Climate Variability and Change in Sub-Saharan and Northwestern Africa

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Sources of information for regional climate assessment

historical data	▪ natural climate variability ▪ observed trends ▪ model validation
global climate models	▪ large-scale features ▪ long-term perspective ▪ uncertainty range from multi-model ensembles
regional downscaling dynamical | statistical	▪ synoptic processes ▪ regional details of climate change
physical process understanding	▪ model evaluation ▪ scenario setup ▪ conclusions for impact research

→ confidence

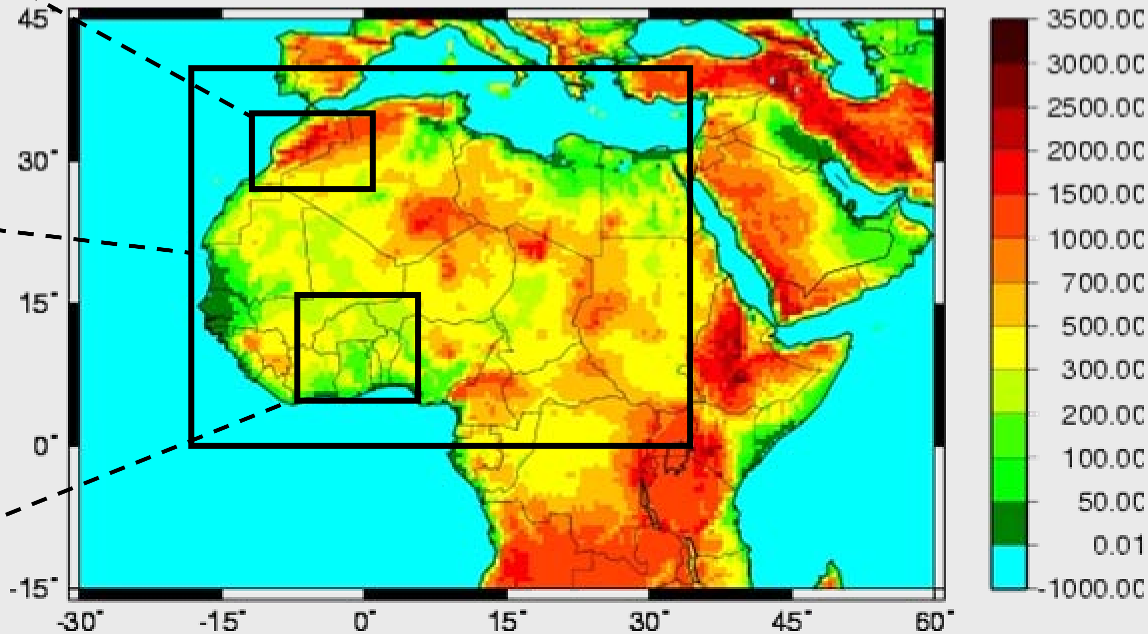
IPCC 2007, S. 849

Different regional foci on Africa

Northwest Africa:
Morocco, Antiatlas

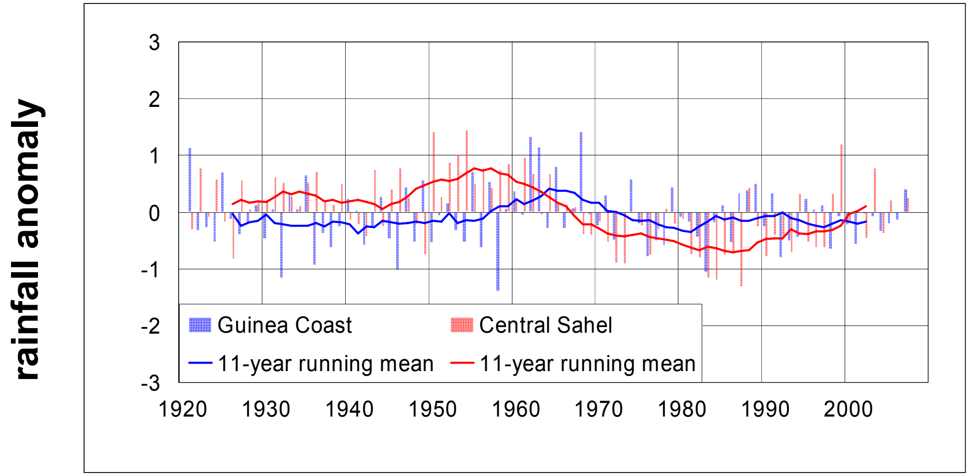
Continental scale

Sub-Saharan Africa:
Benin
Ghana & Burkina Faso

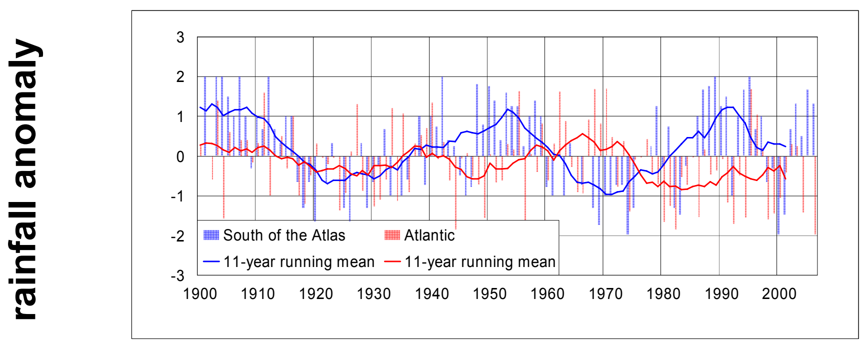


Historical data and driving forces

decadal rainfall variability in West Africa



decadal rainfall variability in Morocco



Figures courtesy of A. Fink & S. Kotthaus

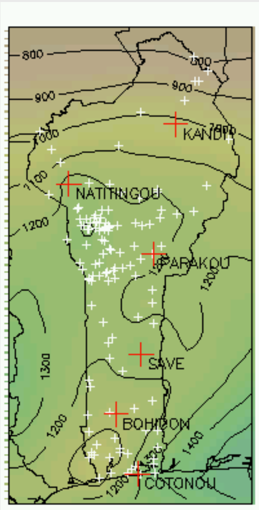
Driving forces

?

- oceanic forcing
- Greenhouse-gas forcing
- feedbacks with land surface / land degradation
- natural variability

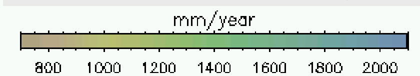
?

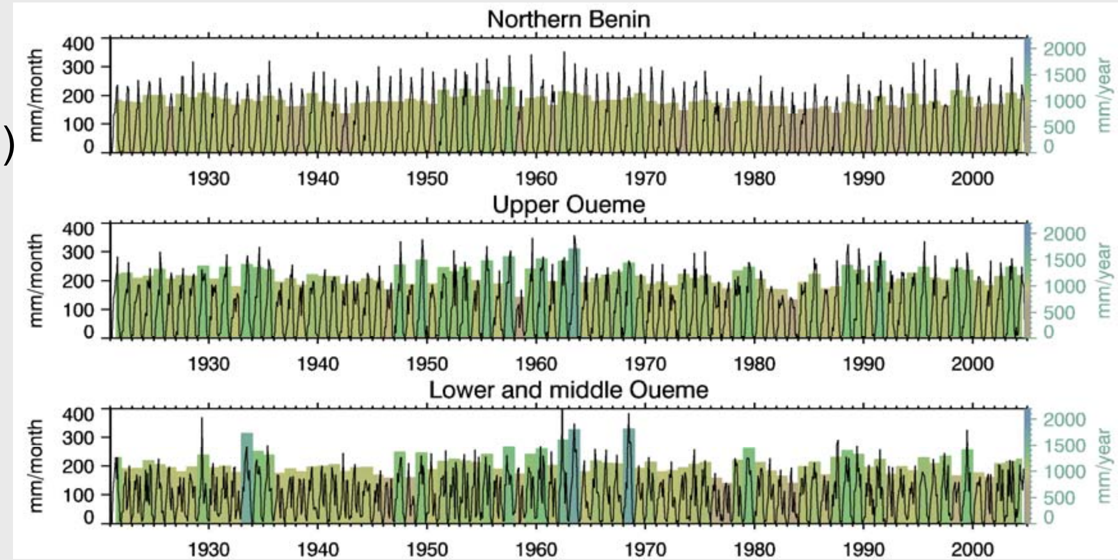
Historical rainfall data for Benin



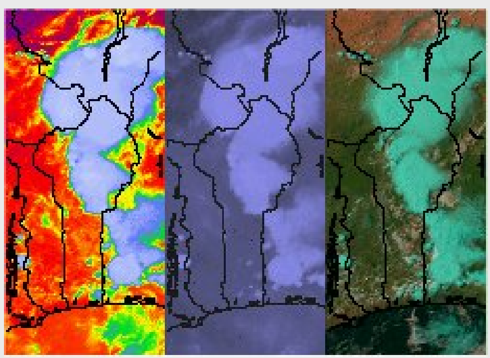
Daily rainfall since 1921
+ Synop since 1950s
(National Weather Service)

Intensified in HVO
since 1997
(CATCH, AMMA, IMPETUS)

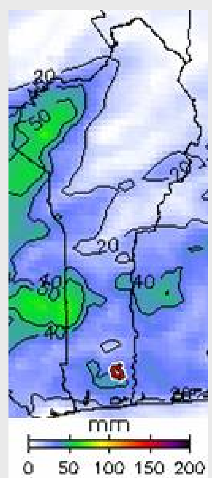




Monthly 0.1 degree gridded rainfall since 1921



METEOSAT
observations since 1983



Hourly 0.1 gridded meteorological parameters since 1983 (satellite/synop-based)

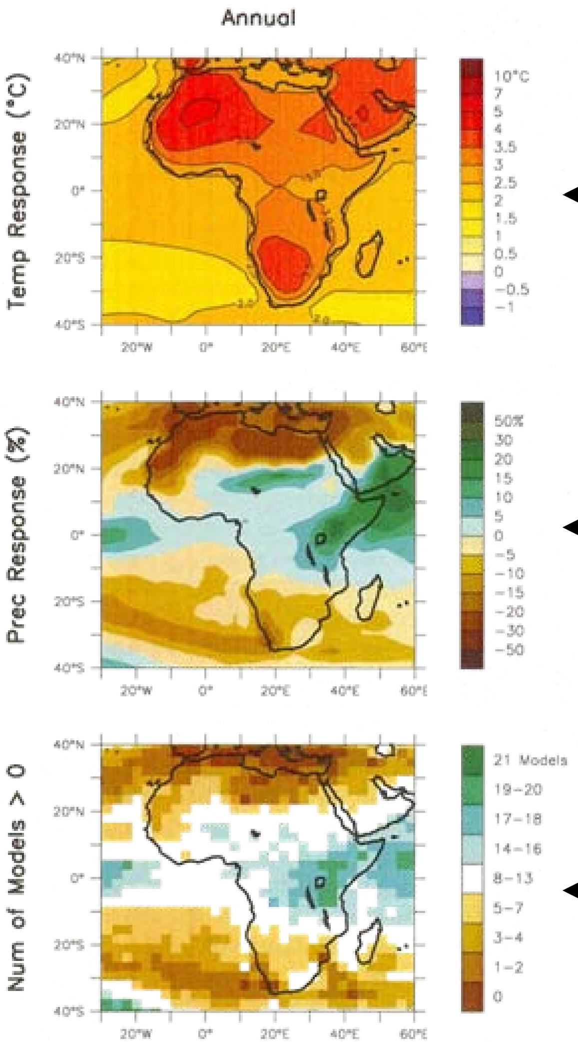
Continued as real-time monitoring system at national weather service

Figures courtesy of M. Diederich

Global climate models

IPCC-AR4 21 global GCMs with radiative forcing

(2080-2099) minus (1980-1999)



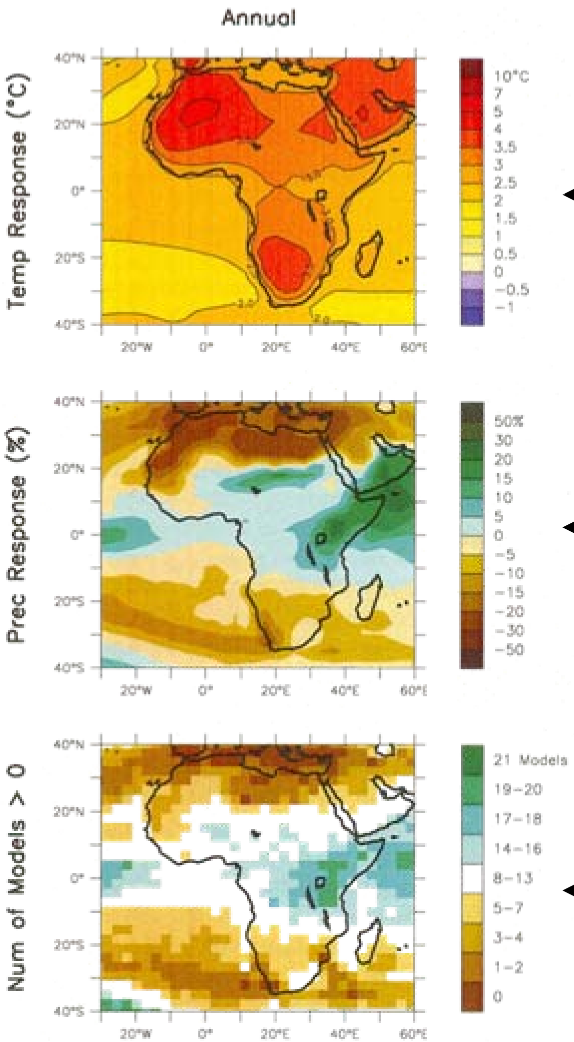
warming all over Africa by 2.5-4°C

innertropics wetter; Northern Sahara/ West Sahel dryer

large model uncertainty over Sub-Saharan Africa

Global climate models

IPCC-AR4 21 global GCMs with radiative forcing



(2080-2099) minus (1980-1999)

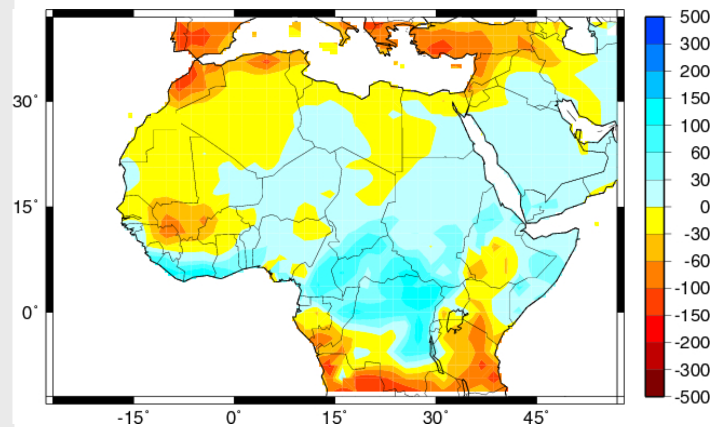
warming all over Africa by 2.5-4°C

innertropics wetter; Sahel and Sahara drier

large model uncertainty over subsaharan Africa

≈

ECHAM5 with radiative forcing

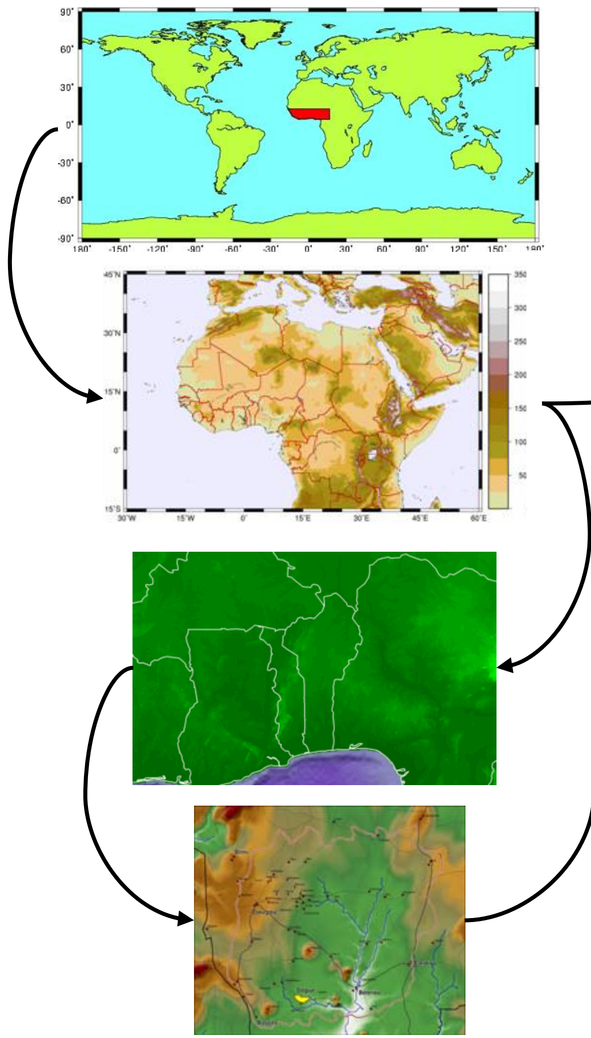


ECHAM5 is consistent with AR4 multi-model ensemble mean

Regional downscaling

dynamical downscaling

- global scale
  - ECHAM4, re-analyses
  - 300 km, 200 years
- synoptic scale
  - REMO
  - 55 km, 90 years
- regional scale
  - LM
  - 7-28 km, 1 year
- local scale
  - FOOT3DK
  - 1-7 km, 1 week



statistical downscaling

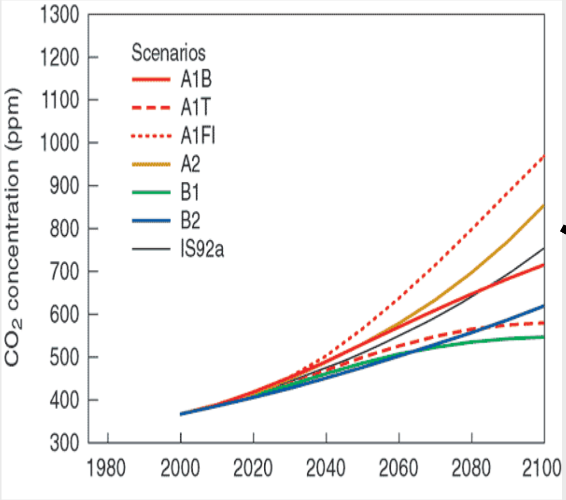
model output statistics (MOS)

weather-type recombination

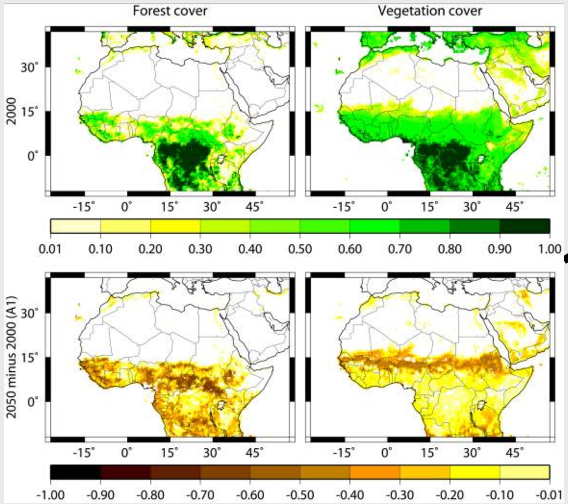
weather generator

Regional downscaling: REMO

greenhouse forcing

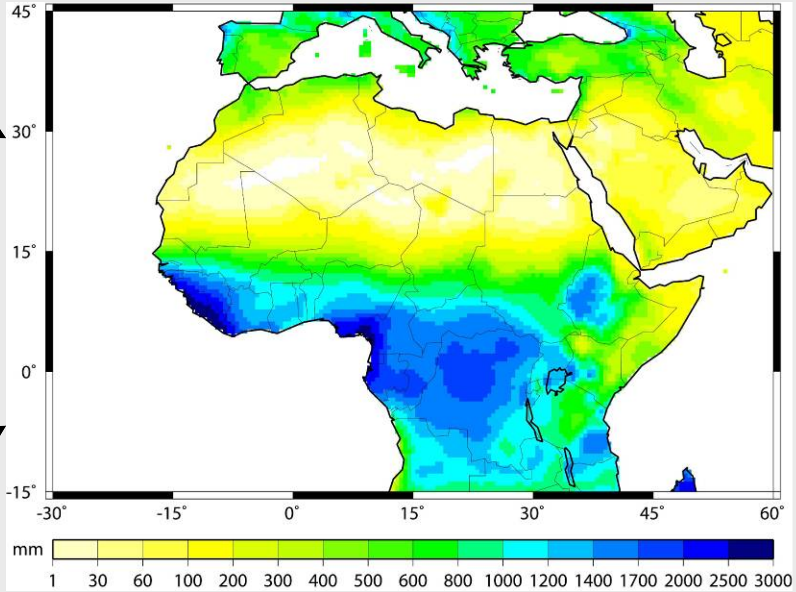


land degradation

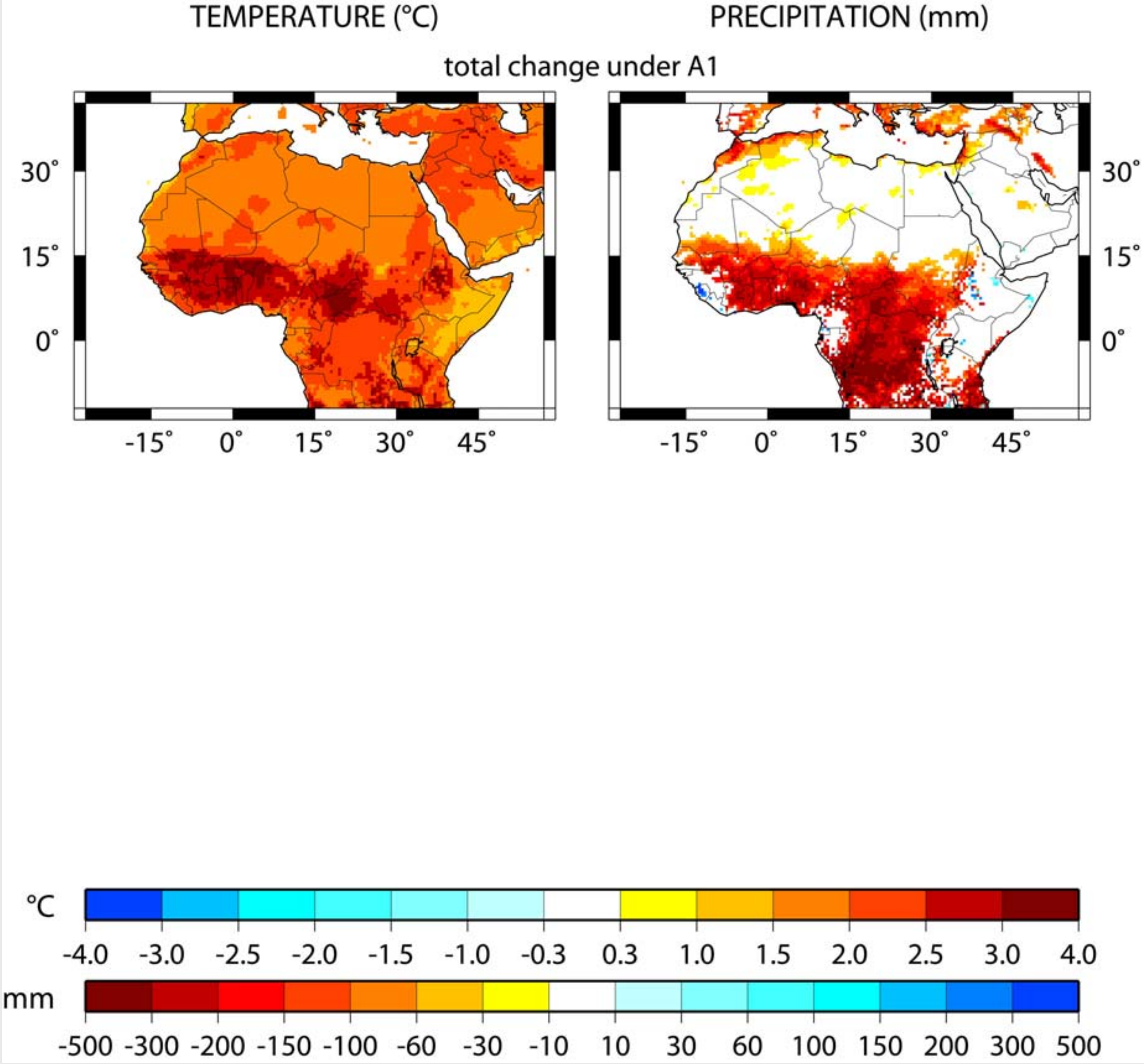


A1B
+
B1

REMO 0,5° , 1960-2050

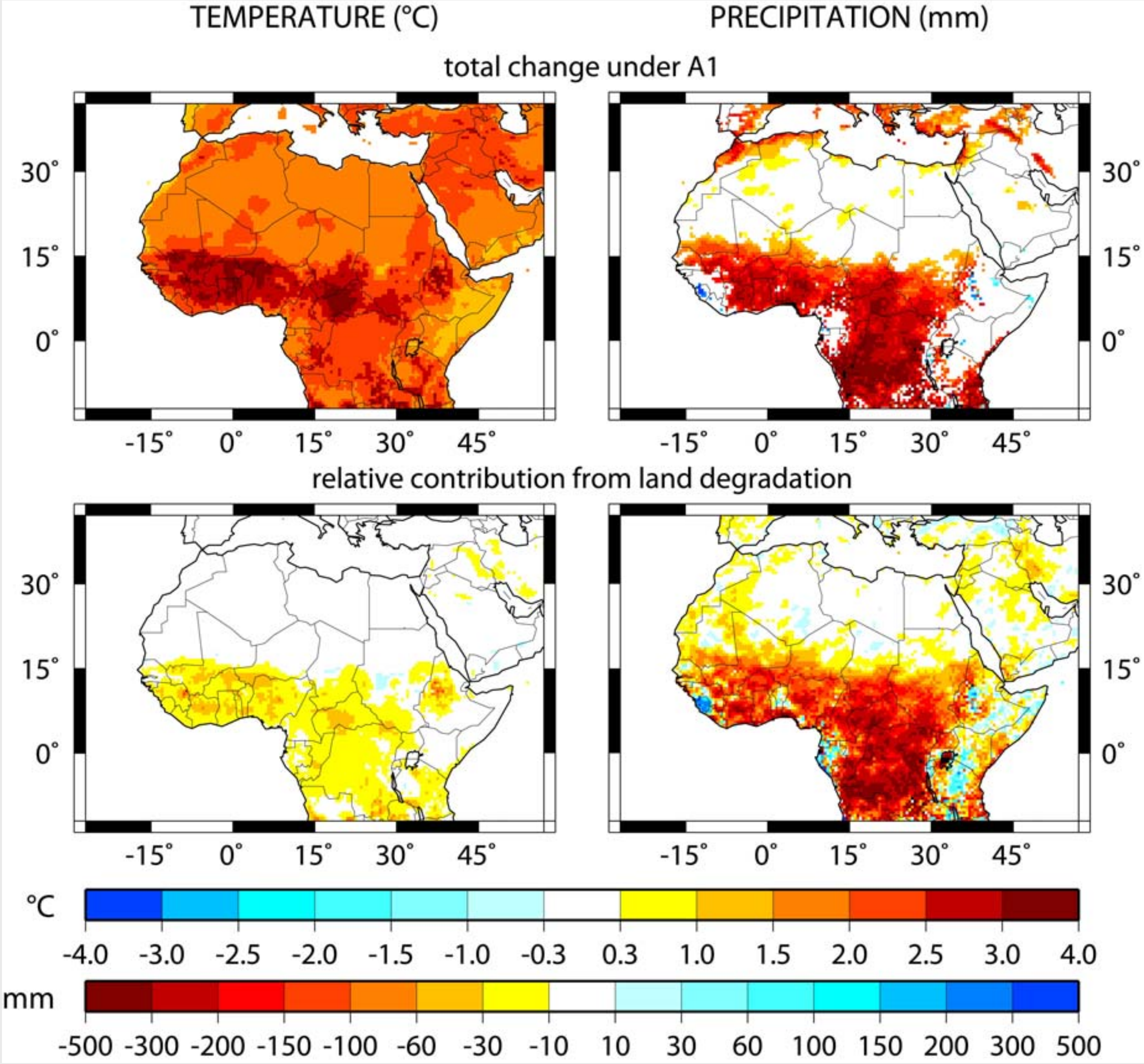


Regional downscaling: REMO



⇒ **prominent warming and drying in sub-Saharan Africa**

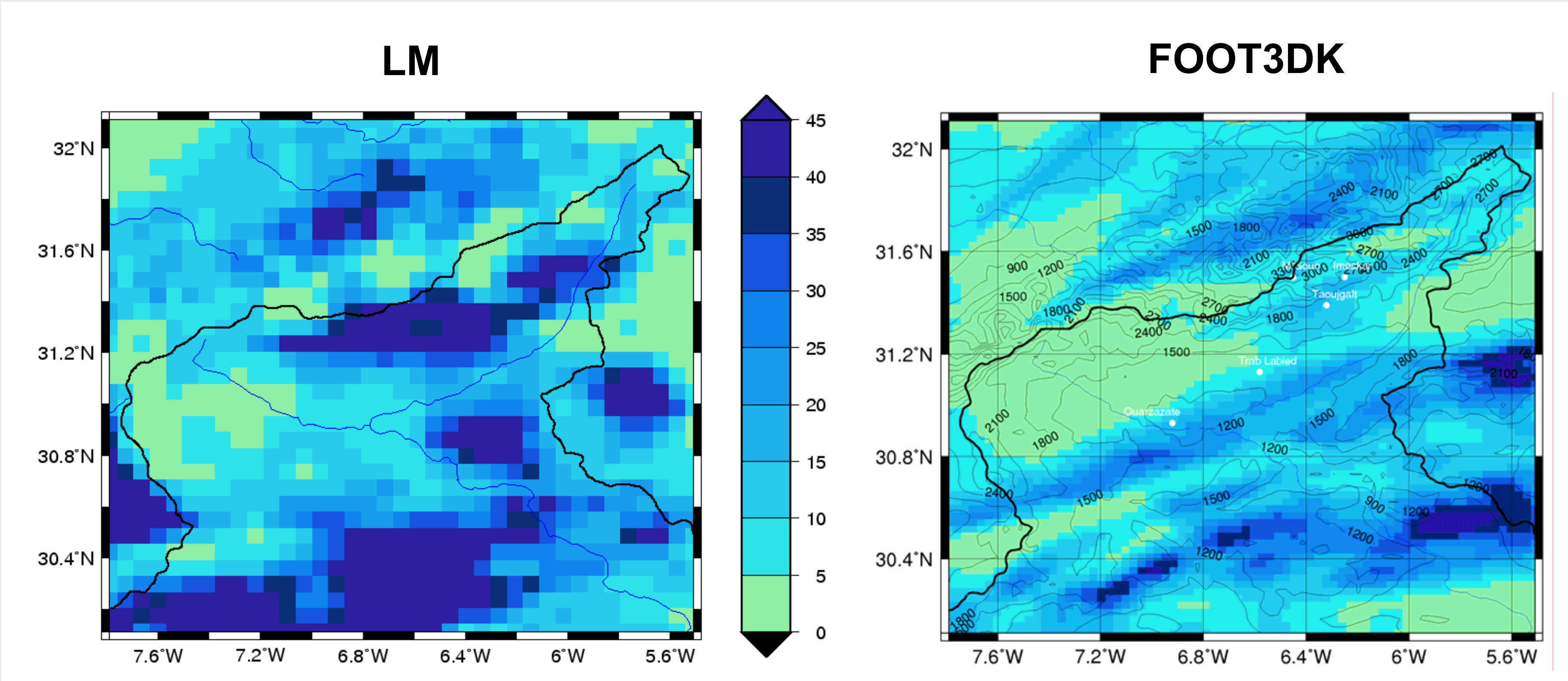
Regional downscaling: REMO



⇒ **prominent warming and drying in sub-saharan Africa**

⇒ **land degradation is primarily responsible for the drying**

Regional downscaling: LM & FOOT3DK

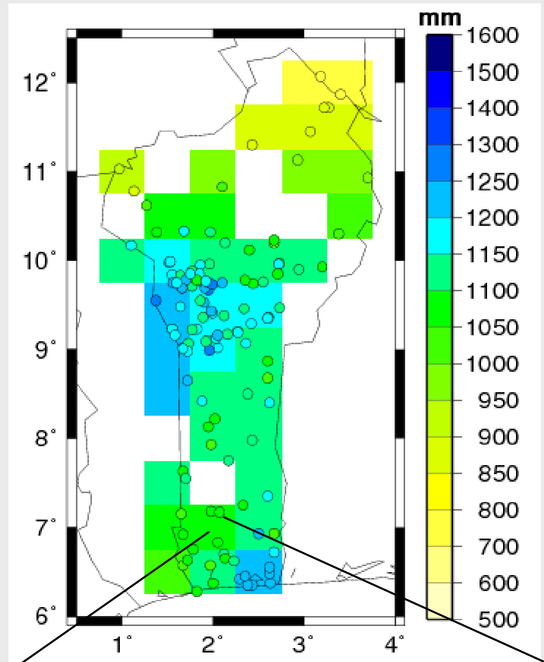


daily rainfall amount for a southwesterly flow over the Drâa region

⇒ windward effect of Antiatlas correctly simulated by high-resolution model FOOT3DK

Figure courtesy of K. Born & K. Piecha

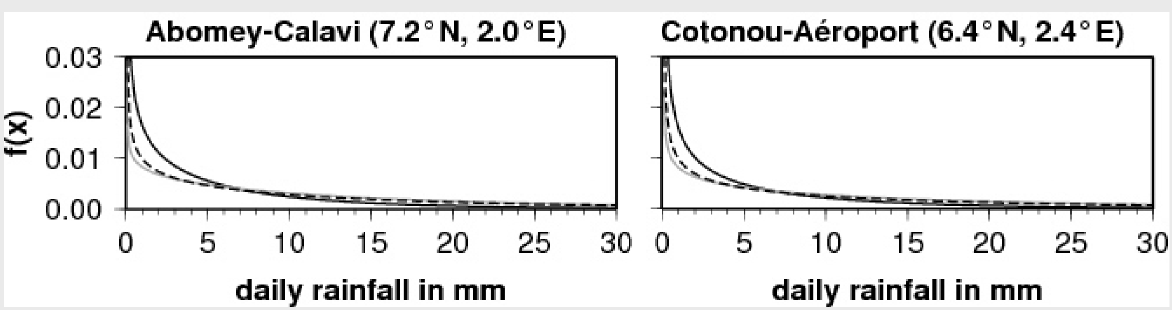
Regional downsc.: weather generator



REMO grid box
(50km x 50km)

comparison ?

observed station
time series
(local information)

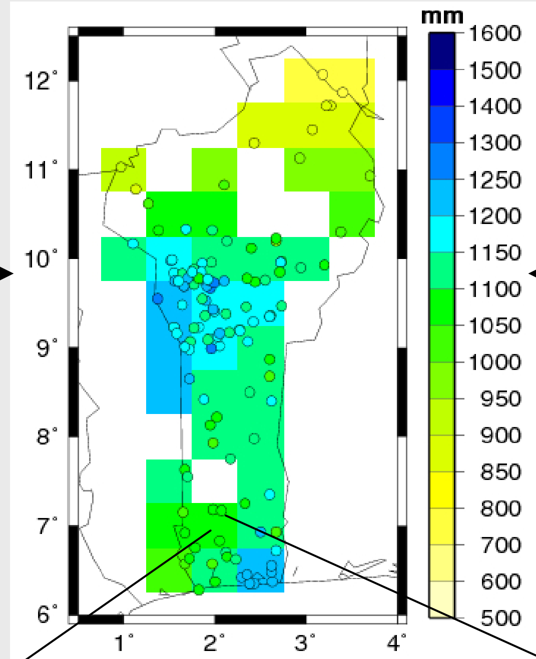


model data

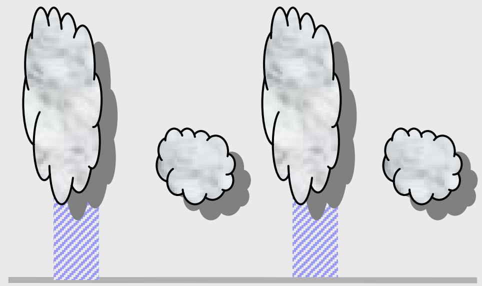
station data

Regional downsc.: weather generator

local topography (physical part)



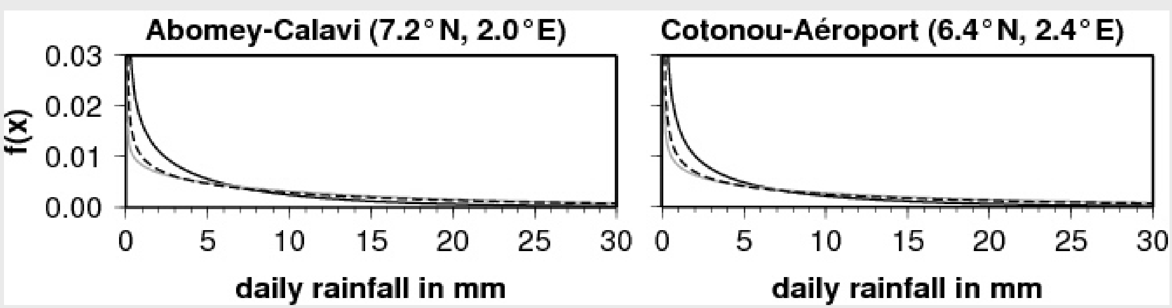
random distribution in space-time (stochastical part)



REMO grid box (50km x 50km)

observed station time series (local information)

comparison ?



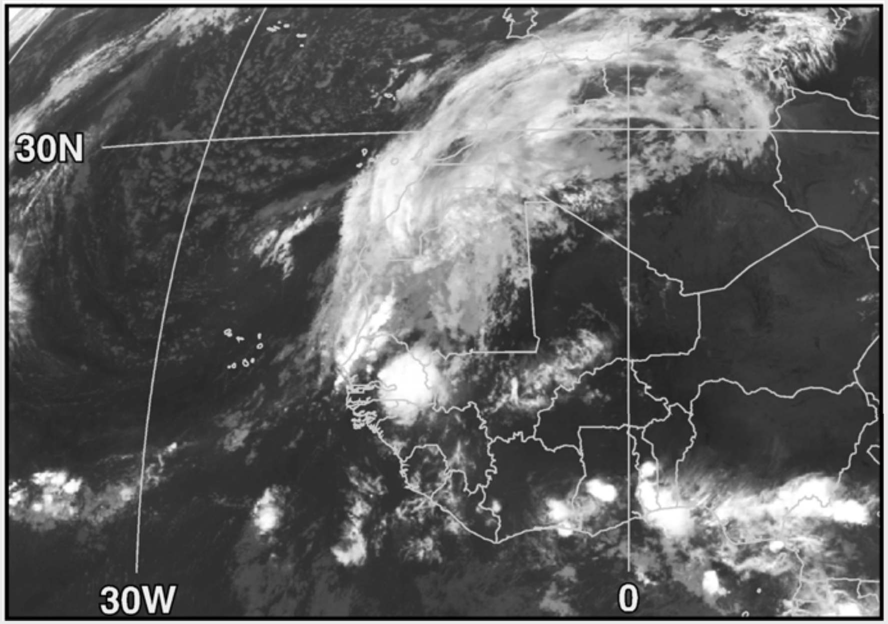
model data

station data

weather generator

Process understanding: Tropical-Extratropical Interaction

IMPETUS finding:
up to 40% of the annual rainfall south of the Atlas Mountains is associated with Tropical-Extratropical Interactions



Tropical Plume, 22.10.2003 12 UTC:
abundant rains from Senegal to the Maghreb set the stage for the locust outbreak in 2004

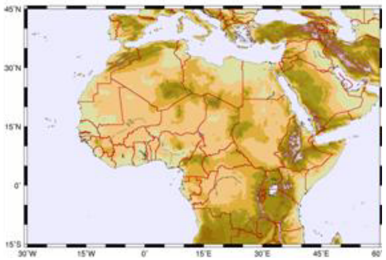
Consequences for IMPETUS climate scenarios:
understanding of regional climate processes lead to an alternative plausible climate future

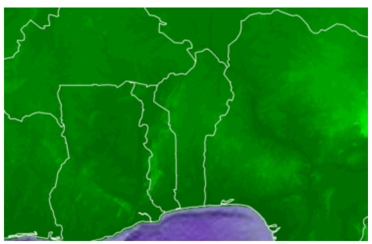
slight increase in annual precipitation at the Saharan flank of the Atlas (Tropical-Extratropical-Interactions) and more rain at the Guinean Coast (land-see breeze convection)

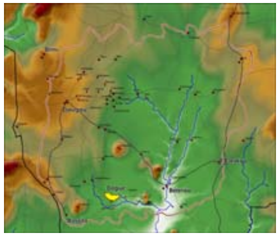
Further reading:
Knippertz (2003, MWR)
Knippertz and Martin (2005, QJRMS)
Knippertz and Fink (2006, PROMET)

Climate model data for impact studies

climate models







→

statistical calibration

model output statistics (MOS)

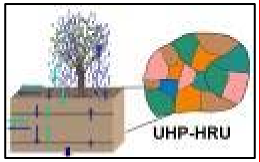
weather-type recombination

weather generator

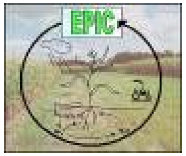
→

impact studies

hydrology



food & agriculture



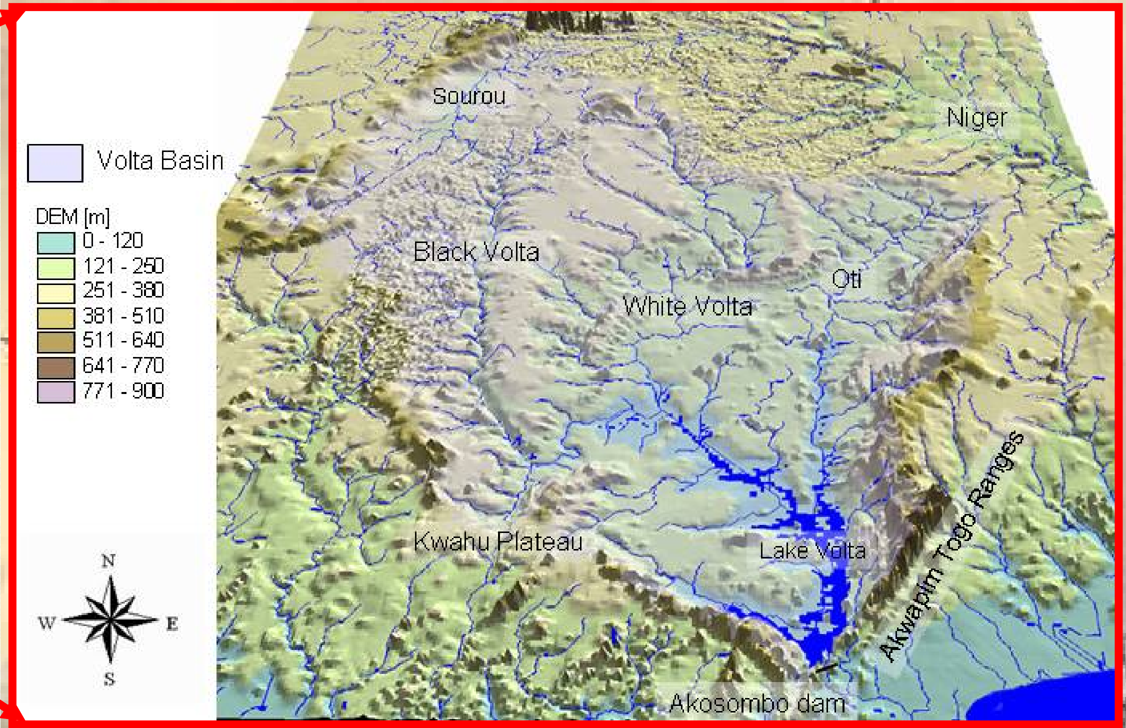
land use

health

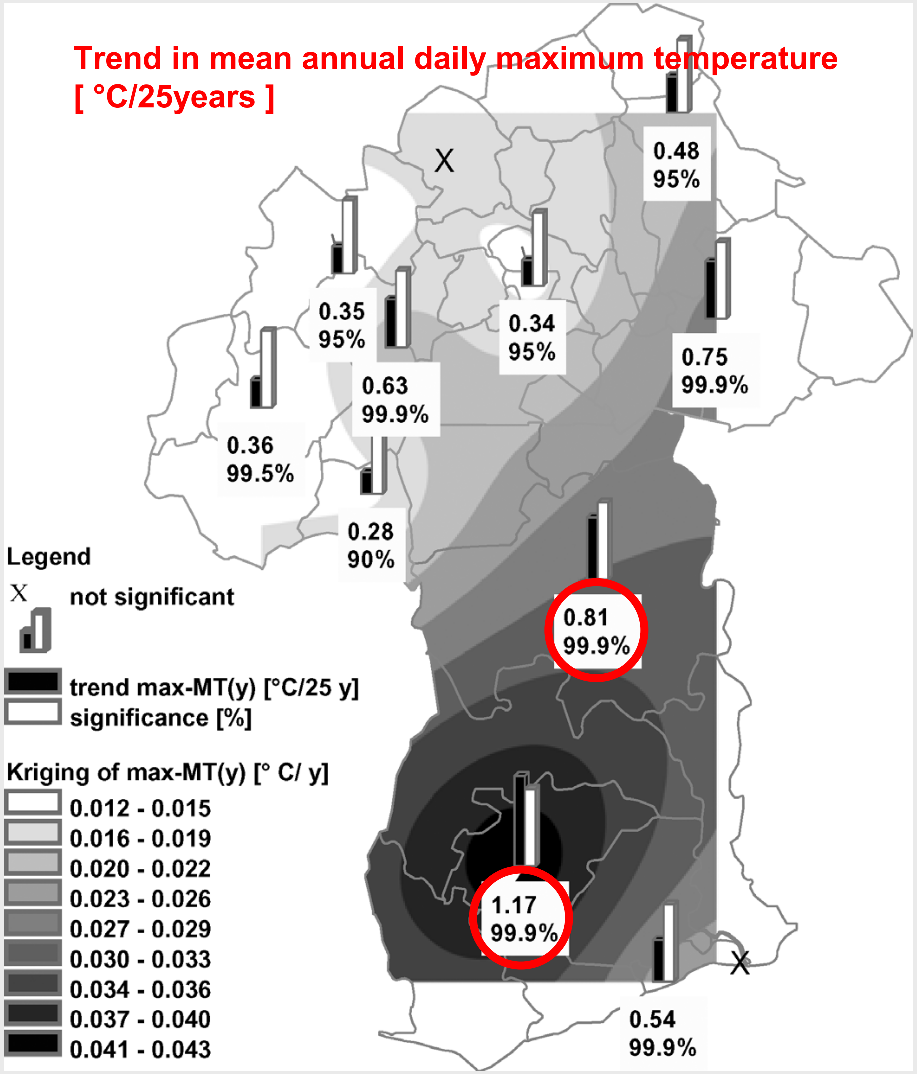
I M P E T U S / G L O W A - V O L T A

Central Question: How Does Climate Change Impact Water Availability in West Africa?

Focus: the Volta Basin



Footprints of Climate Change: Trends in Temperature



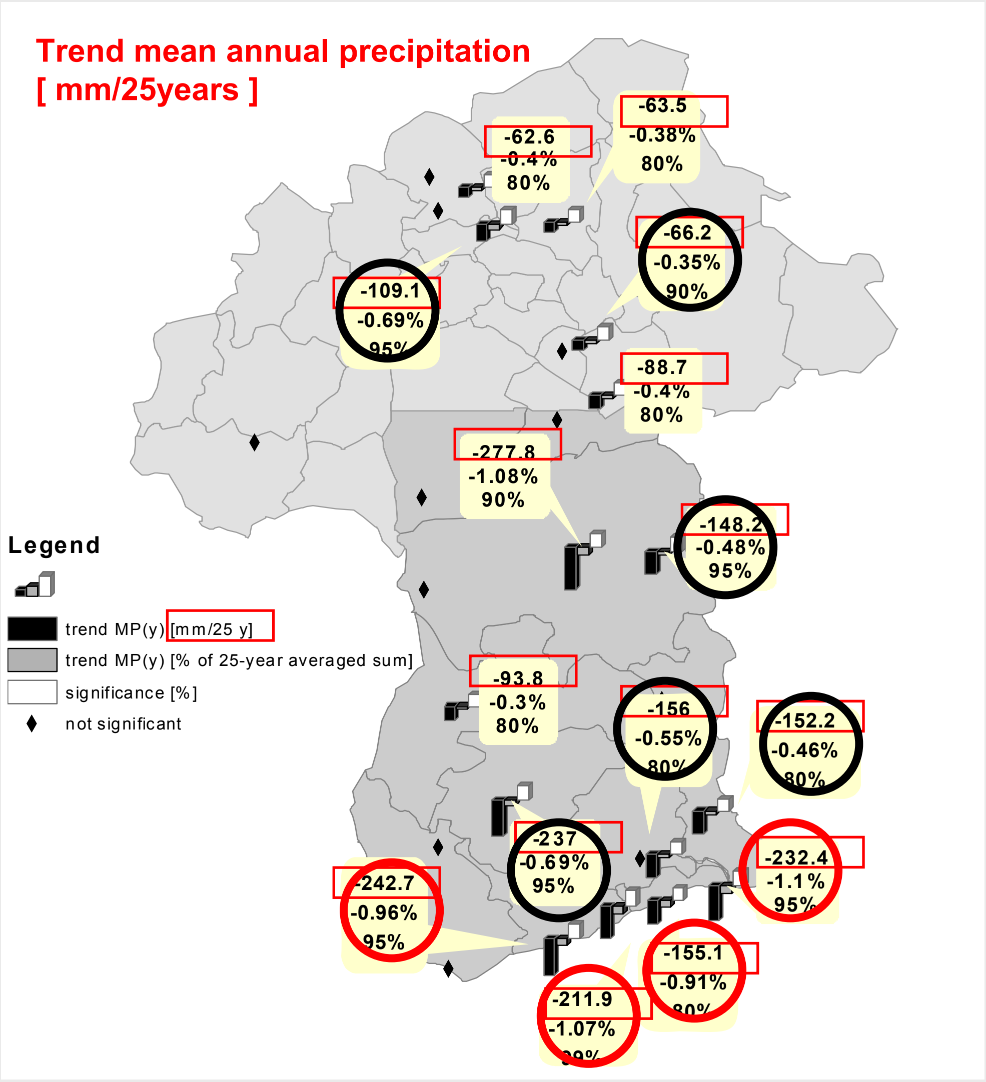
Significant increase of temperature in all areas

Temperature increase in last 25 years up to ≈ 1°C

>> global mean temperature increase

⇒ highly climate sensitive region

Footprints of Climate Change: Trends in Precipitation

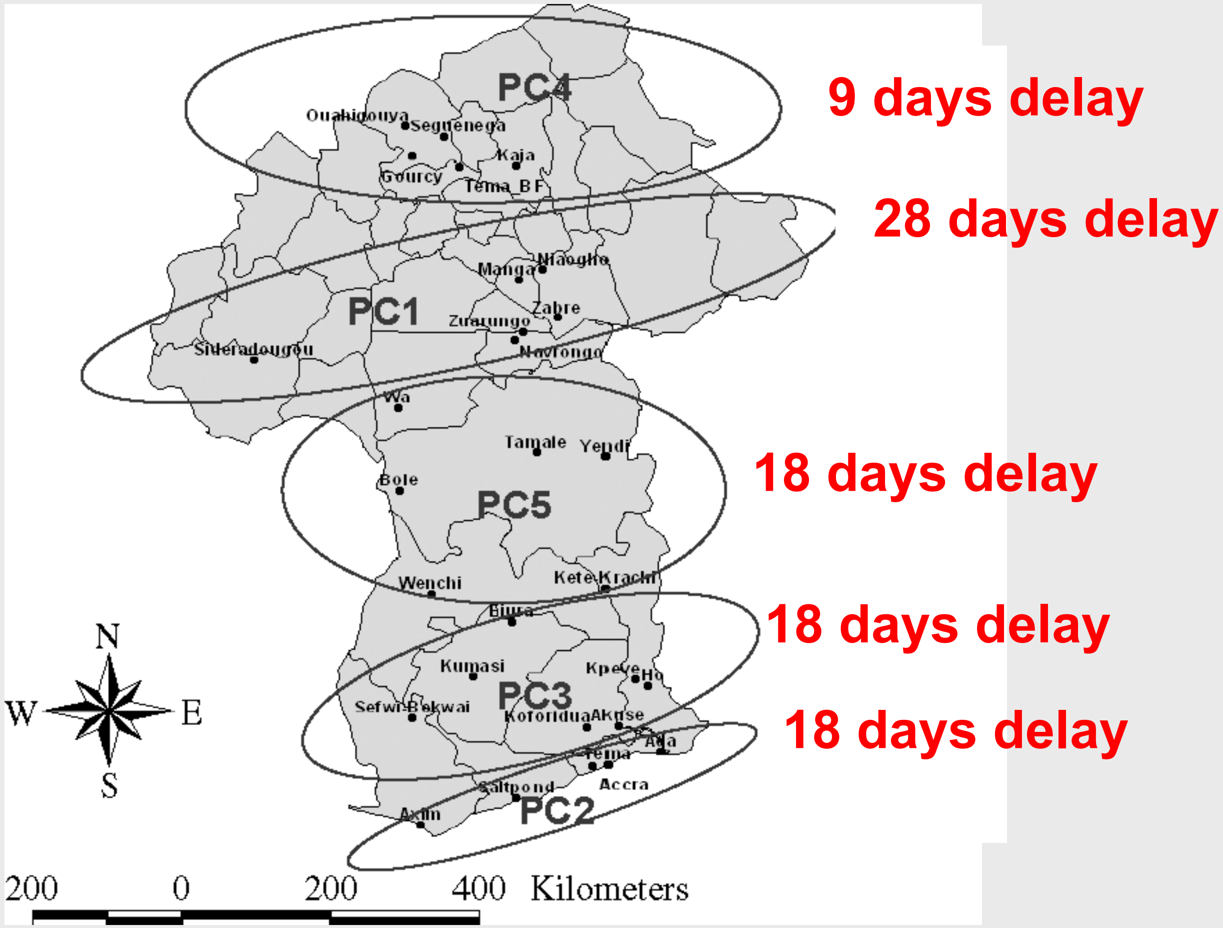


Significant decrease of annual precipitation in specific areas

≈ 15% precipitation decrease in last 25 years!

≈ 25% precipitation decrease in last 25 years!

Footprints of Climate Change: Trends in Onset of Rainy Season



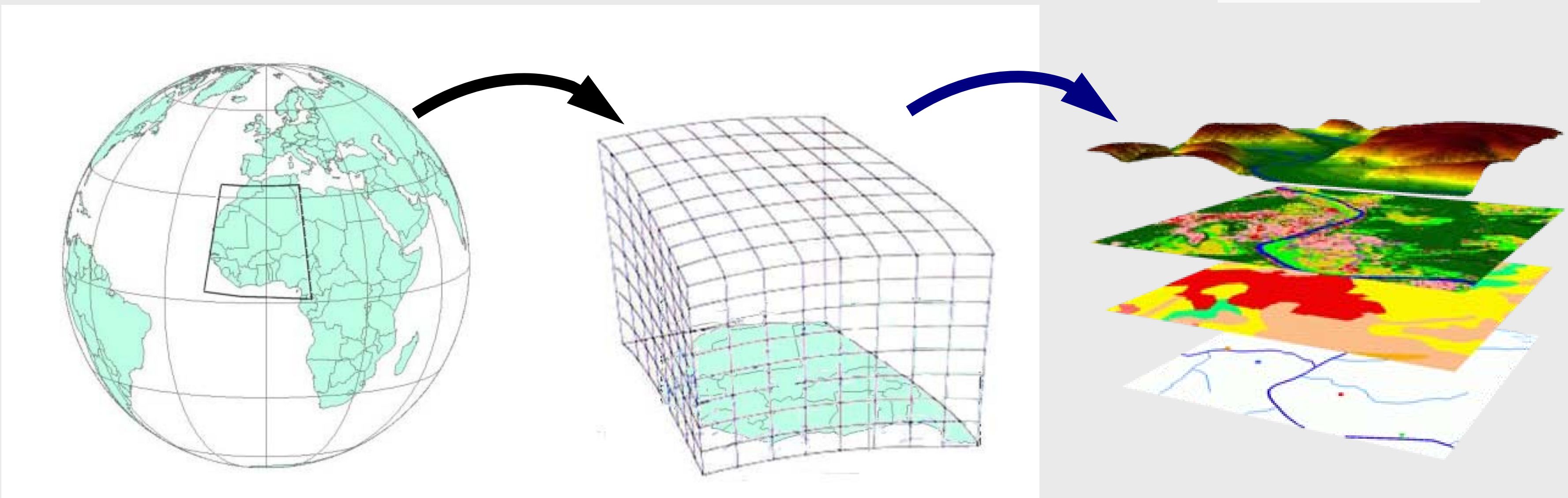
Delay in onset: up to ≈ 30 days in last 40 years!

Looking into the Future: Joint Climate Hydrology Simulations

GCMs
Atmosphere & Ocean
Δx ≈ 300 km

RCMs
Δx ≈ 81…9km

Catchment
Hydrology:
Δx ≈ 1km



Global driving

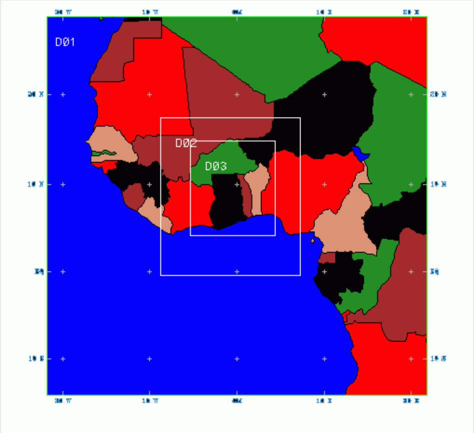
Regional patterns & soil-vegetation-atmosphere feedbacks

Detailed terrestrial water balance

Looking into the Future: Joint Climate Hydrology Simulations

- Temperature
- Precipitation
- Wind
- Relative Humidity
- Radiation

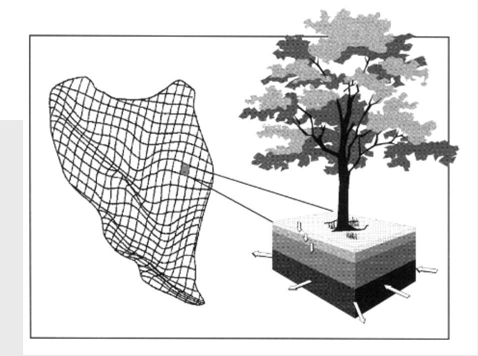
ECHAM4 (IS92a) & MM5



2.8°→ 81, 27, 9 km resolution

WaSiM

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



1 km resolution

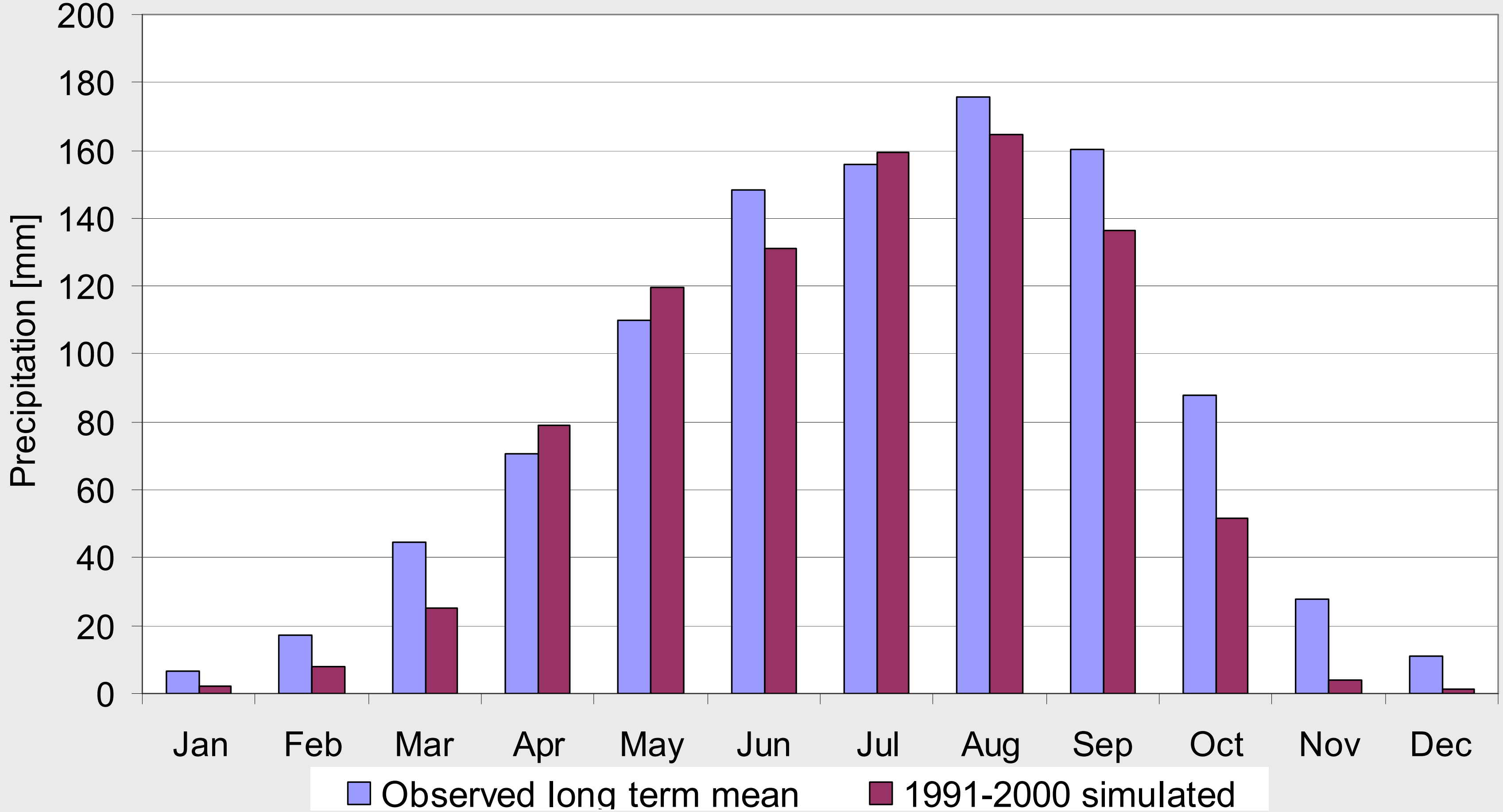
Evapotranspiration

Infiltration

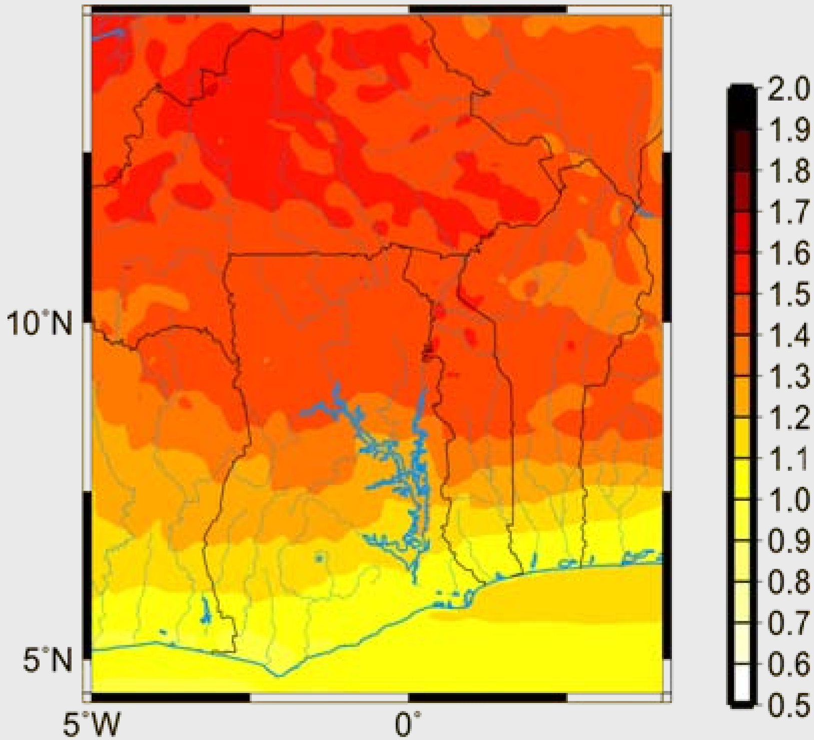
Surface runoff

Groundwater flow

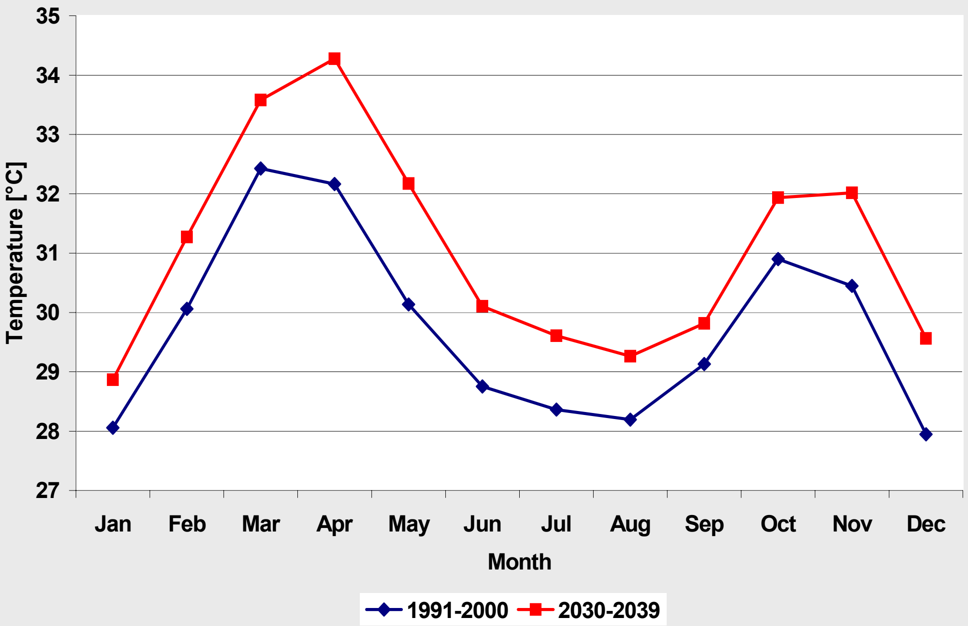
Regional Climate Modeling: Validation Control Run



Regional Climate Modeling: Temperature Change till 2039

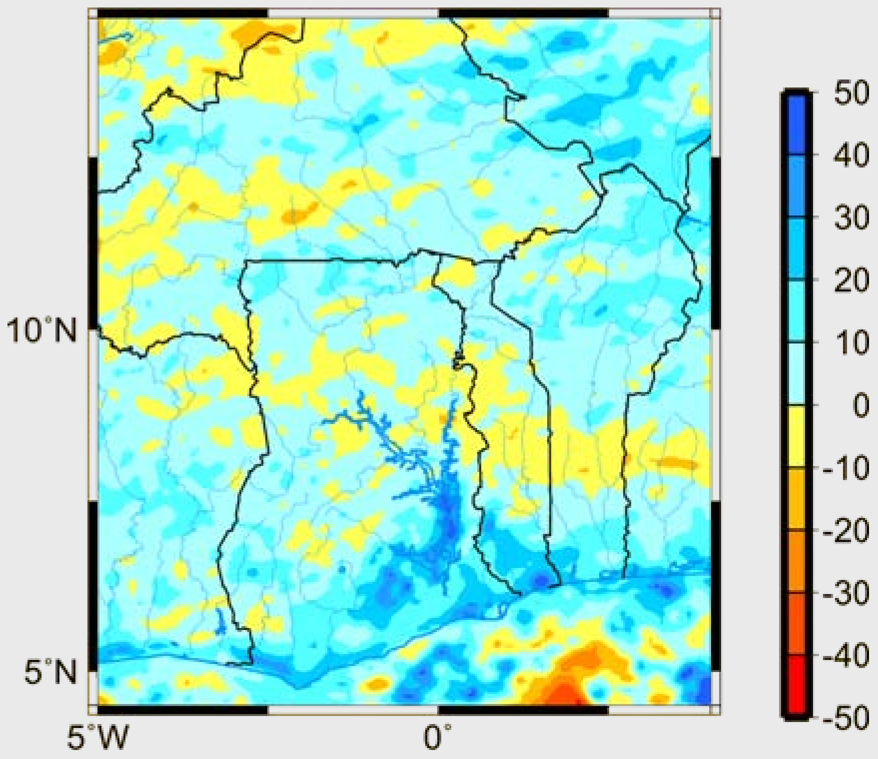


Mean annual temperature change [%]



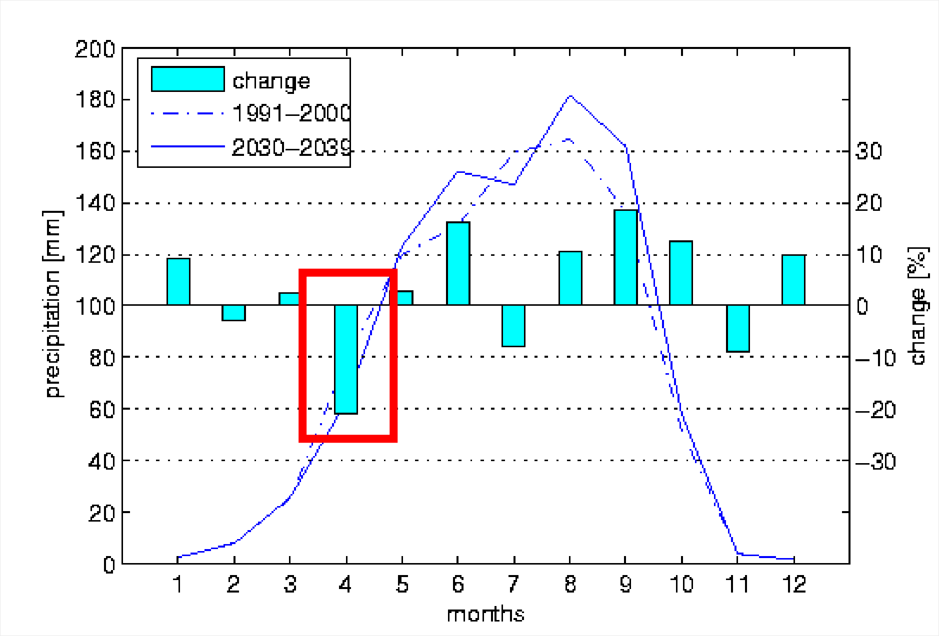
Mean monthly temperature [°C]
(2030-2039 vs. 1991-2000)

Regional Climate Modeling: Precipitation Change till 2039



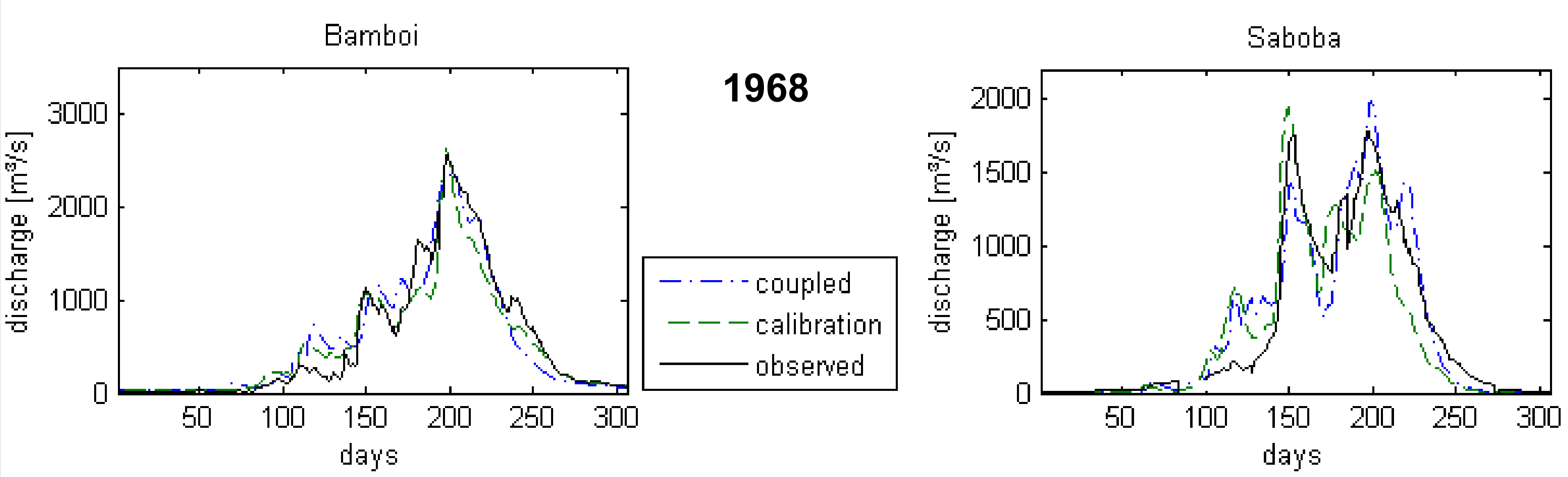
Mean annual precipitation change [%]

Significant decreases in April



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

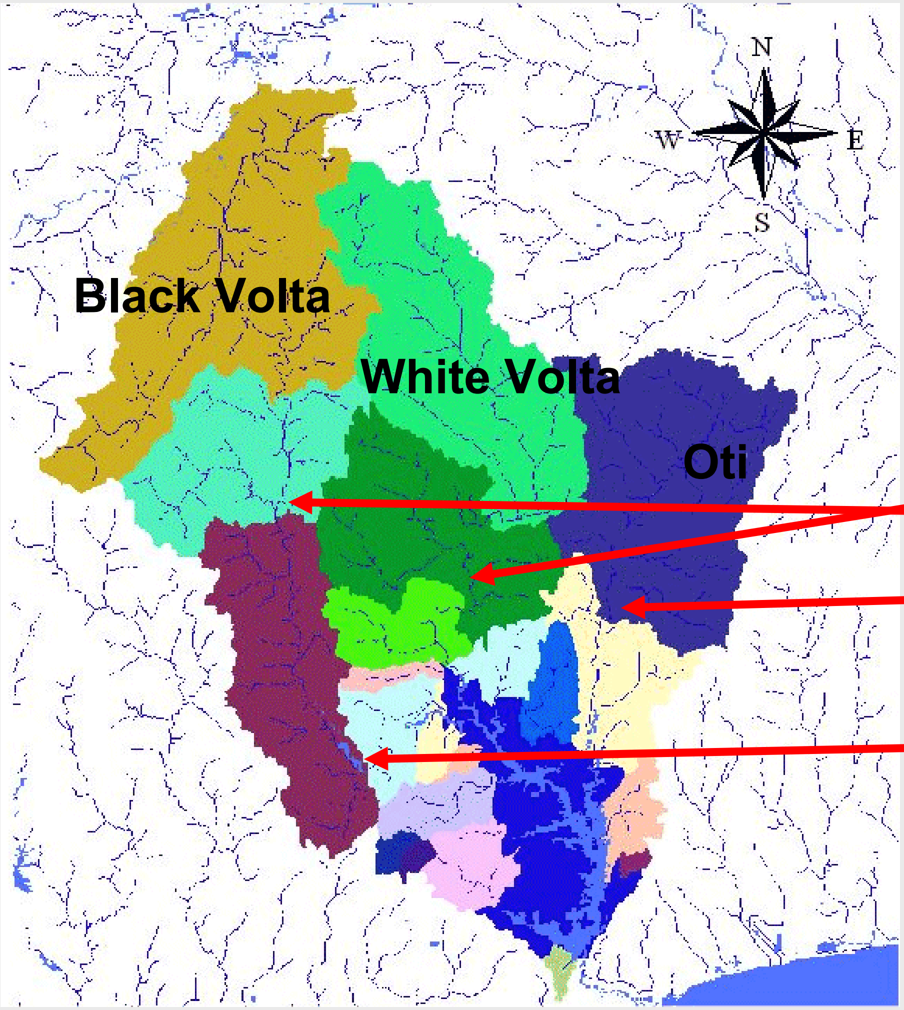
Performance of Joint MM5-WaSiM Simulations



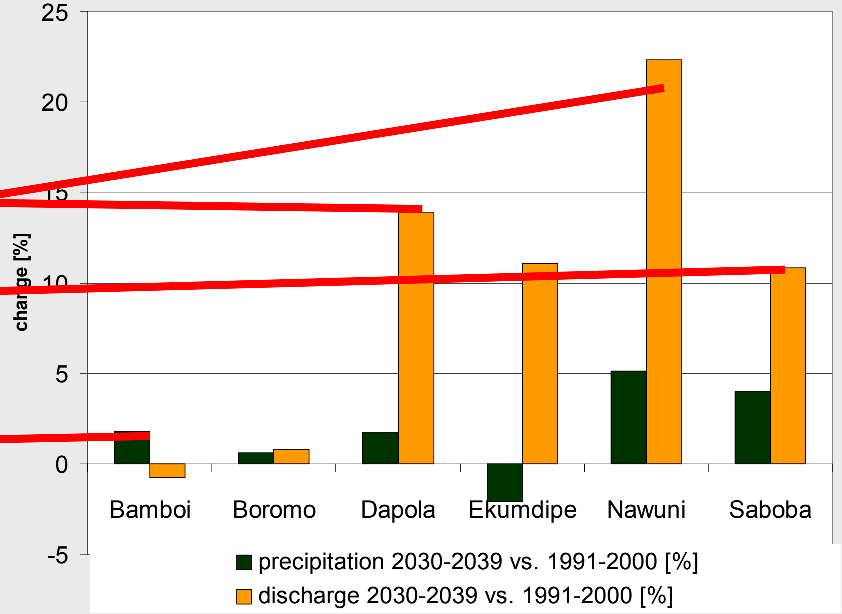
	Bamboi	Boromo	Dapola	Nawuni	Pwalugu	Saboba
NSE(d)	0.95	0.31	0.82	0.84	0.3	0.85
NSE(m)	0.84	0.74	0.85	0.79	0.33	-

Reasonable performance of joint model system

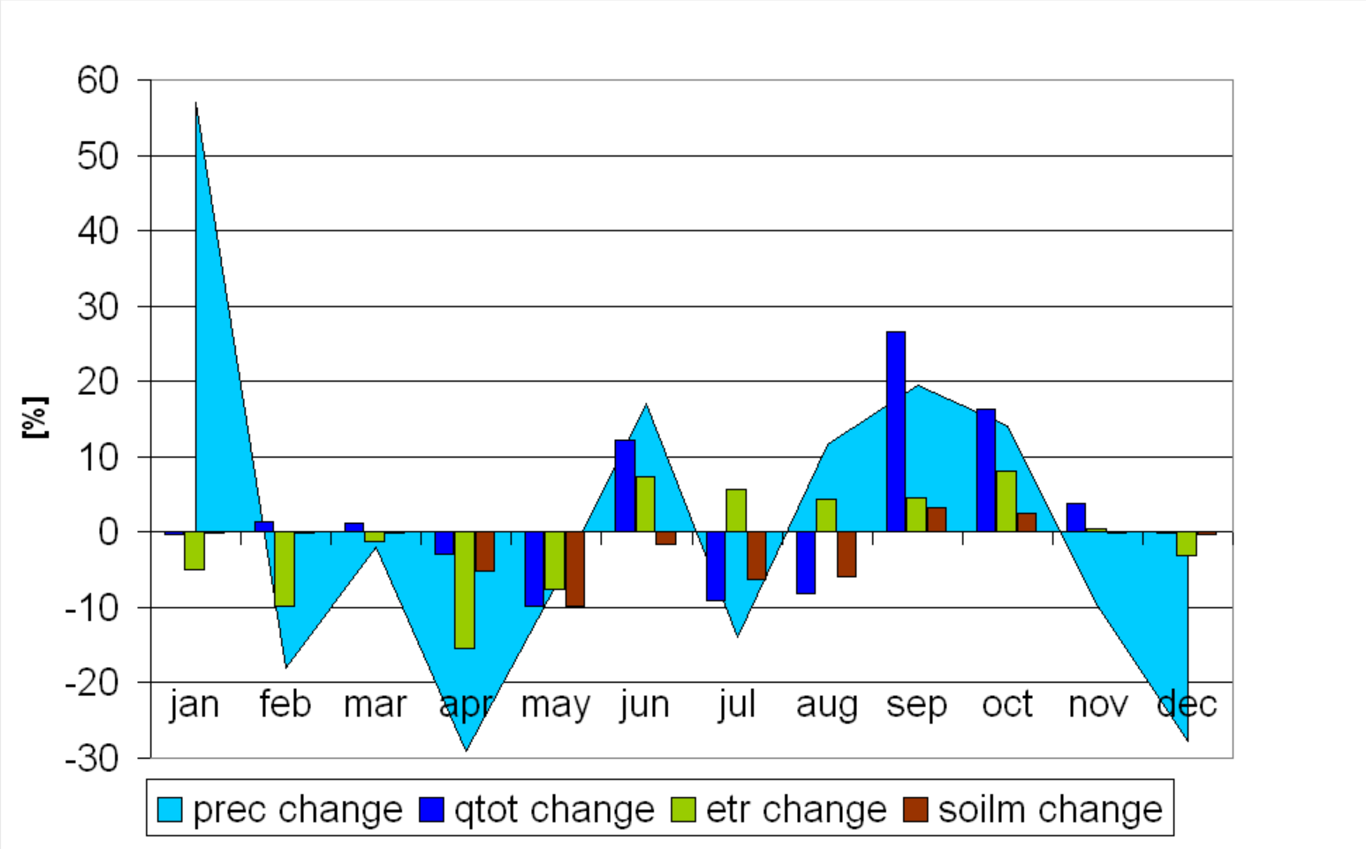
Impact Climate Change on Terrestrial Water Availability



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



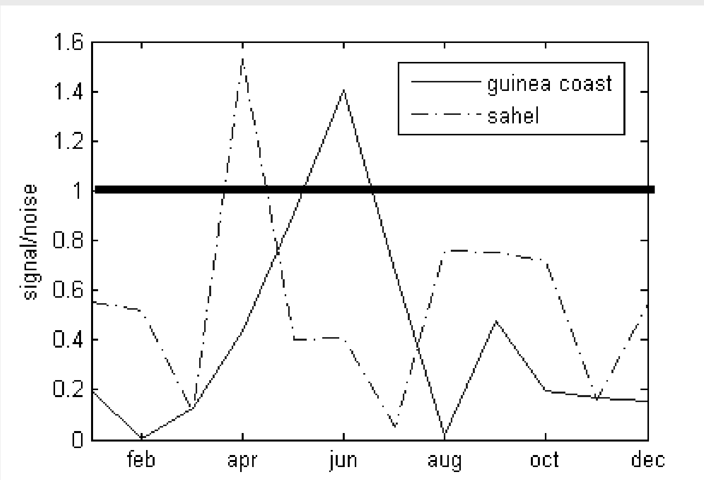
Impact Climate Change on Terrestrial Water Availability



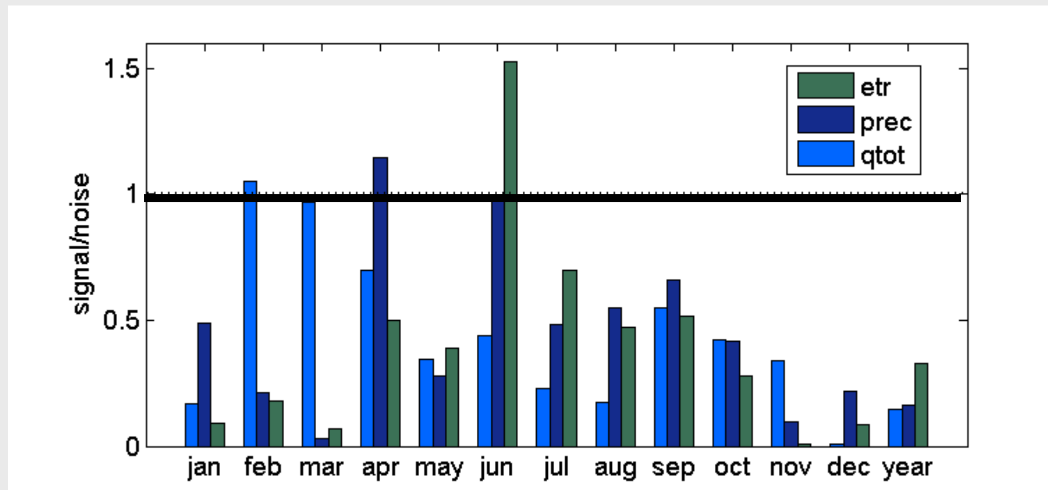
Changes in seasonal distribution of water availability

Impact Climate Change on Terrestrial Water Availability

Signal to Noise ratio: $SN = \frac{|\overline{X}_{fut} - \overline{X}_{pres}|}{\sigma}$ **> 1?**



SN for precipitation



SN for precipitation, evapotranspiration & river runoff

Climate change signal predominantly within range of inter-annual variability

General Conclusions

- GLOWA projects have accounted for **various sources of information** for regional climate change assessment as recommended by IPCC
- **Scale bridging**: from global to catchment scale
- **Compartment bridging**: from the atmosphere to the subsurface
- Clearly significant trends towards **warmer climate** in pilot regions
- Expected land use changes induce **decrease in precipitation**
- Expected GHG-forcing induces **regionally decreased water availability**
- GLOWA projects provide variety of regional climate change information for **impact studies** and **decision making**