From regional climate modelling to hydrological impact analysis: current capabilities and future research needs

Harald Kunstmann

Richard Knoche, Gerhard Smiatek, Peter Suppan, Andreas Heckl

Institute for Meteorology and Climate Research IMK-IFU

Garmisch-Partenkirchen

Email: harald.kunstmann@imk.fzk.de

KIT – die Kooperation von
Forschungszentrum Karlsruhe GmbH
und Universität Karlsruhe (TH)

HELMHOLTZ GEMEINSCHAFT

Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

KIT Karlsruhe Institute of Technology

Atmosphere is primary driver of hydrological processes: brief review

- spatial and temporal distribution of precipitation and temperature
- global warming impacts water vapor carrying capacity & evaporation/condensation
- projections of future terrestrial water availability must consider future atmospheric state
- close linkage atmosphere, precipitation & land surface:
  energy & water fluxes at land surface: latent & sensible heat fluxes
  terrain elevation: e.g. precipitation generation by orographic blocking
  soil: long term memory of previous precipitation & temperature
- interlinked atmosphere & land surface process description & analysis necessary

From global climate modeling to regional climate modeling

Global climate models

- physically based (e.g. conservation laws for energy, momentum, water/humidity variables)
  but: parameterizations for subgridscale processes (turbulence, convective precipitation, …)
- resolution usually ≈ 100-300 km
- designed to reproduce & project global trends
- limited potential for regional analysis
- resolution too coarse for “typical” hydrological impact analysis for mesoscale catchments

Global climate scenarios:

- based on assumed technological development & future emissions (scenarios)
- no forecasts, only projections (possible future states)

Regionalization techniques:

- bridging the gap from global scenarios to regional occurrences
- required for hydrological impact analysis

Regionalization techniques

Statistical downscaling

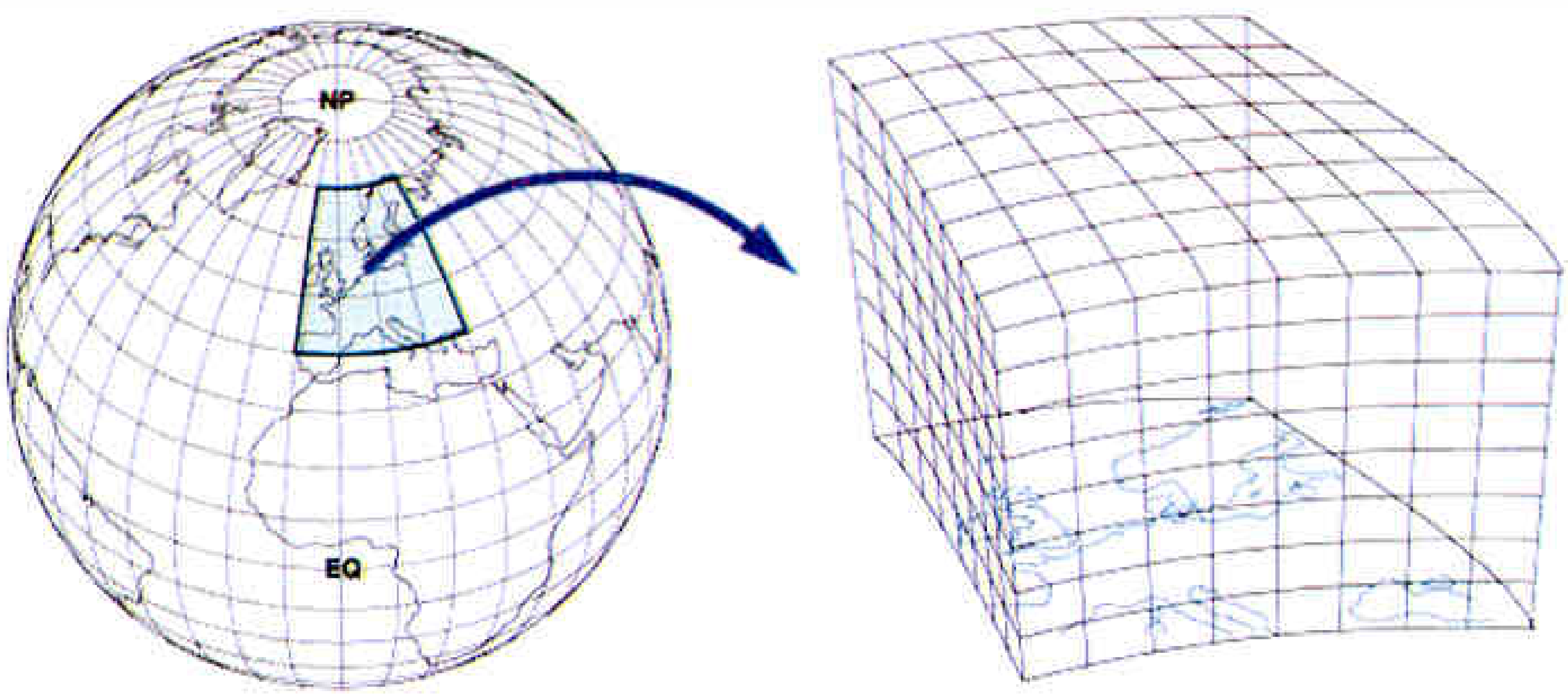
- statistical relations between large scale forcing & station observed variables
- e.g. via multiple regression, canonical correlation analysis, circulation pattern analysis
- computationally efficient
- climate change information derived only at station locations
- gridded fields obtained by spatial interpolation between station locations
- persistence of statistical relations under changing climate conditions assumed

Dynamical downscaling

- 3-dim regional atmospheric models (RCM) based on
  conservation laws, physical relations, parameterizations for subgridscale processes
- nested approach: global model provides lateral boundaries of regional model
- computationally expensive
- examples: *nonhydrostatic* CLM & MM5 & WRF, *hydrostatic* REMO & RegCM & HIRHAM
- usually coupled atmosphere-land surface modeling systems

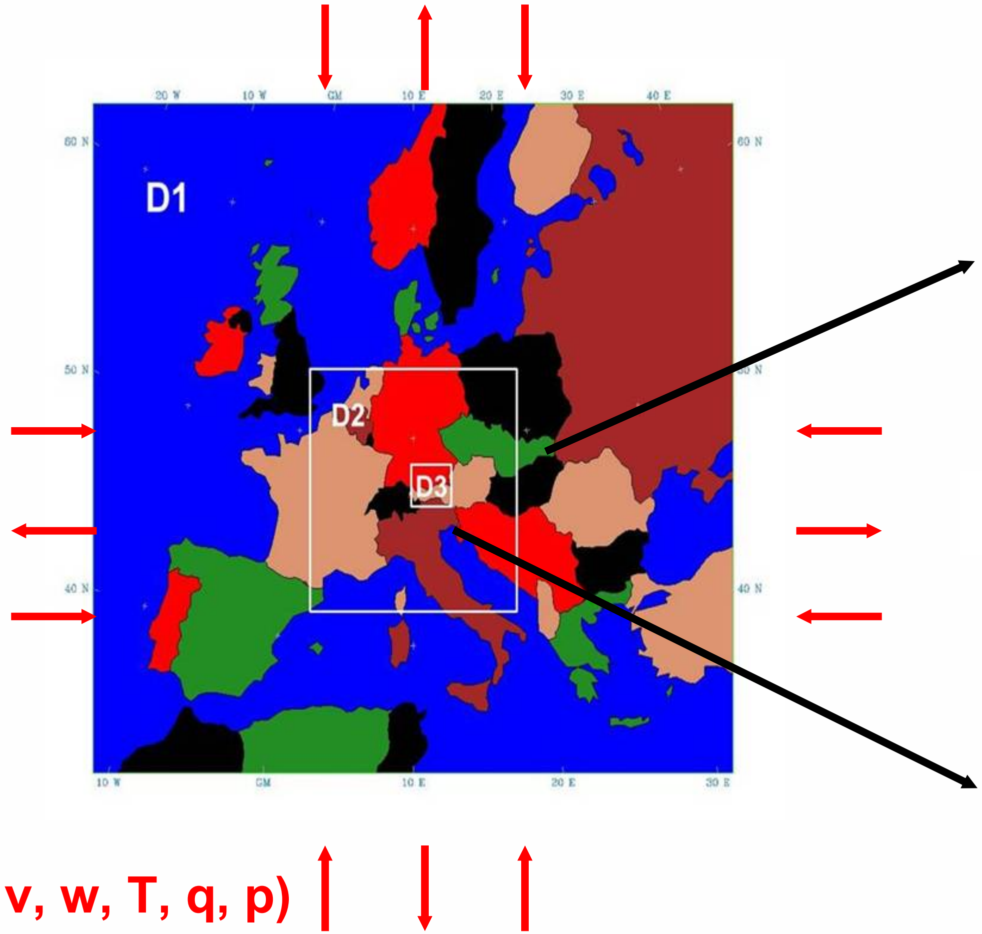
+ Combined statistical-dynamical methods

Dynamical downscaling: Regional Climate Models (RCMs)

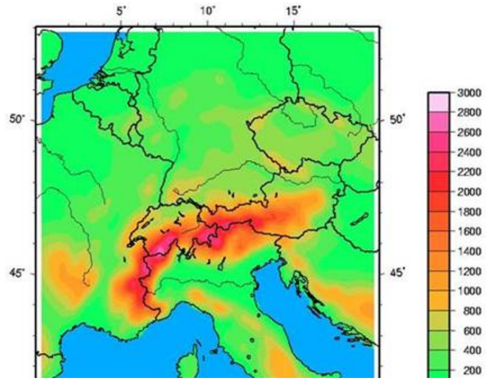


RCM: forced by global model (boundary- & initial value problem)

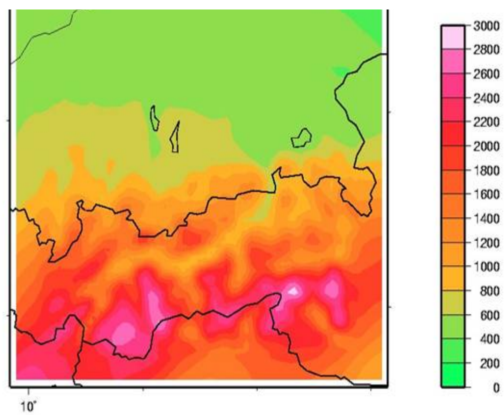
High spatial resolution ⇒ detailed consideration of orography



(u, v, w, T, q, p)

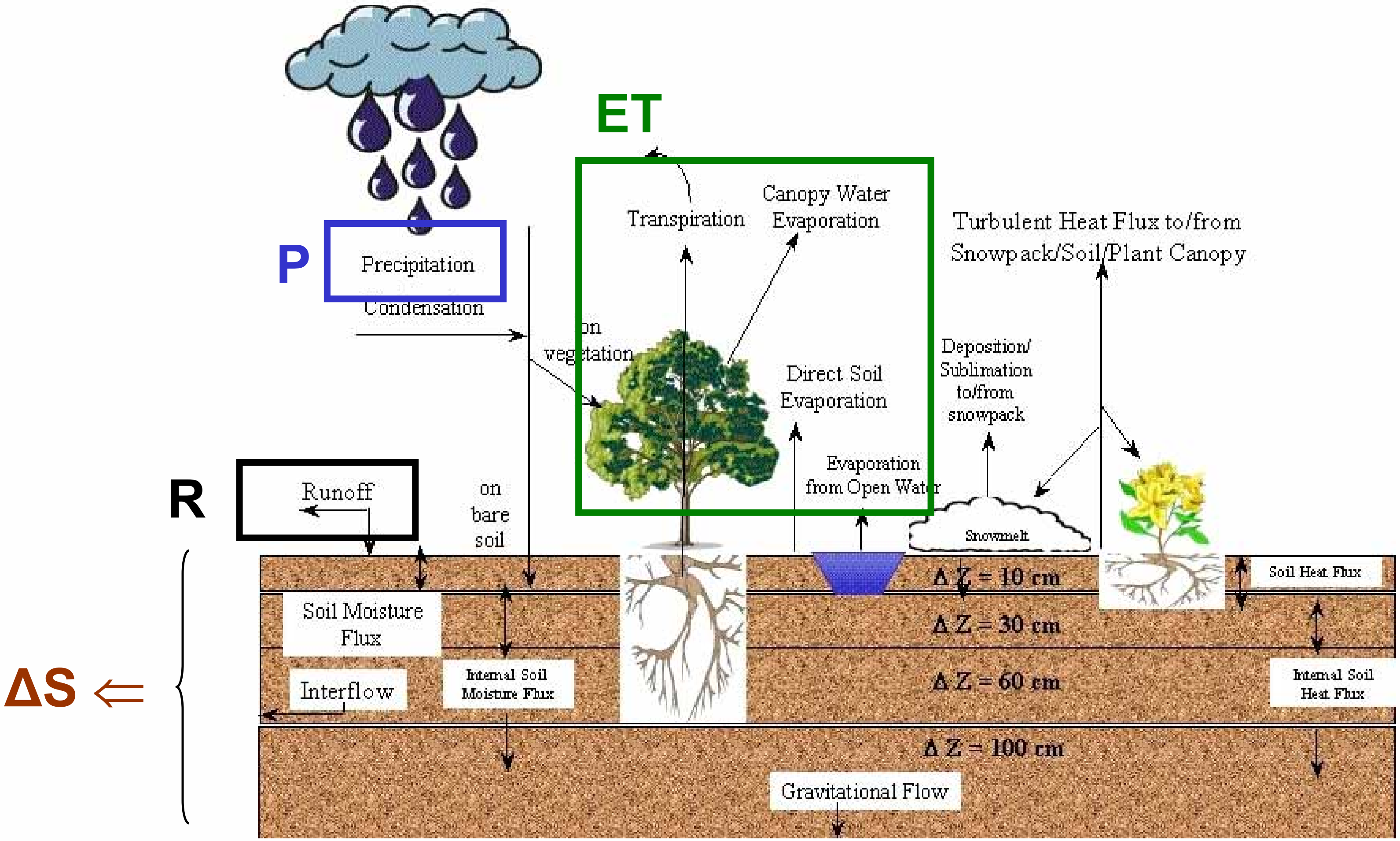


Orography in $20x20\ km^2$ resolution



Orography in $4x4\ km^2$ resolution

Dynamical downscaling: SVAT model as lower boundary at every grid point



Soil-Vegetation-Atmosphere-Transfer (SVAT) Model

Basic differences between SVAT-based hydrological models and "traditional" hydrological models

SVAT- hydro models (designed for atmospheric feedback purposes):
- full energy balance (soil heat & sensible heat fluxes)
- 2-way interaction with PBL
- focus on vertical water fluxes (soil moisture, ET)

"Traditional"- hydro models (designed for pure hydrological applications):
- vertical + lateral water fluxes, surface runoff routing
- deeper soils considered
- finer vertical & horizontal resolutions
- often groundwater interaction
- often extensions for reactive flow & transport, erosion, etc.
- **but of course: depending on specific model choice**

Karlsruhe Institute of Technology

Approaches for joint climate-hydrology simulations

2-way coupling:

- few examples so far, mostly on larger scales (e.g. BALTIMOS)
- based on application of routings schemes to SVAT-model

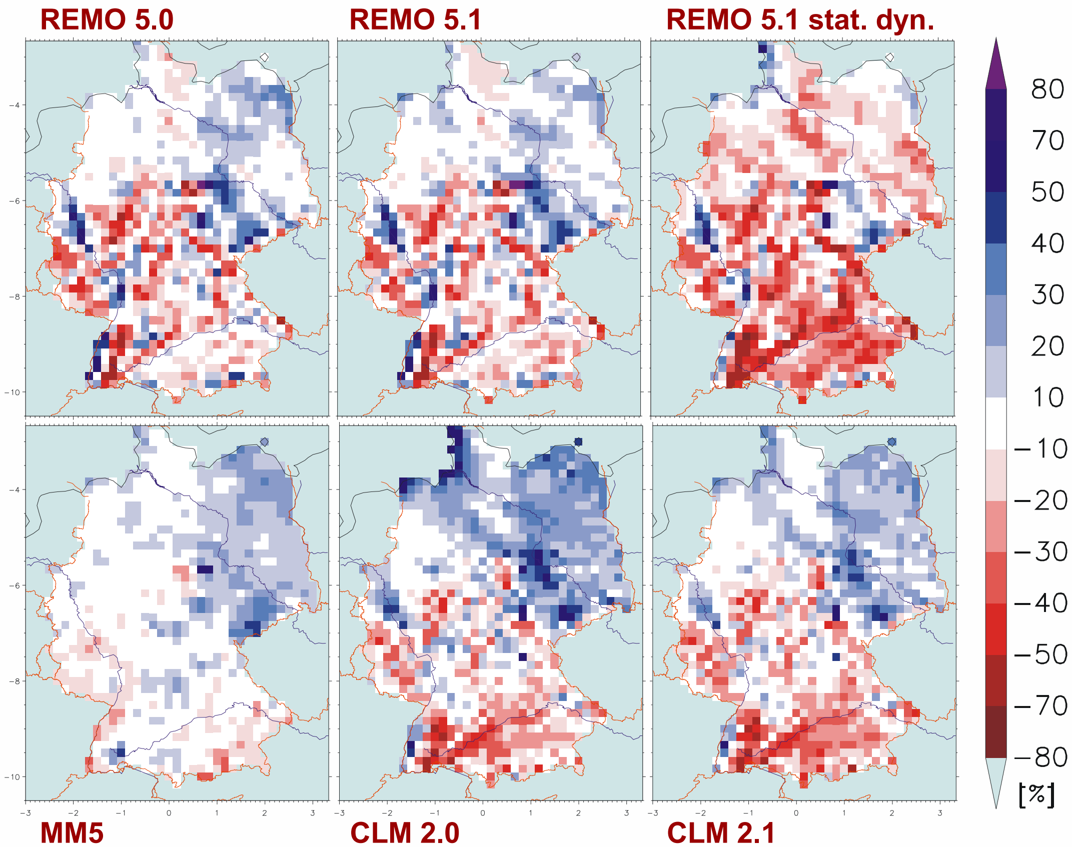
1-way coupling:

- results of RCM passed to stand alone hydrological model
- detailed terrestrial water balance via further hydrological model driven by meteorological fields of RCM
- feedback between land surface & atmosphere via SVAT model of RCM
- multitude of examples: different scales, driving models, scenarios, etc.

KIT
Karlsruhe Institute of Technology

Performance of regional climate simulations for hydrological impact analysis

Evaluation of RCMs (driven by ERA15 reanalyses)

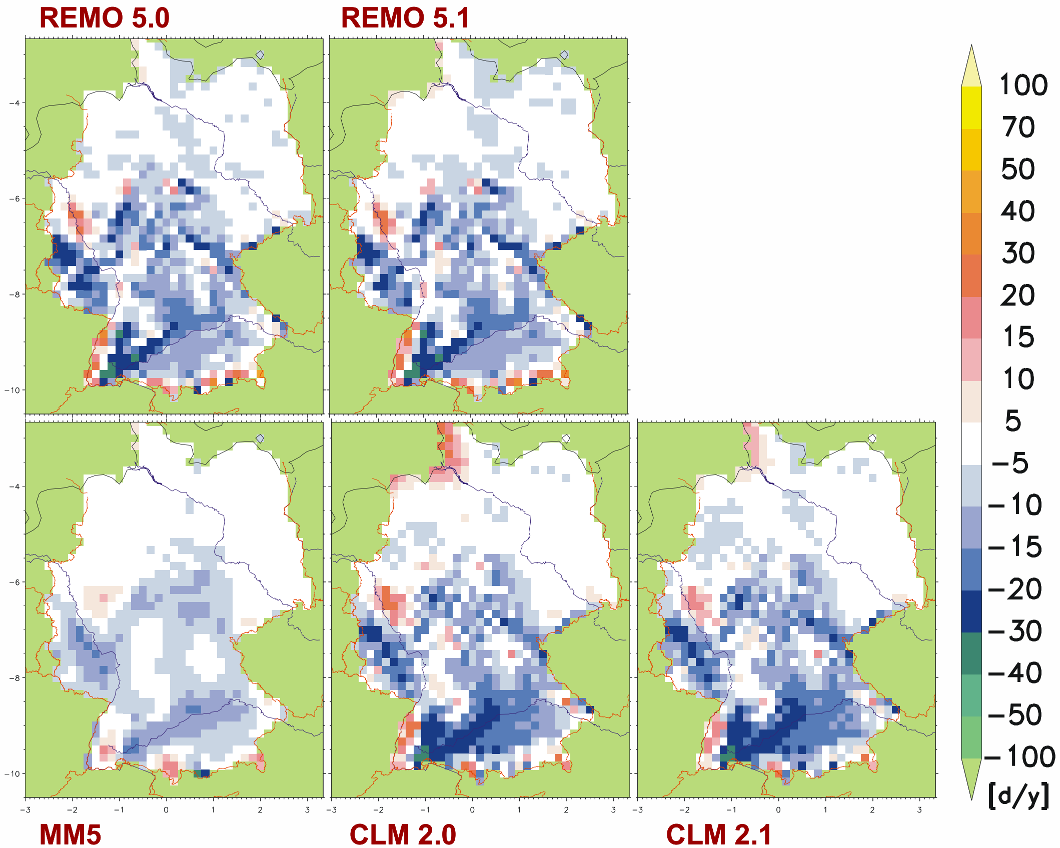


Δx ≈ 18km

% difference simulated vs. gridded observed precipitation 1979-93 *(DEKLIM-QUIRCS, 2006)*

Performance of regional climate simulations for hydrological impact analysis

Evaluation of RCMs (driven by ERA15 reanalyses)

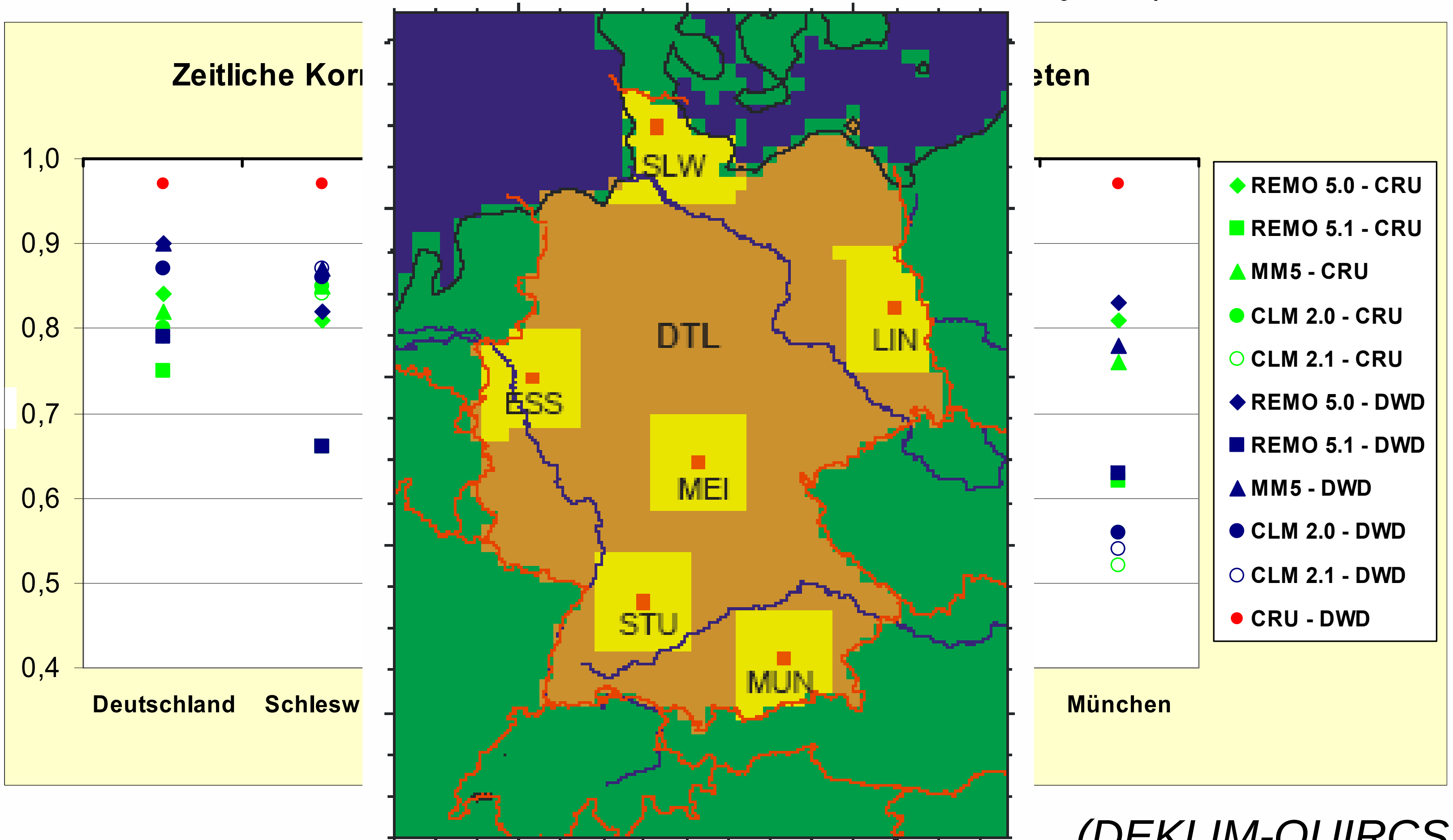


Δx ≈ 18km

Difference in "number of days > 10mm/day precipitation"
simulated vs. gridded observation 1979-93 *(DEKLIM-QUIRCS, 2006)*

Performance of regional climate simulations for hydrological impact analysis

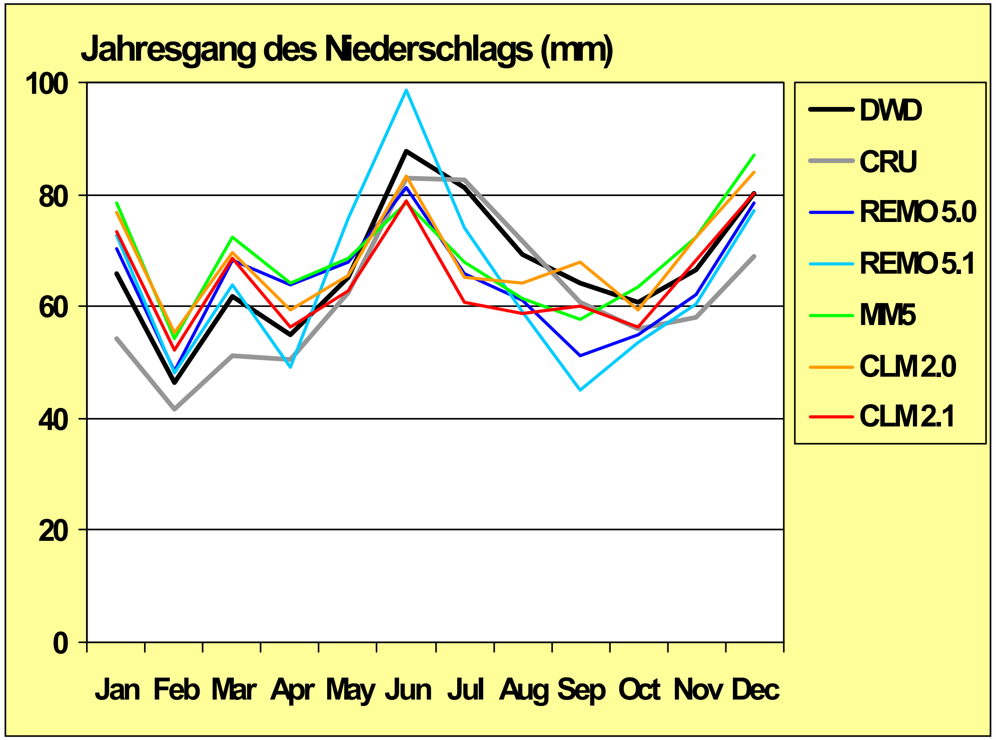
Evaluation of RCMs (driven by ERA15 reanalyses)

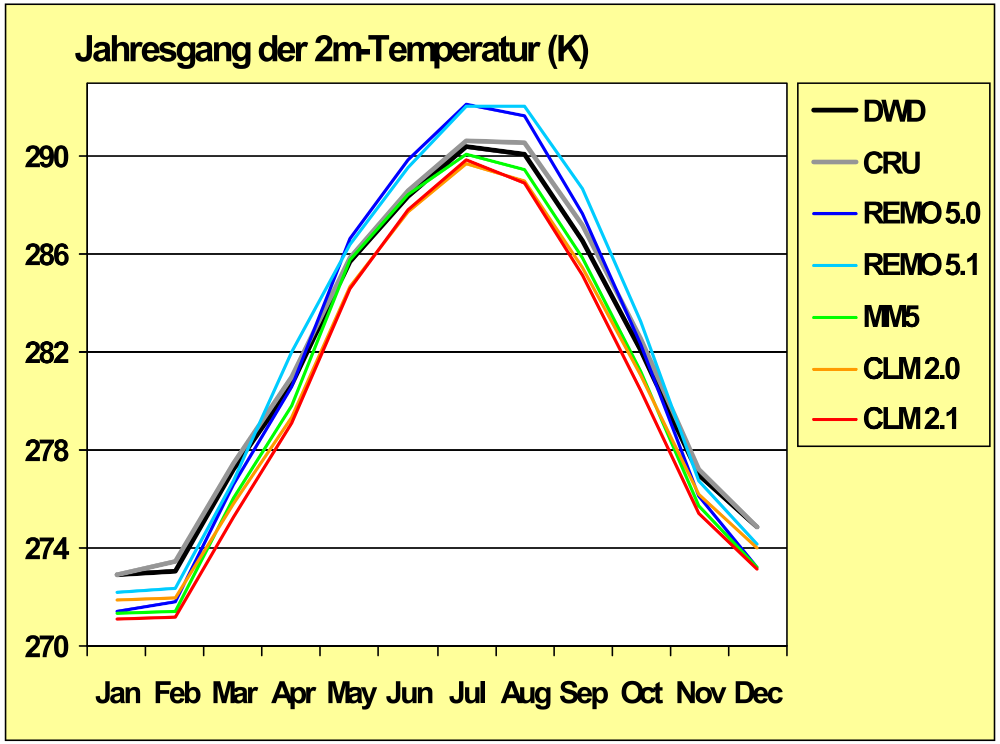


(DEKLIM-QUIRCS, 2006)

Performance of regional climate simulations for hydrological impact analysis

Evaluation of RCMs





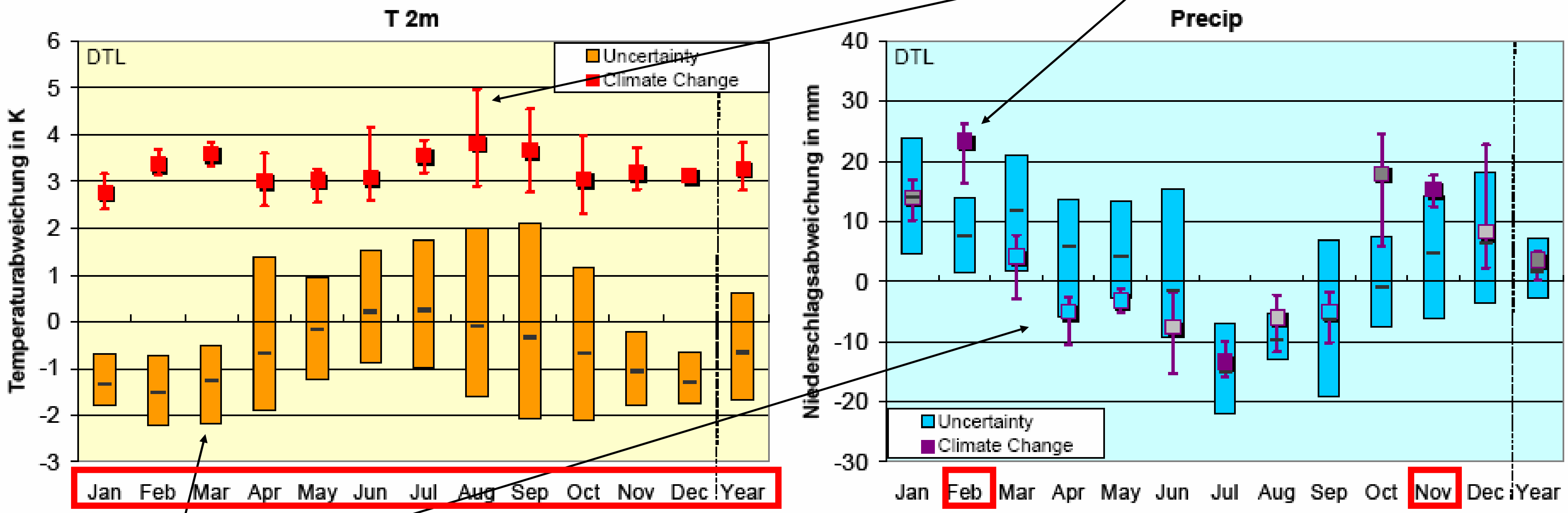
Mean annual cycle of monthly precipitation and 2m-temperature
(Germany, 1979-93, *DEKLIM-QUIRCS 2006*)

Karlsruhe Institute of Technology

Performance of regional climate simulations for hydrological impact analysis

Climate change from RCMs & uncertainties

Uncertainty from 4 model configurations

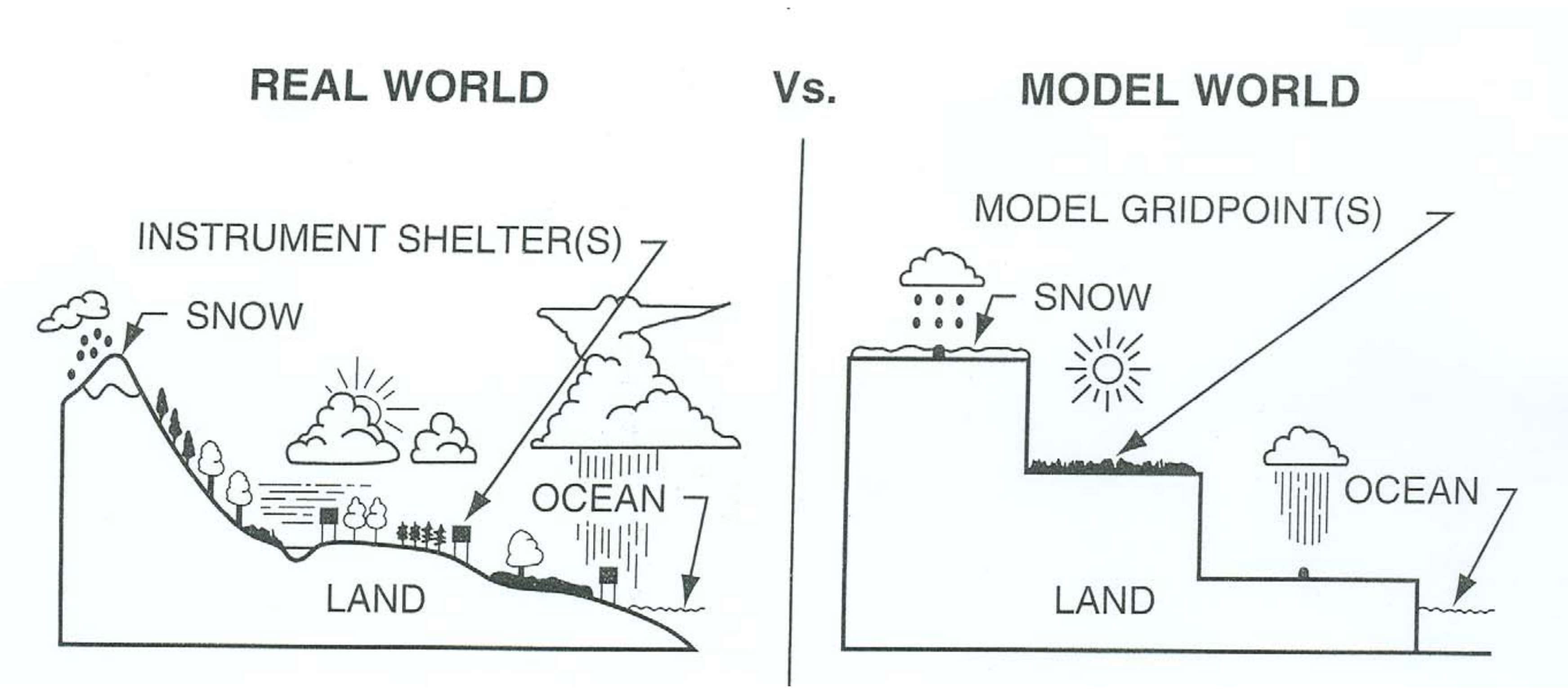


Uncertainty from evaluation runs vs. reference data

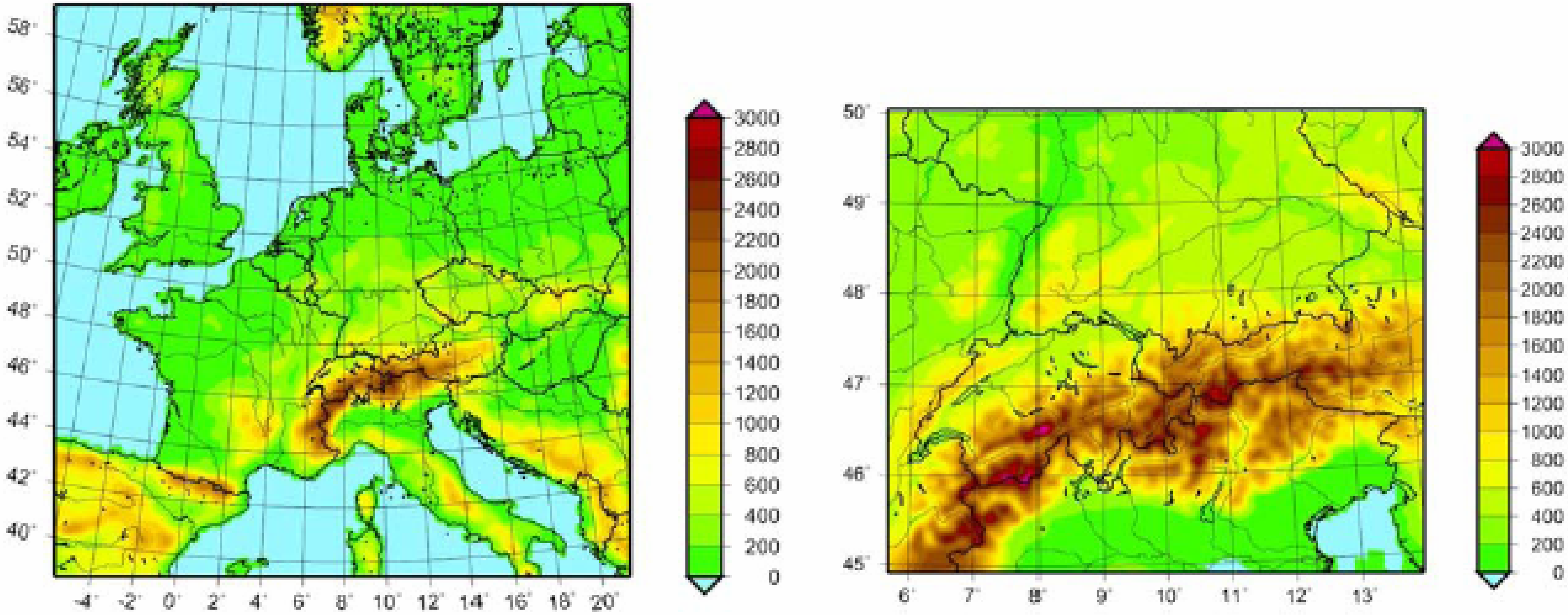
Change of temperature and precipitation & uncertainties (Germany, 2070-99 vs. 1960-89, *DEKLIM-QUIRCS 2006*)

Temperature change reliable for all months, precipitation only Feb & Nov

Impact of resolution : is it worth to downscale to high resolutions?

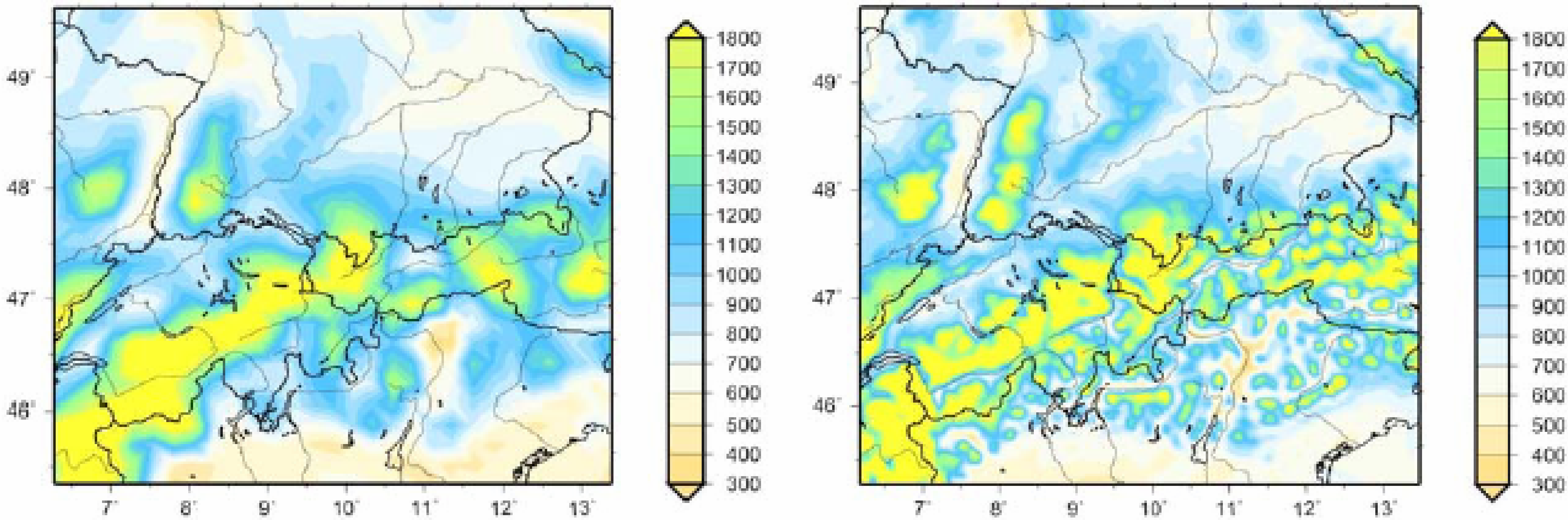


Impact of resolution : is it worth to downscale to high resolutions?



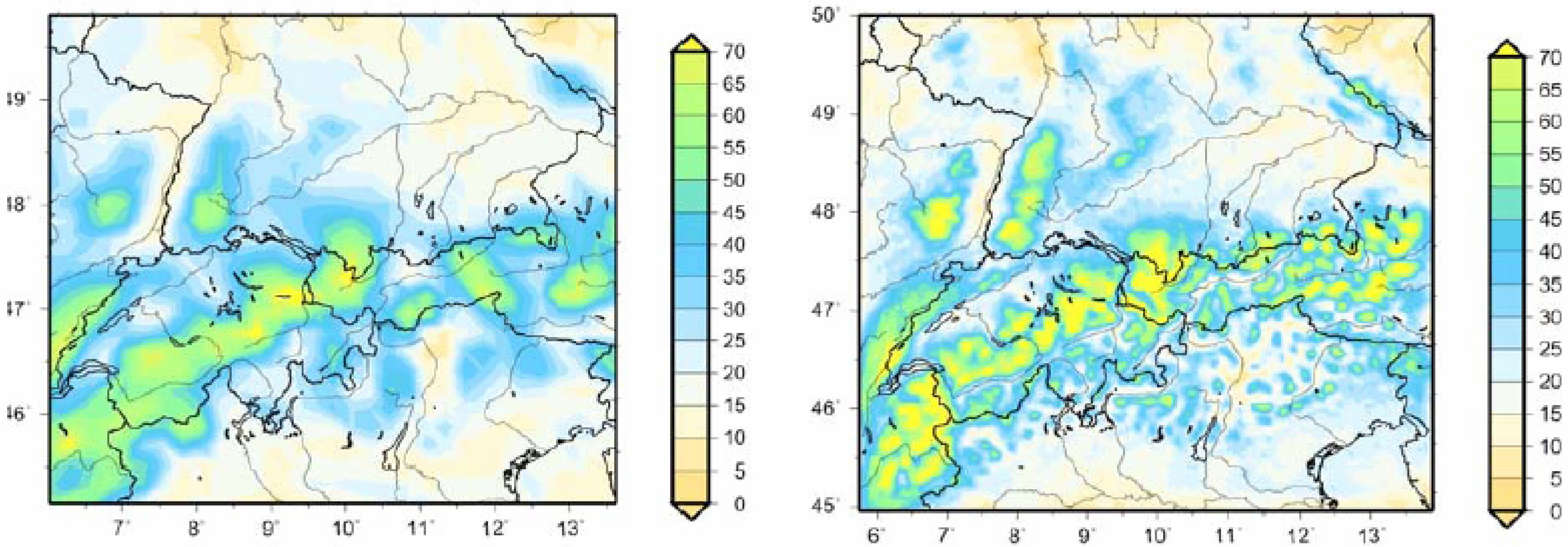
Orography Δx=19.2km vs. Δx=4.8km MM5 (*DEKLIM-QUIRCS 2006*)

Impact of resolution: is it worth to downscale to high resolutions?



Annual precipitation 1990 Δx=19.2km vs. Δx=4.8km MM5 (*DEKLIM-QUIRCS 2006*)

Impact of resolution: is it worth to downscale to high resolutions?



Number of days P> 10mm 1990 Δx=19.2km vs. Δx=4.8km MM5 (*DEKLIM-QUIRCS 2006*)

Resolution also impacts temporal distribution of precipitation: frequencies & intensities

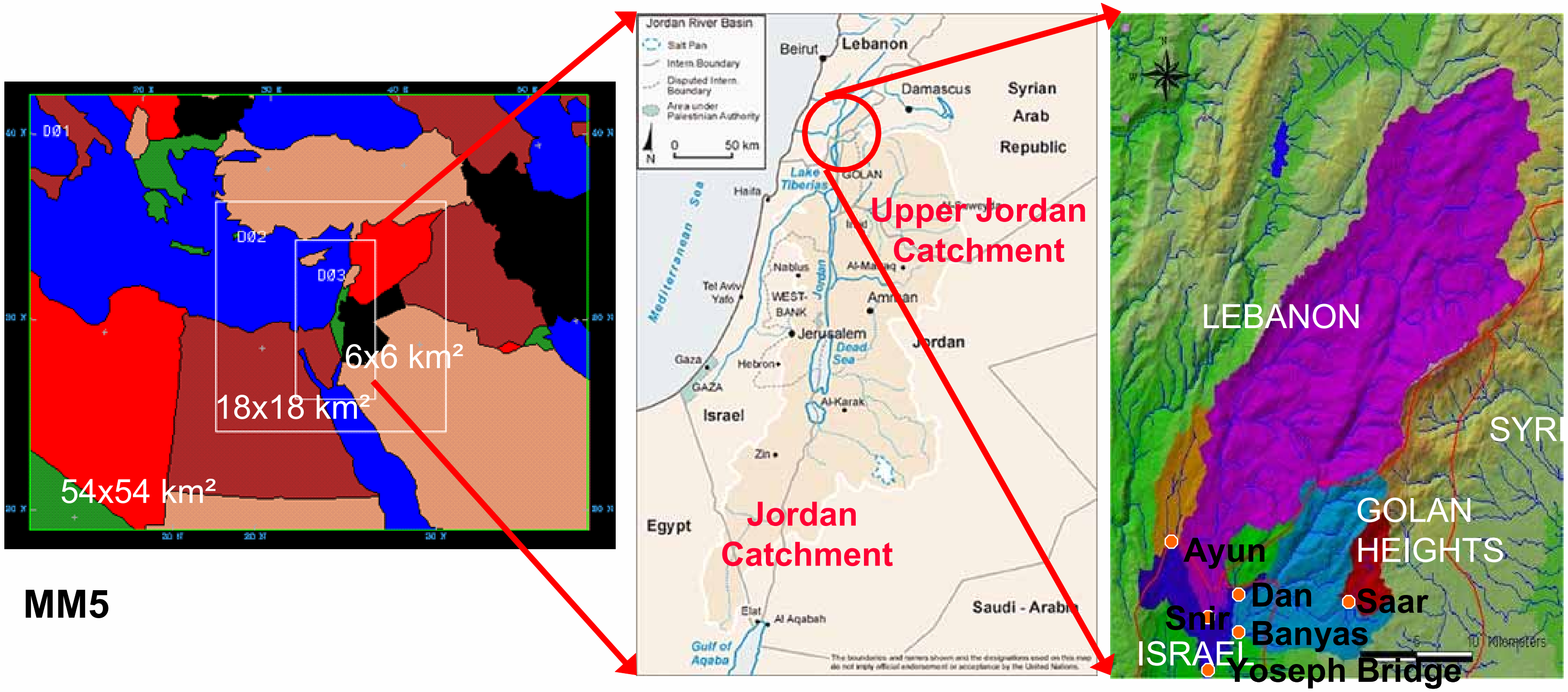
Karlsruhe Institute of Technology

From RCM from hydrological impact analysis…

An example from the Eastern Mediterranean/Near East (EM/NE)

Example of joint climate-hydrology simulation for hydrological impact analysis

Eastern Mediterranean/Near East (**EM/NE**) & Upper Jordan River Catchment



MM5

WaSiM

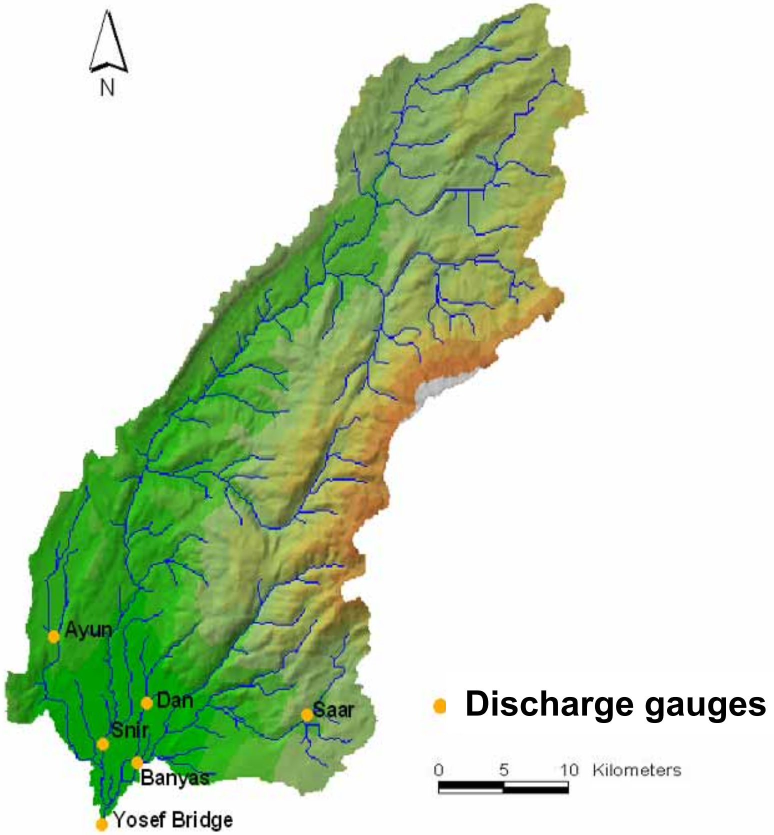
High resolution dynamical downscaling of global climate scenarios

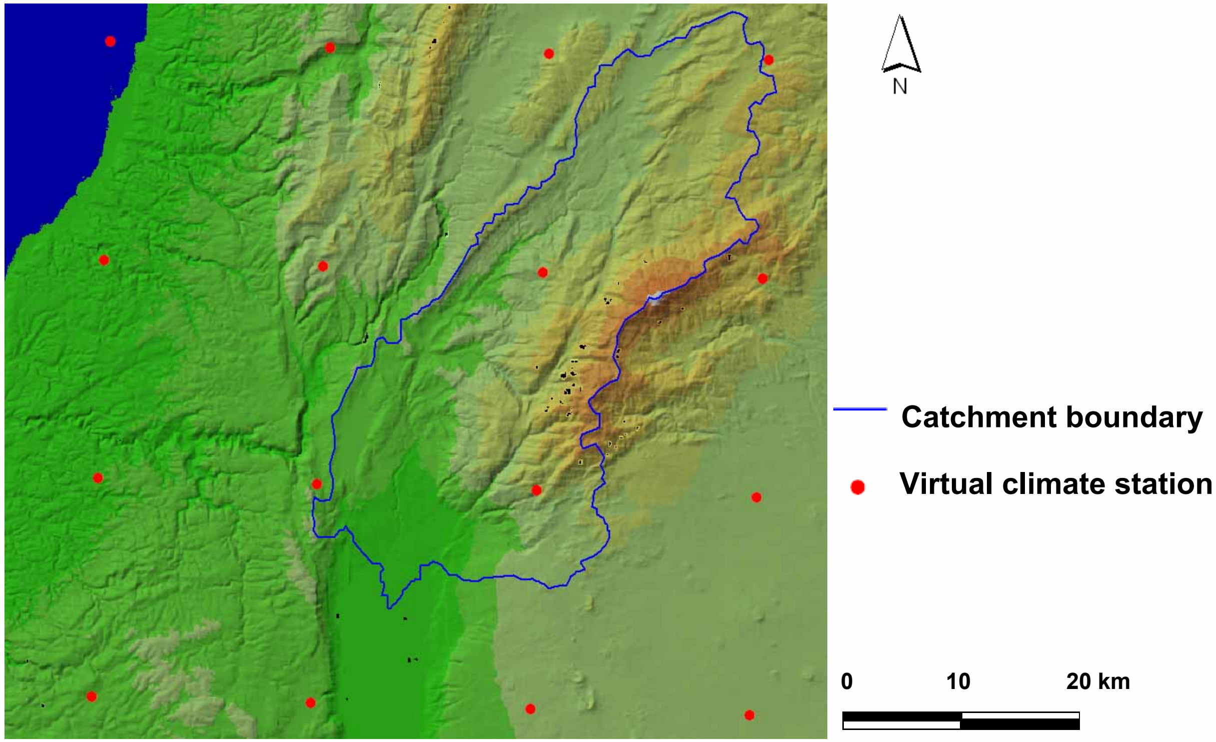
→

Distributed hydrological modeling of surface and subsurface water balance in 90 m resolution

Example of joint climate-hydrology simulation for hydrological impact analysis

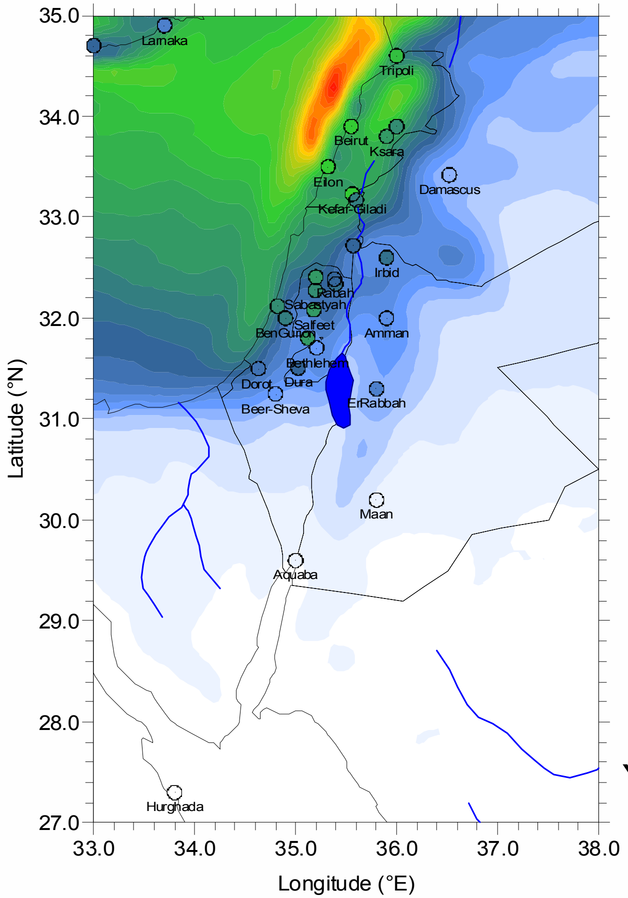
Eastern Mediterranean/Near East (**EM/NE**) & Upper Jordan River Catchment

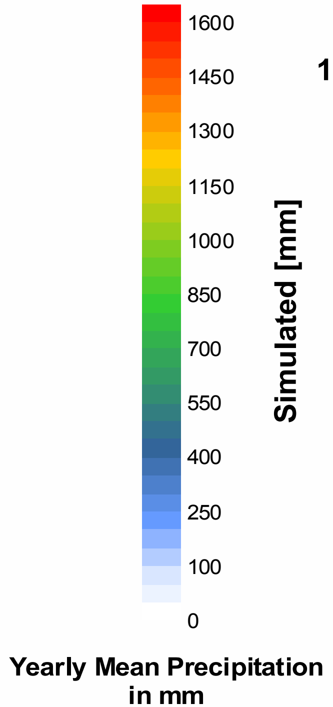


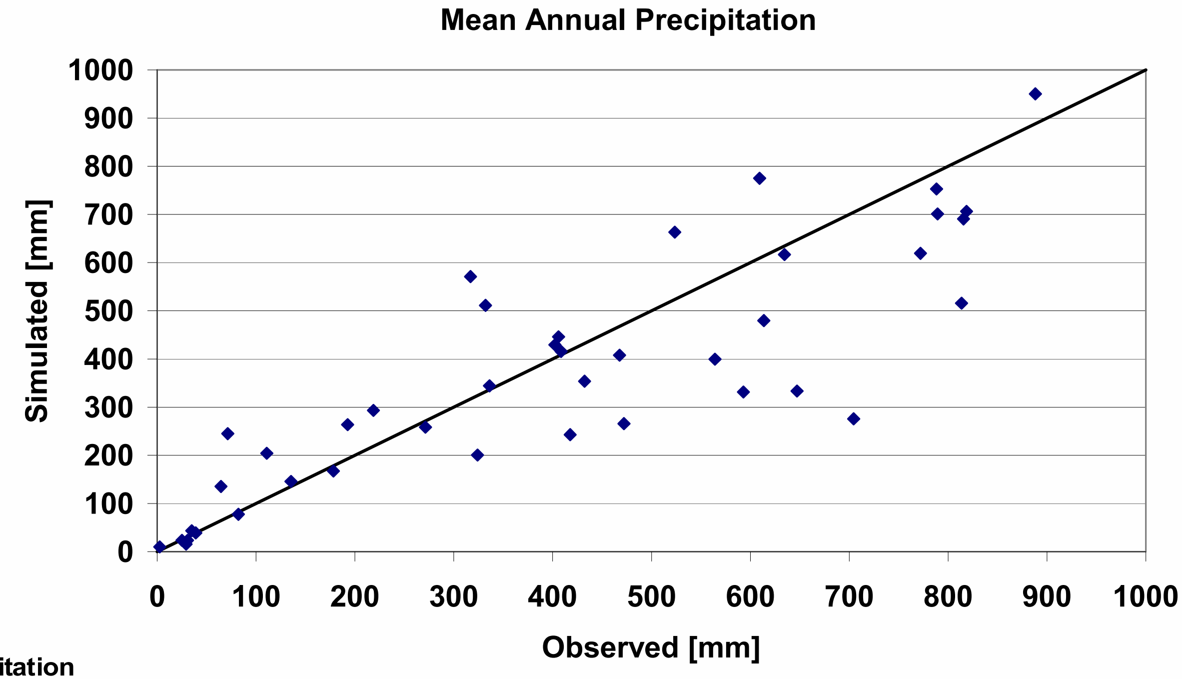


Performance of regional climate simulations for hydrological impact analysis

Control simulations (present day climate)

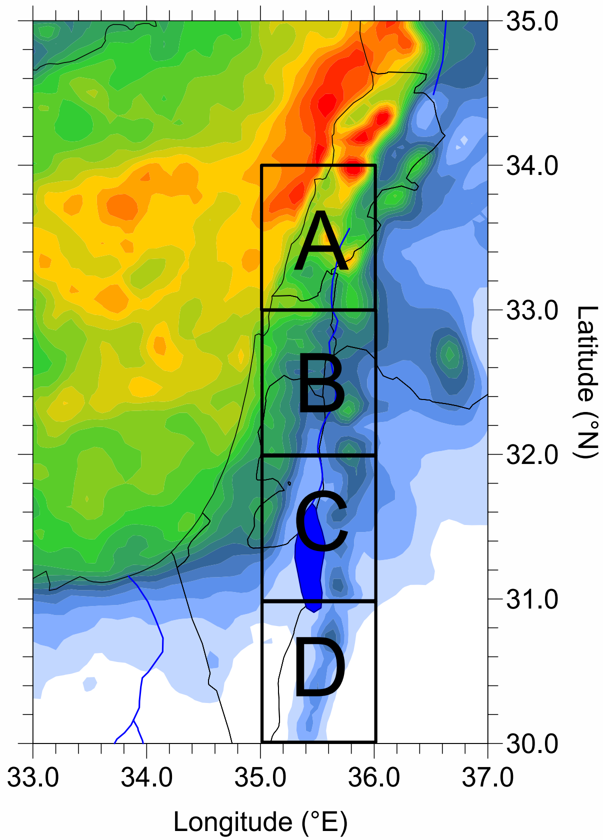


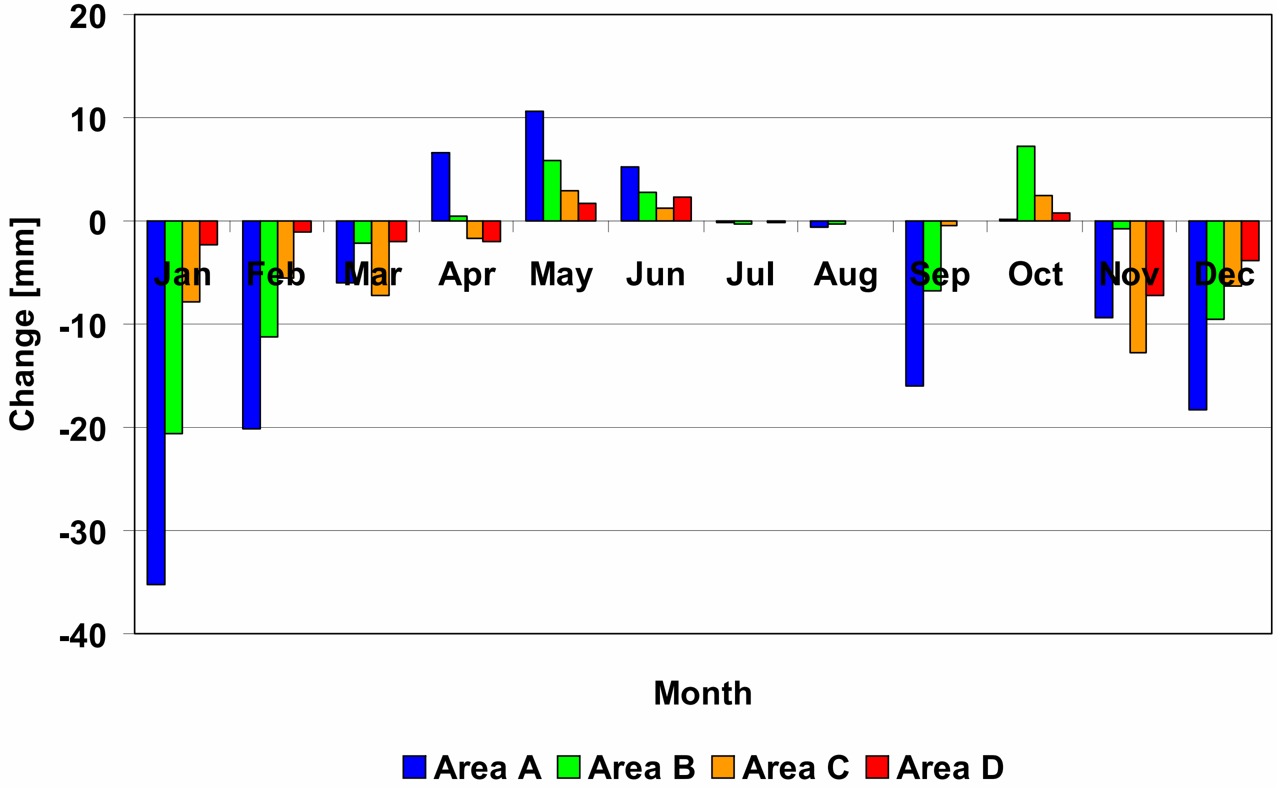




Simulated annual mean precipitation (ECHAM4 + MM5, Δx=18 km, 1961-1990)
vs. observed long term annual mean (for selected stations 1961-1990)

Example of joint climate-hydrology simulation for hydrological impact analysis

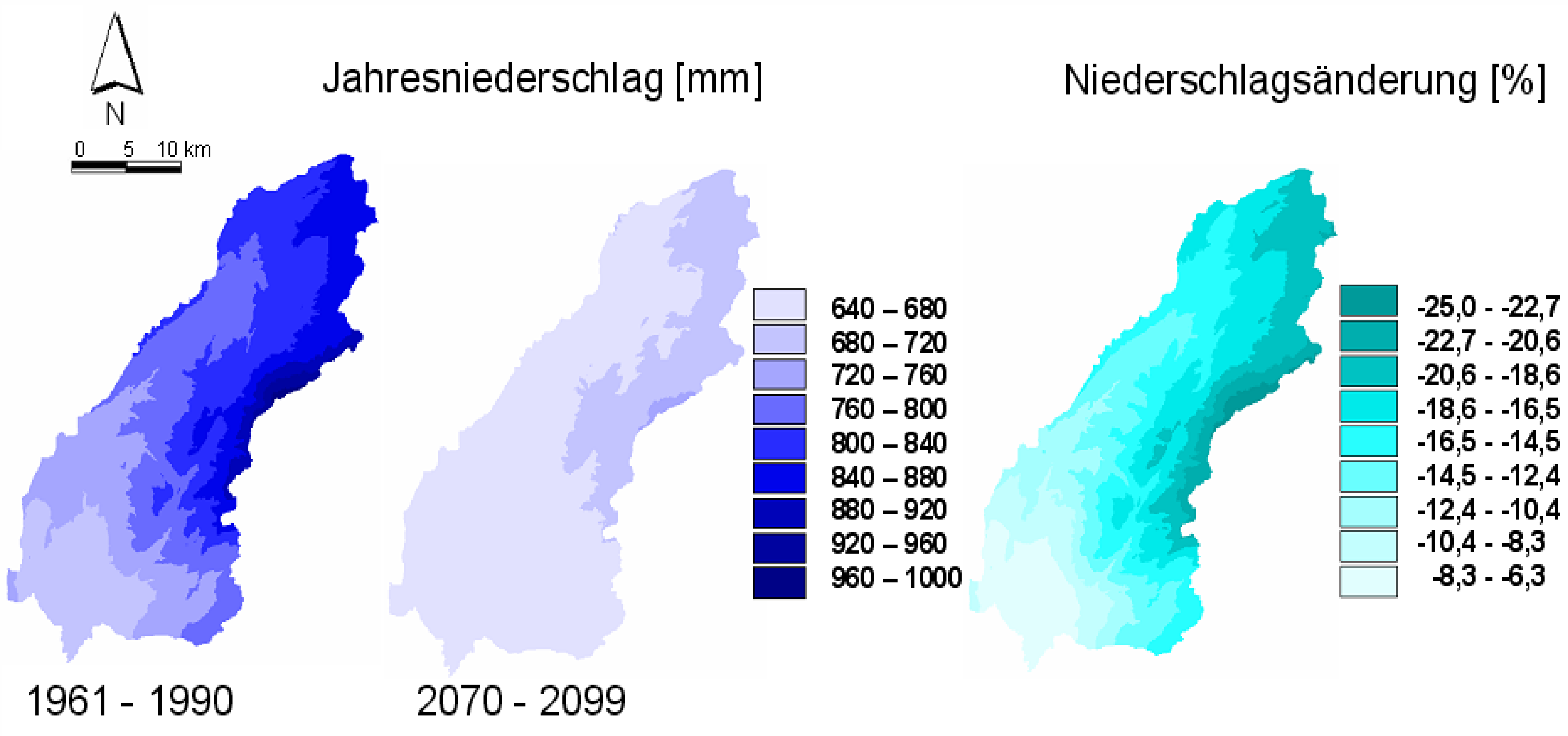




For all subregions: decreased winter, increased spring precipitation

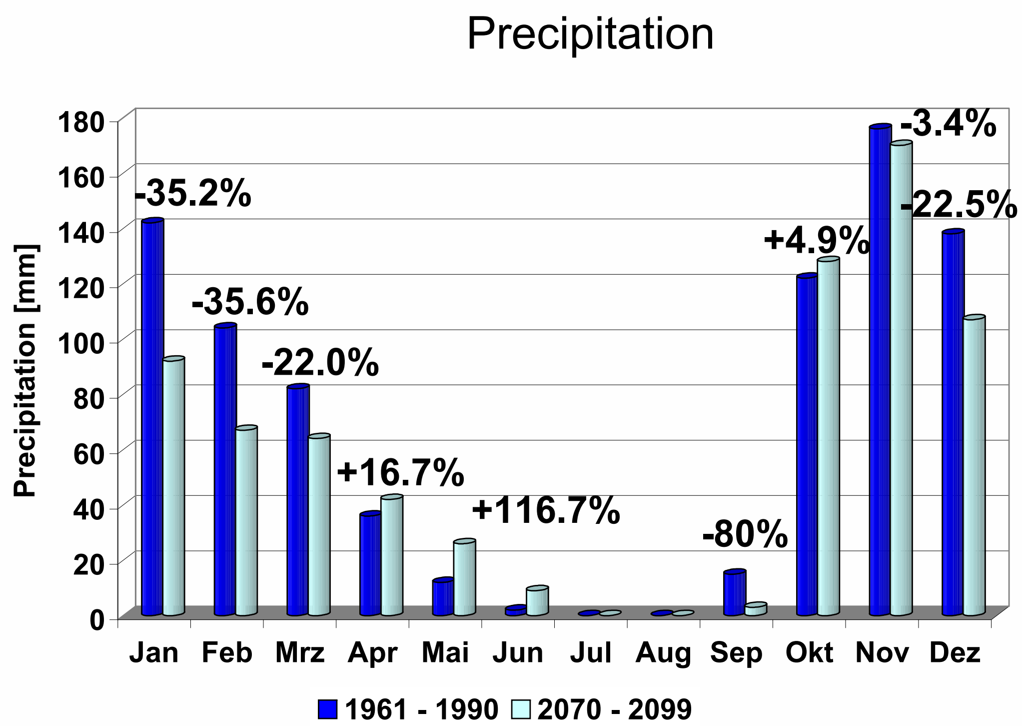
(2070-2099 vs. 1960-89 time slices, ECAHM4+MM5, 18km, scenario B2)

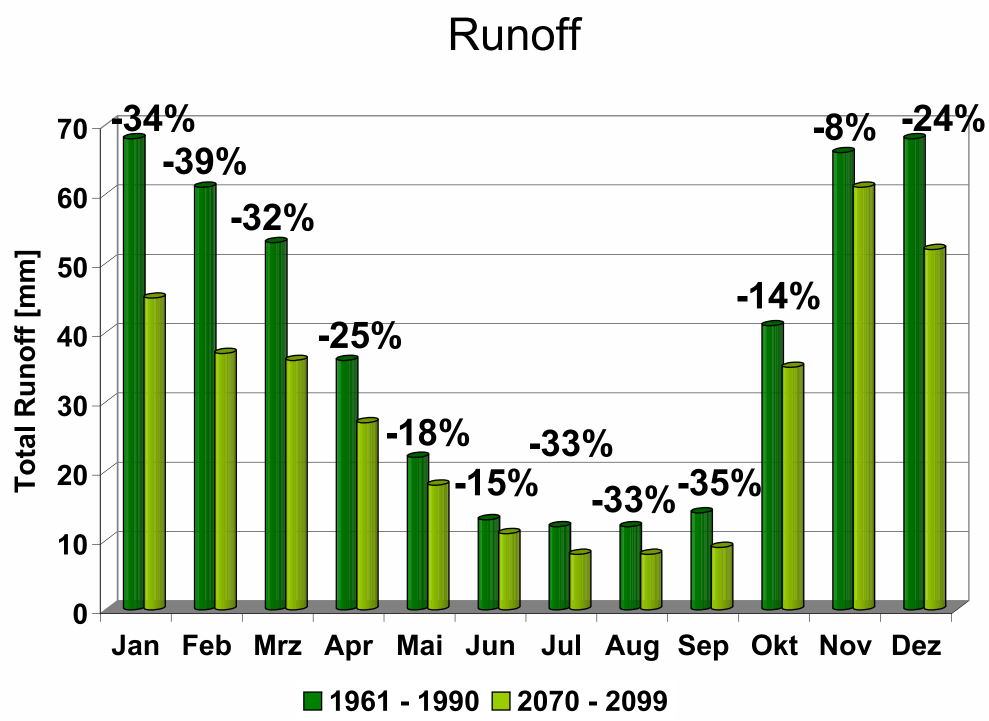
Example of joint climate-hydrology simulation for hydrological impact analysis



Upper Jordan River catchment

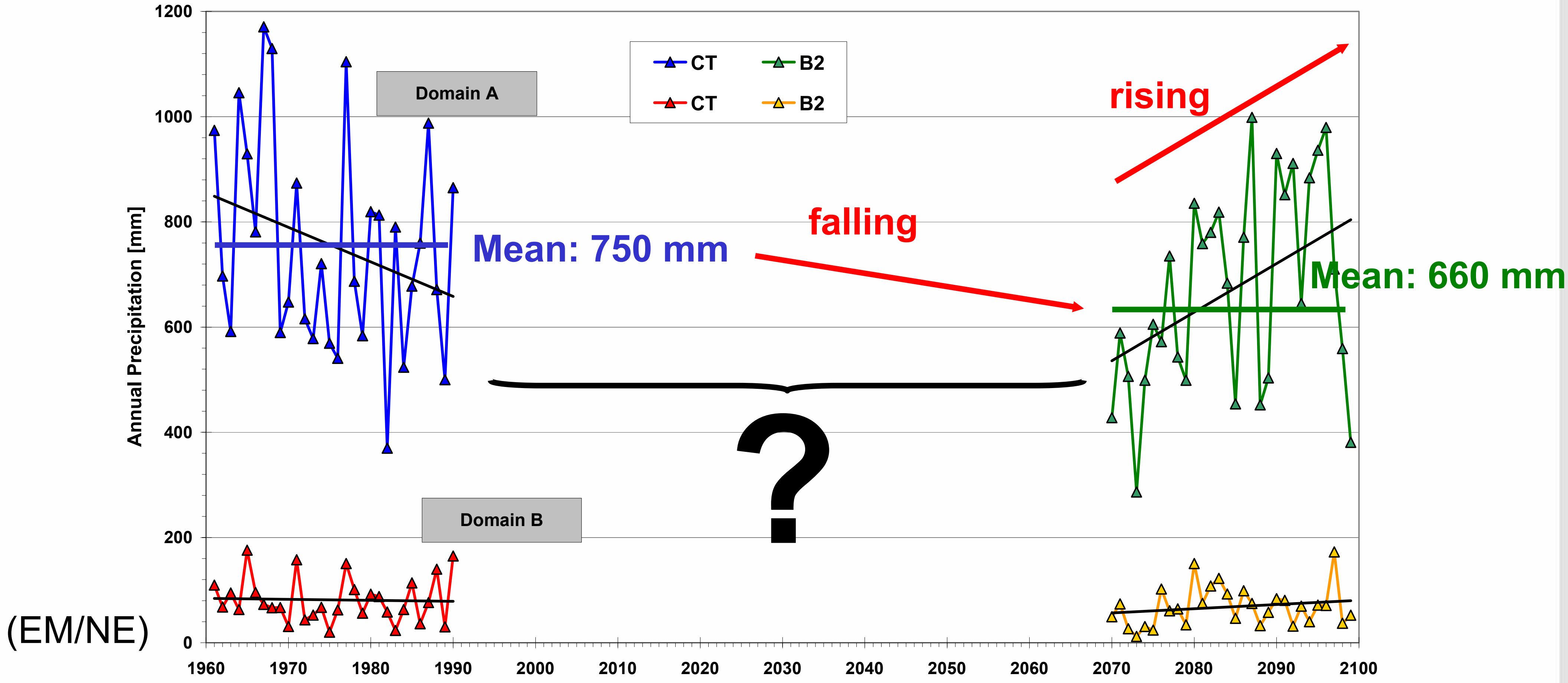
Example of joint climate-hydrology simulation for hydrological impact analysis



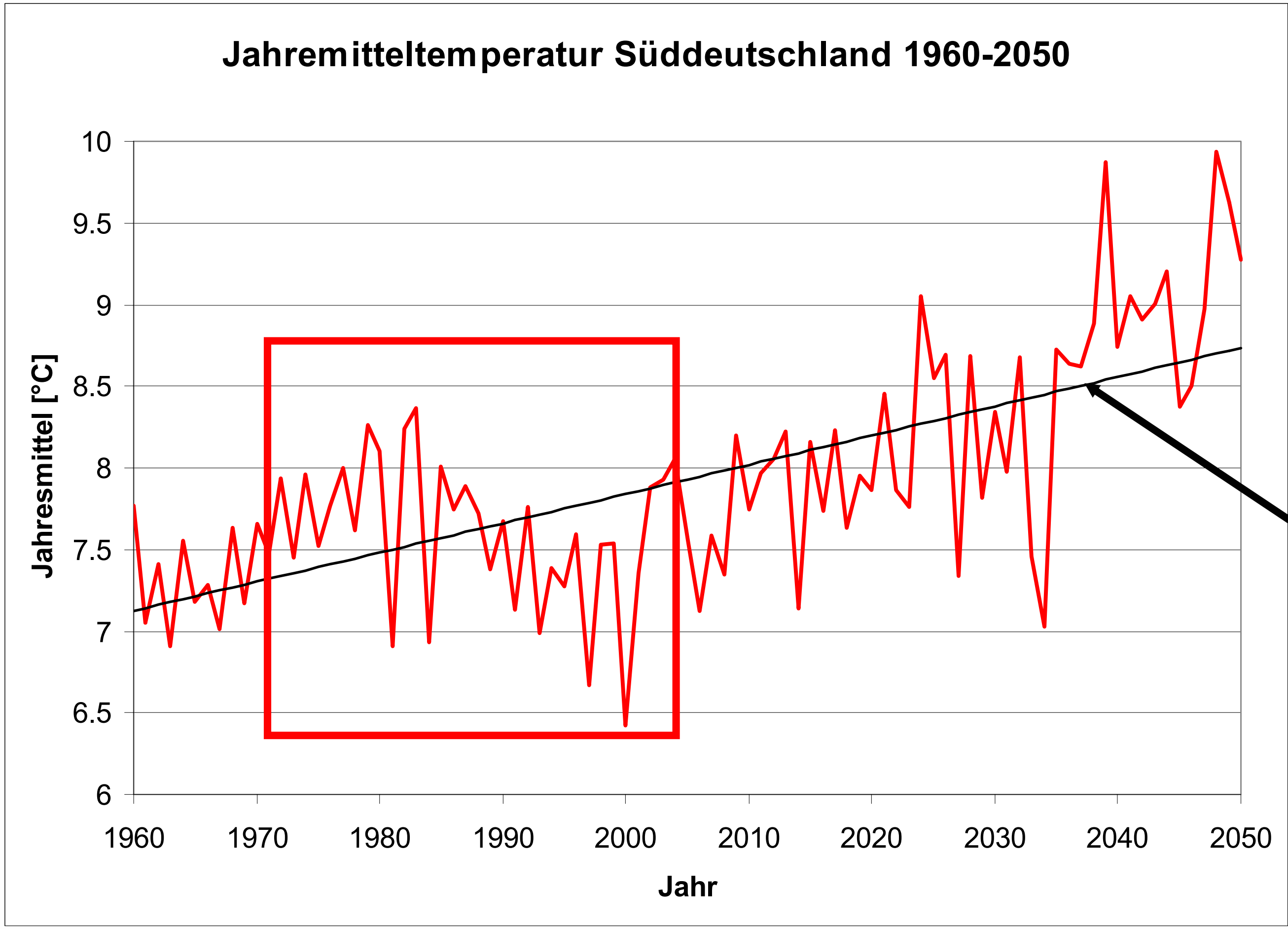


Upper Jordan River catchment

Problem of comparing time slices: long term trend vs. short term trend



… Problem of comparing time slices … towards transient climate simulations



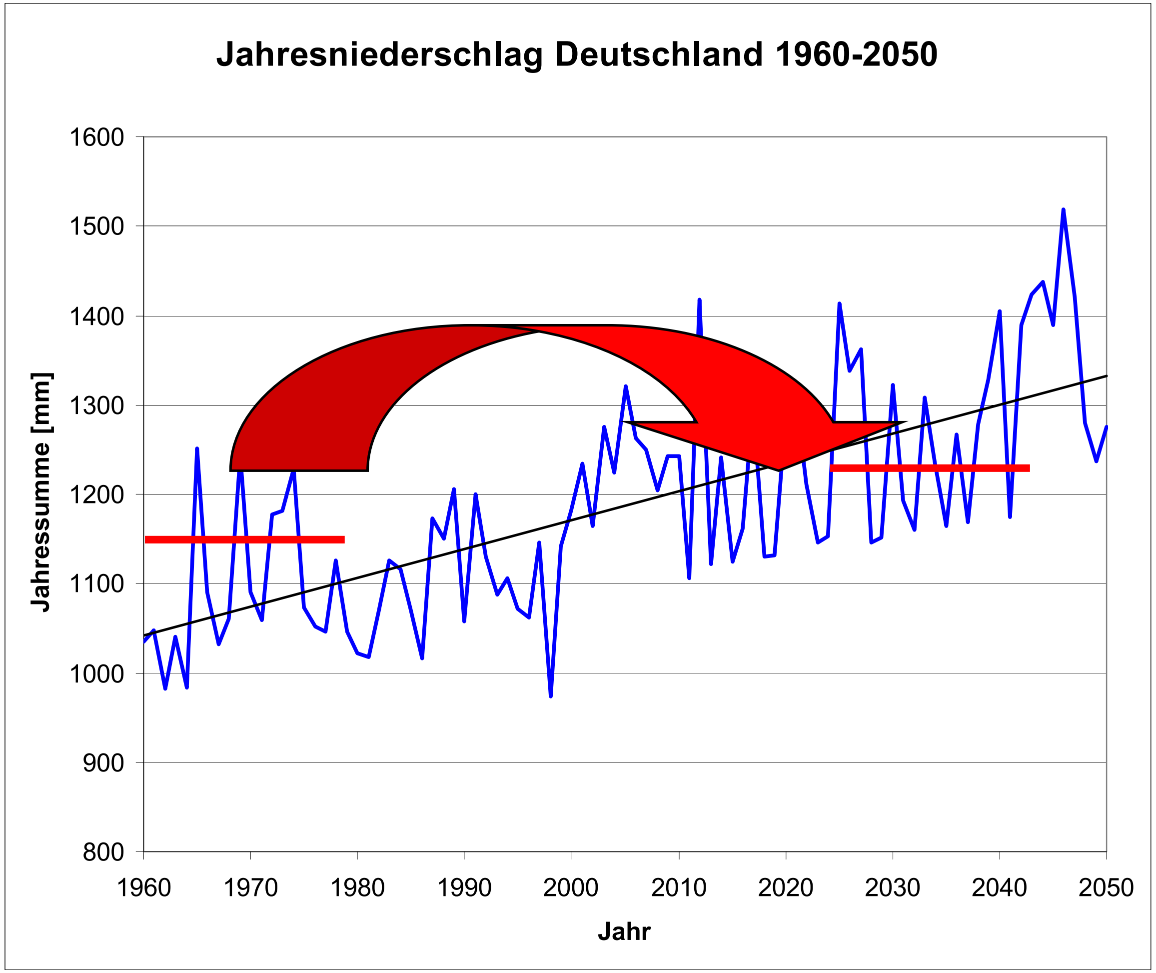
Beside GHG signal
further natural internal variations (i.e. without external reason)

necessity for transient runs & long range considerations

external (GHG) signal

ECHAM5+MM5, Δx=38km, ScenarioA1B

… Problem of comparing time slices … towards transient climate simulations



Again:
time slice comparison would underestimate estimation of GHG signal

ECHAM5+MM5, Δx=38km, ScenarioA1B

Summary: current capabilities

- Regional climate models: spatial resolutions down to 5-10km for climate runs
- non-hydrostatic models for $\Delta x < 10$ km
- reasonable model performance for **evaluation runs** but performance differences
- but often deficiencies in annual course and magnitudes for **control runs**:
  $\Rightarrow$ problematic for hydrological impact analysis
- still large uncertainties for precipitation change estimations
- growing number of 1-way coupled approaches
- crude and pragmatic representation of land surface in RCMs

Research needs to improve projections for GHG-driven hydrological change

- Need for integrated regional atmosphere-hydrology modeling systems to facilitate decision support in water management

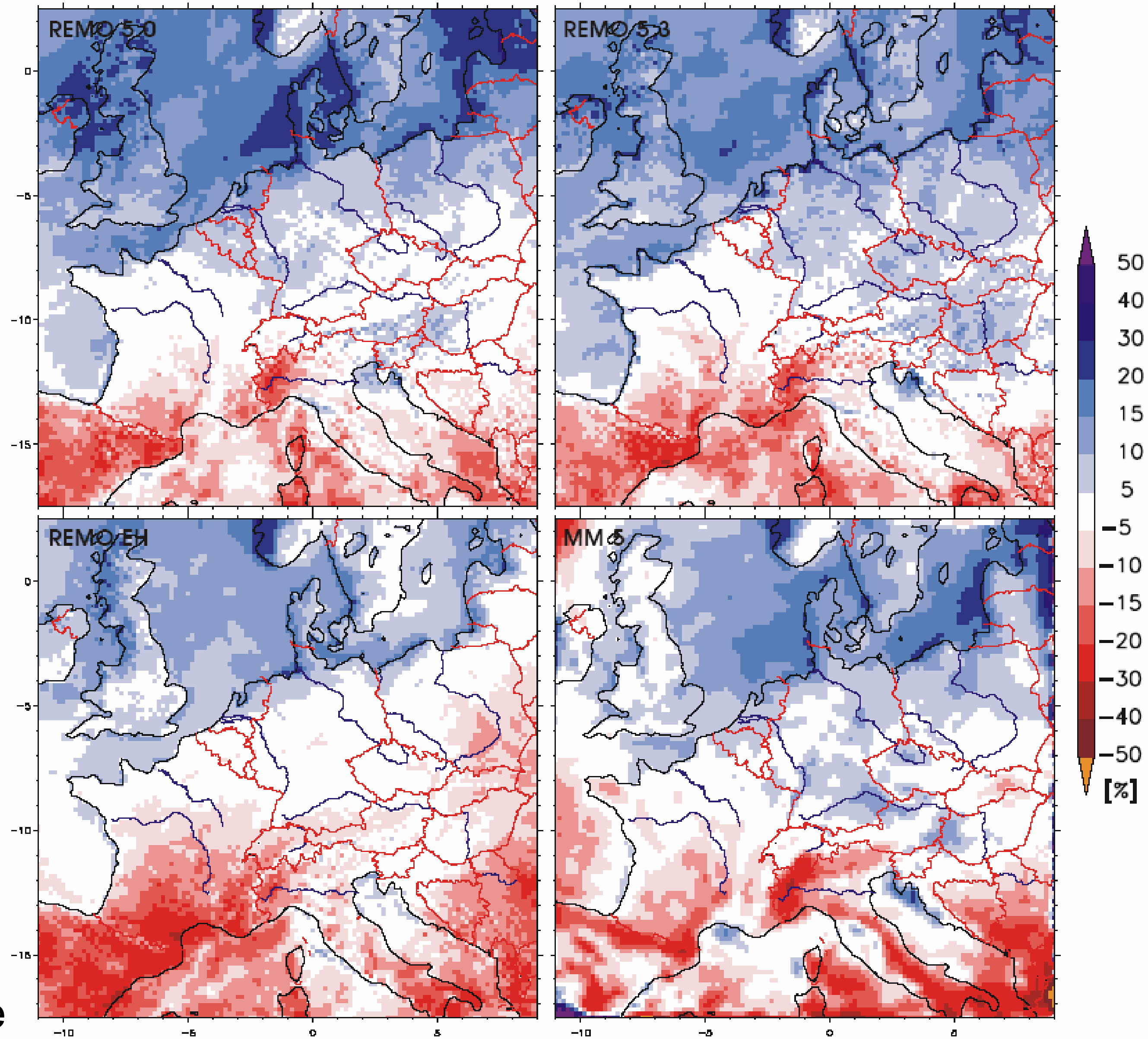
- Need for technical realization of compartment cross-cutting, regional fully 2-way coupled atmosphere-land surface water balance simulations

- Requires/includes development of improved soil-vegetation-atmosphere modules:
  - scaling approaches for soil and vegetation properties
  - regional transferability of parameterization approaches
  - improved descriptions for dynamic vegetation

- Specific research questions:
  - role of “horizontal” hydrological processes on atmospheric processes below 10km
  - impact of soil moisture on precipitation at inter-annual and interdecadal time scale
  - long term feedback between saturated zone, upper soil layers and atmosphere
  - impact of regional land use induced change vs. GHG-induced change on land surface-atmosphere interaction (⇒ precipitation)

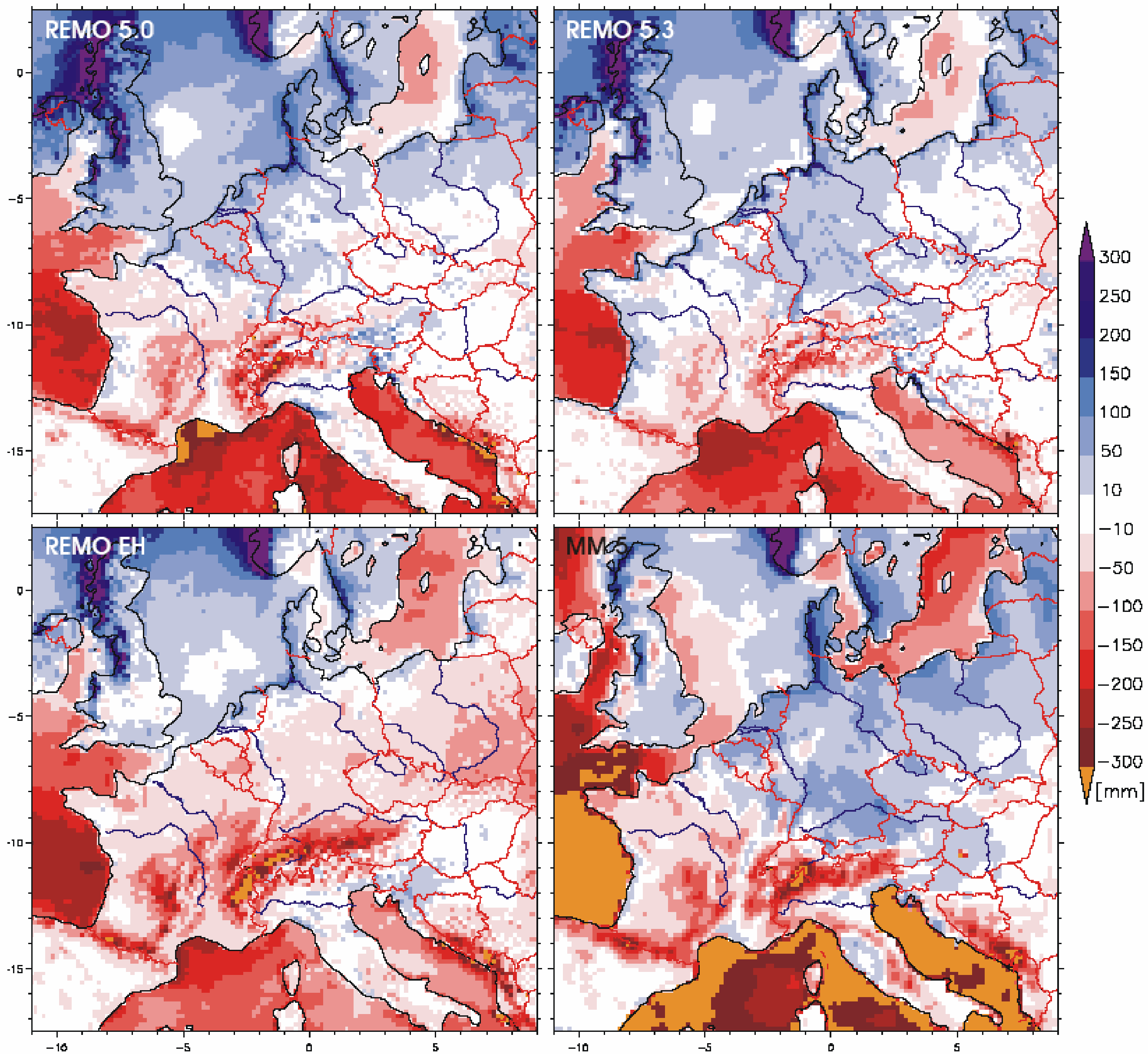

Thank you for your attention

Regional Climate Modeling & Hydrological Impact Analysis



Precipitation change

Regional Climate Modeling & Hydrological Impact Analysis



Change P-ET