Coupled Regional Climate-Hydrology Simulations for the Near East and the Upper Jordan Catchment

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Research questions

1) Is high resolution regional climate modelling able to reproduce the sharp transition of climate zones and the spatial and temporal climatic variability in the Jordan River Basin?

2) What is the expected future climate change and what is its effect on water availability, particularly the Upper Jordan catchment?

3) What are the uncertainties of results with respect to the different driving scenarios (i.e. unknown future emissions)?

Why Worrying about temperature increases?

- **Physical background**:
  1) warm air masses can carry more moisture
  2) increased temperatures yield increased potential evapotranspiration
  3) increase of latent heat ⇒ increase of energy content in atmosphere

- 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) drought risks**
  2) flooding risks

Global Climate Scenarios

Population Growth Economic Development
Technological Progress

↓

Emission Scenarios
Greenhouse Gas Concentrations

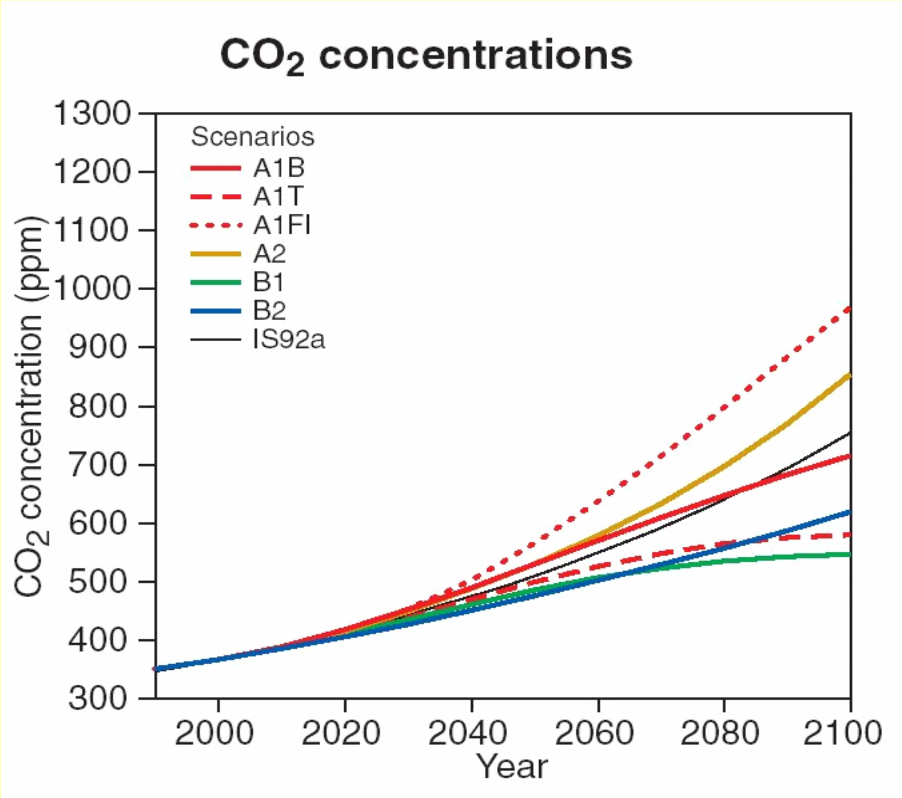
↓

Global Climate Models

↓

Global Climate Scenarios

Global Climate Scenarios

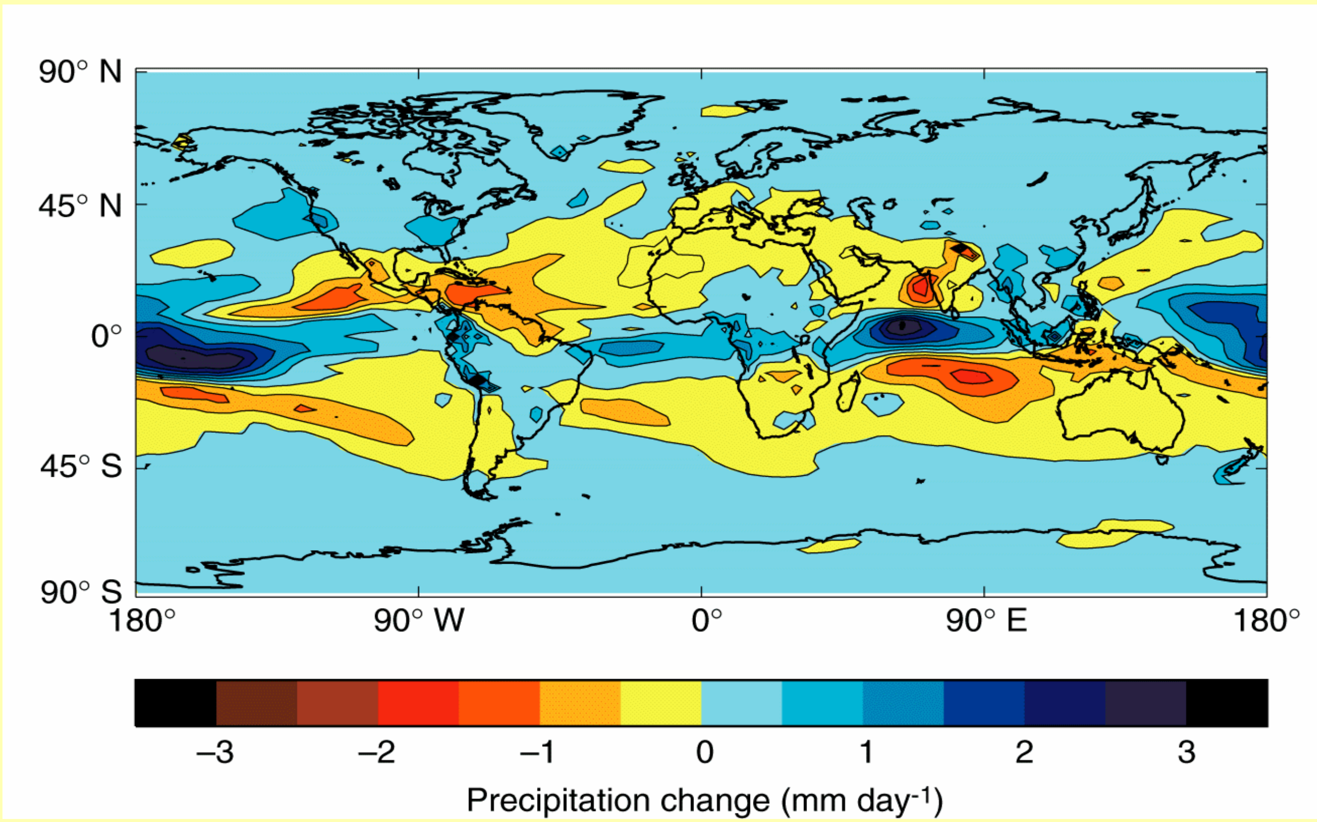


Emission scenarios

Global Climate Scenarios

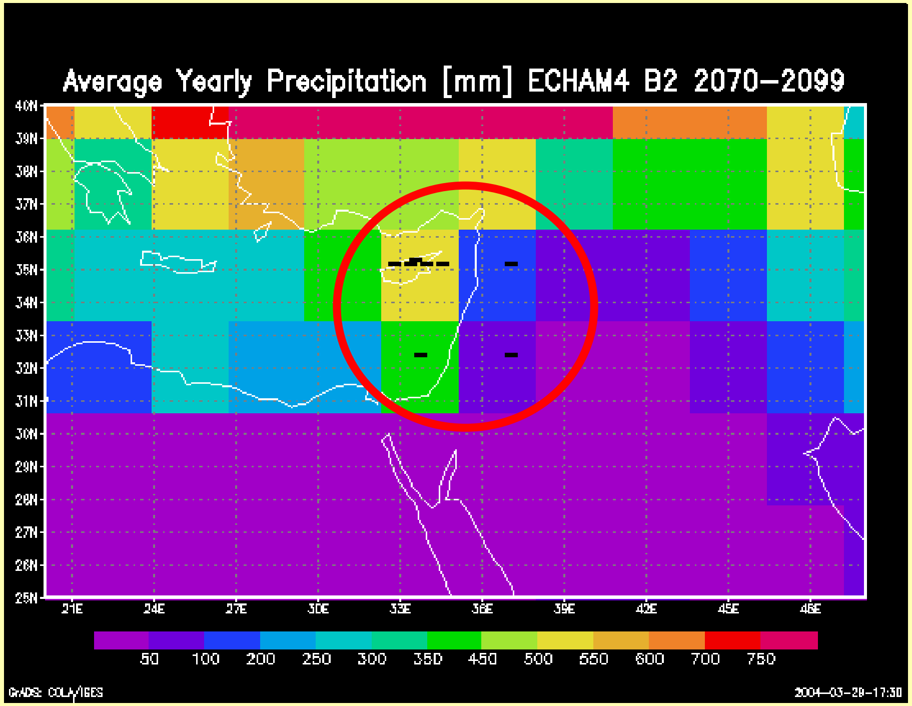
Projected Changes in Annual Precipitation for the 2050s

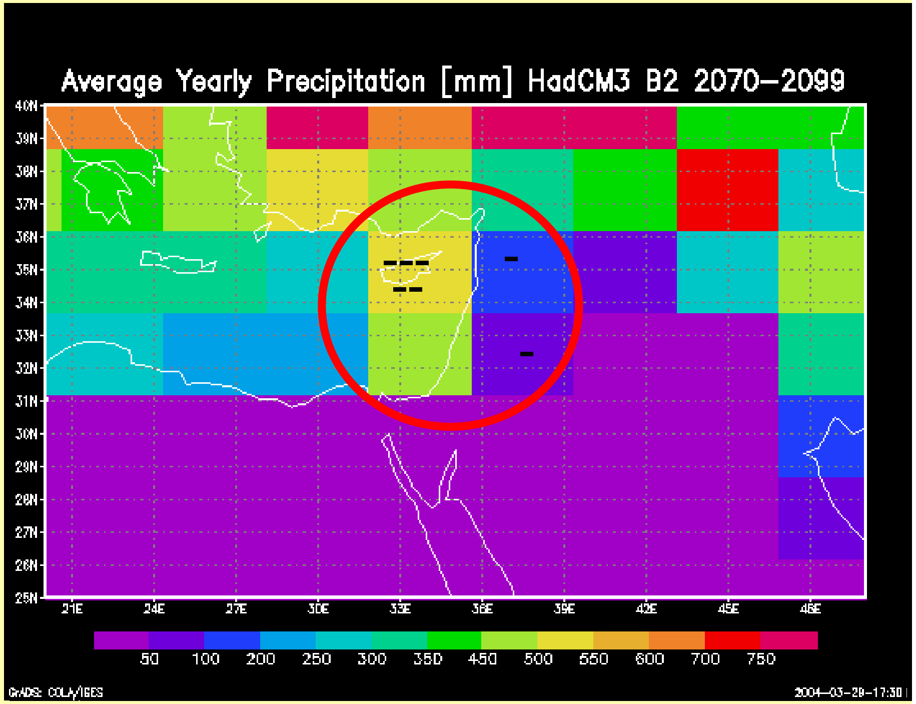
Hadley Centre for Climate Prediction and Research



⇒ Resolution too coarse for regional impact analysis

Global Climate Scenarios





ECHAM4 **Change in precipitation** HadCM3

Regional Climate Scenarios

How does global warming and greenhouse gas emissions impact regional climate in the Eastern Mediterranean/Near East?

Problem:

- Changes in the regional climate can differ significantly from the overall trend of global climate change

- Region has sharp climatic gradients: subhumid mediterranean ↔ arid climate

- Resolution of global climate models are much too coarse for hydrological impact studies

  ⇒ High resolution information required that account for regional and local geographic features (particularly orography, land use and water bodies)

Solution: Dynamic downscaling of global climate scenarios

GLOWA Jordan River

Regional Climate Scenarios

Population Growth Economic Development
Technological Progress

↓

Emission Scenarios
Greenhouse Gas Concentrations

↓

Global Climate Models

↓

Global Climate Scenarios

↓

Downscaling Methods

↓

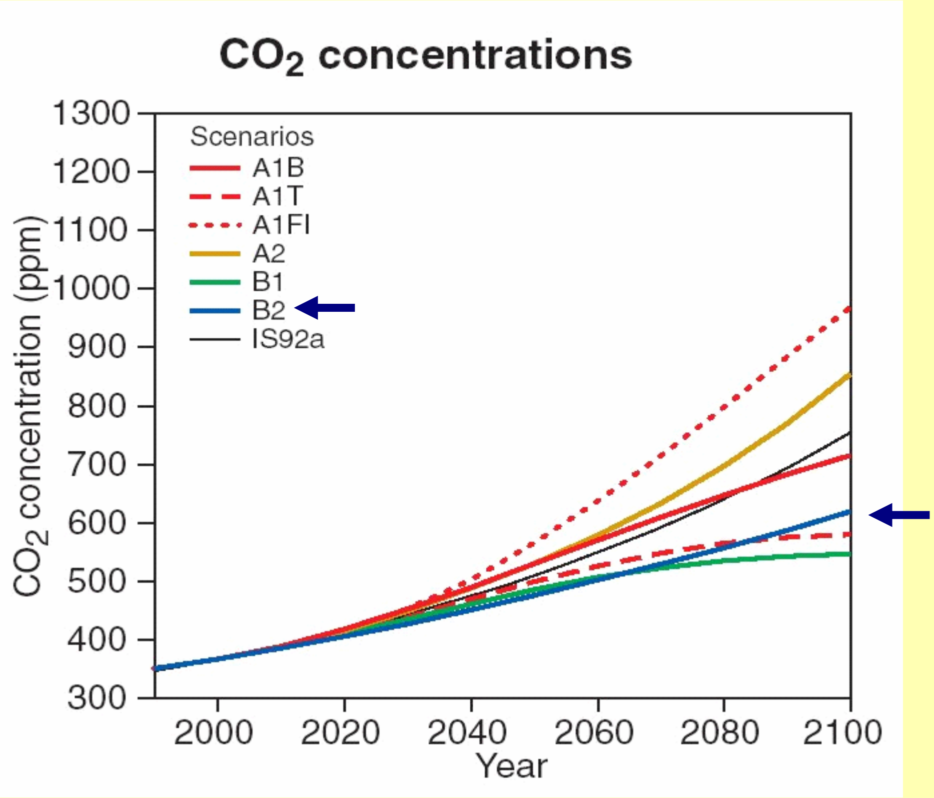
Regional Climate Scenarios

Regional Climate Scenarios

- **This study: scenario B2** (*“local solutions“*)
- Increase of CO_2: 30%

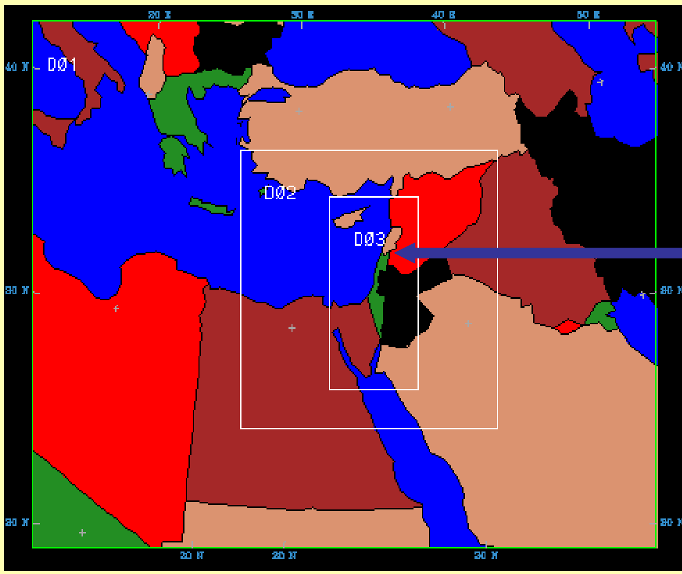
  1990: 350 ppm

  2070: 500 ppm
- Focus on time slices 1961-1990 & 2070-2099



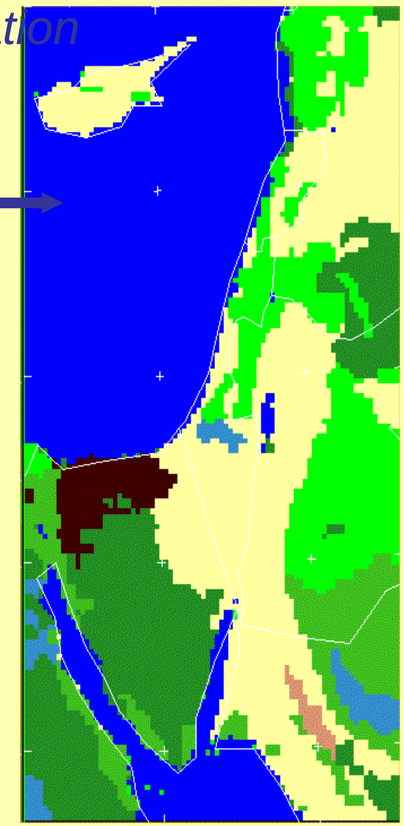
Regional Climate Modeling

The Mesoscale Meteorological Model MM5



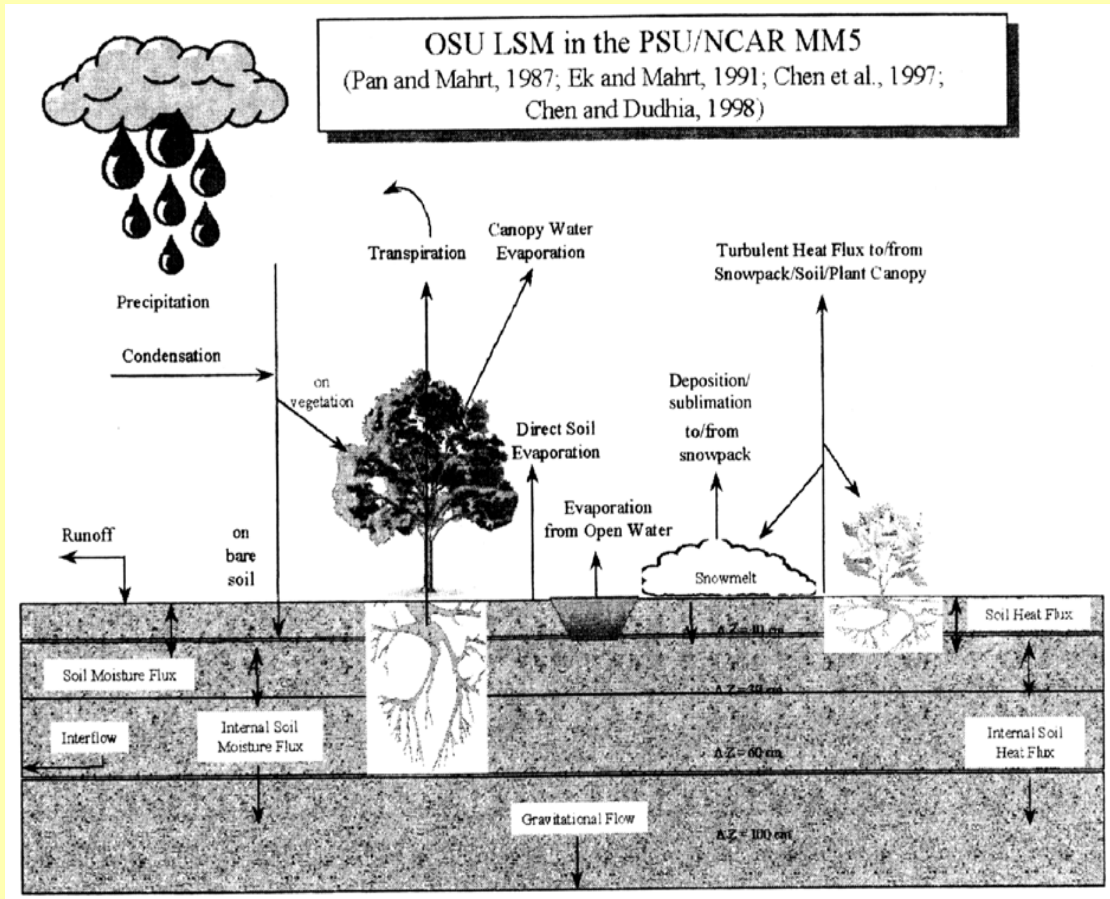
Land Use Discretization

Soil Discretization



- Dynamic Downscaling of ECHAM4 with MM5
- 3 nests: 54x54 km^2, 18x18 km^2, 6x6 km^2
- 26 Vertical Layers, Model Top: 100 mbar (ca. 17 km)
- Coupled OSU-Land-Surface Model
- Time slices: 1961-1990 & 2070-2099

Regional Climate Modeling



… accounts for soil-vegetation-atmosphere feedbacks

GLOWA Jordan River

Note

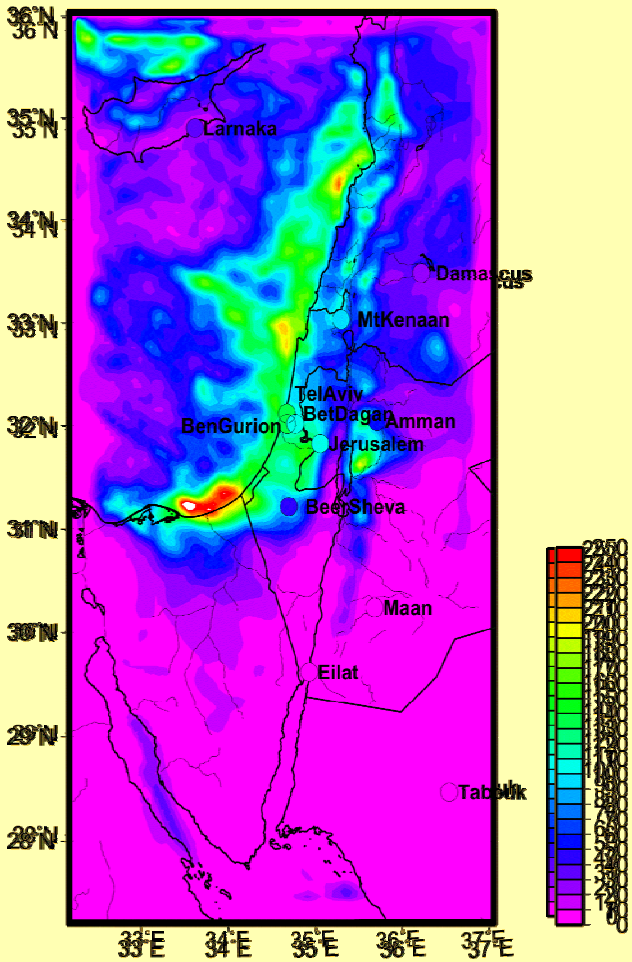
Basic differences between SVAT-based hydrological models and "traditional" hydrological models

- **SVAT-Hydro Models (designed for atmospheric feedback purposes)**:
  - full energy balance (soil heat & sensible heat fluxes)
  - 2-way interaction with PBL
- **"Traditional"-Hydro models (designed for pure hydrol. applications)**:
  - 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: depending on specific model choice**

Necessity of High Resolutions

Modeled vs. observed precipitation [mm]
February, 1993
MM5

6x6 km² resolution !



Rainy season

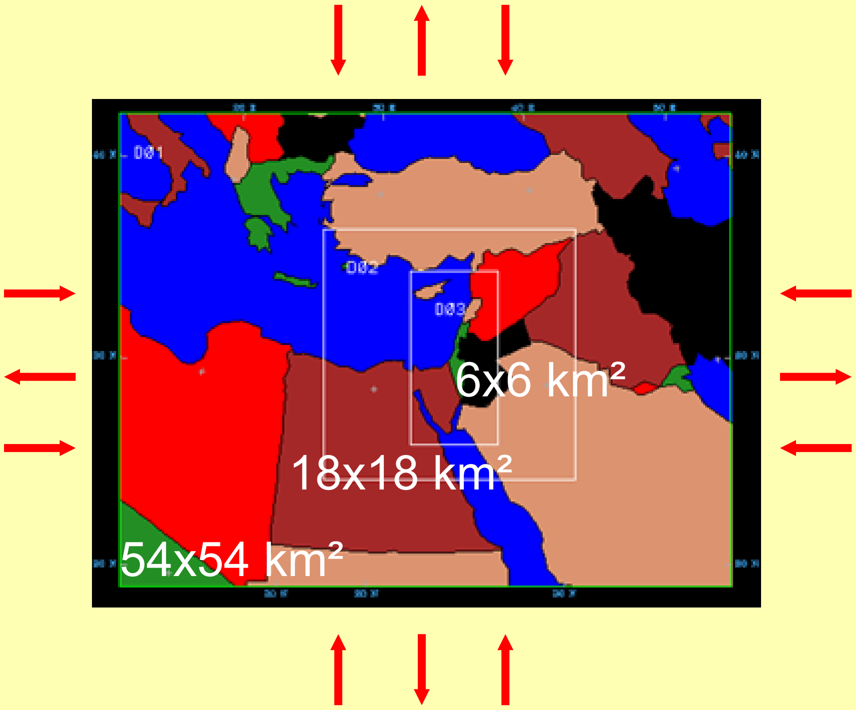
Regional Climate Modeling

Explicit dynamical downscaling of global climate scenarios

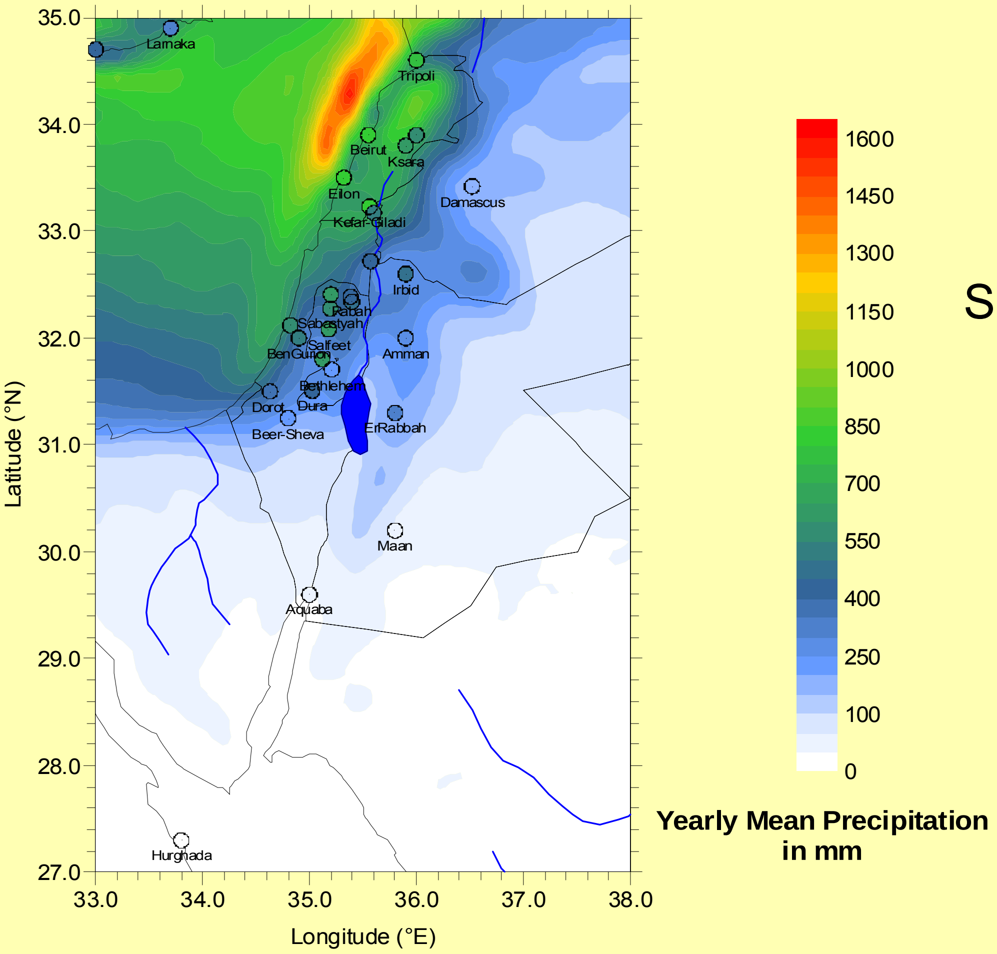
Intermediate results
- Two nesting steps (grid size of 54, 18km)
- 25 vertical levels
- CT & **B2** scenario ECHAM4 data
- 2x30 years time slices
  (1961-1990 & 2070-2099)

Current status
- 60 y simulations
- ~30000 CPUh
- ~5 TByte disc space

Next Steps
- Finishing 6 km
- Additional scenario A2
- Alternative GCM (HadCM3)
- Alternatively: transient run



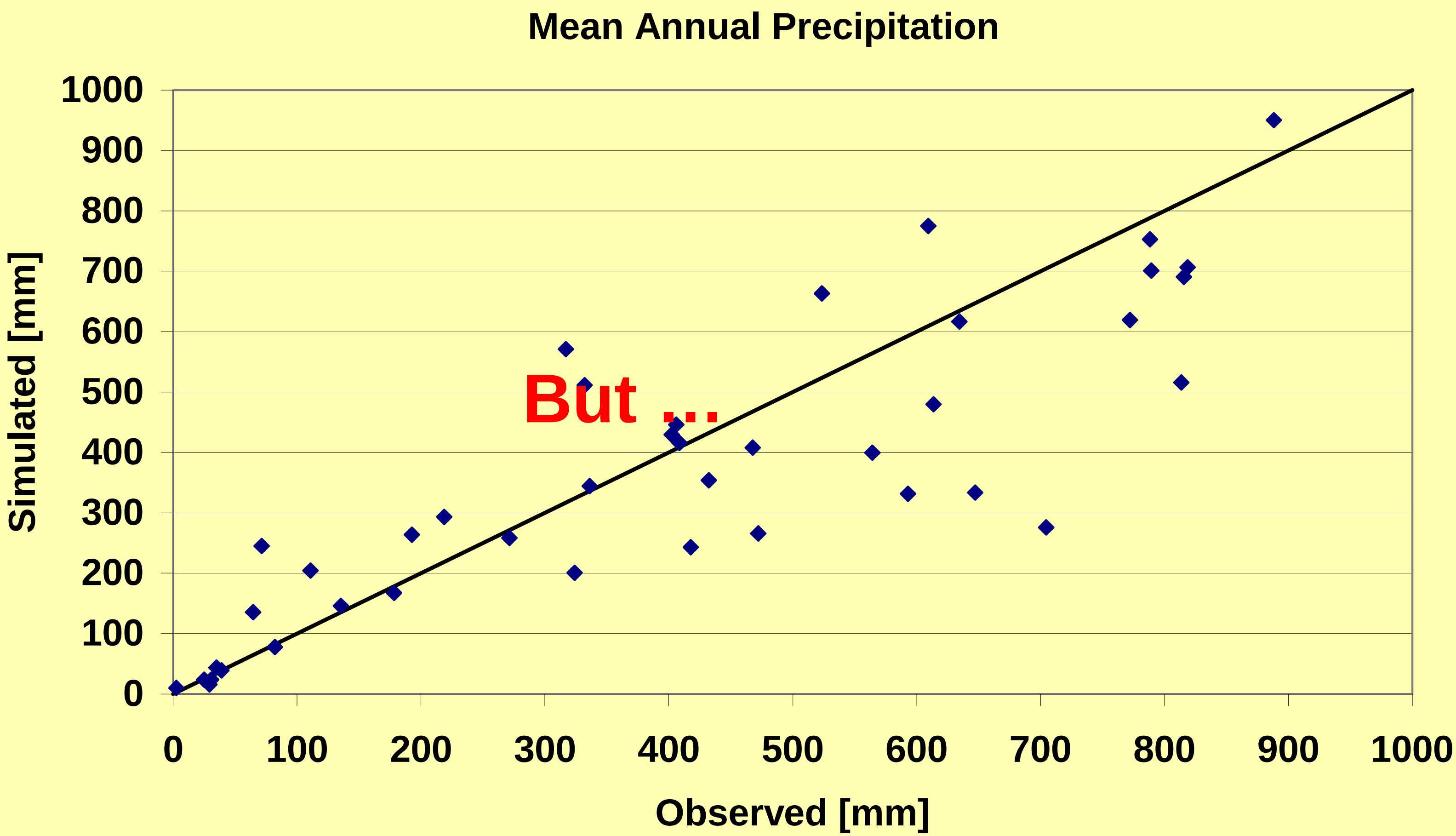
Control Simulation



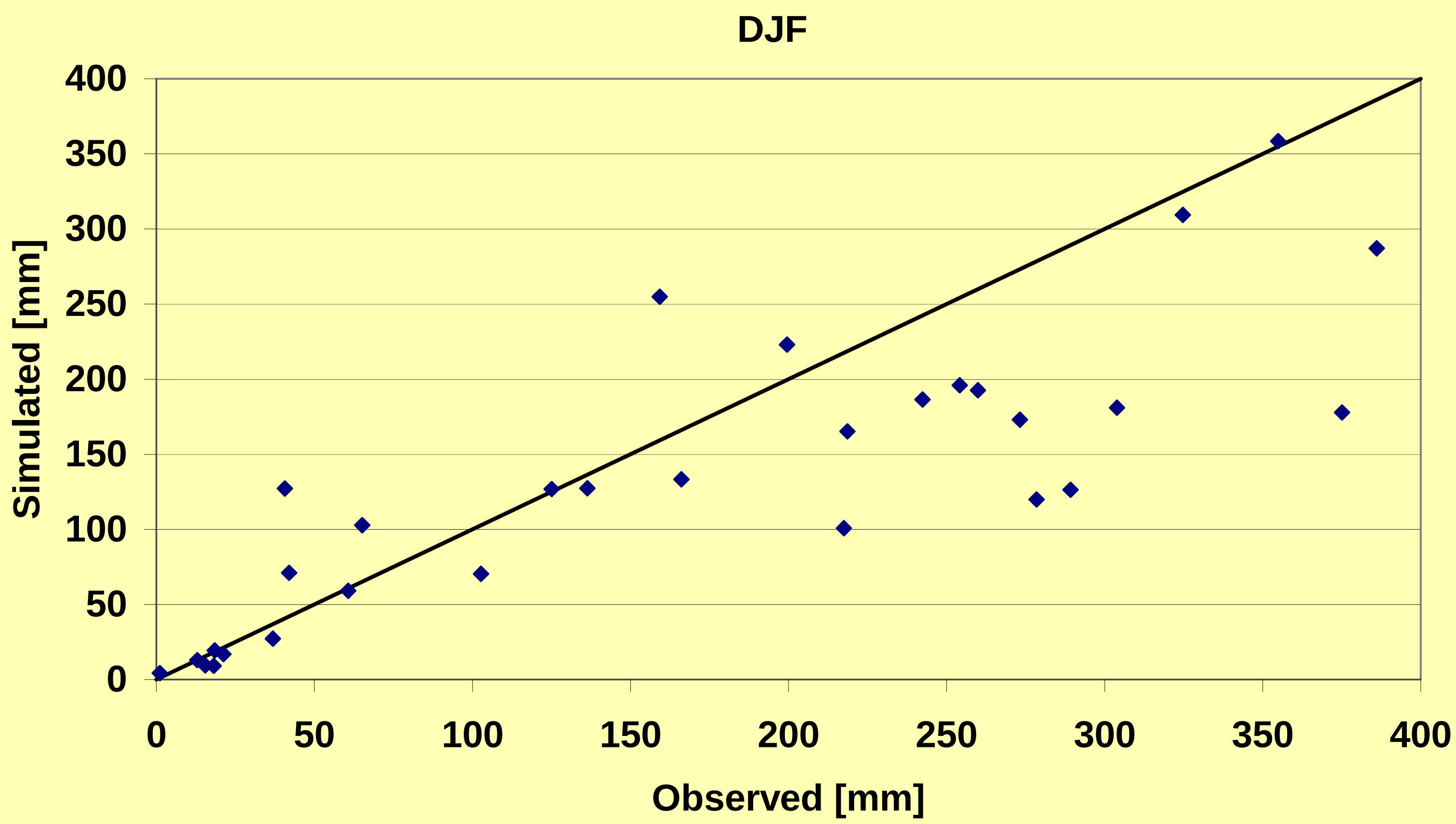
Simulated annual mean precipitation
(ECHAM4, 18 km², 1961-1990)
vs.
observed long term annual mean
(for selected stations 1961-1990)

Control Simulation

How accurate does the downscaled Control Run reproduce observed precipitation?

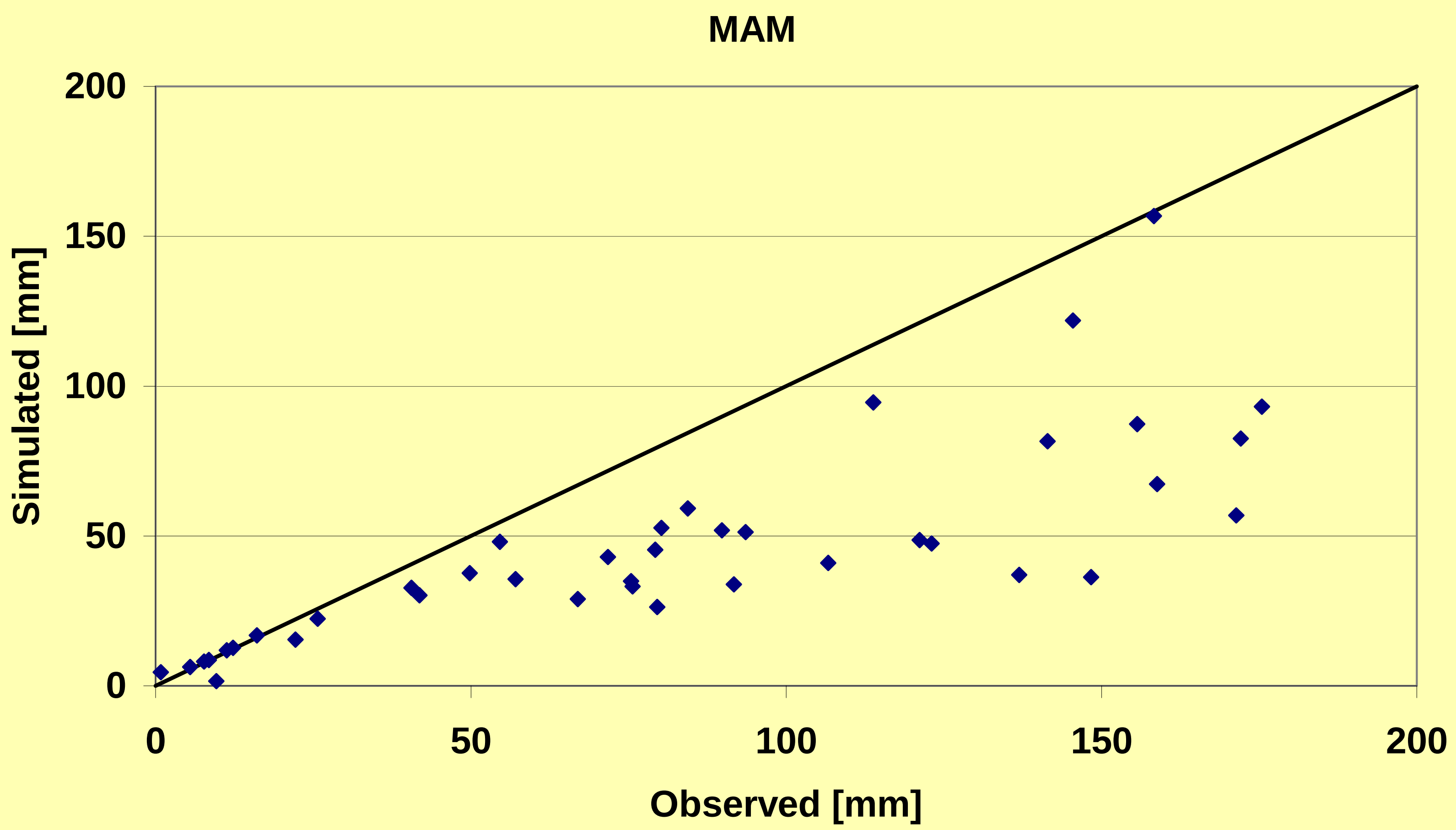


Control Simulation



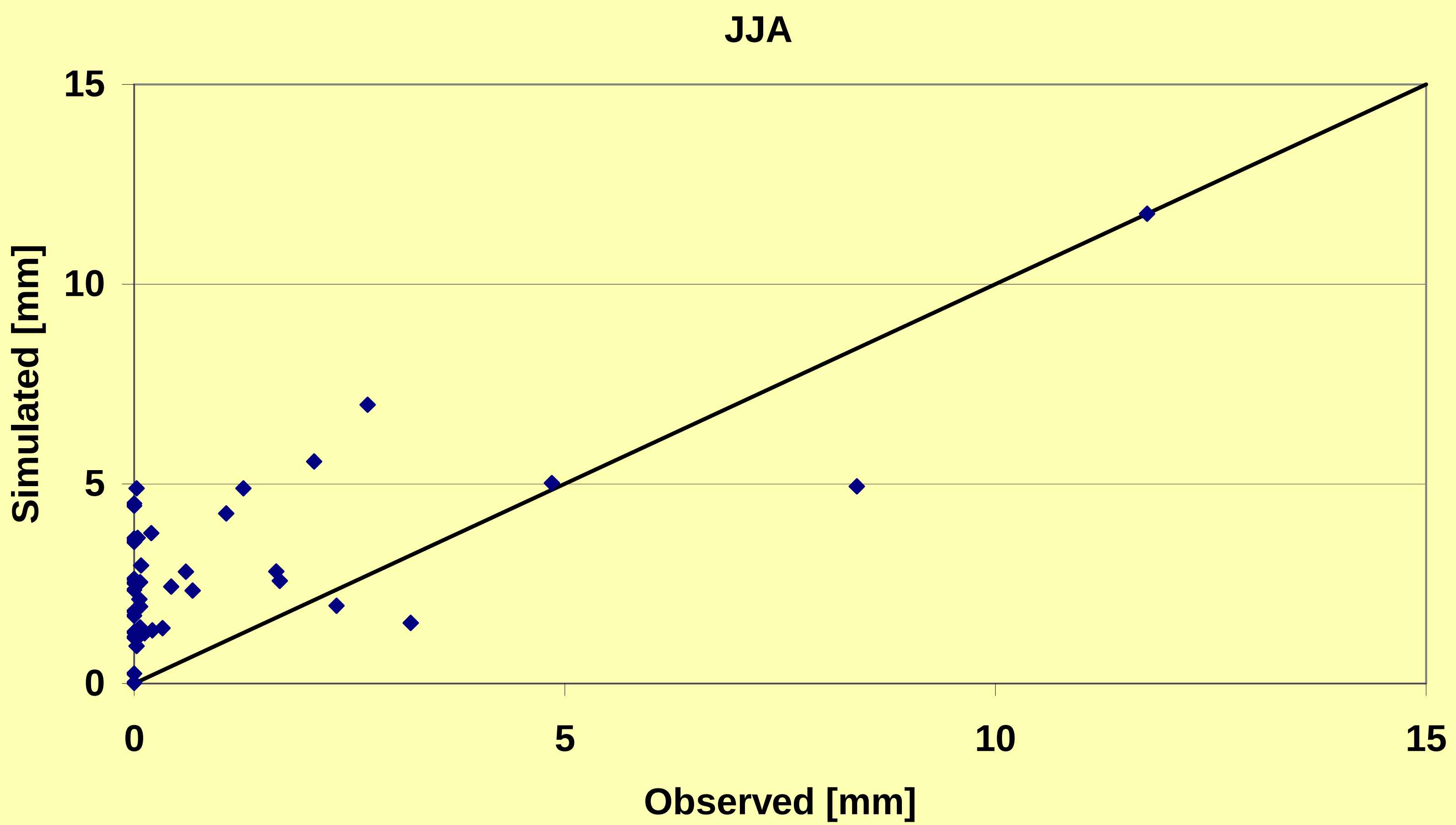
⇒ **Tendency to underestimate high precipitation in winter**

Control Simulation



⇒ **Bias in MAM: Underestimation**

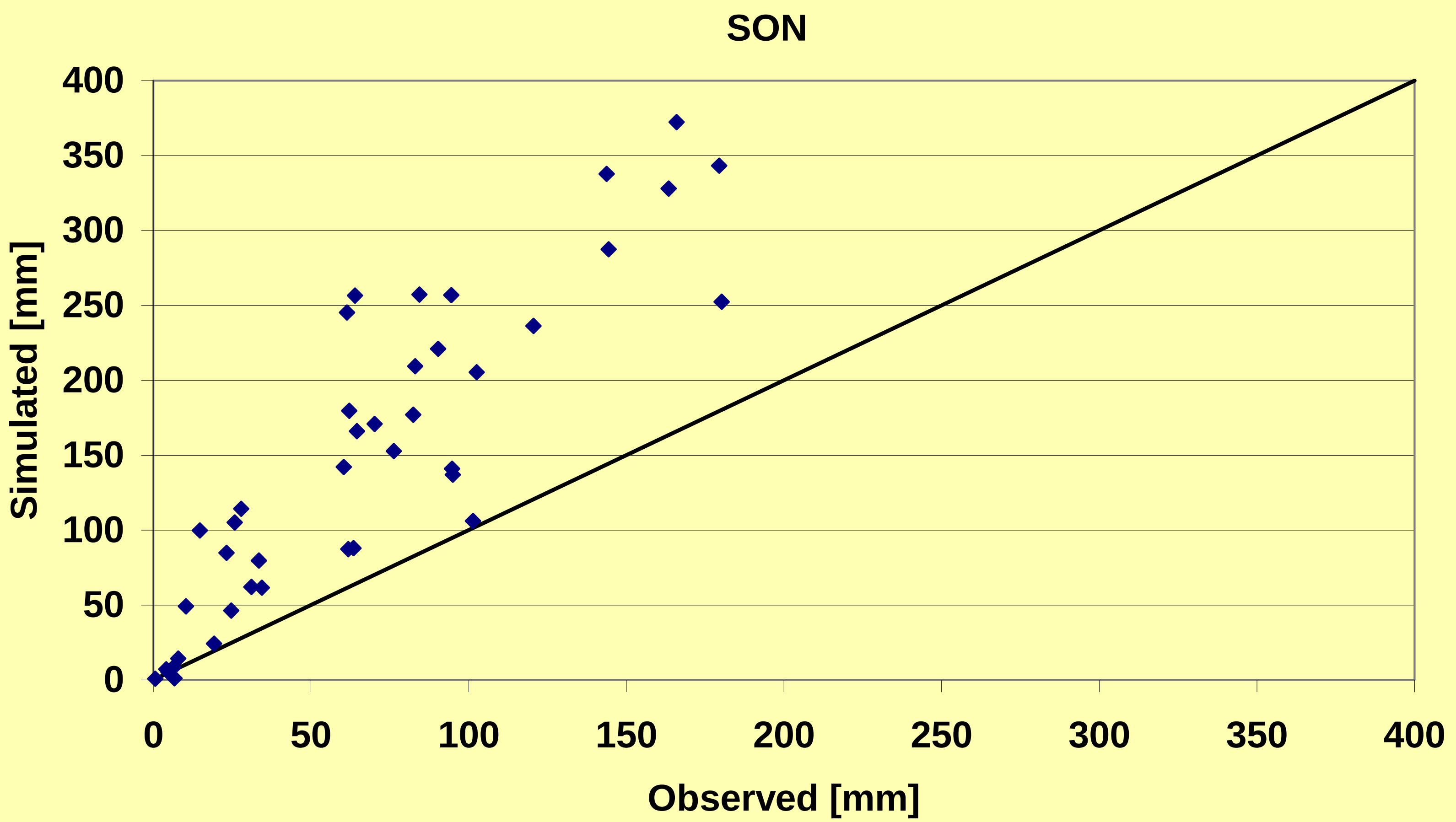
Control Simulation



⇒ **Difficulties to produce "zero" precipitation**

⇒ **But: Absolute errors negligible**

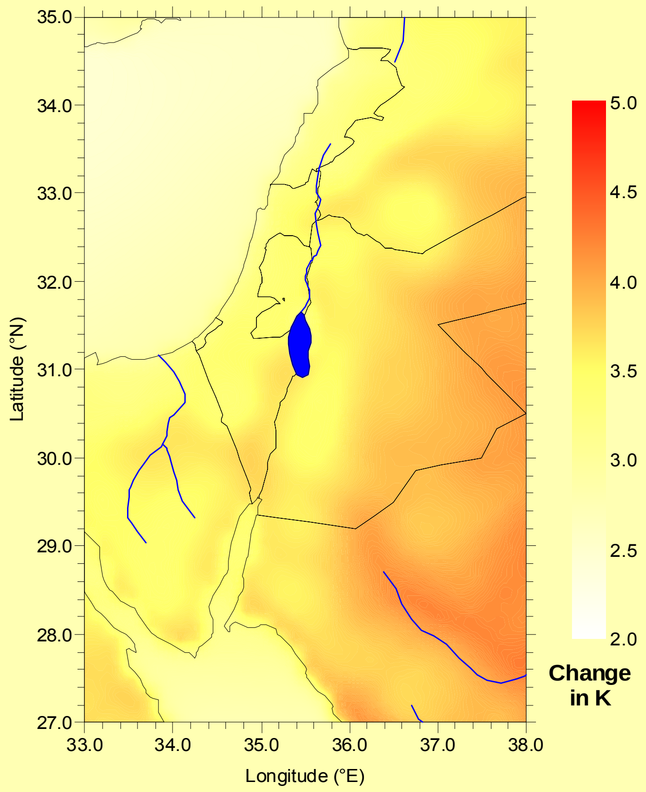
Control Simulation



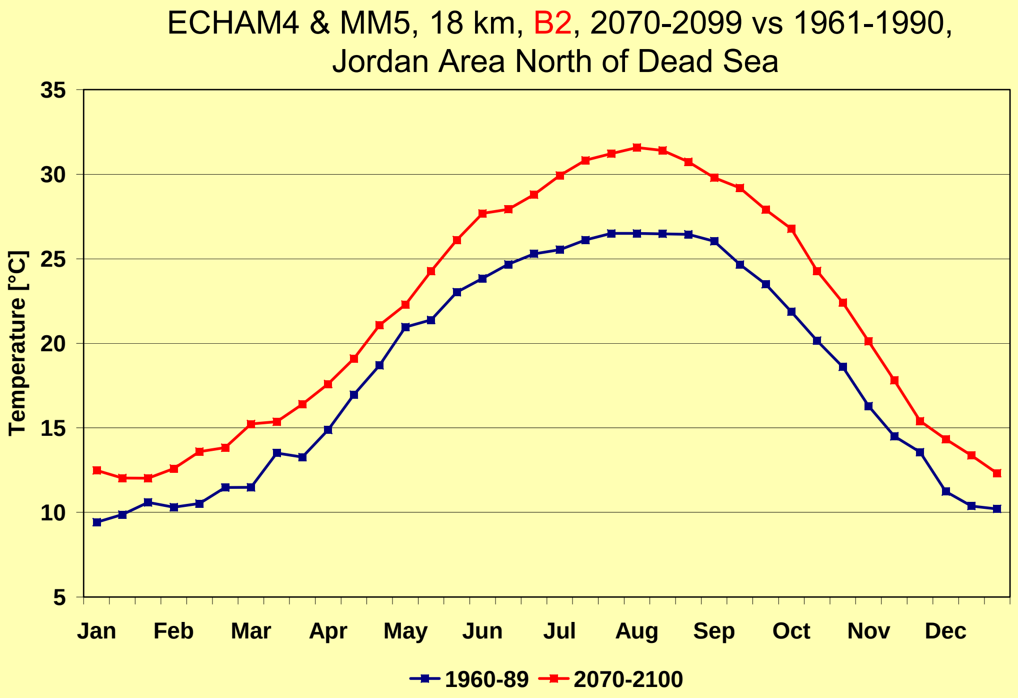
⇒ **Bias in SON: Overestimation of precipitation**

Expected Climate Change

What are the expected changes in temperature?



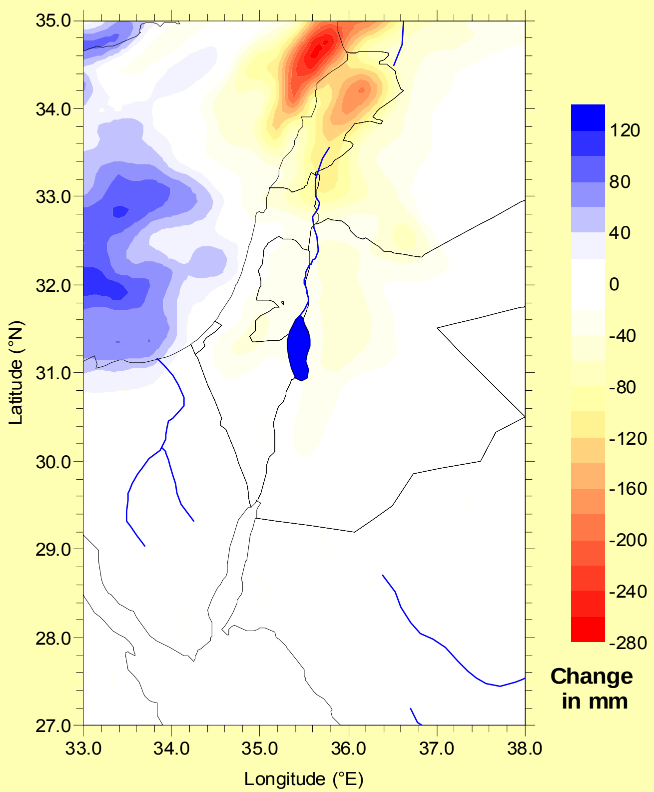
Change in annual mean temperature



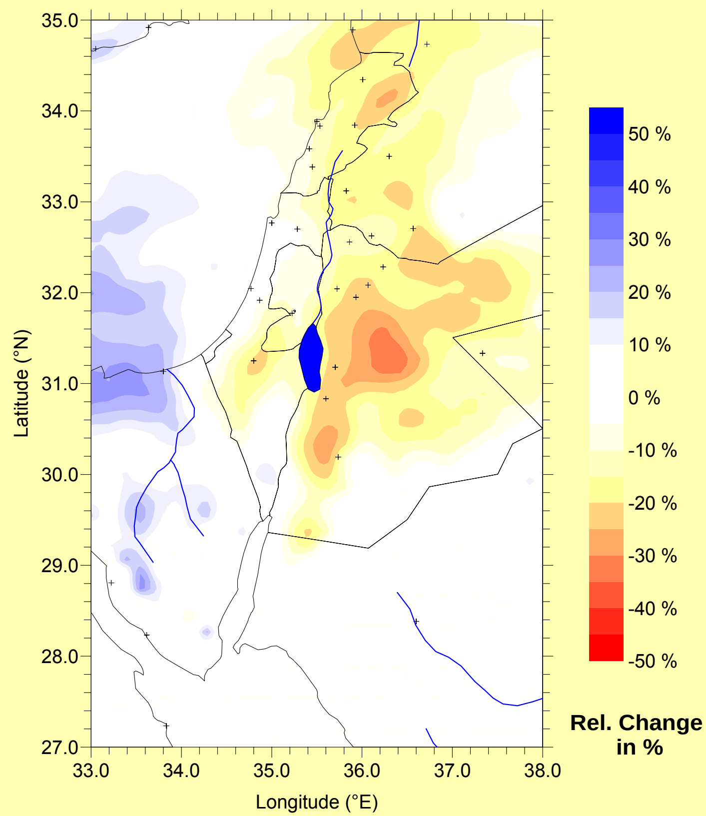
Change in temporal distribution, averaged over domain 2

Expected Climate Change

What are the expected changes in precipitation?



Absolute change in [mm]

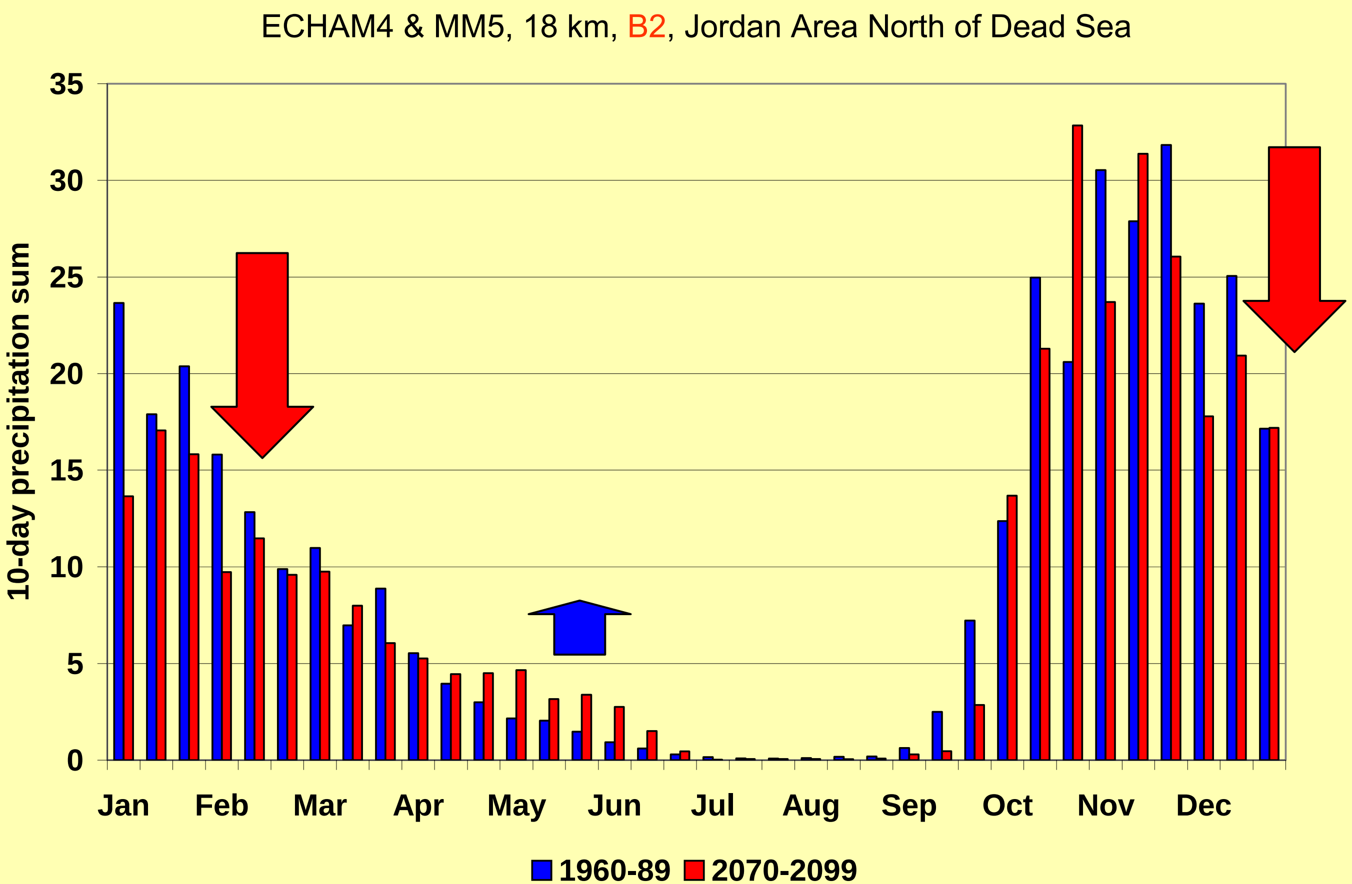


Relative Change in [%]

ECHAM4 & MM5, 18 km, B2, 2070-2099 vs 1961-1990

Expected Climate Change

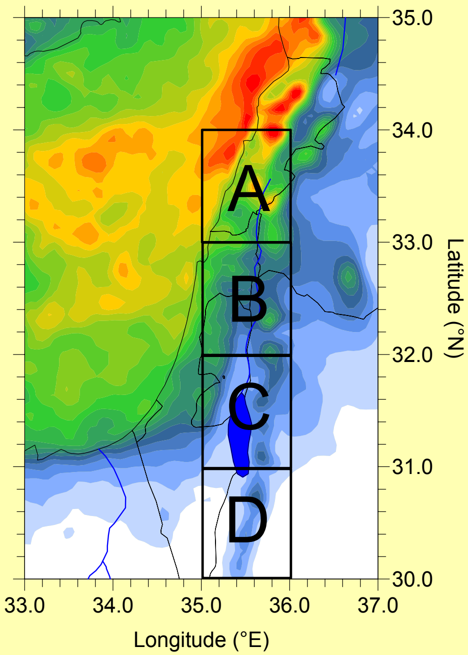
How does the temporal distribution of precipitation change?

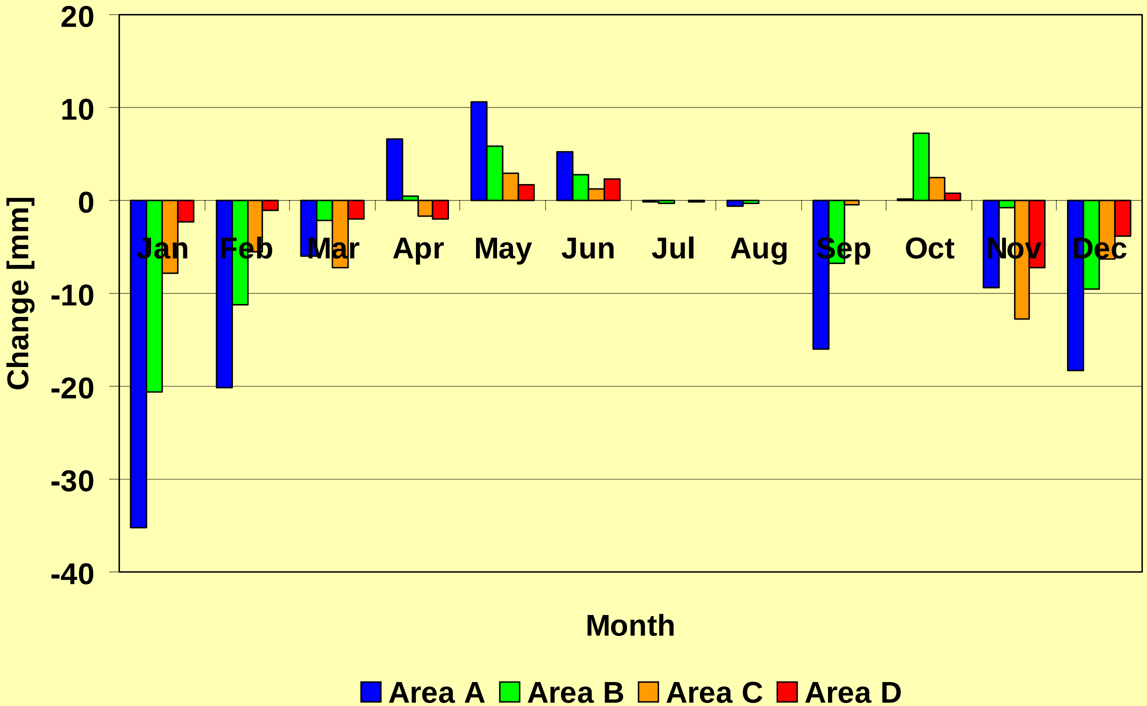


Strongly decreased winter, slightly increased absolute spring precipitation

Expected Climate Change

How does seasonal precipitation change depend on the region?

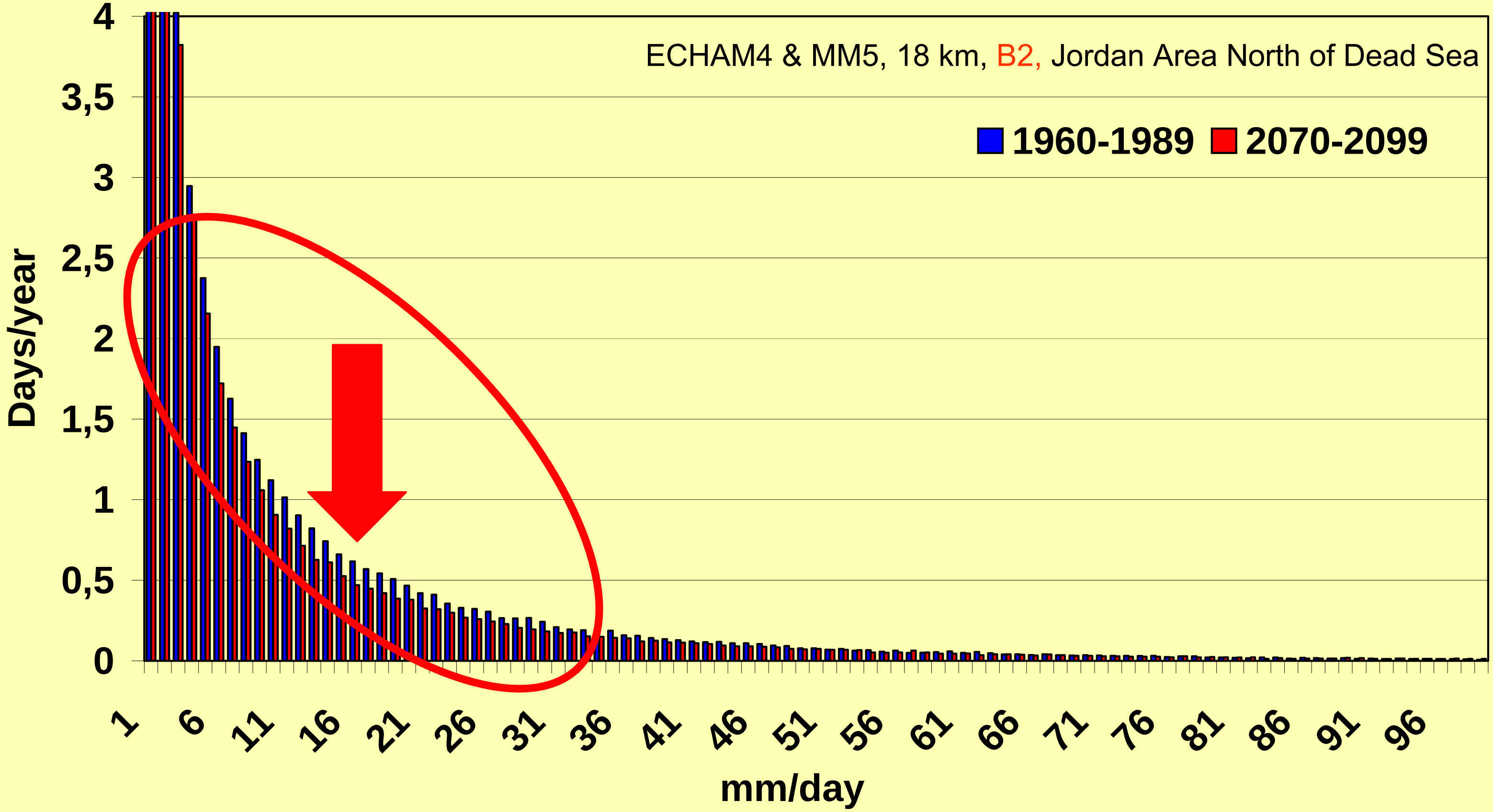




For all subregions: Decreased winter, increased spring precipitation

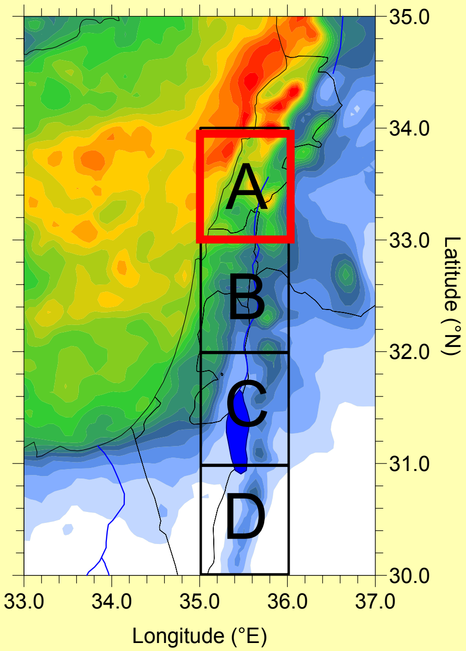
Expected Climate Change

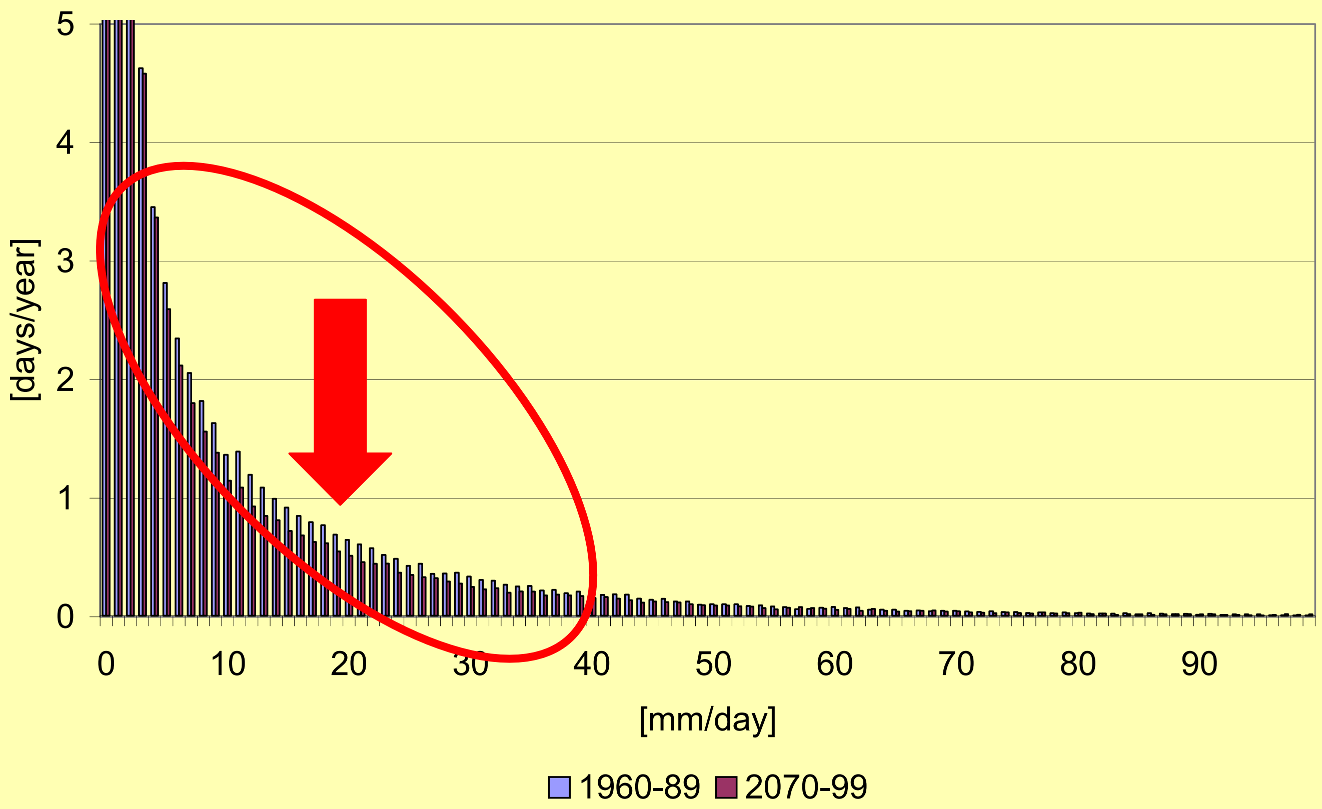
How do precipitation intensities change?



Tendency towards decrease of precipitation intensity

How does precipitation intensity change depend on the region?





Expected Climate Change

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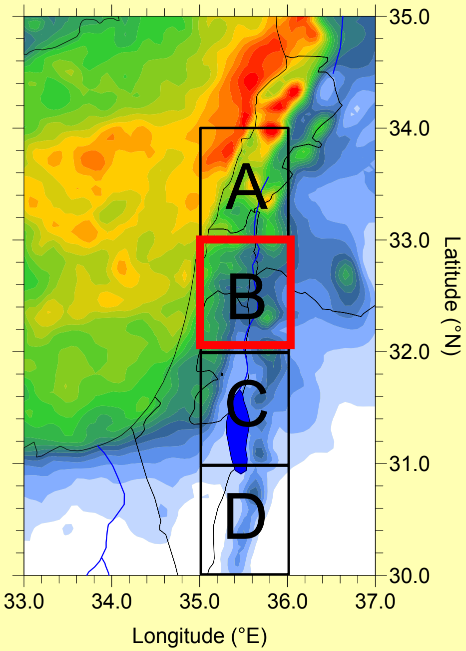

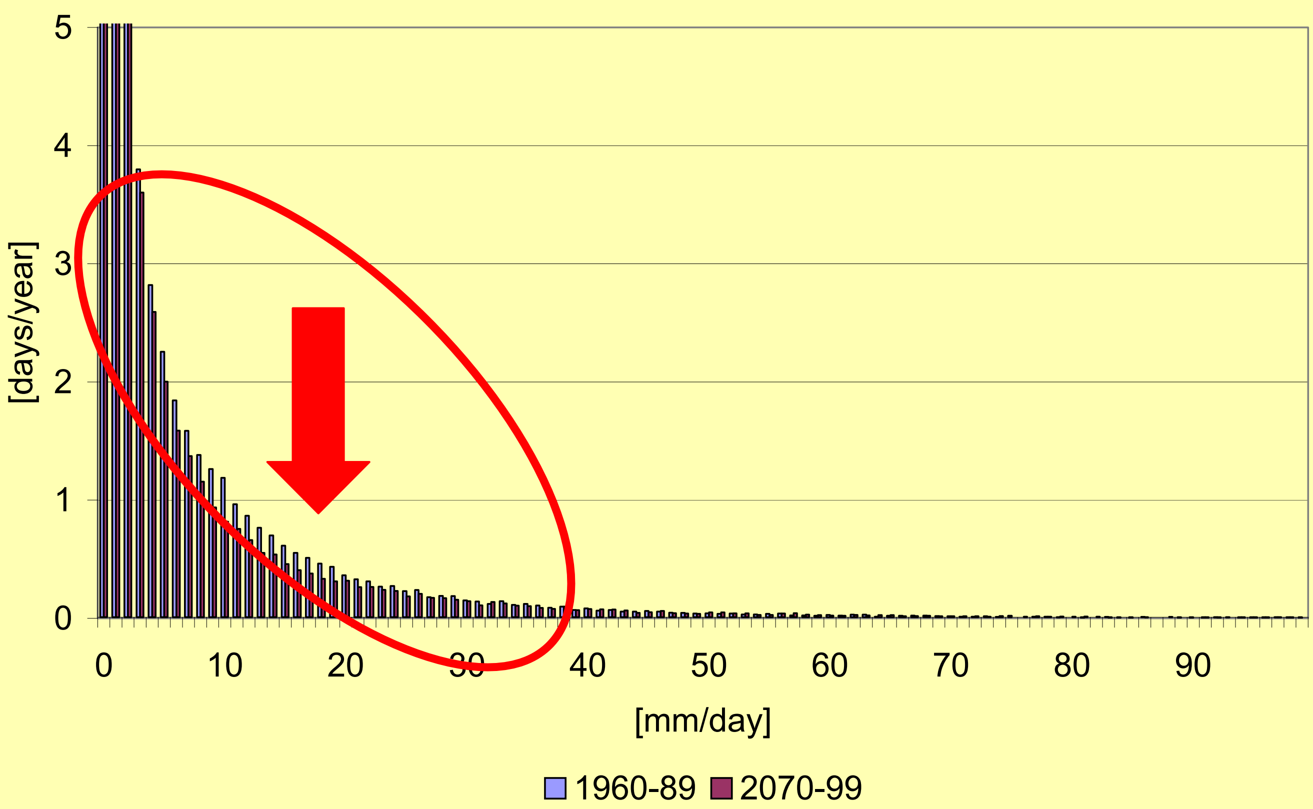

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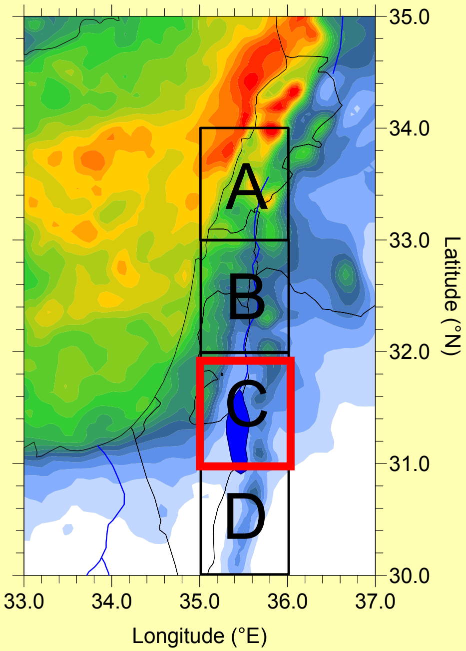
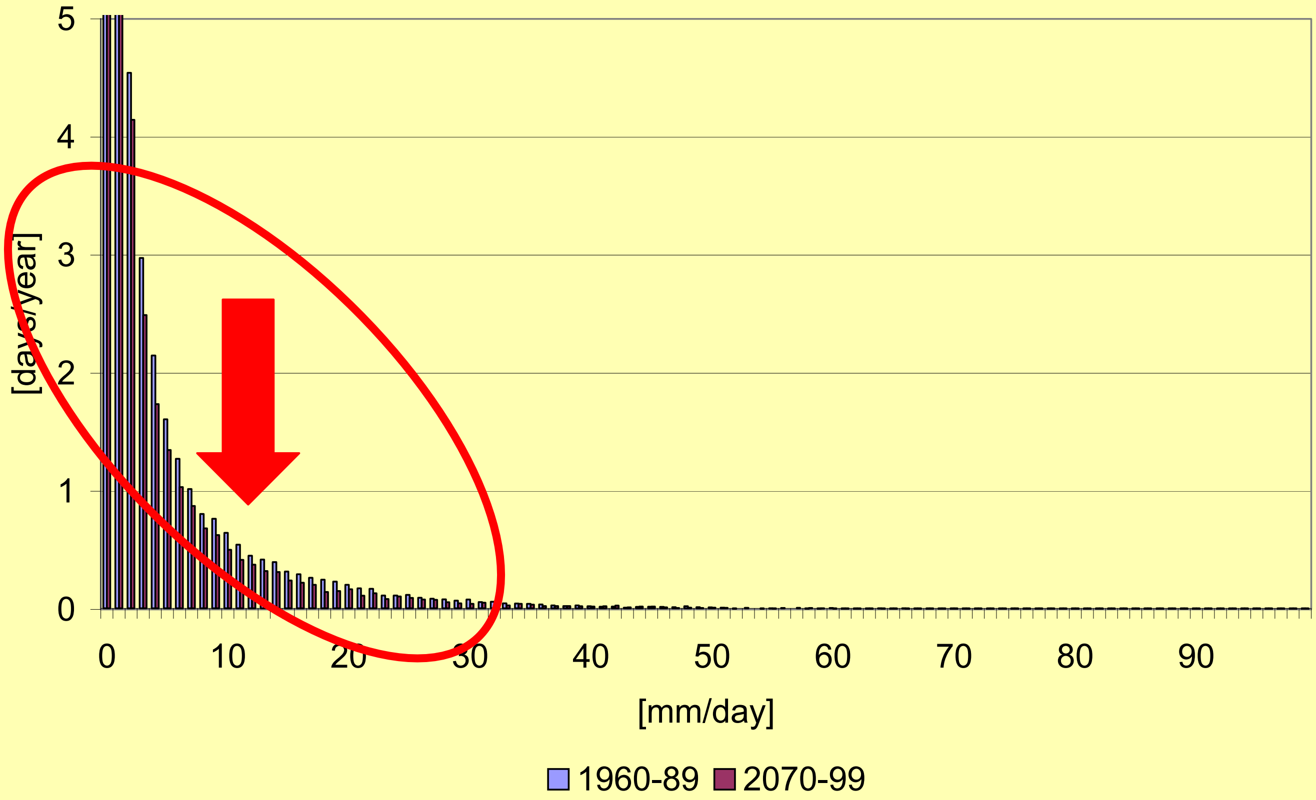
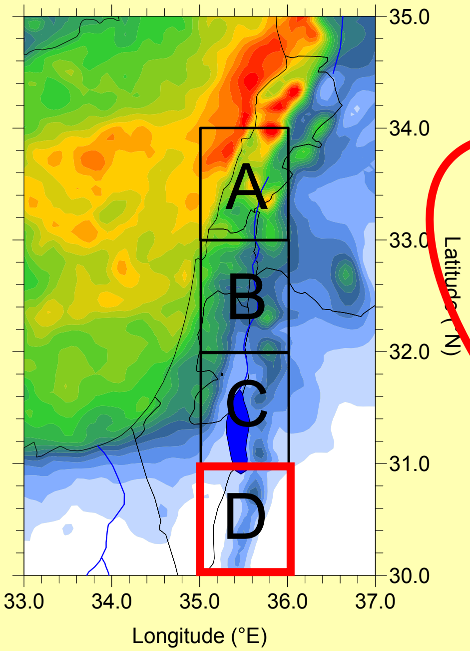
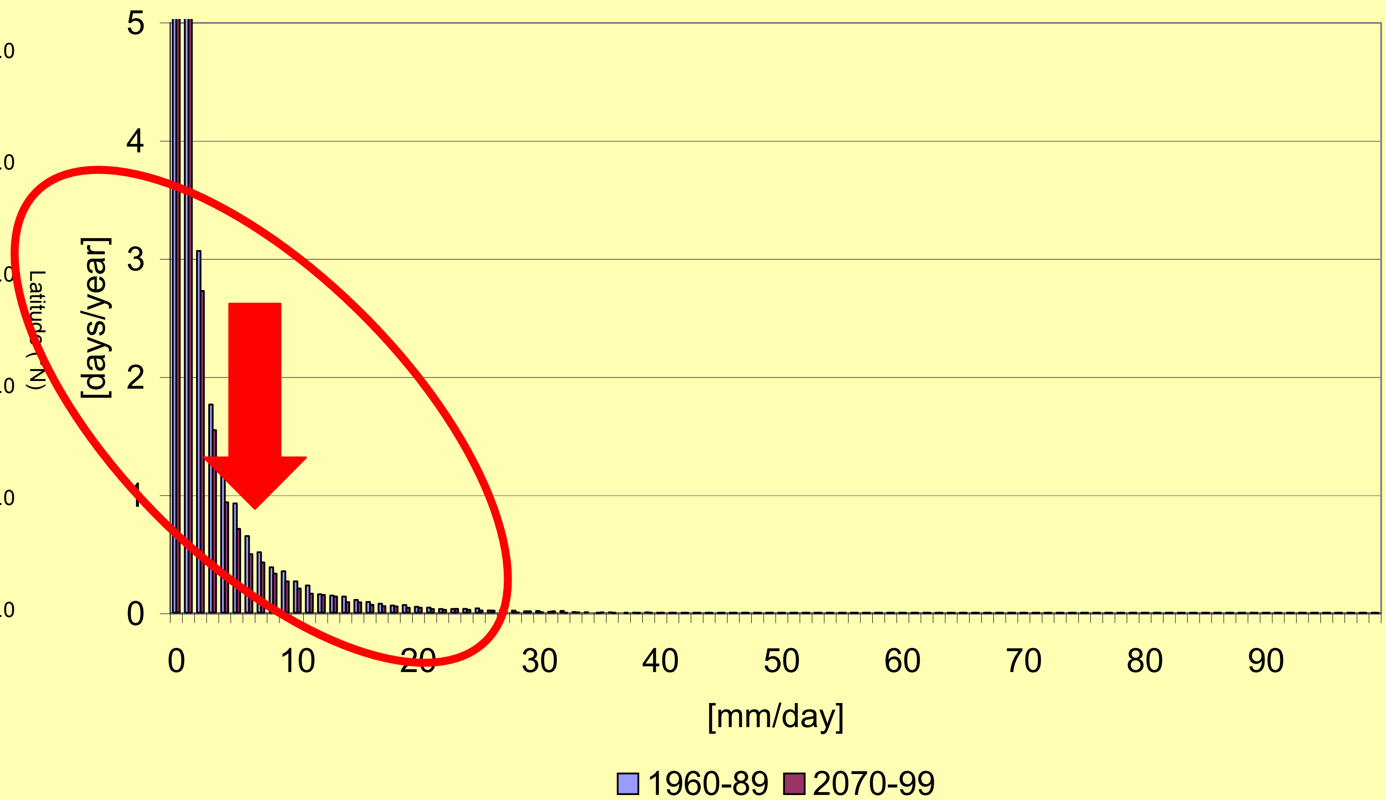




How does seasonal precipitation change depend on the region?

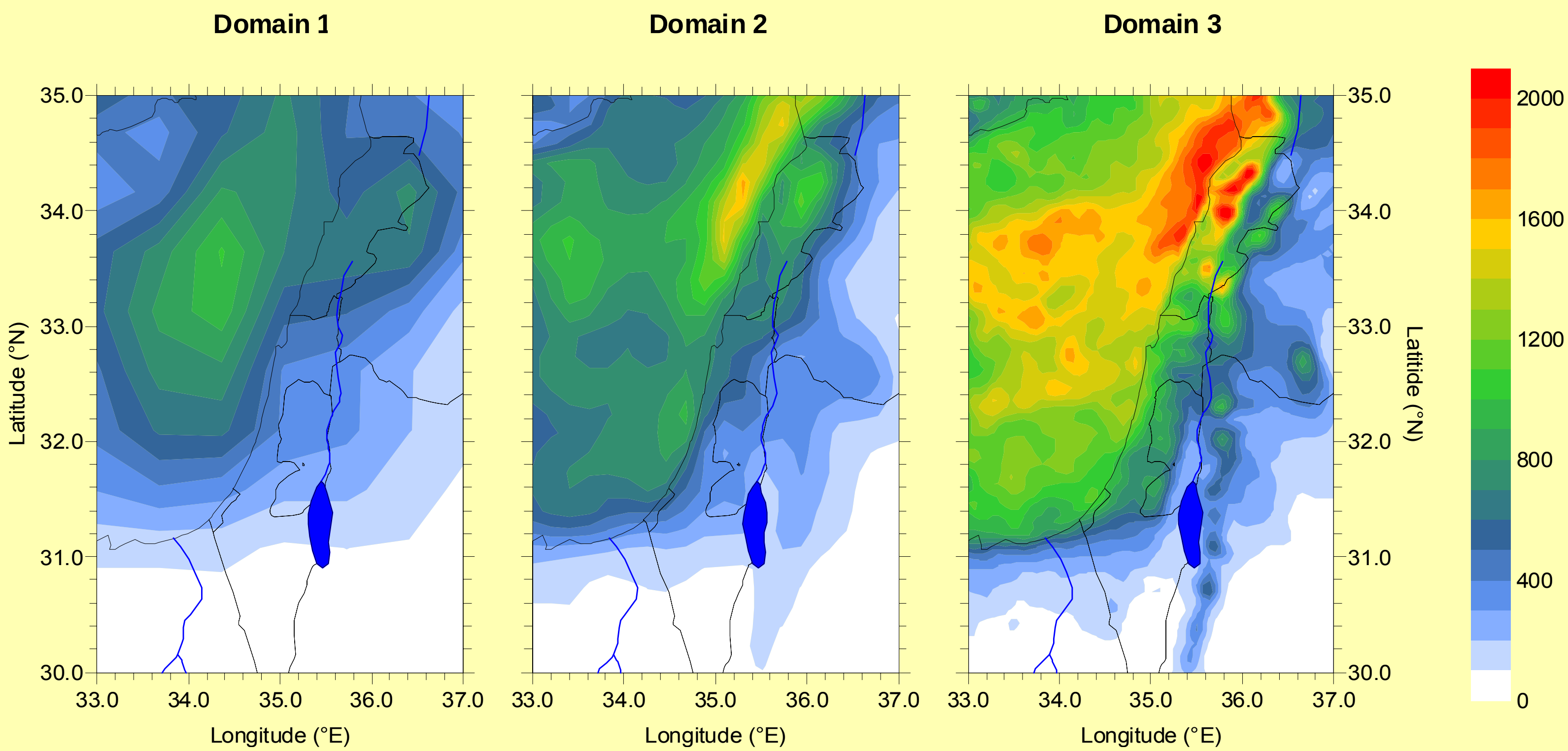




Impact of Resolution

What do we expect from the High Resolution Simulations with 6 km?

First results of 6 km runs: mean 1961 + 1962



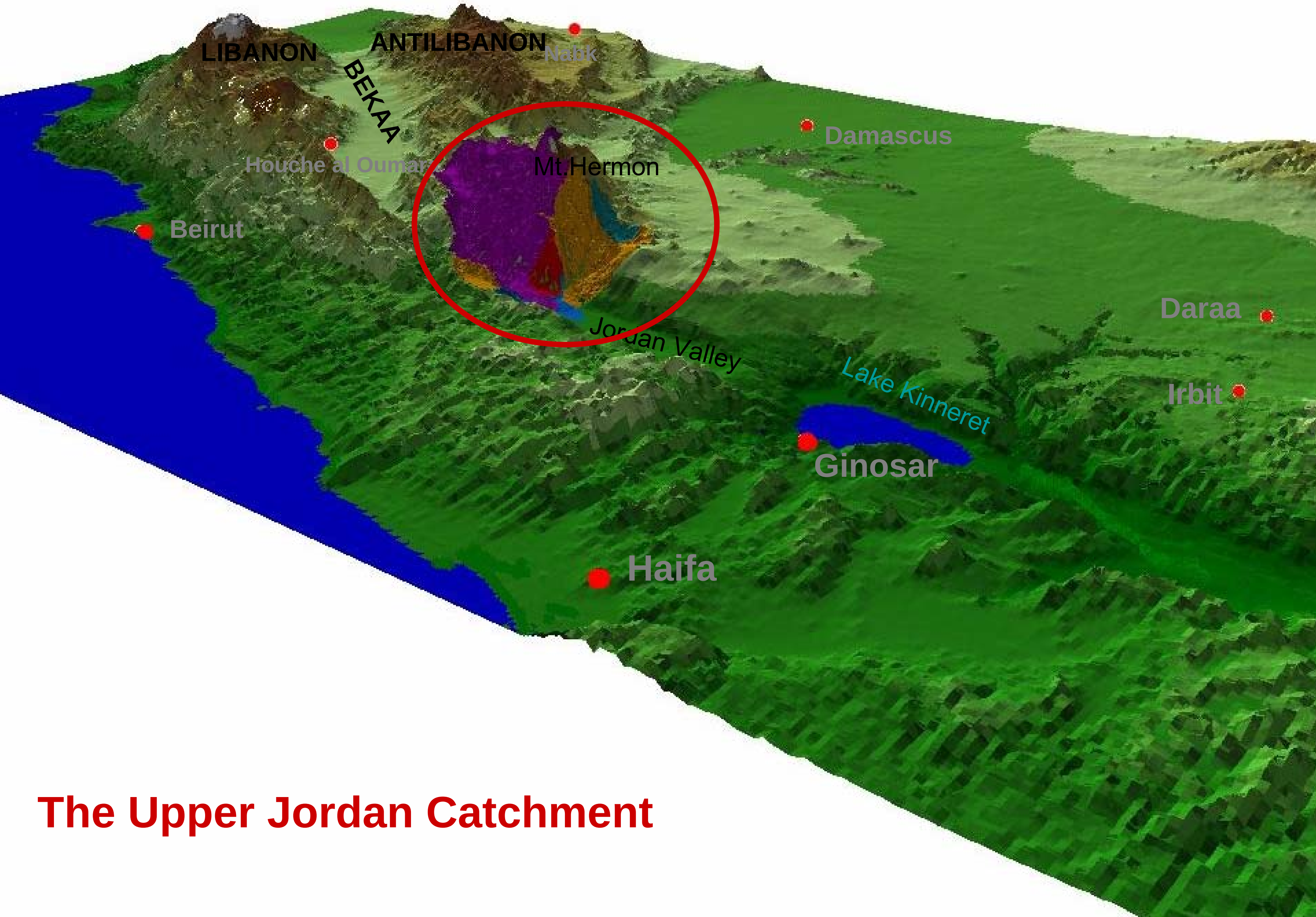
54km   18 km   6 km

… more detailed spatial information: land-sea & orography dependent features

GLOWA Jordan River

The Upper Jordan Catchment

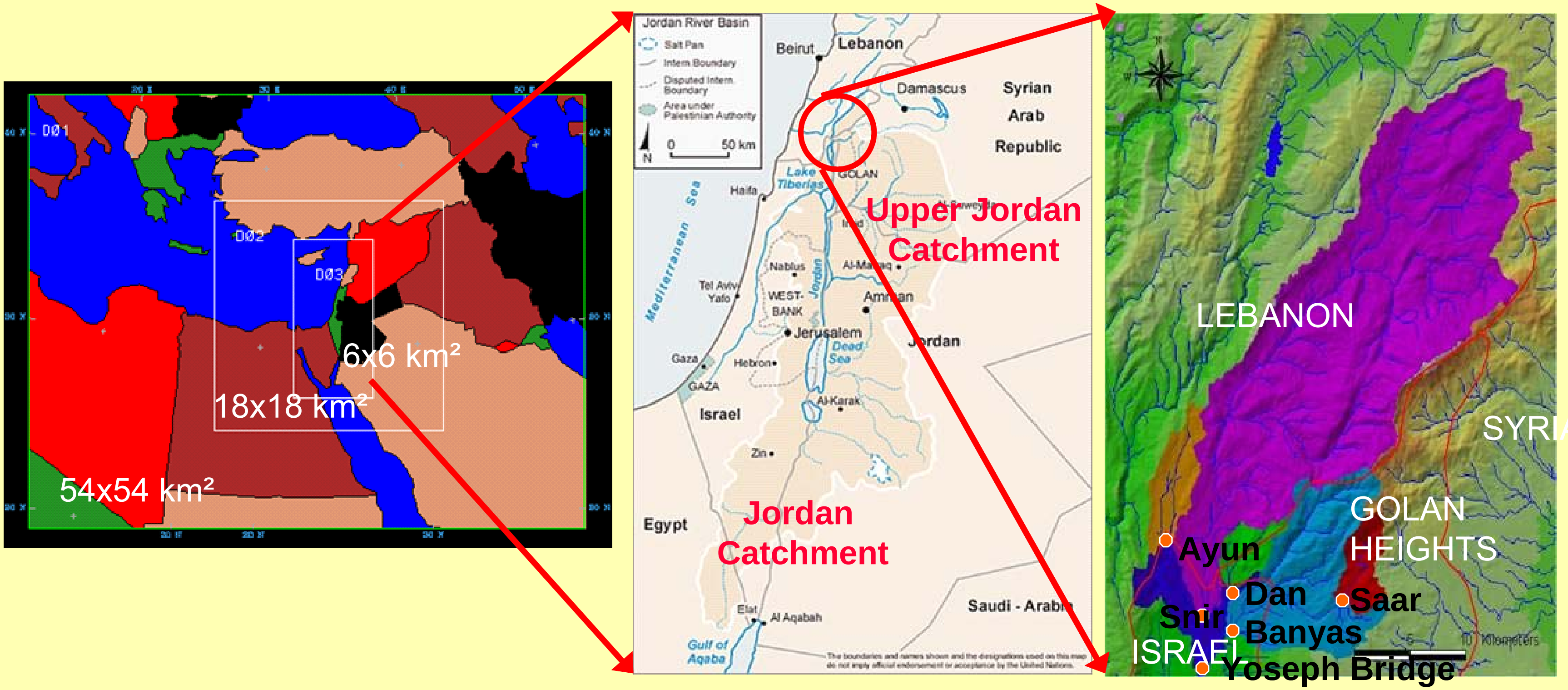
How does the expected atmospheric change translate into change of terrestrial hydrology of Upper Jordan Catchment?



The Upper Jordan Catchment

Towards Coupled Modeling

What is the Impact of Expected Atmospheric Change on Terrestrial Water Availability in the UJC?

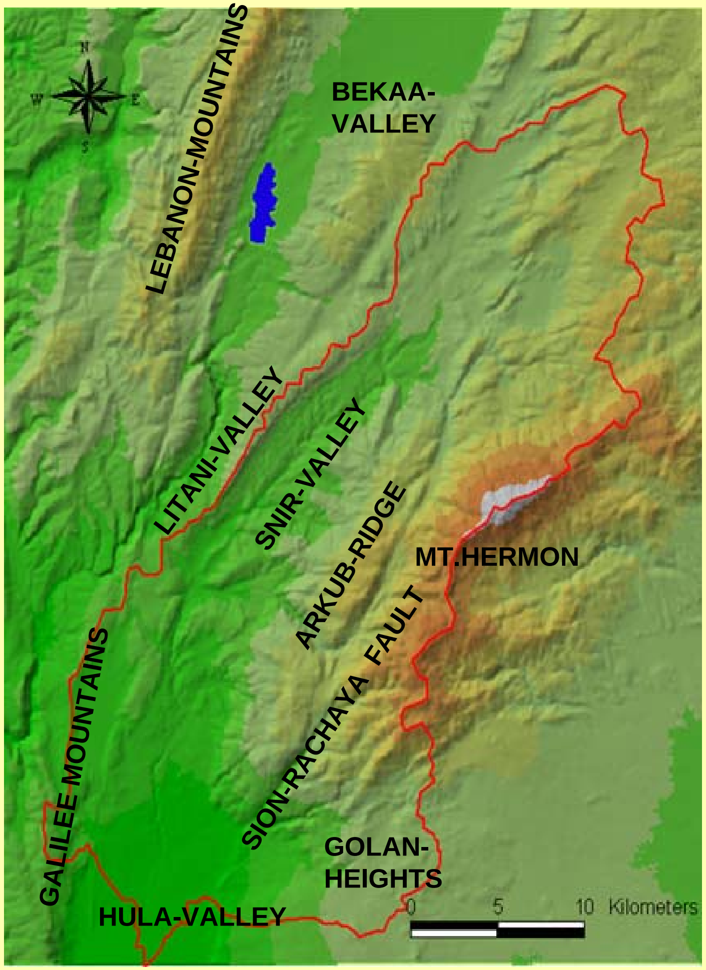


High resolution dynamical downscaling of global climate scenarios

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

Hydrological Modeling

The Upper Jordan Catchment



Area: 855 km²

- Max. height: 2814 m.a.s.l. (Mount Hermon)
- Min. height: 80 m.a.s.l. (Hula-Valley)

Complex hydrogeology &

- groundwater/surface water interactions

Precipitation:

- 750 mm/a: in the valleys
- 1200-1500 mm/a: top of Mt. Hermon

Cross-bordering: Lebanon, Syria, Israel,

- Golan Heights

Restricted and **limited data availability**

6 Gauges: Ayun, Snir, Banyas, Dan, Saar,

- Yoseph Bridge

Jordan River

GLOWA

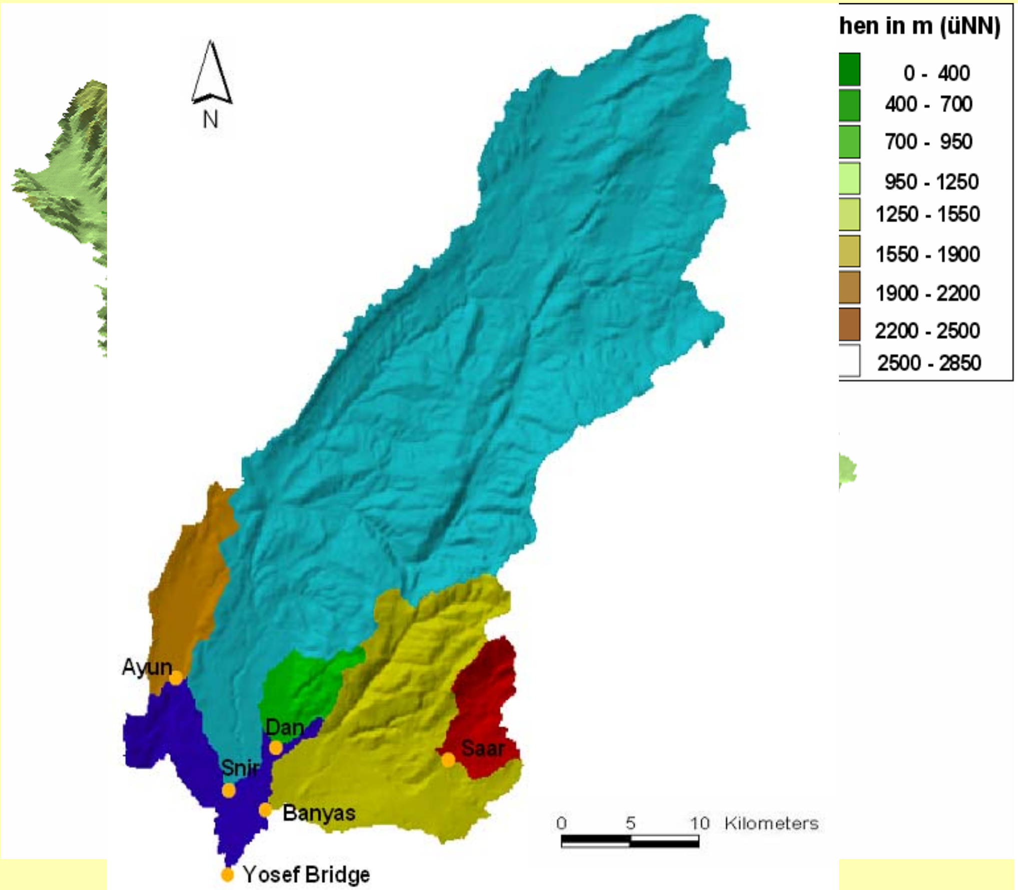
Hydrological Modeling

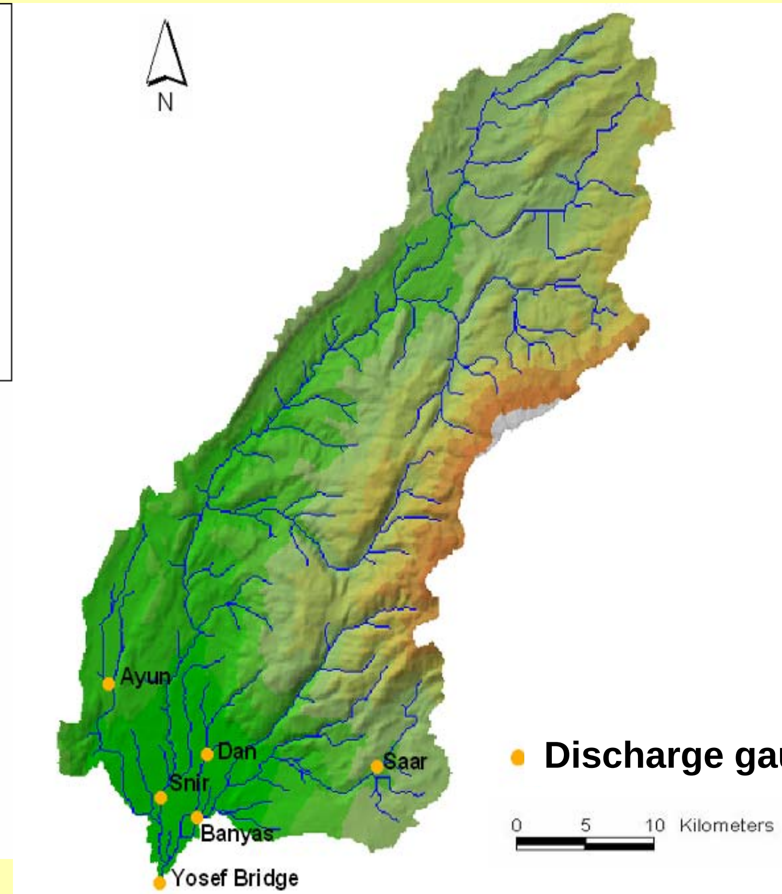
The Distributed Hydrological Model WaSiM

- Physically based algorithms for most process descriptions
- Spatial model resolution for UJC: Δx^2=90x90 m^2
- Flow trough unsaturated zone (Richards, 1931), Δz=0.5m, 200 layers (!)
- Evapotranspiration: soil and vegetation specific (Monteith, 1975; Brutsaert, 1982)
- Snow accumulation & -melt
- Discharge routing: cinematic wave
- 2-dim groundwater model dynamically coupled to unsaturated zone

Upper Jordan River

DEM from SRTM Satellite Mission (90m)

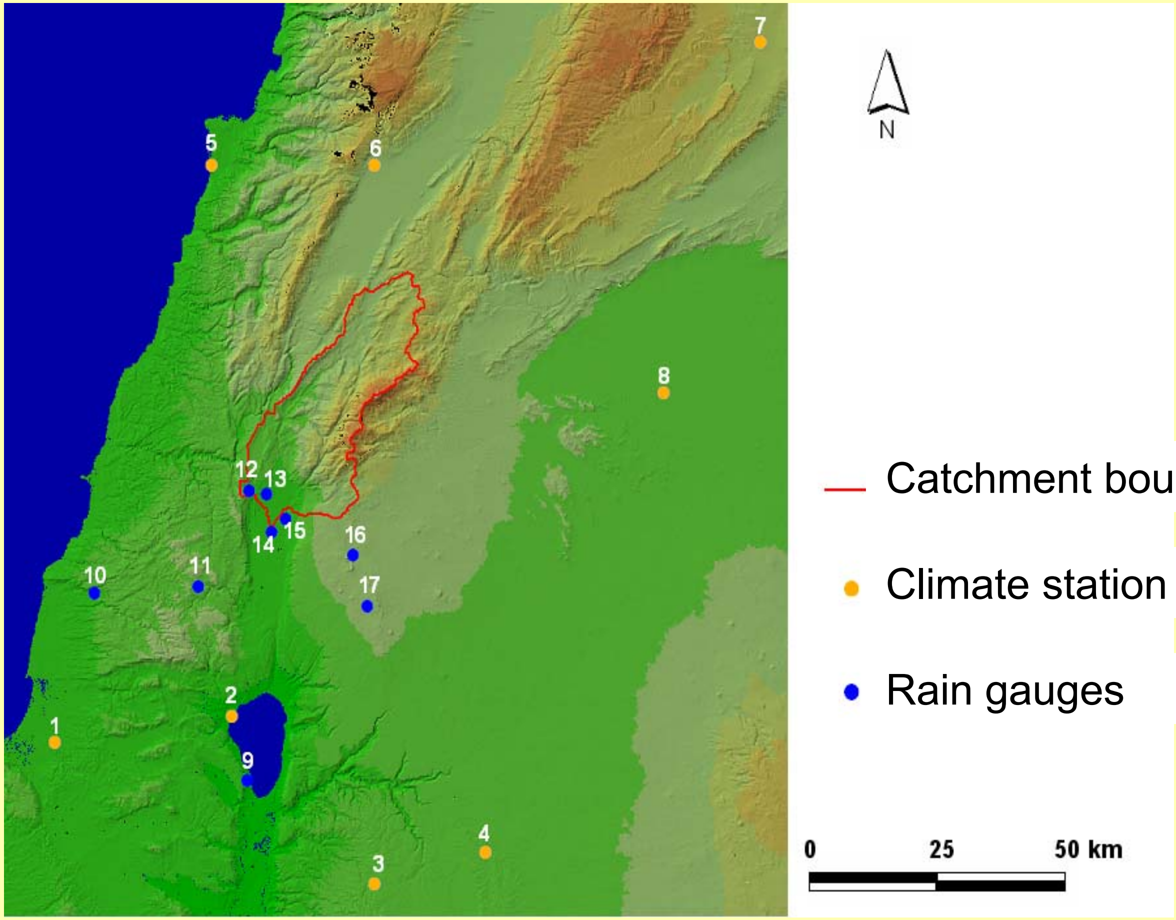




Discharge gauges

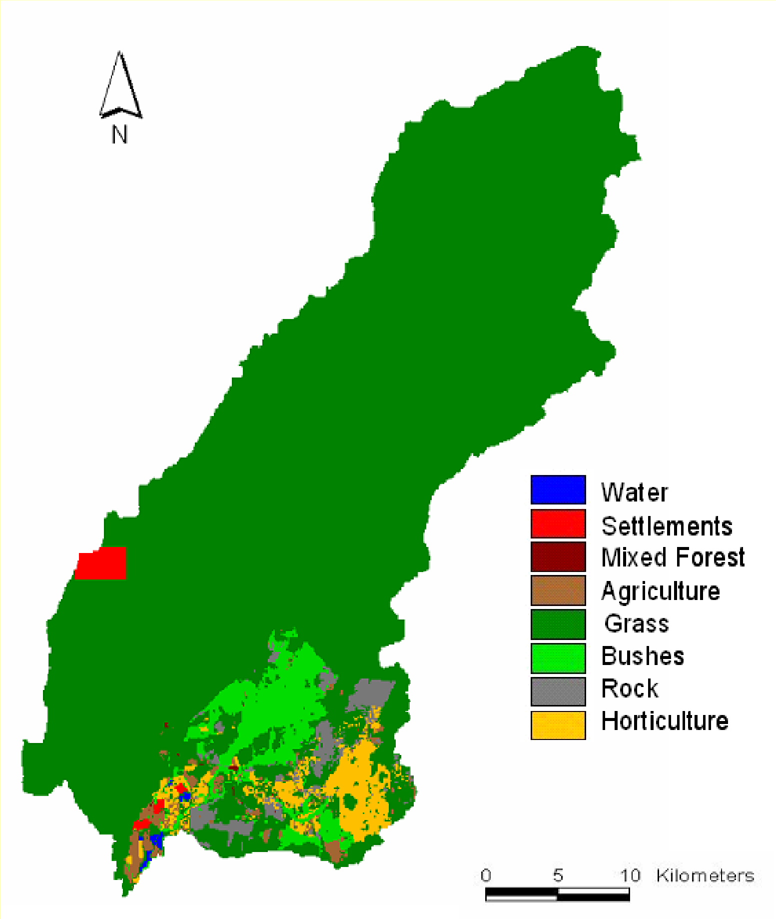
Subcatchments

Meteorological Observation Data

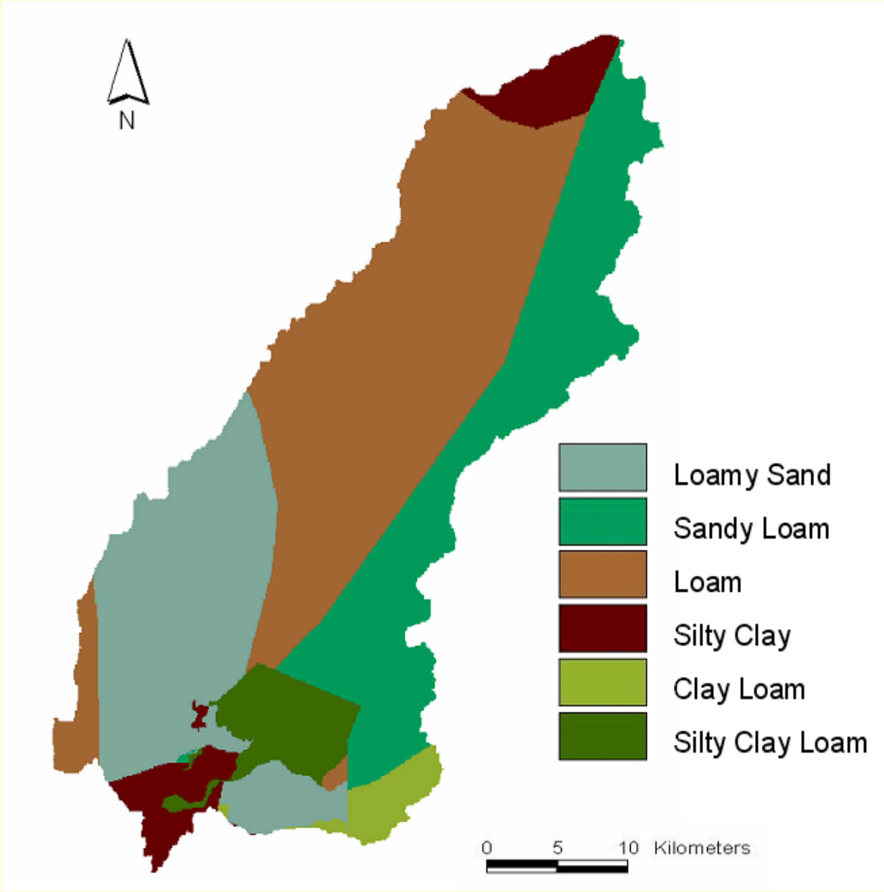


Upper Jordan River

Spatial Data



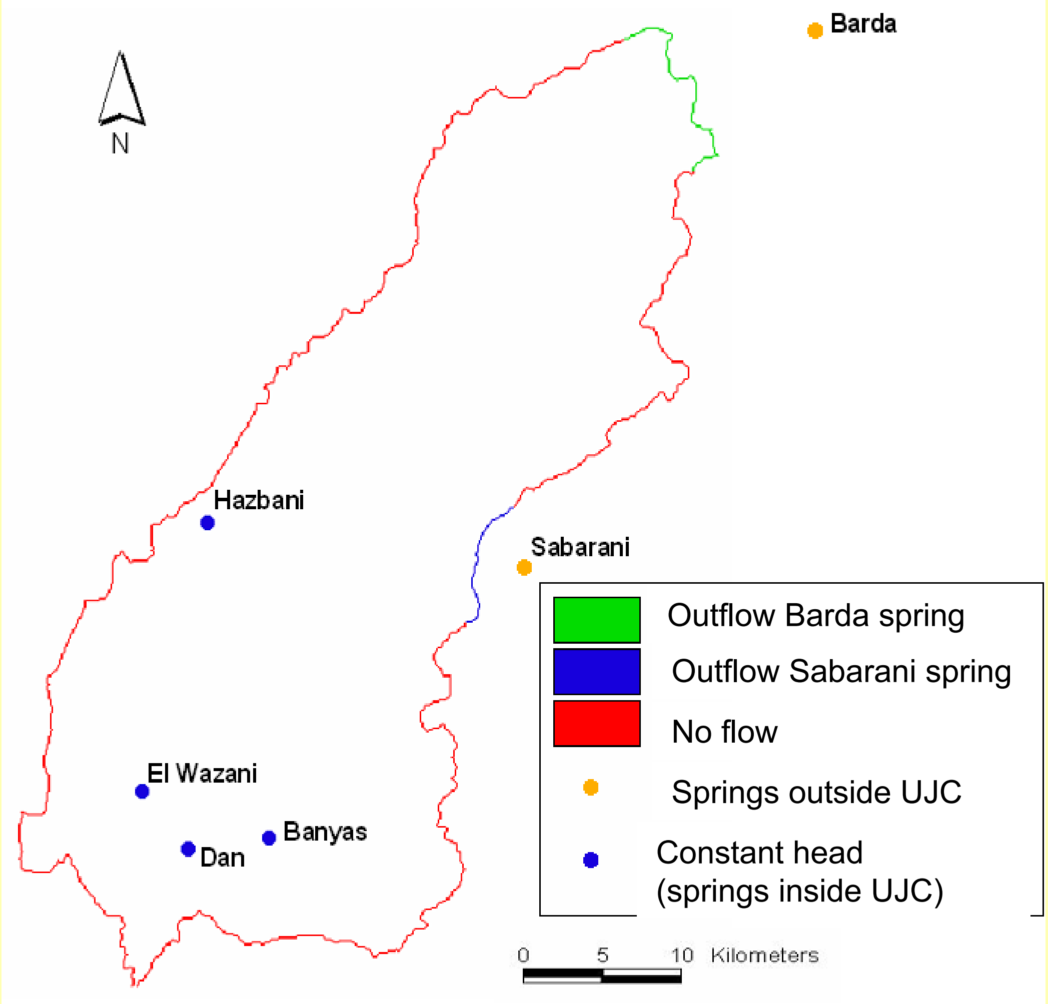
Land use



Soil type

Boundary Conditions for Groundwater Model

Maximum depth of unsaturated zone assumed:
= 100 m

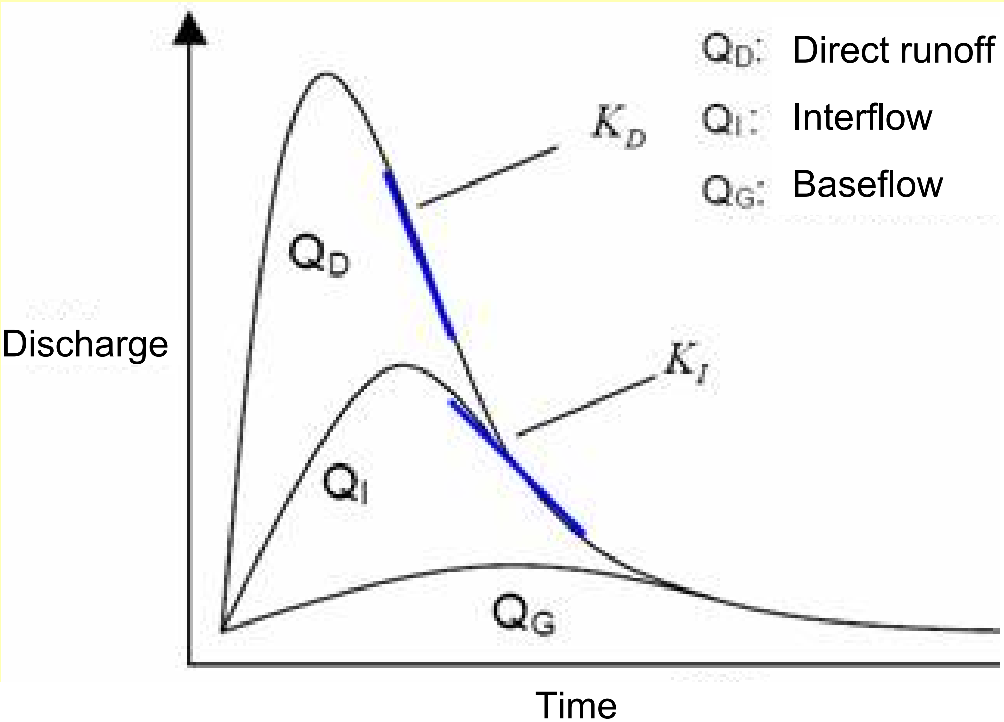


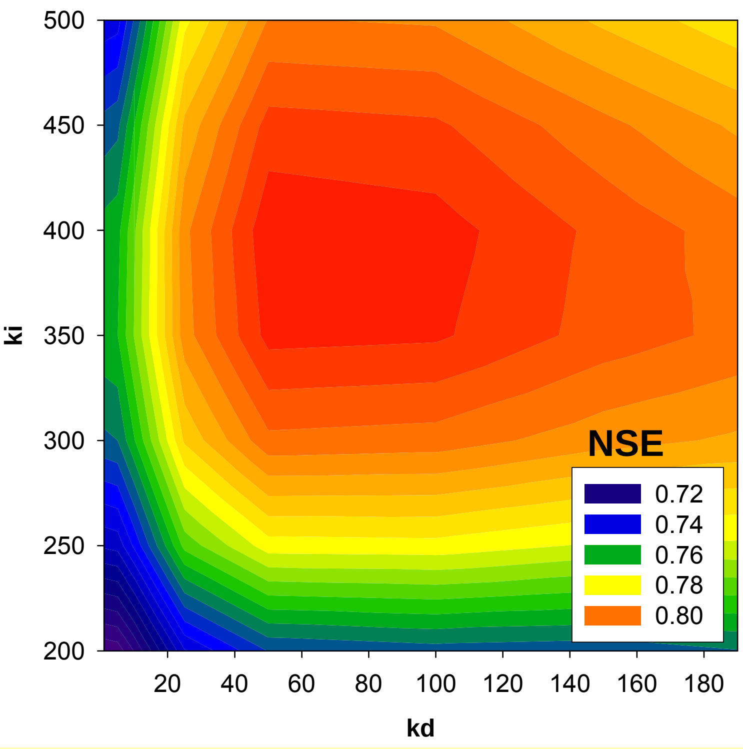
Model Performance

$$NSE = 1 - \frac{\sum_i \varepsilon_i^{\,2}}{\sum_i \left(x_i - \overline{x}\right)^2} = 1 - \frac{\sum_i \left(y_i - x_i\right)^2}{\sum_i x_i^{\,2} - \frac{1}{n}\left(\sum_i x_i\right)^2}$$

Nash Sutcliff Efficiency
(-∞ < NSE < 1)

Parameter Estimation – Inverse Modeling





Parameter Estimation – Inverse Modeling

<table>
<tr><th colspan="3">Parameter</th><th>Banyas</th><th>Saar</th><th>Snir</th><th>Ayun</th><th>Yosef-Bridge</th></tr>
<tr><td rowspan="6">Soil model</td><td rowspan="2">k_d</td><td>Start value</td><td>50</td><td>30</td><td>100</td><td>50</td><td>150</td></tr>
<tr><td>End value</td><td>200</td><td>30</td><td>50</td><td>35</td><td>150</td></tr>
<tr><td rowspan="2">k_i</td><td>Start value</td><td>2000</td><td>350</td><td>150</td><td>400</td><td>200</td></tr>
<tr><td>End value</td><td>2000</td><td>350</td><td>1000</td><td>50</td><td>500</td></tr>
<tr><td rowspan="2">d_r</td><td>Start value</td><td>20</td><td>40</td><td>1</td><td>0.75</td><td>1.5</td></tr>
<tr><td>End value</td><td>10</td><td>35</td><td>1.1</td><td>12</td><td>0.001</td></tr>
<tr><td rowspan="2">Groundwater Model</td><td rowspan="2">k_x / k_y</td><td>Start value</td><td>5.00E-06</td><td>7.50E-07</td><td>1.00E-06</td><td>6.00E-07</td><td>5.00E-08</td></tr>
<tr><td>End value</td><td>5.00E-06</td><td>6.00E-06</td><td>2.50E-06</td><td>1E-0.5</td><td>5.00E-08</td></tr>
<tr><td rowspan="5">Snow model</td><td>$T_{r/s}$</td><td rowspan="5">Start value = End value</td><td colspan="5">1</td></tr>
<tr><td>T_{trans}</td><td colspan="5">2</td></tr>
<tr><td>T_0</td><td colspan="5">0.8</td></tr>
<tr><td>c_1</td><td colspan="5">0.001</td></tr>
<tr><td>c_2</td><td colspan="5">0.001</td></tr>
</table>

Model Performance

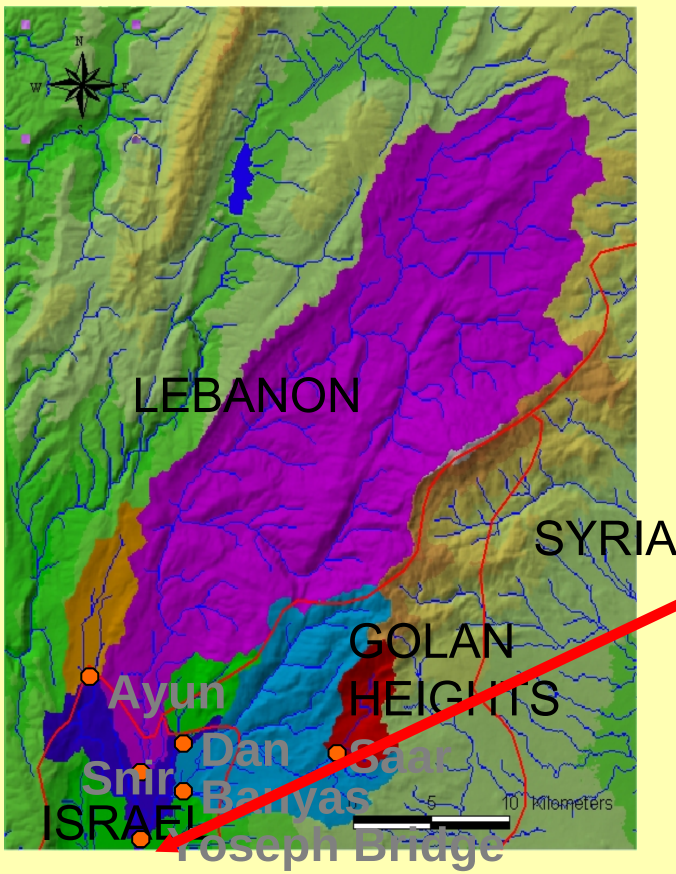
$$NSE = 1 - \frac{\sum_i \varepsilon_i{}^2}{\sum_i (x_i - \bar{x})^2} = 1 - \frac{\sum_i (y_i - x_i)^2}{\sum_i x_i{}^2 - \frac{1}{n}\left(\sum_i x_i\right)^2}$$

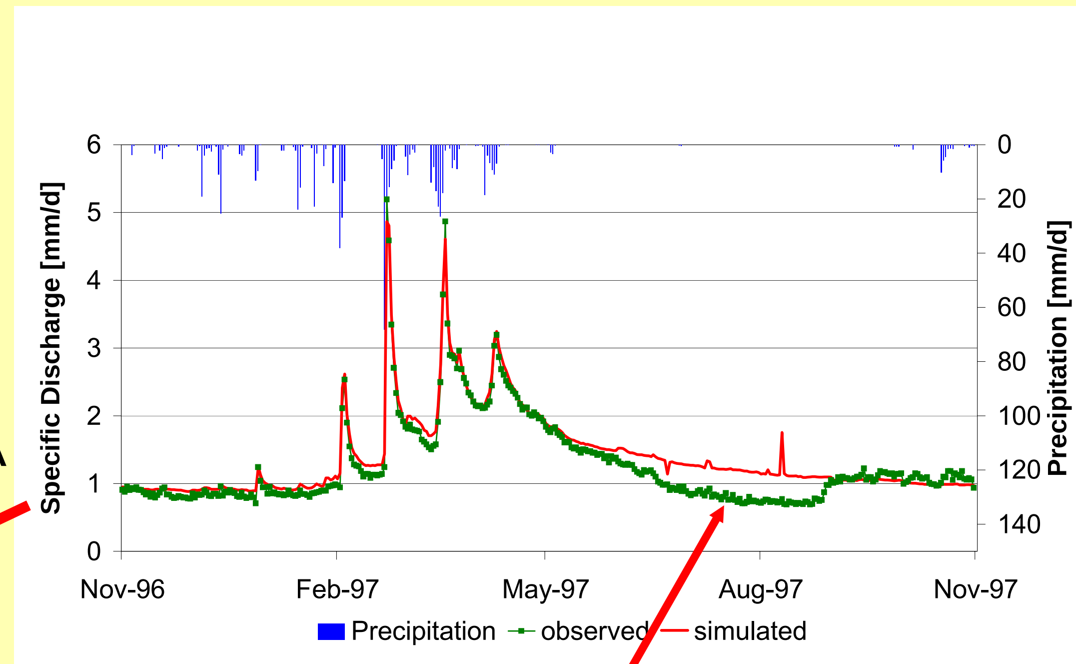
Nash Sutcliff Efficiency
($-\infty < NSE < 1$)

Zeitraum	Pegel	Banyas	Saar	Snir	Ayun	Yoseph Bridge
Validation (1998)	**NSE-lin**	0.8525	0.4066	0.3839	0.5527	0.7402
	NSE-log	0.7894	0.2997	0.6128	0.4098	0.5502
Calibration (1997)	**NSE-lin**	0.7187	0.5938	0.782	0.7311	0.8408
	NSE-log	0.4602	0.5377	0.69	0.3726	0.6472

Hydrological Modeling

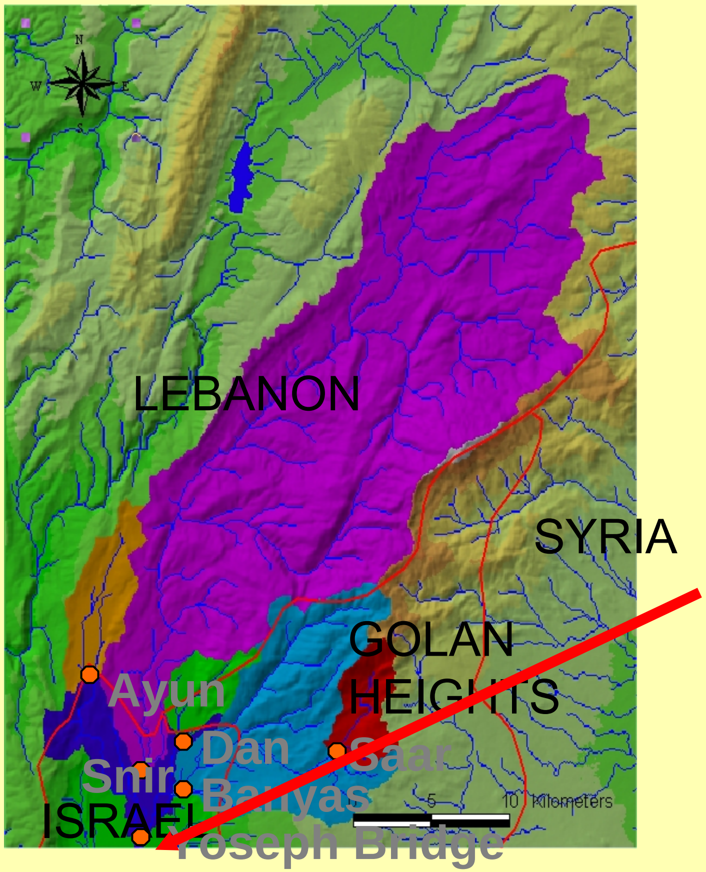
How accurate does the hydrological model reproduce observed discharge?

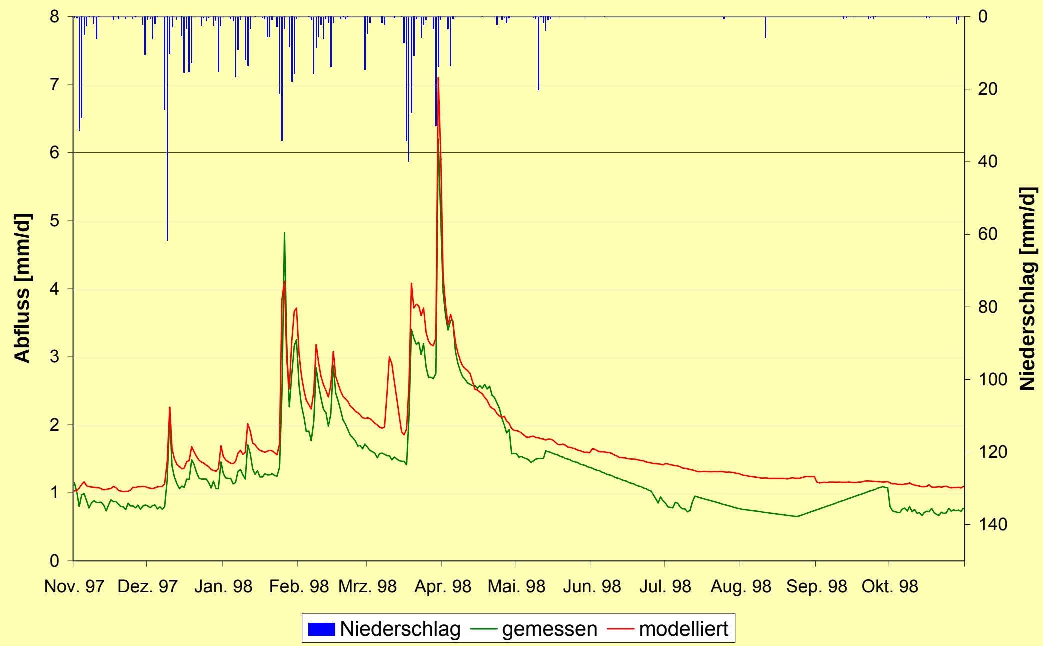




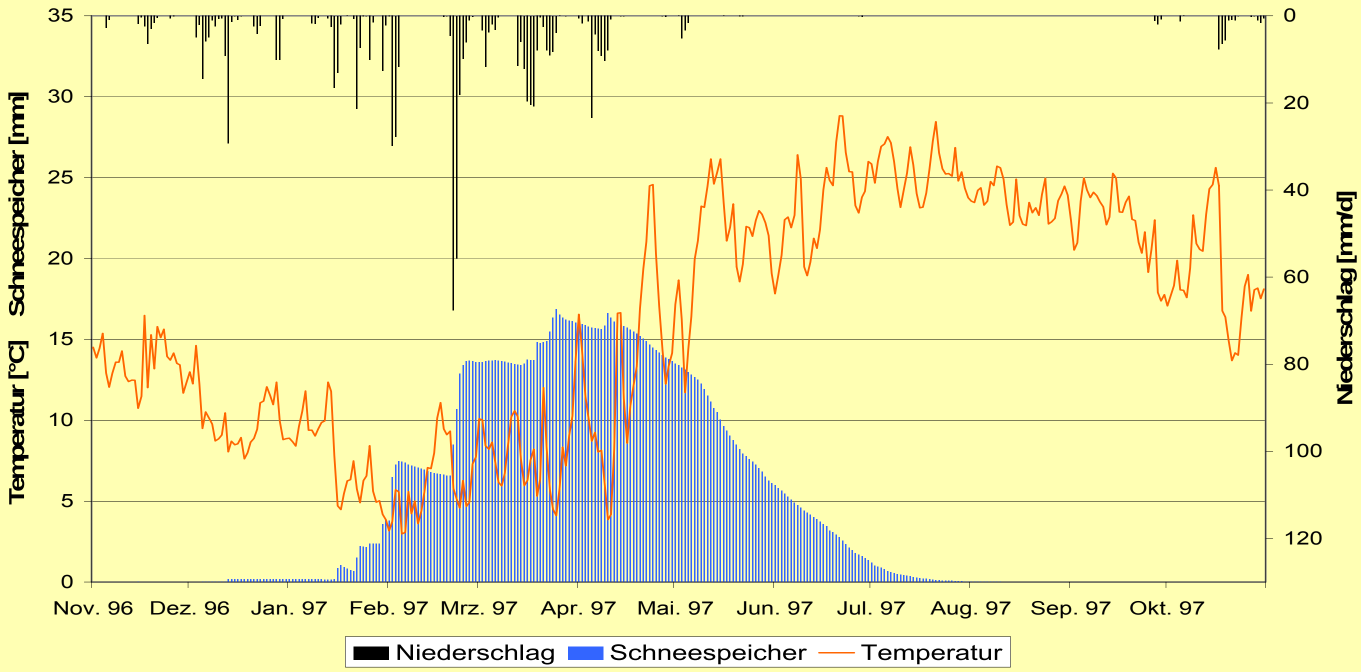
Technically bypassed water
not yet accounted for

How accurate does the hydrological model reproduce observed discharge?



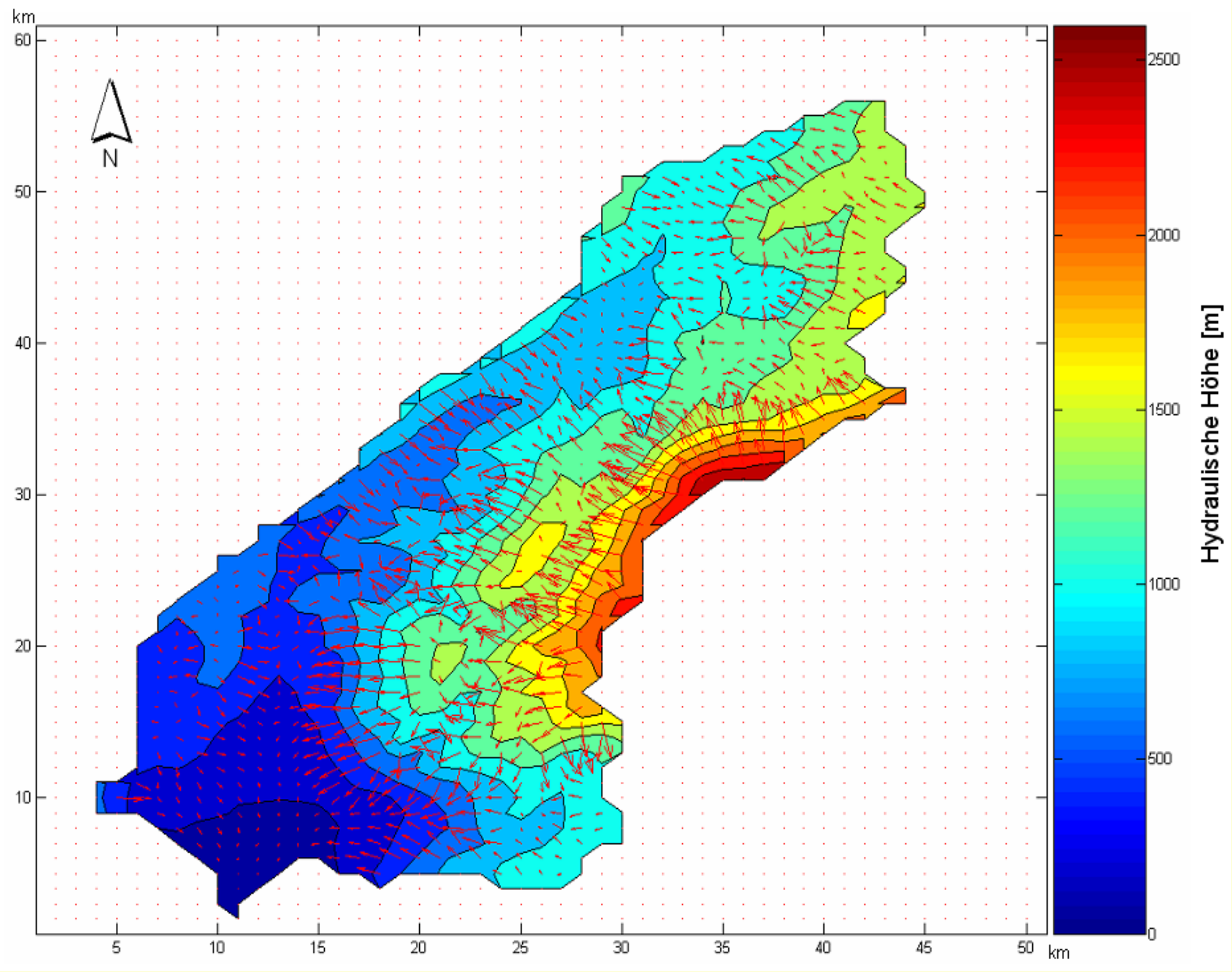


Selected Results



Snow storage

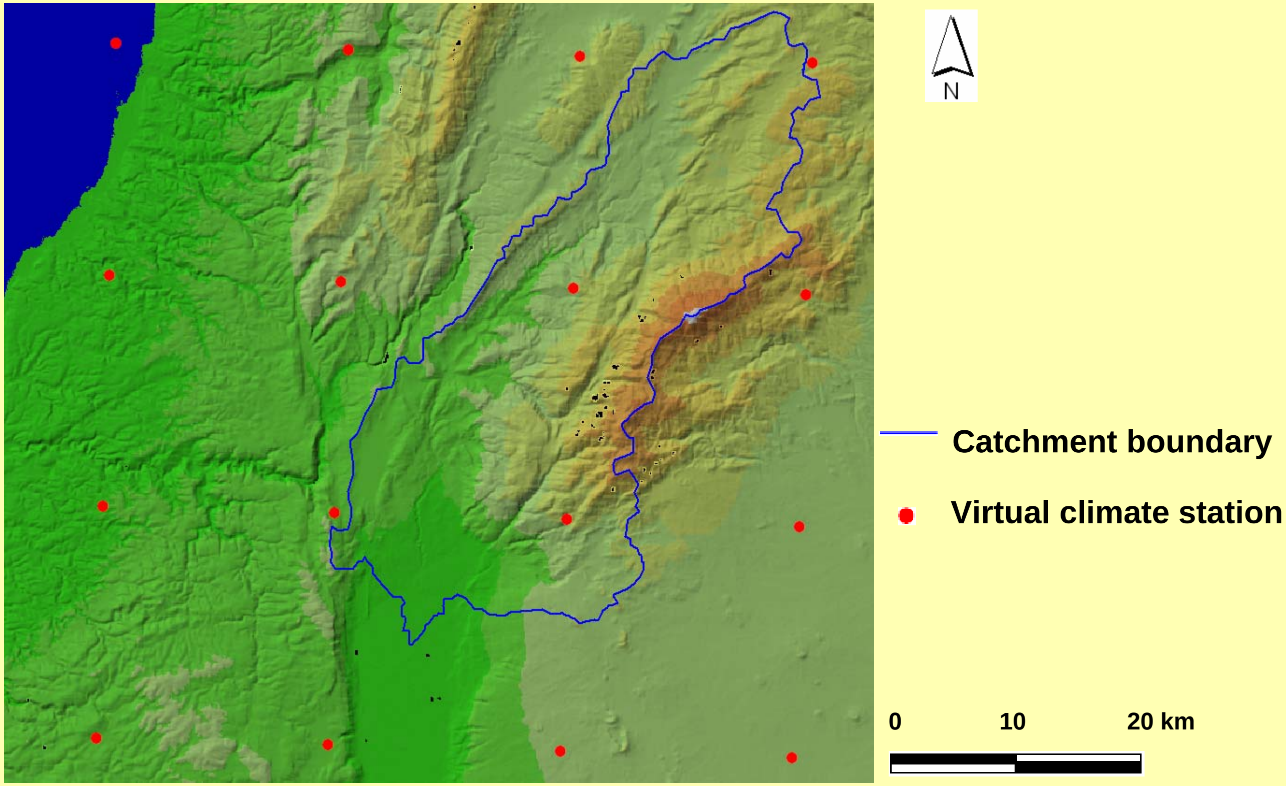
Calculated Mean Heads and Groundwater Flow (1997)



Towards Coupled Modeling ...

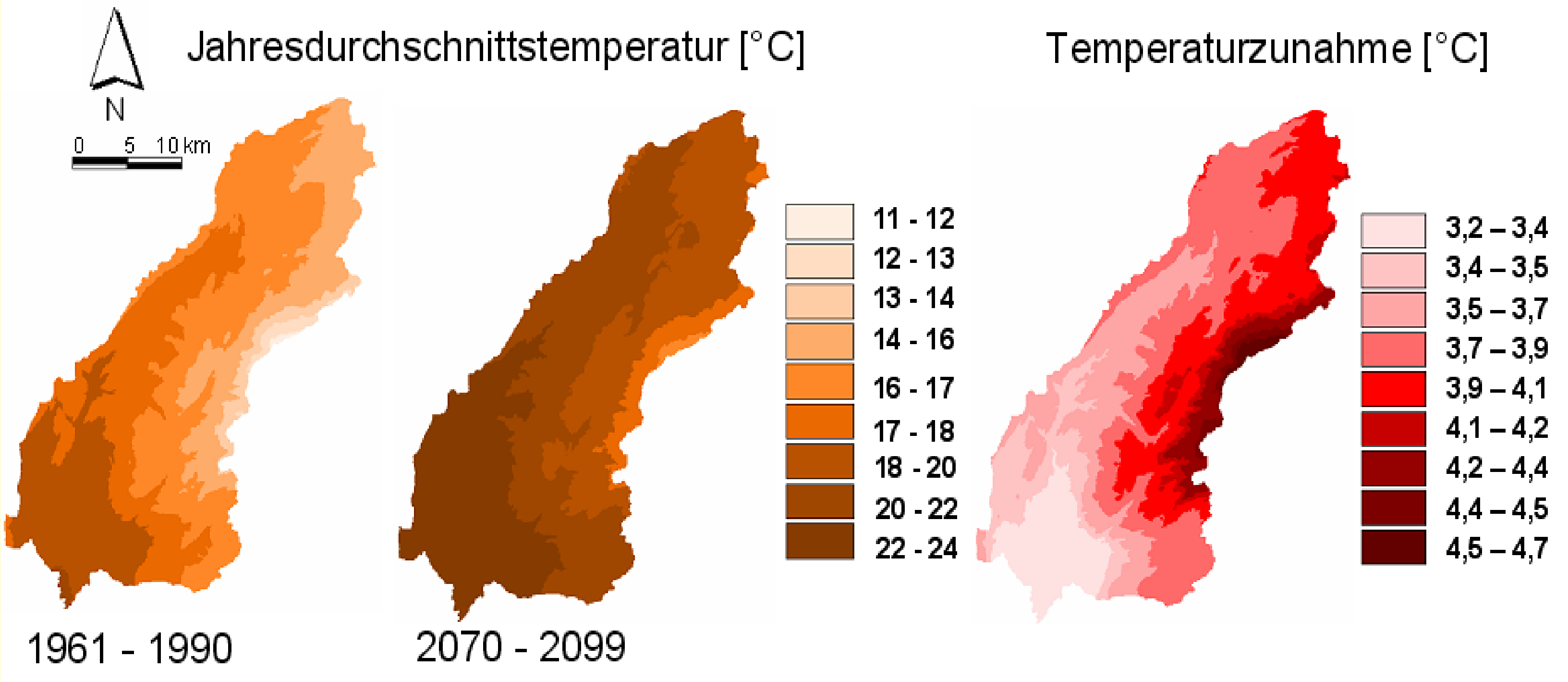
Passed from MM5:

- Precipitation (IDW & regression)
- Temperature (IDW & regression)
- Wind speed
- Rel. humidity
- Global radiation



Results Upper Jordan Catchment

How does expected regional atmospheric change translate into the UJC?



Results Upper Jordan Catchment

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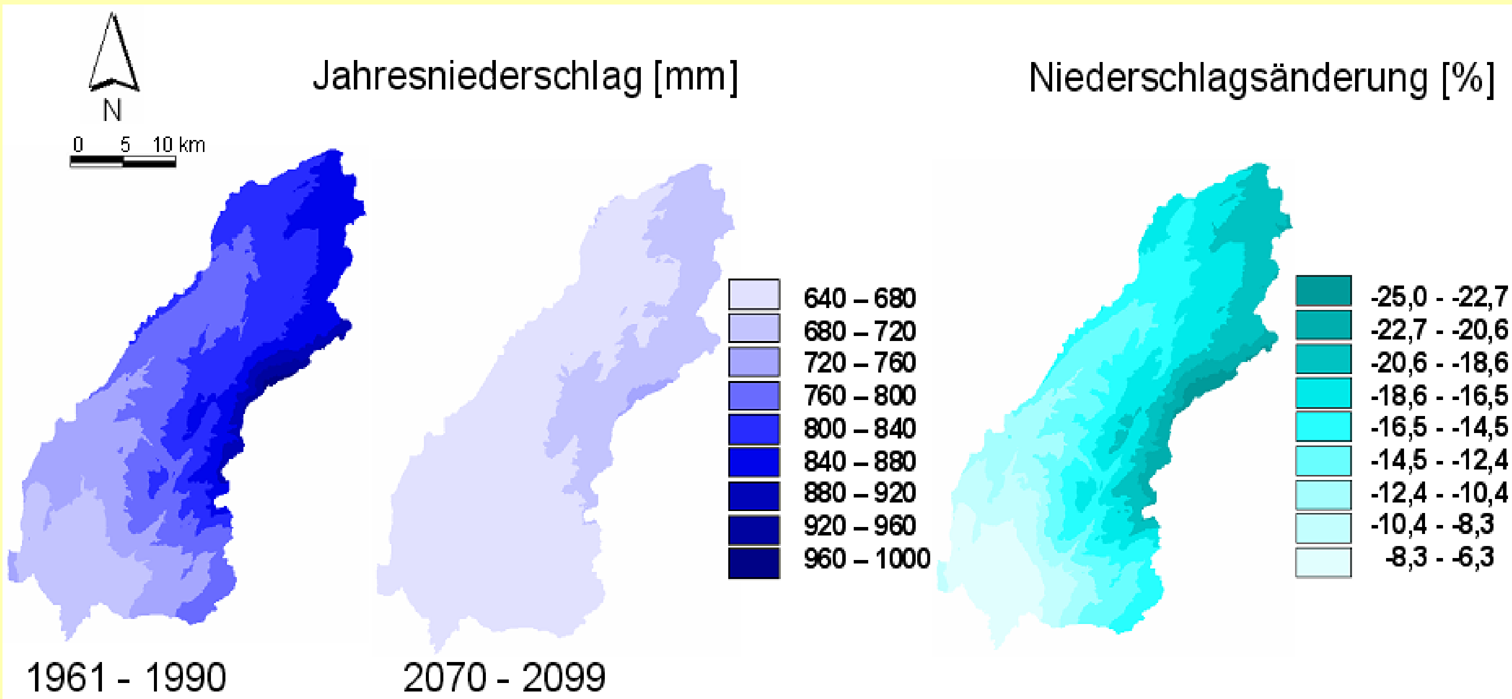
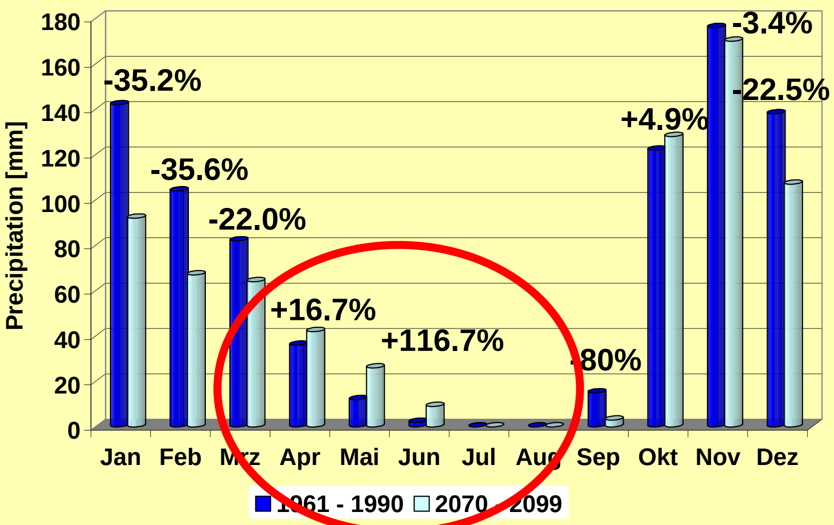


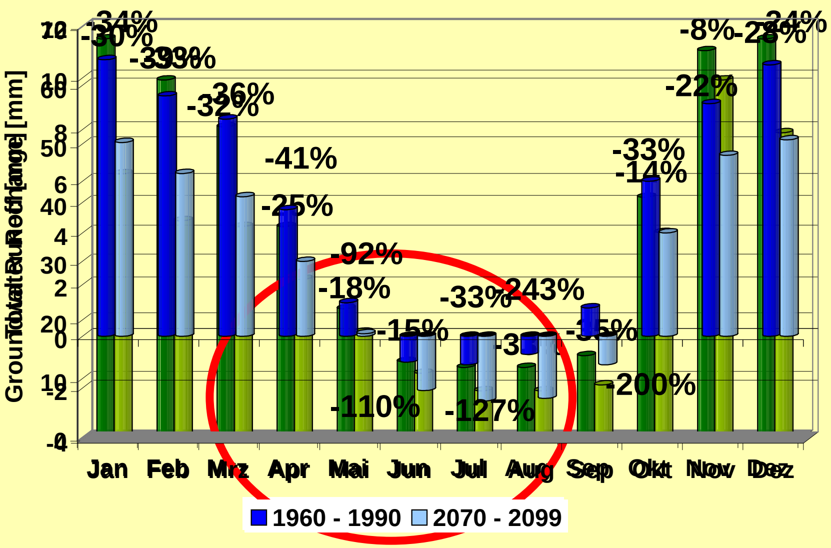
Hydrological Modeling

What is the impact of expected climate change on river discharge in the UJC?

Precipitation



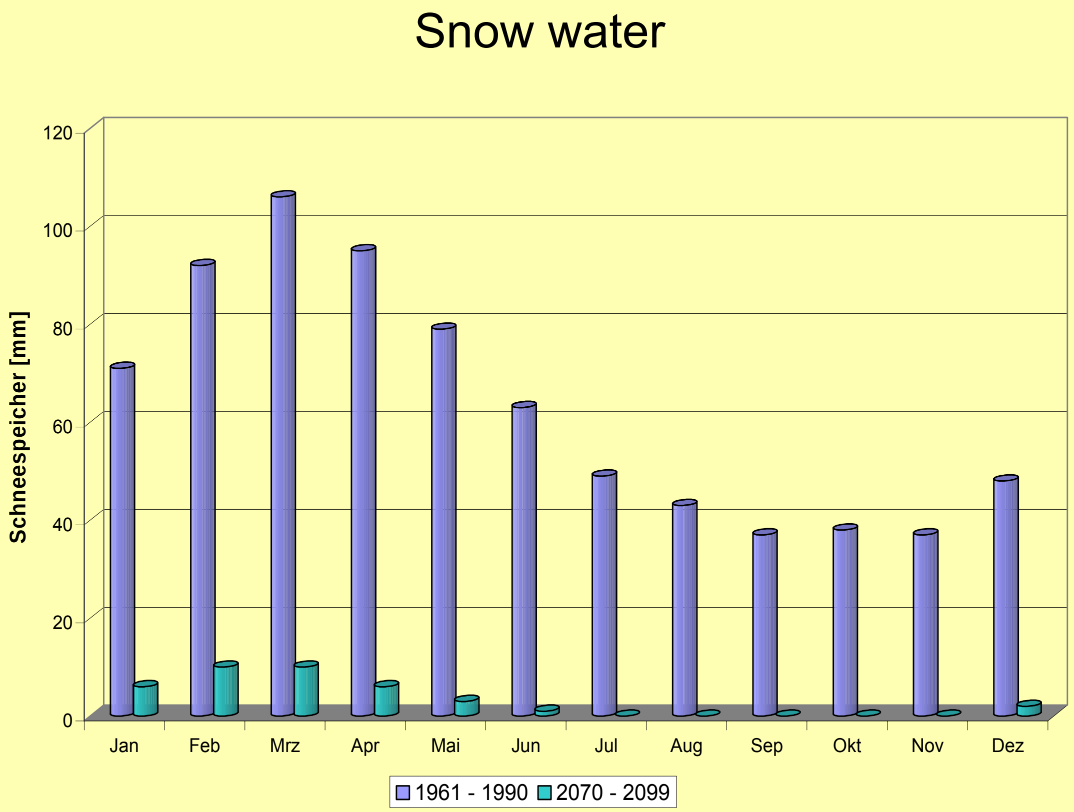
Runoff / Recharge



Different signs of precipitation change and runoff change

Amplified change for groundwater recharge

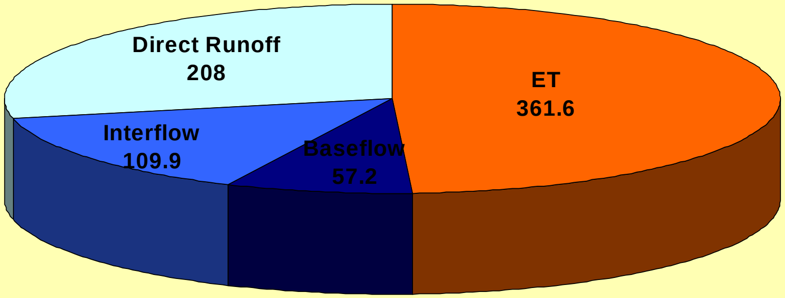
Results Upper Jordan Catchment



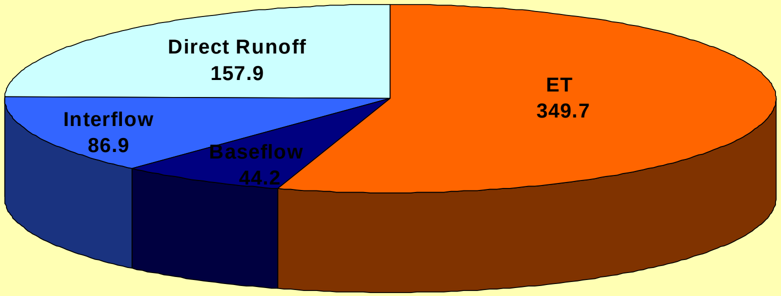
Significant reduction of snow water equivalent!

Impact of expected climate change on water balance in the UJC

[mm/a]



1961-1990



2070-2099

Summary and Conclusions

Performance of regional climate simulations (18 km):
• Reasonable agreement in mean annual precipitation
• But bias: overestimation in SON, underestimation in MAM

Jordan River area north of Dead Sea:
• Temperature increase of annual mean up to 3.5°C
• Summer temperatures up to 5°C

• Decreasing winter (35%!), increasing spring precipitation
• Decrease of precipitation intensities
⇒ impact on conditions for reservoir filling!

Upper Jordan River
• First results joint climate-hydrology simulations UJC
• In spite increased spring precipitation, decreased spring runoff & recharge!
• Significant reduction of snow

⇒ Significantly reduced water availability!

Thank you for your attention


… and greetings from
Garmisch-Partenkirchen