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iiama Research Institute of Water and Environmental Engineering

On the use of weather generators for the estimation of low-frequency floods under climate change scenarios

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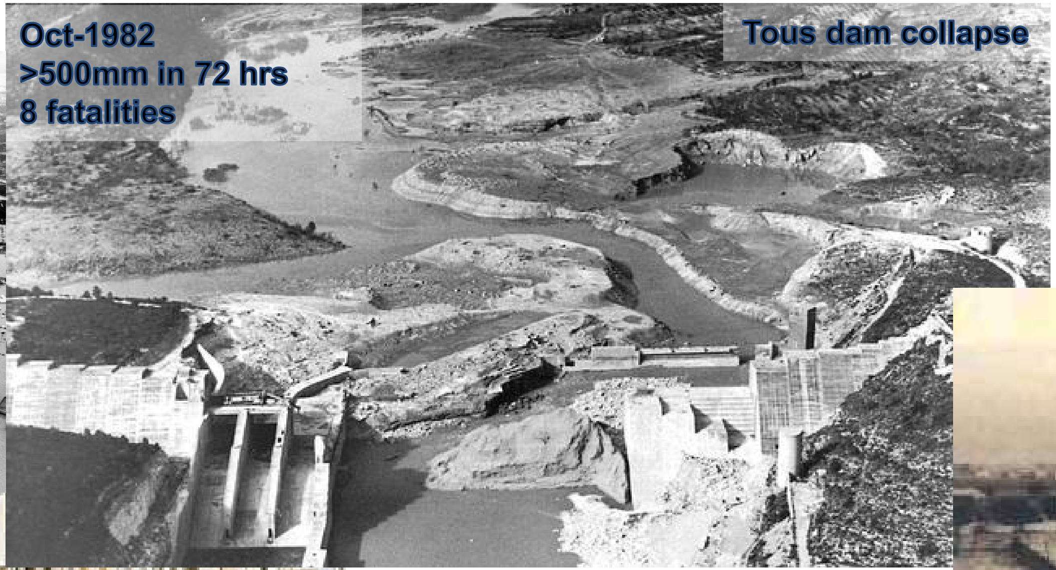
Introduction

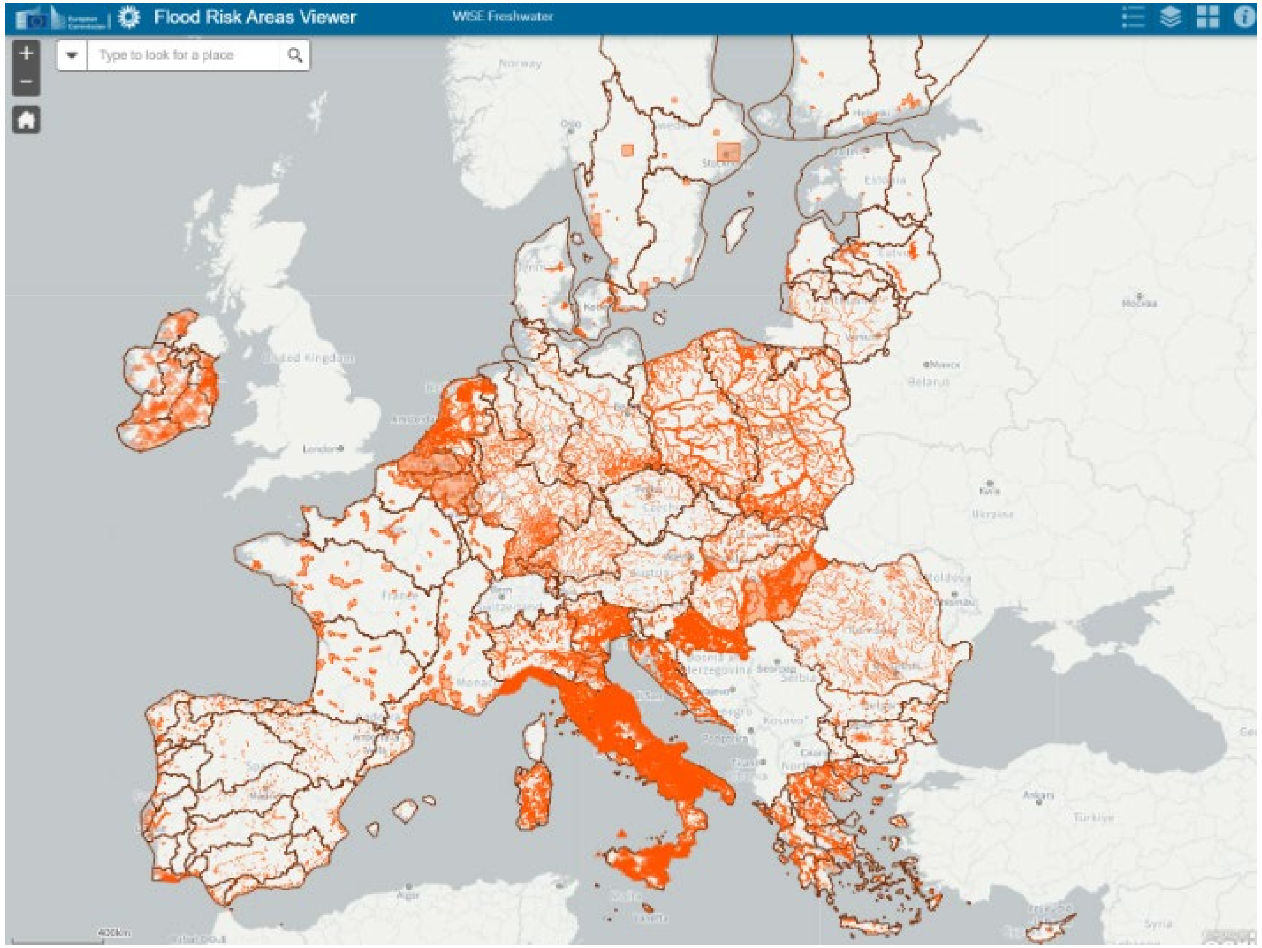
- Long history of devastating floods



- But also many recent ones

Introduction

Climate change: ↑ Frequency
↑ Magnitude



Change in heavy rain (%)

Heavy rain is defined as 95th percentile intensity of total rain events

< -25 | -25 to -15 | -15 to -5 | -5 to 5 | 5 to 15 | 15 to 25 | 25 to 35 | > 35

Introduction and objectives

- Importance of extreme floods studies
  - Hydraulic infrastructures design (Spanish Dam Safety Standards, 2023)
  - Flood maps elaboration (Directive 2007/60 CE)
  - **Climate change**

Develop a new methodology based on stochastic weather generators (weather generator + fully-distributed hydrological model + integration of information) for an adequate estimation of extreme floods (low-frequency) under climate change scenarios

Introduction and objetives

- Traditionally:
  - Q_{obs} fit to a cdf
  - Design Storm

Short length of hydrometeorological records

- Synthetic generation of precipitation (+ hydrological models):
  - Stochastic processes
    - Single storms
    - Storm transposition
    - Clustered point process N-S

Initial state

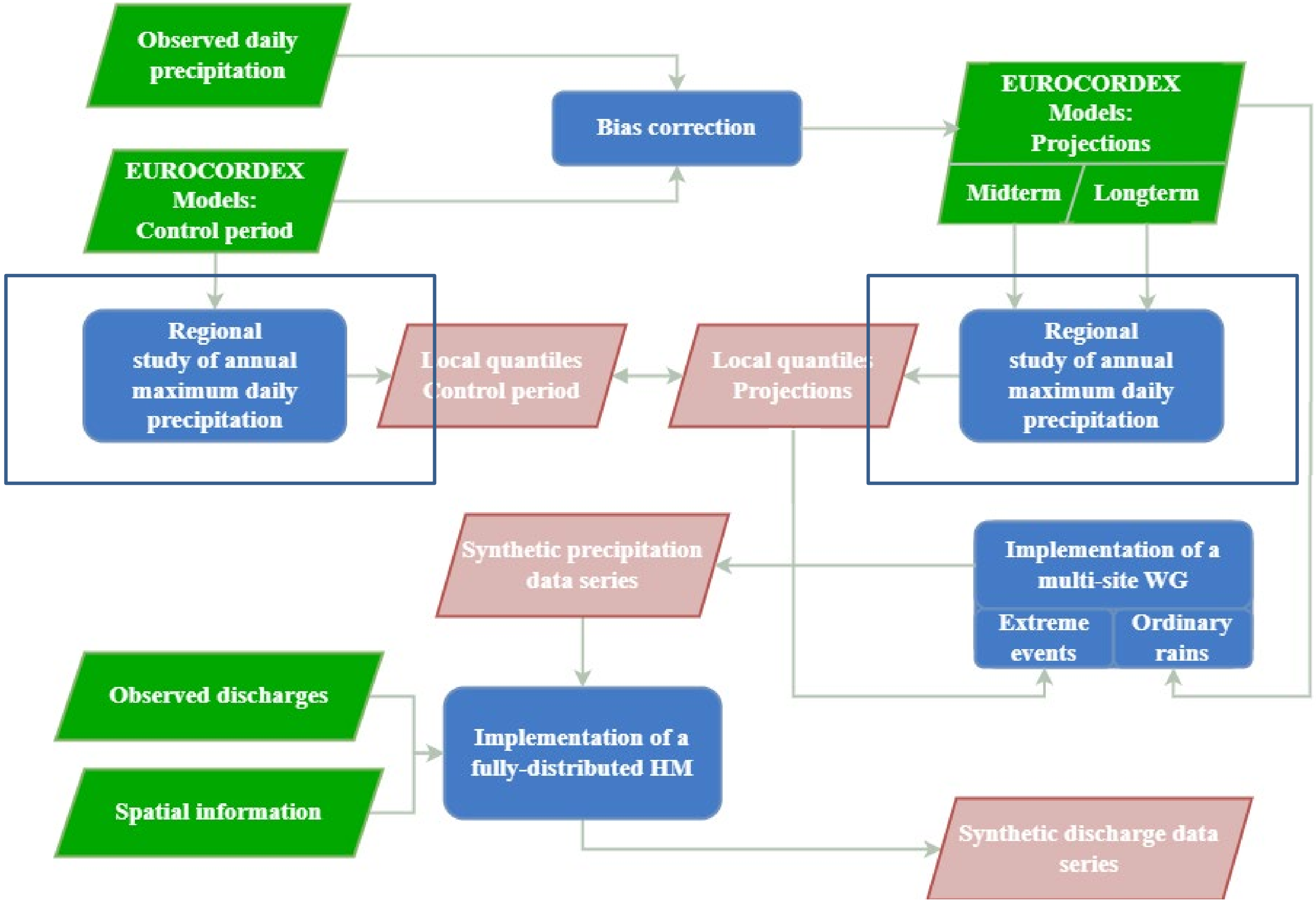
- **Continuous Synthetic Simulation**
- Stochastic simulation + Hydrological Model

✓ Short length of observations
✓ Spatio-temporal distribution of the storm
✓ Initial conditions of the basin

- Drawbacks:
  - Reproduction of extremes in normal conditions of available information
  - Subdaily weather generators still complex and with high computational requirements

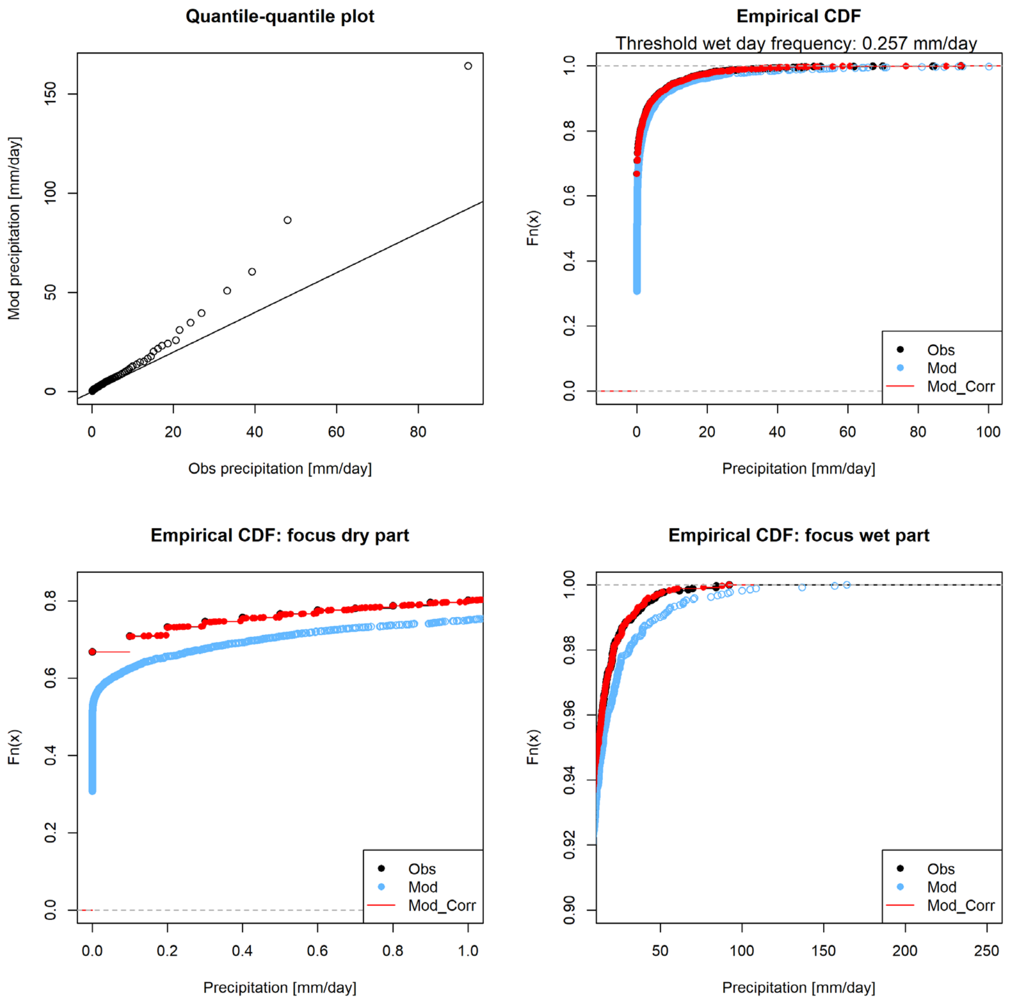
Methodology

Beneyto et al, (2024)



Bias Correction

- T y P from the 12 climate models with the data from Spain02-v5.
- Based on the non-parametrical statistical transformation of the empirical quantiles *(Gudmundsson et al., 2012).*
- Implemented independently for each season and each grid: December - February, March - May, June – August, and September - November
- Dry and wet day frequency also corrected following the approach proposed by Themeβl et al. (2012).



Regional study of annual max. P_d

$$PWM_{p,r,s} = E\{X^p \cdot F_X(x)^r \cdot [1 - F_X(x)]^s\}$$ Greenwood et al. (1979)

$$\beta_r = \frac{1}{n} \cdot \sum_{j=r+1}^{n} \frac{(j-1)\cdot(j-2)\cdot\ldots\cdot(j-r)}{(n-1)\cdot(n-2)\cdot\ldots\cdot(n-r)} \cdot x_j$$ (Hosking y Wallis, 1997)

- **L-moments estimation**
- Homogeneity analysis (discordance)
- Selection of the regional cdf
- Obtention of the local quantiles

$$\lambda_1 = \beta_0$$

$$\lambda_2 = 2 \cdot \beta_1 - \beta_0$$

$$\lambda_3 = 6 \cdot \beta_2 - 6 \cdot \beta_1 + \beta_0$$

$$\lambda_4 = 20 \cdot \beta_3 - 30 \cdot \beta_2 + 12 \cdot \beta_1 - \beta_0$$

$$t = \frac{\lambda_2}{\lambda_1} \qquad t_3 = \frac{\lambda_3}{\lambda_2} \qquad t_4 = \frac{\lambda_4}{\lambda_2}$$

t : L-Coefficient of Variation (L-CV)

t_3 : L- Coefficient of Skewness (L-CS)

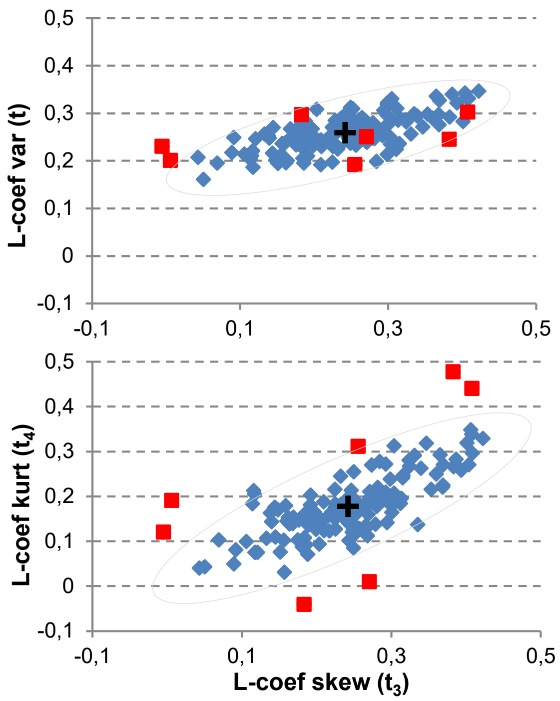
t_4 : L- Coefficient of Kurtosis (L-CC)

$$X_{i,T} = X_{R,T} \cdot \bar{X}_i$$

where $X_{i,T}$ is the quantile of return period T at location i,

$X_{R,T}$ is the regional quantile of return period T

$\bar{X}_i$ is the mean of the registered data at location i.



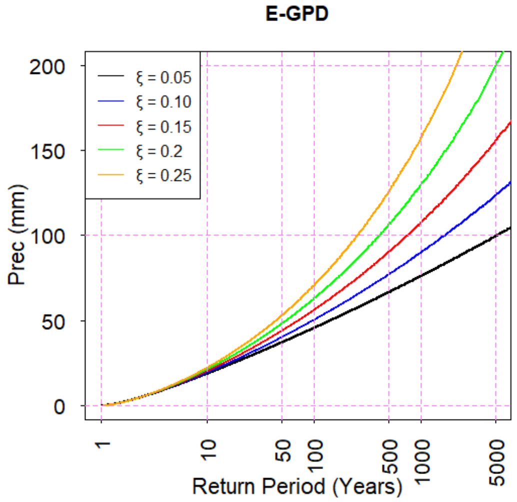
(Hosking & Wallis, 1993, 1997) (Dalrymple, 1960)

Weather Generator GWEX

Weather Generator GWEX *(Evin et al., 2018)*

- Extended Generalized Pareto Distribution (E-GDP) -> heavy-tailed

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



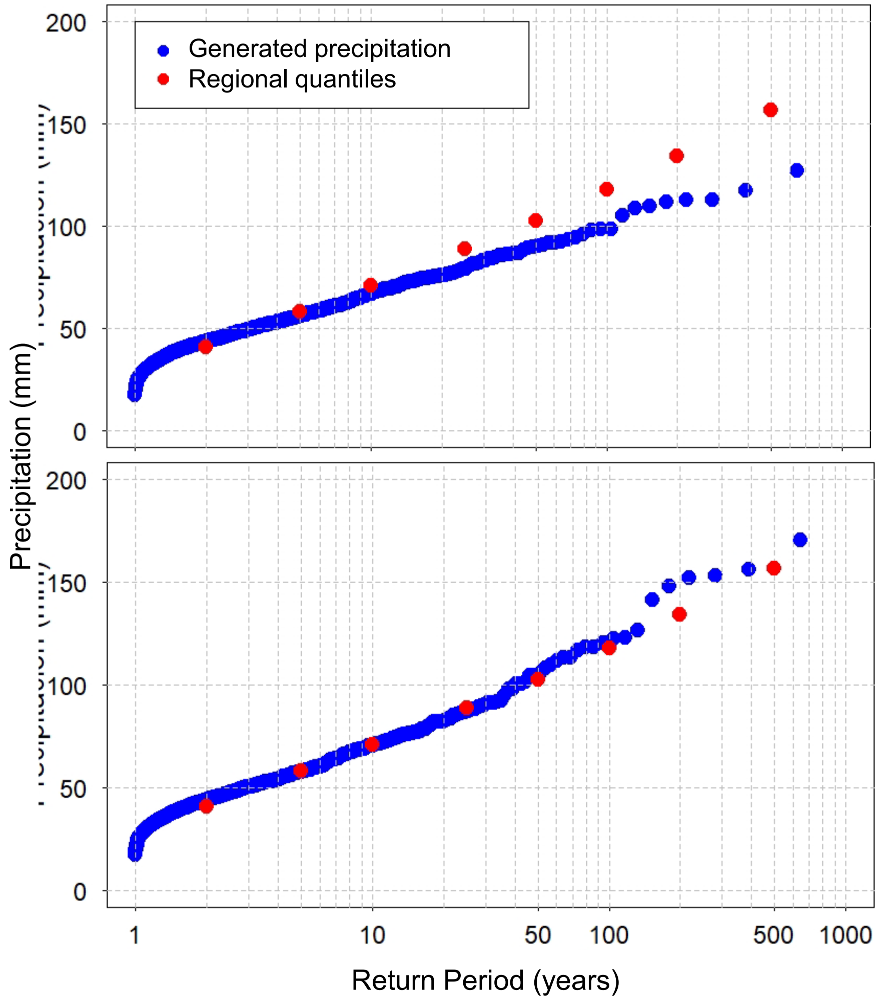
- Parameter estimation

σ, κ, } From observations

ξ, **From more robust studies**

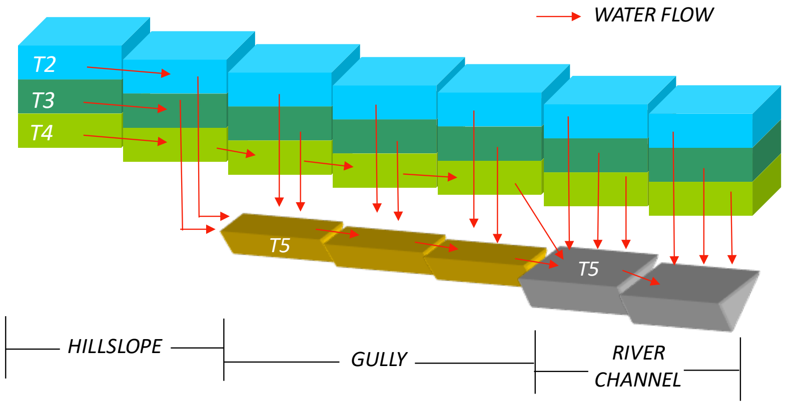
Beneyto et al, (2020)
Beneyto et al, (2023a)
Beneyto et al, (2023b)

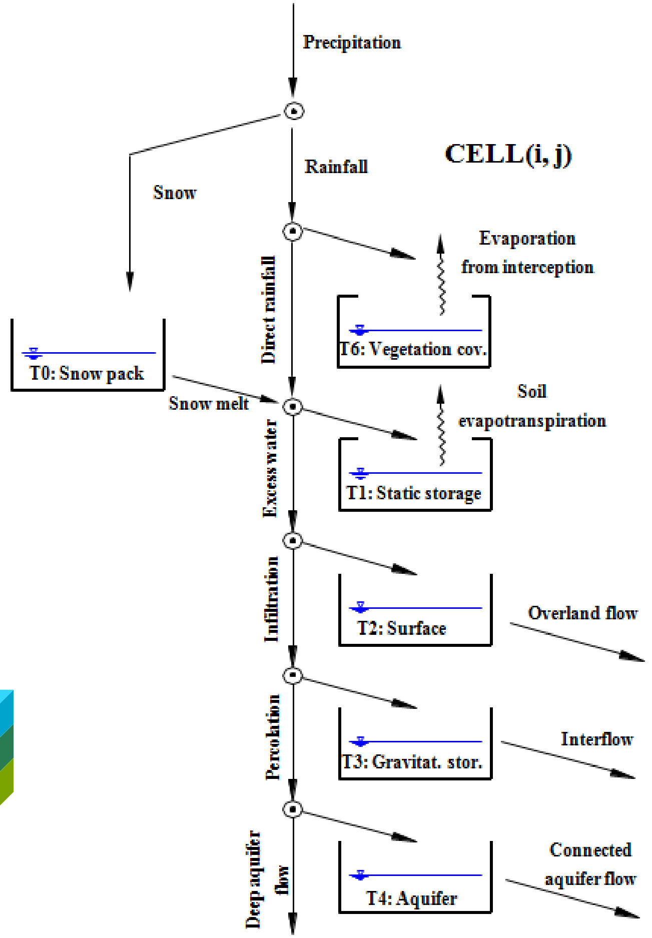
- 3-day aggregation



Eco-hydrological Model TETIS

- **Distributed** in space:
  - Constantly developed by our group since 1994
  - Integral model
  - Parsimonious
  - Reproduces the spatial variability of hydrological cycle
  - Uses all spatial information available
  - Gives results at any point

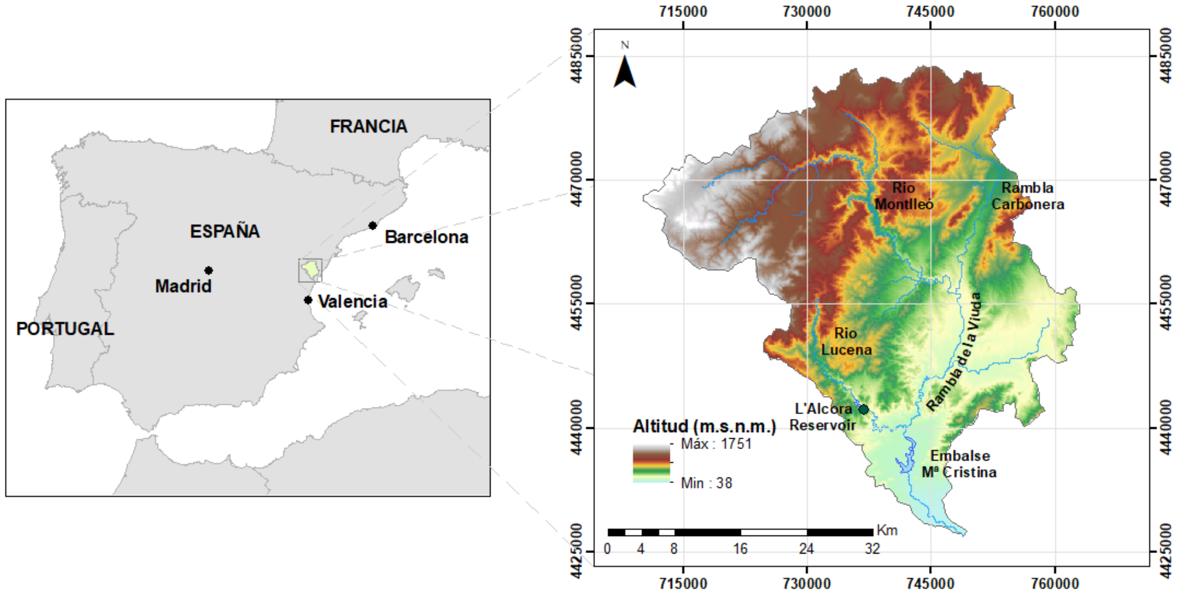




Esquema conceptual del modelo TETIS a escala de celda

Case study

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



Hydrometeorological information

Hydrometeorological information

- Precipitation
  - Grid Spain02-v5: 20 pluviometers + thermometers: 1951-2015 (66 yrs)
- Flow Gauges
  - SAIH Júcar

	Data series length	Period	
	(full 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

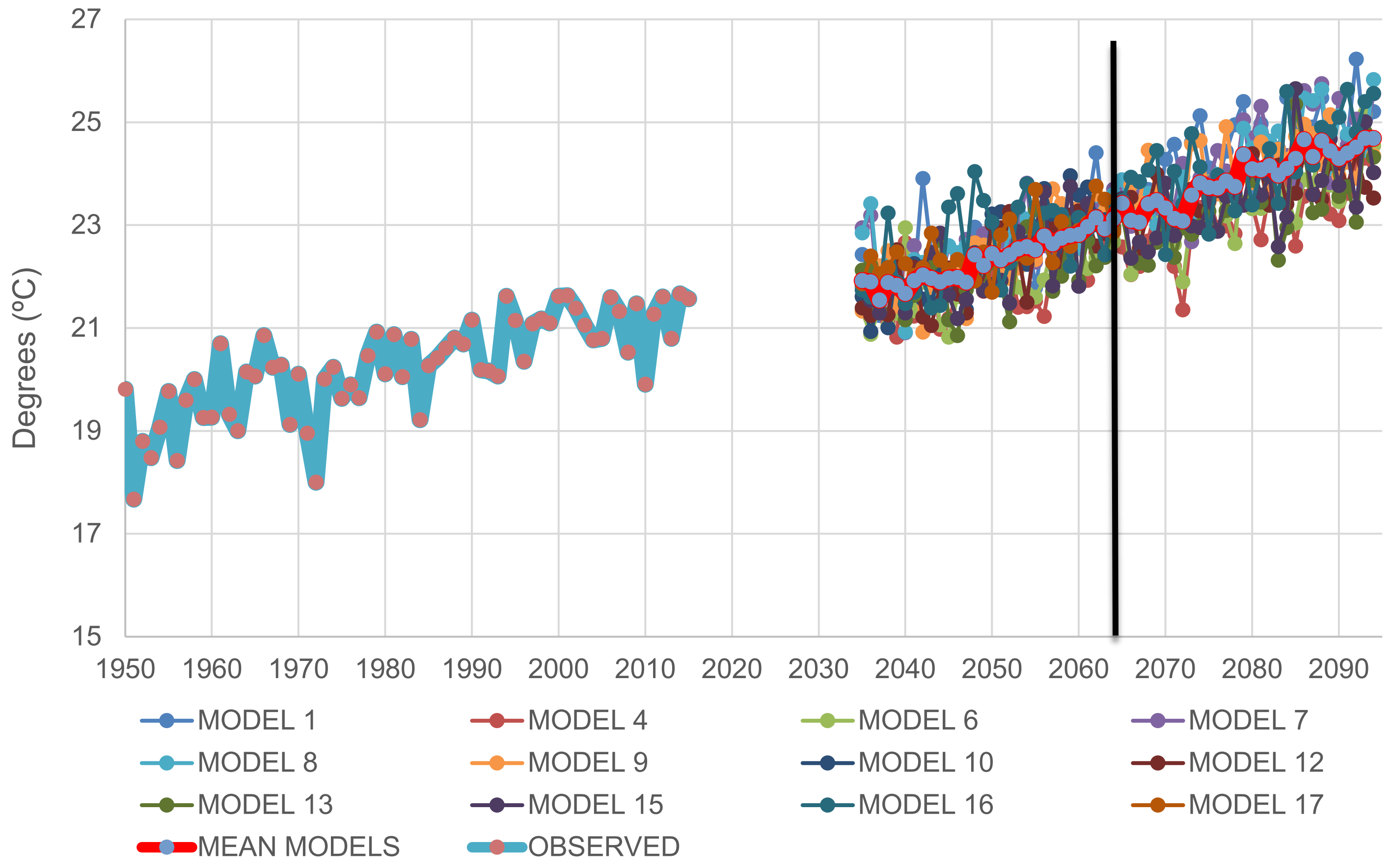
- Climate projections
- 12 Models EUROCORDEX Project
  - Control Period: (1971-2000)
  - Midterm Projection: (2035-2064)
  - Longterm Projection: (2065-2094)

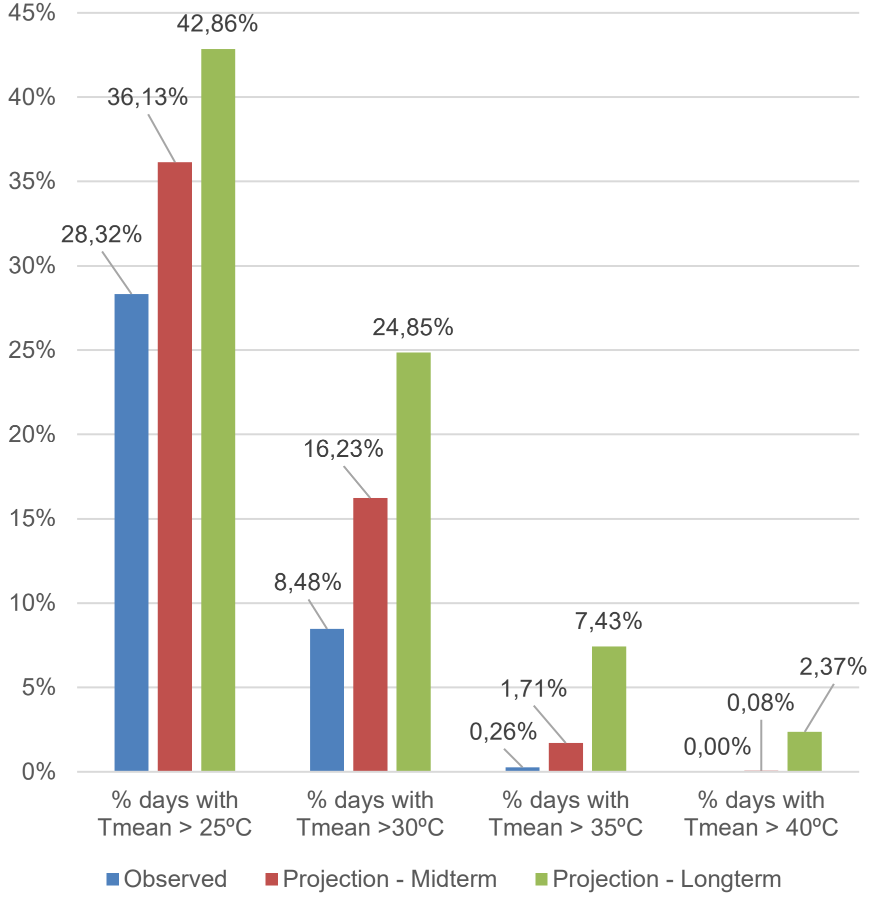
(RCP 8.5)

Model	GCM	RCM	Institute
1	MPI-M-MPI-ESM-LR	COSMO-crCLIM-v1-1	CLMcom-ETH
4	CNRM-CERFACS-CNRM-CM5	CCLM4-8-17	CLMcom
6	CNRM-CERFACS-CNRM-CM5	RACMO22E	KNMI
7	ICHEC-EC-EARTH	COSMO-crCLIM-v1-1	CLMcom-ETH
8	ICHEC-EC-EARTH	RACMO22E	KNMI
9	IPSL-IPSL-CM5A-MR	RACMO22E	KNMI
10	MOHC-HadGEM2-ES	CCLM4-8-17	CLMcom
12	MOHC-HadGEM2-ES	RACMO22E	KNMI
13	MPI-M-MPI-ESM-LR	CCLM4-8-17	CLMcom
15	MPI-M-MPI-ESM-LR	KNMI-RACMO22E	KNMI
16	MPI-M-MPI-ESM-LR	REMO2009	MPI-CSC
17	NCC-NorESM1-M	COSMO-crCLIM-v1-1	CLMcom-ETH

Results: Temperatures

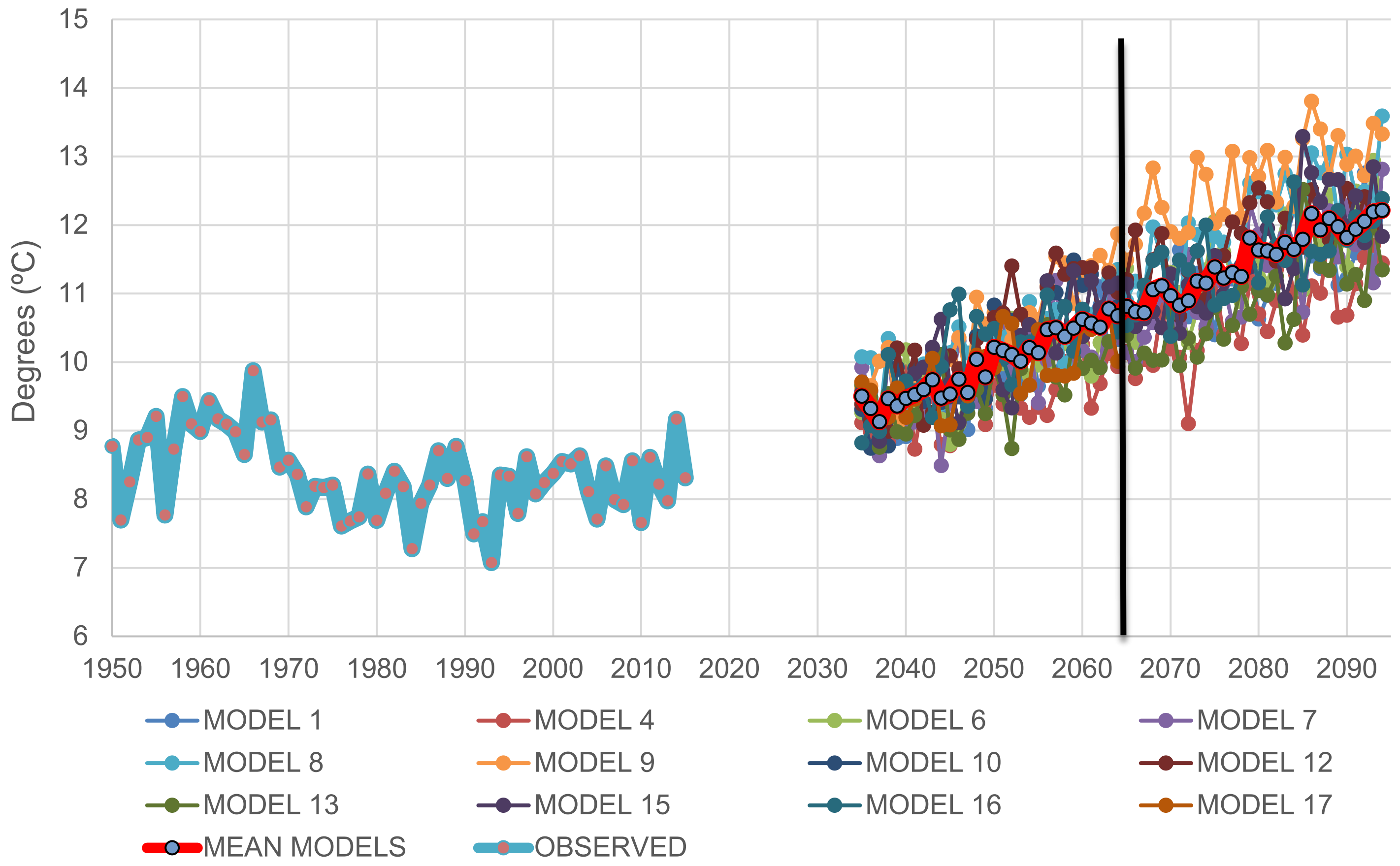
Max. Temperature

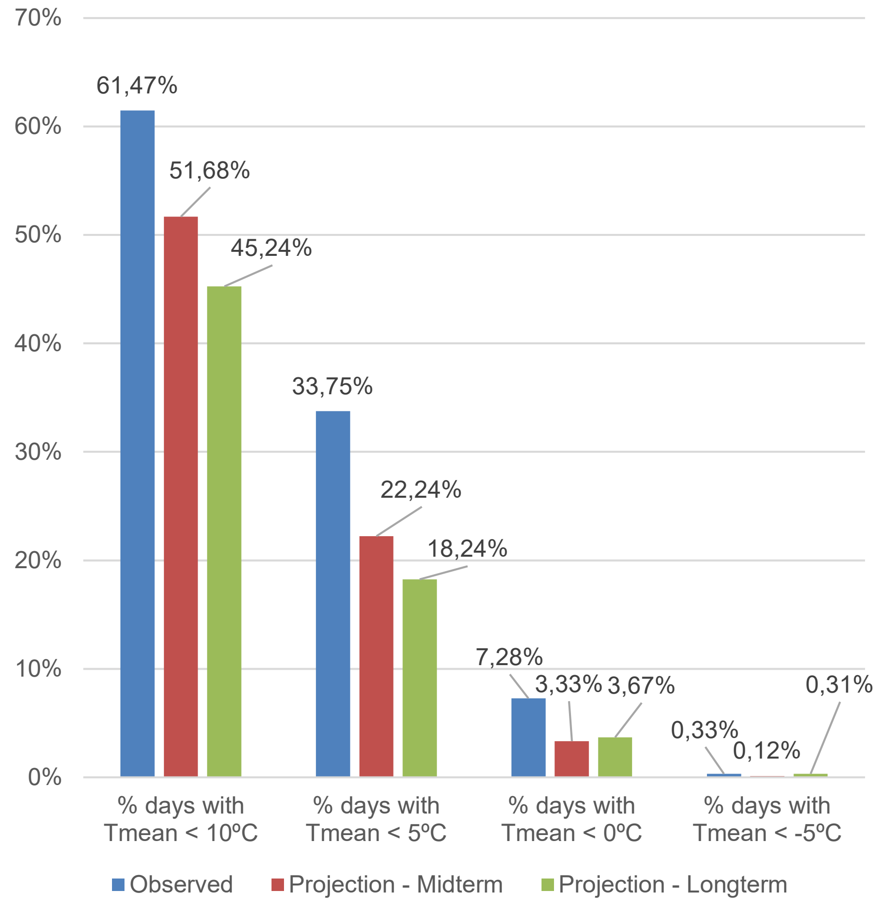




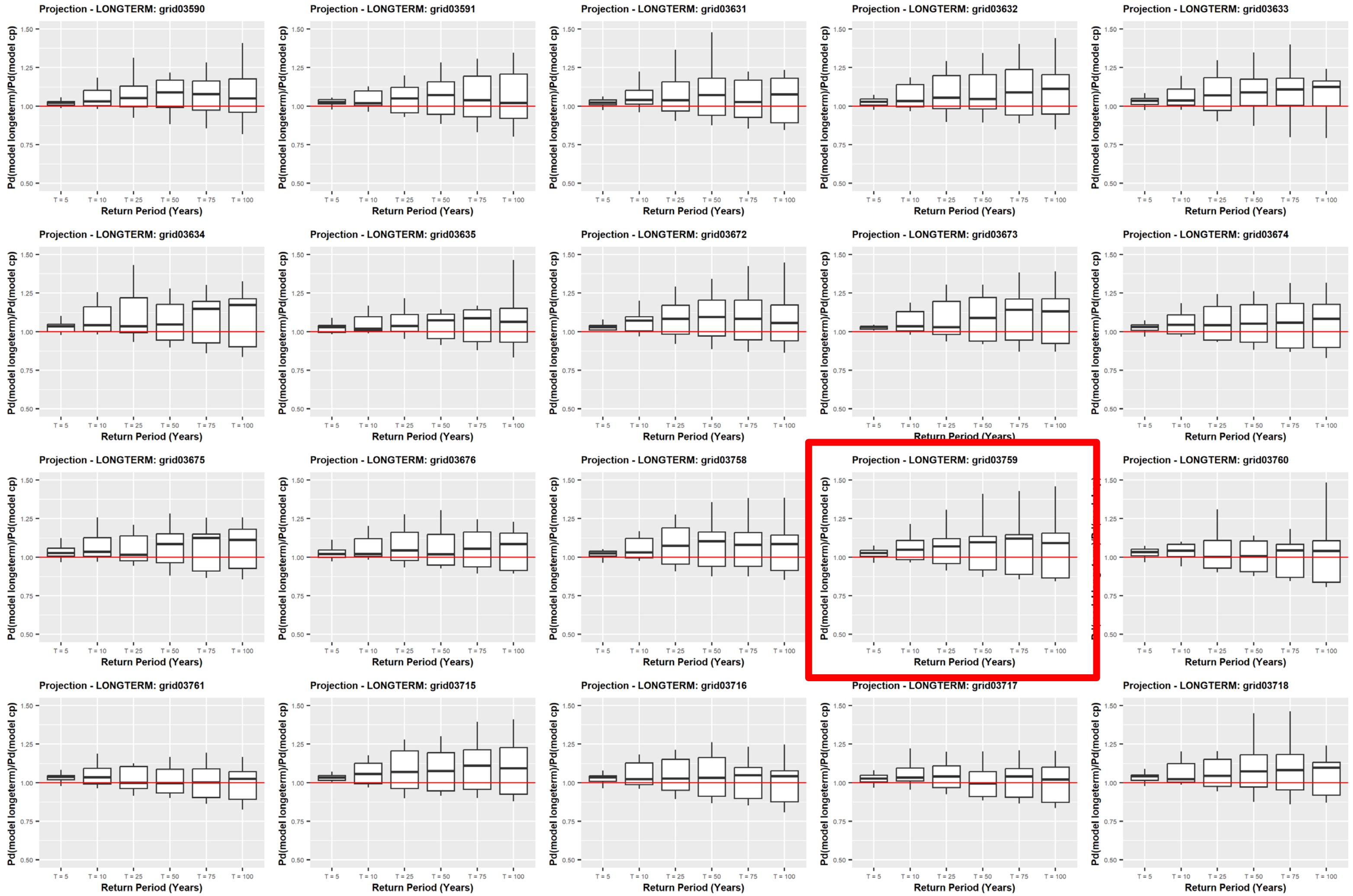
Results: Temperatures

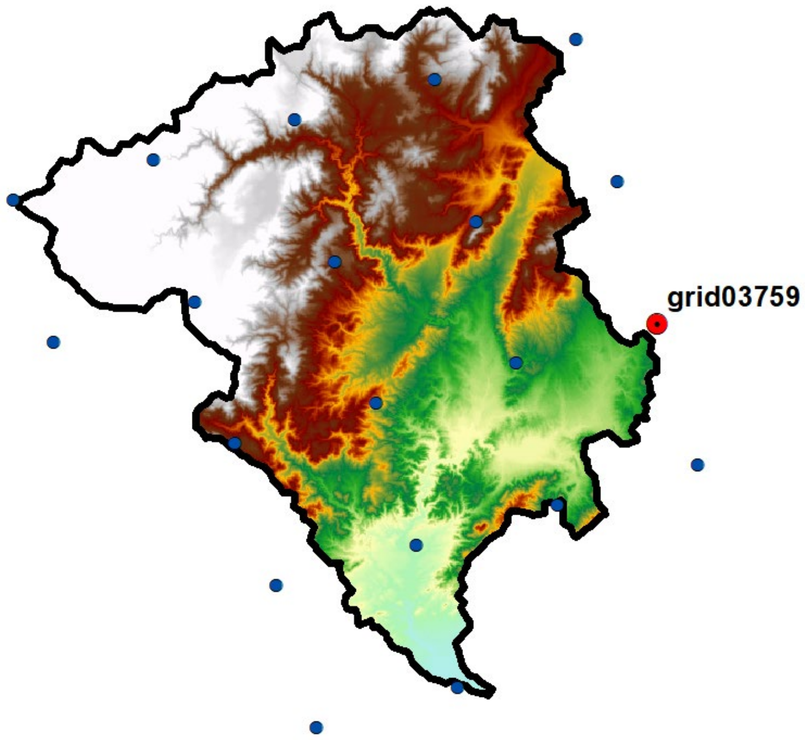
Min. Temperature



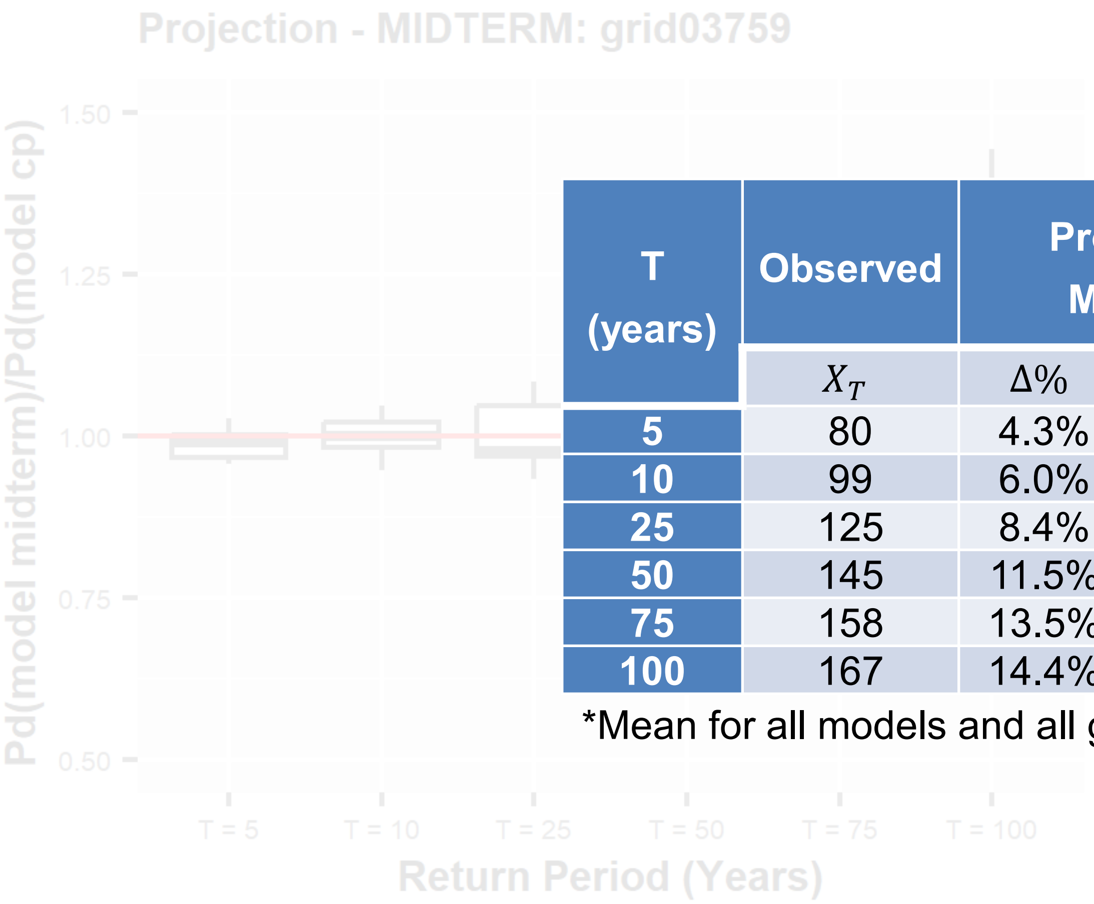


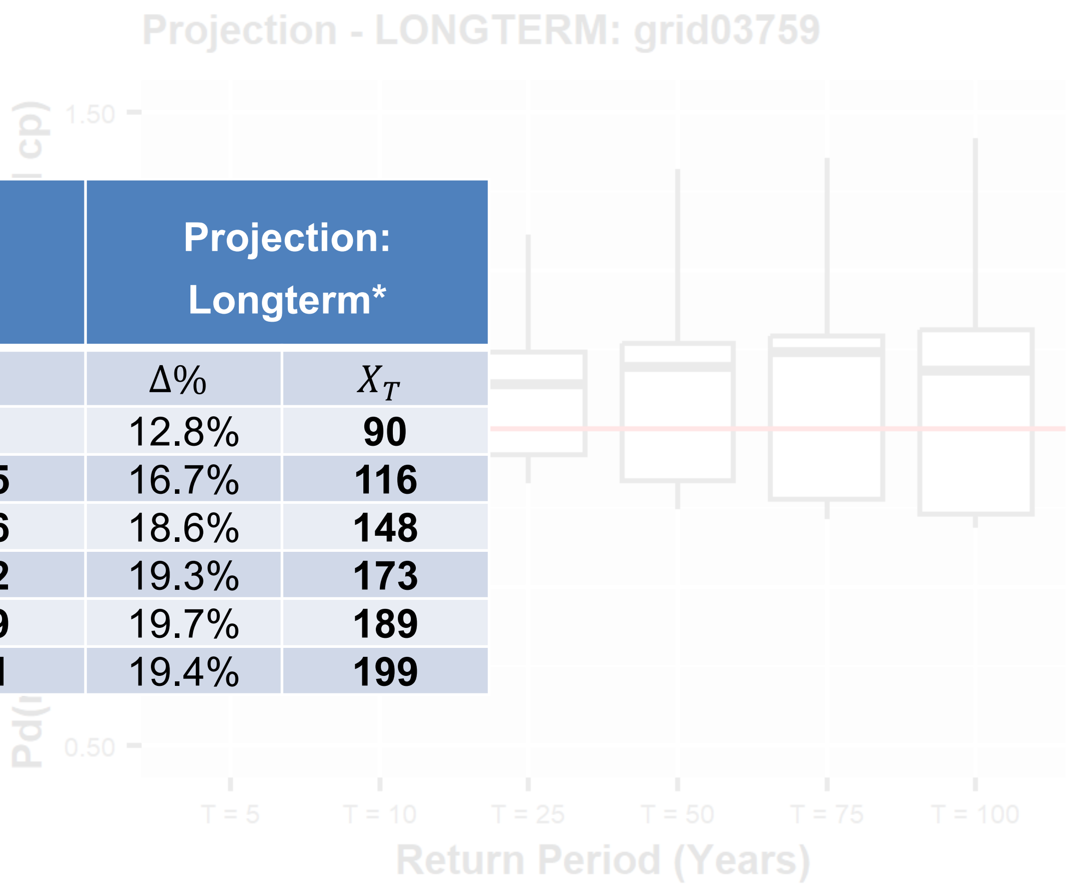
Results: Precipitation





Results: Precipitation





T (years)	Observed	Projection: Midterm*		Projection: Longterm*	
	X_T	$\Delta\%$	X_T	$\Delta\%$	X_T
5	80	4.3%	**83**	12.8%	**90**
10	99	6.0%	**105**	16.7%	**116**
25	125	8.4%	**136**	18.6%	**148**
50	145	11.5%	**162**	19.3%	**173**
75	158	13.5%	**179**	19.7%	**189**
100	167	14.4%	**191**	19.4%	**199**

*Mean for all models and all grids

Results: Discharges

María Cristina (1,447 km²)

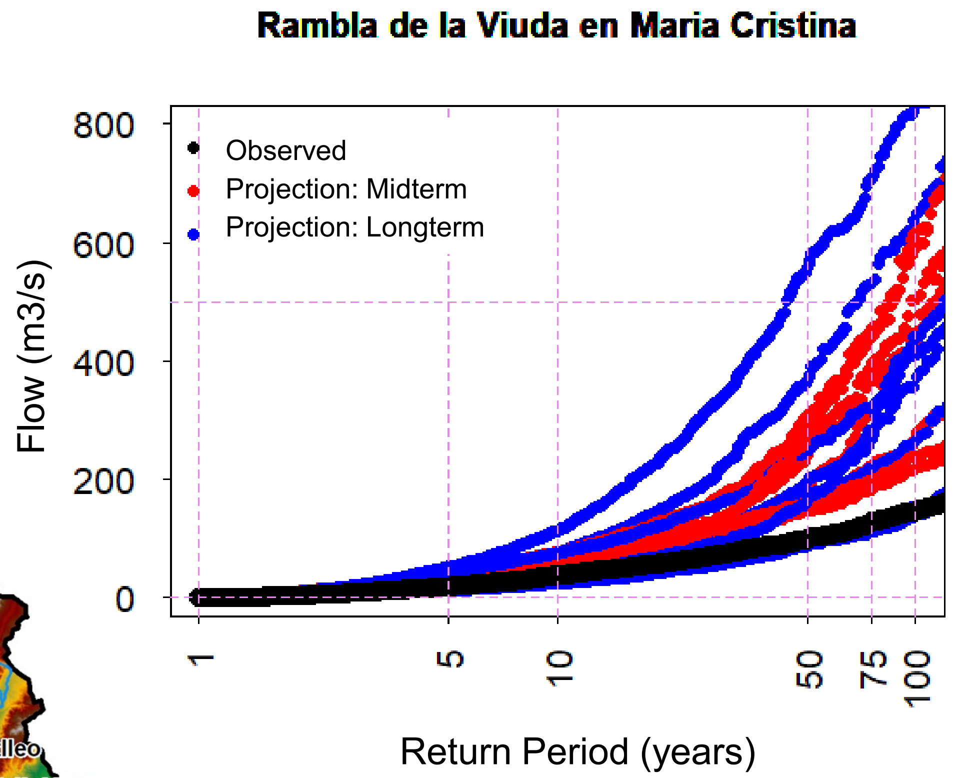
T (years)	OBSERVED (m³)	CLIMATE PROJECTIONS (m³)			
		Delta (%)	MIDTERM	Delta (%)	LONGTERM
5	20	12%	22	8%	21
10	38	12%	43	16%	44
25	68	22%	83	33%	91
50	101	38%	140	54%	155
75	130	48%	192	56%	202
100	147	53%	225	58%	232

Vall d'Alba (906 km²)

T (years)	OBSERVED (m³)	CLIMATE PROJECTIONS (m³)			
		Delta (%)	MIDTERM	Delta (%)	LONGTERM
5	12	11%	14	10%	13
10	22	13%	24	33%	29
25	39	21%	47	64%	64
50	56	41%	79	88%	105
75	69	49%	103	86%	130
100	80	50%	121	80%	145

Montlleó (501 km²)

T (years)	OBSERVED	CLIMATE PROJECTIONS (m³)			
		Delta (%)	MIDTERM	Delta (%)	LONGTERM
5	4	3%	4	5%	4
10	6	7%	6	42%	8
25	11	27%	14	111%	23
50	17	57%	27	137%	40
75	21	73%	37	145%	52
100	28	77%	49	130%	64



Conclusions

- The high spatio-temporal variability of floods makes it necessary to use a weather generator in combination with a fully-distributed hydrological model against Design Storm approach and lumped or semi-lumped models.
- Additional information must be incorporated into the implementation of the weather generator for adequate modeling of low frequency quantiles, especially when extreme precipitation records are scarce.
  - Our proposal is to incorporate a regional analysis of annual maximum daily precipitation in climate models to expand the amount of information
- This methodology has been applied in a case study with a semi-arid Mediterranean climate and a reasonable extension, with satisfactory results.

Conclusions

- In terms of temperatures, these will experience a notable increase in both Tmax and Tmin, also increasing the episodes of heat waves and reducing the cold ones.
  - Initial state of the basin: higher ET0
- Precipitation quantiles will also experience a significant increase in both the medium- and long-term projections.
- The methodology estimates a systematic increase in all flood quantiles, which is accentuated in the long-term projection and, especially, when the size of the basin is reduced. Furthermore, these increases in flood quantiles are systematically greater than their respective precipitation quantiles.

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Thank you for your attention!

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