Usage of a global statistical bias correction to enhance simulations of the current and future hydrological cycle

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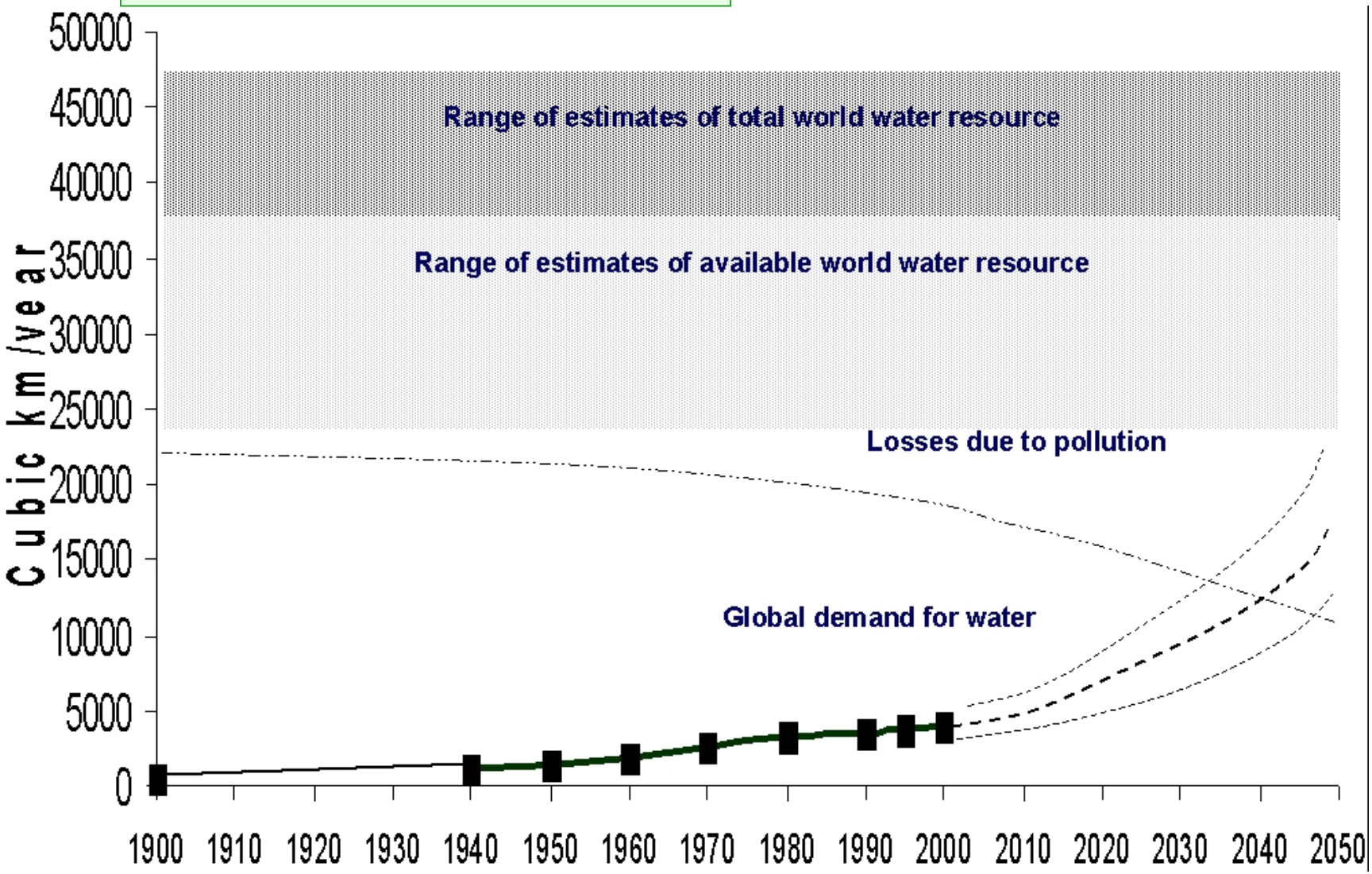
Overview

- Introduction to EU project WATCH – WATer and global CHange
- Climate model – Hydrological model (HM) modelling chain
- Global statistical bias correction of Precipitation and Temperature
- First application using the MPI-HM (SL scheme/HD model)
- Summary and Future Work

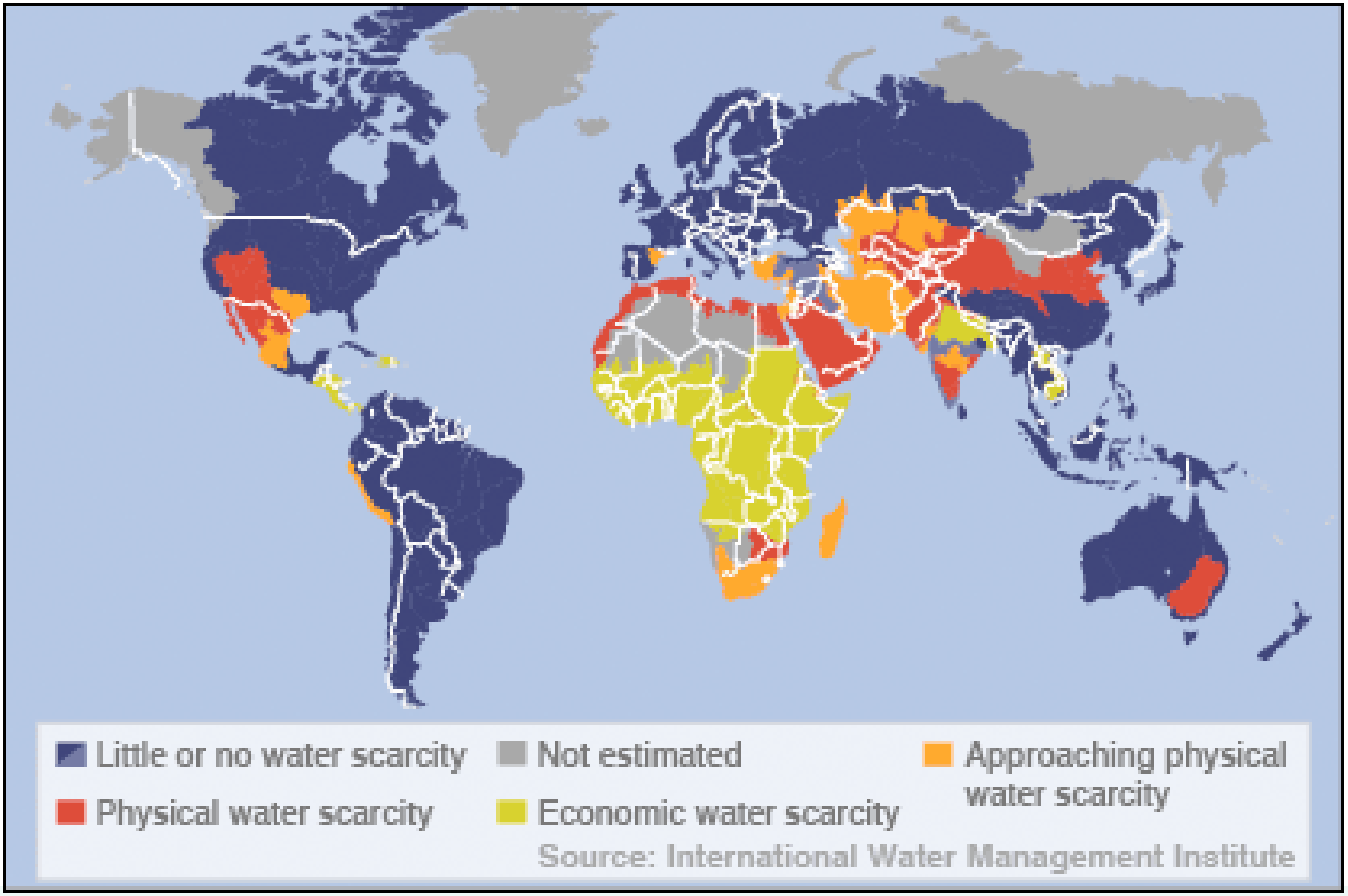
WATCH motivation



R. Harding, CEH, after Shiklomanov 2000

WATCH motivation

Areas of physical and economic water scarcity (*IWMI, 2006)*



WATCH motivation

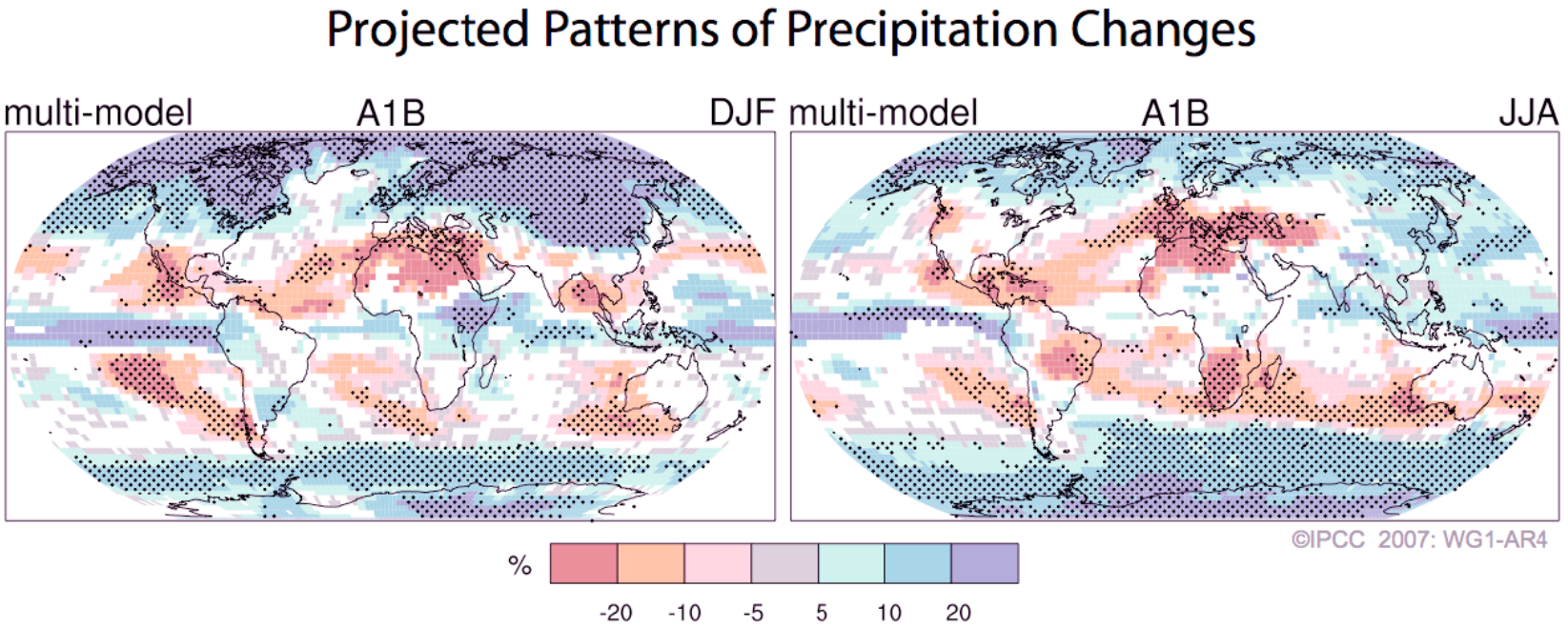
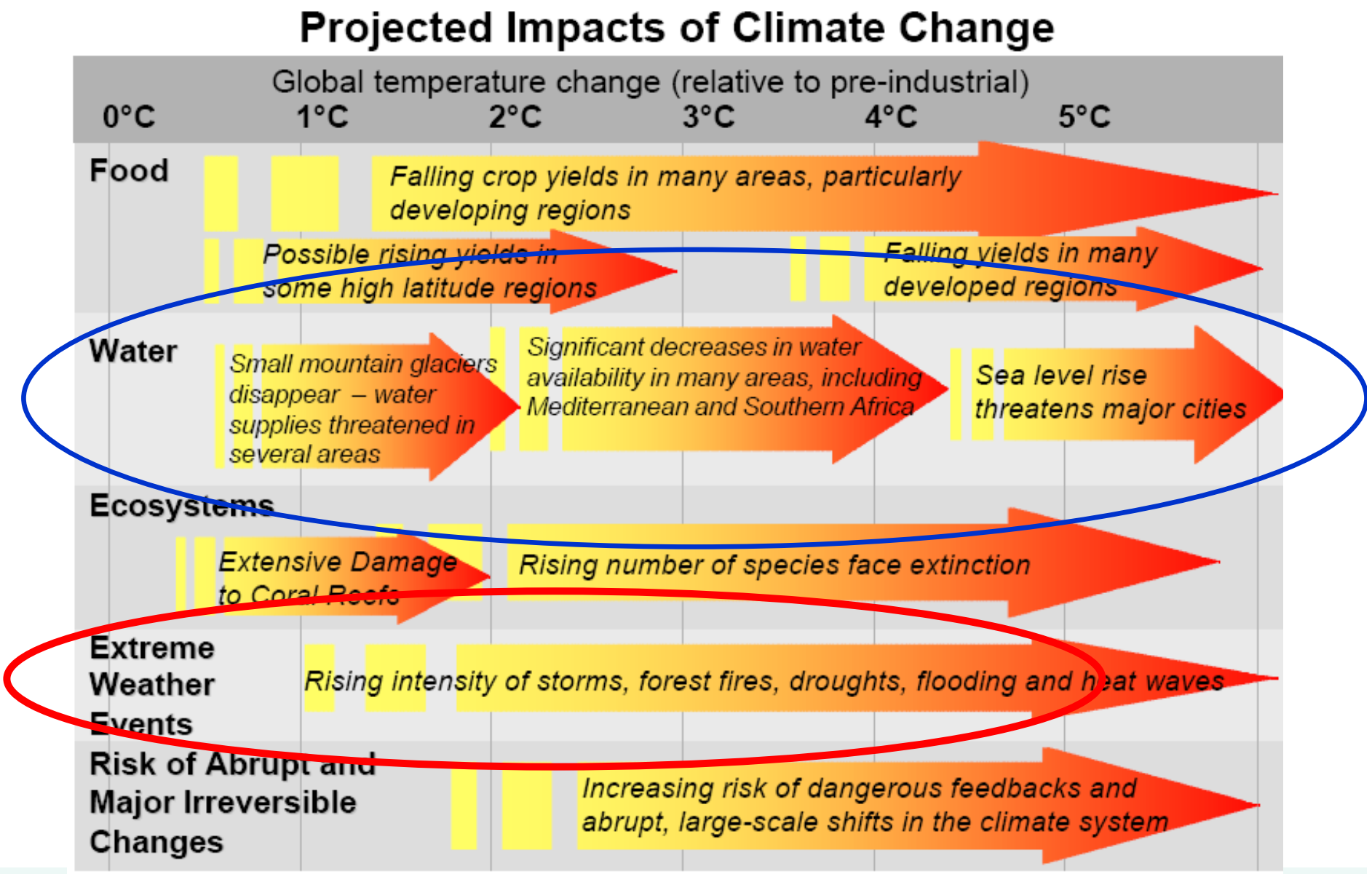


FIGURE SPM-6. Relative changes in precipitation (in percent) for the period 2090–2099, relative to1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change.

IPCC 2007

WATCH motivation

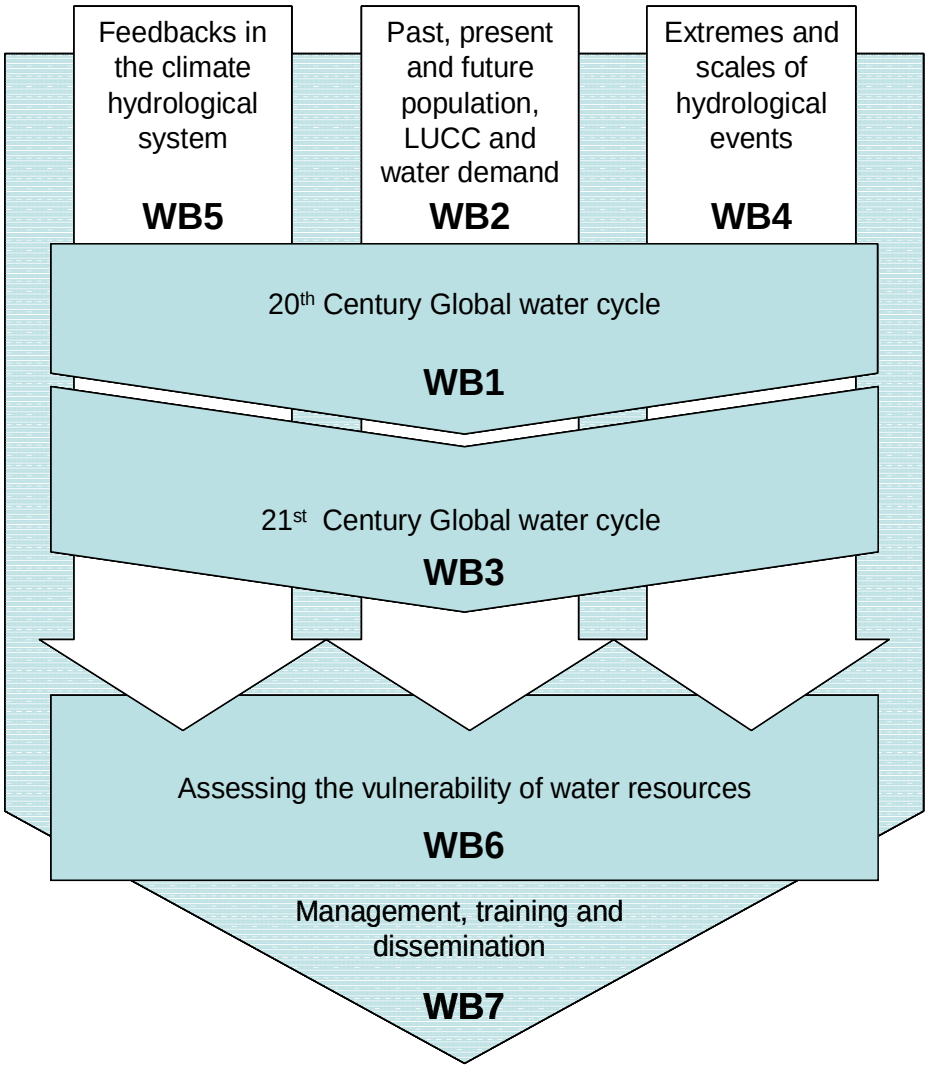
Stern Review (2006)



WATCH – FP6 Integrated project

The WATCH Integrated Project:

- 25 European partners: hydrology, climate and water resource scientists
- Coordinator: Richard Harding (CEH)
- Co-Coordinator: Pavel Kabat (WU)
- International programme
- Research, workshops, training, dissemination
- Start: 1 Feb 2007, 4 years.
- **http://www.eu-watch.org**



WATCH – FP6 Integrated project

WATCH – WATer and global CHange

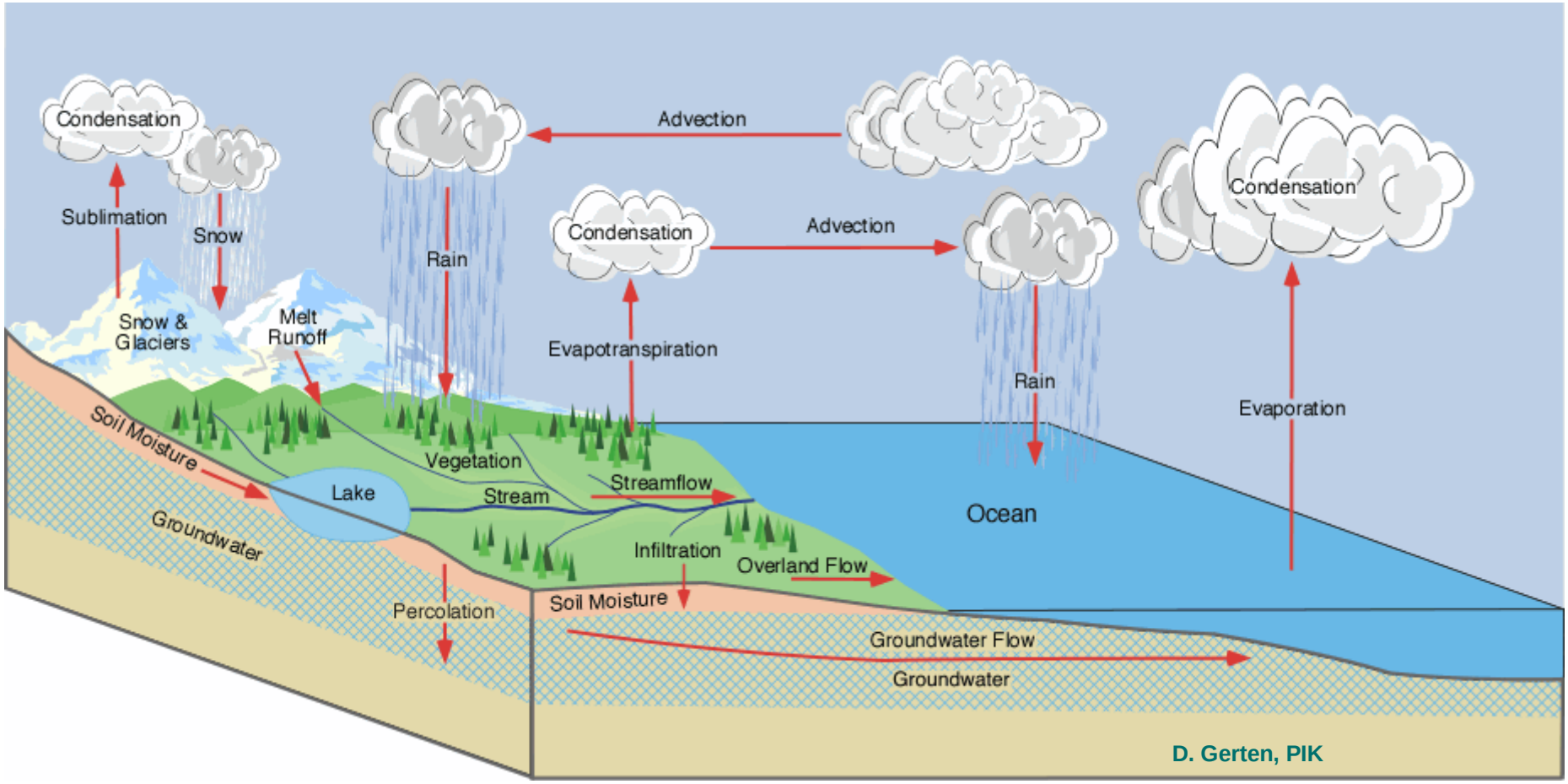
- **http://www.eu-watch.org**
- Analyse and describe the **current** global water cycle
- Evaluate how the global water cycle and its extremes respond to **future** drivers of global change
- Evaluate **feedbacks** in the coupled system as they affect the global water cycle
- Evaluate the **uncertainties** in the predictions
- Develop a modelling and data framework to assess the future **vulnerability of water as a resource**

WATCH – FP6 Integrated project

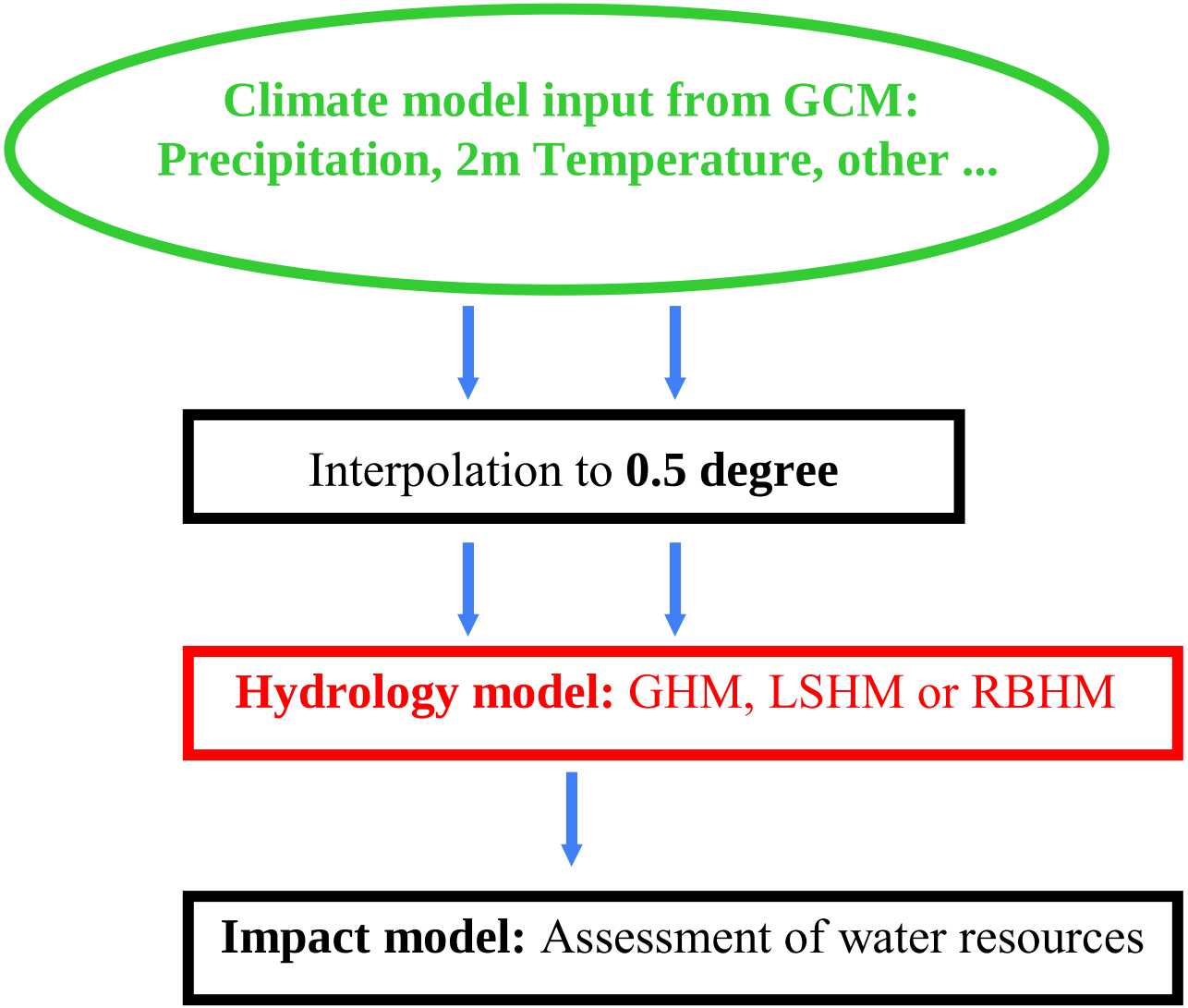
Highlights

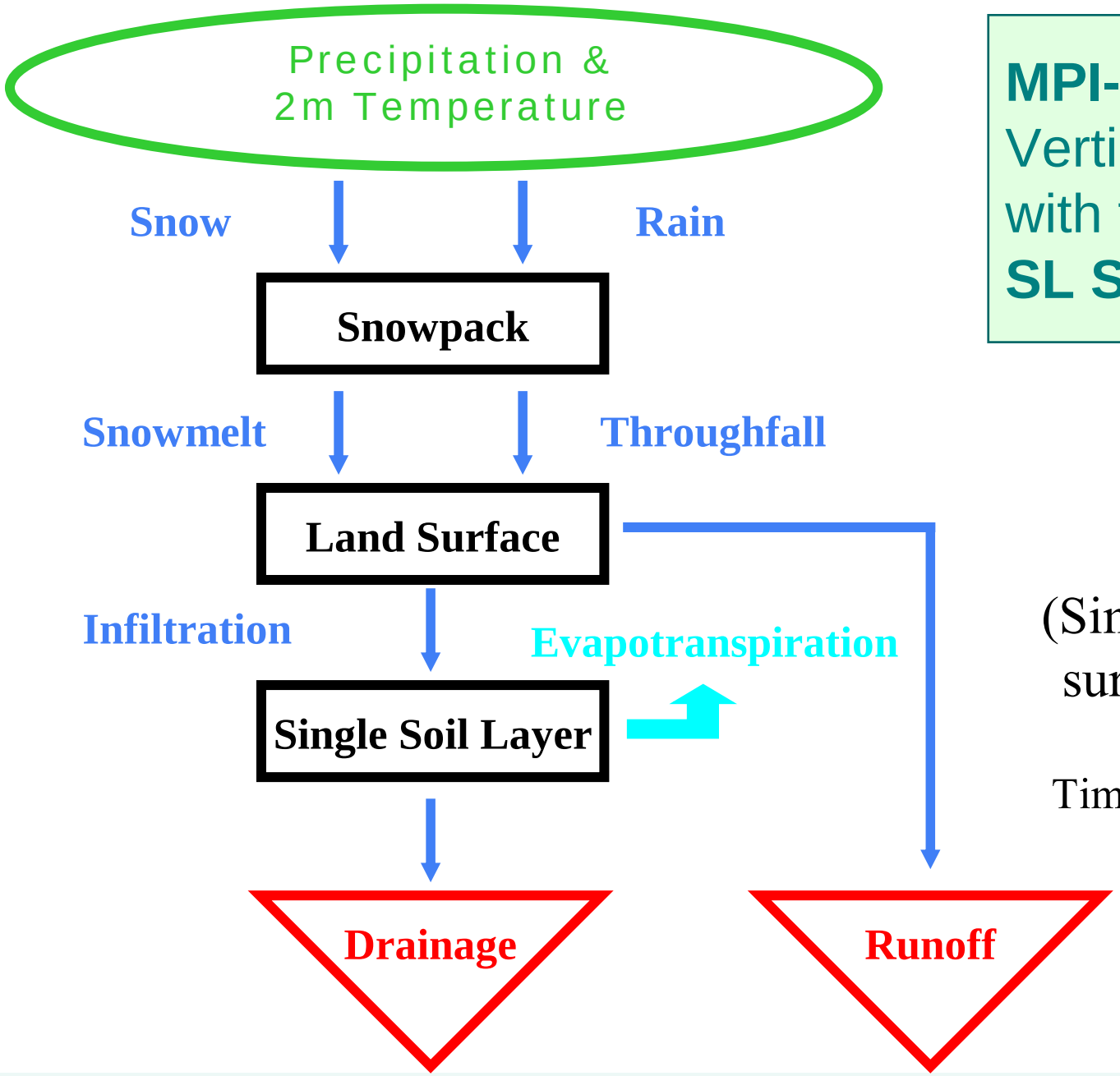
1. A new consolidated and integrated gridded data system for the 20th century
2. A new global hydrological modelling structure which is consistent for offline and online simulations
3. Improved data - model syntheses
4. Improved handling of uncertainties – linking climate, hydrological and data uncertainties
5. Improved catalogue of floods and droughts
6. Improved handling of extremes within global models
7. An understanding of hydrological/climate feedbacks (and how these affect the hydrological cycle)
8. A more explicit link between water resources and climate modelling

Hydrological Cycle



Global modelling chain in WATCH





MPI-HM:
Vertical Fluxes with the
SL Scheme

(Simplified Land surface scheme)

Time Step: 1 day

MPI-HM: Lateral Soil Water Fluxes with the **HD Model**

HD Model

(Hydrological Discharge)

- Hagemann & Dumenil (1998), Clim. Dyn. 14
- Hagemann & Dumenil Gates (2001), J Geo. Res. 106

State of the art discharge model

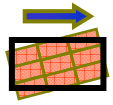
- Applied and validated on global scale at 1/2 deg.

Part of ECHAM5-MPIOM

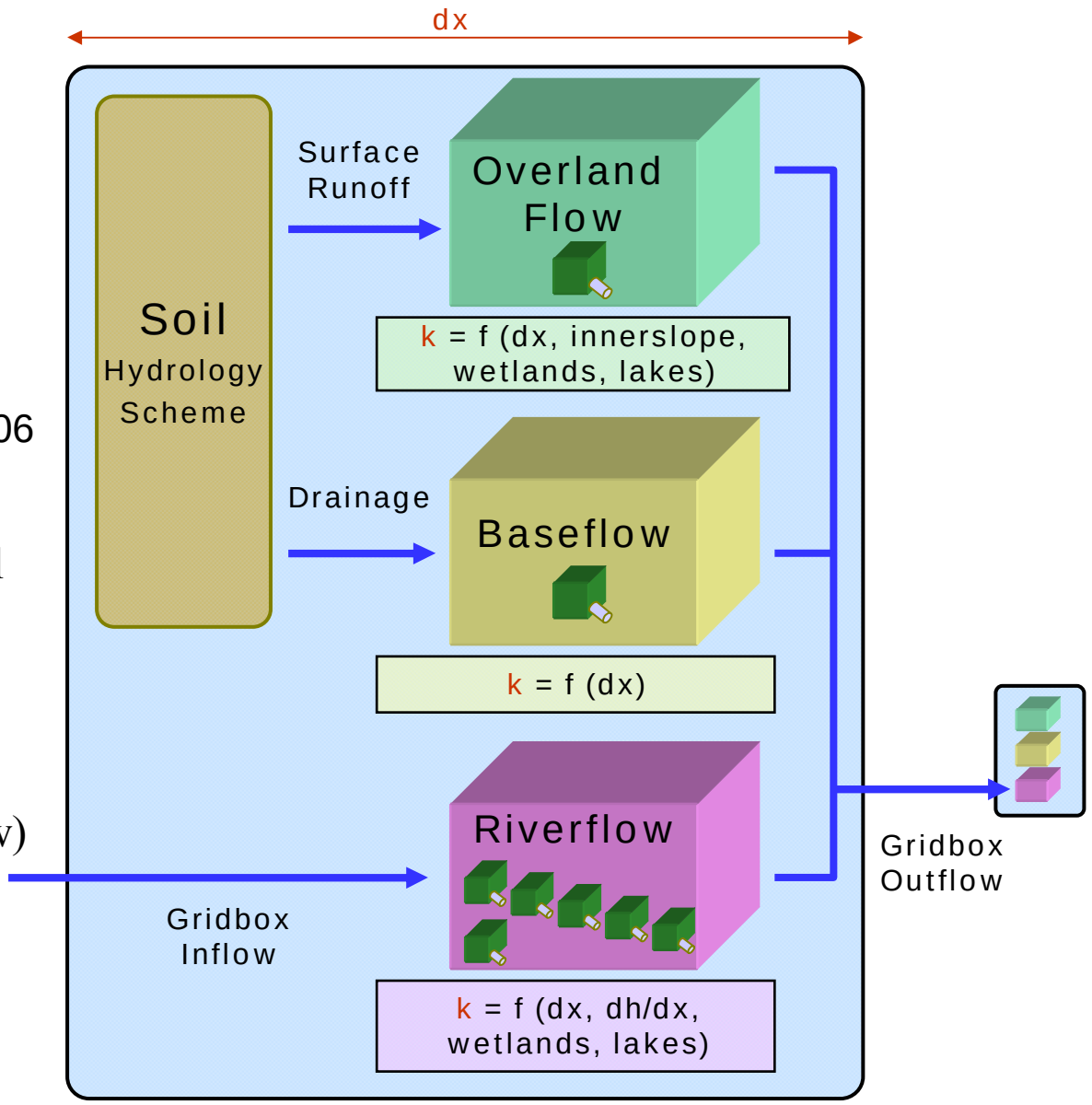
Time step: 1 day

(internally 6 hours for riverflow)

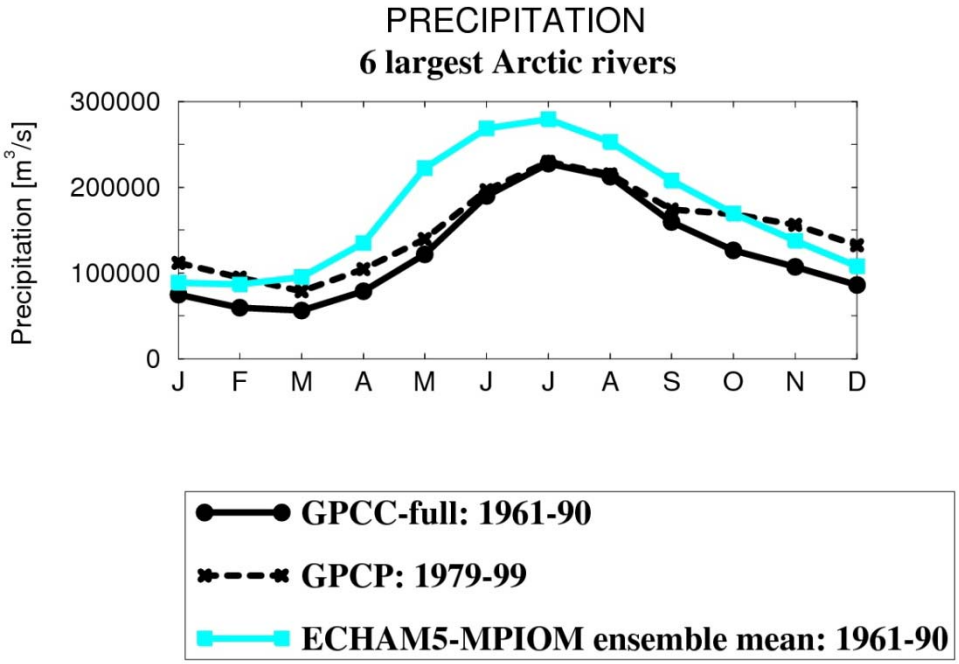
European version by Kotlarski:

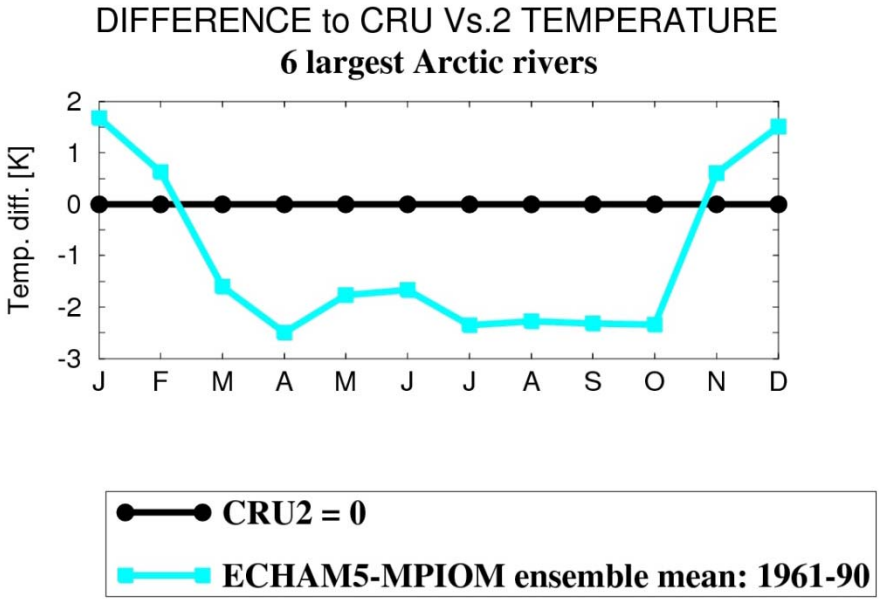
1/2 º  1/6 º

1 d → 1 h

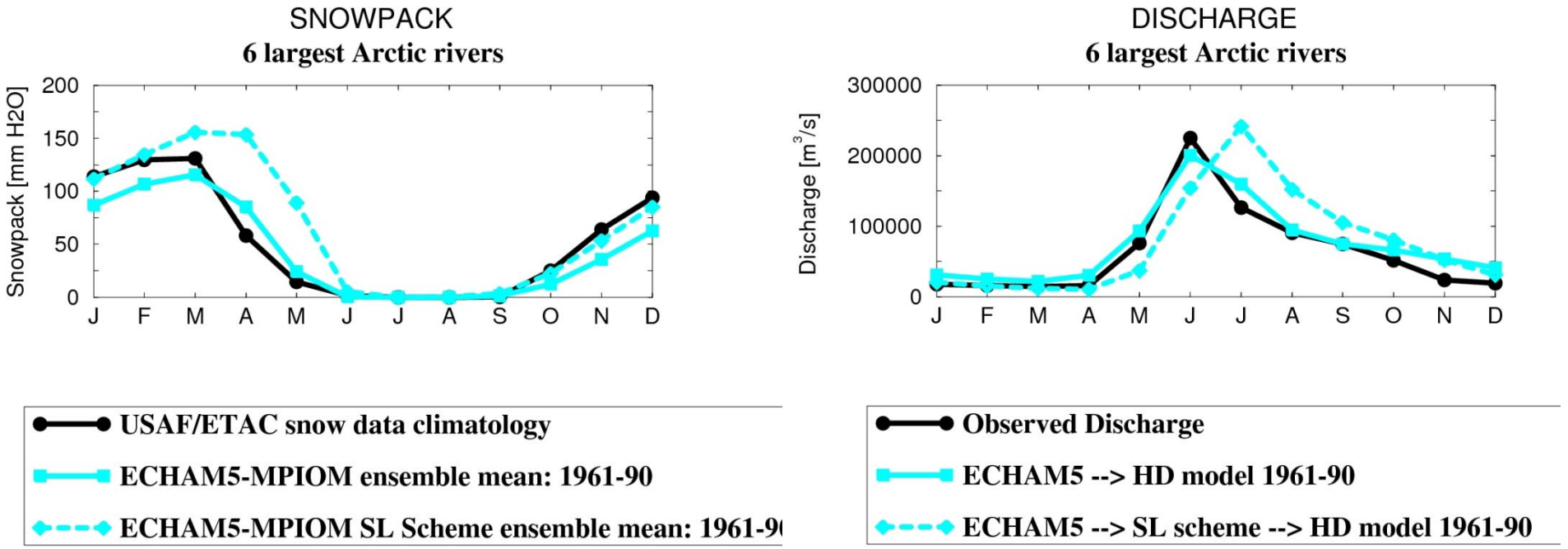


GCM output has biases

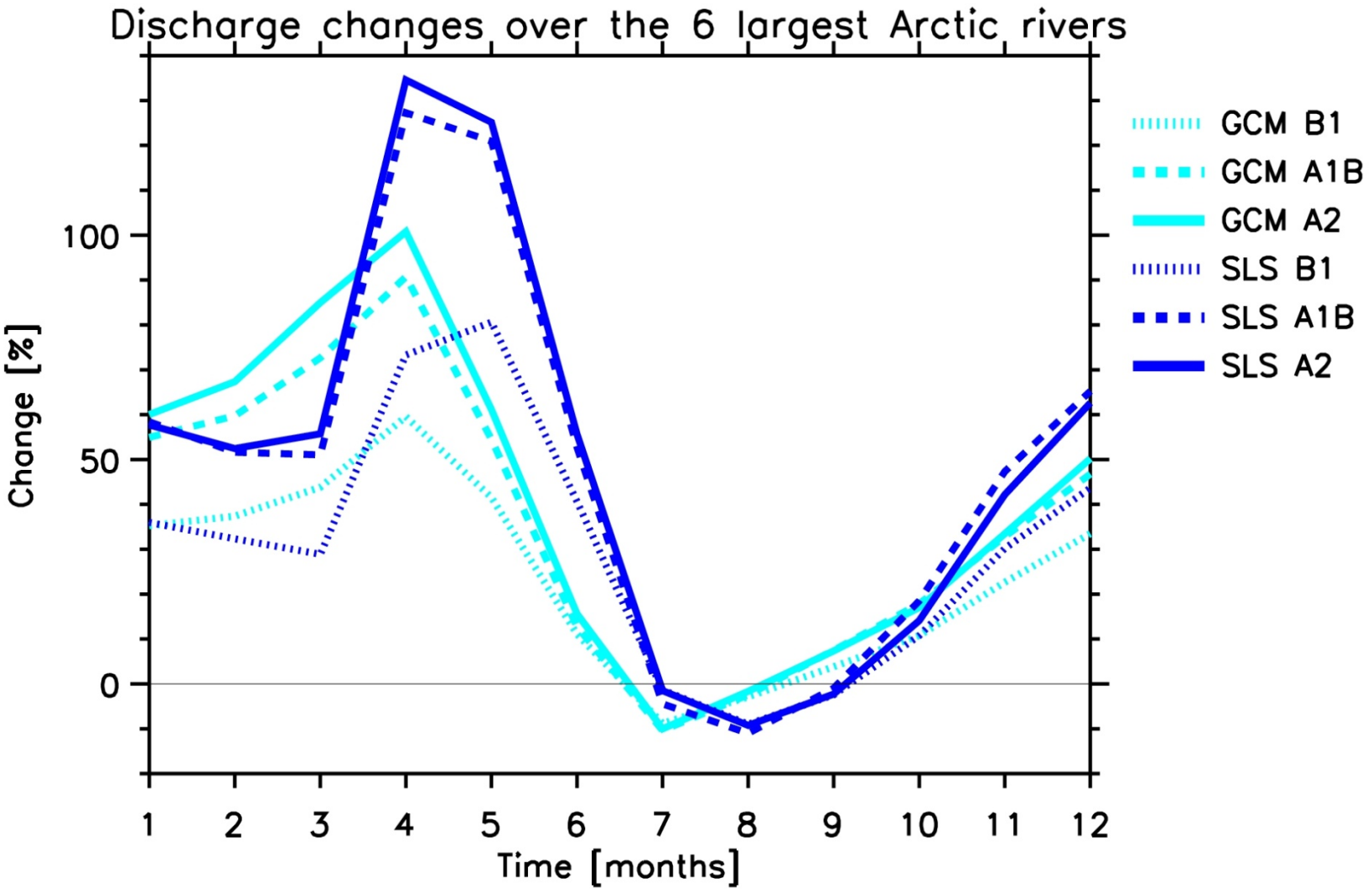




Biases may lead to further biases if GHM is applied



Implication on projected changes of discharge



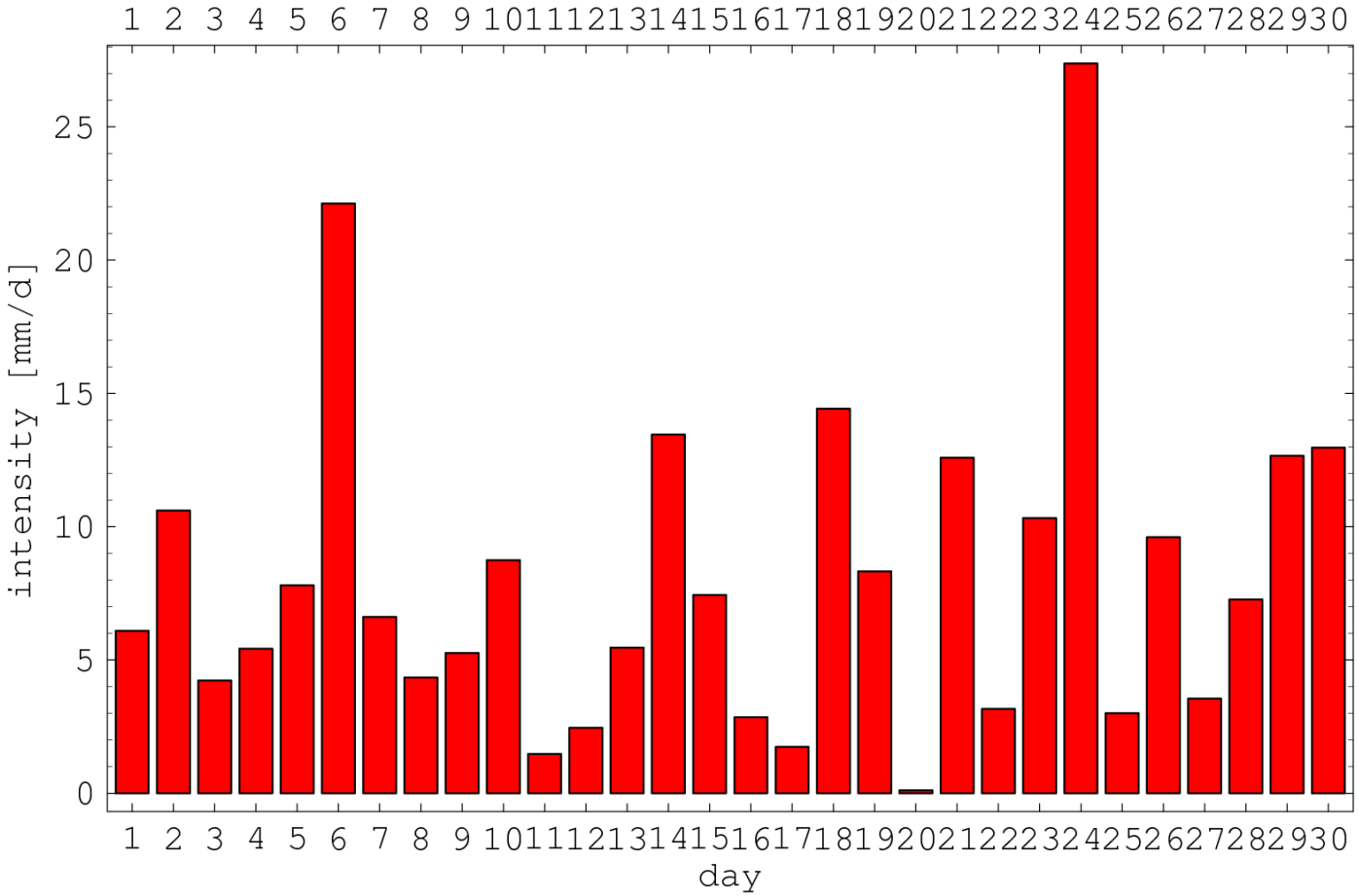
Bias correction required

- Bias correction should be applied to GCM data
- As large scale extremes shall also be considered, a simple correction of the mean values is not sufficient.
- Bias correction is required that corrects the whole distribution.

Methodology for simple statistical bias correction of precipitation and temperature time-series

- Based on Piani et al. (2009), TAC, accepted

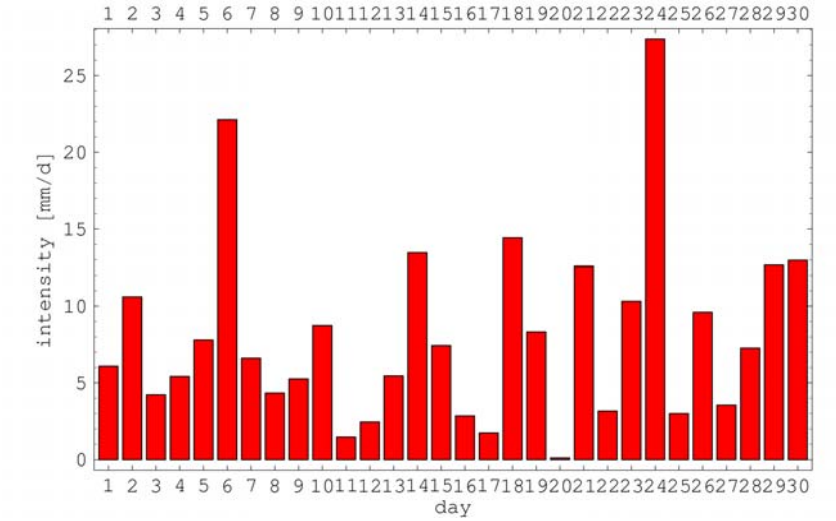
Observed daily precipitation time series



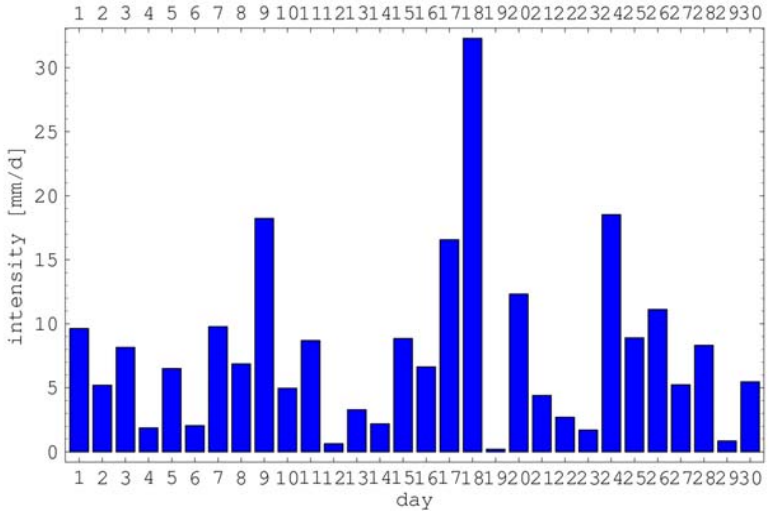
- such time-series are produced for **every single grid-point** on the globe

Observed and modeled time series

observed



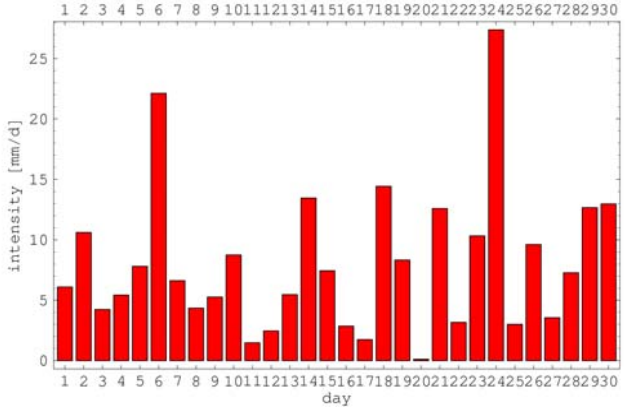
modeled

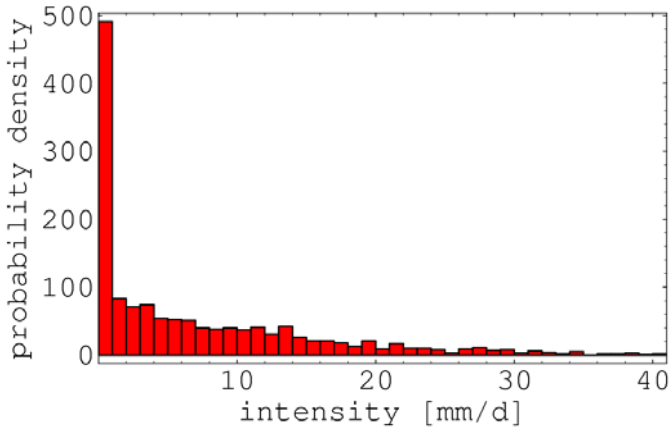


- a day-by-day comparison of observed and modeled data is not possible
- but climate is defined by the statistics of the data
- a bias-correction should impact on the **climatological statistics** of the time-series

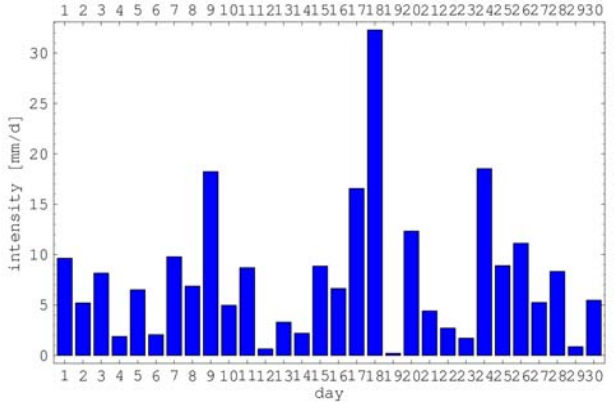
Observed and modeled time series

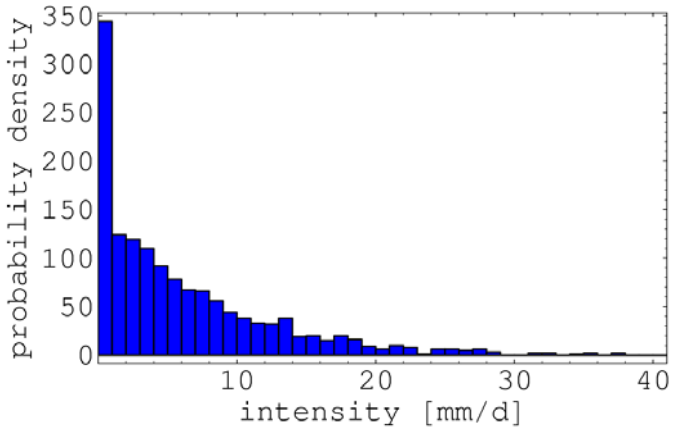
observed





modeled



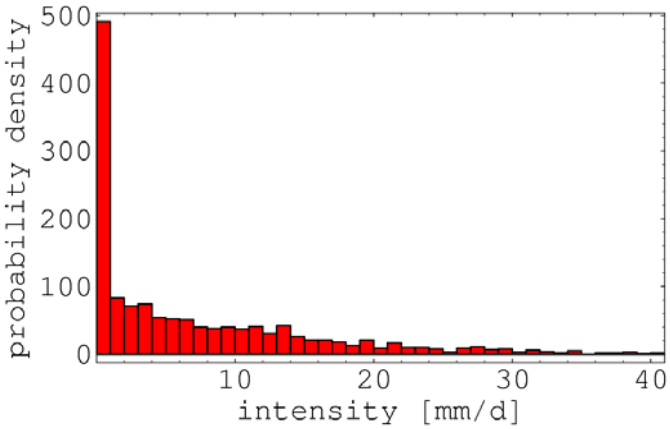


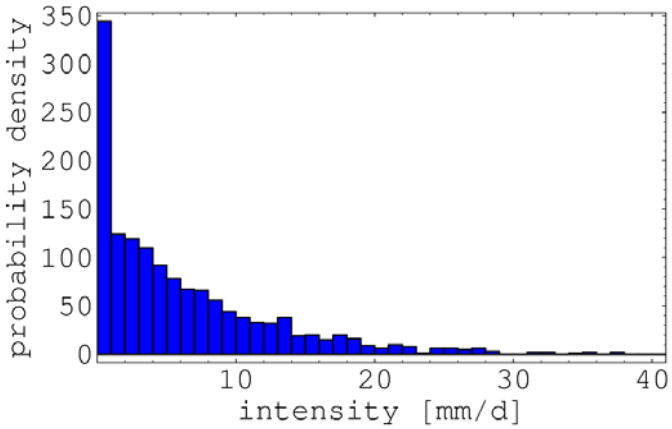
- produce histograms (probability density functions) of observed and modeled data
- many days are dry days (spike at zero intensity)

Observed and modeled time series

observed **modeled**

now we are independent of the time-series





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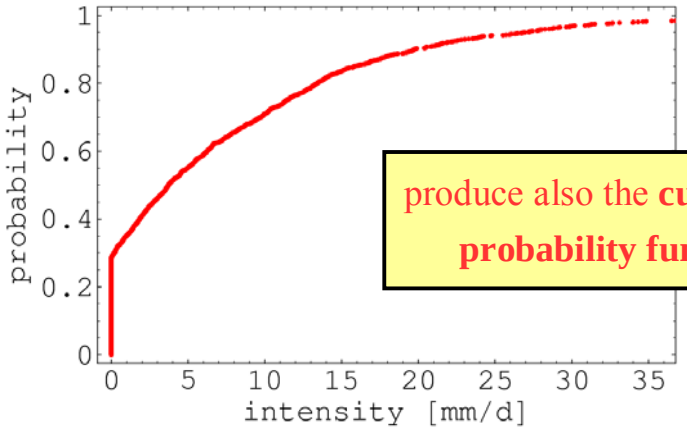
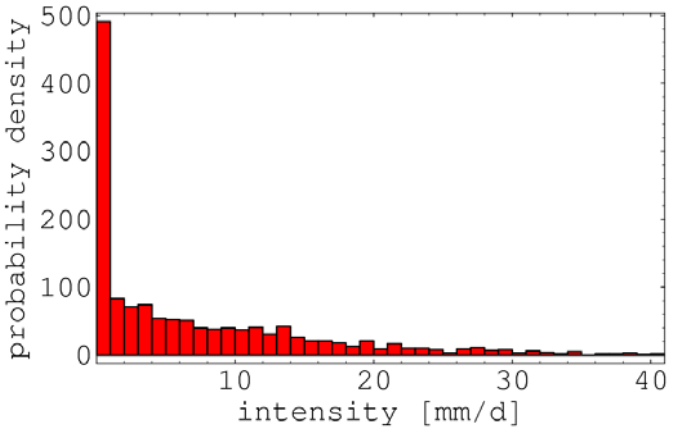
Observed and modeled time series

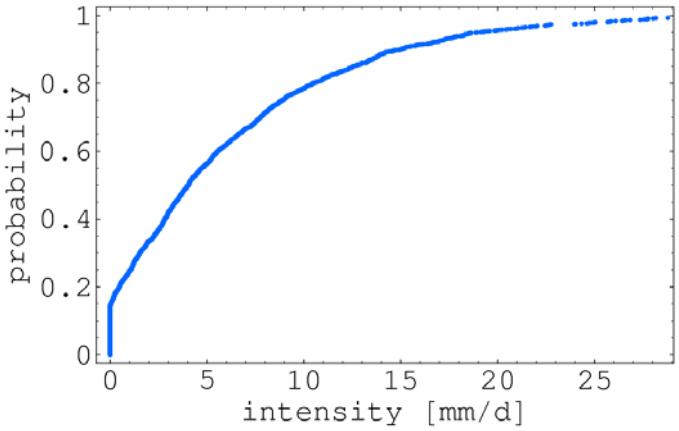
observed

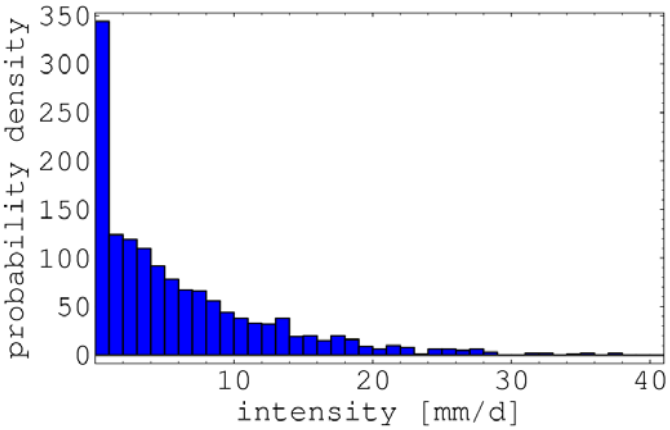


produce also the **cumulative probability function**



modeled





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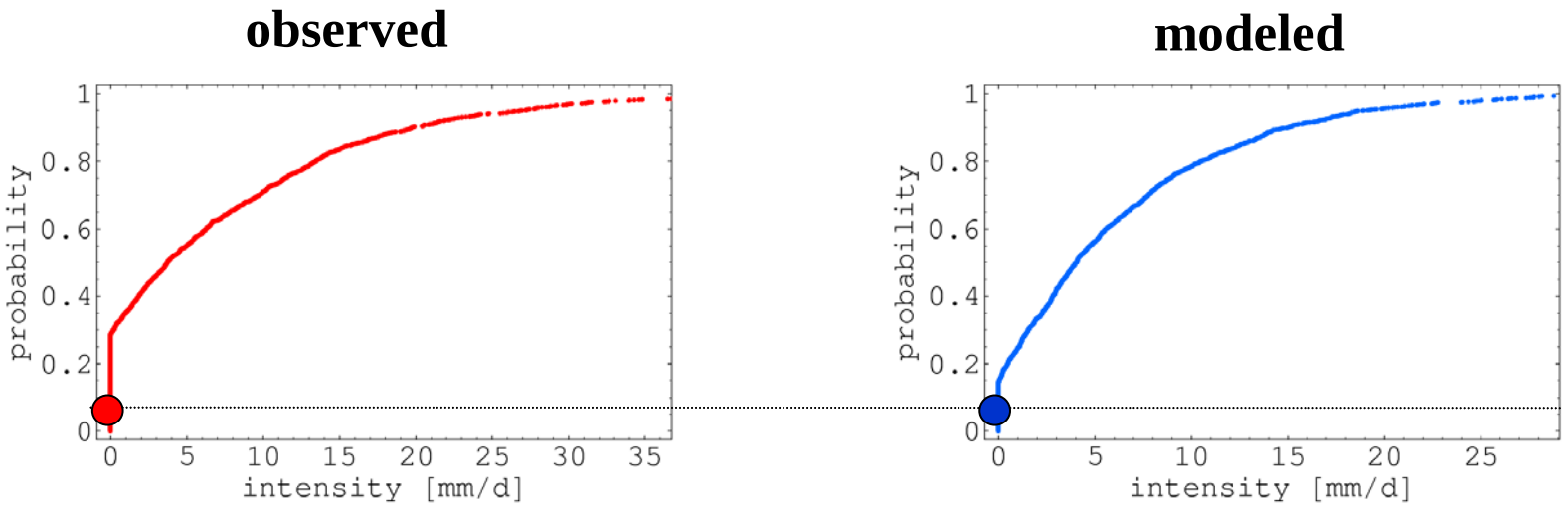
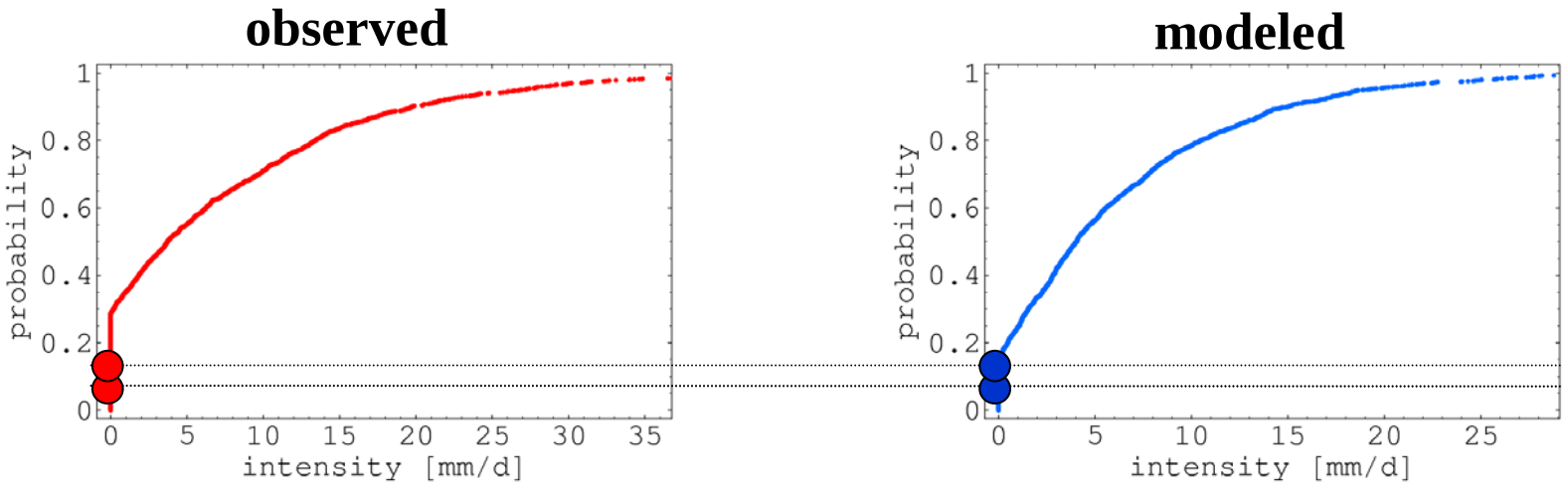
Observed and modeled time series



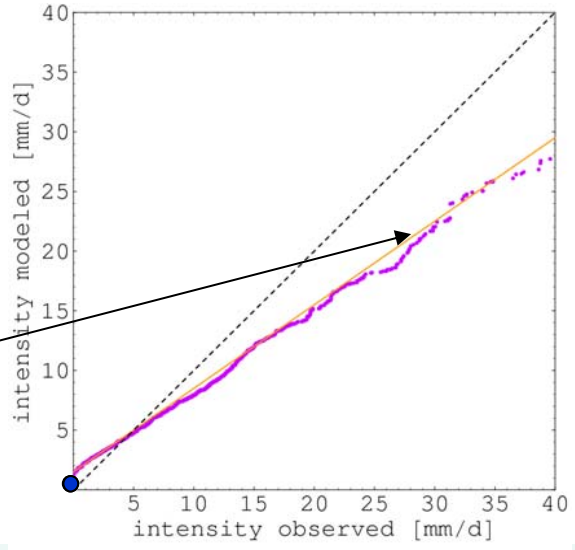
- probability mapping defines a **transform function**

Observed and modeled time series



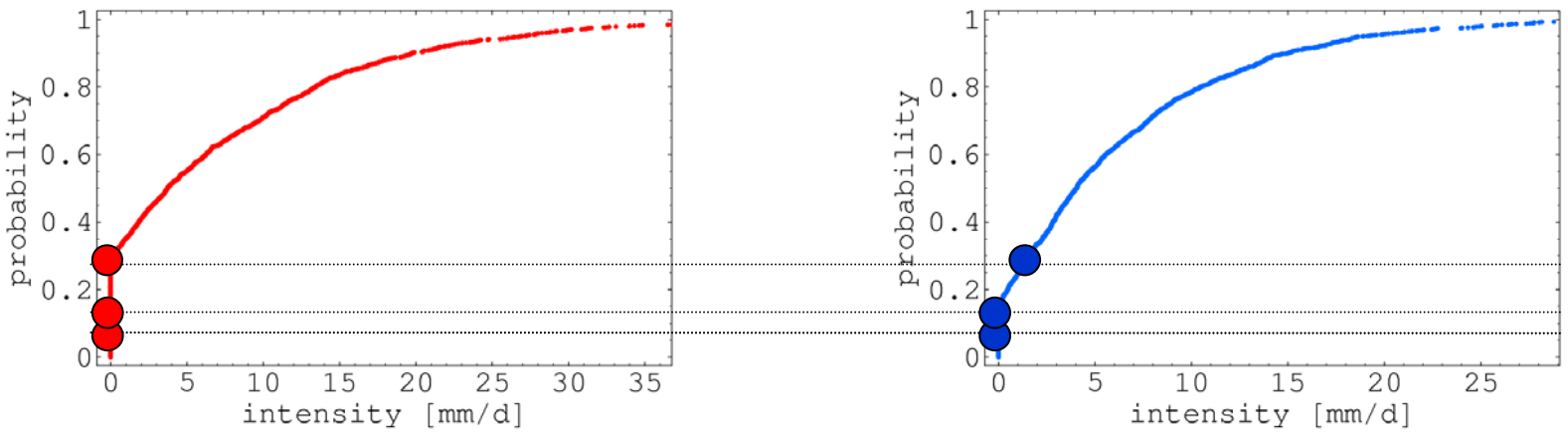
- probability mapping defines a **transform function**

orange: 2-parameter fit to transform function



Observed and modeled time series

observed **modeled**



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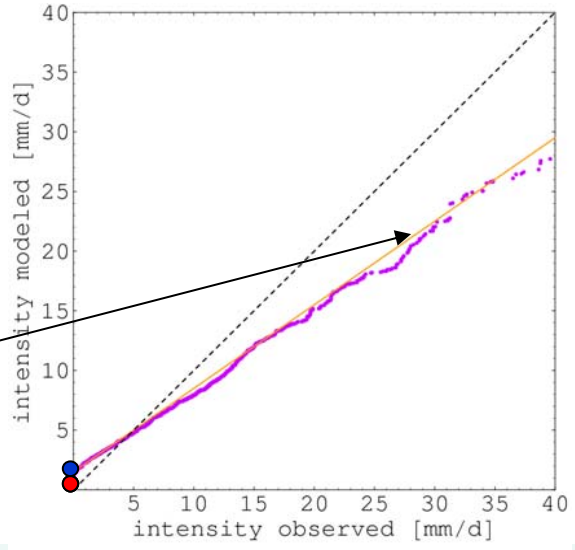
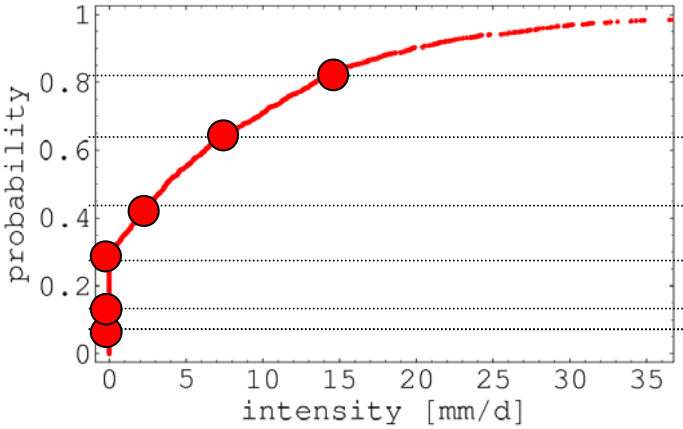
orange: 2-parameter fit to transform function

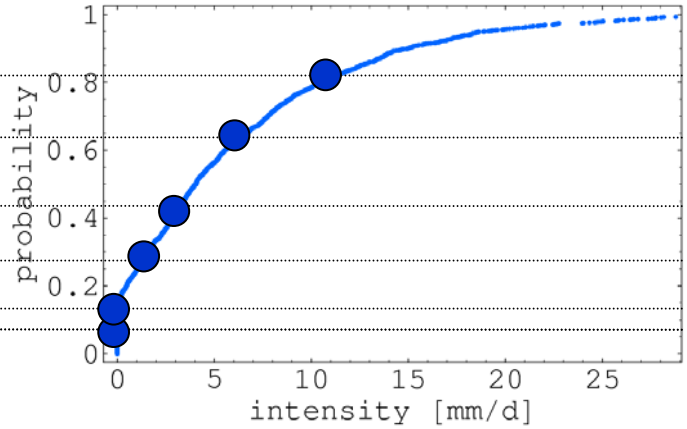


Observed and modeled time series

observed



modeled



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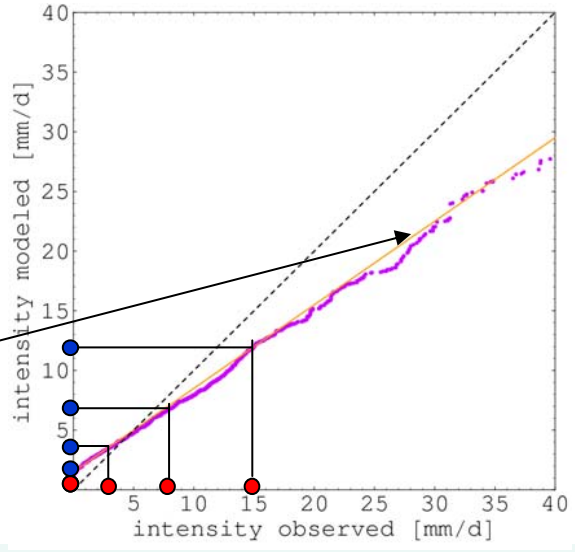
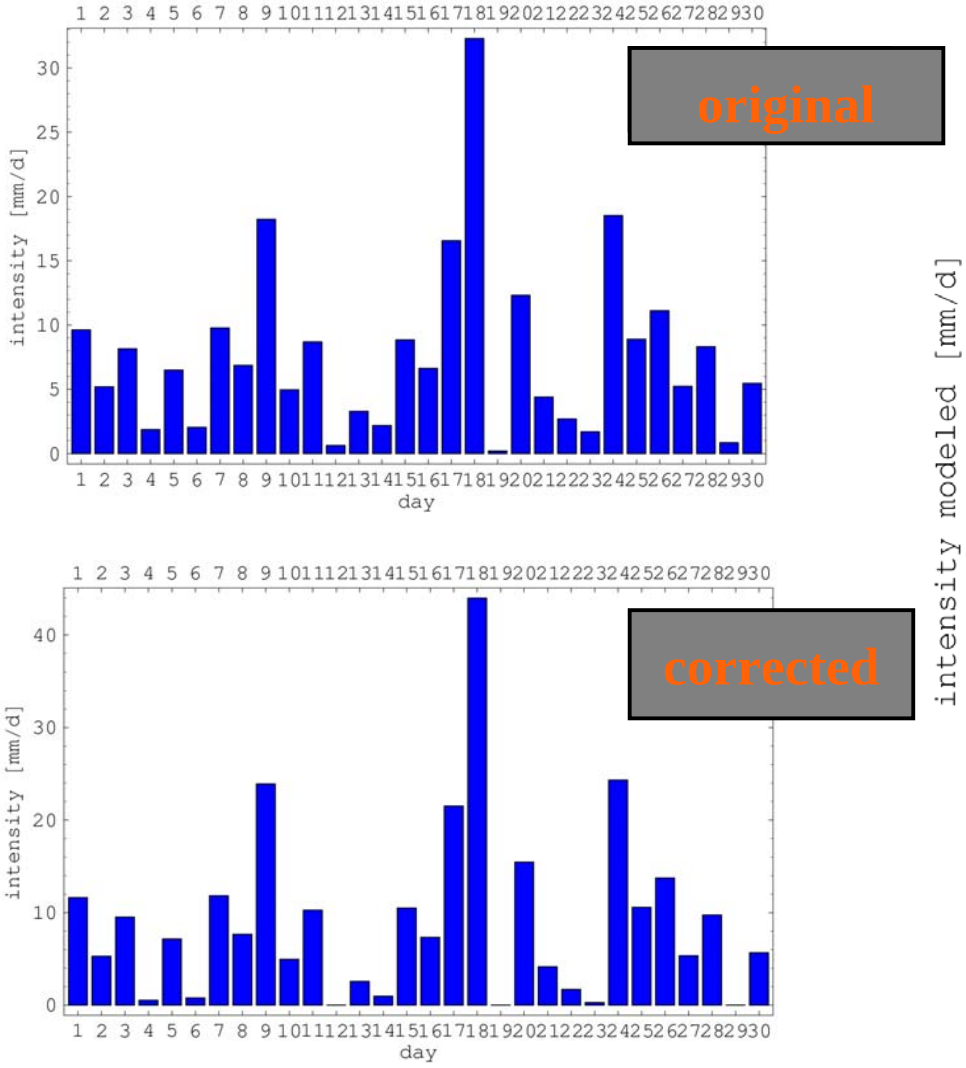
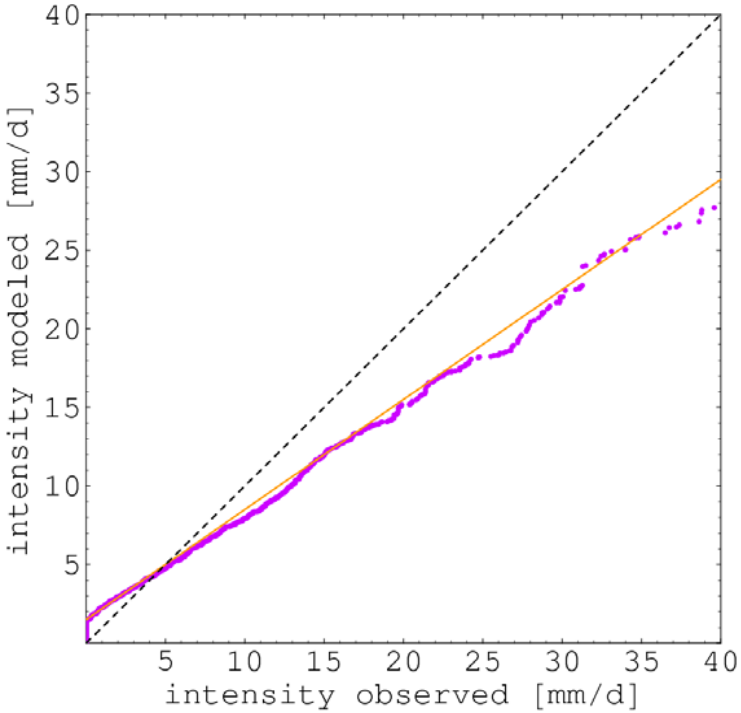


Observed and modeled time series

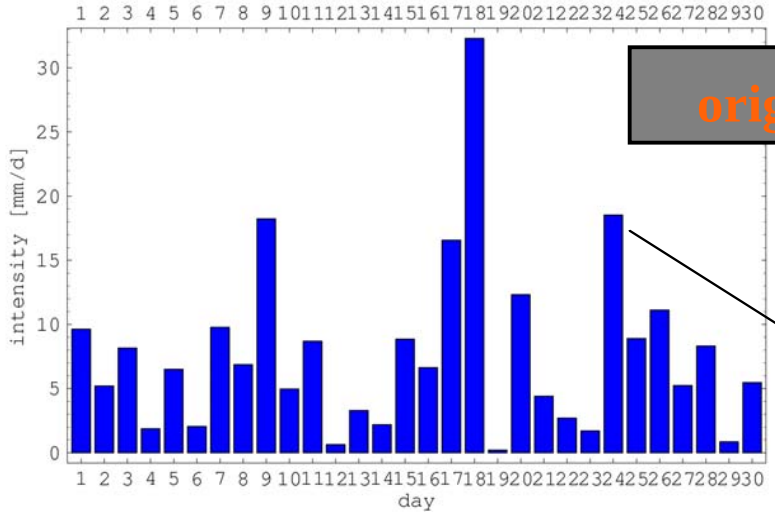
modeled



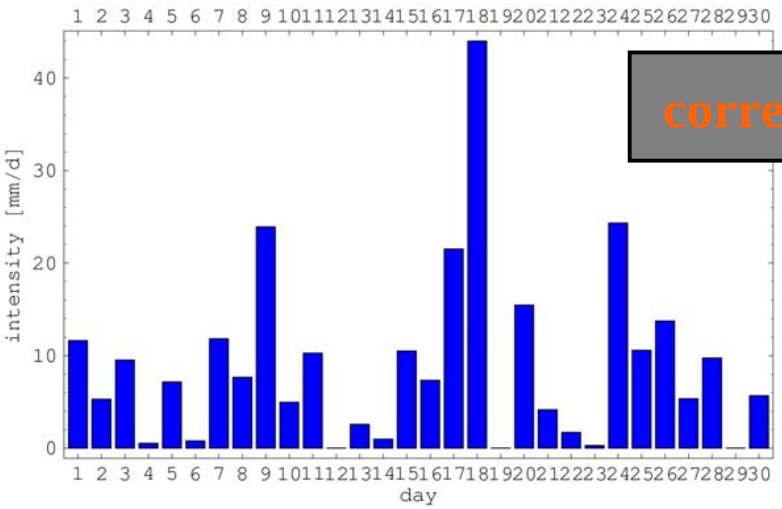


Observed and modeled time series

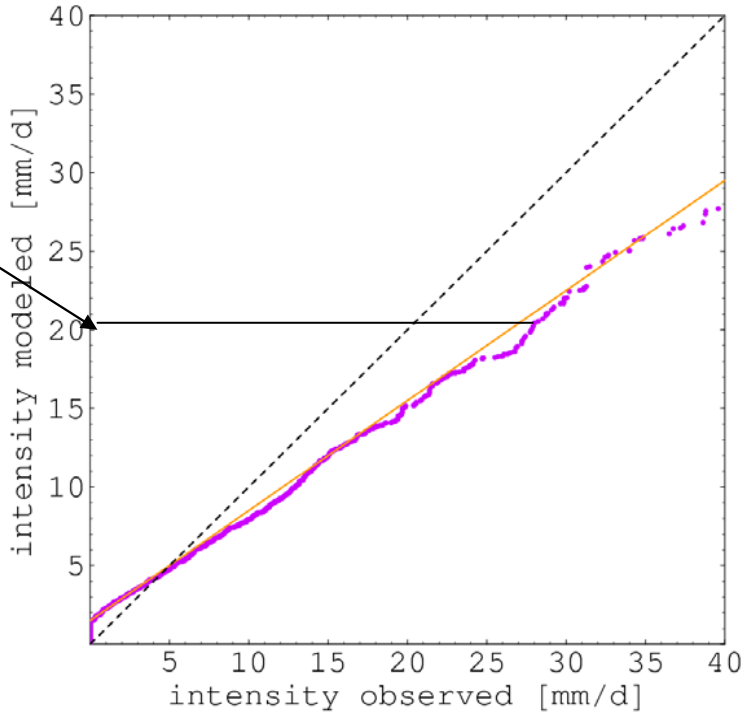
modeled



original

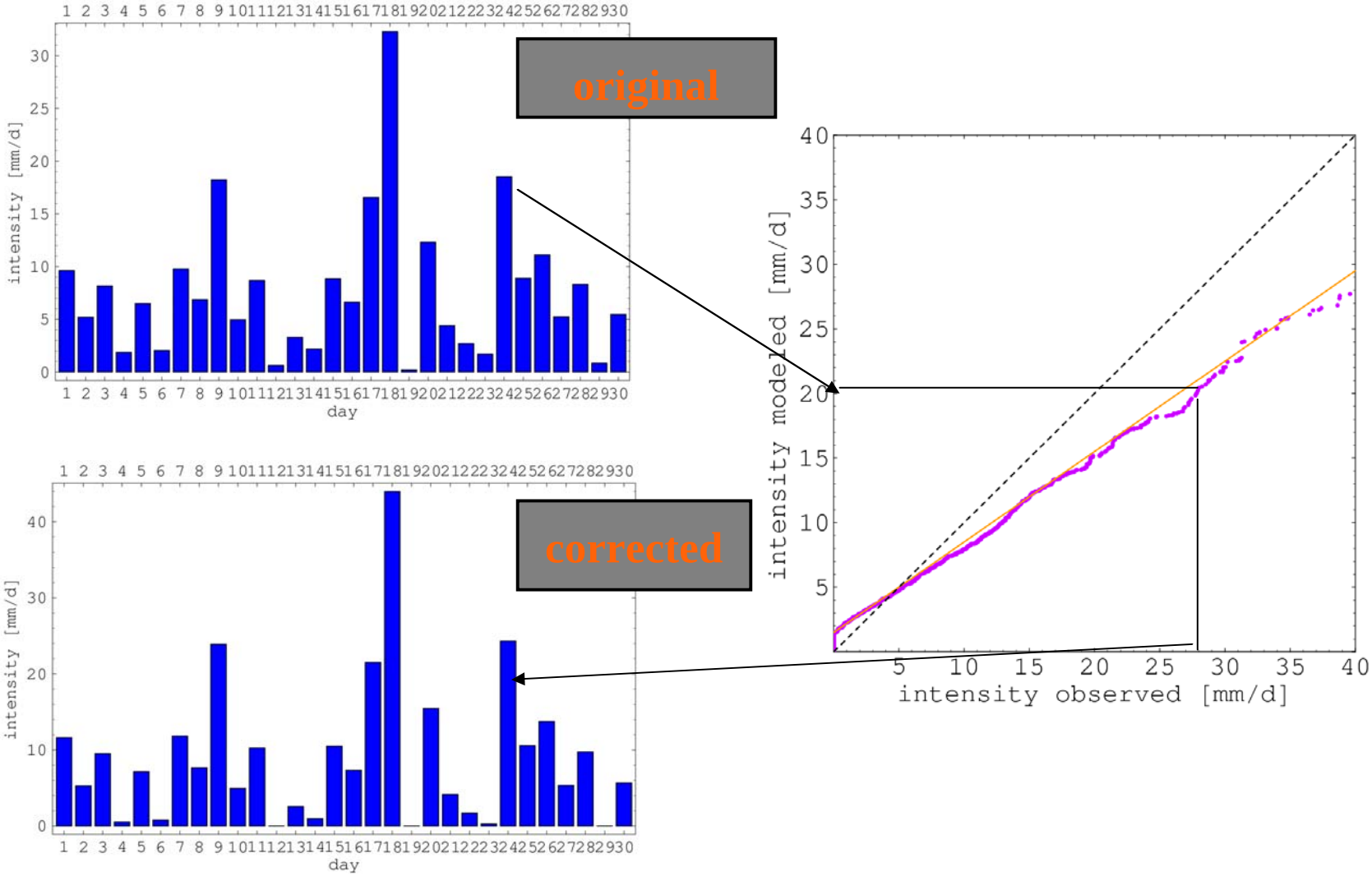


corrected



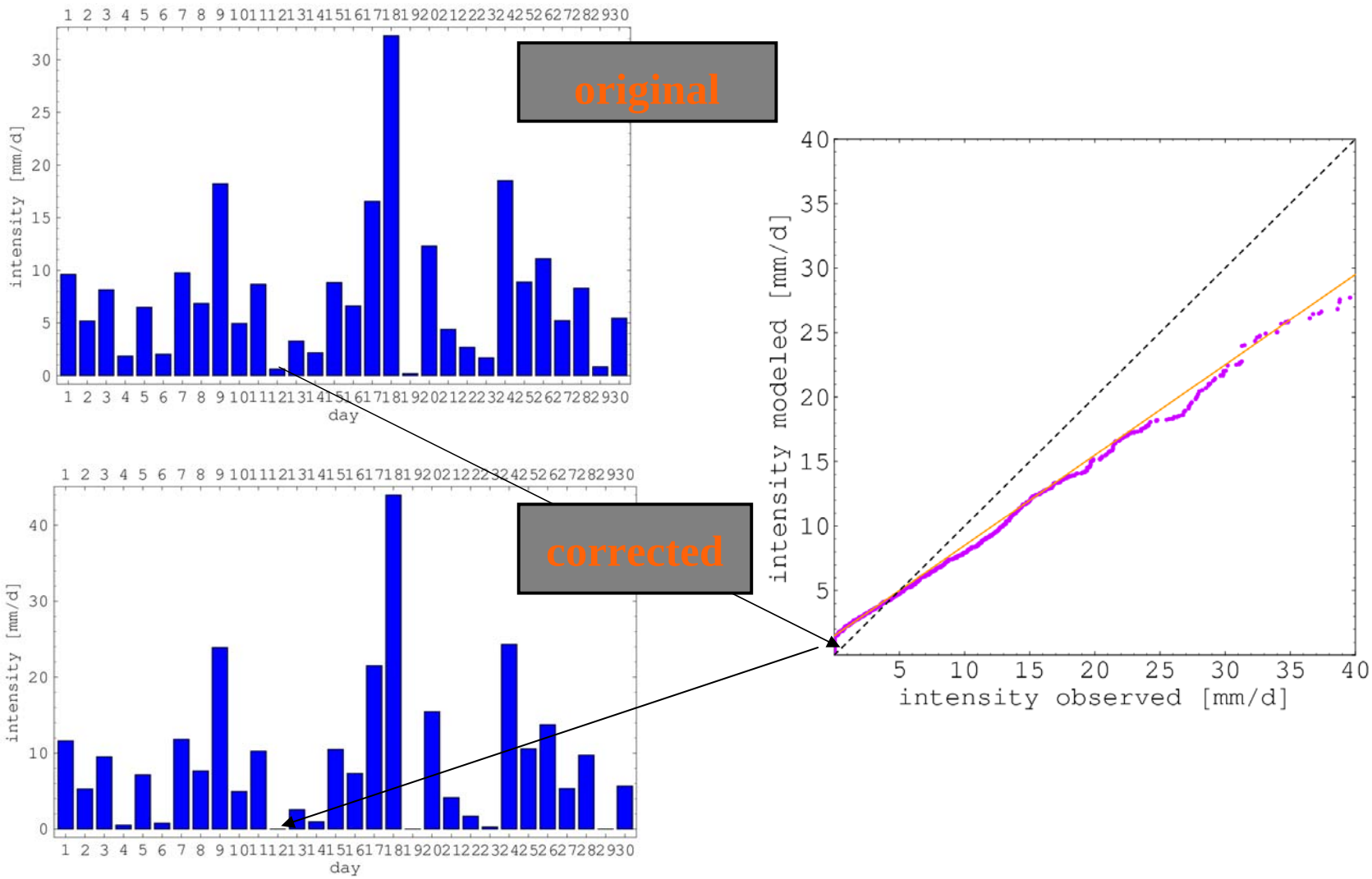
Observed and modeled time series

modeled

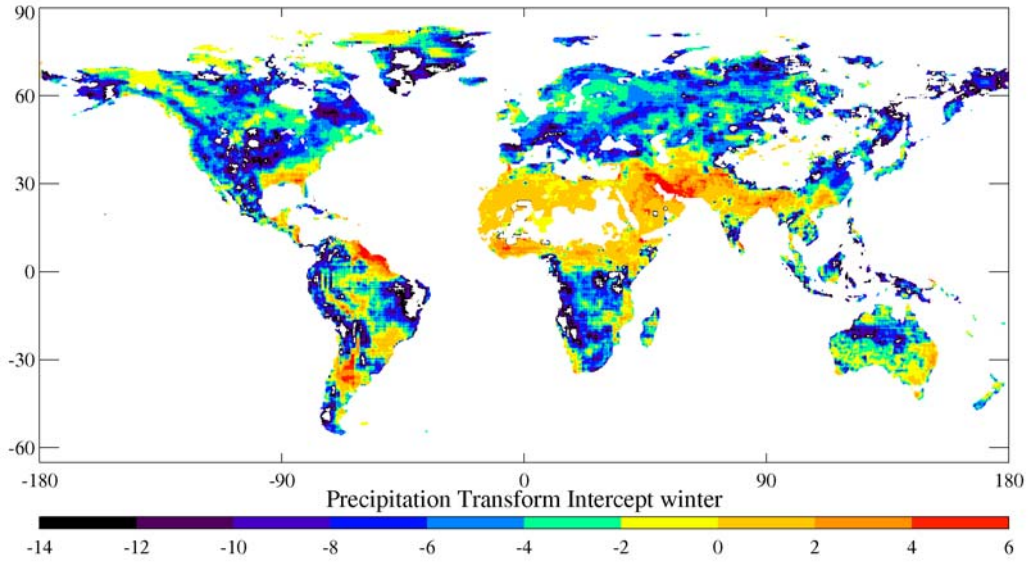


Observed and modeled time series

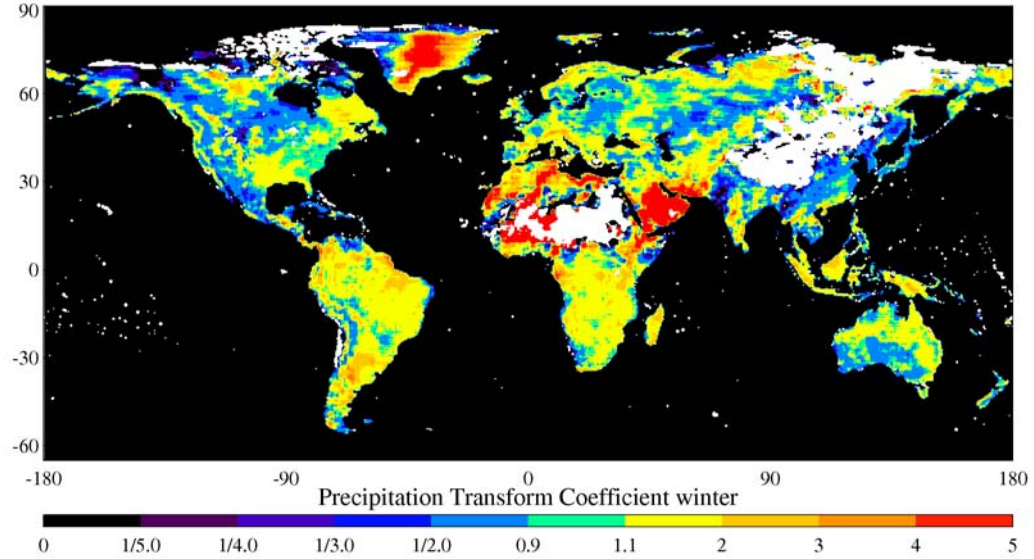
modeled



Global map of transform function coefficients



intercept



slope

- In regions with insufficient data, only the mean will be corrected.

Summary of methodology

- In theory: bias correction **adjusts all moments** of distribution function for each day
- In practice: a **2-parameter fit to the transform function** is used
- For most regions this is a **good approximation**
- Using larger number of parameters may not be adequate as correction needs to be **time-independent on climatological time-scales** (>10 years)
- Similar procedure has been followed for temperature correction
- First try: seasonal transfer functions are used.

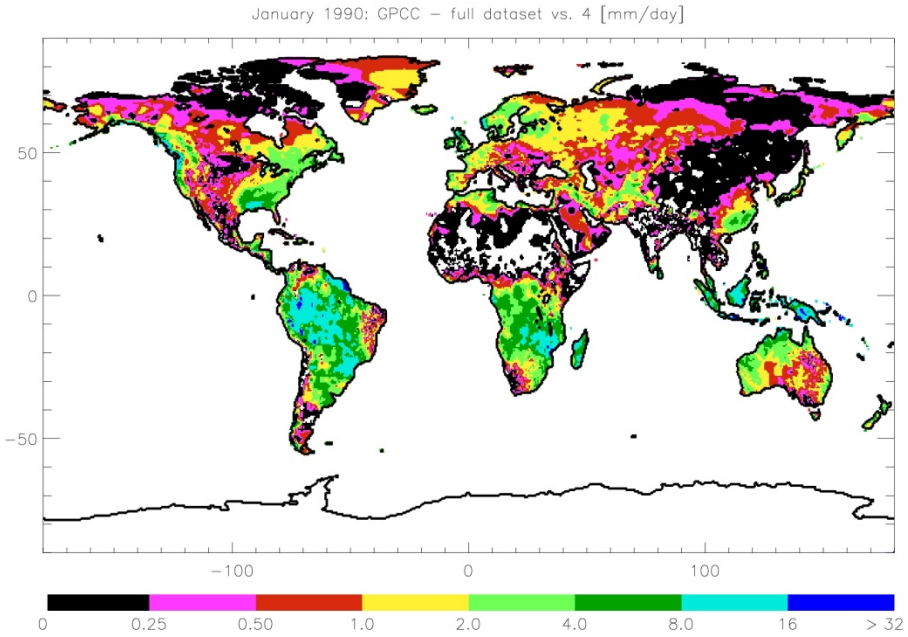
WATCH reference dataset

WATCH forcing data by Graham Weedon (UKMO), Pedro Viterbo, Sandra Gomes (Uni Lisboa)

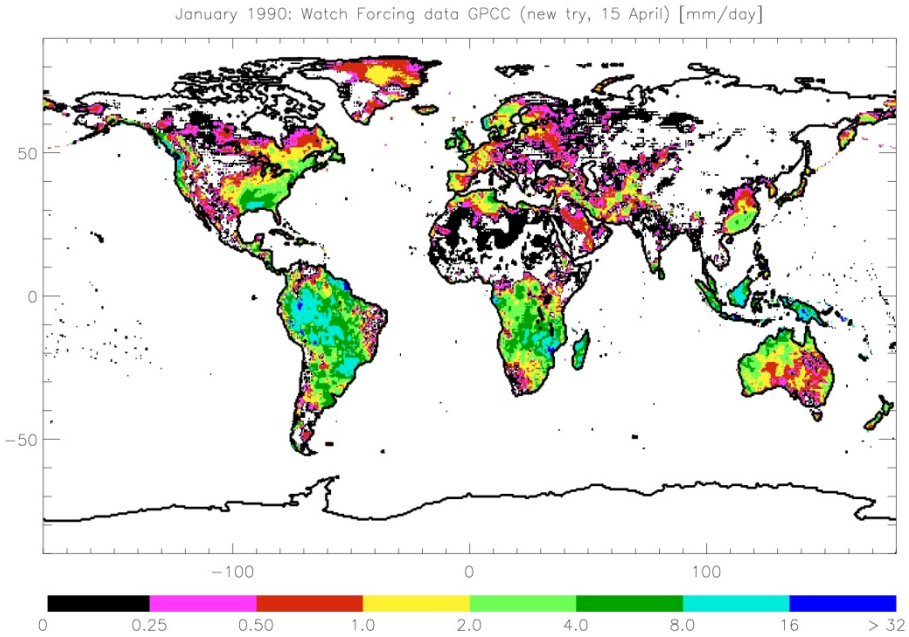
- ERA40 data (1958-2001) were interpolated to 0.5 degree, 3-hourly data, land points only (CRU TS2.1 land-sea mask).
- A correction for elevation differences between ERA40 and CRU was applied.
- For 2m temperature, a correction of the monthly means with CRU data was performed.
- For rain and snowfall, a correction of the monthly means with GPCC Vs.4 data was conducted.
- In addition, a gauge-undercatch correction created by Jennifer Adam (Washington State University) was used.
- 3-hourly data were aggregated to daily data by Jens Heinke (PIK).

Precipitation January 1990

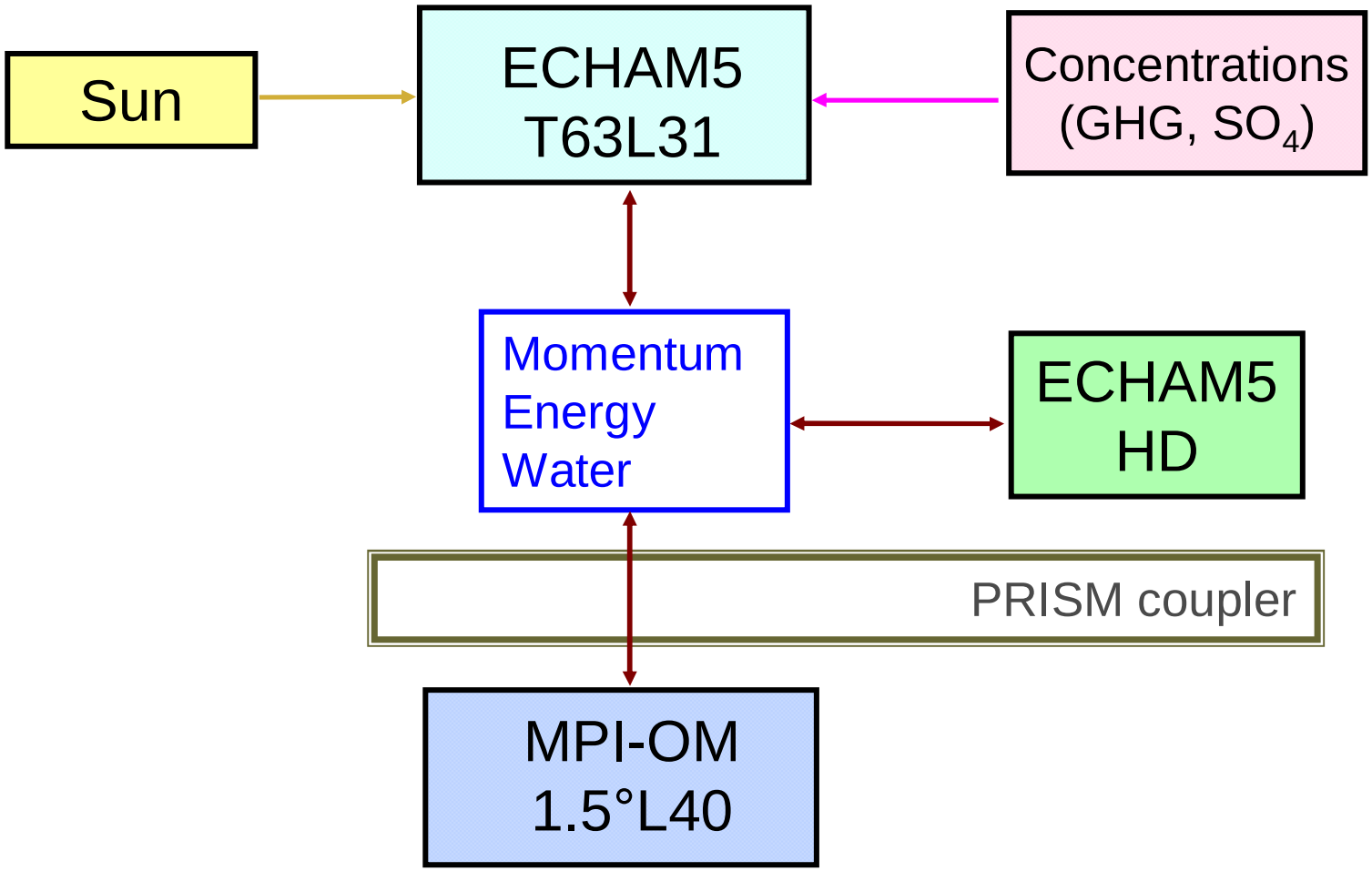
GPCC Vs. 4



WATCH Forcing data



IPCC AR4 simulations: ECHAM5/MPIOM model components



IPCC simulations: Setup for 20th century

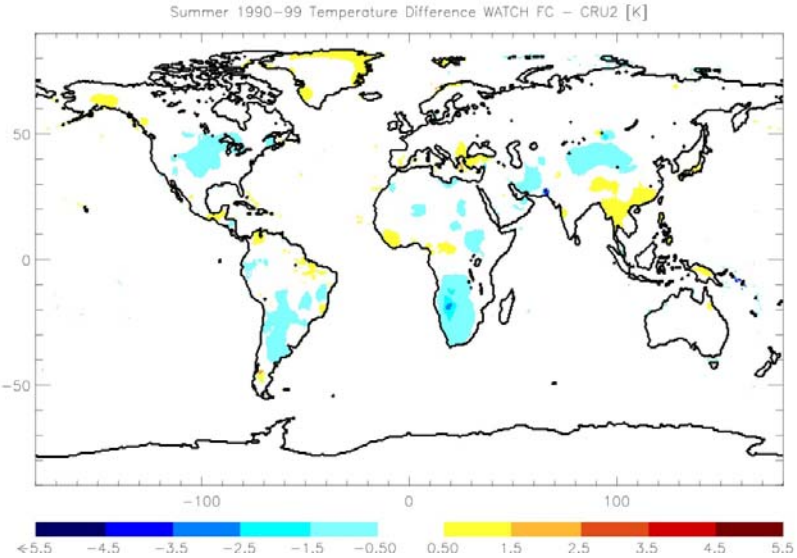
- GCM ECHAM5/MPIOM

- Horizontal Resolution of ECHAM5: T63 ~ 200 km
- Historical Climate (1860 – 2000)
- Forcing with observed concentrations of CO2, Methane, N2O, CFCs, Ozone (Tropos-/Stratosphere), Sulfate Aerosols (direct and 1. indirect effect)

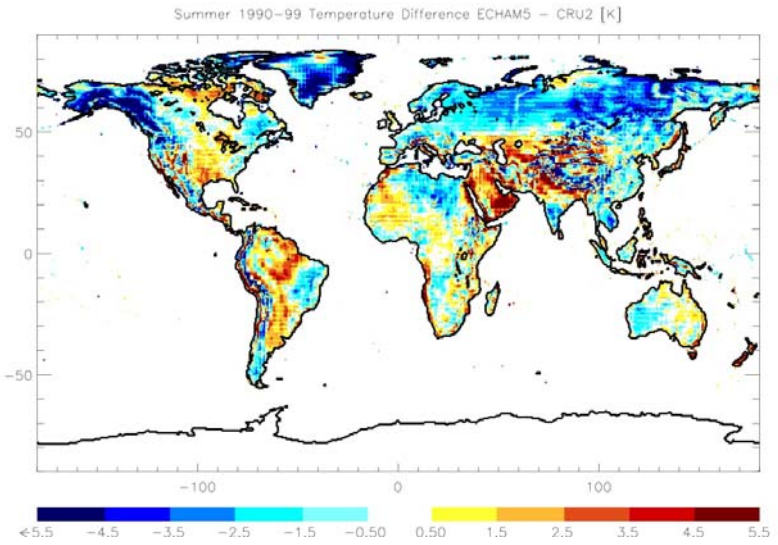
- **Bias correction factors derived in 1960-1969**
- **Factors applied for 1990-1999**

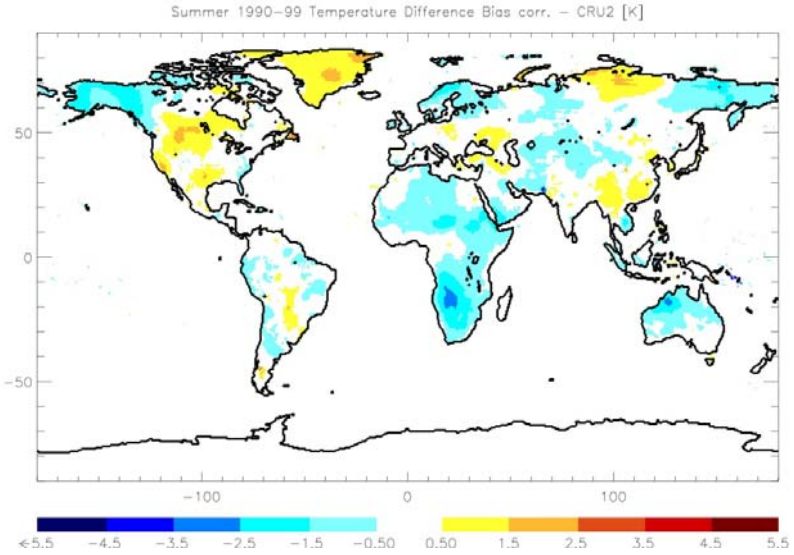
Mean temperature difference to CRU2 for summer 1990-1999

WATCH Forcing data



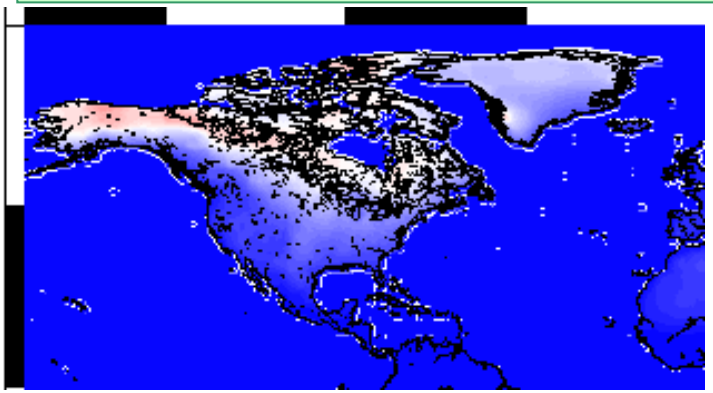
ECHAM5/MPIOM



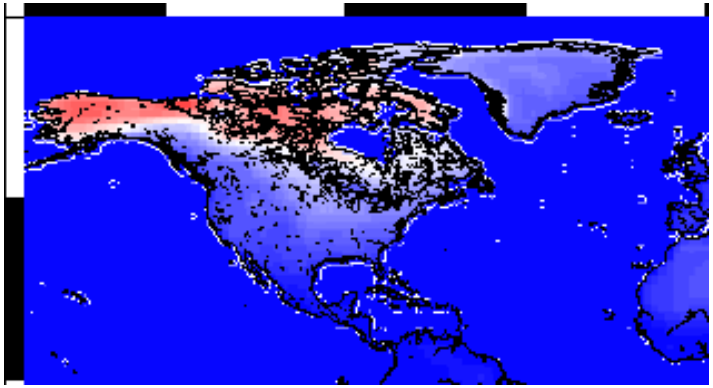


Bias-corrected ECHAM5/MPIOM data

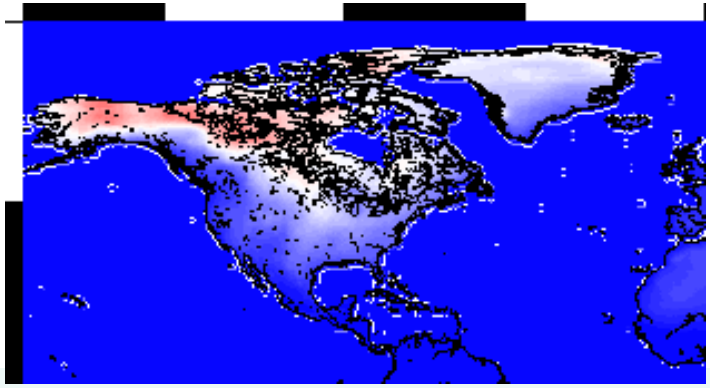
Temperature variance in winter (DJF) 1990-1999



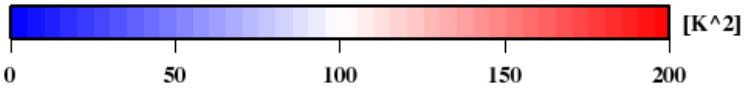
WATCH Forcing data



ECHAM5/MPIOM

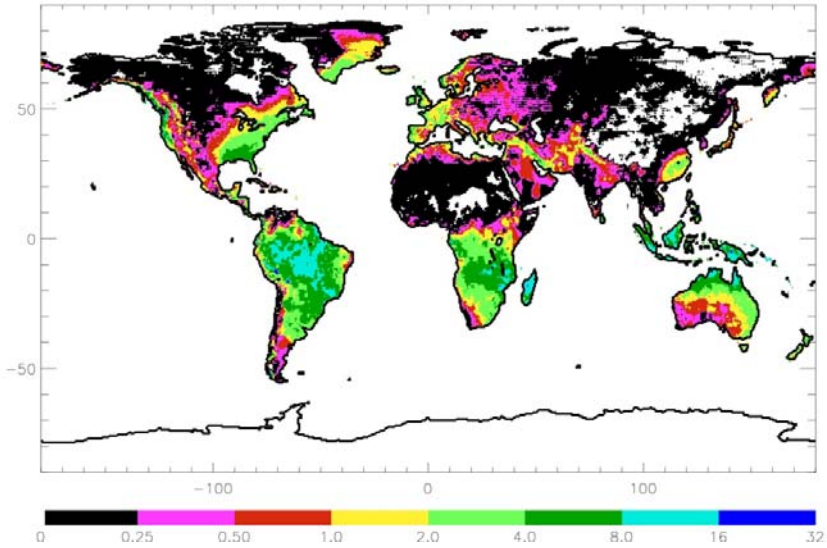


Bias-corrected ECHAM5/MPIOM data

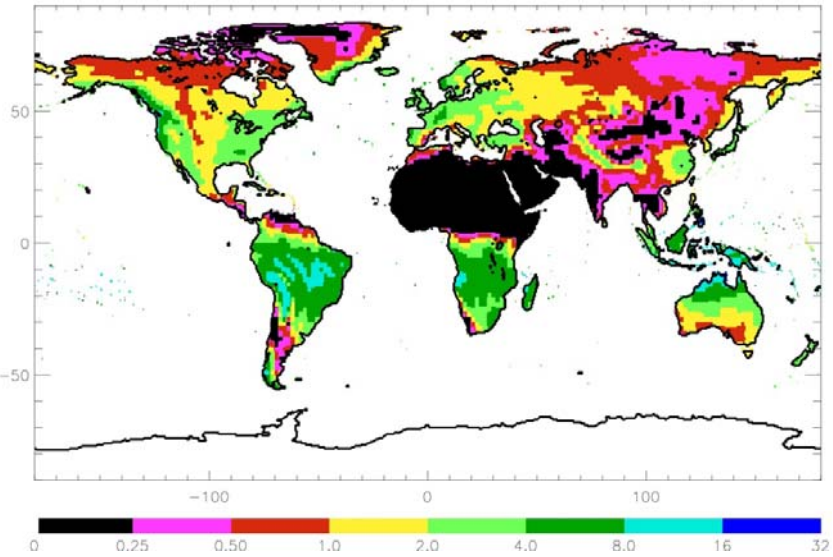


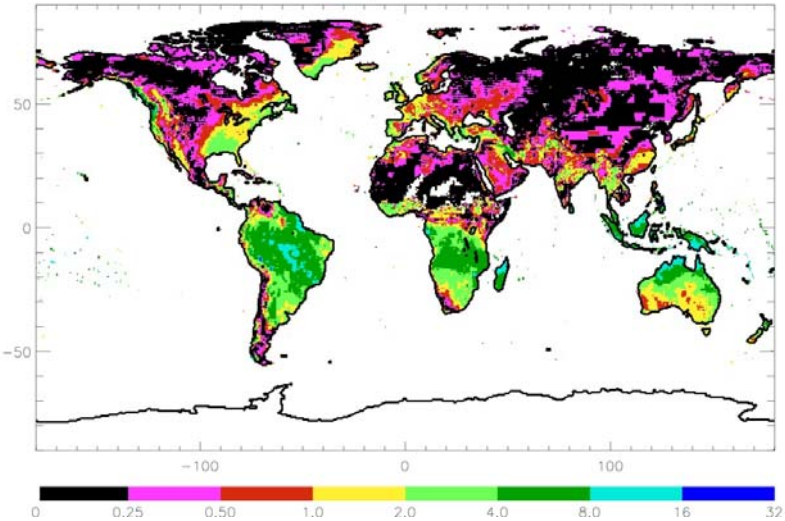
Mean Precipitation for January 1990-1999

WATCH Forcing data



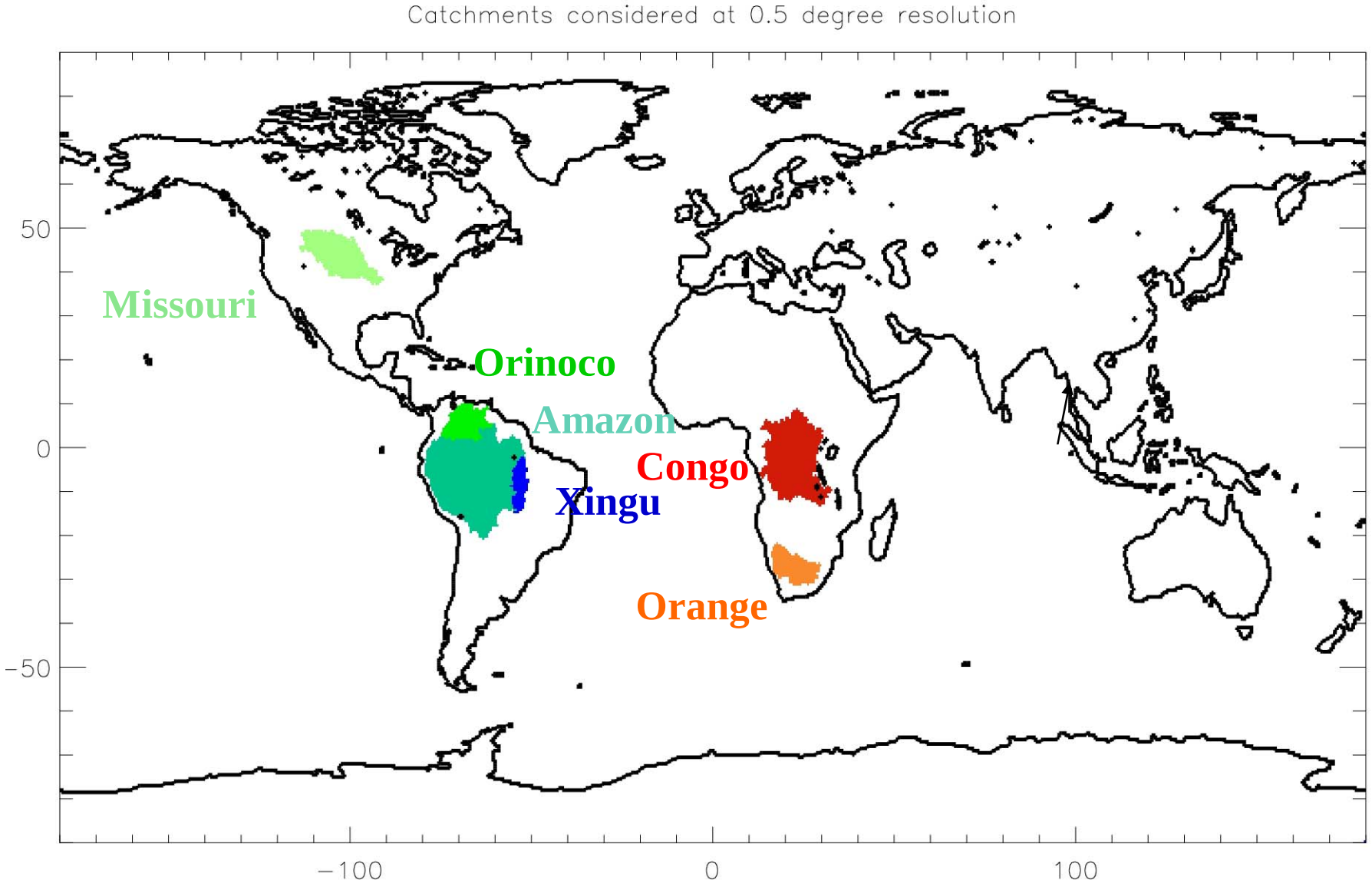
ECHAM5/MPIOM

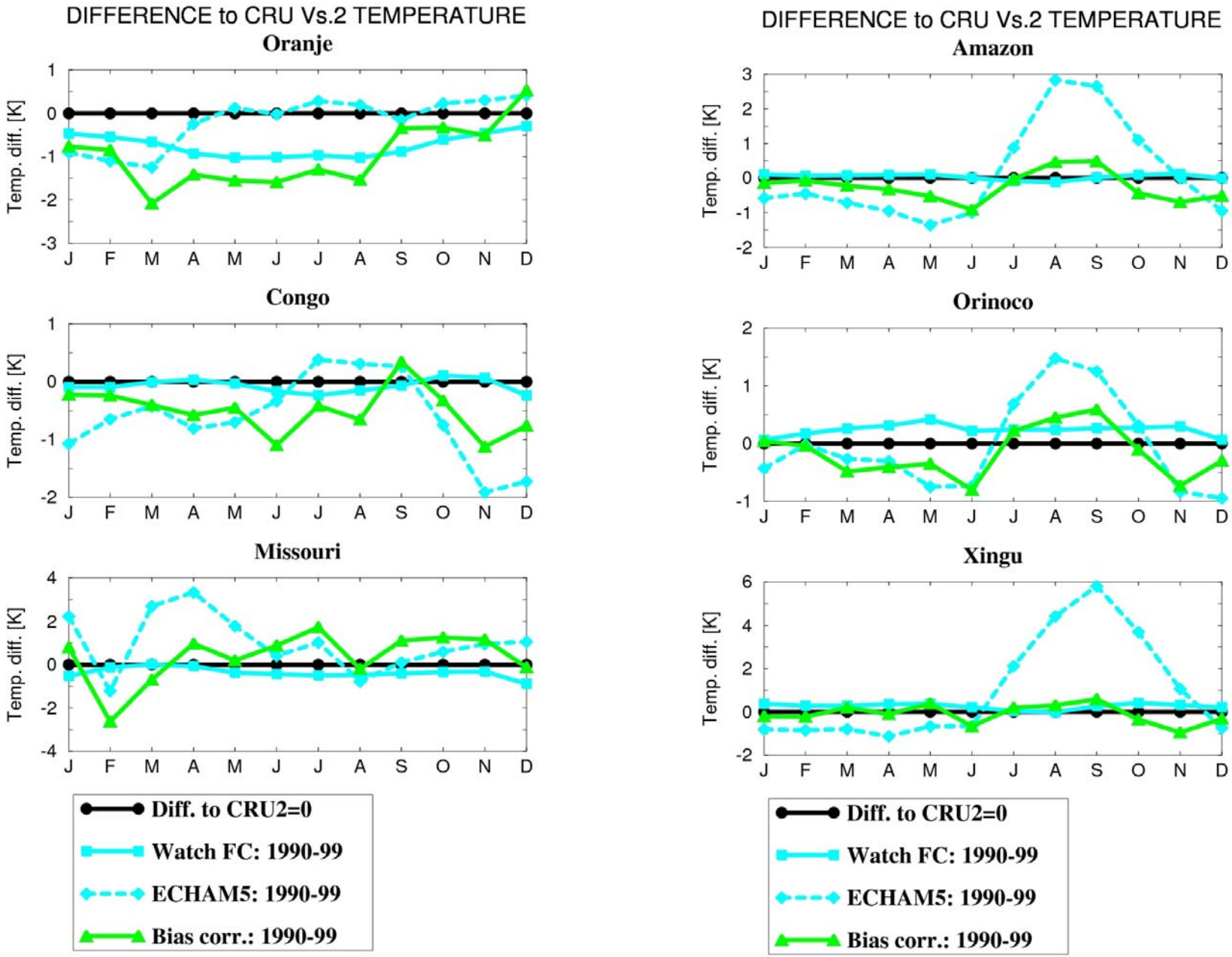


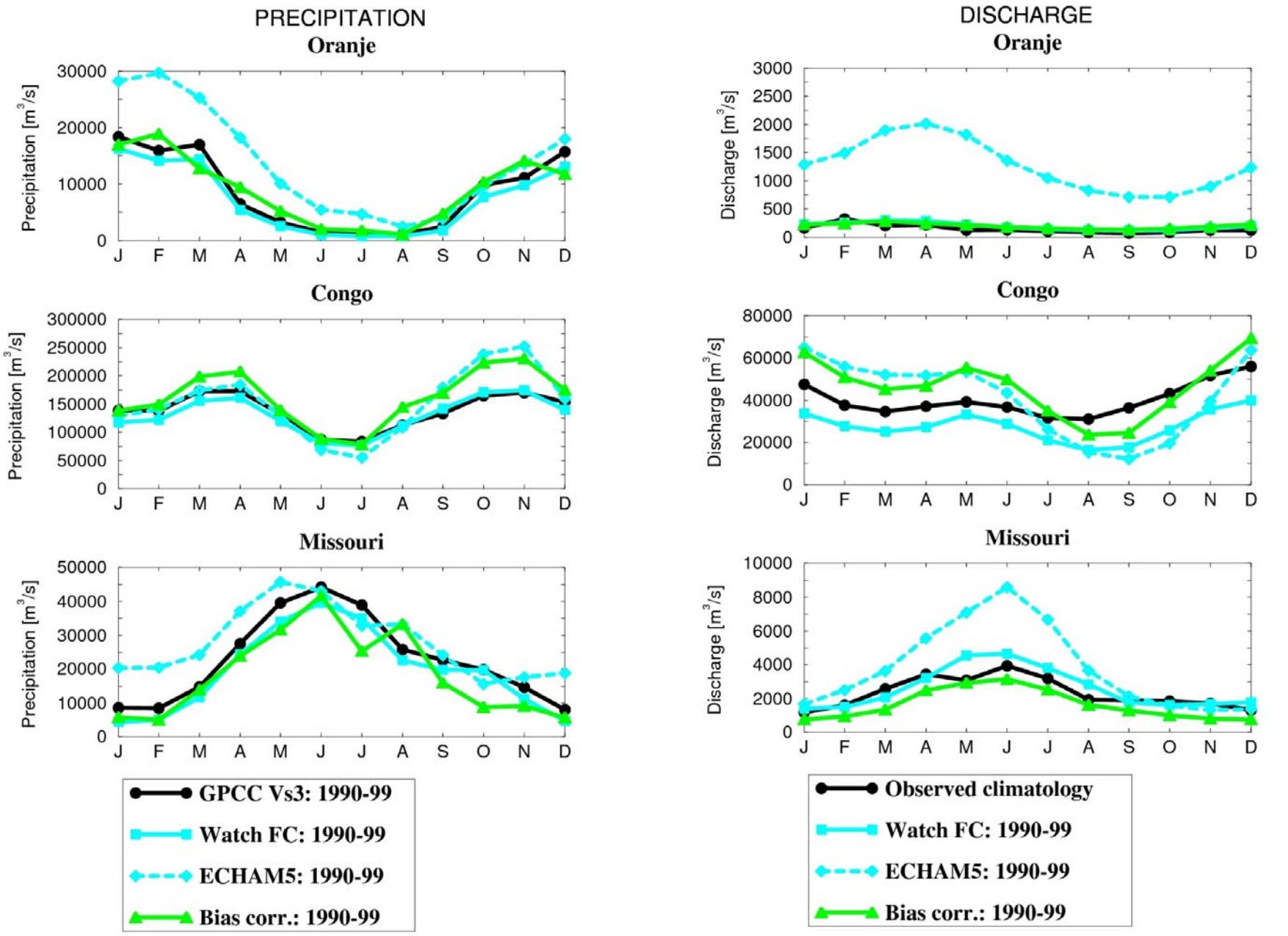


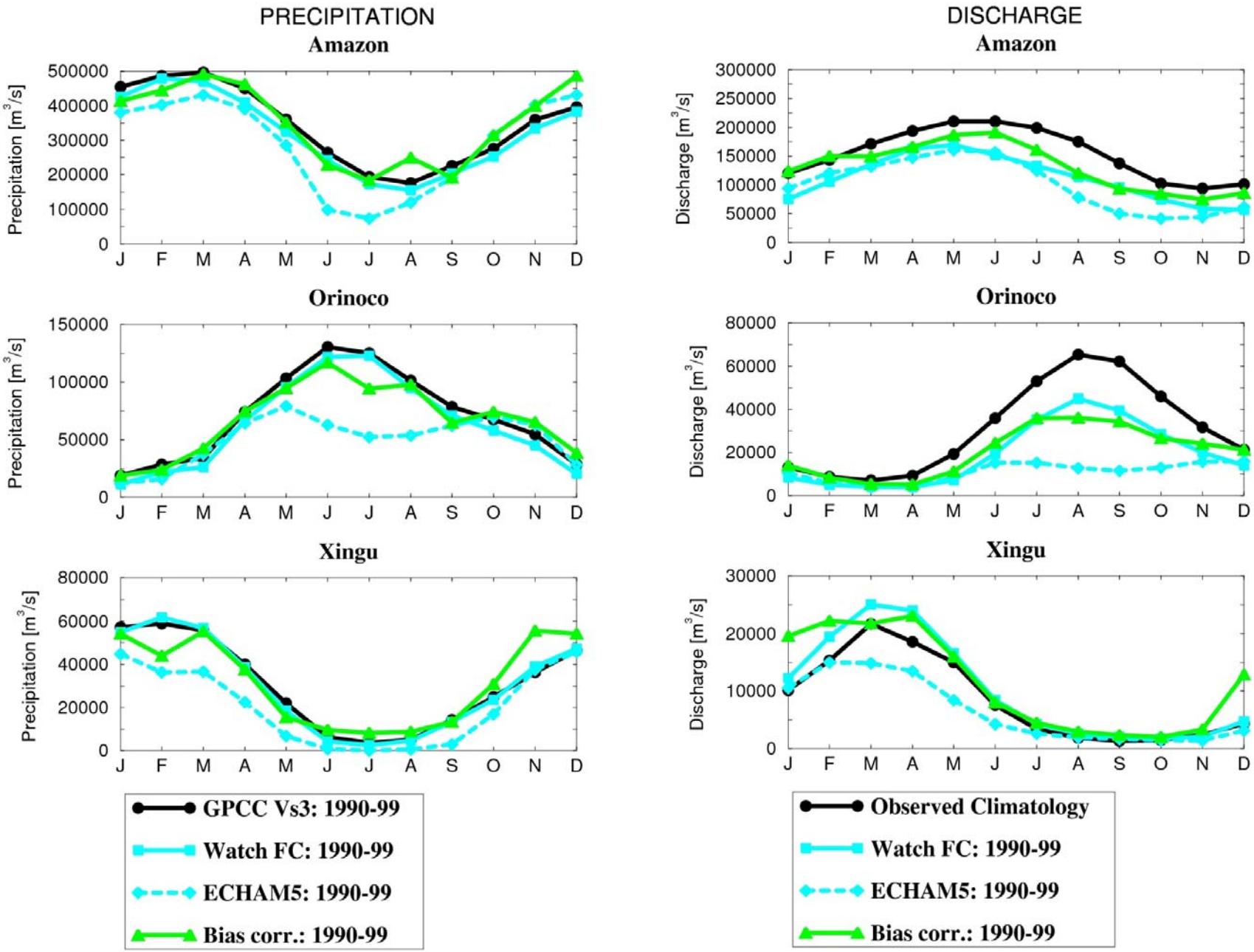
Bias-corrected ECHAM5/MPIOM data

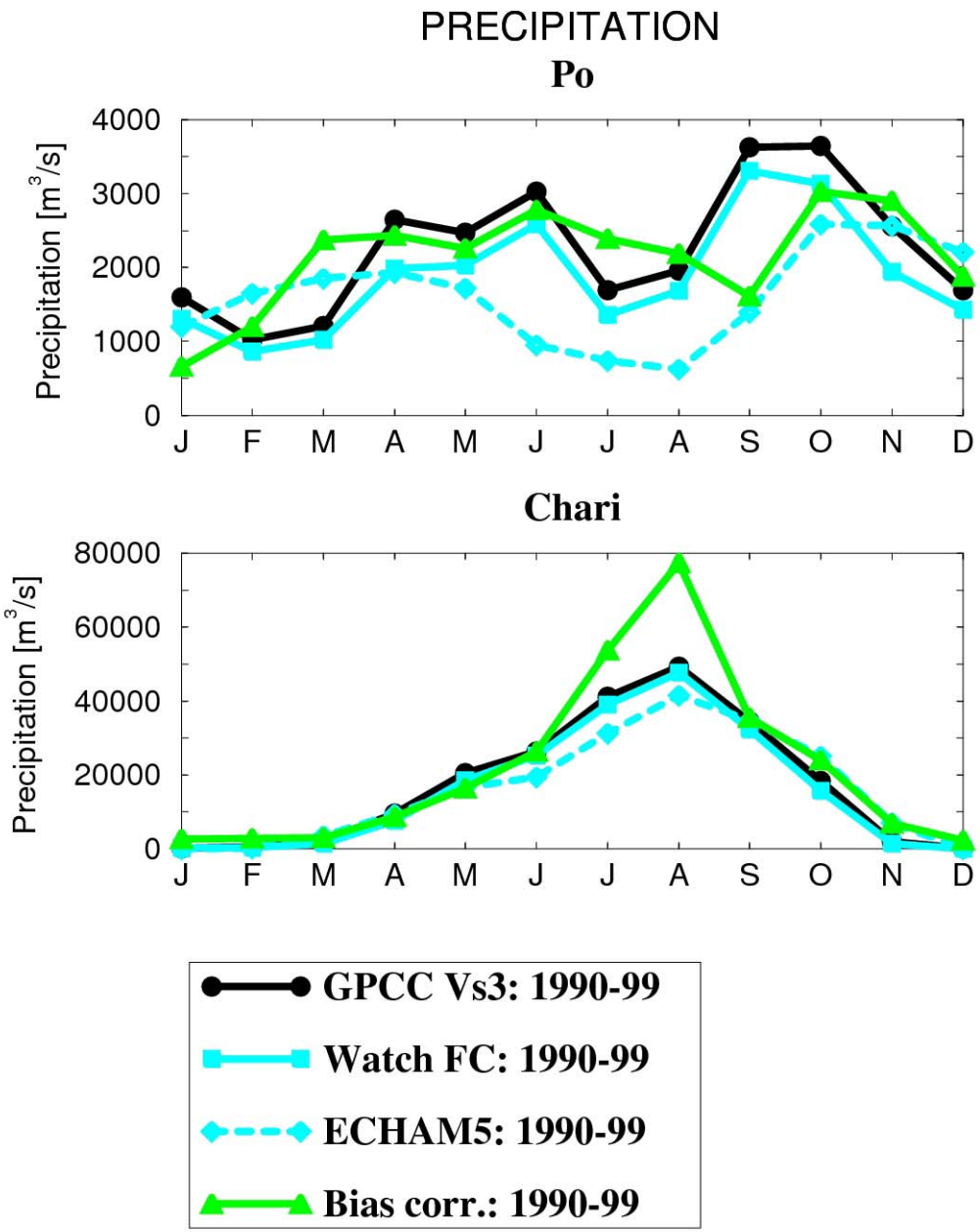
Large catchments are considered




DIFFERENCE to CRU Vs.2 TEMPERATURE
Oranje
Congo
Missouri
Amazon
Orinoco
Xingu
Temp. diff. [K]
J F M A M J J A S O N D
Diff. to CRU2=0
Watch FC: 1990-99
ECHAM5: 1990-99
Bias corr.: 1990-99


PRECIPITATION
Oranje
Precipitation [m3/s]
30000
20000
10000
0
J F M A M J J A S O N D
Congo
300000
250000
200000
150000
100000
50000
0
Missouri
50000
40000
30000
20000
10000
DISCHARGE
Oranje
Discharge [m3/s]
3000
2500
2000
1500
1000
500
Congo
80000
60000
40000
20000
Missouri
10000
8000
6000
4000
2000
GPCC Vs3: 1990-99
Watch FC: 1990-99
ECHAM5: 1990-99
Bias corr.: 1990-99
Observed climatology
Watch FC: 1990-99
ECHAM5: 1990-99
Bias corr.: 1990-99


PRECIPITATION
Amazon
Precipitation [m3/s]
500000
400000
300000
200000
100000
0
J F M A M J J A S O N D
Orinoco
Precipitation [m3/s]
150000
100000
50000
0
J F M A M J J A S O N D
Xingu
Precipitation [m3/s]
80000
60000
40000
20000
0
J F M A M J J A S O N D
GPCC Vs3: 1990-99
Watch FC: 1990-99
ECHAM5: 1990-99
Bias corr.: 1990-99
DISCHARGE
Amazon
Discharge [m3/s]
300000
250000
200000
150000
100000
50000
0
J F M A M J J A S O N D
Orinoco
Discharge [m3/s]
80000
60000
40000
20000
0
J F M A M J J A S O N D
Xingu
Discharge [m3/s]
30000
20000
10000
0
J F M A M J J A S O N D
Observed Climatology
Watch FC: 1990-99
ECHAM5: 1990-99
Bias corr.: 1990-99



Seasonal correction factor is partially leading to problems → Monthly correction factors will be constructed

(but monthly factors are less constrained than seasonal factors)

Summary

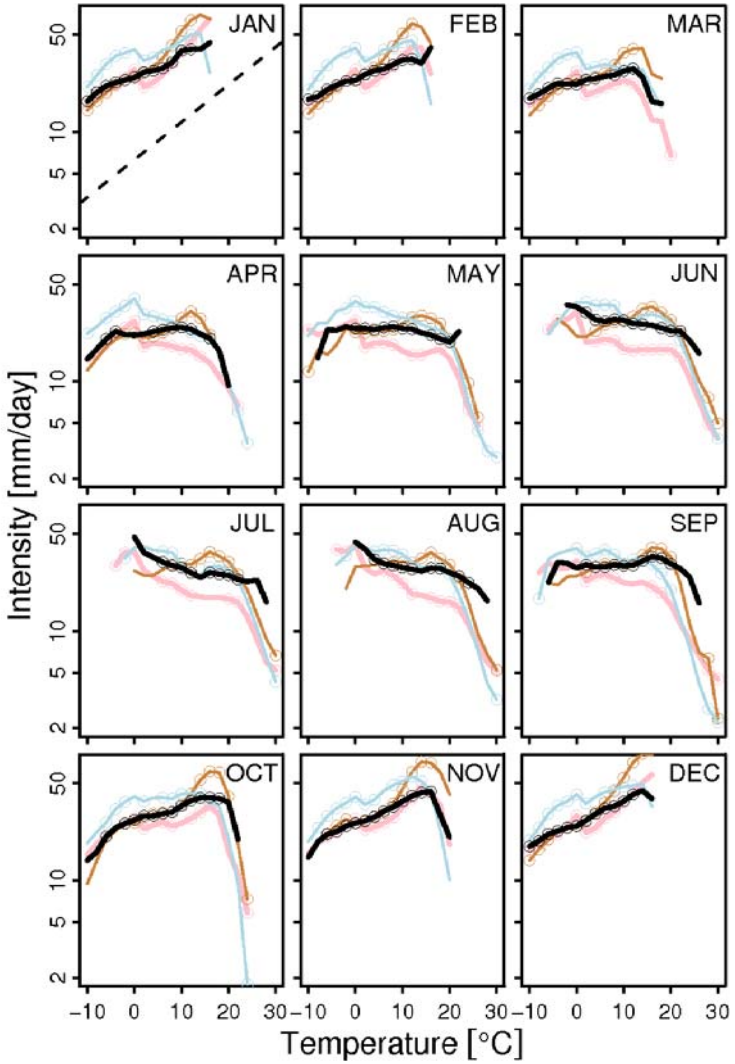
- A global statistical bias correction for precipitation and temperature data is being developed.
- A first application shows satisfactory results.
- Simulated discharge with the MPI-HM shows an improvements especially for catchments, where GCM precipitation has improved due to the bias correction.
- The statistical bias correction is enhancing the applicability of global climate change simulations for hydrological models.

Future work

- WATCH forcing data are currently being updated.
- Derivation of monthly correction factors instead of seasonal.
- Bias correction will be based and conducted on 40 years time series from 1961-2000 for several IPCC GCMs.
- Based on these 40 years, the bias-correction will be conducted for two transient scenarios from 2001-2100.
- Several WATCH hydrology models will be forced by these bias-corrected climate change data.
- Berg et al. (2009) have shown a dependency of precipitation PDFs to temperature
  Is it sufficient to bias-correct precipitation and temperature independently?

Caveats

- a simultaneous bias-correction of precipitation and temperature is non-trivial
- precipitation and temperature are **not independent !**
- the **relation of precipitation and temperature depends on season and region**
- when temperature is adjusted, **precipitation statistics change in relation to temperature**
- in a **warming climate**, different precipitation-temperature relation may emerge



Berg et al., 2009, JGR (submitted)

Thank you for your attention!

WATCH partners

Centre for Ecology and Hydrology (CEH)
Wageningen University and Research Centre (WU)
Free University of Amsterdam
Danish Meteorological Institute
CEMAGREF
University of Frankfurt
International Centre for Theoretical Physics – ICTP Triest
UK Met Office - Hadley Centre
Max Plank Institute for Meteorology (MPI-M)
Polish Academy of Science
Potsdam Institute for Climate Impact Research
Technical University of Crete
University of Oslo
University of Valencia
University of Oxford
IIASA - Int. Institute for Aplied Systems Analysis
Laboratoire de Meteorologie Dynamique, Paris
University of Lisbon
Comenius University, Bratislava
Consejo Superior de Investigaciones Científicas
University of Kassel
KIWA
Observatoire de Paris
T.G. Masaryka Water Research Institute
Norwegian Water Resources and Energy Directorate

Coordinator:
Richard Harding (CEH)
Co-Coordinator:
Pavel Kabat (WU)

External Partners
University of Washington
University of New Hampshire
Nagoya and Tokyo University
GEWEX
GWSP
Universities in India (to be arranged)

IPCC simulations: Setup

- Historical Climate (1860 – present), Focus: 1961-1990

- Scenarios (present to 2100), Focus: 2071-2100
  - Low emission scenario: **B1**
  - Moderate emission scenario: **A1B**
  - High emission scenario: **A2**

- **GCM ECHAM5/MPIOM**: 3 ensemble members for historical control simulation and each scenario
  - Horizontal Resolution of ECHAM5: T63 ~ 200 km

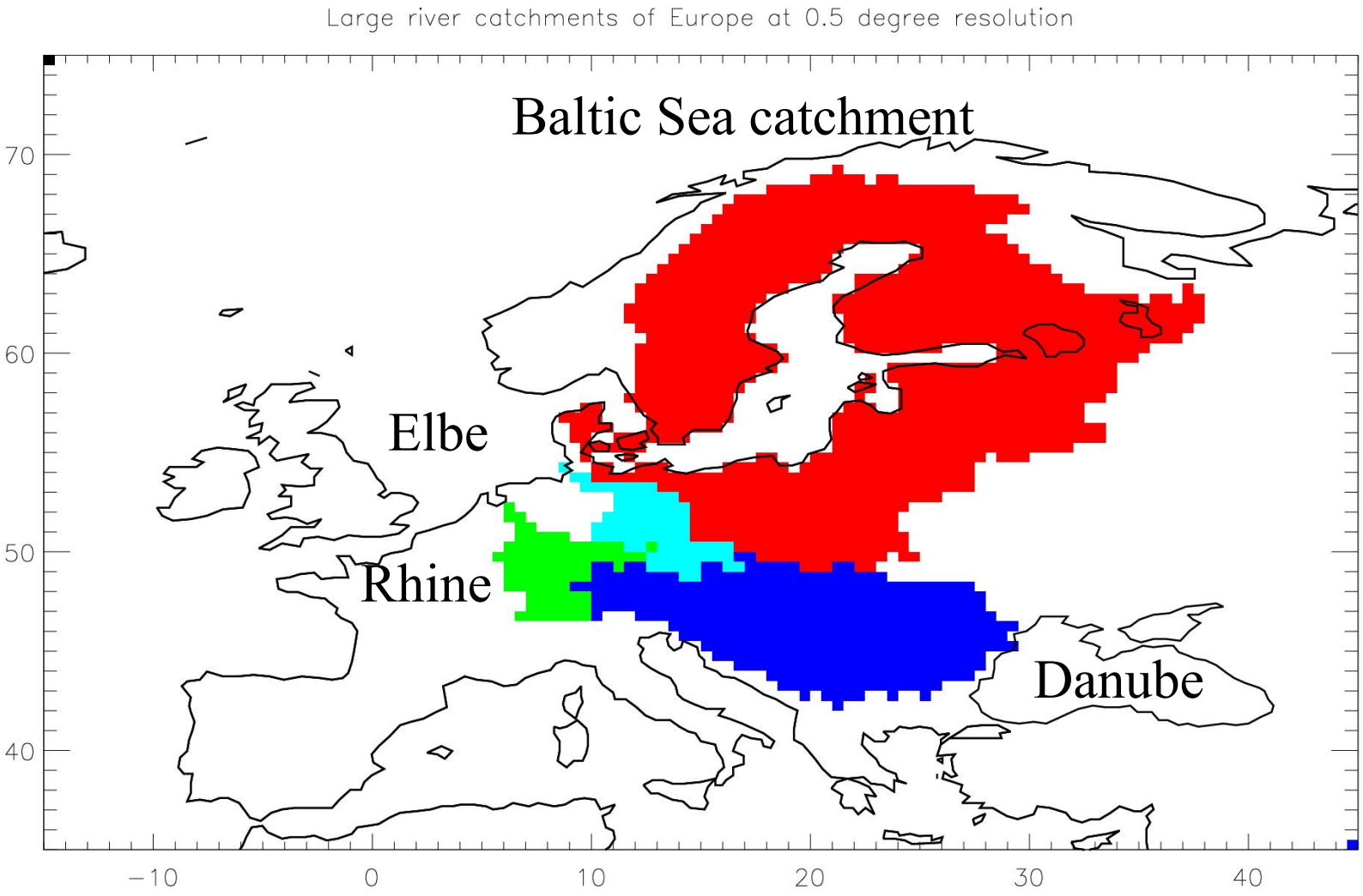
- Forcing with observed / prescribed (for scenarios) concentrations of CO2, Methane, N2O, CFCs, Ozone (Tropos-/Stratosphere), Sulfate Aerosols (direct and 1. indirect effect)

Daily data

Centre	GCM	Horiz. Resolution	Vert.
MPI-M	ECHAM5/MPIOM	T63 ~ 1.9° ~ 200 km	L31
CNRM	CNRM-CM3	T42 ~ 2.8° ~ 300 km	L45
UKMO	HadCM3	3.75° x 2.75° ~ 300 km	L19
IPSL	LMDZ-4	3.75° x 2.5° ~ 300 km	L19
BCCR	BCM 2.0	T42 ~ 2.8° ~ 300 km	L31

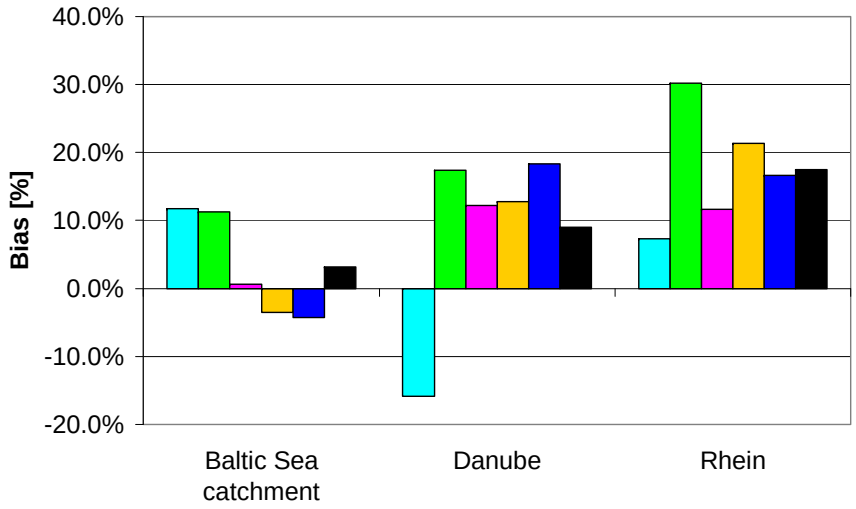
Centre	Archived	Simulations
MPI-M	CERA, MPI-M	3*(C20,B1,A1B,A2)
CNRM	CERA	2*C20, B1,A1B,A2
UKMO	UKMO (CERA)	2*C20, B1,A1B,A2
IPSL	IPSL	C20, B1,A1B,A2
BCCR	CERA	C20, B1,A1B,A2

Large European catchments

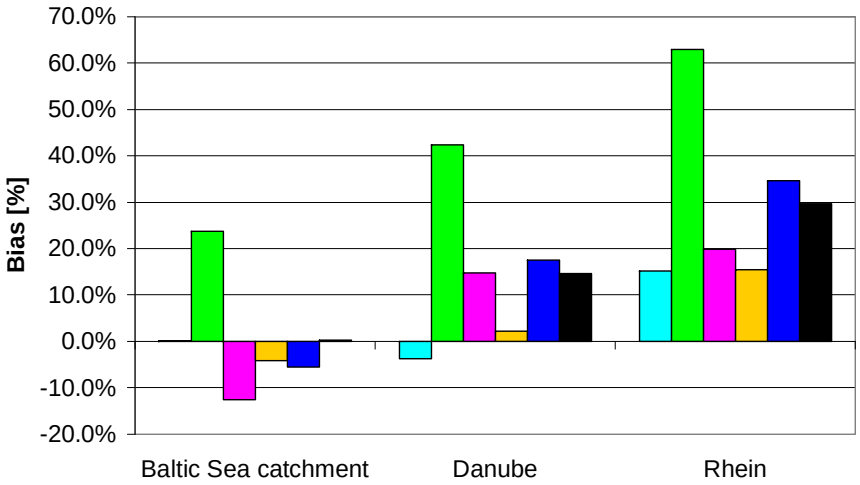


Biases control period 1961-90

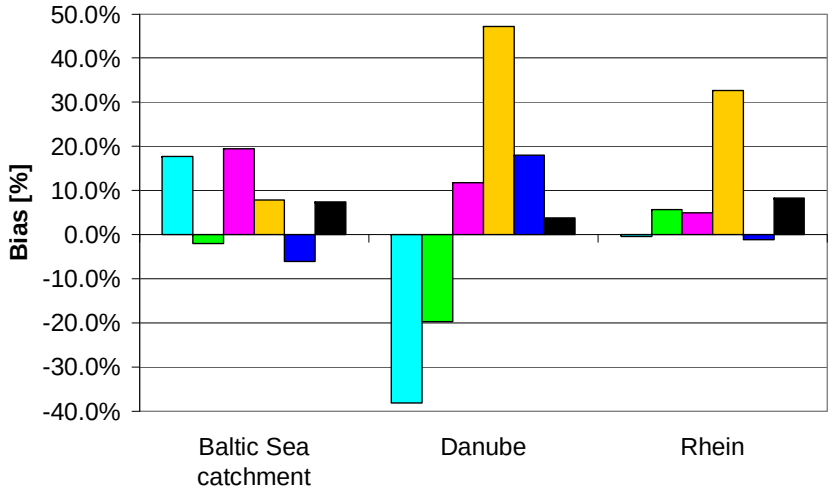
Precipitation

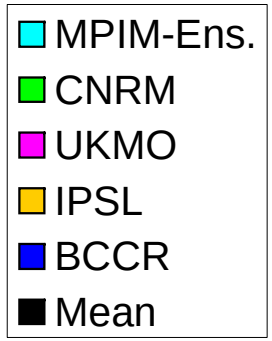


Evapotranspiration

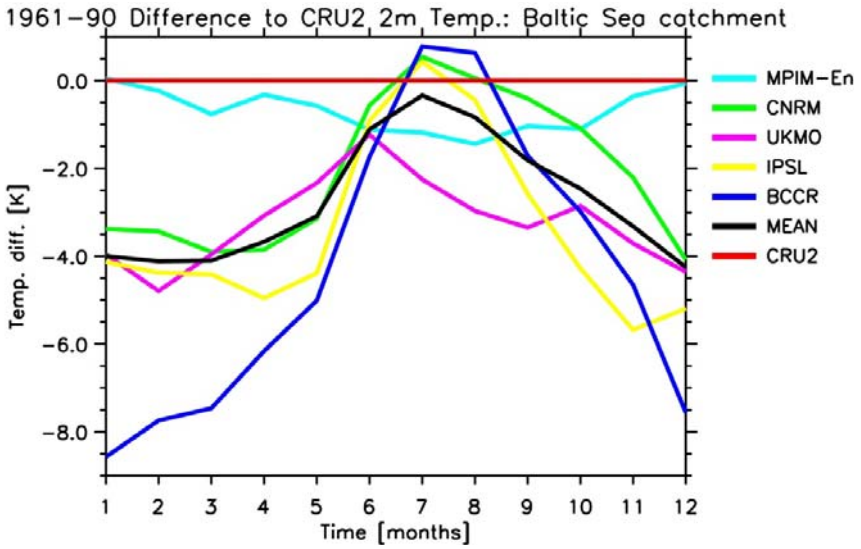


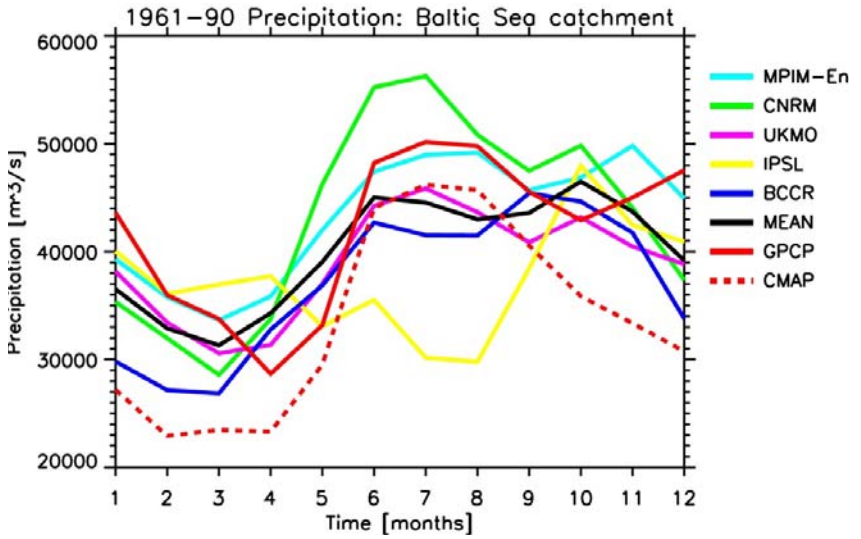
Runoff

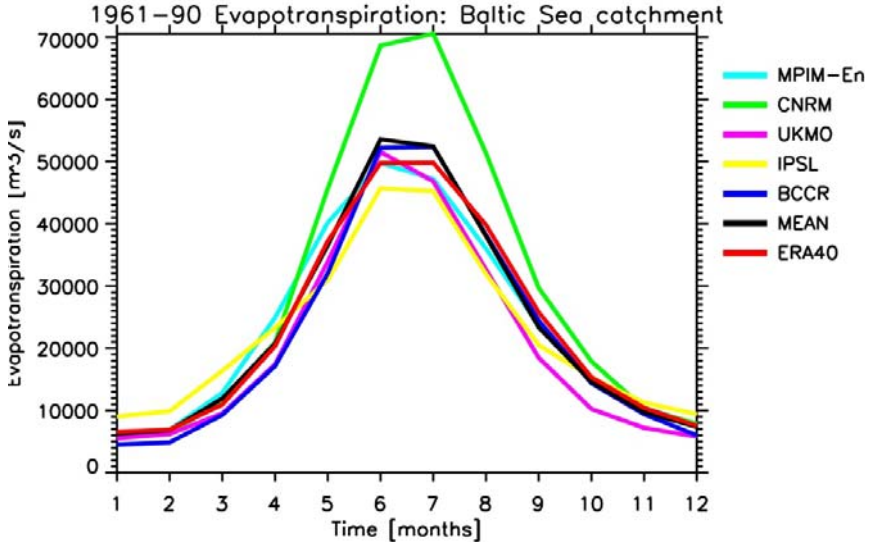


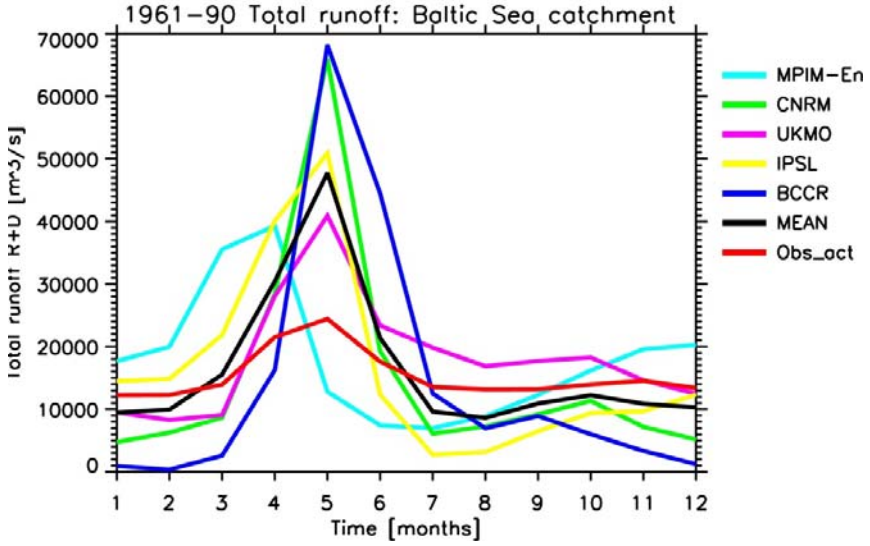


Baltic Sea catchment 1961-90

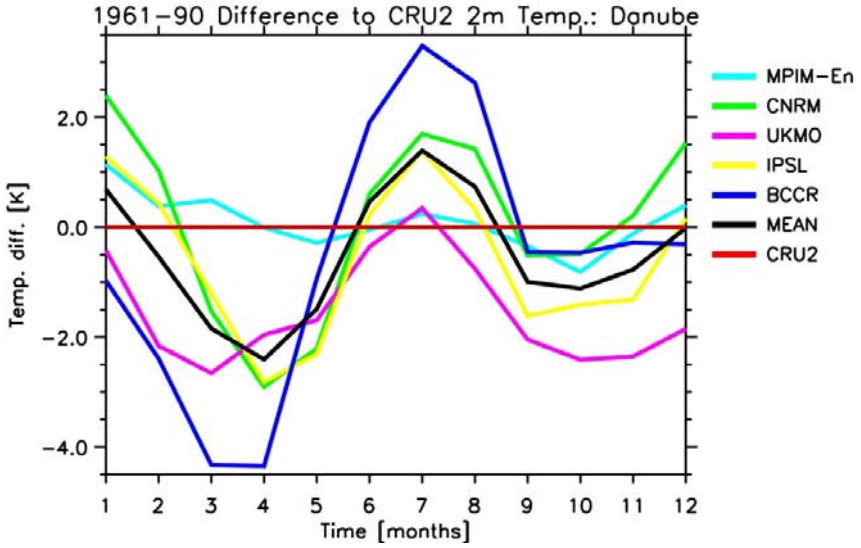


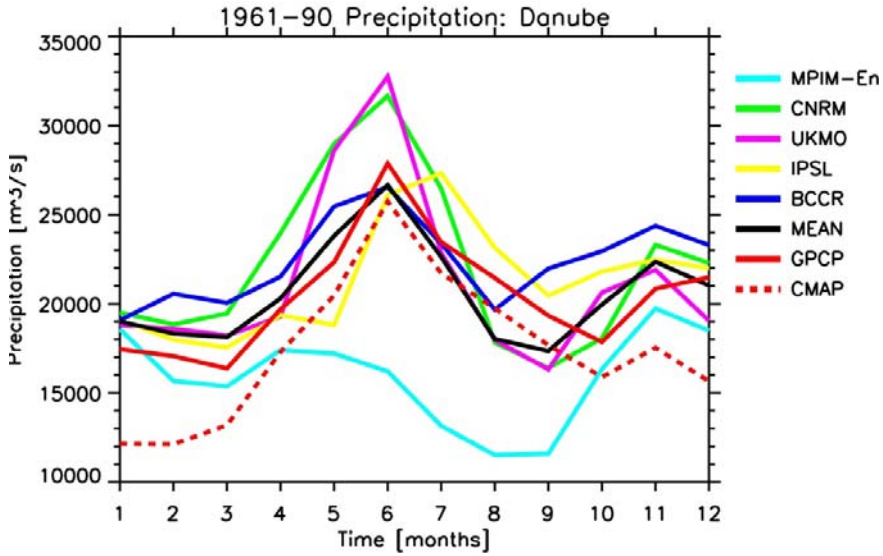


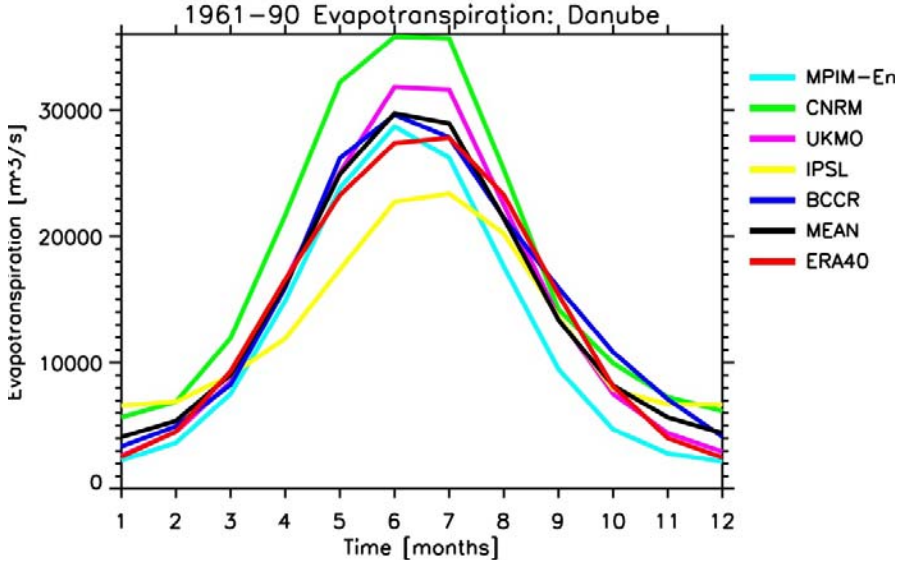


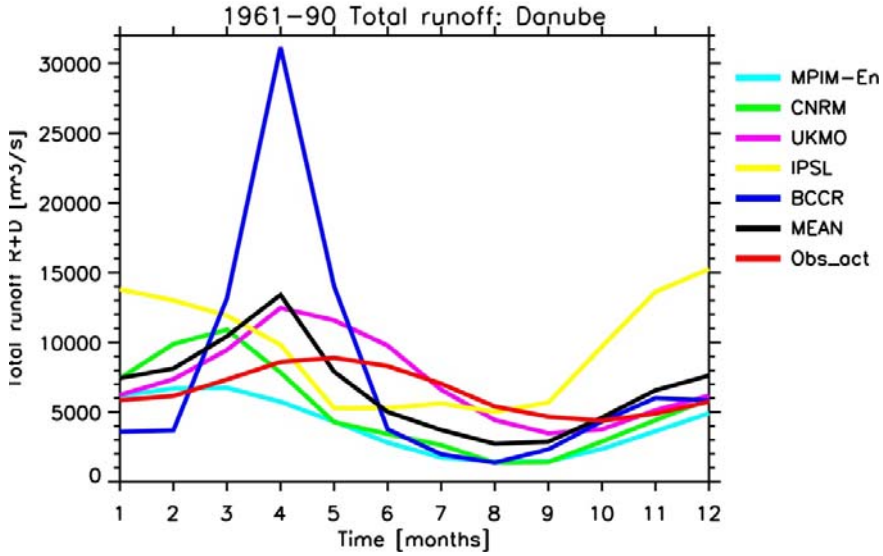


Danube catchment 1961-90

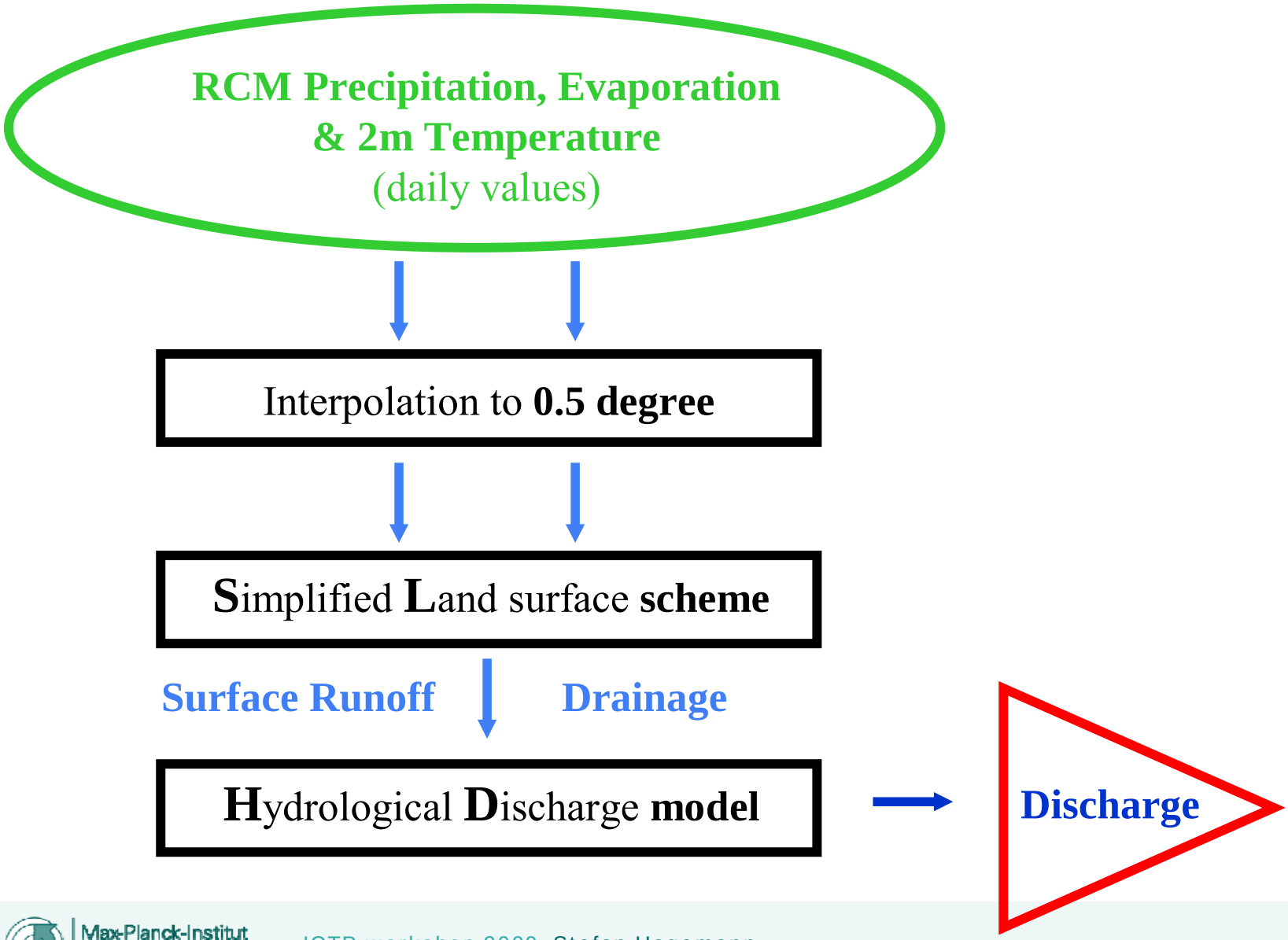


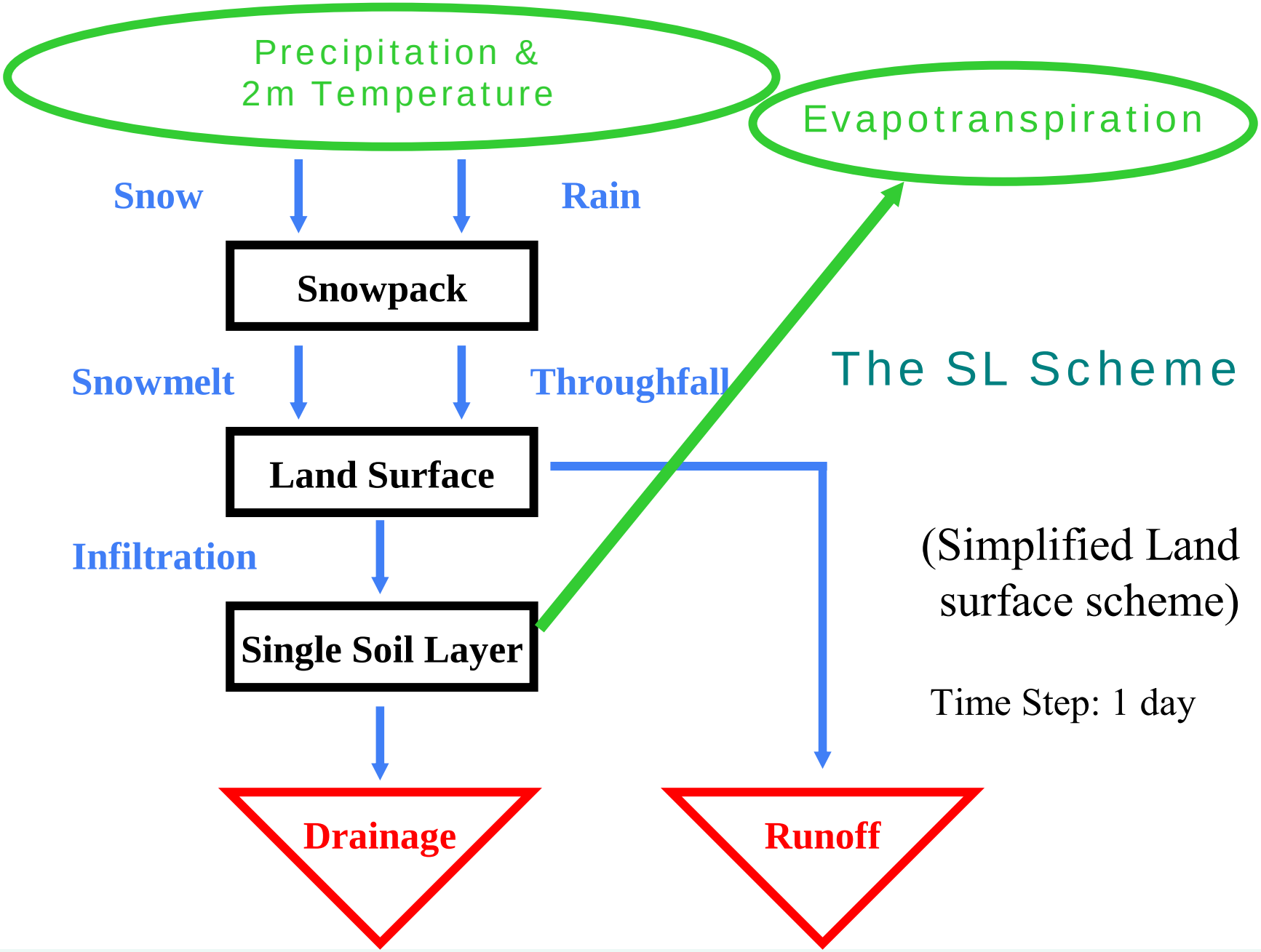






SL scheme/HD model LSHM as used in PRUDENCE



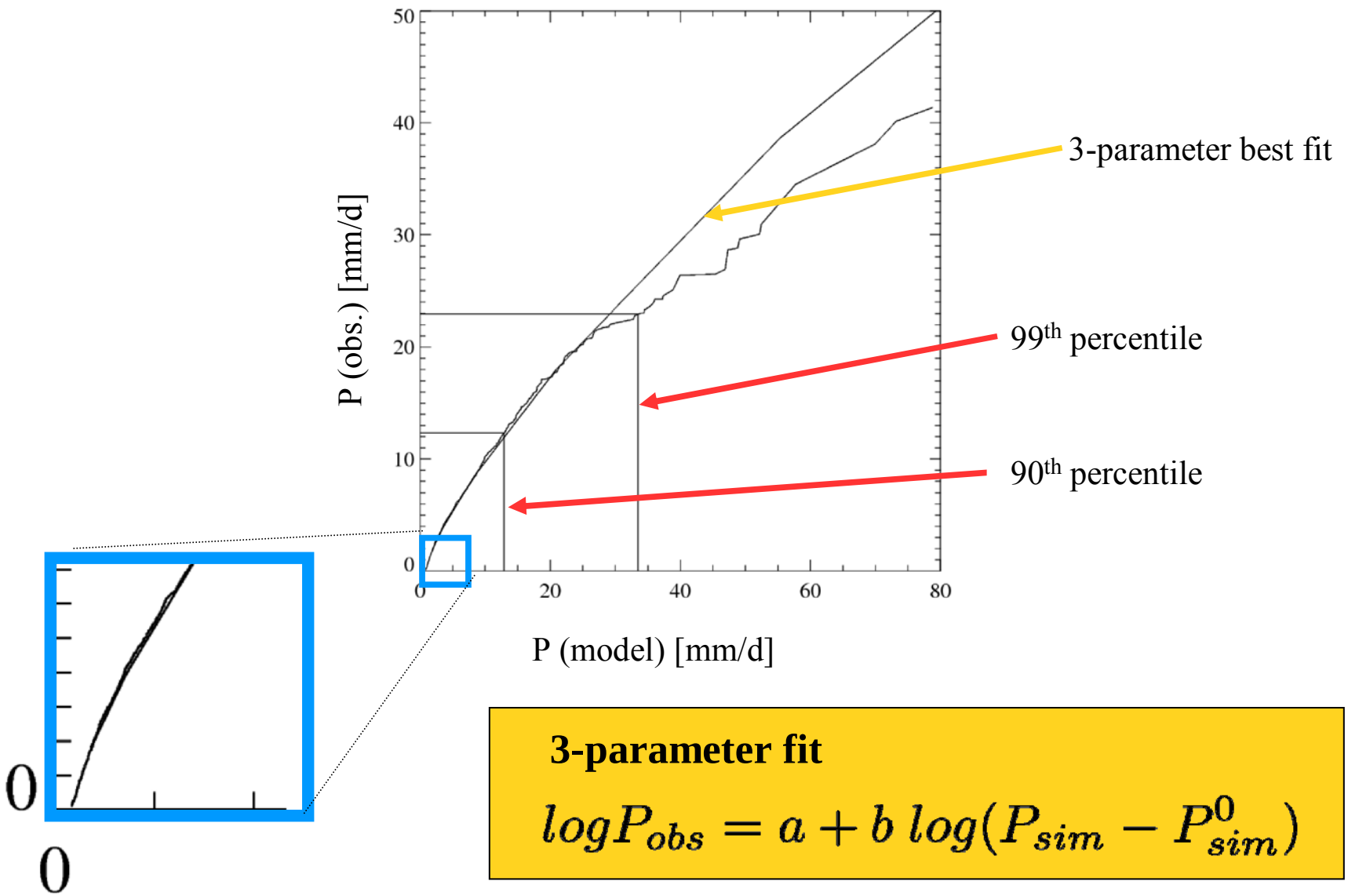


The SL Scheme

(Simplified Land surface scheme)

Time Step: 1 day

Transfer function for daily precipitation



3-parameter fit

$$log P_{obs} = a + b\, log(P_{sim} - P^0_{sim})$$

3-parameter fit

$$log P_{obs} = a + b\, log(P_{sim} - P^0_{sim})$$

(1) $\mathbf{P^0_{sim}}$ takes care of *drizzle-problem* of many models

(2) **a** is overall factor, eliminates general slope difference between model and observations

(3) **b** curvature factor: many models perform differently at low/high precip. intensities

employing weighting ~ P ensures more accurate representation of higher precipitation events (important for floods etc.)

Merit of using fit (as opposed to brute-force transfer function):

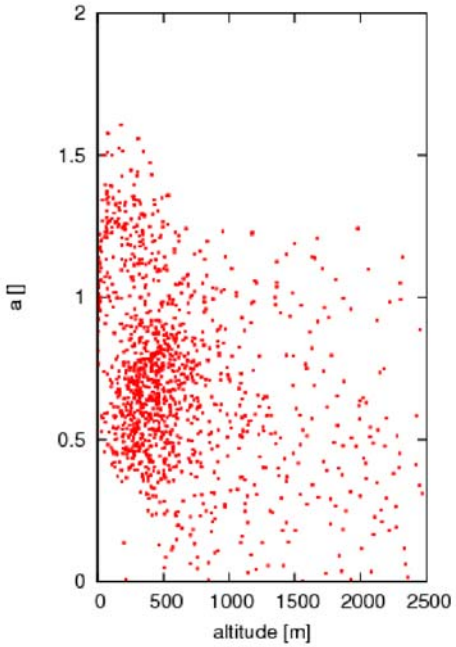
- interested in spatially coherent bias correction
- want to capture decadally independent features of obs.-mod. mapping
- point-by-point transfer function obscures physical picture

Topographic Bias

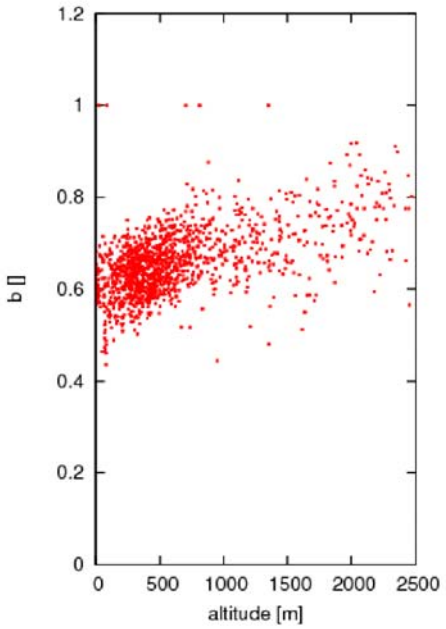
Topographic effects are biasing model results

- Model orography does not adequately represent real-life topography
- Severely effects precipitation
- Understanding orographic bias in alps region (e.g. HIRHAM model, 1960-90)

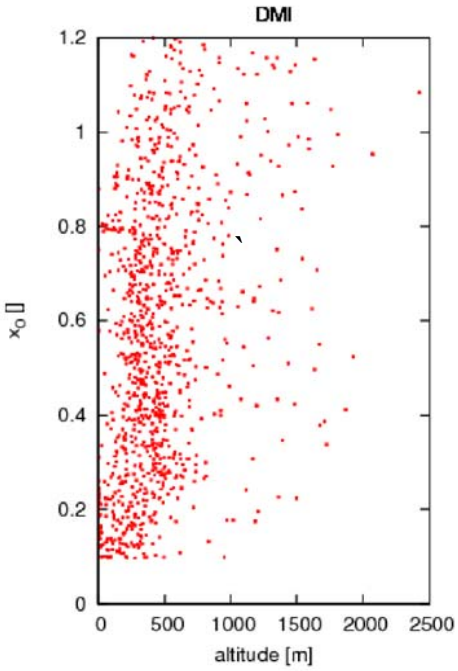
- overall a~1 for low altitude
- decline at high altitude



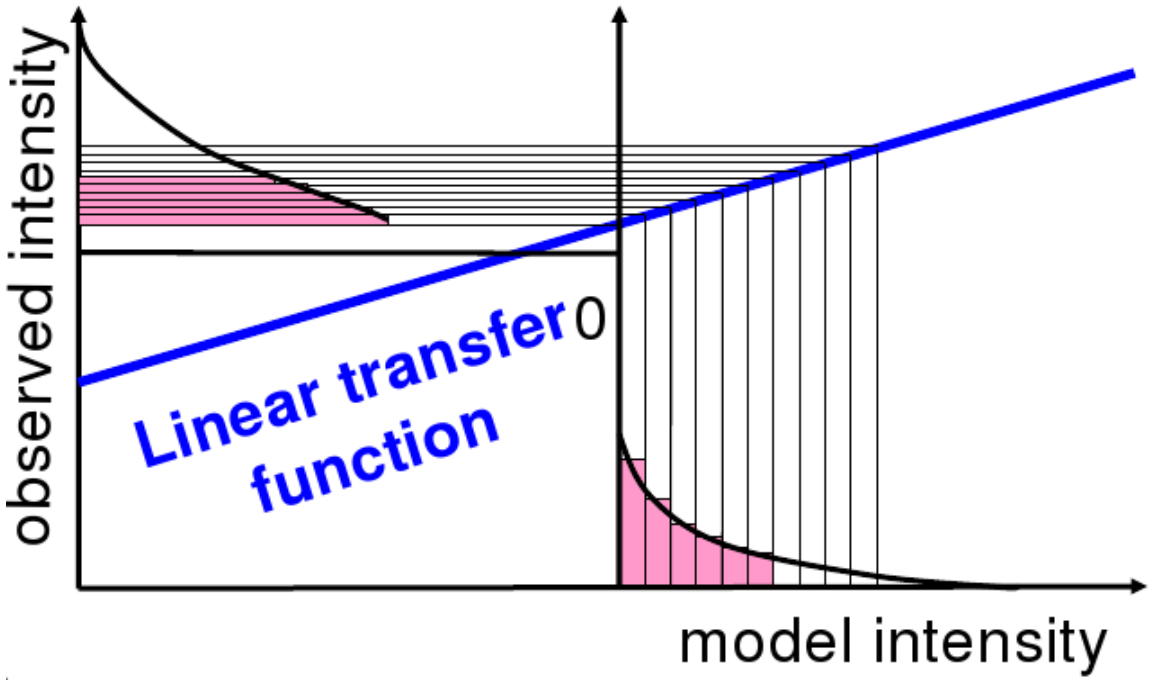
- b<1 : generally concave transfer function
- increase with altitude



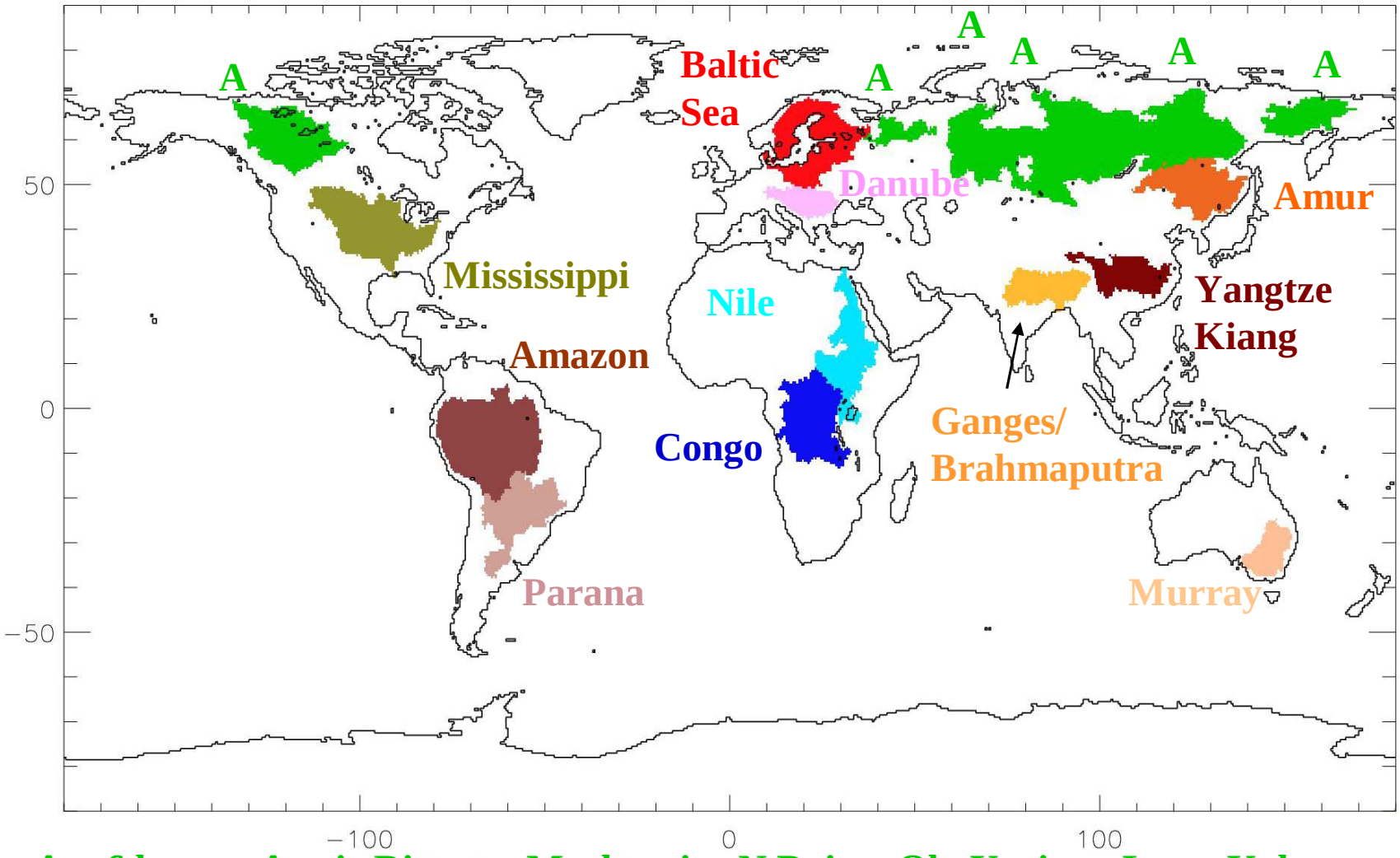
Rather erratic behavior of offset



Methodology



Large catchments are considered



A = 6 largest Arctic Rivers = Mackenzie, N Dvina, Ob, Yenisey, Lena, Kolyma