Uncertainty propagation in the assessment of climate change impact on runoff

Challenging Cassandra prophecies in the western Mediterranean

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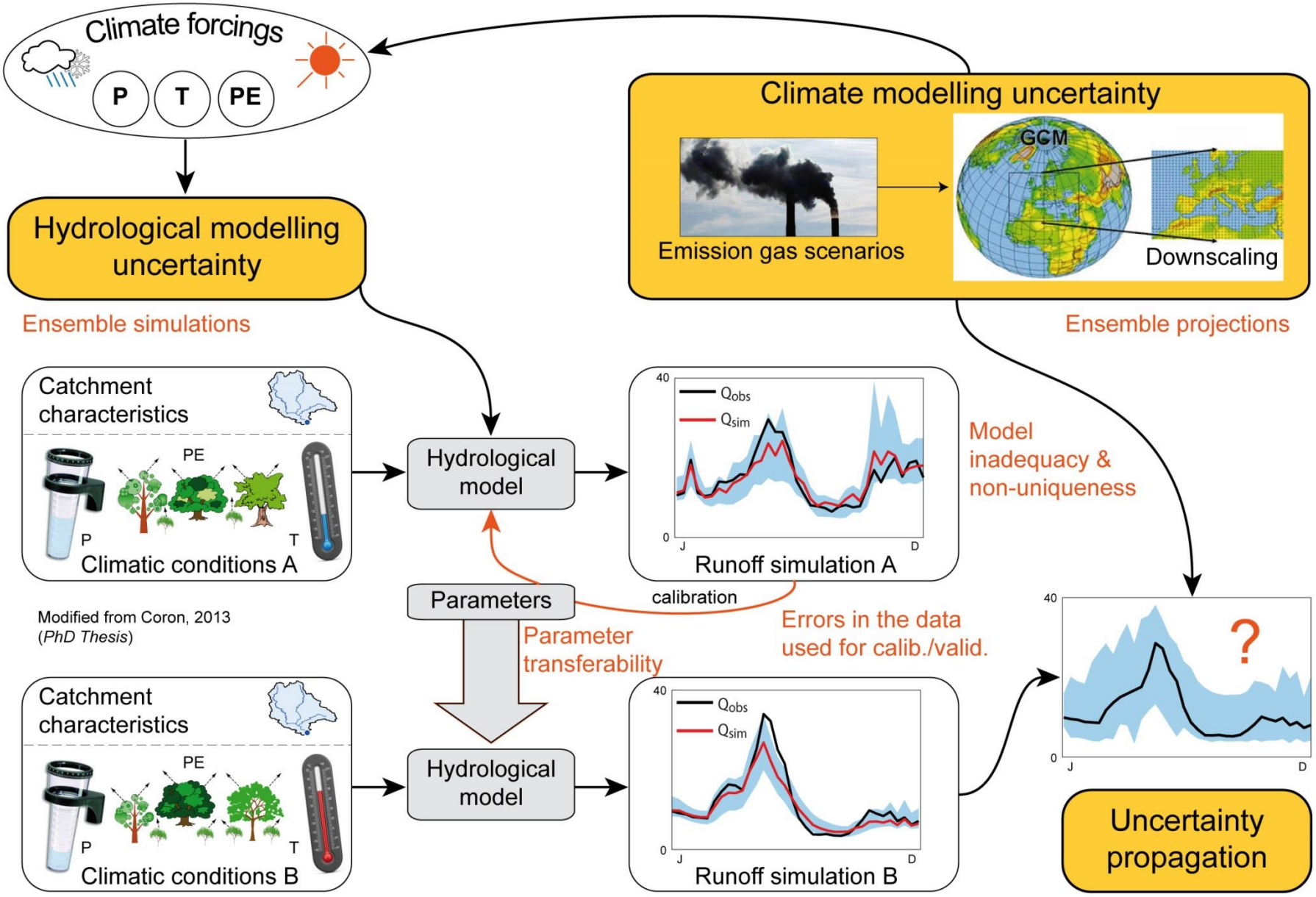
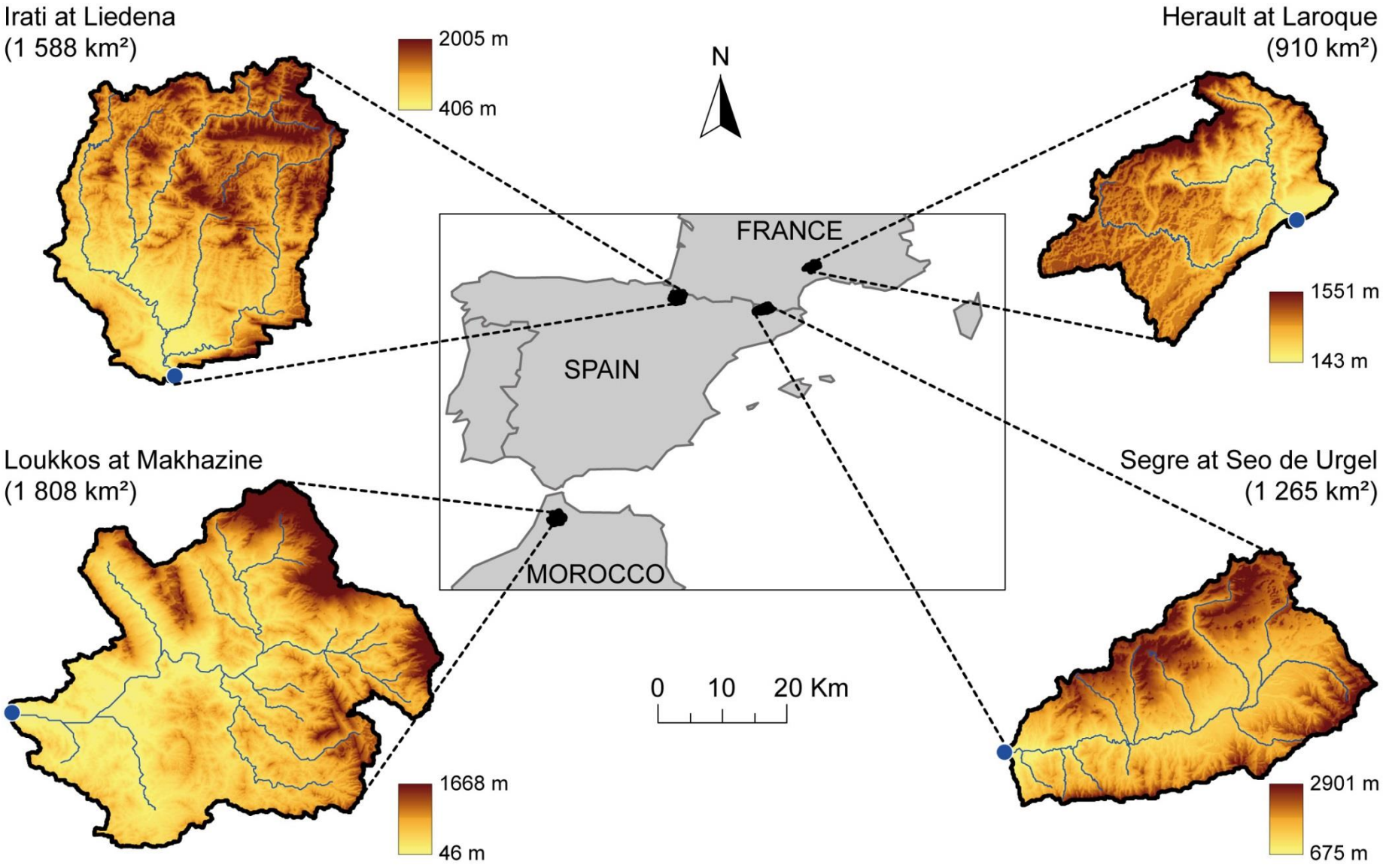
Uncertainties associated to hydrological projections



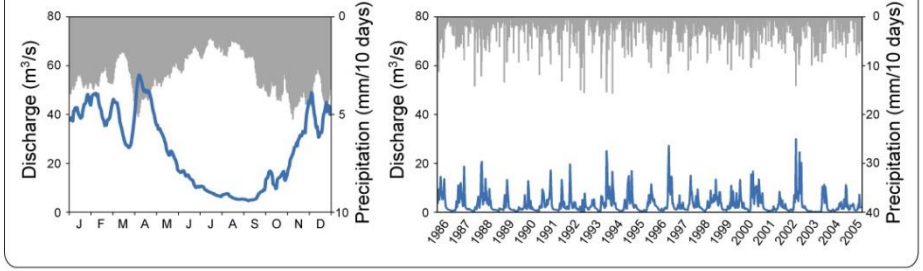
Evaluation on 4 Mediterranean non-influenced basins



Hydro-climatic context over 1986–2005

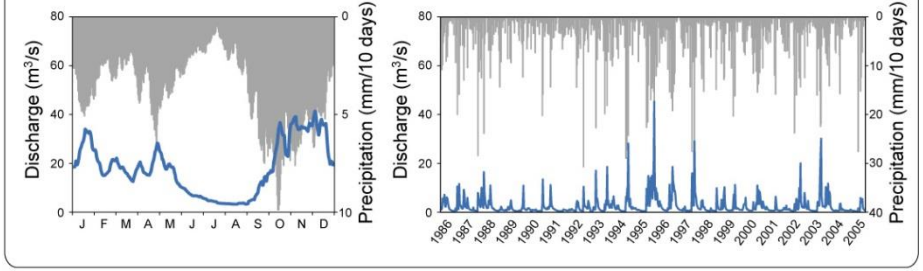
Irati at Liedena (1 588 km²)

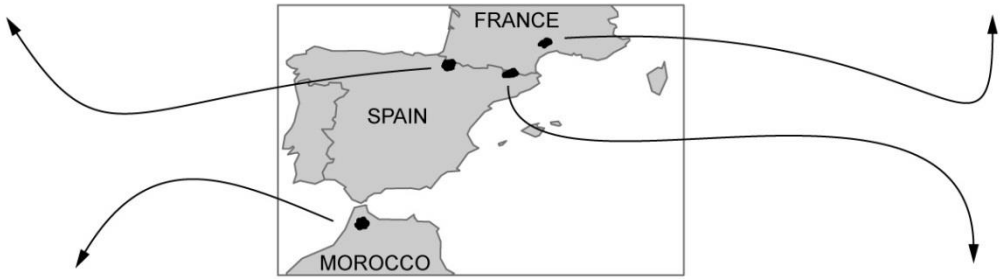
Mean annual precipitation: 1078 mm
Mean annual runoff: 25.6 m³/s (508 mm/47%)



Herault at Laroque (910 km²)

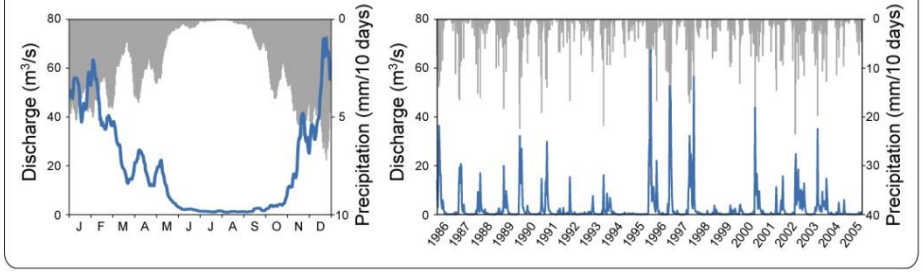
Mean annual precipitation: 1397 mm
Mean annual runoff: 18.1 m³/s (627 mm/45%)





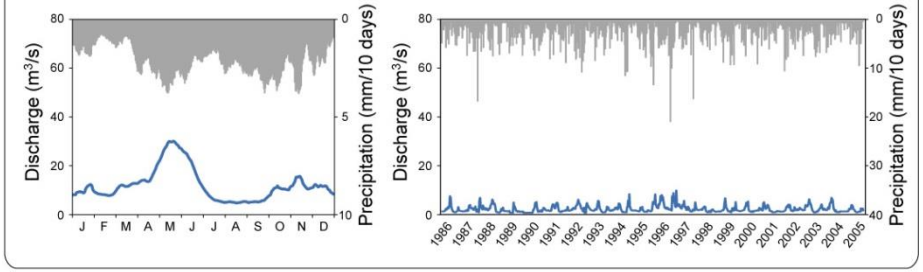
Loukkos at Makhazine (1 808 km²)

Mean annual precipitation: 935 mm
Mean annual runoff: 19.7 m³/s (343 mm/37%)



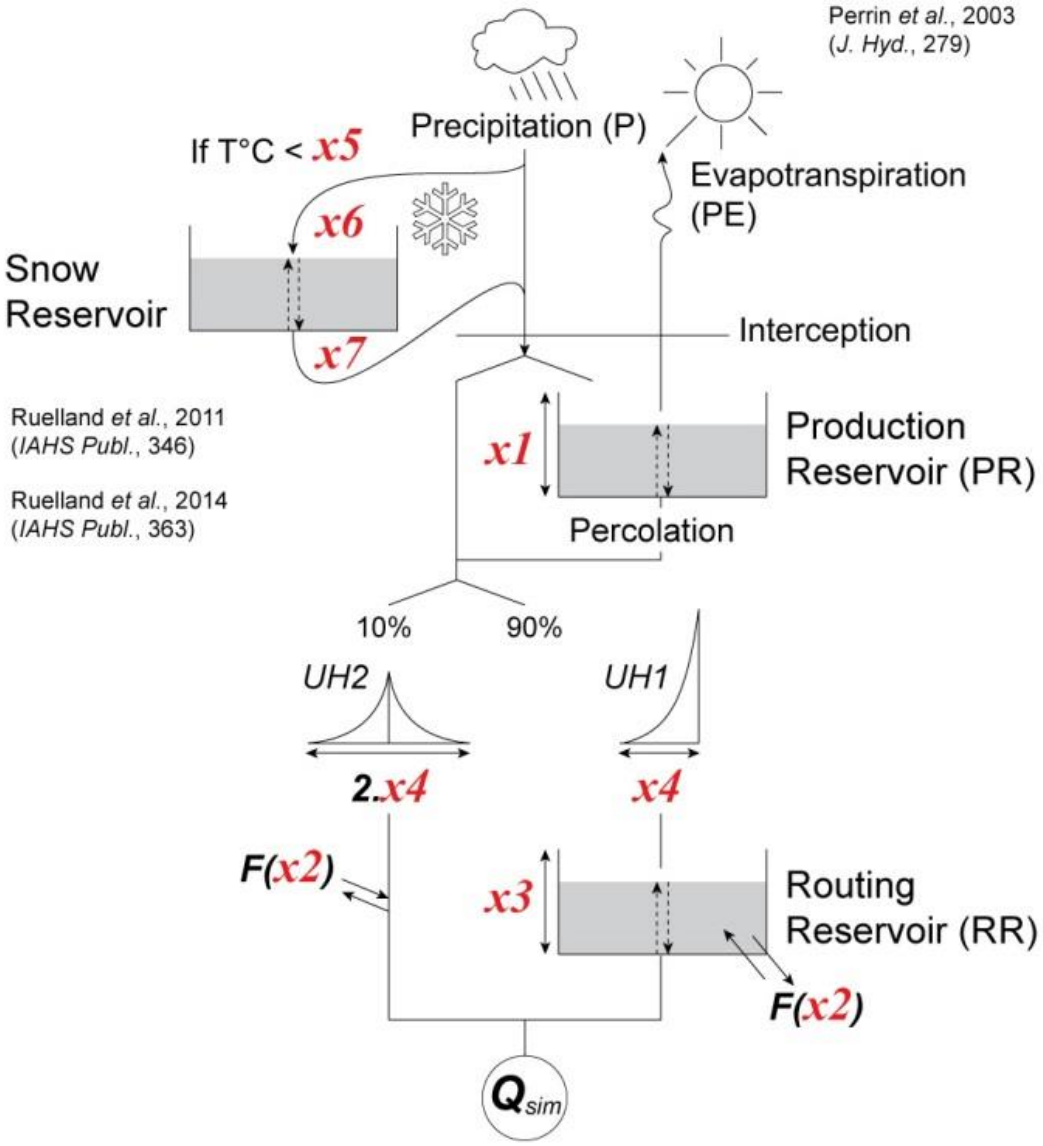
Segre at Seo de Urgel (1 265 km²)

Mean annual precipitation: 813 mm
Mean annual runoff: 12.2 m³/s (304 mm/37%)



Precipitation Runoff

Modified version of the GR4j hydrological model



Calibration parameters

GR4j basic parameters

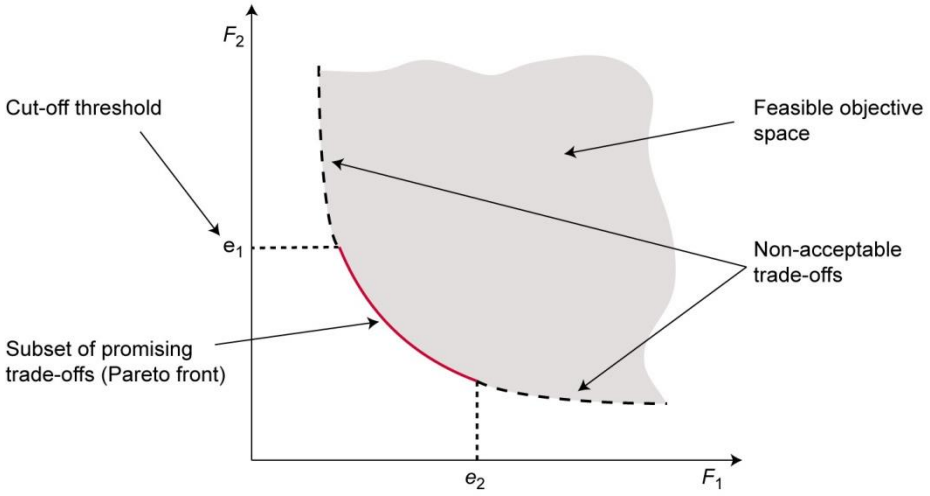
- *x1*: maximum capacity of the PR (mm)
- *x2*: groundwater exchange coef. (mm)
- *x3*: 1day ahead max. capacity of the RR (mm)
- *x4*: time base of unit hydrograph UH (d)

Snow module parameters

- *x5*: temperature threshold (°C)
- *x6*: snow feeding fraction (%)
- *x7*: snowmelt runoff rate (%)

Model calibration & validation based on observed runoff

- **Objective functions and Pareto-optimality principle**
  - NSE: Nash-Sutcliffe Efficiency metric
  - NSE_{Log}: modified, log version of NSE
  - VE_C: cumulated volume error
  - VE_M: mean annual volume error

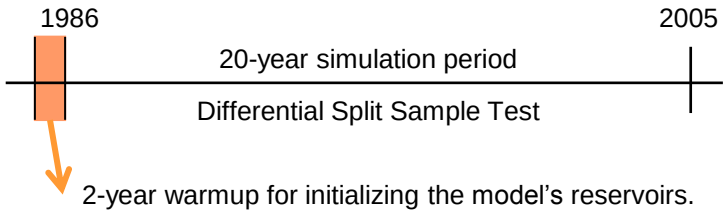


- **Best Compromise Solution (BCS) among the Pareto-optimal simulations**

$$\gamma = (1 - \mathrm{NSE}) + \left(1 - \mathrm{NSE}_{\mathrm{Log}}\right) + |\mathrm{VE}_{\mathrm{C}}| + \mathrm{VE}_{\mathrm{M}}$$

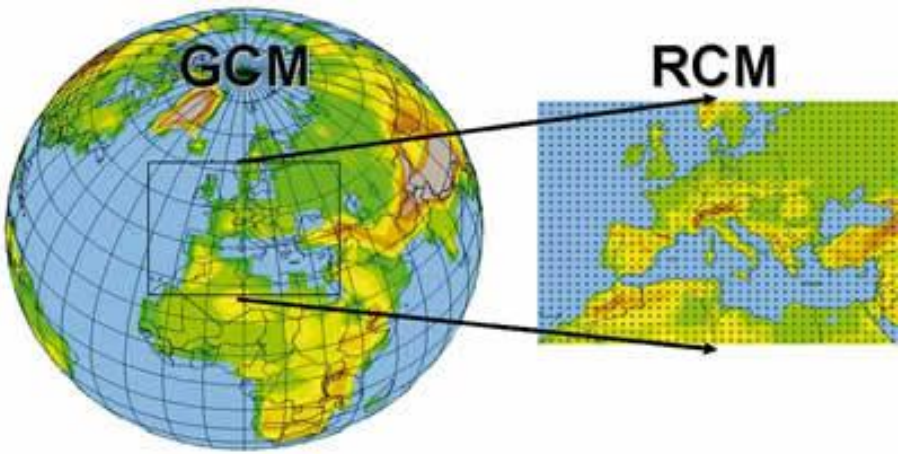
- **Multi-objective optimization**
  - Calibration of the Pareto-optima solutions based on the Non-dominated Sorted Genetic Algorithm (NSGA II, Deb, 2002)
  - Providing bounds associated to the structural uncertainty of the hydrological model

- **Calibration & validation periods**



  - Defining two 10-year sub-periods (here after called dry years and wet years) according to median annual precipitation over the period
  - Testing if the model calibrated on a given period is able to simulate streamflow with a similar efficiency on another period when it differs dramatically

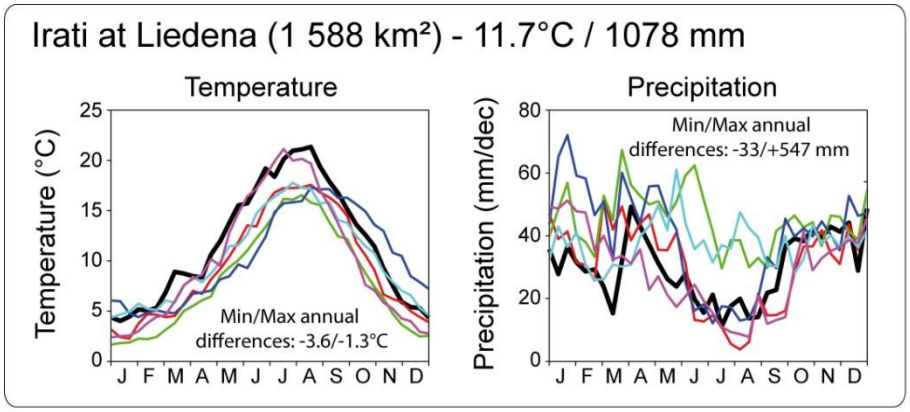
Simulations from 5 Med-CORDEX RCMs (50 x 50 km)

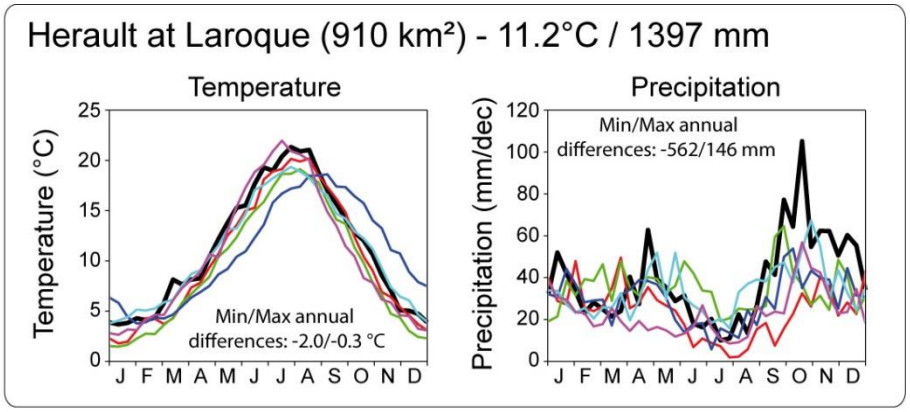


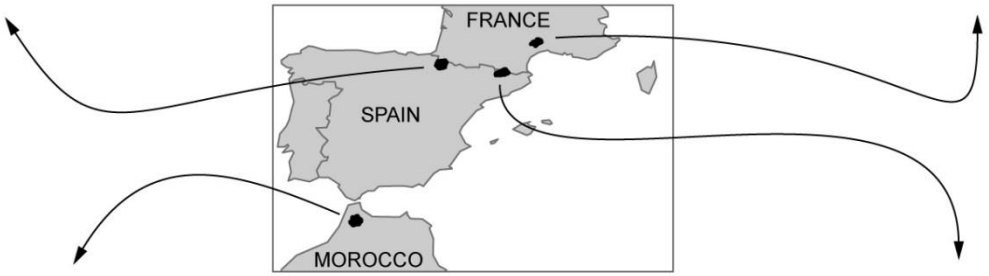
Regional Climate Model	Associated GCM	Acronym	Country
CMCC (Centro euroMedit. sui Cambiamenti Climatici)	CMCC	CMCC/CMCC	Italy
CNRM (Centre National des Recherches Météorologiques)	ARPEGE (Action de Recherche Petite Echelle Grande Echelle)	CNRM/ARPEGE	France
GUF (Goethe Universität Frankfort)	MPI (Max Planck Institute)	GUF/MPI	Germany
ICTP (International Centre of Theoretical Physics)	MPI (Max Planck Institute)	ICTP/MPI	Italy
IPSL (Institut Pierre Simon Laplace)	IPSL	IPSL/IPSL	France

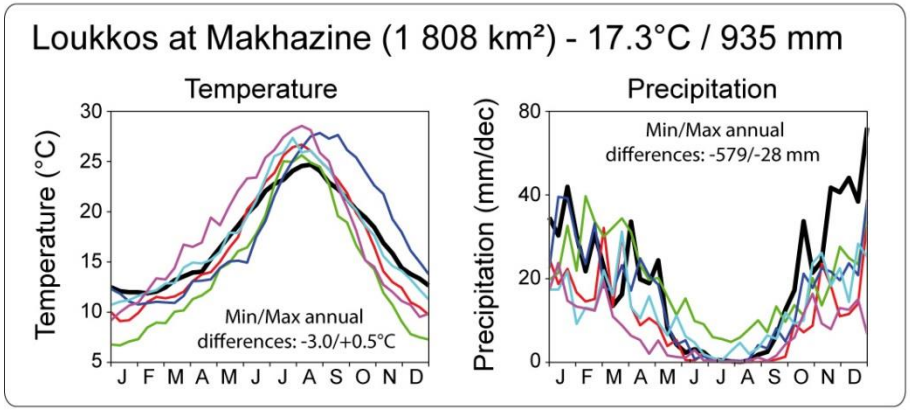
http://www.medcordex.eu

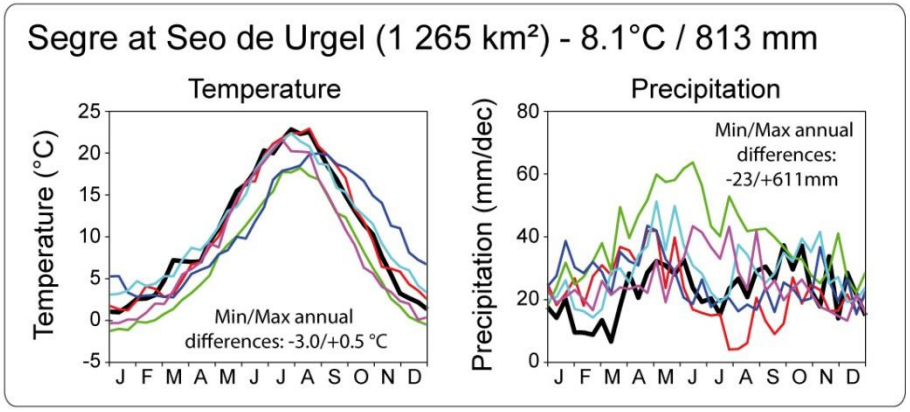
Evaluation of the RCM simulations over 1986–2005





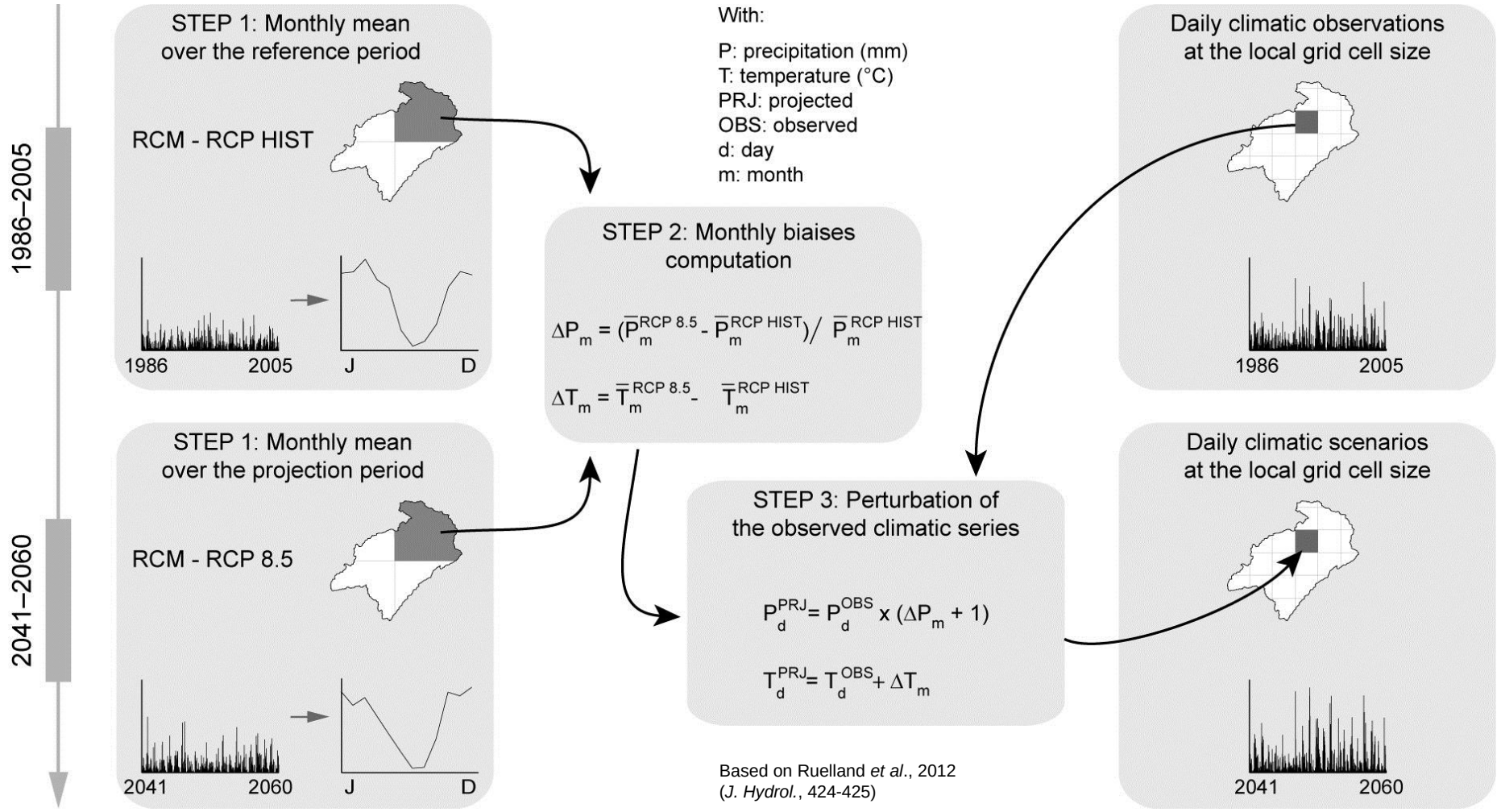






Obs — CMCC/CMCC — CNRM/ARPEGE — GUF/MPI — ICTP/MPI — IPSL/IPSL

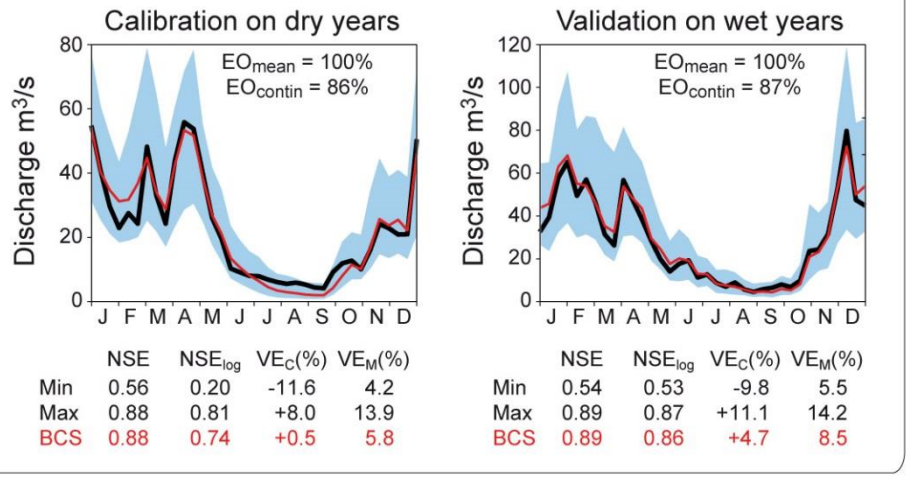
Climate scenarios with a monthly perturbation method



Based on Ruelland *et al.*, 2012 (*J. Hydrol.*, 424-425)

Hydrological model efficiency and uncertainties

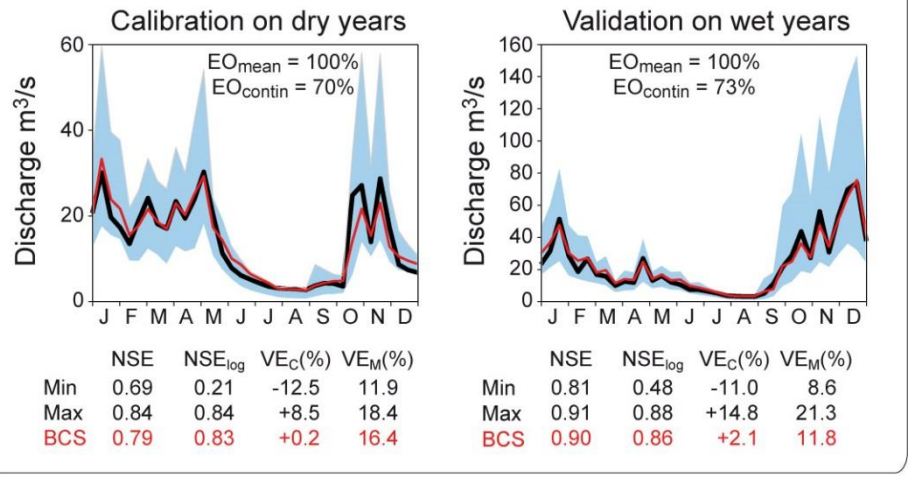
Irati at Liedena (1 588 km²)



	NSE	NSE$_{log}$	VE$_C$(%)	VE$_M$(%)
Min	0.56	0.20	-11.6	4.2
Max	0.88	0.81	+8.0	13.9
BCS	0.88	0.74	+0.5	5.8

	NSE	NSE$_{log}$	VE$_C$(%)	VE$_M$(%)
Min	0.54	0.53	-9.8	5.5
Max	0.89	0.87	+11.1	14.2
BCS	0.89	0.86	+4.7	8.5

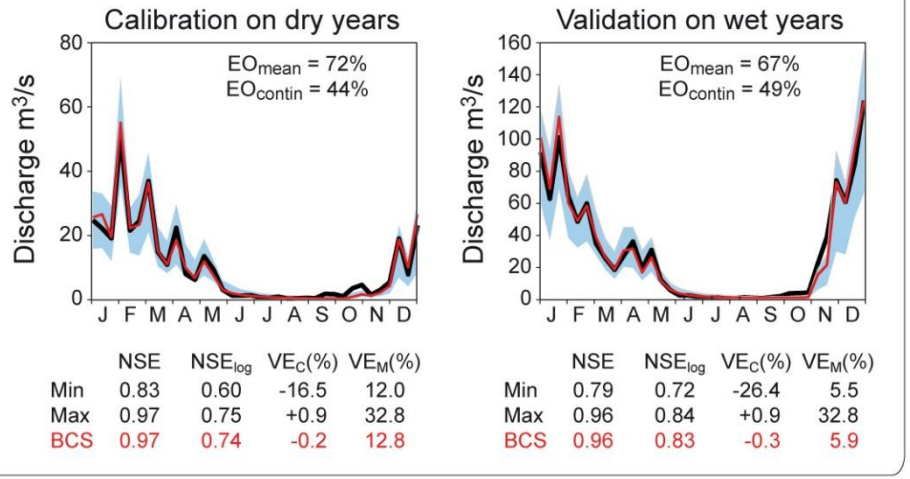
Herault at Laroque (910 km²)



	NSE	NSE$_{log}$	VE$_C$(%)	VE$_M$(%)
Min	0.69	0.21	-12.5	11.9
Max	0.84	0.84	+8.5	18.4
BCS	0.79	0.83	+0.2	16.4

	NSE	NSE$_{log}$	VE$_C$(%)	VE$_M$(%)
Min	0.81	0.48	-11.0	8.6
Max	0.91	0.88	+14.8	21.3
BCS	0.90	0.86	+2.1	11.8

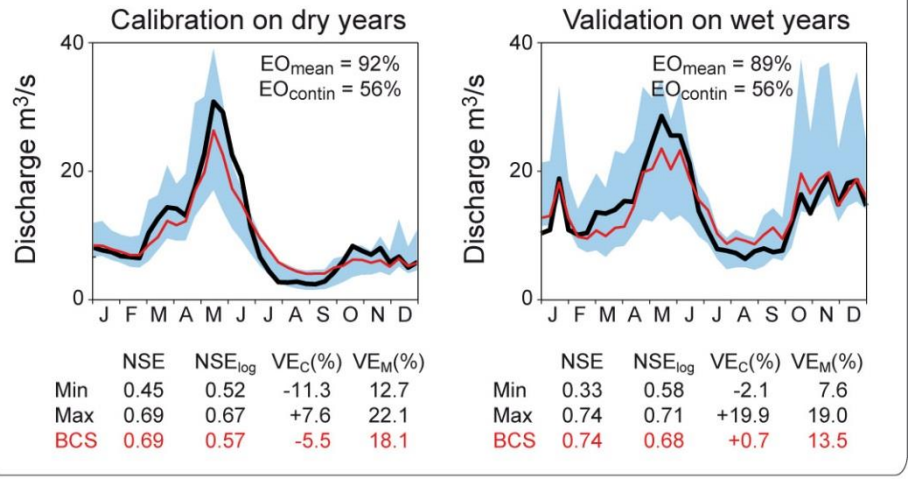
Loukkos at Makhazine (1 808 km²)



	NSE	NSE$_{log}$	VE$_C$(%)	VE$_M$(%)
Min	0.83	0.60	-16.5	12.0
Max	0.97	0.75	+0.9	32.8
BCS	0.97	0.74	-0.2	12.8

	NSE	NSE$_{log}$	VE$_C$(%)	VE$_M$(%)
Min	0.79	0.72	-26.4	5.5
Max	0.96	0.84	+0.9	32.8
BCS	0.96	0.83	-0.3	5.9

Segre at Seo de Urgel (1 265 km²)

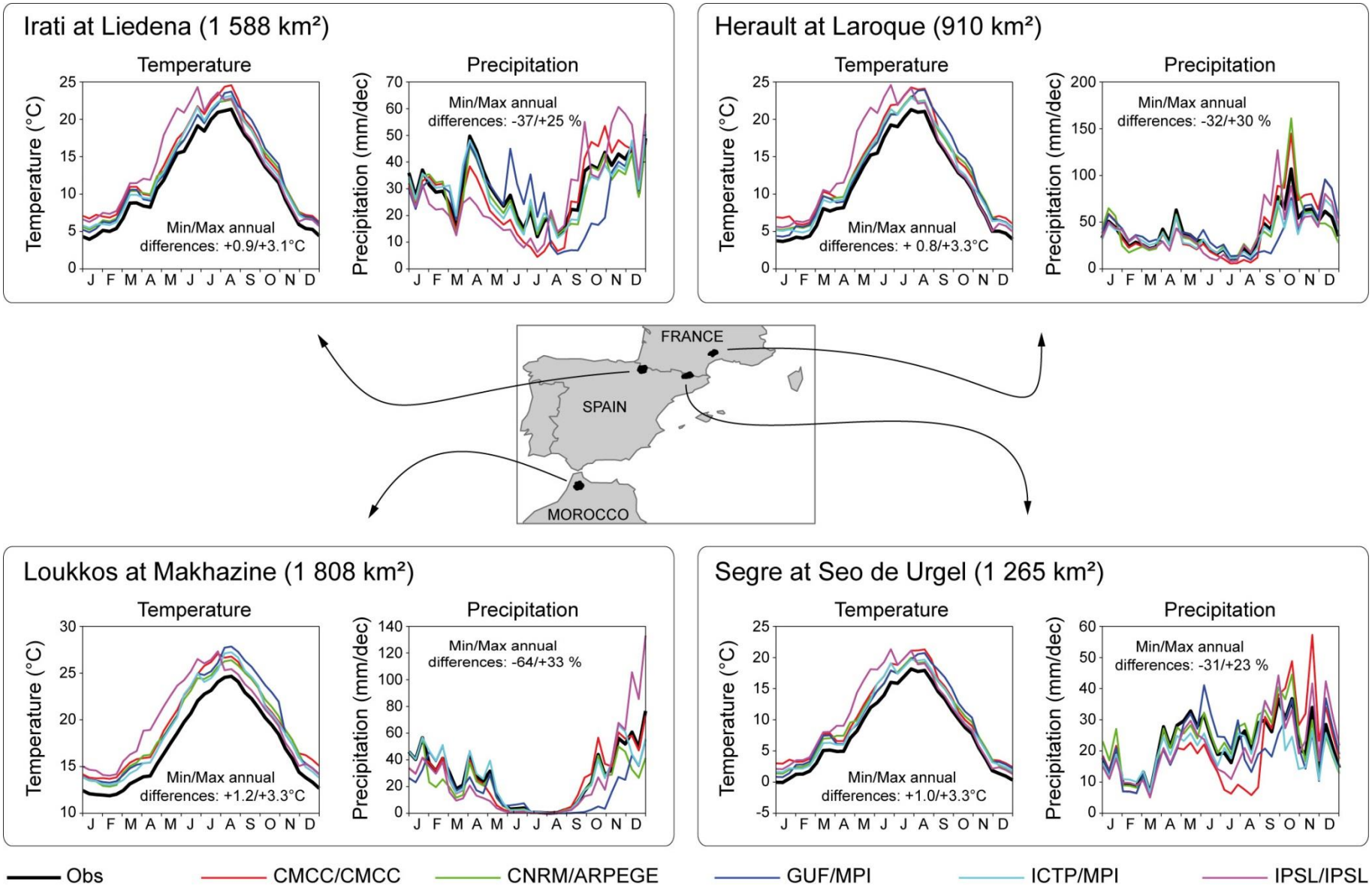


	NSE	NSE$_{log}$	VE$_C$(%)	VE$_M$(%)
Min	0.45	0.52	-11.3	12.7
Max	0.69	0.67	+7.6	22.1
BCS	0.69	0.57	-5.5	18.1

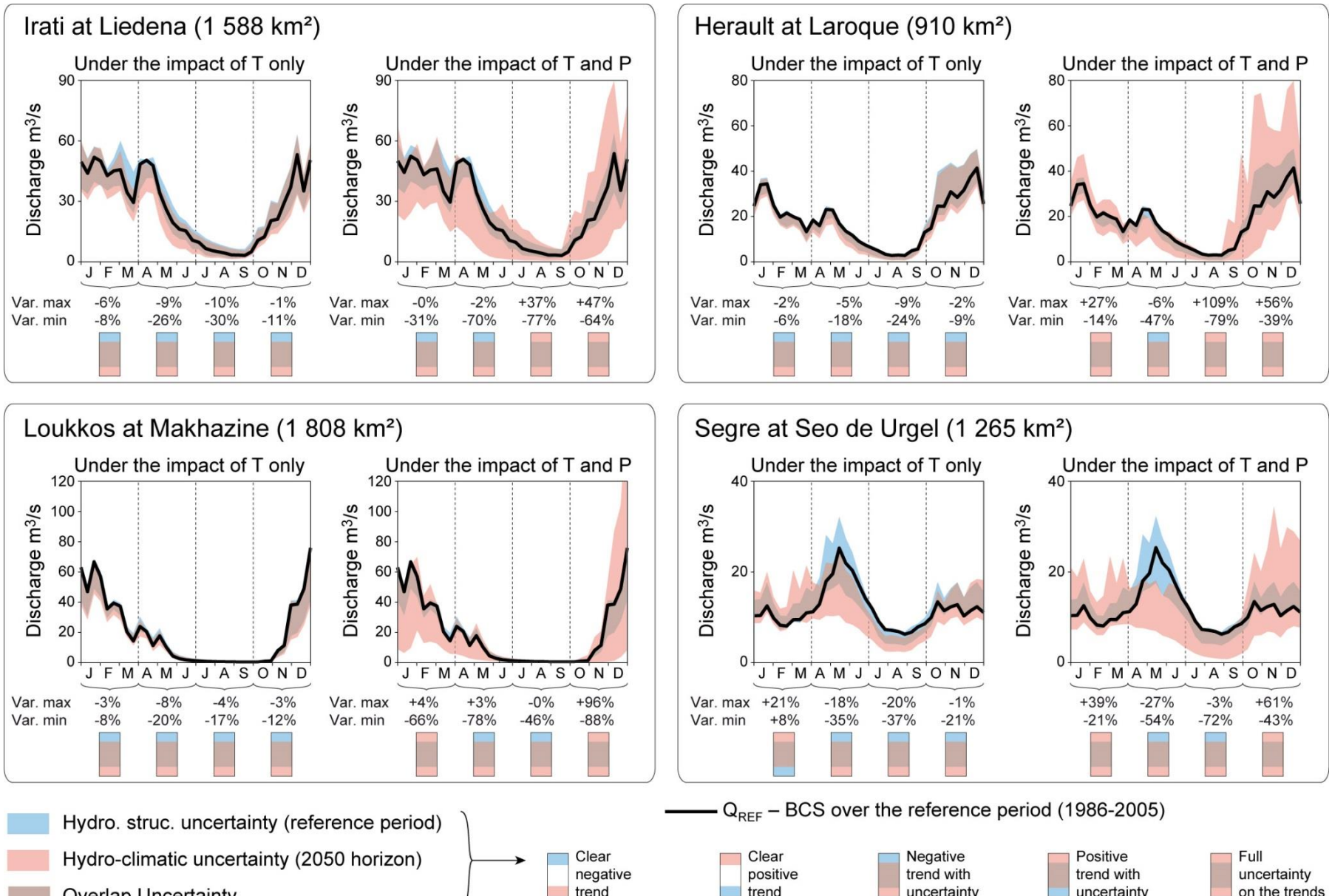
	NSE	NSE$_{log}$	VE$_C$(%)	VE$_M$(%)
Min	0.33	0.58	-2.1	7.6
Max	0.74	0.71	+19.9	19.0
BCS	0.74	0.68	+0.7	13.5

Q_{obs} Q_{BCS} Uncertainty envelope

Future climatic trends and uncertainties



Future hydrological trends and uncertainties



Conclusions: back to Cassandra myth

How were challenged the hydroclimatic prophecies of Cassandra?

- Hydrological uncertainty investigated using a multi-objective approach and a DSST
- Climate-related uncertainties considered via an ensemble of Med-CORDEX RCM simulations

Is Cassandra really able to hear the (hydro)future?

- The tested RCM do not reproduce seasonal dynamics nor mean annual values of P
- T projections are convergent while P projections are largely uncertain
- No clear trend in runoff could be put in evidence for all seasons due to the superposition of the uncertainty bounds between past and future hydrological simulations
- The lack of robustness of the hydrological model was a major source of variability among streamflow projections under future climate conditions

How could we consider however uncertain prophecies from Cassandra?

- Limit the analysis to a multi-model ensemble mean of future projections
- Adopt a model-free approach relying on a sensitivity analysis under basic climate scenarios leading progressively to warmer and drier conditions

Thank you for listening. Any questions?

For more details:

Ruelland, D., Hublart, P. & Tramblay, Y. (2015). Assessing uncertainties in climate change impacts on runoff in western Mediterranean basins. In: Hydrologic non-stationarity and extrapolating models to predict the future. IAHS Publ., 371, 75–81.