AG 4 – Workshop Großskalige Hydrologische Modellierung
Kelkheim-Eppenhain, 31.10.–02.11.2007

Kopplung von Prozessen in Hydrosphäre, Atmosphäre und terrestrischer/aquatischer Biosphäre

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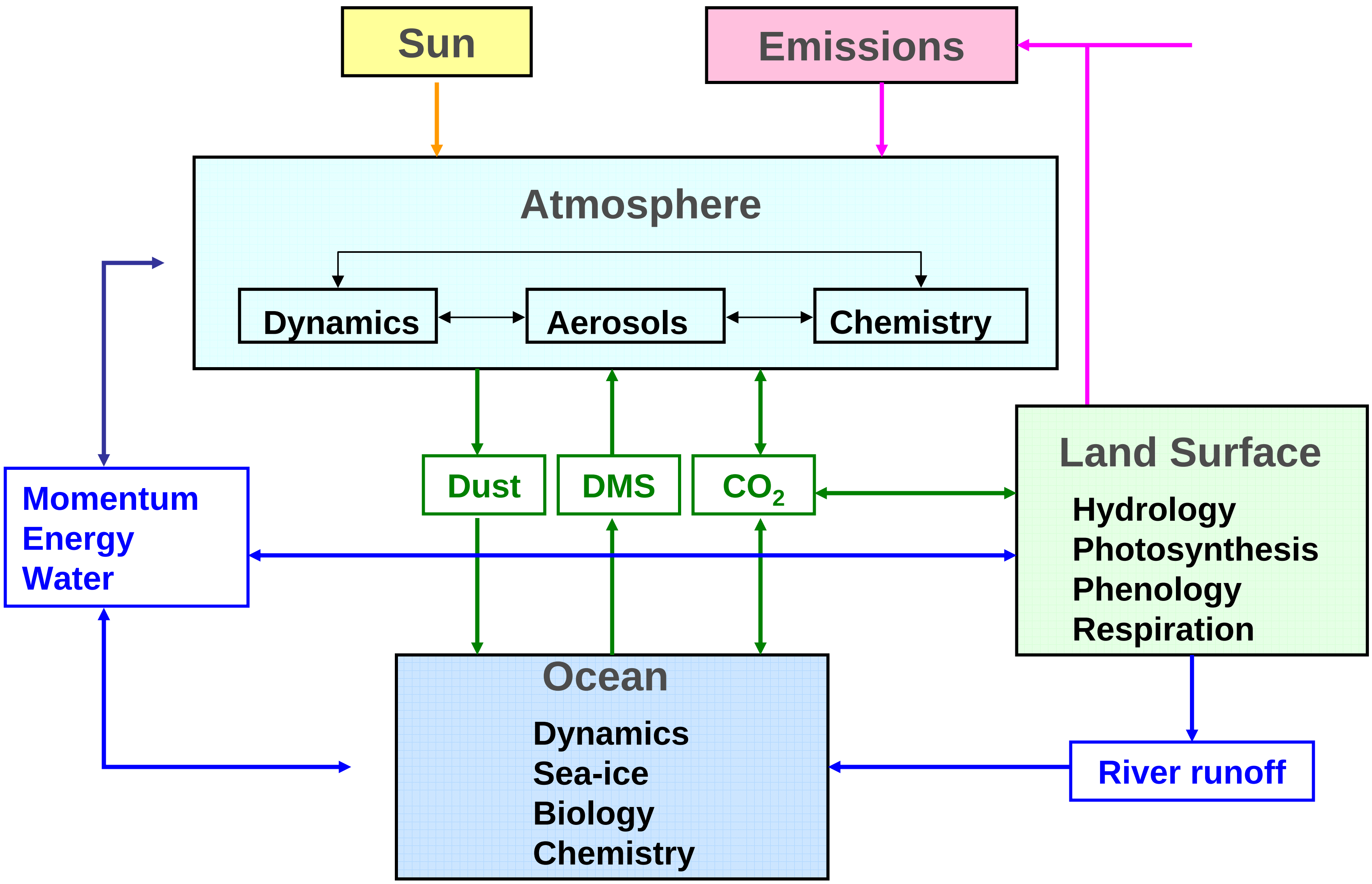
P I K

Content of this talk

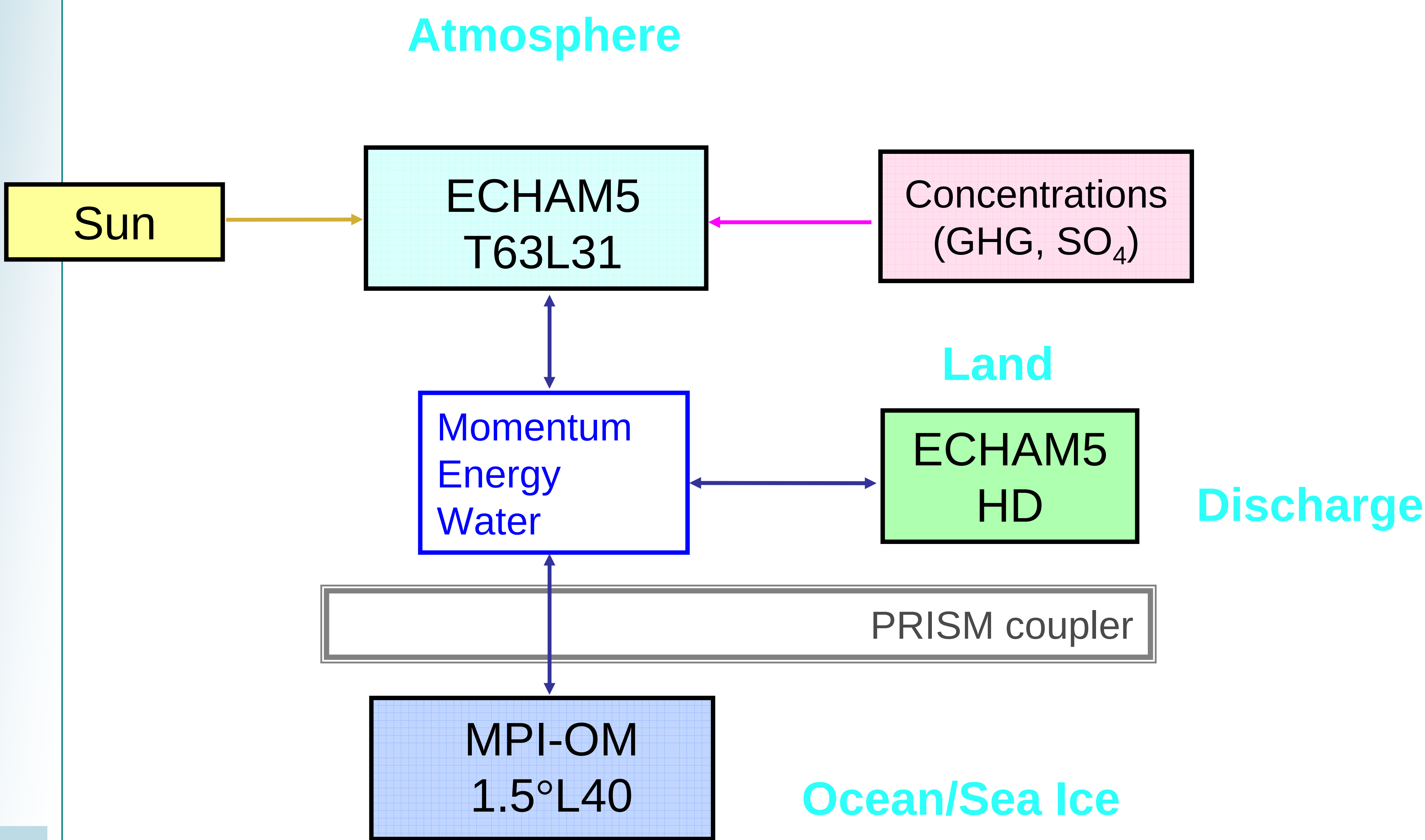
- Current Earth System Model components
- Hydrological extremes
- Forcing hydrology models with climate model output
- Feedbacks Atmosphere – Hydrosphere

- Feedbacks Land use change – Hydrosphere
- Feedbacks Hydrosphere – Terrestrial & Aquatic Biosphere
  (Ecological Impacts of Changing Water Quantities)

MPI-ESM: Processes



IPCC simulations: MPI-M GCM model components



Climate change impacts

- Change in the mean climate

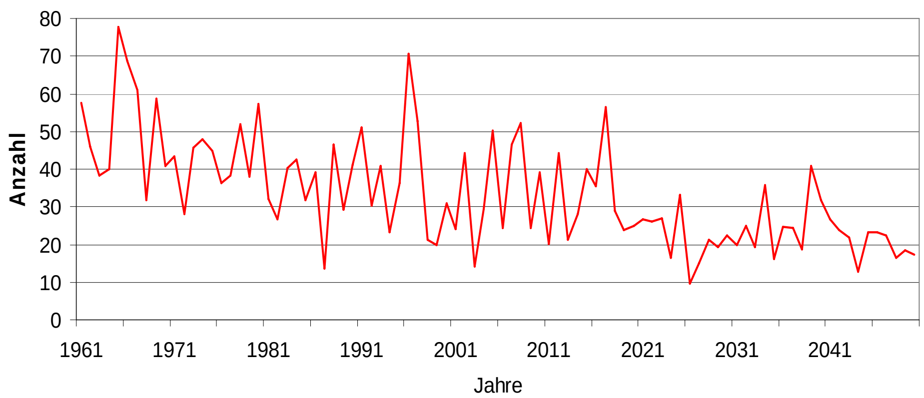
- Change in extremes

- Large regional dependence
- High resolution required → Downscaling of GCM results necessary
- Dynamical downscaling using RCMs, e.g. REMO
- Statistical downscaling, e.g. WETTREG

Rheineinzugsgebiet: (REMO 0.16º SRES B2)

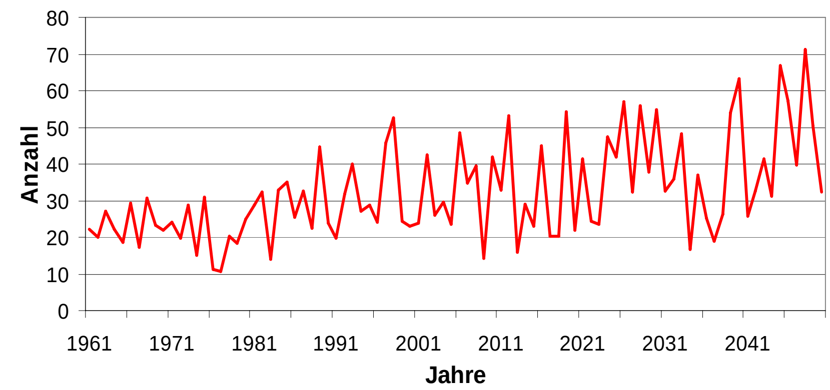
Frosttage (min < 0 ºC)

))



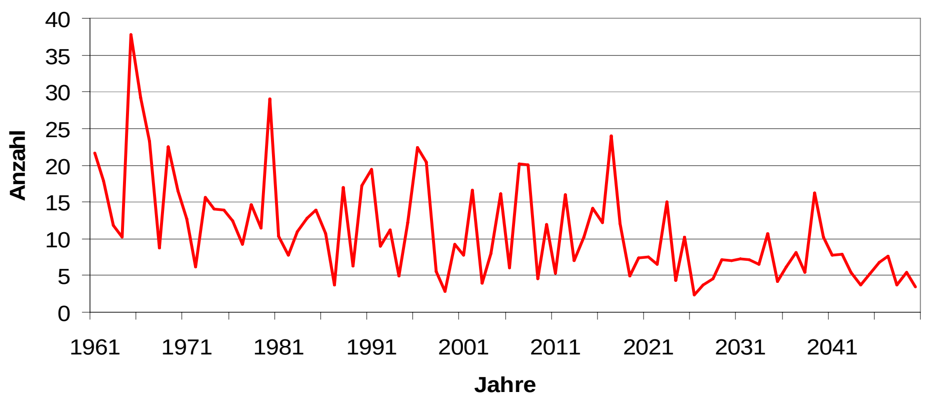
Sommertage (max >25 ºC)

ıax>25)



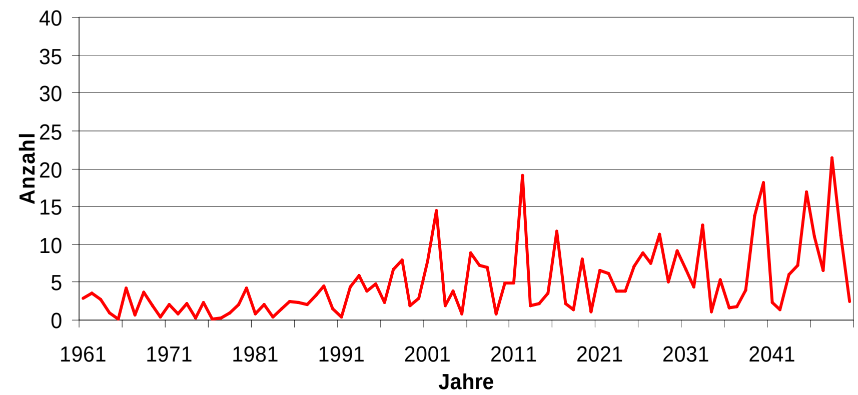
Eistage (max < 0 ºC)

(max<0)



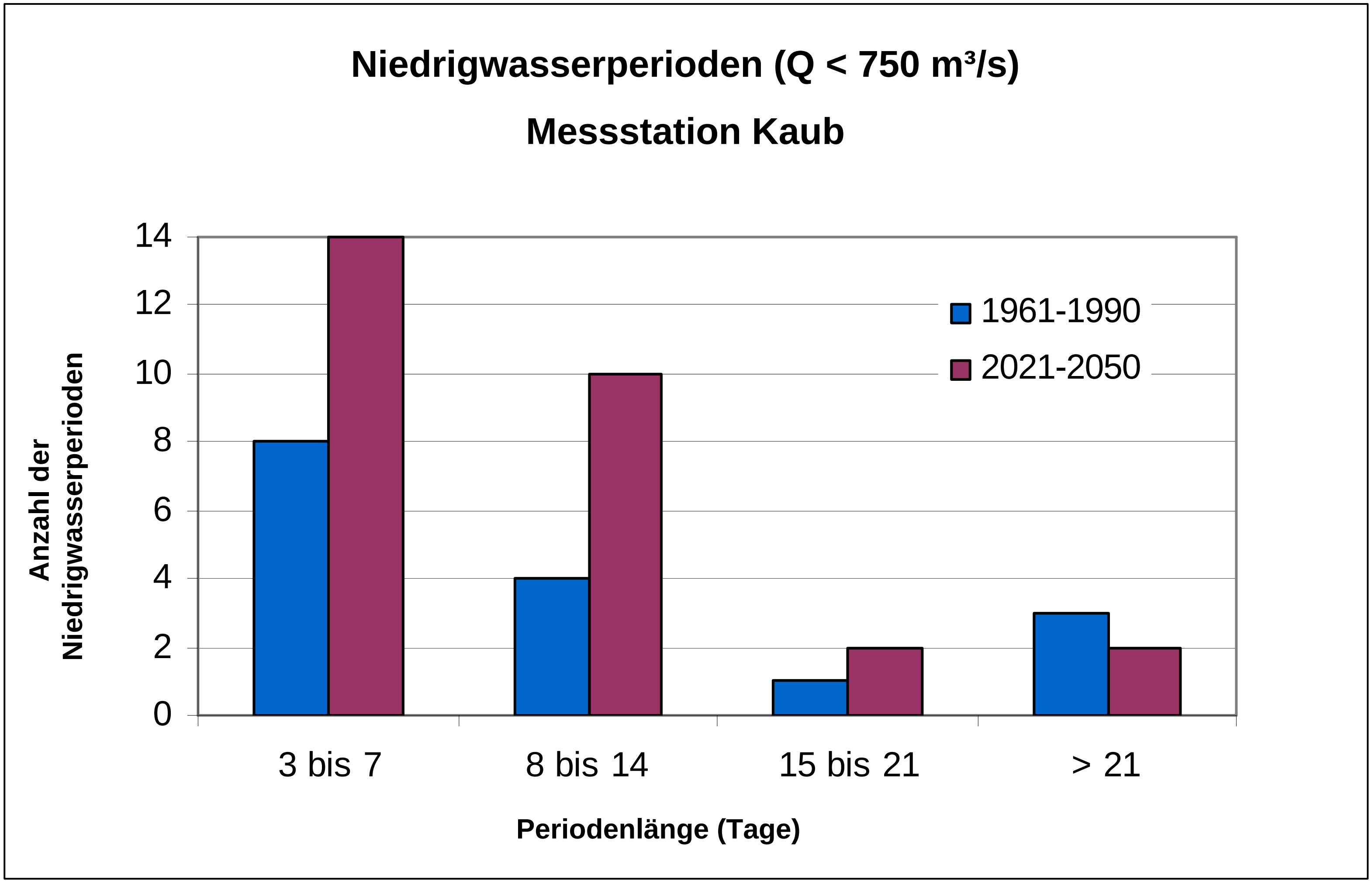
Heisse Tage (max >30 ºC)

>30)



Plot by Katharina Bülow, MPI-M

Niedrigwasserperioden im Rhein, B2



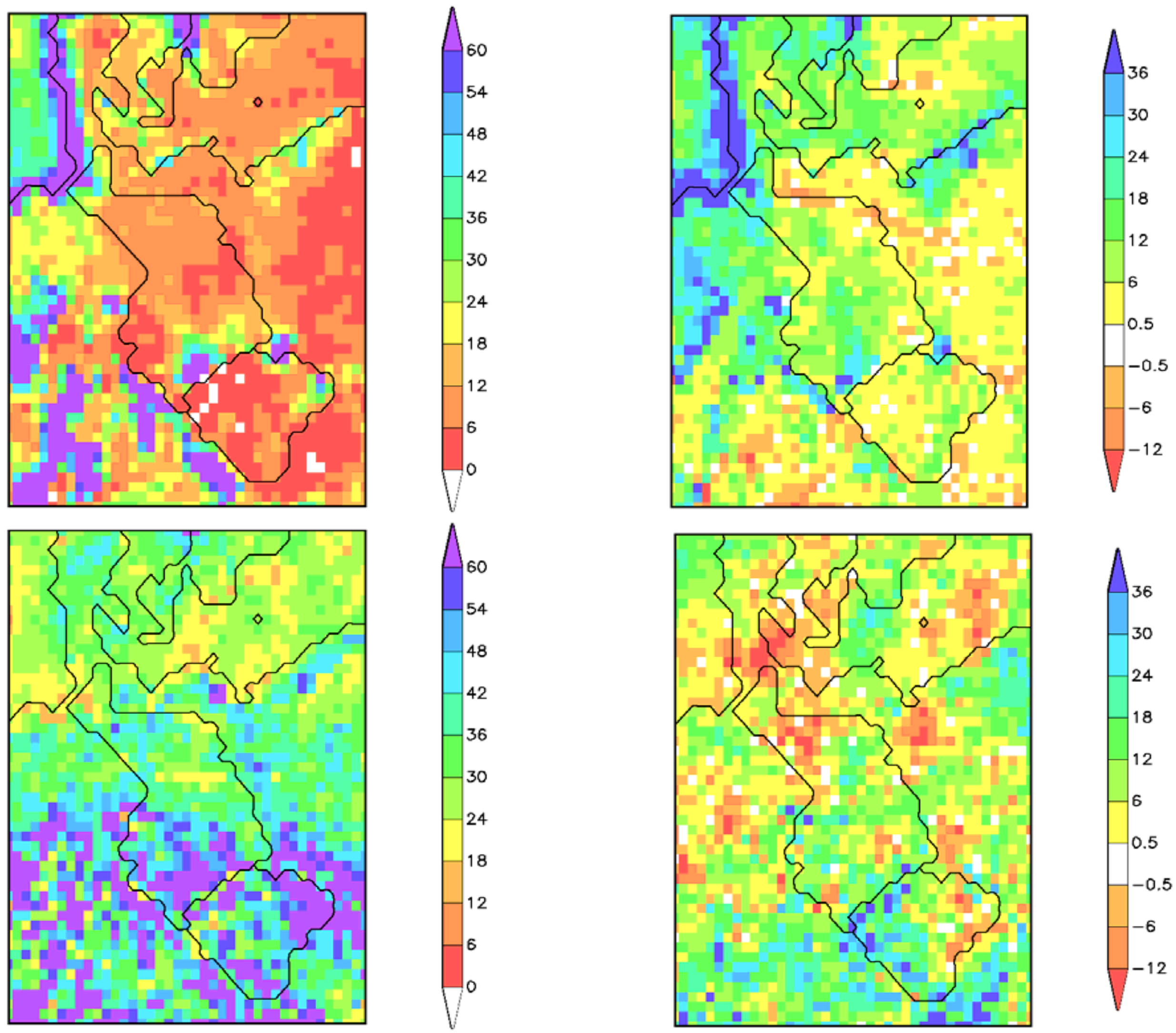
Plot by Eva Starke, MPI-M

B2 Zahl der nassen Tage (>20 mm/Tag) : Elbe

1961-1990 | (2021-2050) - (1961-1990)

Winter

Sommer



Plot by Katharina Bülow, MPI-M

Hydrology model forced by climate model input

Precipitation, Evaporation
& 2m Temperature
(daily values)

Interpolation to **0.5 degree**

Land **S**urface **H**ydrology **M**odel
e.g. **S**implied **L**and surface scheme

Surface Runoff | **Drainage**

River Routing
e.g. **H**ydrological **D**ischarge model

Discharge

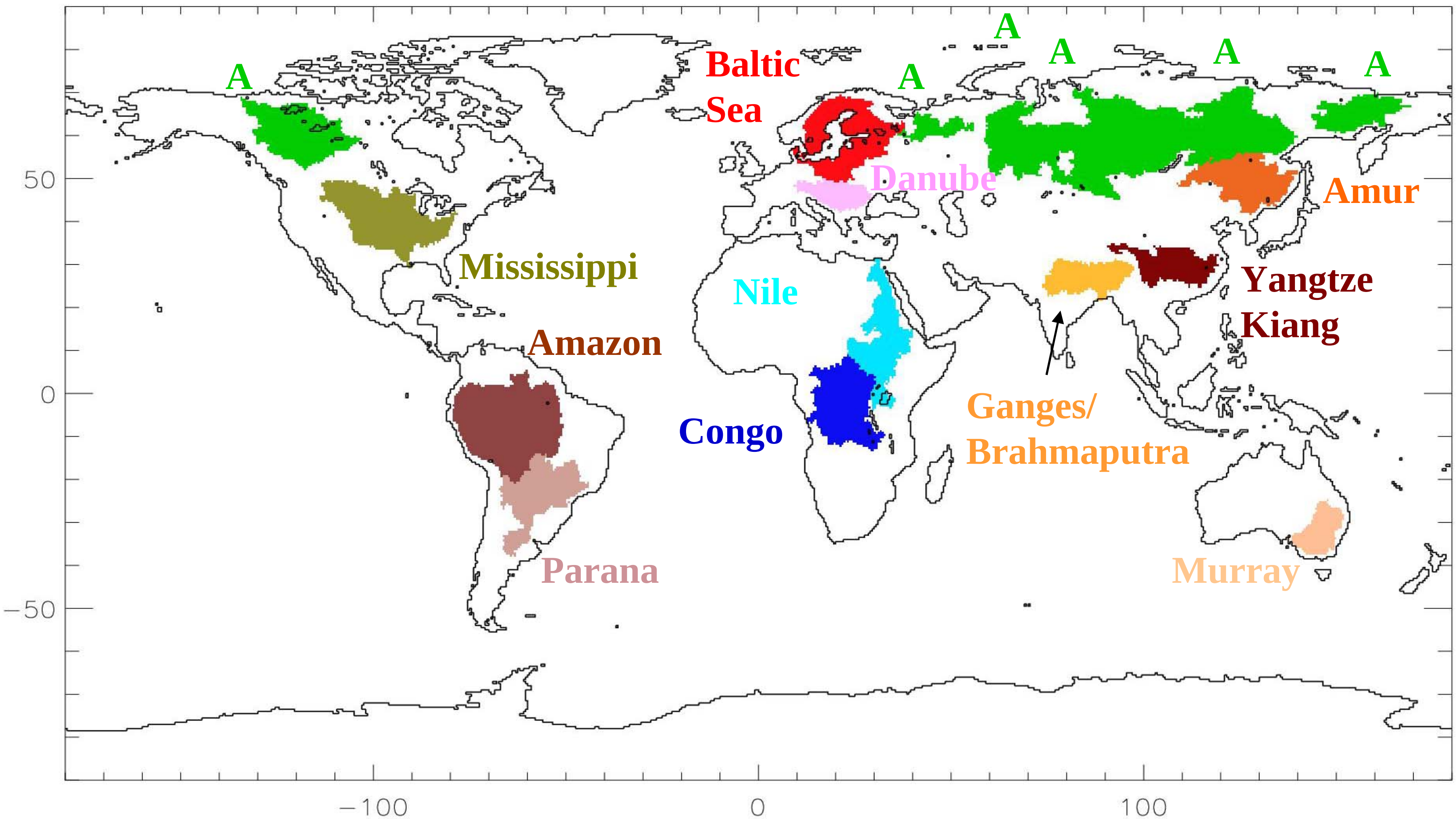
Application to GCM: MPI-M IPCC simulations

- 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**

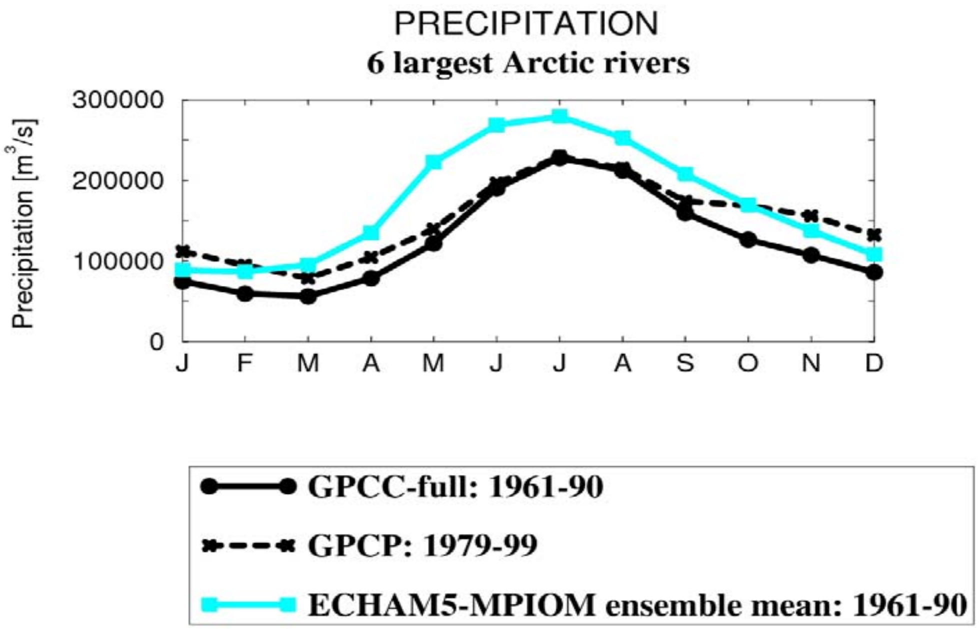
- GCM: ECHAM5 / MPI-OM
- 3 ensemble members for historical control simulation and each scenario

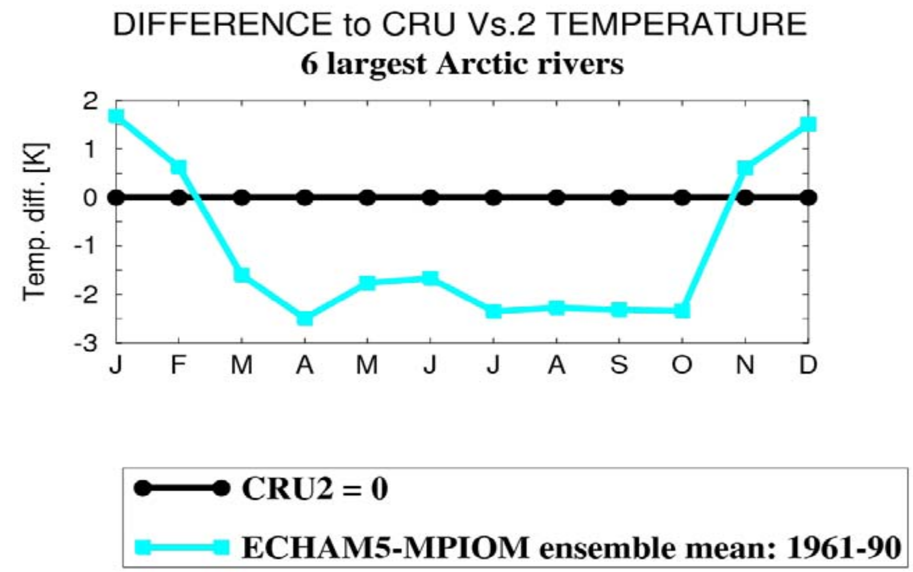
  - Horizontal Resolution of ECHAM5: T63 ~ 200 km
  - Forcing with observed / prescribed (for scenarios) concentrations of CO2, Methane, N2O, CFCs, Ozone (Tropos-/Stratosphere), Sulfate Aerosols (direct and 1. indirect effect)

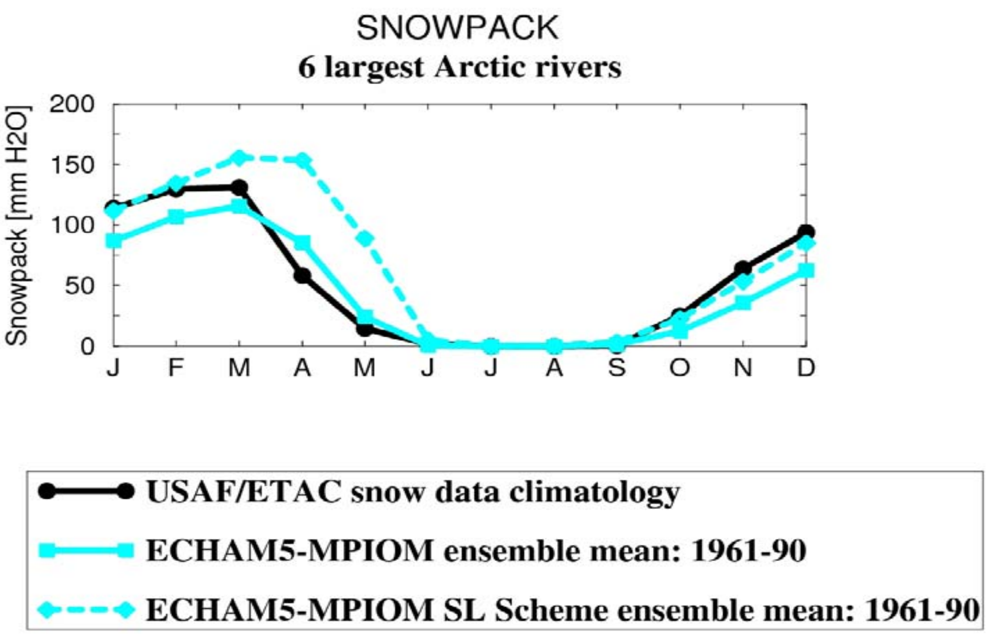


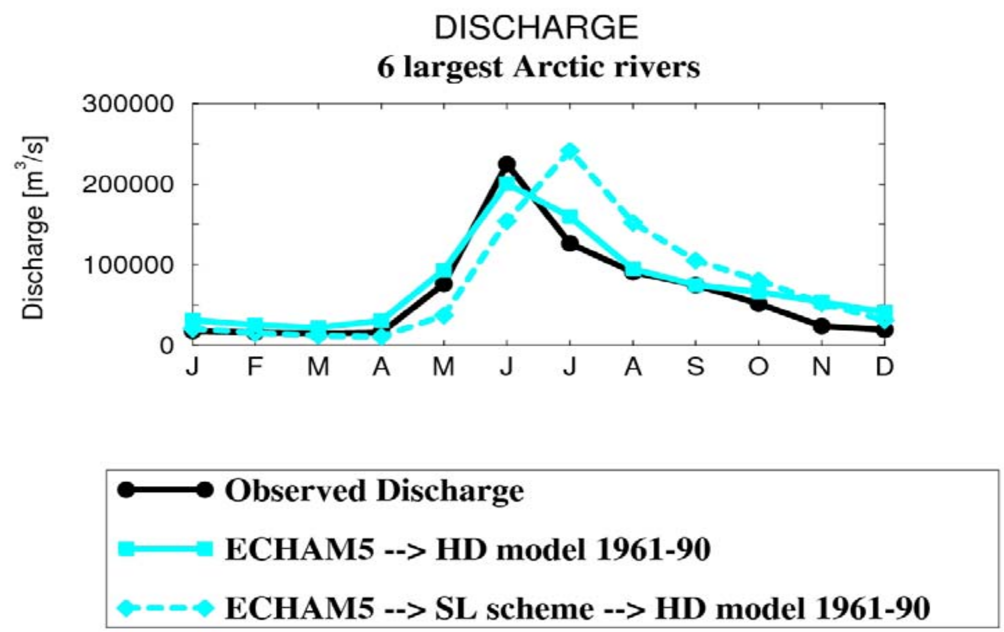
A = 6 largest Arctic Rivers = Mackenzie, N Dvina, Ob, Yenisey, Lena, Kolyma

Vertical fluxes by GCM or by LSHM

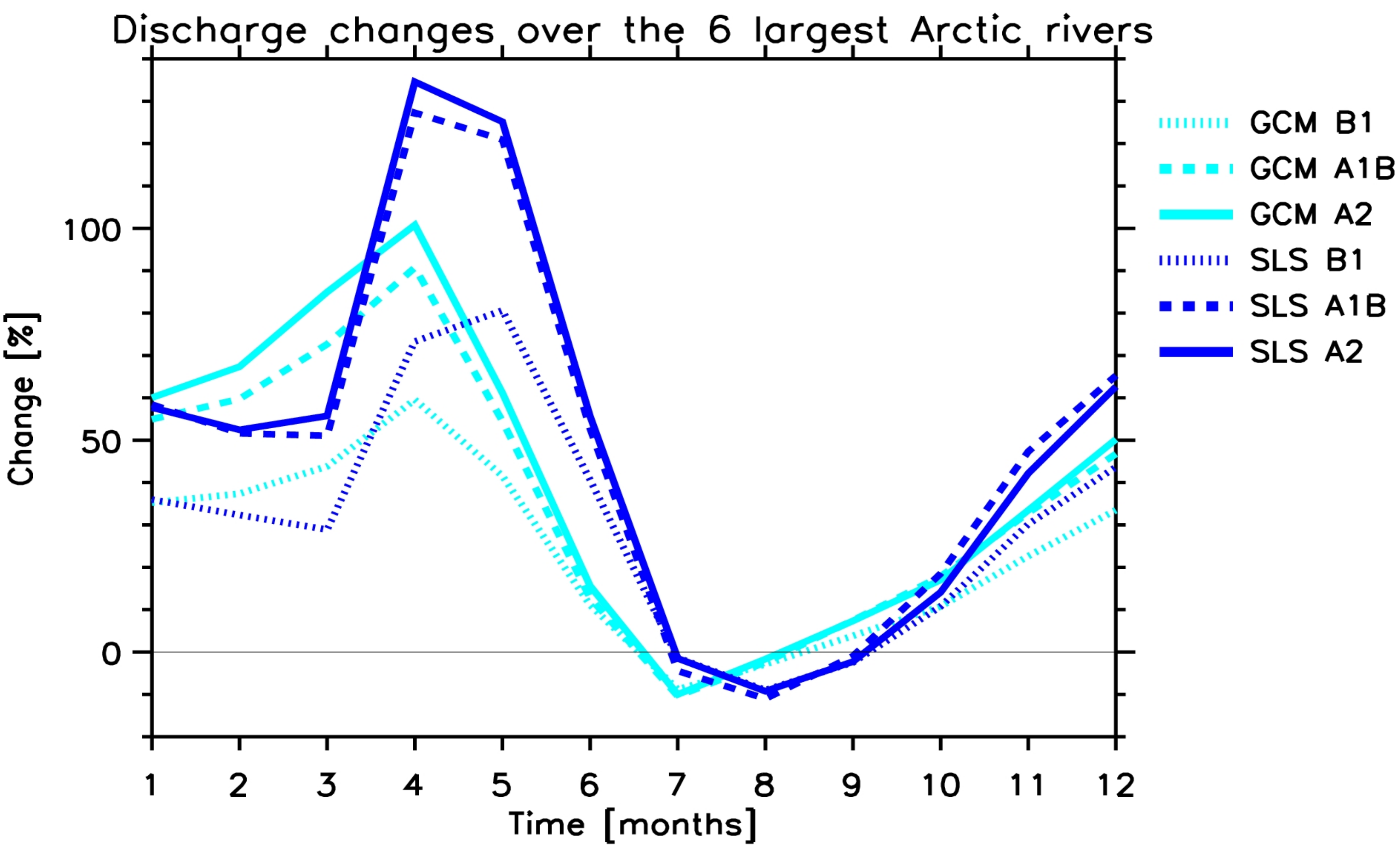








Implication on projected changes of discharge



Problems and uncertainties

Uncertainties

- Choice of the climate model (GCM or RCM)
- Choice of the emission scenario
- Natural climate variability
- Choice of the GCM forcing used for downscaling
- Choice of the hydrology model

Problems in river routing

- Interpolation from climate model grid to 0.5 grid required
- Often a Land Surface Hydrology Model (LHSM) is required to force a river routing model
- Simulated discharge largely depends on the quality of precipitation and snowmelt used as forcing
- Available discharge observations (e.g. from GRDC) often end in the 80s

Future Work

- One aim of WATCH is to provide global LSHMs and methods to use forcing from climate models
- These LSHMs shall include river routing, irrigation, dams, and groundwater schemes

Climate model → LHSM = One way coupling

- Investigation of feedbacks requires two-way coupling

Feedbacks: Atmosphere–Hydrology

- Soil moisture – precipitation feedback
- Reduced precipitation → Drying of soil = less soil moisture → less evapotranspiration → less local recycling of moisture into the atmosphere → less precipitation

- Snow – albedo feedback
- Warming → less precipitation falling as snow, increased snowmelt → lower surface albedo → more energy uptake of surface → warming of surface → increased snowmelt

- Desertification
- Warming → more droughts → drying of soil and erosion → less water storage capacities of soil → more runoff, less infiltration → further drying

Feedbacks: Atmosphere–Hydrology

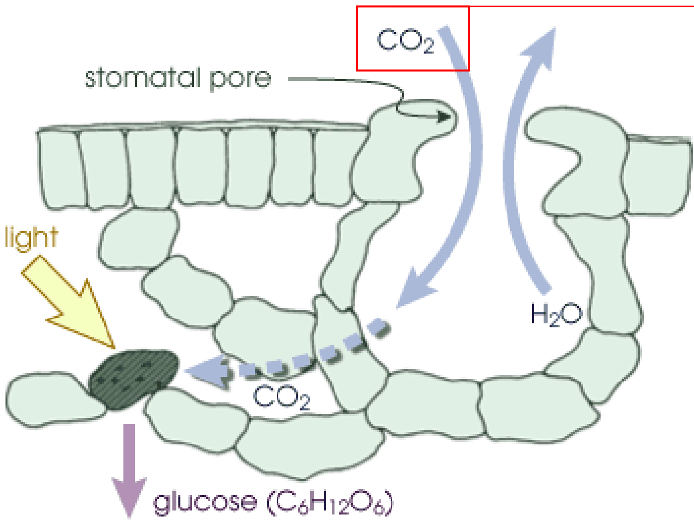
- Permafrost
  - Warming → permafrost melting
    - → increase in wetlands → increased methane production
    - → release of stored soil carbon
  - → increased atmospheric GHG

- Wetlands
  - Increase may lead to more methane production
  - Decrease may yield results similar to the soil moisture–precipitation feedback

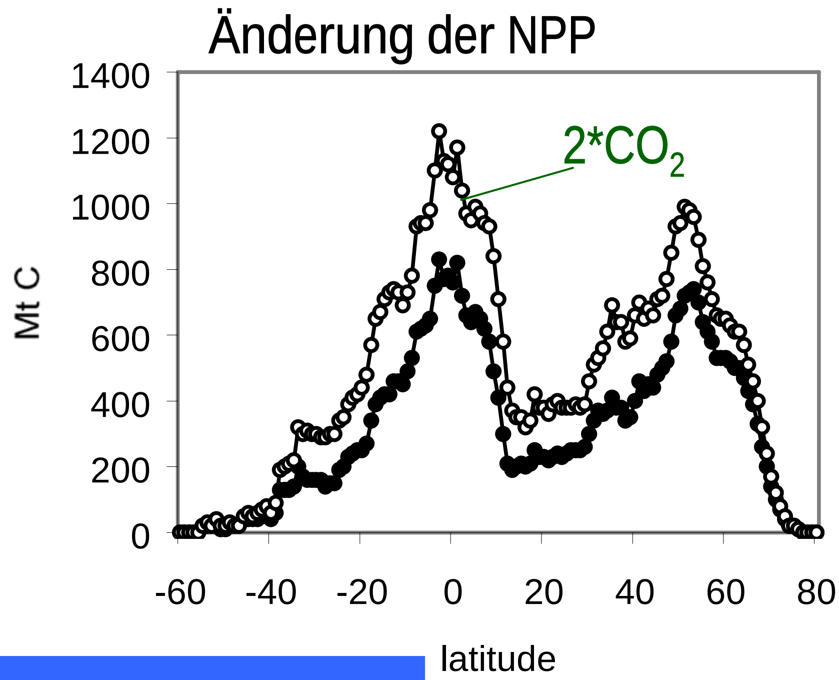
- Further topics that may involve important feedbacks
  - Groundwater

Feedbacks Atmo-/Hydro-/Biosphäre: Die direkten CO_2-Effekte

<u>Hohe CO_2-Konzentration</u>
⇒ Stomata schließen eher
⇒ Wasserverlust durch Transpiration sinkt
bei gleicher CO_2-Aufnahme
⇒ höhere Wassernutzungseffizienz



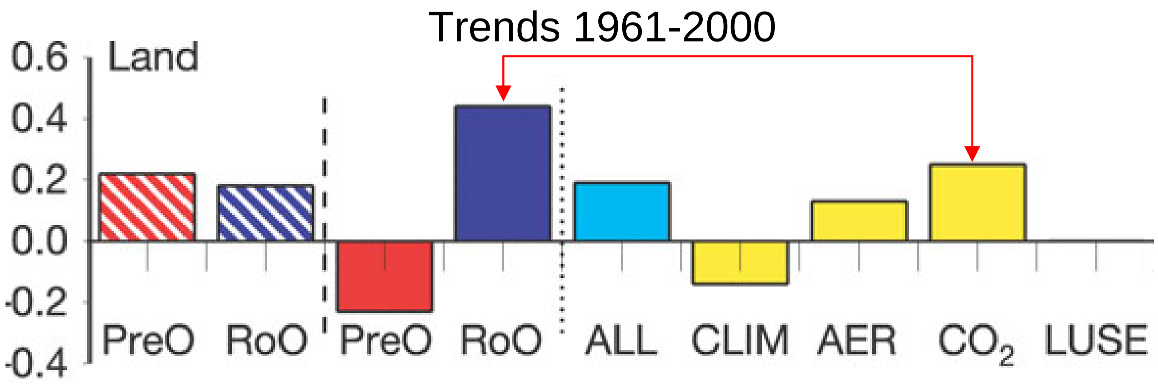
physiologischer CO_2-Effekt
⇒ geringere Transpiration



Leipprand 2004

→struktureller CO_2-Effekt
⇒ höhere Biomasse
⇒ höhere Transpiration

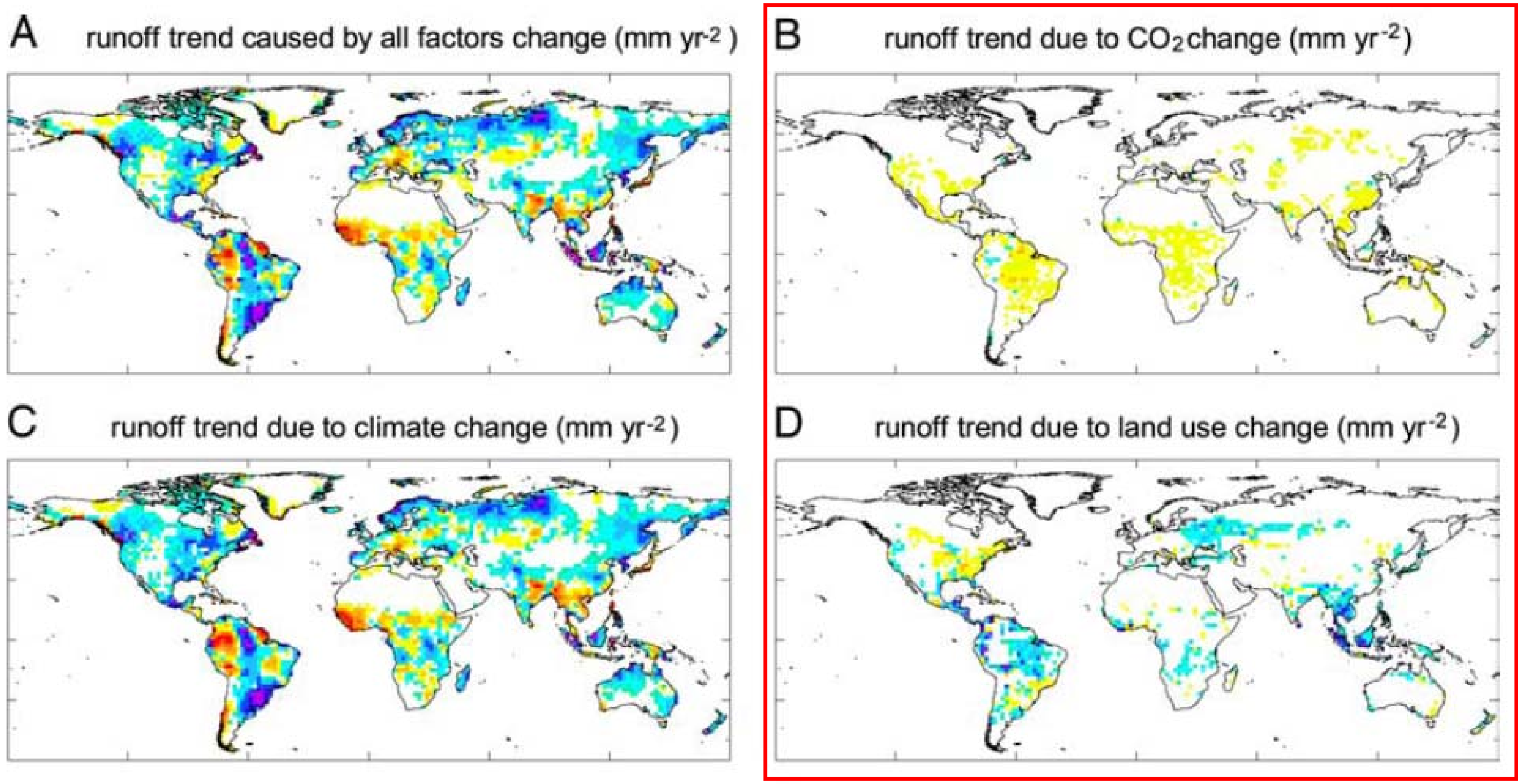
Mögliche Auswirkungen der CO_2-Effekte auf den Abfluss



Gedney et al., *Nature*, 2006

- Quantifizierung der (simultanen) physiologischen und strukturellen Effekte erfordert Kopplung von hydrologischer und Vegetationsmodellierung

Piao et al., *PNAS*, 2007



Welche makroskaligen hydrologischen Modellfamilien gibt es?

General Circulation Models

Klimasystem

Biogeography models

BIOME (Prentice et al. 1992), ...

Biogeochemistry models

CENTURY, TEM, ...

Biosphere models

BIOME3 ...
(Haxeltine & Prentice 1996)

Dynamic Global Vegetation Models

IBIS, HYBRID, SDGVM, TRIFFID, MC1

LPJ
(Sitch et al. 2003)

terrestrische Biosphäre (und Wasser)

WaterGAP (Alcamo/Döll, Universitäten Kassel/Frankfurt)

Macro-PDM (Arnell, Universität Southampton)

WBM (Vörösmarty, Universität New Hampshire)

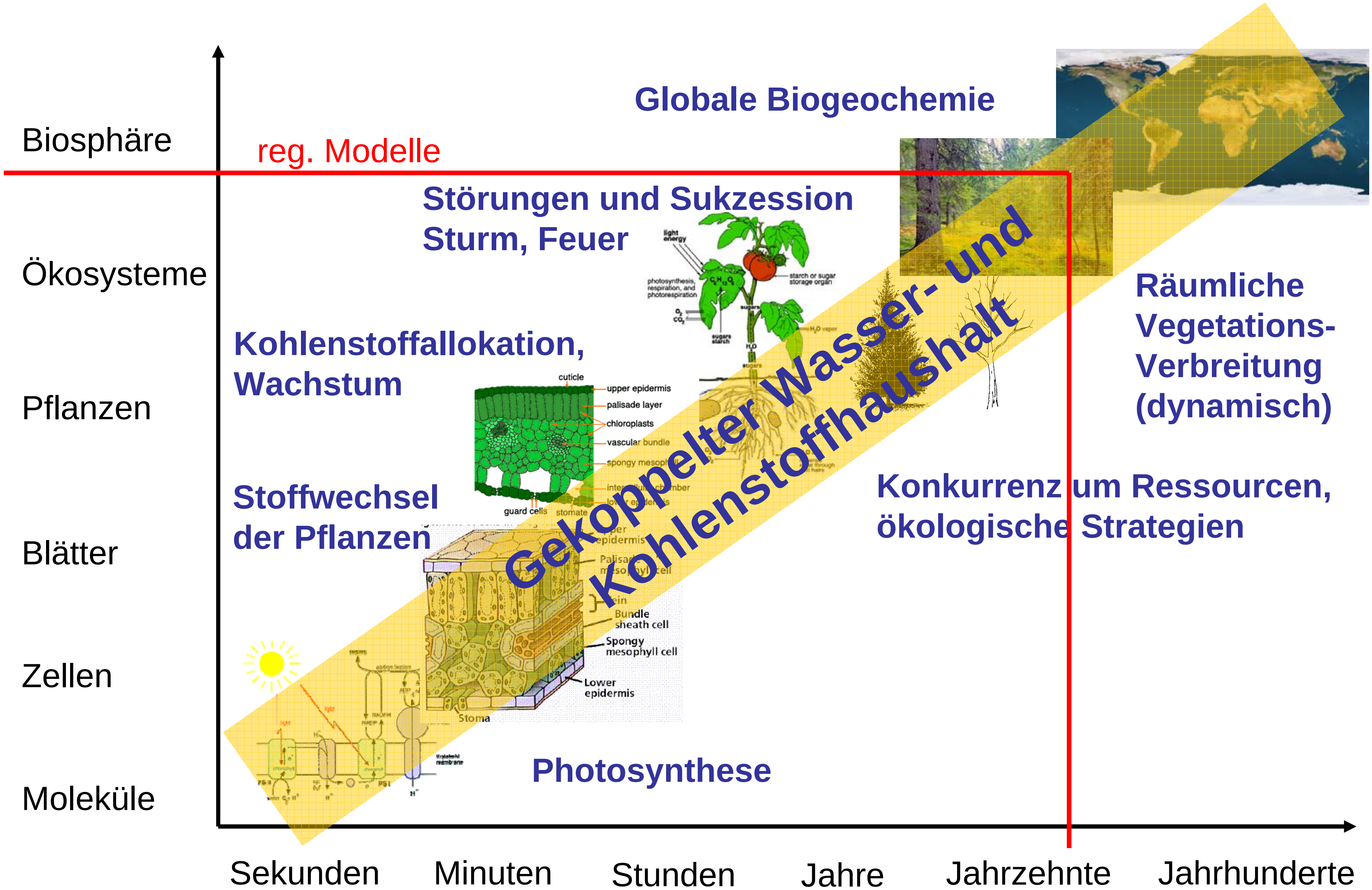
TRIP (Oki, Universität Tokyo)

IMPACT-WATER (Rosegrant, Int. Food Policy Research Institute)

+ HBV etc. (< kontinentale Skala)

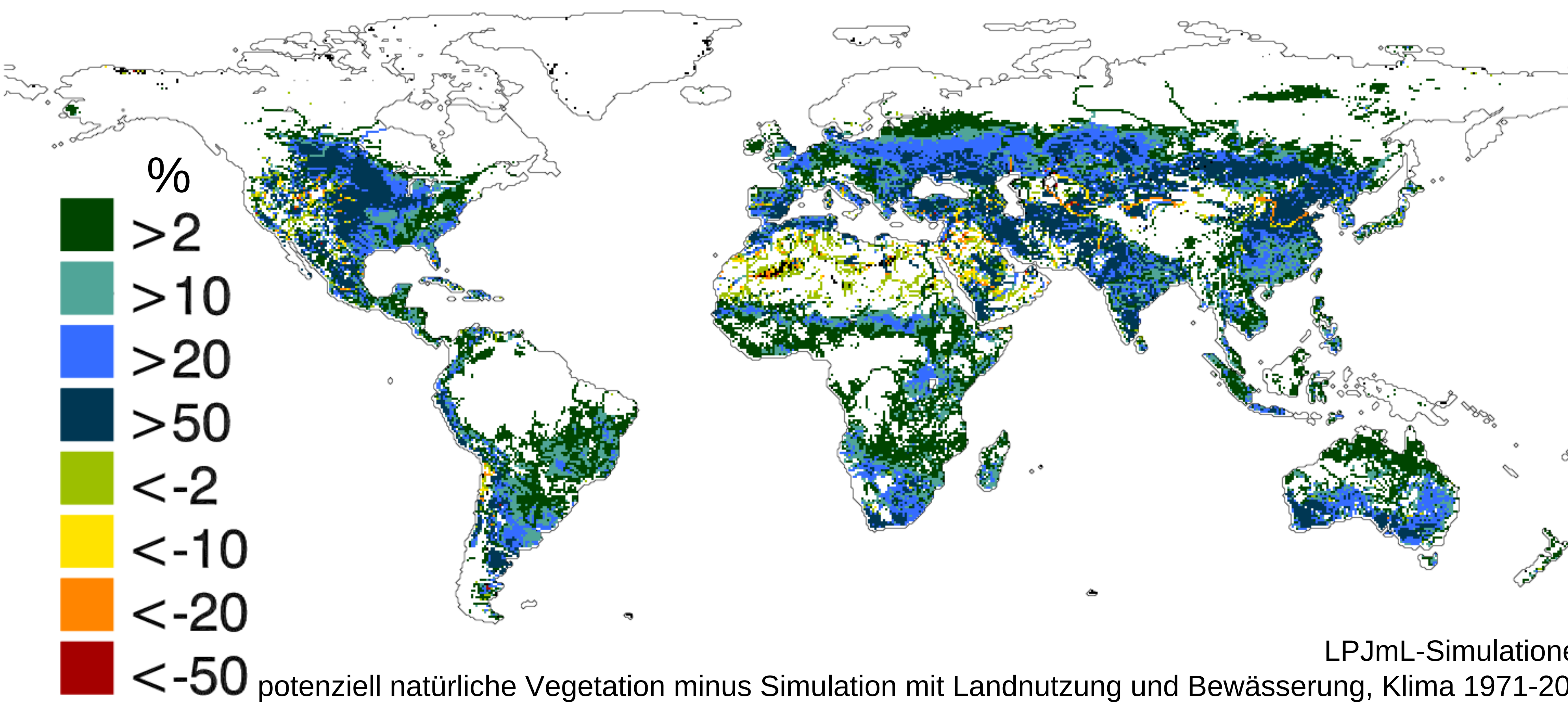
Wasserbedarf u. -dargebot

Prozesse in Biosphärenmodellen (z.B. LPJ)



Feedback Bewässerung/Landbedeckung – Durchfluss

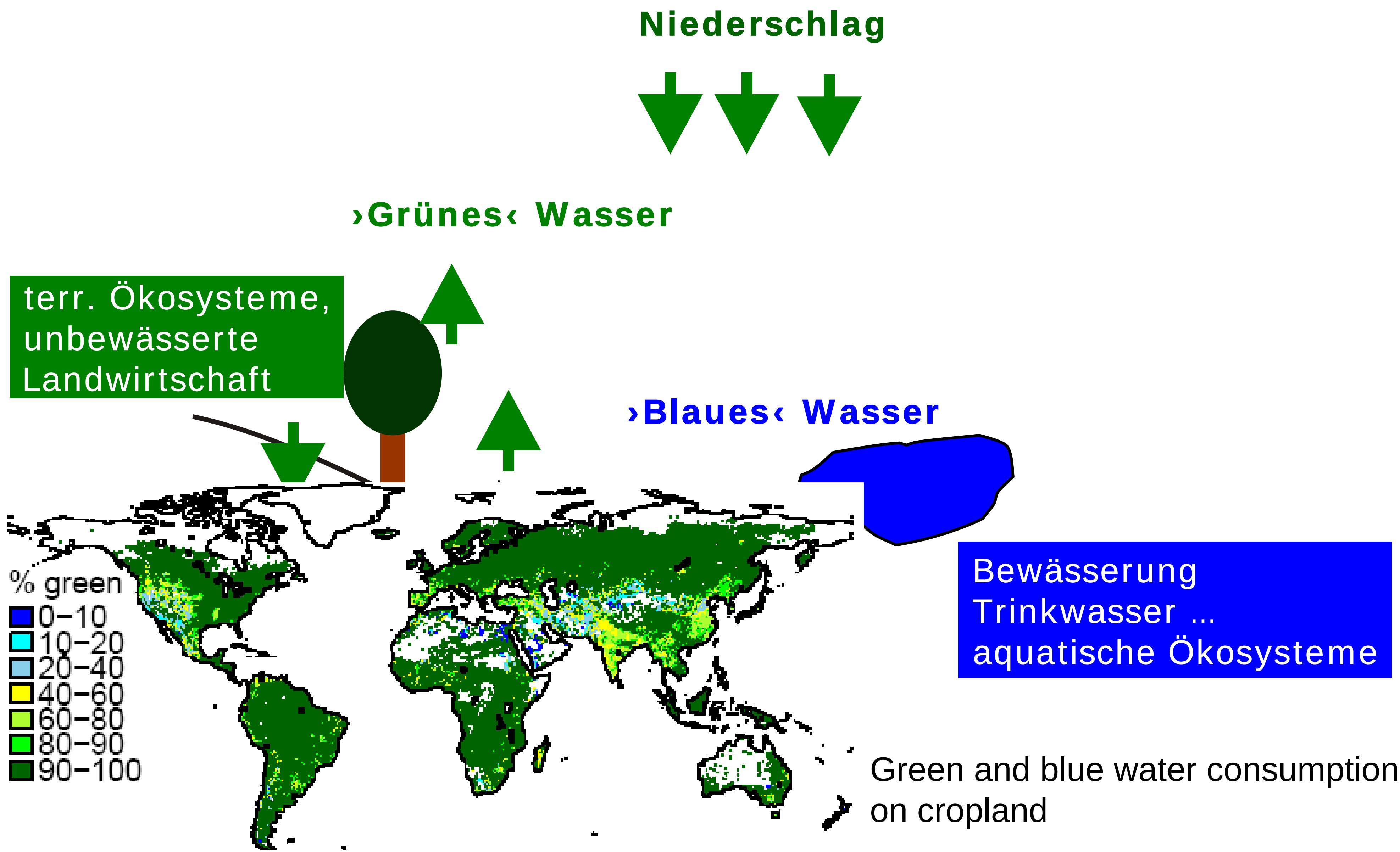
%-Änderung durch Landbedeckungsänderungen <u>und</u> Bewässerung



LPJmL-Simulationen,
potenziell natürliche Vegetation minus Simulation mit Landnutzung und Bewässerung, Klima 1971-2000

Globaler Impakt von Landnutzungsänderungen:	4.8% mehr Durchfluss
Globaler Impakt von Bewässerung:	1.3% weniger Durchfluss
Globaler Impakt von 2 x CO_2 (Zukunft):	~ 2% mehr Durchfluss

Wasserressourcen für Mensch und Biosphäre



Konzeptionalisierung eines neuen Wasserstress-Indikators

Bisherige Wasserstress-Indikatoren nur für blaues Wasser, z.B.:

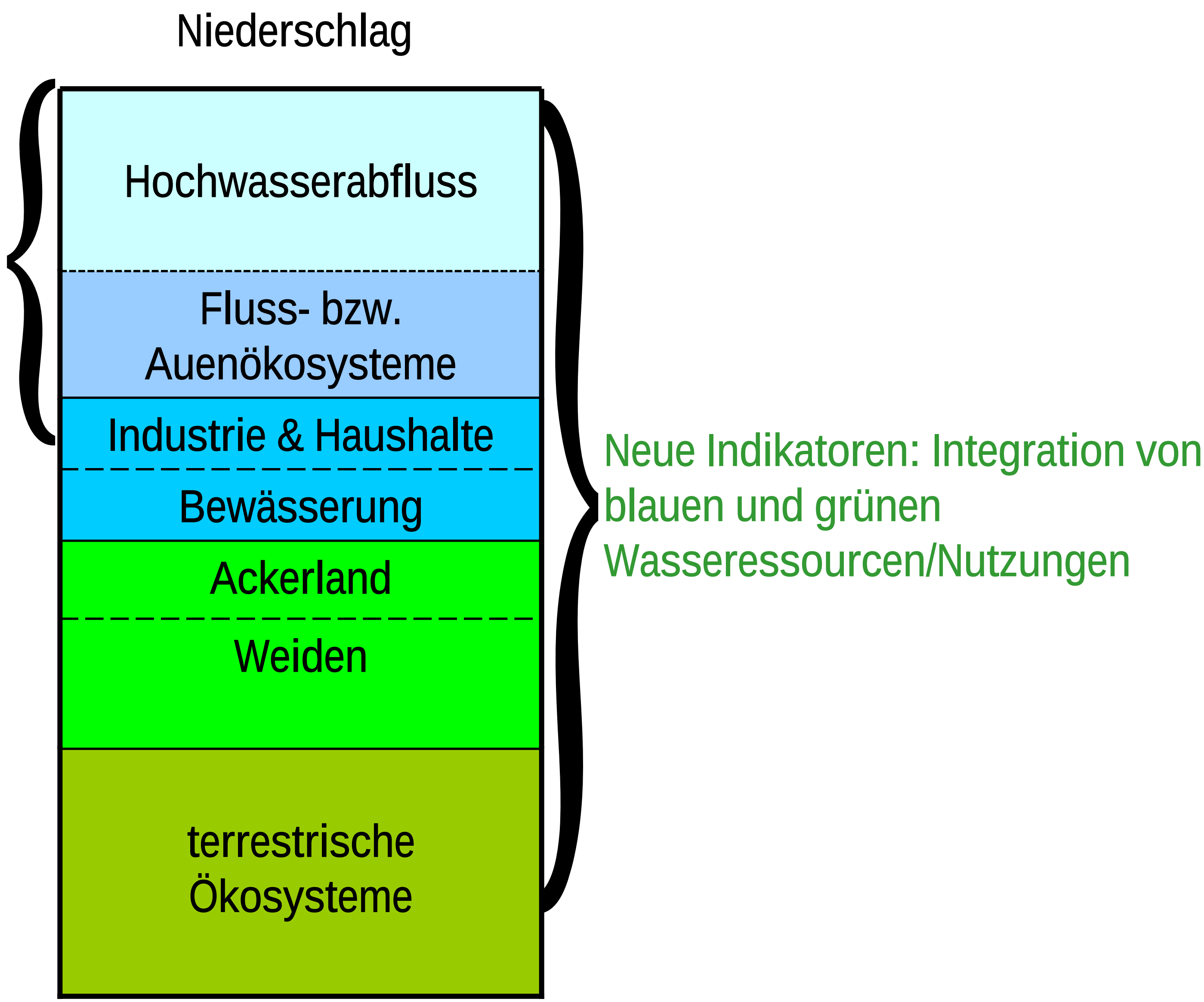
- Kritikalitäts - Index :

$$CR = \frac{\text{Entnahme}}{\text{Verfügbarkeit}}$$

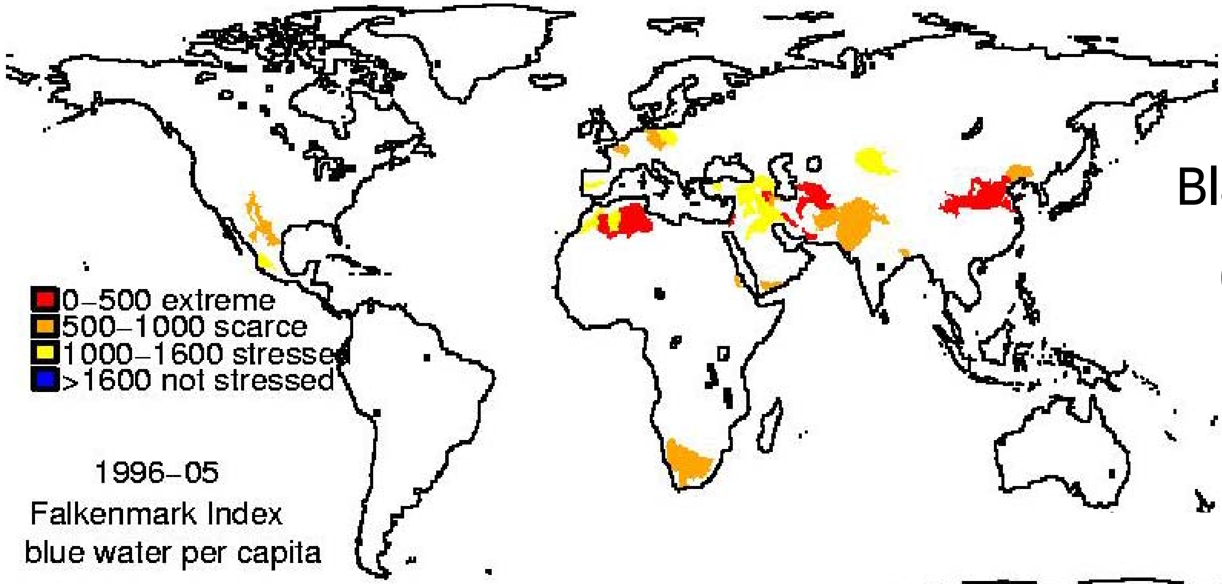
$$CR * \text{Bevölkerungsdichte}$$

- Falkenmark - Index :

Verfügbarkeit pro Person



Blauer und grüner Wasserbedarf/-stress in der Landwirtschaft



Blaues Wasser

(BW / cap.)

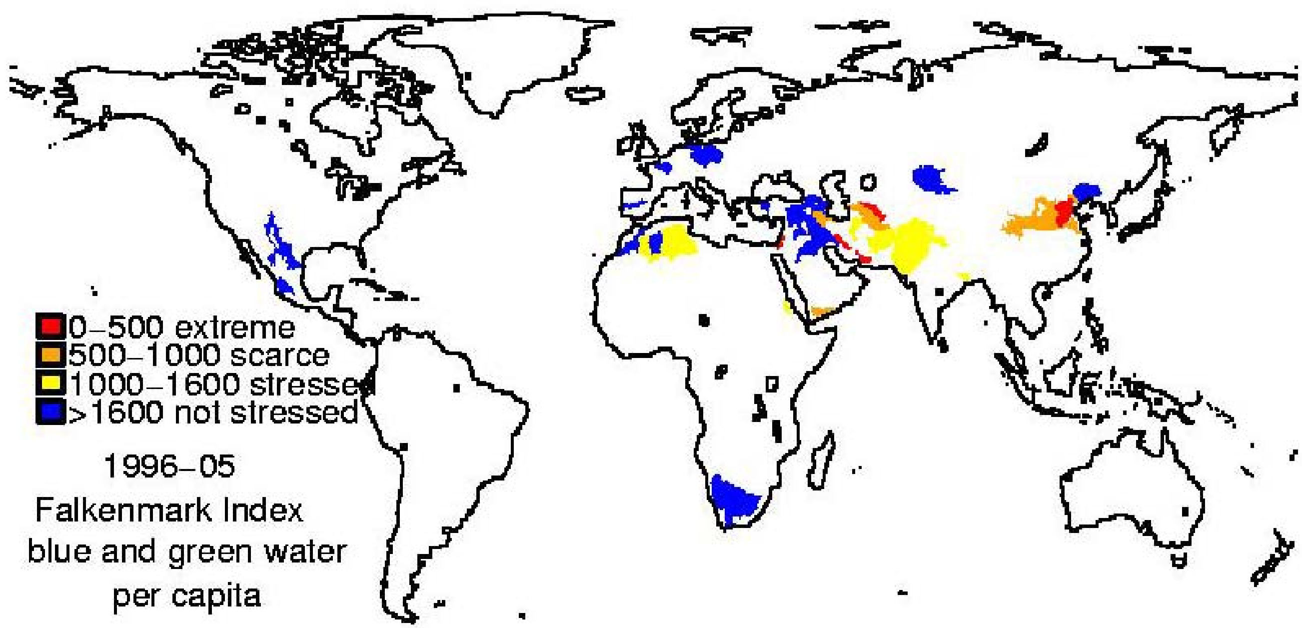
BW = Q

Blaues u. grünes Wasser

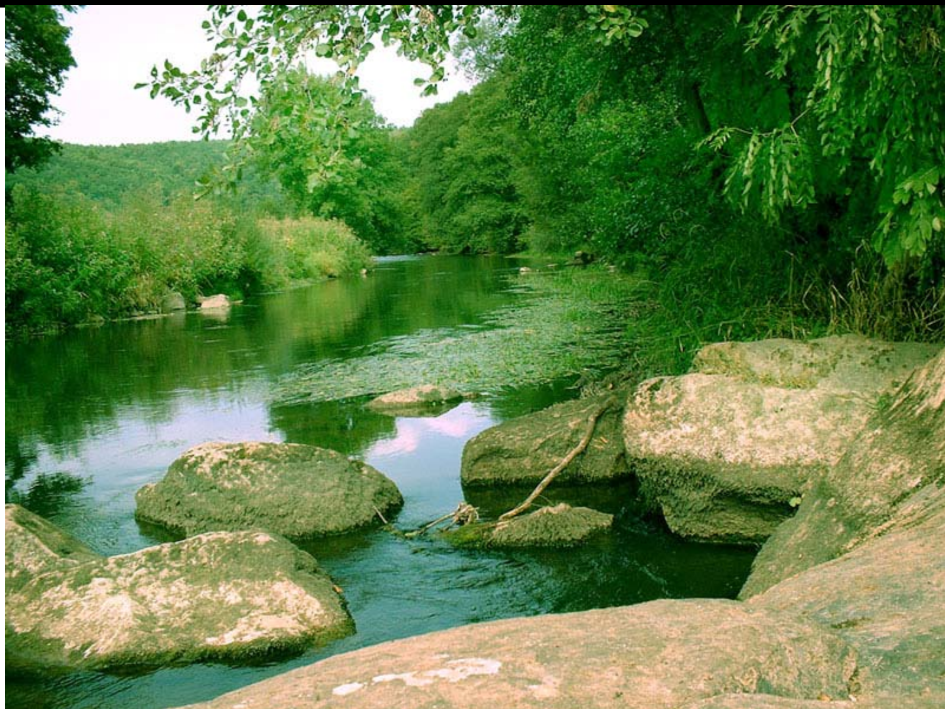
(BW / cap. + GW / cap.)

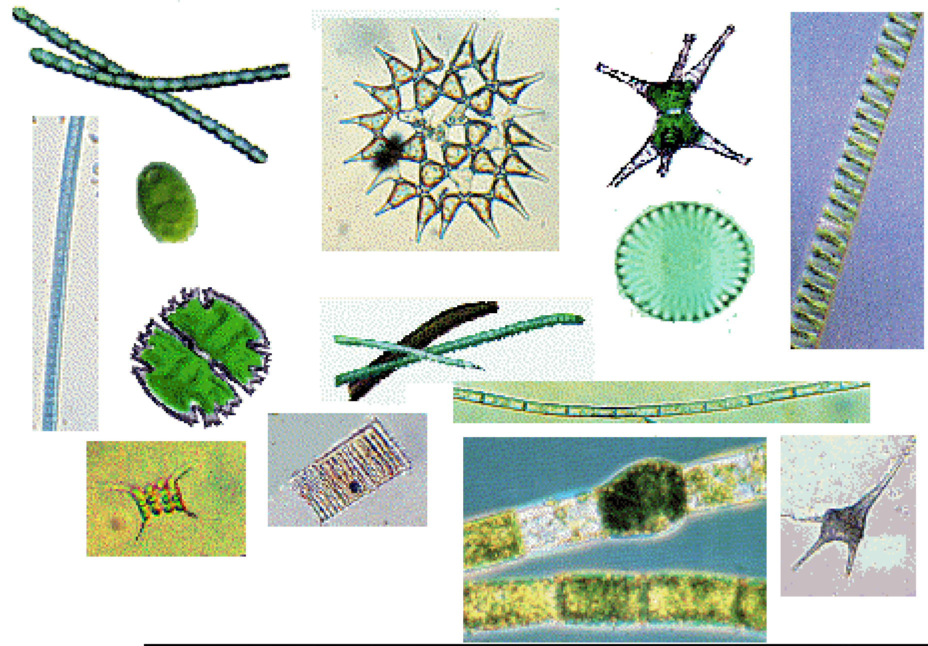
$GW = P_c - Q_c$

c = Ackerland



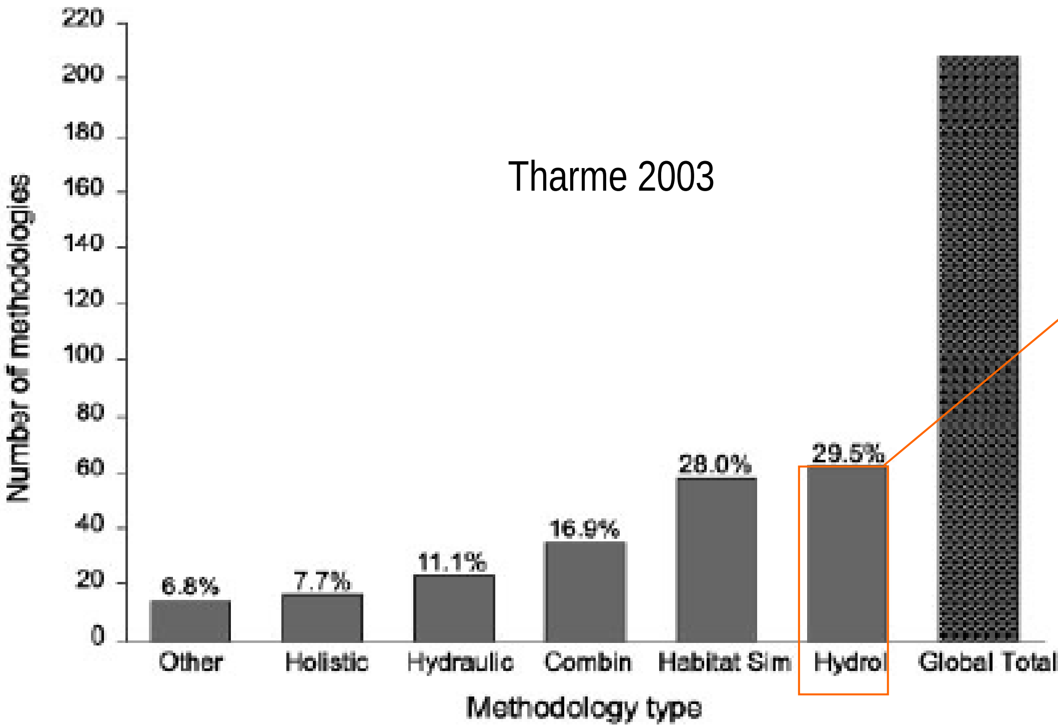
Wasserbedarf/-stress aquatischer Ökosysteme





„Environmental Flow Assessment“:
„How much of the original flow regime of a river should continue to flow down it and onto its floodplains in order to maintain specified, valued features of the ecosystem?“ (Tharme 2003)

Eine Ableitung des ökologischen Wasserbedarfs



Smakhtin, Revenga & Döll 2004

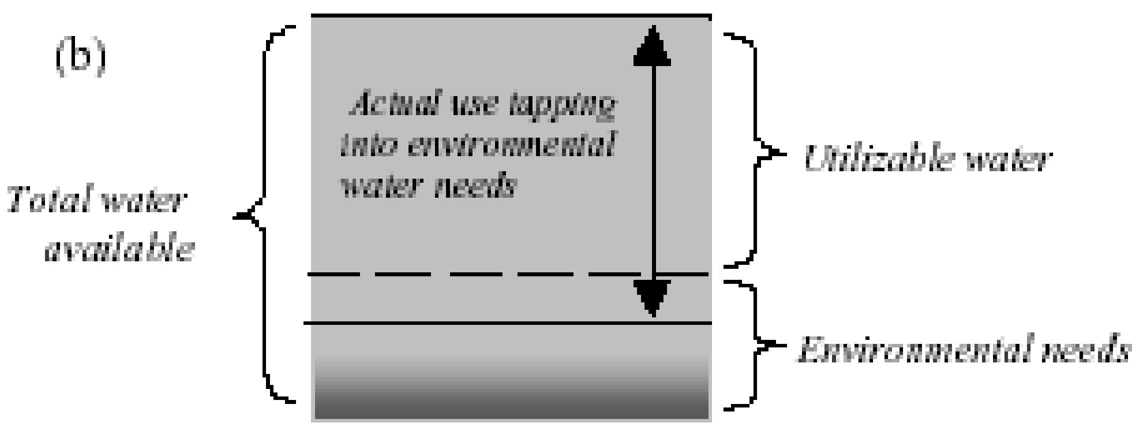
Ökologischer Niedrigwasserbedarf (ÖNB)

Gewässerzustand	Bedarf
natürlich	Q50
gut	Q75
moderat	Q90
schlecht	–

Ökologischer Hochwasserbedarf (ÖHB)

– dto. abhängig vom Abflussregime (Q90)

ÖWB = ÖHB + ÖNB



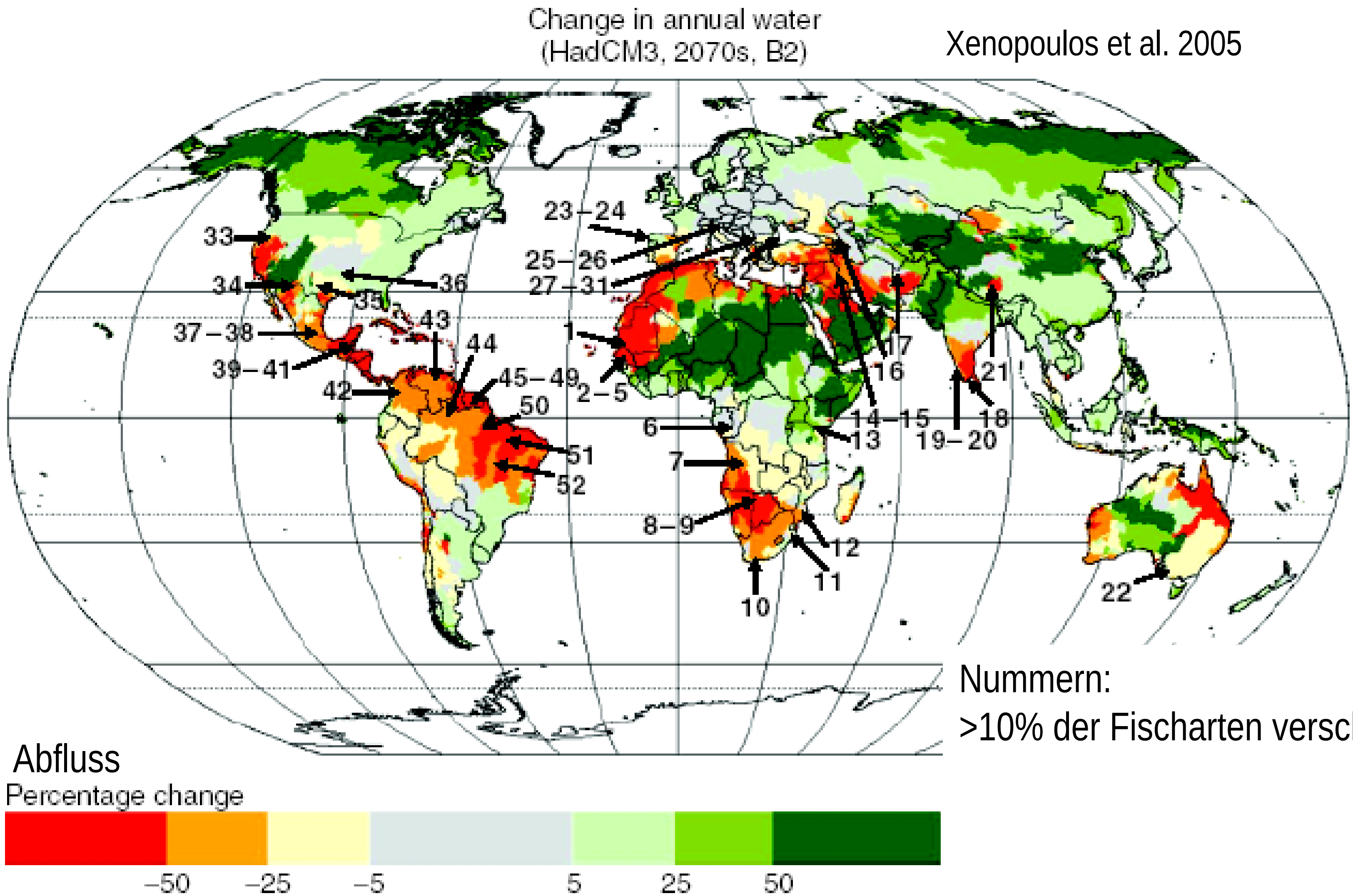
ein erweiterter Wasserstress-Index:

WSI = Entnahme / Dargebot

$WSI_{Ö}$ = Entnahme / (Dargebot – ÖWB)

Zusammenhänge mit Fischartenspektrum

Xenopoulos et al. 2005

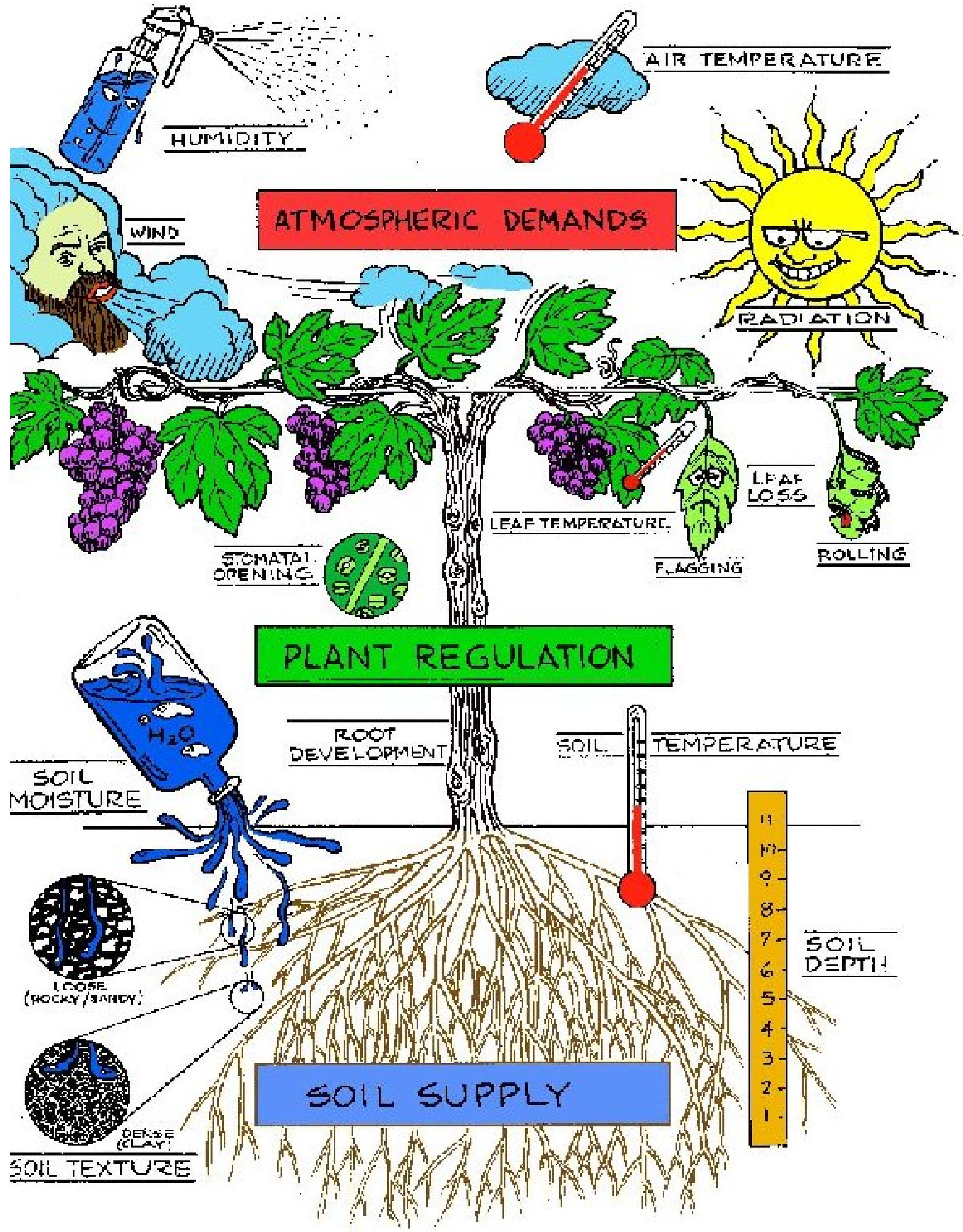


Abfluss

Nummern:

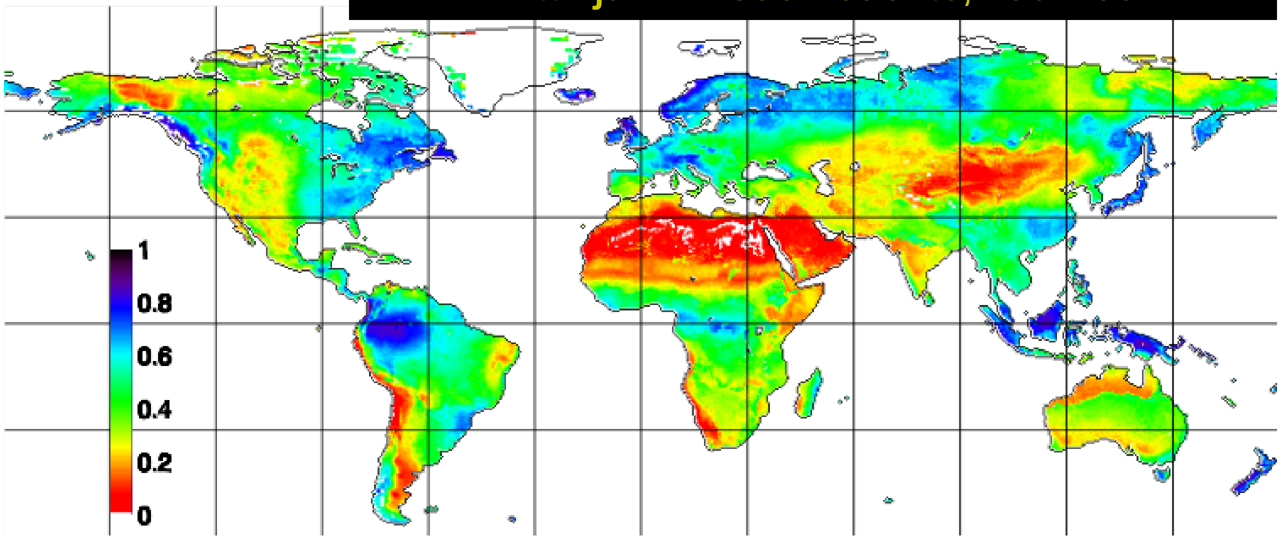
>10% der Fischarten verschwinden.

Wasserbedarf-/stress terrestrischer Ökosysteme

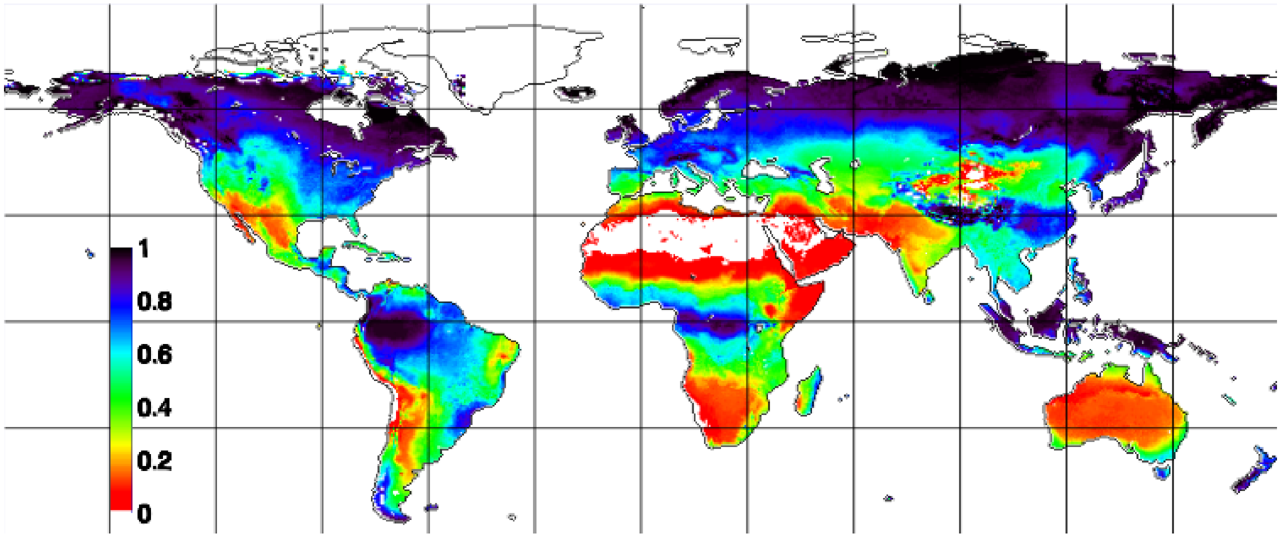


Wasserlimitation der terrestrischen Nettoprimärproduktion

mittl. jährl. Bodenfeuchte, 1961–90



mittl. jährl. Wasserlimitierung, 1961–90



Gerten et al., *GRL*, 2005

Danke für die Aufmerksamkeit!