Modelling regional climate change and the impact on surface and sub-surface hydrology in the Volta Basin (West Africa)

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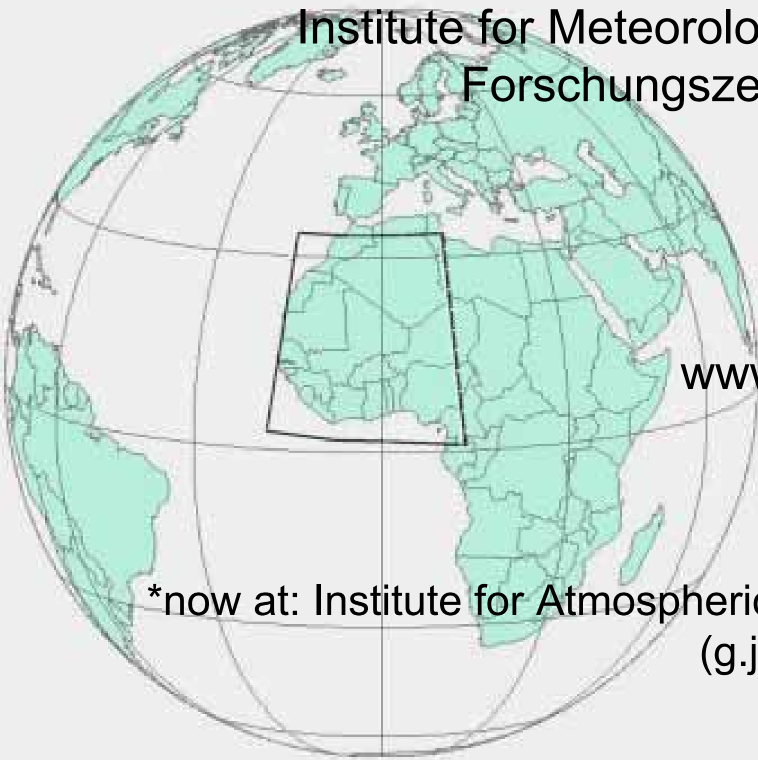
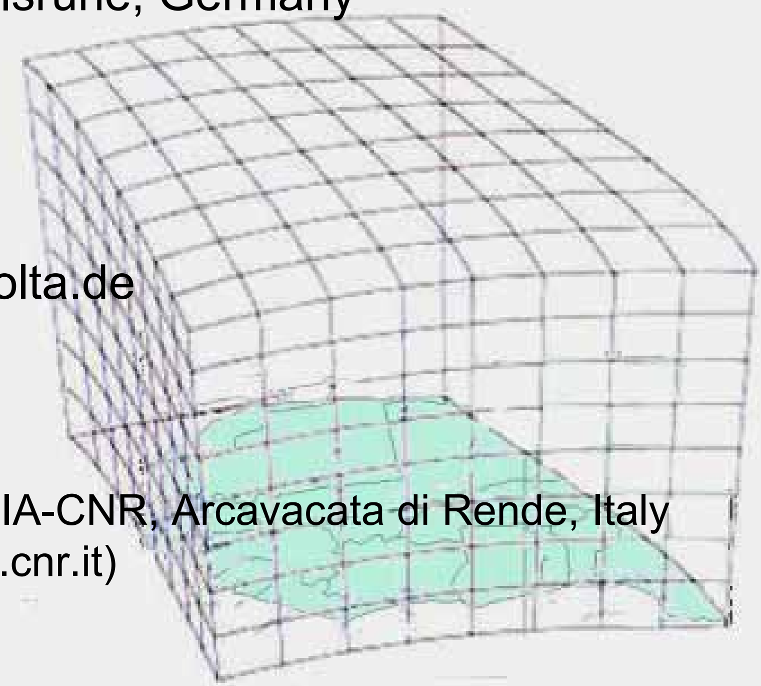


www.glowa-volta.de



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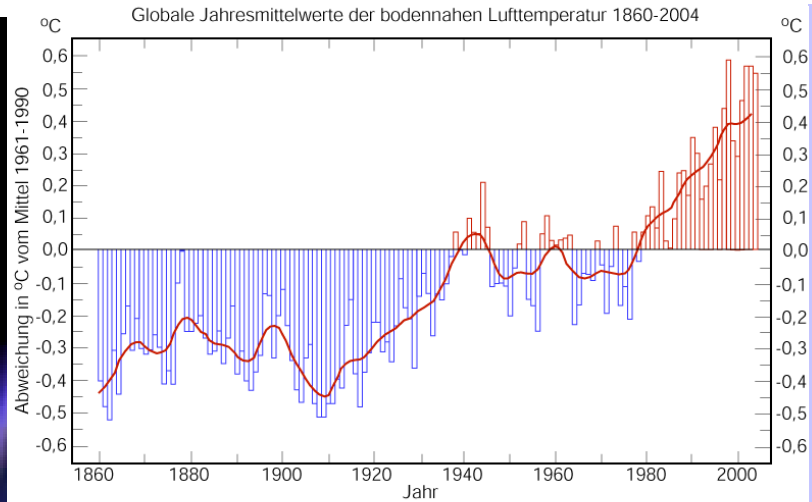
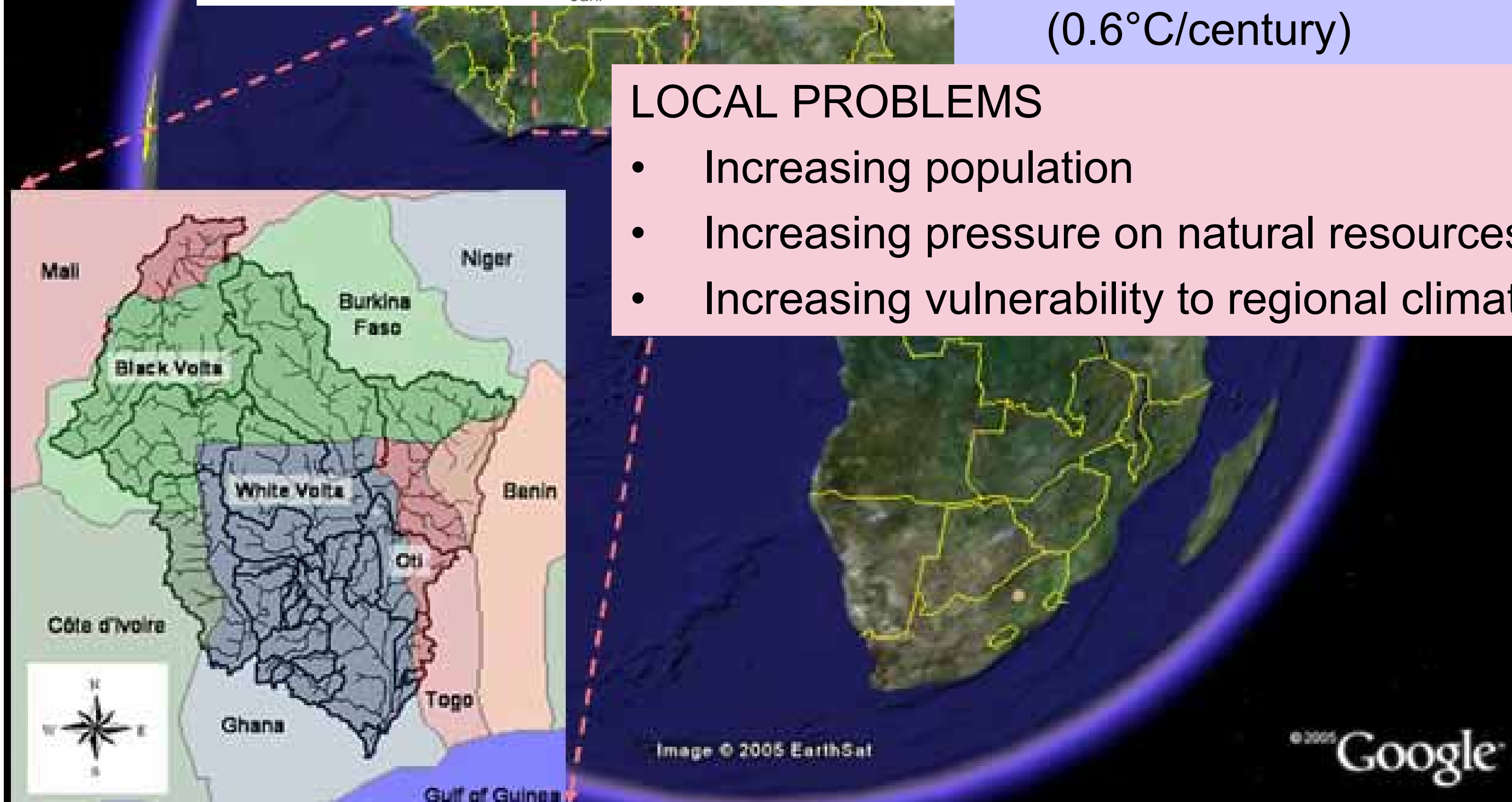


GLOBAL PROBLEMS

- Increased greenhouse gas concentration due to anthropogenic activities (CO_2, CH_4, N_2O, etc.)
- Anthropogenic enhanced greenhouse effect contributing to globally increasing temperatures (0.6°C/century)

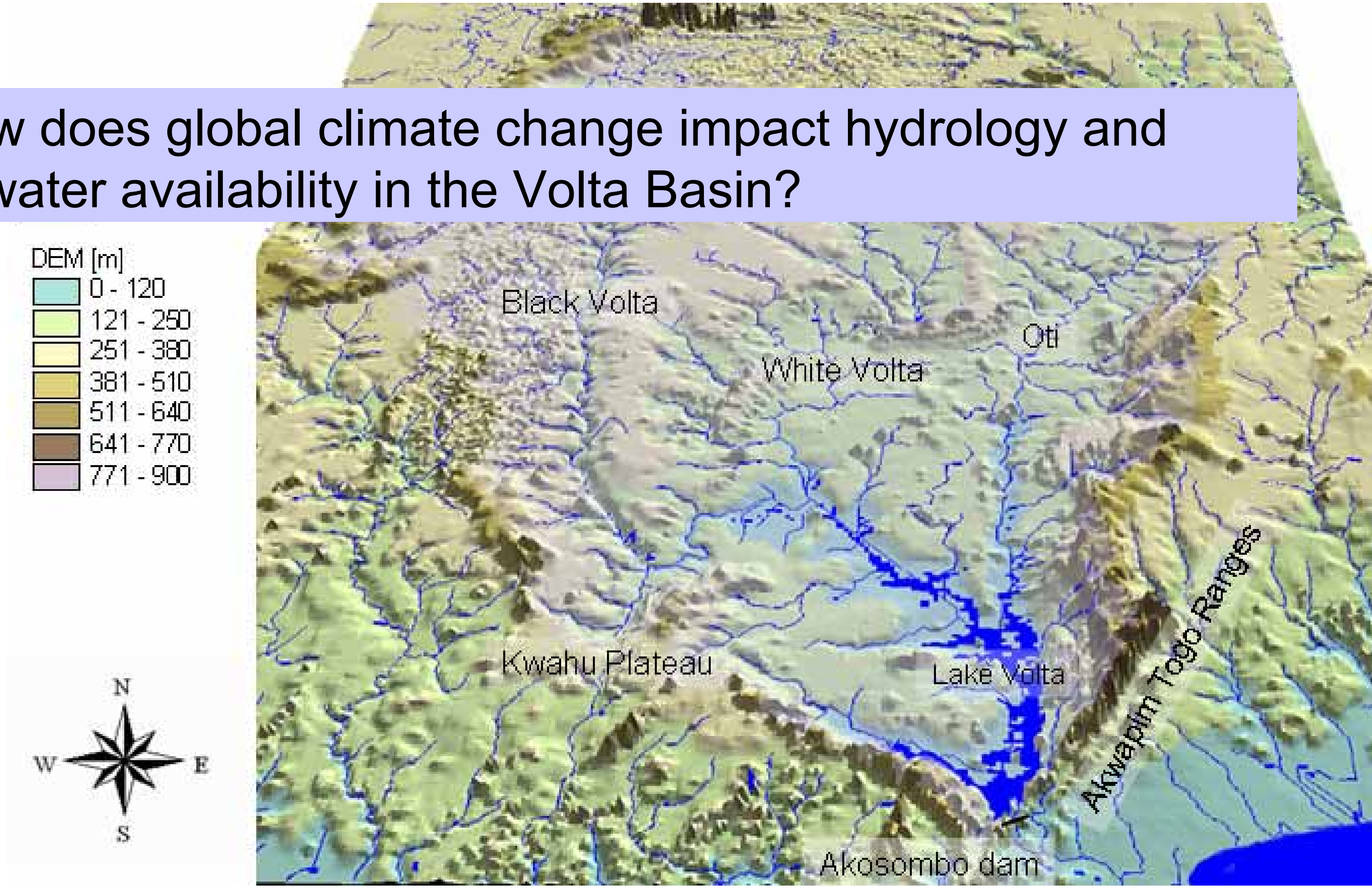
LOCAL PROBLEMS

- Increasing population
- Increasing pressure on natural resources
- Increasing vulnerability to regional climate change



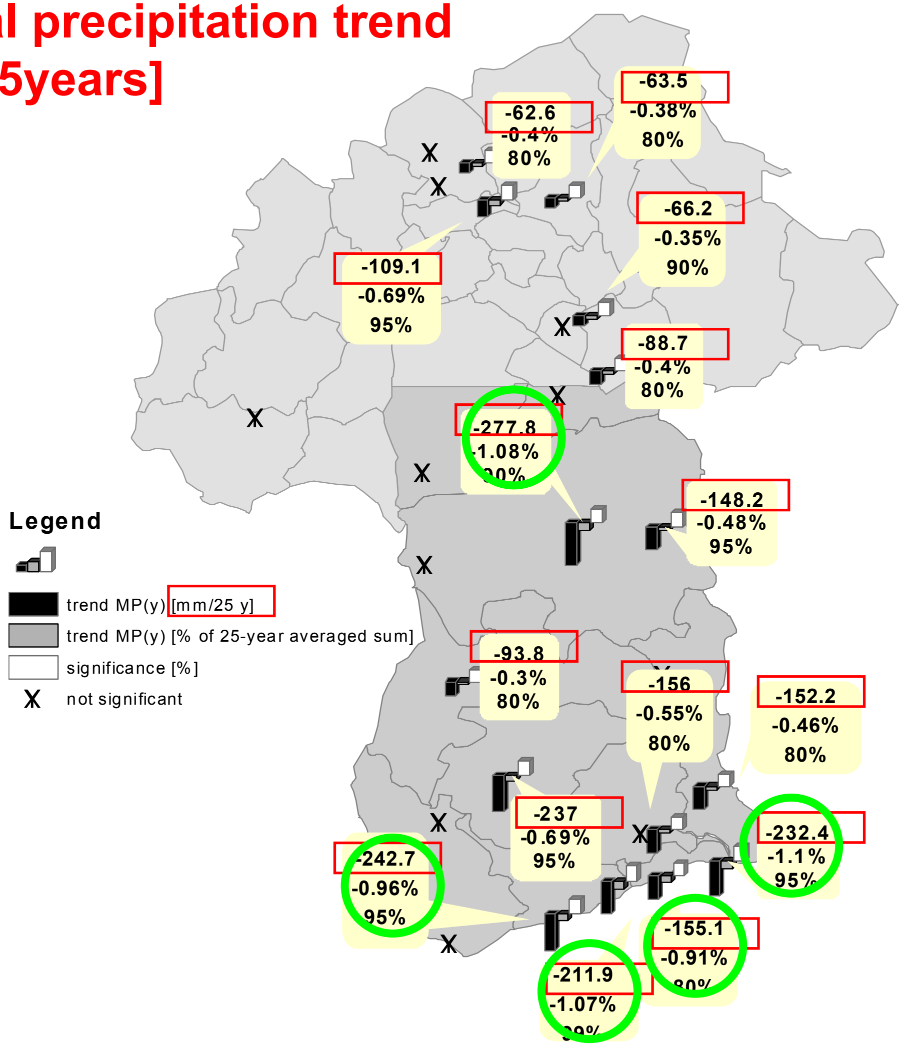
The Volta Basin

How does global climate change impact hydrology and water availability in the Volta Basin?



Recent Climate Trends in the Volta Basin

Annual precipitation trend [mm/25years]



Significant decrease of annual precipitation in specific areas

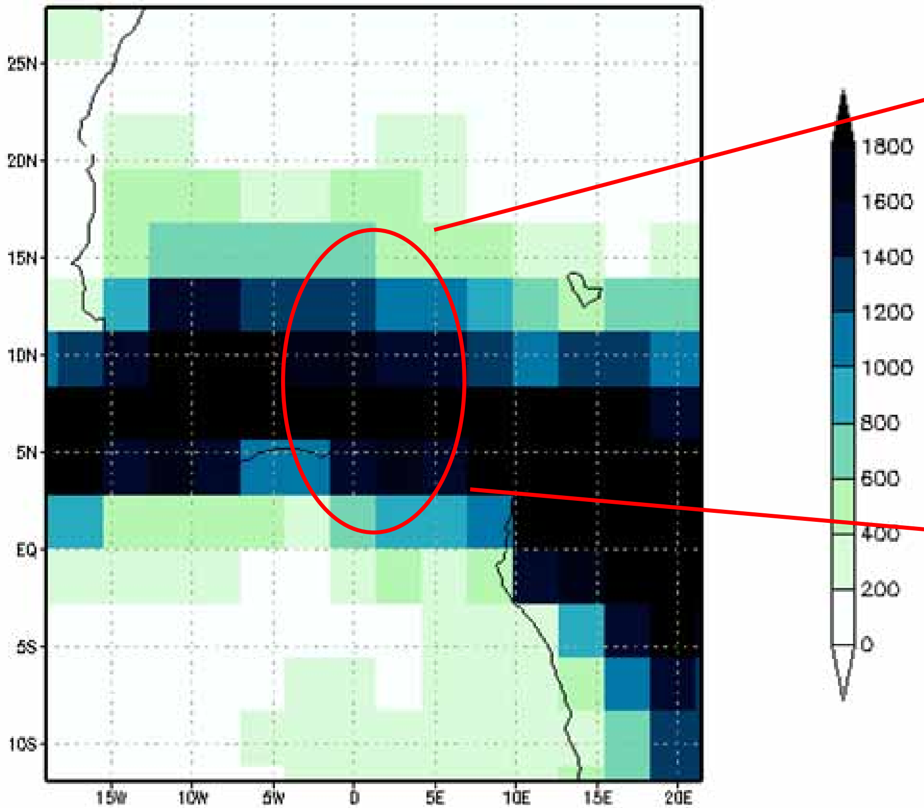
≈ 25% precipitation decrease in last 25 years!

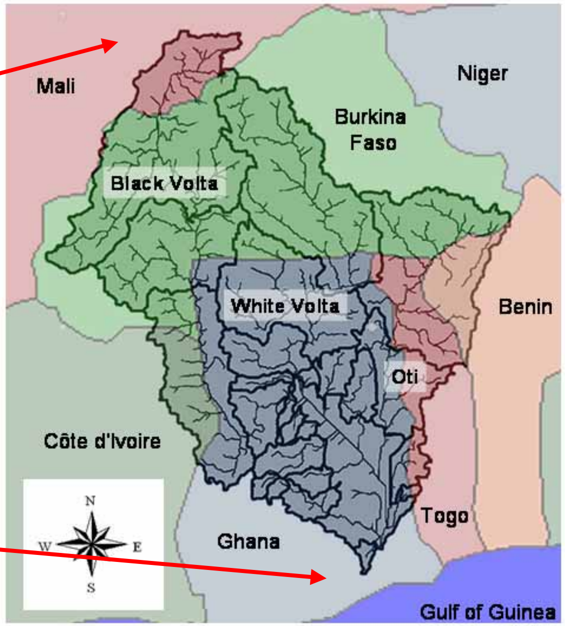
Recent Climate Trends in the Volta Basin

Challenge:
Scientifically sound information
under weak infrastructure

Global Climate Models – Impact Analysis

Mean annual precipitation
(ECHAM4, IS92a scenario) [mm]





1991-2000

Resolution: 2.8° (T42)

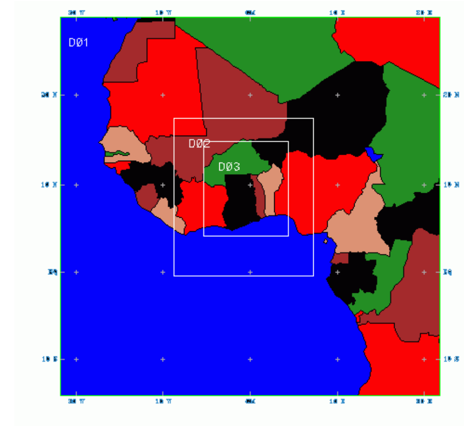
⇒ Resolution much too coarse for regional impact analysis

⇒ Dynamical downscaling

Joint Regional Climate-Hydrology Simulations

- Temperature
- Precipitation
- Wind
- Relative Humidity
- Radiation

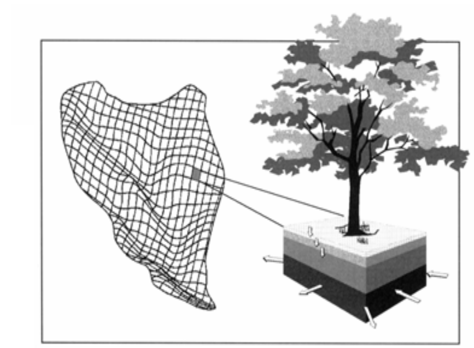
ECHAM4 & MM5



2.8°→ 9 km resolution

WaSiM

- Orography
- Land use
- Soil properties
- Aquifer properties
- Flownet structure



1 km resolution

Evapotranspiration

Infiltration

Surface runoff

Groundwater flow

Distributed Hydrological Model WaSiM-ETH

Physically based algorithms for vertical fluxes & groundwater

- Evapotranspiration: soil and vegetation specific (Monteith; Brutsaert)
- Flow through unsaturated zone (Richards)
- Suction head & hydraulic conductivity (van Genuchten)
- 2-dim groundwater model dynamically coupled to unsaturated zone

Conceptual approaches for lateral runoff aggregation

- Translation & retention of infiltration excess to sub basin outlet (flow time zones)
- Discharge routing: cinematic wave

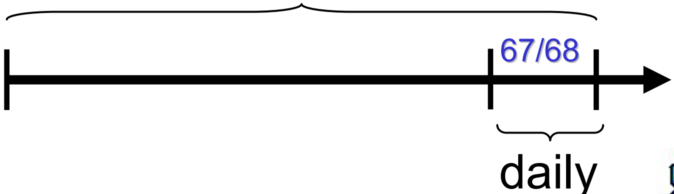
Setup for Volta basin

- spatial resolution: 1x1 km², temporal resolution: daily
- subdivision into sub-catchments

Setup of Hydrological Model

Total area **400.000 km²**

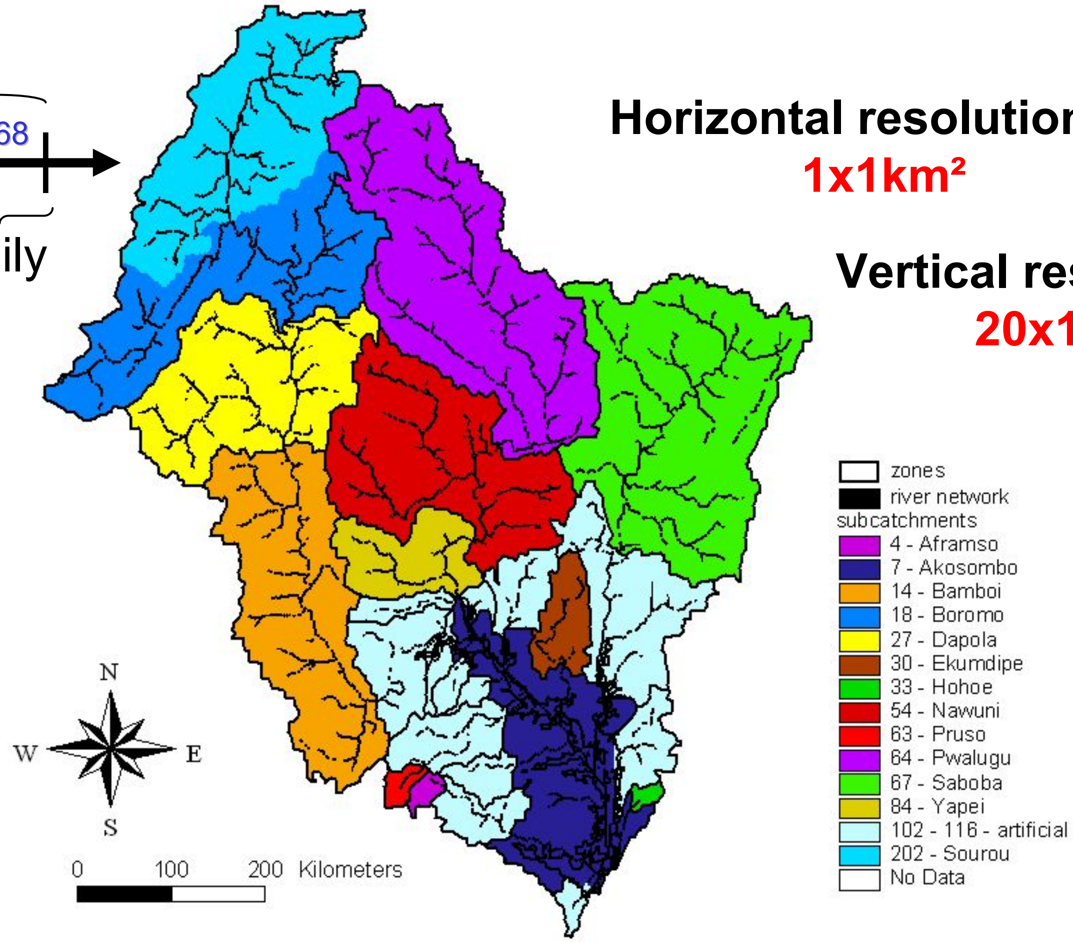
Calibration period: 1962-68



Horizontal resolution
$1x1km^2$

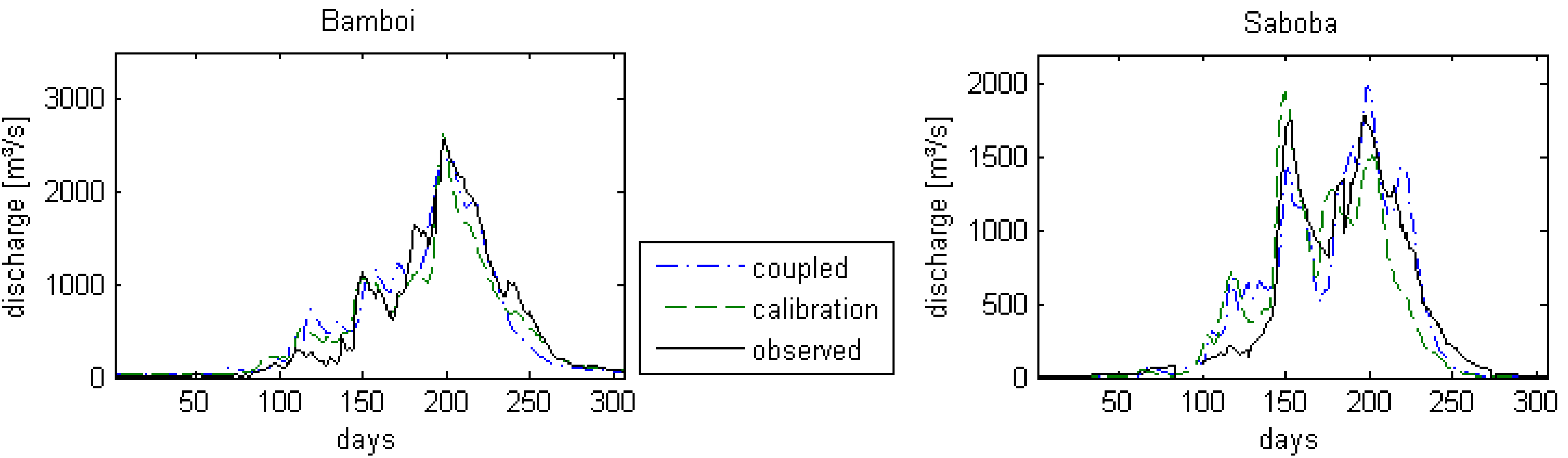
Vertical resolution
20x1m

Temporal resolution
1 day



Performance of Joint Modeling System

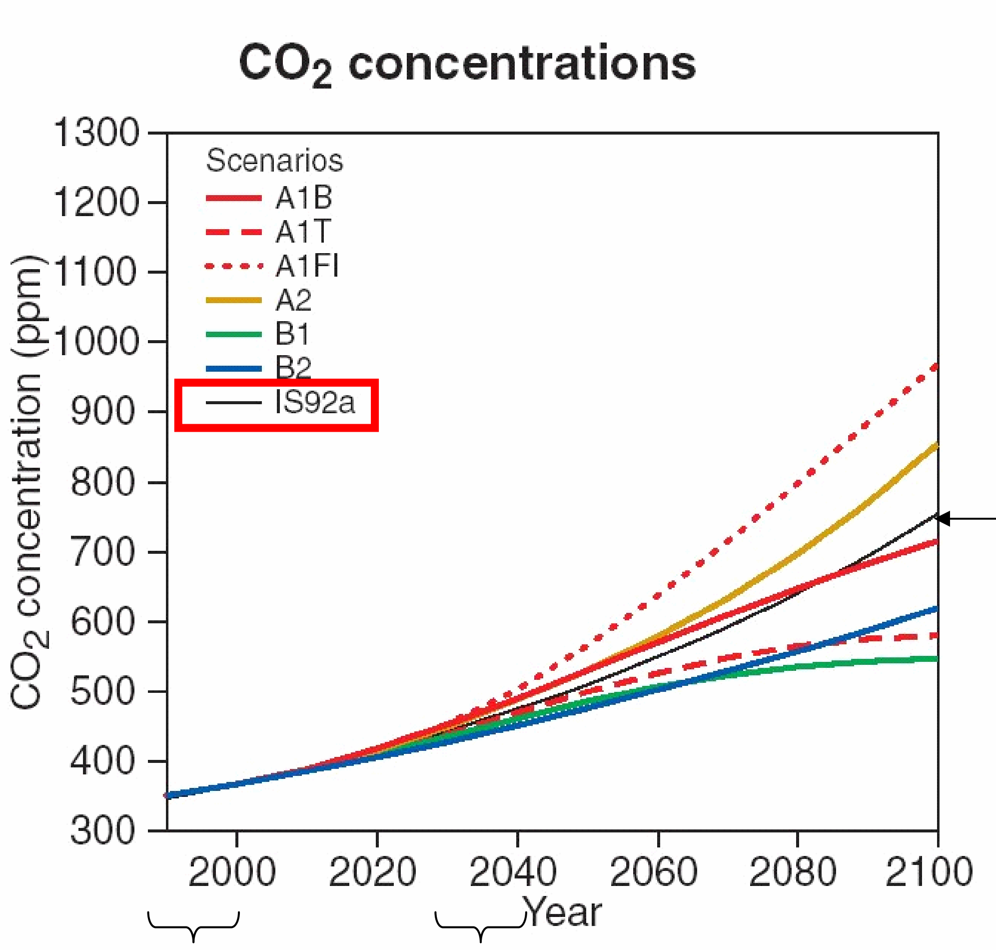
Performance of WaSiM
1) Calibration period 1967/68, station data input
2) Joint MM5-WaSiM run



	Bamboi	Boromo	Dapola	Nawuni	Pwalugu	Saboba
NSE(d)	0.95	0.31	0.82	0.84	0.3	0.85
NSE(m)	0.84	0.74	0.85	0.79	0.33	-

⇒ Sufficient modeling performance
⇒ WaSiM is suited to simulated runoff processes in the Volta Basin

Joint Regional Climate-Hydrology Simulations

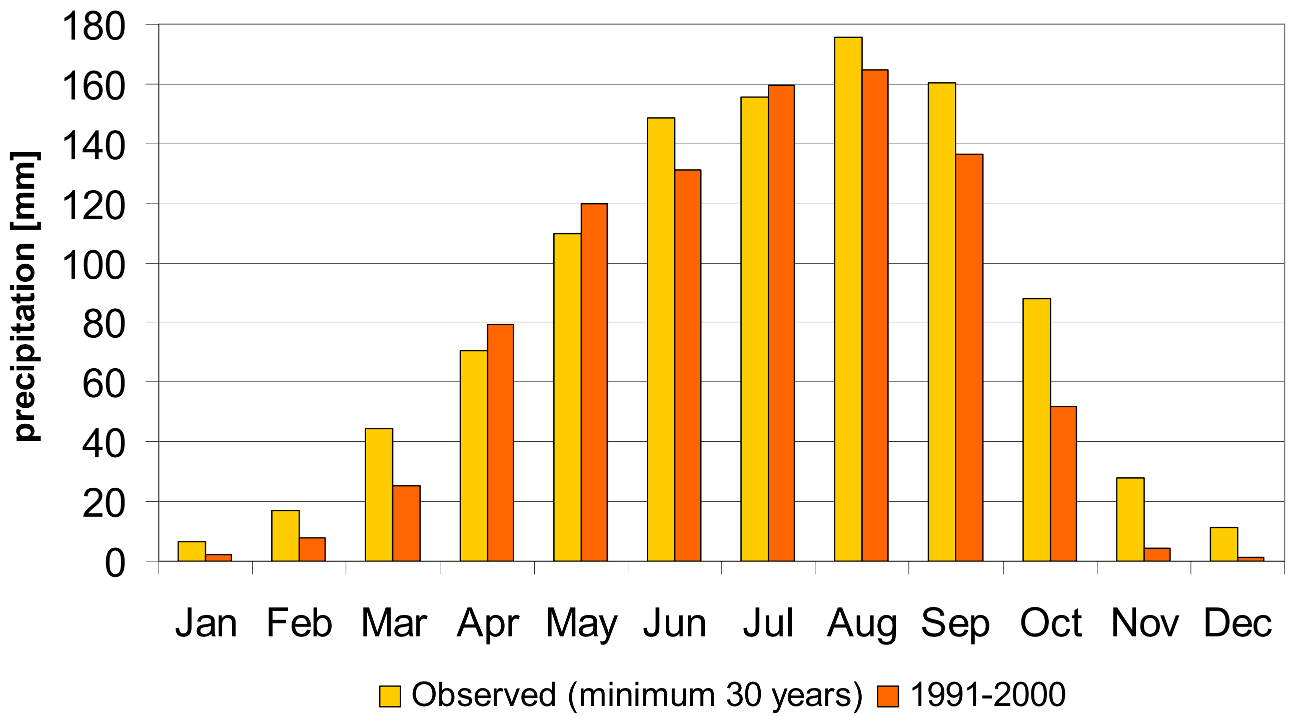


This study: scenario IS92

This study: time slice 2030-39 vs. 1991-2000

Results – Regional Climate Simulations

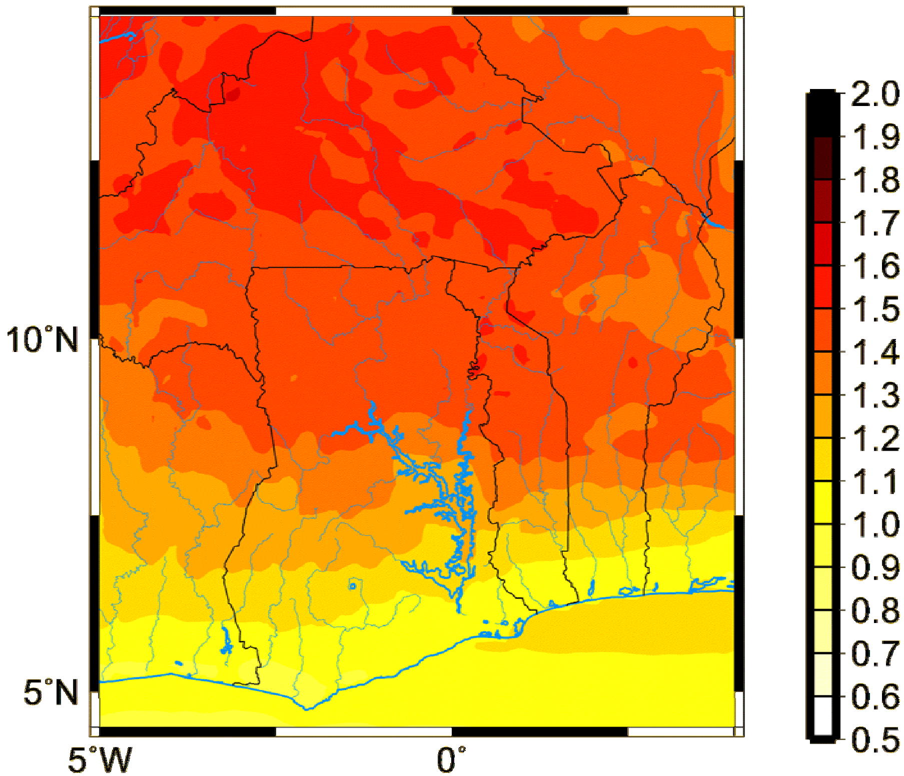
Simulated (1991-2000) vs. interpolated station data



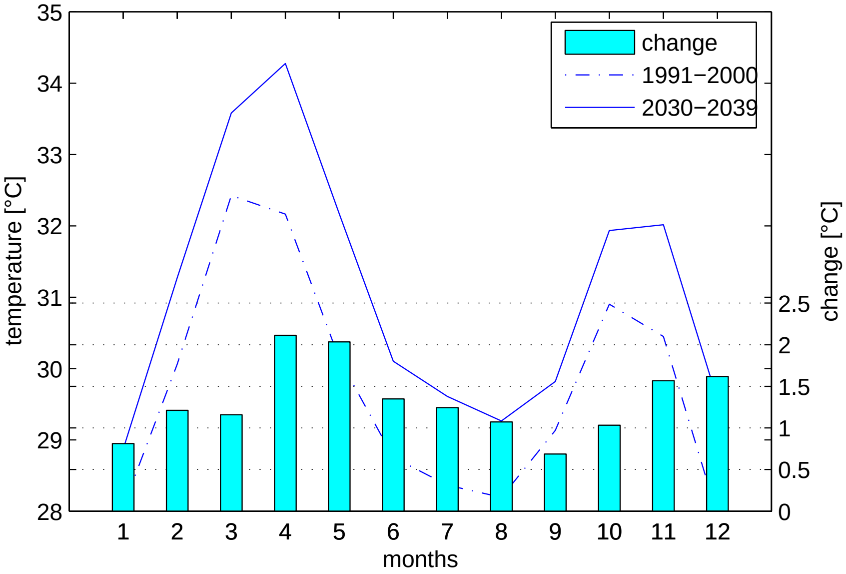
⇒ Reasonable simulation of annual cycle

Results – Regional Climate Simulations

Mean annual temperature change [°C] 2030-2039 vs. 1991-2000



Mean monthly temperature and change [°] 1991-2000 vs. 2030-2039



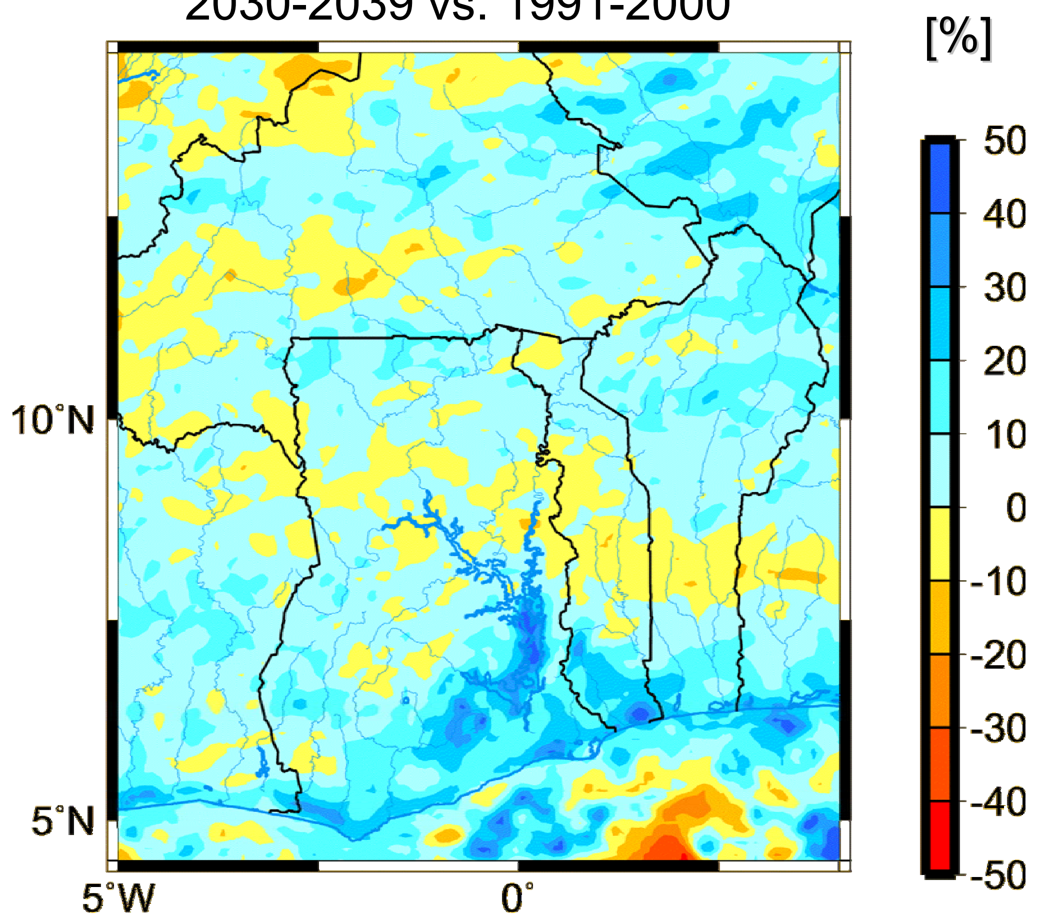
⇒ temperature increase

⇒ increase in SST

⇒ increase in atmospheric moisture content

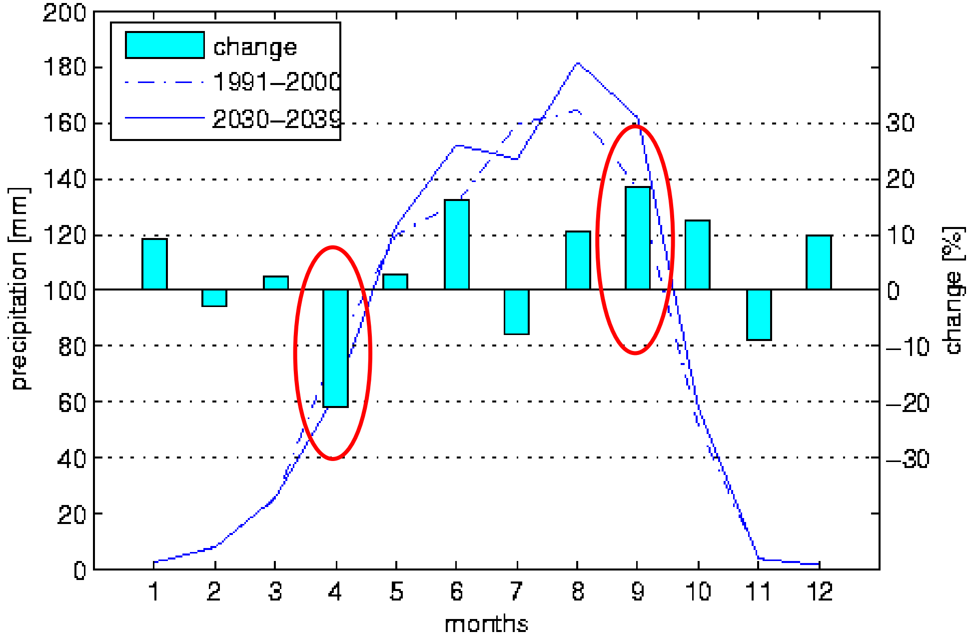
Results – Regional Climate Simulations

Mean annual precipitation change
2030-2039 vs. 1991-2000



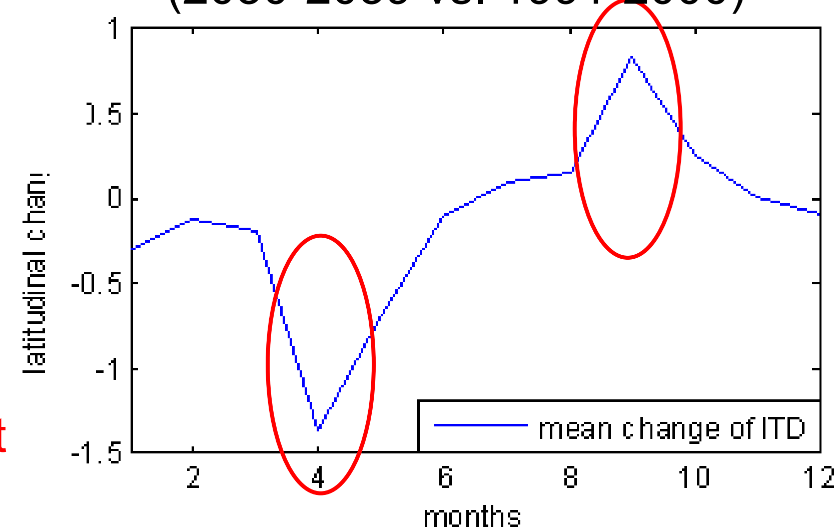
(Domain mean: +4.8 %)

Results – Regional Climate Simulations



Monthly mean precipitation [mm] and change in precipitation [%] (2030-2039 vs. 1991-2000)

Monthly mean ITD displacement (2030-2039 vs. 1991-2000)



⇒ Precipitation decrease: ITD southshift

⇒ Precipitation increase: ITD northshift

Results – Regional Climate Simulations

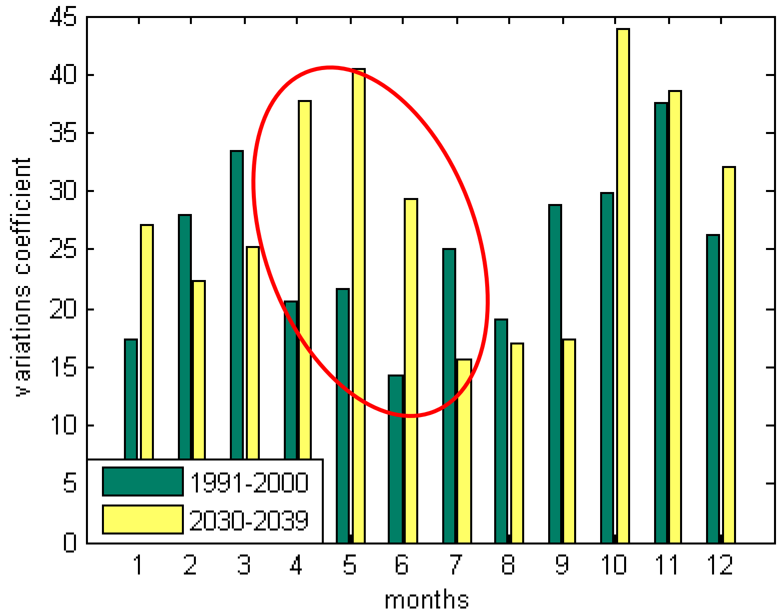
Change in the Onset of the Rainy Season

	Sahel	Guinea Coast
1991-2000 [DOY]	124	105
2030-2039 [DOY]	133	108
Mean change in onset date [days]	9	3

Definition of onset of the rainy season (Stern et al. 1981)

Interannual variability

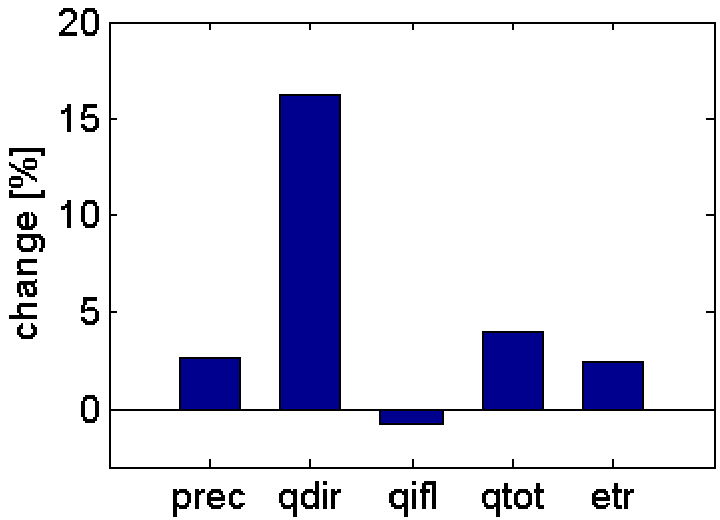
$$\mathrm{var} = \frac{\sigma}{\overline{X}} 100$$

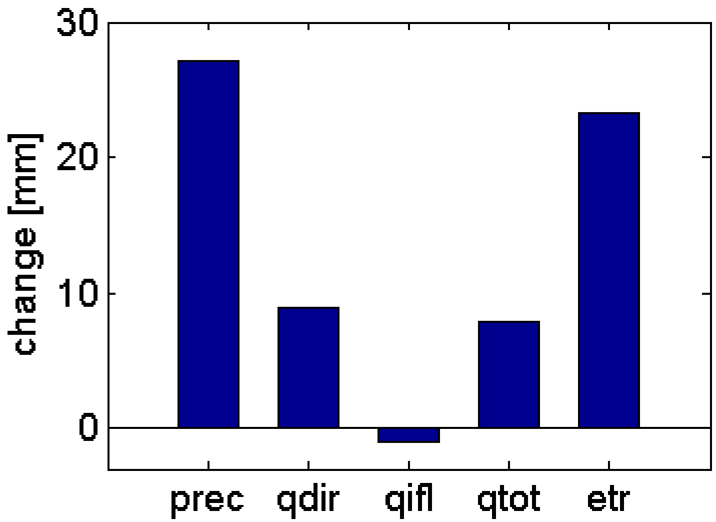


⇒ Delay in the onset of the rainy season

⇒ Increase in interannual variability

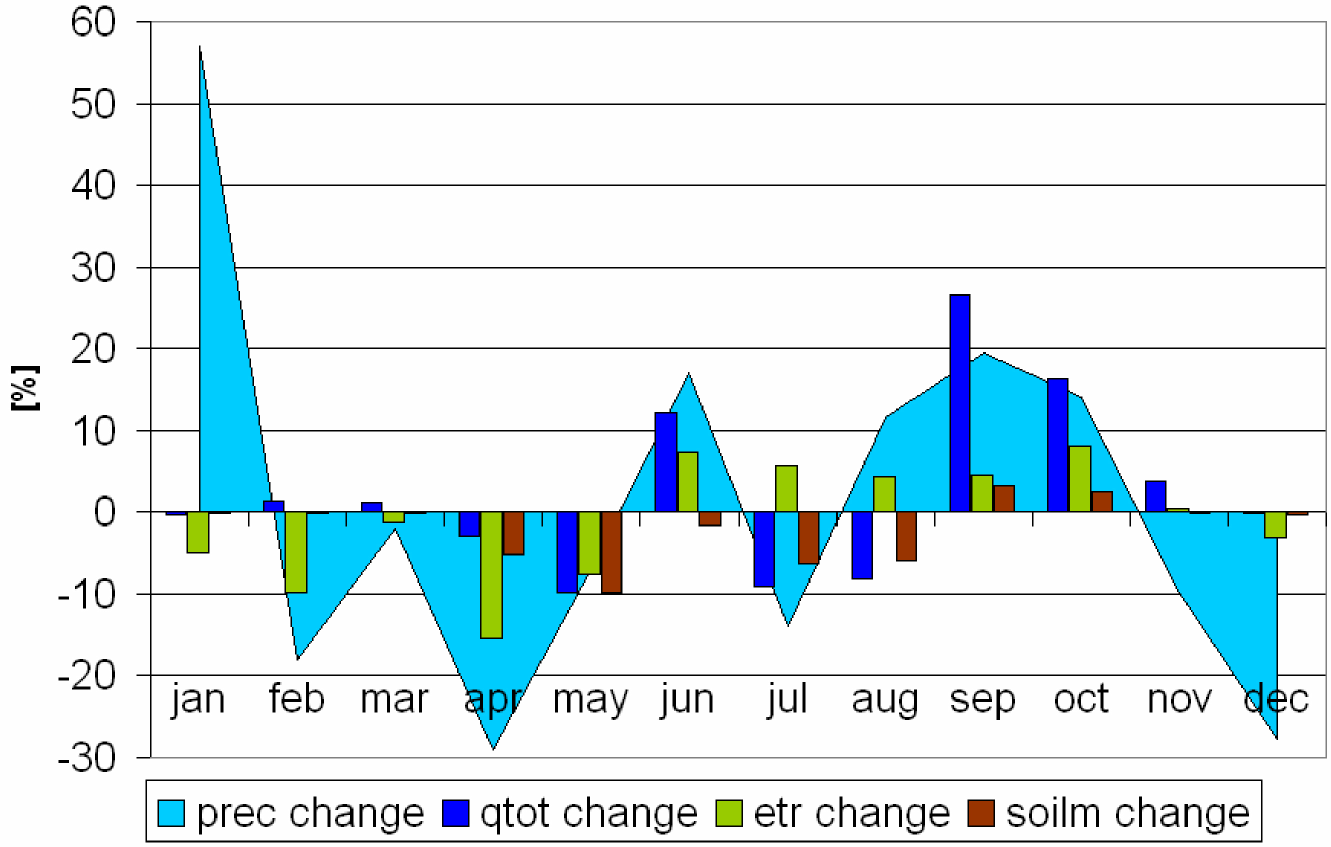
Results – Joint Climate-Hydrology Simulations





$\Rightarrow$ Direct runoff: largest percentage change
$\Rightarrow$ Most of surplus rainfall evaporates

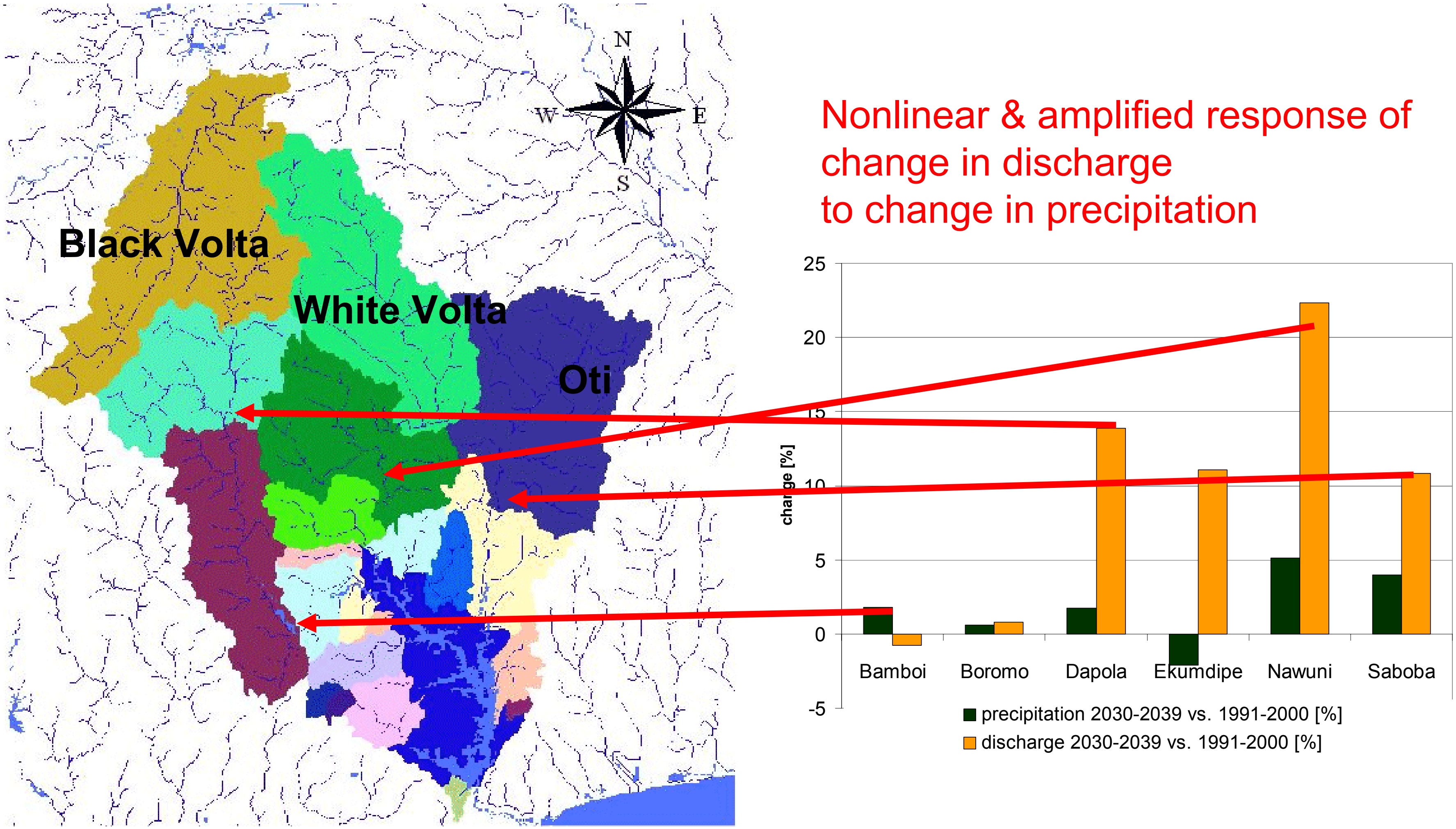
Results – Joint Climate-Hydrology Simulations



Results – Joint Climate-Hydrology Simulations

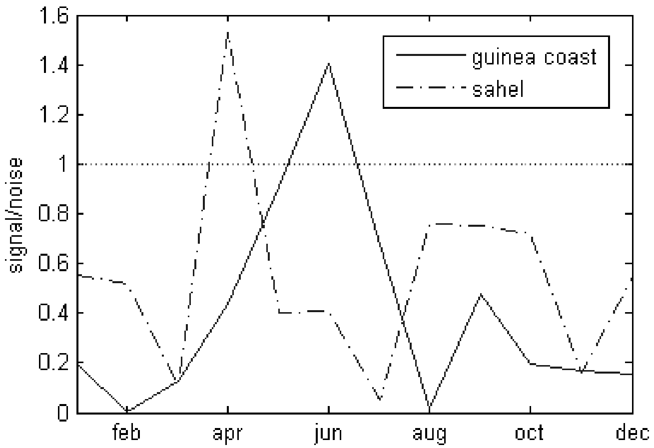
Results: precipitation change 2030-2039 vs. 1991-2000

Nonlinear & amplified response of change in discharge to change in precipitation

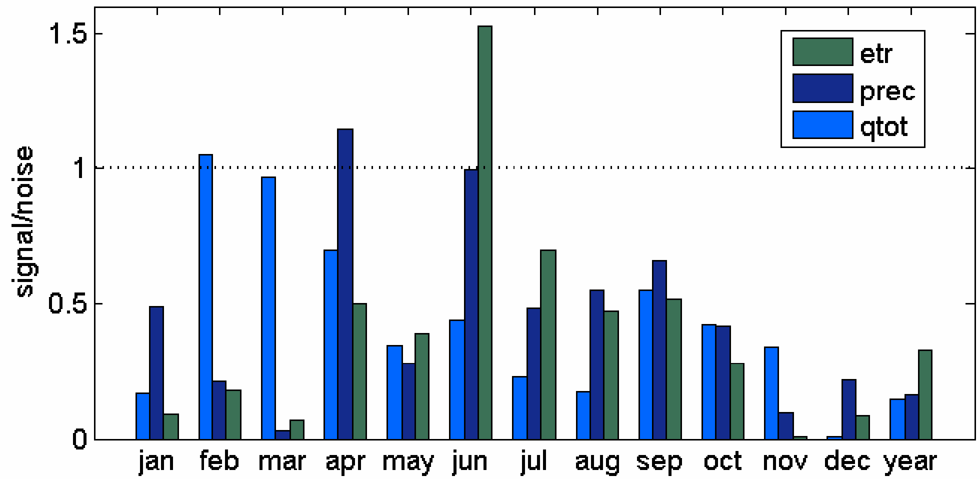


Results – Coupled Climate-Hydrology Simulations

Signal to Noise ratio: $$SN = \frac{|\bar{X}_{fut} - \bar{X}_{pres}|}{\sigma}$$



SN for precipitation



SN for precipitation, evapotranspiration and river runoff, Volta Basin

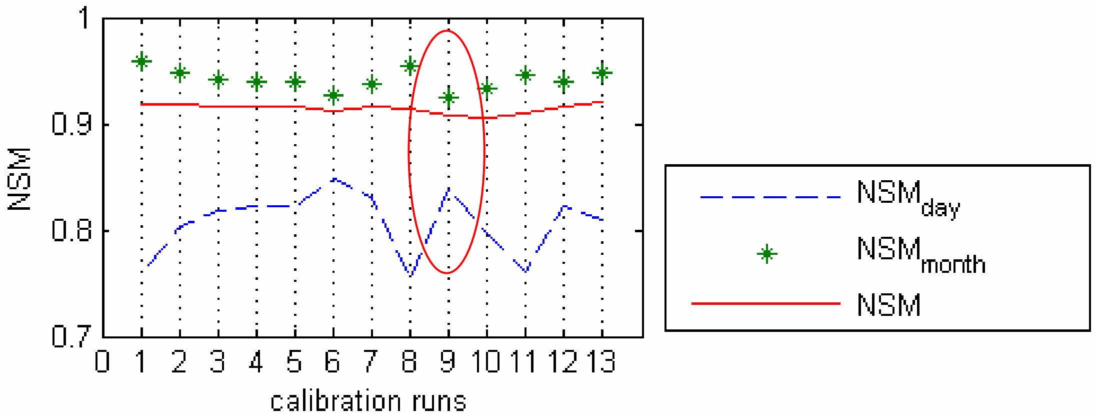
⇒ Climate change signal predominantly within the range of inter-annual variability

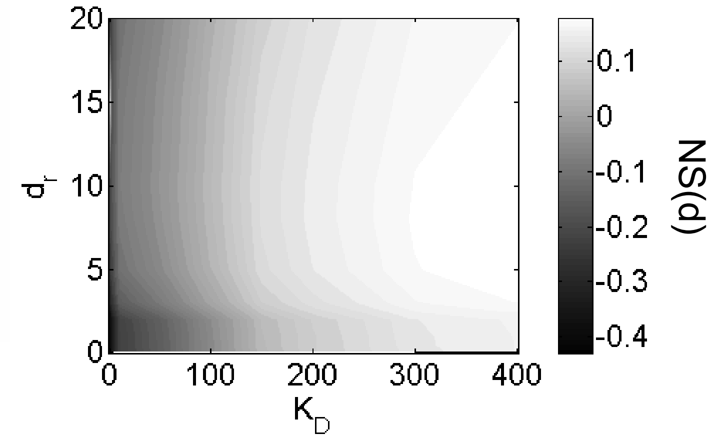
Summary and Conclusions

- Joint regional climate (MM5) and hydrological (WaSiM) simulations for the Volta Basin (2030-2039 vs. 1991-2000)
- Increase in mean annual temperature: 1.0 (coast) -1.5° (Sahel)
- Spatially distributed change of precipitation (between -20 and +50%)
- Increase in precipitation in the rainy season
- Decrease of rainfall at the onset of the rainy season and delay in the onset of the rainy season
- Nonlinear response of discharge change to precipitation change
- Most surplus rainfall evaporates
- Simulated climate change signal predominantly within the range of simulated inter-annual variability


Thank you for your attention

Calibration strategy





Nash-Sutcliffe efficiency:

$$NSE = \underbrace{\alpha\left(1-\frac{\sqrt{\sum_i \left(sim(m)-obs(m)\right)_i^2}}{\sqrt{\sum_i \left(obs_i(m)-\overline{obs(m)}\right)^2}}\right)}_{NSE(m)} + \underbrace{(1-\alpha)\left(1-\frac{\sqrt{\sum_i \left(sim(d)-obs(d)\right)_i^2}}{\sqrt{\sum_i \left(obs_i(d)-\overline{obs(m)}\right)^2}}\right)}_{NSE(d)}$$

m …month
d … day

⇒ Calibration on monthly and daily time scale for higher transferability

(Hartmann & Bardossy, 2005)