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Assessing conceptual model uncertainty for hydrological impact analysis

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MOVED!

(6 weeks ago) from

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Hydrology

Hydrological science is young

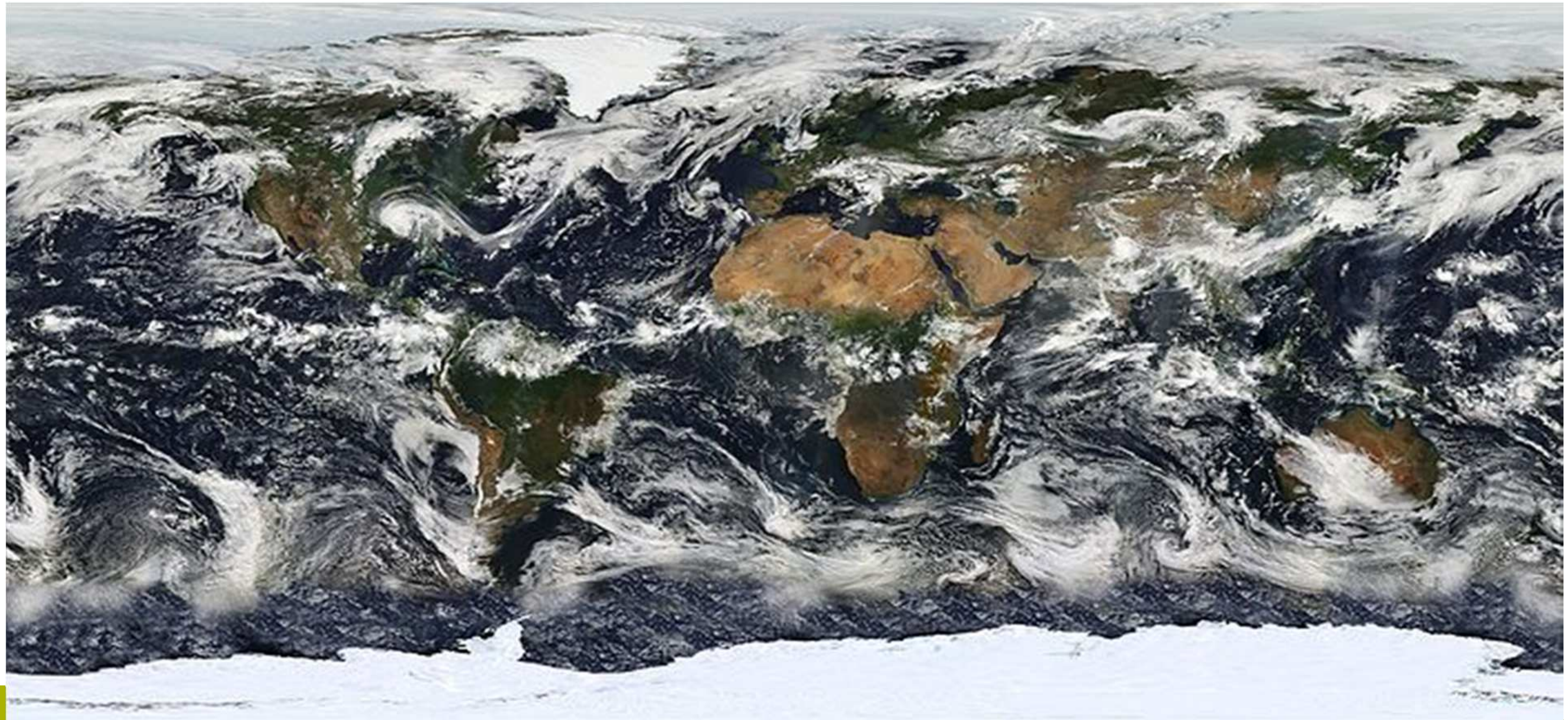
A lot of discussion:

- From where do we come?
- Where should we head to?
- Interdisciplinary?
- PUB
- …

Major challenge

Assessing impact of climate change (CC) on hydrological cycle

(IPCC, 2007; Peel and Blöschle, 2011)



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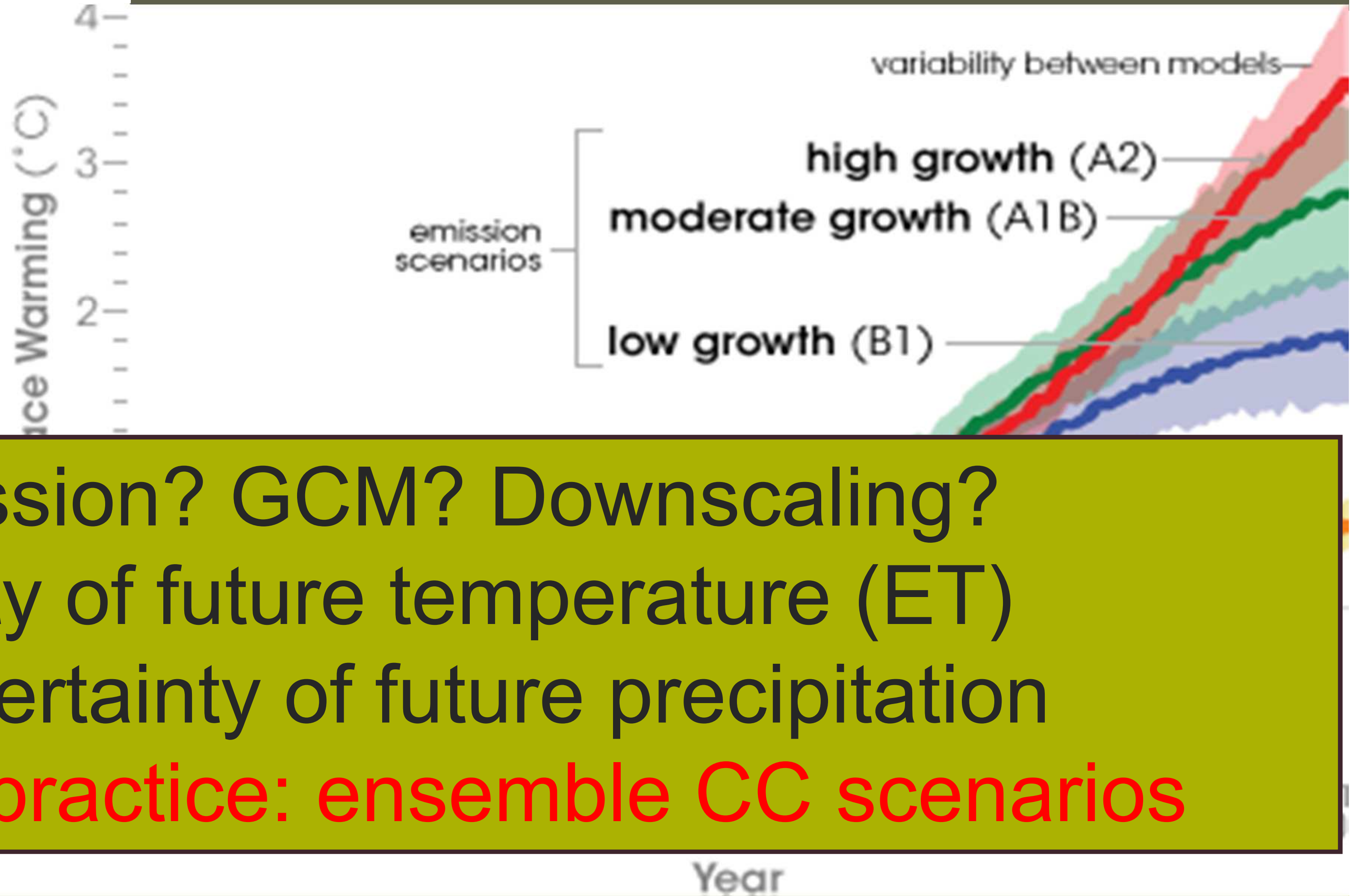
Uncertainty CC



- GHG emission? GCM? Downscaling?
- Uncertainty of future temperature (ET)
- Large uncertainty of future precipitation
- Common practice: ensemble CC scenarios

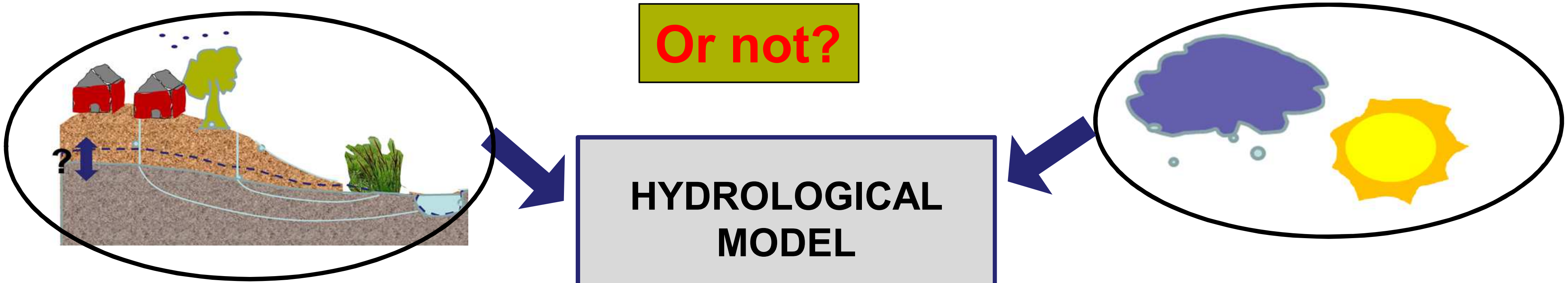
Classical approach

Hydrological impact analysis of climate change:

1. Calibrating and validating hydrological model
2. Applying hydrological model under reference conditions
3. Applying hydrological model under range of CC

So, we can determine hydrological CC uncertainty.

Or not?



Sources of uncertainty hydrological models

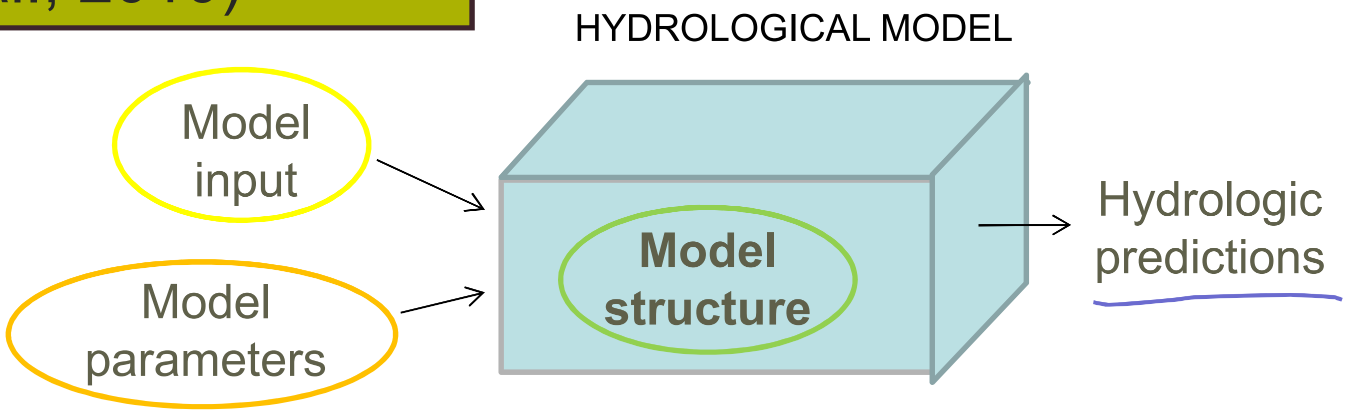
- Input and output data uncertainty
- Parameter uncertainty
- Model equifinality

Stochastic

- Recently lots of new techniques for optimal parameter estimation

- Model **structural** uncertainty

- Much less attention (Refsgaard et al., 2006; Rojas et al., 2010)



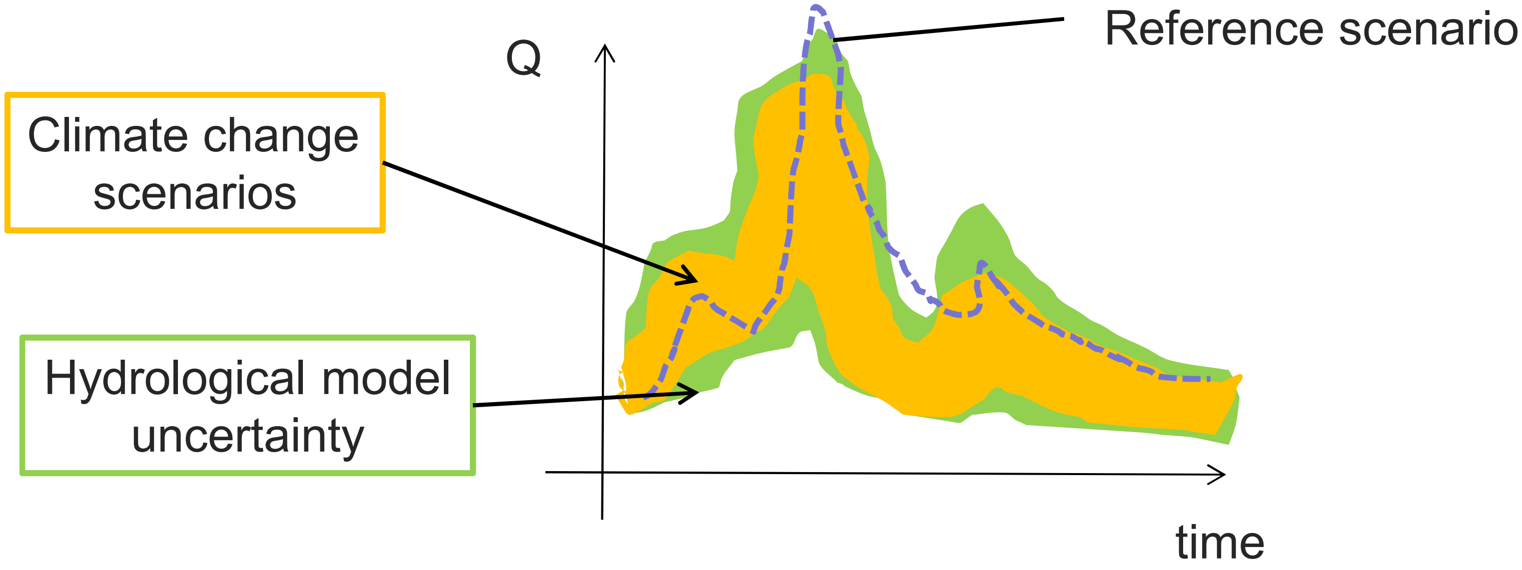
Objective

Our role in improving prediction of hydrological impact of climate change?

A:
Wait for more accurate climate change scenarios?

B:
Reach out to community and active role?

Hypothesis



- There is a large structural hydrological uncertainty, considerably contributing to the uncertainty of the impact of hydrological CC scenarios

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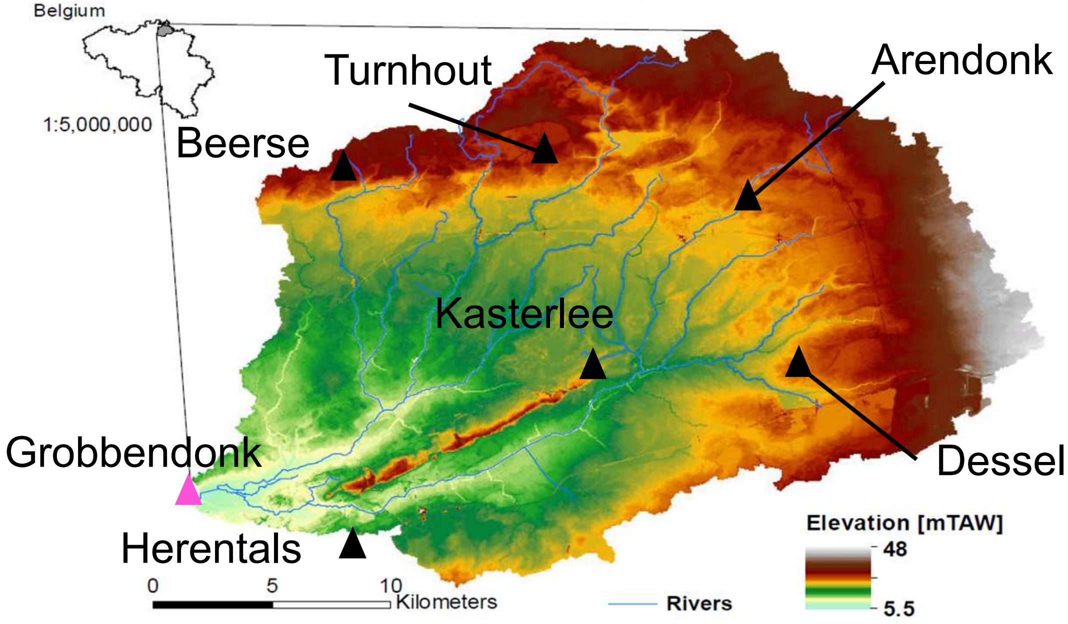
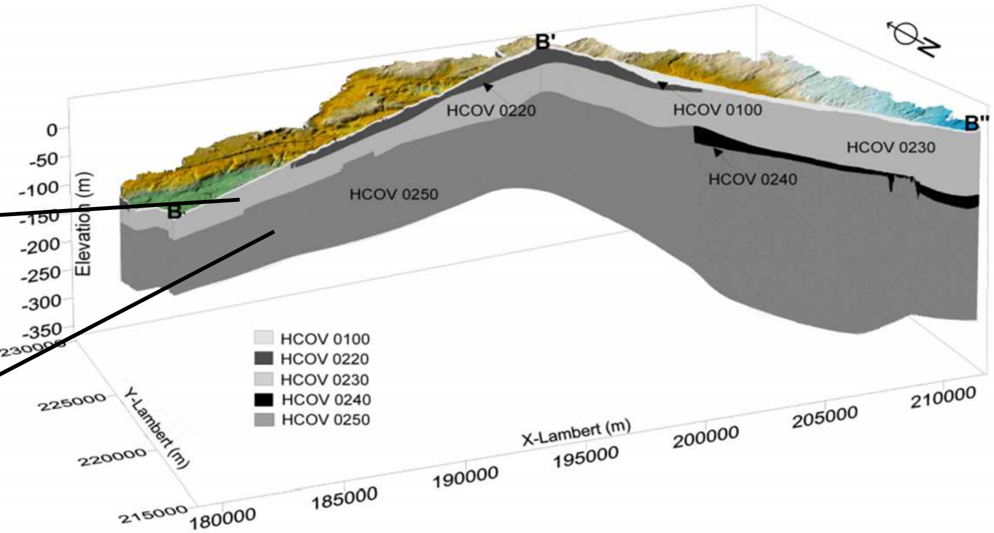
Study area



- Part of Scheldt Basin
- 581 km²
- Flat area, average slope 0.36%
- Sandy soil (72%)

Pleistocene and Pliocene aquifer



Miocene aquifer

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Methodology

Reference scenario

CC scenarios: High / mean / low

Different physically based distributed hydrological models Which? One you know...

Compare differences

Fully distributed
- MIKE-SHE
- WaSiM-ETH
- WetSpa
- GSFLOW
- PROMET
- HydroGeoSphere

Semi-dist-HRU
- SWAT
- PRMS
- PREVAH
- HYDROTEL
- SLURP

Subbasin scale
- BHV
- LASCAM
- WetSpa

~~Conceptual lumped~~
- ...

Model comparison, see: DMIP2: Smith et al., 2012)

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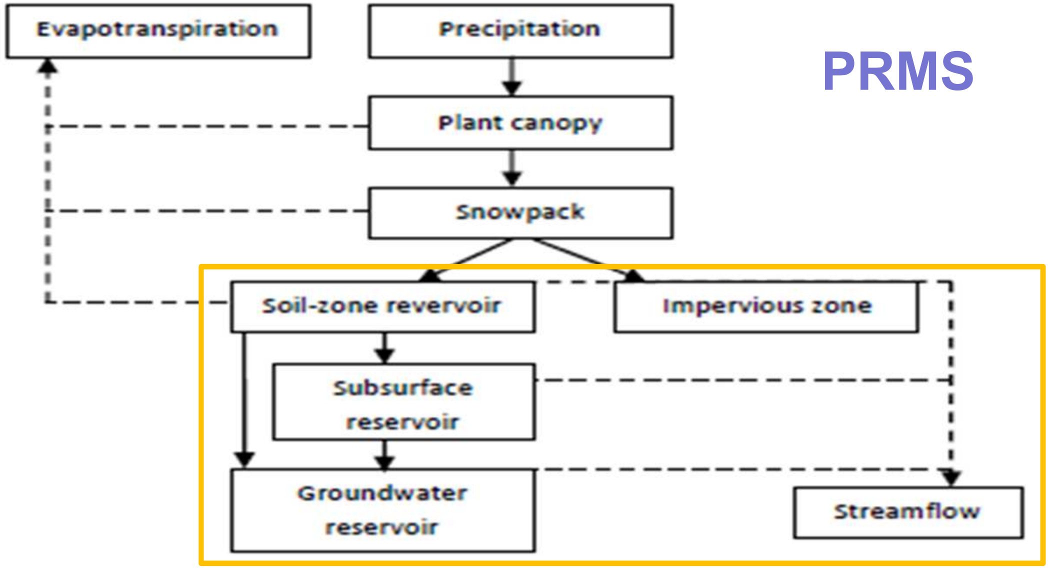
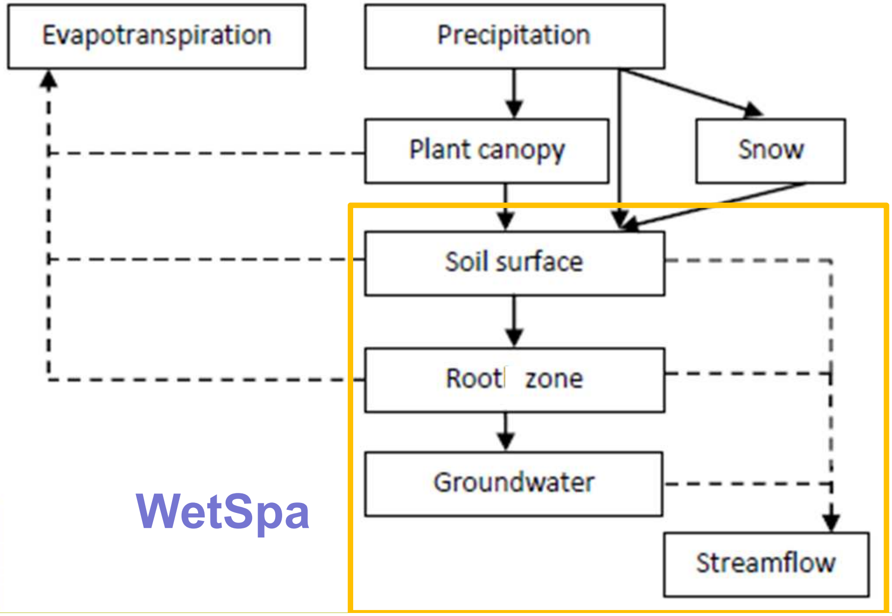
Multi-model approach

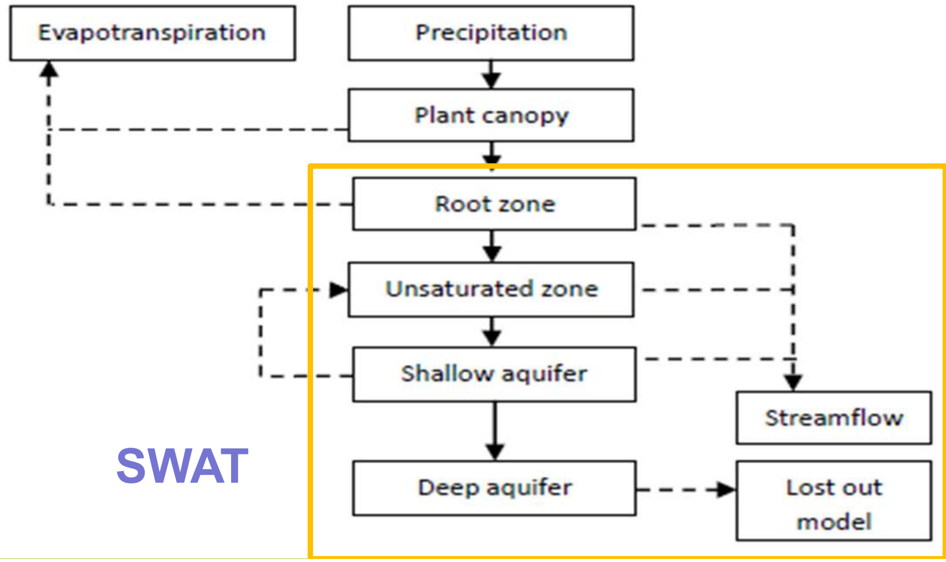
- Dist WetSpa
- SWAT
- PRMS
- Semi-dist WetSpa



PRMS



WetSpa



SWAT

Description	WetSpa		SWAT	PRMS
	semi-distributed	fully-distributed	semi-distributed (HRU)	semi-distributed (HRU)
Spatial distrubution	31 sub-basins	50 ×50 m	6 sub-basins, 51 HRU's	56 HRU's
Time step	daily		daily	daily
Spatial input data	DEM, land-use and soil texture		DEM, land-use and soil texture	DEM, land-use and soil texture
Meteorological data	PET, mean temp and ppt		PET, min and max temp and ppt	PET, min and max temp and ppt
Soil horizons	1		1	2
Snow balance	Degree based		Degree based	Energy balance
Evaporation	PET based		PET based	PET based
Interception	Land-cover based		LAI based	Land-cover based
Surface runoff	Runoff coefficient method		SCS Curve number method	Non-linear variable source area method
River routing	Diffusive wave approximation (De Smedt et al., 2000)		Muskingum routing	Kinematic wave approximation
Interflow	Darcy's Law and kinematic wave approximation		Kinematic storage model	Non linear relation based on storage volume
Groundwater flow	Linear reservoir		Head dependent flow	Linear reservoir

•Same boundary
•Input conditions

Multiple objective fct

Four different objective functions:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Q_i^{sim} - Q_i^{obs})^2}{\sum_{i=1}^{n}(Q_i^{obs} - Q_{mean}^{obs})^2}\right]$$

cal: 2001-2007; val:1997-2000 (***NSE_1***)
cal: 1997-2004; val:2004-2007 (***NSE_2***)

$$LNSE = 1 - \left[\frac{\sum_{i=1}^{n}[ln(Q_i^{sim} + \epsilon) - ln(Q_i^{obs} + \epsilon)]^2}{\sum_{i=1}^{n}[ln(Q_i^{obs} + \epsilon) - ln_{mean}(Q^{obs} + \epsilon)]^2}\right]$$

cal:2001-2007
val:1997-2000

$$HNSE = 1 - \left[\frac{\sum_{i=1}^{n}(Q_i^{obs} + Q_{mean}^{obs}) \times (Q_i^{sim} - Q_i^{obs})^2}{\sum_{i=1}^{n}(Q_i^{obs} + Q_{mean}^{obs}) \times (Q_i^{obs} - Q_{mean}^{obs})^2}\right]$$

cal:2001-2007
val:1997-2000

Hydrological models

Dist WetSpa
NSE_1, NSE_2, LNSE, HNSE

PRMS
NSE_1, NSE_2, LNSE, HNSE

SWAT
NSE_1, NSE_2, LNSE, HNSE

Semi-dist WetSpa
NSE_1, NSE_2, LNSE, HNSE

4 different model structures and 4 different objective functions → 16 hydrological models

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CC scenarios 2070-2100

PRUDENCE & IPCC AR4 database

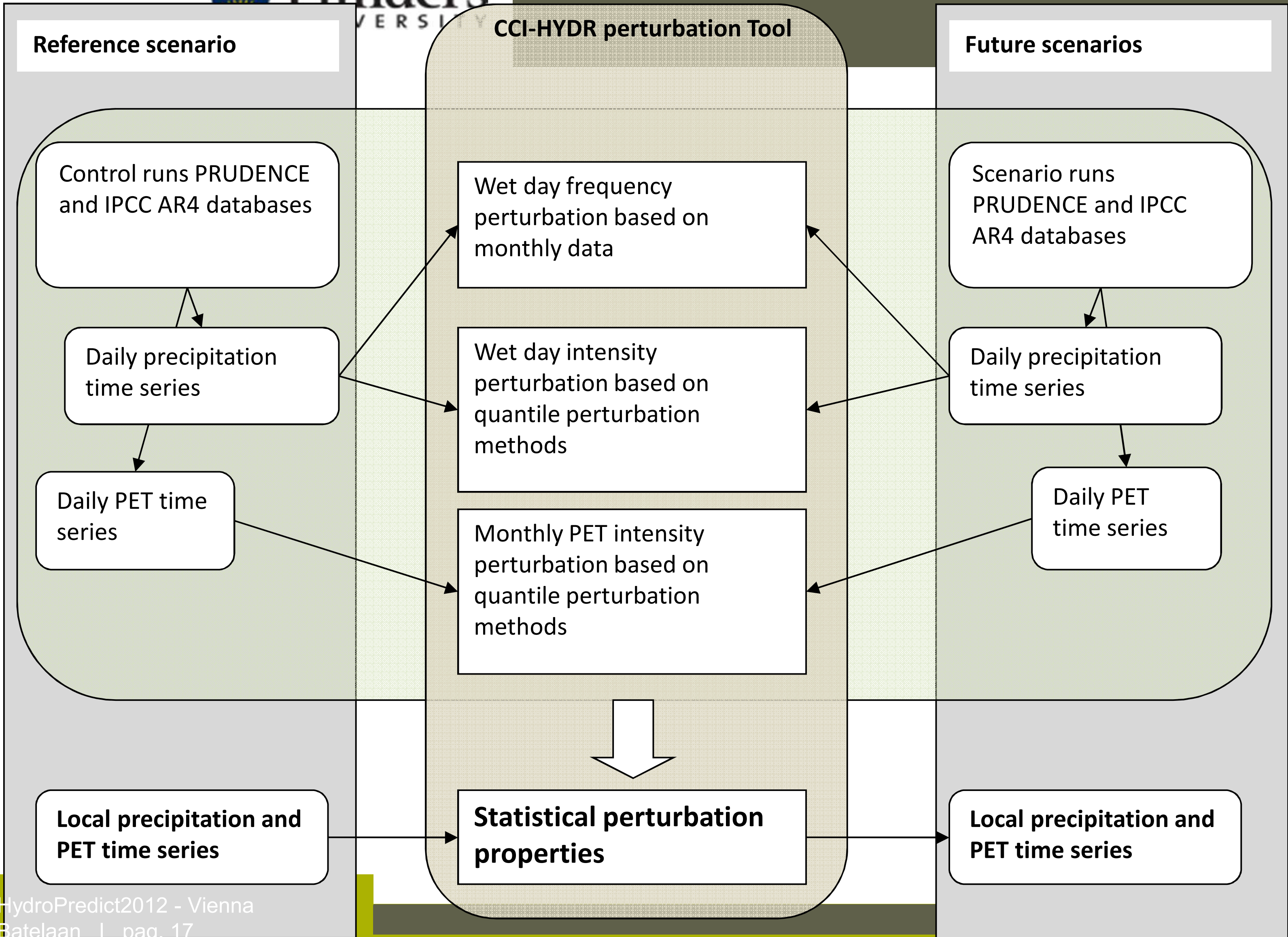
PRUDENCE scenarios (high resolution simulations, 50 km^2):

- 4 GCM’s, 10 RCM’s, A2 and B2 simulations

IPCC AR4 scenarios (medium to coarse resolution simulations, 150-450 km^2):

- 22 GCM’s, A1B, A2 and B1

CC scenarios 2070-2100



- Perturbation tool (Ntegeka and Willems, 2009)
- Based on quotients calculated from differences in ref and future PPTand PET
- High, mean and low hydrological impact scenarios
- Scenarios focus on extreme events

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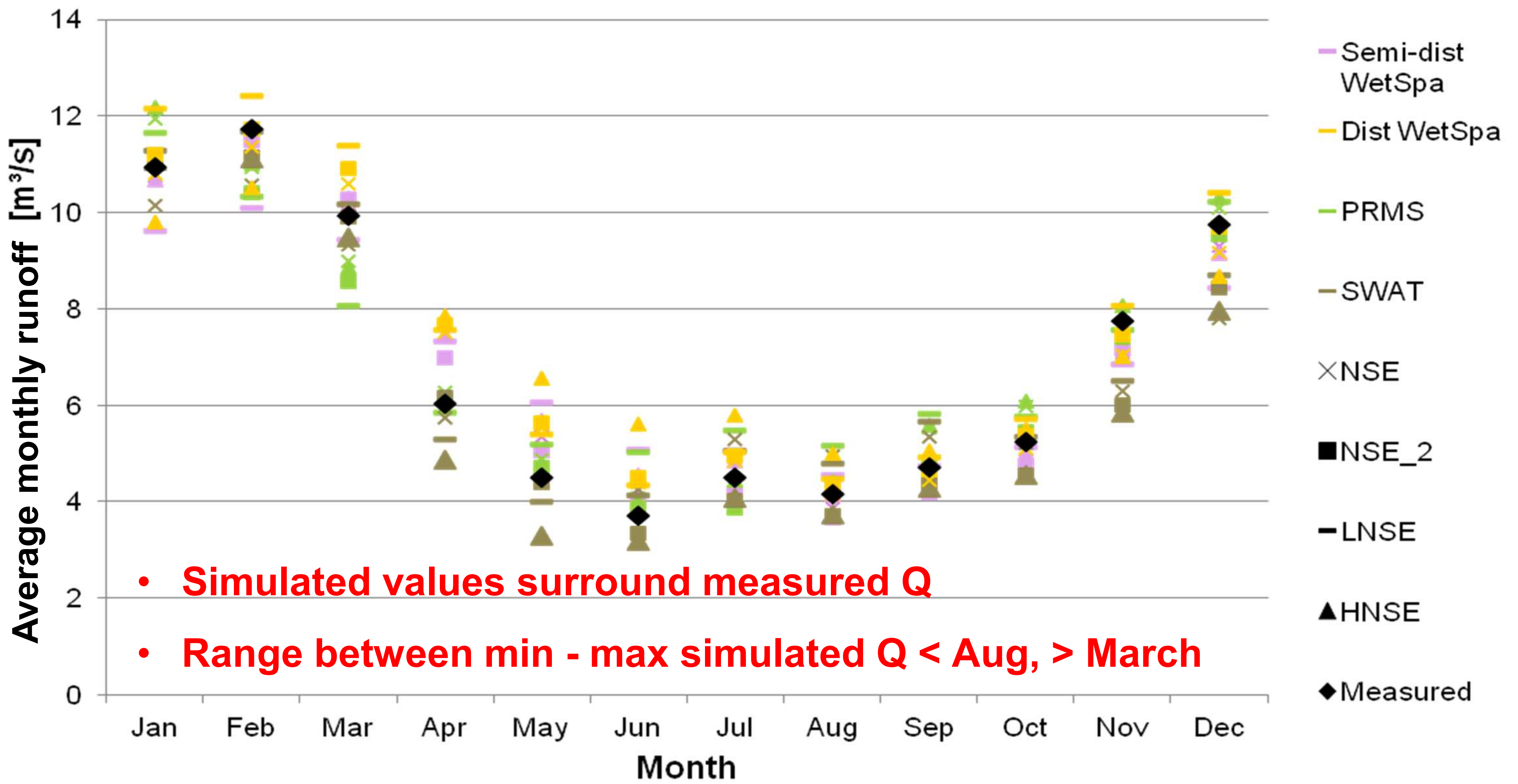
Calibration and validation

	Obj fct	Bias [%]		NSE [-]		LNSE [-]		HNSE [-]	
		cal	val	cal	val	cal	val	cal	val
PRMS	NSE_2	3.18	3.43	0.81	0.74	0.77	0.62	0.82	0.78
	NSE	-4.9	-2.1	0.80	0.85	0.66	0.76	0.80	0.86
	LNSE	3.2	5.8	0.68	0.67	0.75	0.76	0.73	0.69
	HNSE	2.4	6.3	0.78	0.81	0.68	0.78	0.81	0.82
SWAT	NSE_2	-0.9	-10.7	0.87	0.71	0.84	0.63	0.89	0.75
	NSE	-9.0	-3	0.82	0.83	0.65	0.67	0.86	0.87
	LNSE	-1.7	2.4	0.80	0.81	0.77	0.80	0.83	0.83
	HNSE	-12.7	-8.5	0.80	0.82	0.58	0.64	0.84	0.87
WetSpa Semi-dist.	NSE_2	1.74	-5.23	0.80	0.69	0.73	0.25	0.82	0.72
	NSE	-2	2.4	0.76	0.81	0.43	0.65	0.79	0.85
	LNSE	-1.8	1.9	0.69	0.76	0.67	0.71	0.69	0.77
	HNSE	0.5	4.7	0.75	0.82	0.43	0.65	0.79	0.86
WetSpa Dist.	NSE_2	4.45	-0.73	0.79	0.68	0.64	0.17	0.82	0.74
	NSE	5	9.1	0.75	0.82	0.53	0.66	0.79	0.87
	LNSE	4.4	7.6	0.70	0.78	0.64	0.70	0.72	0.82
	HNSE	9.6	13.6	0.73	0.79	0.43	0.59	0.79	0.86

0.68 – 0.87 | 0.67 – 0.85 | 0.17 – 0.80 | 0.69 – 0.87

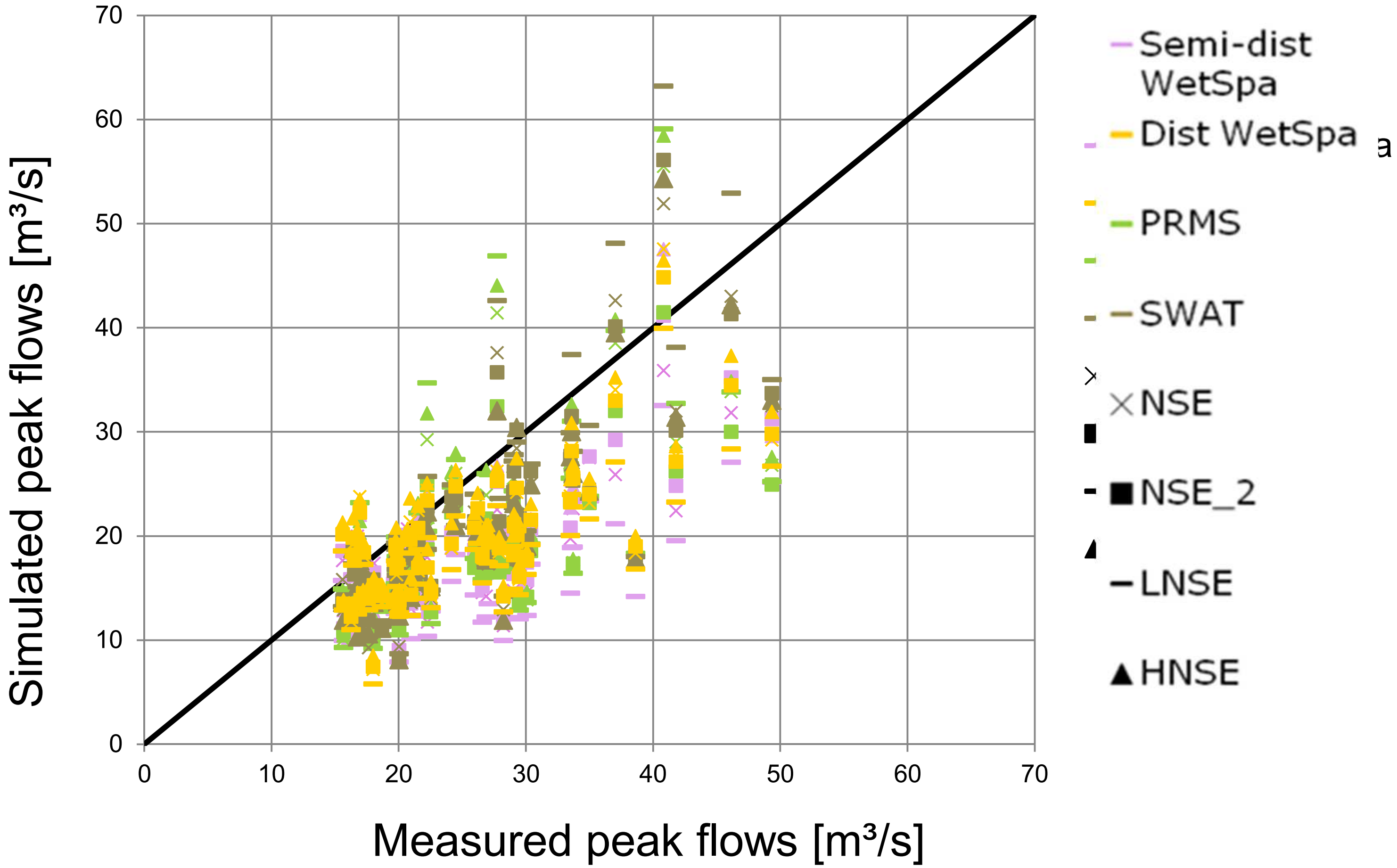
- Good to very good cal and val results for NSE
- Very good performance for HNSE
- Efficiency of LNSE sensitive to objective function
- Non of the models outperforms the other

Validation avg monthly Q 1960-1990



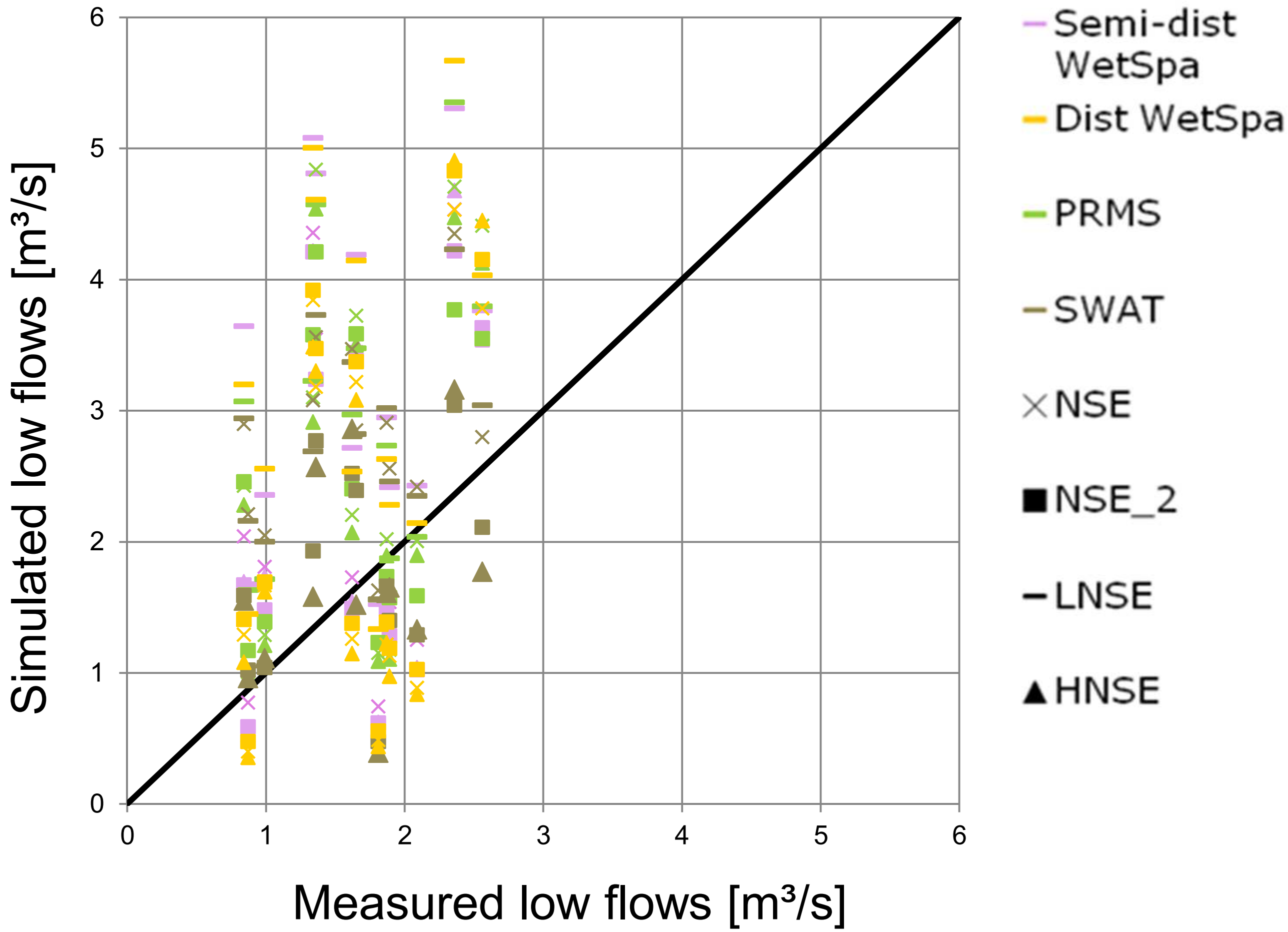
- **Simulated values surround measured Q**
- **Range between min - max simulated Q < Aug, > March**

Validation extreme HIGH Q



- Average under-prediction of peak flows by 21%
- SWAT model lowest bias (-18%), semi-dist WetSpa highest bias (-28%)
- Models not calibrated on extreme flows

Validation extreme LOW Q



- Average overprediction of the peaks by 80%
- SWAT and distributed WetSpa perform best: over-prediction +52%
- Models not calibrated on extreme flows

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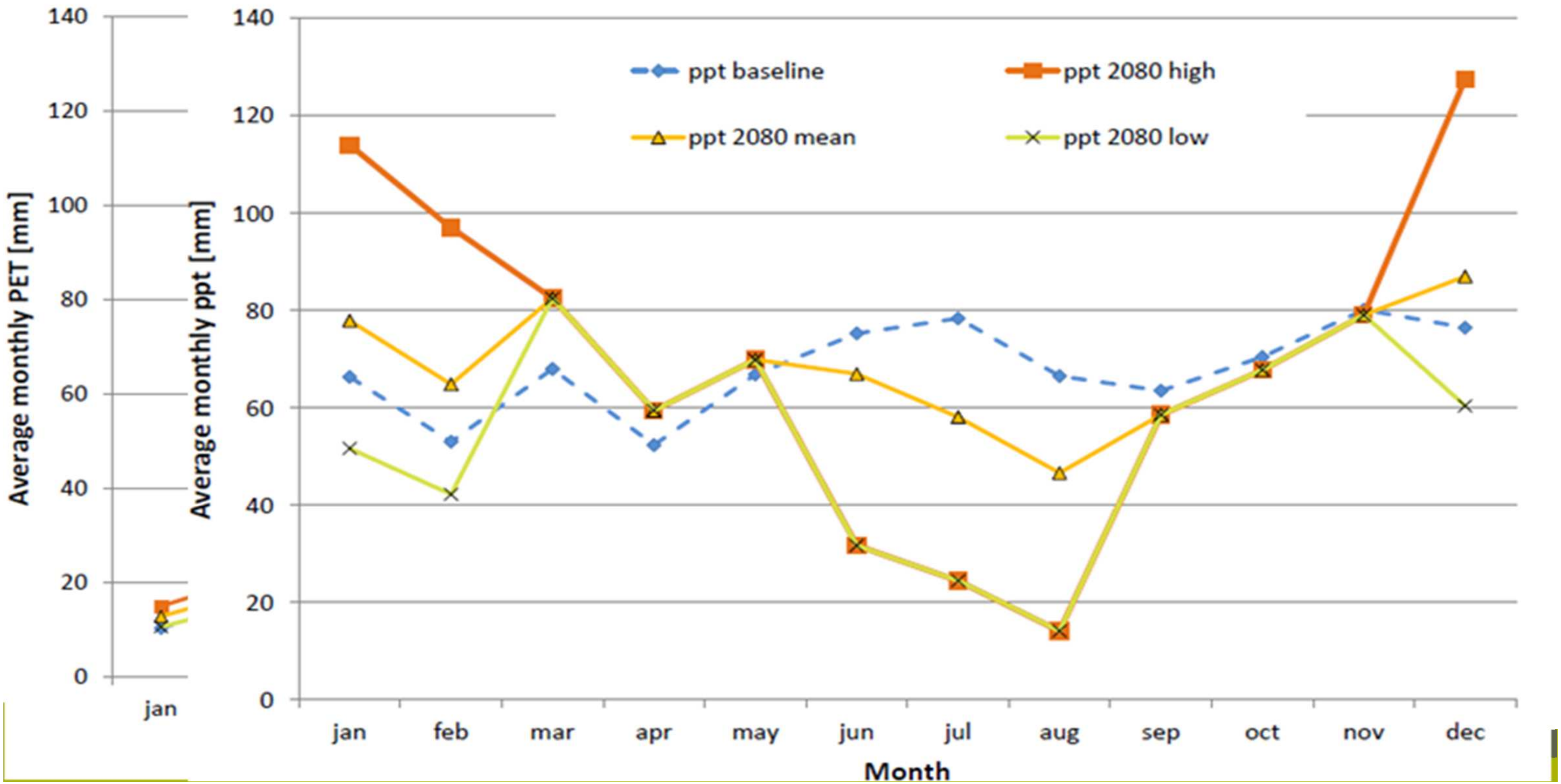
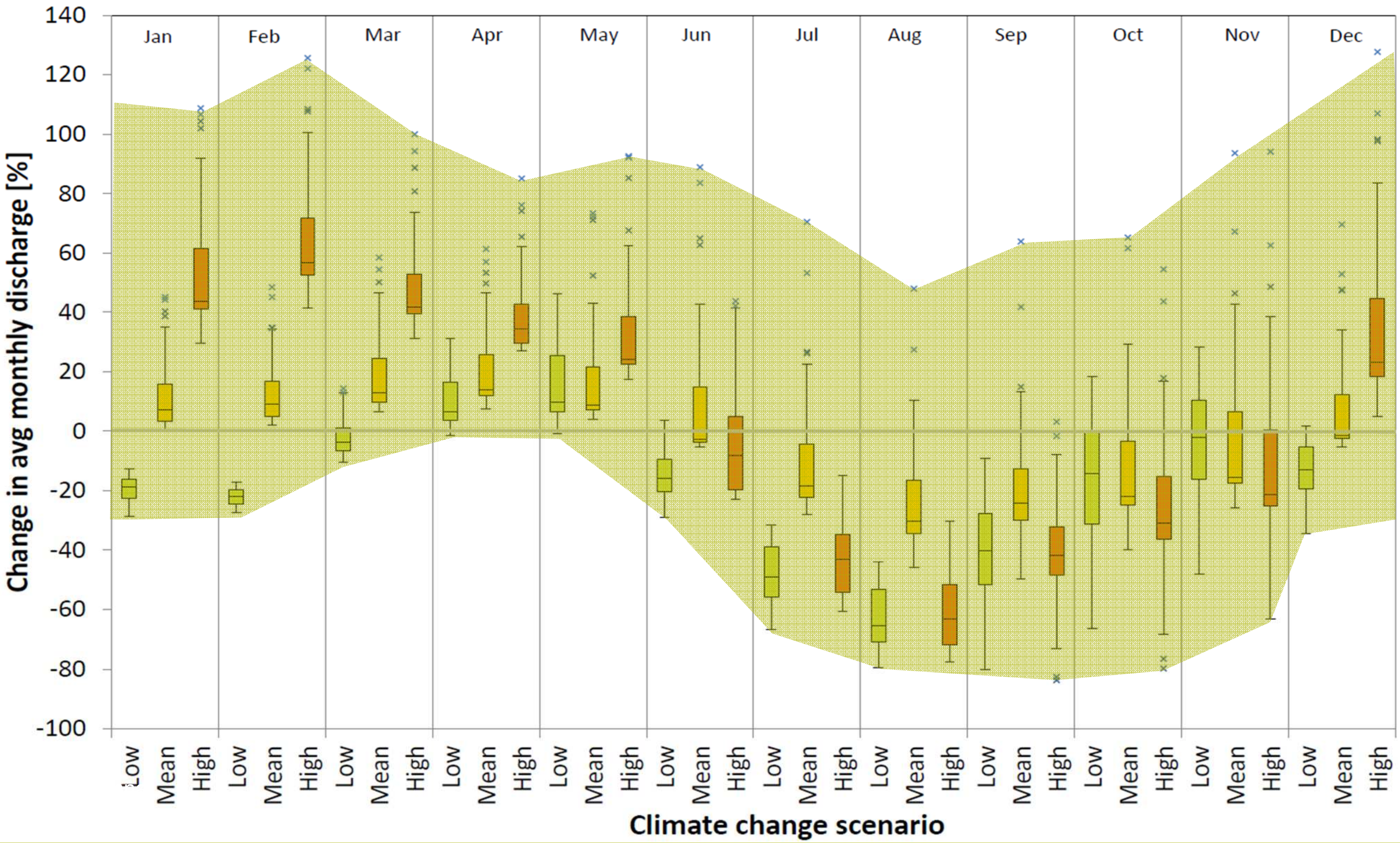
Climate change scenarios

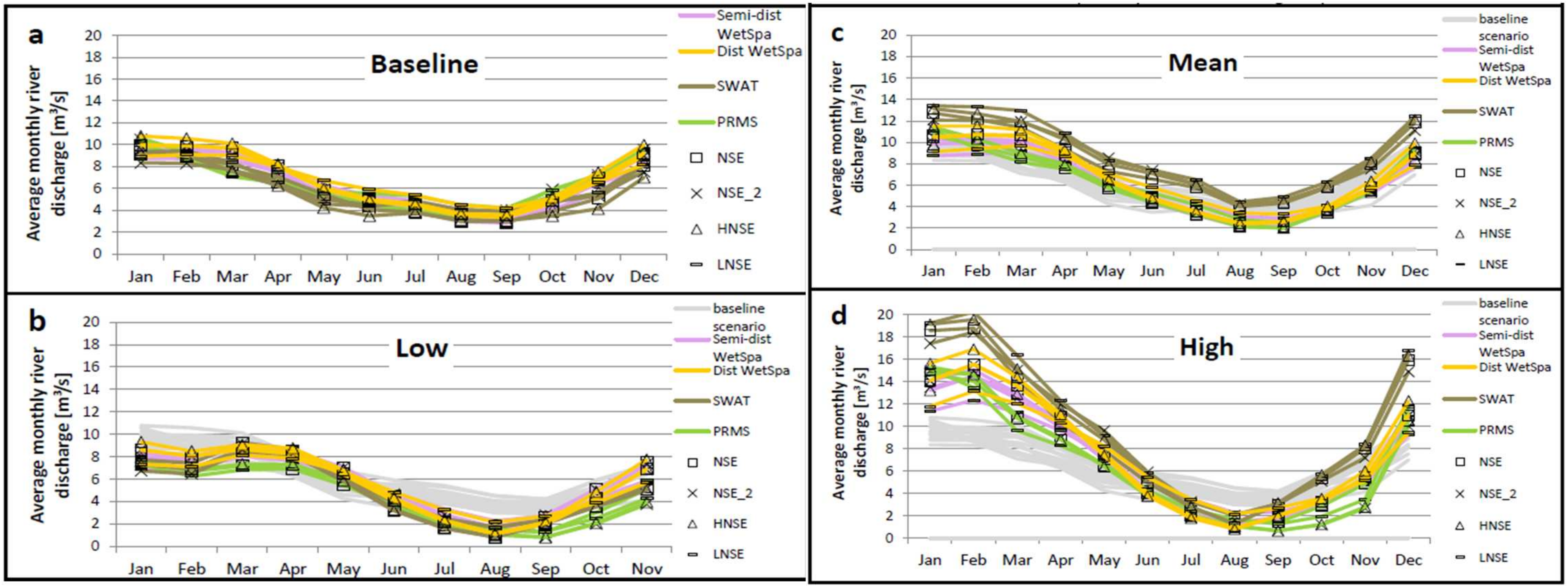
Potential evapotranspiration **Precipitation**



Monthly average discharge CC scenario's

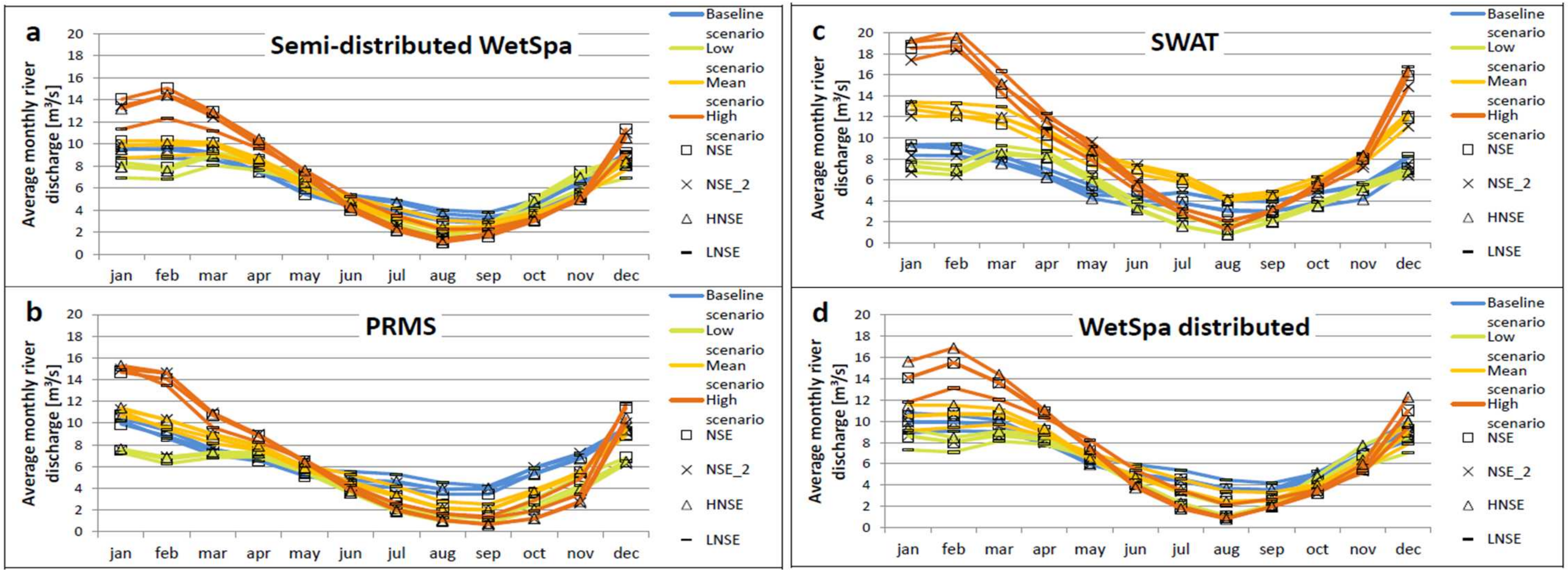


Uncertainty hydrological models

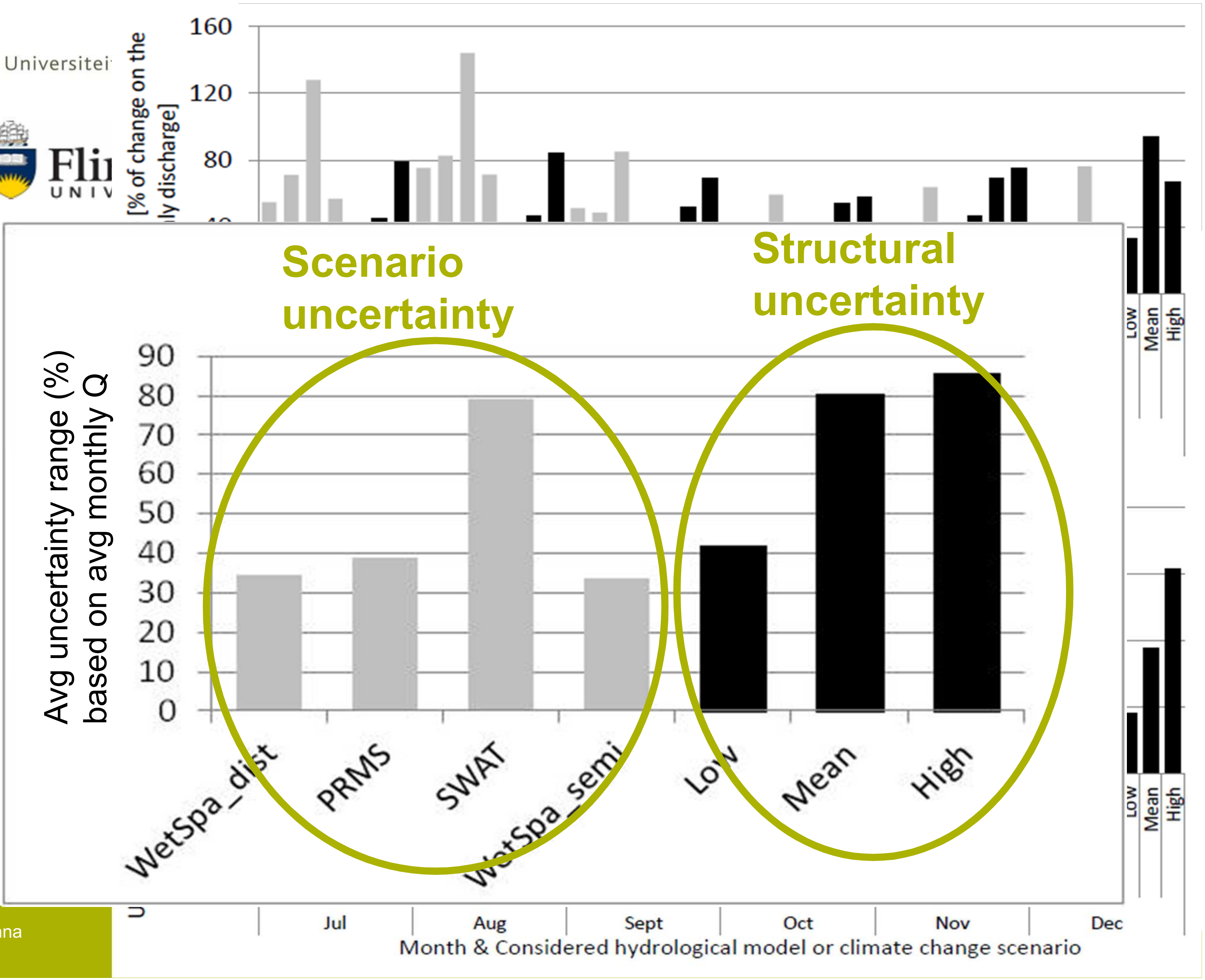


Range between minima en maxima monthly Q per CC scenario indicates the **uncertainty introduced by hydrological models**

Uncertainty CC



Range between minima en maxima monthly Q per hydrological model indicates the **uncertainty introduced by CC**



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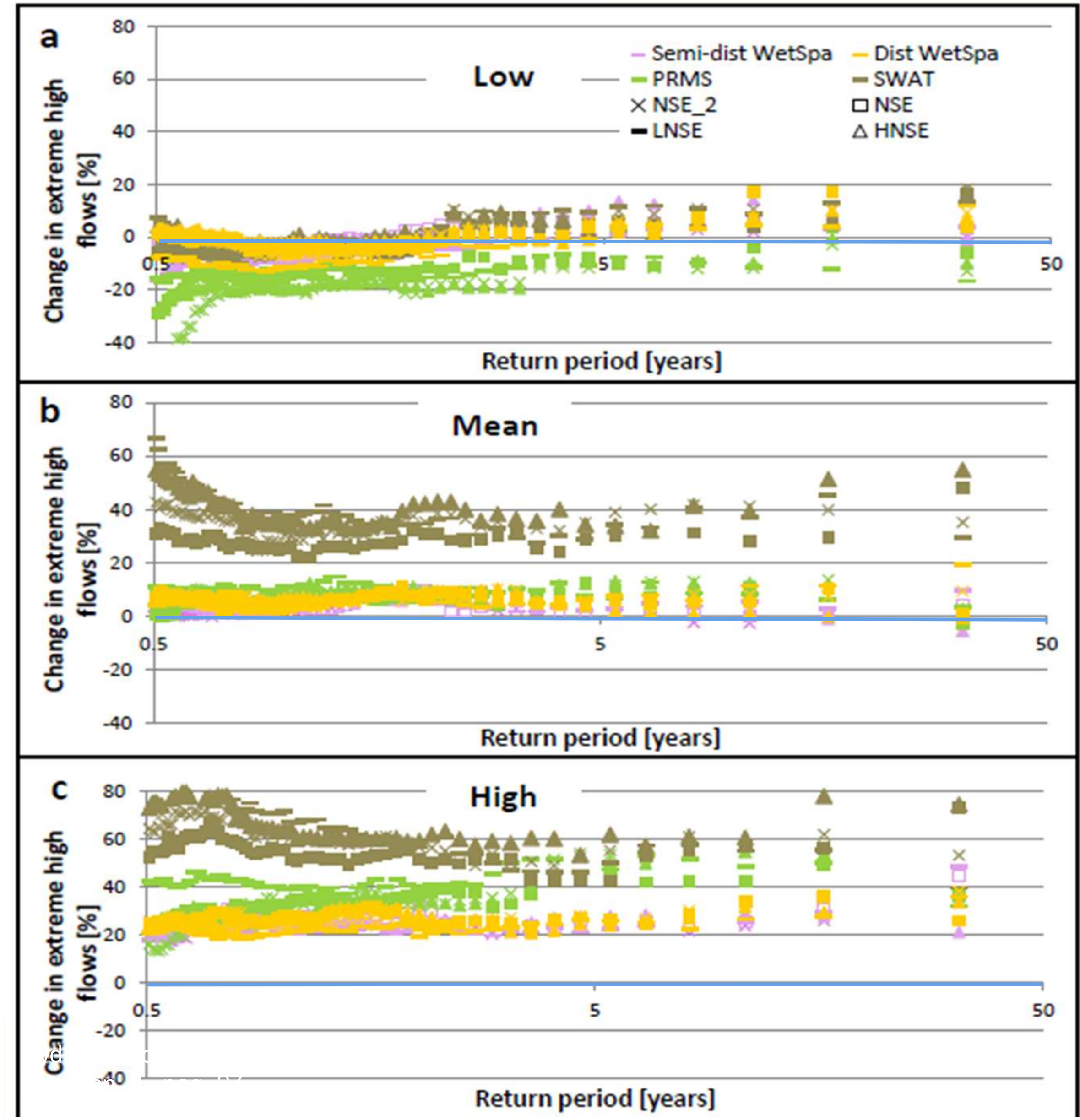
Extreme high flows



- Increase of highest flows in all scenarios
- High increases for High scenarios, low changes for Low and Mean scenario
- In Mean scenario SWAT model deviates from other models

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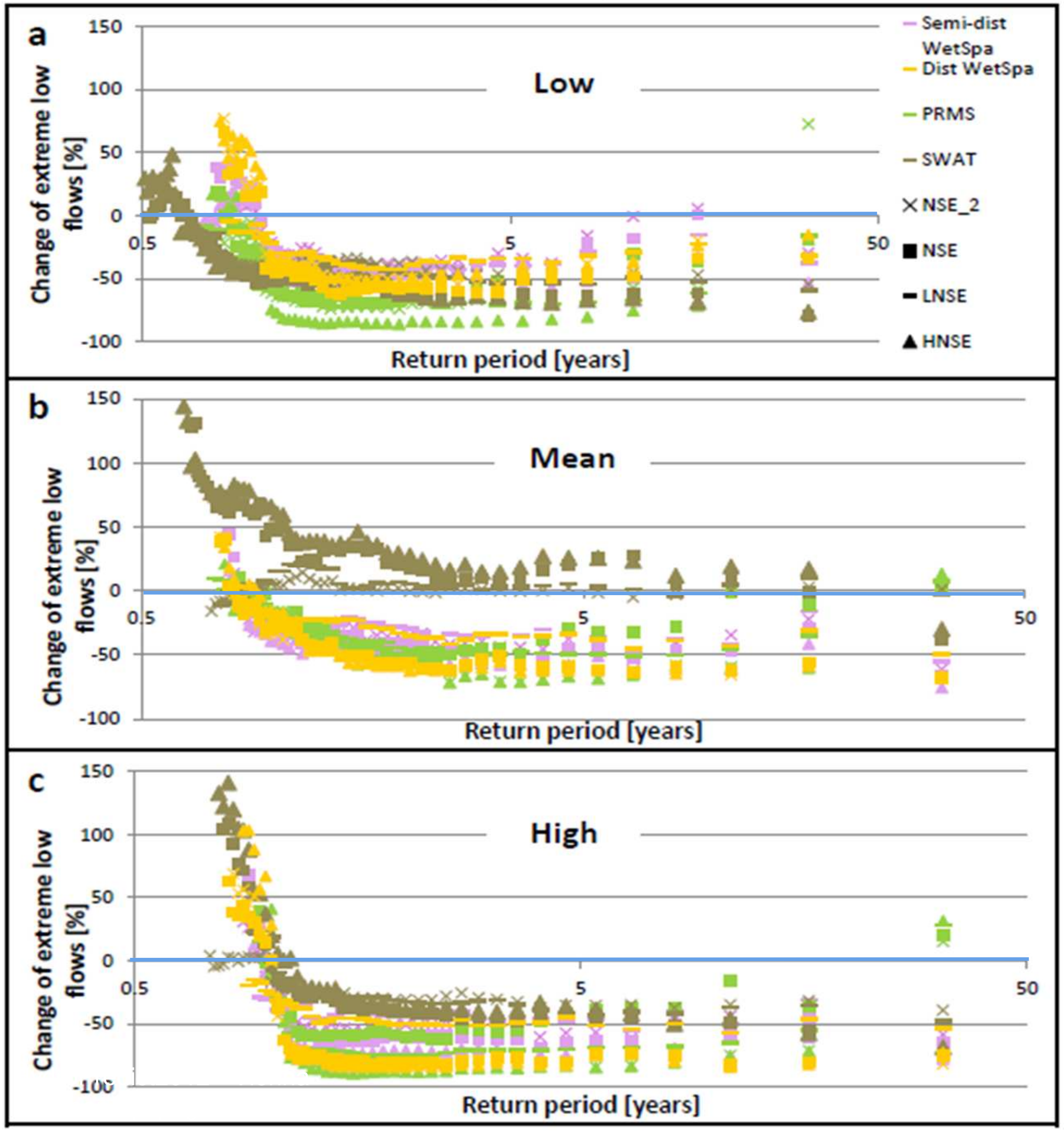
Extreme low flows



- Reduction of lowest flows for all scenarios
- Highest decrease for High impact scenario (PET , PPT); slightly lower decrease for Low (PET =, PPT) and Mean scenario (PPT)

Conclusions

Q CHANGE	CC-model DISAGREE
Increase in avg Spring Q	**none**
Decrease avg summer Q	SWAT-mean
Decrease extreme low Q	SWAT-mean
Increase in high Q, R>1.6yr	PRMS-low

So, on what output results do scenario's and models 'Taking into account uncertainty' AGREE or DISAGREE?

Conclusions

- Large impact of hydrological model structure on predicted change in discharge
- Large climatic change → large model structure uncertainty
- Need for flexible model structures
- No model validation possible, alternative: model guided learning

Remember there are still unknown unknowns…