Climate Change impacts: challenges and opportunities for a German-Nigerian collaboration and its regional agricultural and hydrological impacts for West Africa: Challenges and opportunities for a German-Nigerian collaboration

Patrick Laux

Institute for Meteorology and Climate Research (IMK-IFU)
Garmisch-Partenkirchen, Germany

Motivation

- Rainfall distribution in time and space has significant im… …er **availability** and socio-economy in West Africa
  - Severe droughts in 1970s and 1980s (i.e. …
- **Rainfed agriculture** highly expos… …ariability
  - 70% of population depe… …agriculture
  - Food Security: *se… …ere*
- Crucial prob… …d agriculture: Decision about the **sowing date**
  - S… …as possible to avoid wasting of valuable growth time
  - … early may lead to crop failure and high economic losses
  - …: **Prediction of Onset of the Rainy Season (ORS)**

Global climate change is expected to aggravate rainfall variability and water scarcity in 21. Century (IPCC, 2007)

“Challenge” West Africa

Required:

Scientifically sound information

under weak infrastructure

Outline

Case study 1: Volta Basin (Ghana & Burkina Faso)

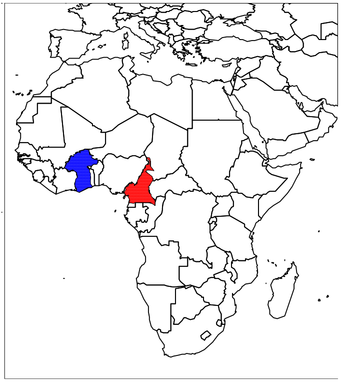
- Observed signals of climate change
- Regional climate modeling: expected future climate
  - Impact climate change on regional water availability
  - Impact climate change on agricultural sector

Case study 2: Cameroon

- Impact climate change on food production

Conclusions

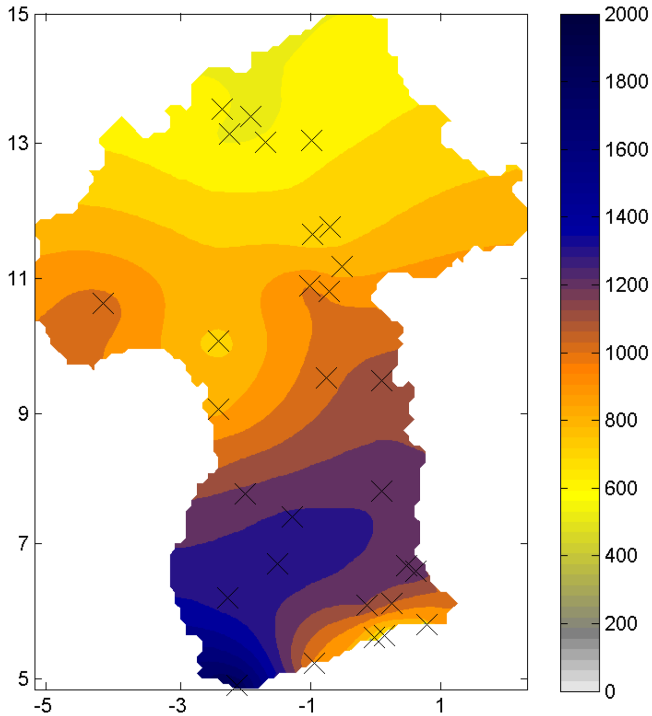
Research foci

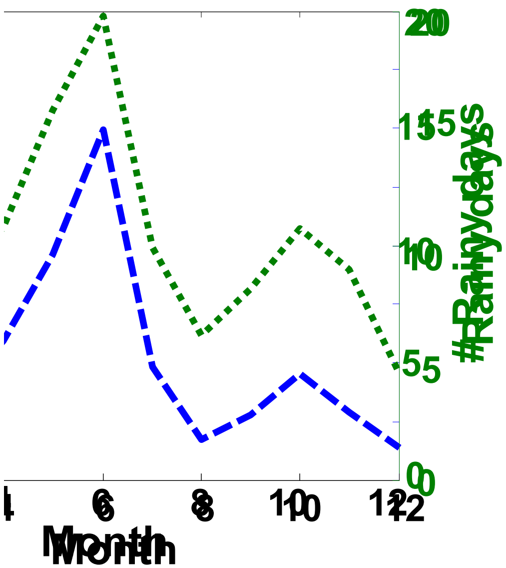


- Volta Basin (Ghana & Burkina Faso), Cameroon
- Similar climate: High spatial and temporal rainfall variability
  - ➢ Climate: sub-humid to arid
  - ➢ Rainy Season (*Intertropical Convergence Zone* ITCZ)

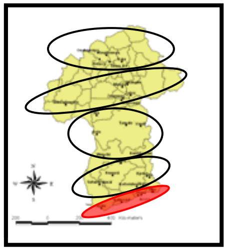
ximum June)

ximum August)





Volta Basin



Case study 1: Volta Basin (Ghana & Burkina Faso)

- Observed signals of climate change
- Regional climate modeling: expected future climate
  - ➢ Impact climate change on regional water availability
  - ➢ Impact climate change on agricultural sector

Case study 2: Cameroon

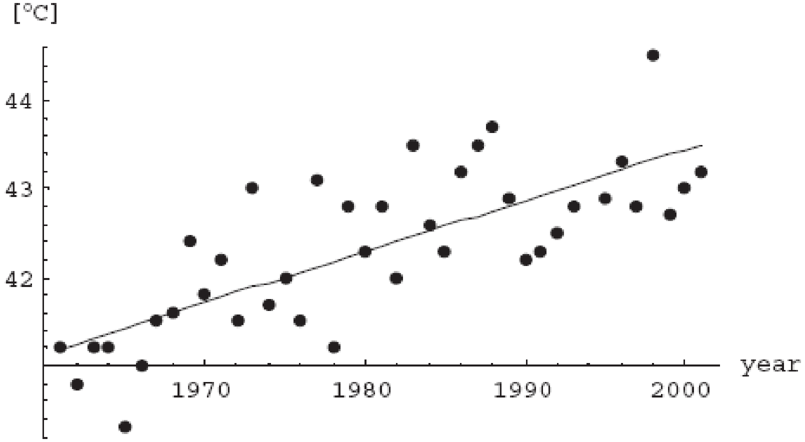
- Impact climate change on food production

Conclusions

Observed Climate Change (1961-2000)

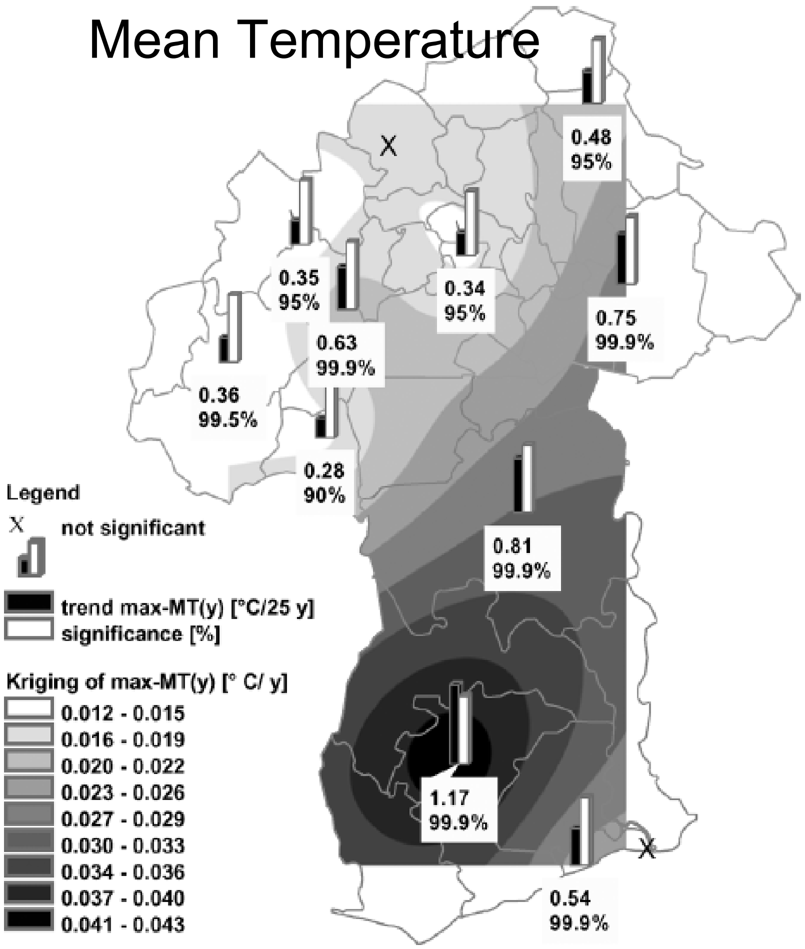
Trends in Temperature

Maximum Temperature Fada N'Gourma



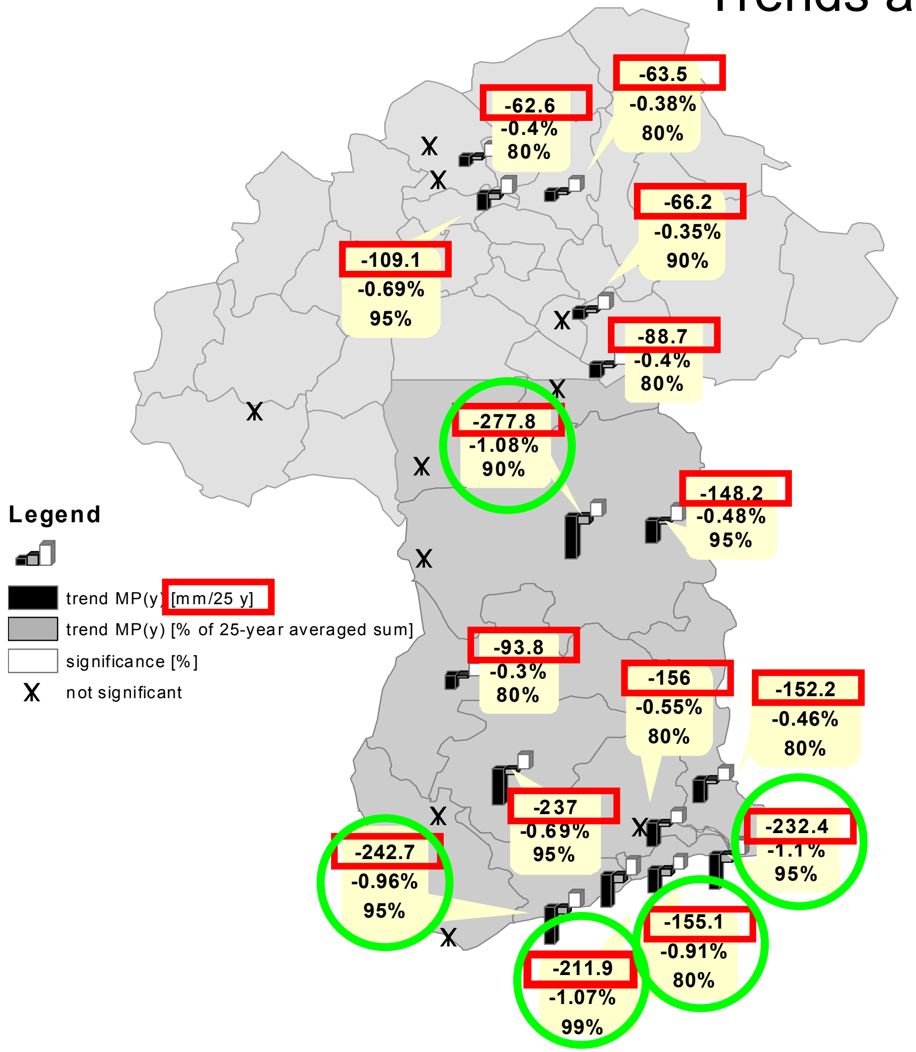
[Neumann et al., 2007]

Mean Temperature



Observed Climate Change (1961-2000)

Trends annual rainfall amounts



Significant decrease of annual rainfall amount

≈ 25% decrease annual rainfall amount within 25 years

Outline

Karlsruhe Institute of Technology

Case study 1: Volta Basin (Ghana & Burkina Faso)

- Observed signals of climate change
- Regional climate modeling: expected future climate
  - Impact climate change on regional water availability
  - Impact climate change on agricultural sector

Case study 2: Cameroon

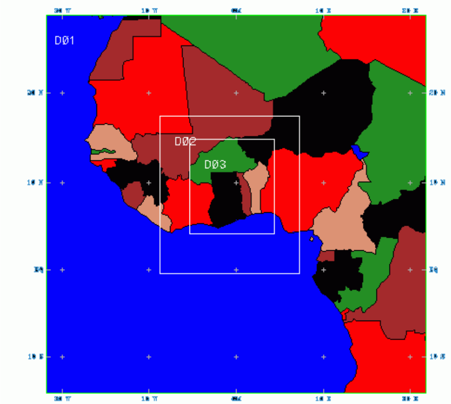
- Impact climate change on food production

Conclusions

Regional Climate Modeling
(Dynamical Downscaling)

- Temperature
- Precipitation
- Wind
- Relative Humidity
- Radiation

ECHAM4 & MM5
Scenario IS92a



2.8°→ 9 km resolution

WaSiM

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

1 km resolution

Evapotranspiration

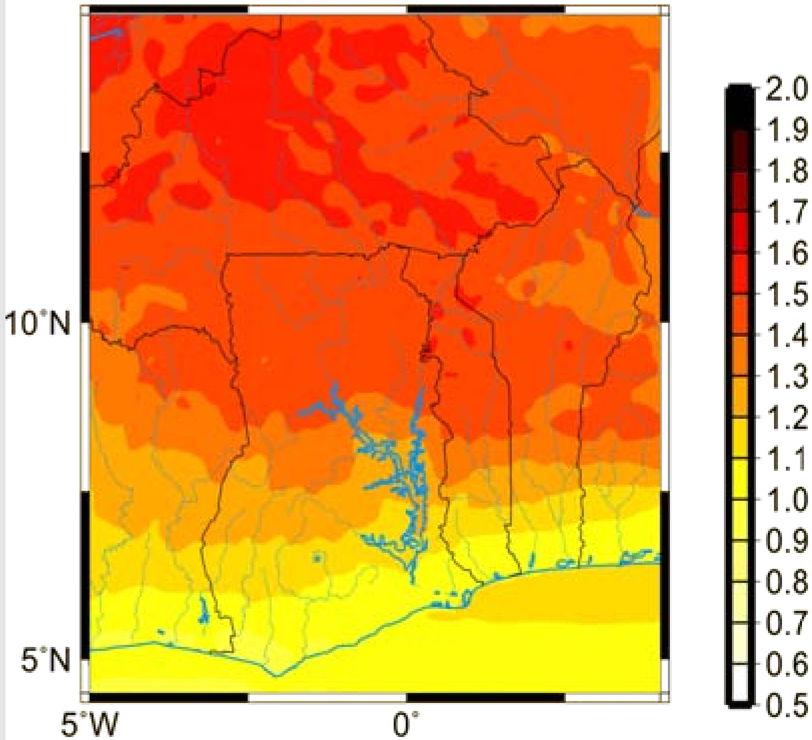
Infiltration

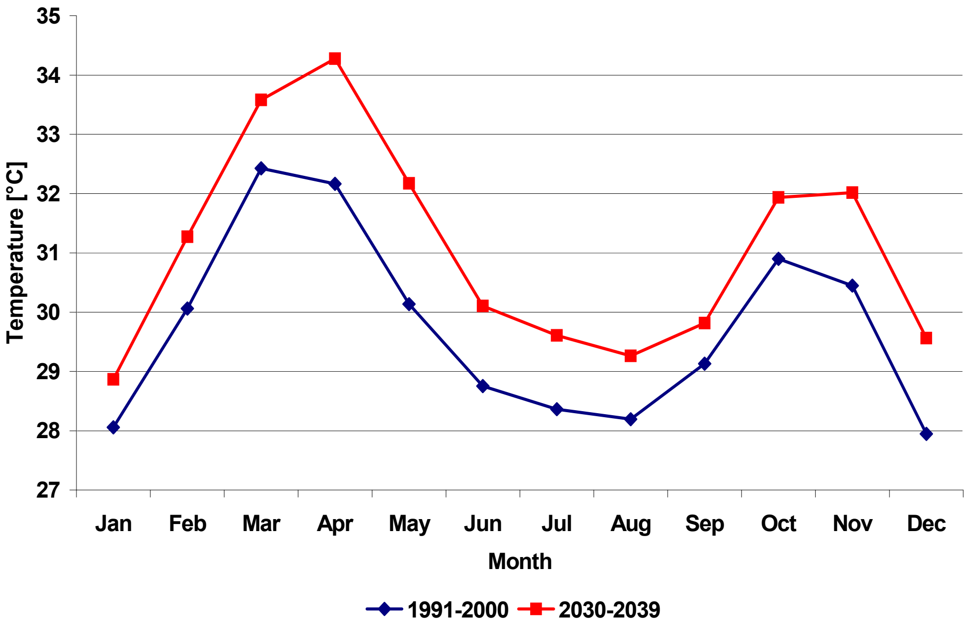
Surface runoff

Groundwater flow

Regional Climate Modeling

Temperature Change till 2039



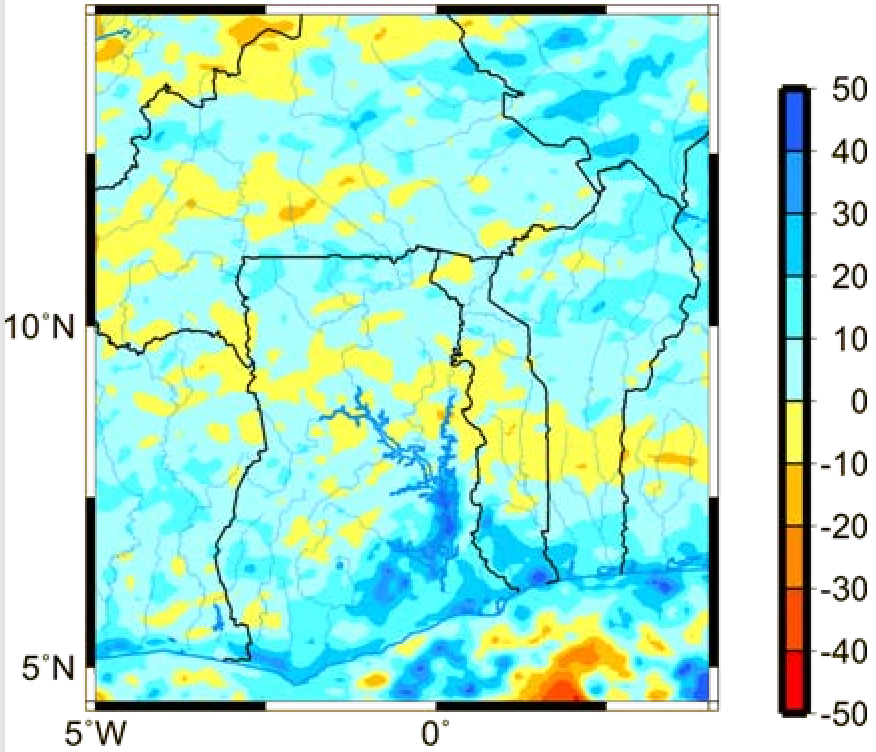


Mean annual temperature change [%]

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

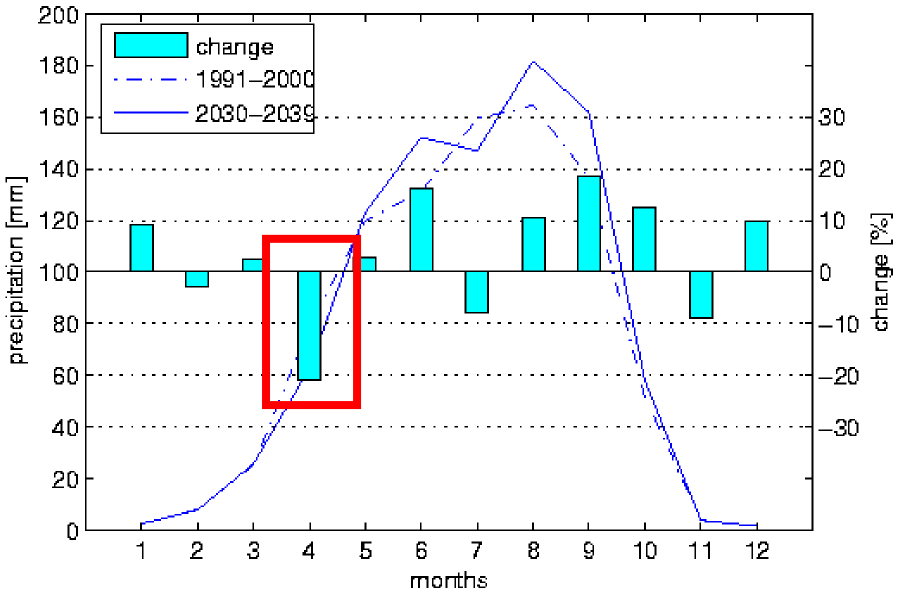
Regional Climate Modeling

Precipitation Change till 2039



Mean annual precipitation change [%]

Significant decreases in April



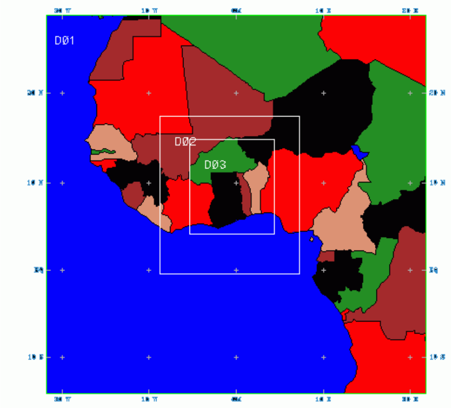
Monthly mean precipitation [mm] and change [%] (2030-2039 vs. 1991-2000)

Regional Hydrological Modeling

Joint Regional Climate-Hydrology Simulations

- Temperature
- Precipitation
- Wind
- Relative Humidity
- Radiation

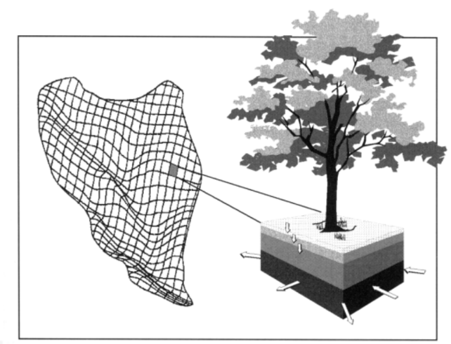
ECHAM4 & MM5



2.8°→ 9 km resolution

WaSiM

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

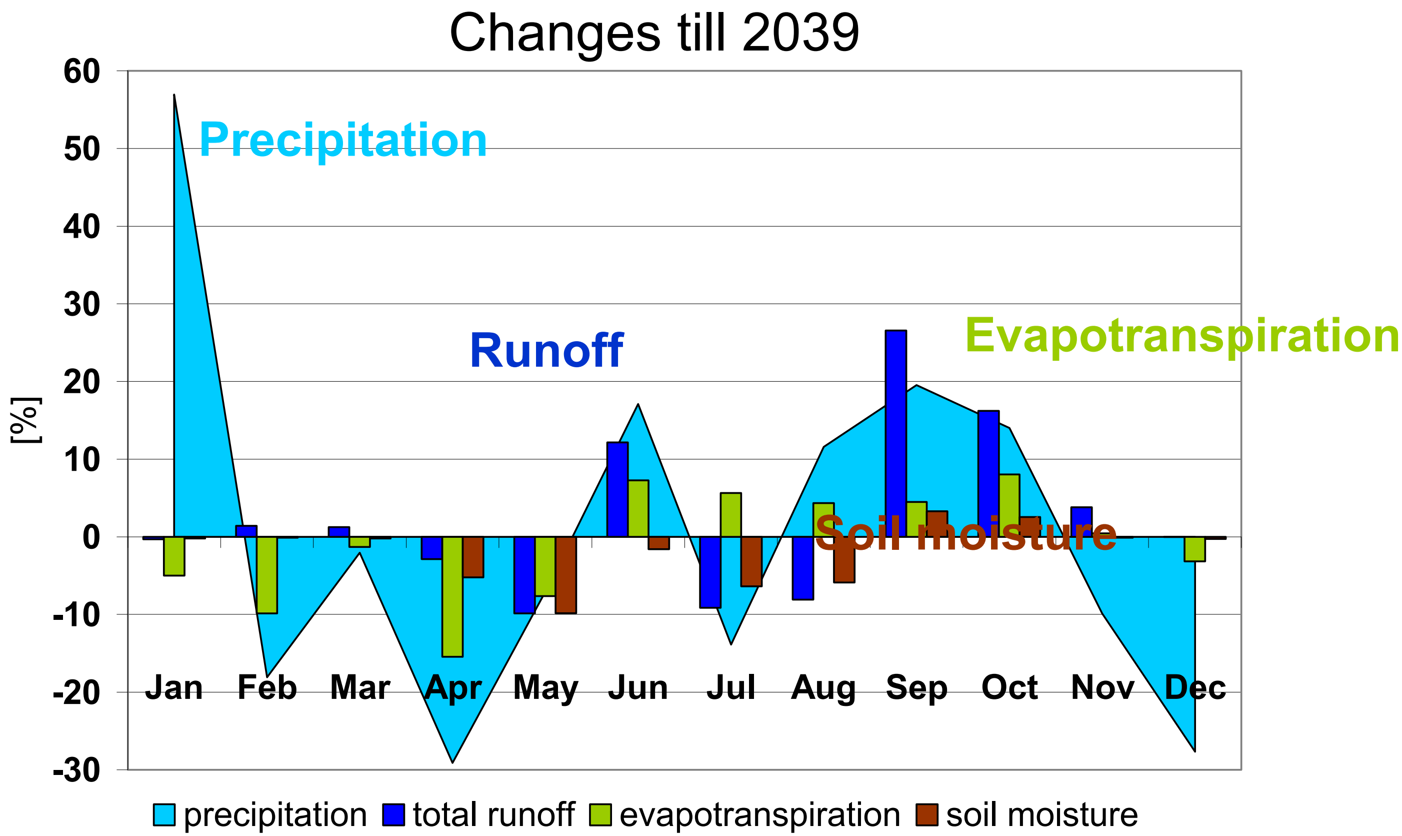


1 km resolution

Evapotranspiration
Infiltration
Surface runoff
Groundwater flow

Regional Hydrological Modeling

Impact Climate Change on Water Balance



Outline

Case study 1: Volta Basin (Ghana & Burkina Faso)

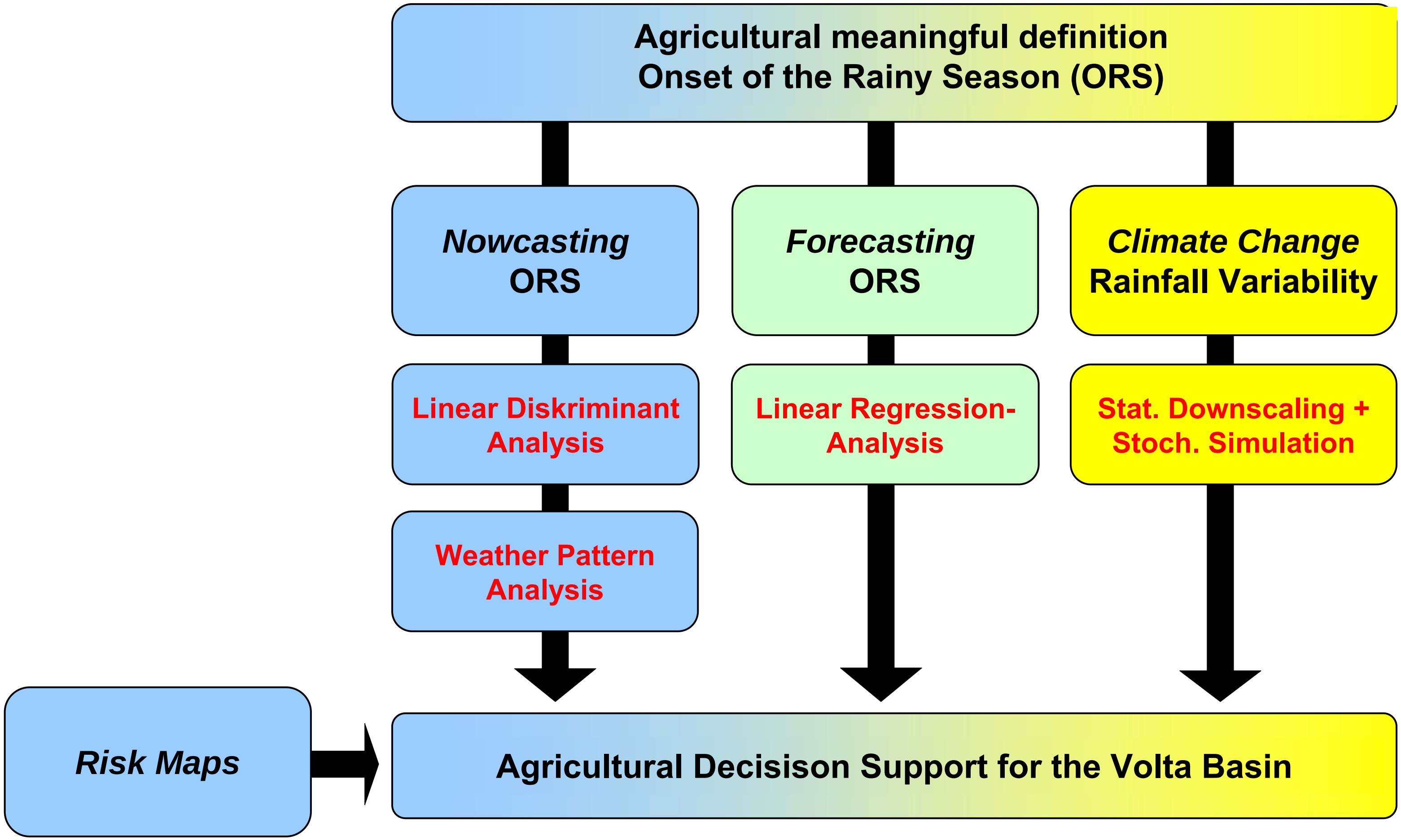
- Observed climate change
- Regional climate modeling: expected future climate
  - Impact Climate Change on regional water availability
  - Impact Climate Change on agricultural sector

Case study 2: Cameroon

- Impact Climate Change on food production

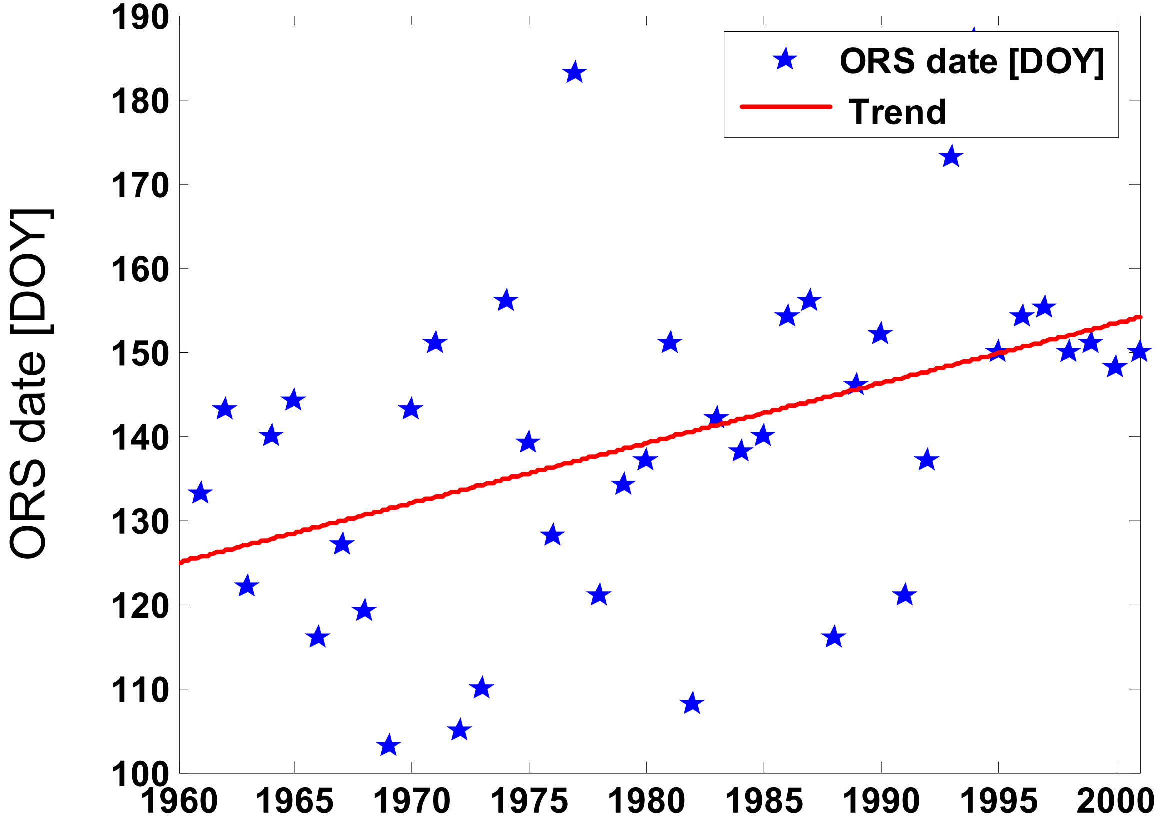
Conclusions

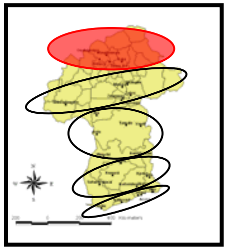
Agricultural *Decision Support System DSS*



[Laux et al., 2007, 2008 & 2009]

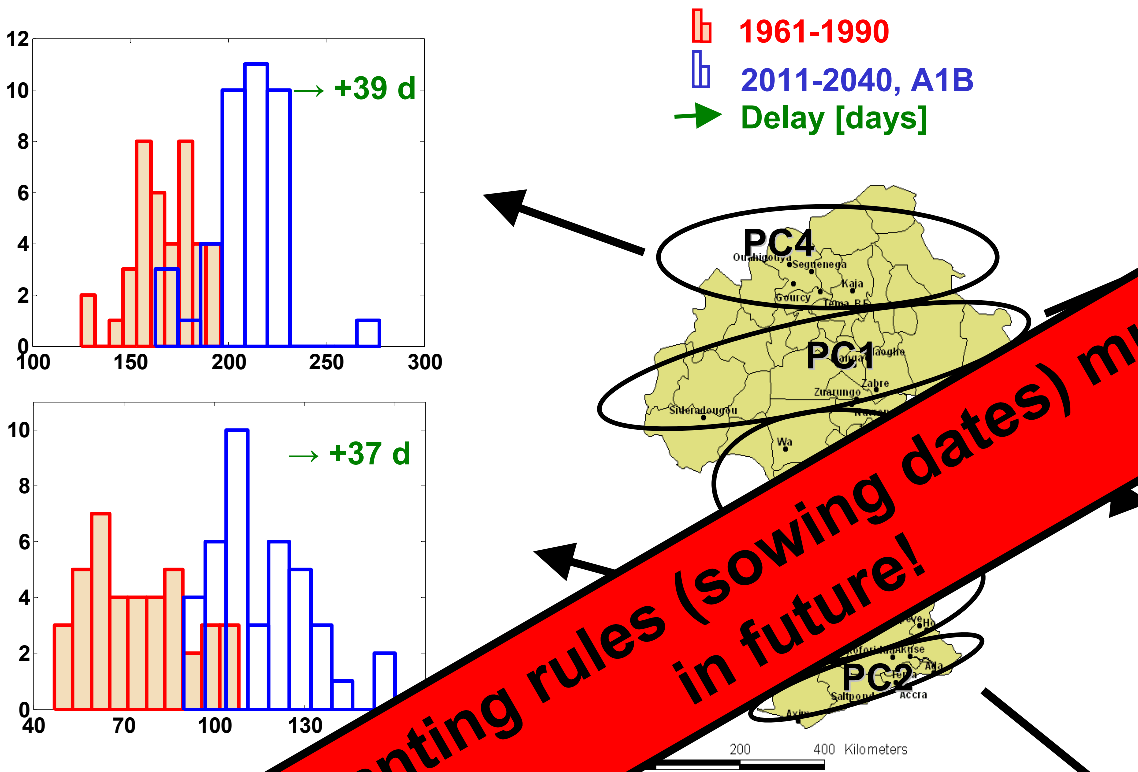
Climate Change and Onset of the Rainy Season

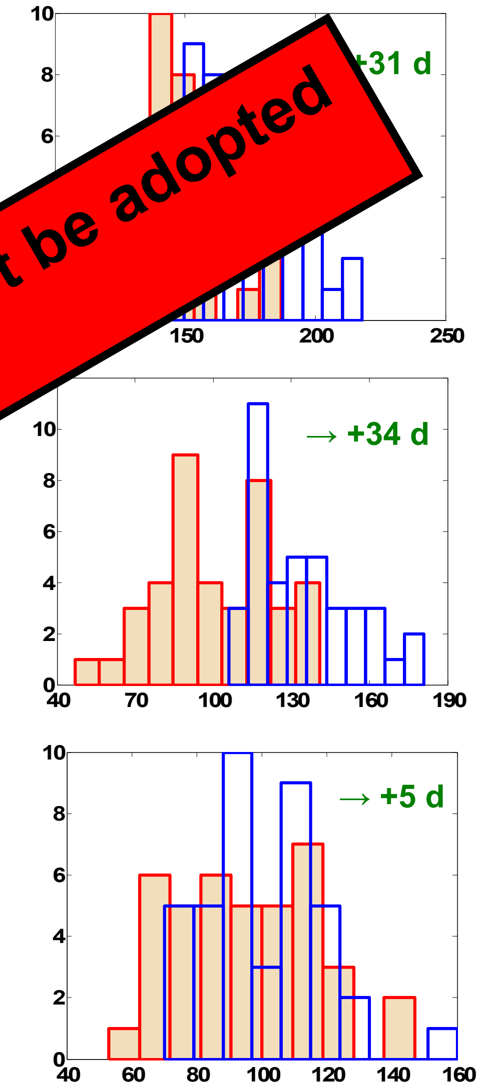




→ Significant delay of the ORS up to 30 days for 1961-2001

Onset of the Rainy Season in future?





- Delay ORS dates (μ)
- ability ORS dates (δ) remains similar

Case study 1: Volta Basin (Ghana & Burkina Faso)

- Observed climate change
- Regional climate modeling: expected future climate
  - ➢ Impact CC on regional water availability
  - ➢ Impact Climate Change on agricultural sector

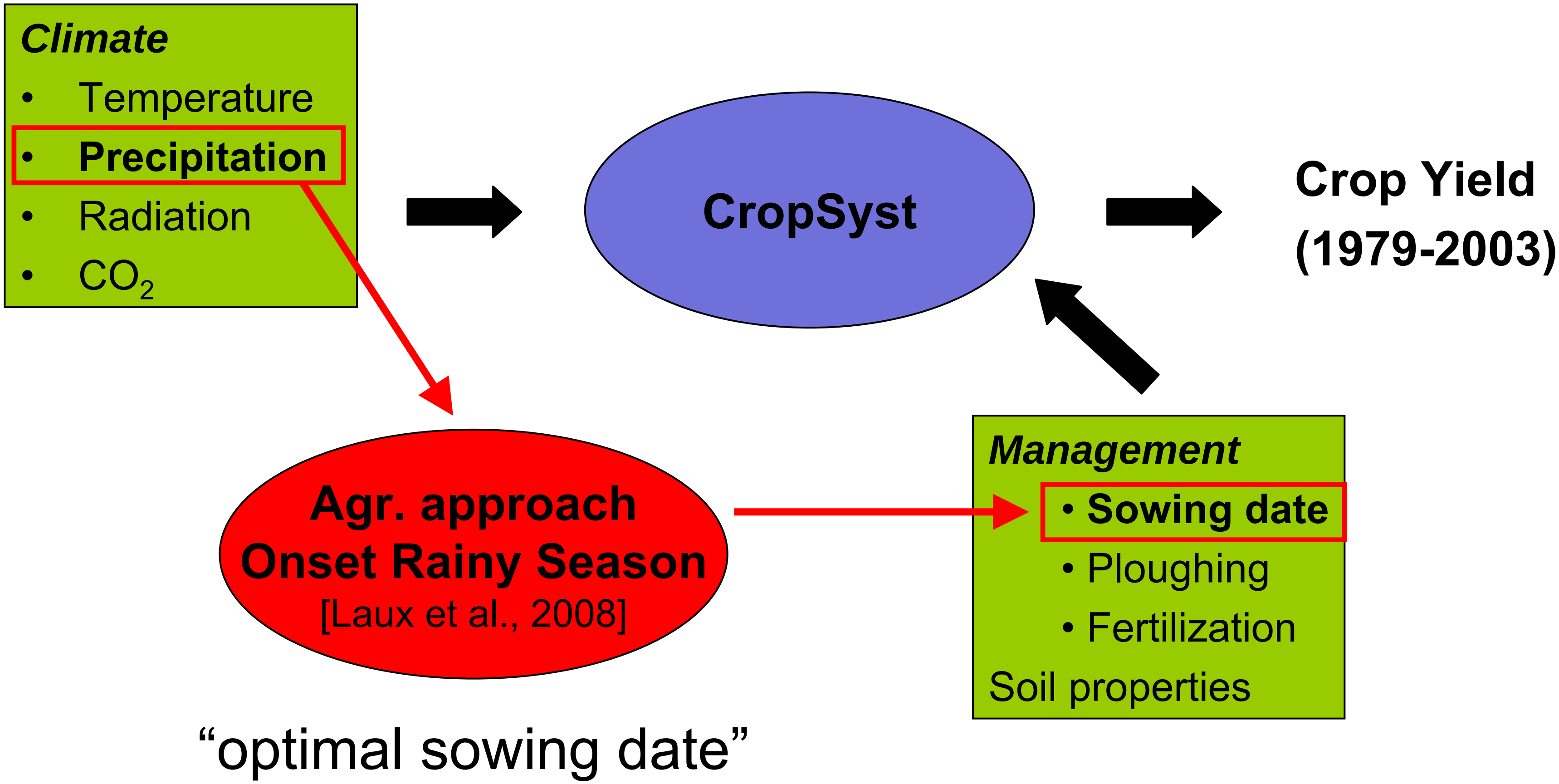
Case study 2: Cameroon

- Impact Climate Change on food production

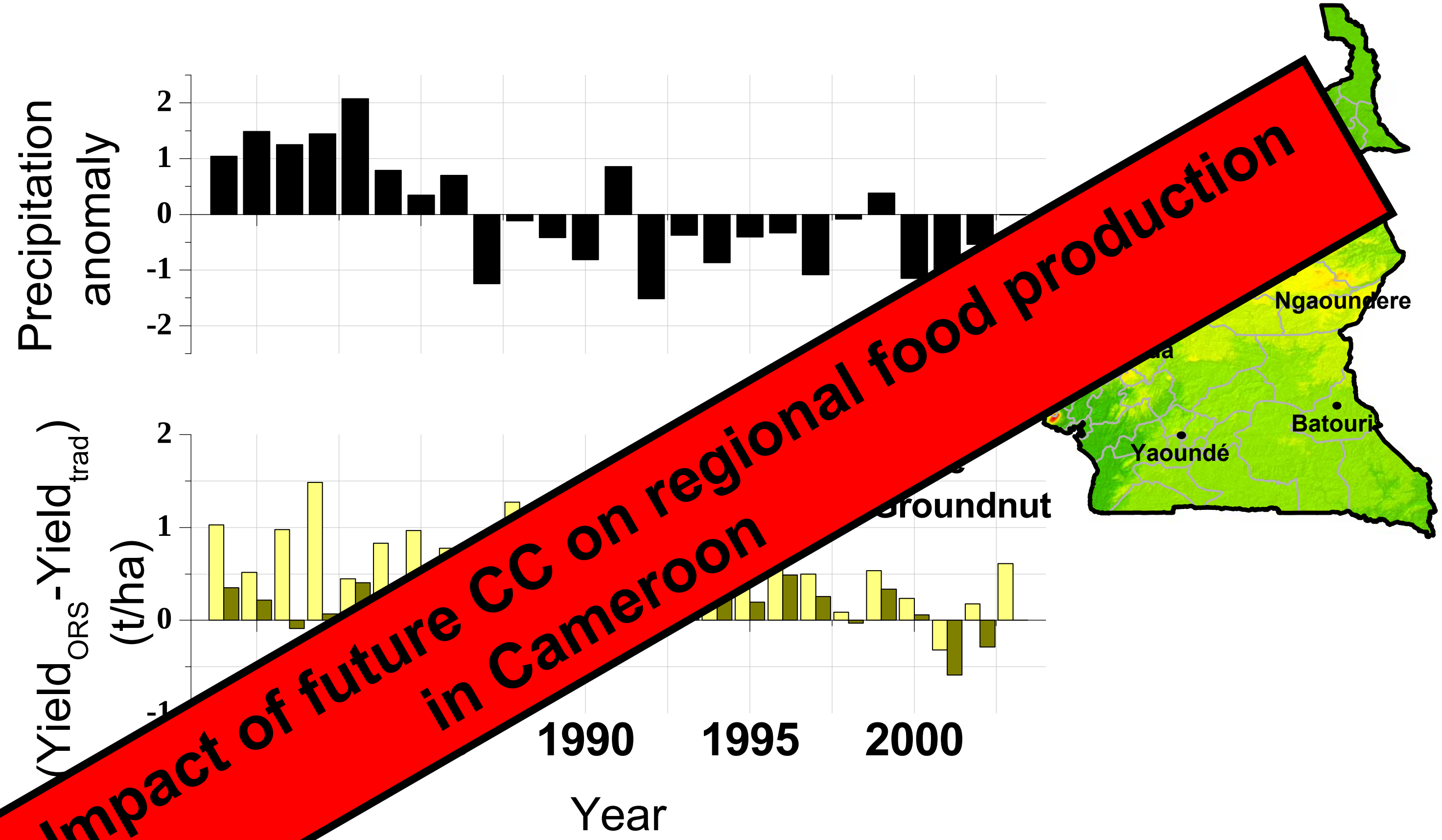
Conclusions

Impact Sowing Date on Crop Yield

Joint Climate Crop Modelling (only useful for rainfed agriculture)



Approach ORS vs. Traditional Sowing Rules



In work: Impact of future CC on regional food production in Cameroon

…979-2003) increased up to 20% using ORS approach

Some conclusions

- Spatially distributed **change of precipitation** (between -20 and +50%) in the Volta Basin
  - Increase in the rainy season
  - Decrease at the onset of the rainy season
  - Significant delay of ORS expected in future

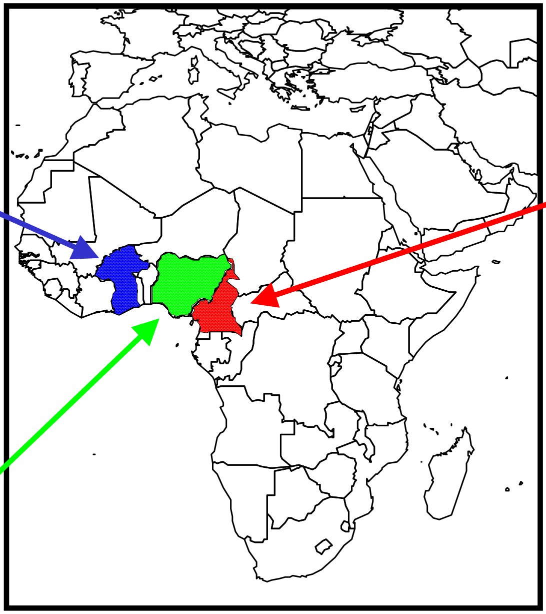
- **Agricultural DSS** could significantly increase crop yield (food security) in a cost-effective way

- Spatially distributed climate information **useful for different sectors** e.g. health sector

Challenges and opportunities for a German-Nigerian collaboration

Development Agro-Hydro-Meteorological Decision Support System for Ghana & Burkina Faso

Status: finalized



Evaluation of methods for Cameroon

Status: ongoing

Application for Nigeria: German-Nigerian cooperation

Status: wanted?

Further Information

Grote, R., Lehmann, E., Brümmer, C., Brüggemann, N., Szarzynski, J., Kunstmann, H. (2008) Modeling and observation of biosphere-atmosphere interactions in natural savannah and agriculture in Burkina Faso - West Africa, *Physics and Chemistry of the Earth*, accepted for publication

Wagner, S., Kunstmann, H., Bárdossy, A., Conrad, C., Colditz, R. (2008) Water balance estimations of poorly gauged catchments in West Africa using dynamical downscaling of meteorological fields and remote sensing information, *Physics and Chemistry of the Earth*, doi:10.1016/j.pce.2008.04.002

Marx, A., Kunstmann, H., Burose, D., Moene, A. (2008) Uncertainty analysis for satellite derived sensible heat fluxes and scintillometer measurements over Savannah environment and comparison to mesoscale meteorological simulation results, *Journal of Agricultural Meteorology*, doi:10.1016/j.agrformet.2007.11.009

Ahrends, H., Mast, M., Rodgers, Ch., Kunstmann, H. (2007) Coupled Hydrological-Economic Modelling for Optimised Irrigated Cultivation in a Semi-arid Catchment of West Africa, *Environmental Modelling and Software*, doi:10.1016/j.envsoft.2007.08.002

Jung, G., Kunstmann H. (2007): High-resolution Regional Climate Modelling for the Volta Basin of West Africa, *Journal of Geophysical Research*, doi:10.1029/2006JD007951, 17 pages

Laux P., Kunstmann H., Bárdossy A. (2007): Predicting the Regional Onset of the Rainy Season in West Africa, *International Journal of Climatology*, DOI: 10.1002/joc.1542

Kunstmann, H., Jung, G., Wagner, S., Clottey, H. (2007) Integration of atmospheric sciences and hydrology for the development of decision support systems in sustainable water management, *Physics and Chemistry of the Earth*, doi:10.1016/j.pce.2007.04.010

Kunstmann, H., Jung, G. (2007) Influence of soil moisture and land use change on precipitation in West Africa, *International Journal of River Management*, Vol. 5, issue 1, 9-16.

Neumann, R., Jung, G., Laux, P., Kunstmann, H. (2007) Climate trends of temperature, precipitation and river discharge in the Volta Basin of West Africa, *International Journal of River Management*, Vol. 5, issue 1, 1-13

Wagner, S., Kunstmann, H., Bárdossy, A. (2006) Model based distributed water balance monitoring of the White Volta catchment in West Africa through coupled meteorological- hydrological simulations, *Advances in Geosciences*, 9, 39-44.

Jung, G., Kunstmann H. (2007): Modelling regional climate change and the impact on surface and sub-surface hydrology in the Volta Basin (West Africa). *IAHS publication 313, Quantification and reduction of predictive uncertainty for sustainable water resources management*, pp. 150-157

Laux P., Kunstmann H., Bárdossy A. (2007): Linking West African Monsoon's onset with atmospheric circulation patterns. *IAHS publication 313, Quantification and reduction of predictive uncertainty for sustainable water resources management*, pp. 40-50

Kunstmann, H., Jung, G. (2003) Investigation of feedback mechanisms between soil moisture, land use and precipitation in West Africa, *IAHS publication 280: Water Resources Systems – Water Availability and Global Change*, pp. 149-159.

Laux, P., Wagner, S. Wagner, A., Jacobeit, J., Bárdossy A., Kunstmann, H. (2009): Modelling daily precipitation features in the Volta Basin in West Africa; Int. Journal of Climatology; International Journal of Climatology, DOI: 10.1002/joc.1852.

Thank you for your attention!

What can be done to help farmers?

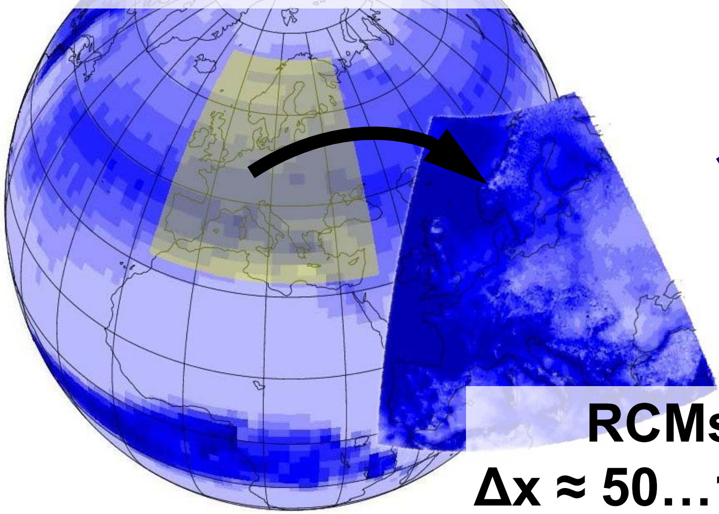
- **Evaluation & Improvement of existing tools (further projects)**
- **Capacity building at a very early stage of collaboration**
- **Reading the rains: intra-annual time scale**
- **Spreading the risk (alternatives)**
  - Irrigation strategies
  - Drought resistant species
  - DSS for rainfed agriculture …

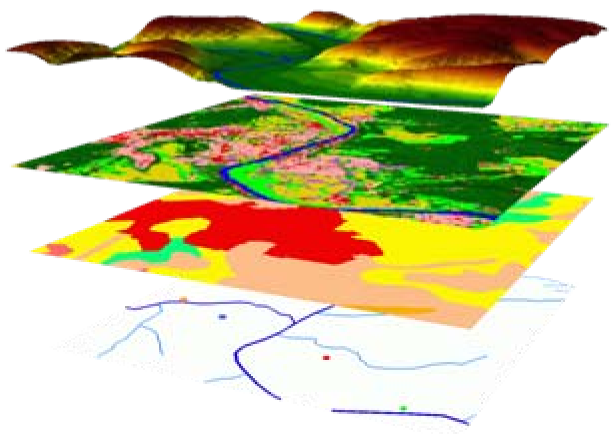
Regional Climate Modelling: Downscaling

GCMs
Atmosphere & Ocean
Δx ≈ 300…100km

Hydrology

Catchment
Hydrology:
Δx ≈ 1km…100m





RCMs
Δx ≈ 50…10km

Dynamic downscaling by RCMs

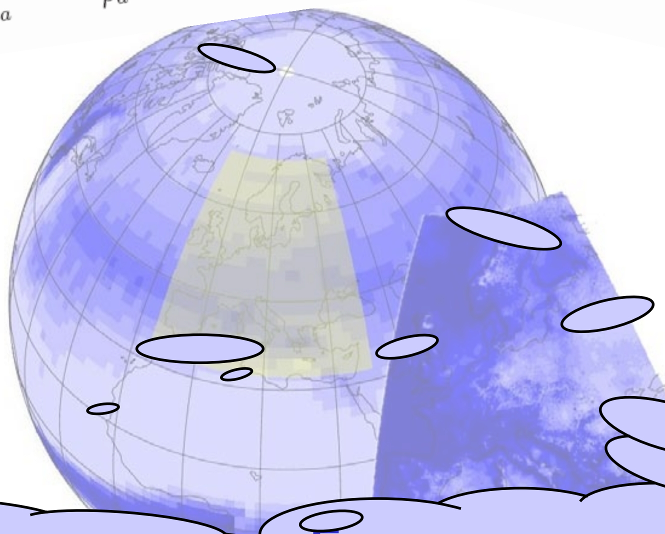
Regional Climate Modeling

Momentum conservation

$$\frac{\partial \vec{v}}{\partial t} + (\vec{v} \cdot \nabla)\,\vec{v} = -f\vec{k} \times \vec{v} - \nabla\Phi - \frac{1}{\rho_a}\nabla p_a + \frac{\eta_a}{\rho_a}\nabla^2 \vec{v} + \frac{1}{\rho_a}(\nabla \cdot \rho_a \mathbf{K_m} \nabla)\,\vec{v}$$

Energy conservation

$$\frac{\partial \theta_v}{\partial t} + (\vec{v} \cdot \nabla)\,\theta_v = \frac{1}{\rho_a}(\nabla \cdot \rho_a \mathbf{K_h} \nabla)\,\theta_v + \frac{\theta_v}{c_{p,d} T_v} \sum_{n=1}^{N} \frac{dQ_n}{dt}$$



Gas law

$$p = \frac{nR^*T}{V}$$

Air mass conservation

$$\frac{\partial \rho_a}{\partial t} + \nabla \cdot (\vec{v}\rho_a) = 0$$

Conservation water mass

$$\begin{aligned}
\frac{\partial q_v}{\partial t} + (\vec{v} \cdot \nabla)\,q_v &= \frac{1}{\rho_a}(\nabla \rho_a \mathbf{K_h} \nabla)\,q_v + R_{evap} - R_{cond} - R_{iini} - R_{idep/sub} \\
\frac{\partial q_c}{\partial t} + (\vec{v} \cdot \nabla)\,q_c &= \frac{1}{\rho_a}(\nabla \rho_a \mathbf{K_h} \nabla)\,q_c + R_{cond} + R_{iini} + R_{idep/sub} - R_{aconv} - R_{accr} \\
\frac{\partial q_r}{\partial t} + (\vec{v} \cdot \nabla)\,q_r &= \frac{1}{\rho_a}(\nabla \rho_a \mathbf{K_h} \nabla)\,q_r - R_{evap} + R_{aconv} + R_{accr} - \frac{\partial V_f \rho_a g q_r}{\ldots}
\end{aligned}$$

Energy conservation at land surface

$$\begin{aligned}
L_v E + H + G &= SW_{net} + LW_{net} \\
&= (1-\alpha) SW\downarrow + LW\downarrow - \epsilon\, \sigma_B\, T^4_{surf}
\end{aligned}$$

Soil temperature diffusion

$$C_t(\Theta)\frac{\partial T_s}{\partial t} = \frac{\partial}{\partial z}\left[K_t(\Theta)\frac{\partial T_s}{\partial z}\right]$$

Precipitation physics

$$R_{evap\ (rain)} = \frac{2\pi N_{0r}(S_w - 1)}{A_r + B_r}\left[\frac{0.78}{\Lambda_r^2} + 0.32\left(\frac{a_r \rho}{\eta_a}\right)^{1/2} S_c^{1/3} \frac{\Gamma(5/2 + b_r/2)}{\Lambda_r^{5/2 + b_r/2}}\right]$$

Soil water infiltration

$$\frac{\partial \Theta}{\partial t} = \frac{\partial}{\partial z}\left[D(\Theta)\frac{\partial \Theta}{\partial z}\right] + \frac{\partial k(\Theta)}{\partial z}$$