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An alternate approach for assessing impacts of climate change on water resources: combining hazard likelihood and catchment sensitivity



Meuse, Transbordeur, summer 2003



*Charleville-Mézières (France) 1995
(Source: EPAMA)*

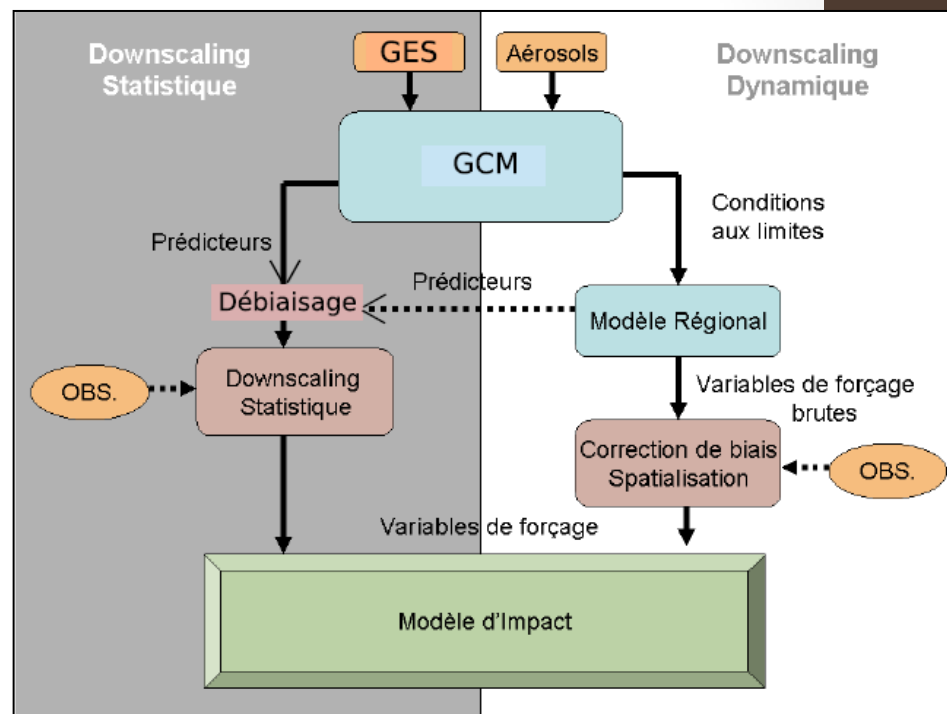
Introduction

Climate change impact
study approaches:
= *TOP-DOWN* or *PREDICT
AND ACT*
= **hazard-centred**

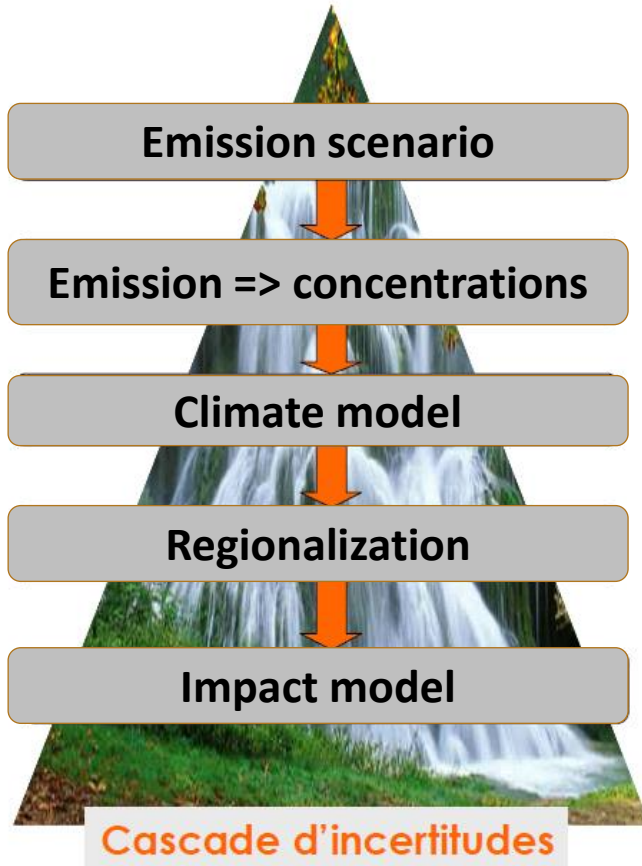


**Decision-makers perception: climate scenarios have a
deterministic status and so a predictive dimension**

In Lafaysse, 2011



Introduction



- **BUT...**

➔ **HIGH UNCERTAINTIES from climate models IPCC/CMIP5**

GCMs/RCMs provide only a range of potential future climates and simulations can be hazardous

Need of an **alternate approach**



to put more **good uncertainty** in the climatic hazard assessment in order to **add robustness to adaptation**

Introduction

Definition : good uncertainty is « the one we would like to maximize in order to not exclude possible futures » (<http://www.drias-climat.fr/>)

Issue: How introducing **good uncertainty** in the climate impact study ?

Idea:

*Sampling the **historical climate variability** (≈ -500 BP) to extend spectrum of climate and hydrological projections and provide more robustness to the adaptation procedure*

(+) The impact study is still hazard-centered but **IPCC scenarios get a new status**: they are « neutralized » in the impact study (from predictive to informative dimension).

(+) The basin climatic future **is no more conditioned only to uncertain IPCC simulations**, but consider the historical climate variability.

(+) It allows to **explore the hydrological response surface** of the catchment (vulnerability) according to the climatic forcing.

(+) the impact study and adaptation measures (e.g. safety margin) are based on a past-present-future climate continuum (historico-prospective approach).

Study area

Meuse basin

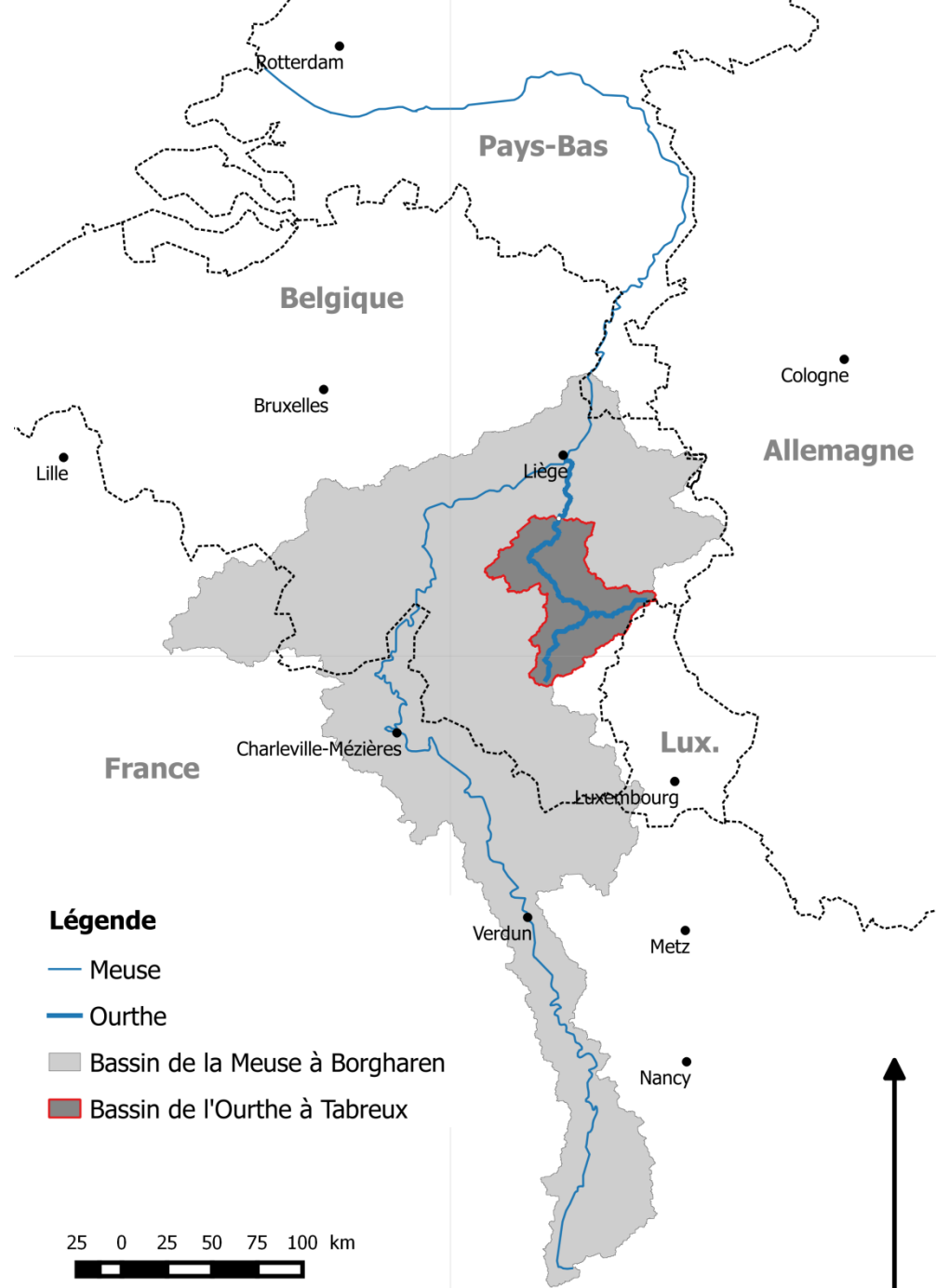
➔ Meso-scale atmospheric circulation

Ourthe basin

➔ surface atmospheric variables, hydrology and hydraulic

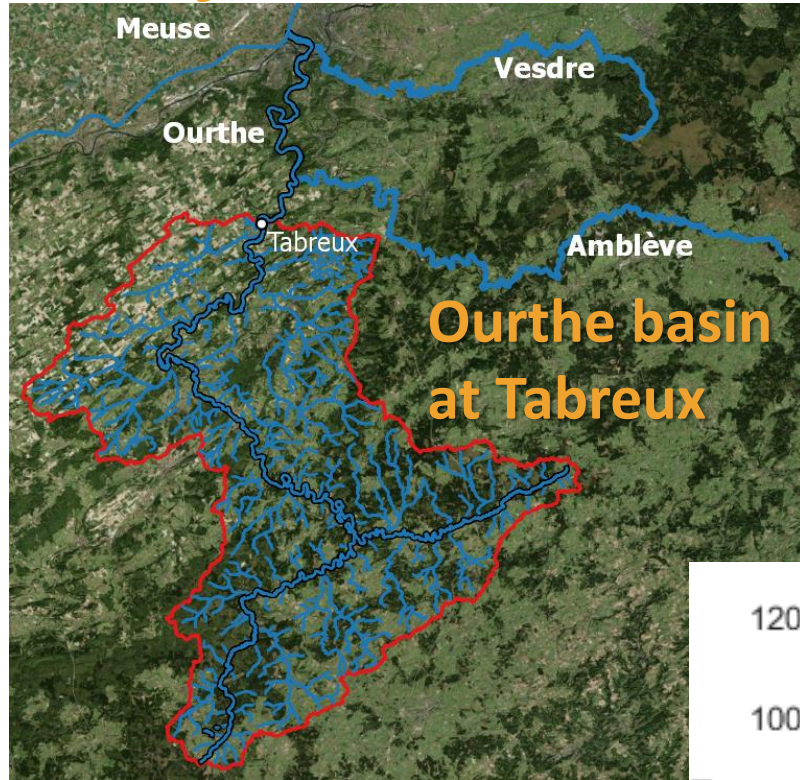
Two main steps:

- *Impacts on the catchment climate (precipitations and air temperatures: useful for catchment hydrology)*
- *Impacts on surface hydrology*



Study area

Ourthe basin



Ourthe basin at Tabreux

Area = 1607 km²

Precipitation: 900-1200 mm/year

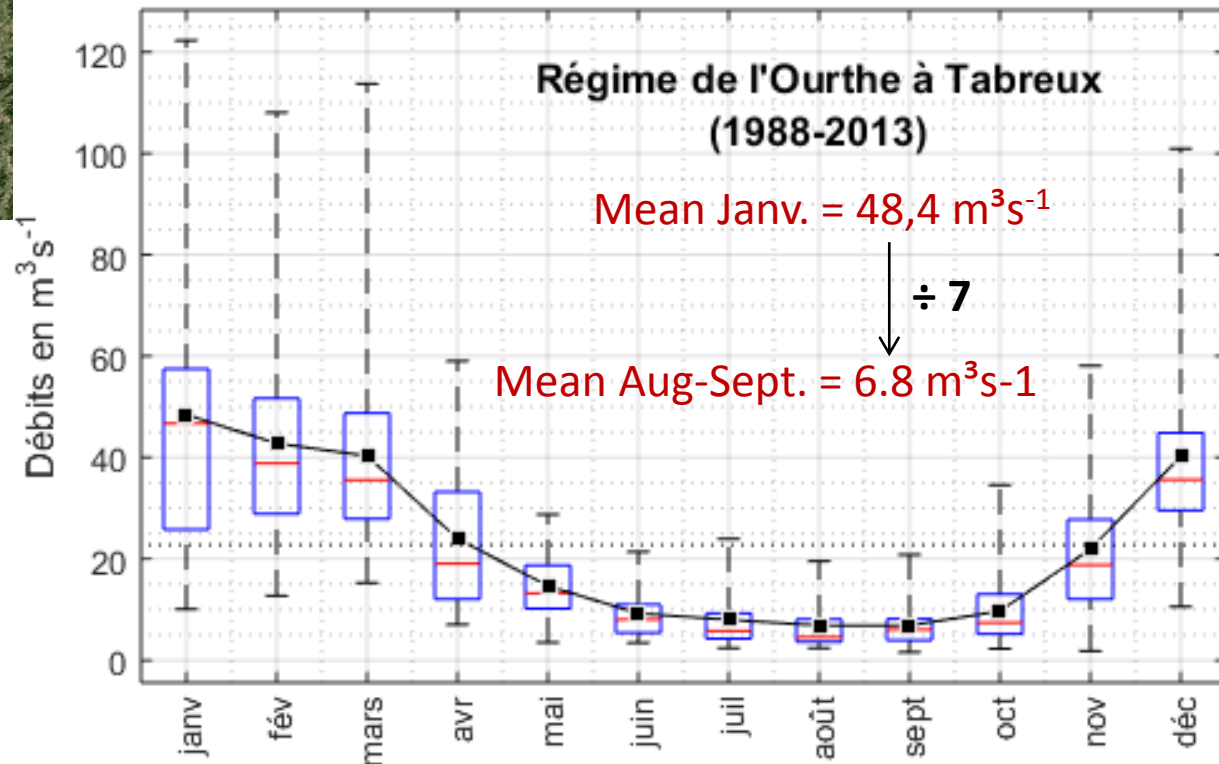
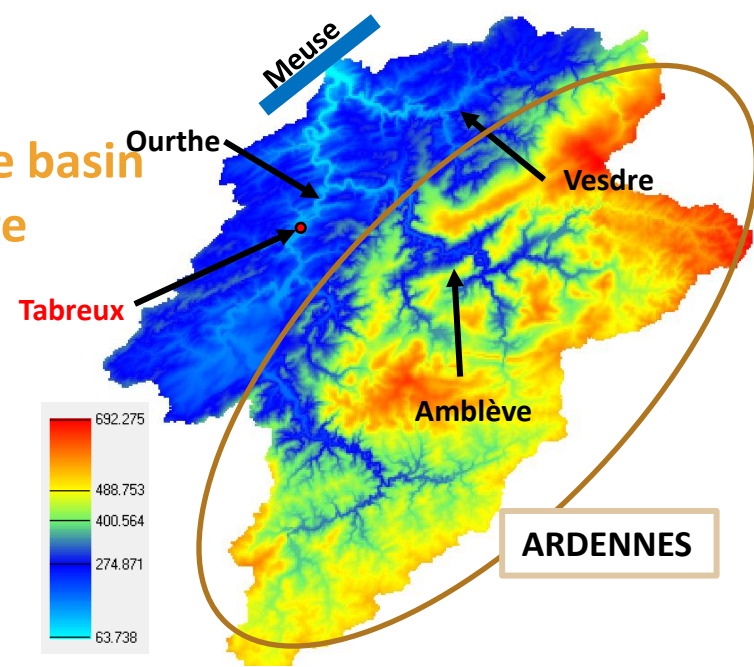
Mean discharge = 22,7 m³s⁻¹

Runoff yield= 446 mm/an

Geology : schist and sandstone

Climate regime: pluvio-evaporal

Ourthe basin at Liège

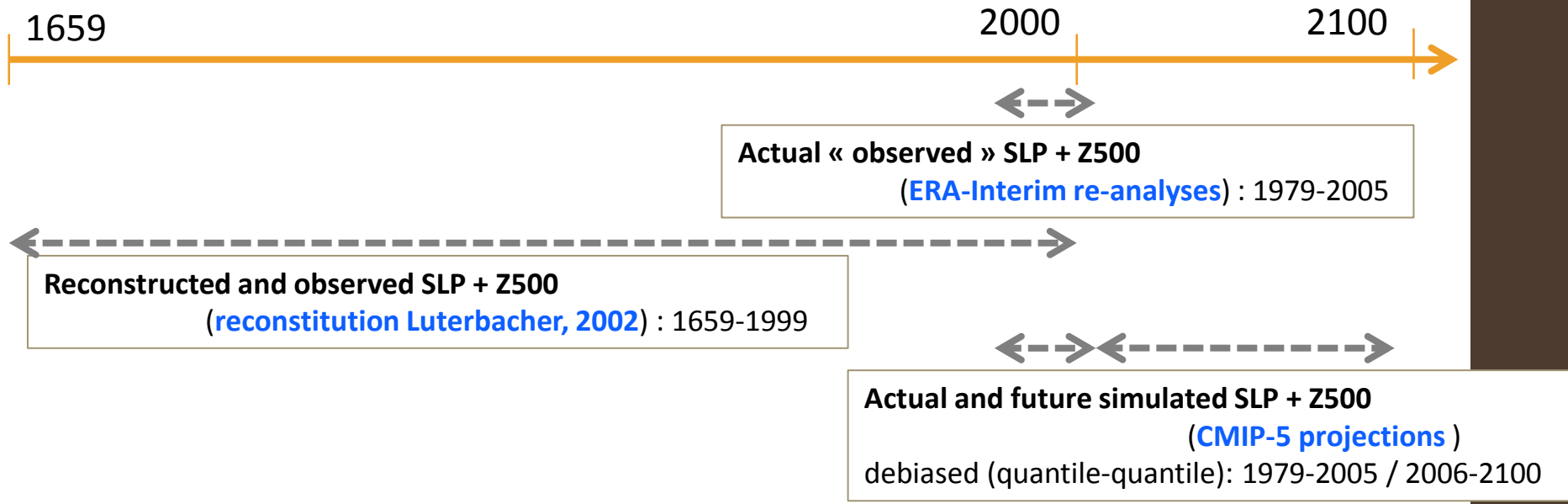


**Impact on the climate of
the Ourthe basin
*(precipitations and air
temperatures)***

Data and method

SLP: Sea Level Pressure
Z500: geopotential at 500 hPa

Atmospheric circulation data (low biased predictors in GCM/RCM) → SLP + Z500



Data of monthly precipitations and air temperatures (local target-variables)

→ IRM (Institut Royal de Météorologie de Belgique) data on the Ourthe basin

- Air temperature and precipitation: 1961-2013
- 10x10 km grid

→ Determination of a basin precipitation and temperature: average of all cells situated in the Ourthe basin

Data and method – Transfer function

Link **atmospheric circulation** (SLP + Z500) and **locale climatic variables** (Precip, Temp)

- **SLP** and **Z500** at central point (5°E – 50°N)
(→ synoptic situation : HP/LP)
- **MPG** : Monthly Pressure Gradients (SLP et Z500) (signe and intensity):

- East-West (→ meridian flux)

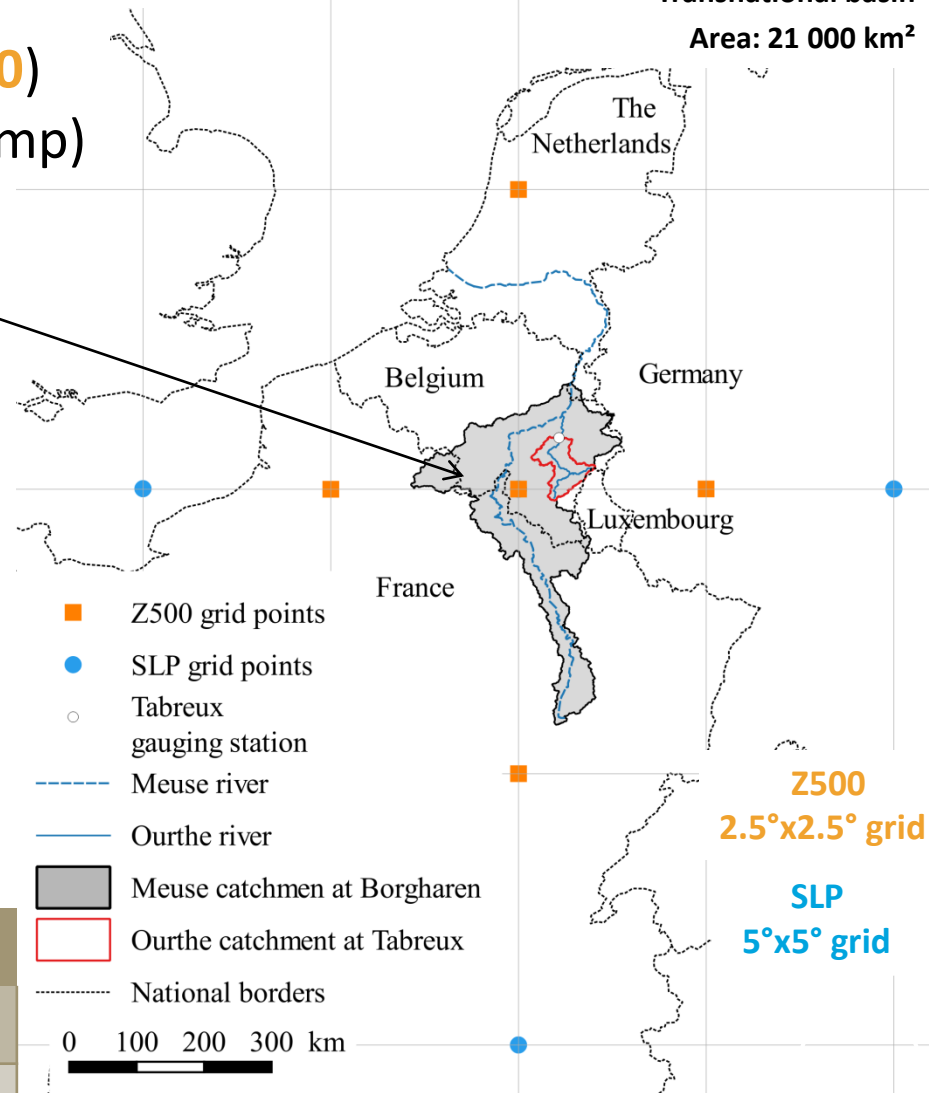
$$X_{MPG} = (P_{(E)} - P_{(W)}) / \text{distance}_{(\text{east-west})}$$

- North-South (→ zonal flux)

$$Y_{MPG} = (P_{(N)} - P_{(S)}) / \text{distance}_{(\text{north-south})}$$

The Meuse at Borgharen (NL)

Transnational basin
Area: 21 000 km²



Regressions	SLP			Z500		
	P _{central}	X _{MPG}	Y _{MPG}	P _{central}	X _{MPG}	Y _{MPG}
Precipitation	P _{central}	X _{MPG}	Y _{MPG}	P _{central}	X _{MPG}	Y _{MPG}
Temperatures	P _{central}	X _{MPG}	Y _{MPG}	P _{central}	X _{MPG}	Y _{MPG}



« stepwise » mode multiple linear regression on period 1961-2005

Results

→ **Medium to high correlation (Pearson r correlation)** between observed and estimated series (1961-2013)

Air temperatures

Month	r	Intercept	X of PGF	Y of PGF	Pressure
J	0.93	192.9		-217.6*	-0.4*/0.4**
F	0.92	190.3		-153.7*	-0.4*/0.4**
M	0.97	157	-140.9*/ 94.6**	-98.3*/ 55.4**	-0.4*/0.4**
A	0.89	149.5	108.2*		-0.3*/0.3**
M	0.92	141.5		-117.3*	-0.2*/0.4**
J	0.94	56.6	241.2*	53.5**	-0.2*/0.4**
J	0.94	72.3	94.8**	122.5**	-0.4*/0.3**
A	0.92	187	186.4*	93.1**	-0.4*/0.3**
S	0.88	236.4	149.1*		-0.4*/0.3**
O	0.91	169.5	105.3*	-69.1*	-0.3*/0.3**
N	0.87	213.2		-131.4*	-0.4*/0.3**
D	0.88	33.1		-208.8**	-0.2*/0.3**

*Calculated from SLP data. **Calculated from Z500 data.

Adding Z500 to the SLP provides better correlations

The multi-predictors approach is more powerful than other proxies (NAO, MSLP, Paris-London Index)

Precipitations

Month	r	Intercept	X of PGF	Y of PGF	Pressure
J	0.80	2156.2	-4738.7*	-4861.2**	-2.1*
F	0.86	1437.4	-2561.7**	-6372.1*	
M	0.81	1436.1		-4818.8**	-2.6**
A	0.71	1556.8		-5145.5*	-2.7**
M	0.69	2676.3	4675.3*		-4.6**
J	0.67	10959.9			-10.7**
J	0.75	11592.1			-8.7*/ -4.5**
A	0.61	13278.0			-13.0*
S	0.83	12119.4	-8456.3*	-2363.8*	-11.9*
O	0.78	2458.6		-4983.9*	-4.3**
N	0.78	4469.6	-6552.8*	-3919.1*	-4.3*
D	0.84	2531.1	-6284.1*	-6347.8**	-2.4*

*Calculated from SLP data. **Calculated from Z500 data.

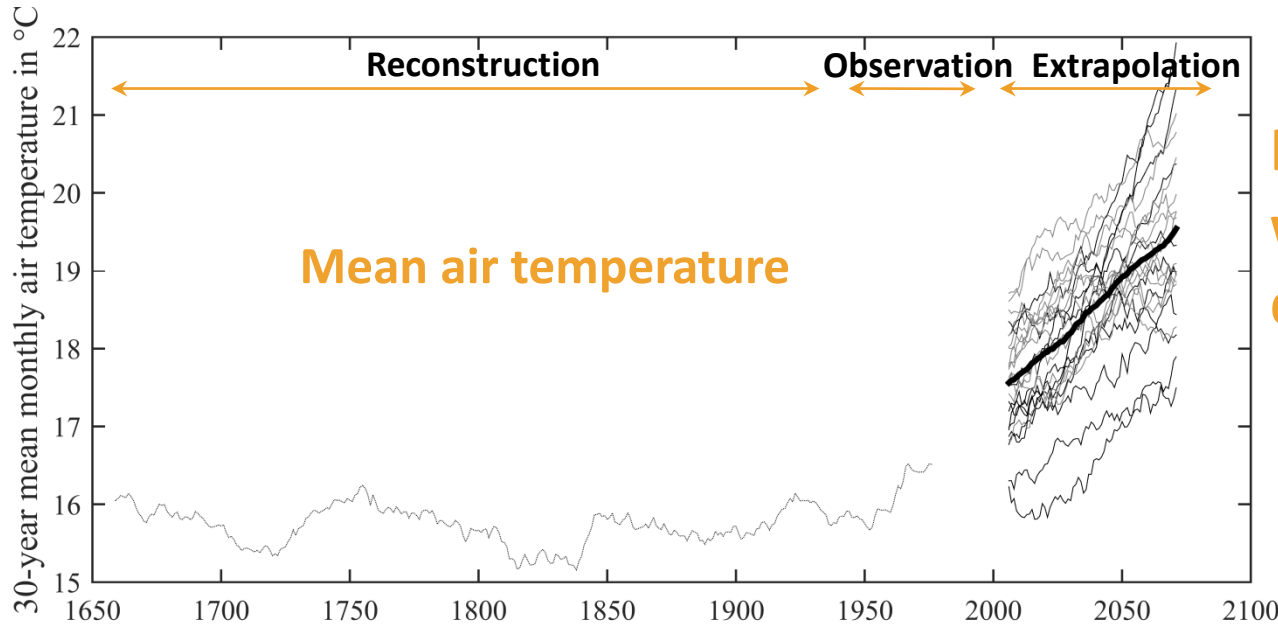
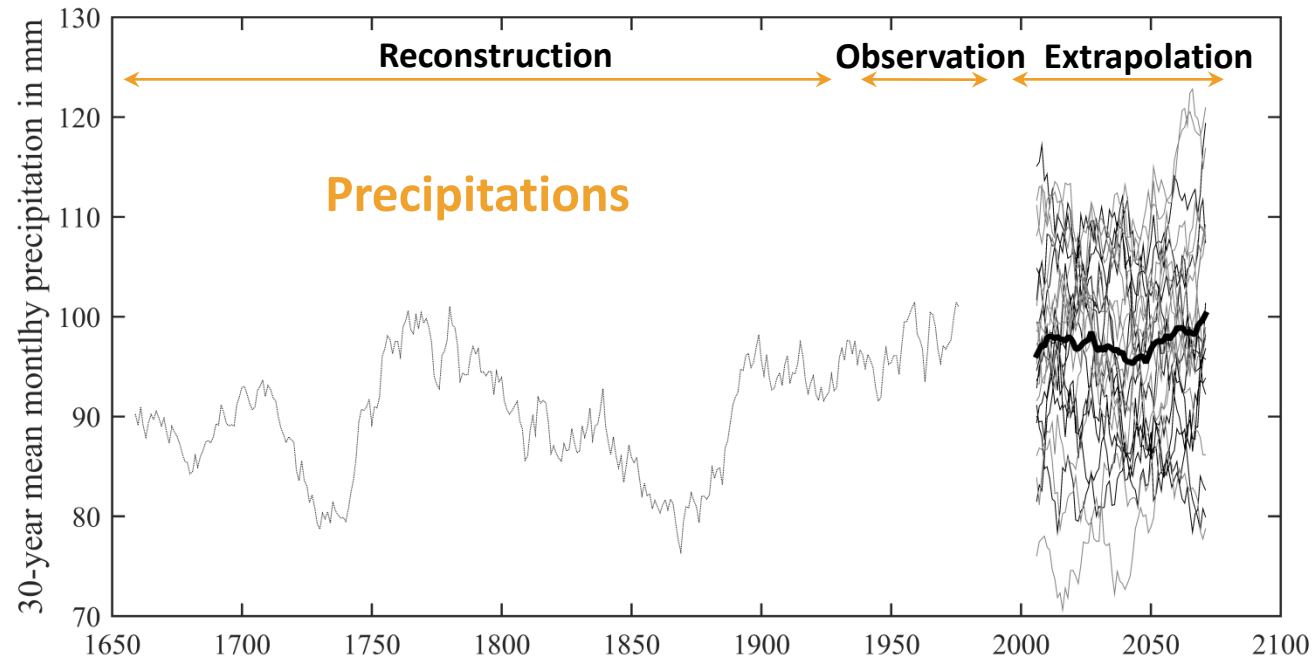
Results

Estimations (historic + future)

January

13 GCMs x 2 RCPs

30-years moving average



High scattering
when considering
different GCMs

Perturbation of daily precipitation and air temperature series

Baseline daily series of 30 years
(precipitations and air temperature)

Delta method perturbation :
multiplicative (precip.) /
additive (temp.)
coefficient

Application of monthly
computed anomalies to
daily values

Limit :
→ No change of the actual
daily series structure
(variability)

← 2006 sets of monthly anomalies

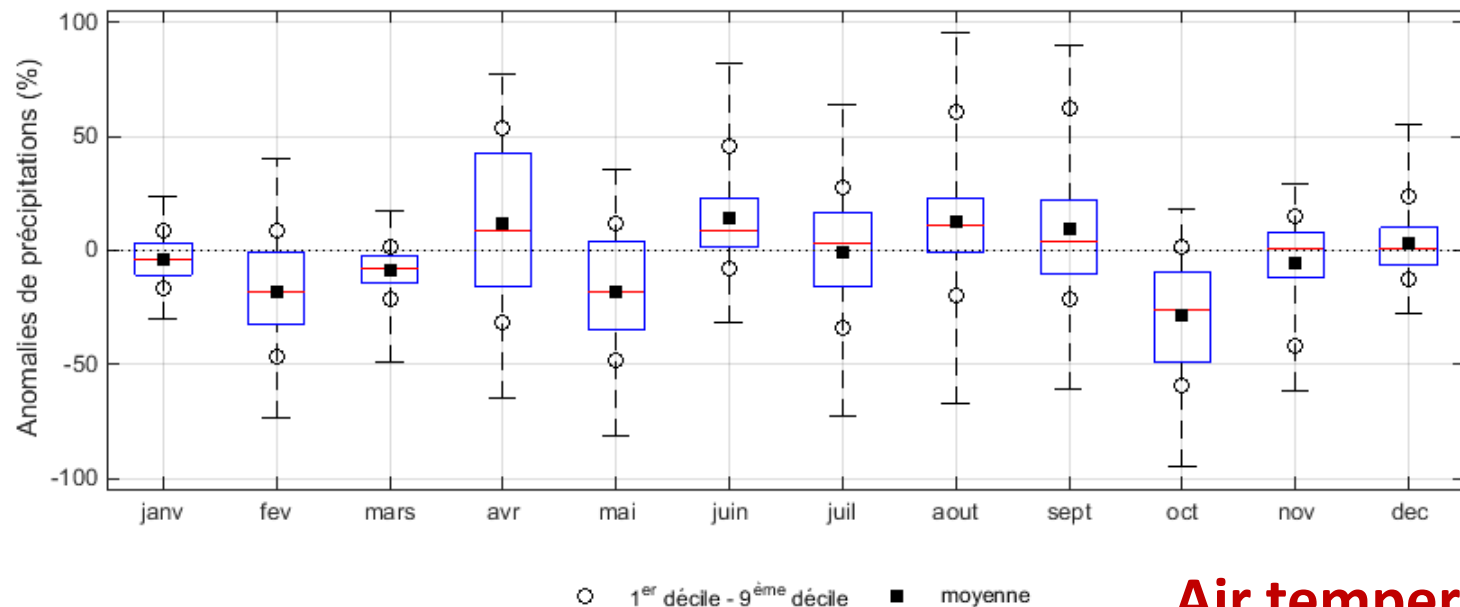
2006 perturbed daily series of
30 years
(precipitations and temperature)

Anomaly =
monthly mean value of
each series of 30 years
(scenario)
compared to the
monthly mean value of
the baseline period

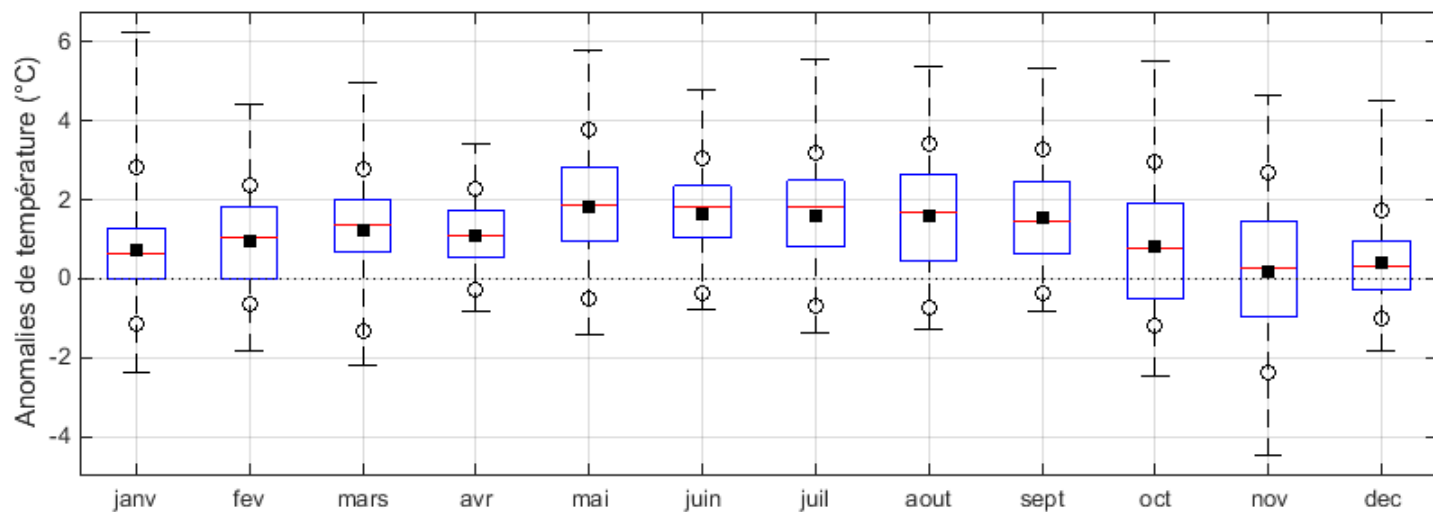
Results

2006 Anomalies (historic + future)

Precipitations

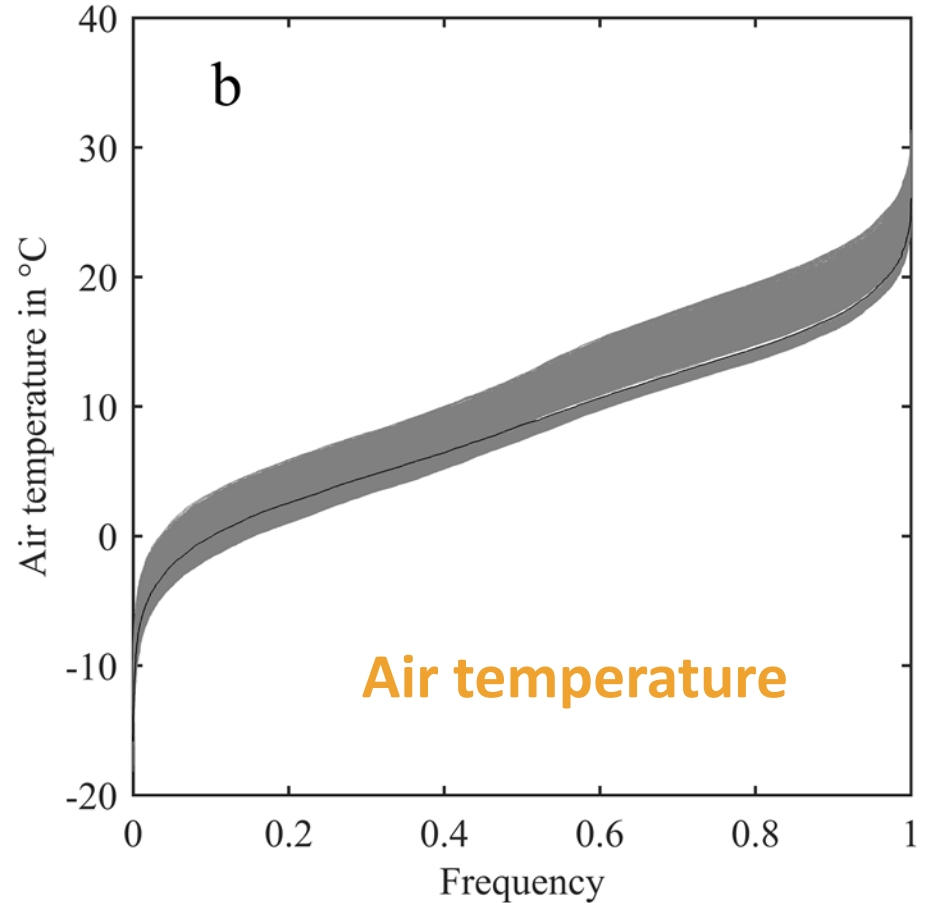
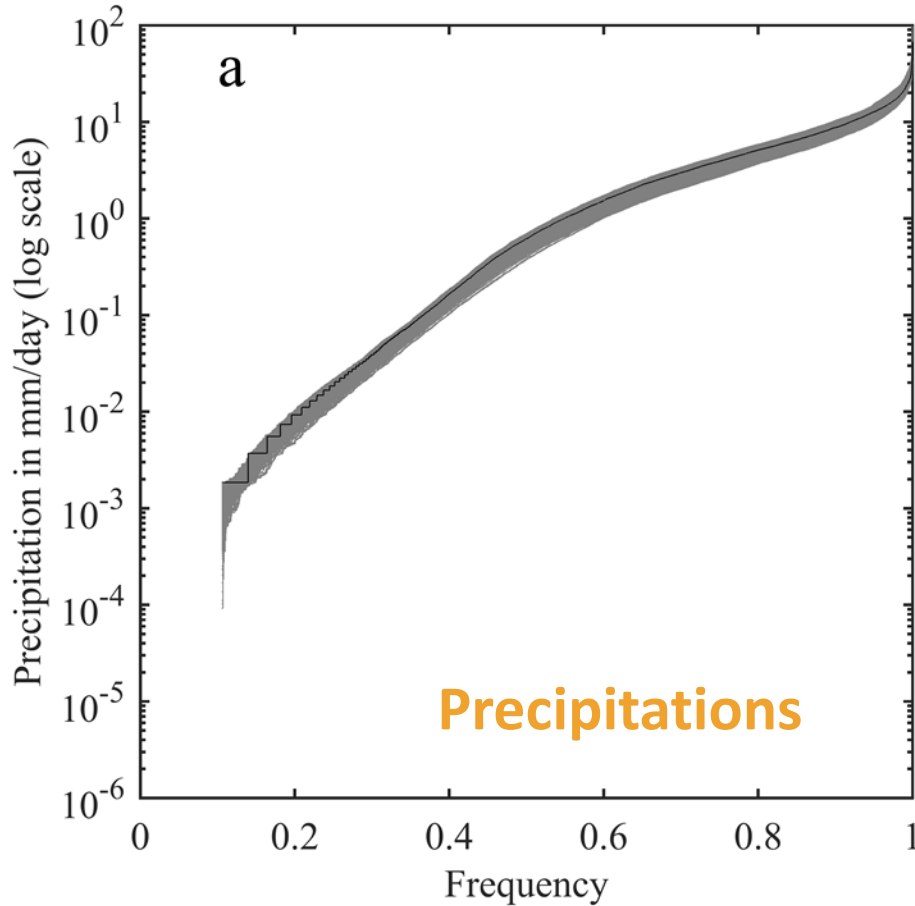


Air temperature



Results

Our the catchment daily modified time series (1975-2004)



The range of possible futures is not limited to only a few scenarios

Impact on hydrology – The case of the Ourthe at Tabreux catchment

Method

Hydrological model and calibration strategy

GR4J model
(IRSTEA, Perrin et al., 2003)

Model (4 parameters – daily time step)

Empirical model → 4 calibrated parameters

X1 : Capacity of the production soil store (mm),

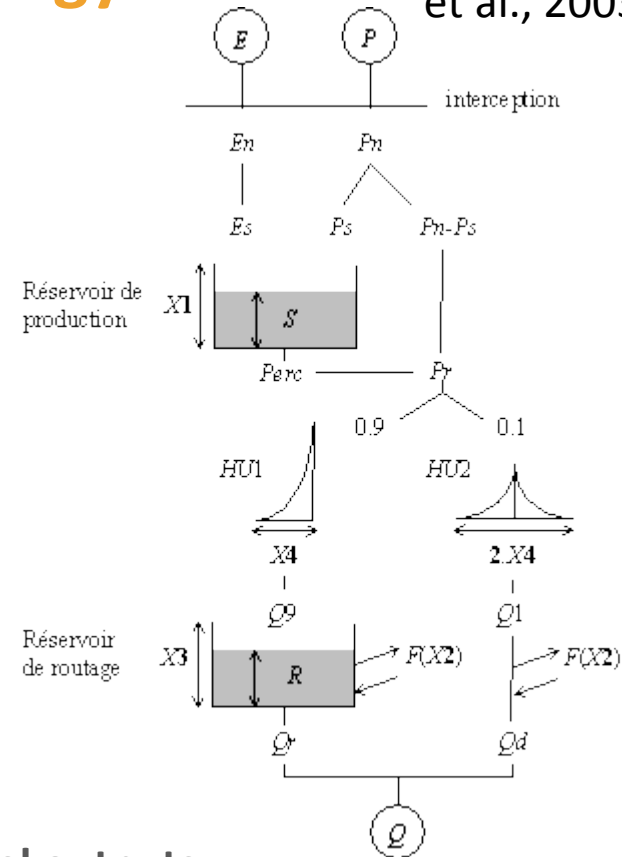
X2 : Water exchange coefficient (mm),

X3 : Capacity of the routing store (mm),

X4 : Time parameter for the unit hydrograph (day).

Objective function : KGE (Kling-Gupta Efficiency)

- High flows → KGE (Q)
- Low flows → KGE (log (Q))



Calibration strategy

Past/future scenarios = ungauged climate

→ no observation to test the accuracy of model outputs...

➔ what is the behavior of model parameters sets in extrapolation ??

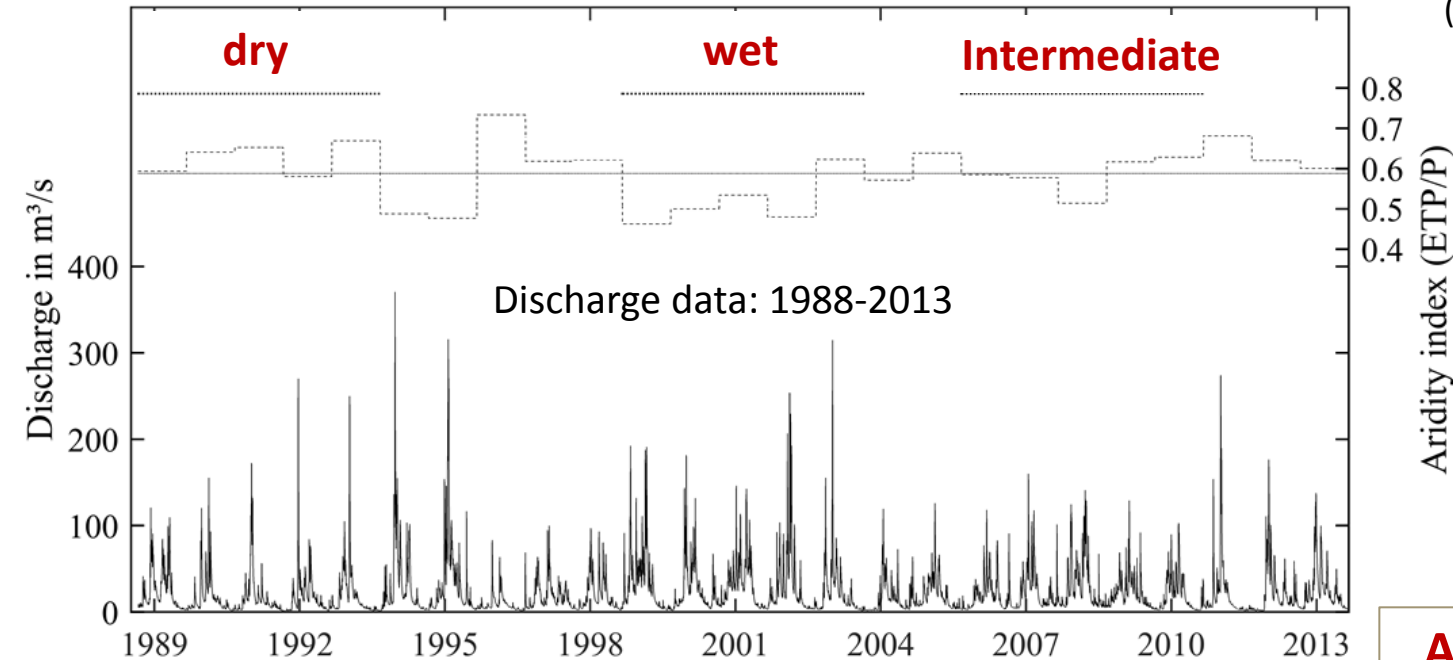
Option chosen: considering the model behavior according to the climate since the model parameters are related to the climate characteristics

Method

Hydrological model climatically robust calibration

3 climatic subperiods of 5 years are selected according to the aridity index

(Brigode et al, 2013)



Aridity index:
AI = ETP/P

Model optimization (GR4J) for each of the 3 subperiods

Objective functions computed:

- . KGE (Q) → high flows
- . KGE (log (Q)) → low flows

→ 6 parameter sets in total
(3 subperiods x 2 objective functions)

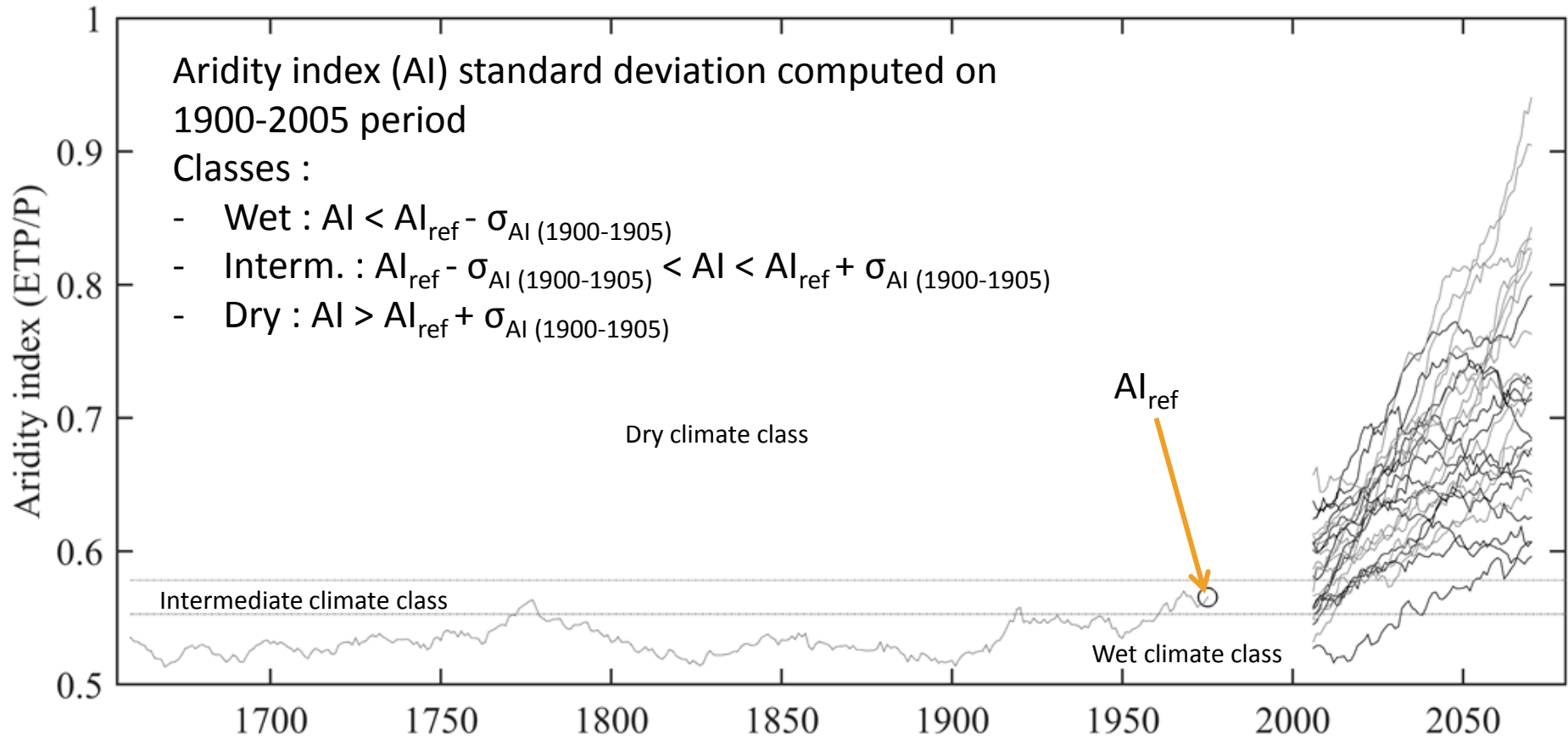
Calibration – Ourthe at Tabreux

Climatic period	KGE (log (Q))	KGE (Q)
- Wet	0.98	0.97
- Dry	0.97	0.98
- Intermediate	0.96	0.94
Whole period	0.97	0.92

Method

To each of the 30 years moving averaged period is attributed a climatic class:

dry – intermediate – wet - according to the aridity index ($AI_{ref} \pm \sigma_{AI(1900-1905)}$)



Each moving period is modelled using:

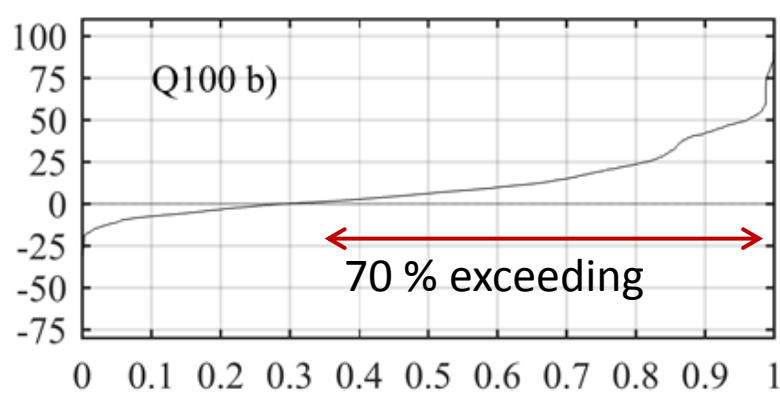
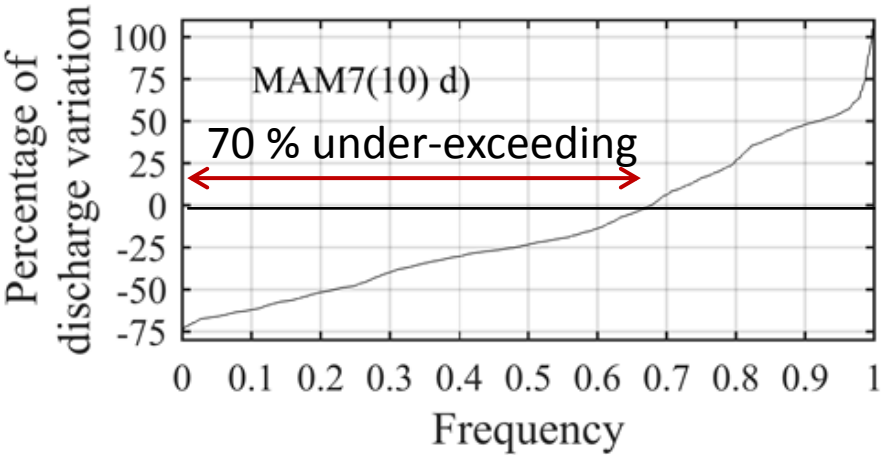
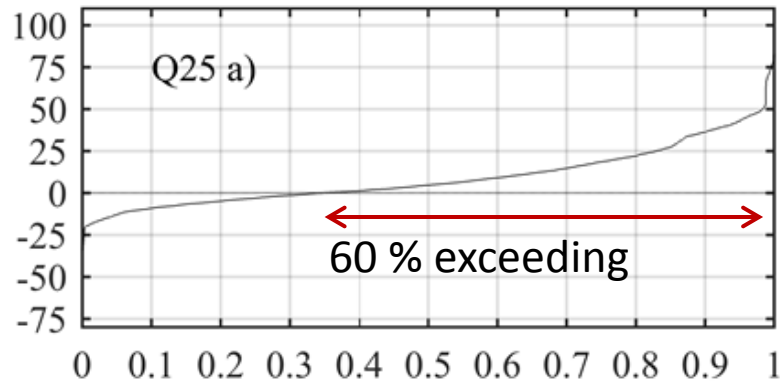
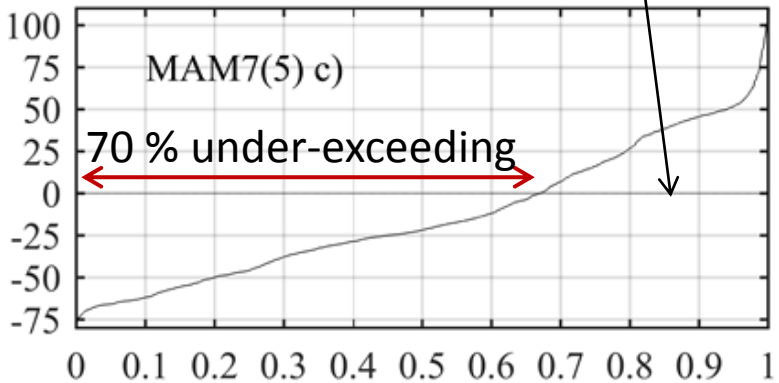
- input data: corresponding estimated precip. and air temp. time series
- parameter set of the corresponding climatic class

→ a KGE (Q) simulation and a KGE (log (Q)) simulation

Results

« Extreme » discharges

Baseline value

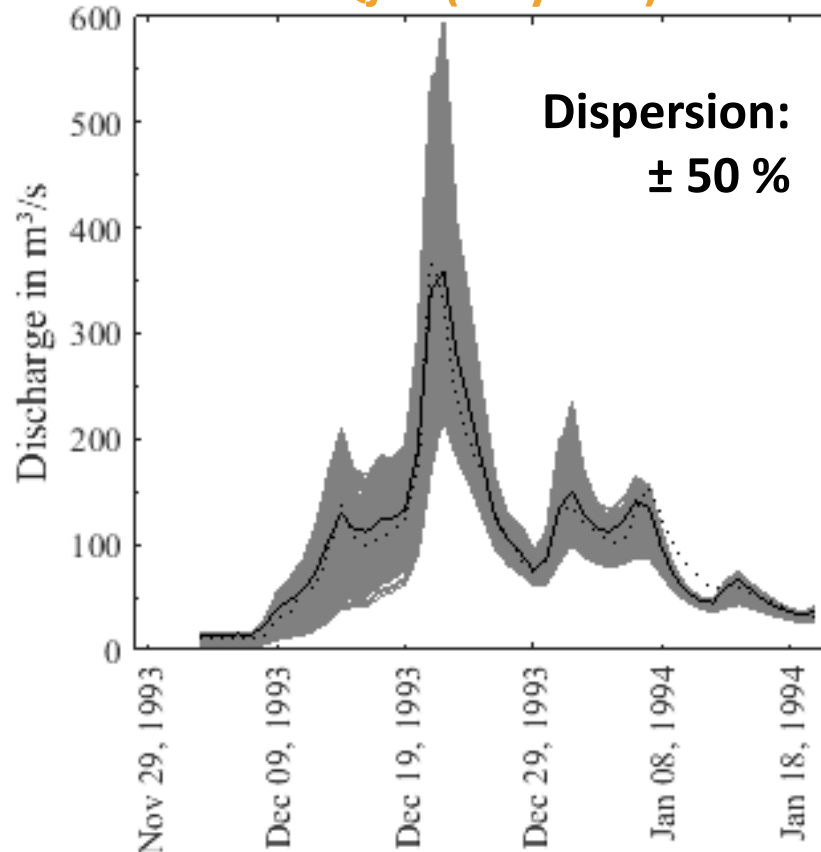


Results

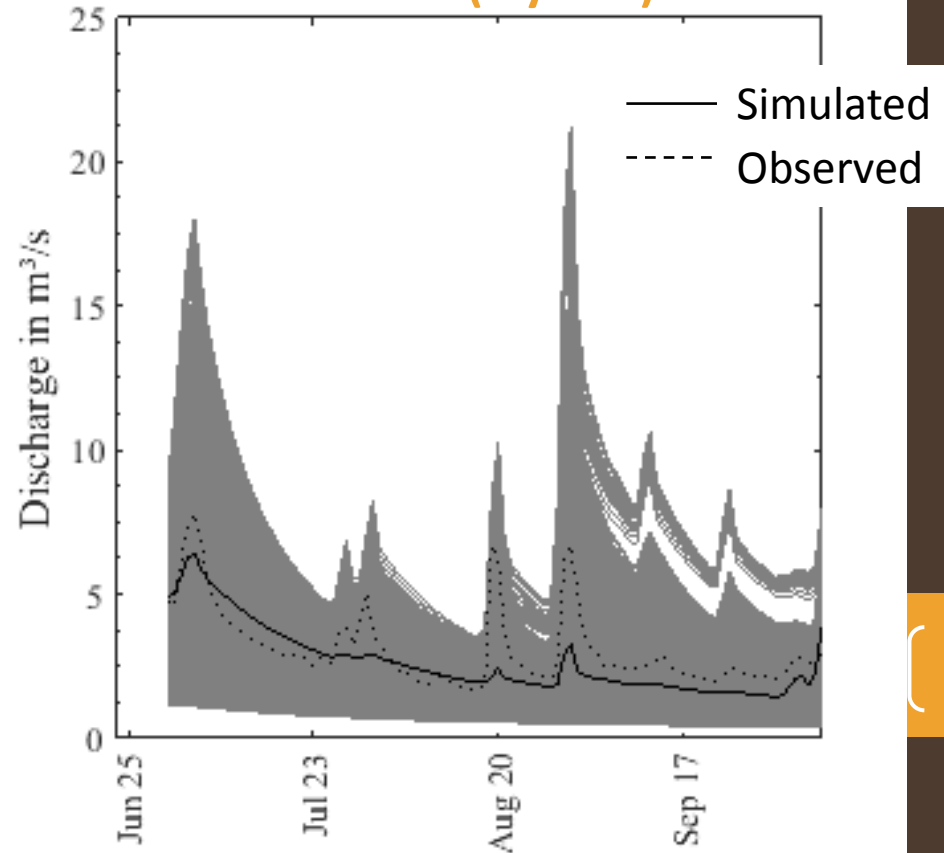
Revisiting historical hydrological events with climate scenarios

Climate change impact study on hydrology **still hazard-centered** but **good uncertainty is maximized** by taking into account **historical climate replica** used as future plausible climate scenarios

Dec. 1993 flood
= ca. Qjxa (25 years)



Aug. 2003 low flow
= ca. MAM7 (5 years)



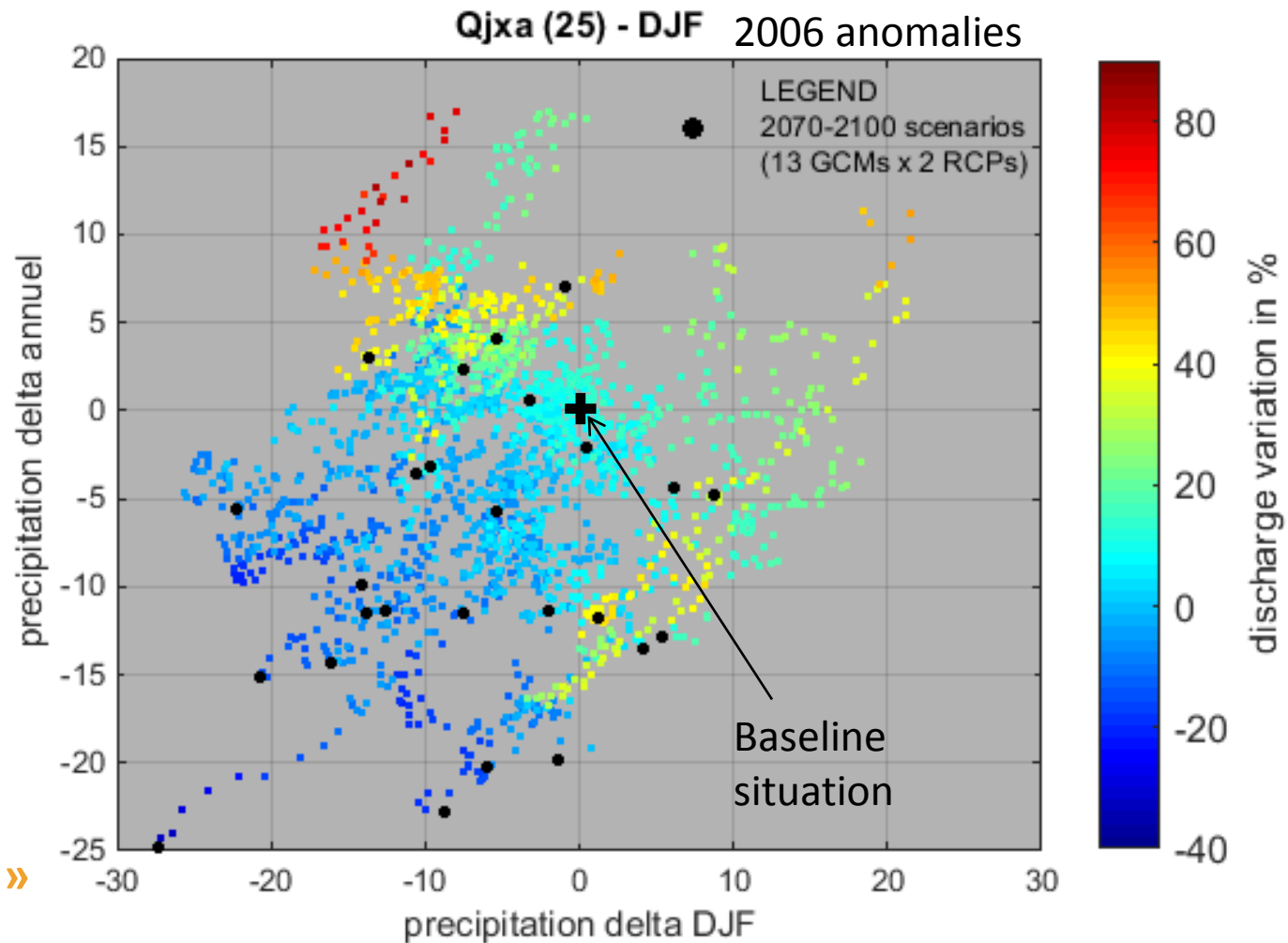
Results

Exemple of a response surface of a daily peak flow with a return period of 25 years

High dispersion according to models

→ **Need to take distance from a purely « predictive » approach based only on few scenarios**

- **How deciding what to implement?**
- **Which level for a climatic security margin?**



Conclusions and perspectives

- Contribution to the developpement of catchment climate resilience
 - ❑ Analysis of the plausible changes of climate responsible of hydrological extremes
 - ❑ Developping climate robust adaptation strategies (e.g. climate safety margin)
 - ❑ A first step toward a « climate change adaptation » component in the planification and risk management policies (e.g. PAPI in France)
- Further works
 - ❑ Impact assessment of climate scenarios on the frequency of occurrence of a bankfull discharge in the Ourthe basin → **focus on « small » floodings change**
 - ❑ Hydraulic model on an Ourthe river segment
 - ❑ QdF analysis (Discharge-duration-Frequency)
 - ❑ Assessment of river-floodplain design measures to cope with and anticipate the climatic impacts on the Ourthe hydrology

Thank you for your
attention !