Klimawandel und Auswirkungen auf den Wasserhaushalt

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GIS as Central Tool in Climate Research & Hydrology

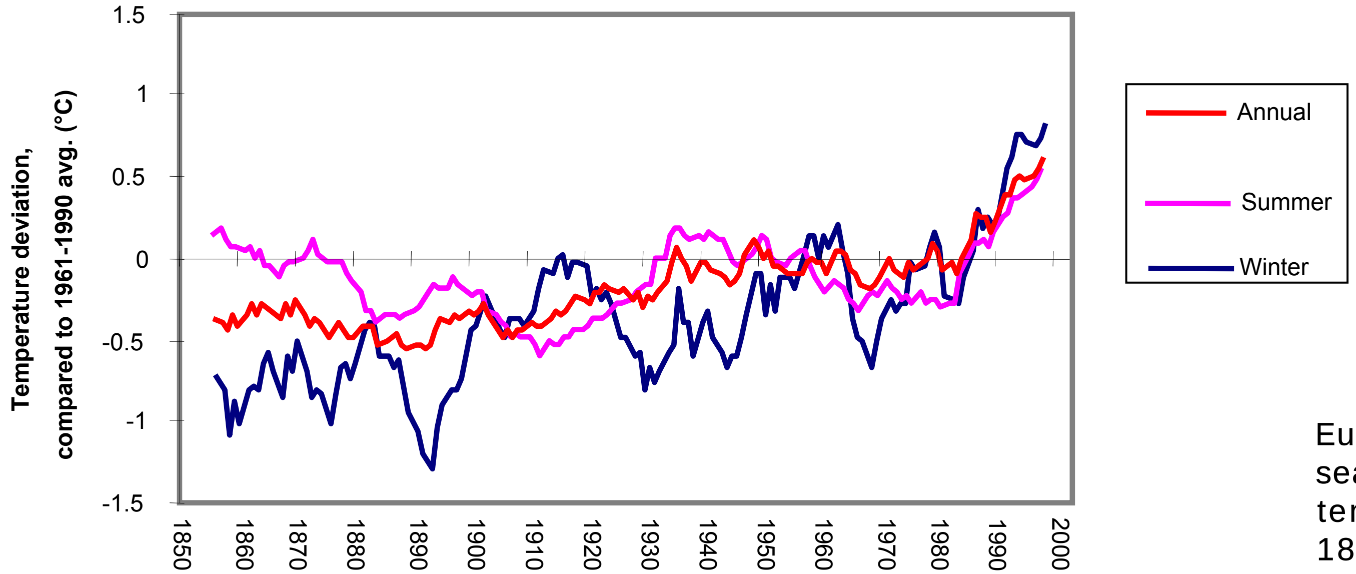
• Data base of spatial and tabular data

• Processing of vector and raster model input data adapted for specific model needs (e.g. land use, topography, soil type/texture, …)
  - data exchange in standardized formats
  - resampling (e.g. change of resolutions)
  - change of projection
  - tool boxes for hydrological applications
    (flow net, slope, etc from DEM)

• Visualisation of spatial data

• Trend towards web services: access of GIS functionalities without own programming over internet

Global Change – Global Warming



European annual and seasonal mean temperature deviations, 1850-2002

- Global temperature: + 0.7 ±0.2 °C in last 100 years
- Europe: +0.95 °C; **Alps +1.6°C**
- Summer +0.7°C ; Winter +1.1°C

Why Worrying About Temperature Increases?

- **Physical background**:
  1) warm air masses can carry more moisture
  2) increased temperatures yield increased potential evapotranspiration

- Consequence**: Intensification of water cycle**
  increased atmospheric humidity, increased precipitation amounts

- Changes in seasonality, regional distribution and intensities
  - large regional differences possible
  - small large scale changes can yield large regional impacts

- **Socioeconomic implications through changing 1) flooding risks**
  2) drought risks

Looking into the future: Climate Scenarios

Population Growth   Economic Development
Technological Progress

↓

Emission Scenarios
Greenhouse Gas Concentrations

↓

Global Climate Models

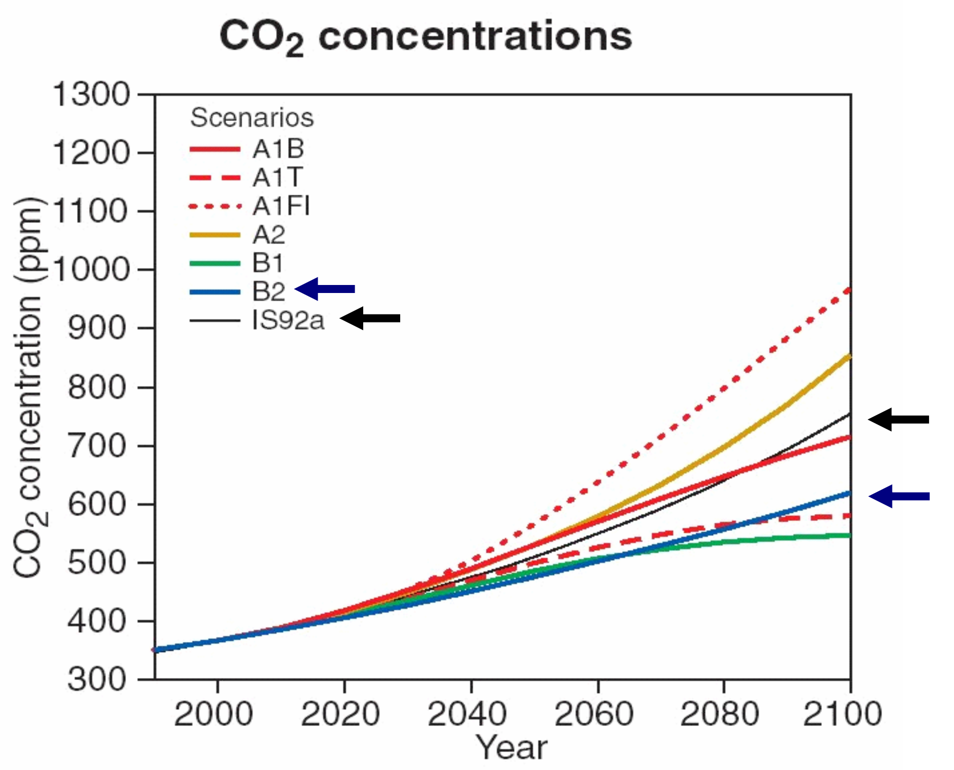
↓

Global Climate Scenarios

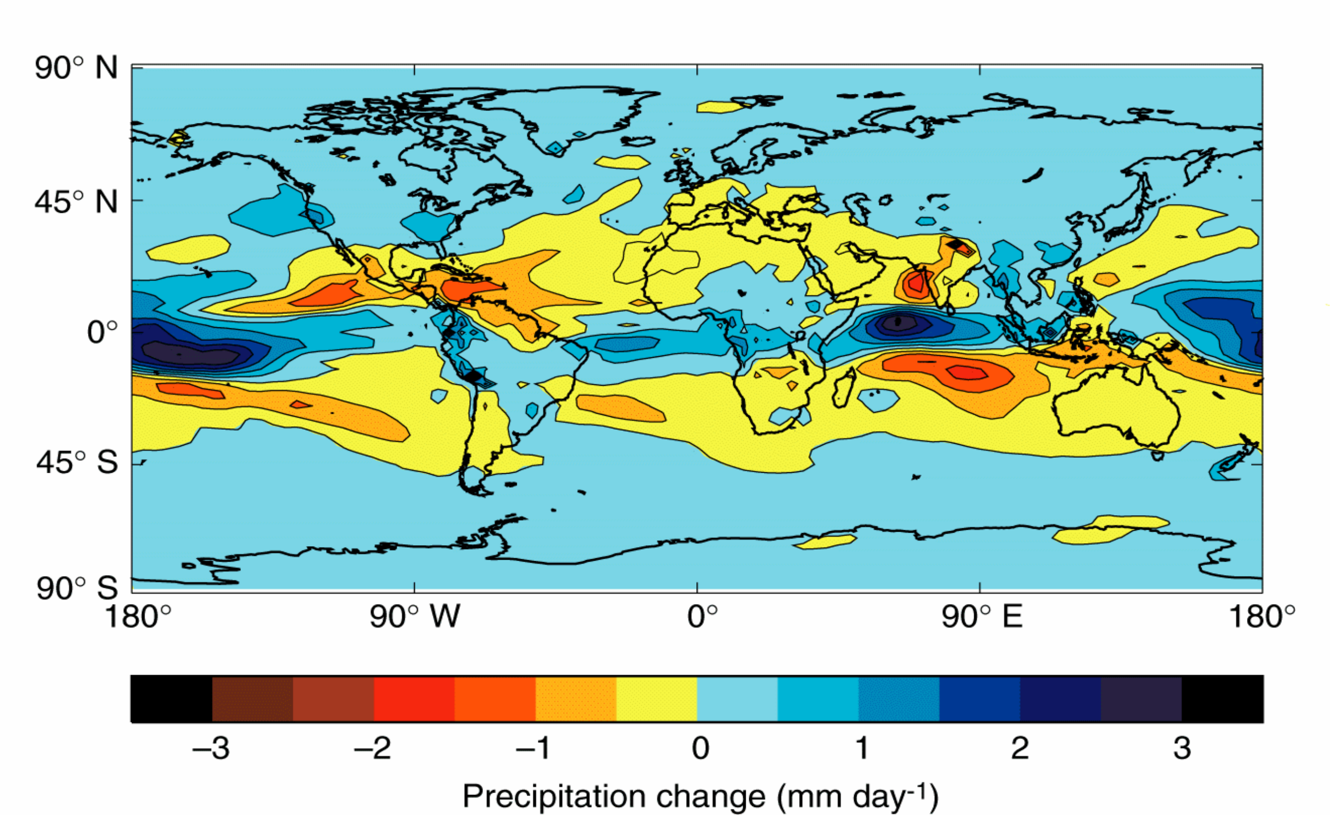
Looking into the future: Climate Scenarios

- **Our studies:**
  scenario B2 (*“local solutions“*)
  scenario IS92a (“business as usual”)

- Focus on time slices
  B2: 1960-1989 & 2070-2099
  IS92a: 1991-2000 & 2030-2039



Global Climate Scenarios: Projected Changes in Annual Precipitation for the 2050s



Hadley Centre for Climate Prediction and Research

⇒ Resolution too coarse for regional impact analysis !

Population Growth Economic Development
Technological Progress

⇩

Emission Scenarios
Greenhouse Gas Concentrations

⇩

Global Climate Models

⇩

Global Climate Scenarios

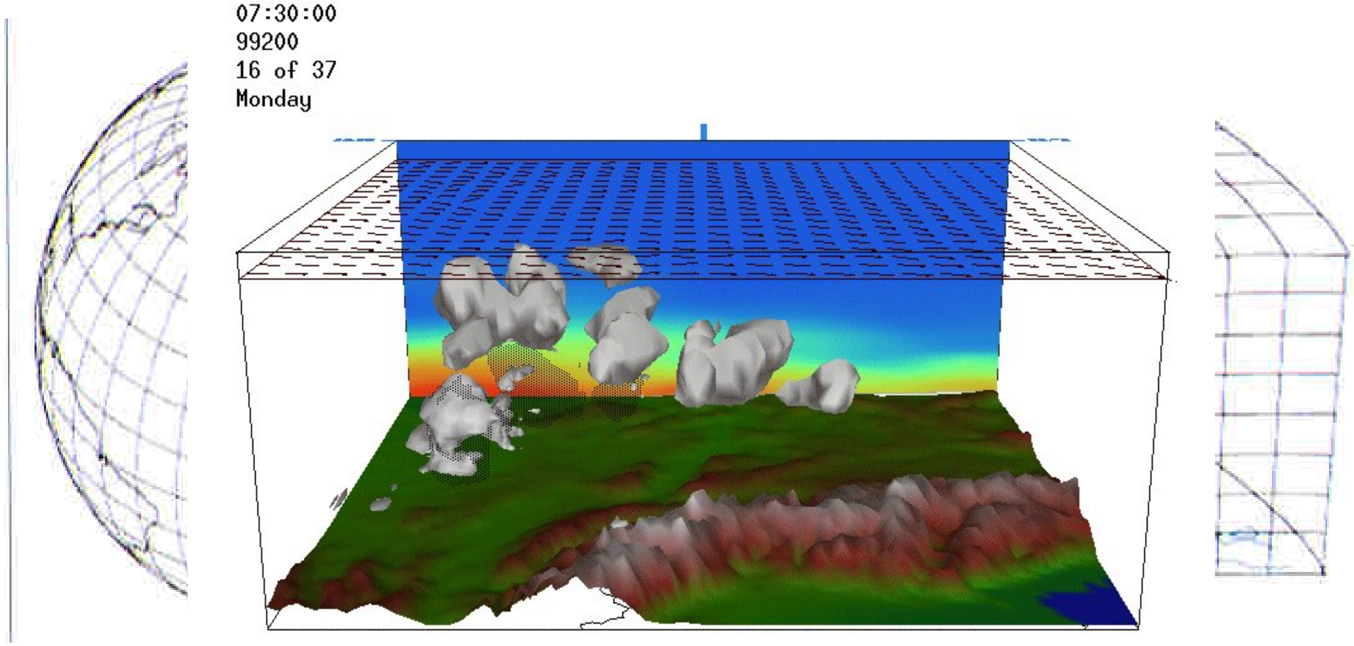
⇩

Downscaling Methods

⇩

Regional Climate Scenarios

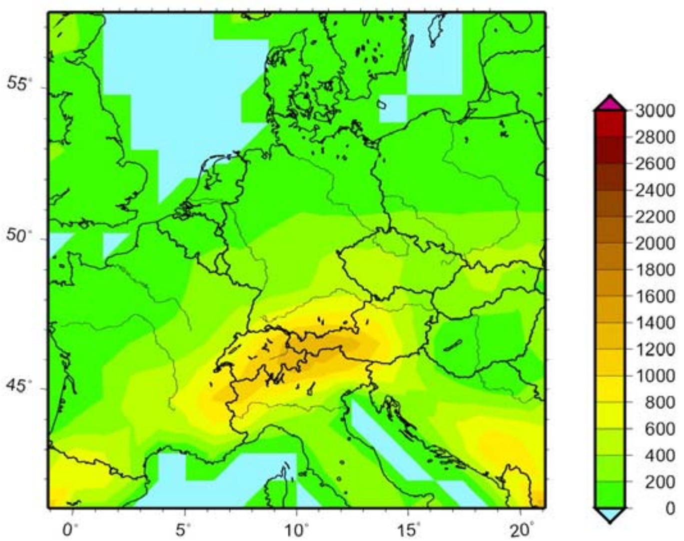
Looking into the Future: Regional Climate Modeling



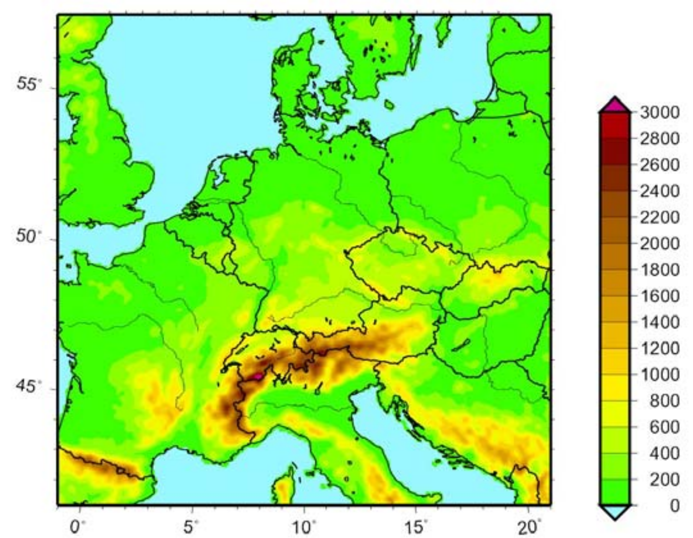
Explicit dynamical downscaling:
Numerical simulation of atmospheric processes
by finite difference schemes solving atmospheric PDEs

Looking into the Future: Regional Climate Modeling

Orography with different resolutions



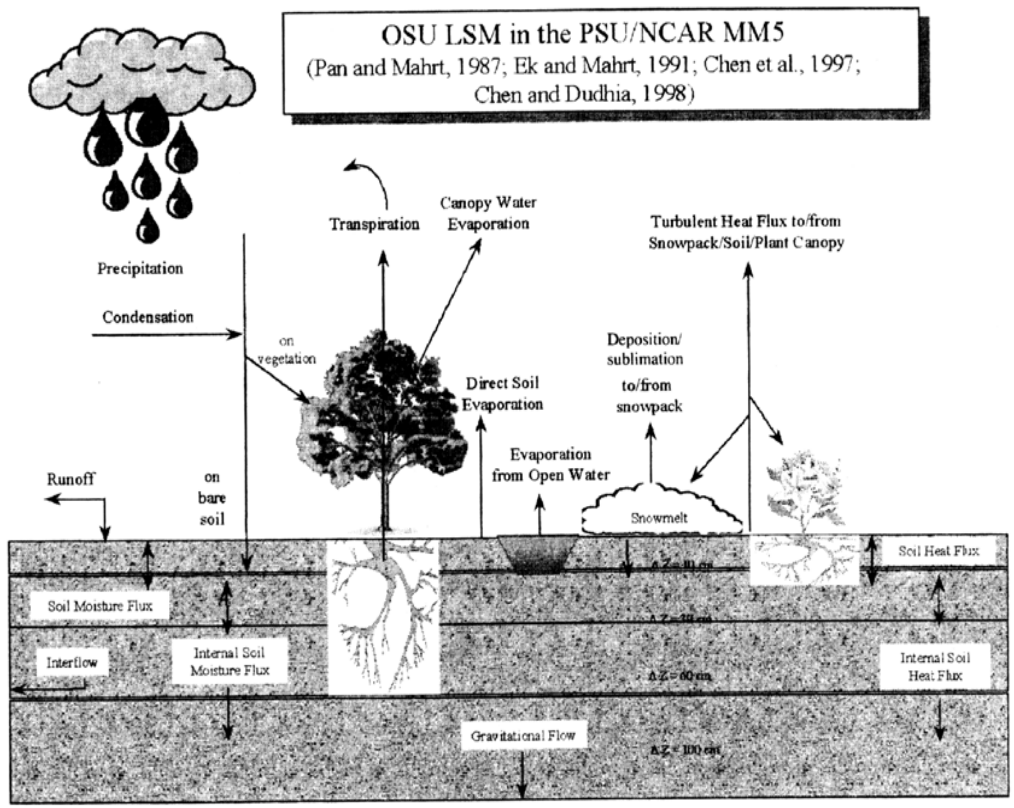
Δ = 100 km



Δ = 10 km

Looking into the Future: Regional Climate Modeling

Lower boundary for atmospheric model: SVAT-model



Accounting for soil-vegetation-atmosphere feedback effects

Examples

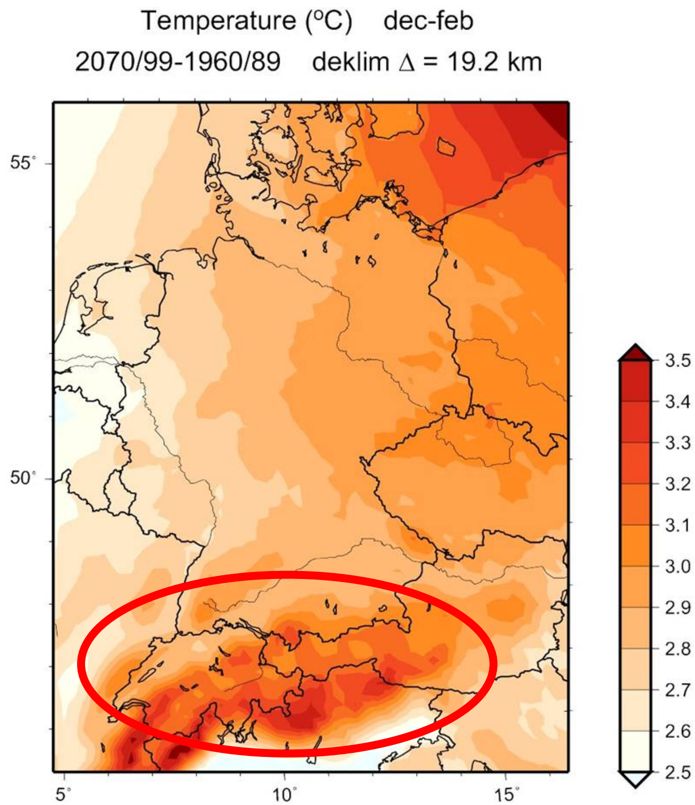
1) Germany
- **Changing flood risks?**
- **Changing snow conditions?**

2) West Africa: Volta Basin
- **Changing water availability?**

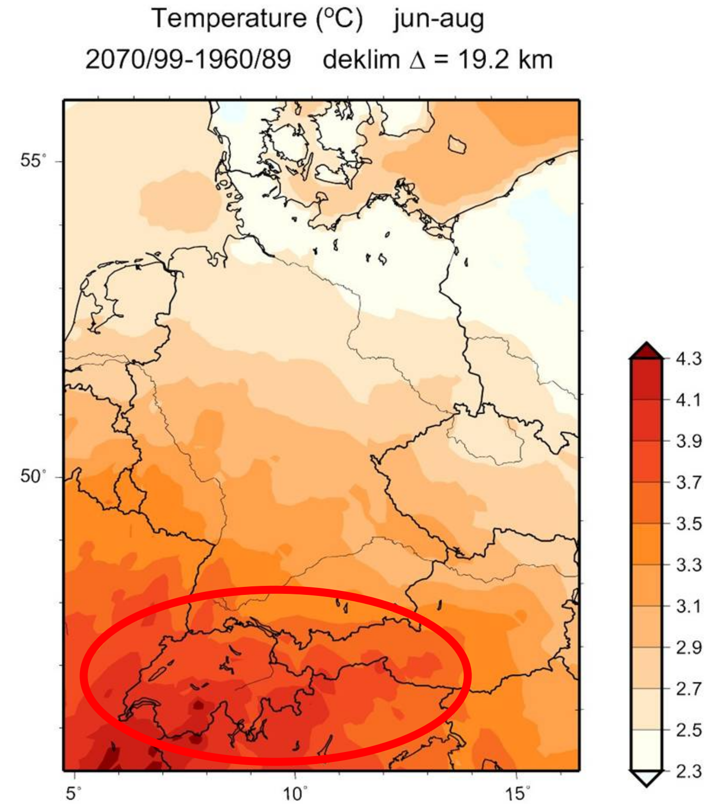
Example 1:

Regional Climate Change Germany

Regional Climate Change Germany



Winter

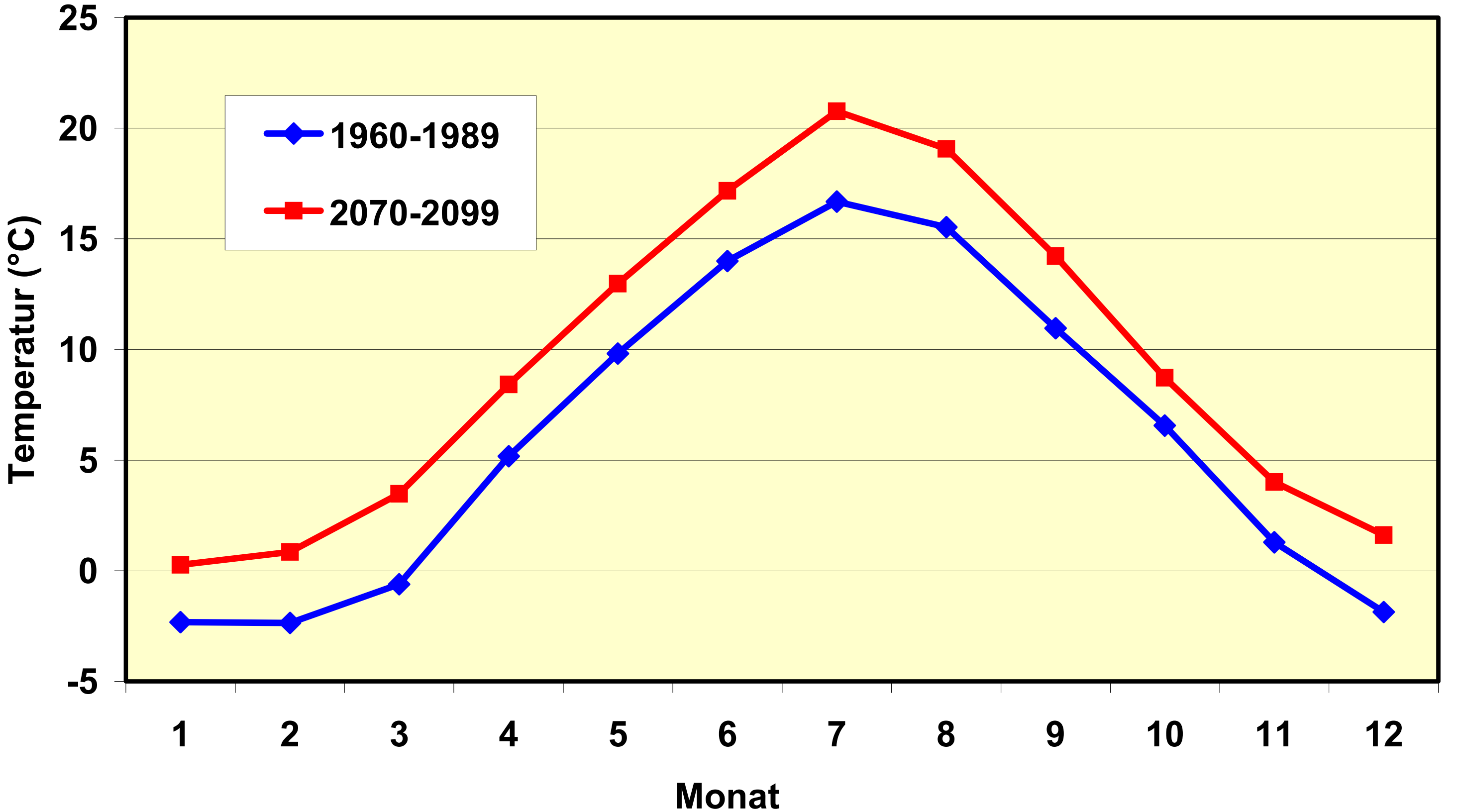


Sommer

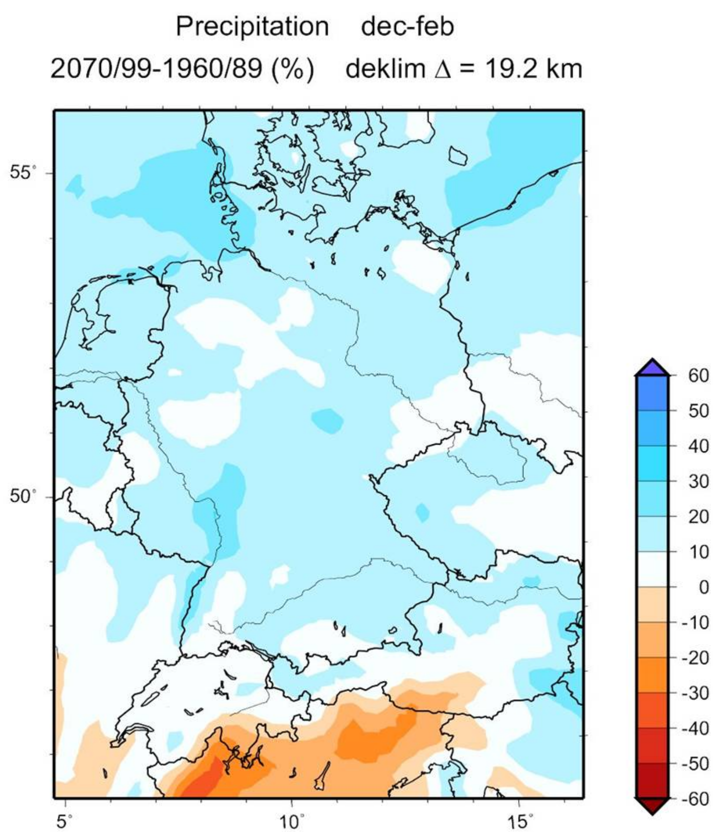
Alpine area: 3-4°C „hot spot“ in Europe

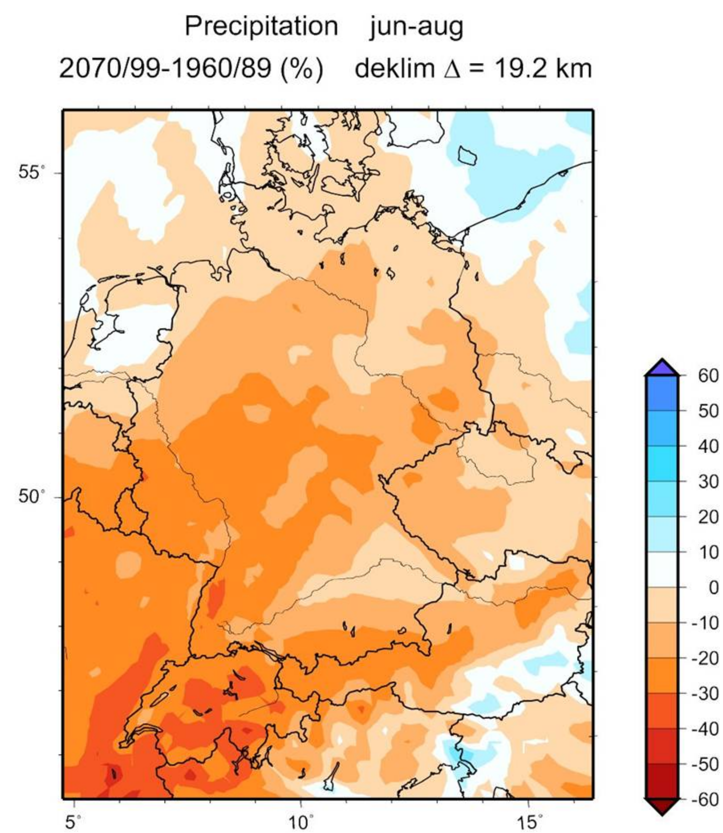
Regional Climate Change Southern Germany

Temperature Change [°C] , 2070-99 vs. 1960-89, Δ=19km



Regional Climate Change Germany

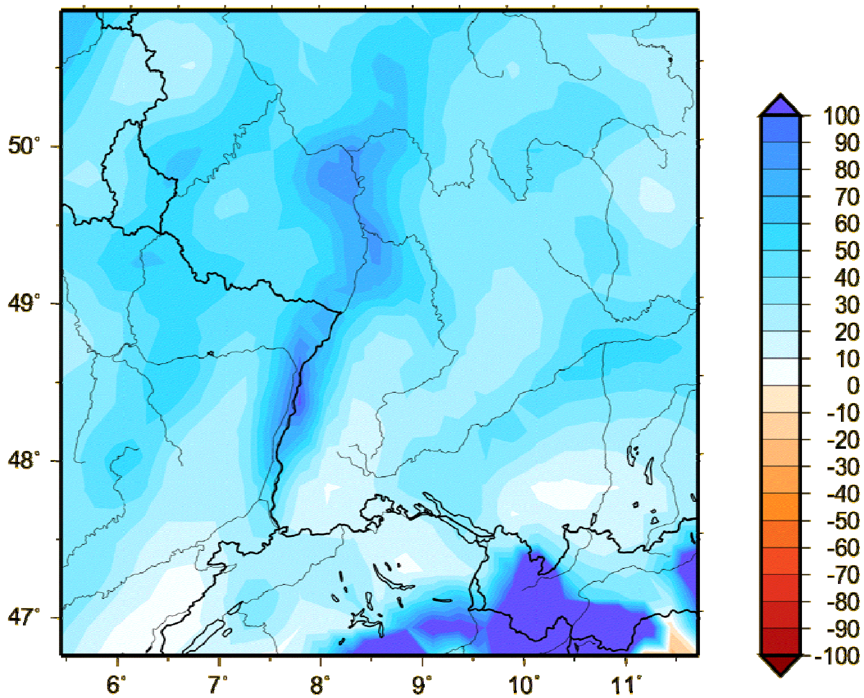




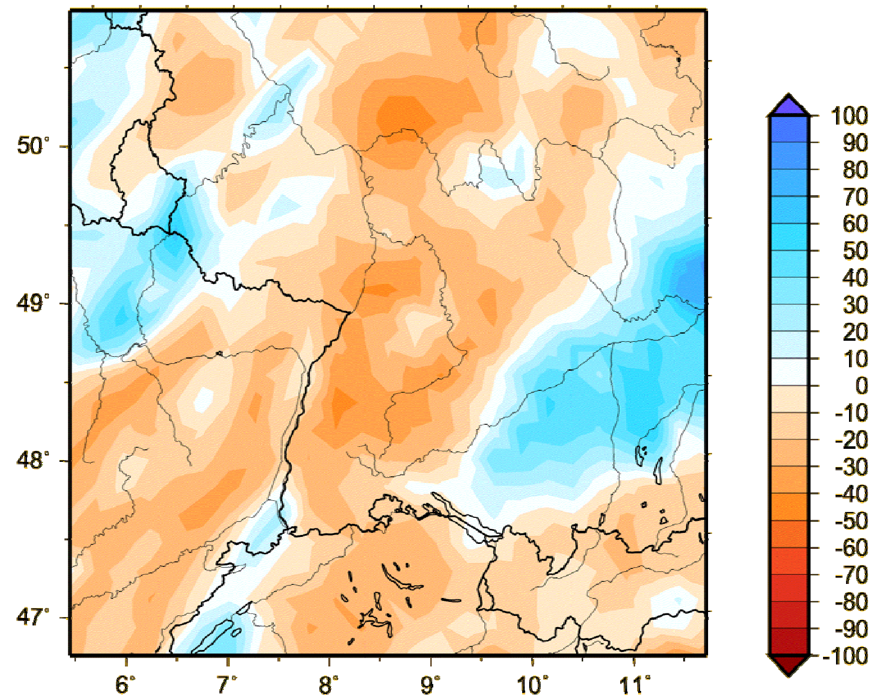
Up to 30% more precipitation in winter (Europe ≈ +11%)
Up to 40% less precipitation in summer (Europe ≈ -1%)

Regional Climate Change South West Germany

Surface Runoff Change [%], 2070-99 vs. 1960-89, Δ=19km



Winter DJF

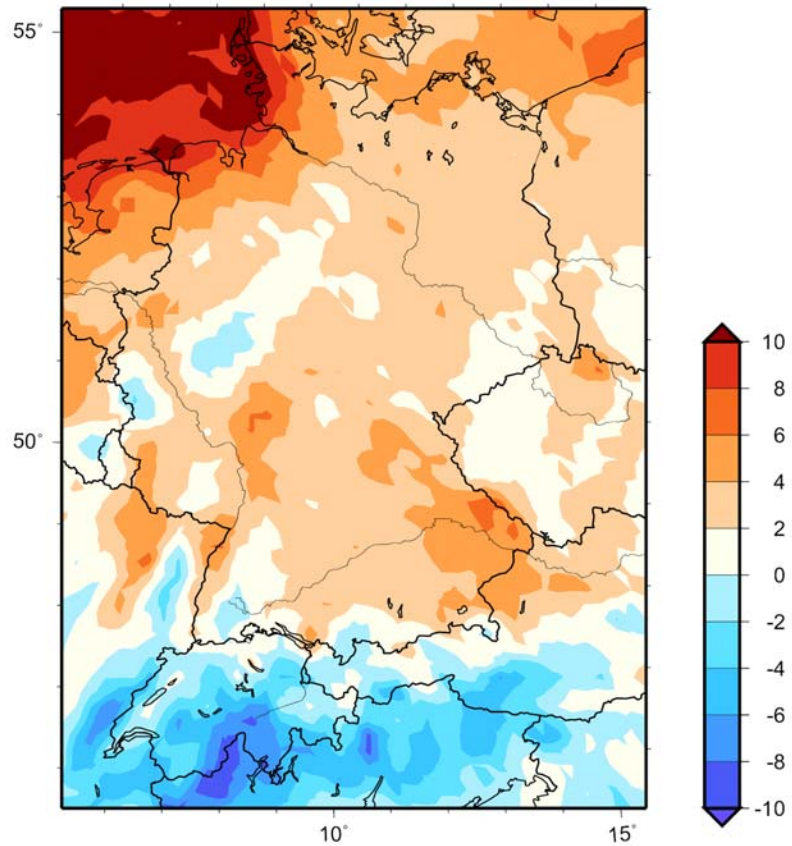


Summer JJA

Up to 80% more surface runoff in winter
Up to 50% less surface runoff in summer

Regional Climate Change Germany

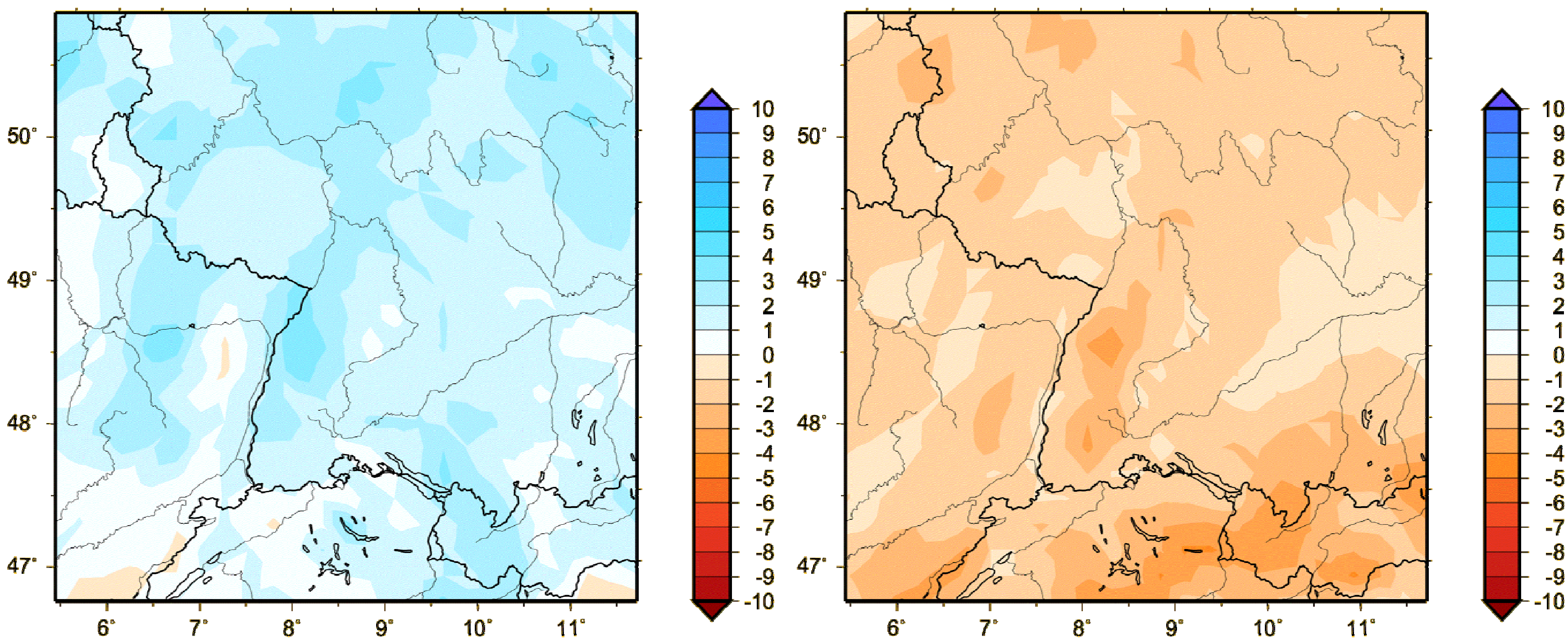
Change in frequency of heavy precipitation (2070-99 vs. 1960-89)



Change in number of days/year P > 10 mm

Regional Climate Change South West Germany

Change in frequency of heavy precipitation P > 10mm



Winter DJF

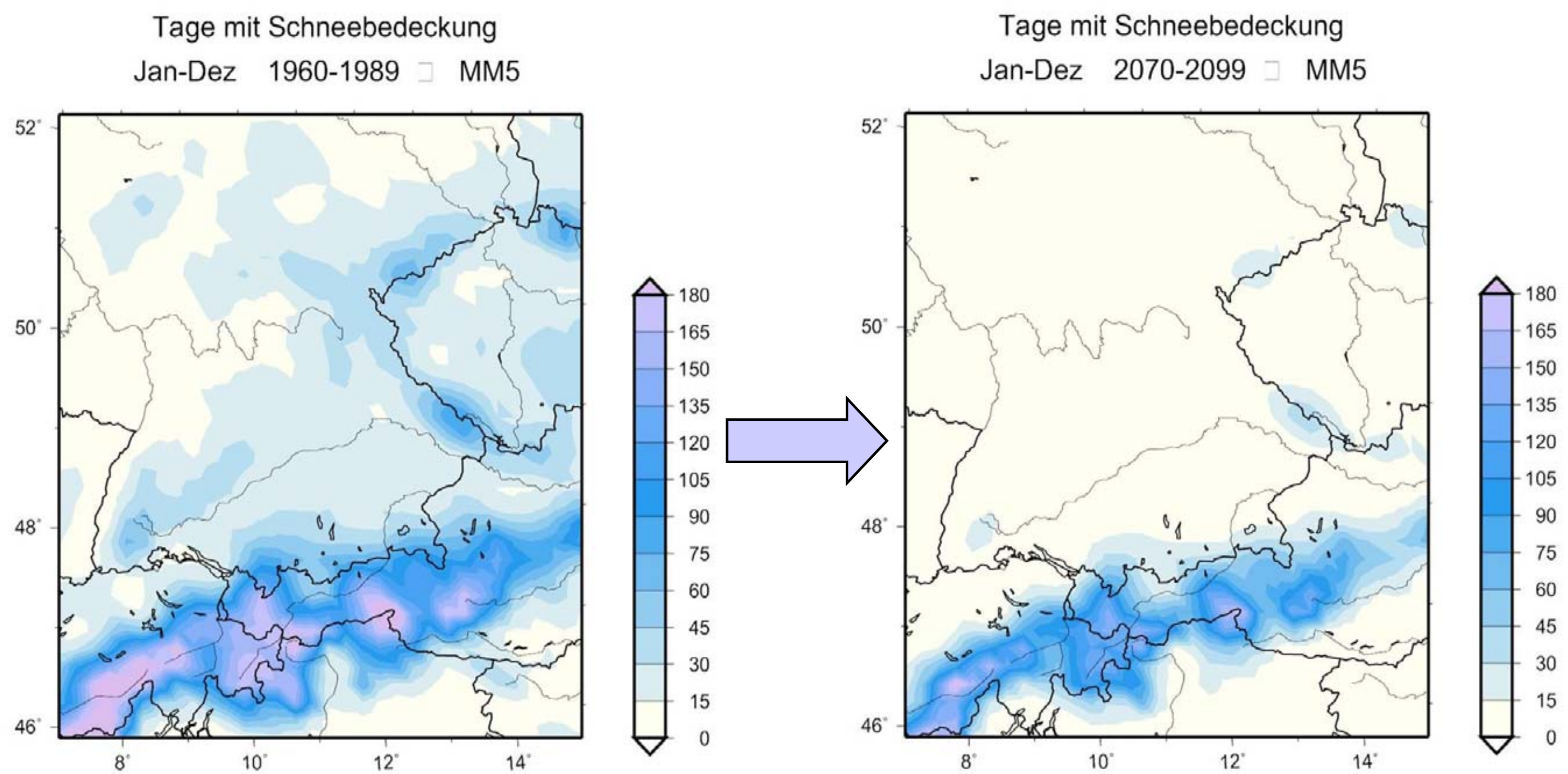
Summer JJA

Increase of days with heavy precipitation in winter

Decrease of days with heavy precipitation in summer

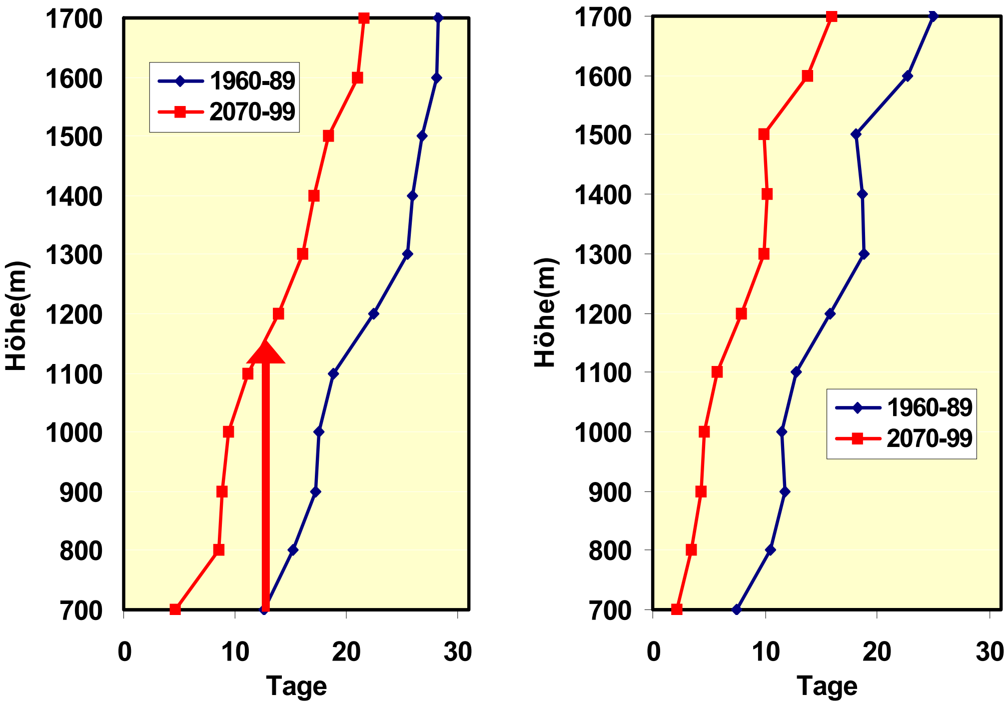
Regional Climate Change

Days with Snow Cover



Decrease of number of days with snow cover

Regional Climate Change: Northern Alpine Area



January

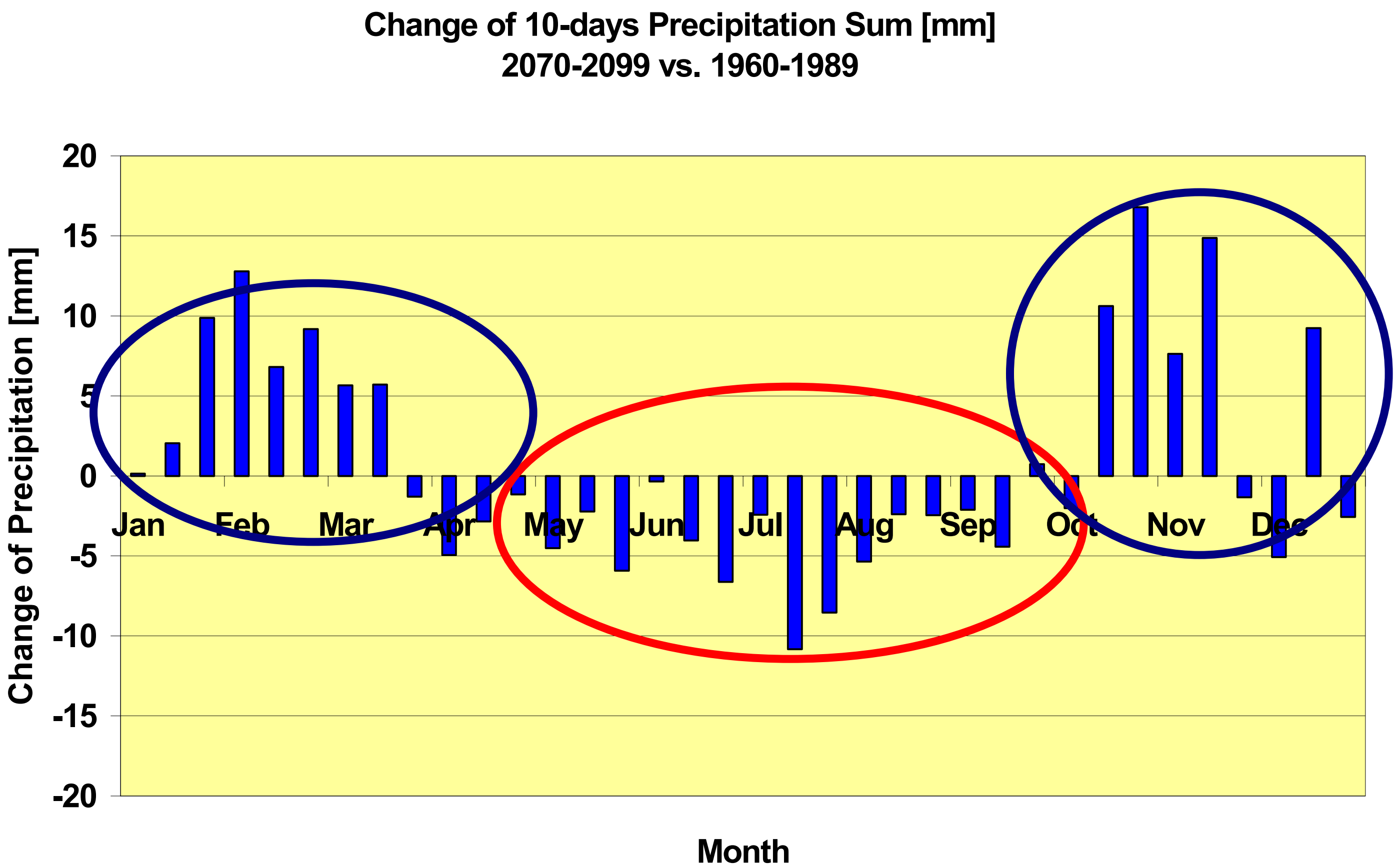
March

Days with Snow cover

Changes of snow cover with height: ≈ 500m

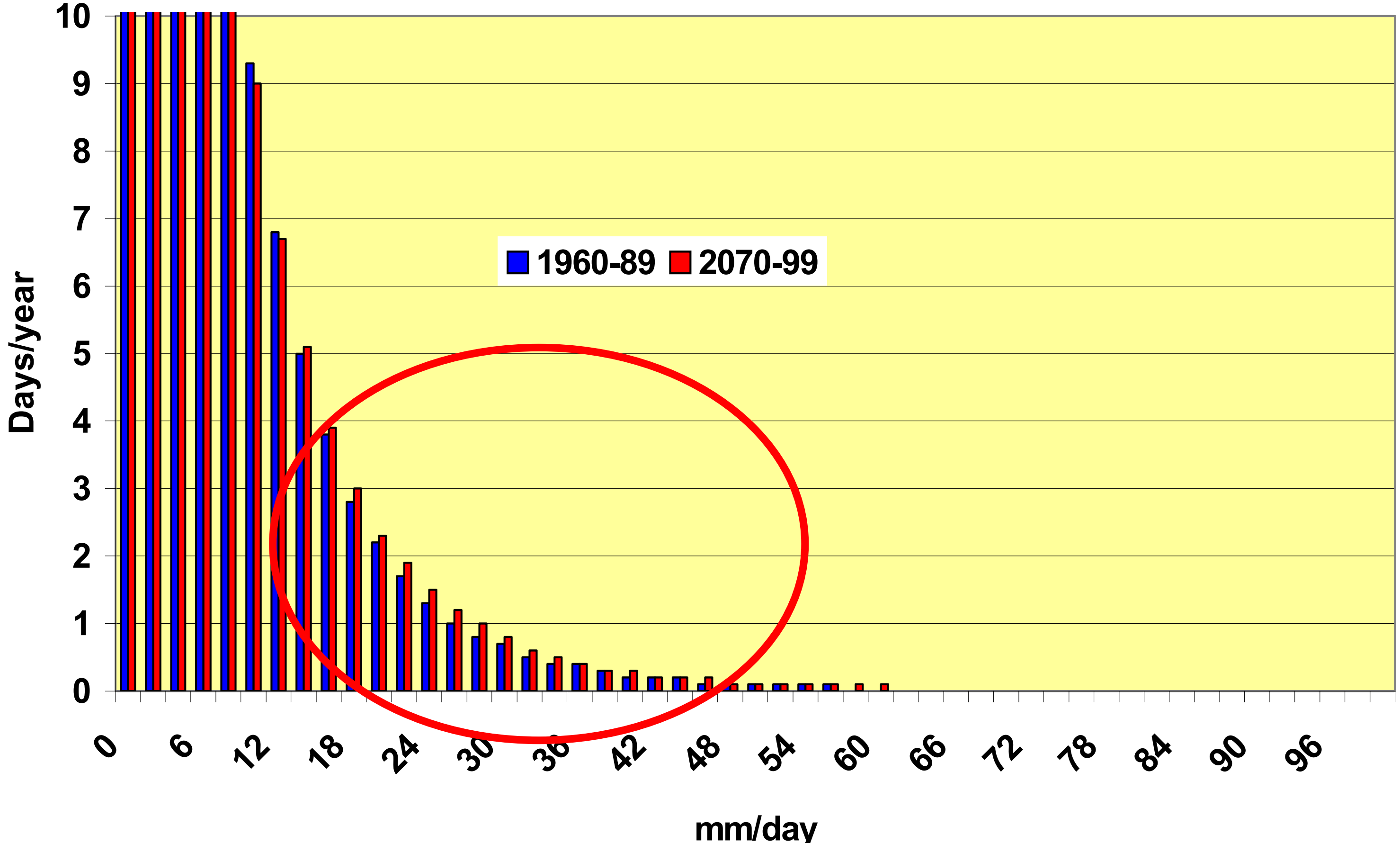
⇒ Runoff amplification

Regional Climate Change South West Germany



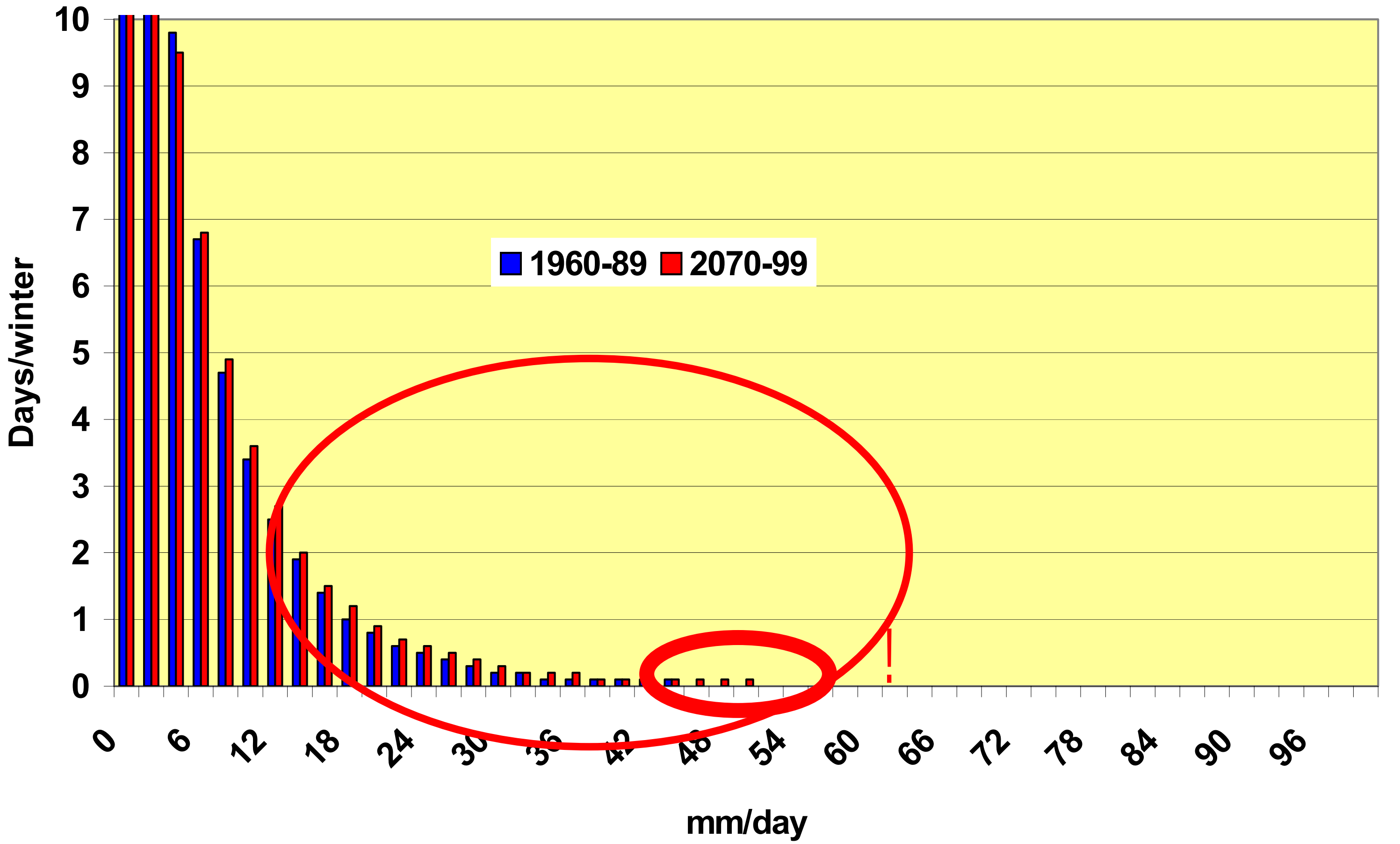
Increased winter-, decreased summer precipitation

Regional Climate Change South West Germany



Increase of frequency of heavy precipitation

Regional Climate Change South West Germany



Winter (DJF): Increase of frequency of heavy precipitation

Impact of Climate Change on Runoff Germany

Change in runoff characteristics

1) less pronounced low water in wintertime
   increase of wintertime flooding
   (snow ↓, precipitation ↑)

2) decrease in summer runoff
   - anticipated precipitation decrease
   - reduced snow melt water
   - increased evapotranspiration

3) Reduction of buffering by glaciers

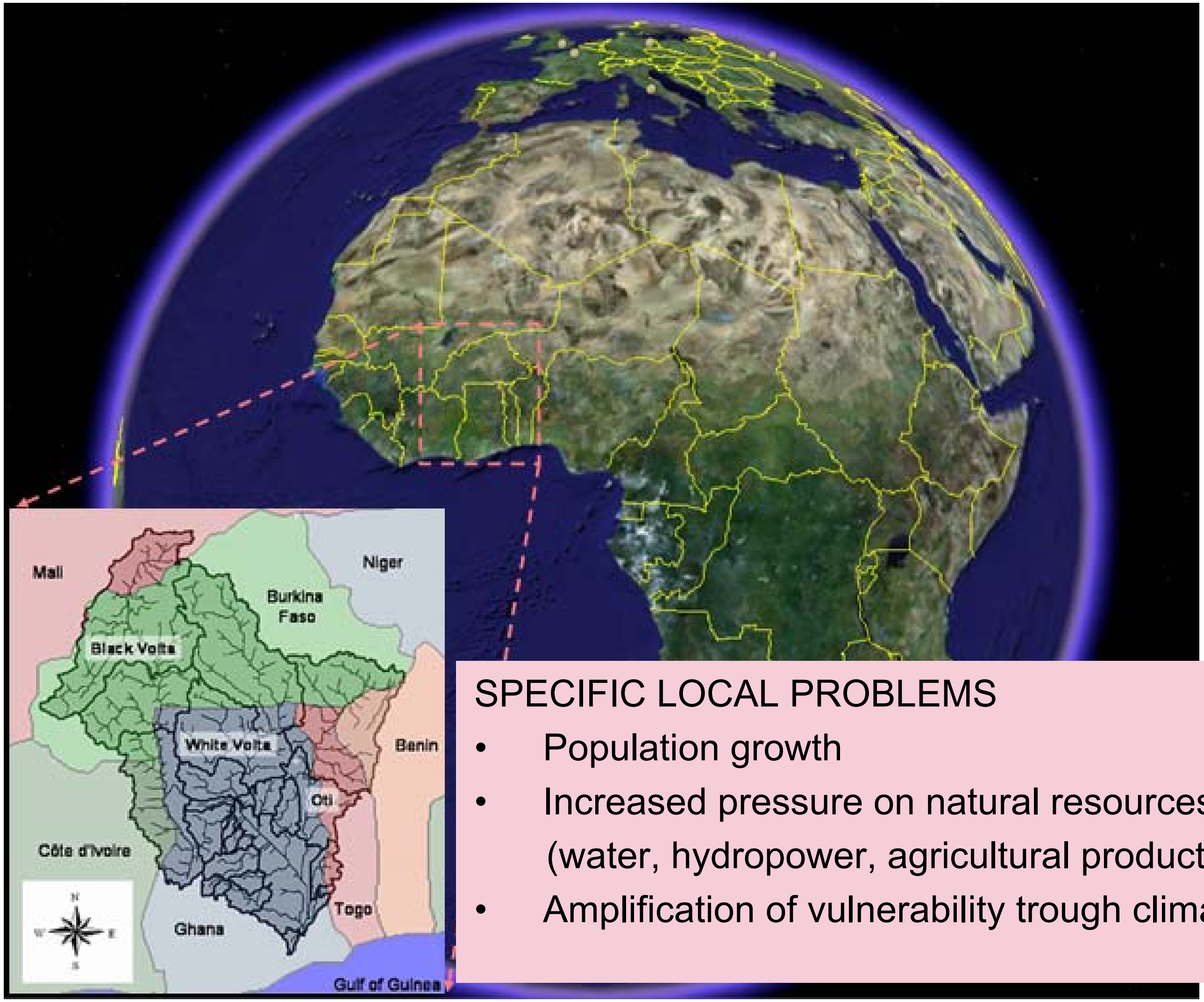
⇒ tendency towards smoothed runoff characteristics

But: - in general increased flooding risk (increase in heavy precipitation)
- large regional differences

Example 2:

Regional Climate Change

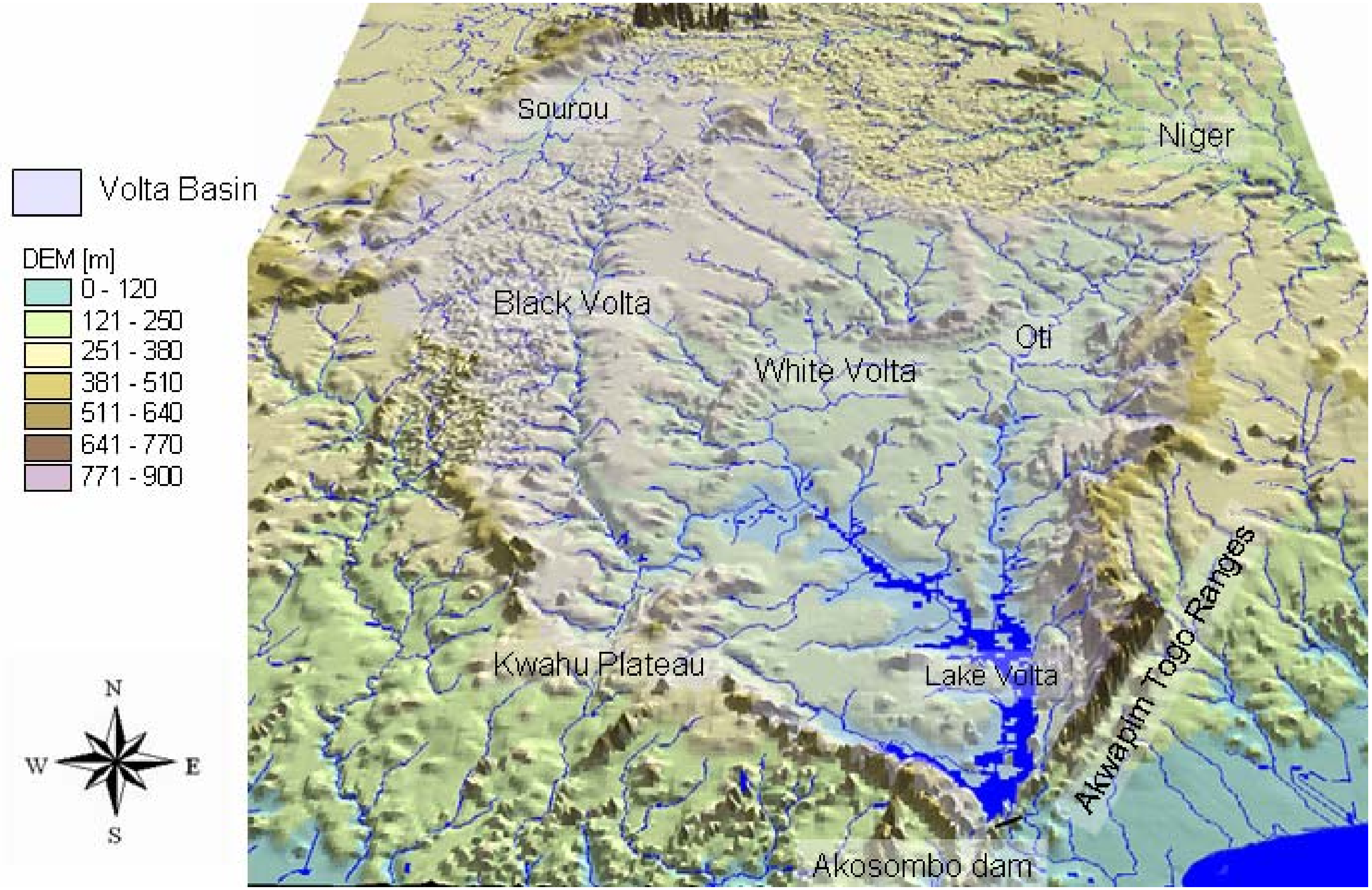
West Africa & Volta Basin



SPECIFIC LOCAL PROBLEMS

- Population growth
- Increased pressure on natural resources (water, hydropower, agricultural products)
- Amplification of vulnerability trough climate chnage?

The Volta Basin



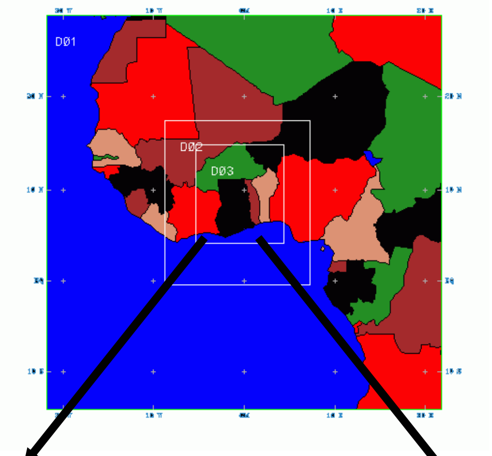
Research question

How does atmospheric change translate into change of terrestrial hydrology?

Methodology: 1-Way Coupled Meteorology-Hydrology Simulations

- Temperature
- Precipitation
- Wind
- Relative Humidity
- Global Radiation

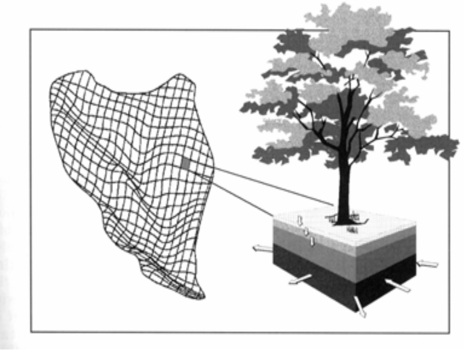
MM5
3-dim
Atmospheric model



2.5x2.5° → 9x9 km^2 Resolution

WaSiM
Distributed Hydrological
Modell

- Orography
- Land Use
- Soil Properties
- Aquifer Properties
- Flownet Structure



1000x1000 m^2 Resolution

Evapotranspiration **Infiltration** **Surface Runoff** **Groundwater Flow**

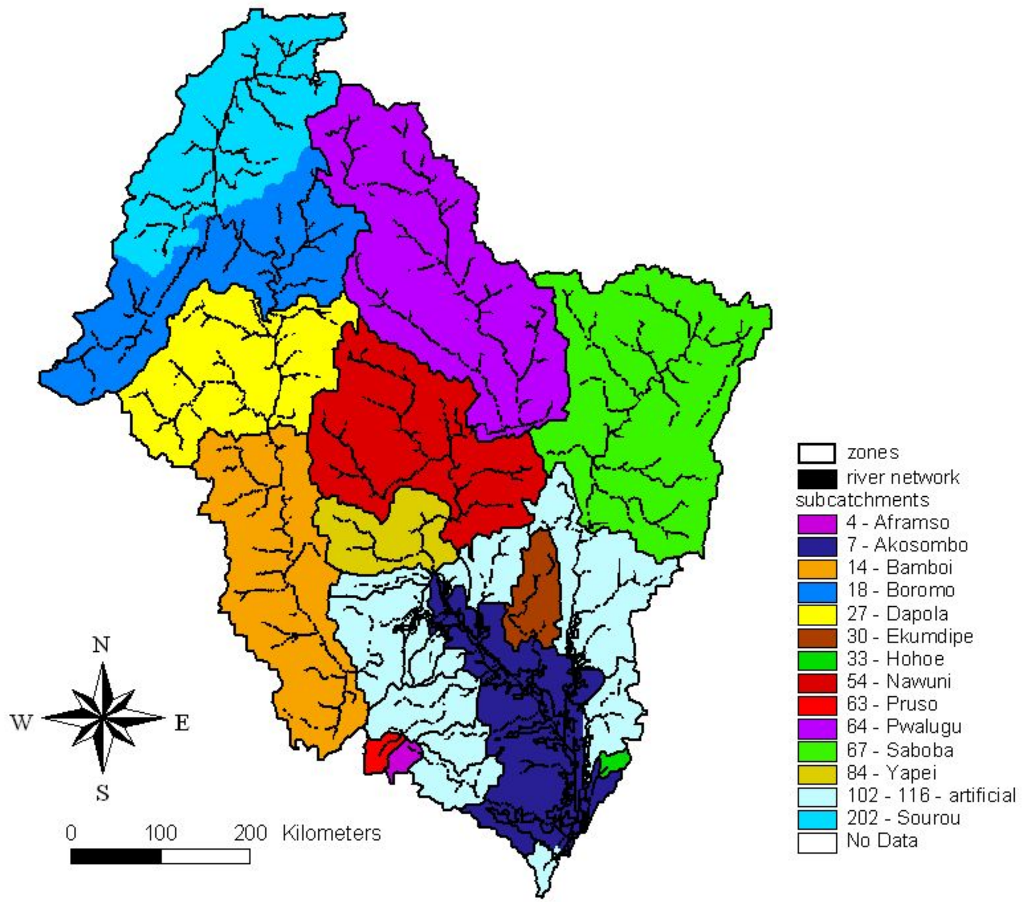
Setup Hydrological Model

Total Area 400.000 km²

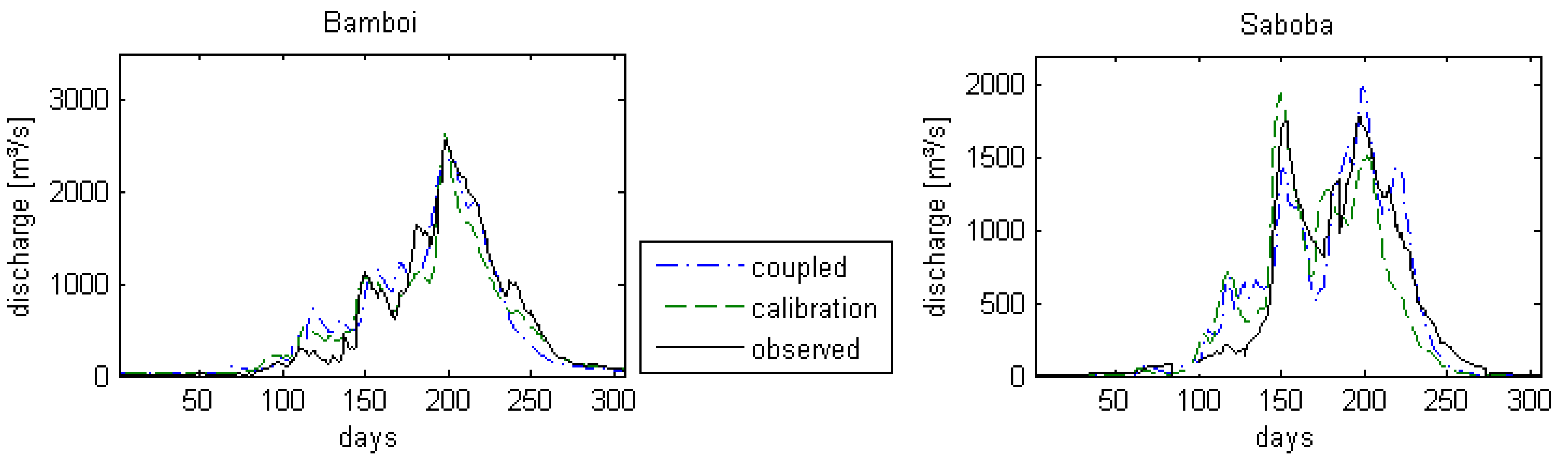
Horizontal resolution
1x1km²

Vertikal resolution
20x1m

Temporal resolution
1 day



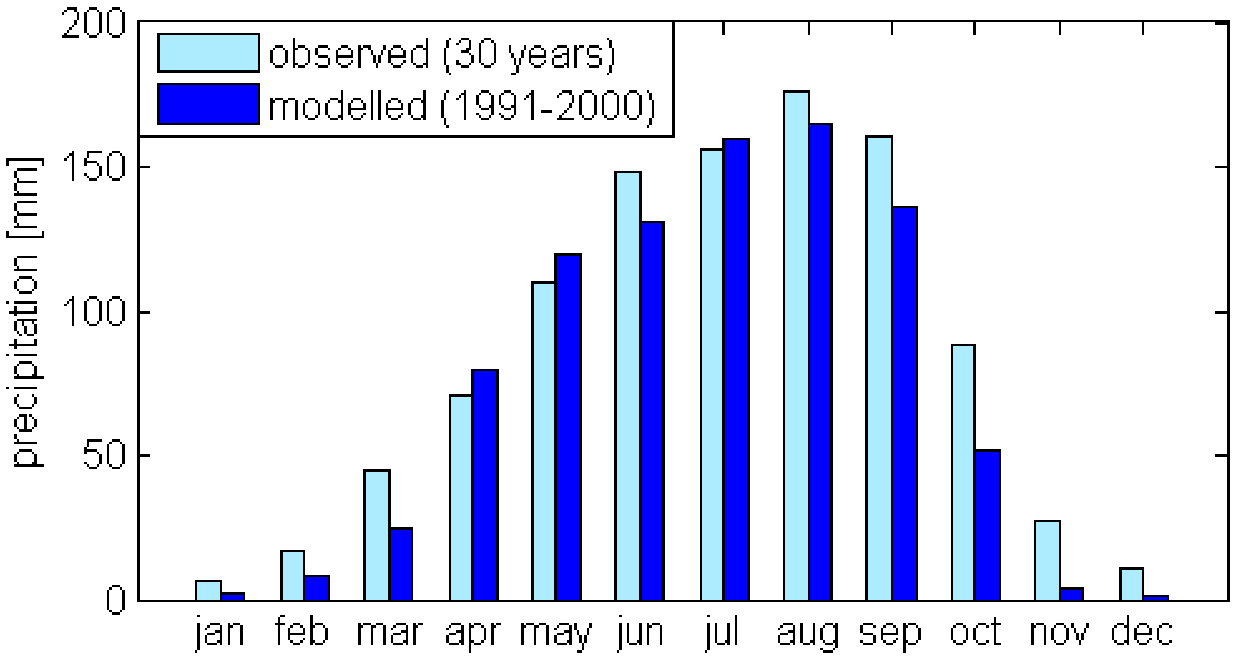
Performance of Coupled Model System



⇒ Satisfying model performance

⇒ model is suited to reproduce hydrological processes in Volta Basin

Validation Regional Climate Simulations

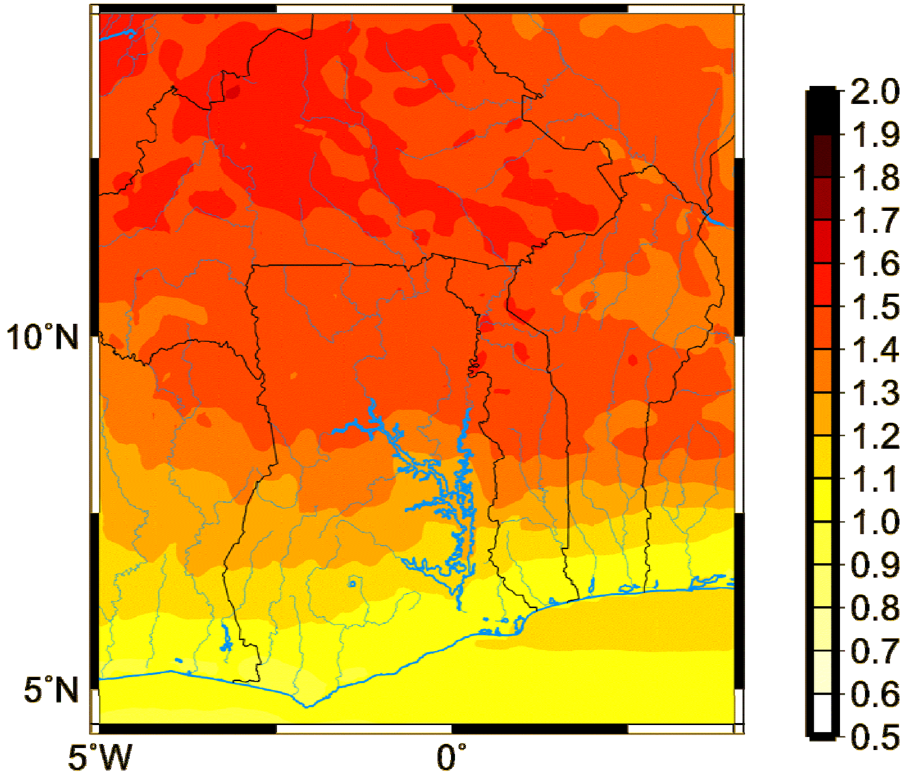


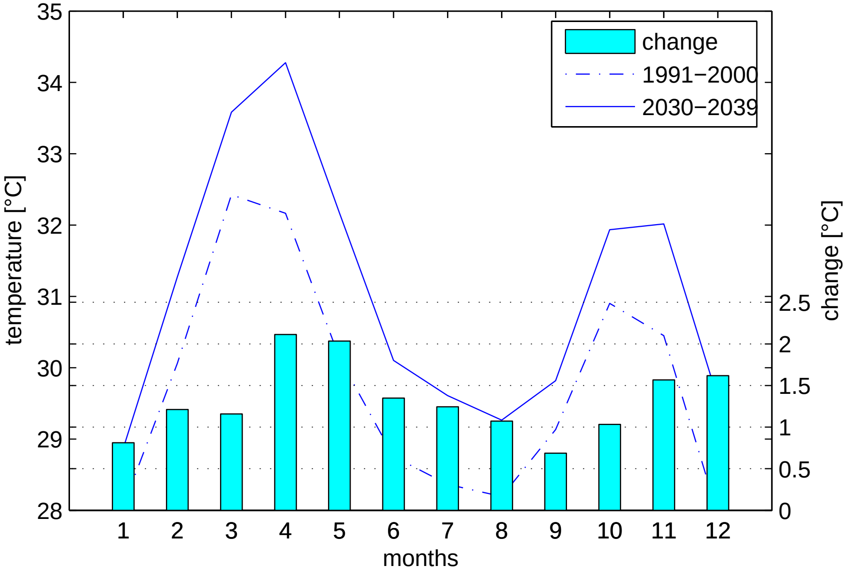
Mean monthly precipitation [mm] domain3

⇒ Satisfying reproduction of annual precipitation course & monthly amounts

Results Regional Climate Simulations

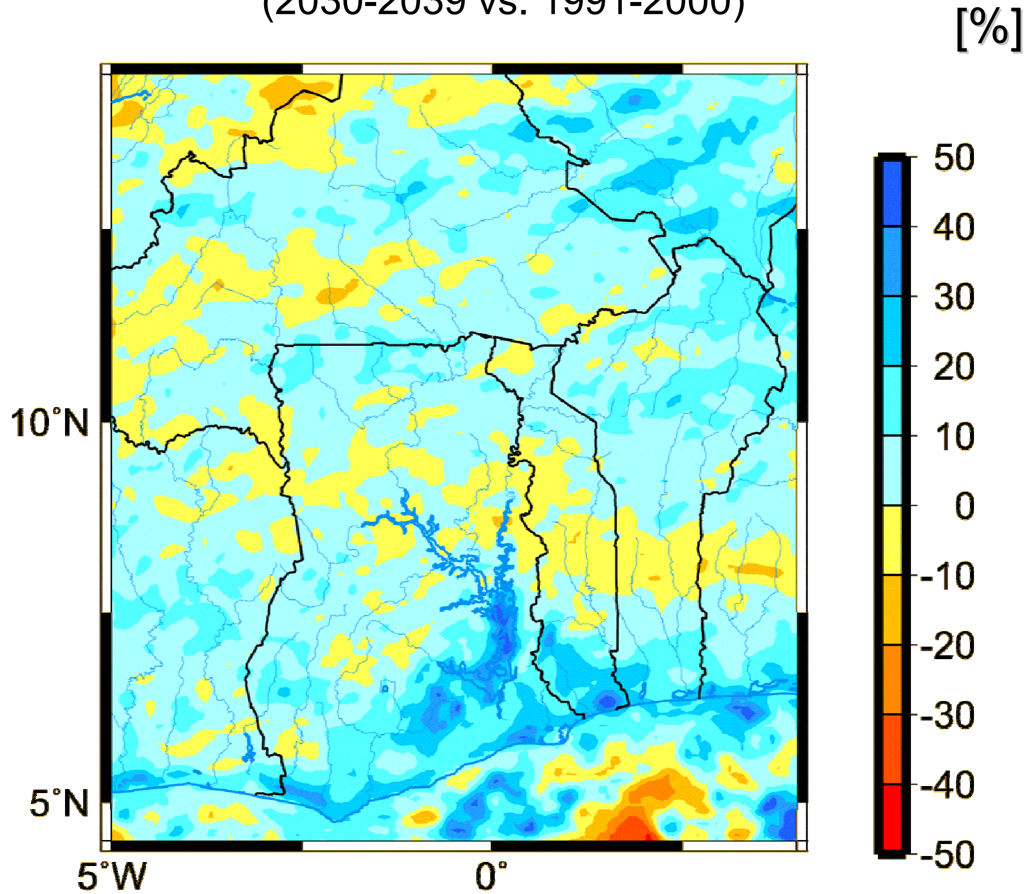
Temperature Change [°C]
(2030-2039 vs. 1991-2000)



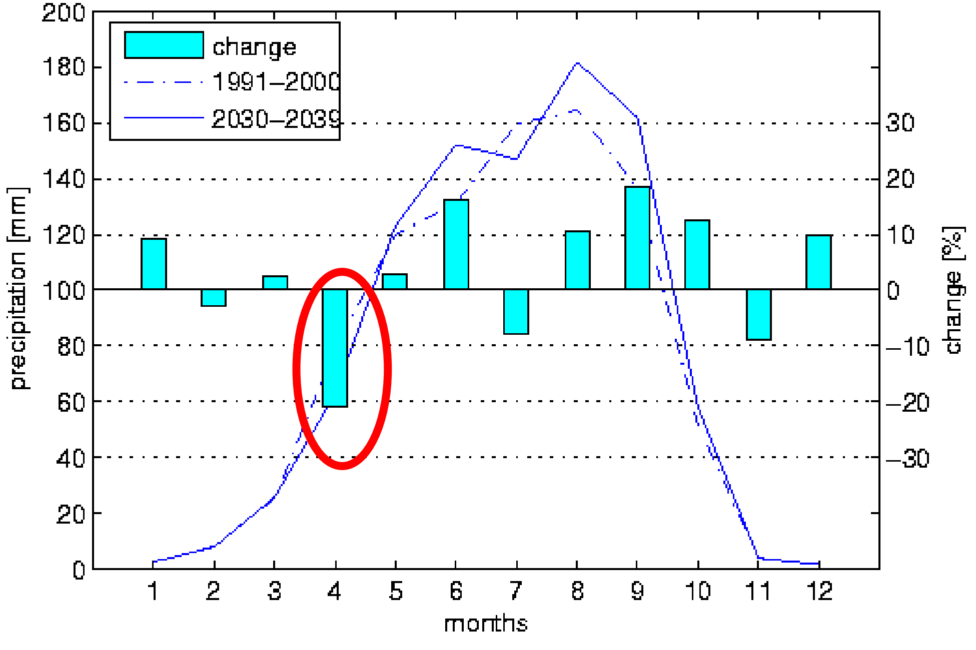


Results Regional Climate Simulations

Precipitation Change [°C]
(2030-2039 vs. 1991-2000)



Results Regional Climate Simulations



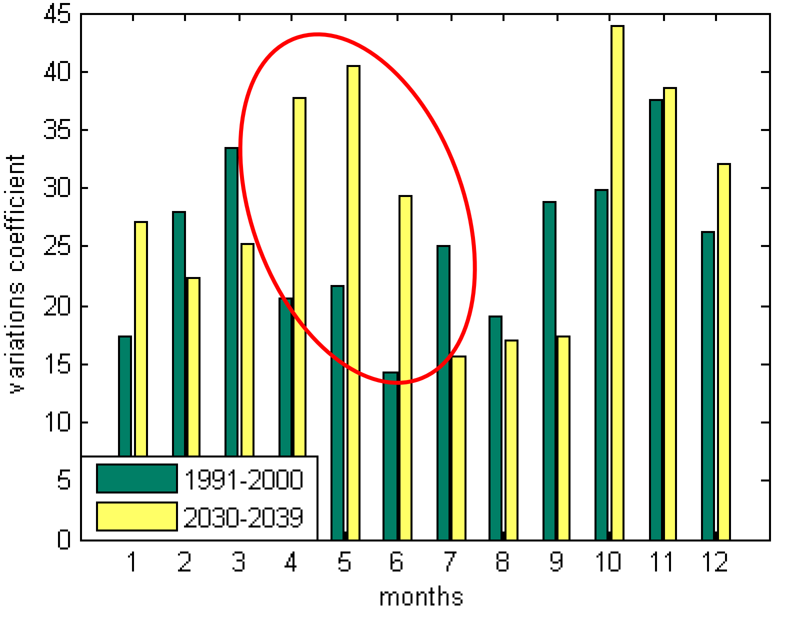
⇒ Significant decrease of precipitation in April (onset rainy season)

Änderung im Beginn der Regenzeit

	Sahel	Guinea Coast
1991-2000 [DOY]	124	105
2030-2039 [DOY]	133	108
Mittlere Änderung [days]	9	3

Interannual variability

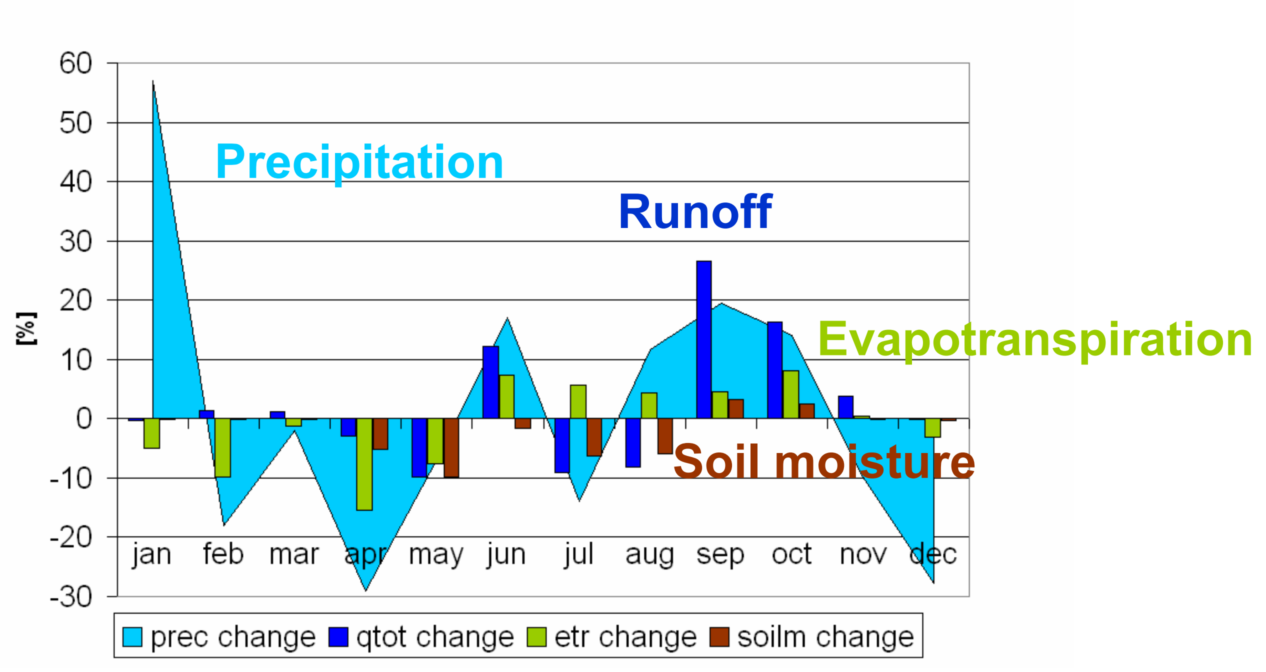
$$\mathrm{var} = \frac{\sigma}{\overline{X}} 100$$



Definition des Regenzeitbeginns
(Stern et al. 1981)

⇒ Verzögerung im Regenzeitbeginn
⇒ Zunahme der interannuellen Variabilität

Results Regional Climate Simulations



⇒ **Nonlinear response of runoff change with respect to precipitation change**

Summary and conclusions

- *Regional* climate modeling required to get *spatial* information for decision making in risk analysis, water management, etc.

- Regional differences:
  1) regional climate change differs from global signal
  2) focus not only on floods but also on droughts

⇒ **challenge for sustainable water & landscape management**

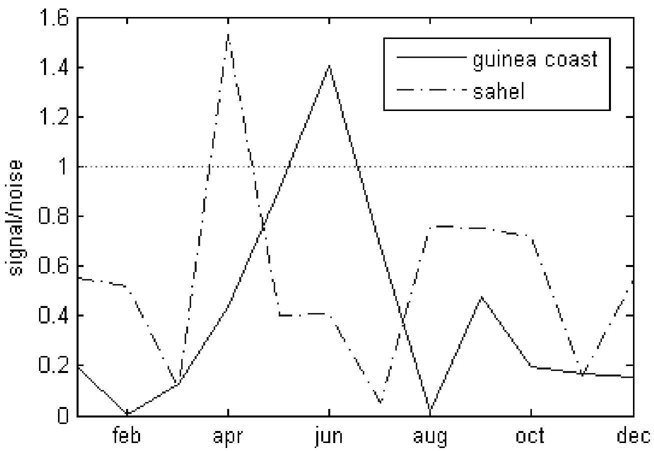
- Changes in spatial and temporal distributions (⇒ change in statistics!)

- Necessity for new early warning systems

- Only possible with GIS …

Danke für die Aufmerksamkeit

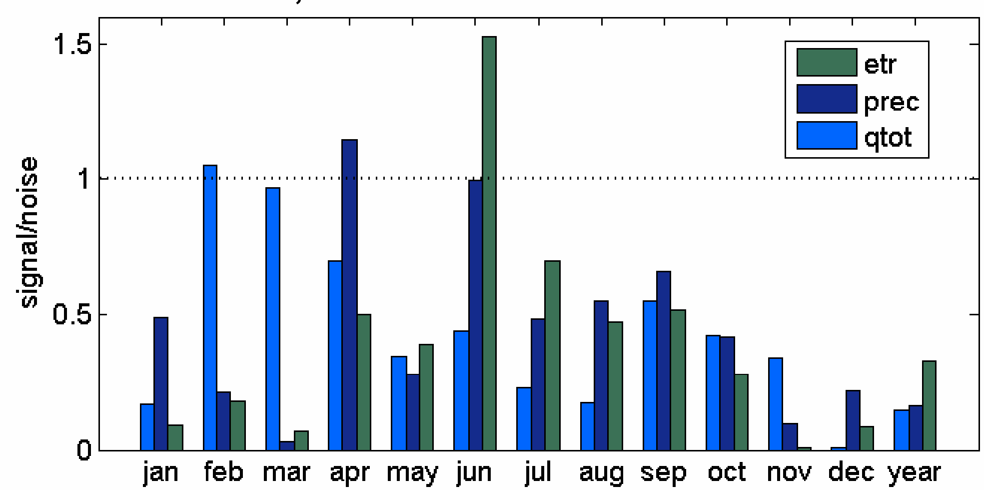
Signal to Noise Verhältnis: $SN = \frac{|\bar{X}_{fut} - \bar{X}_{pres}|}{\sigma}$



SN Niederschlag, Domain1

Temperatur:
SN=3.9 (Domain1)

SN für Niederschlag, Verdunstung und Abfluss, Volta Basin

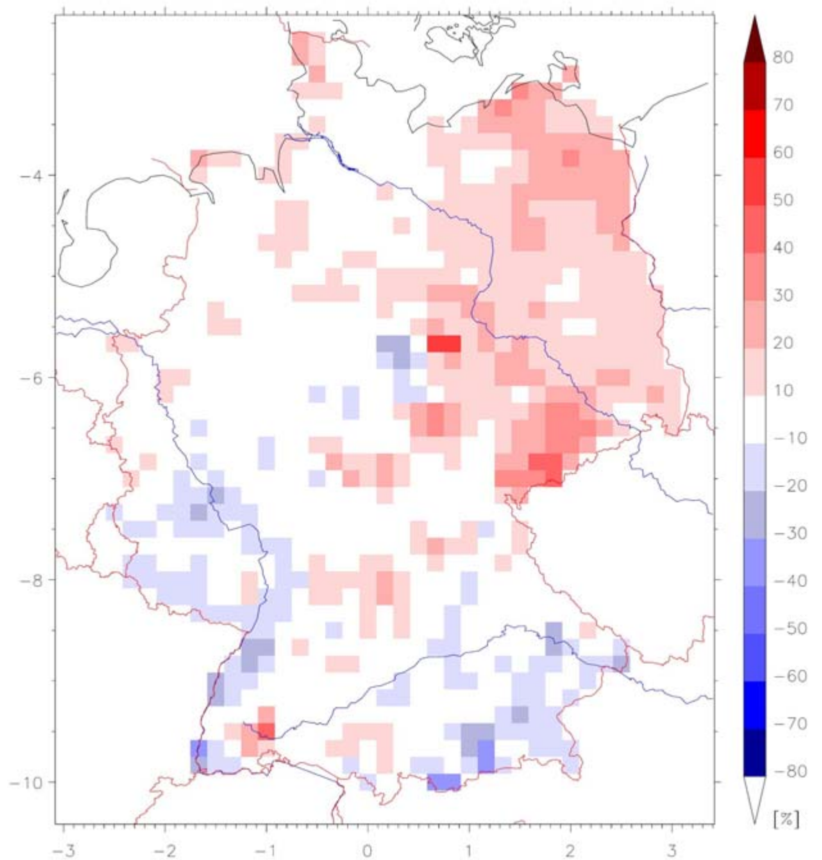


⇒ Klimaänderungssignal liegt fast ausschließlich im Bereich der interannuellen Variabilität

Evaluation of Regional Climate Models

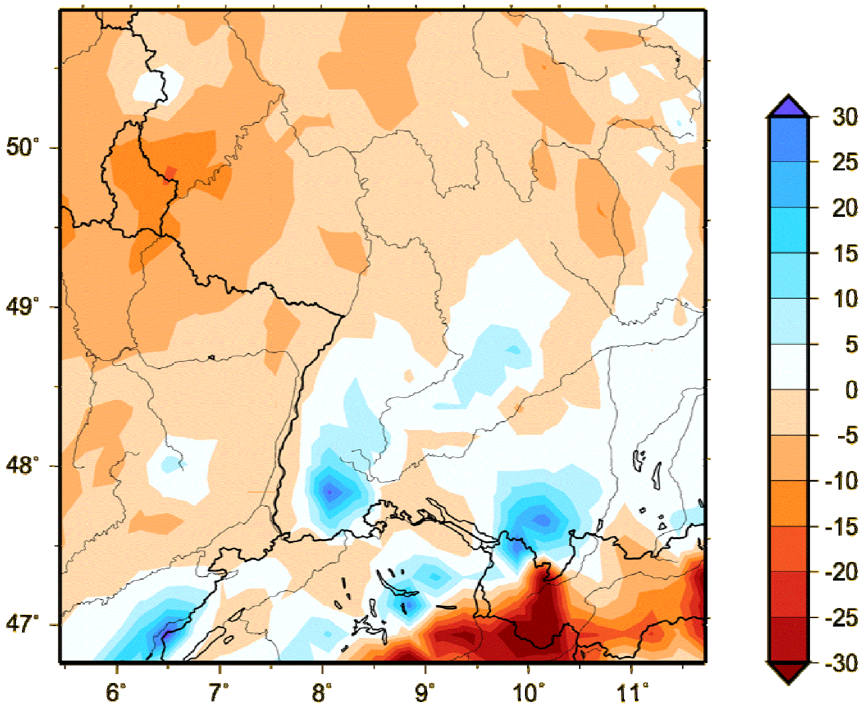
Deviation of annual precipitation (%)

MM5-Simulation (IMK)
vs.
DWD-Observation

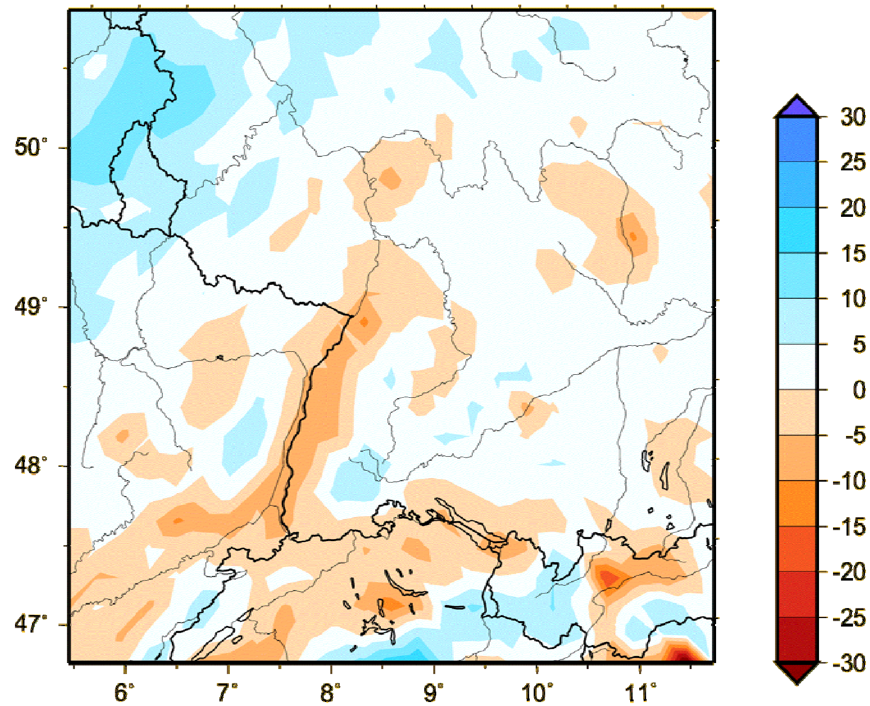


Regional Climate Change Rhine Catchment (till Cologne)

Evapotranspiration Change [%], 2070-99 vs. 1960-89, Δ=19km



Winter DJF



Summer JJA

Up to 20% less evapotranspiration

Looking into the Past: Trend Analysis of Precipitation Time Series

Results of *KLIWA* initiative

- Little changes in sum of yearly precipitation

- Trends towards increased winter and spring precipitation
  & decreased summer precipitation

- Changes in frequency distribution: increased probability for heavy precipitation
  in winter & spring

(KLIWA, 2003)

Looking into the Past: Trend Analysis of Runoff Time Series

Results of *KLIWA* initiative

- No significant trends for increase of magnitude of yearly maximum runoff however, if only last 30 years considered: increase

- Increased *frequency* of winter floods in Baden-Württemberg & Bavaria

- Change in annual course: increased winter runoff

- Little changes in yearly runoff sums

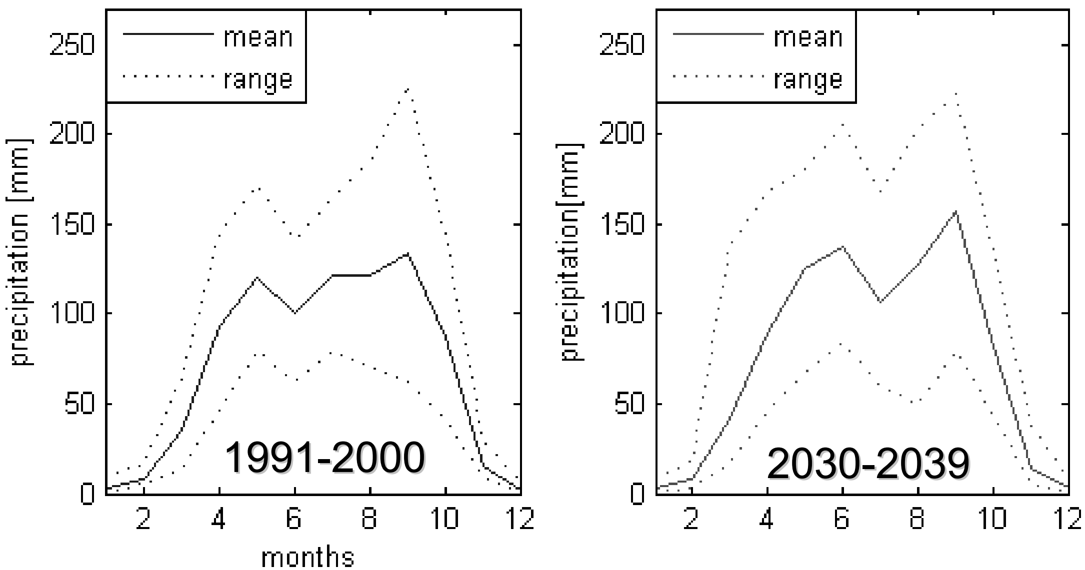
(KLIWA, 2003)

- **But:** direct anthropogenic impact difficult to separate from pure climate signal (dams, weirs, changing retention areas)

Outlook: Coupled Regional Climate/Hydrology Simulations

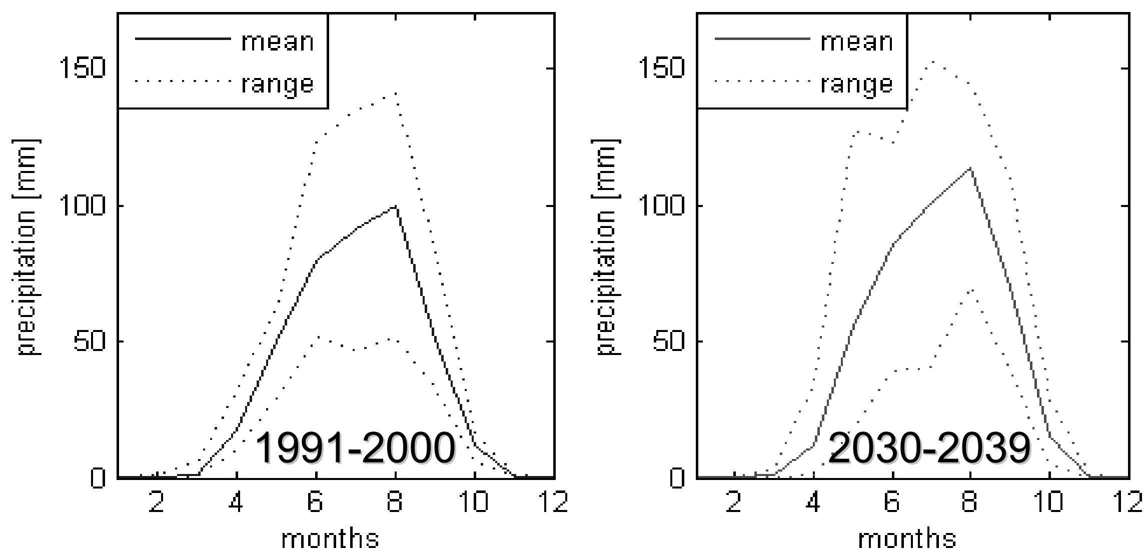
Problems & Challenges:

- Is recent climate properly reproduced in climate scenario?
- Dynamical downscaling is extremely CPU intensive
- No direct comparison to observed runoff -> frequency distributions
- Error propagation downstream of catchment cannot be corrected !



Guinea Coast Region
(South of 10°N)

Mean monthly precipitation [mm]



Sahel Region
(North of 10°N)