HydroPredict, Vienna, 24-27 September 2012
Special Session 3: Choosing Models for Resilient Water Resources Management Water Partnership Program (WPP)/TWIWA-The World Bank

SWIM model for resilient water resources assessment under scarce data

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P I K

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OUTLINE

1. Introduction to SWIM model

- Model overview

- Model structure & development

- Model validation

2. SWIM applications

3. Concluding remarks

SWIM

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MOTIIVATION

Development of integrated tools for coupled modelling of water flow, vegetation and water quality at the river basin scale is motivated by **water resources management** in

- densely populated rural areas (water availability & pollution),
- arid and semi-arid regions (water scarcity), and
- mountainous and loess regions (erosion problem).

The other motivation is the ongoing **climate change, land-use change, and land-cover change**. Development of water resources in conditions of global change requires a thorough understanding and adequate representation of basic hydrological and related processes.

FROM SWAT & MATSALU to SWIM

The continuous-time semi-distributed watershed model **SWIM** (**S**oil and **W**ater **I**ntegrated **M**odel) was developed at PIK, specifically to investigate climate and land-use change impacts at the regional scale (1,000 – 100,000 km^2). It is based on two tools: **SWAT**, developed by Arnold, Williams et al. in the USA and **MATSALU** developed by Krysanova et al. in Estonia.

Krysanova, V., Mueller-Wohlfeil, D.I., Becker, A., 1998. Development and test of a spatially distributed hydrological / water quality model for mesoscale watersheds. *Ecological Modelling,* 106, 261-289.

Krysanova, F. Wechsung, J. Arnold, R. Srinivasan, J. Williams, 2000. *"SWIM (Soil and Water Integrated Model), User Manual",* 239pp. PIK Report Nr. 69.

MODEL of INTERMEDIATE COMPLEXITY

SWIM is a model of intermediate complexity for the river basin and regional scale. It is:

- more comprehensive than purely hydrological and rainfall-runoff models (more reliable representation of coupled vegetation processes and nutrient cycling),
- driven by commonly available regional data (→easier parametrization than for more detailed fully distributed hydrological models like MIKE SHE),
- more reliable as hydrological tool compared to large scale climate models like RCMs, continental-scale terrestrial models like LPJ, and large-scale water resources models like WaterGap.

SWIM is **a useful tool for climate and land use change impact assessment**.

SWIM TECHNICAL FEATURES

Temporal resolution: Simulation step: 1 day

Spatial resolution: SWIM includes a three-level disaggregation scheme: basin – sub-basins – hydrotopes. Hydrotopes, created by overlaying sub-basin, land use and soil maps, create the lowest disaggregation units or classes of units. Lateral flows are aggregated at the sub-basin scale.

Operating system: Unix, Linux and Windows platforms

Programming language: Fortran (model code) and C (interface)

Parameterization: The model can be parameterized using regionally available information (DEM, land use, soil, climate, etc.).

GIS interface: The model setup and post-processing are supported by a GIS interface (GRASS and Map Windows).The results are presented as time series and maps for a number of variables.

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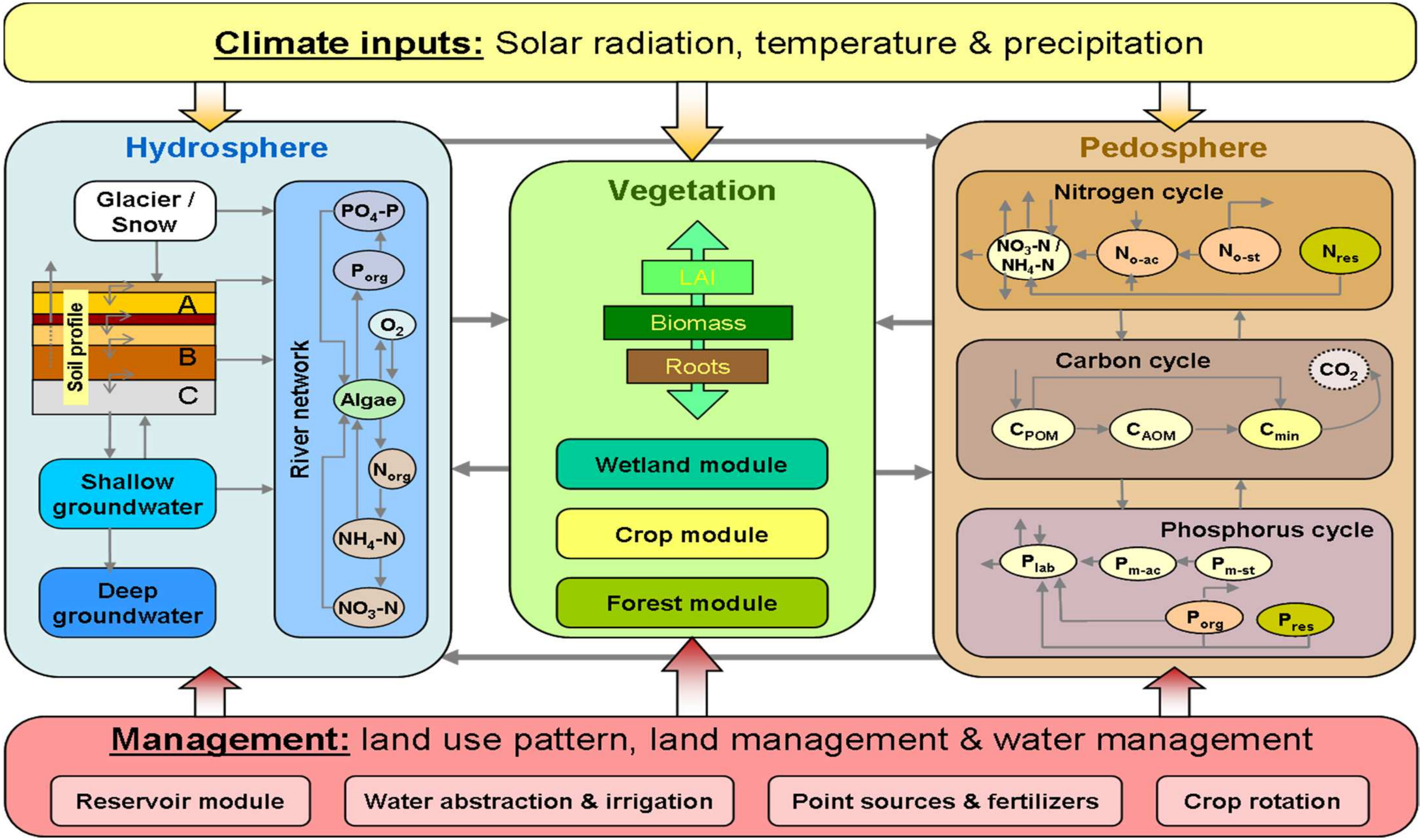
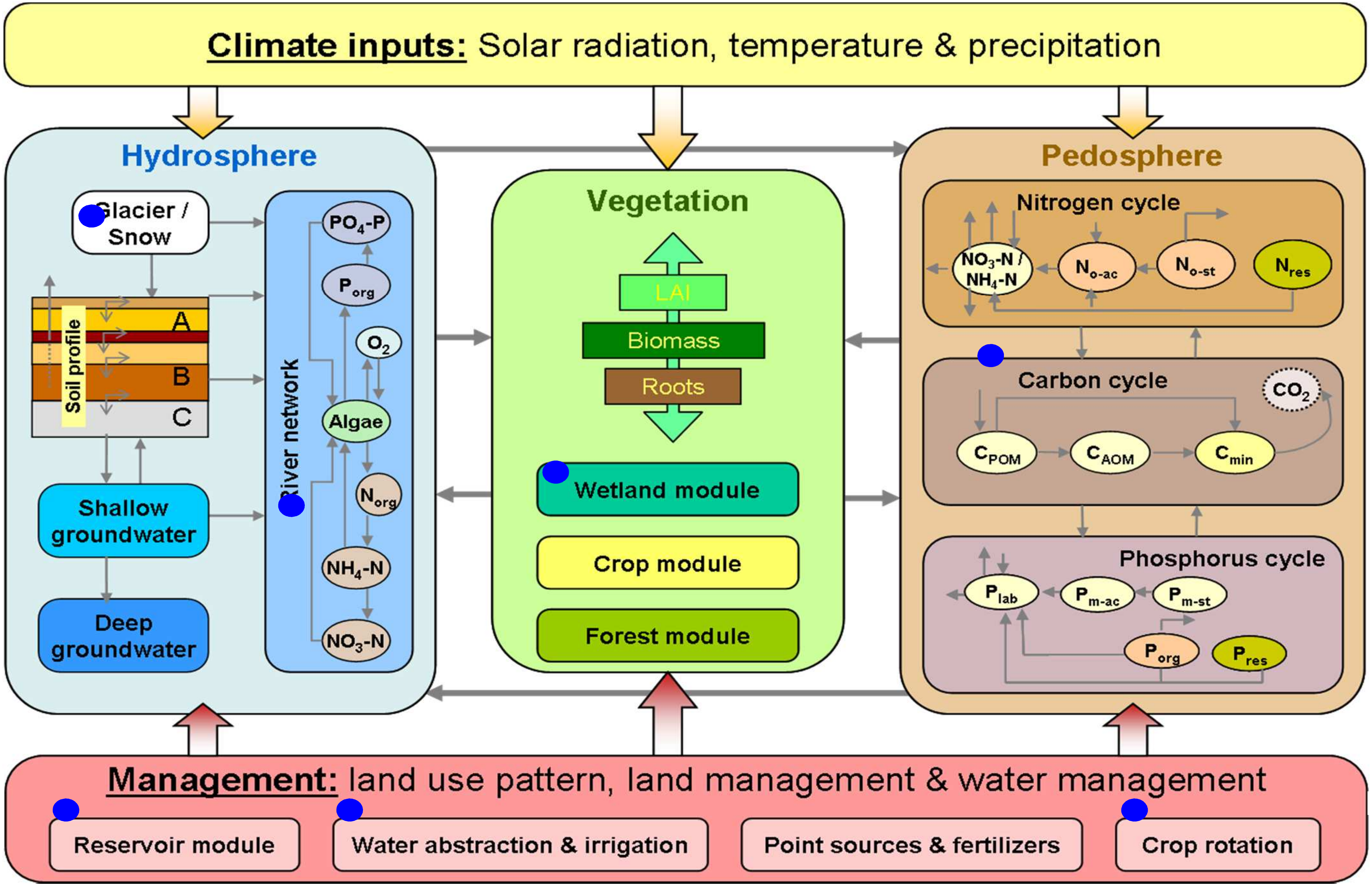
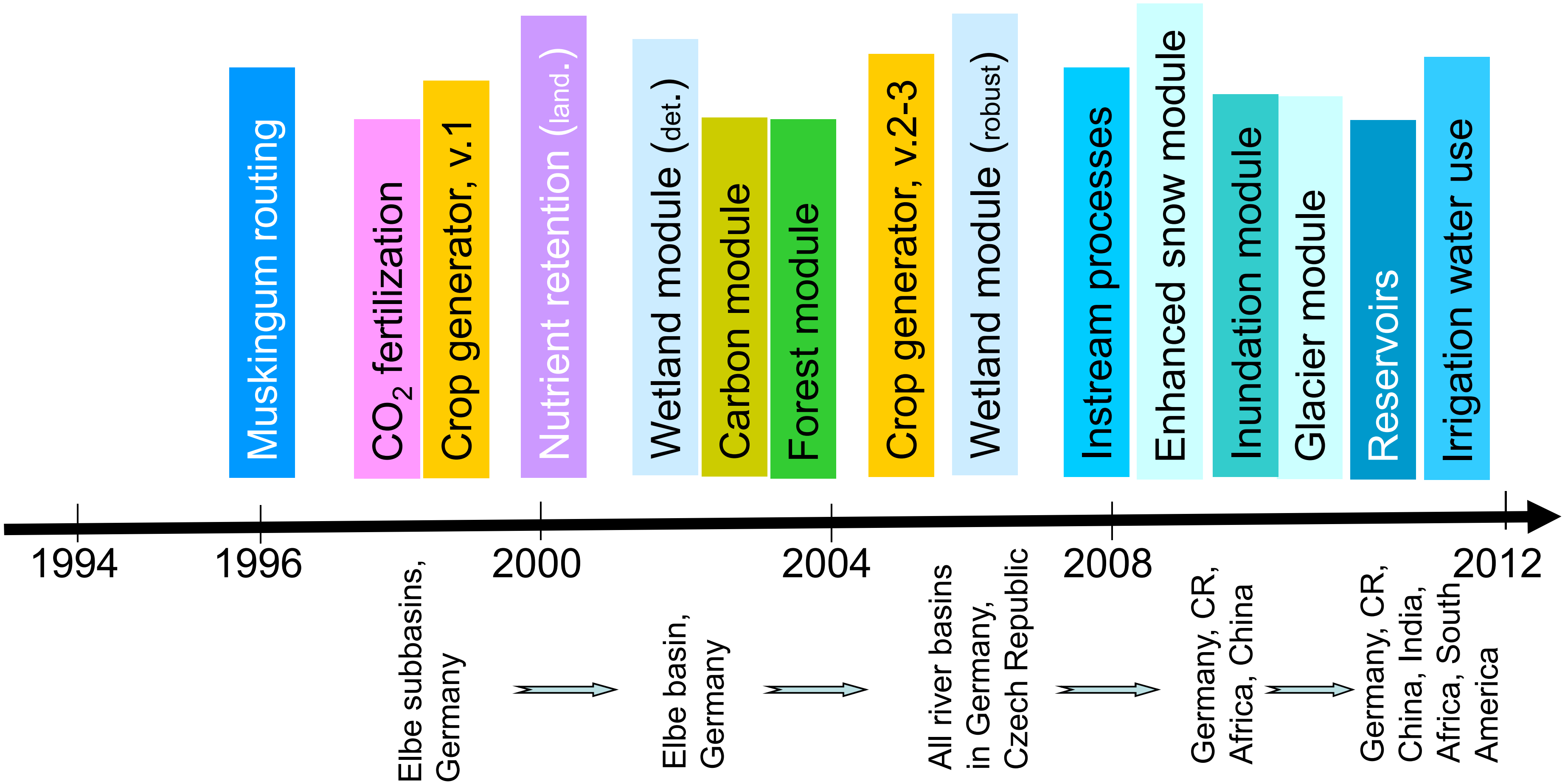
SWIM STRUCTURE



SWIM: recents developments ( )



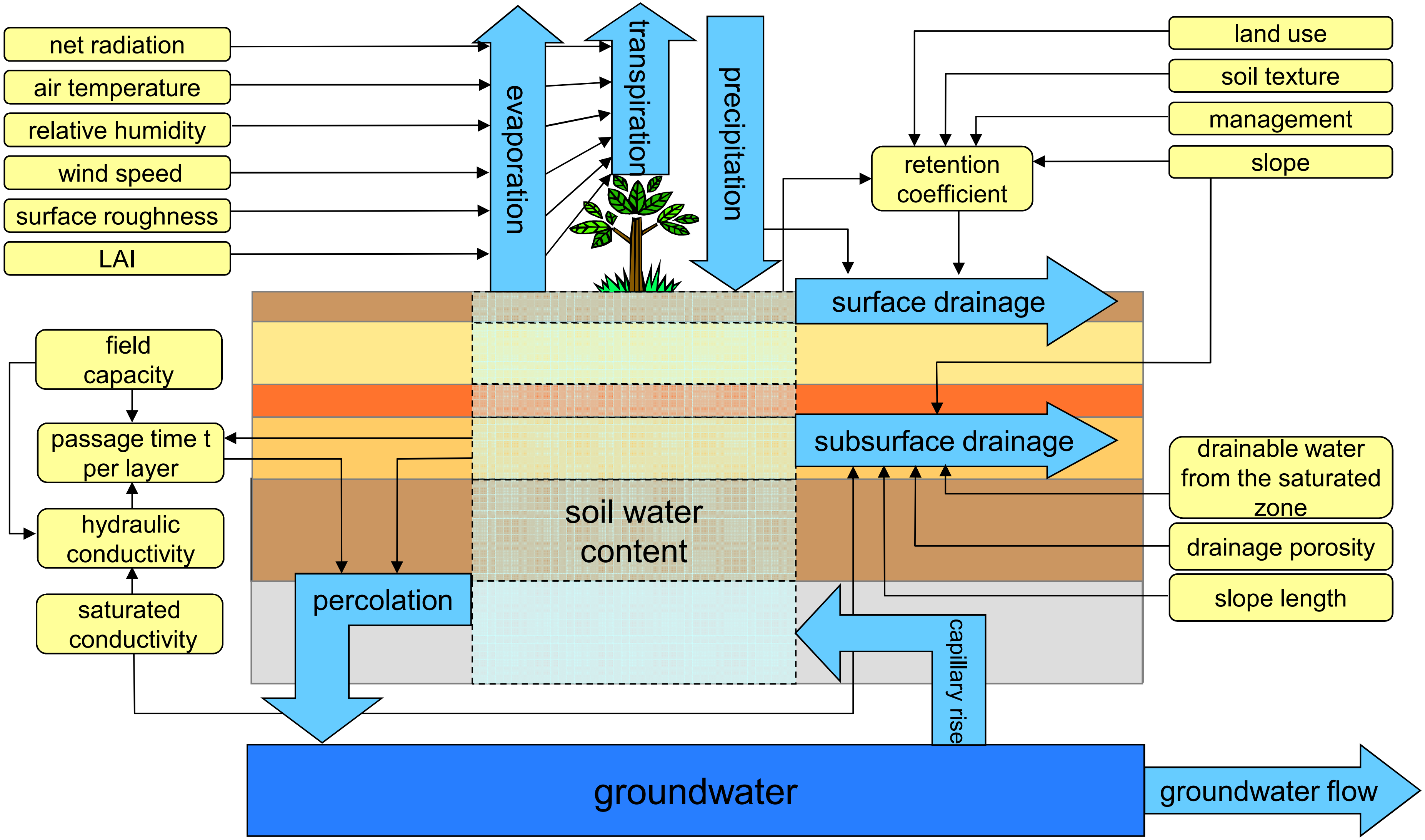
DEVELOPMENT of new SWIM MODULES



Valentina Krysanova: Musk. routing, CO2 fert., crop gener.
Fred Hattermann: nutrient retention, groundwater, wetlands
Frank Wechsung: CO2 fert., crop generator
Tobias Vetter: wetland module, MAPWindows interface
Cornelia Hesse: in-stream nutrient processes
Joachim Post: carbon cycle

Shaochun Huang: snow & glacier modules, irrigation
Martin Wattenbach: extended forest module
Stefan Liersch: inundation processes
Hagen Koch: reservoirs
Tobias Conradt: groundwater, coupling with WBalMo
Jan Volkholz: coupling with CCLM (RCM)

HYDROLOGICAL PROCESSES in SWIM



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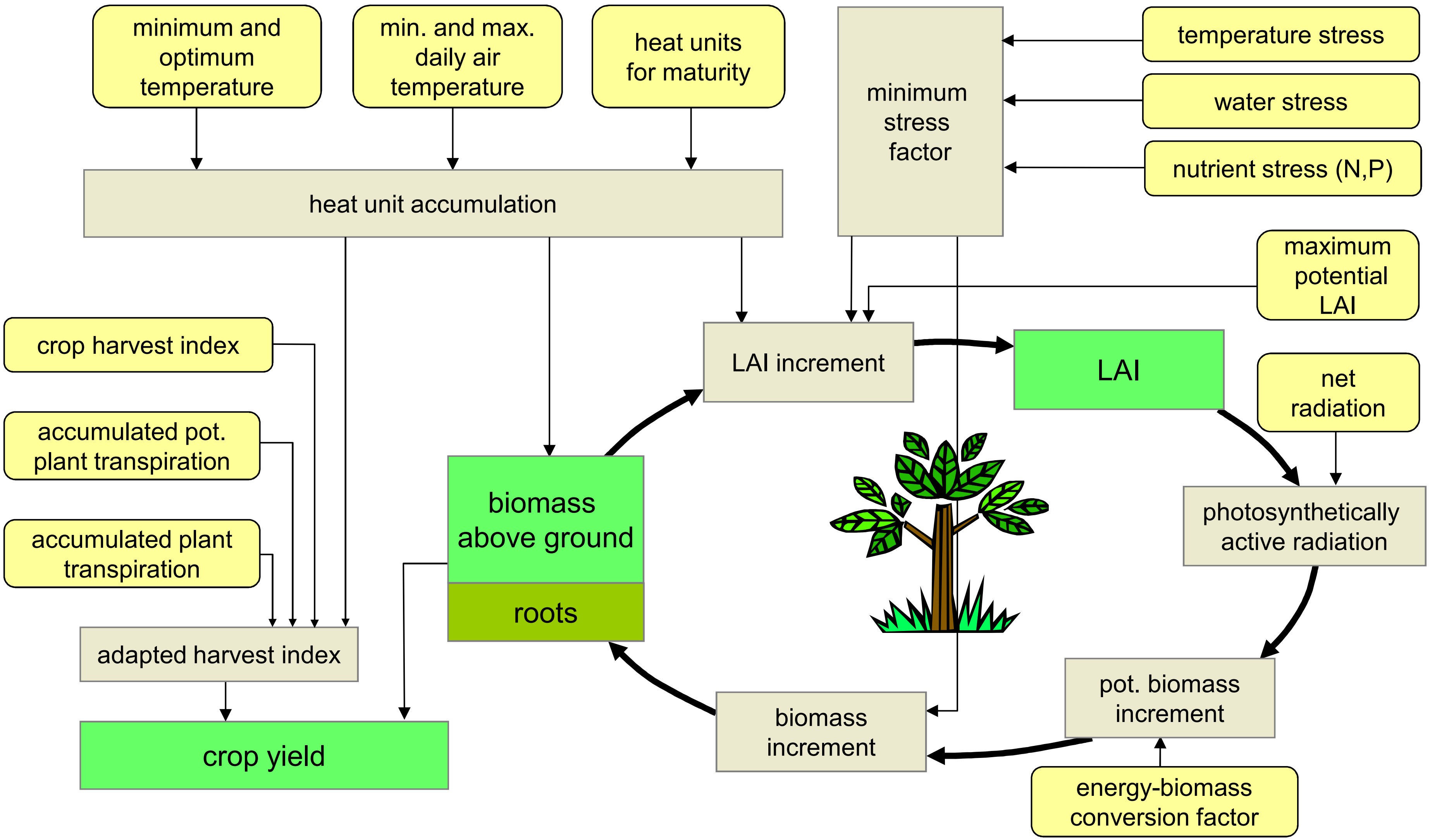
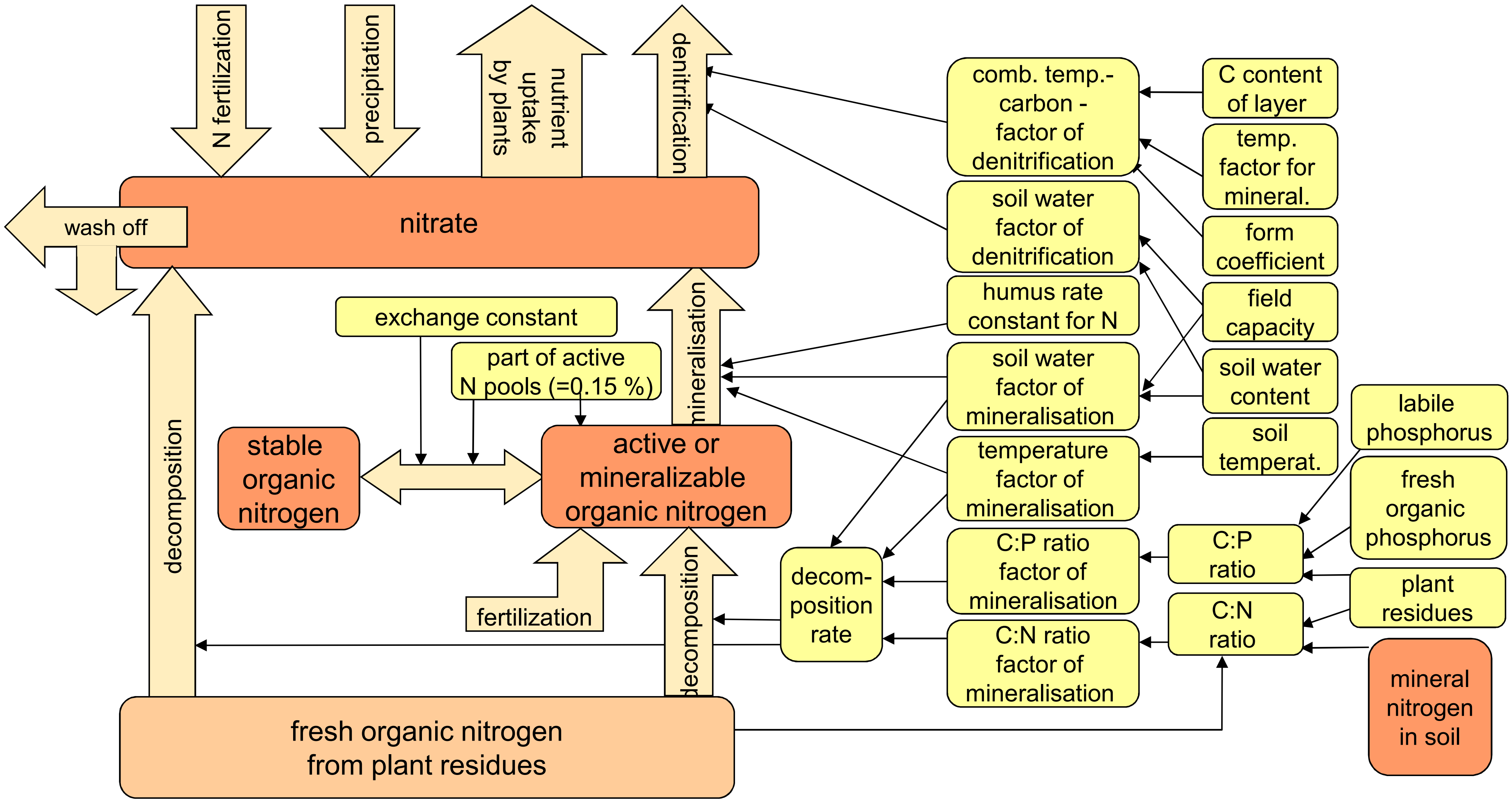
VEGETATION PROCESSES in SWIM



NITROGEN CYCLE in SWIM



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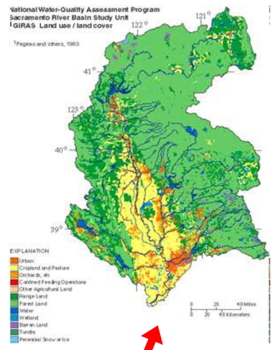
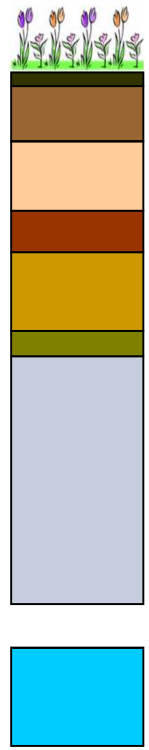
MODEL INPUTS

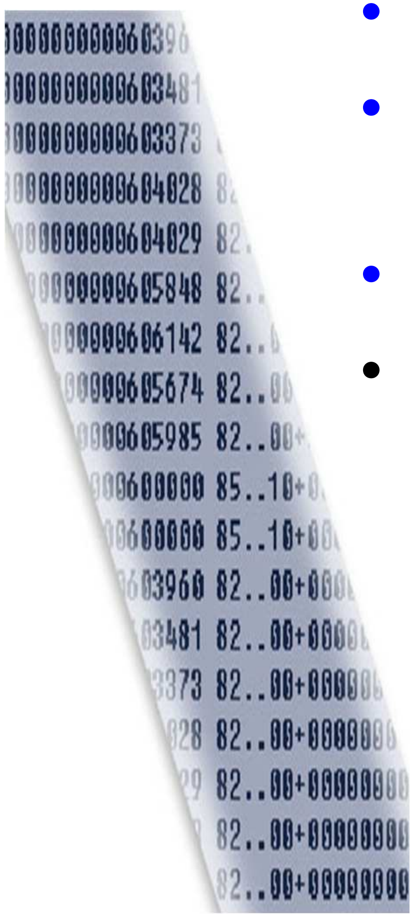


- **Spatial Data (maps)**
  - **DEM**
  - **Subbasins (could be outlined from DEM)**
  - **Land use (15 land use classes, 72 crop/vegetation types)**
  - **Soil types (with parameterization of soil layers)**

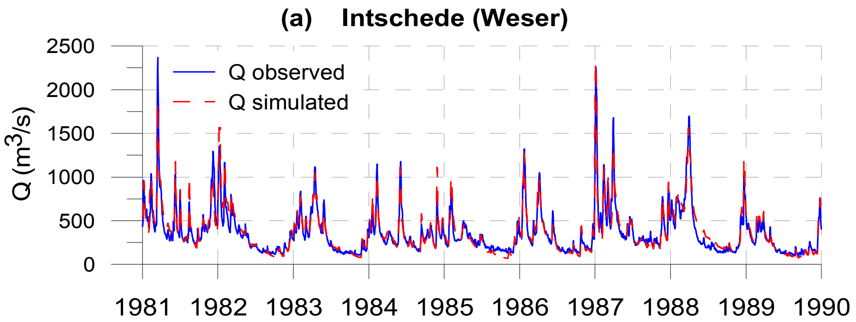


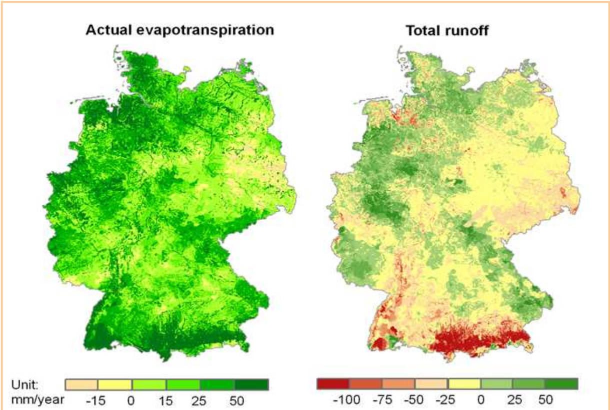
- **Time series**
  - **Climate data (daily: min ave max T, precipitation, humidity, solar radiation)**
  - **Water discharge (daily)** → **for calibration/validation**
  - **Water quality measurements (N, P, Chl a)** → **for calibration/validation**
- **Management information**
  - **Crop types / crop rotations**
  - **Fertilization (dates and rates)**
  - **Water management (if any)**
  - **Point sources (location and emission rates)**

MODEL OUTPUTS



- **Water discharge** at the basin outlet and intermediate gauges (m^3 s^{-1})
- **Sediment and Nutrient** (NO_3-N, PO_4-P, NH_4-N) concentrations (mg L^{-1}) and loads (kg d^{-1}) at the basin outlet (optional in several subbasins)
- **Chlorophyll a, Oxygen** (SWIM version with in-stream processes)
- **GIS-Outputs: maps of Water components** (Evapotranspiration, Runoff, Groundwater Recharge) and **Nutrients** (N, P) per hydrotope





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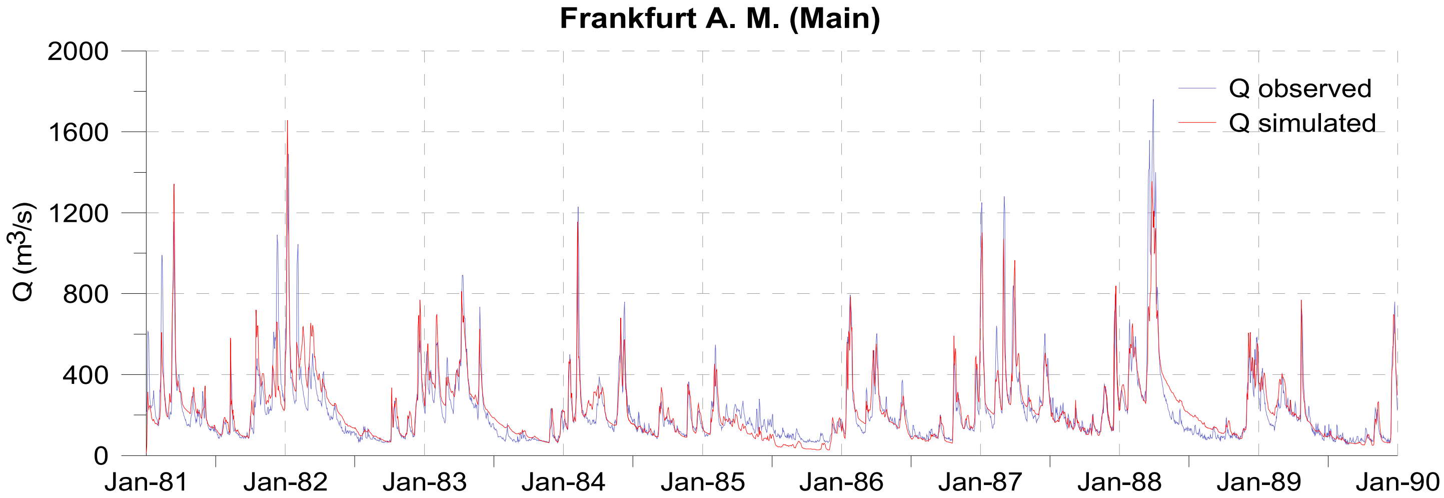
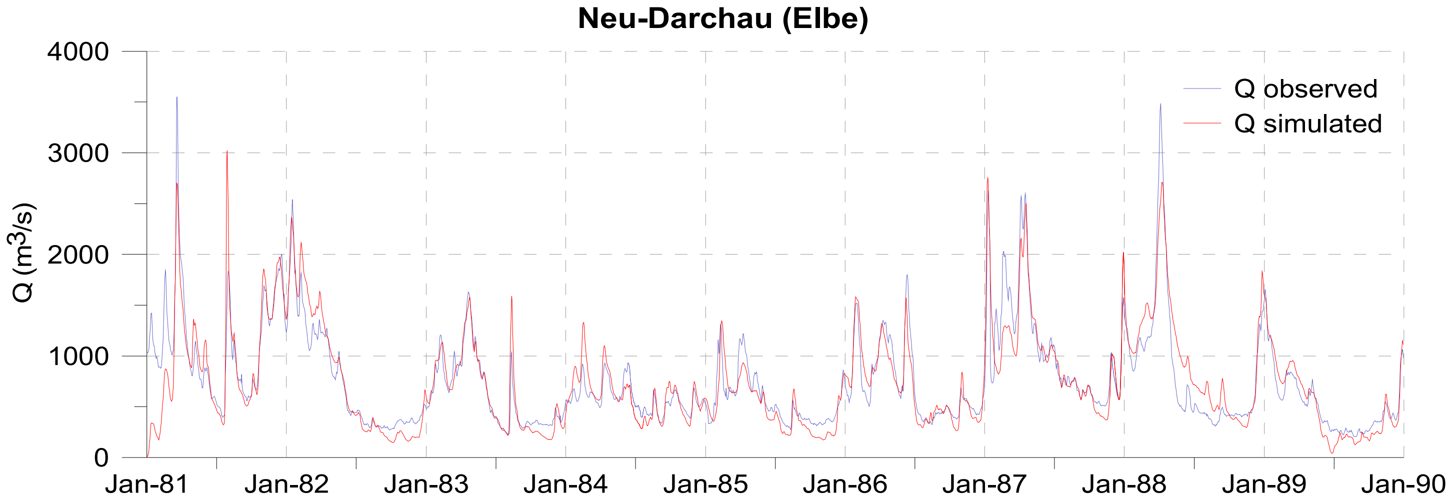
CALIBRATION & VALIDATION: water discharge, Main and Elbe



Calibration period
Efficiency: 0.80
Deviation: 3%
Validation period
Efficiency: 0.78
Deviation : 4%

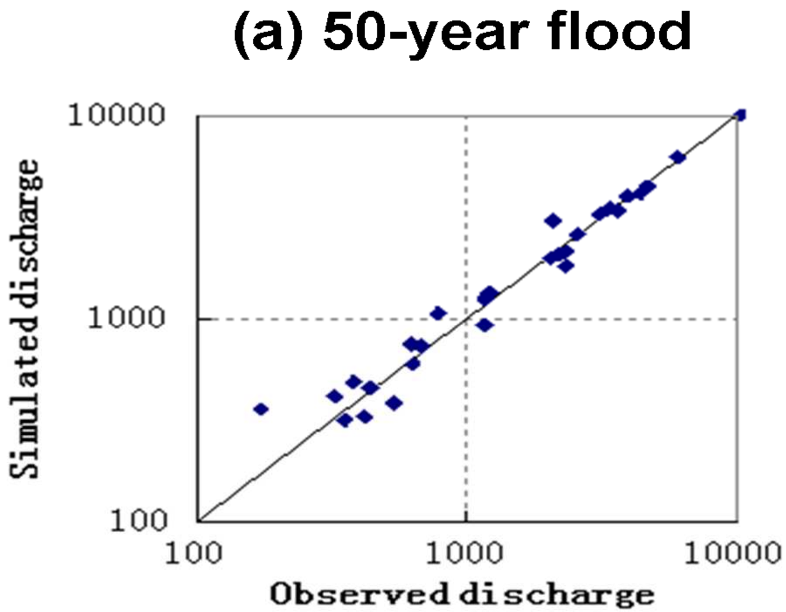


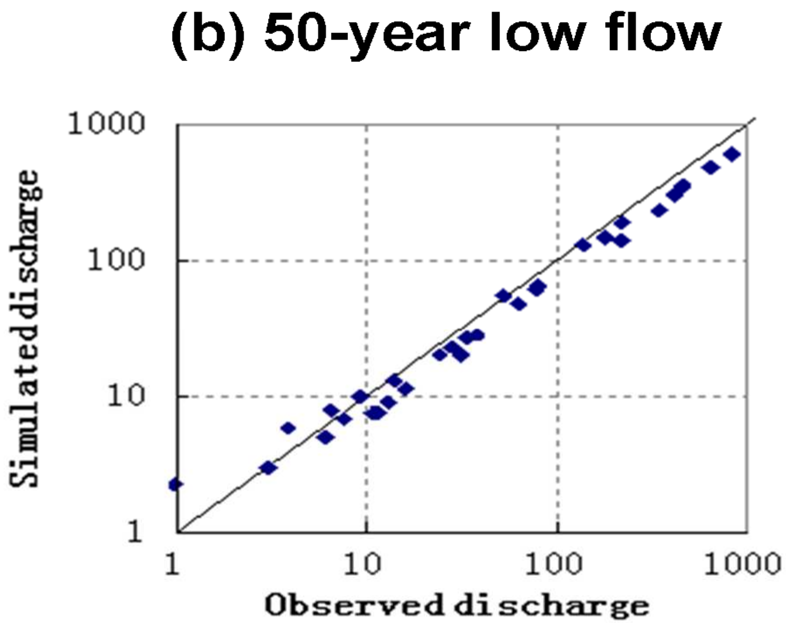
Calibration period
Efficiency: 0.86
Deviation: 0%
Validation period
Efficiency: 0.86
Deviation: -1%

Huang, Krysanova, Österle, Hattermann (2010): Hydrol. Processes, 24: 3289-3306.

Extreme flows validation, Germany

50-year flood and low flow level at 29 gauges estimated for the control period 1961 – 2000 and compared with observed discharges





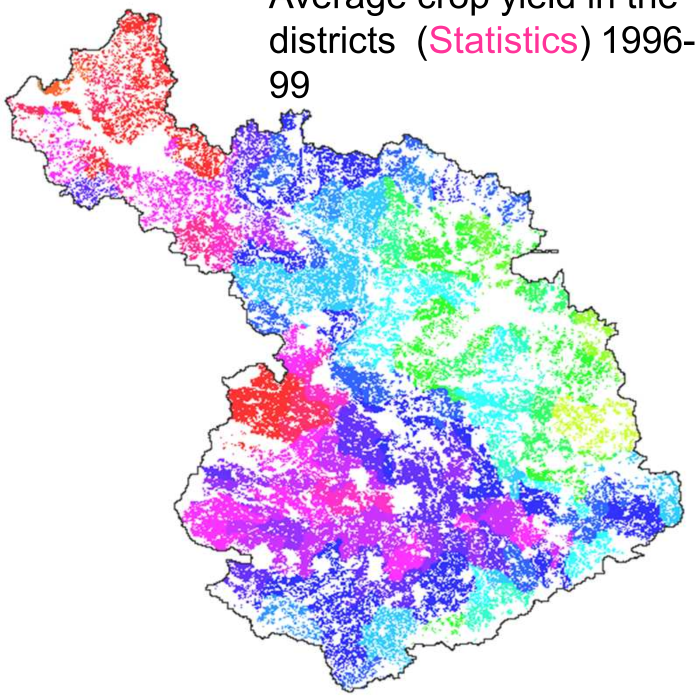
- Floods are well simulated by SWIM using observed climate data
- Low flows are generally slightly underestimated by SWIM

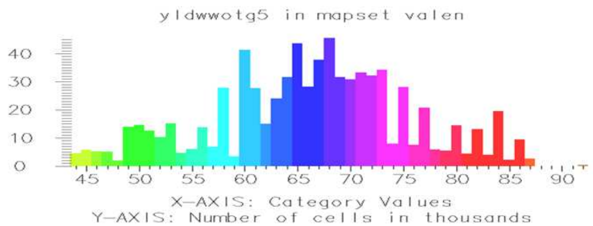
Huang, Hattermann, Krysanova & Bronstert (2012) Climatic Change. Huang, Krysanova & Hatterman (2012) Acta Geophysica.

CROP YIELD VALIDATION (winter wheat), Elbe

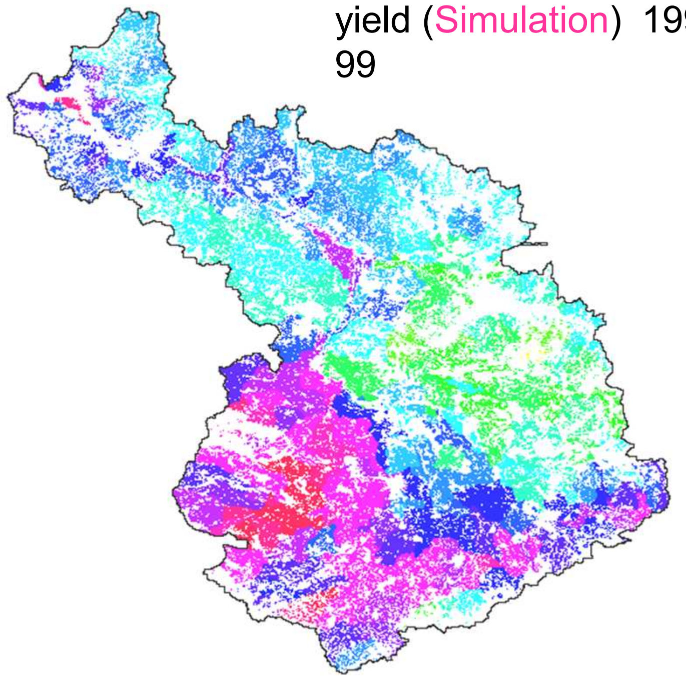
Krysanova, Hattermann, & Wechsung 2007. Environmental Modelling & Software, 22, 701-709.

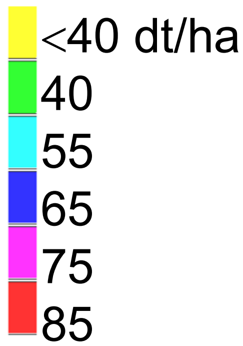
Average crop yield in the districts (Statistics) 1996-99

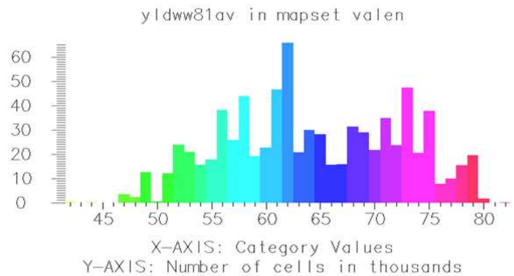




Average potential crop yield (Simulation) 1996-99







	Aver	Variation
Sim	64.3	7.9
Stat	64.1	9.6

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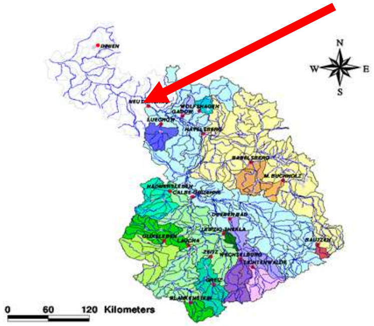
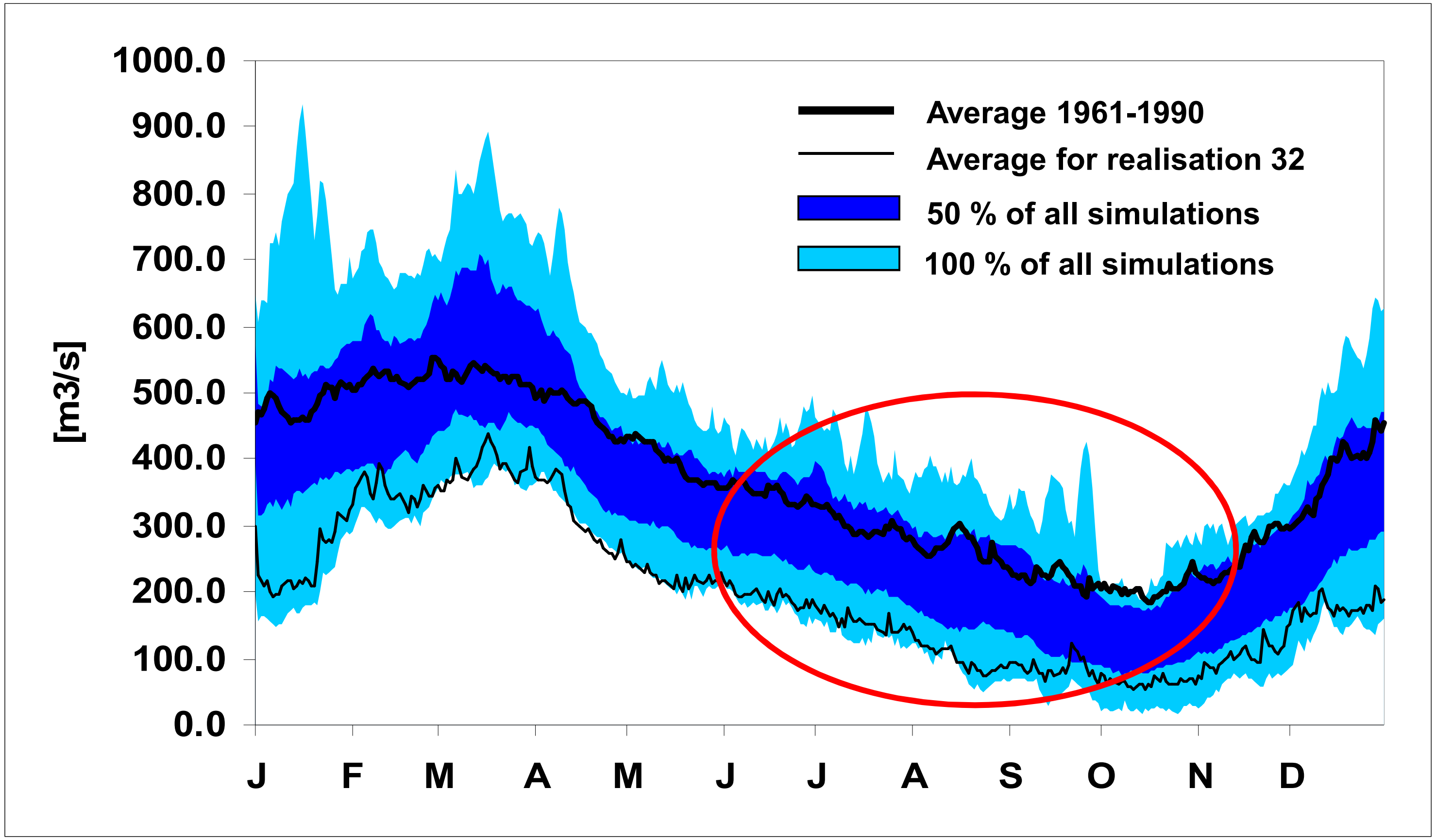
Comparison of average daily discharges at Neu Darchau: reference (1961-90) and scenario (2050-55)





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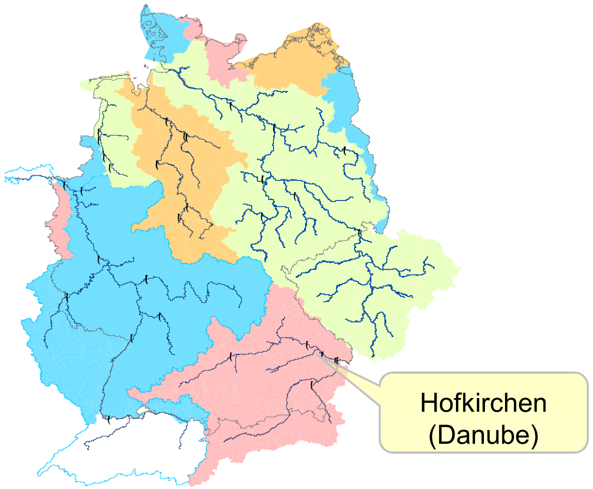
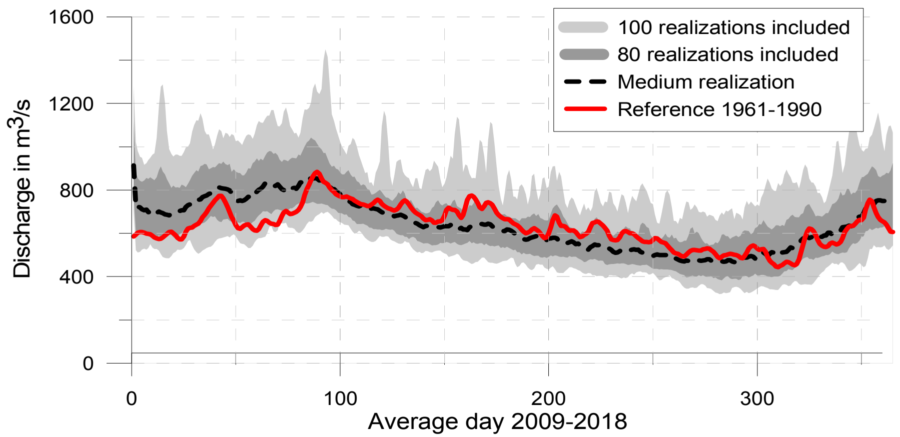
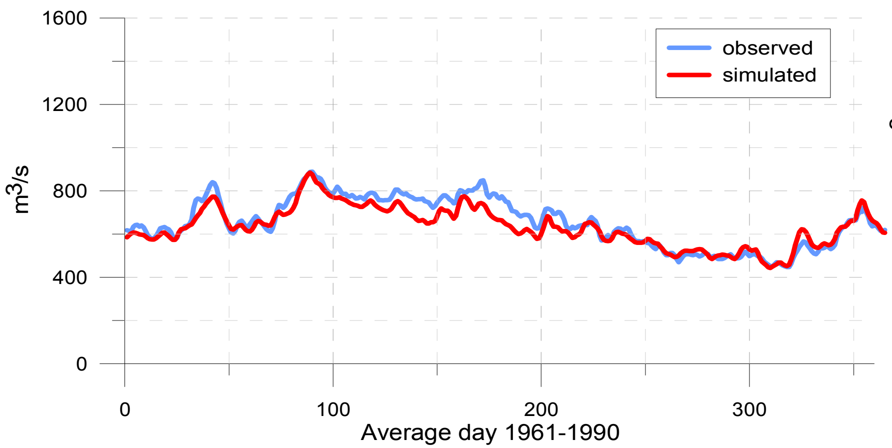
Climate change impact: seasonal changes in river discharge in the upper Danube

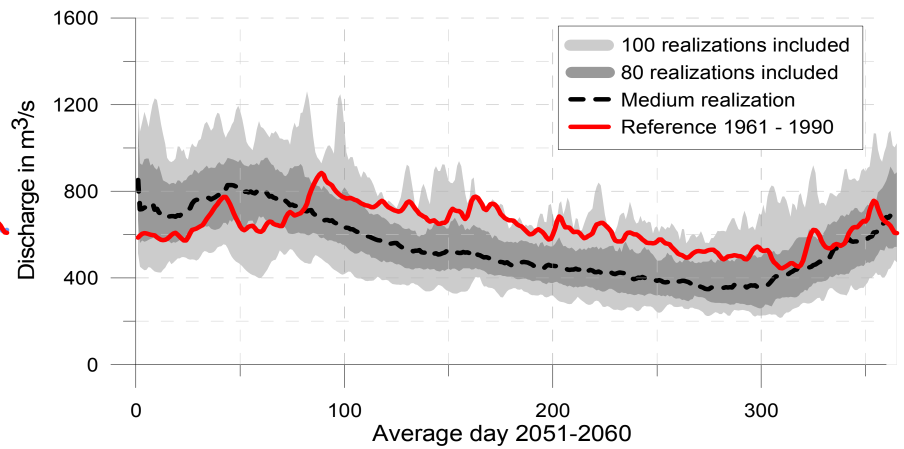
Climate scenarios: from STAR

Huang, Krysanova, Österle, Hattermann, (2010): Hydrological Processes, 24: 3289-3306.









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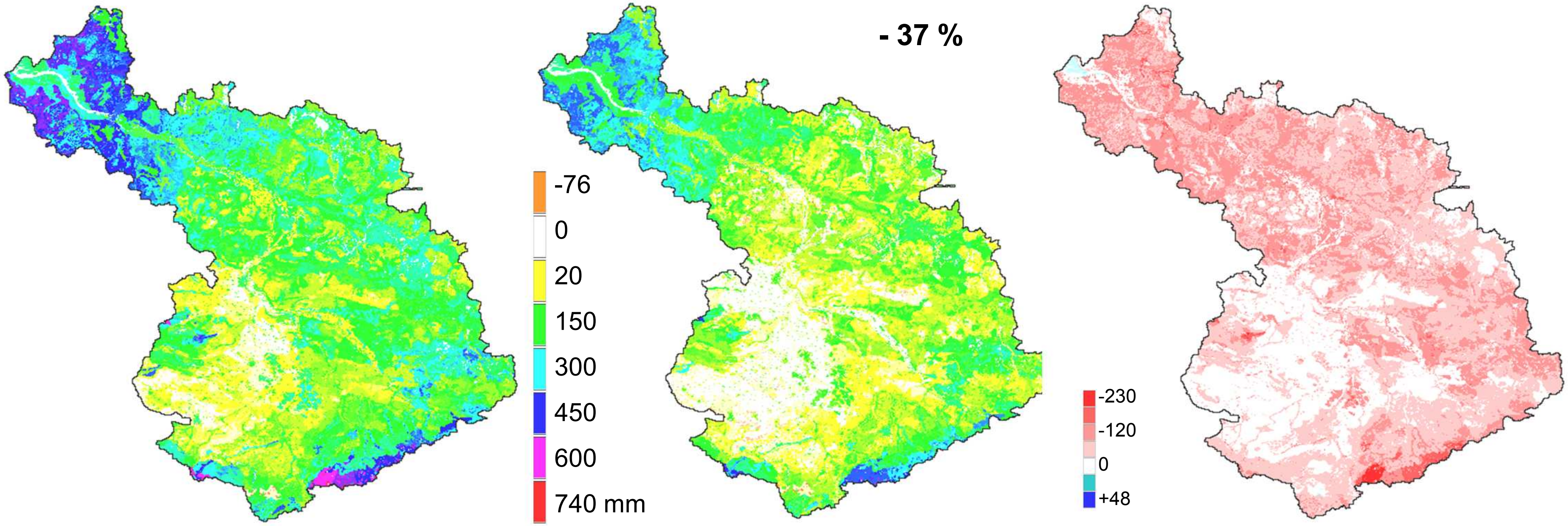
Climate change impact on groundwater recharge

Reference period
1991-2000
Average = 133 mm

Scenario (v. 32)
2046-2055
Average = 84 mm
- 37 %

Difference map
(Scenario – Reference)



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Climate change impact on crop yield

Winter wheat:

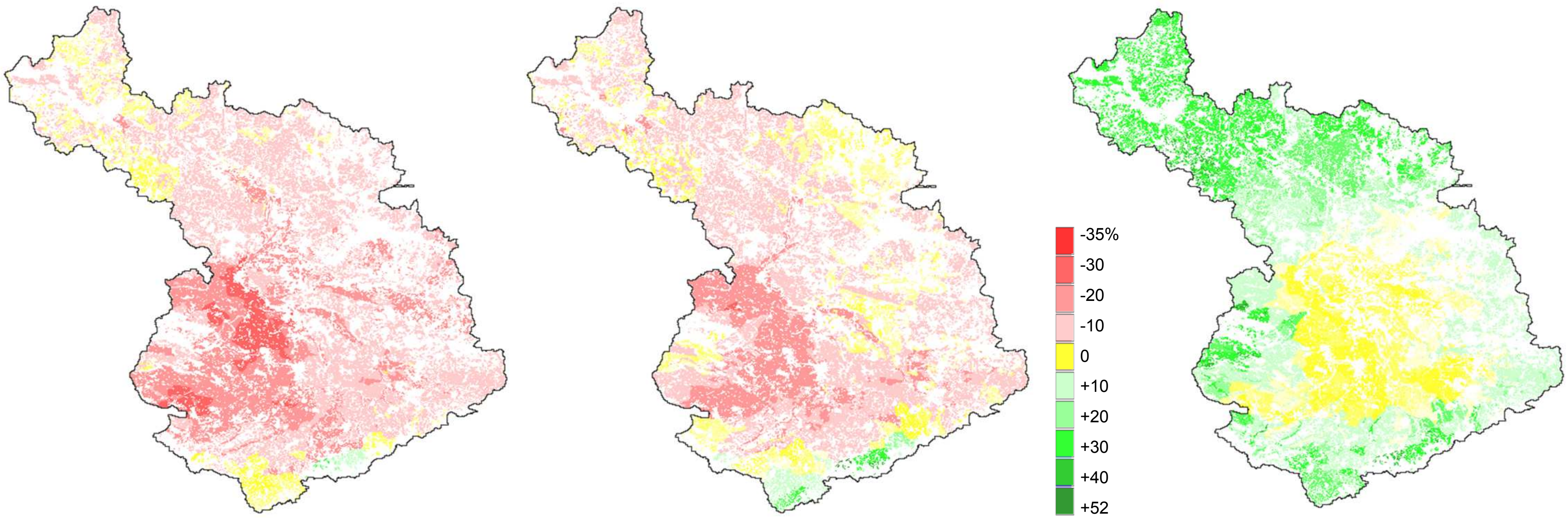
Change in %

Winter barley:

Change in %

Silage maize:

Change in %

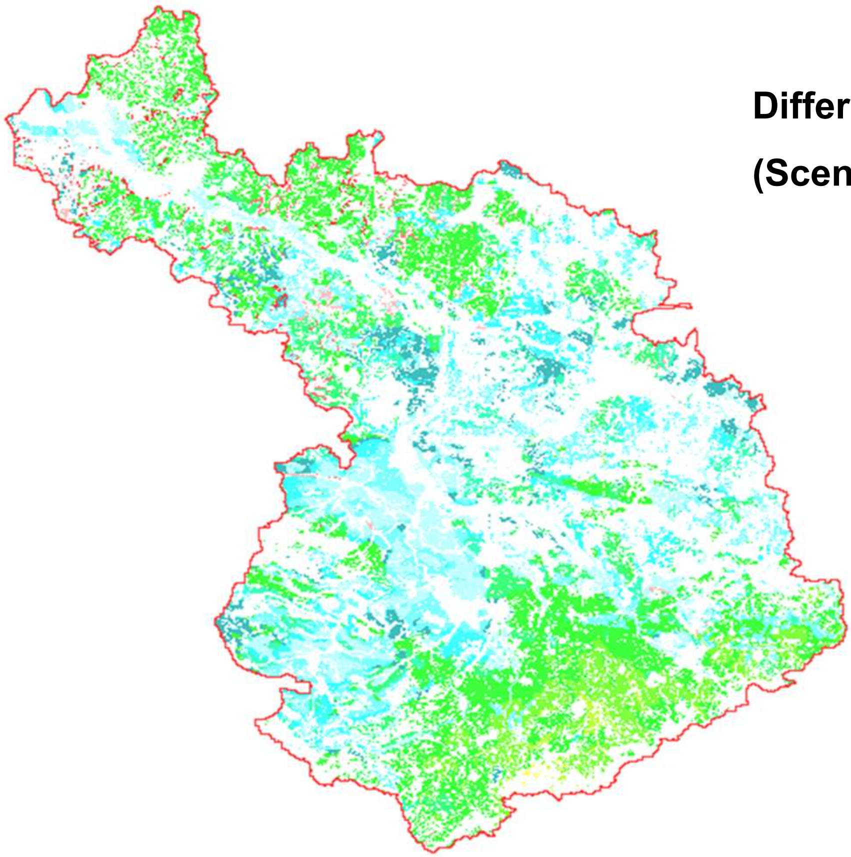


Average = - 13 %

Average = - 9 %

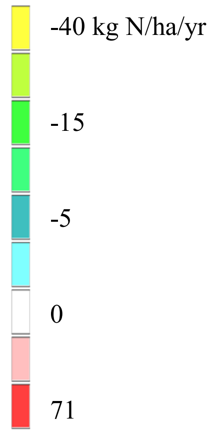
Average = + 9 %

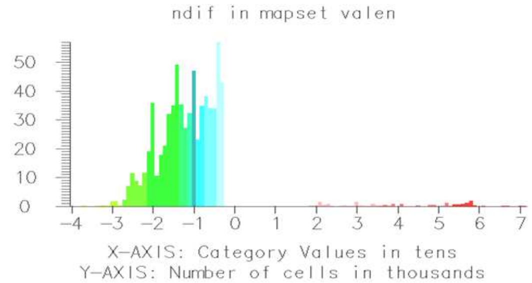
Climate change impact on N losses with water from arable land



Difference map

(Scenario – Reference)

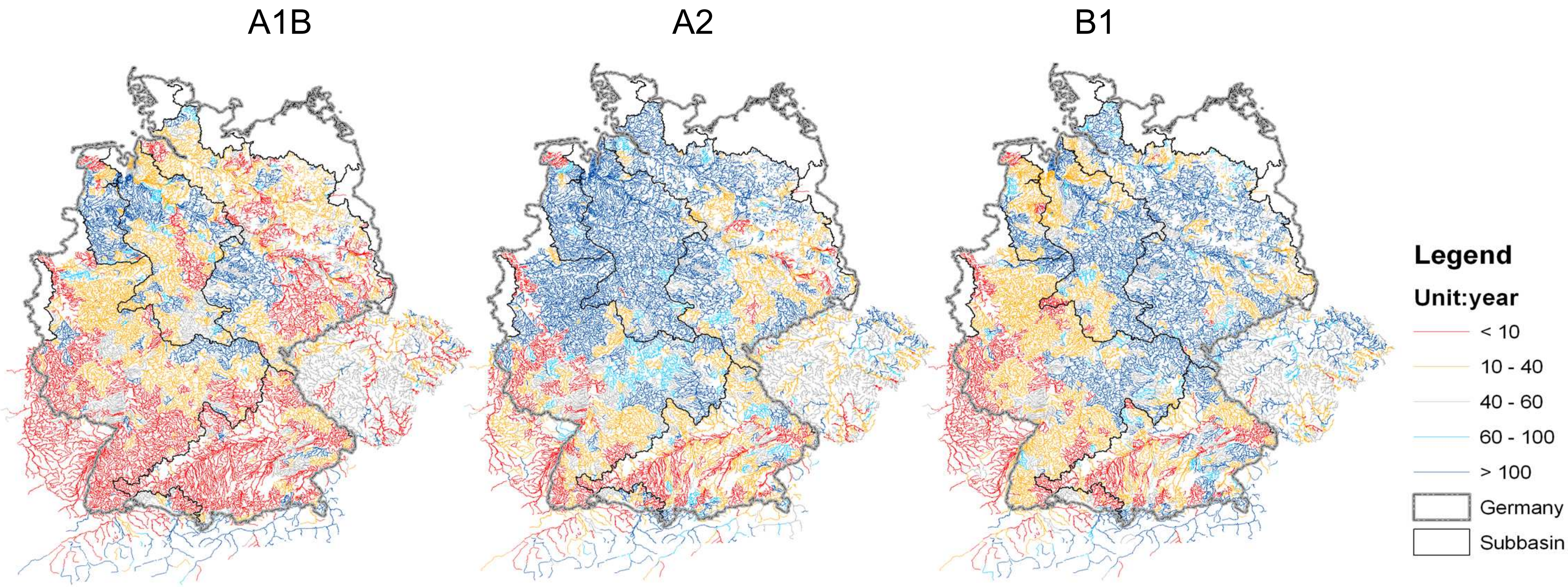




Climate change impact: changes of return period for the 50-yr low flow

Huang, Krysanova & Hatterman (2012) Acta Geophysica.

Climate scenario: REMO (2061 – 2100)



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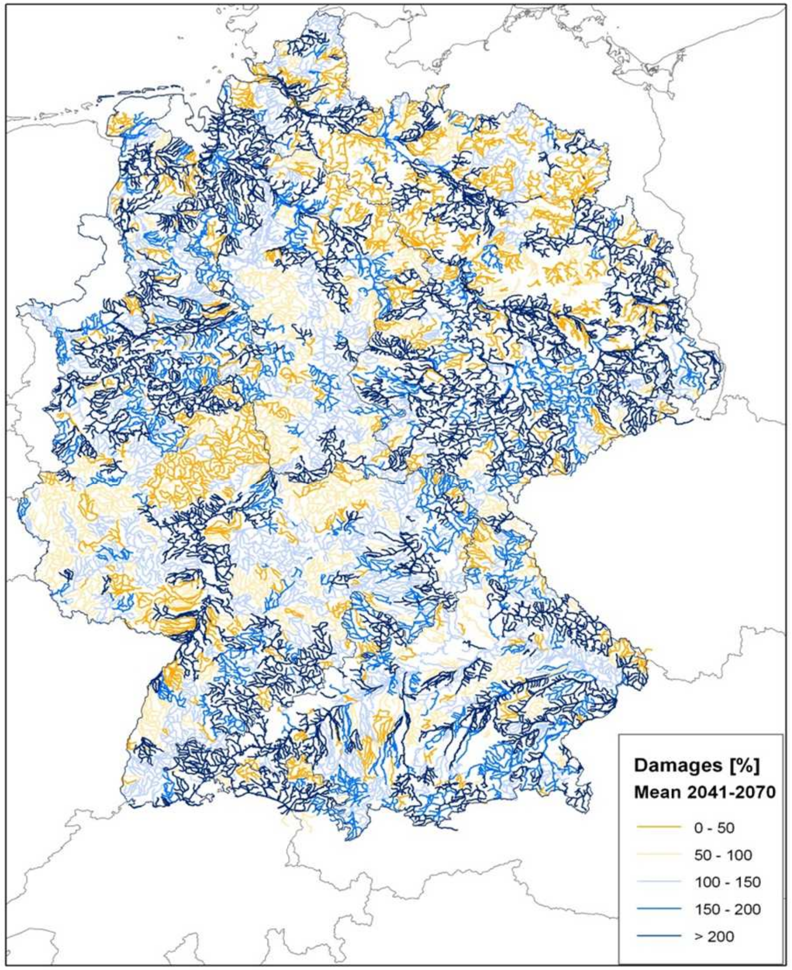
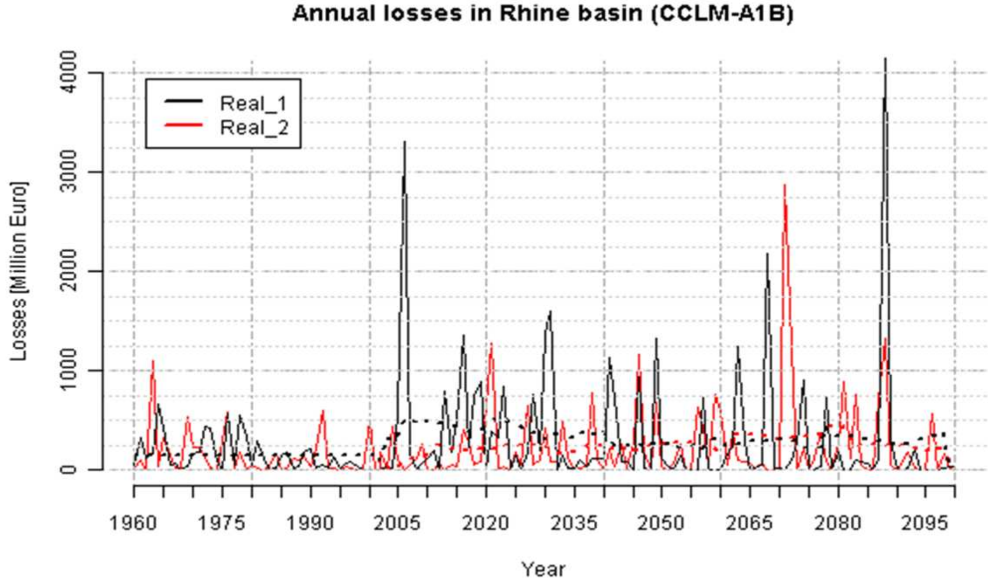
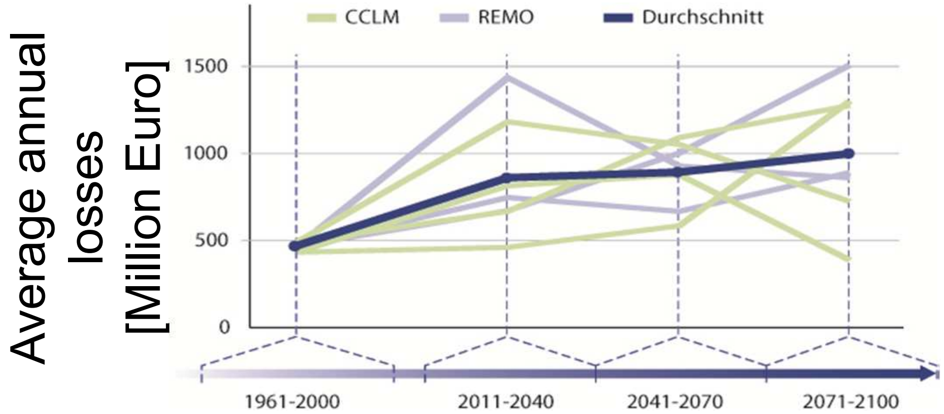
Application of SWIM driven by CCLM & REMO: Trend in flood-caused damage in Germany

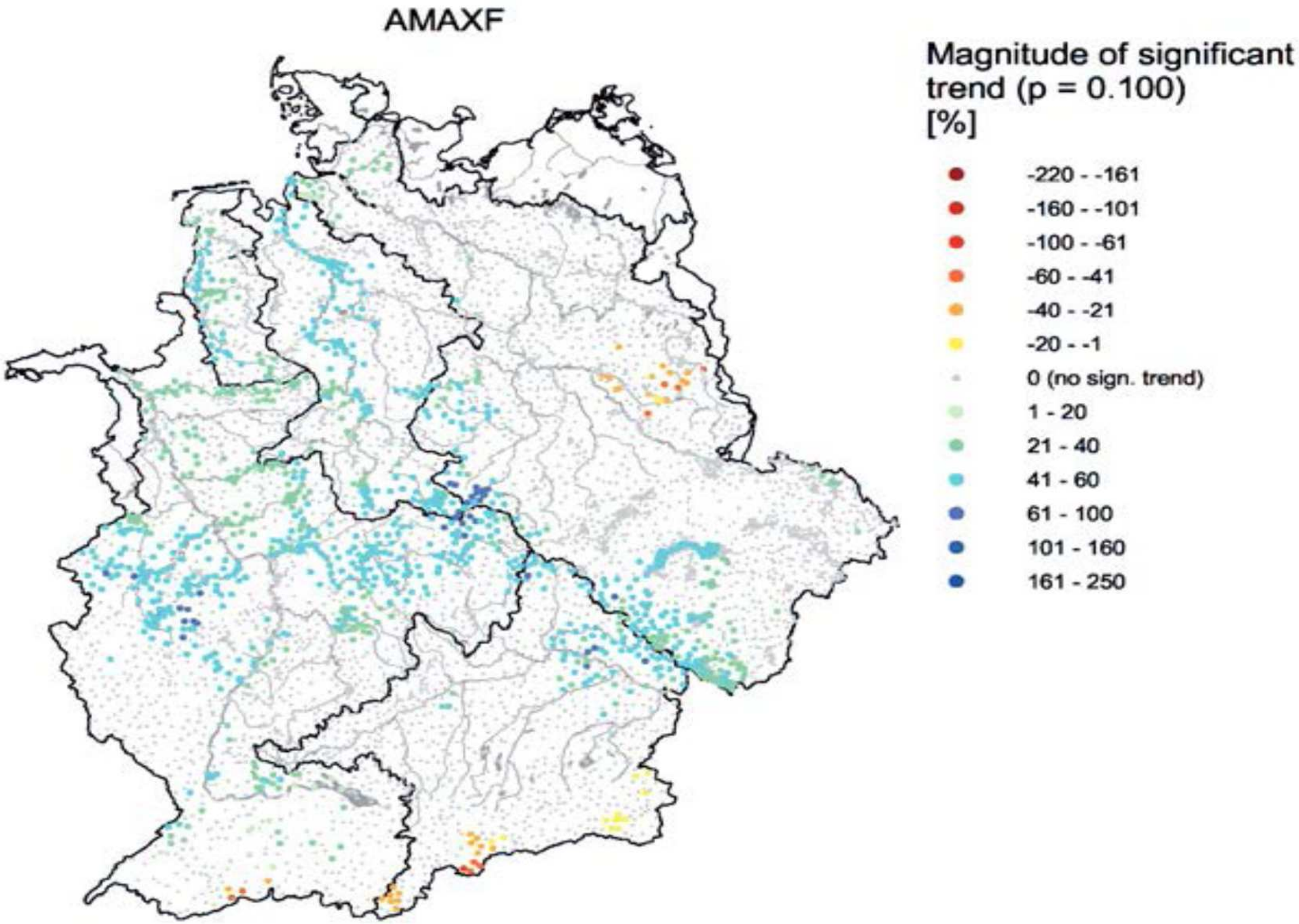
Hattermann, Weiland, Huang, Krysanova, Kundzewicz (2011) Model-supported Impact Assessment for the Water Sector in Central Germany under Climate Change – a Case Study. Water Resources Management.





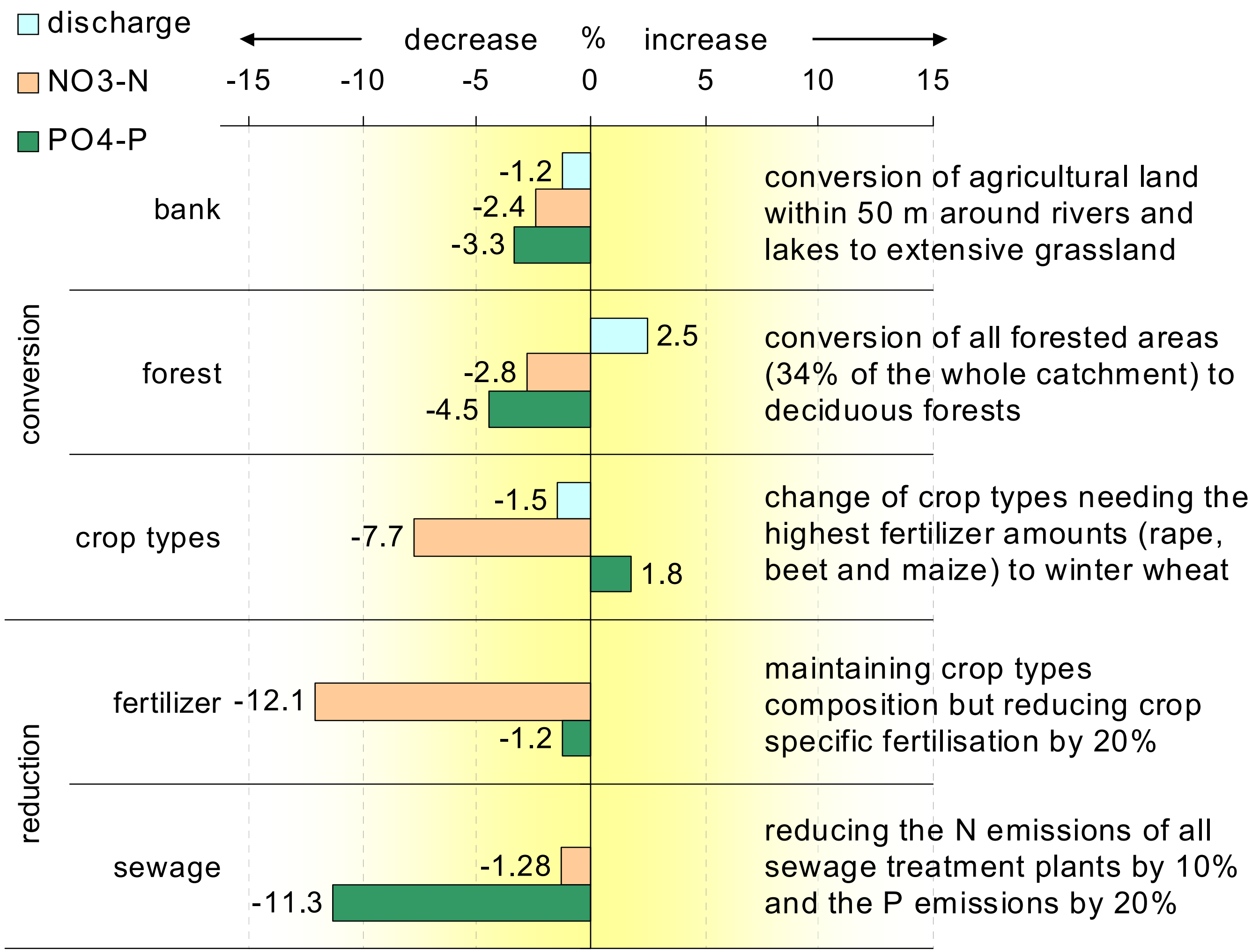


Trends in annual maxima of river discharges in the five big German river basins, including their upstream parts in neighbouring countries in the period 1951–2003, estimated with the help of the SWIM model (based on Huang et al., 2010).



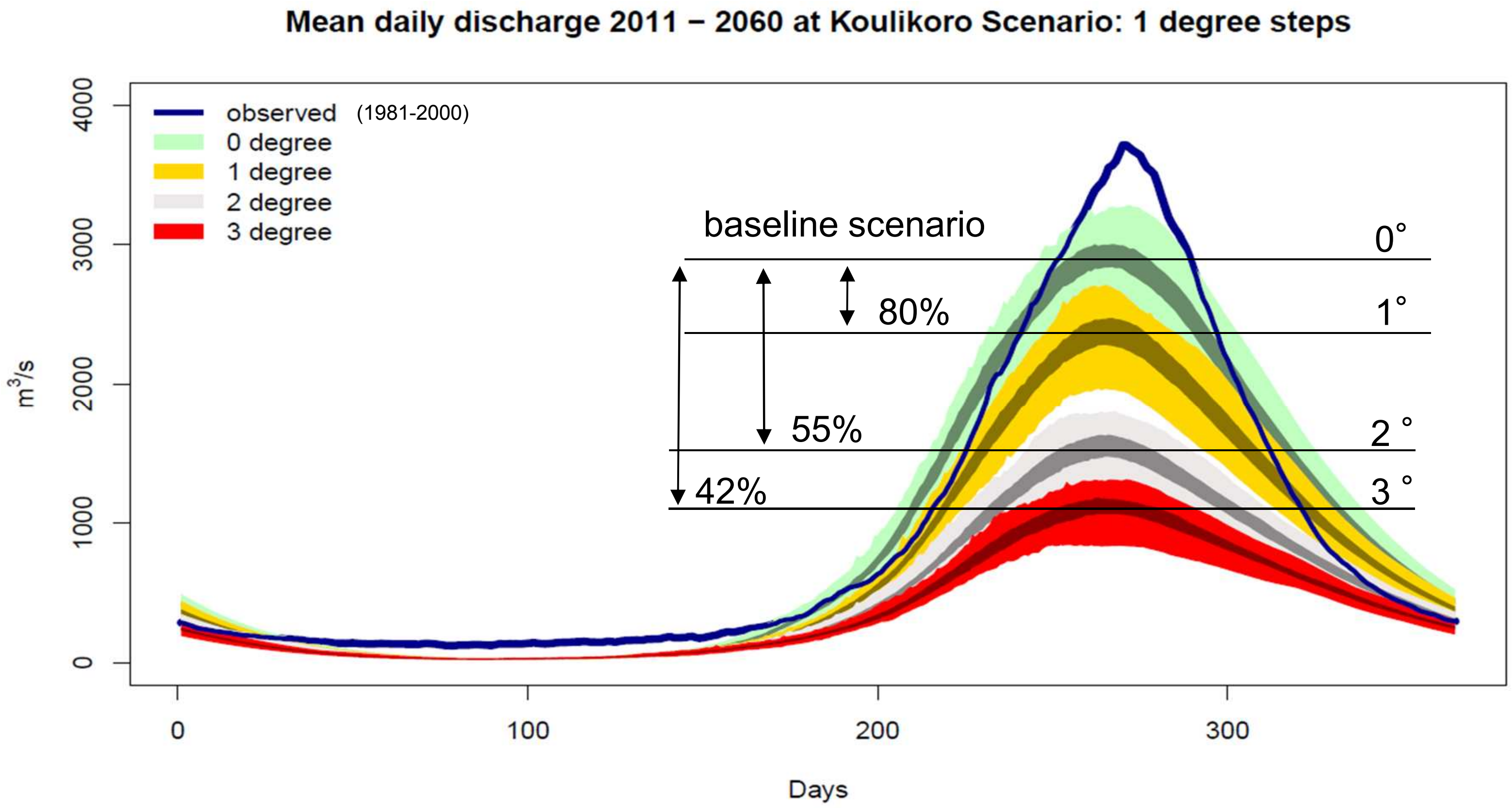
Land use change impact for the Rhine catchment, Germany

Hesse, C.; Krysanova, V.; Voß, A. (2012) Environmental Modeling & Assessment



Application of SWIM driven by STAR: significantly lower water availability in the Niger basin, Africa

Liersch, Cools, Kone, Diallo, Koch, Fournet, Hattermann, Vulnerability of agricultural production in the Inner Niger Delta to water resources management under climate variability and change. Subm. to Environmental Science and Policy



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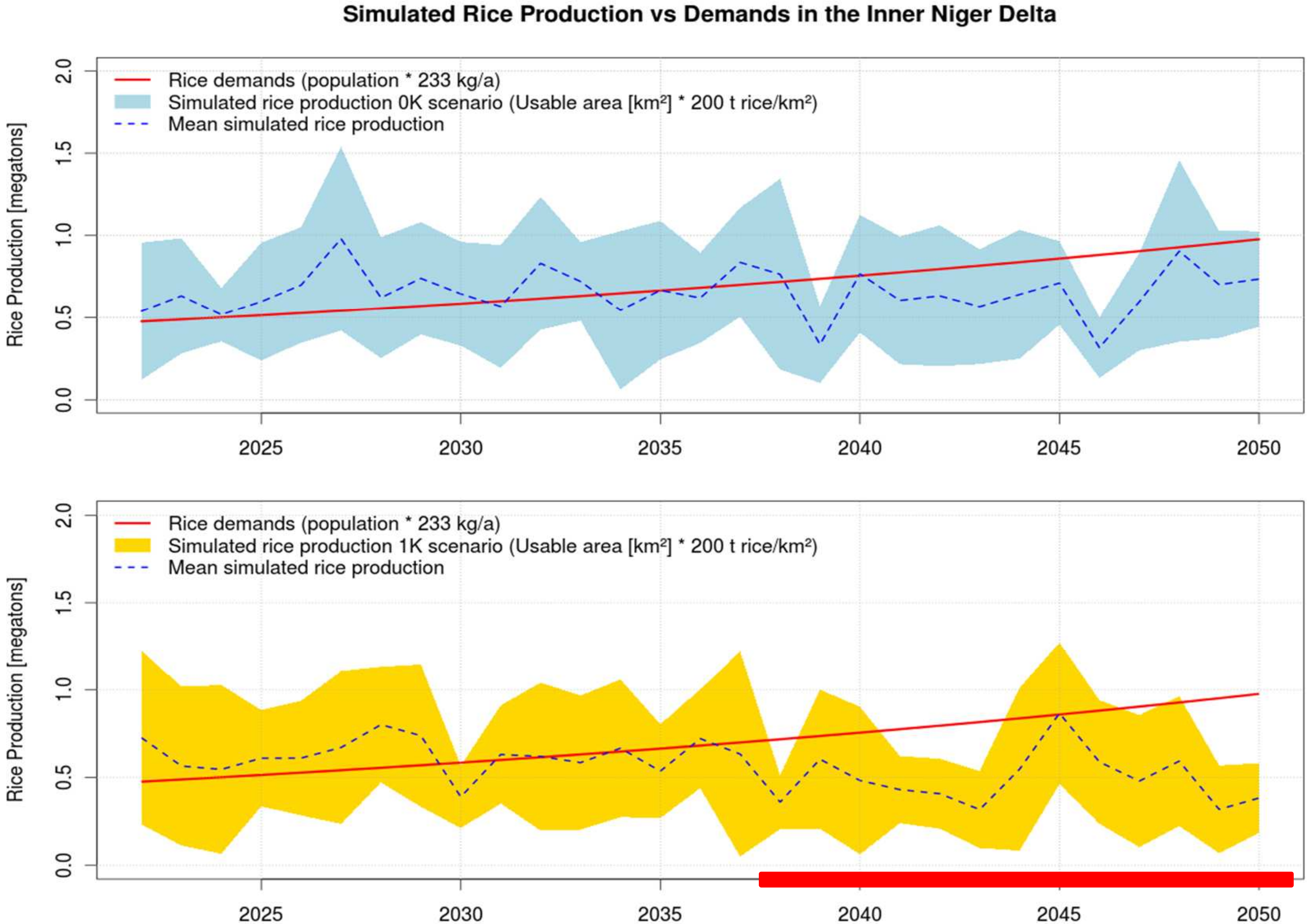
Application of SWIM driven by STAR: simulated rice production vs demand in the Inner Niger Delta, Africa

Simulated rice production = rice siutable area x average yield

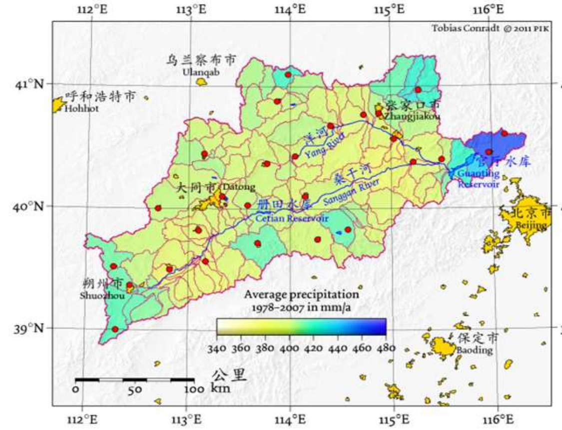


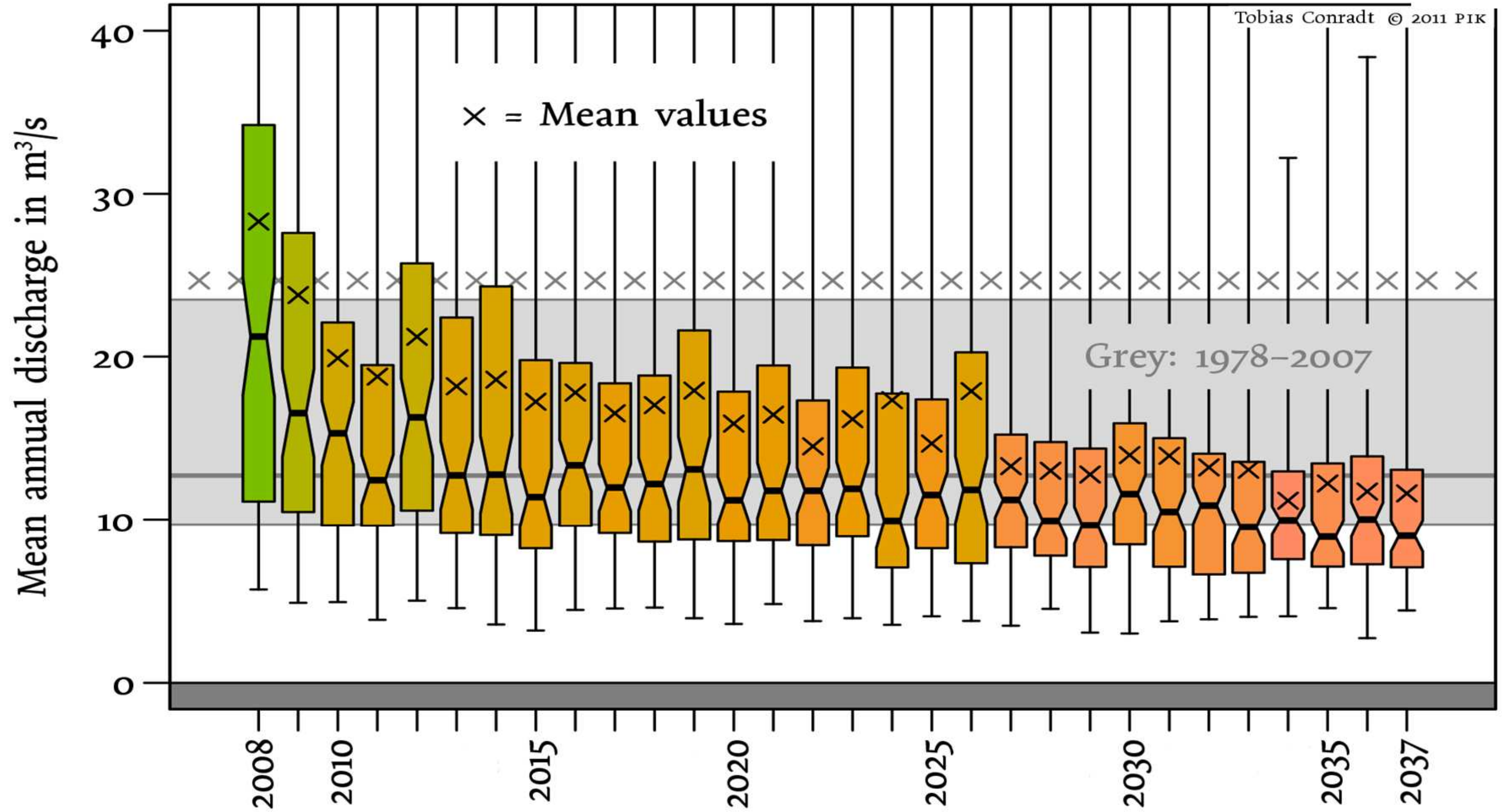
0K scen.

1K scen.

Liersch, Cools, Kone, Diallo, Koch, Fournet, Hattermann, Vulnerability of agricultural production in the Inner Niger Delta to water resources management under climate variability and change. Subm. to Env. Science and Policy

Application of SWIM driven by STAR: decrease in water availability for the Guanting basin, NW of Beijing, China

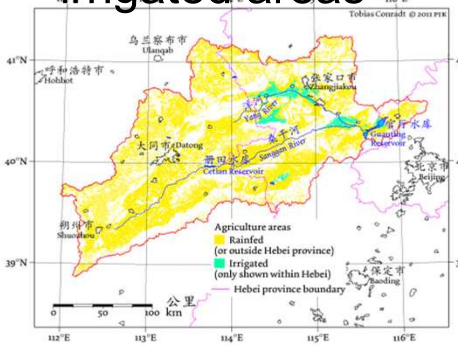




Average precipitation 1978-2007

Conradt et al., 2012

Rainfed and irrigated areas



SWIM

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ADVANTAGES of SWIM as a tool for impact studies

- Possibility to perform **water resources and water quality assessments in mesoscale and large river basins**.
- Since the model is **firmly anchored in physical principles** that hold also in changing climate, one can have reasonable confidence that the uncertainty introduced by hydrological modeling, on top of the climate modeling, is tolerable.
- **Direct connection to vegetation, land use and climate data** provides a possibility to use the model for analysis of climate change and land-use change impacts on hydrology, agricultural production, and water quality.
- **Modest data requirements**.

PROBLEMS and RESTRICTIONS in the use of SWIM

➢ **SWIM cannot be used for**

- operational flood forecasting,
- intensively managed catchments without management data,
- forest dynamics (only using the special model version & forest inventory data).

➢**SWIM simulation of climate and land use change impacts is inevitably connected with uncertainty**, partly due to uncertainty of climate scenarios and input data, and partly due to the model structure and model parameterization.

➢**SWIM use in data-scarce regions** requires previous modelling experience and additional analysis of data.

➢ **Newly developed and enhanced modules allow fixing some of the problems.**

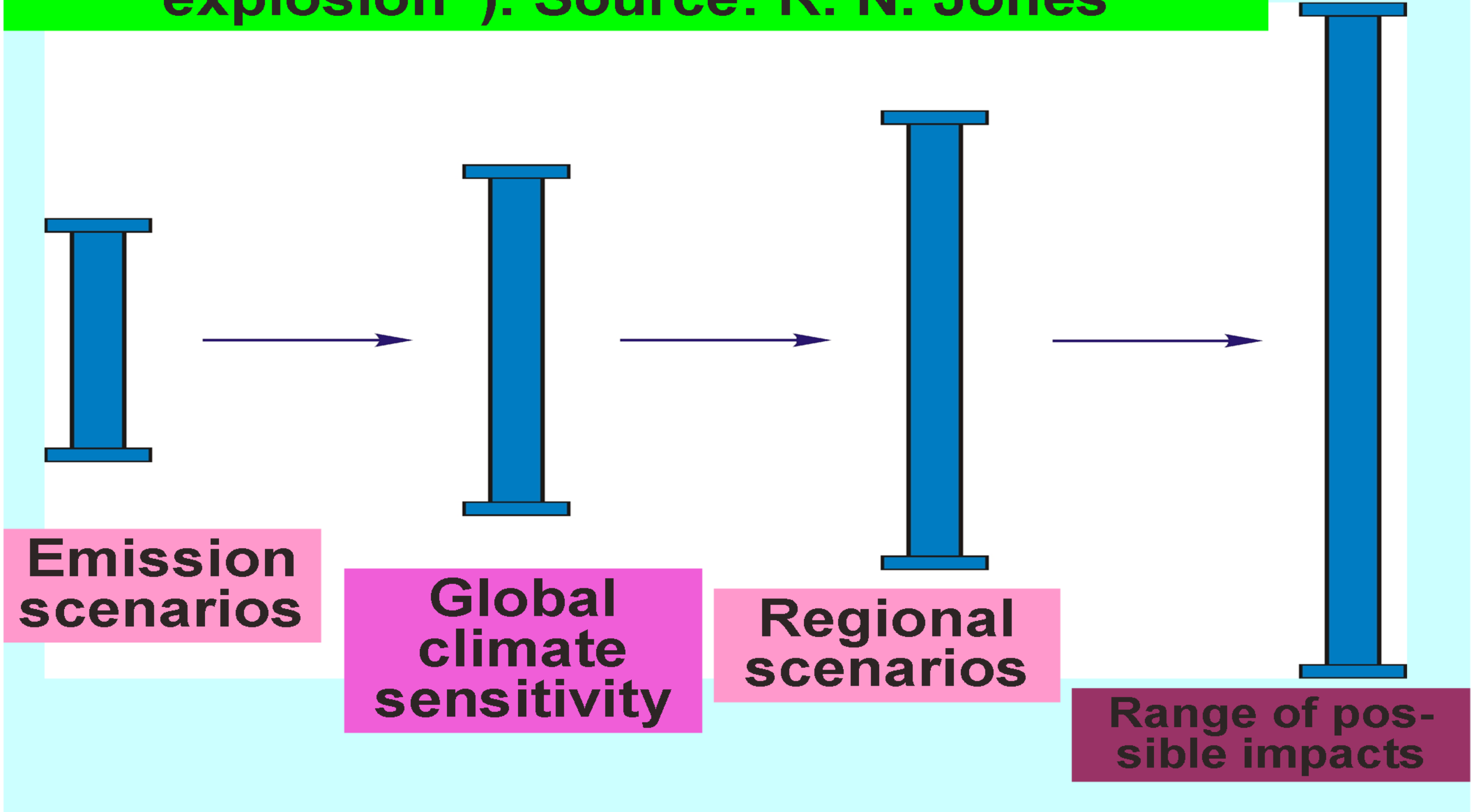
➢ The model is complex (not “push-a-button” model), and should be used only by experienced or specially trained model users.

SWIM

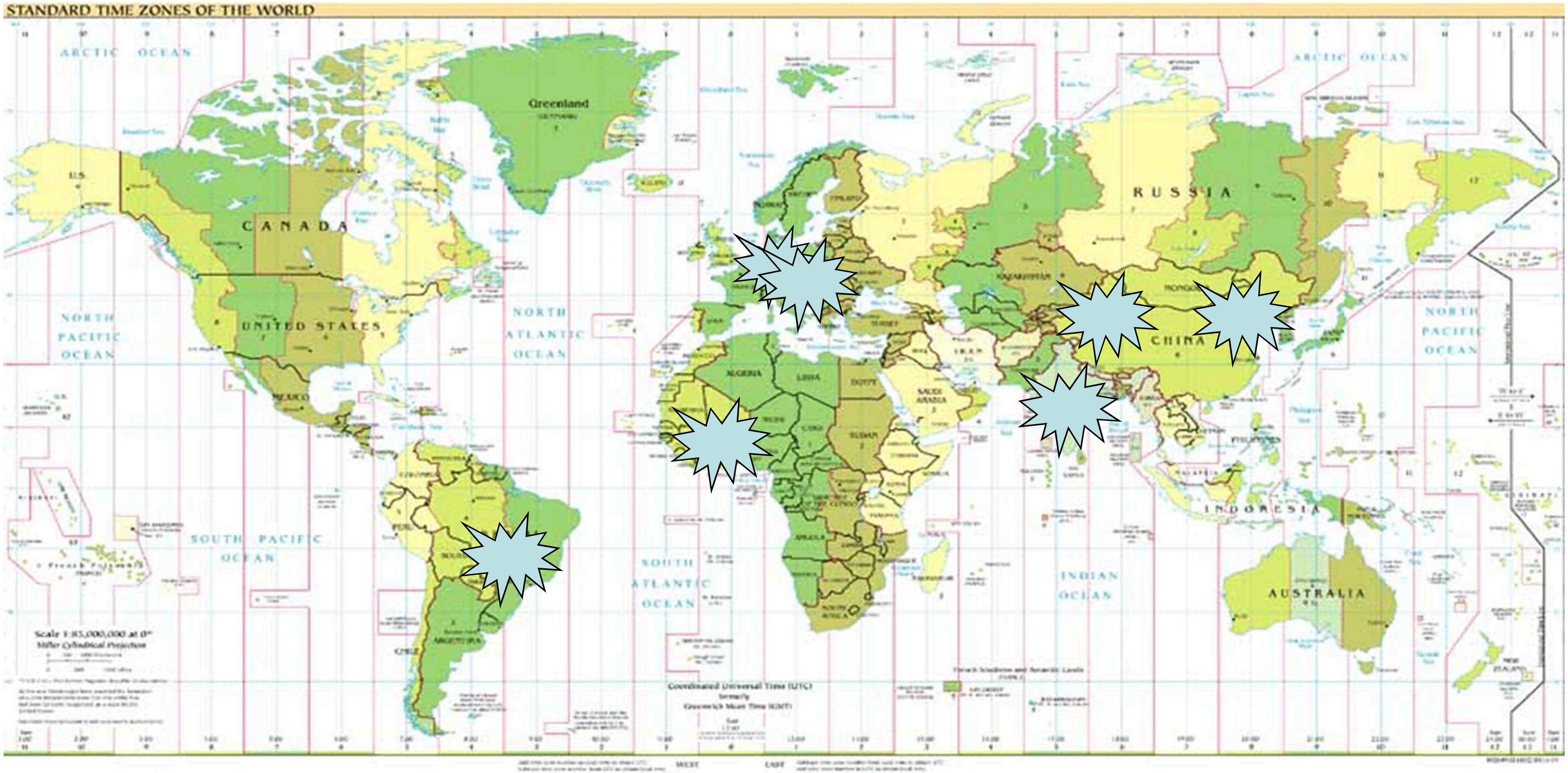
The SWIM model, developed over the last two decades at PIK, holds a prominent place among the many existing hydrological models used for climate change and land-use impact studies, especially at the regional scale, where the impacts are manifested and adaptation measures take place.

The model has proven itself versatile and capable of being applied for unprecedented conditions of future climate projections.

Range of major uncertainties in climate impact assessments („uncertainty explosion”). Source: R. N. Jones



SWIM model has been applied in four continents




Thank you