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eawag aquatic research

Limitations, problems and solutions in the setup of SWAT for a large-scale hydrological application

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Outline

1. Global modeling project
2. Continental modeling approach: Africa
3. Large-scale modeling: West Africa
   a) Daily weather generator
   b) Annual and monthly calibration
4. Conclusions and Outlook

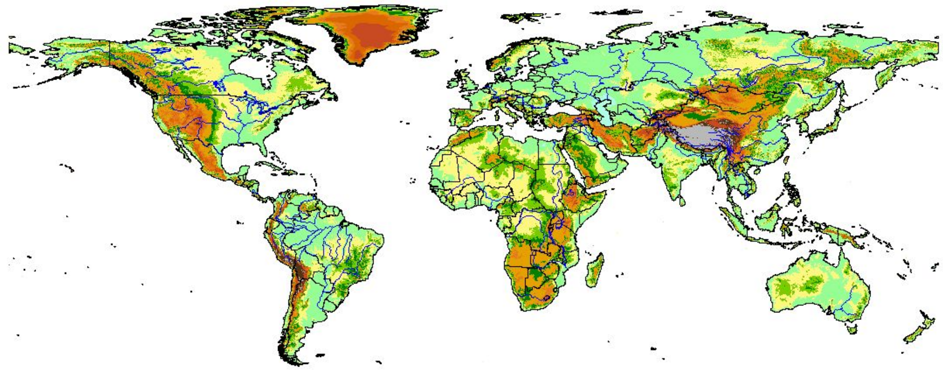
Project: Hydrological modeling of global freshwater availability using SWAT

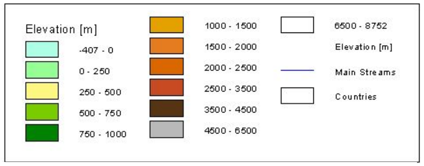
Objectives

- quantification of the country-based freshwater availability at a sub-country level on a monthly time-scale
- quantification of the uncertainty associated with the freshwater figures
- identify important factors concerning the freshwater availability (sensitivity analysis)
- calculate the spatial soil water (green water) distribution and its temporal trends at a country level
- using the calibrated hydrological model for studies of county-based food and water security

Global data sets (1)

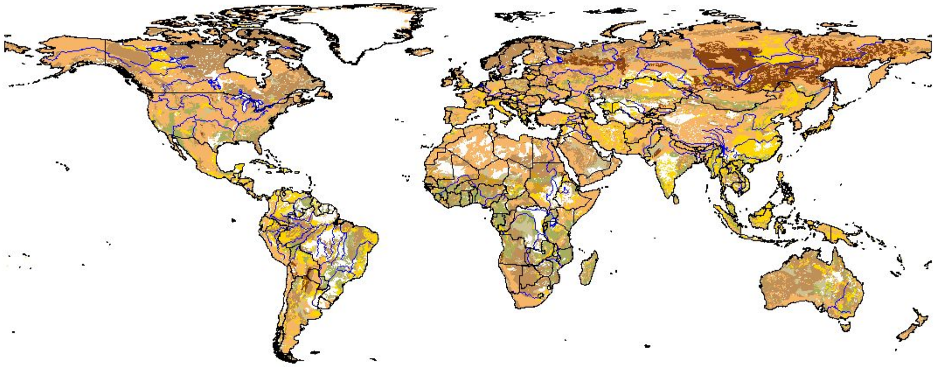
Global digital elevation map

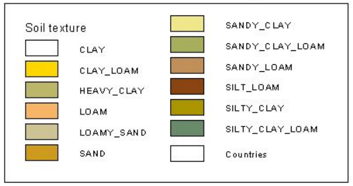




Spatial resolution: 1 kilometre
Source: USGS Hydro1k, 2003

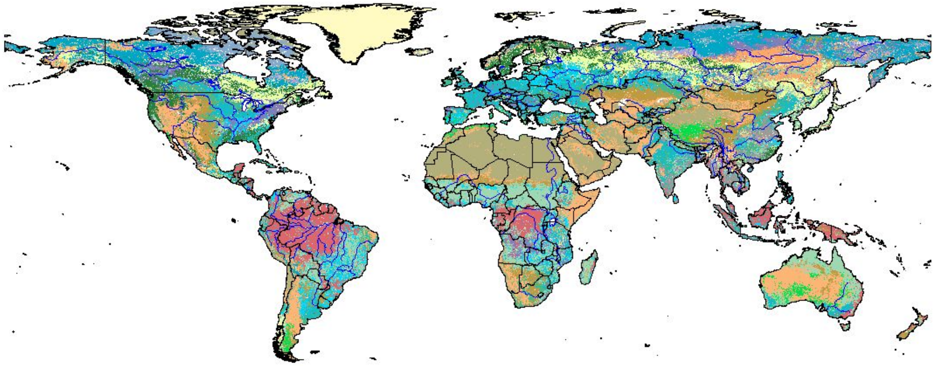
Soil texture

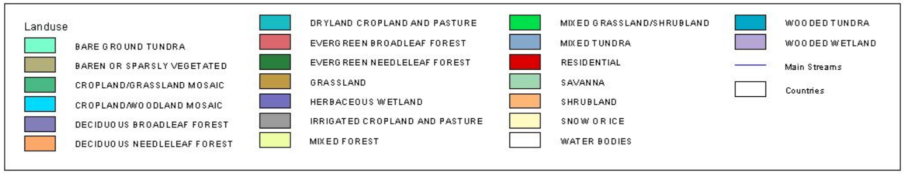




Spatial resolution: ~10 kilometre
Source: based on C. A. Reynolds et al., 1999

Global landuse

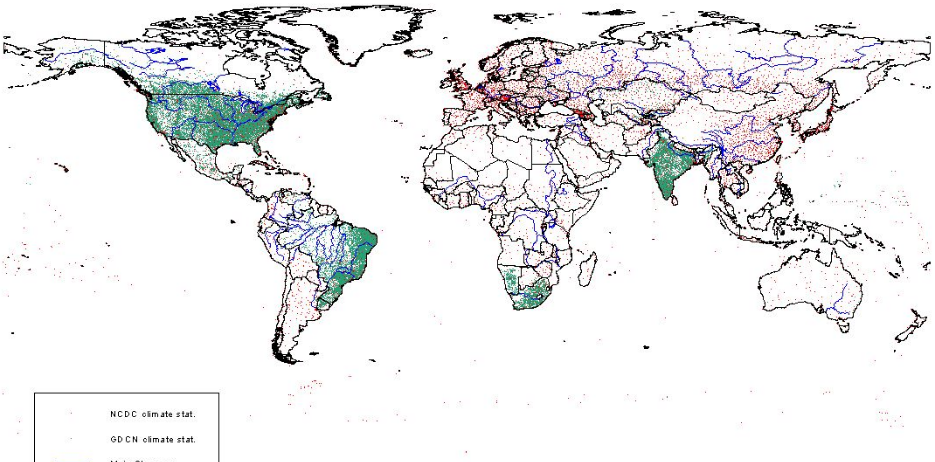




Spatial resolution: 1 kilometre; Source: USGS, 2004

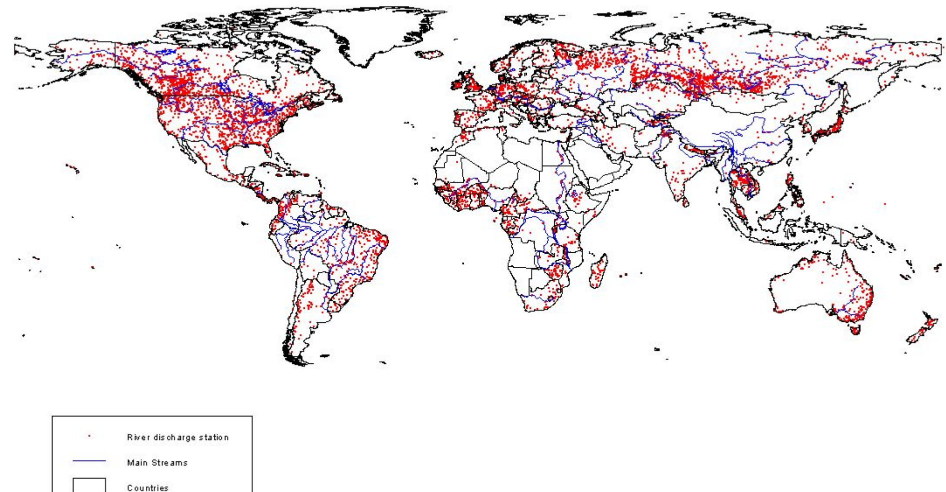
Global data sets (2)

Global climate stations



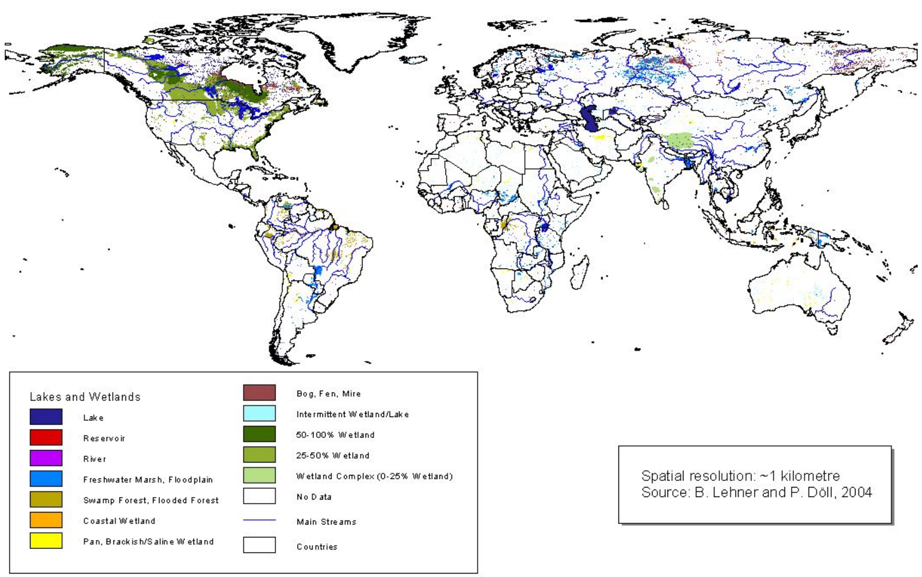
Source:
National climatic cata centre (NCDC), 1994
Global daily climatology network (GDCN), 2002

Global river discharge stations



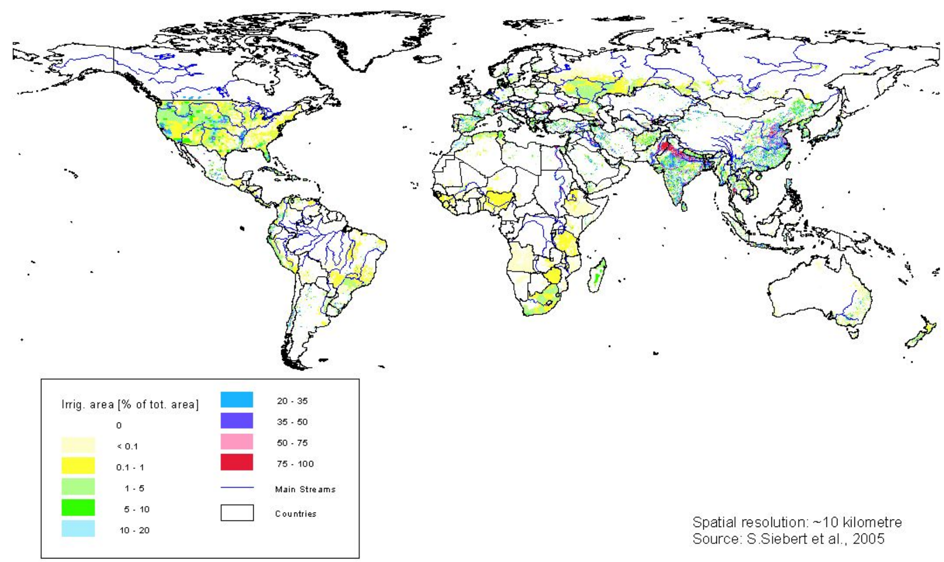
Source: Global Runoff Data Centre, 2004

Global lakes and wetlands



Spatial resolution: ~1 kilometre
Source: B. Lehner and P. Döll, 2004

Global map of irrigated areas



Spatial resolution: ~10 kilometre
Source: S.Siebert et al., 2005

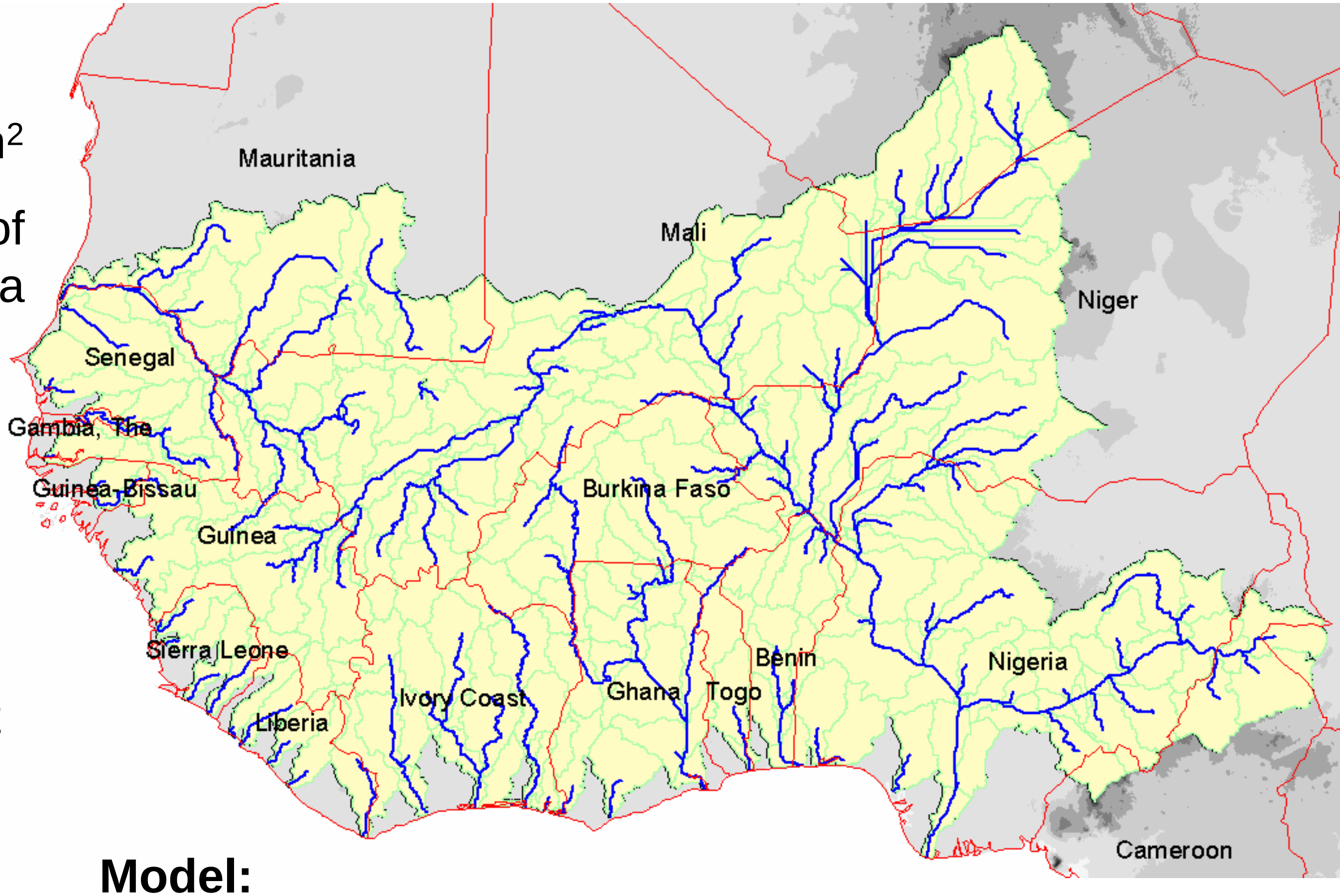
The continental model attempt

- Start with Africa, the continent where the freshwater availability problem is among the most severe in the world
- delineation of Africa into ~1500 subbasins using the ArcView interface (threshold area 10,000 sqkm)
- calculation of the geomorphic subbasin-parameters within the **ArcView interface failed**
- with the existing interface (and the selected resolution) you are limited to areas smaller than about one-seventh of Africa
- tests with a preliminary version of the newly developed **ArcGIS SWAT interface** showed that this version can handle the great number of subbasins – **BUT:** up to now there are still some other problems with the interface

Case study: West Africa

Study site:

- basin area: 4 mil. km^2
- includes the basins of the rivers Niger, Volta and Senegal
- 18 countries share the basin
- climatic zones from hyper-arid to humid
- land use from desert to rainforest (mainly savannah)
- challenging due to comparably small database

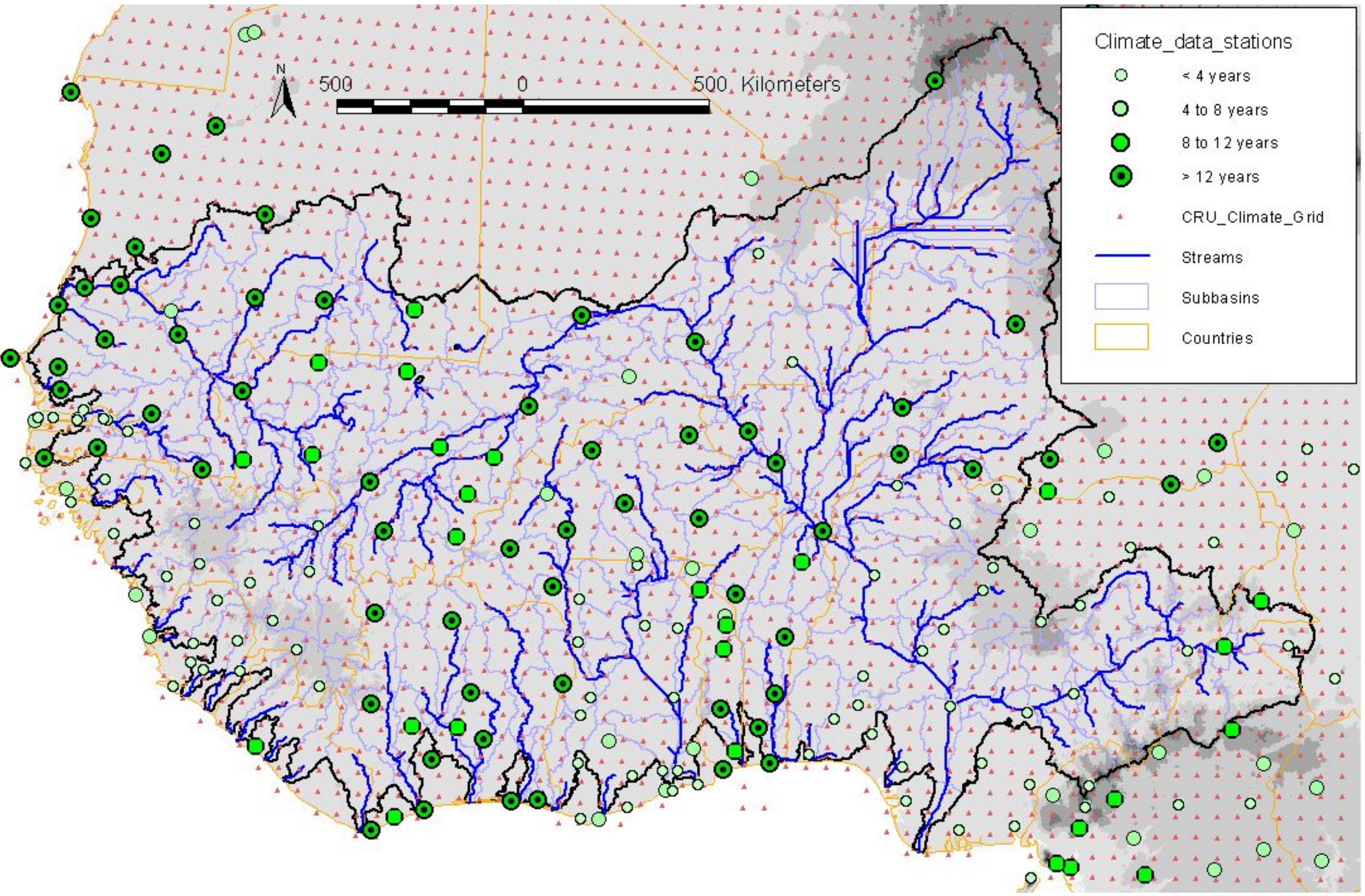


Model:

- watershed divided in 292 sub-basins
- minimum drainage area is 10,000 km^2
- simulation period: 1971 (1966) to 1995

Climate data availability

SWAT requires climate **station** data on a **daily** basis, but...



Problems:

- not very dense and unevenly distributed gauging station network
- short time periods with measured data
- many missing and sometimes erroneous data
- 104 stations are included as weather input for the 292 subbasins

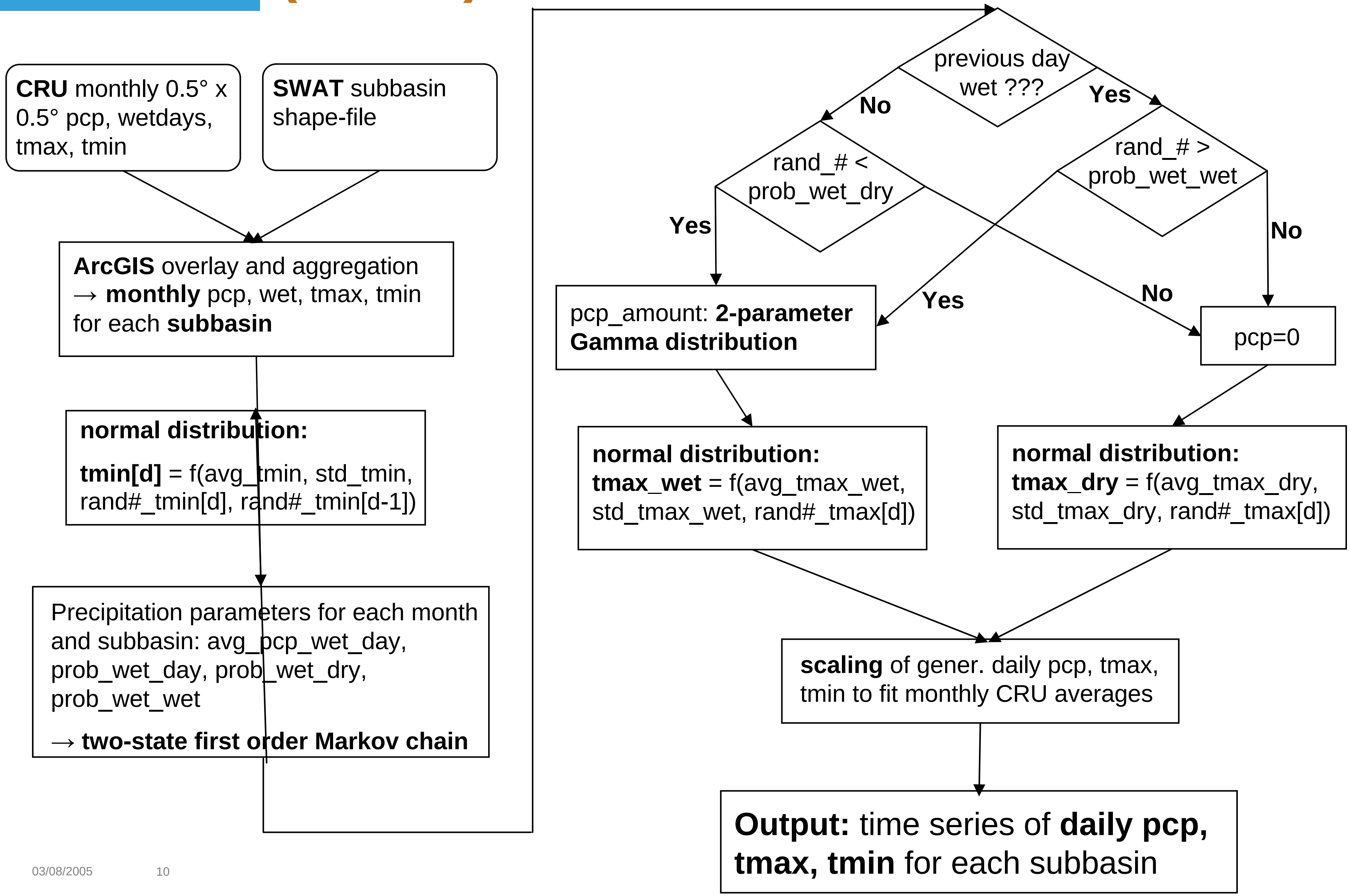
→ Climatic Research Unit (CRU) provides 0.5° **gridded monthly** climate data

Daily weather generator

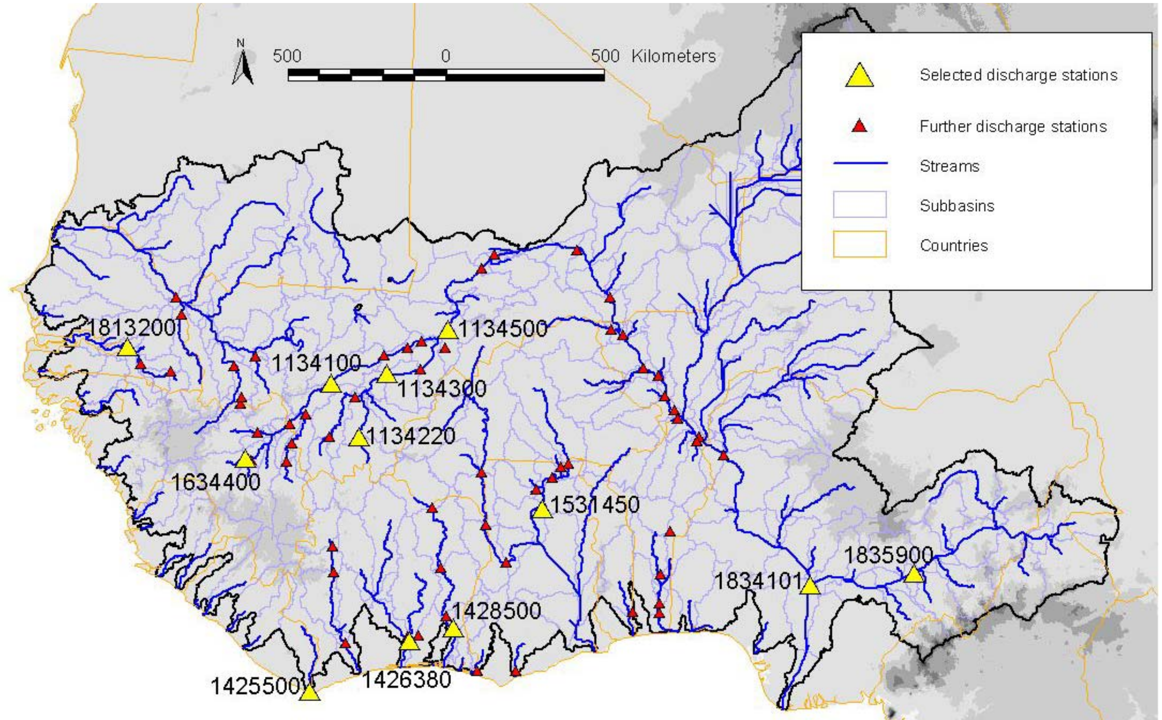
- **WXGEN** weather generator model included in SWAT, BUT:
  - developed for the contiguous US
  - needs daily measured values in order to determine monthly statistical values
  - useful in order to fill data gaps

- Developed our own **daily climate generator algorithm (DCGA)** based on SIMMETEO (Geng et al., 1986)
  - sufficient to provide monthly summaries instead of daily values
  - uses global 0.5 degree (~50 km) climate grids with monthly values (precipitation, wet days per month, min. and max. temperature) for the time-period from 1901 to 1995 provided by the Climatic Research Unit (CRU)

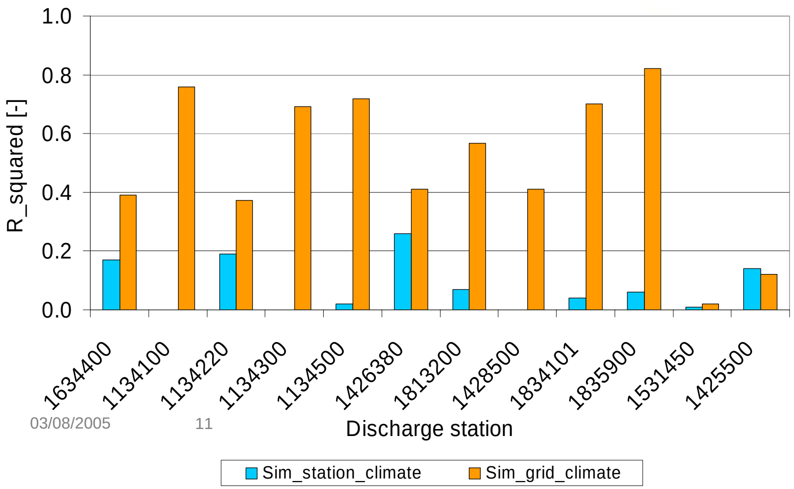
Daily climate generator algorithm (DCGA)



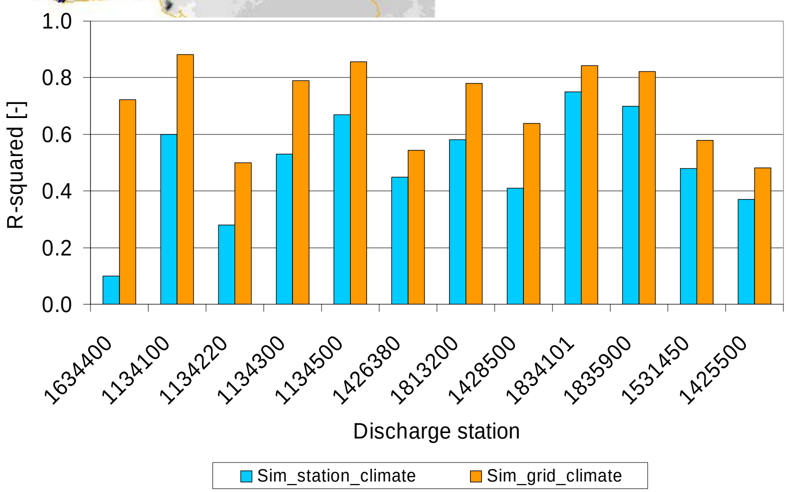
R^2 values between measured and simulated discharge (uncalibrated model)



Annual:



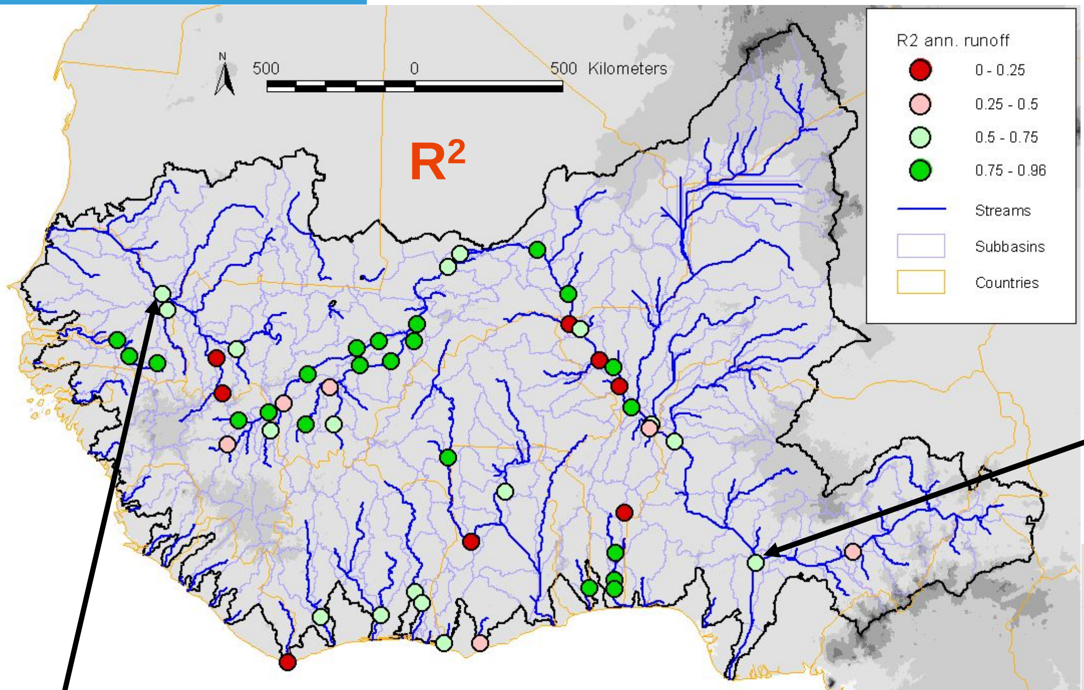
Monthly:



Calibration procedure

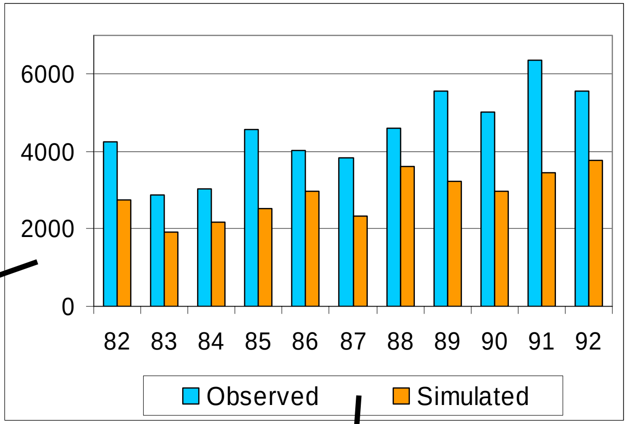
- measured river discharge at 68 stations in West-Africa is used for calibration
- one half of the runoff data at each station is used for calibration, the other half for verification
- an initial annual calibration is followed by a monthly calibration
- multi-site automated calibration using SUFI-2 (Abbaspour et al., 2004)
  - inverse modeling routine (parameter estimation)
  - global search procedure using the RMSE as objective function
  - uses Latin hypercube sampling
  - goal is to bracket most of the measured data within the 95% prediction uncertainty (95PPU) and a significant coefficient of efficiency (NS) between the observed and measured runoff
  - initial uncertainties in the model parameters are progressively reduced (→ parameter ranges are narrowed)
- SWAT–SUFI-Interface for the assignment and updating of parameters (Yang et al., 2005)

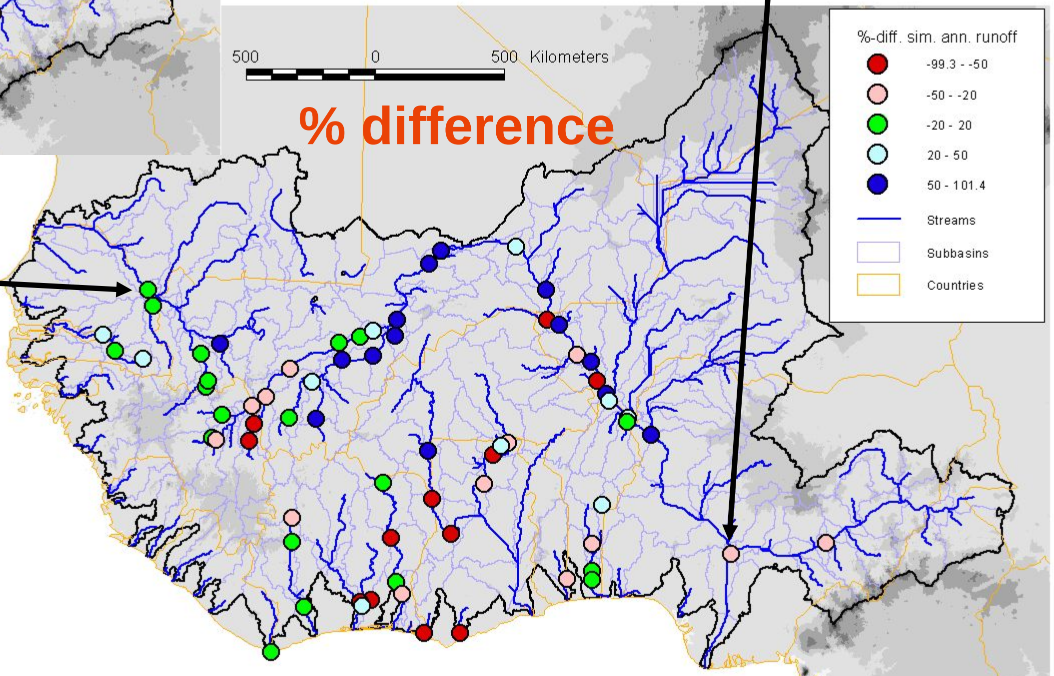
Annual runoff calibration: R^2 and percent difference



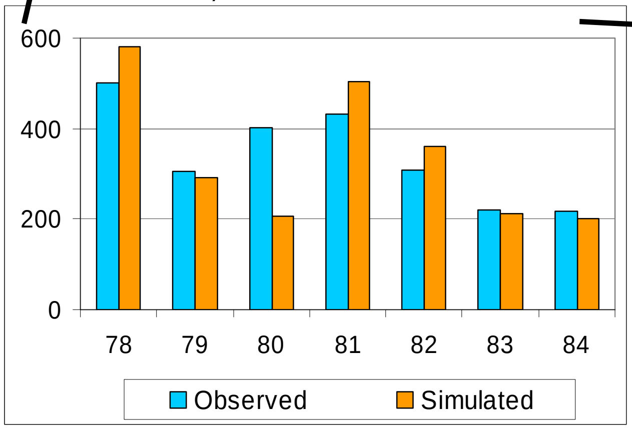
Lokoja, River Niger
A ~ 2,000,000 km²

$R^2 = 0.69$
Diff. = -36%



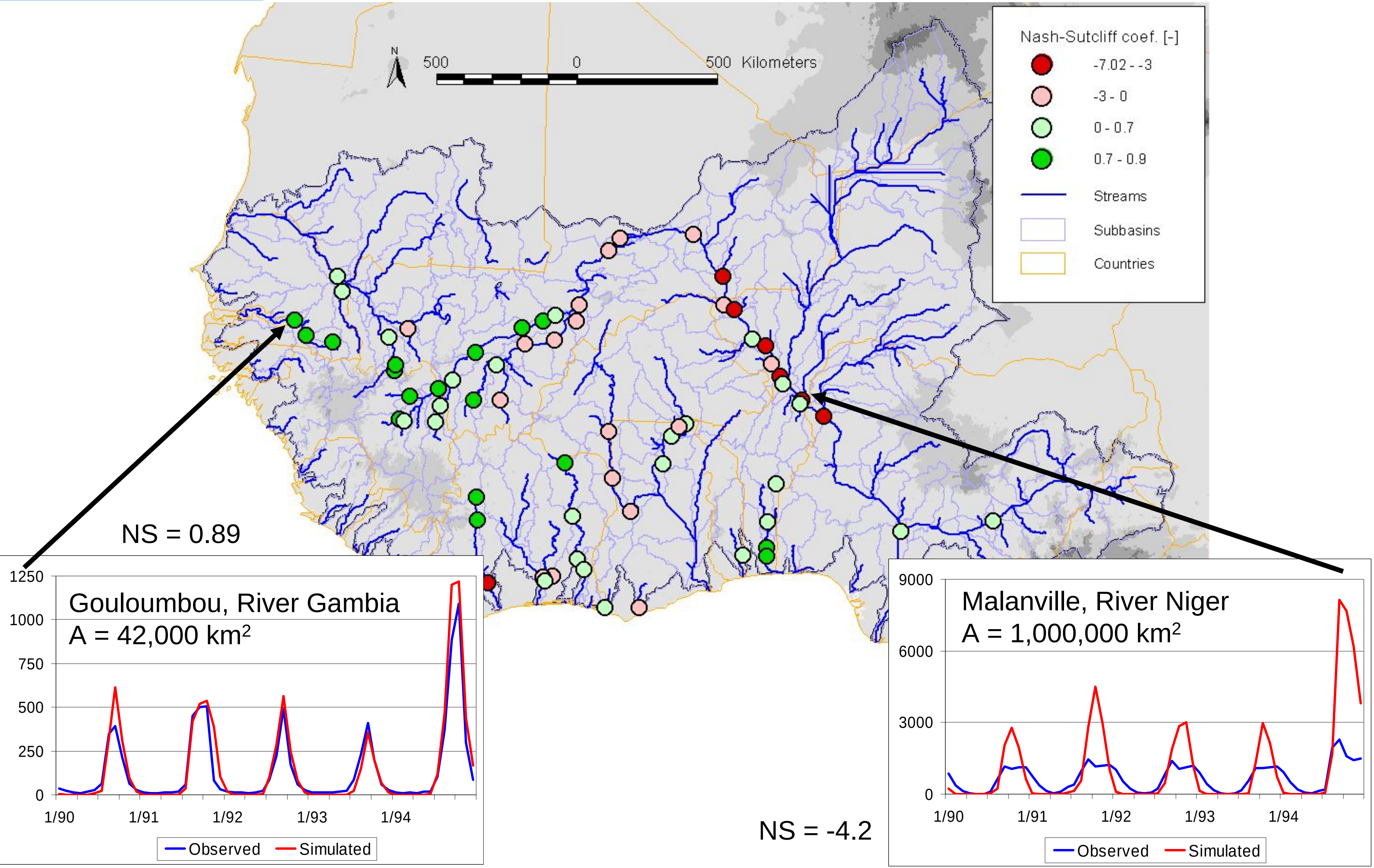


Bakel, River Senegal
A = 218,000 km²



$R^2 = 0.64$
Diff. = -1%

Monthly runoff calibration: coefficient of efficiency (NS)



West Africa: further model improvements

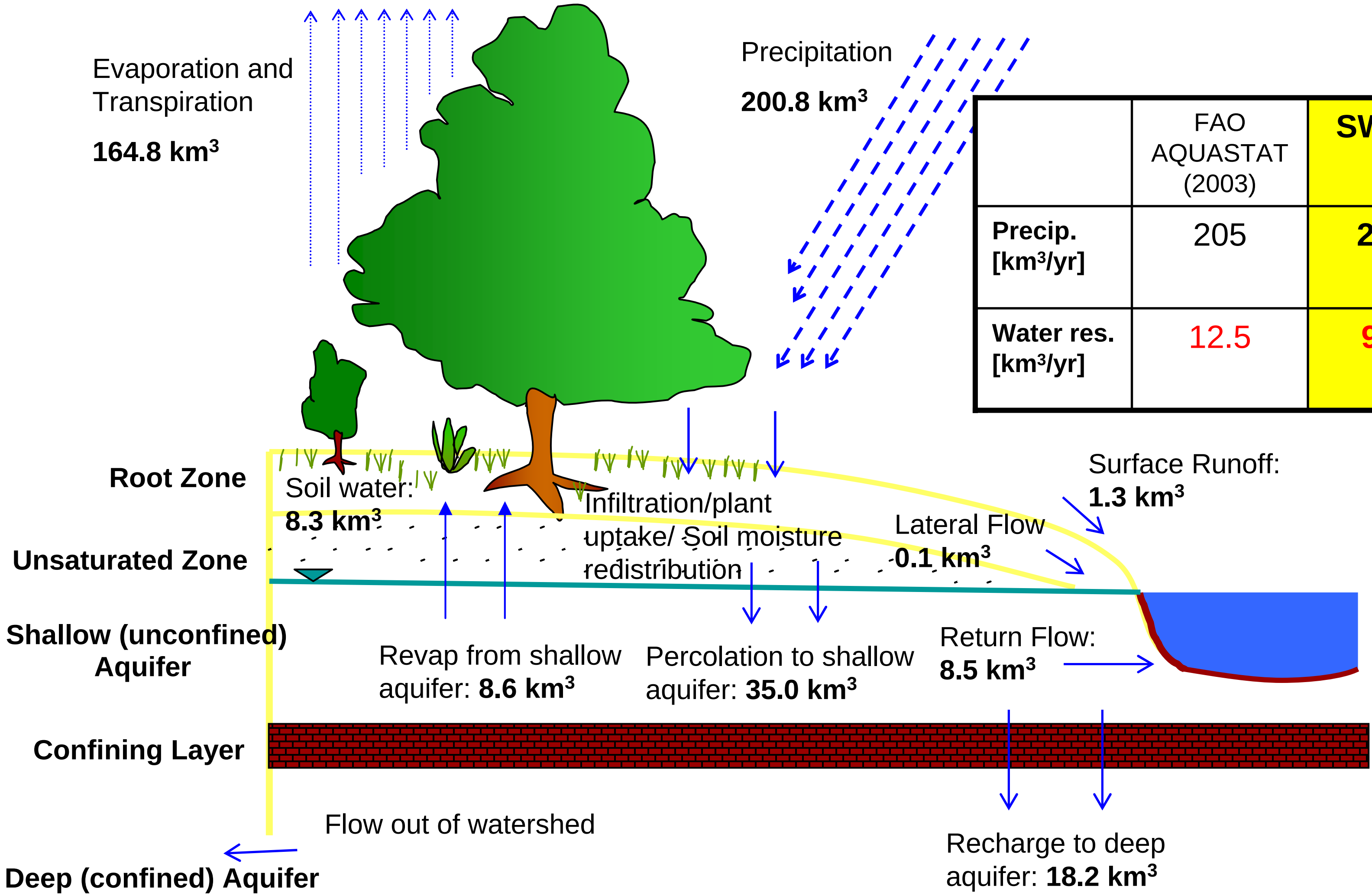
- ideal would it be to include **reservoirs, wetlands, irrigation and domestic/industrial water use, BUT:**
  - need of information on reservoir surface area, reservoir volume and outflow
  - need of information on the volume of water stored and the surface area of the wetland at different water levels
  - limited water use information

- ongoing automated calibration using different procedures and different parameter sets
  - region-dependent calibration
  - inclusion of further constraints in the objectives function

Hydrologic balance – Burkina Faso

Area Burkina Faso: ~ 500,000 km^2

	FAO AQUASTAT (2003)	**SWAT**	WaterGAP (2003)
Precip. [km³/yr]	205	**201**	
Water res. [km³/yr]	12.5	**9.9**	8.6



Conclusions and Outlook

Conclusions

- SWAT can be used for (very) large scale water quantity investigations but there are quite a few stumbling blocks
  - incapability of the AVSWAT interface to calculate the geomorphic subbasin-parameters for very large areas → new ArcGIS Interface will be a solution
  - need of daily weather station data → use of monthly climate data and our Daily Climate Generator Algorithm
- Main problem: lack of information and data on...
- An improved calibration is realistic but due to the non-uniqueness of effective parameters there will never be one best fit

Outlook

- create a model of the whole continent Africa, making use of the experience gained in West-Africa
- quantification of the uncertainty in the freshwater availability estimates
- include large-scale water quality simulation

Thank you!