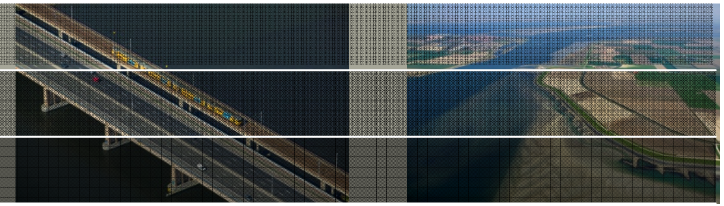
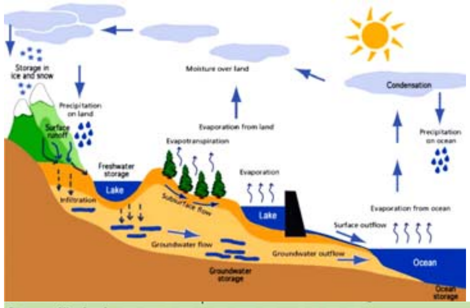
Discharges in the future
(from a dutch perspective)

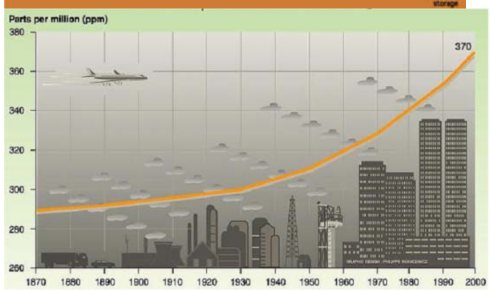
Jaap Kwadijk
(using the work of many many others)

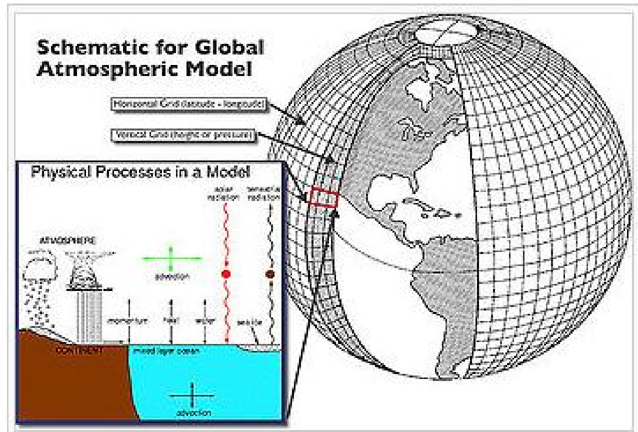
CHR – Spring seminar 2014. March 26-27,
Bregenz-Austria

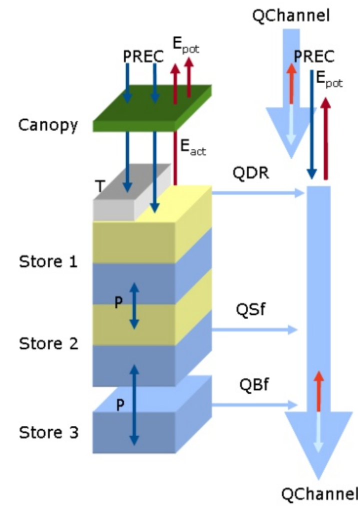
Generating water scenario's

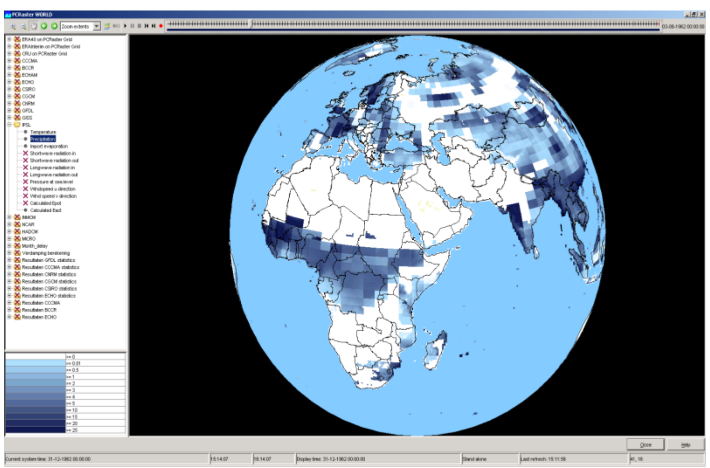


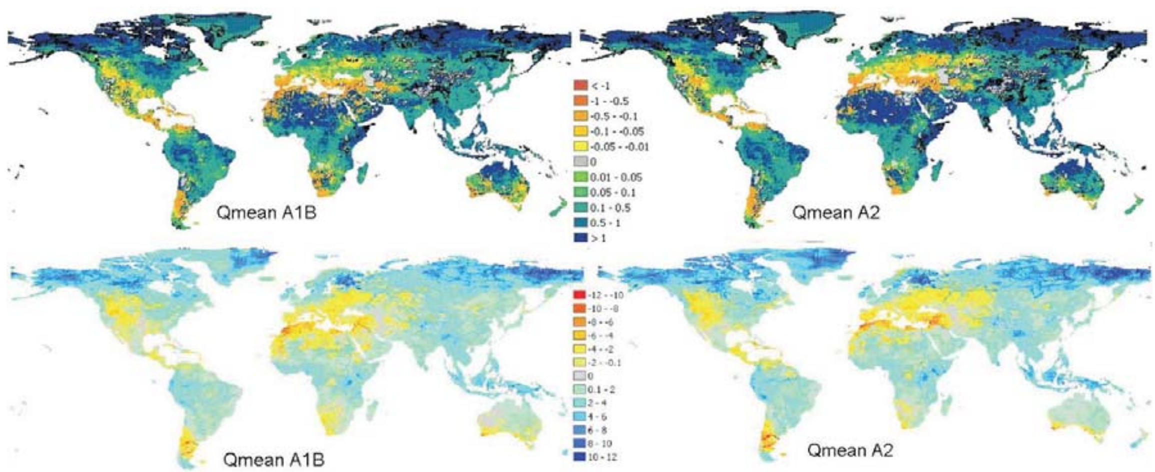






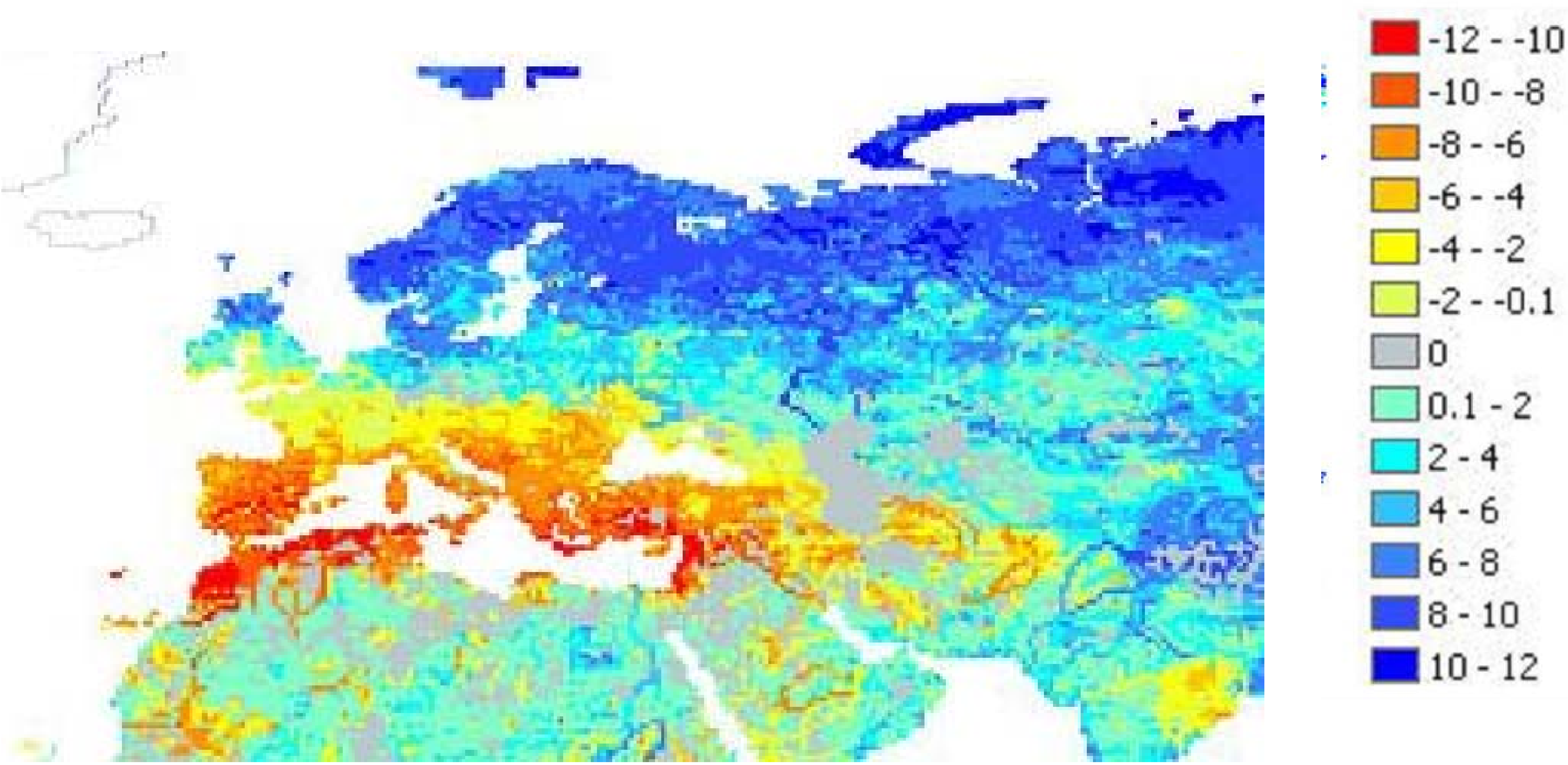






Deltares

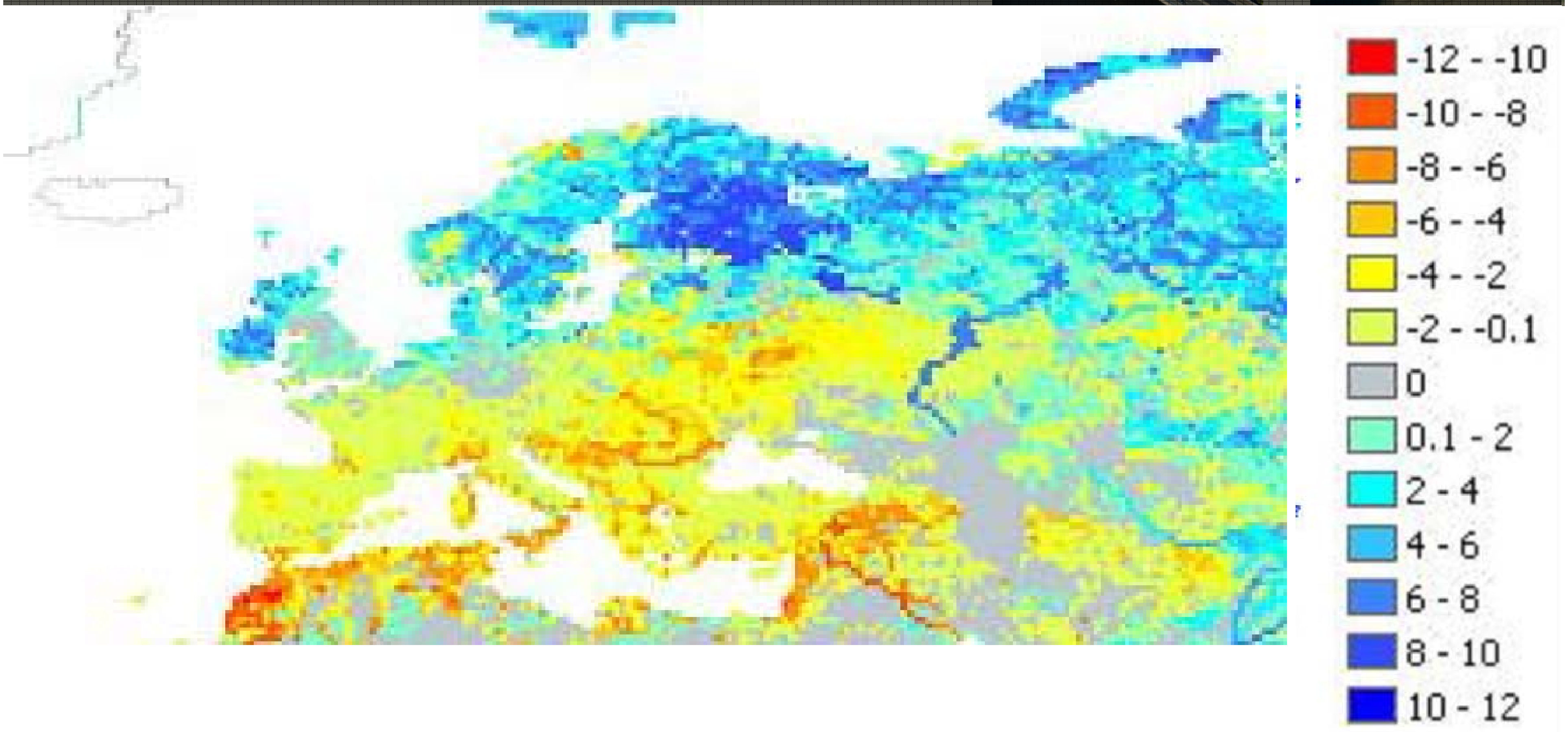
What do the climate models show us: Consistency in changes in average annual flow (12 AR4 models)



After Sperna Weiland et al, 2012

Deltares

What do the climate models show us: Consistency in change maximum flow (12 AR4 models)

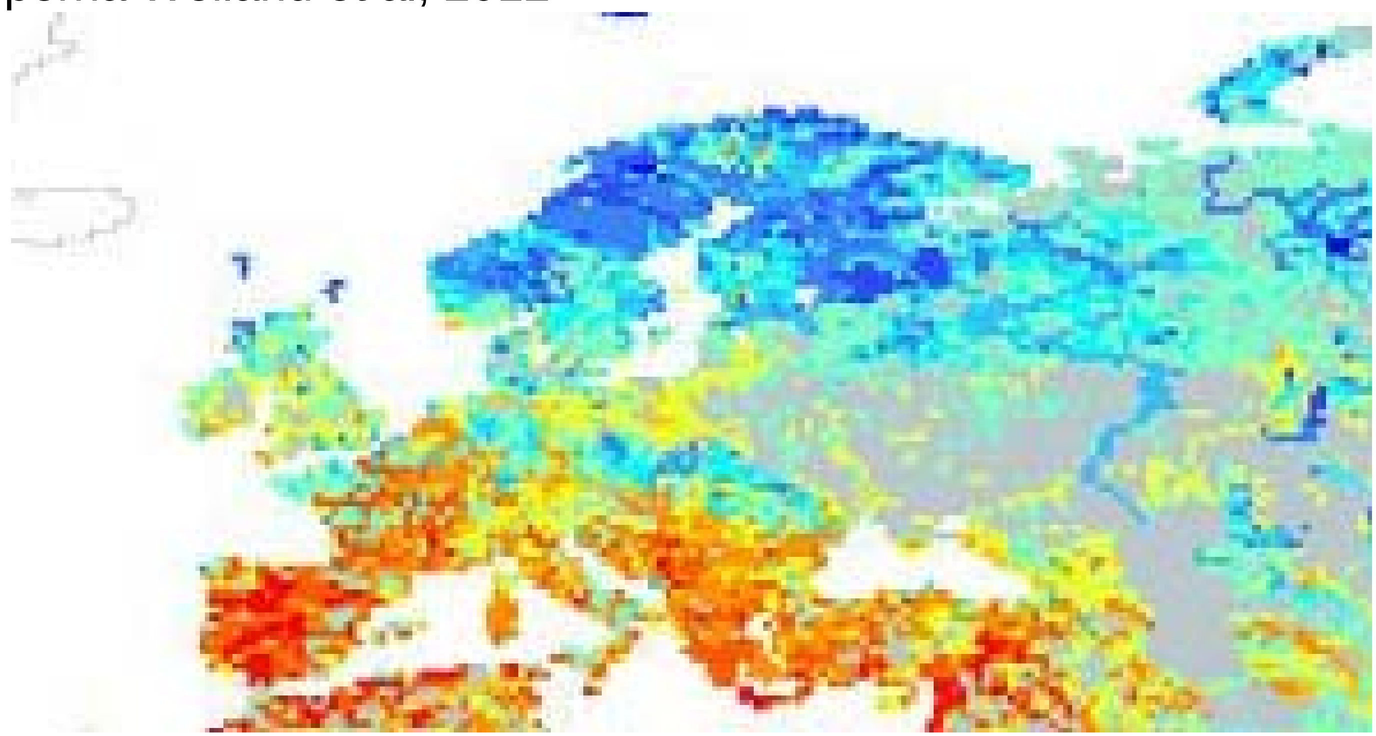


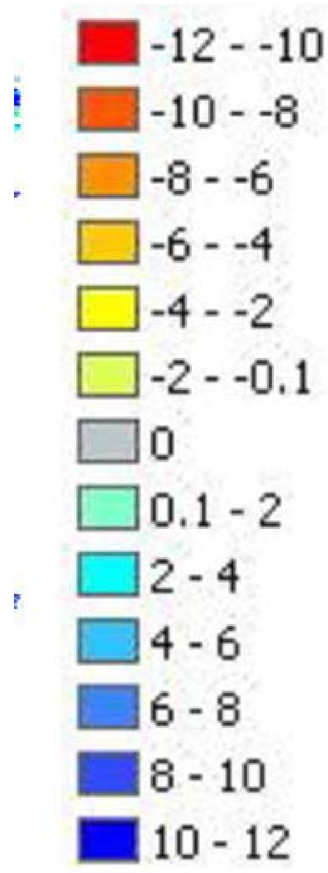
After Sperna Weiland et al, 2012

Deltares

What do the climate models show us: Consistency in change of the minimum flow (12 AR4 models)

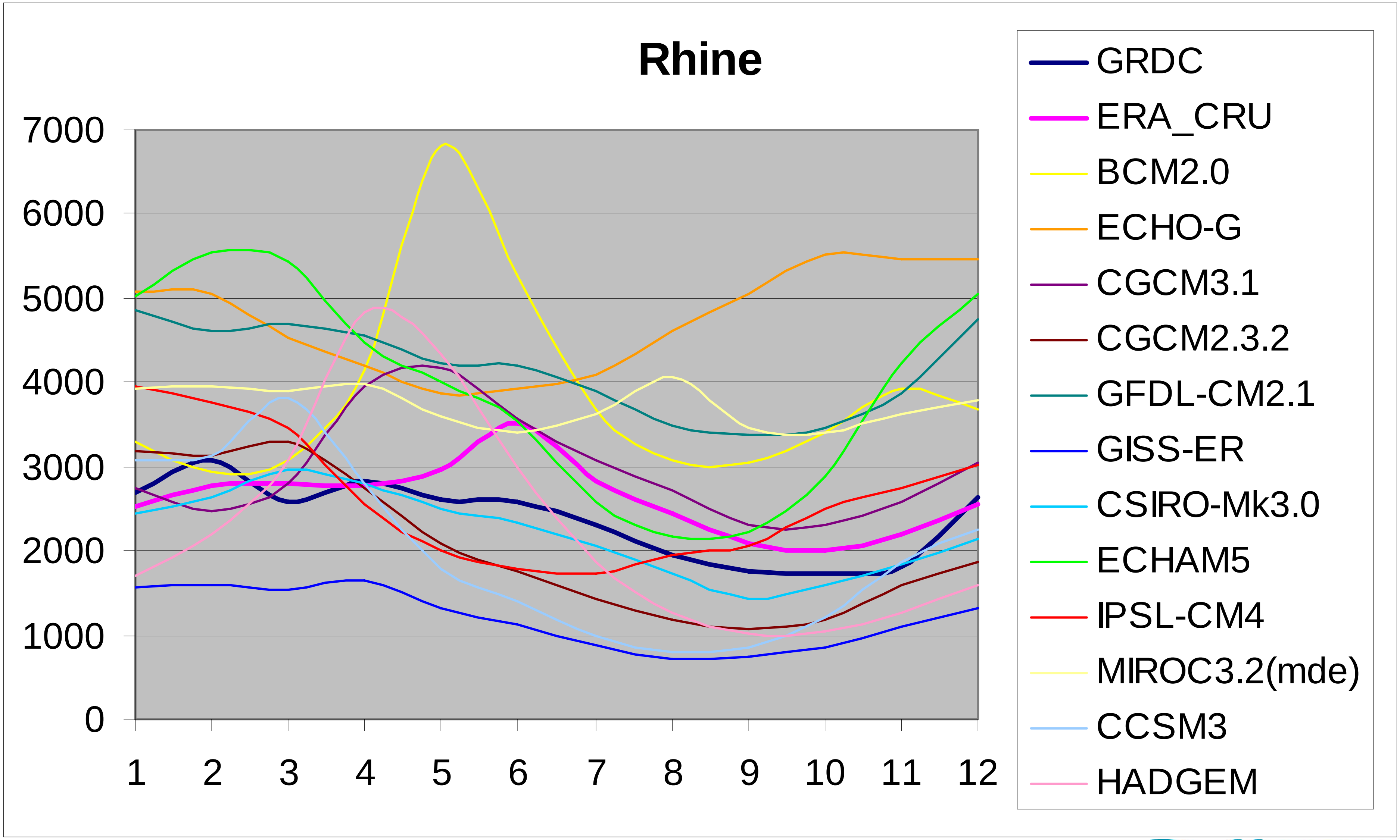
After Sperna Weiland et al, 2012





- The Rhine basin is located between areas that may become wetter (N) or dryer (S)
- Consistency in predicting lower minimum flows
- No consistency in projections for change in maximum and average flows

How good are the climate models in representing the Rhine discharge (average monthly flow according to different GCM's)



After Sperna Weiland et al, 2011

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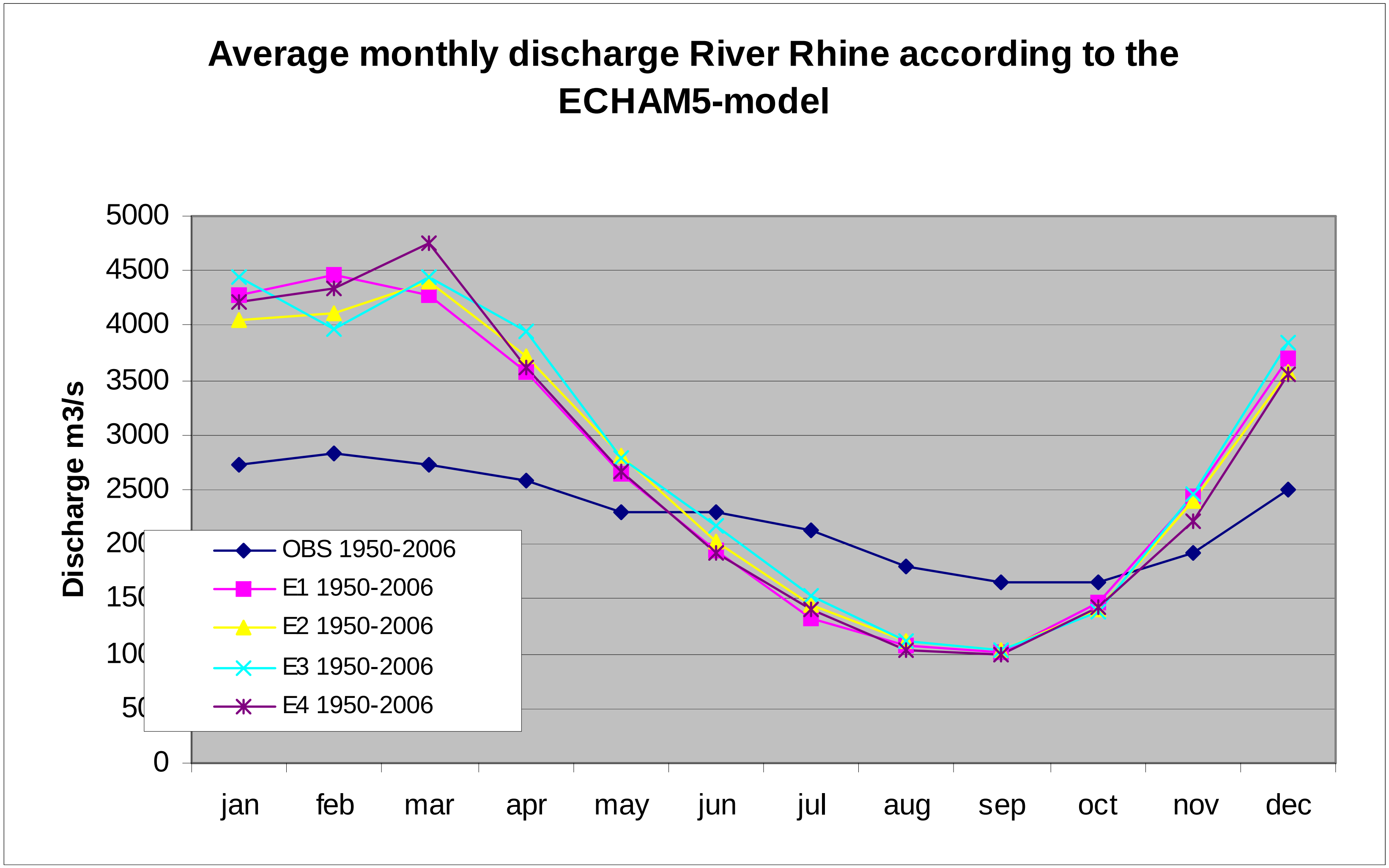
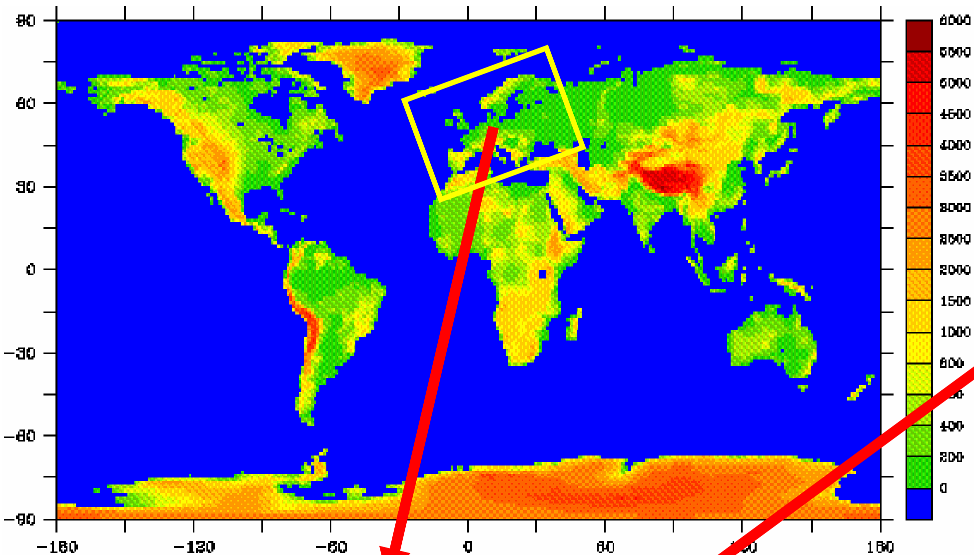
The Rhine according to the ECHAM5-model (2009)

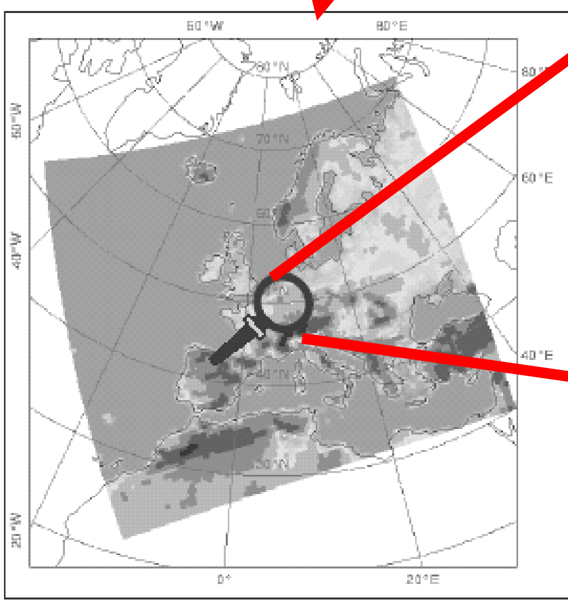


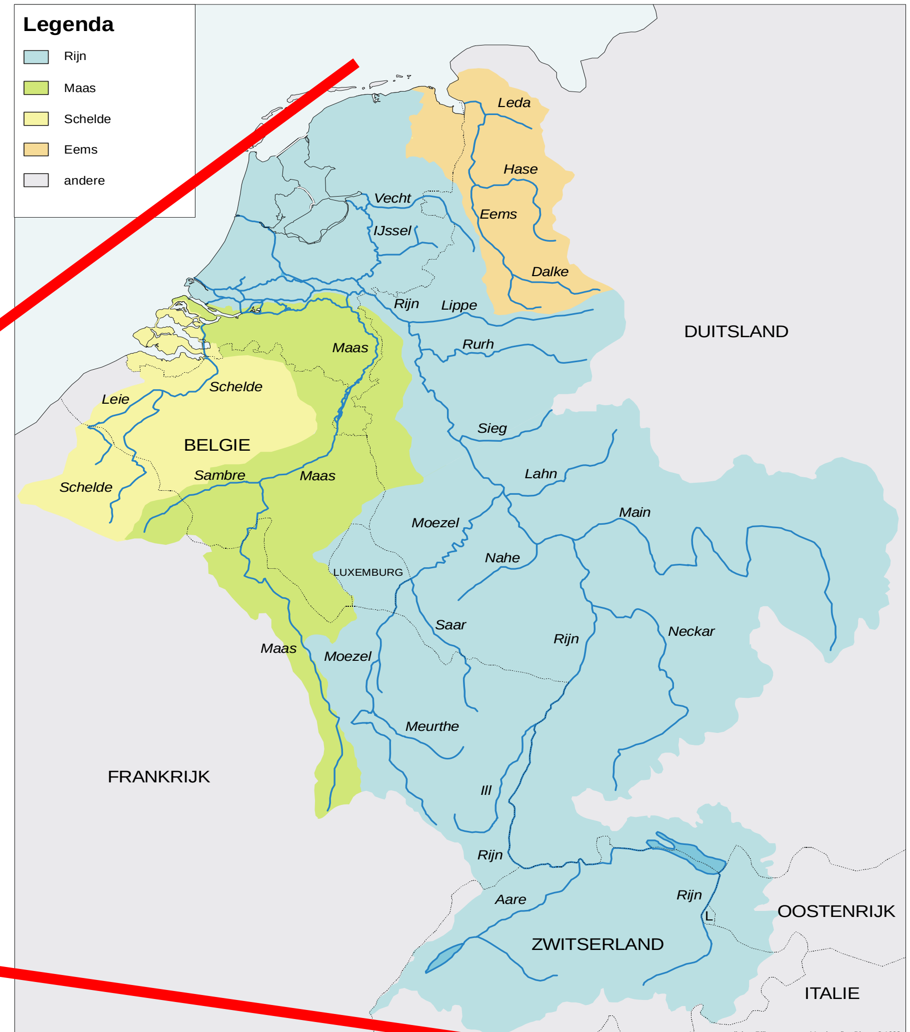
After Weerts, pers. Comm, 2009)

Deltares

So bias correction and downscaling







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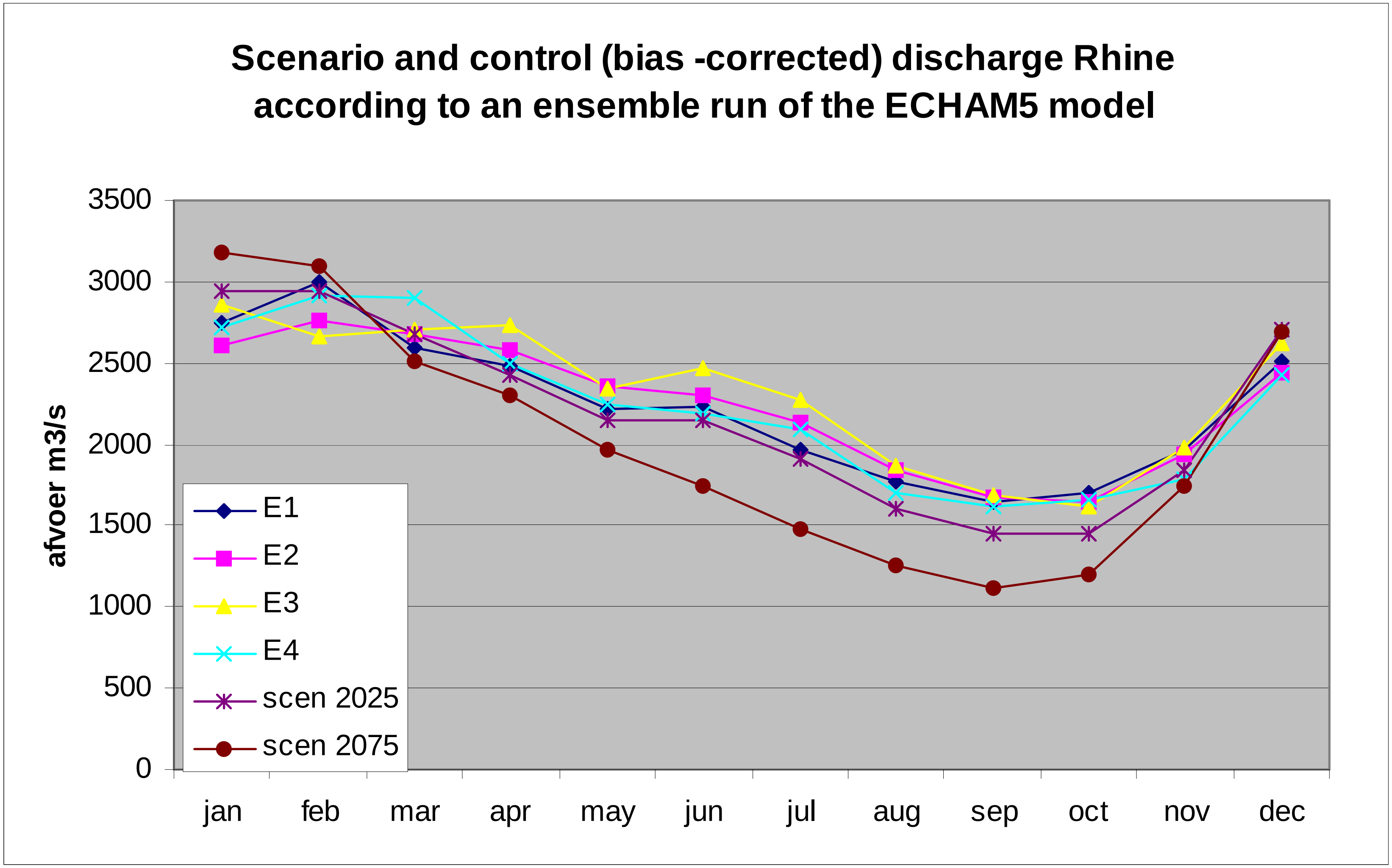
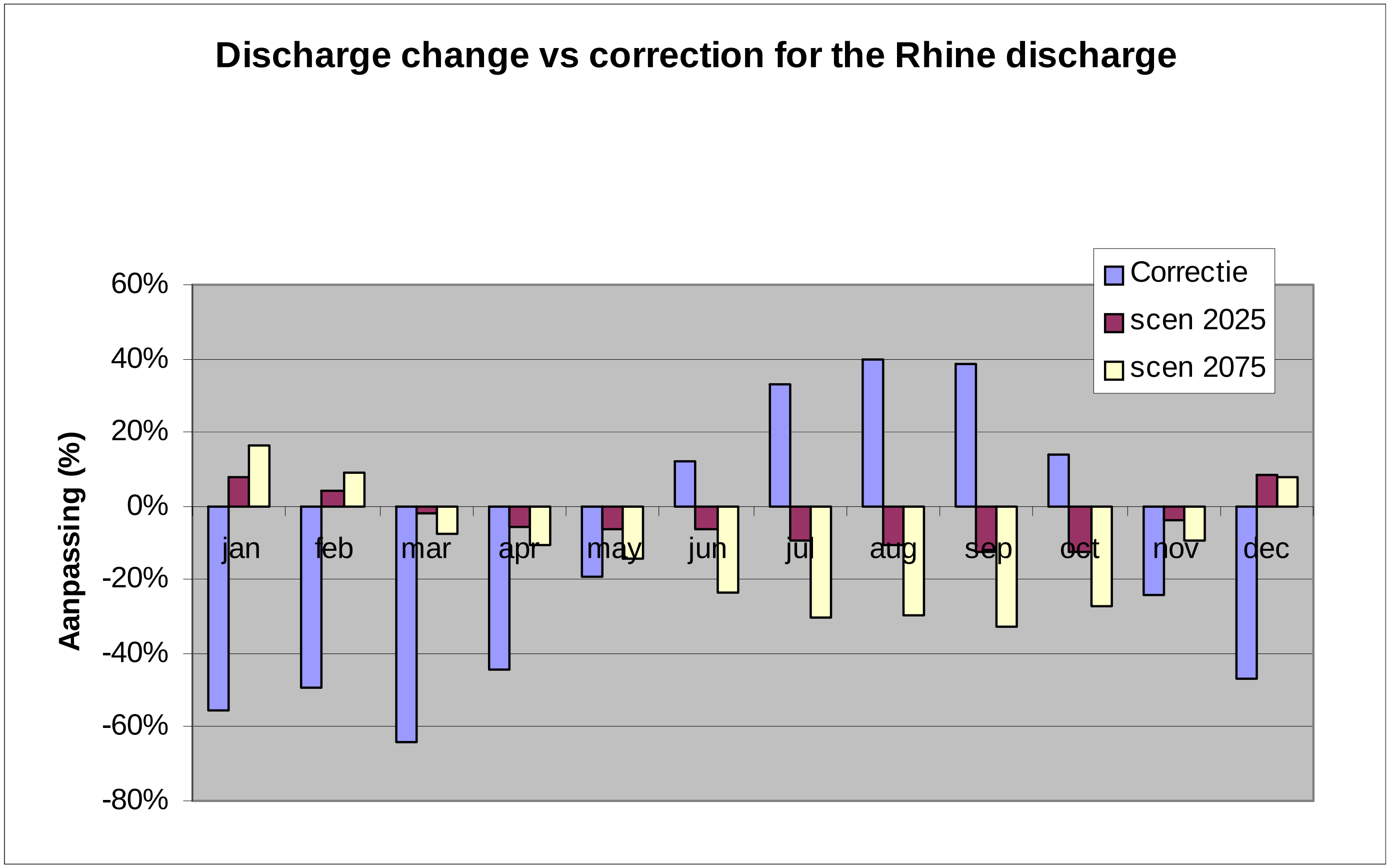
Direct approach scenario discharges



Deltares

Comparison change predicted and correction needed



Correction (bias correction) as large as the signal (change) predicted (or even larger)

Projection of CC scenarios on hydrology 1988-2006, Delta approach

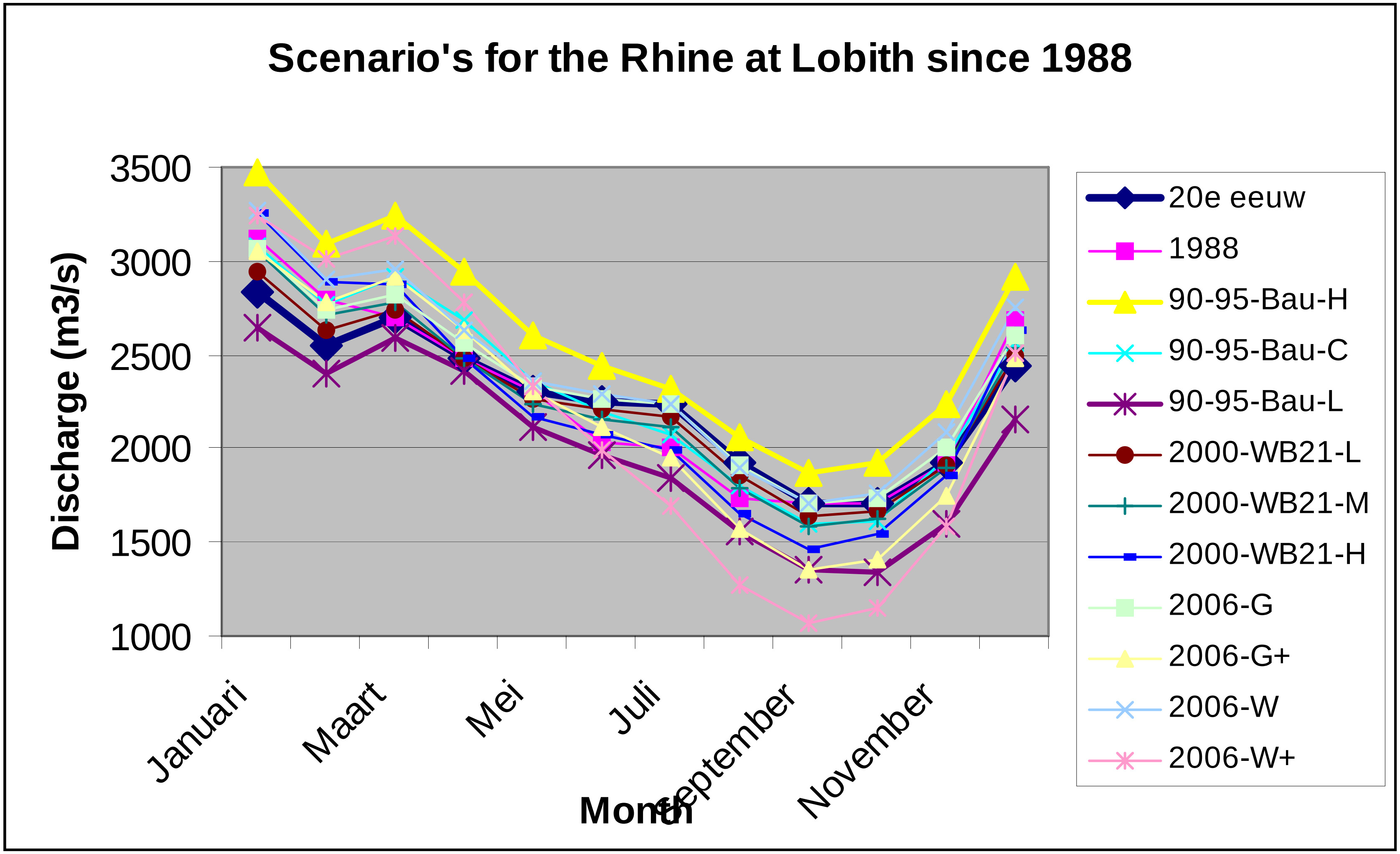
Fixed change (GCM-scenario – GCM-ref.)/GCM-Ref

Observed record (P,T,EP) → Fixed change → Changed record (P,T,EP)

Observed record (P,T,EP) → Hydrological model → Change in discharge

Changed record (P,T,EP) → Hydrological model → Change in discharge

Scenario's between 1988 and 2006 (projection for 2050)



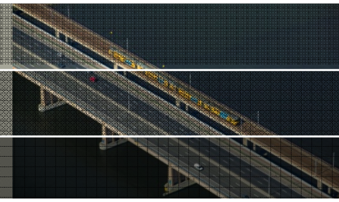
Deltares

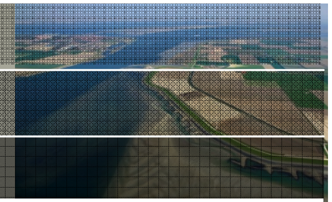
Since 2006 major improvements in the modelling capacity

- Many more GCM experiments (now selection of 191 from CMIP5, ipcc AR5)
- Improvements of the GCM's in reproducing realistic weather
- Introduction High Resolution GCM's (RCM's)
- Advanced downscaling methods (ADC)
- Weather generator to produce many thousands of climate series
- Hydrological models 10d basis -> daily basis
- Application of different hydrological models (HBV,VIC, Wasim, Rhineflow)
- Hydraulic models introduced to simulate the propagation of the flood waves

Substantial improvements in our capacity to simulate floods

Many scientific studies



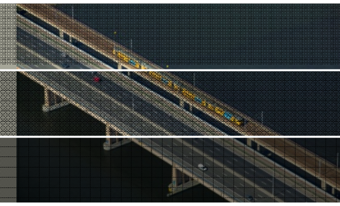


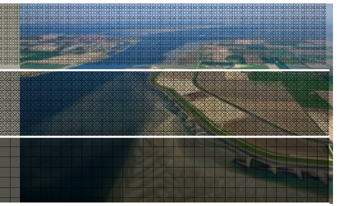
Study	Year	GCM	IPCC Scenario	Hydrol Model	Spatial resolution RCM	Temporal resolution	Projected change in Rhine discharge
(Kwadijk & Rotmans)	1995	CLIMAPS	BaU & AP	RhineFlow	0.5° x 1.0°	2100	Up to 20% increase in average winter discharge and up to 15% decrease in summer discharge, BaU scenario at Lobtih
(Middelkoop, et al.)	2001	UKHI/ XCCC	IS92a	RhineFlow	0.5° x 0.5°	2050	Annual peak flows increase 20 % in winter and decrease 5% in summer in the Lower Rhine
(Shabalova, Van Deursen, & Buishand)	2003	HadRM2	IS92a	RhineFlow	50 km	2080-2099	Increase of 30 % average winter discharge and a decrease of 30% or even up to 50% in summer at Lobith
(Jasper, Calanca, Gyalistras, & Fuhrer)	2004	HadCM3	A2-B2	Wasim	-	2081-2100	Average increase of 14% to 31 % in two Alpine Rhine basins in winter and 16-33% decrease in summer
(Klein, et al.)	2004	HadCM3	A2-B2	RhineFlow	-	2070-2099 2010-2039	Increased winter discharge and decreased summer discharge, no percentages or numbers given

After Van Pelt, 2014

Deltares

And more…

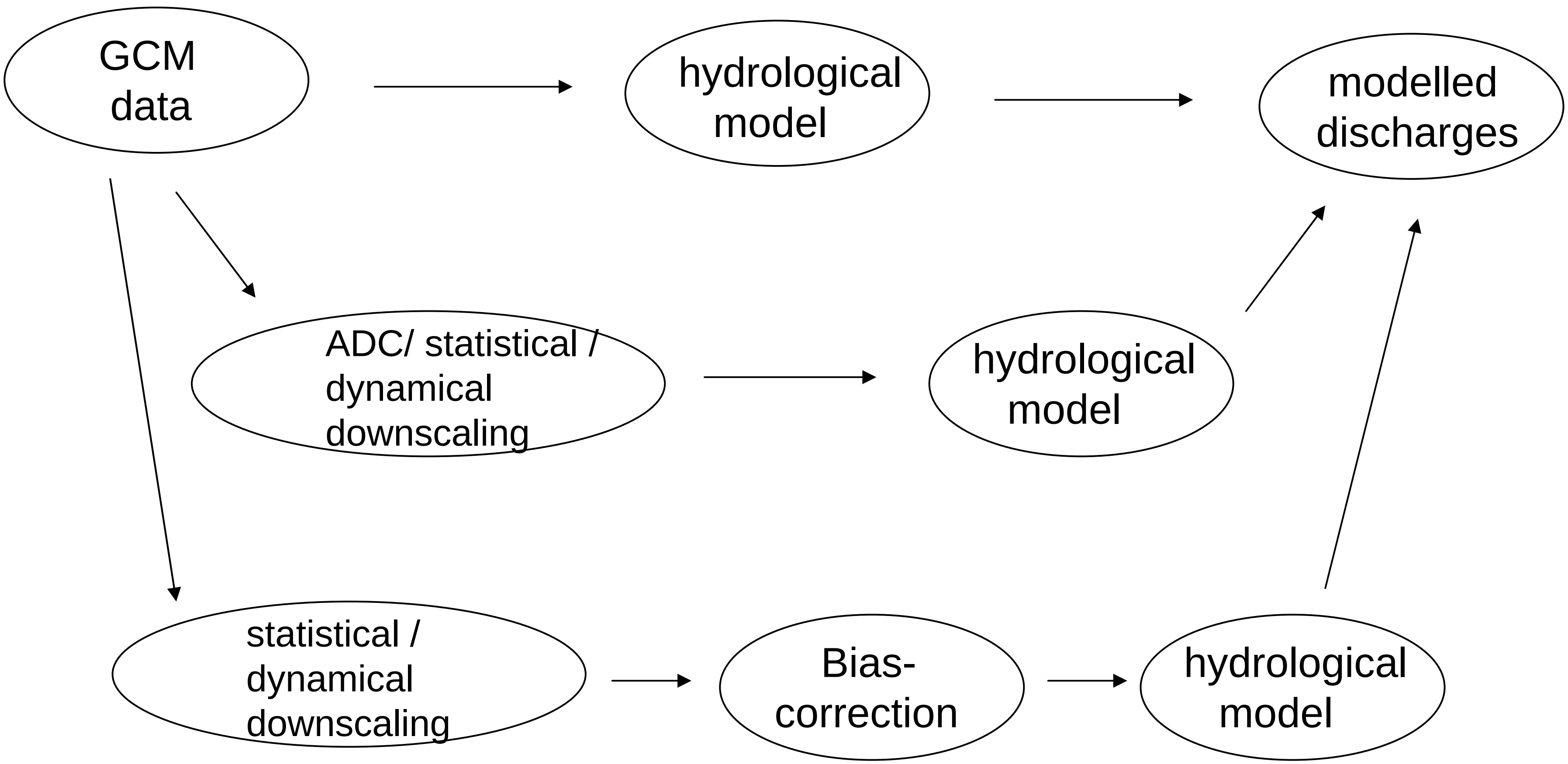




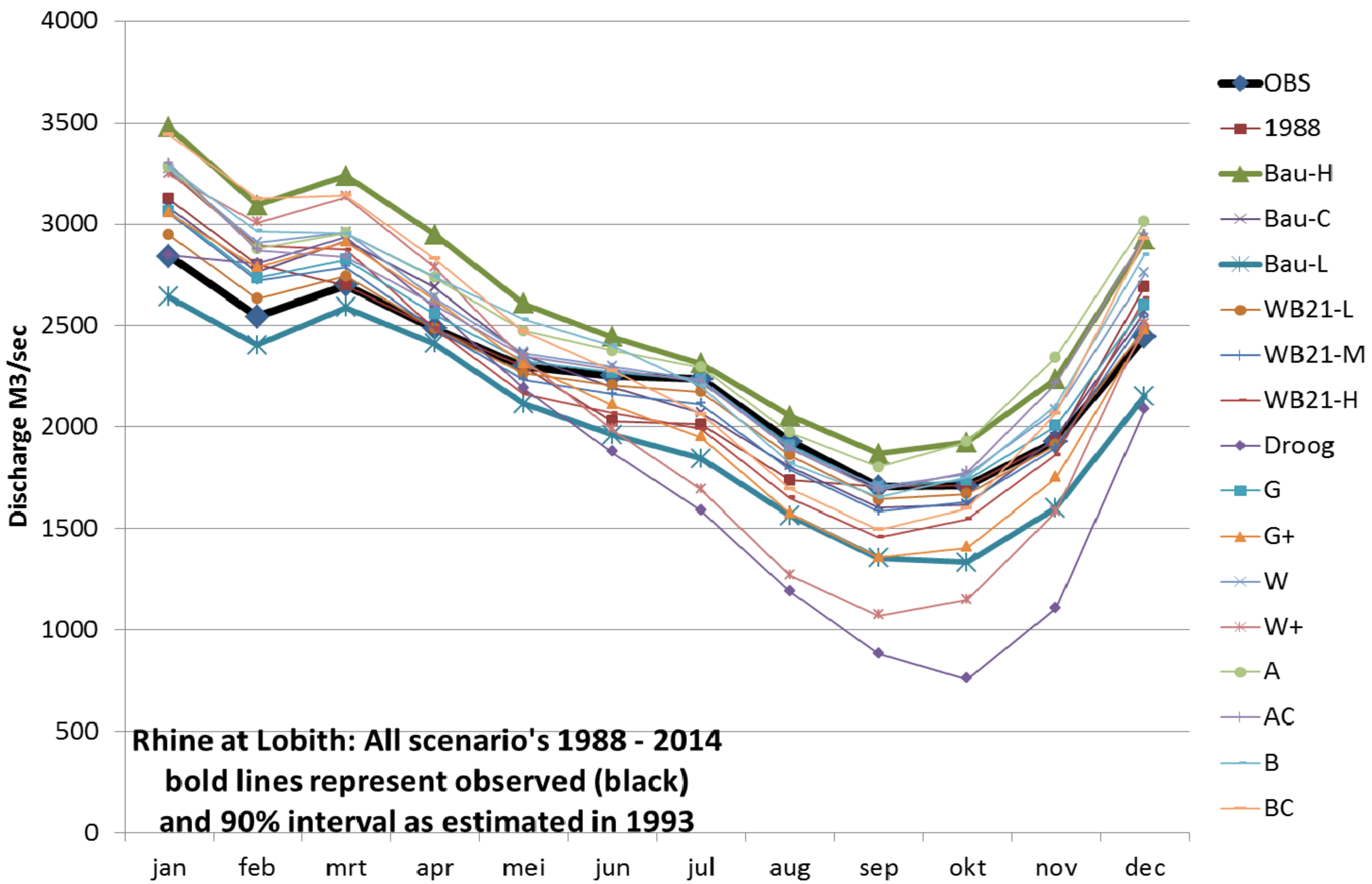
(Menzel, Thieken, Schwandt, & Bürger)	2006	HadCM3	IS92a	HBV-D	-	2061-2095	Increased winter discharge, no percentages or numbers given
(Lenderink, Buishand, et al.)	2007a	HadRM3H	A2	RhineFlow	50 km	2070-2099	Increase of about 30% in average winter discharge and a decrease of 40 % in average summer discharge at Lobith
(L.P. Graham, Hagemann, Jaun, & Beniston)	2007	HadAM3H	A2	HD/Wasim	50 km	2071-2100	Mean decrease in summer discharge up to 40%, increased winter discharge at Cologne
(Hurkmans, et al.)	2010	ECHAM-5	A2-A1B and B1	VIC	10 km	2052-2100	Increase of 30% in average winter discharge and decrease of 30% in summer discharge at Lobith
(Te Linde, et al.)	2010	ECHAM-5	A1B	HBV	25 km	2050	Average discharge increase of 13% in winter, decrease of 17.4% in summer months at Lobith
(Görgen, et al.)	2010	Mostly ECHAM-5	Mostly A1B	HBV	25km	2050-2100	Average winter discharge increase up to 25% and summer decrease up to 30% for different Rhine gauging stations

After Van Pelt, 2014

Since 2006: Scenario's developed using the direct method (closer related to the output of the climate models



1988-2014 Scenario flows 2050,



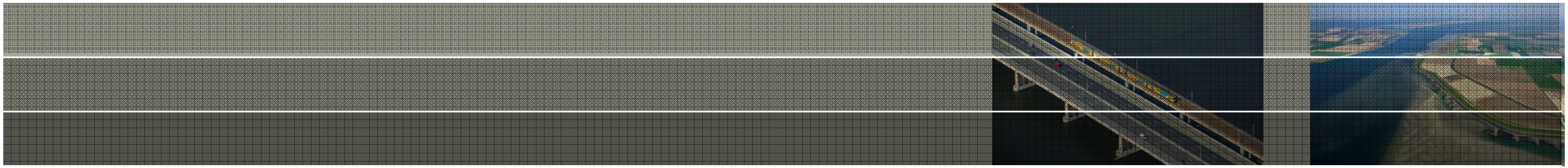
Some important international projects that learned us a lot

GRADE Rhine: Weather+ discharge generator: Enables to simulate changes in flood level, volume and duration of flood waves. **Learned us a lot more about the expected loads on the levees**

Niederrhein study: Introduced hydraulic modelling in the assessments, **learned us a lot about the huge effect of flooding in Germany on the design discharge of the Netherlands**

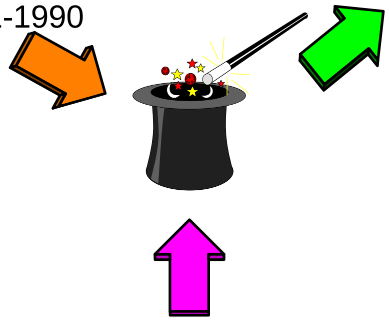
EU-FP6 Ensembles / KLIWAS/ Rheinblick: A1B emission scenario forcing the GCMs HadCM3 and ECHAM5 => downscaling using different High Resolution Regional Climate Models=> ADC => Rainfall generator applied on the Rhine (20,000 30yrs time series). **Learned us a lot on the maximum discharges and the spread in projections**

Most recent: CMIP5 , KNMI 2014 scenarios:

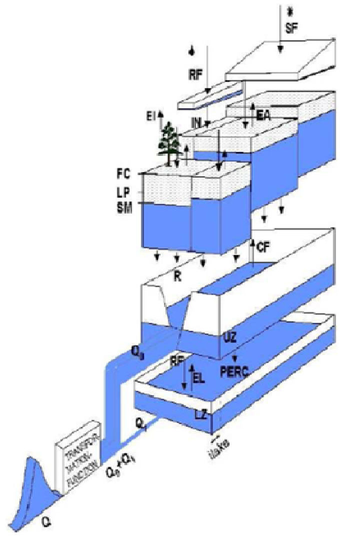


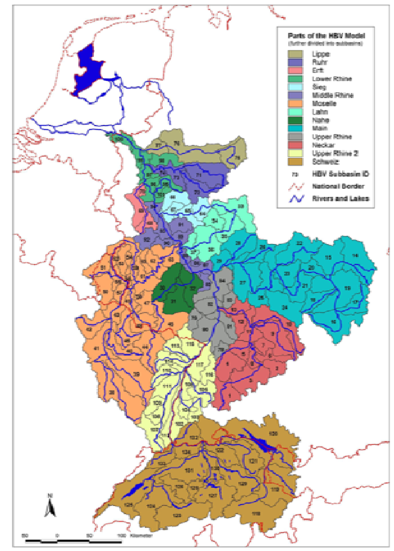
spatial patterns of observed daily T and P 1961-1990

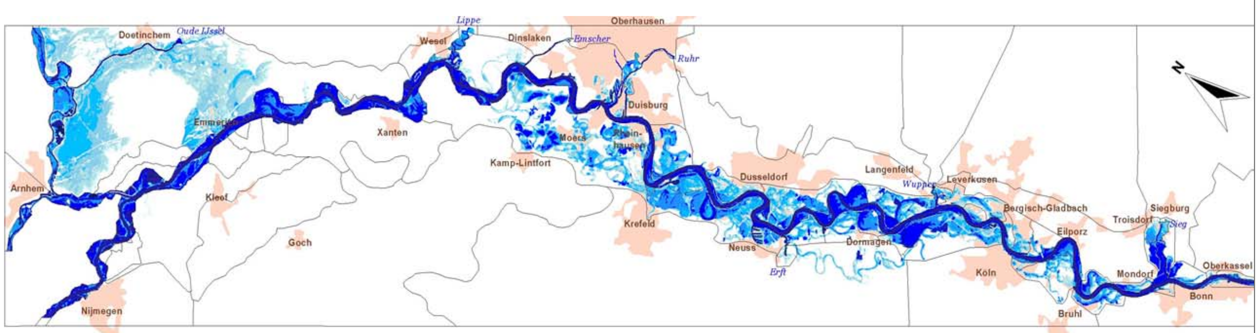
n-year sequence of daily T and P patterns

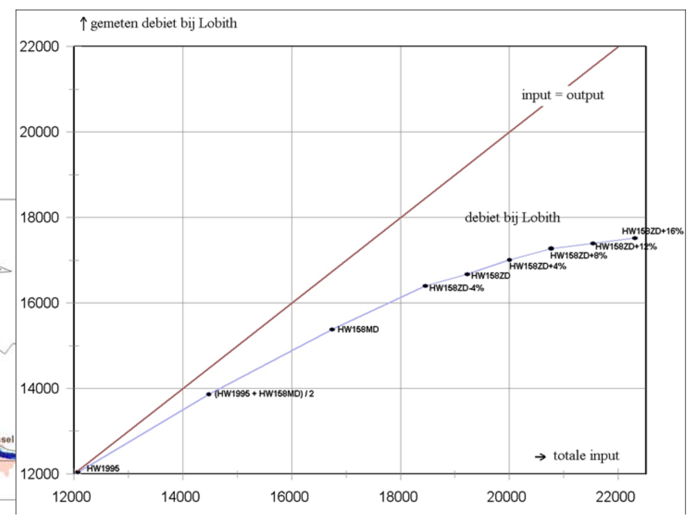


analysis of day to day persistence

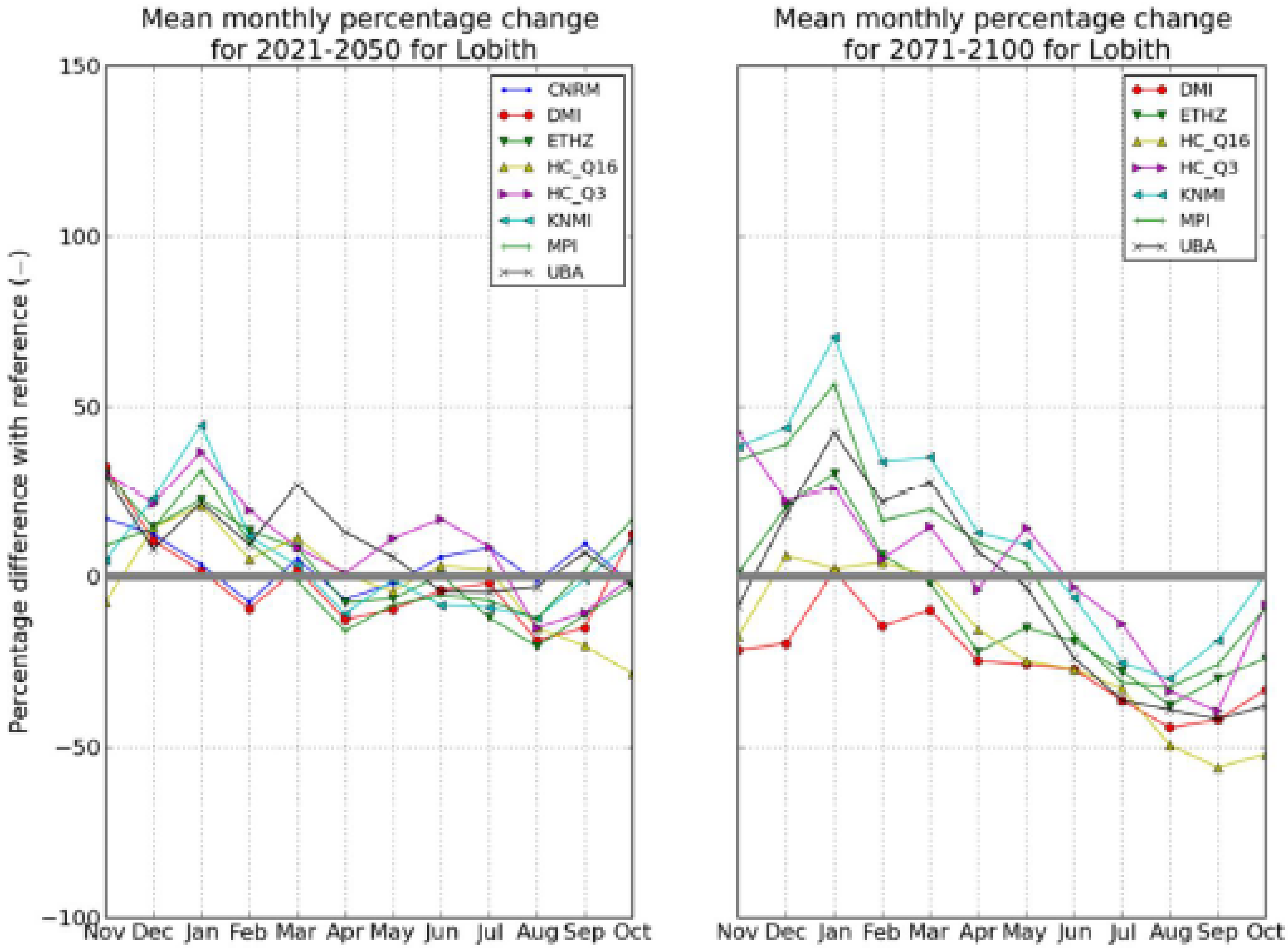




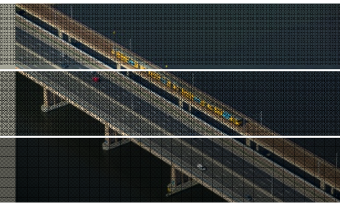
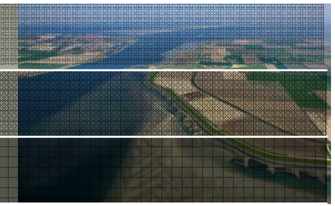




Rheinblick projections for Lobith



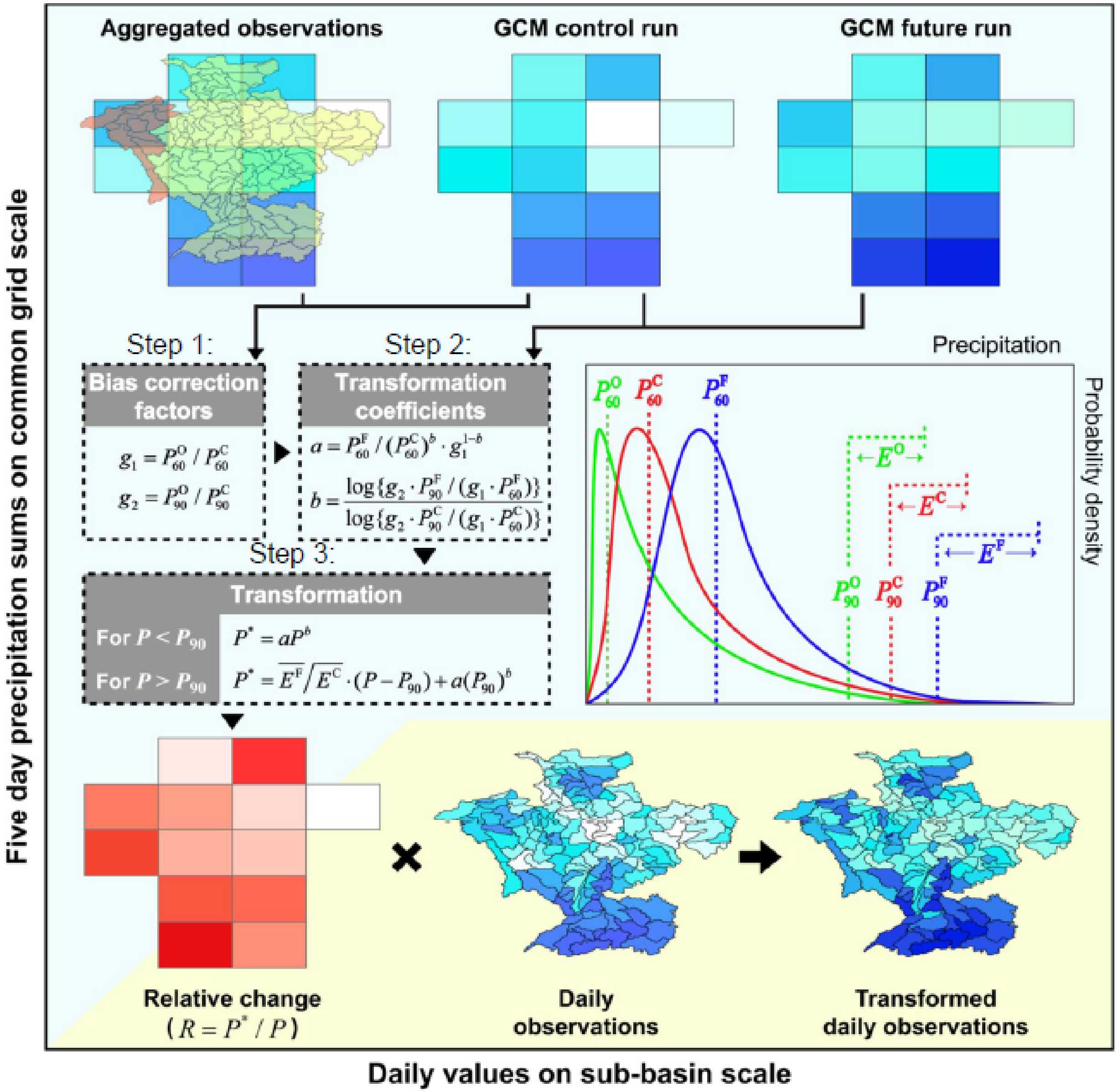
CMIP 5 set

Model (n=31)	Model runs	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5	Total
ACCESS1-0	1	-	1	-	1	2
ACCESS1-3	1	-	1	-	1	2
bcc-csm1-1	1	1	1	1	1	4
bcc-csm1-1-m	1	1	1	1	1	4
BNU-ESM	1	1	1	-	1	3
CanESM2	5	5	5	-	5	15
CCSM4	3	3	3	3	3	12
CMCC-CESM	1	-	-	-	1	1
CMCC-CM	1	-	1	-	1	2
CMCC-CMS	1	-	1	-	1	2
CNRM-CM5	1	1	1	-	1	3
CSIRO-Mk3-6-0	10	10	10	10	10	40
FGOALS-s2	3	1	3	1	3	8
GFDL-CM3	1	1	-	1	1	3
GFDL-ESM2G	1	1	1	1	1	4
GFDL-ESM2M	1	1	1	1	1	4
GISS-E2-R	1	-	1	-	-	1
HadGEM2-CC	3	-	1	-	3	4
HadGEM2-ES	4	4	4	4	4	16
inmcm4	1	-	1	-	1	2
IPSL-CM5A-LR	4	4	4	1	4	13
IPSL-CM5A-MR	1	1	1	1	1	4
IPSL-CM5B-LR	1	-	1	-	1	2
MIROC-ESM	1	1	1	1	1	4
MIROC-ESM-CHEM	1	1	1	1	1	4
MIROC5	3	3	3	1	3	10
MPI-ESM-LR	3	3	3	-	3	9
MPI-ESM-MR	3	1	3	-	1	5
MRI-CGCM3	1	1	1	1	1	4
NorESM1-M	1	1	1	1	1	4
EC-EARTH-v2.3	8	-	-	-	8	8
Total	69	46	57	30	66	**199**

Deltares

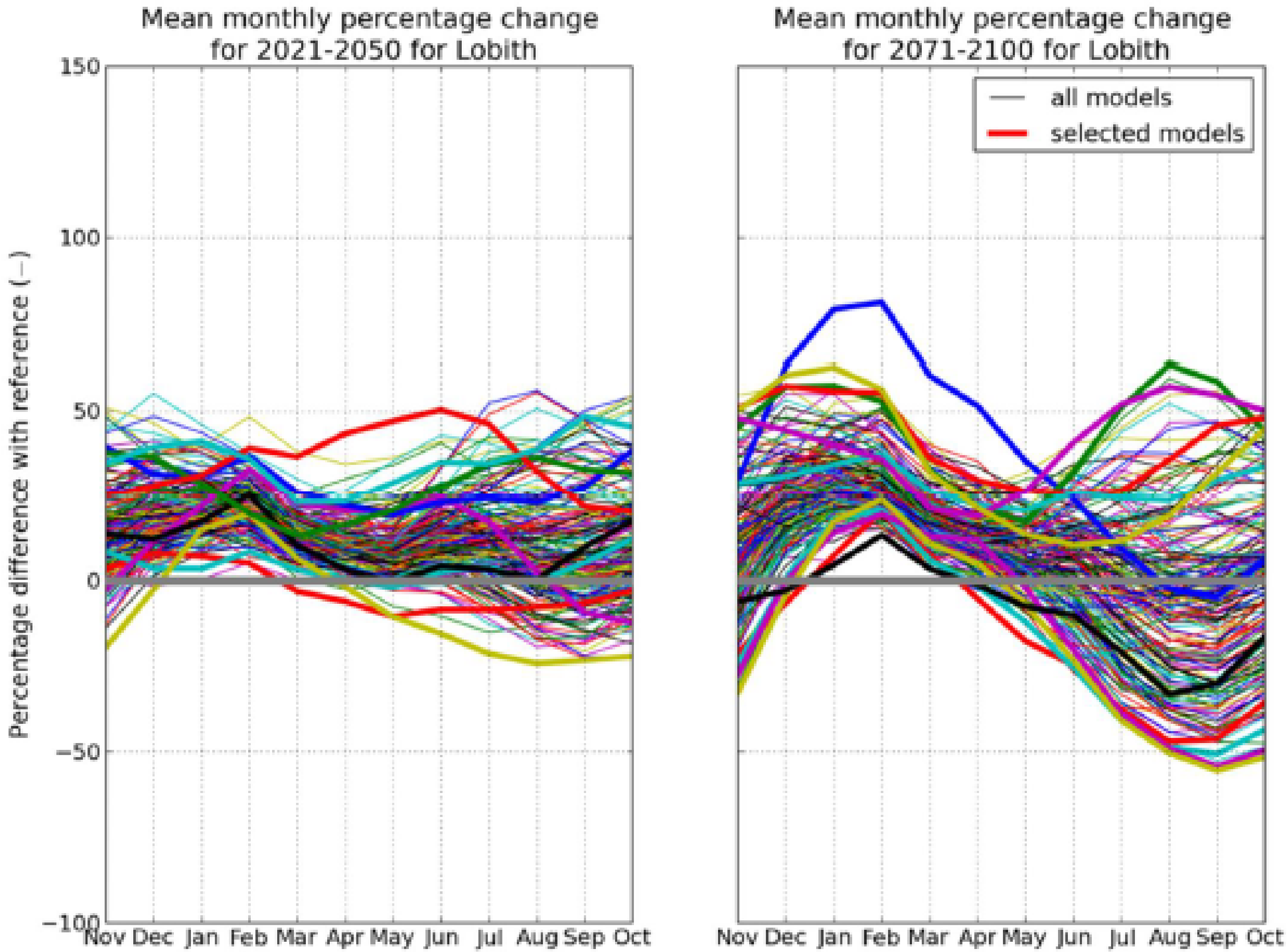
Downscaled using the Advanced delta change method



Main advantage:
keeps the changes
in variability preserved
(van Pelt, 2014)

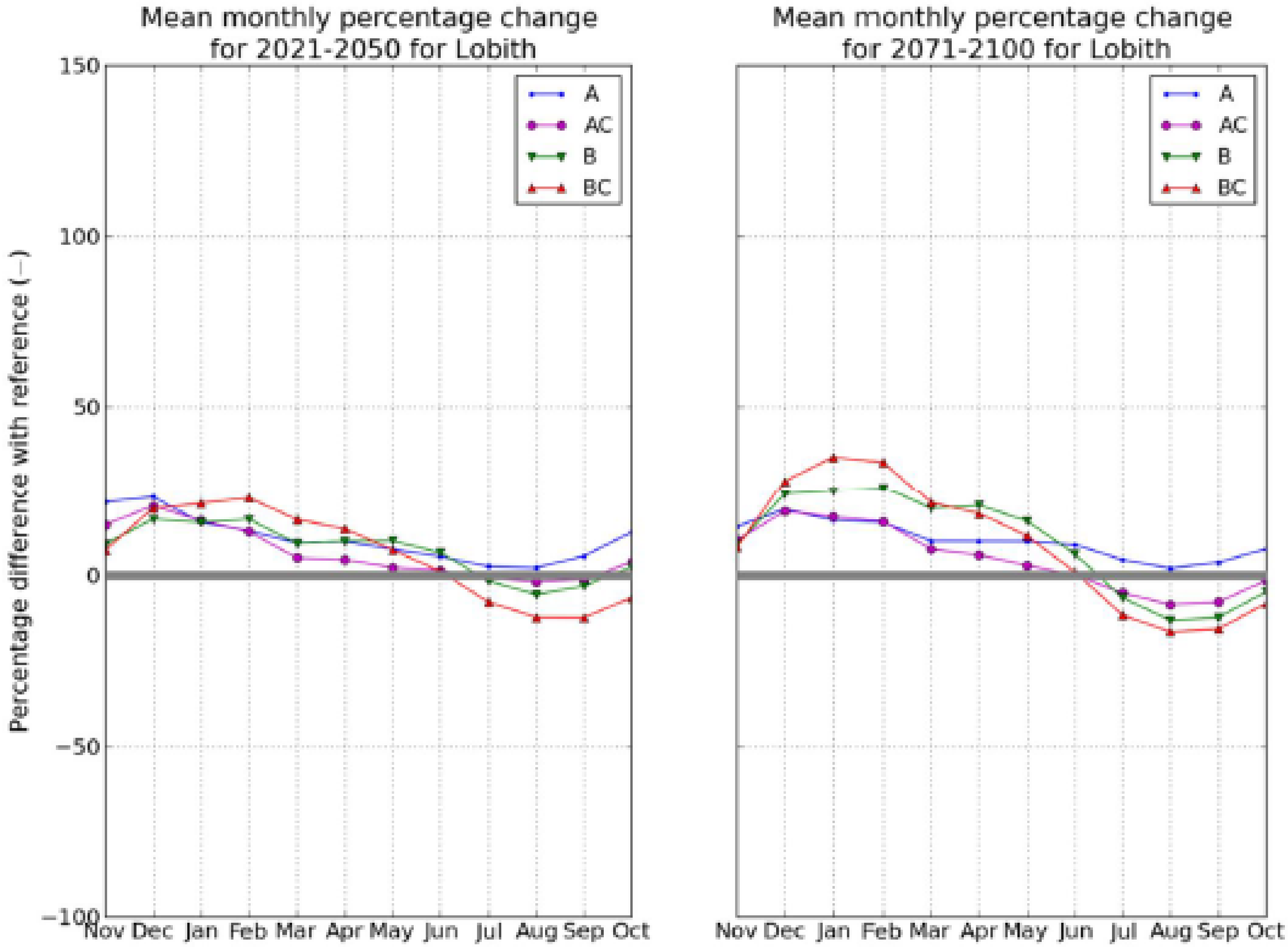
Deltares

CMIP5 projections for Lobith



After Sperna Weiland and Bouaziz, 2014

KNMI 2014 projections for Lobith



Over 25 years research, consistency in:

- Winter discharges will increase (High Confidence). Robust estimate: 30-40% (JK)
- Summer discharges will decrease (Medium-High Confidence); robust estimate: 15-40% (JK)
- 18,000 m3/s is close to the maximum plausible flood at Lobith (High Confidence) (JK)
- Discharges currently considered being extreme will become common (medium confidence)

Future research

- We have a lot of information about the climate (change)
- We have put a lot of effort in making assessments on changes in high discharges/floods

- We still know less about changes in low discharges, particularly on return periods and duration
- There are very Rhine basin studies focusing on future water consumption (I know 1).

There are many more studies addressing the question "how much change can we expect"

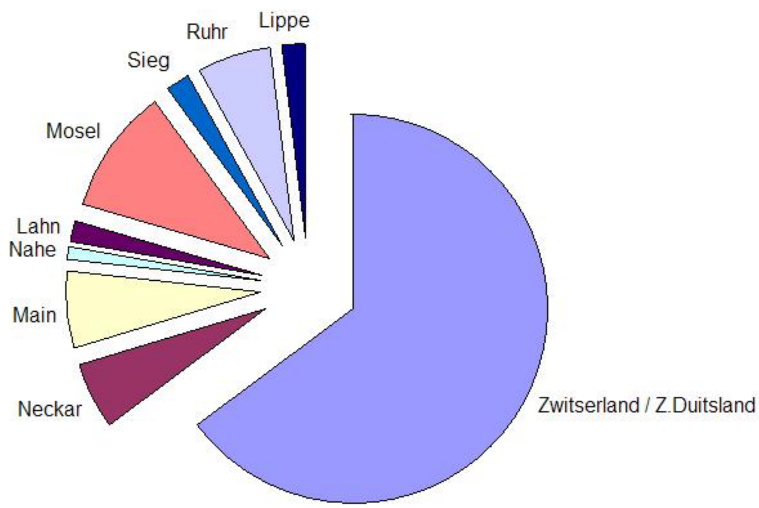
than

there are studies addressing the question "How much change can we cope with?" (vulnerability assessments)

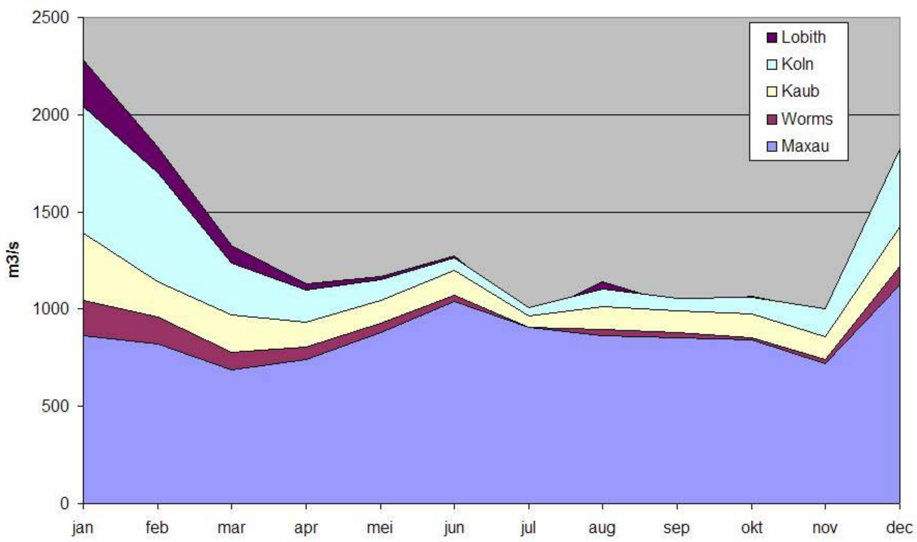
(is needed for informed decision making, also promising way forward according to PROVIA report UNEP (2013)

Examples: Low flow research, focus on Alpine region:

Aandeel van de deelstroomgebieden aan de de afvoer in 1976



Opbouw van de afvoer gedurende de laagwaterperiode 1976



- The Alpine region supplies up to 90 % of the water during low flows (while only 20% of the basin)
- They have the capacity to control these low flows (reservoirs and lakes) almost completely

Examples vulnerability assessments

Fresh water intake at Gouda no longer reliable **(35cm of sea level rise,20% low flow reductior**

Design criterium Maeslant barrier will be exceeded **(50cm sea level rise)**

Protection of the coast by sand nourishment **(> 150 cm Sea level rise)**

Deltares