precipitation occurrence and amount handled separately)

GWEX
(*Evin et al., 2018*)

- Daily precipitation fitted to:

Multi-Gamma (or Multi-Exponential)

- Daily scale
- Matlab

- Daily precipitation fitted to :

Extended Generalised Pareto Distribution (E-GDP)

Parameter estimation

$\sigma,\ \kappa,$ From observations

$\xi,$ From more robust studies?

- 3-day aggregation ➡ daily
- Implemented in R

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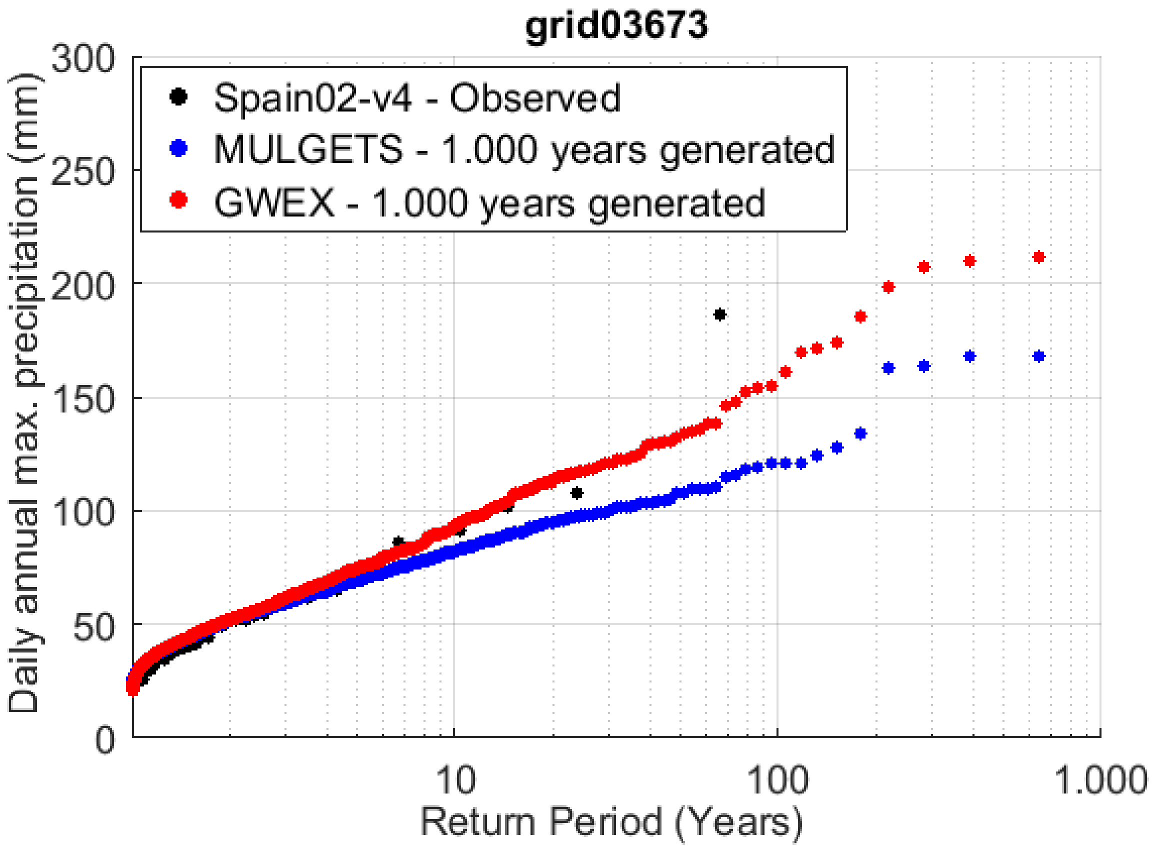
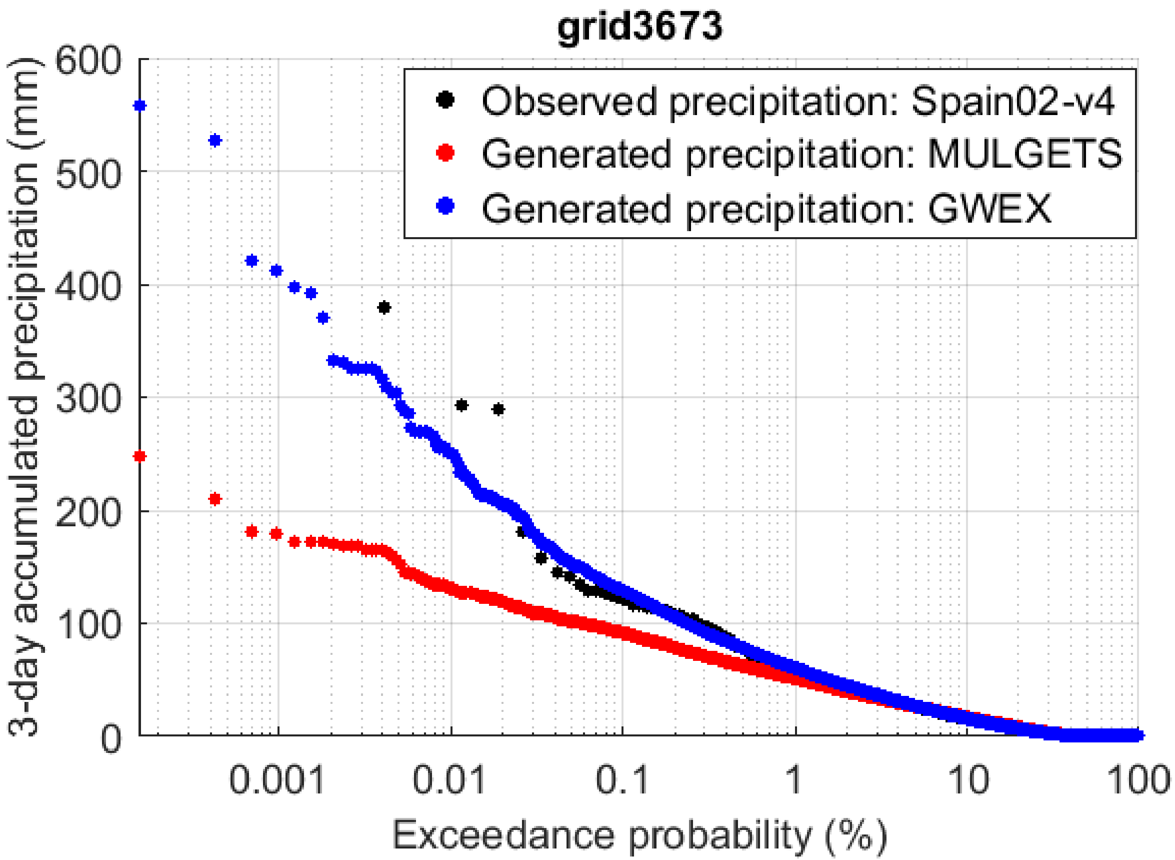
Selection of weather generator





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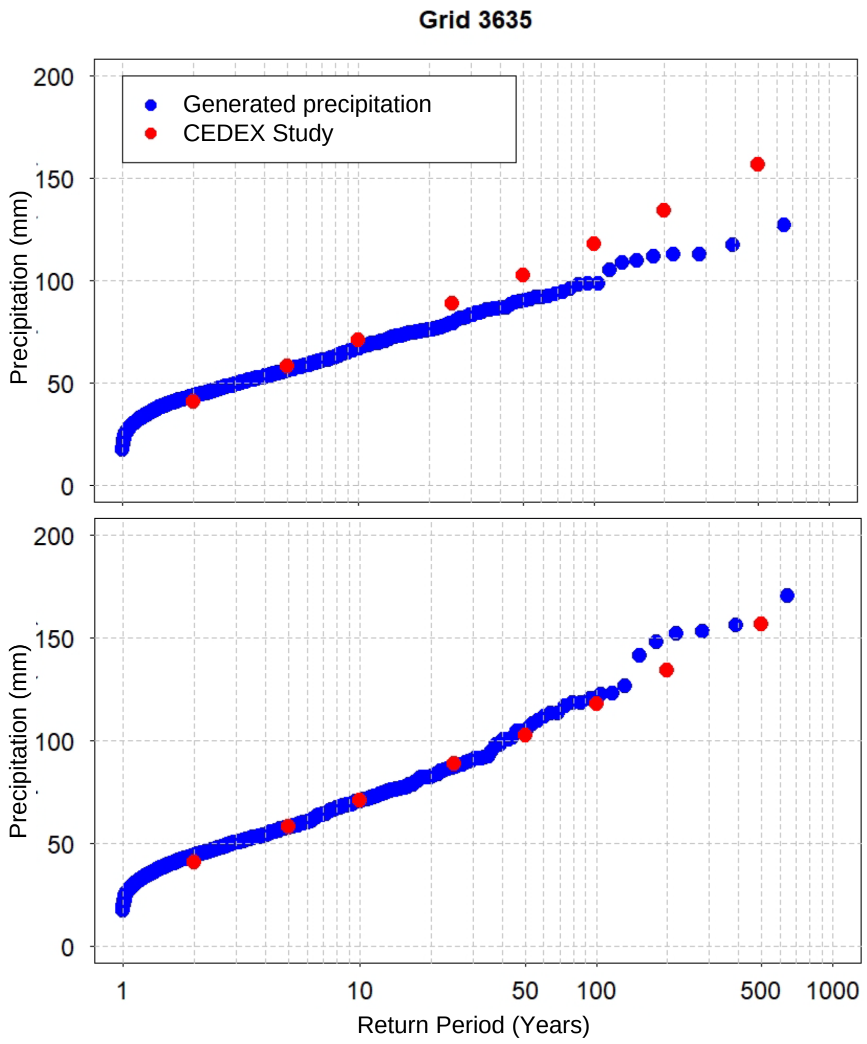
Calibration of weather generator

- First calibration=> Observed precipitation from Spain02-v4: 37 years
  - Validation with regional analysis of daily max. precipitation *(CEDEX, 1994)*
    - Updated values with Spain02-v4 observations

- Second calibration => Shape parameter ξ fit:
  - Two populations:
    - Autumn months (SON) => To calibrate (minimising RMSE)
    - Rest of months



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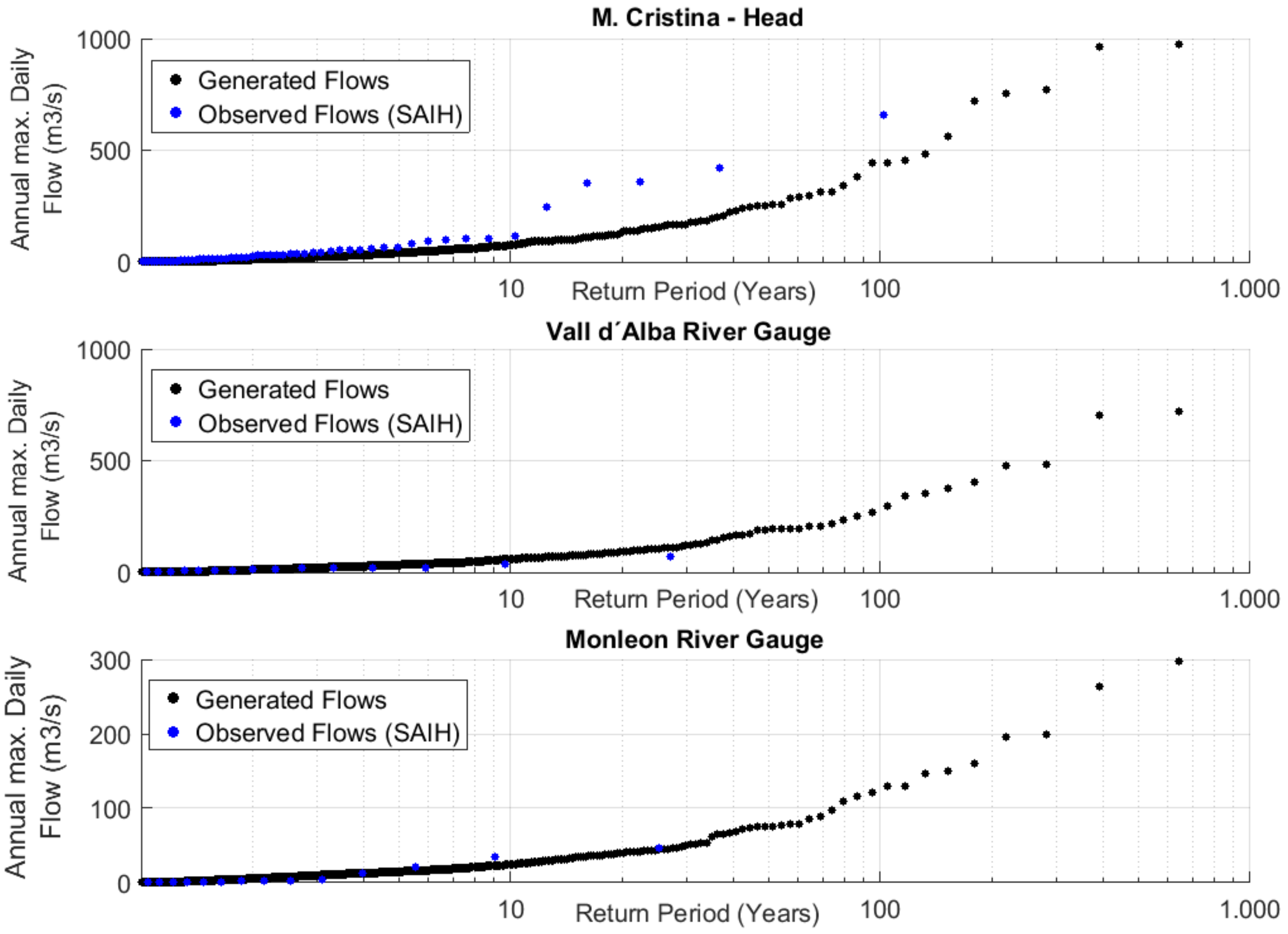
Low T Flows Validation

- Plotting positions at the three gauge stations of the observed flows (SAIH) and the simulated flows with the precipitation generated by GWEX



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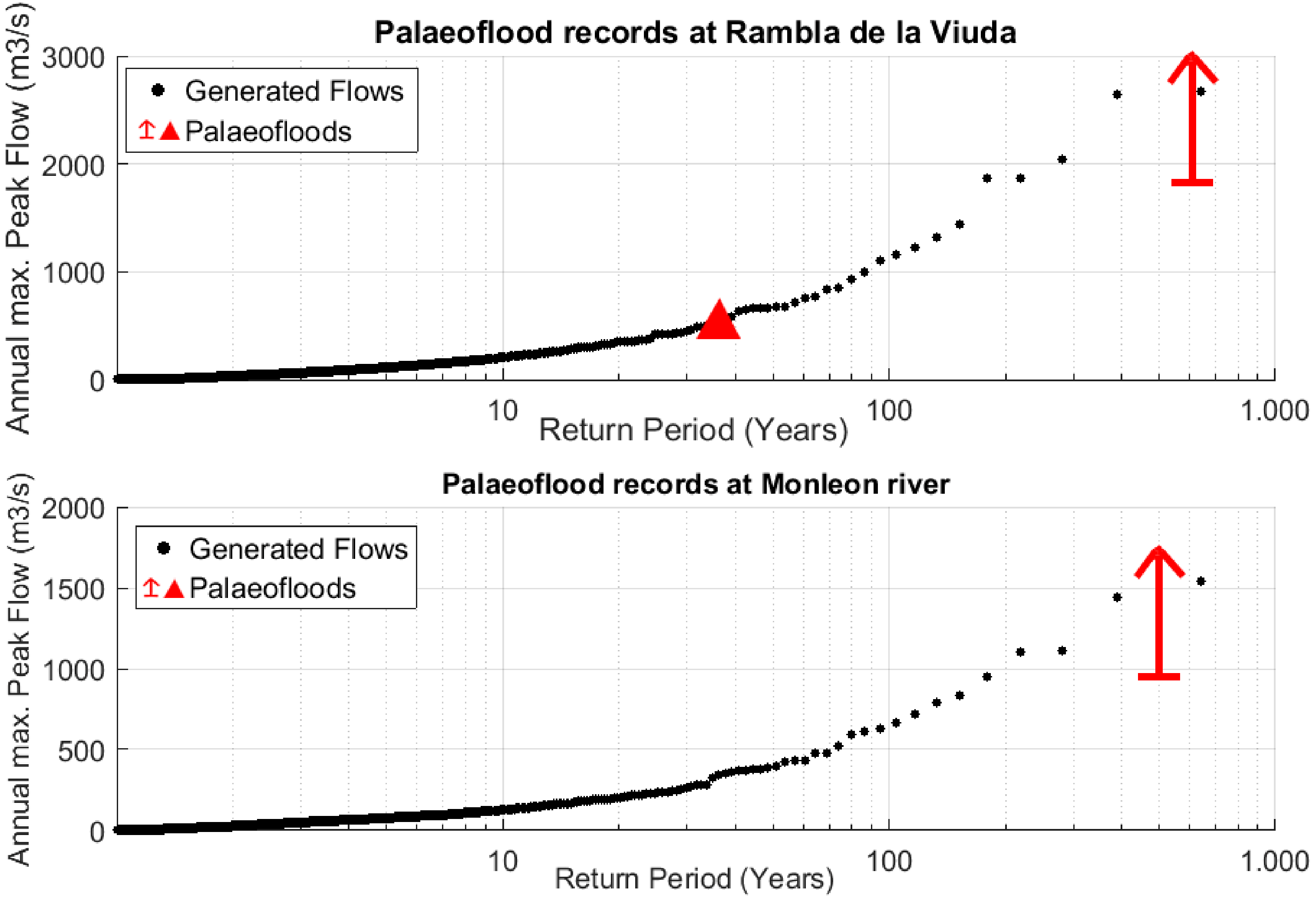
Results

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



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Conclusions

- It is important to review the state of the art and check the performance of at least two weather generators in the study area. In our case, GWEX clearly reproduced better the extremes generated by those heavy convective events characteristics of the region.

- The integration of regional studies of precipitation in the calibration of the weather generator clearly improved the reproduction of extreme phenomena

- The length of the available flow and precipitation records are not and will not be sufficient by themselves for an adequate estimation of extreme phenomena

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Conclusions

- The integration of additional information (historical and palaeofloods) is necessary for a better estimation of the flows associated with high return periods.

- The non-operability nature of the continuous sub-daily weather generators along with the high computational time requirements of these and also of the hydrological models means that, today, timescales lower than daily cannot be considered.

- However, the methodology proposed here with the results obtained in the case study presented, show that on a daily scale it is possible to obtain satisfactory results

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Thanks for your attention!

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