Regional Climate Change Projections for the Eastern Mediterranean/Middle East: Expected Changes in Water Availability and Droughts

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Regional Climate Change Eastern Mediterranean/Middle East

Motivation

- Water availability per capita in the Middle East one of the lowest worldwide (150 m³/a)
- Distribution of resource freshwater has high conflict potential
- Future availability may be further restricted by population pressure and **climate change**
- Specific hydrological focus: Upper Jordan catchment (⇒ provides 1/3rd of drinking water resources in Israel)

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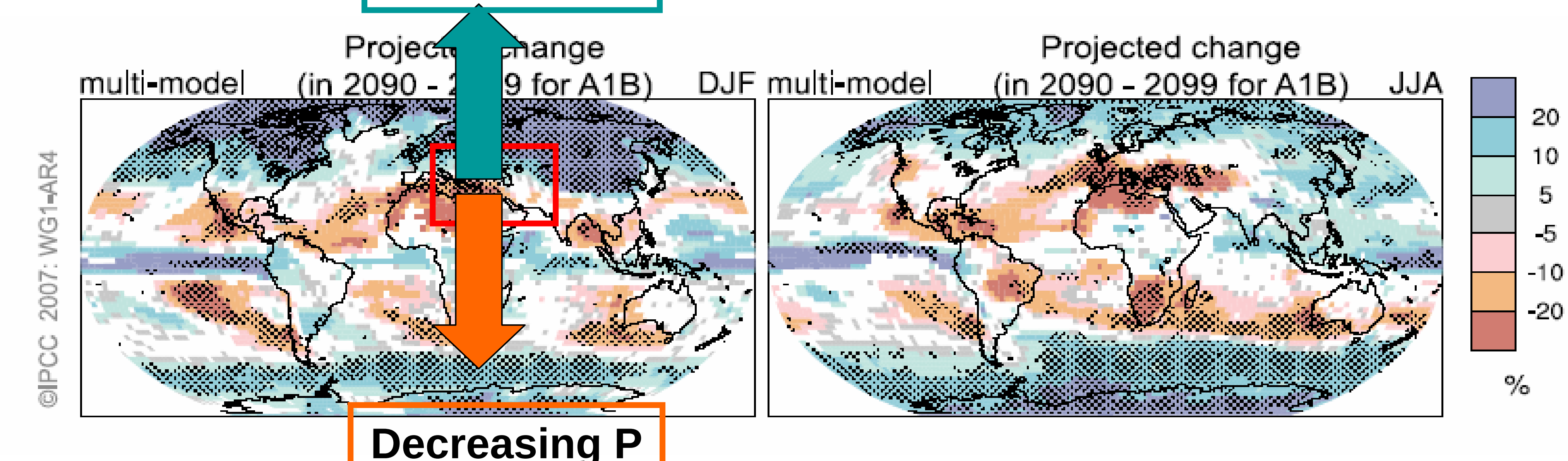
Increasing P



Decreasing P

IPCC 4AR, 2007

Eastern Mediterranean/Near East:
is in between increasing and decreasing dominant large scale patterns of DJF precipitation change

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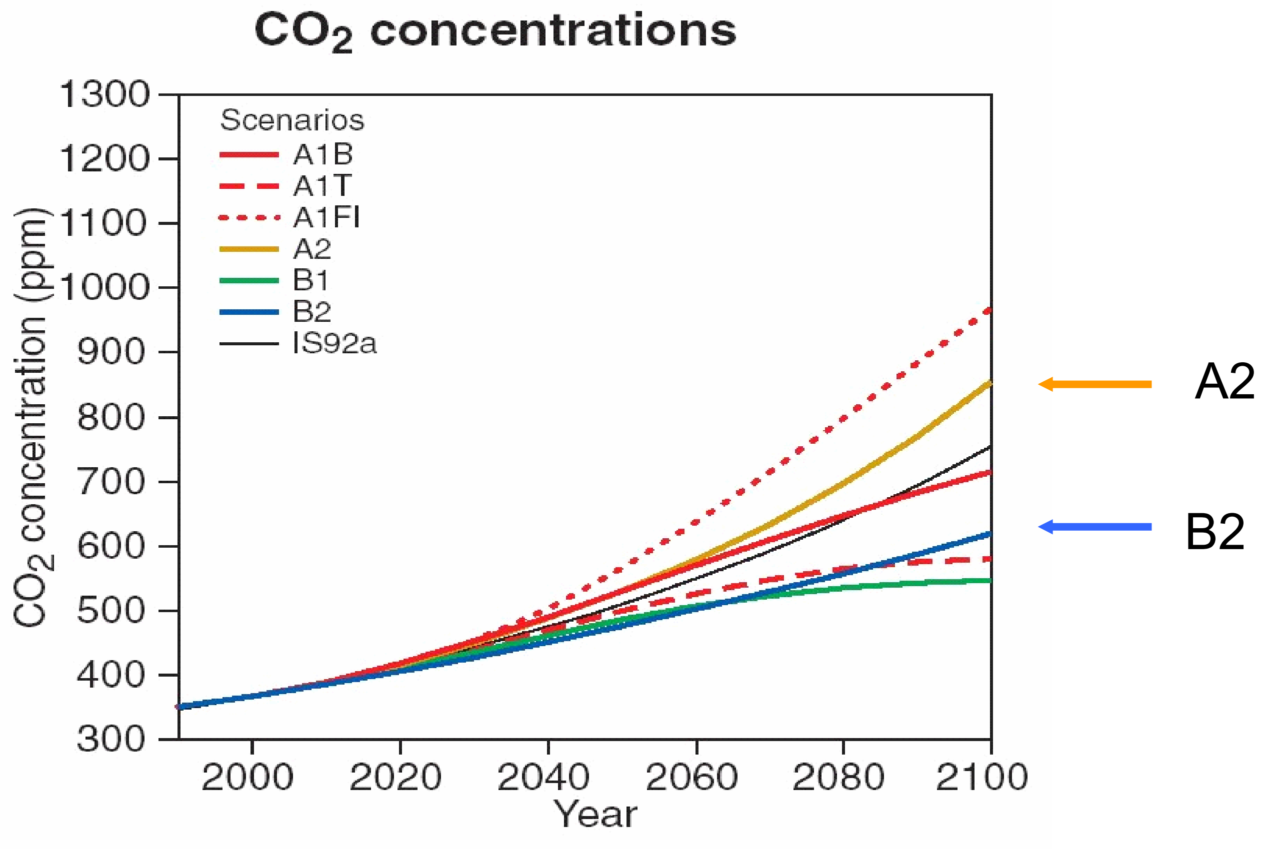
Global Emission Scenarios



Emission scenarios: based on different assumptions on future GHG emissions

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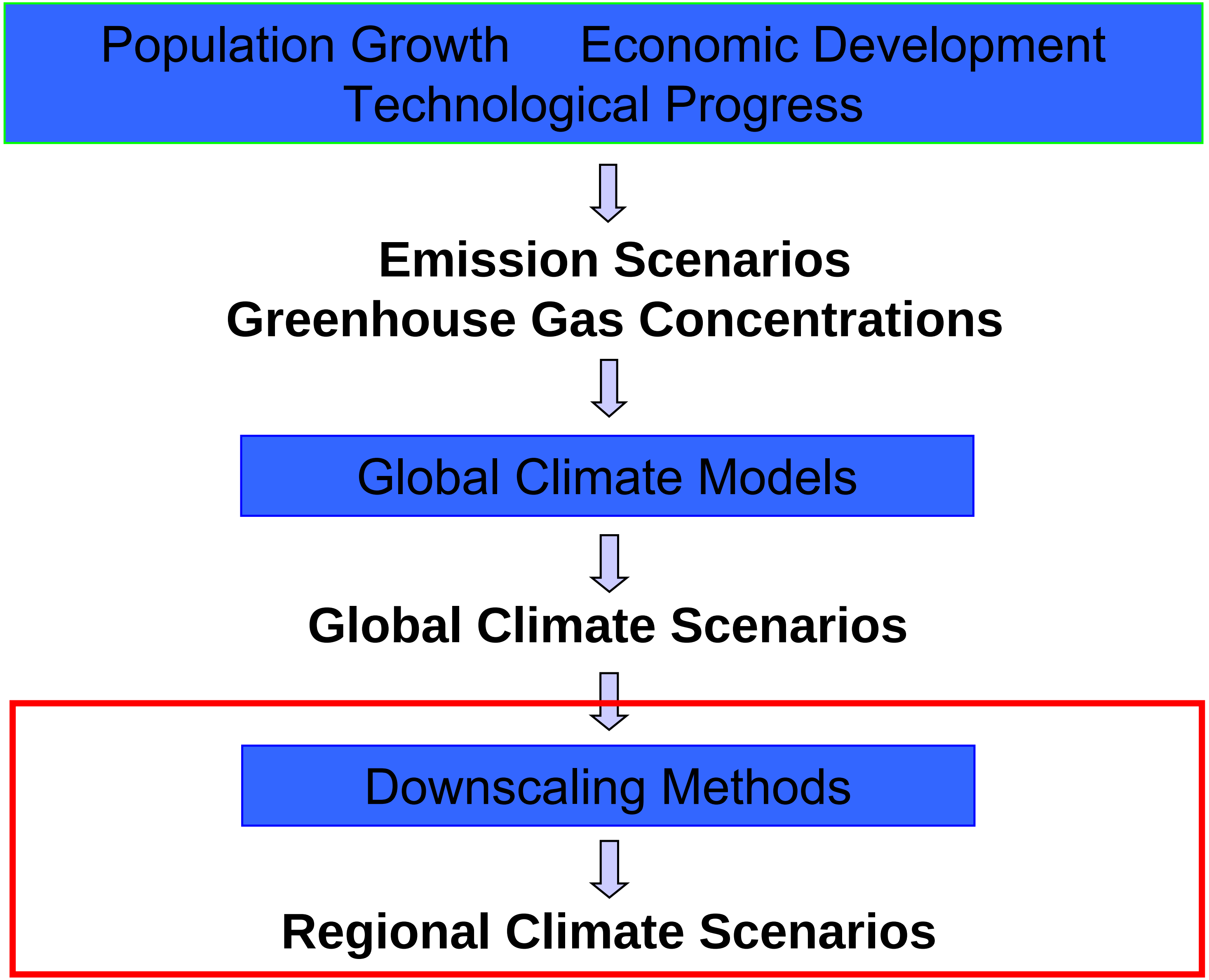


Population Growth Economic Development
Technological Progress

⇩

Emission Scenarios
Greenhouse Gas Concentrations

⇩

Global Climate Models

⇩

Global Climate Scenarios

⇩

Downscaling Methods

⇩

Regional Climate Scenarios

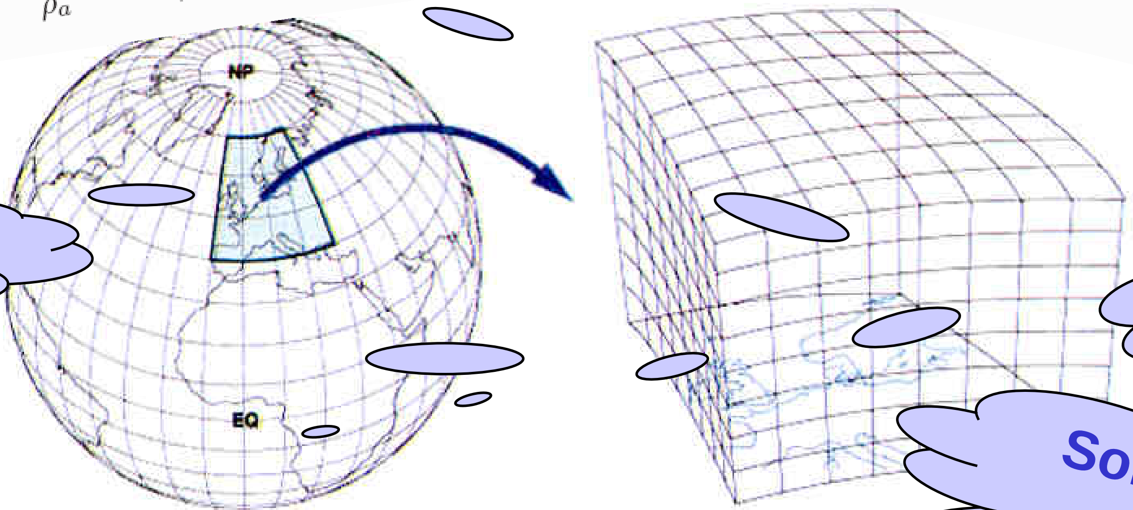
Regional Climate Change Eastern Mediterranean/Middle East

Momentum conservation

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

Energy conservation

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



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

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

Energy conservation at land surface

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

Soil temperature diffusion

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

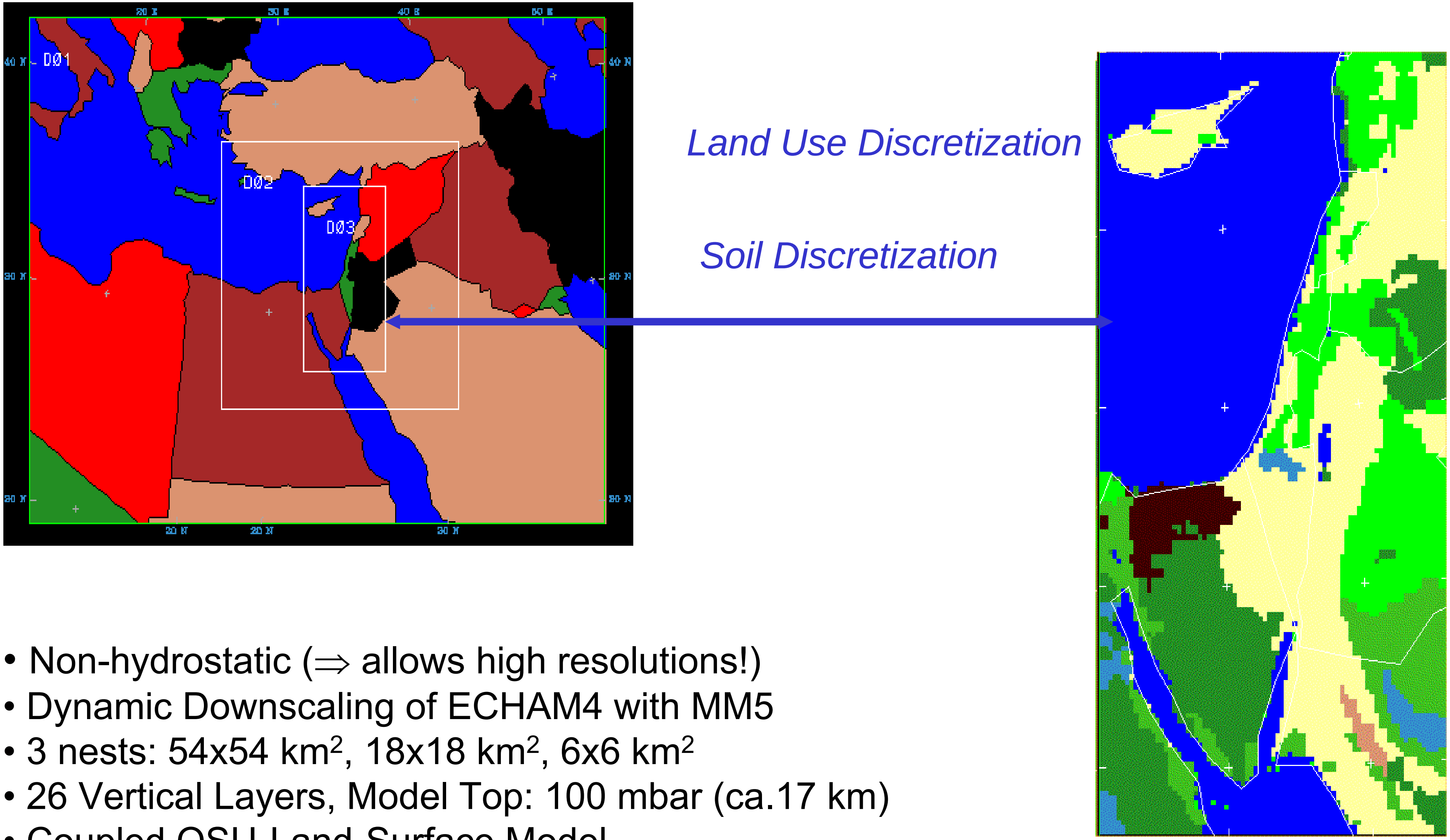
Precipitation physics

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

Soil water infiltration

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

Example: The Mesoscale Meteorological Model MM5



Land Use Discretization

Soil Discretization

- Non-hydrostatic (⇒ allows high resolutions!)
- 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

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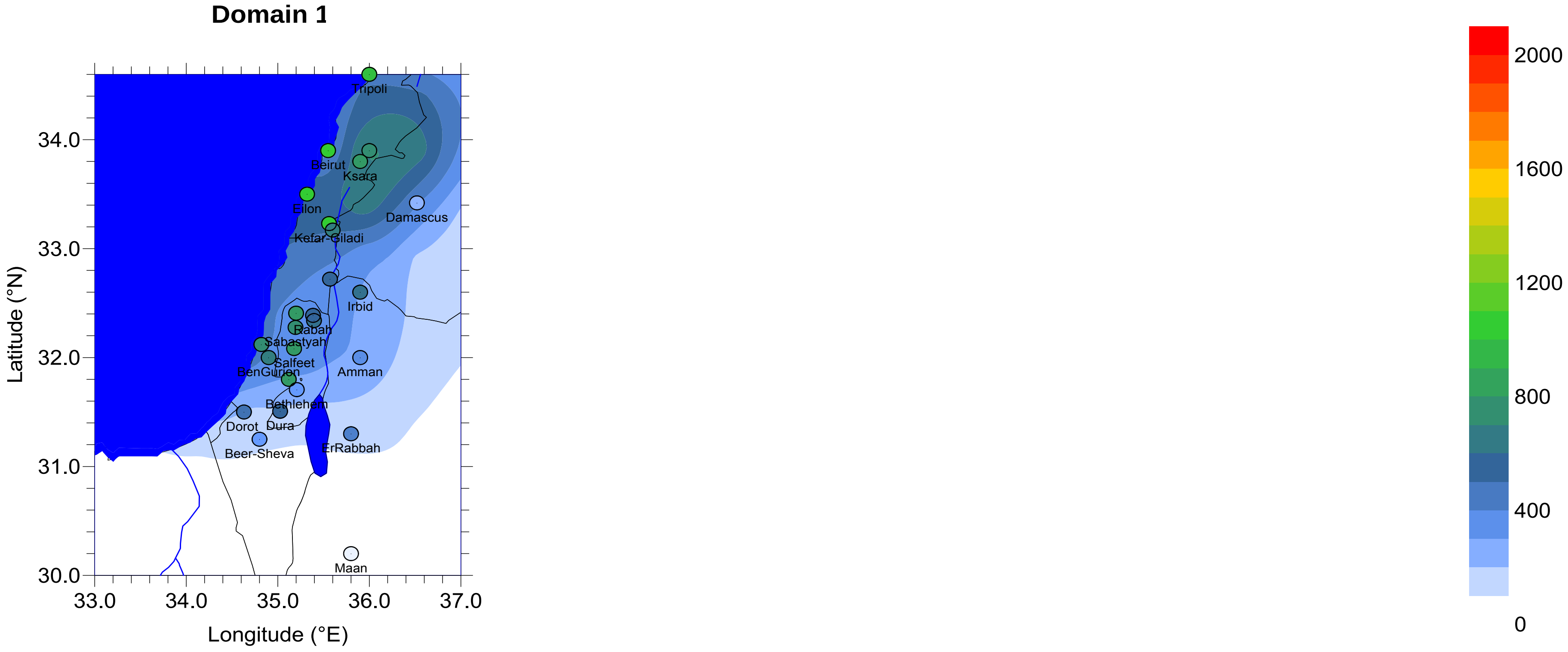
What do we expect from the High Resolution Simulations?

Control Runs: mean 1961-1975



Yearly Mean Precipitation 1961-1975

54km 18km 6km

… the finer the spatial resolution, the better the agreement with observation

First example: LONG TERM PROJECTIONS

ECHAM4, B2, 18km, 2070-99 vs. 1961-90

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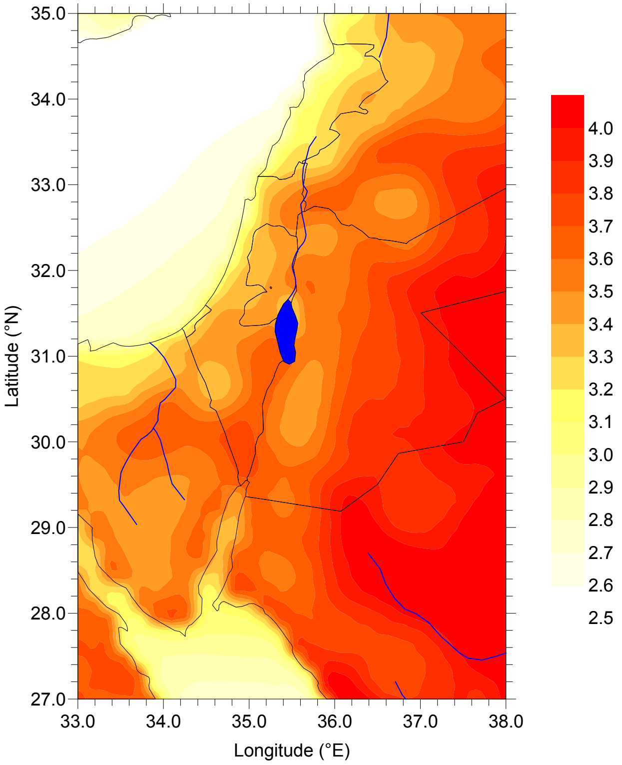
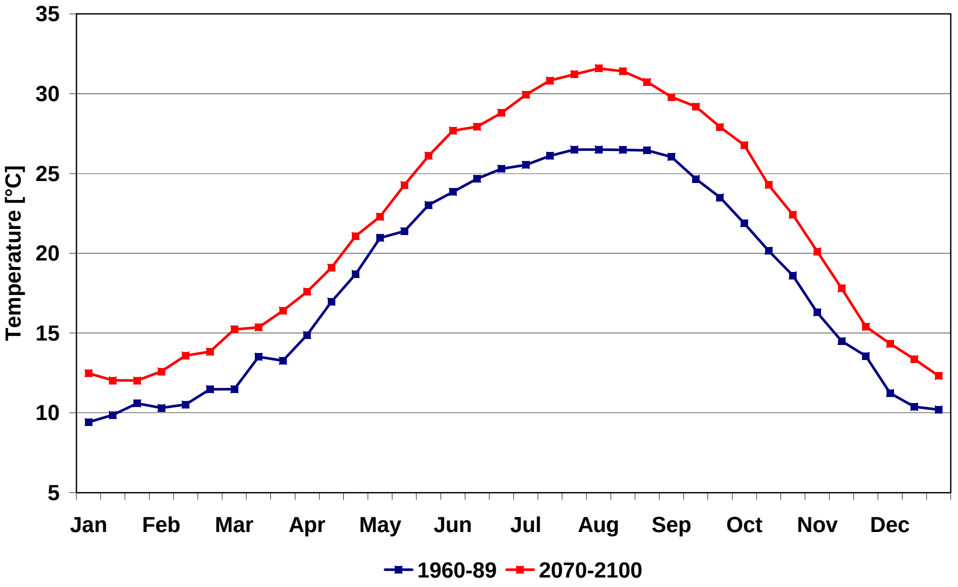
What are the expected changes in temperature?

Absolute Change of Yearly Mean Temperature Future - Past





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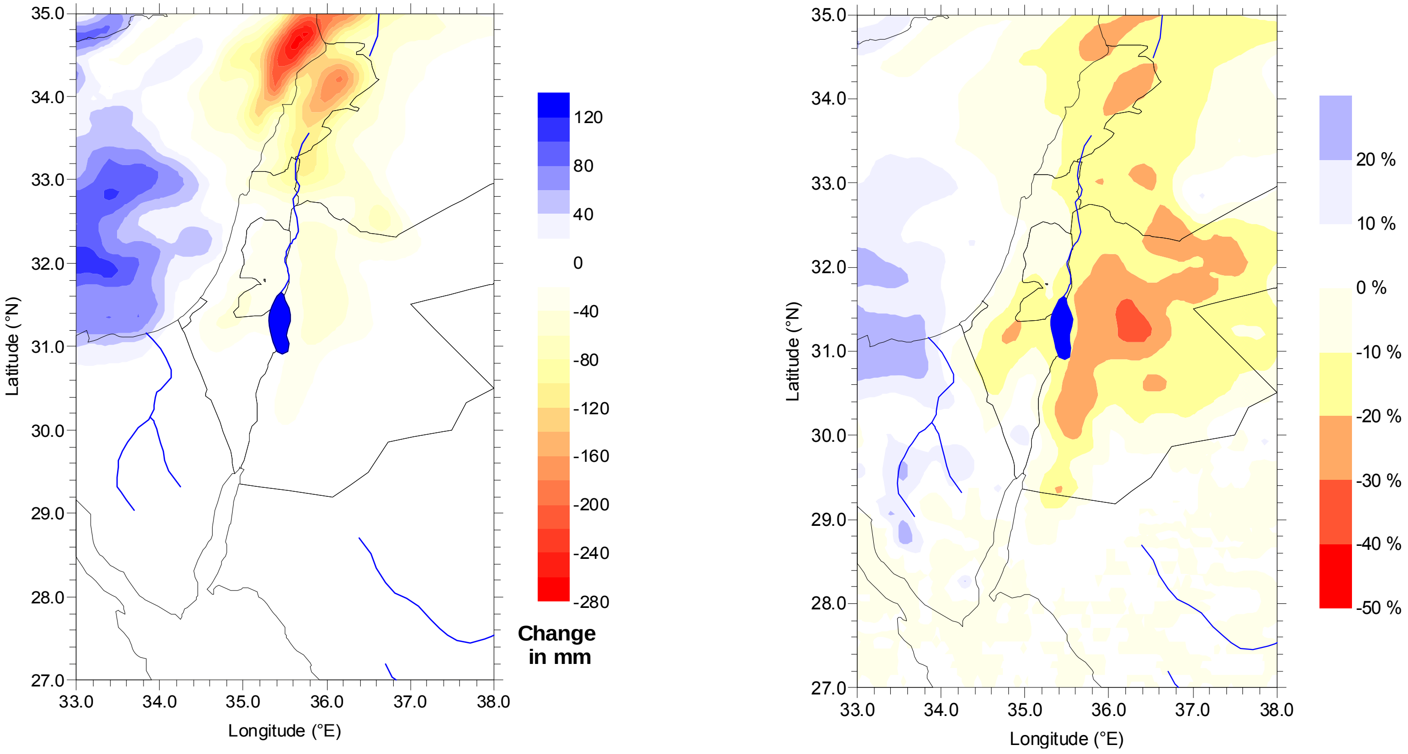
What are the expected changes in precipitation?



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

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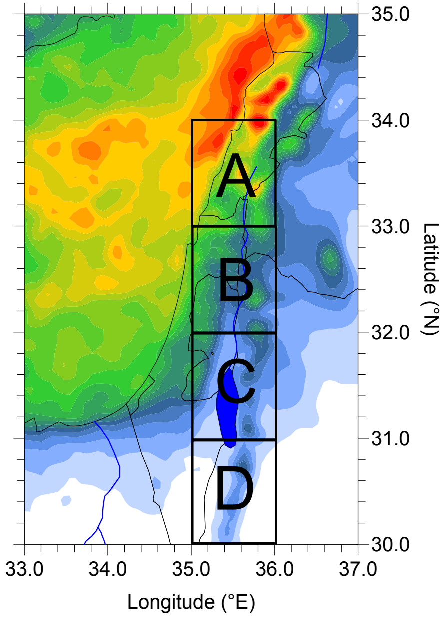
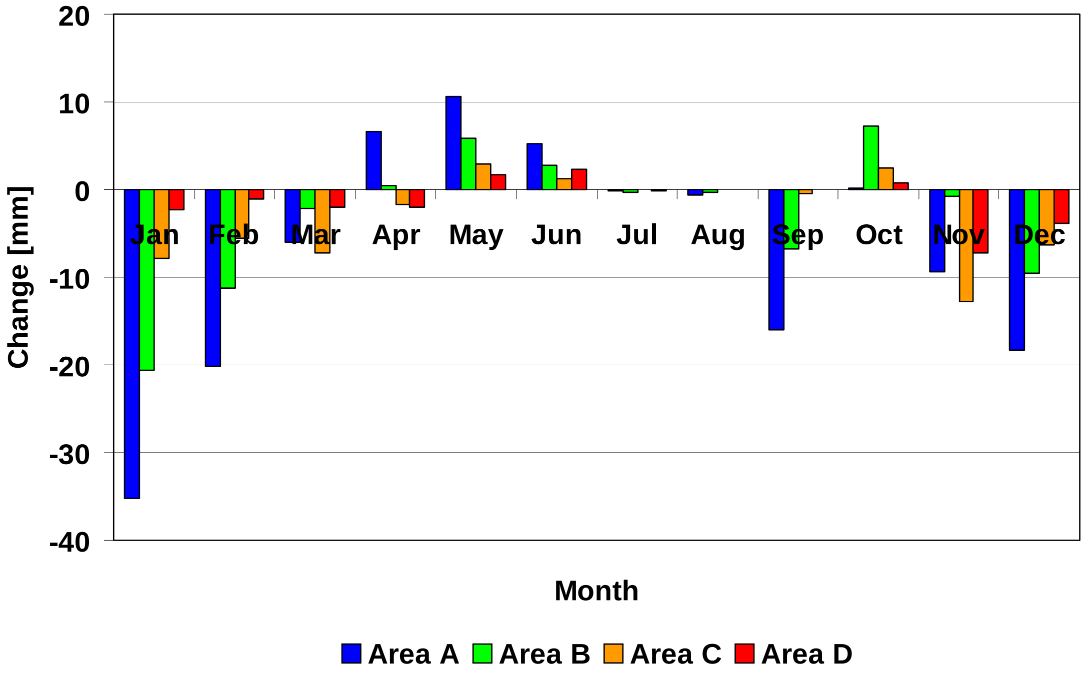
How does seasonal precipitation change depend on the region?





For all subregions: Decreased winter, increased spring precipitation

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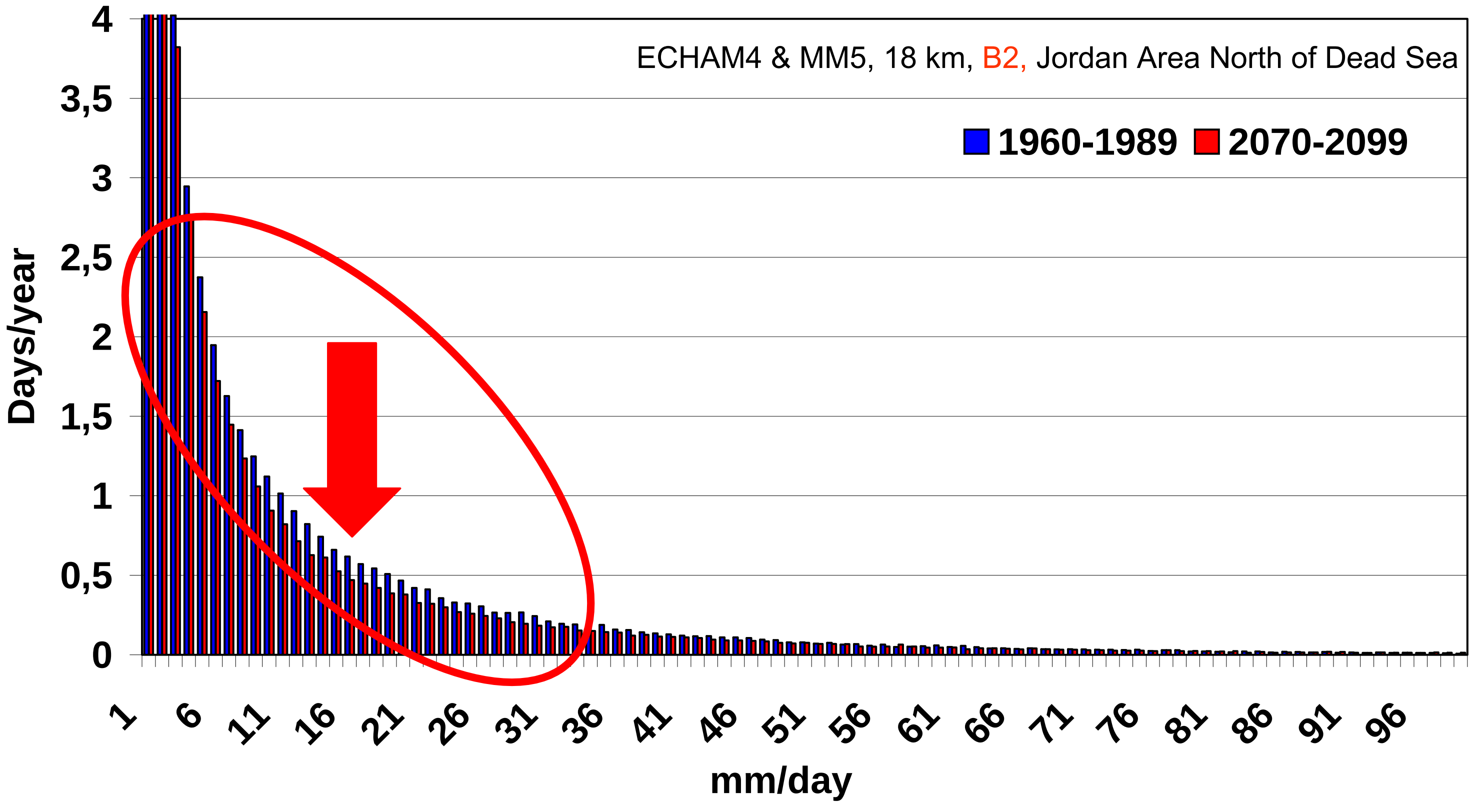
How do precipitation intensities change?



Tendency towards decrease of precipitation intensity

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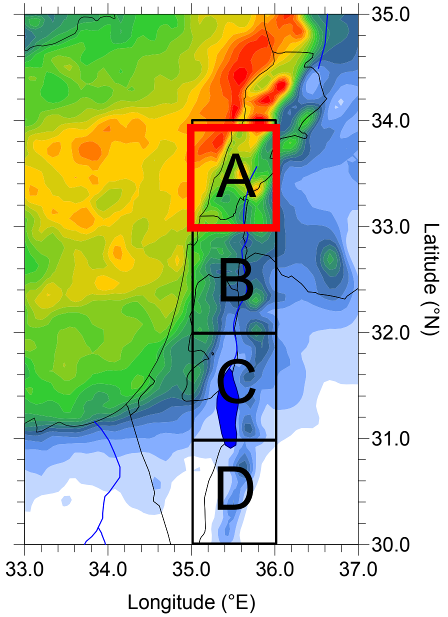
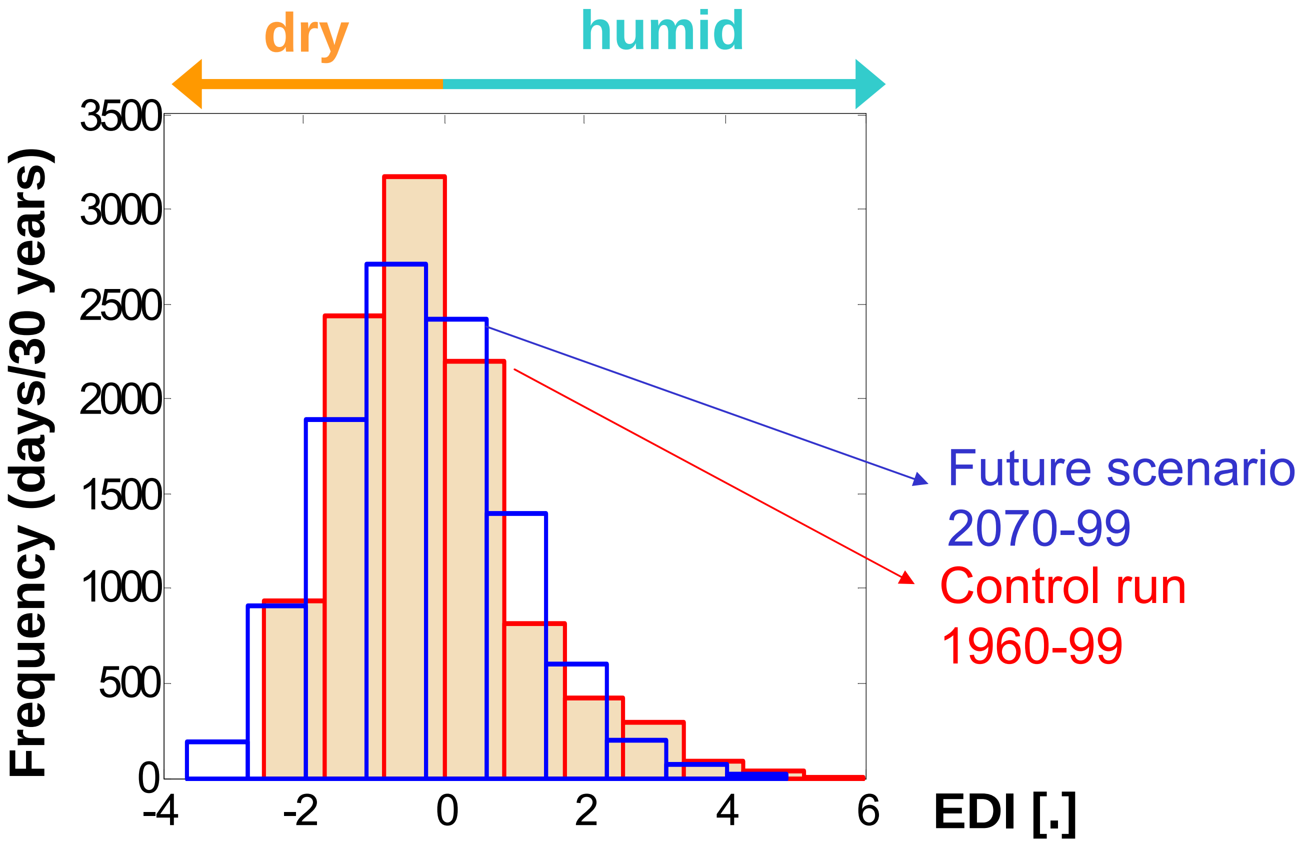
Are drought risks changing? Analysis of effective drought index EDI

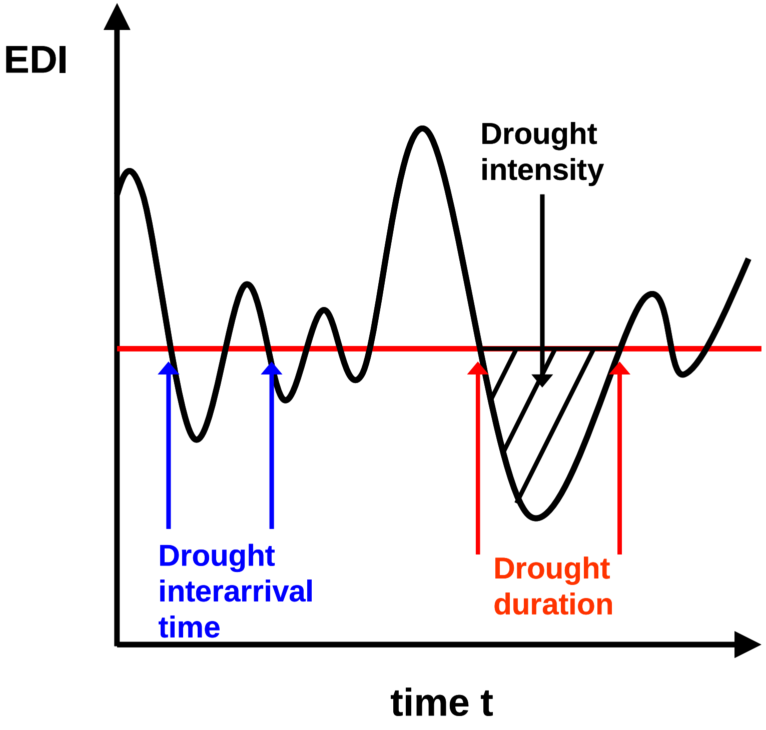


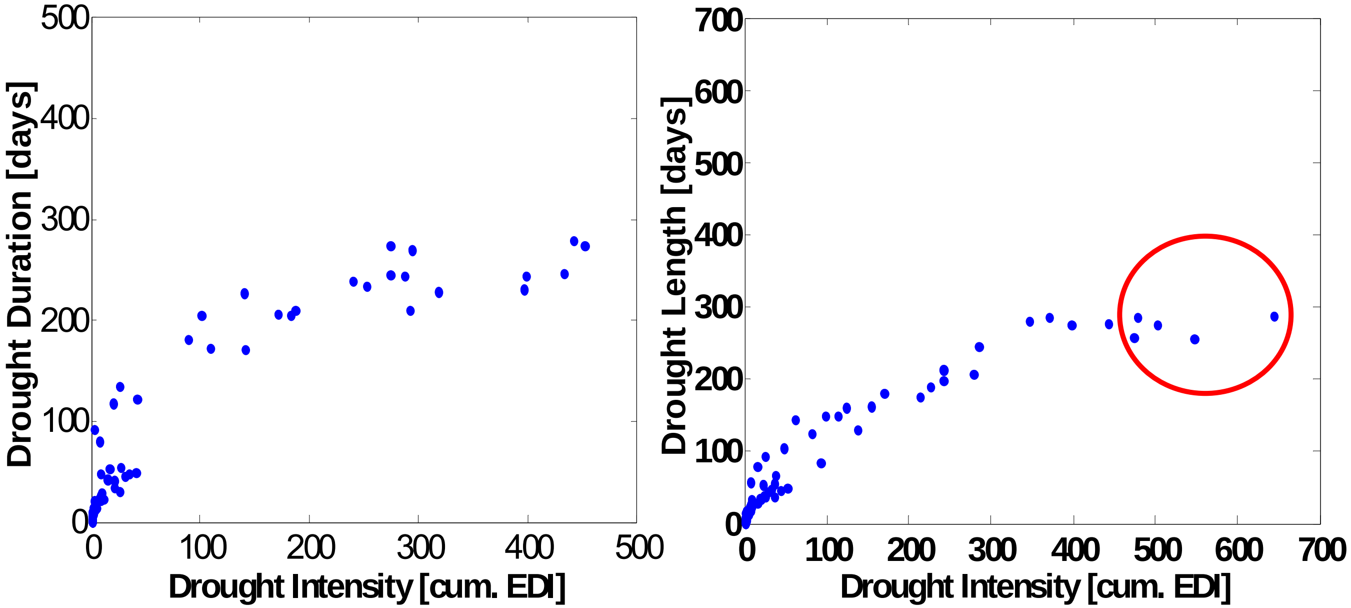


Subregion A: shift towards drier conditions & increased drought risks

Regional Climate Change Eastern Mediterranean/Middle East

Are drought risks changing? Analysis of effective drought index EDI





Subregion A: Increasing drought intensities, but "unchanging" max. drought durations

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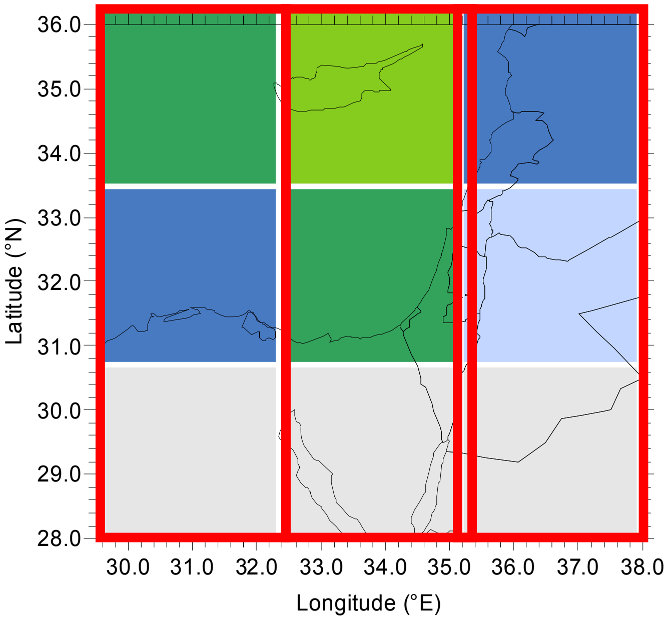
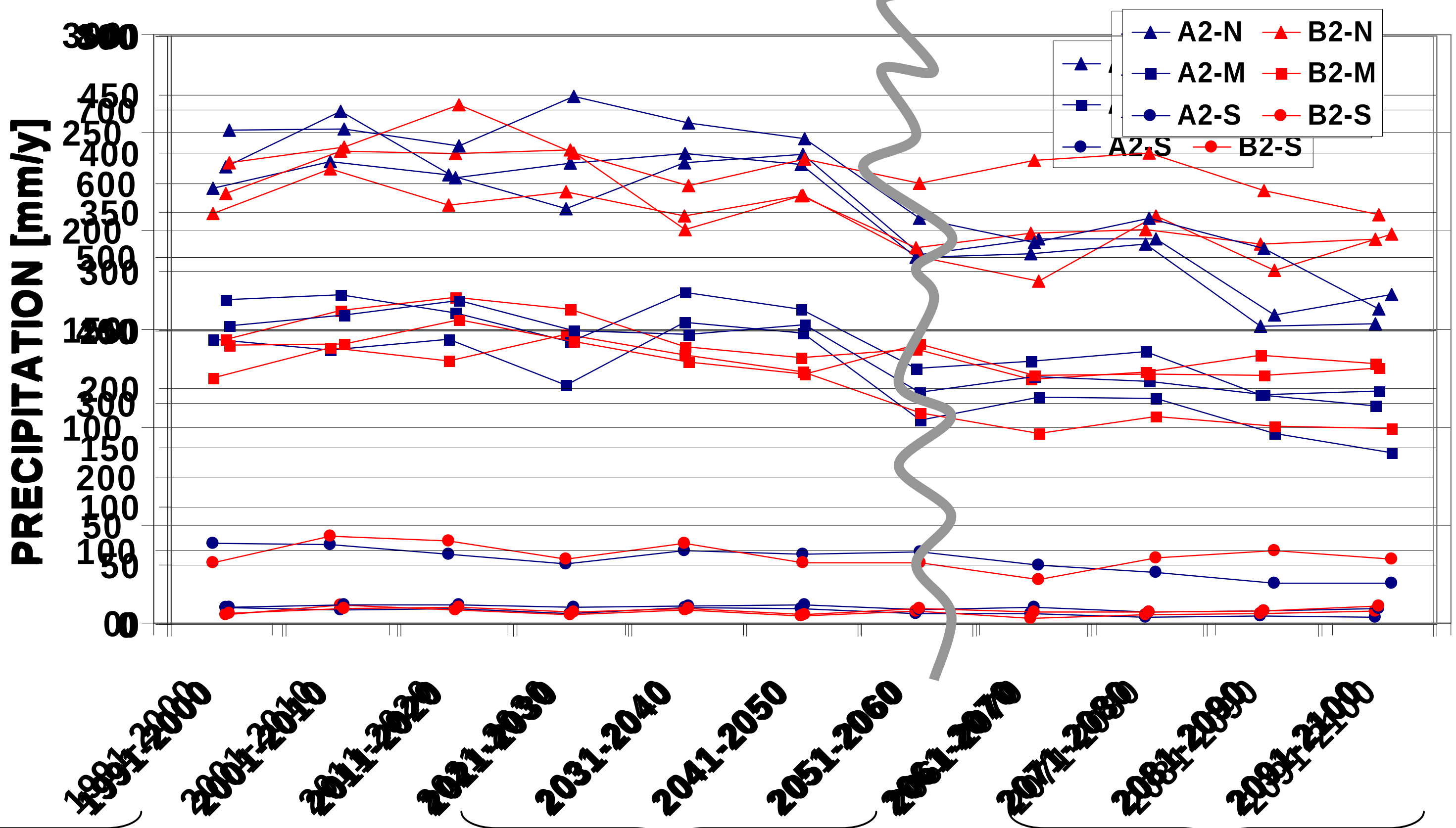
Long term vs. medium term: indications from GLOBAL CLIMATE MODELS



Small changes, slight increases

Clear decreases



recent climate… ⇐

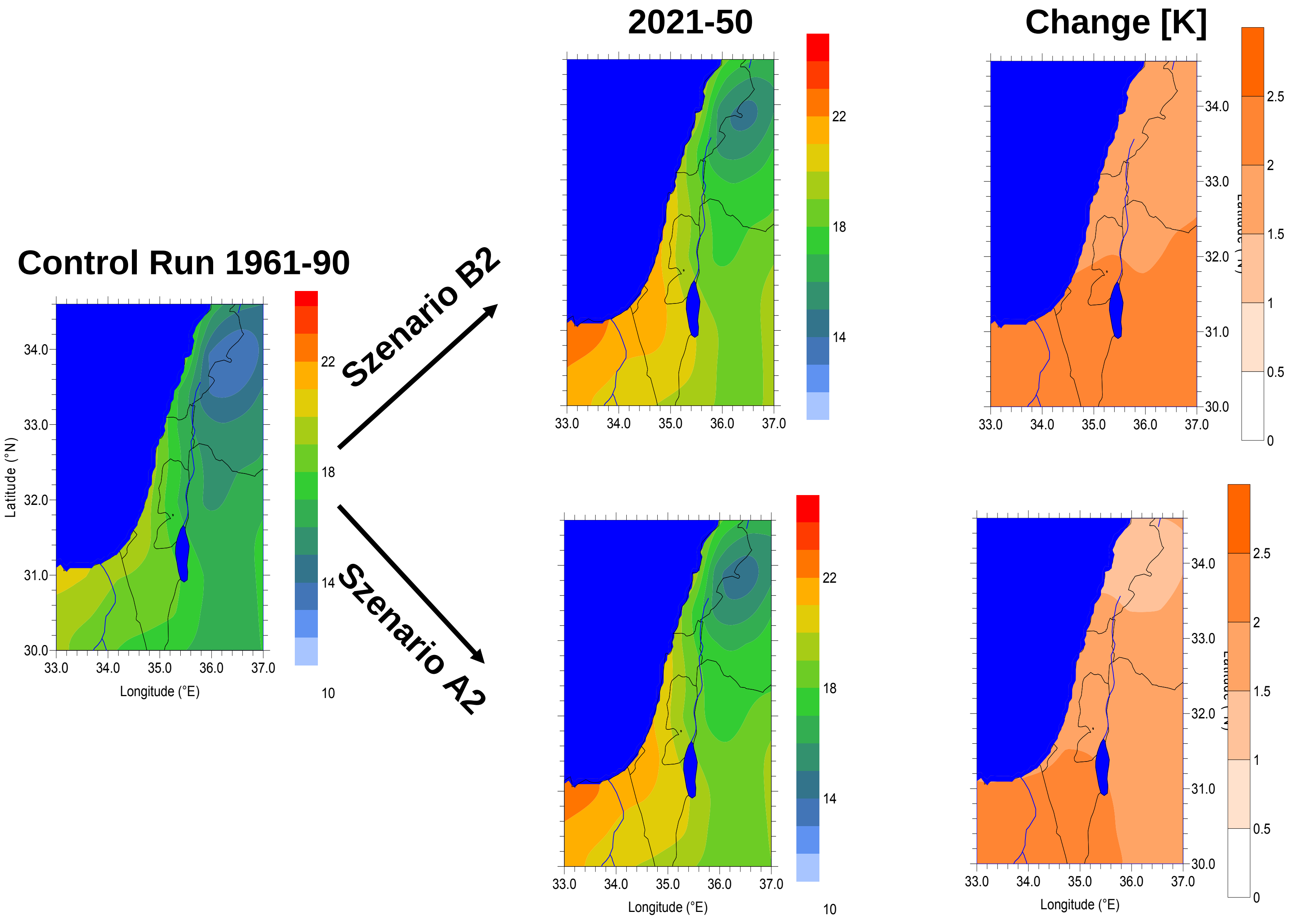
⇒ medium term

⇒ long term

Second example: MEDIUM TERM PROJECTIONS

ECHAM4, A2 & B2, 54km, 1961-2050 <u>transient</u>

Regional Climate Change Eastern Mediterranean/Middle East



Control Run 1961-90

Szenario B2

Szenario A2

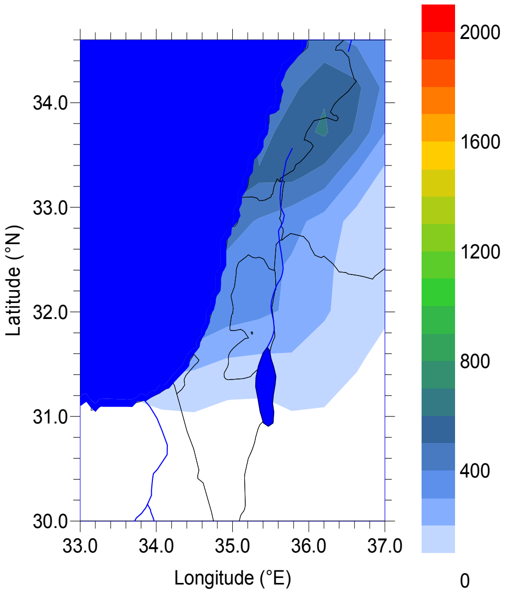
2021-50

Change [K]

Regional Climate Change Eastern Mediterranean/Middle East

Precipitation

Control Run 1961-90

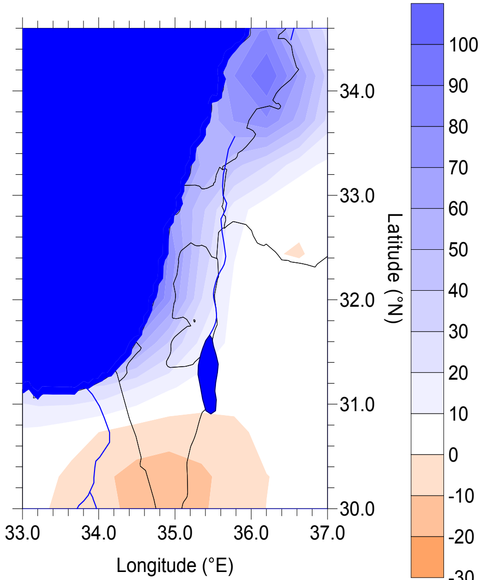


Scenario B2

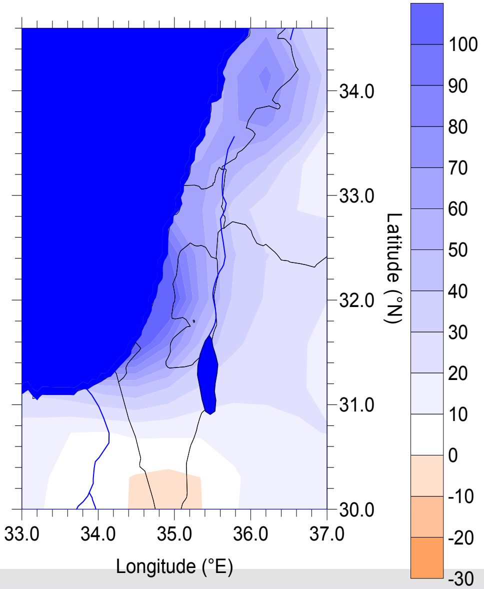
Scenario A2

2021-50

Change [mm]

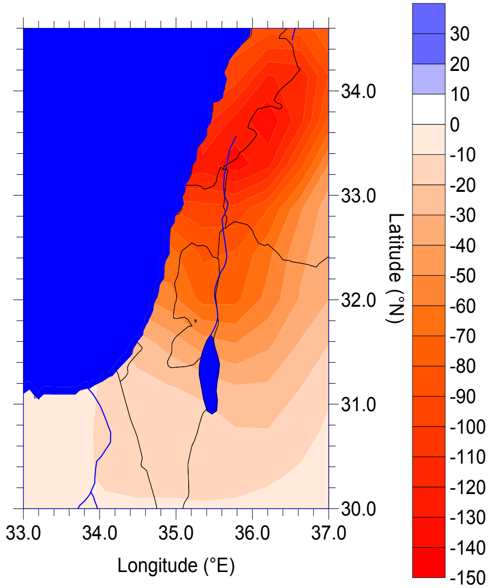


Change [mm]



2070-99

Change [mm]

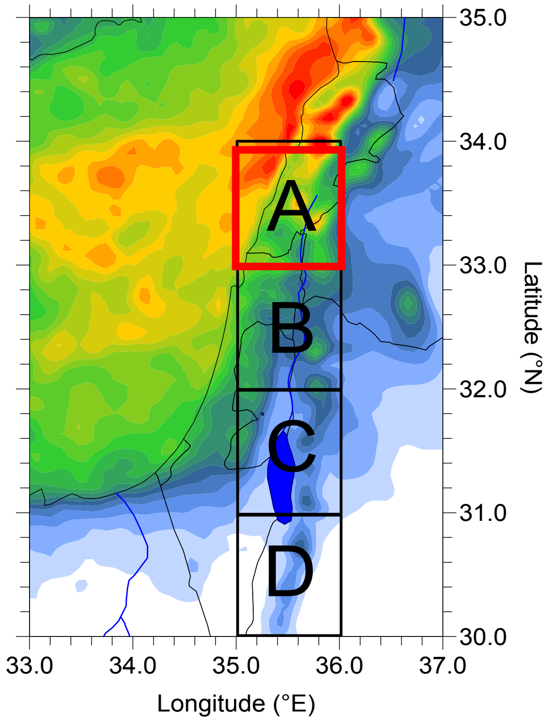


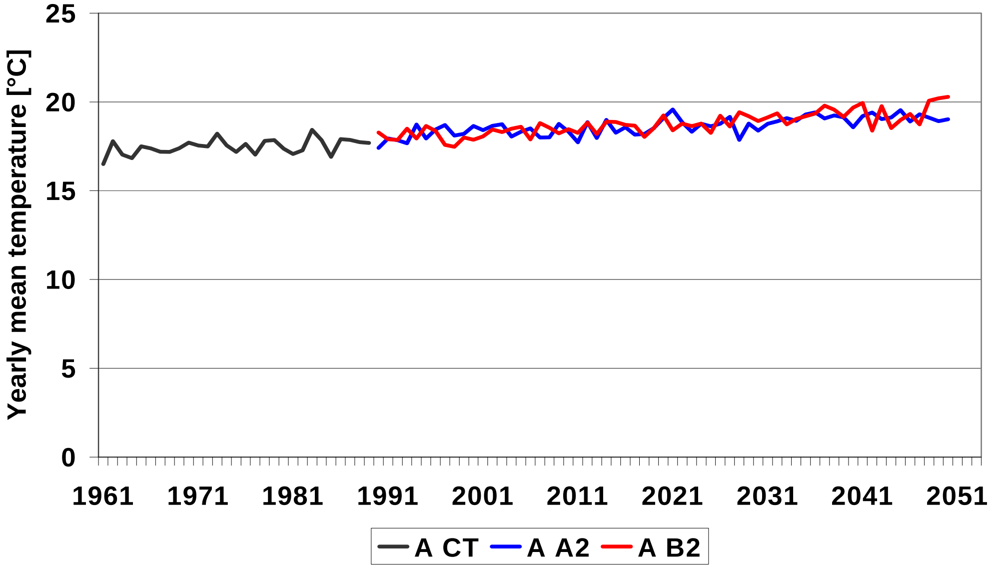
- Increase in precipitation
- Little differences between A2 + B2 till 2050

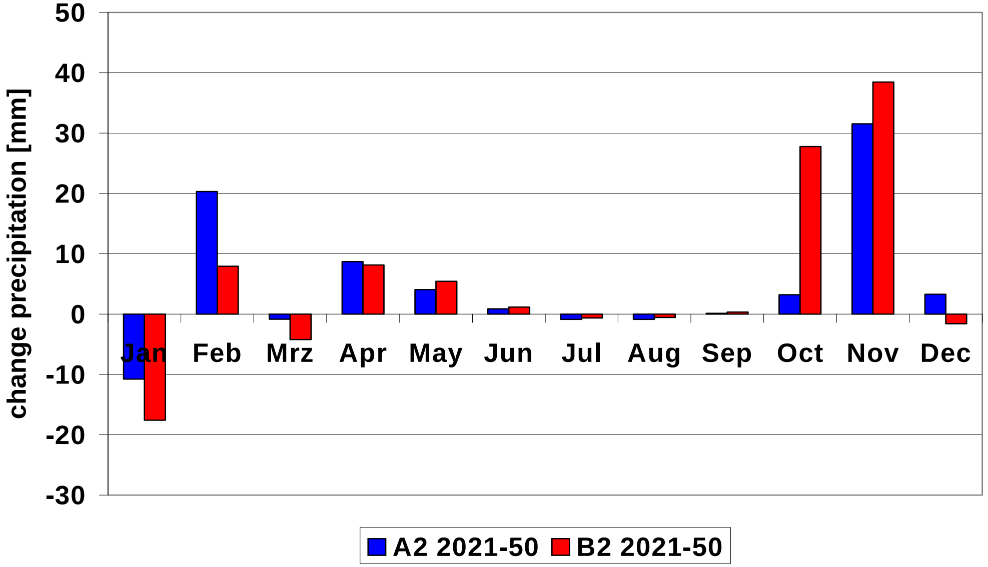
- **But:** significant decrease in 2070-99!

Regional Climate Change Eastern Mediterranean/Middle East

Changes in temperature and precipitation

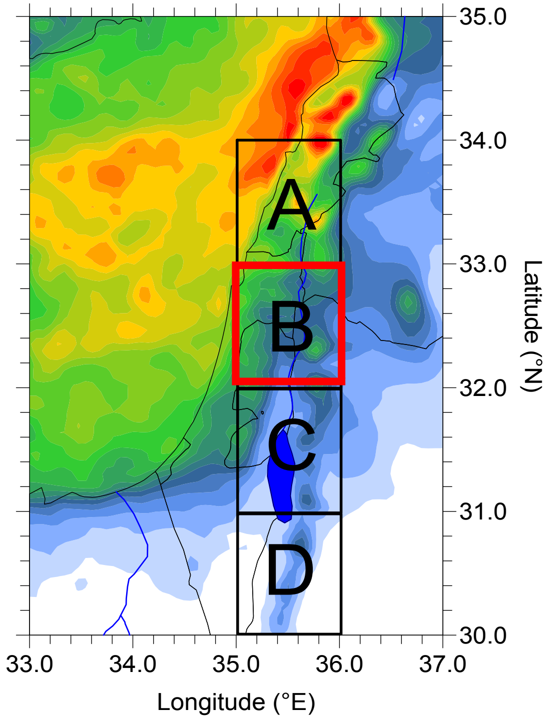


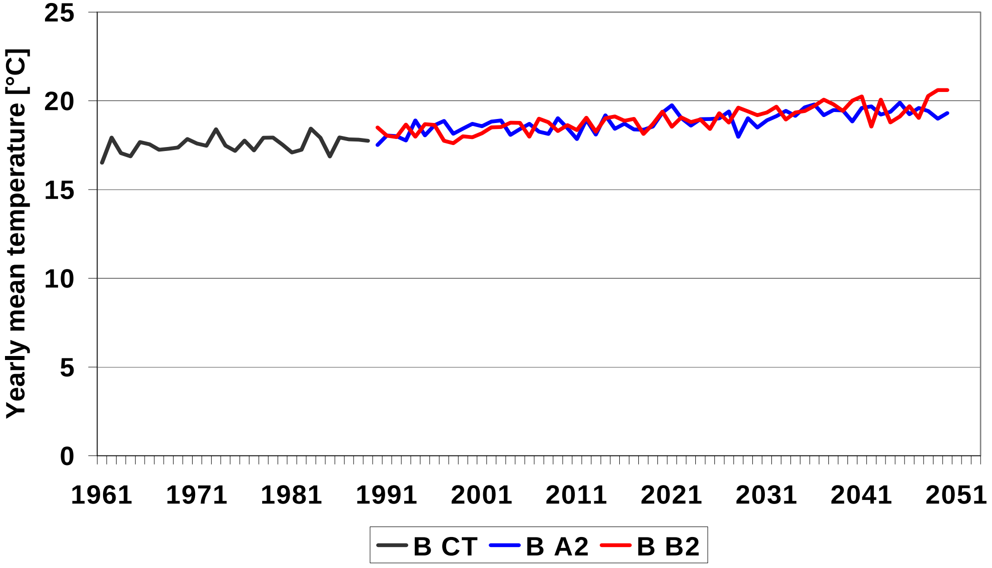


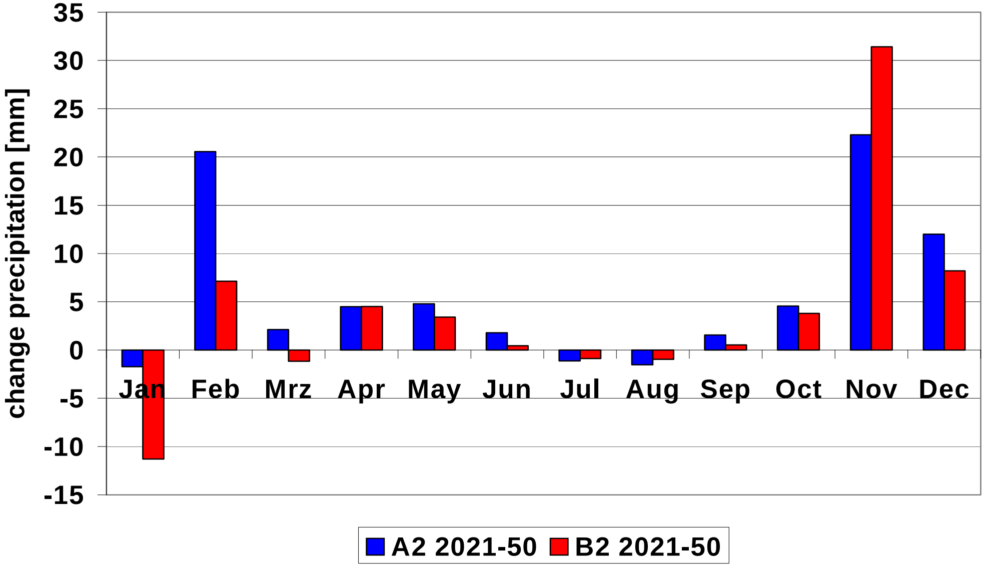


Regional Climate Change Eastern Mediterranean/Middle East

Changes in temperature and precipitation





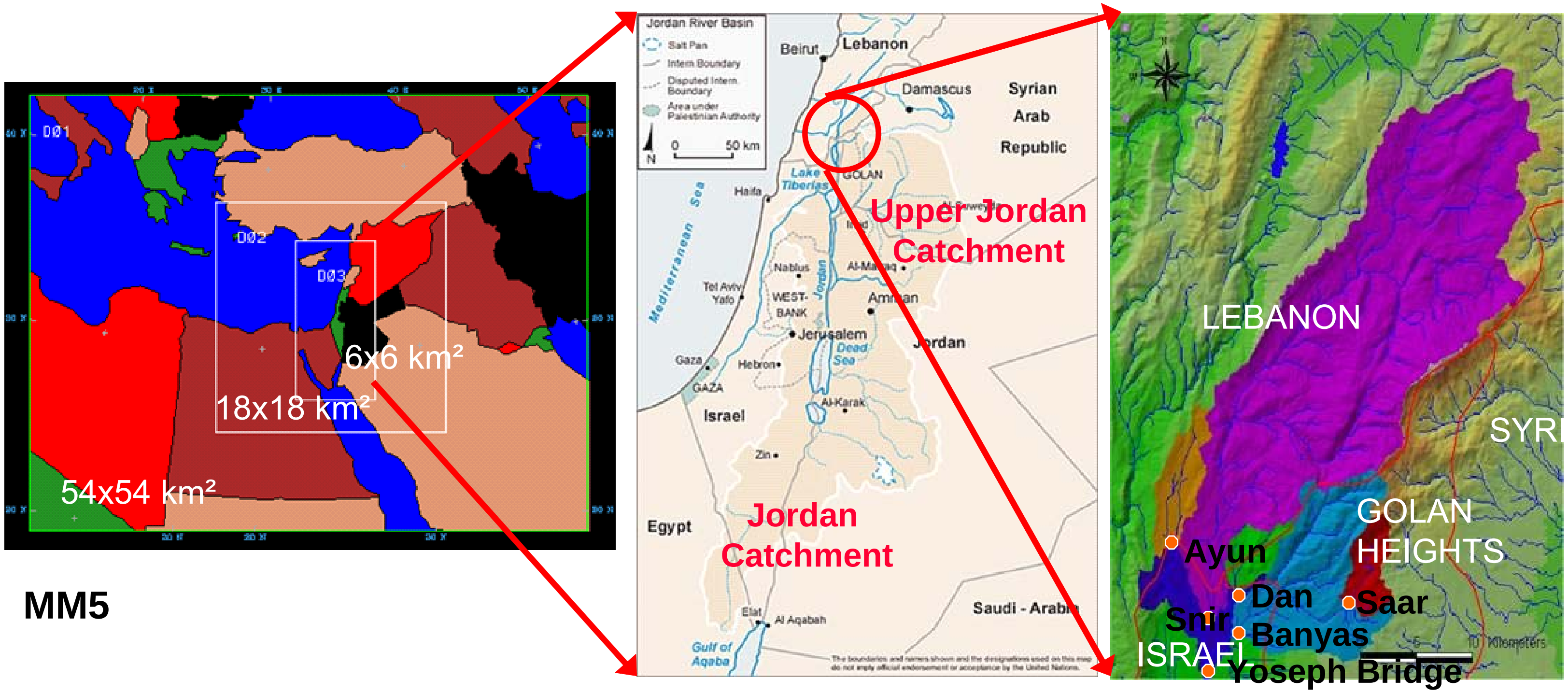


How does the expected atmospheric change translate into water availability in the of Upper Jordan River Catchment?

Regional Climate Modeling & Hydrological Impact Analysis

Example of joint climate-hydrology simulation for hydrological impact analysis

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



MM5

WaSiM

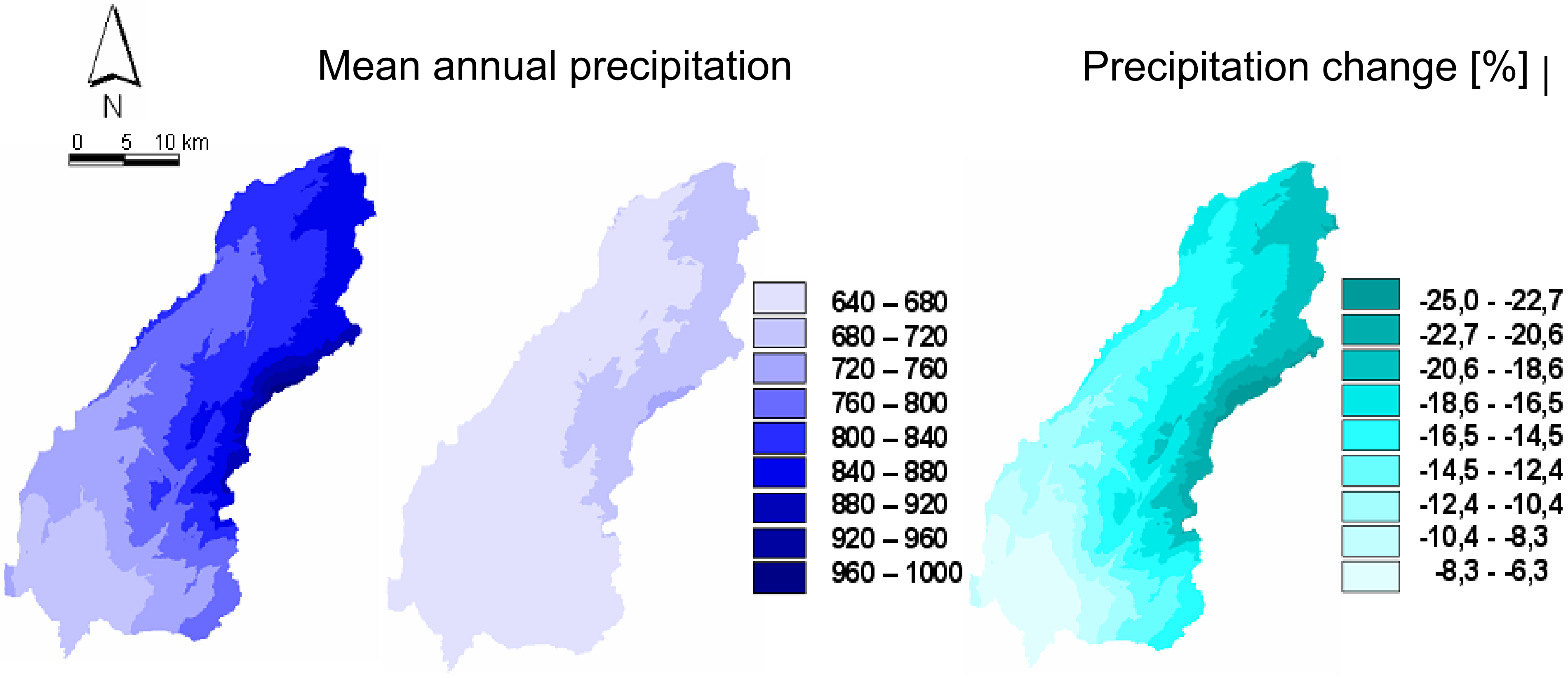
High resolution dynamical downscaling of global climate scenarios

→

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

Regional Climate Modeling & Hydrological Impact Analysis

Joint climate-hydrology simulation for hydrological impact analysis


Mean annual precipitation

Precipitation change [%]

1961 - 1990

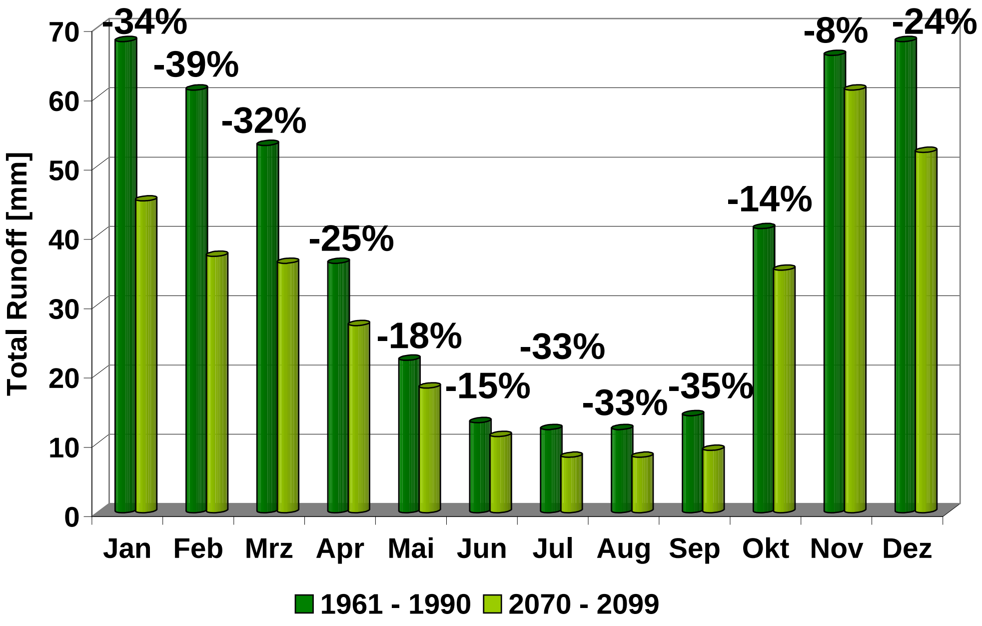
2070 - 2099

Upper Jordan River catchment

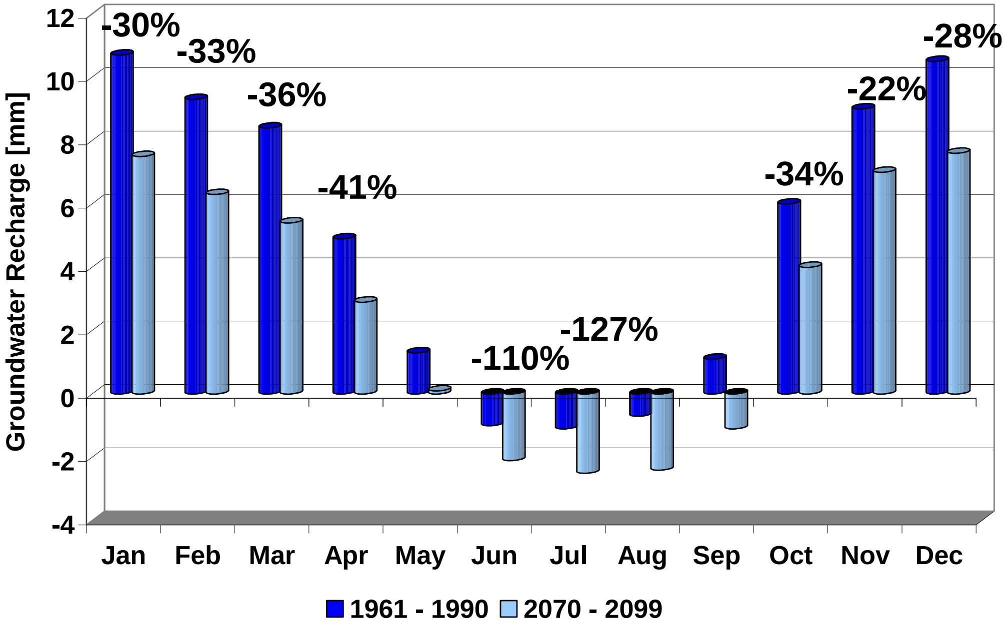
Regional Climate Modeling & Hydrological Impact Analysis

Joint climate-hydrology simulation for hydrological impact analysis

Runoff



Groundwater Recharge



Upper Jordan River Catchment

Regional Climate Modeling & Hydrological Impact Analysis

Summary & Conclusions

- Increase of temperatures in all scenarios (up to +4°C till 2100), Δt summer > Δt winter

- **Long term** projections of precipitation differ from **medium term** projections:

  1) precipitation & intensity increase till 2050 for scenarios A2 & B2 (transient)
  2) precipitation & intensity decrease till 2100 for scenario B2 (time slice)

- Little differences between A2 and B2 till 2050 in mean annual precipitation change **but significant differences in monthly changes**

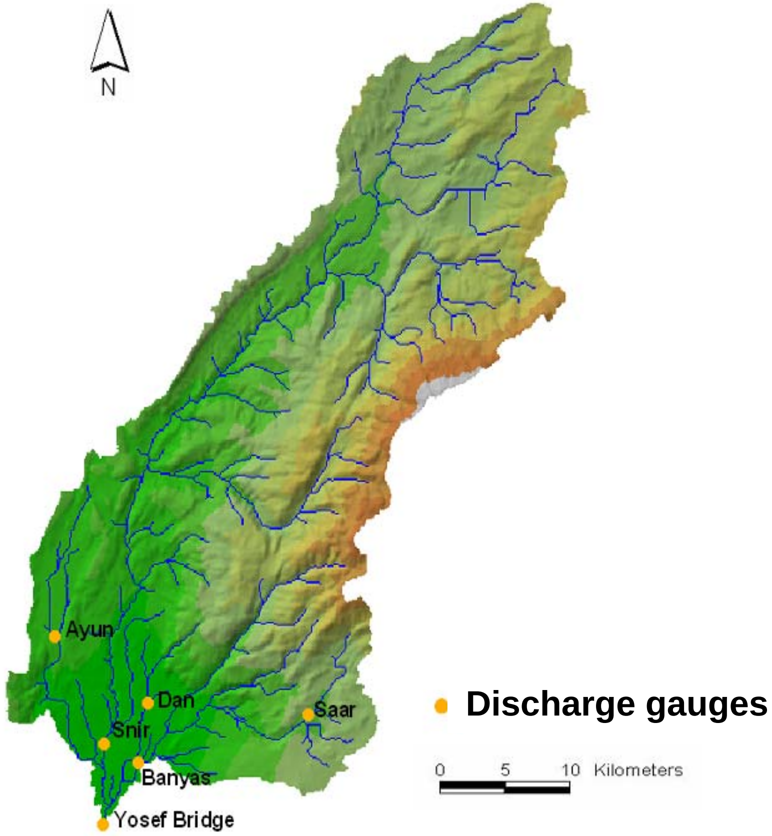
Upper Jordan River Catchment (long term projection)

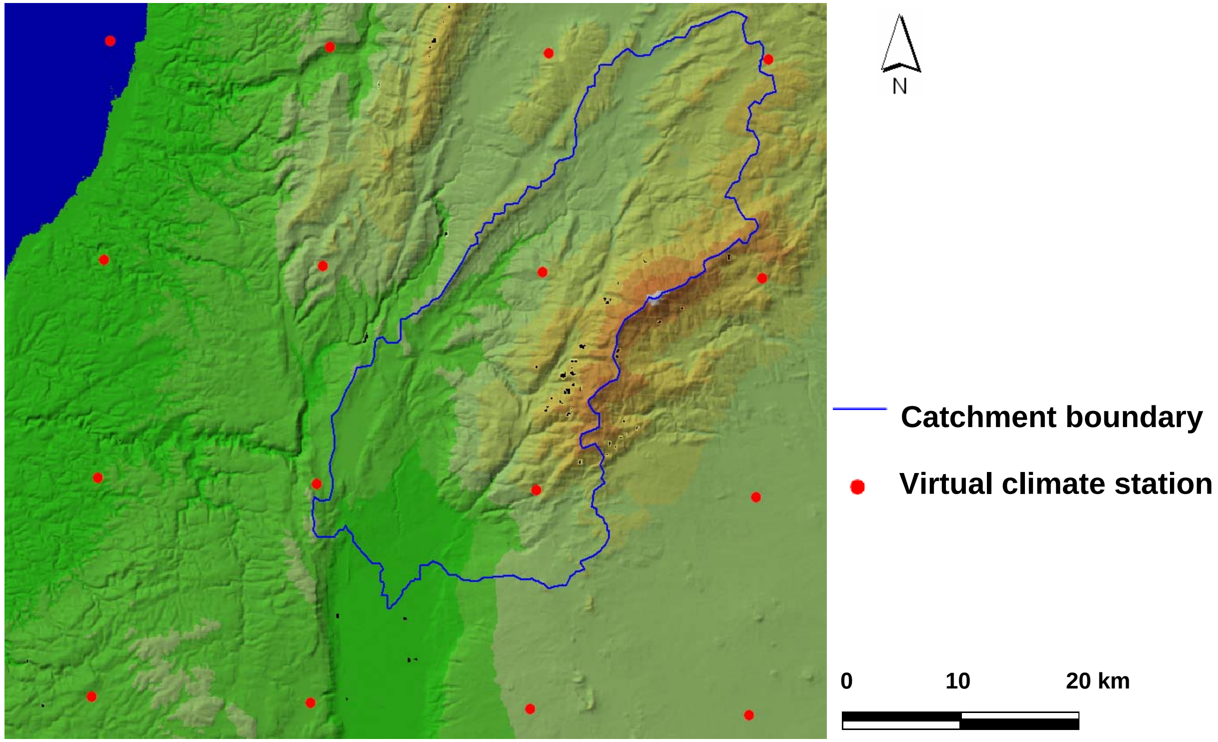
- In spite increased spring precipitation, decreased spring runoff & recharge
- Significant reduction of snow

- **Significantly increased drought risks in long term (EDI)**

Thank you for your attention

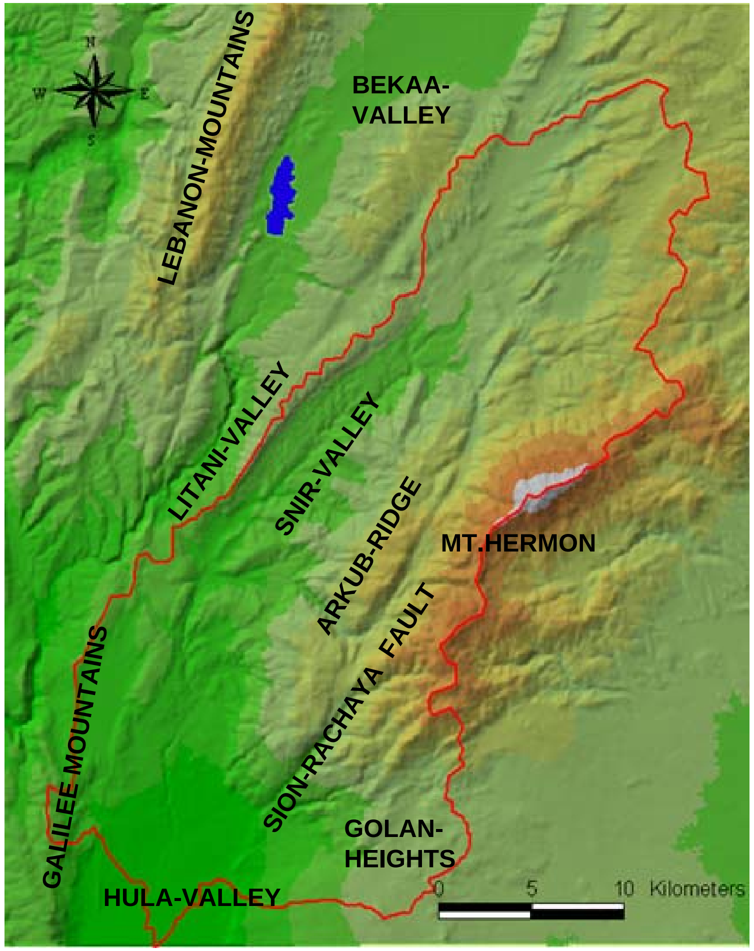
Joint climate-hydrology simulation for hydrological impact analysis





Regional Climate Change Middle East and Upper Jordan River

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

Hydrological Model WaSiM-ETH

Physically based algorithms
for vertical water fluxes & groundwater:

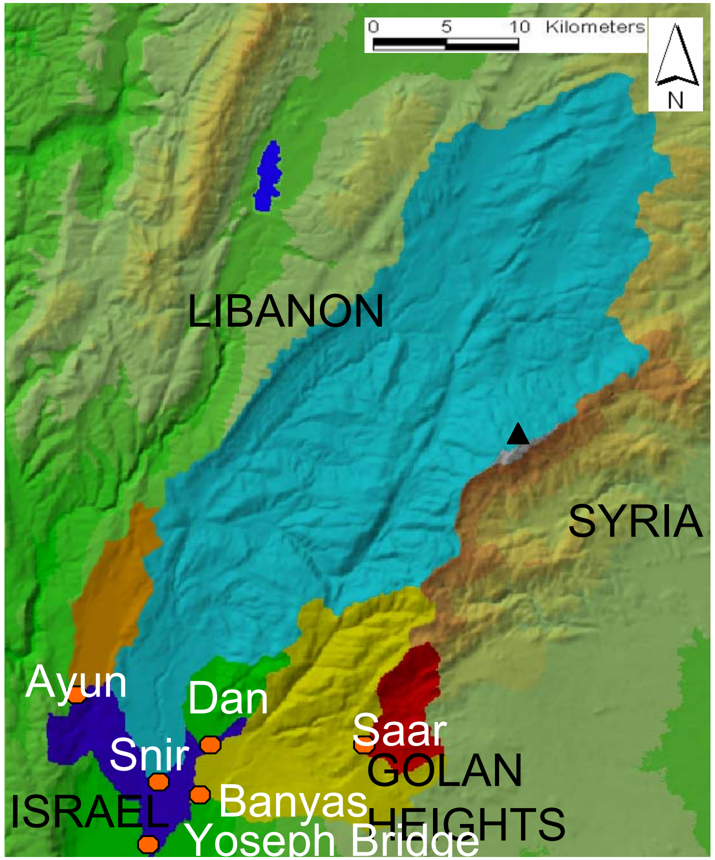
- Evapotranspiration: soil and vegetation specific (Monteith)
- Flow through unsaturated zone (Richards)
- Suction head & hydraulic conductivity (van Genuchten)
- 2-dim groundwater model dynamically coupled to unsaturated zone

Conceptual approaches for lateral runoff aggregation

- Traveltime approach folded with linear storage
- Discharge routing: cinematic wave

Setup Upper Jordan River catchment

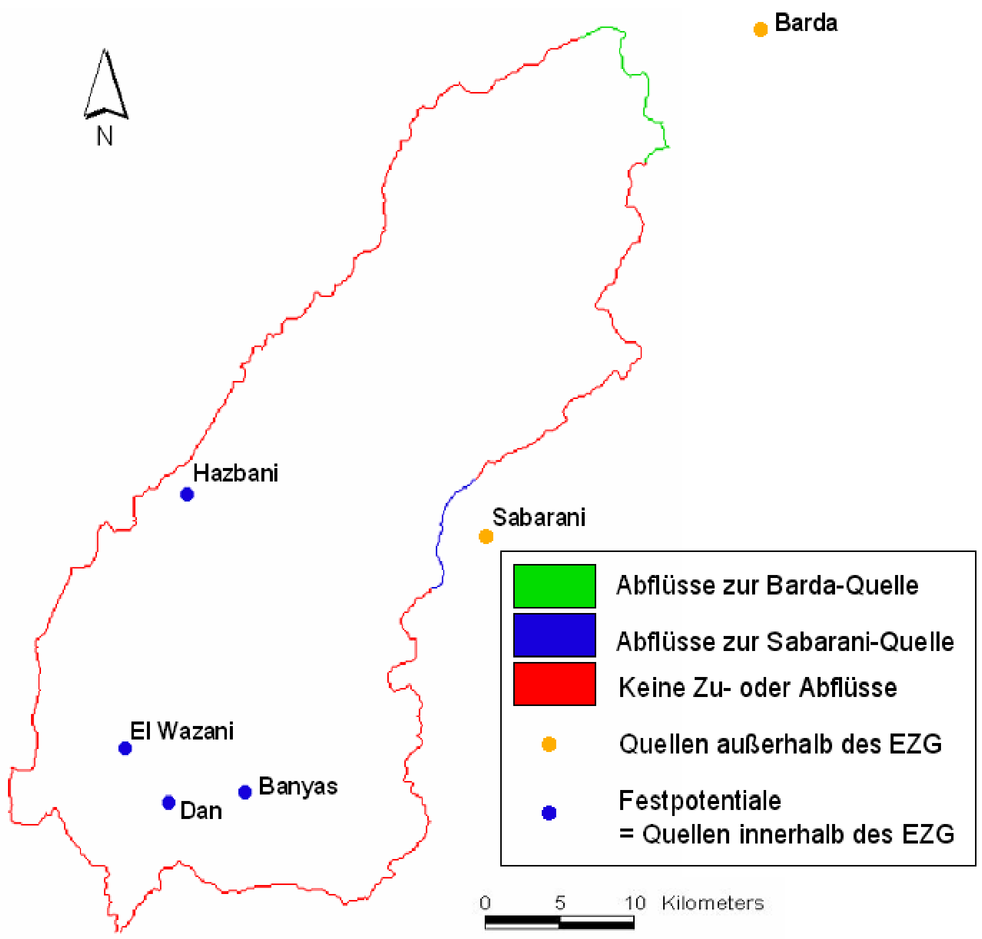
- spatial resolution: 90x90 m², temporal resolution: daily
- subdivision into 6 sub-catchments



Regional Climate Change Middle East and Upper Jordan River

Boundary Conditions for Groundwater Model

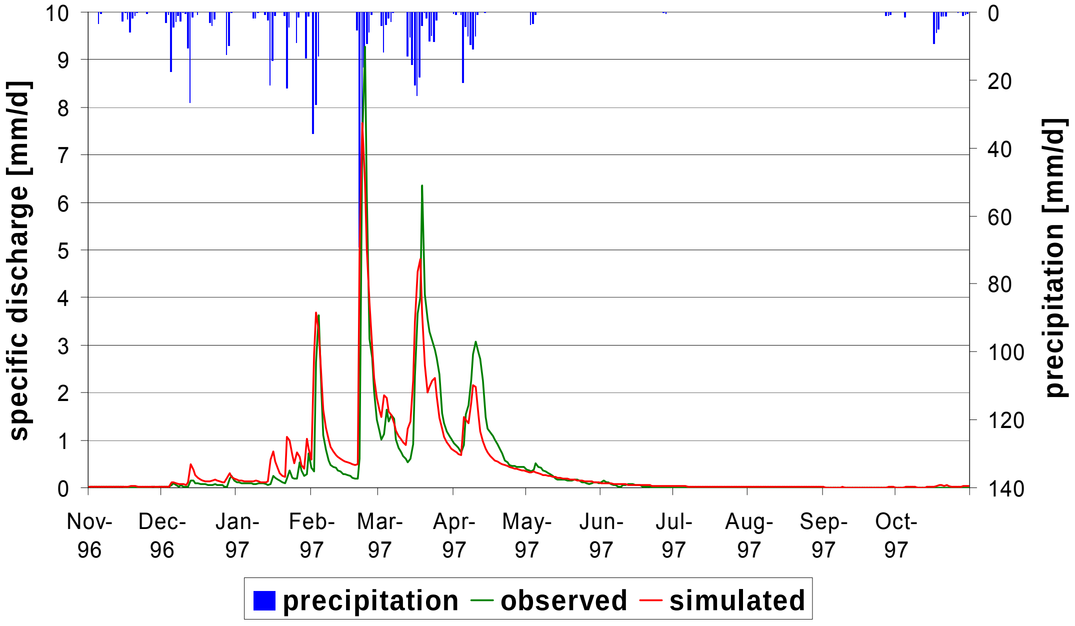
Maximum depth of unsaturated zone assumed:
= 100 m



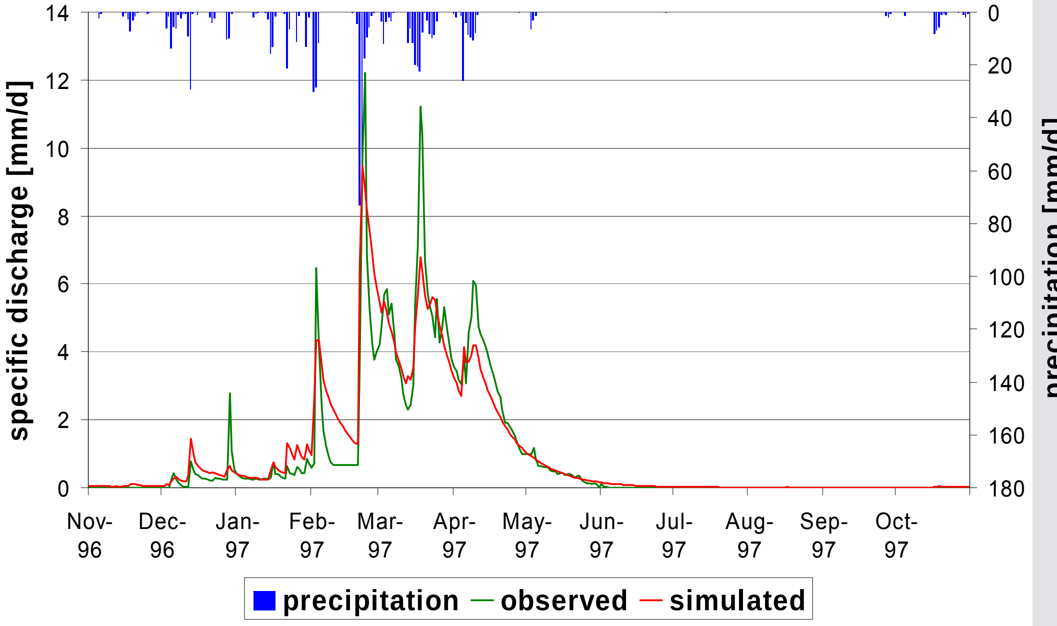
Regional Climate Change Middle East and Upper Jordan River

Hydrological Simulations

Episode	Gauge	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



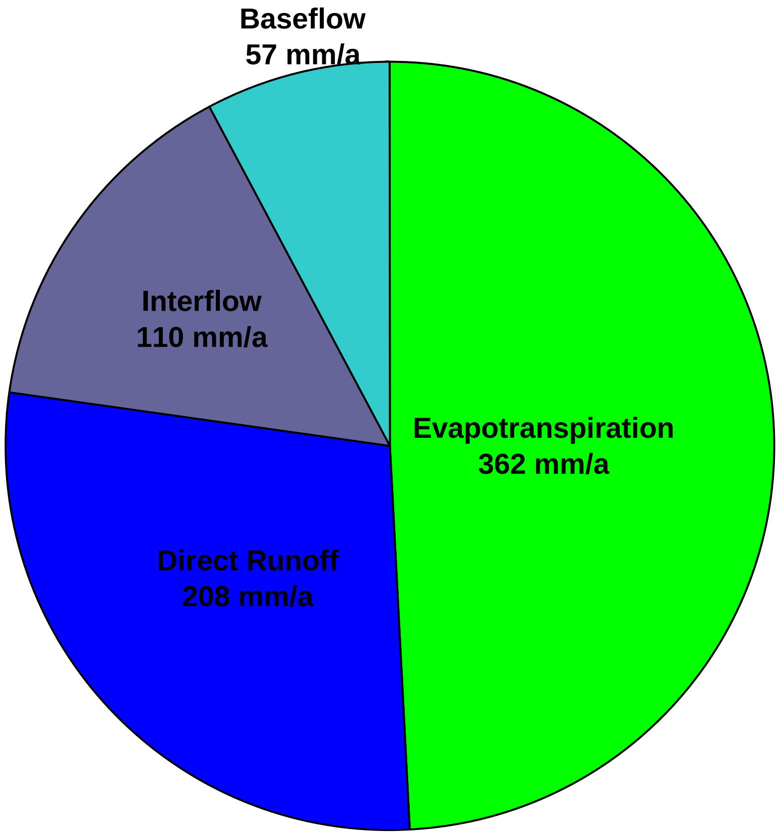
Gauge Ayun



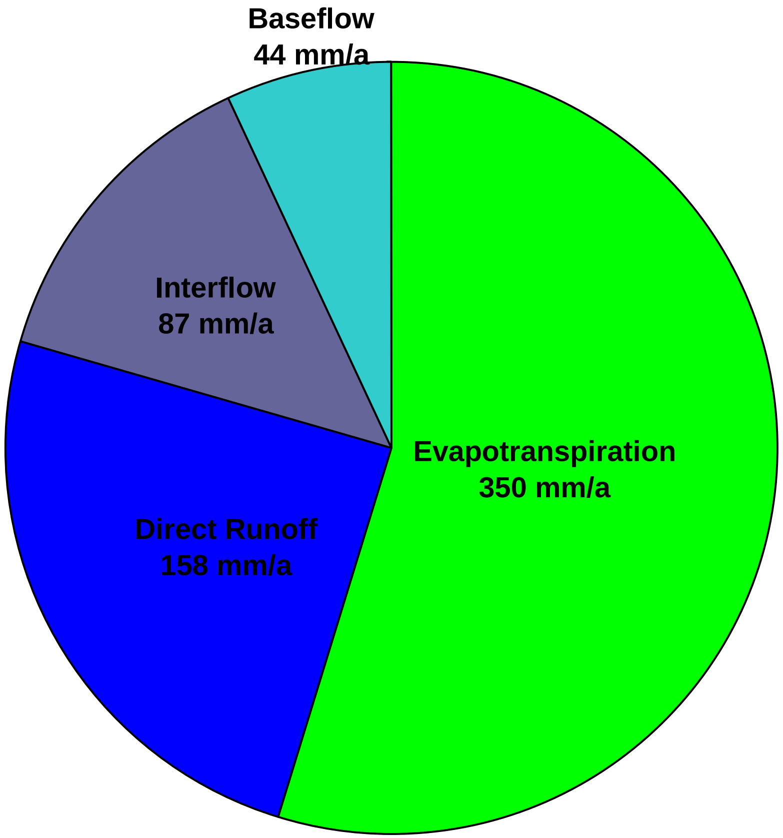
Gauge Saar

Regional Climate Change Middle East and Upper Jordan River

Joint climate-hydrology simulation for hydrological impact analysis



1961-90



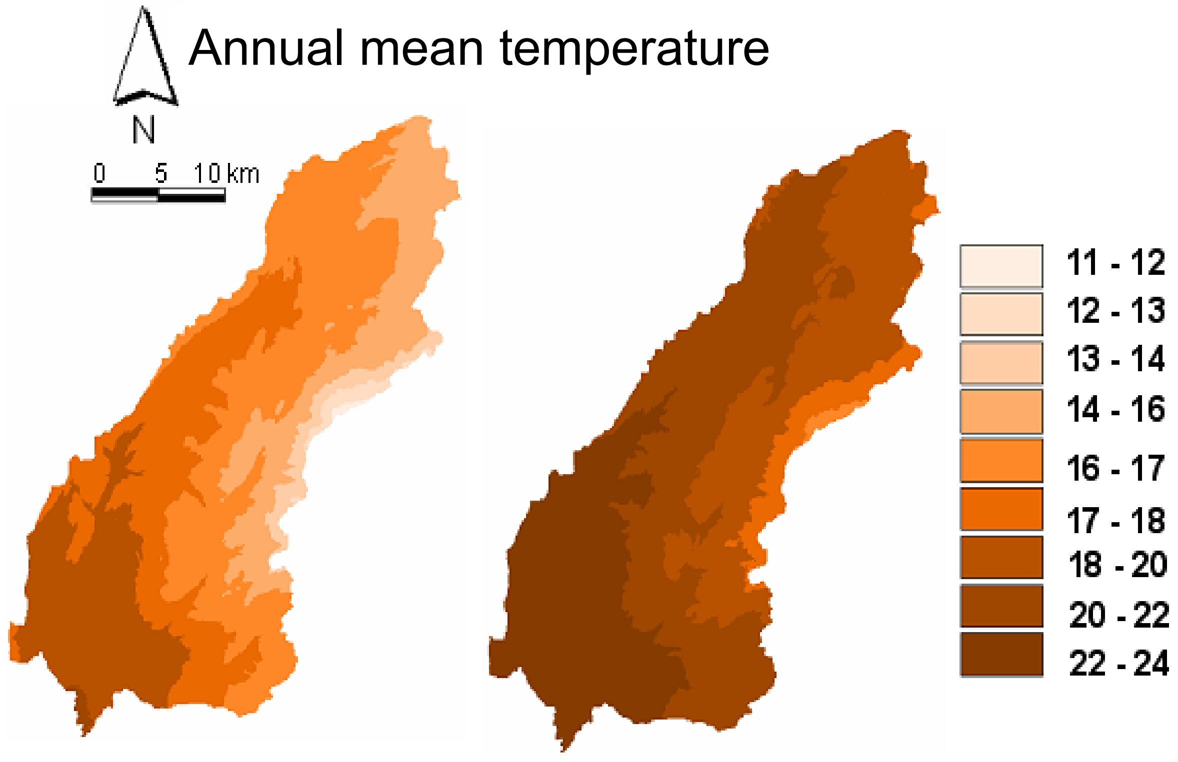
2070-99

Q_{tot}+ET: 737mm ⇒ 639 mm (-13%)
Q_{tot}: 375 mm ⇒ 289 mm (-23%)

Regional Climate Modeling & Hydrological Impact Analysis

Joint climate-hydrology simulation for hydrological impact analysis

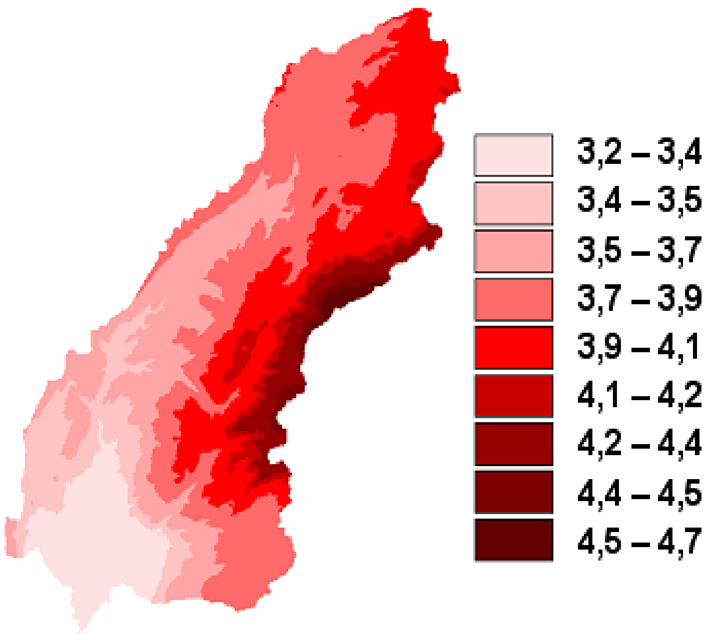
Annual mean temperature



1961 - 1990

2070 - 2099

Temperature change [°C]



Upper Jordan River catchment