# Regional Climate Simulations

# for the Middle East

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# Regional Climate Simulations

**Objectives**

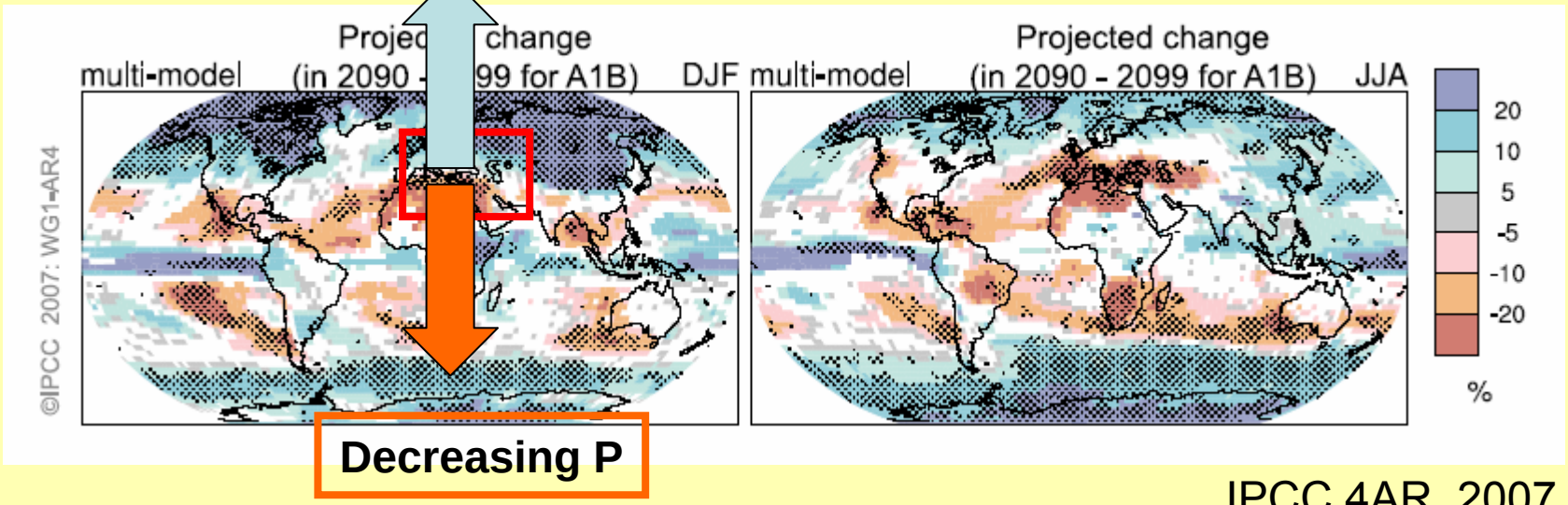
1) Estimation of future temporal and spatial distribution of temperature and precipitation

2) Provision of climate change information to impact WPs in GLOWA-Jordan

3) Estimation of uncertainty bounds of climate change projections

# Regional Climate Simulations

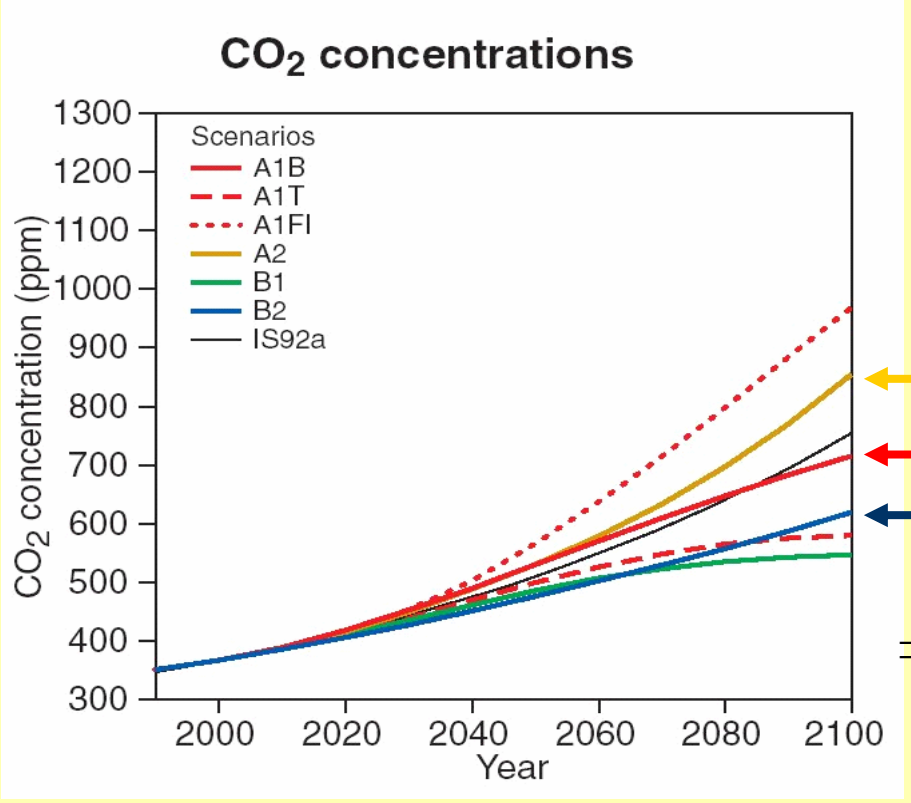
## Scientific Challenge




IPCC 4AR, 2007

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

# Regional Climate Simulations




Phase II+III

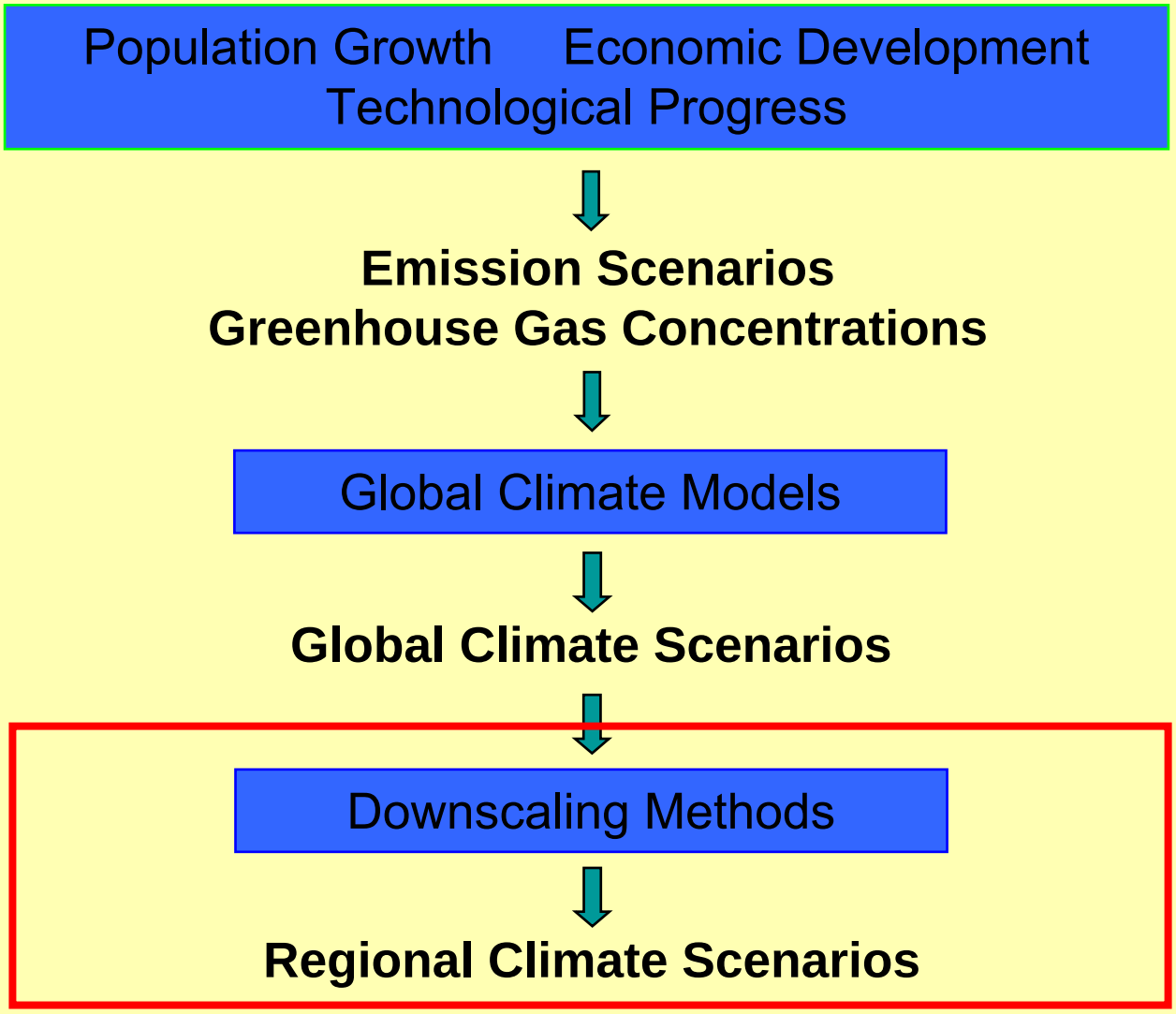
Phase III

Phase II+III

⇒ Uncertainty bounds

Emission scenarios: based on different assumptions on future GHG emissions

# Regional Climate Simulations



# Regional Climate Simulations

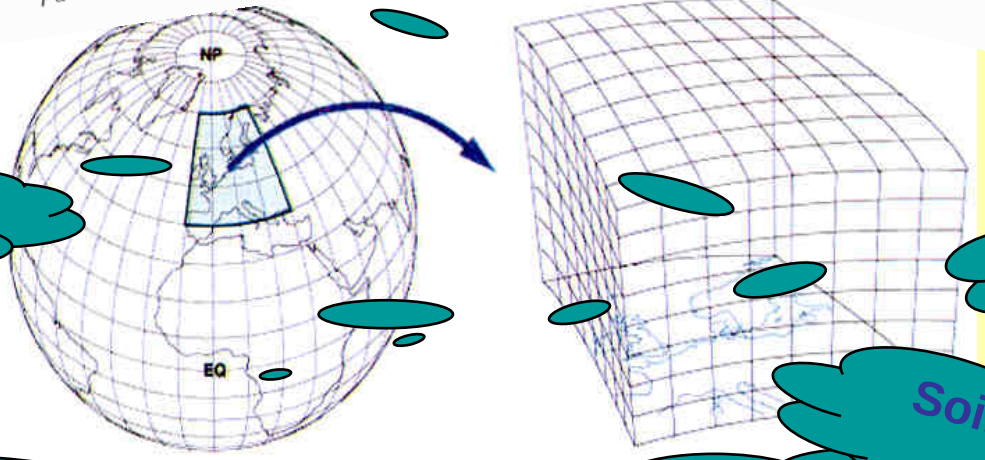
GLOWA Jordan River

## 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

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

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

## Soil temperature diffusion

## Precipitation physics

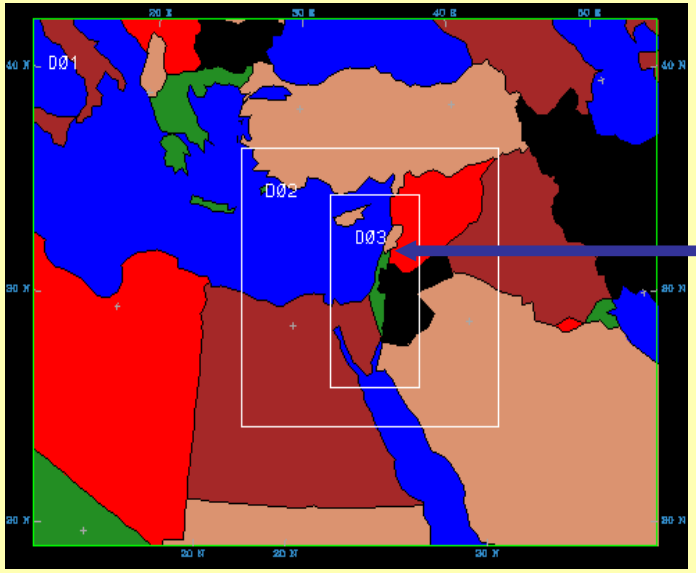
$$R_{evap\ (rain)} = \frac{2\pi N_{0r}(S_w - 1)}{A_r + B_r}\left[\frac{0.78}{\Lambda_r^2} + 0.32\left(\frac{a_r \rho}{\eta_a}\right)^{1/2} S_c^{1/3}\frac{\Gamma(5/2 + b_r/2)}{\Lambda_r^{5/2+b_r/2}}\right]$$

## Soil water infiltration

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

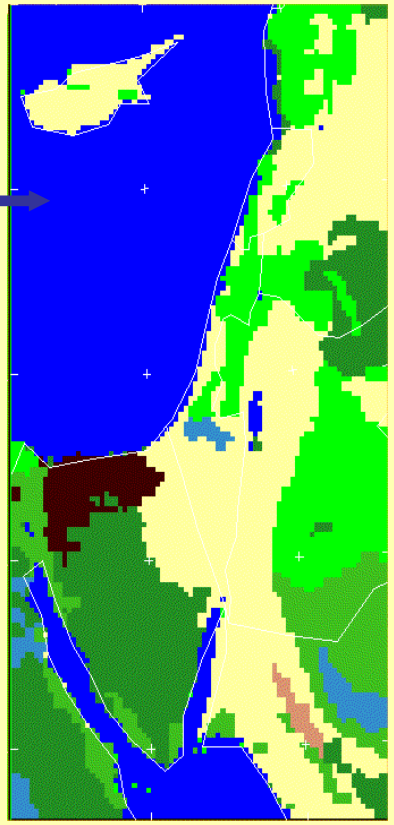
# Regional Climate Modeling

## Example: The Mesoscale Meteorological Model MM5




*Land Use Discretization*

*Soil Discretization*



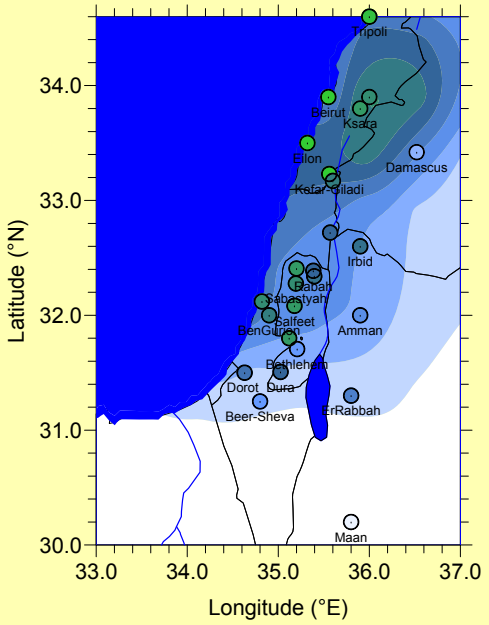
- Non-hydrostatic ($\Rightarrow$ allows high resolutions!)
- Dynamic Downscaling of ECHAM4 with MM5
- 3 nests: 54x54 km$^2$, 18x18 km$^2$, 6x6 km$^2$
- 26 Vertical Layers, Model Top: 100 mbar (ca.17 km)
- Coupled OSU-Land-Surface Model

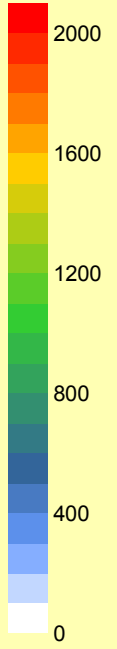
# Regional Climate Simulations

## What do we expect from the High Resolution Simulations?

Results of 6 km runs: mean 1961-1975

**Domain 1**




**Yearly Mean Precipitation 1961-1975**

54km 18km 6km

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

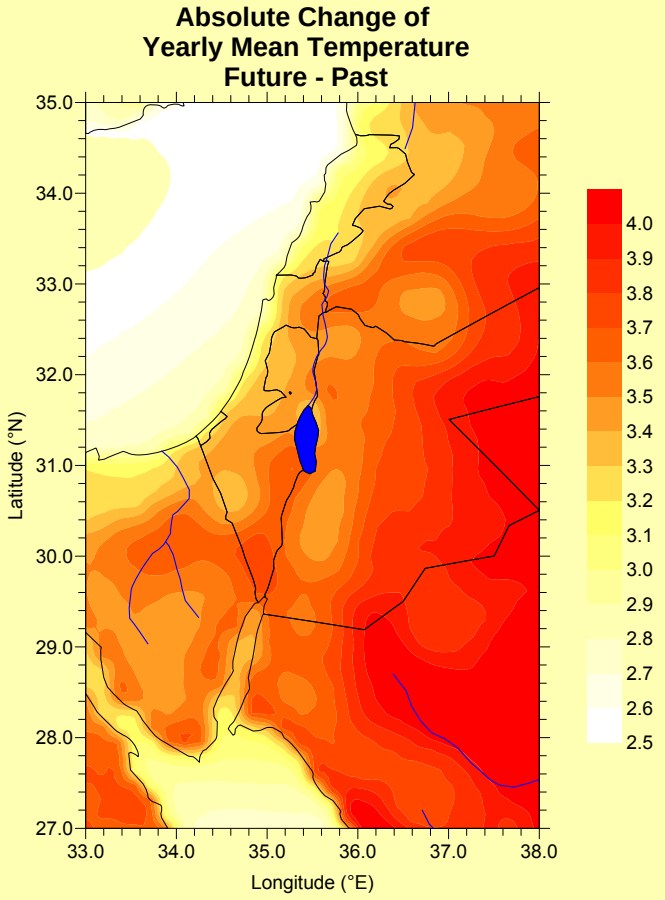
# Regional Climate Simulations

**First example: LONG TERM PROJECTIONS**

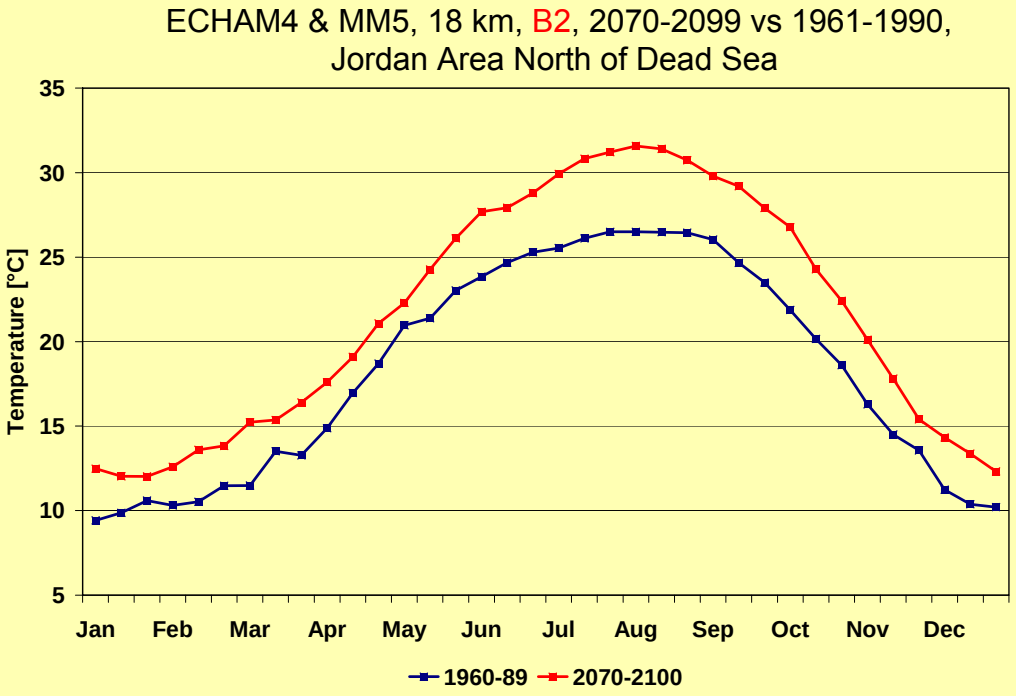
**ECHAM4, B2, 18km, 2070-99 vs. 1961-90**

# Regional Climate Simulations

## What are the expected changes in temperature?



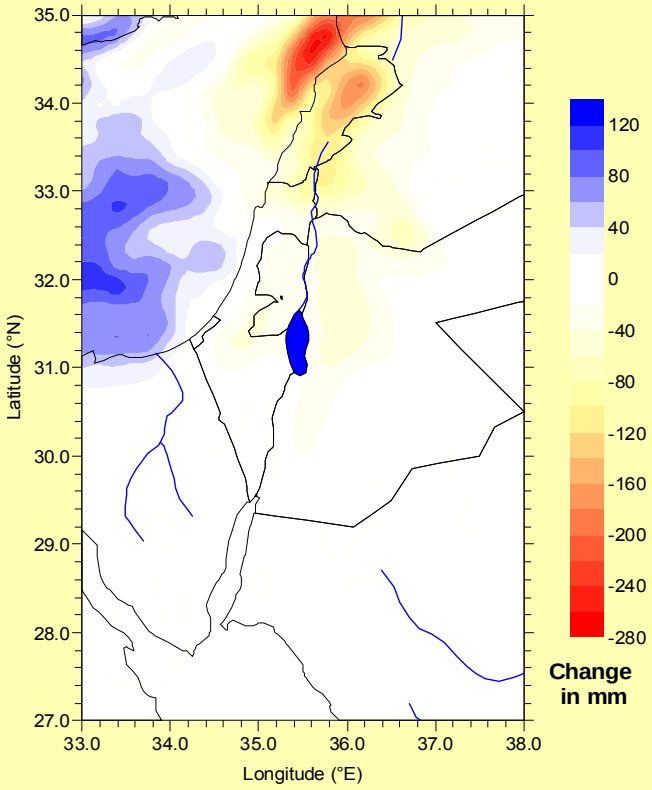

Change in mean annual temperature



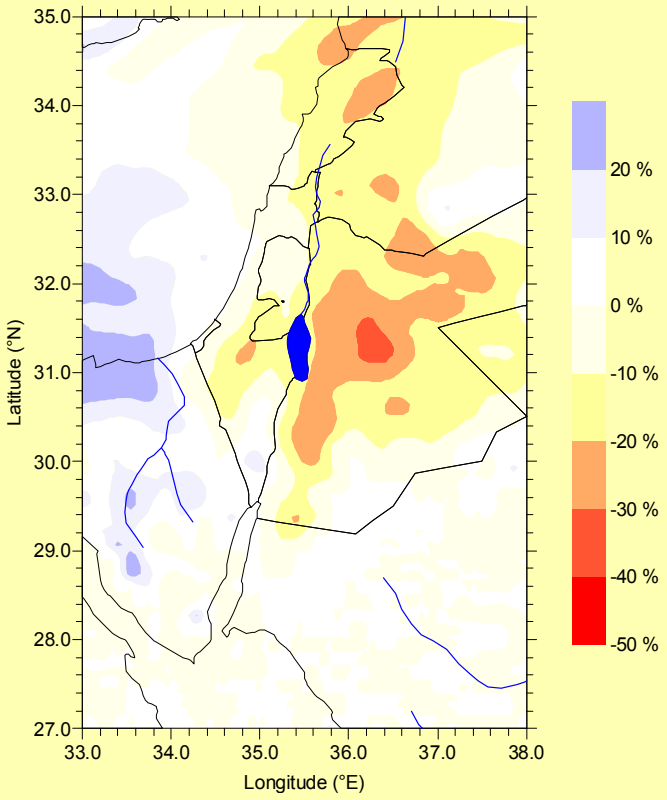

Change in temporal distribution

# Regional Climate Simulations

## What are the expected changes in precipitation?




Absolute change in [mm]

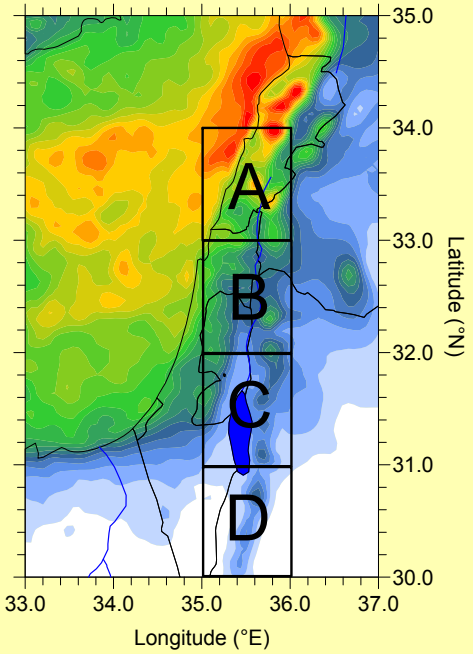



Relative Change in [%]

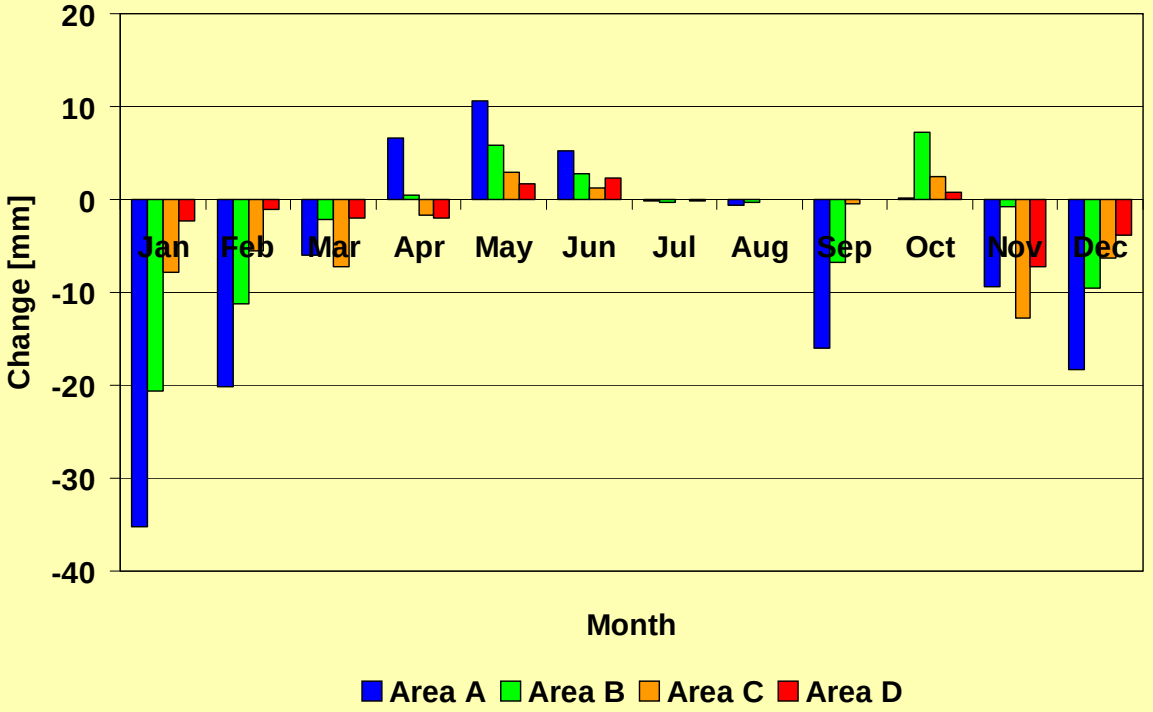
ECHAM4 & MM5, 18 km, B2, 2070-2099 vs 1961-1990

# Regional Climate Simulations

## How does seasonal precipitation change depend on the region?



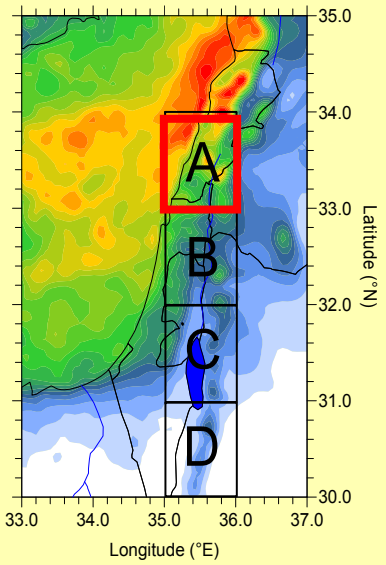

2070-2099 vs. 1961-1990, ECHAM4, B2, 18km

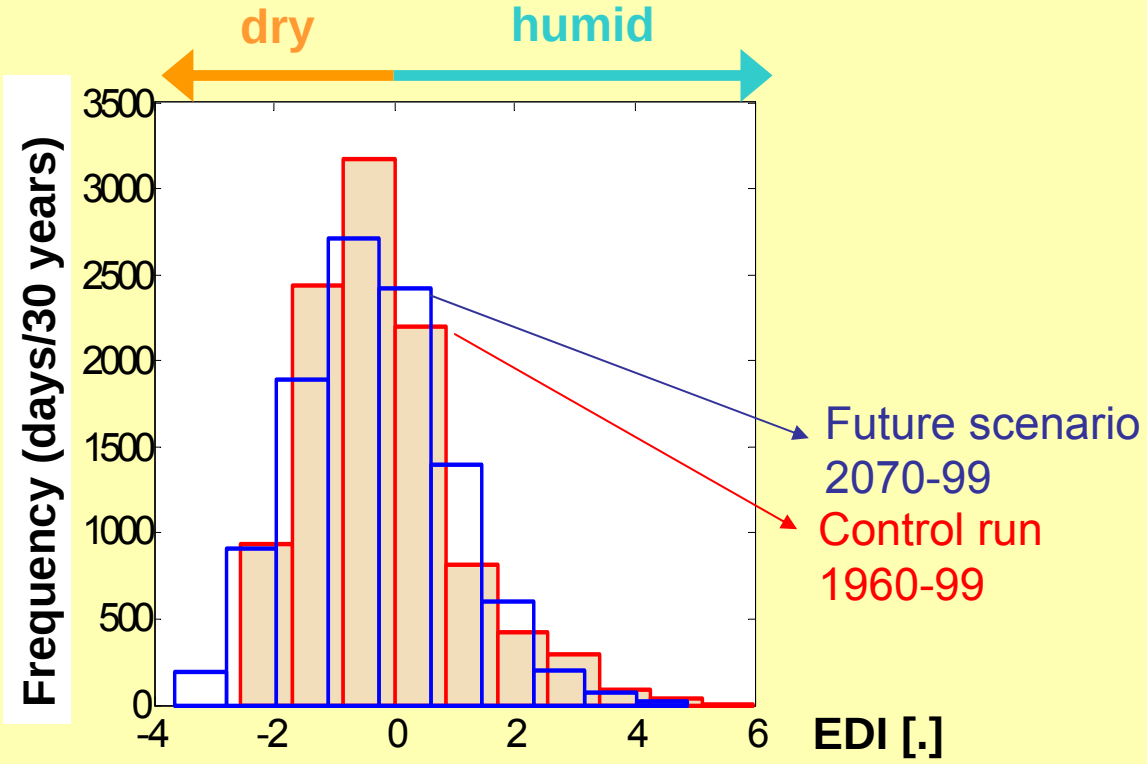



**For all subregions: Decreased winter, increased spring precipitation**

# Regional Climate Simulations

**Are drought risks changing? Analysis of EFFECTIVE DROUGHT INDEX *EDI***

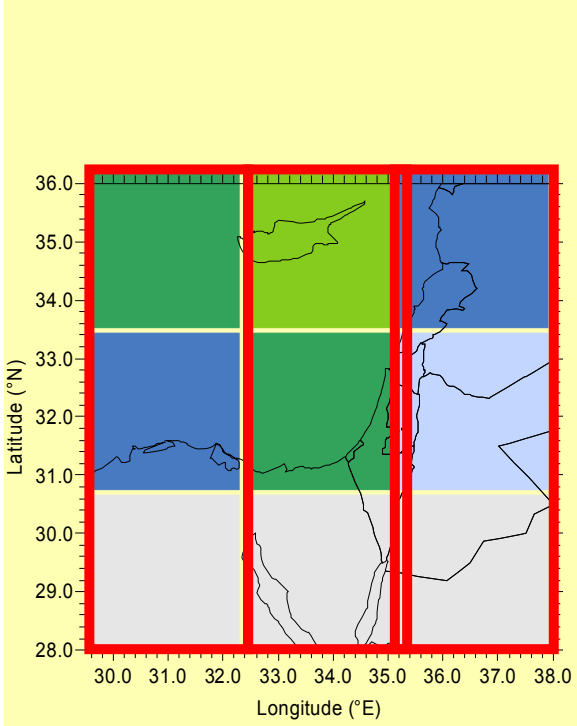


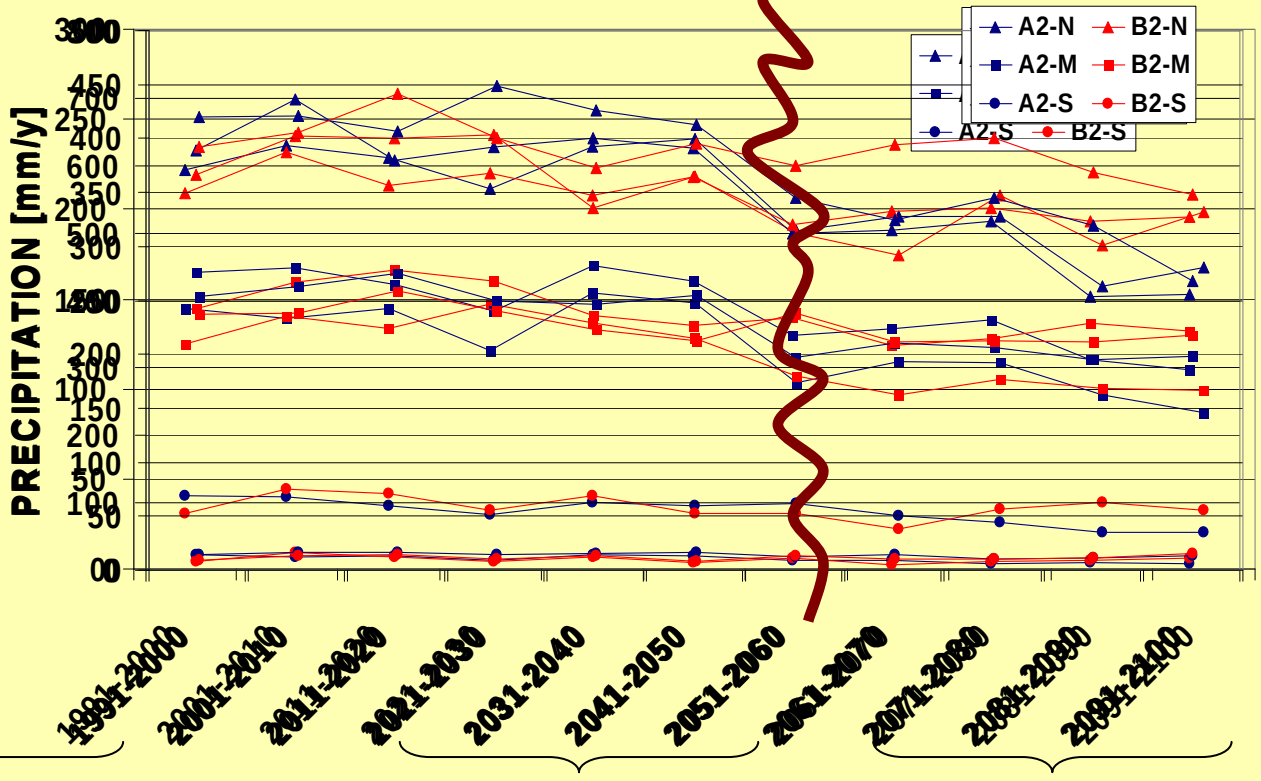




**Subregion A: shift towards drier conditions & increased drought risks**

# Regional Climate Simulations

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




recent climate… ⇐ ⇒ medium term ⇒ long term

# Regional Climate Simulations

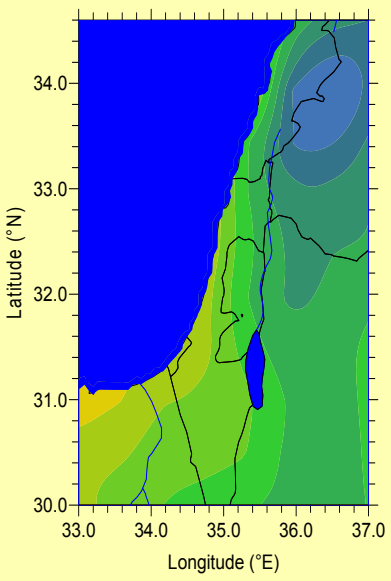
**Second example: MEDIUM TERM PROJECTIONS**

**ECHAM4, A2 & B2, 54km, 1961-2050 transient**

# Regional Climate Simulations

## Temperature

### Control Run 1961-90

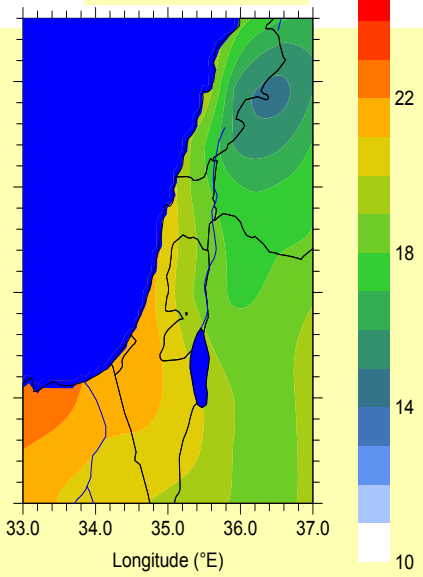




Szenario B2

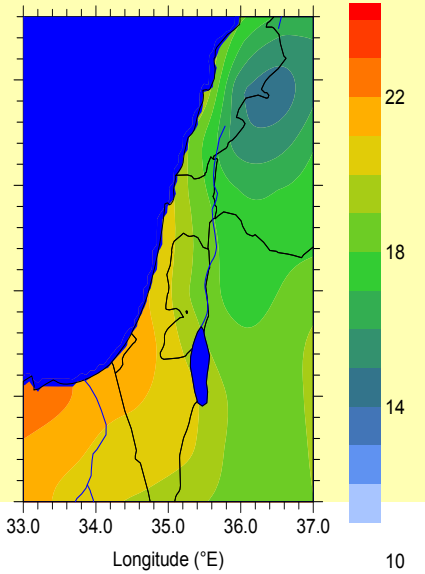
Szenario A2

**2021-50**





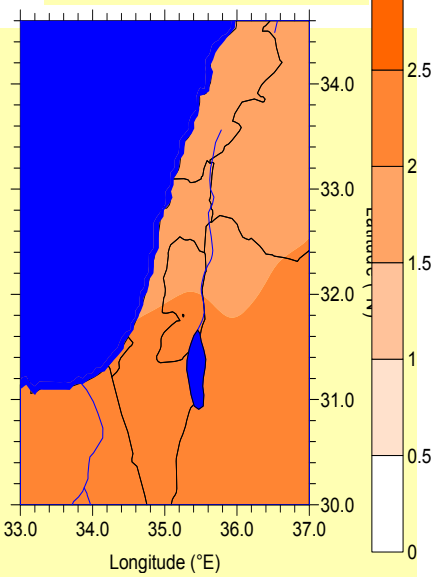


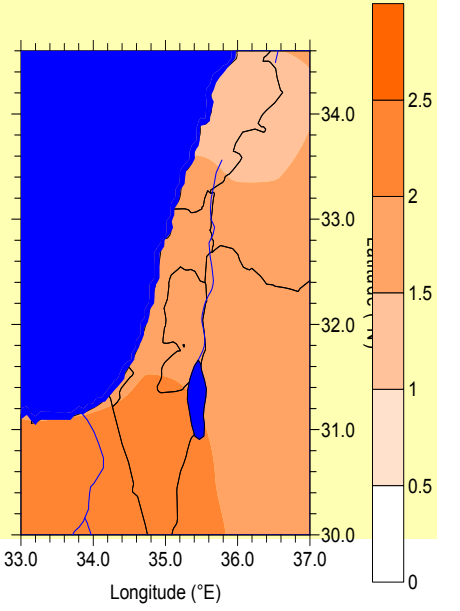






**Change [°C]**

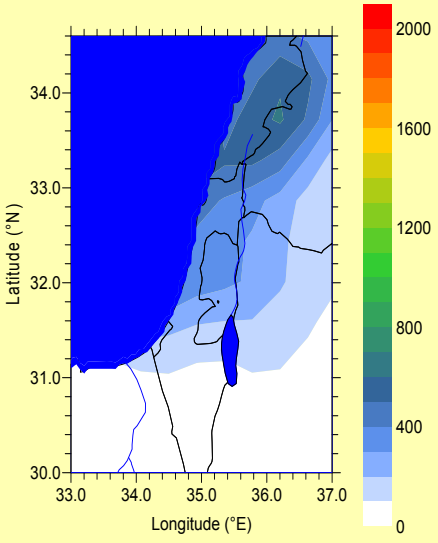


# Regional Climate Simulations

## Precipitation

### Control Run 1961-90

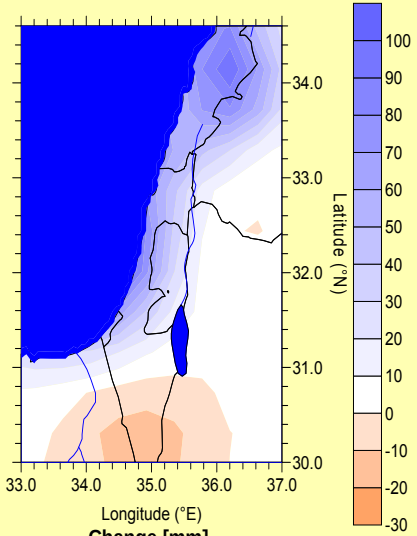



Scenario B2

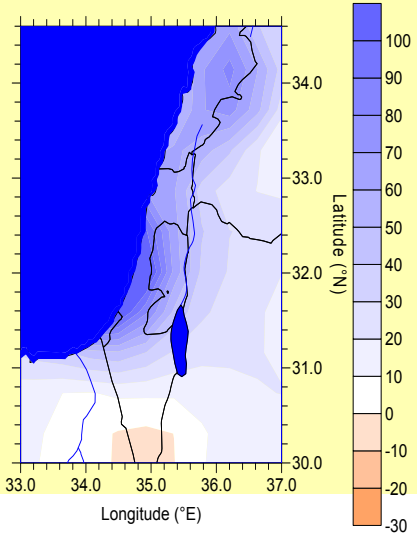
Scenario A2

### 2021-50

Change [mm]

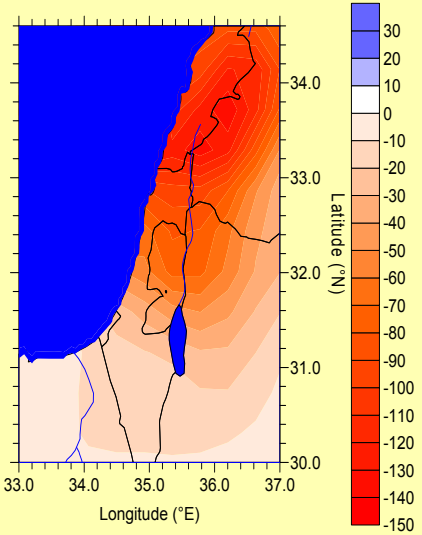



Change [mm]




### 2070-99

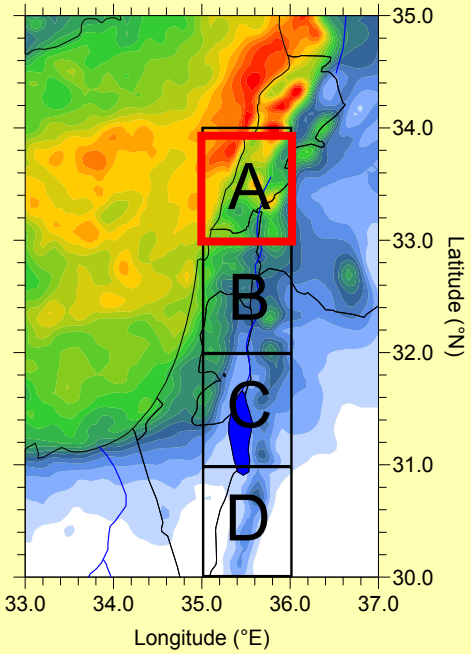
Change [mm]

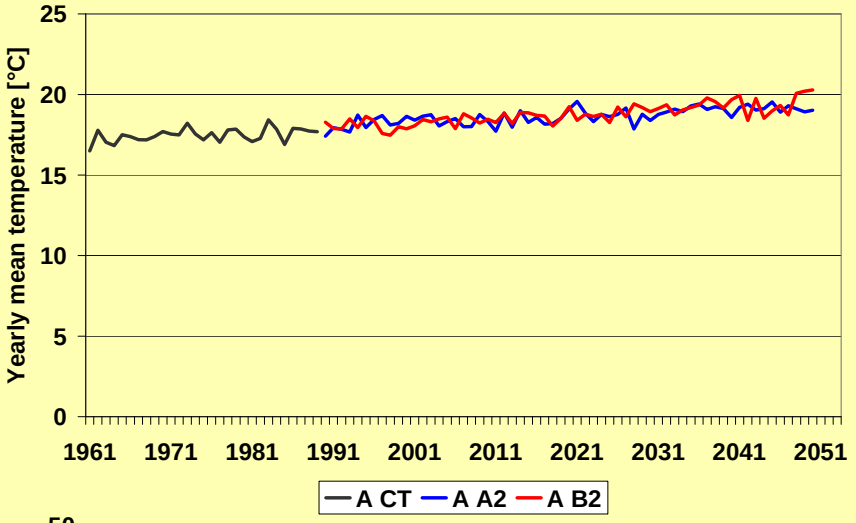


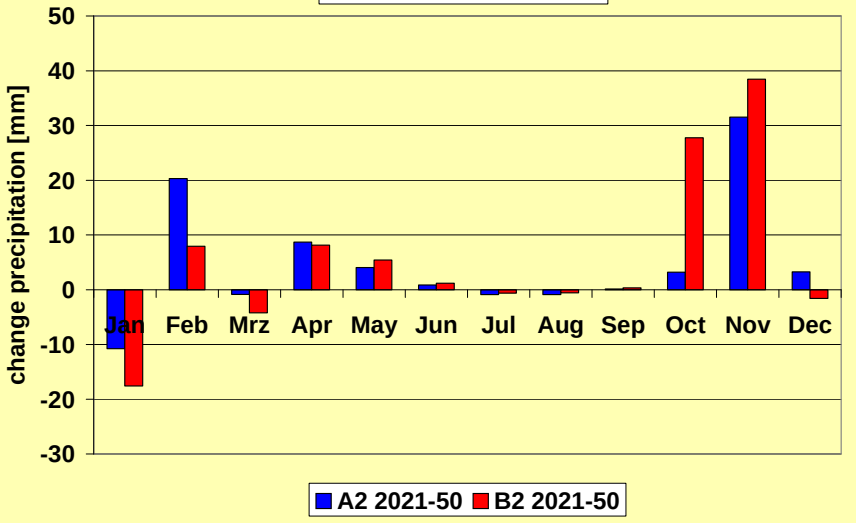

- Increase in precipitation
- Little differences between A2 + B2 till 2050

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

# Changes in temperature and precipitation

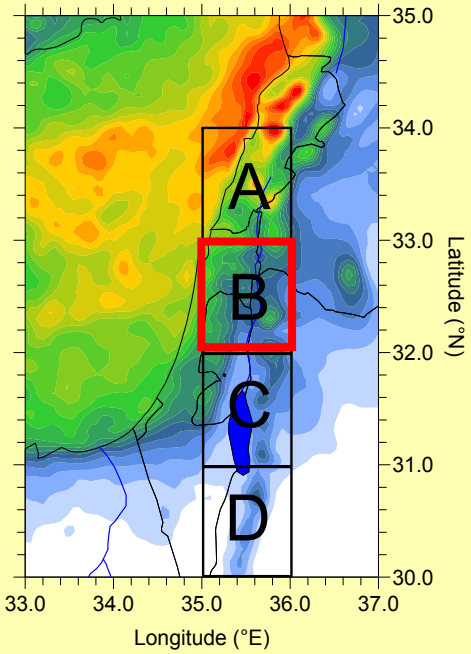


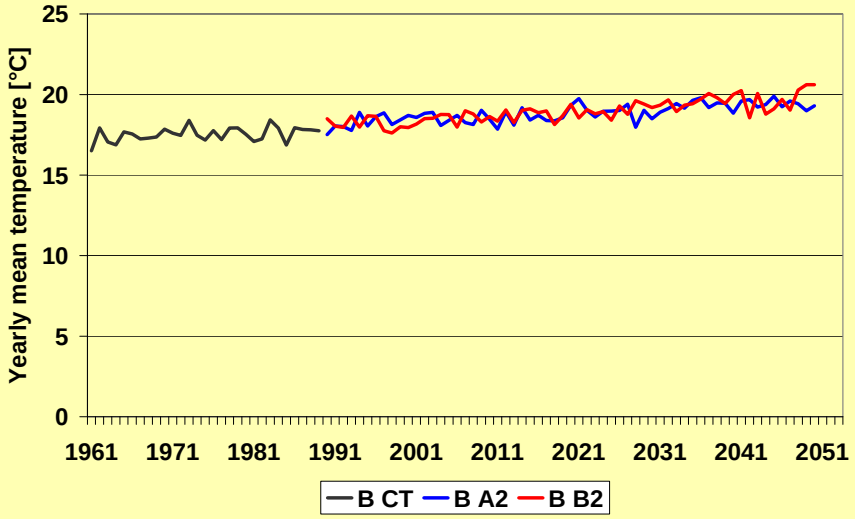



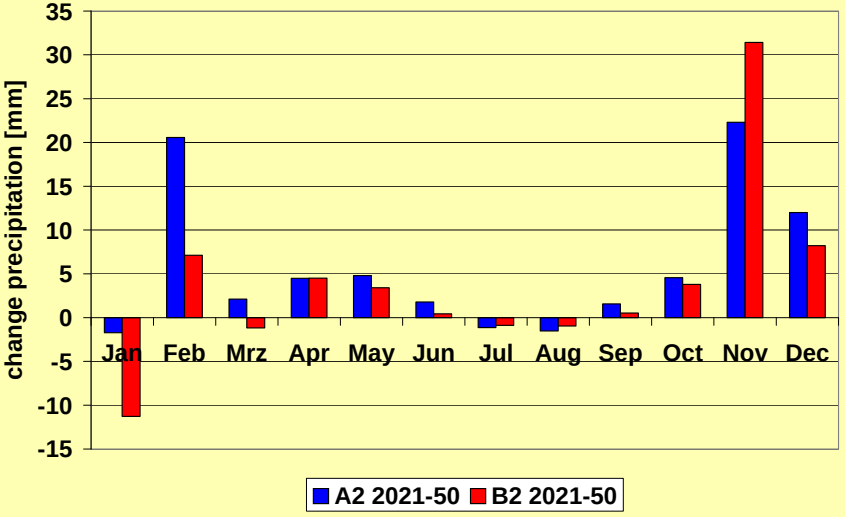



# Regional Climate Simulations

## Changes in temperature and precipitation



# Regional Climate Simulations

**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**

**Phase III**

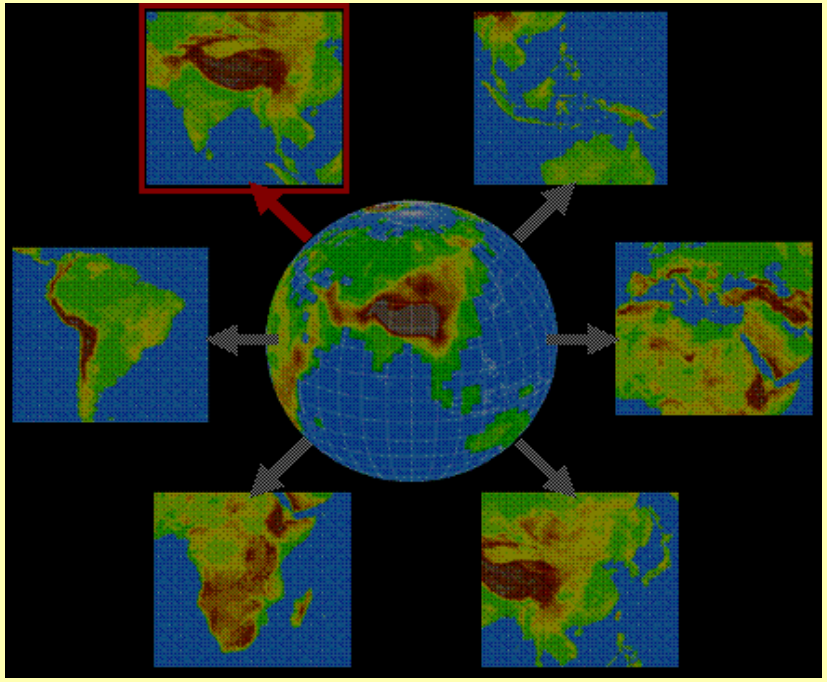
⇒ continuation of transient simulations in 18km resolution
⇒ extension towards HadCM3 and ECHAM5 (A1B)
⇒ **full set of uncertainty ranges**

# TAU

# Regional Climate Simulations

## The ICTP Regional Climate Model version 3 (RegCM3)

(a hydrostatic version of NCAR/NCEP MM5)



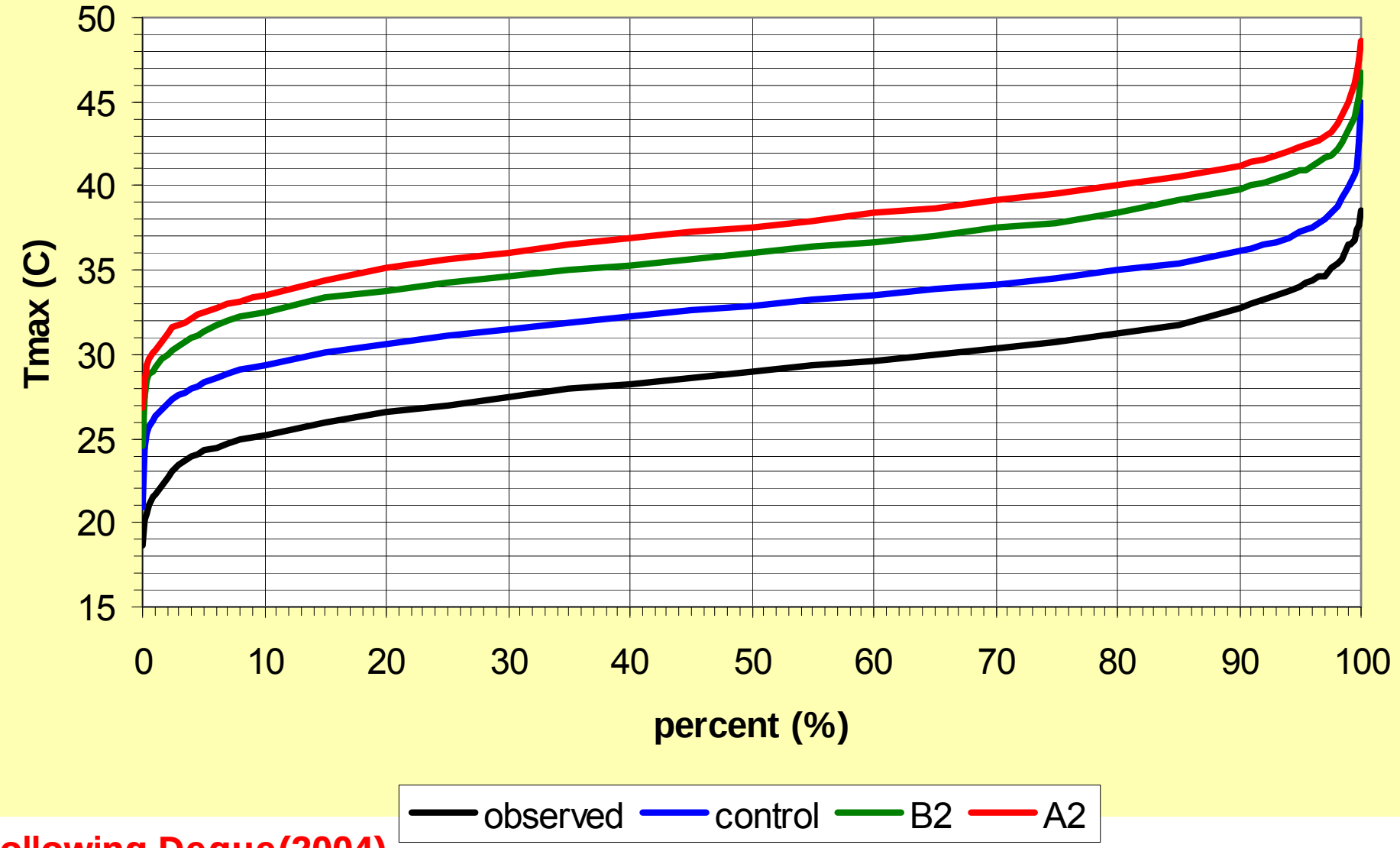
Scenarios used
A2, B2 – sliced simulations
HadCM3-HadAM3;

Transient simulations
ECHAM5 (MPI-M, Hamburg)
A1B (Phase II)
B2, A1B (Phase III)

Filippo Giorgi, Xunqiang Bi, Jeremy Pal, Nellie Elguindi,
Fabien Solmon, Raquel Francisco, Xuejie Gao,
Allison Steiner and many more

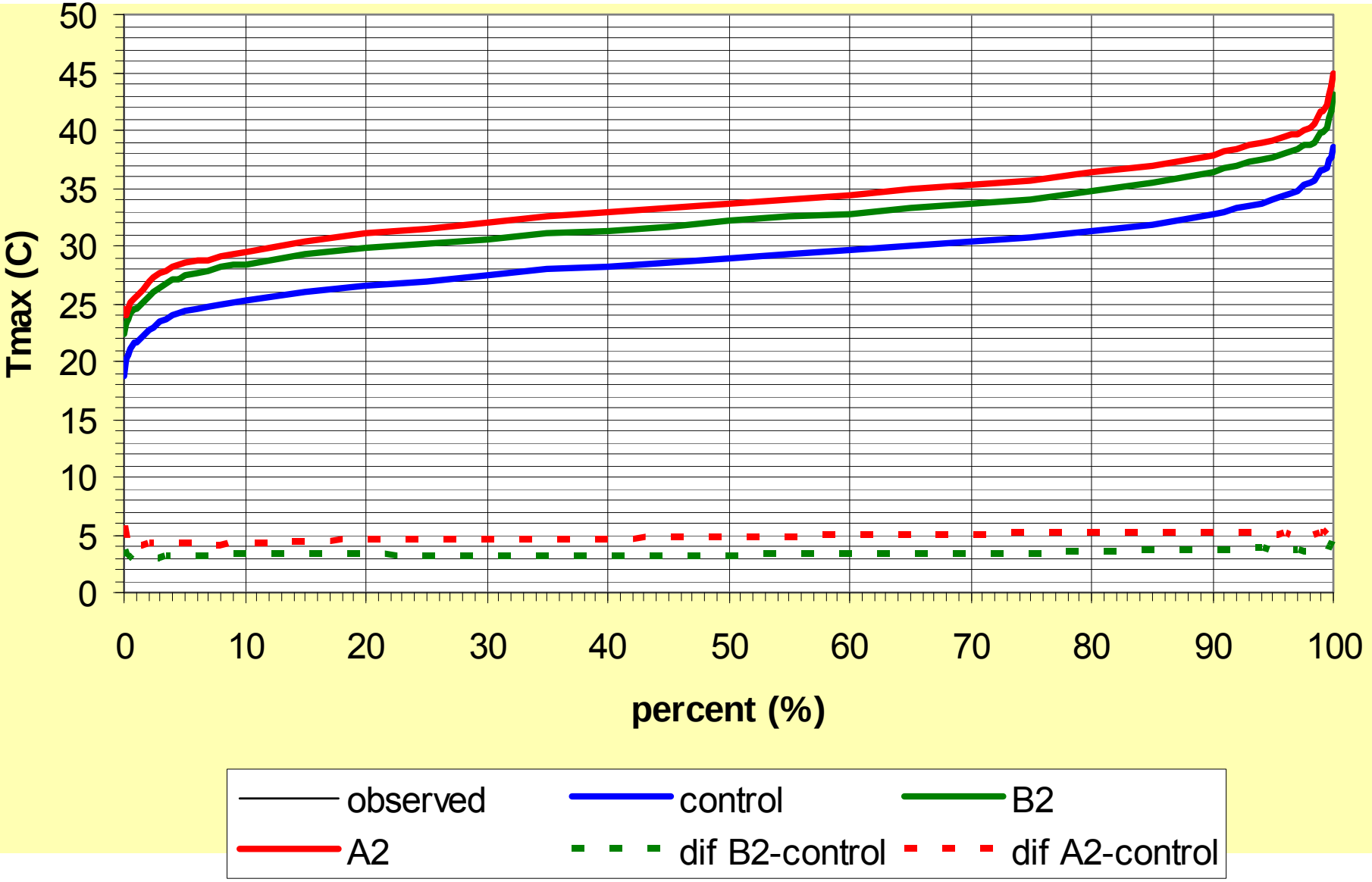
Tmax, summer, Har-Knaan **Mountain St.**

# Downscaling Daily Temperatures (1961-1990)



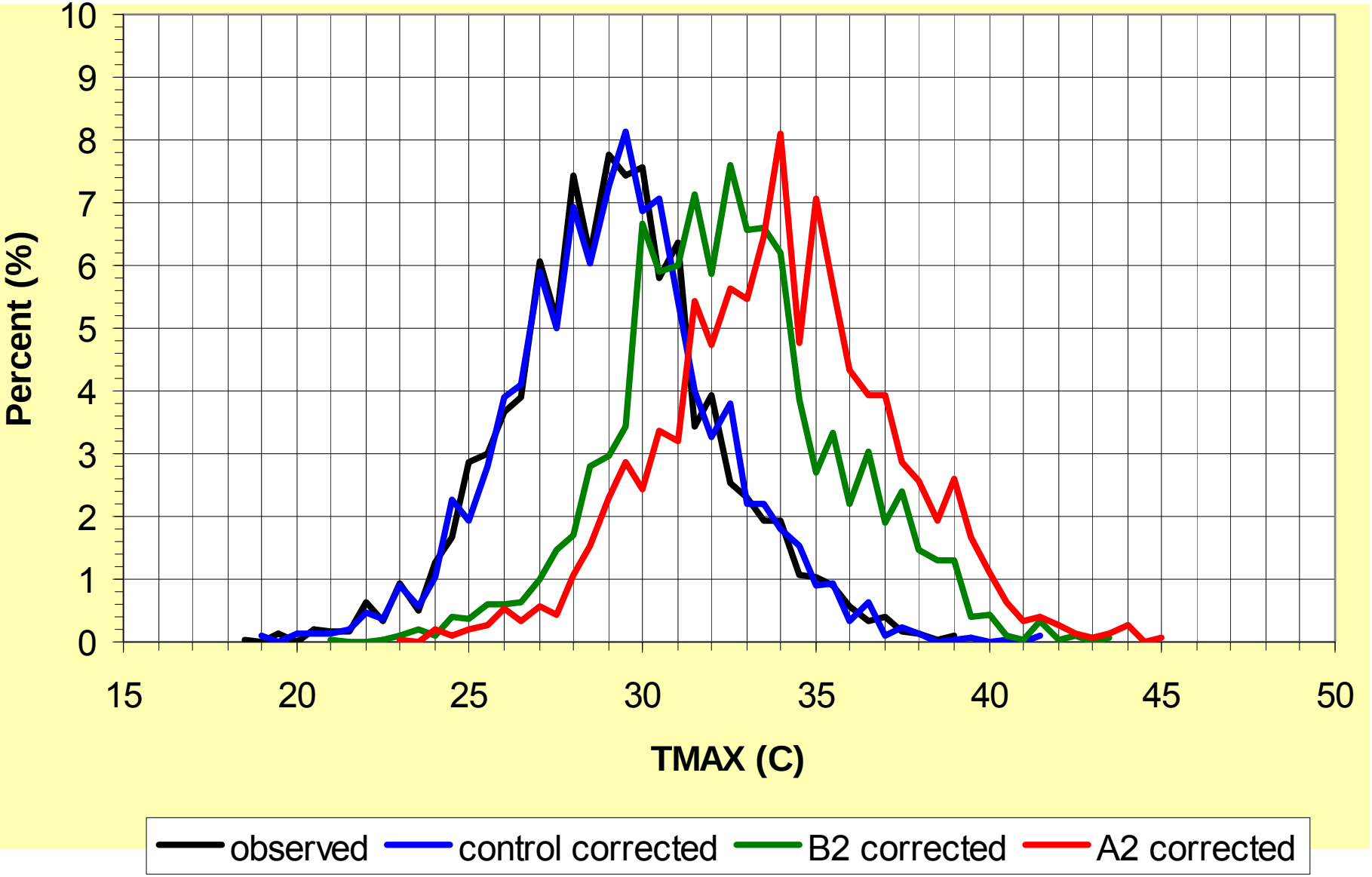

Following Deque(2004)

# Tmax, Har-Knaan, corrected **Mountain St.**



# Har-Knaan, TMAX, distribution

## Mountain St.

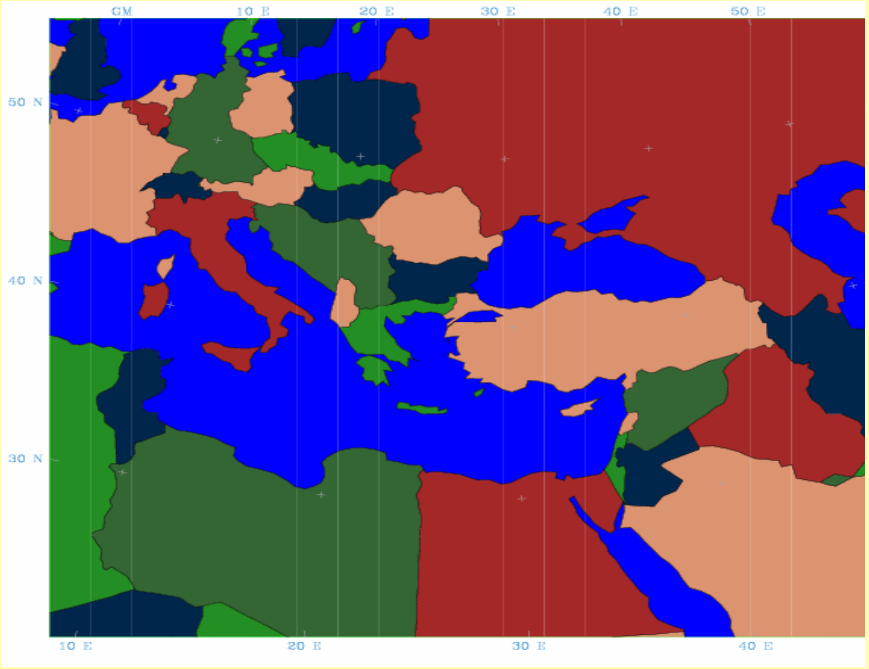


# Regional Climate Simulations

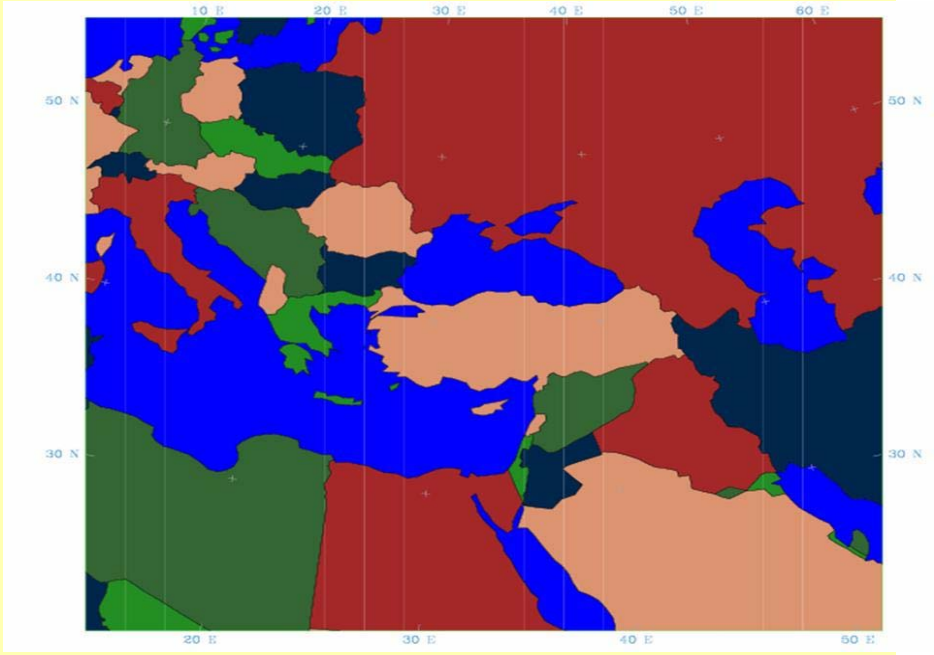
## RegCM3 – domains used

Horizontal resolution 50 km (free atmosphere), 12 km (parameters near surface)
Driving data: ECHAM5-MPI-OM, (emission scenario A1B, transient run from 1960 to 2060)
Two model runs – with different domains (80 x 80)

A



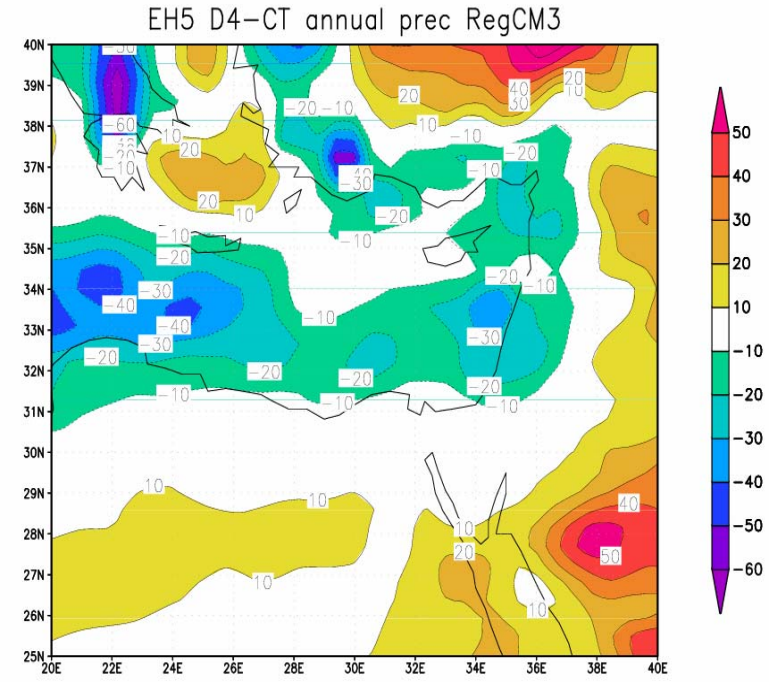

B




Only results of the simulations with domain B are presented below

# Regional Climate Simulations

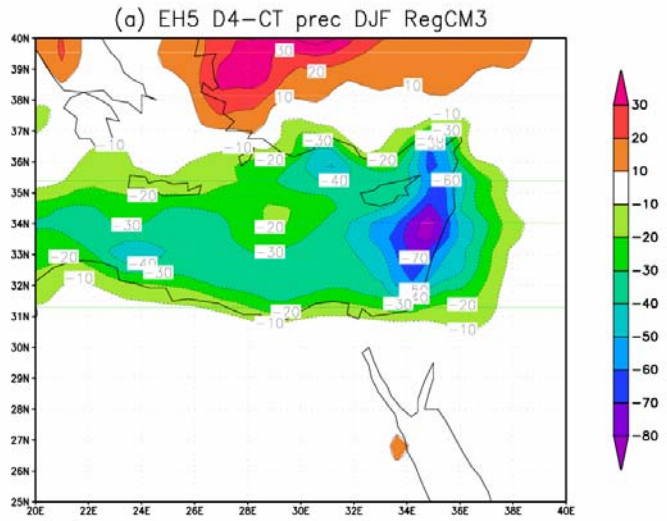
Projected climate change – annual precipitation

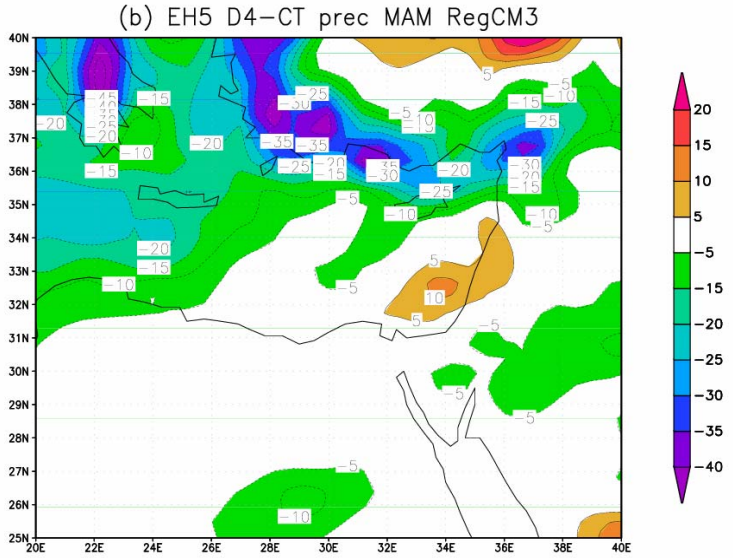



2021-2050 minus 1961-1990

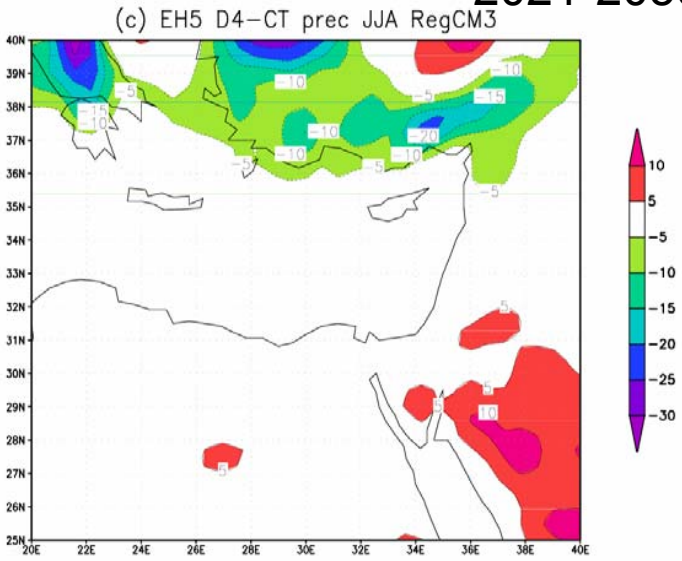
# Regional Climate Simulations

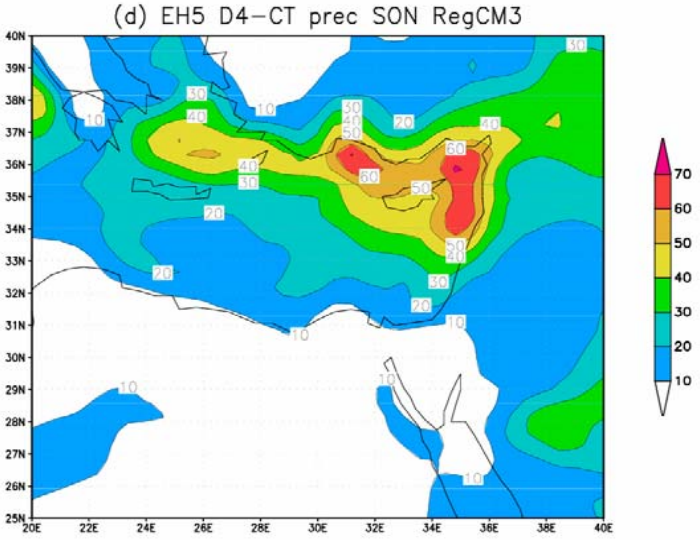
## Projected climate change - seasonal precipitation



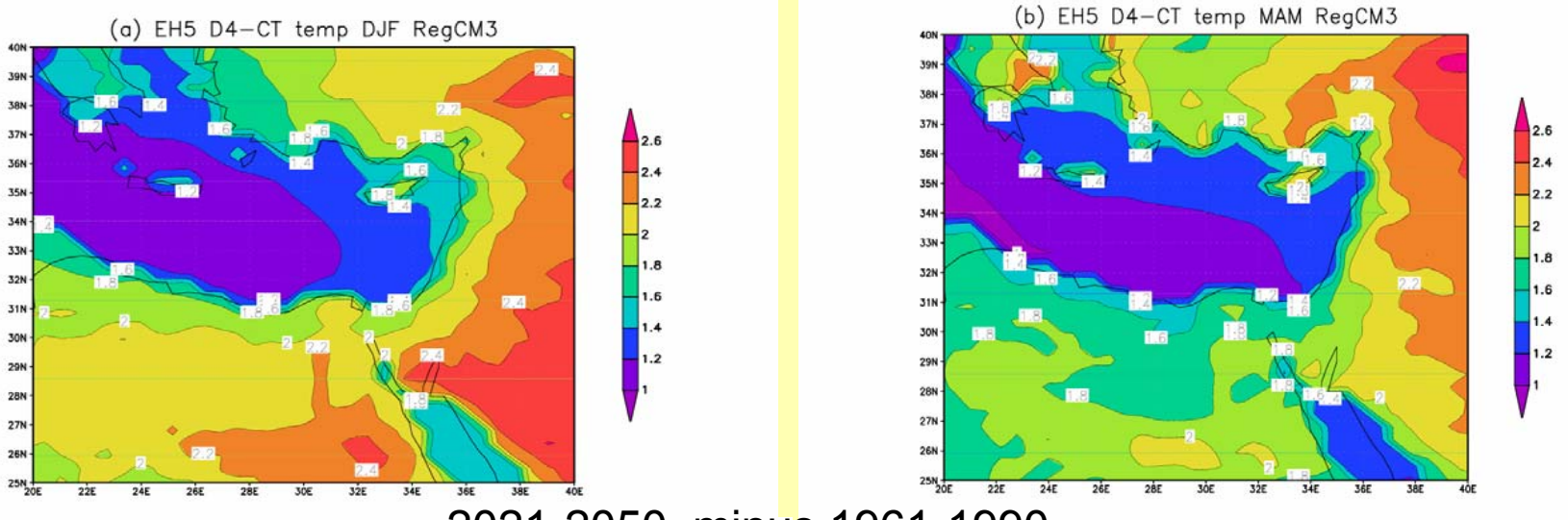

2021-2050 minus 1961-1990



# Regional Climate Simulations

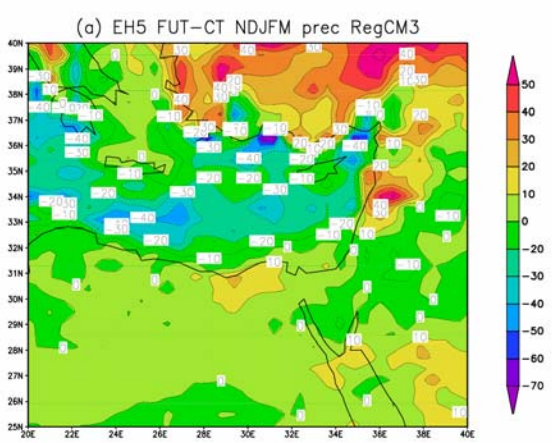
Projected climate change – seasonal air temperature (2m)



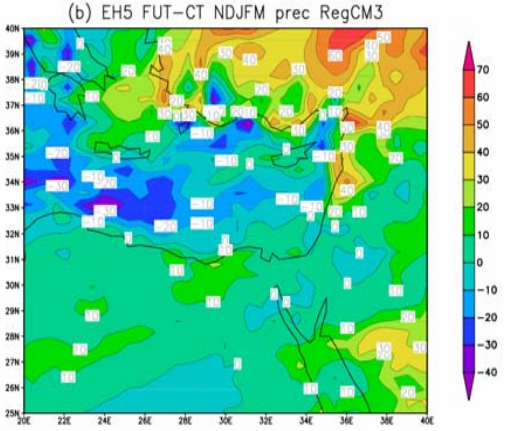

2021-2050 minus 1961-1990

# Regional Climate Simulations

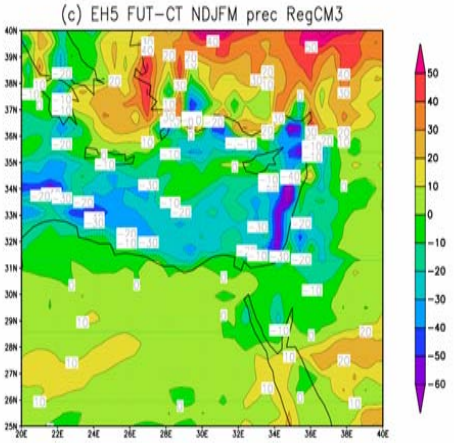
Projection of climate change decadal – wet season precipitation




2001-2030 minus 1961-1990



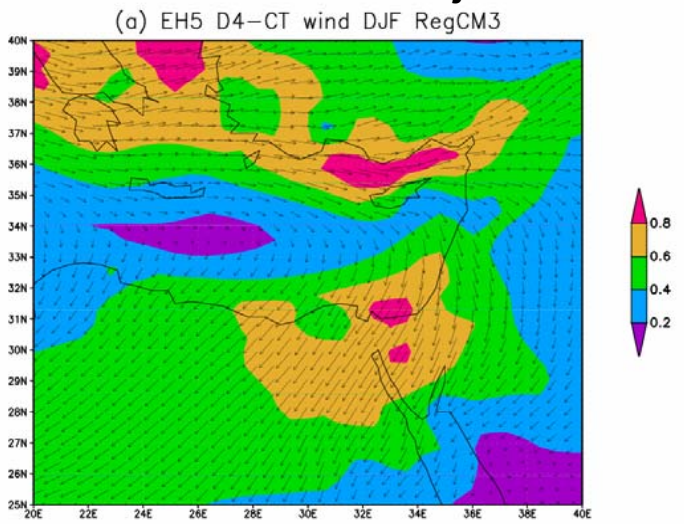

2011-2040 minus 1961-1990

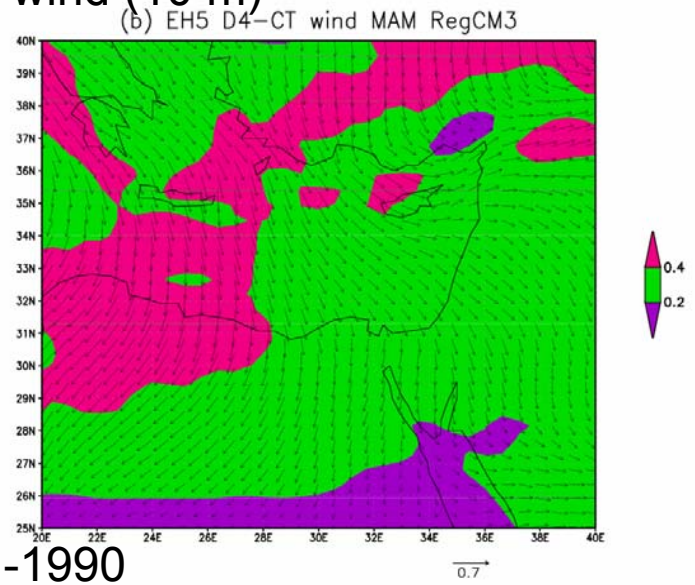



2021-2050 minus 1961-1990

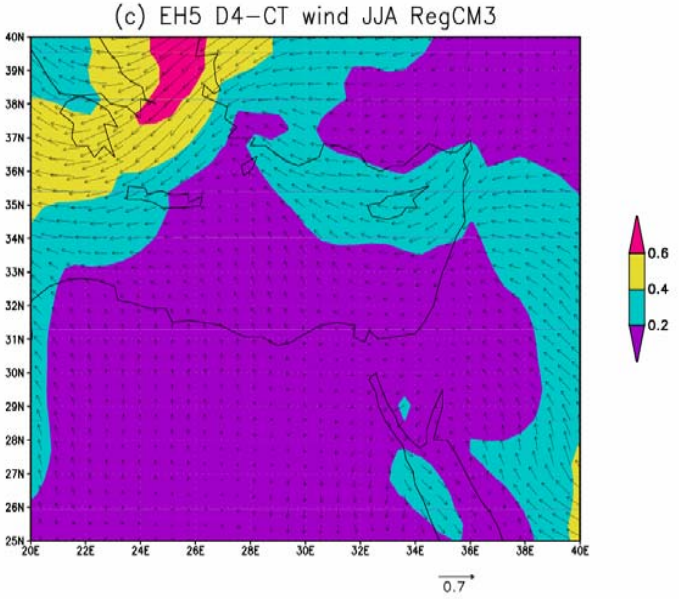
# Regional Climate Simulations

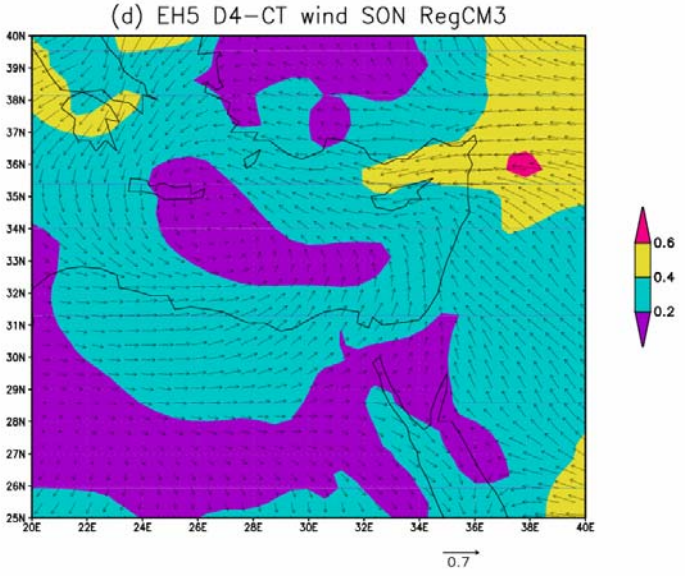
## Projected climate change – wind (10 m)




2021-2050 minus 1961-1990



# Regional Climate Simulations

**Summary & Conclusions**

- Air temperature rise to 2050 (to ~ 1-2°C)

- A ~5% precipitation decline to 2050

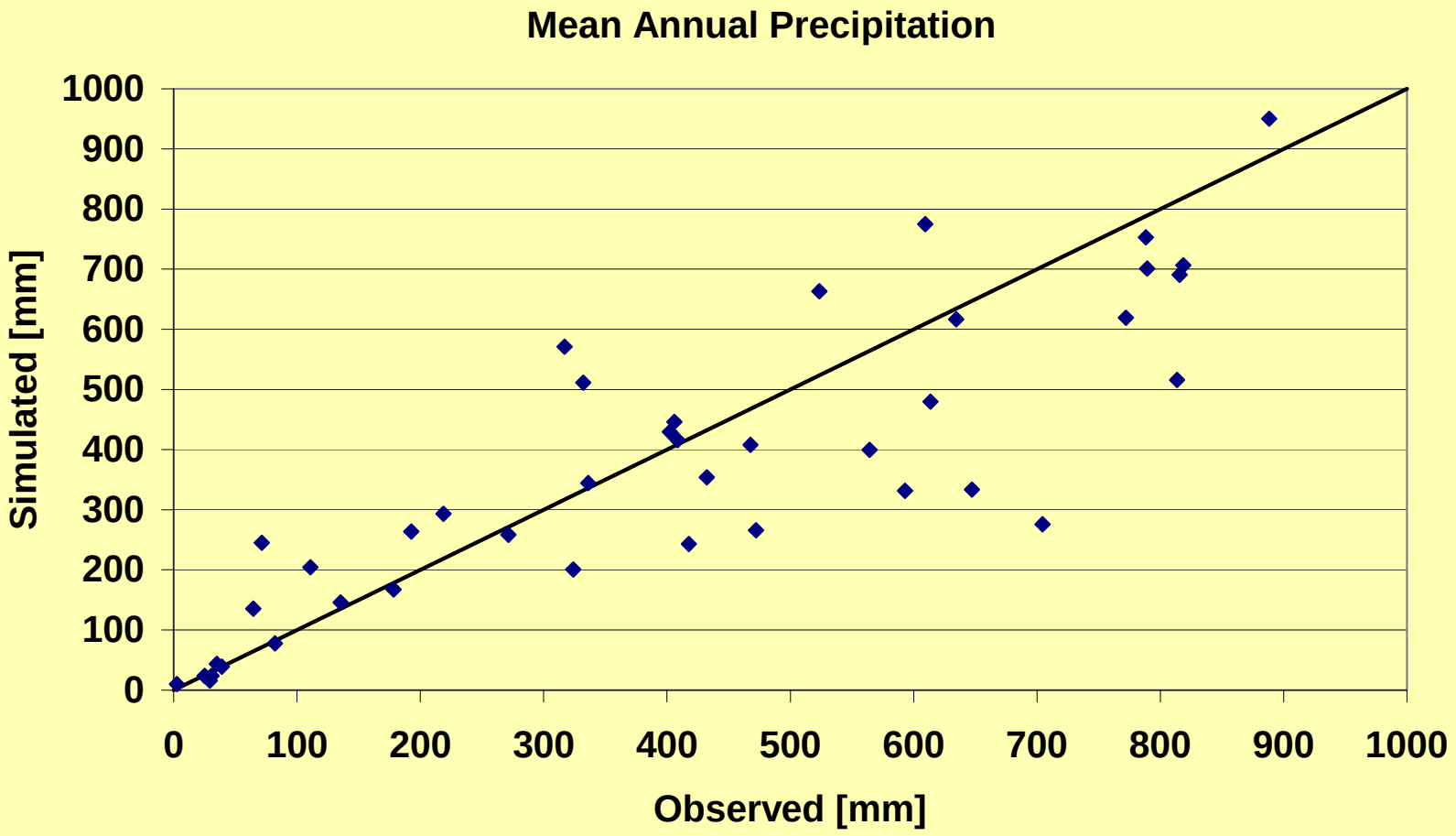
**Phase III**

⇒ continuation of transient simulations with 50 - ~10 km (surface) resolution
⇒ ECHAM5 (A2)
⇒ **full set of uncertainty ranges**


Thank you for your attention

# Control Simulation

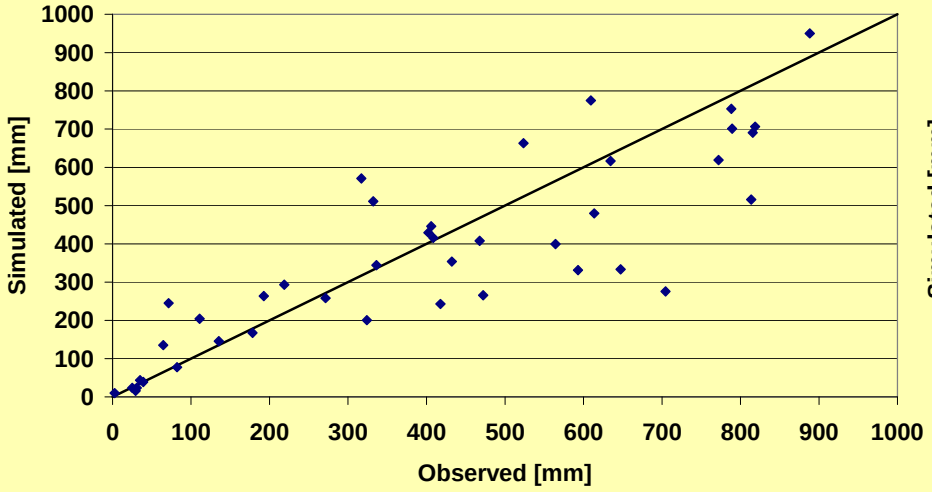
**How accurate does the downscaled Control Run reproduce observed precipitation?**



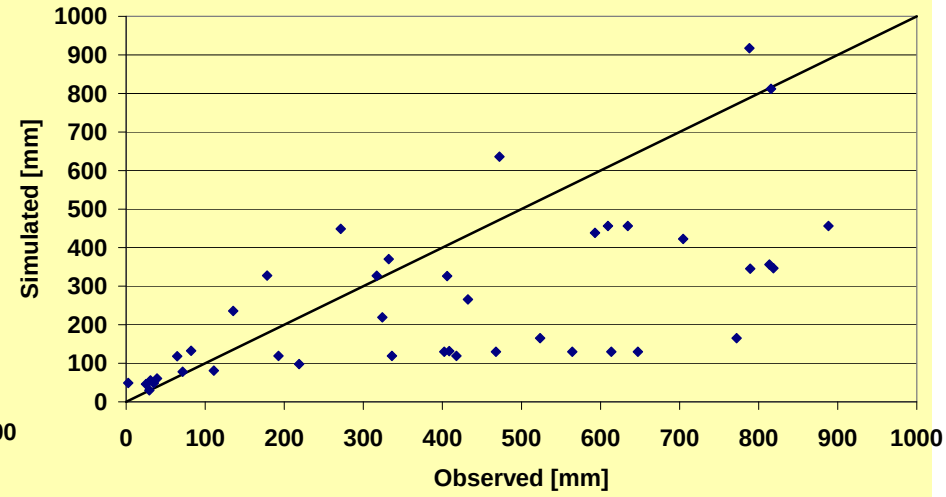
# Regional Climate Simulations

## ECHAM5 transient vs. ECHAM4 transient

### Mean Annual Precipitation




ECHAM4-**MM5**, Δx=18km

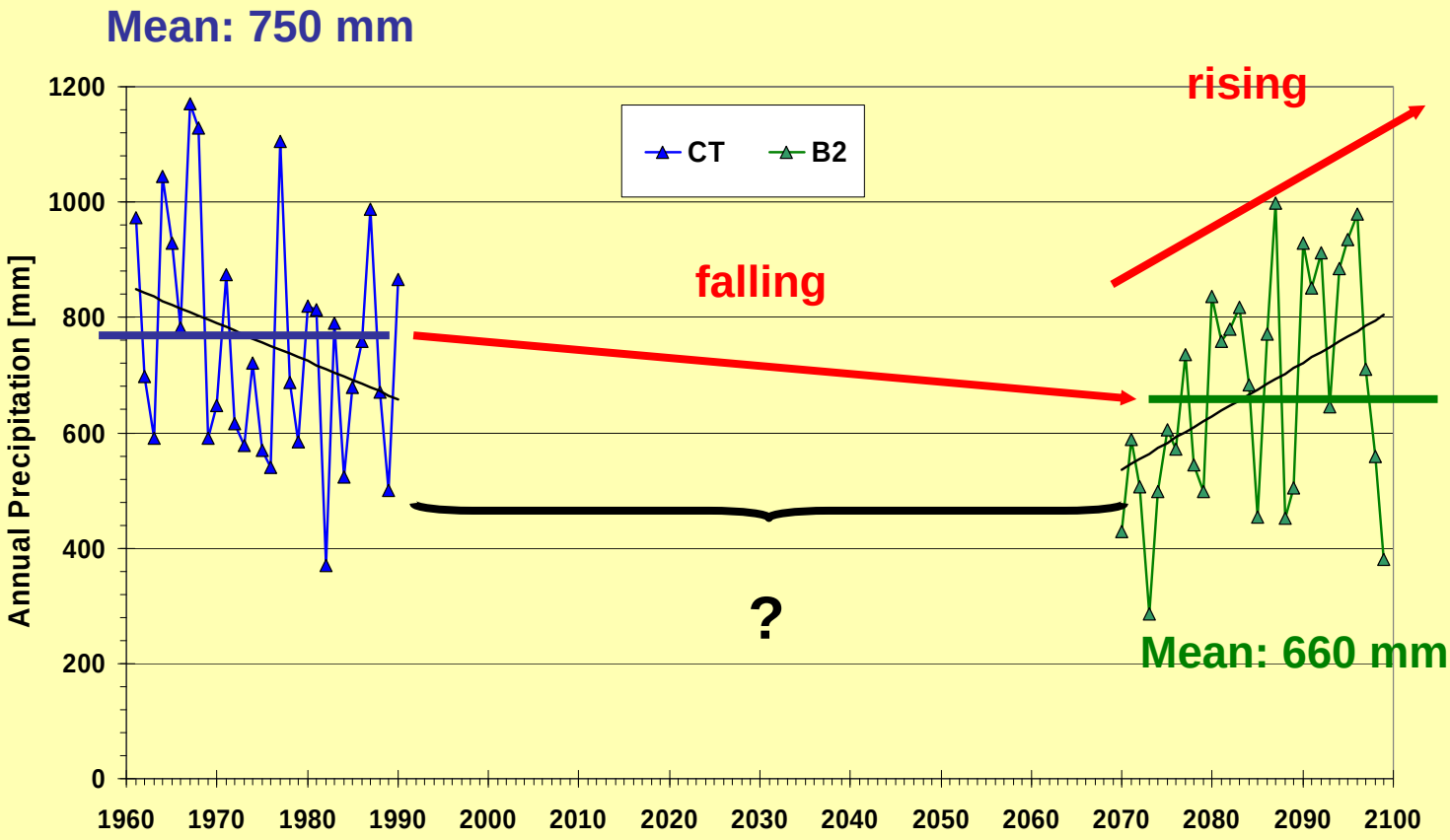



ECHAM5-**RegCM**, Δx=50km

Control runs 1961-90 vs. long term observation at 41 stations in the Near East

# Regional Climate Simulations

**Problem of comparing time slices: long term trends ⇔ short time trends**




**Solution: transient simulations**

# Regional Climate Simulations

**Scientific Challenge**

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

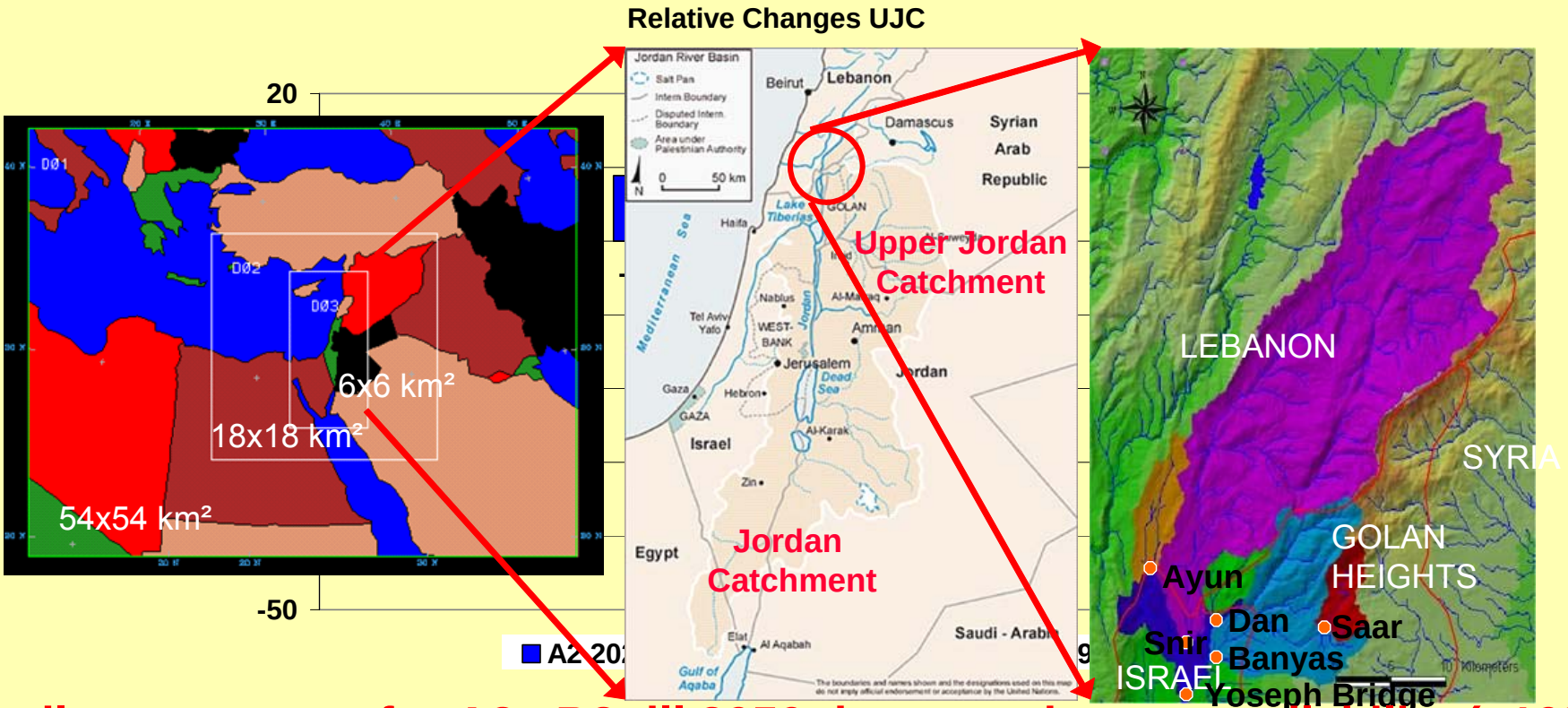
2) Region has sharp climatic gradients:
subhumid mediterranean ↔ arid climate

3) Resolution of global climate models are too coarse for hydrological & biological impact studies
⇒ Higher resolution information required that account for regional and local geographic features (particularly orography, land use and water bodies)


**Approach:**
**Dynamic downscaling of global climate scenarios**

# Regional Climate Simulations

## Joint climate hydrology simulations for the Upper Jordan River catchment

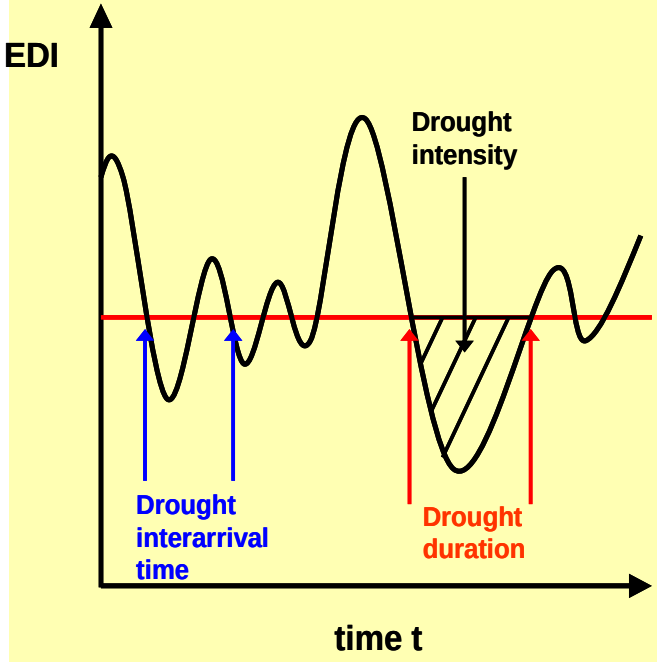


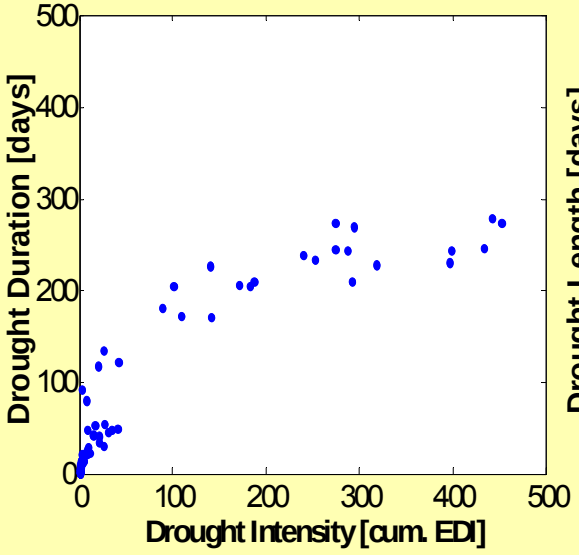

**Similar responses for A2 , B2 till 2050: increased water availability (+10%)**

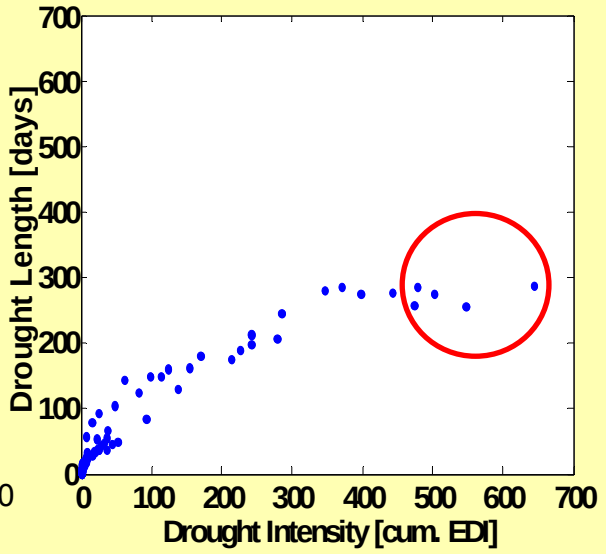
**But: till 2100 significantly decreased water availability (-30%) in B2**

# Regional Climate Simulations

## Are drought risks changing? Analysis of effective drought index EDI




**Subregion A: Increasing drought intensities, but “unchanging” drought durations**