Integration of Atmospheric Sciences and Hydrology for the Development of Decision Support Systems in Sustainable Water Management

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Background

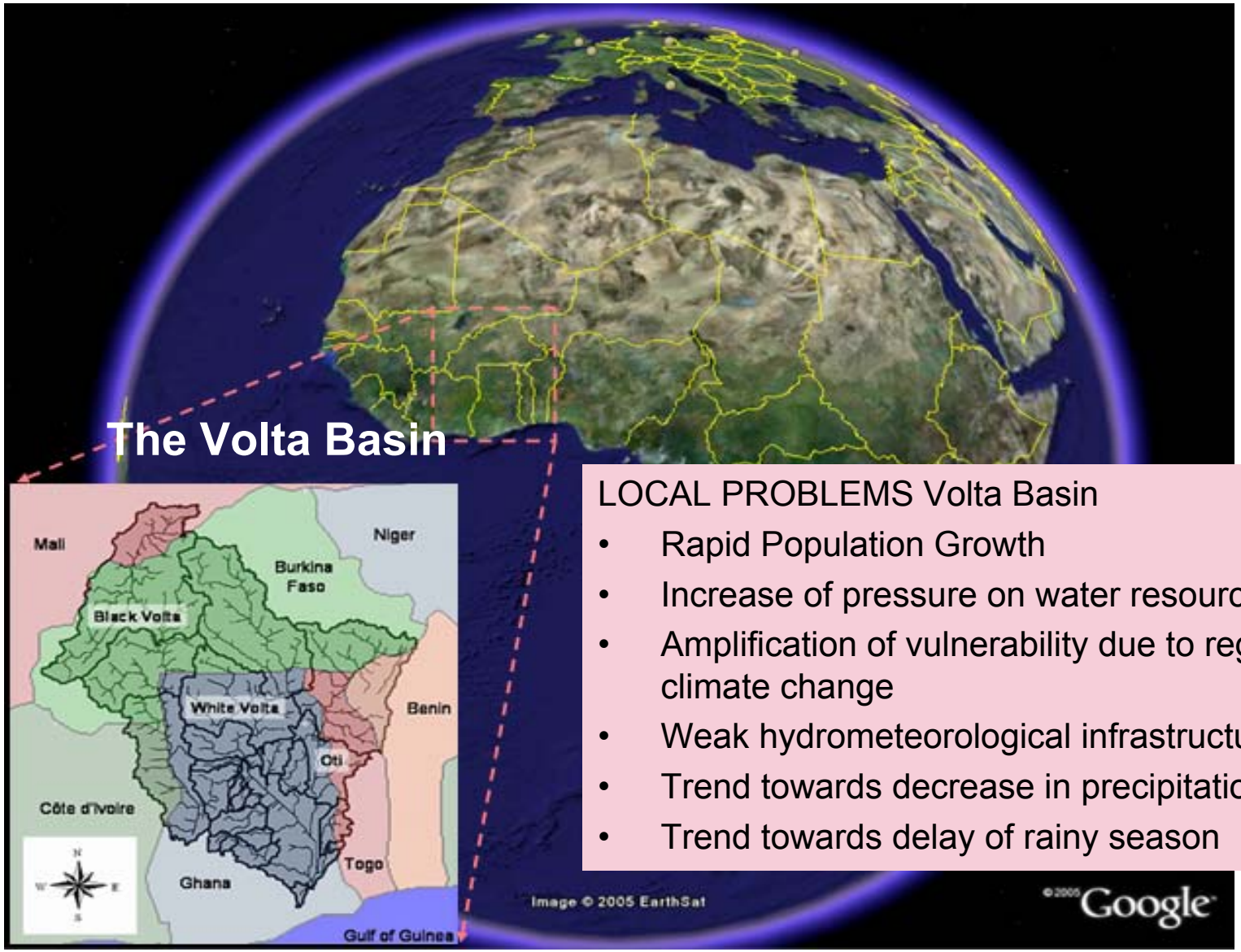
- Most severe water management problems in areas with weak infrastructure: e.g. water scarce environments in developing countries
- Increasing pressure on water resources due to population pressure
- Sustainable water management strategies require hydrological modeling
- … and hydrological modeling requires meteorological input …

General Problems

- Limited observation networks, particularly for precipitation
- Observation information only available with delay
- Global warming changes statistical behavior of meteorological variables (e.g. temporal and spatial distribution of precipitation)

Technical/model based solutions for Decision Support must account for both atmosphere & terrestrial hydrology

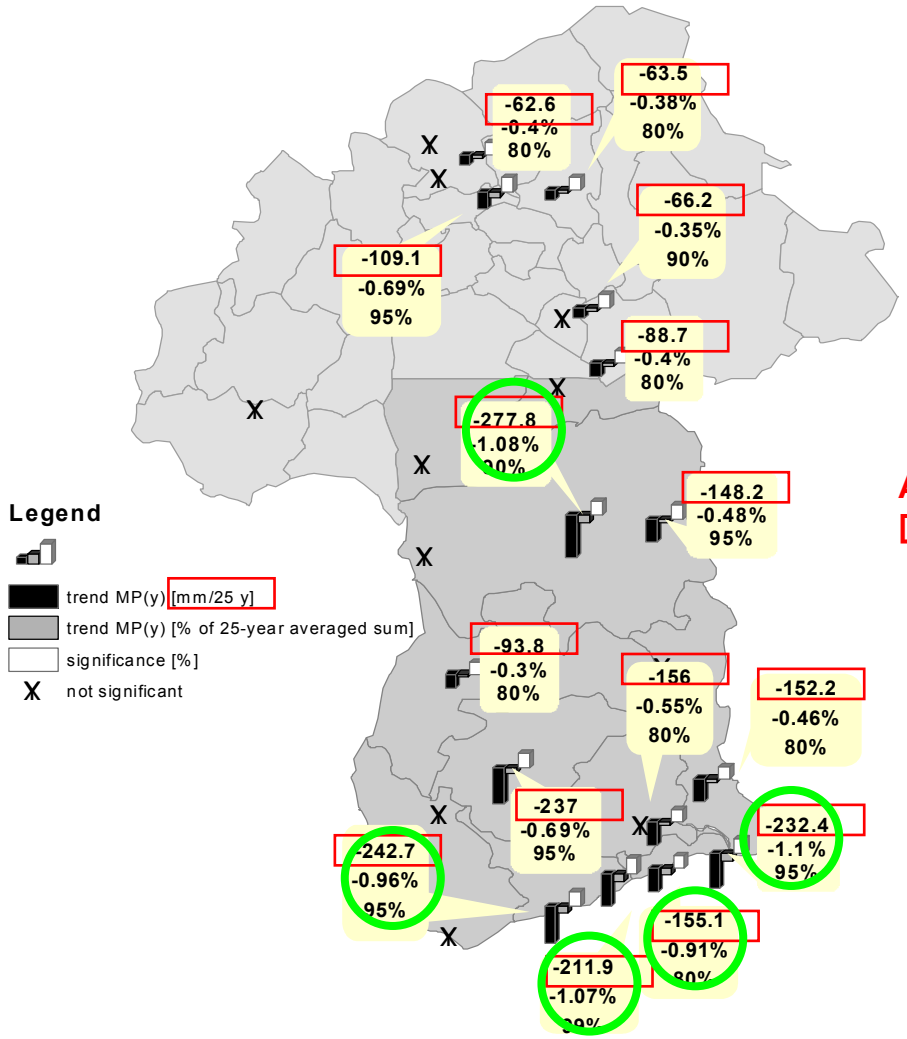
Focus: Hydrometeorological Decision Support Volta Basin



LOCAL PROBLEMS Volta Basin

- Rapid Population Growth
- Increase of pressure on water resources
- Amplification of vulnerability due to regional climate change
- Weak hydrometeorological infrastructure
- Trend towards decrease in precipitation
- Trend towards delay of rainy season

Footprints of Climate Change in the Volta Basin



Annual precipitation trend [mm/25years]

Significant decrease of annual precipitation in specific areas

≈ 25% precipitation decrease in last 25 years!

Challenge:
Scientifically sound information
under weak infrastructure

Water management problems in the Volta Basin/West Africa

Hydrometeorological Decision Support for specific questions:

- How does climate change impact water availability in the Volta Basin?
  ⇒ Identification of future water availability gaps (drought risks)

- What are the current water resources and -fluxes in the catchment?
  ⇒ Near-real time distributed identification of natural water balance

- How can the current onset of the rainy season reliably estimated?
  ⇒ Vital for correct sowing dates and sustainable livelihood

Hydrometeorological DSS is part of overall DSS, including socioeconomical-, land use-, and agricultural aspects (http://www.glowa-volta.de)

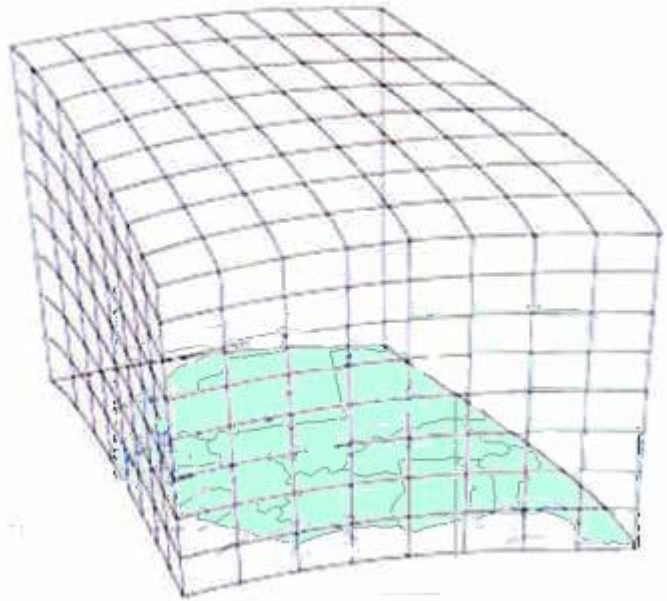
Atmospheric Science in Hydrological Decisions Support

Hydrometeorological Decision Support

Long term planning	Short/mid term planning	Short term decision
Spatial distribution of changing water availability	Model based operational water balance information system	Prediction of current regional onset date of rainy season
Coupled regional climate-hydrology simulations	Near real time coupled atmosphere-hydrology simulations (*hindcasts*)	• circulation pattern analysis • *linear discriminant analysis*

Coupled meteorological-hydrological simulations

Atmospheric modeling



Dynamic downscaling of global atmospheric fields
by mesoscale meteorological models

⇒ Provides all required meteorological variables for hydrology

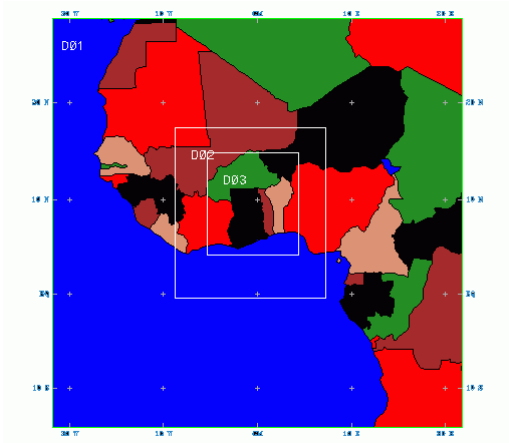
Decision Support (1):

Delineation of spatial and temporal distribution of changes in water availability Volta Basin through coupled regional climate-hydrology simulations

Impact of Regional Climate Change on Water Availability

- Temperature
- Precipitation
- Wind
- Relative Humidity
- Radiation

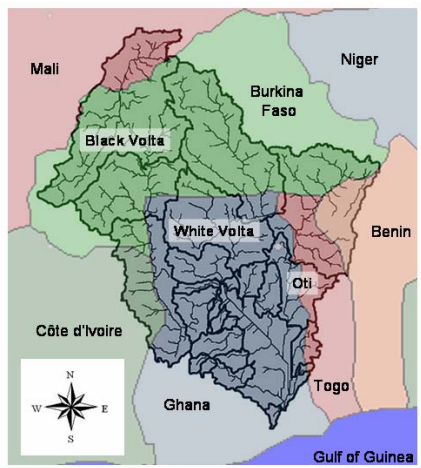
ECHAM4 & MM5
Scenario IS92a
2030/39 vs.
1991/2000



2.8° → 9x9 km² Resolution

Distributed
Hydrological Model
WaSiM

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



1x1 km² Resolution

Evapotranspiration

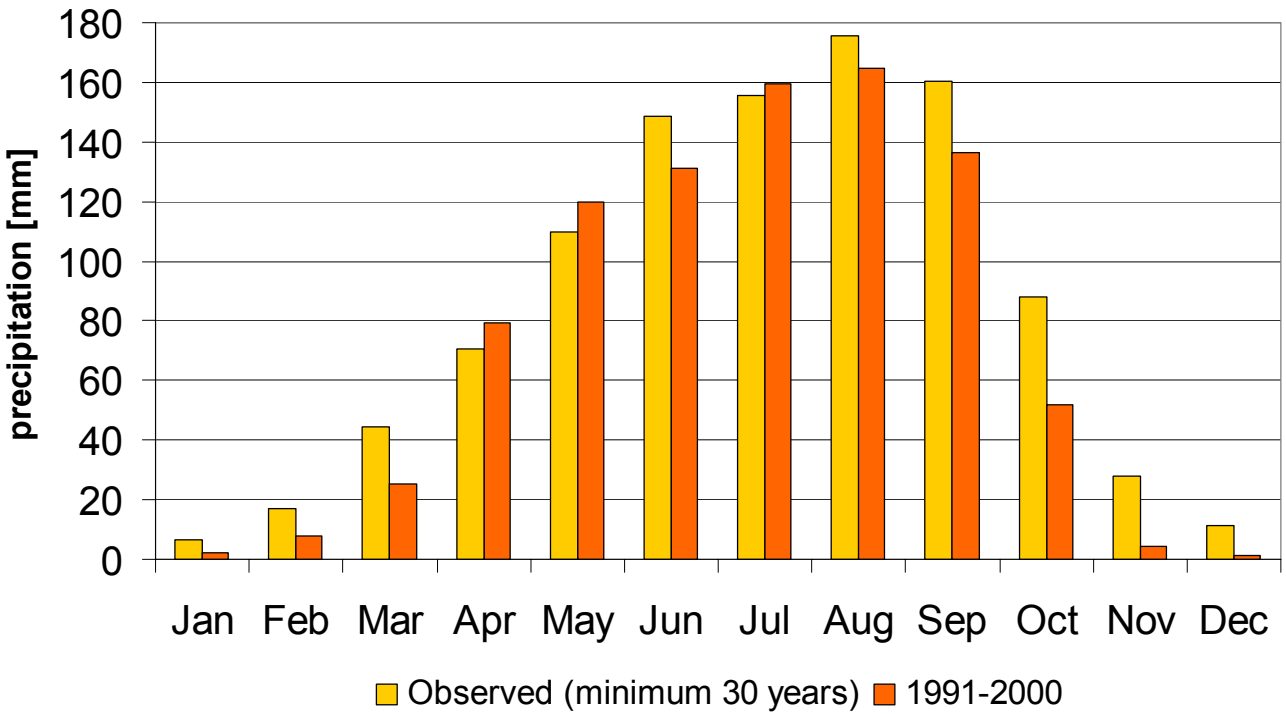
Infiltration

Surface runoff

Groundwater flow

Validation Regional Climate Simulations

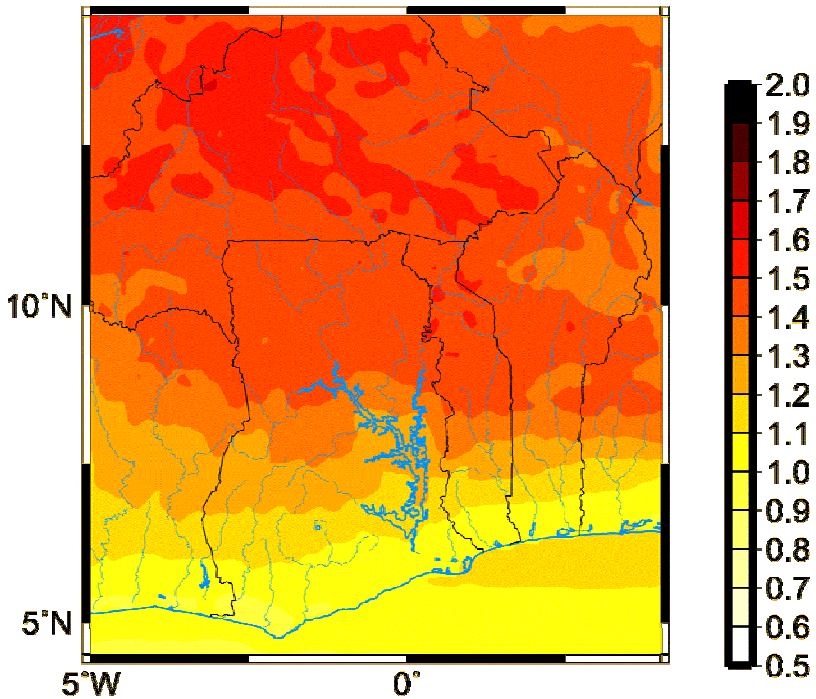
Simulated (1991-2000) vs. interpolated station data



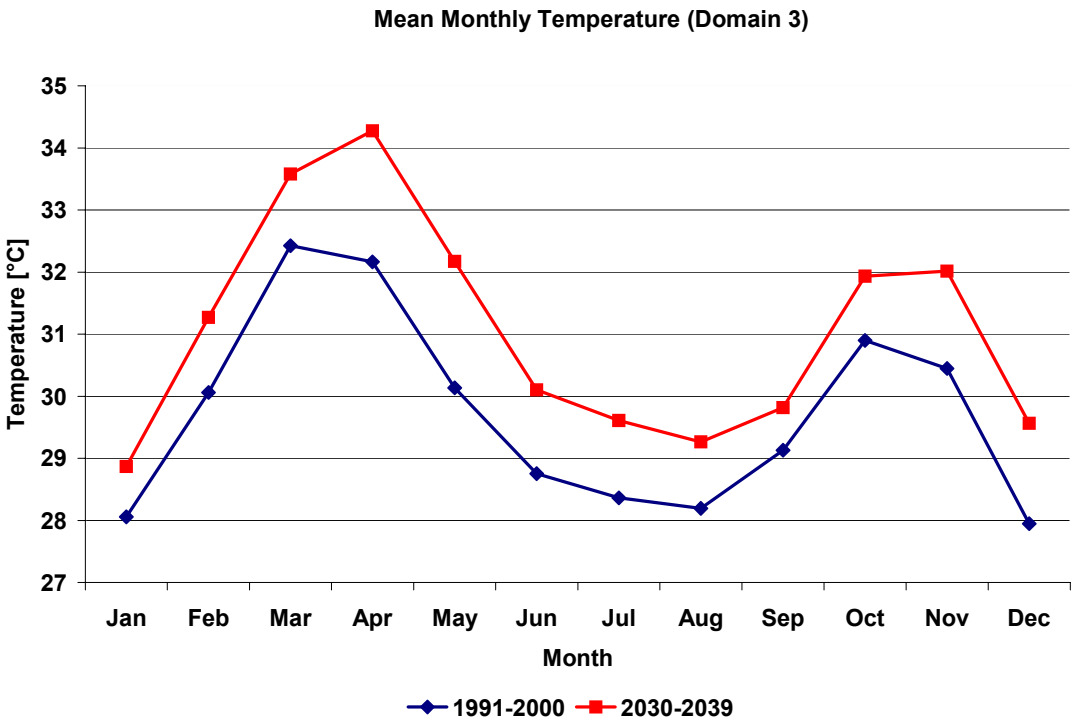
⇒ Realistic annual cycle

Impact of Regional Climate Change on Water Availability

Results: temperature change [°C] 2030-2039 vs. 1991-2000

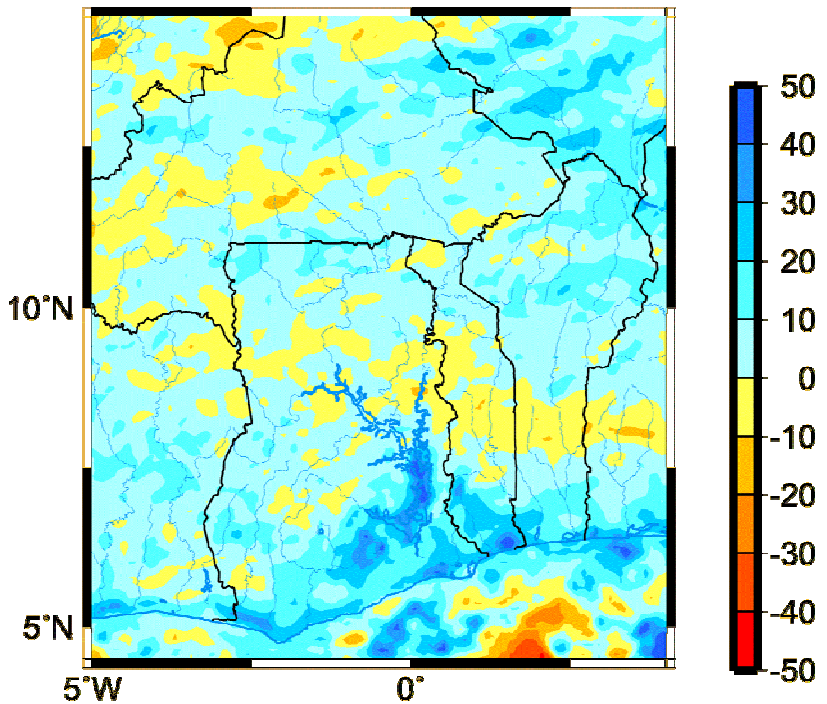


Change in annual mean temperature [°C]

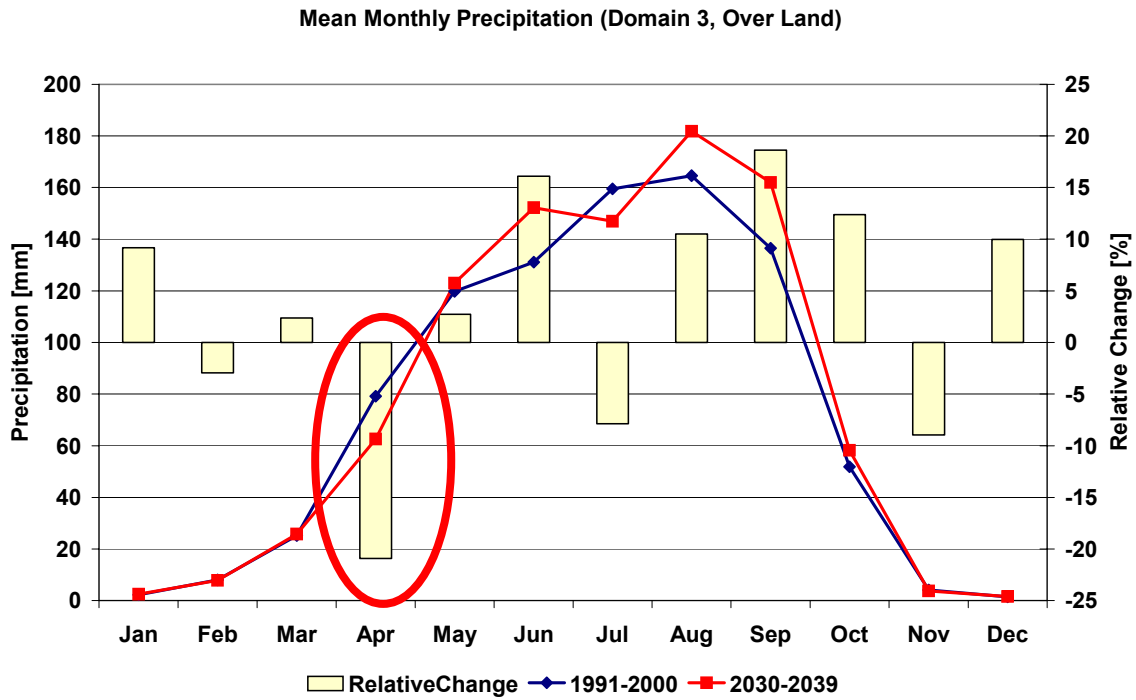


Impact of Regional Climate Change on Water Availability

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

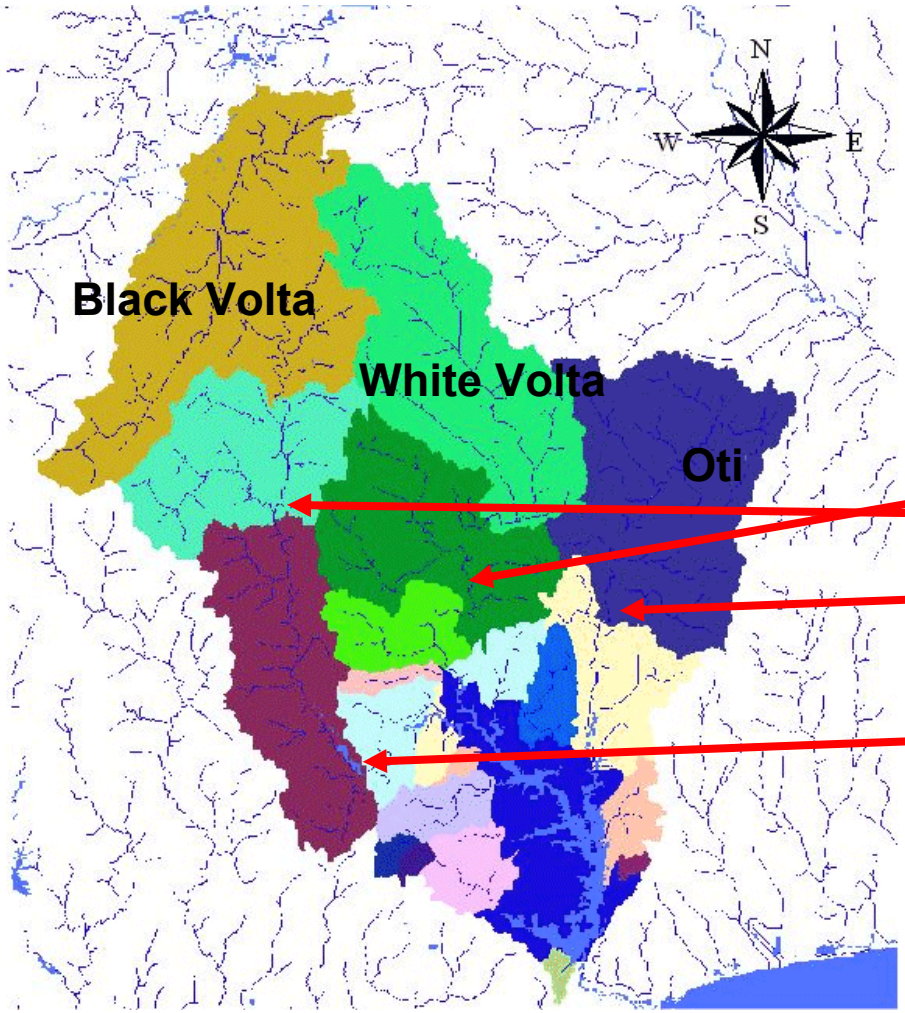


Mean annual precipitation change [%]

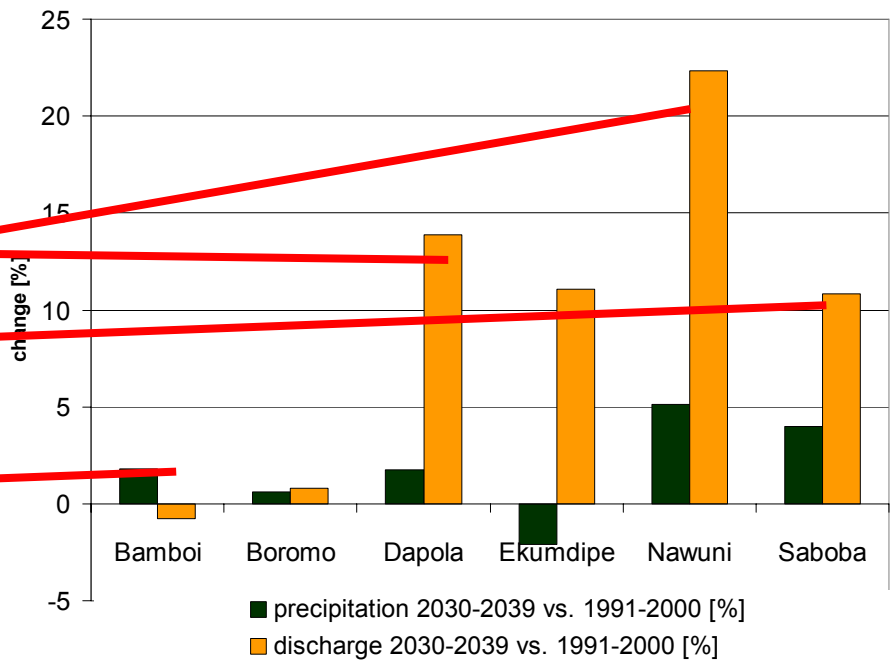


Decreased precipitation at onset of rainy season

Impact of Regional Climate Change on Water Availability



Nonlinear response of change in discharge to change in precipitation



Decision Support (2):

Model Based Operational Water Balance System

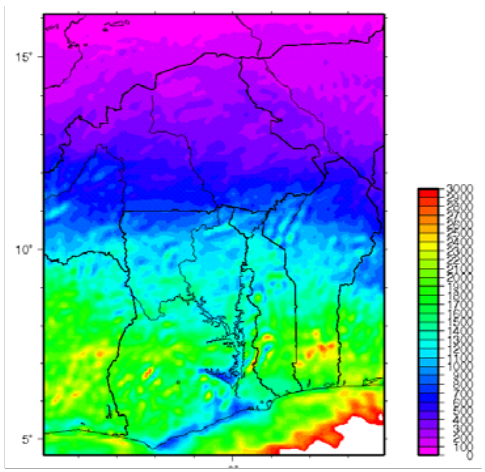
White Volta Subcatchment

through

Coupled Regional Atmospheric-Hydrological Simulations

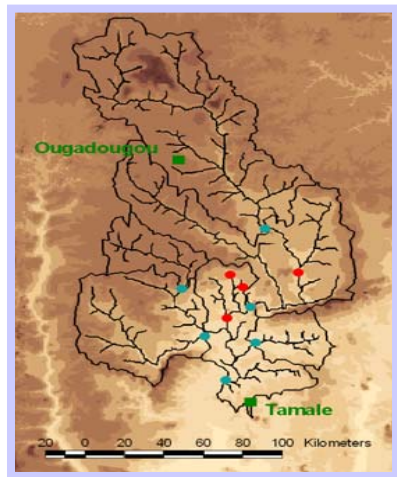
Model Based Operational Water Balance System

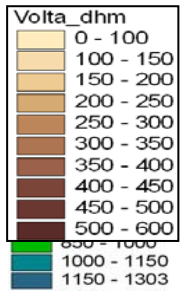
Meteo-Model: MM5



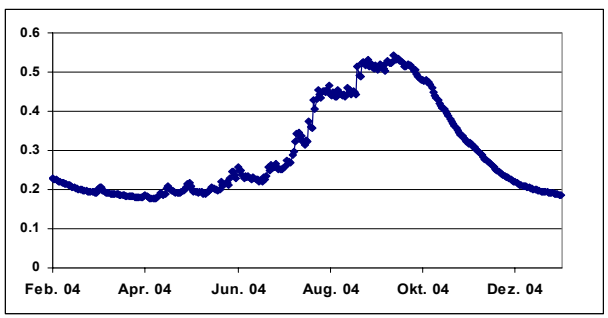
Modelbased
Monitoring
Terrestrial
Water Balance

Hydro-Model: WaSiM

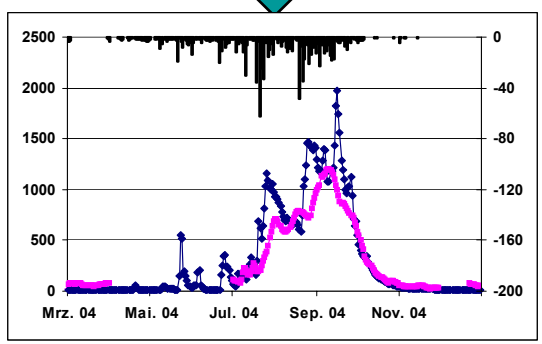




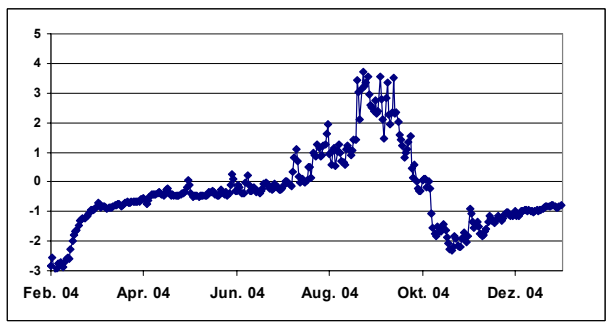
Evapotranspiration [mm/a]



Soil humidity



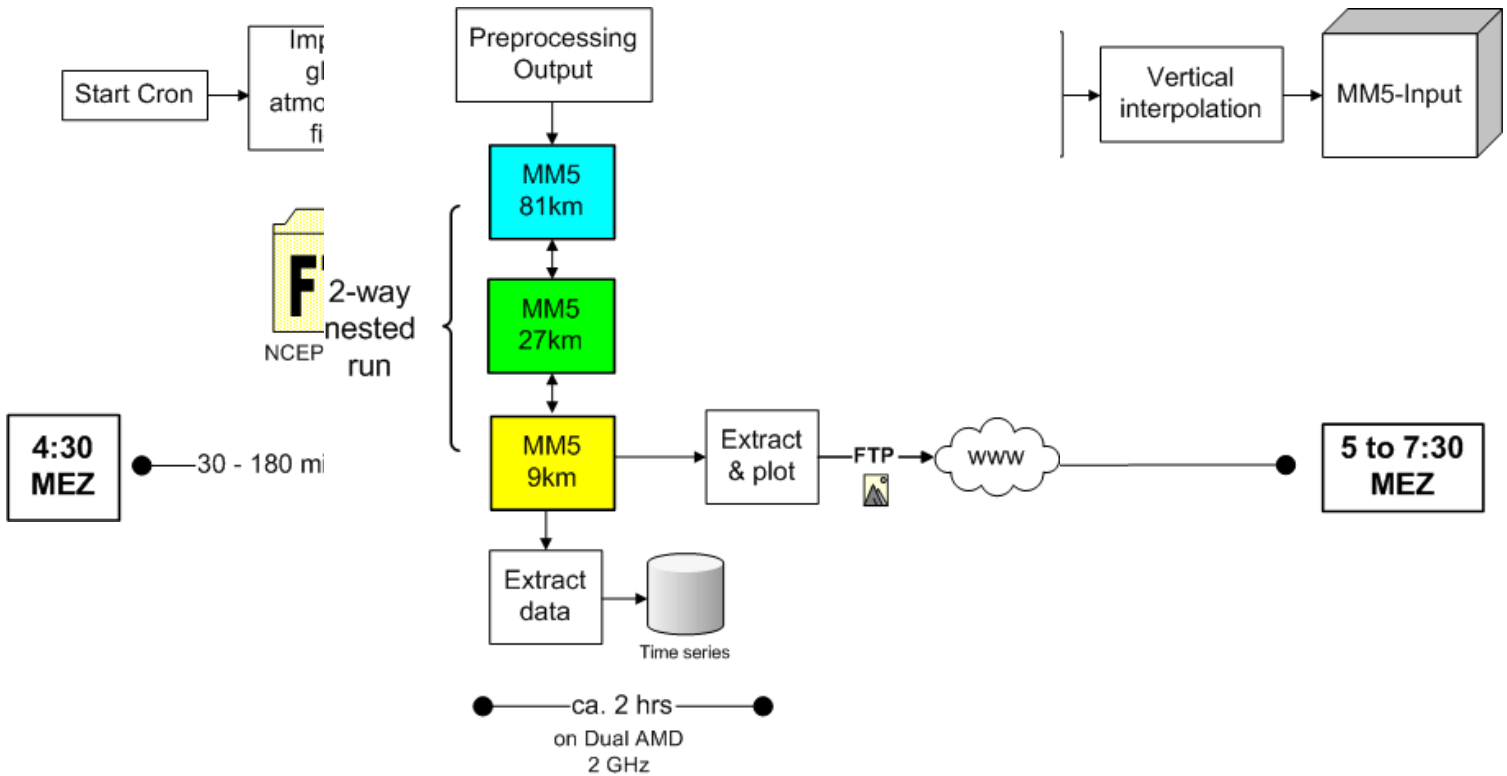
Surface Runoff [m³/s]



Groundwater Recharge [mm]

Model Based Operational Water Balance System

Operationalisation of atmospheric hindcasting with 48h delay



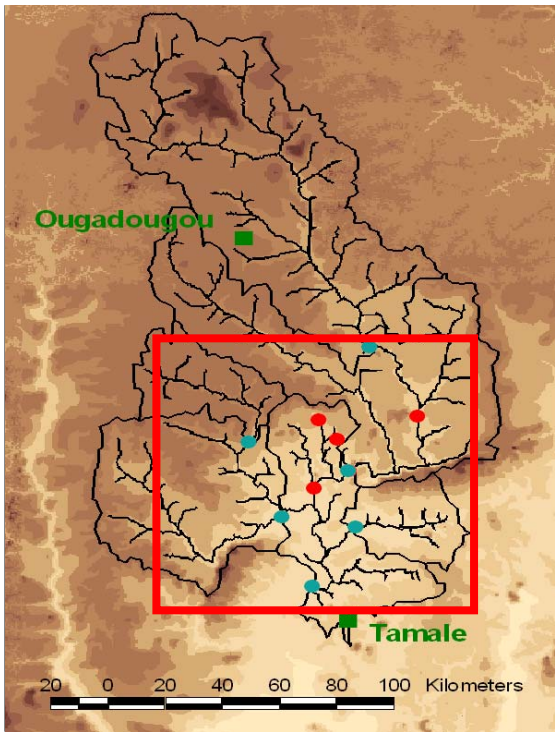
… using only public domain data sources …

… applicable for all regions worldwide …

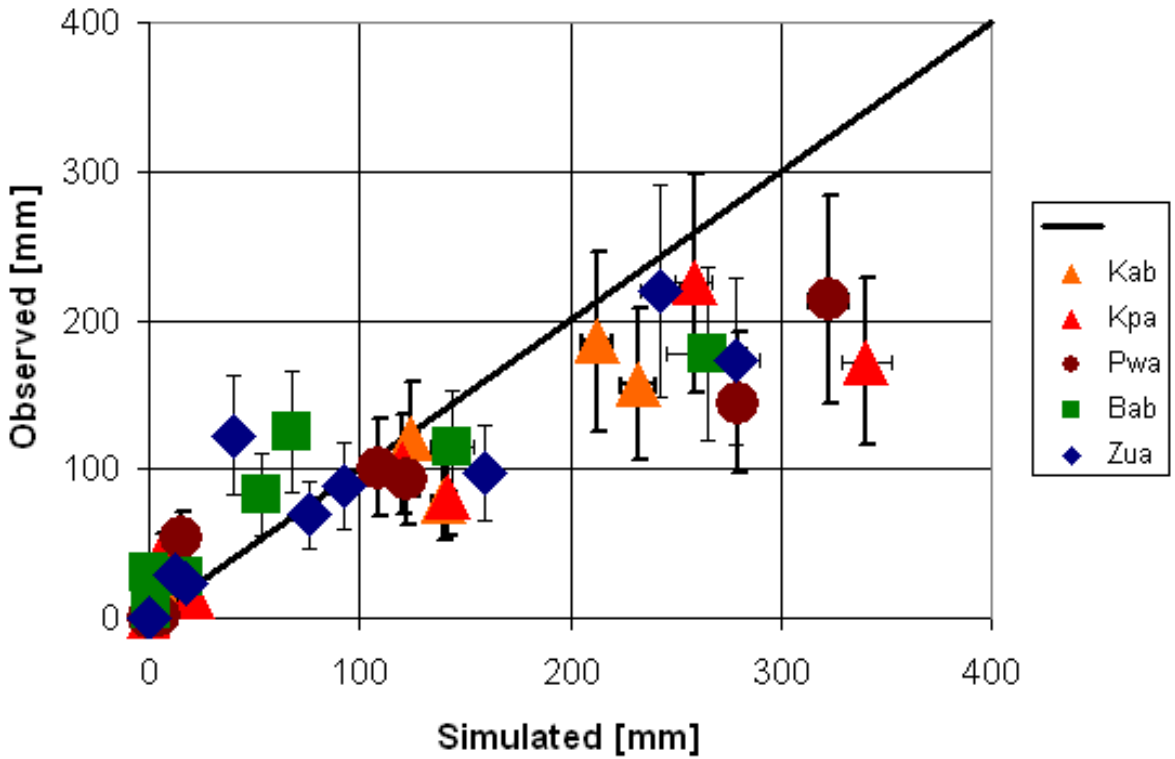
http://www.glowa-volta.de/atm/hindcast/atm.htm

Model Based Operational Water Balance System

Performance of meteorological model



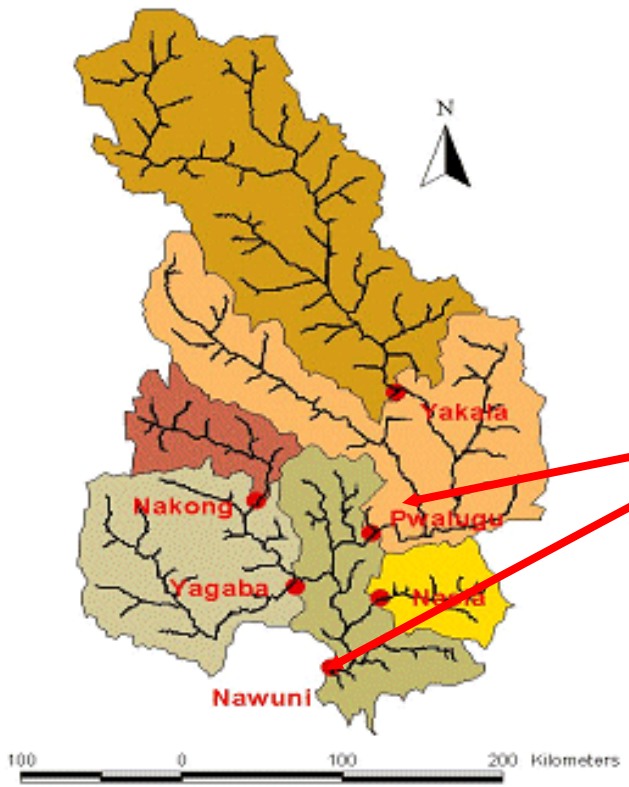
- precipitation station
- river gauges

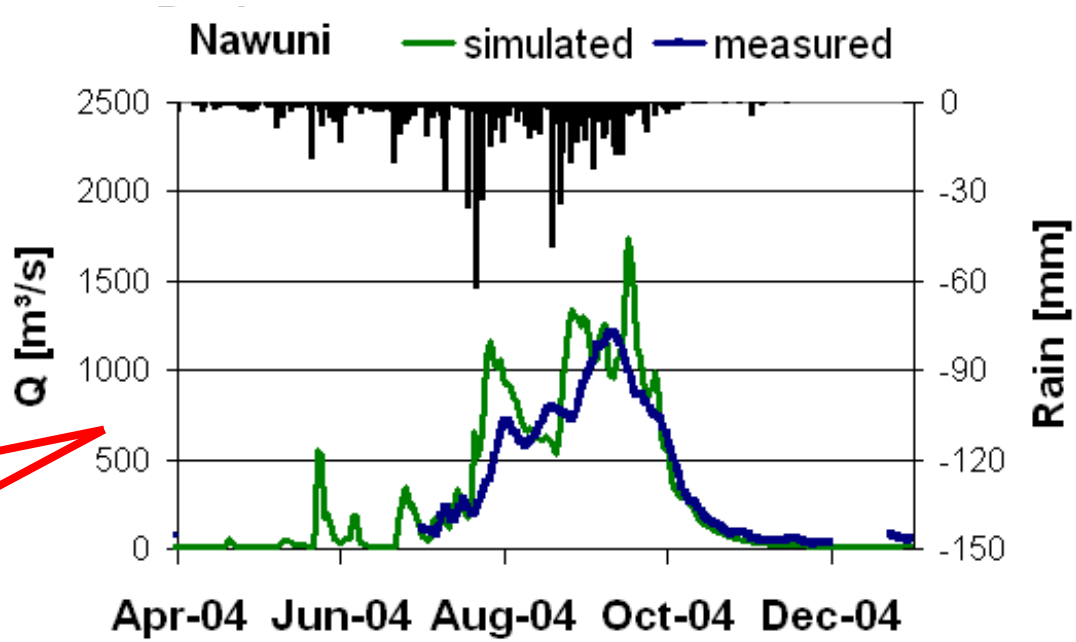


Overestimation of monthly precipitation at precipitation stations

Model Based Operational Water Balance System

Performance of coupled meteorological-hydrological model system

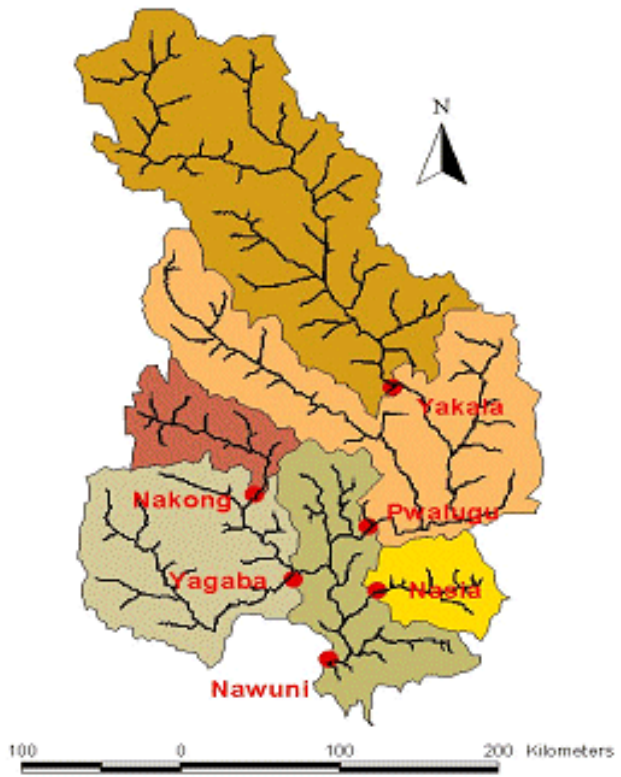




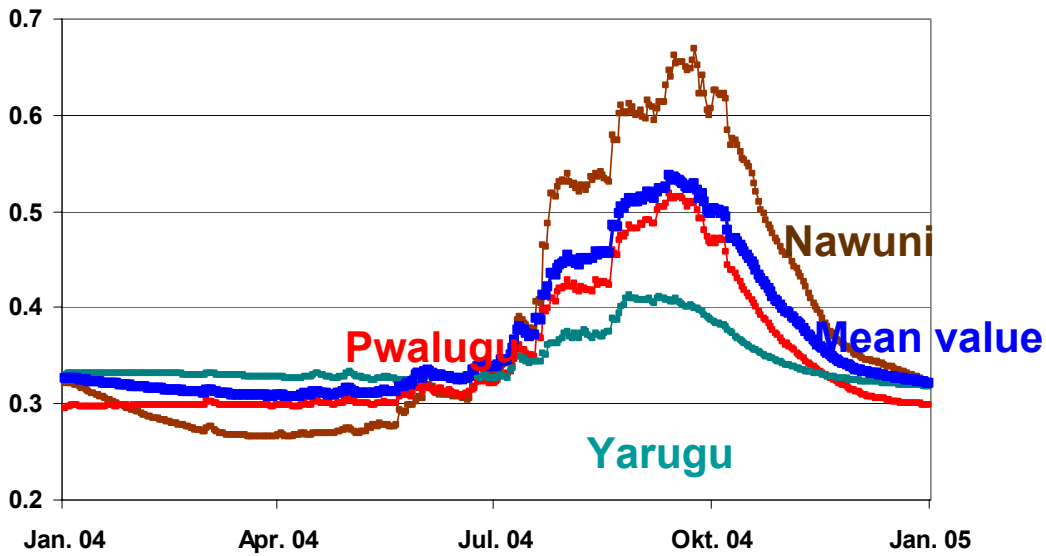
Shortcomings of met-model in simulating exact location & magnitude is smoothed on sub/catchment scale

Model Based Operational Water Balance System

Quantification of water balance variables

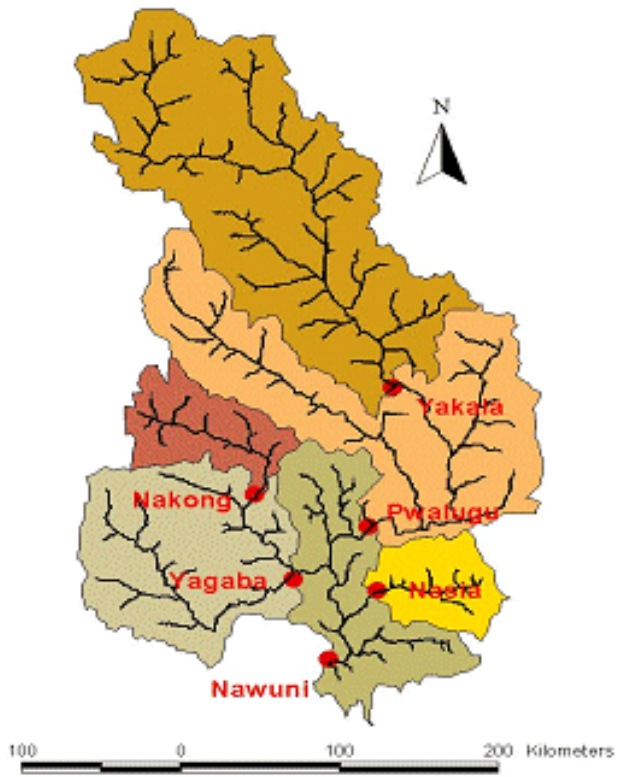


Relative soil humidity

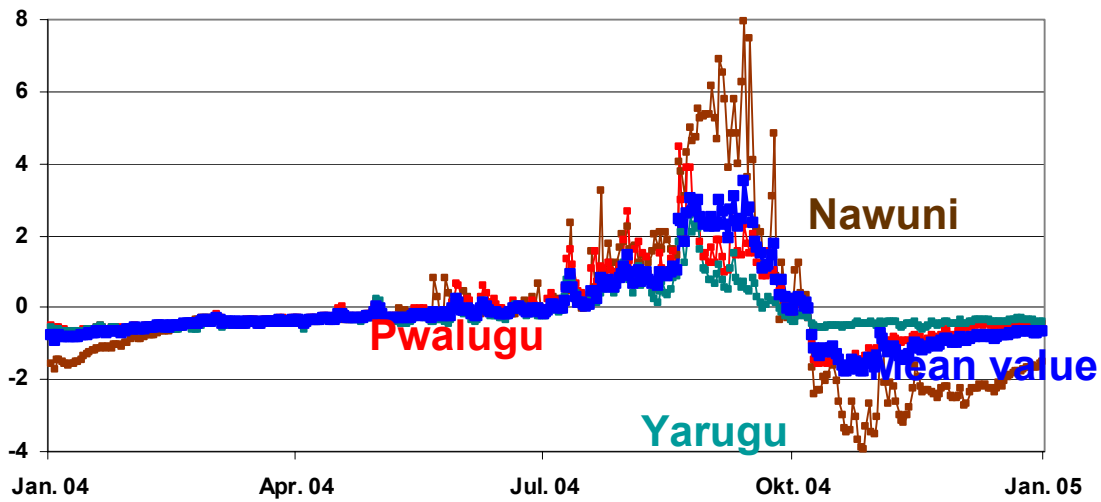


Model Based Operational Water Balance System

Quantification of water balance variables

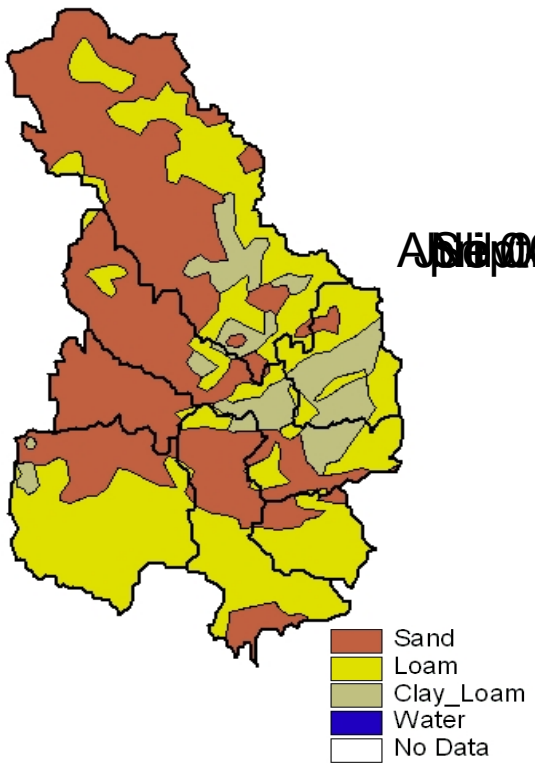


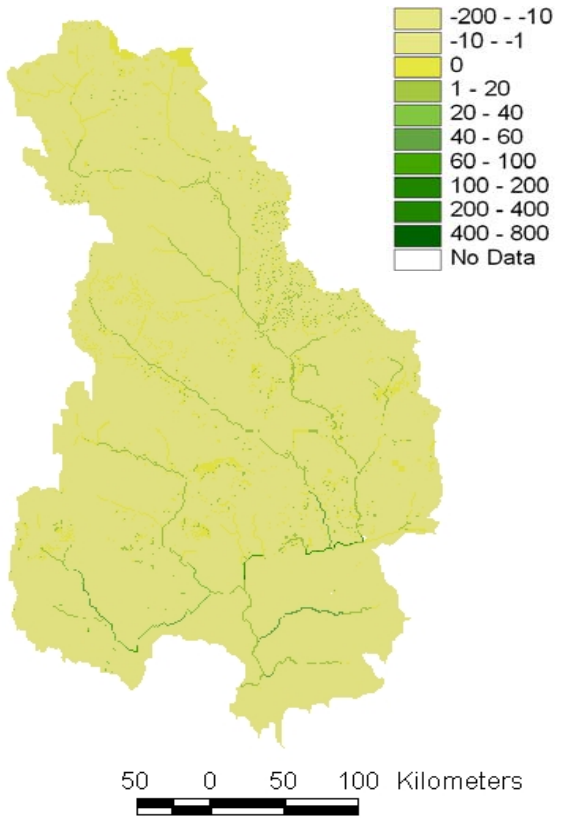
Groundwater recharge



Model Based Operational Water Balance System

Quantification of water balance variables





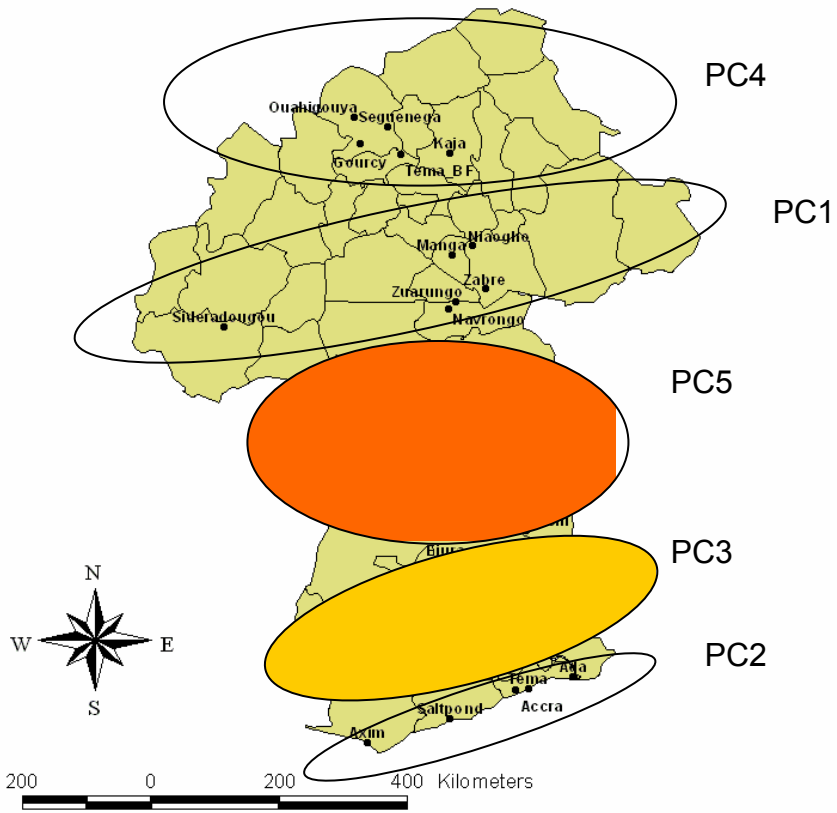
Groundwater recharge

Decision Support (3):

Techniques for estimating current

onset of rainy season

Estimation Current Onset of Rainy Season



Methodological approach:

- Principal Component Analysis (PCA) 29 precipitation stations
- 5 PCs, explaining ~60% of daily precipitation variance
- Grouping of 29 stations into 5 regions through correlation analysis
- Definition of onset dates for each region through Fuzzy-logic extension of modified Stern's (1981) definition

Search for Circulation Pattern anomalies occurring at regional onset dates

Estimation Current Onset of Rainy Season

- Automated objective circulation pattern classification based on optimized fuzzy rules (Bárdossy et al., 2002 - *Climate Research*)

- Originally developed and applied for downscaling of precipitation and temperature

- NCEP/NCAR reanalysis fields (2.5°x 2.5°),
  optionally: operational AVN-NCEP analyses (1°x1°)

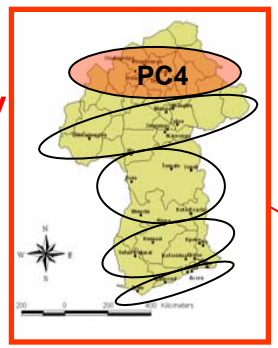
Research question

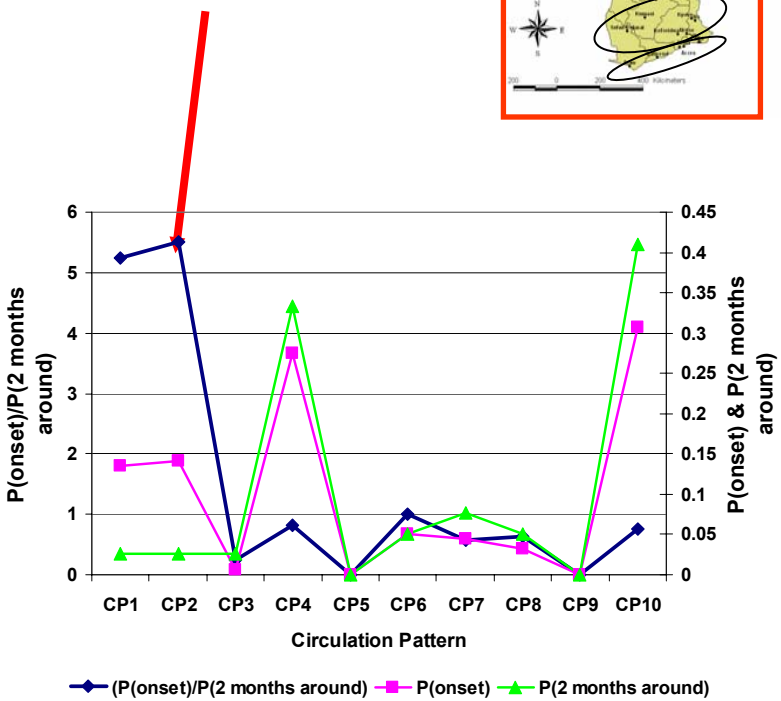
Is onset date related to specific atmospheric circulation pattern anomalies?

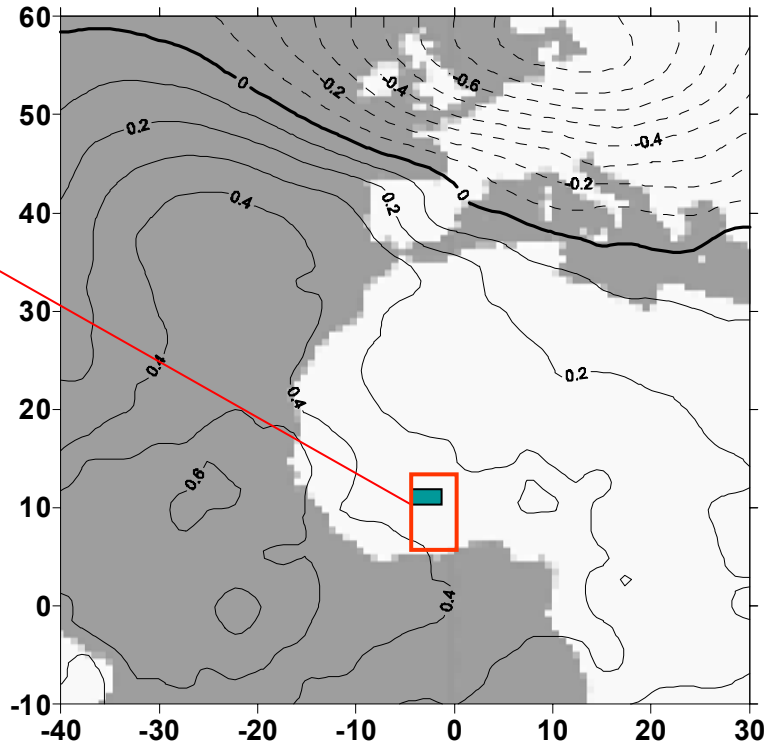
Estimation Current Onset of Rainy Season

Example 1: Sea Level Pressure conditioned on PC4

5 times higher occurrence probability of CP4 at onset





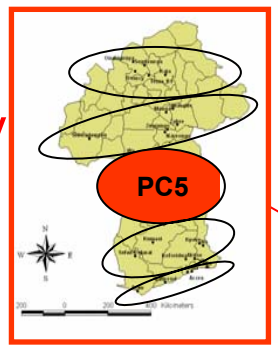


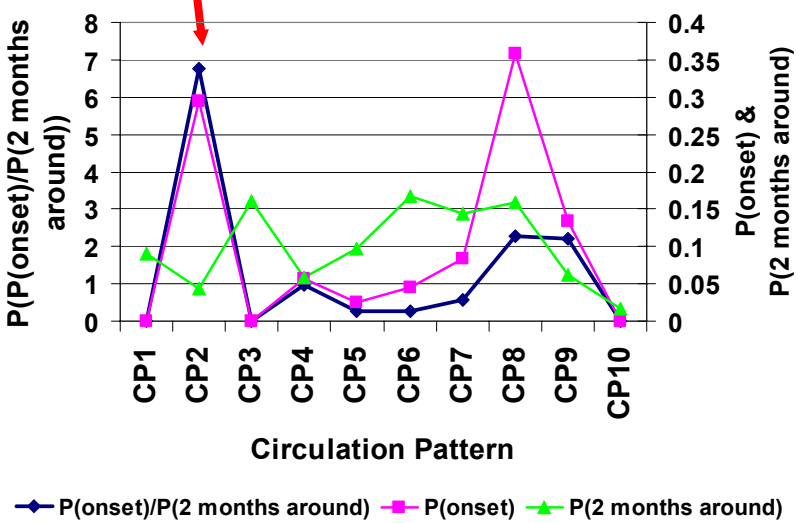
Mean SLP anomaly pattern of CP2 (1961-1999), conditioned on onset of PC4

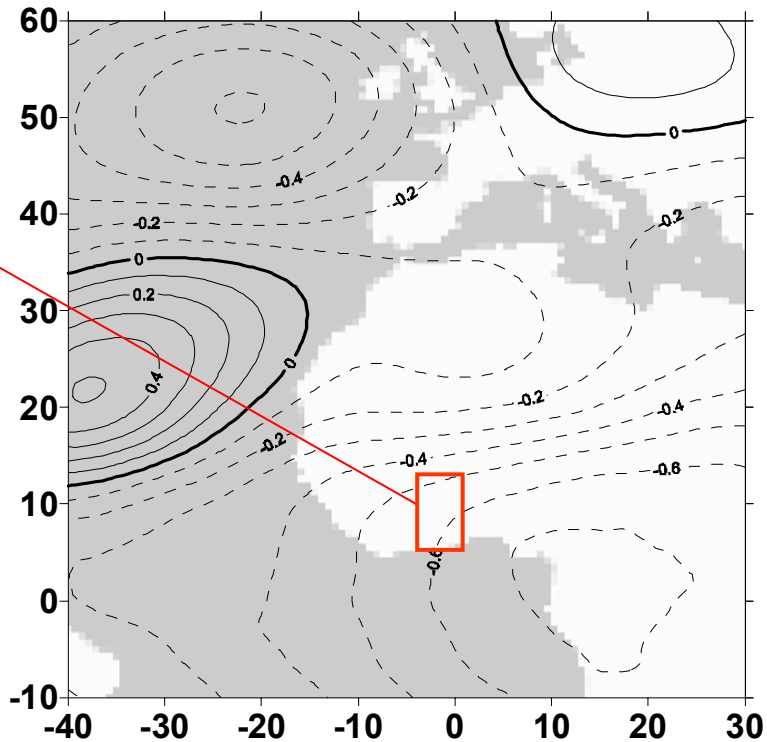
Estimation Current Onset of Rainy Season

Example 2: Geopotential height 500hPa conditioned on PC5

7 times higher occurrence probability of CP2 at onset







Mean GPH anomaly pattern of CP2 (1961-1999), conditioned on onset of PC5

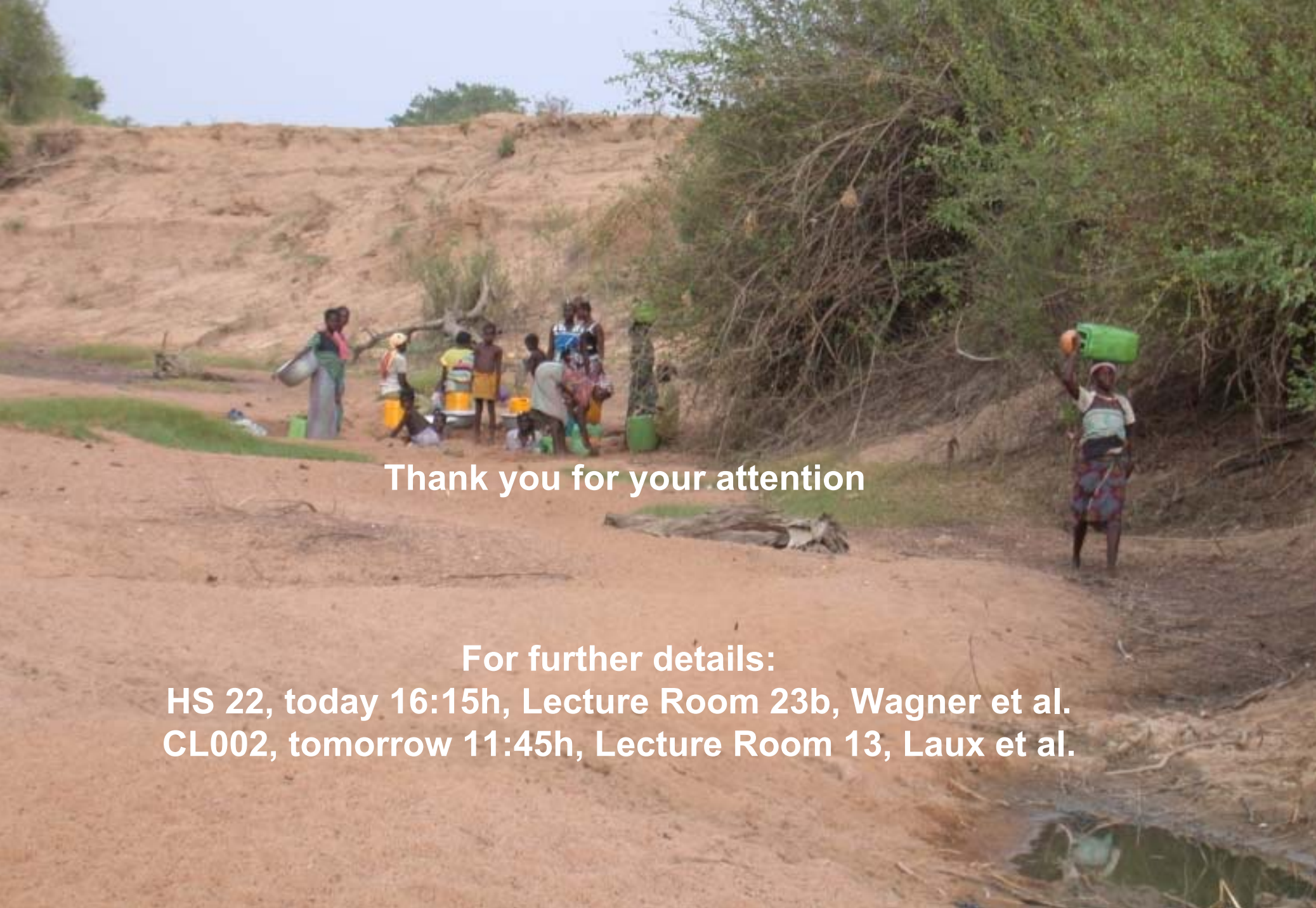
Summary & Conclusion

- Scientifically sound decisions under weak infrastructure?

- Hydrological decision support via atmospheric modeling
  - climate change
  - near real time weather & hydrology
  - atmospheric anomalies at onset of the rainy season

- Coupled atmospheric-hydrological simulations as potential tool for decisions in regional scale sustainable water management

- Limitation: validation only via river discharge
  $\Rightarrow$ performance of other water balance variables difficult to assess



Thank you for your attention

For further details:
HS 22, today 16:15h, Lecture Room 23b, Wagner et al.
CL002, tomorrow 11:45h, Lecture Room 13, Laux et al.

Impact of Regional Climate Change on Water Availability

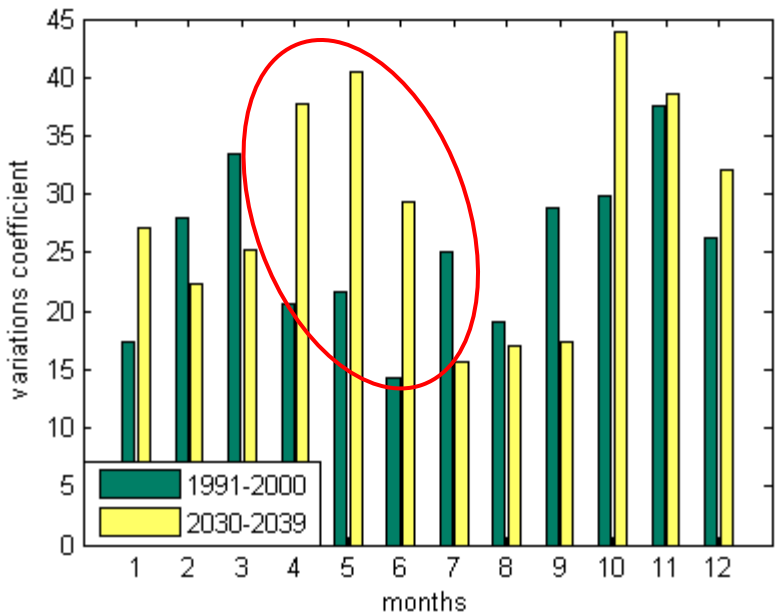
Results: change in onset dates 2030-2039 vs. 1991-2000

Change in Onset of 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: Stern et al. (1981)

Inter-annual variability

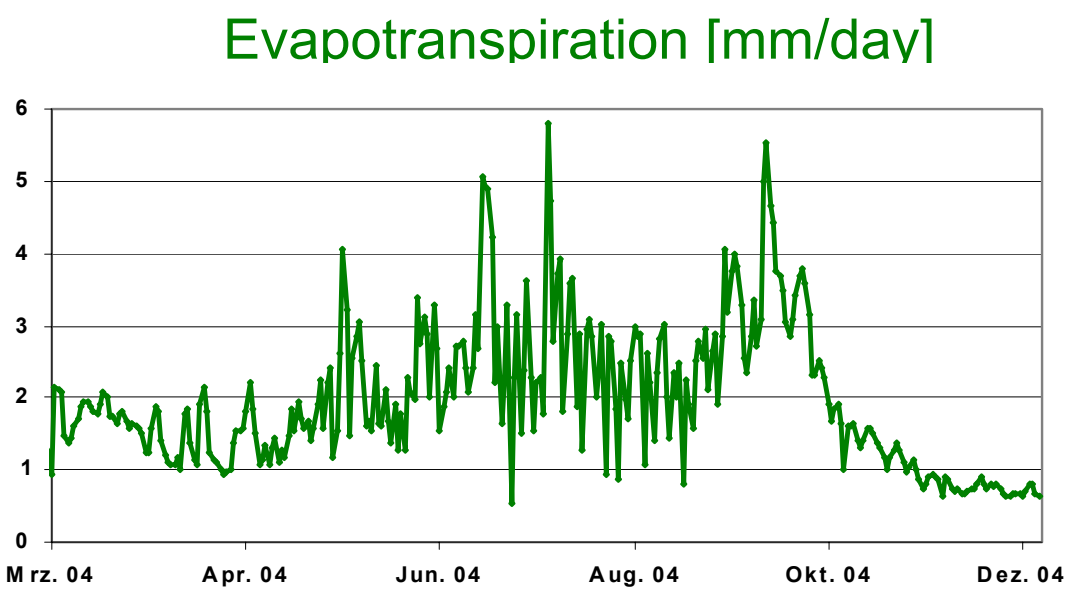


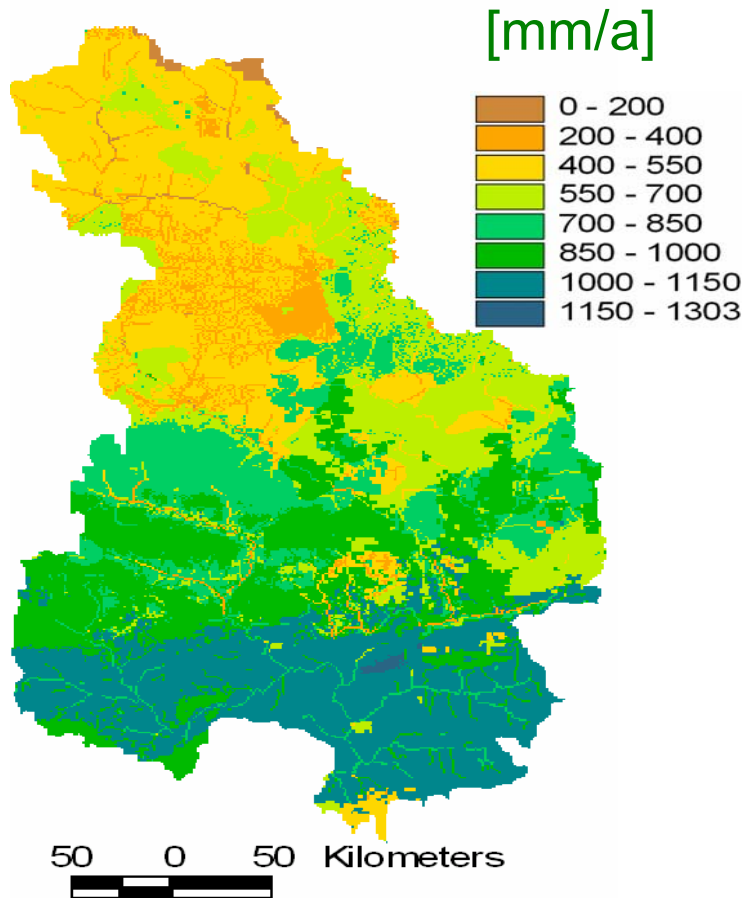
⇒ Delay in the onset of the rainy season

⇒ Increase in inter-annual variability

Model Based Operational Water Balance System

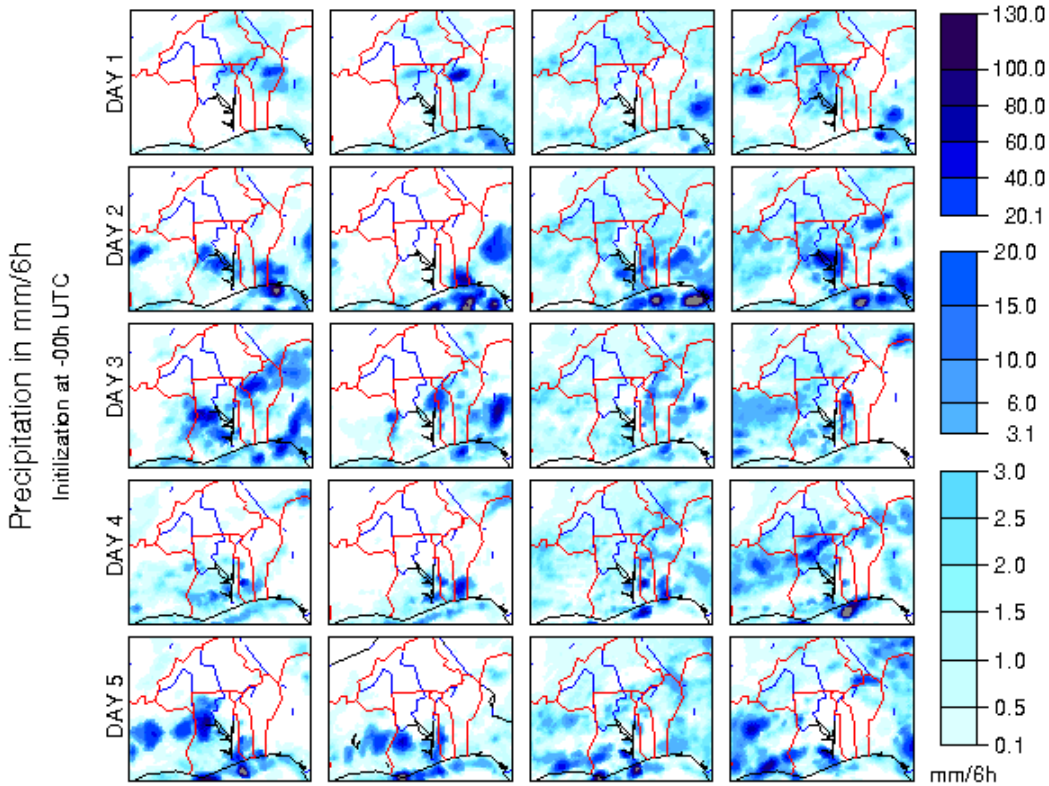
Quantification of water balance variables





Model Based Operational Water Balance System

Operational 5-day Numerical Weather Prediction



http://www.glowa-volta.de/atm/forecast/atm.htm

Focus: Hydrometeorological Decision Support Volta Basin