Regional Climate Simulations

for the Middle East

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Regional Climate Simulations

Objectives

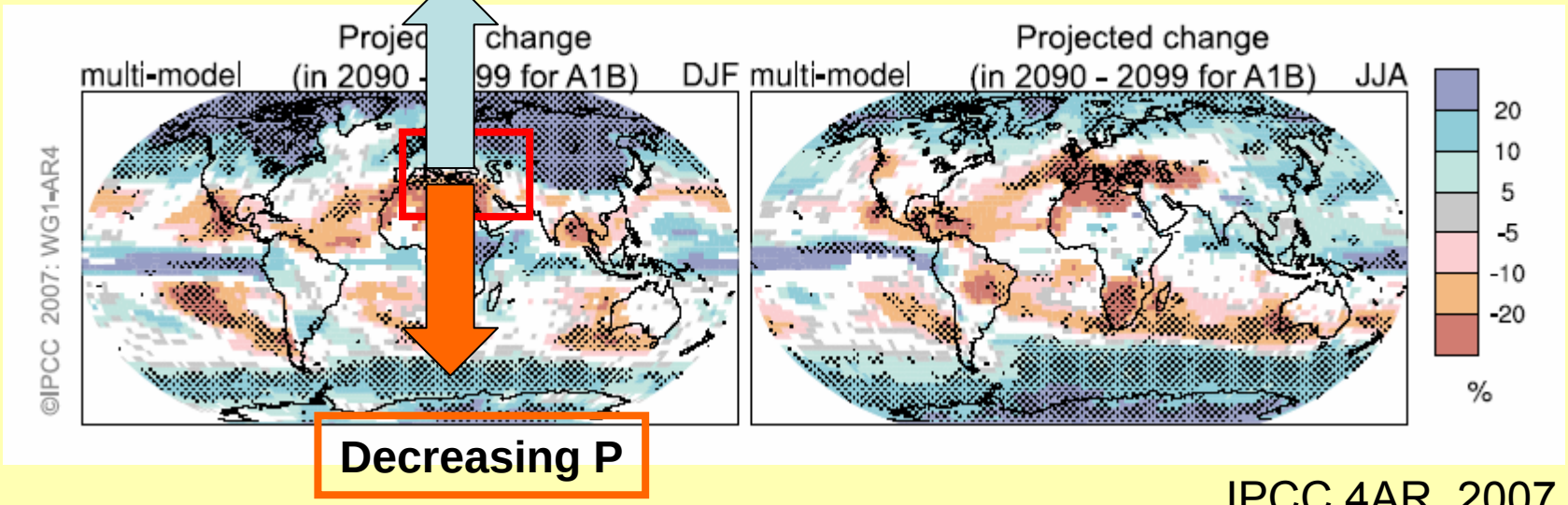
1) Estimation of future temporal and spatial distribution of temperature and precipitation

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

3) Estimation of uncertainty bounds of climate change projections

Regional Climate Simulations

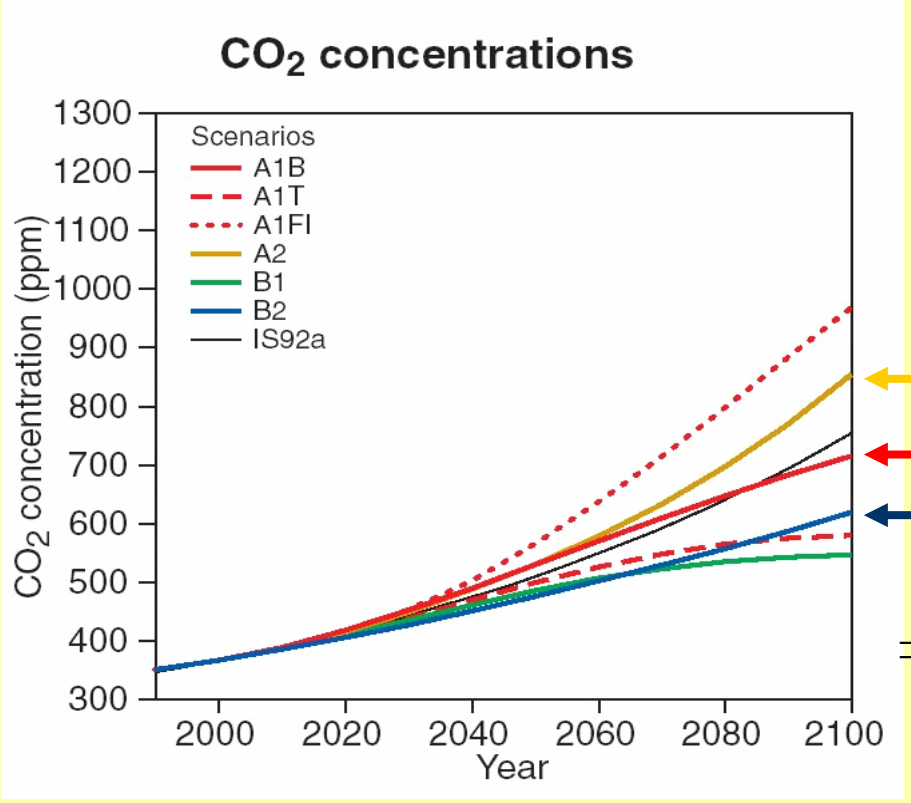
Scientific Challenge



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

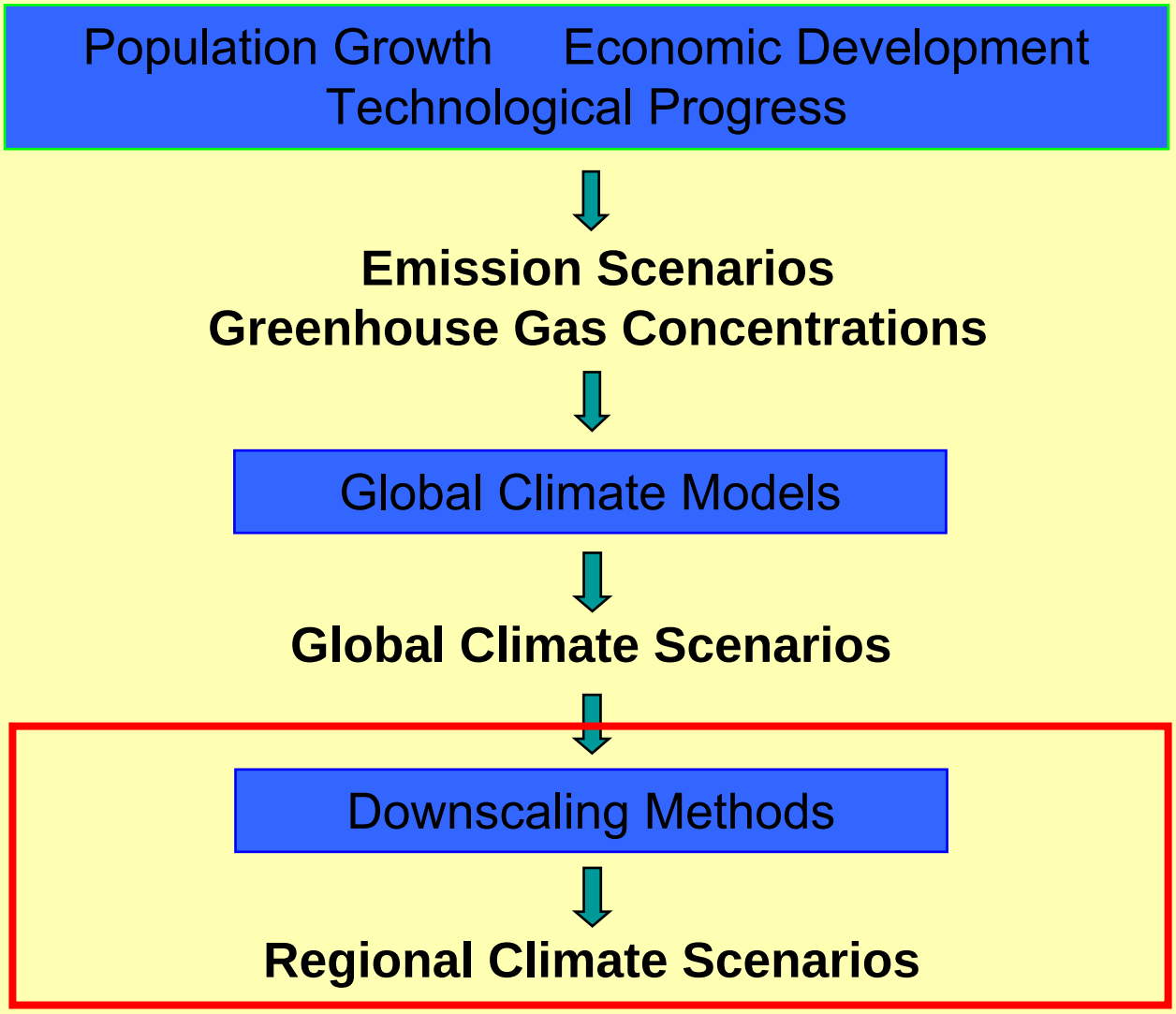
Phase III

Phase II+III

⇒ Uncertainty bounds

Emission scenarios: based on different assumptions on future GHG emissions

Regional Climate Simulations



Regional Climate Simulations

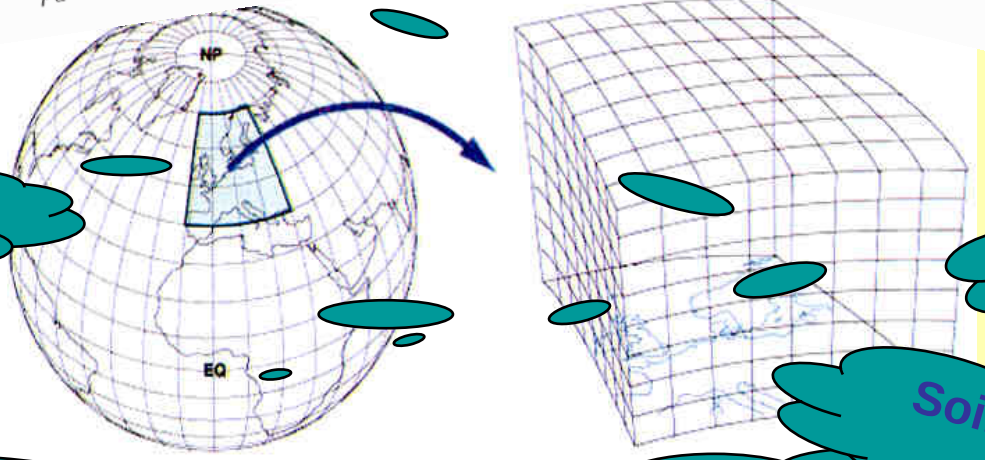
GLOWA Jordan River

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

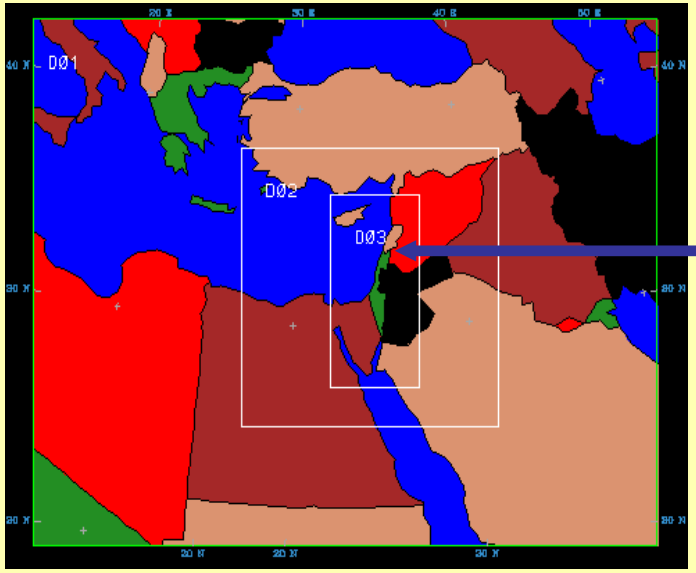
$$R_{evap\ (rain)} = \frac{2\pi N_{0r}(S_w - 1)}{A_r + B_r}\left[\frac{0.78}{\Lambda_r^2} + 0.32\left(\frac{a_r \rho}{\eta_a}\right)^{1/2} S_c^{1/3}\frac{\Gamma(5/2 + b_r/2)}{\Lambda_r^{5/2+b_r/2}}\right]$$

Soil water infiltration

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

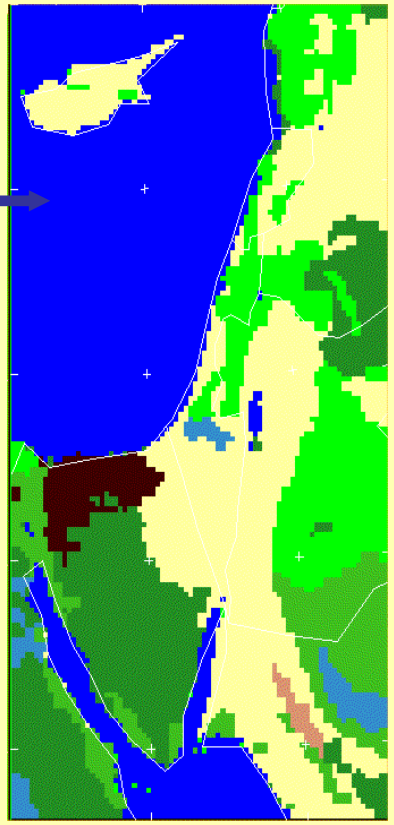
Regional Climate Modeling

Example: The Mesoscale Meteorological Model MM5



Land Use Discretization

Soil Discretization



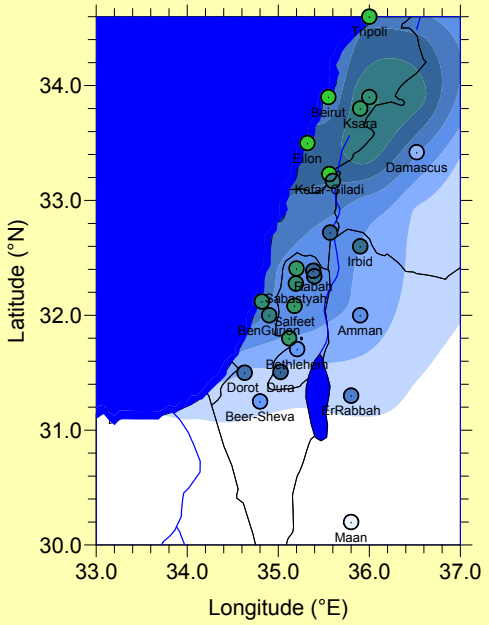
- Non-hydrostatic ($\Rightarrow$ allows high resolutions!)
- Dynamic Downscaling of ECHAM4 with MM5
- 3 nests: 54x54 km^2, 18x18 km^2, 6x6 km^2
- 26 Vertical Layers, Model Top: 100 mbar (ca.17 km)
- Coupled OSU-Land-Surface Model

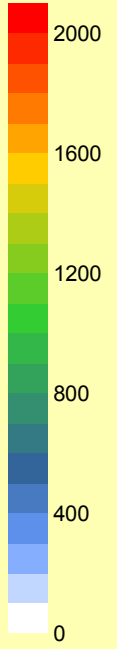
Regional Climate Simulations

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

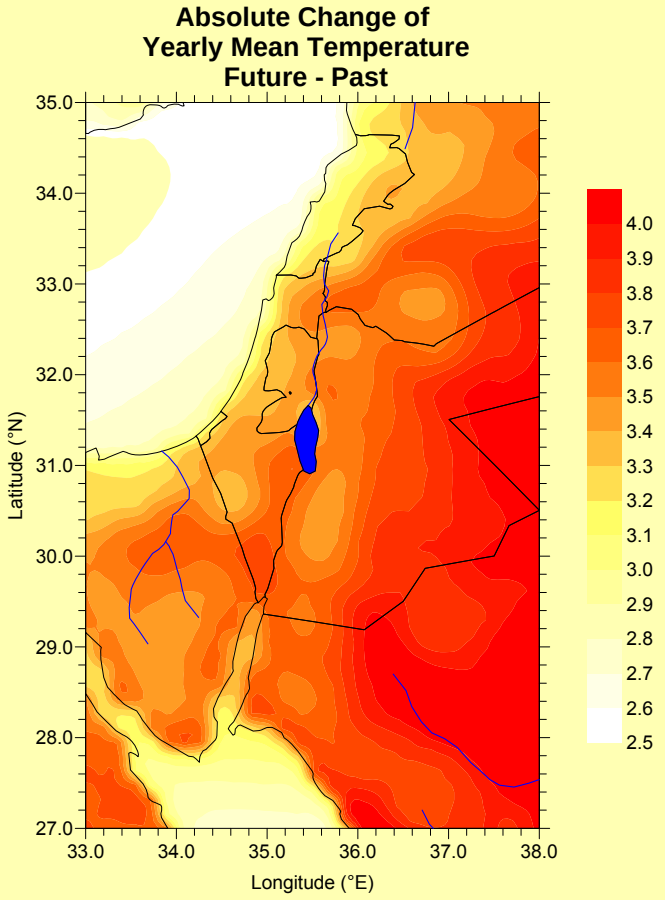
Regional Climate Simulations

First example: LONG TERM PROJECTIONS

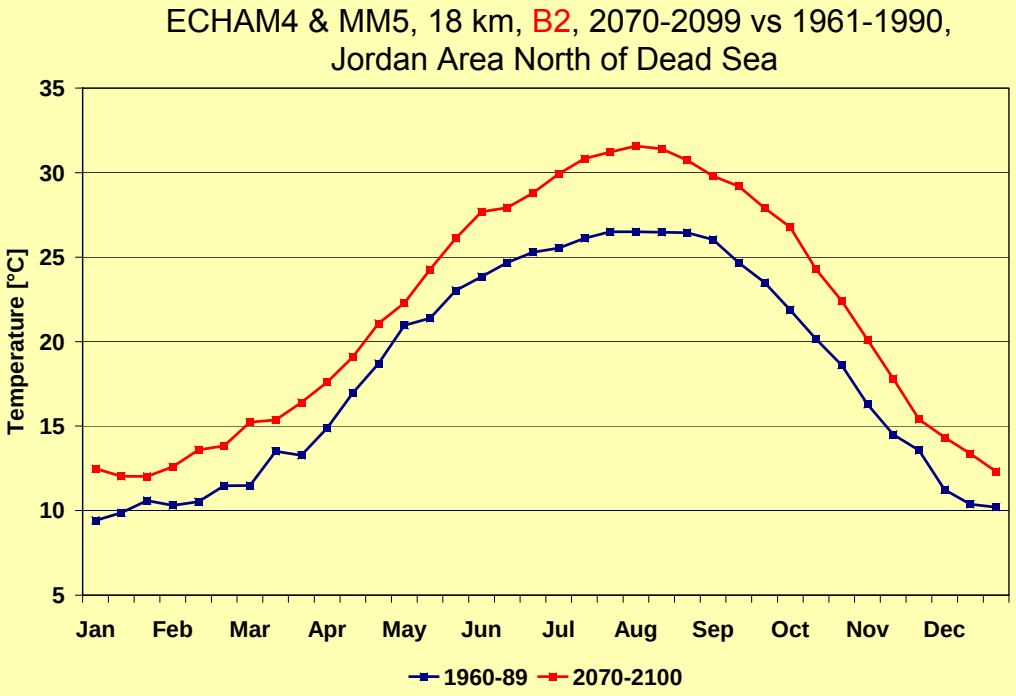
ECHAM4, B2, 18km, 2070-99 vs. 1961-90

Regional Climate Simulations

What are the expected changes in temperature?



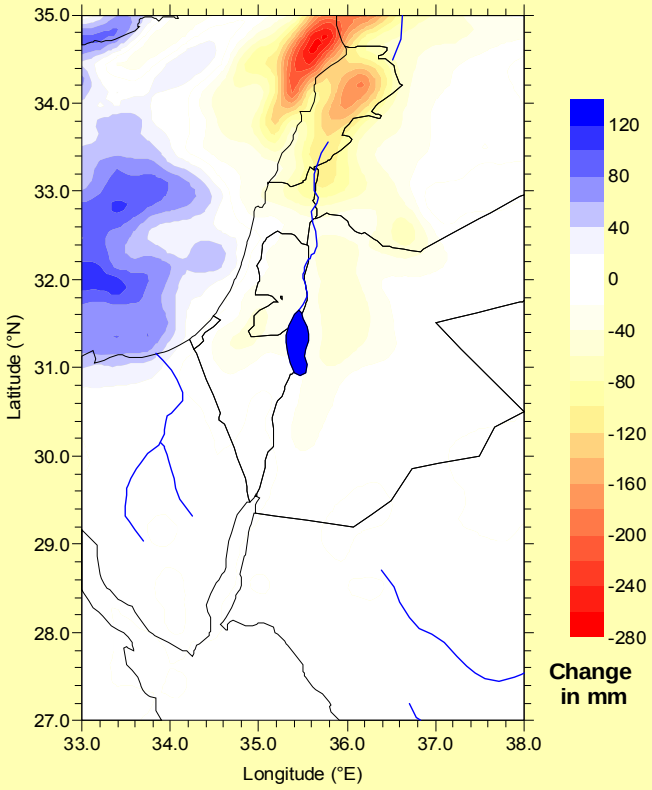
Change in mean annual temperature



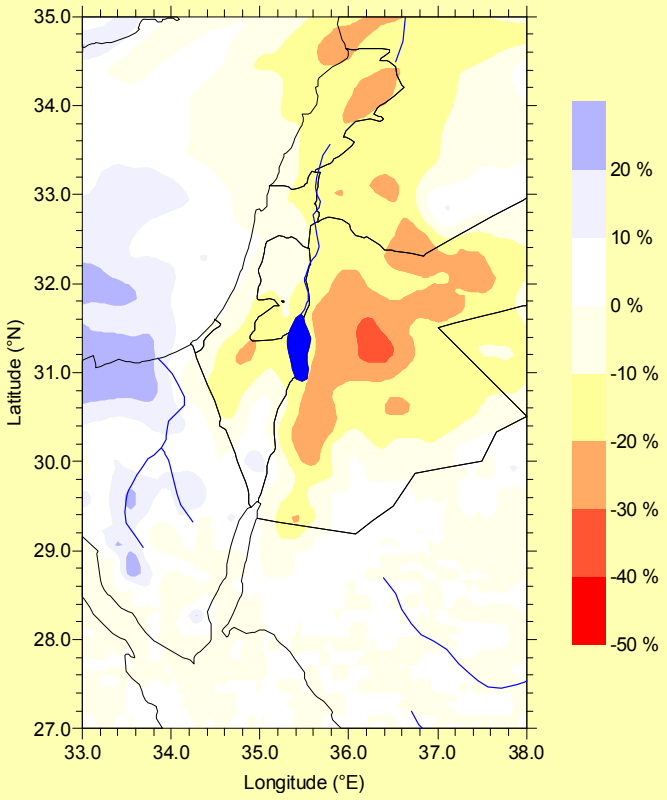
Change in temporal distribution

Regional Climate Simulations

What are the expected changes in precipitation?



Absolute change in [mm]

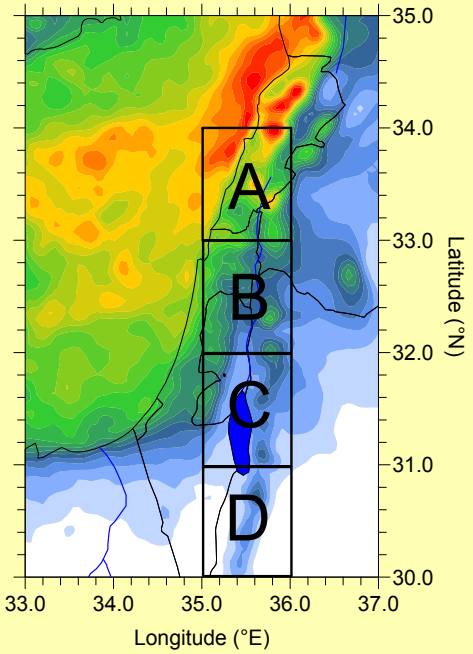


Relative Change in [%]

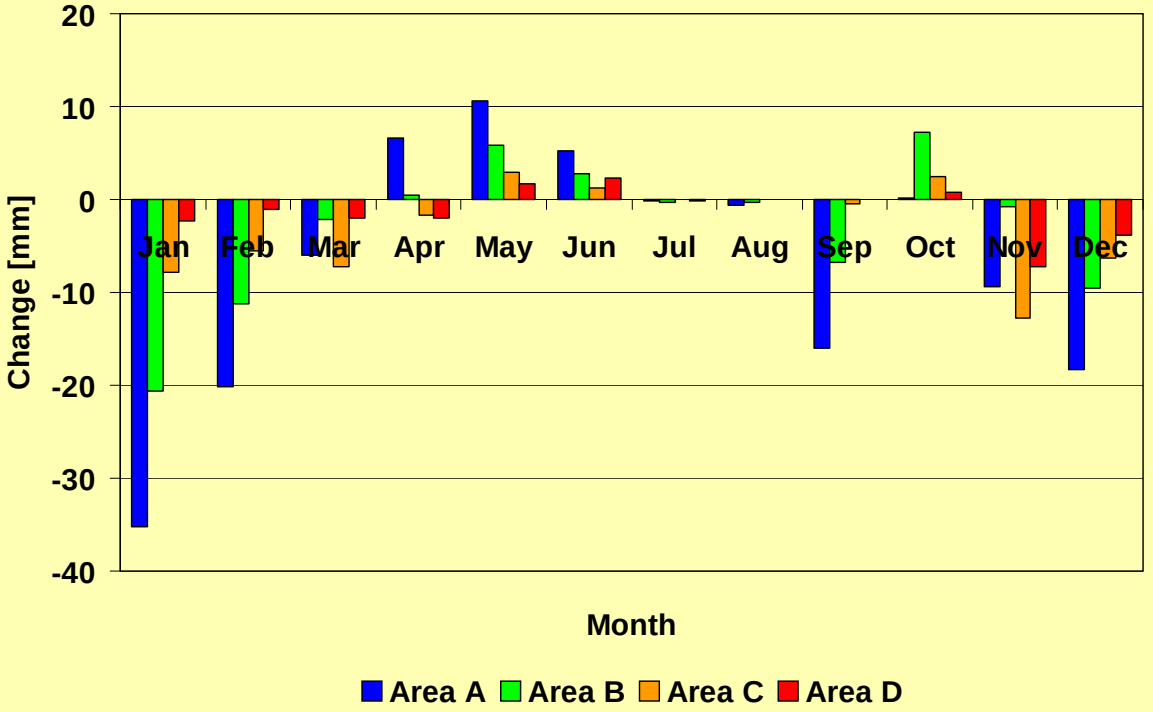
ECHAM4 & MM5, 18 km, B2, 2070-2099 vs 1961-1990

Regional Climate Simulations

How does seasonal precipitation change depend on the region?



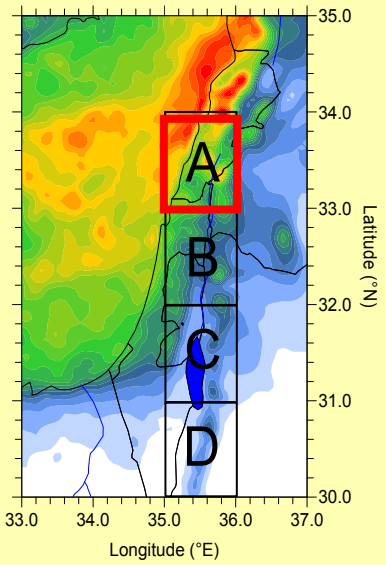
2070-2099 vs. 1961-1990, ECHAM4, B2, 18km

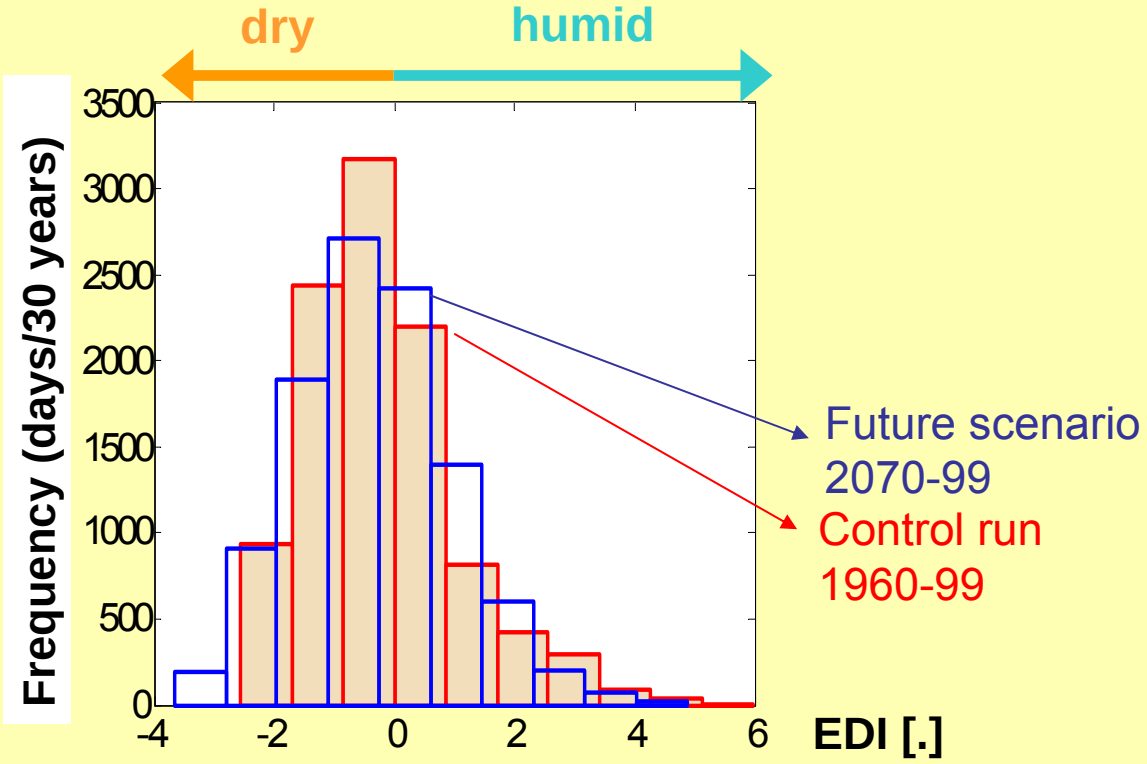


For all subregions: Decreased winter, increased spring precipitation

Regional Climate Simulations

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

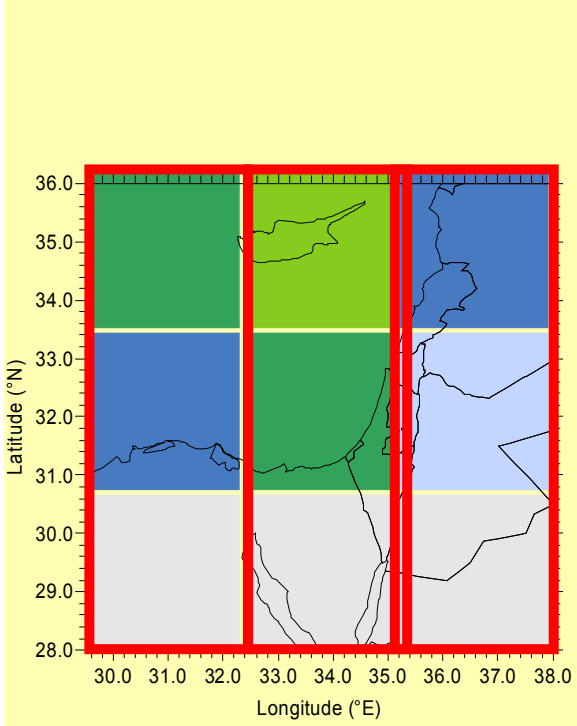


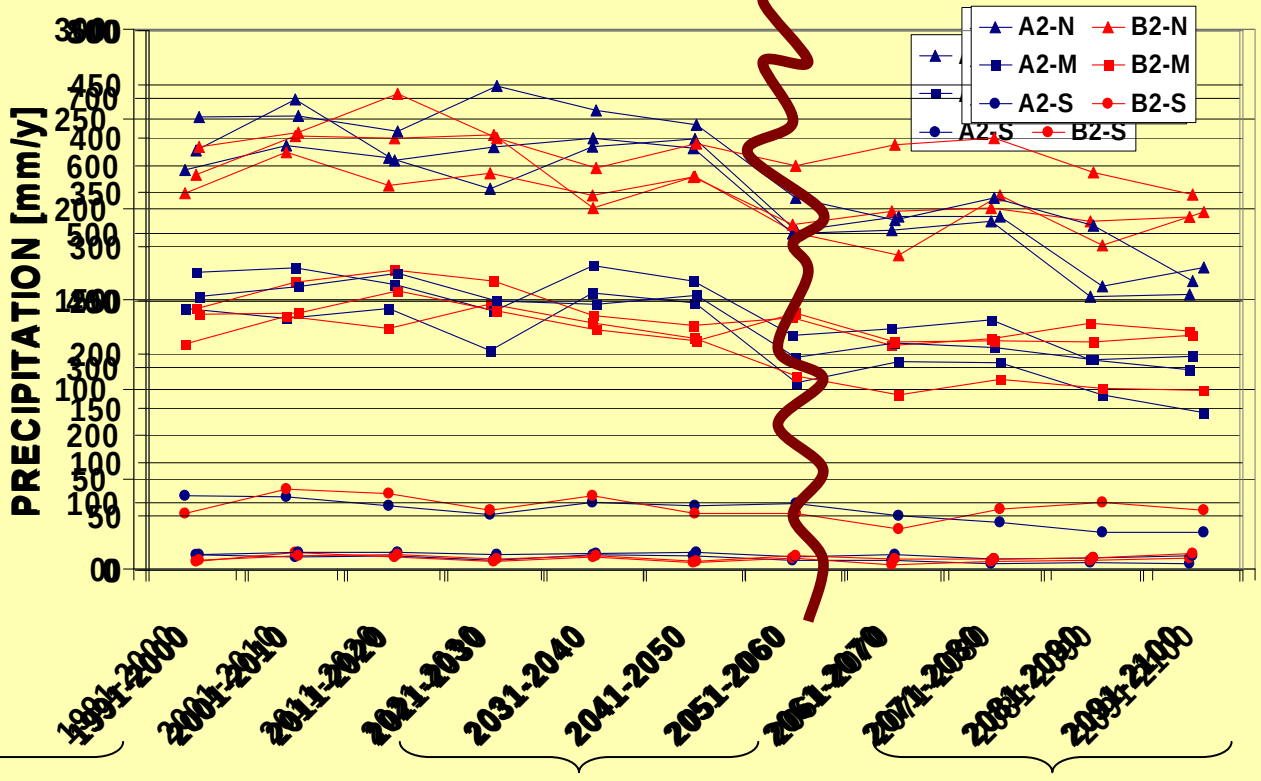


Subregion A: shift towards drier conditions & increased drought risks

Regional Climate Simulations

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





recent climate… ⇐ ⇒ medium term ⇒ long term

Regional Climate Simulations

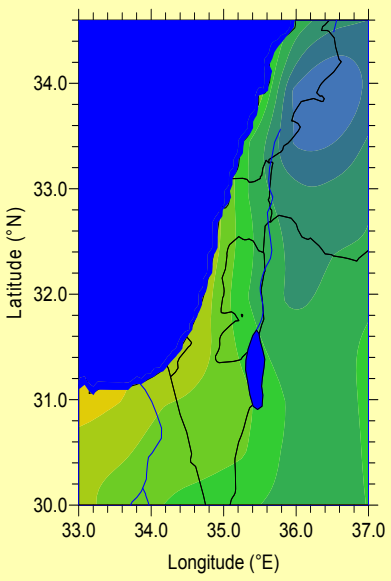
Second example: MEDIUM TERM PROJECTIONS

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

Regional Climate Simulations

Temperature

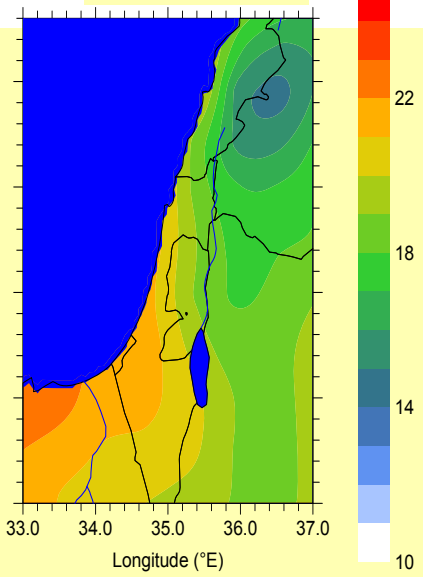
Control Run 1961-90

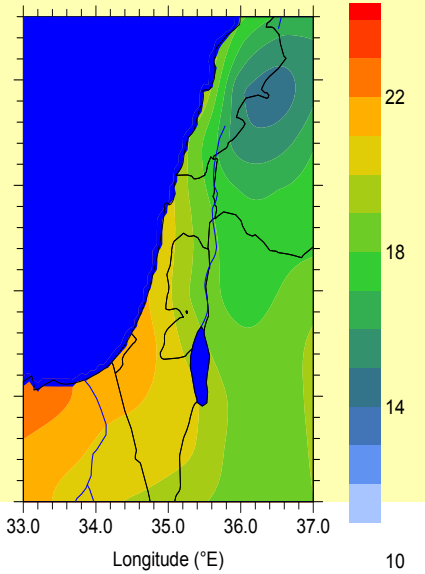


Szenario B2

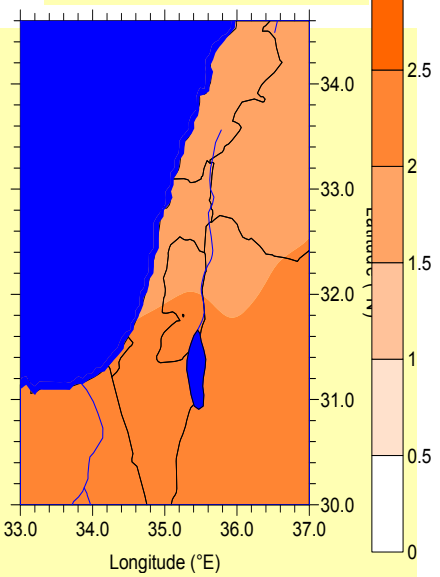
Szenario A2

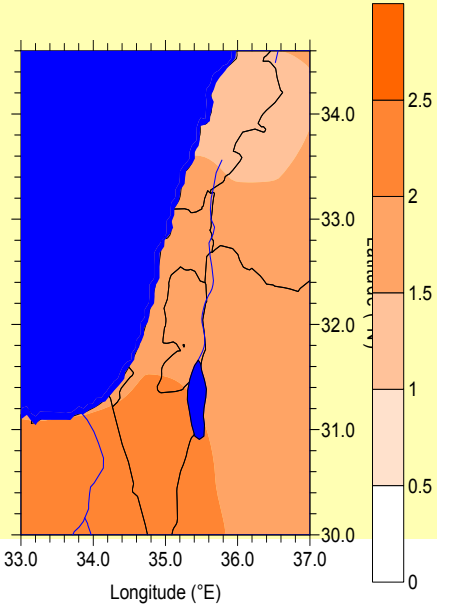
2021-50





Change [°C]

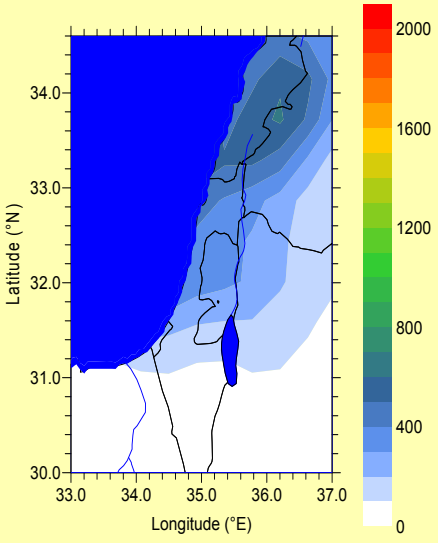




Regional Climate Simulations

Precipitation

Control Run 1961-90

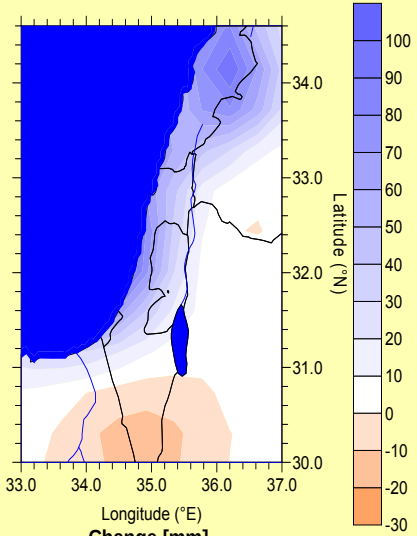


Scenario B2

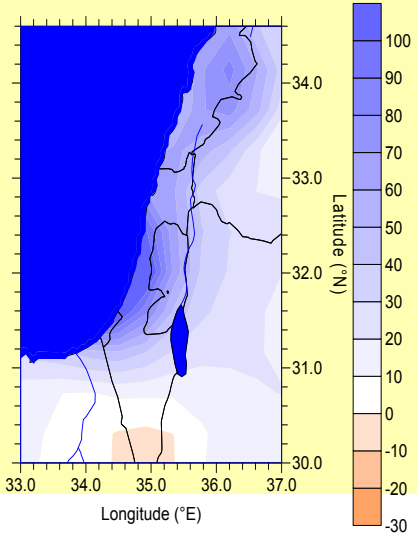
Scenario A2

2021-50

Change [mm]

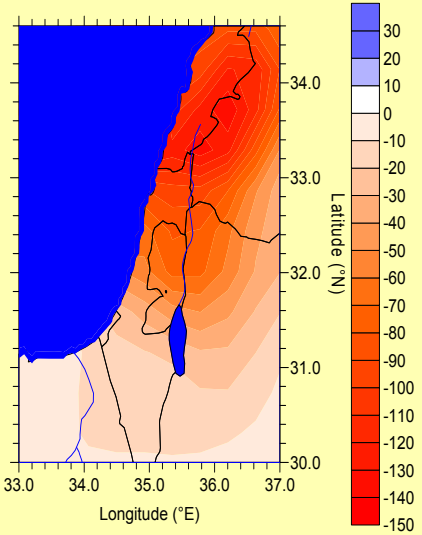


Change [mm]



2070-99

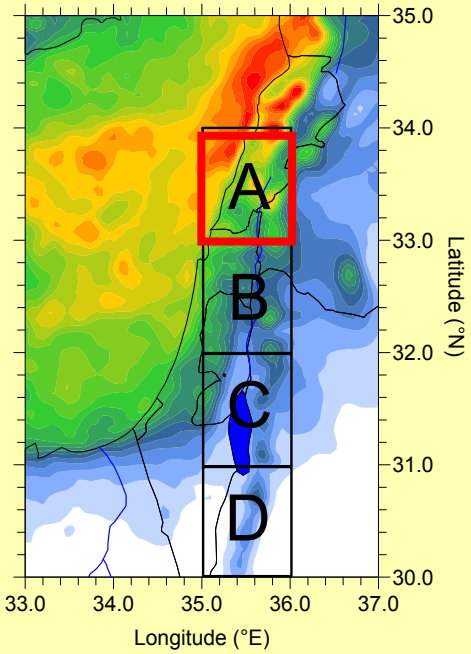
Change [mm]

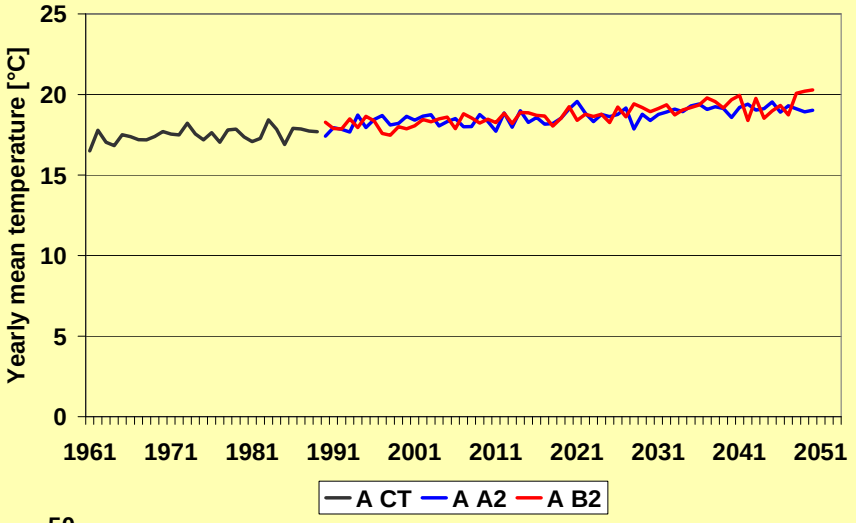


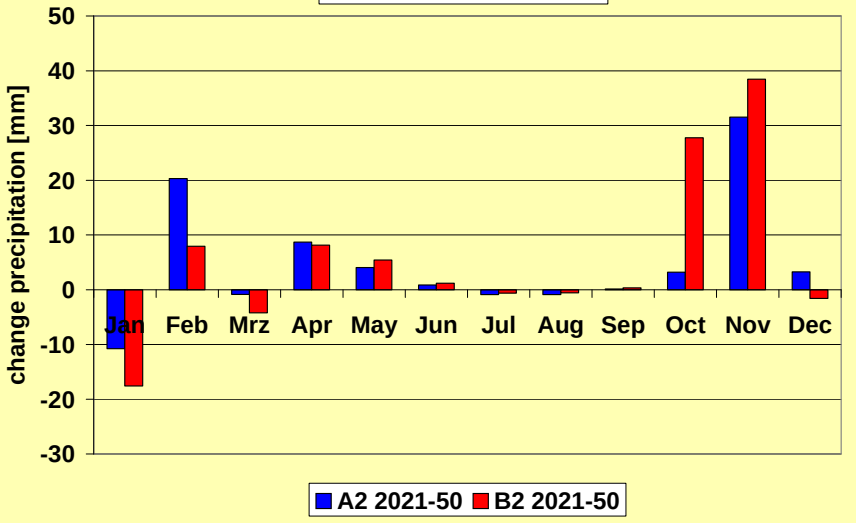
- Increase in precipitation
- Little differences between A2 + B2 till 2050

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

Changes in temperature and precipitation

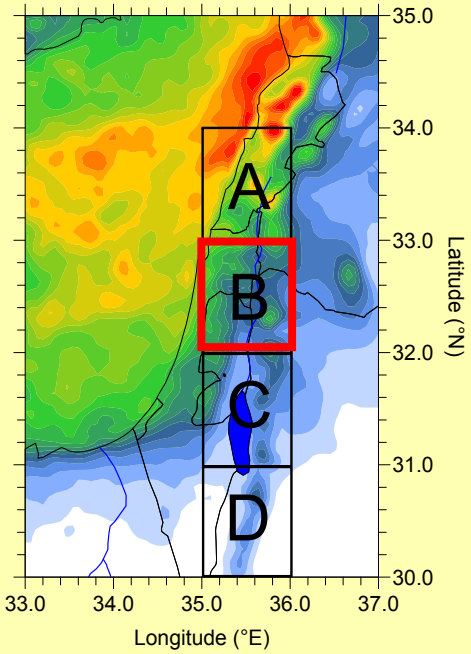


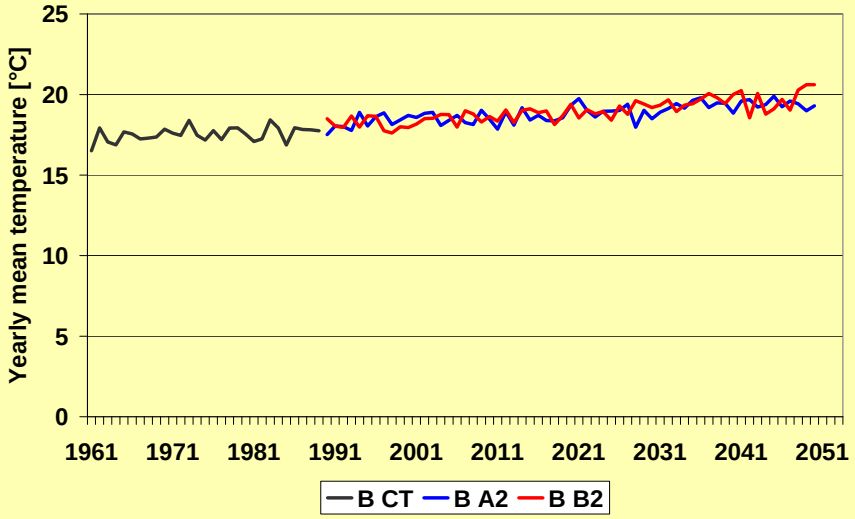


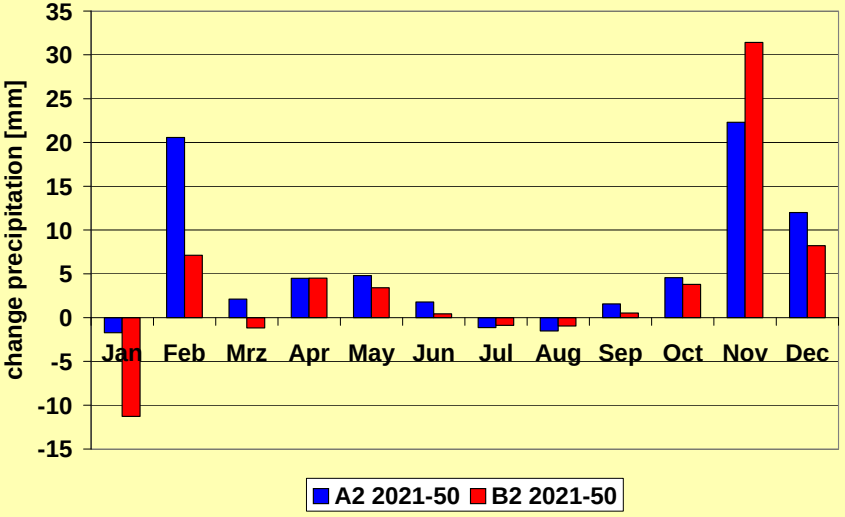


Regional Climate Simulations

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

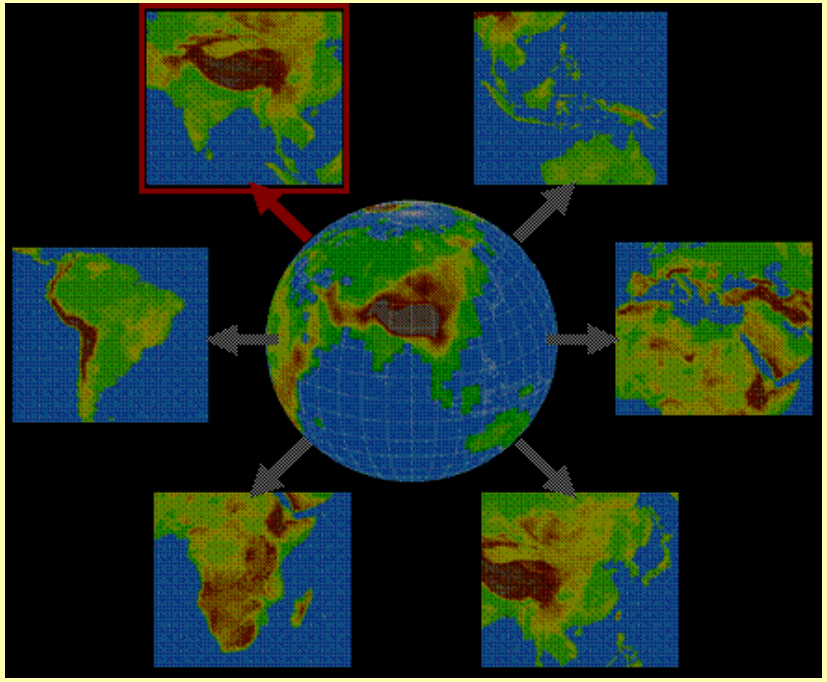
⇒ continuation of transient simulations in 18km resolution
⇒ extension towards HadCM3 and ECHAM5 (A1B)
⇒ **full set of uncertainty ranges**

TAU

Regional Climate Simulations

The ICTP Regional Climate Model version 3 (RegCM3)

(a hydrostatic version of NCAR/NCEP MM5)



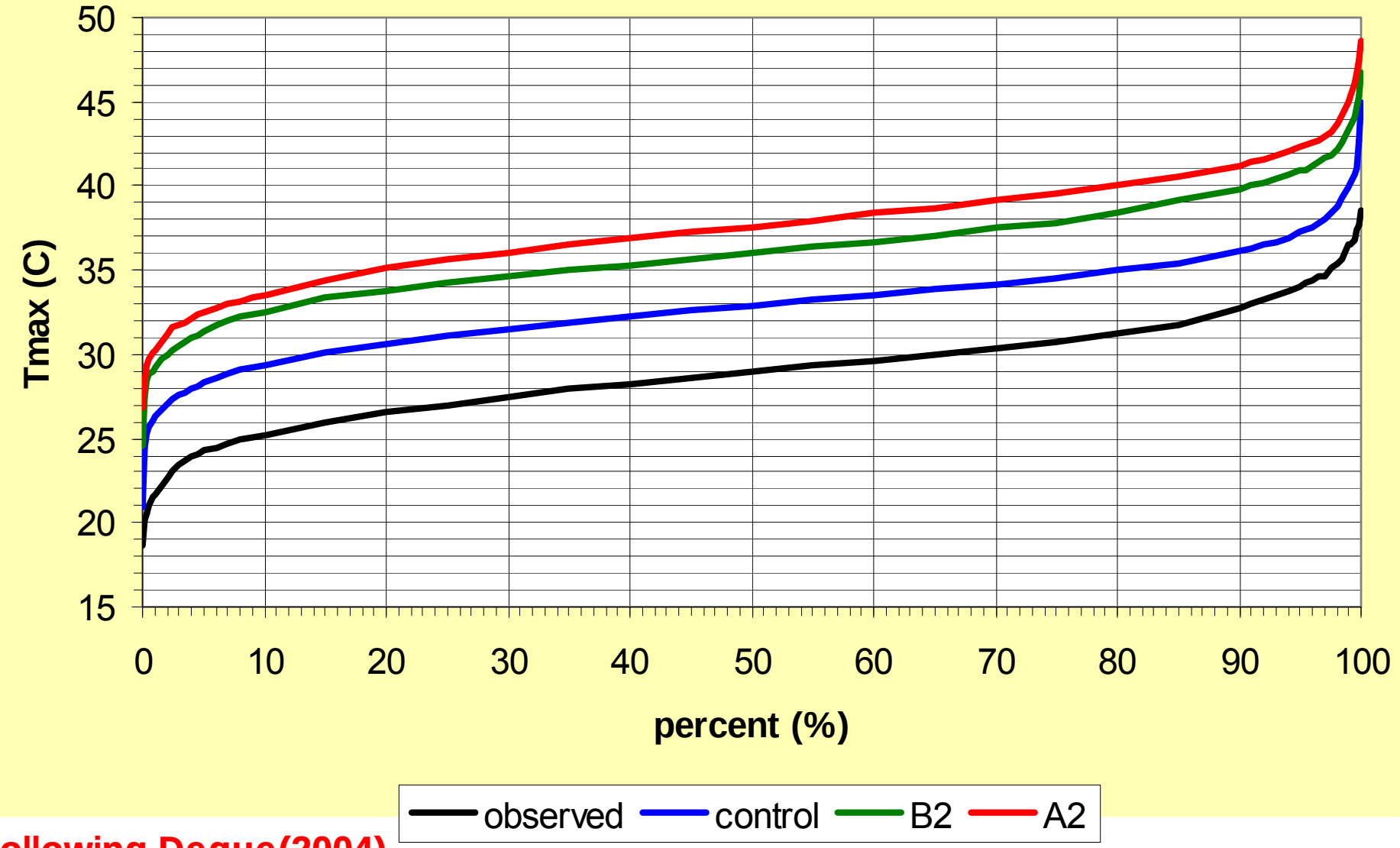
Scenarios used
A2, B2 – sliced simulations
HadCM3-HadAM3;

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

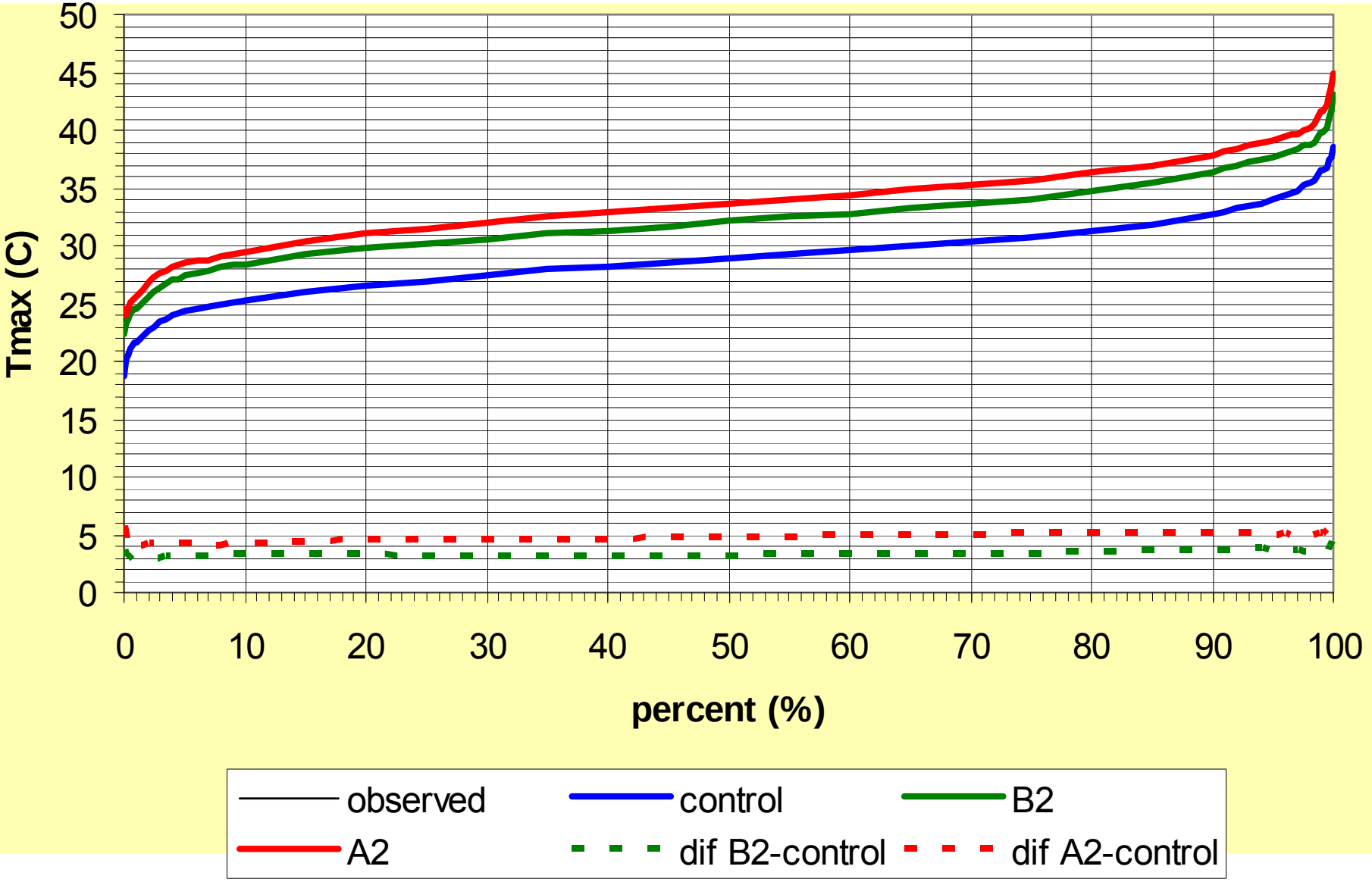
Tmax, summer, Har-Knaan **Mountain St.**

Downscaling Daily Temperatures (1961-1990)



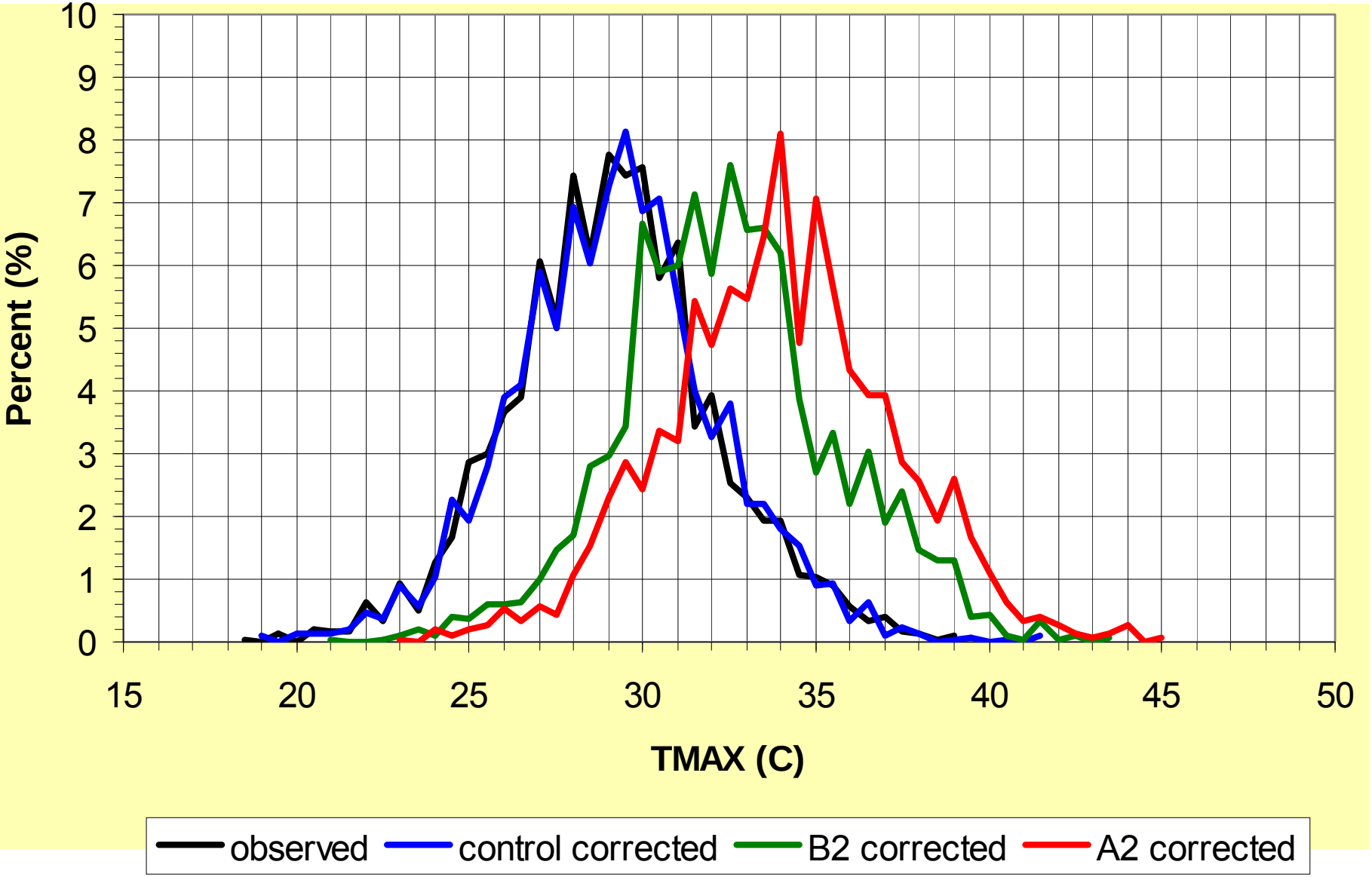
Following Deque(2004)

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



Har-Knaan, TMAX, distribution

Mountain St.

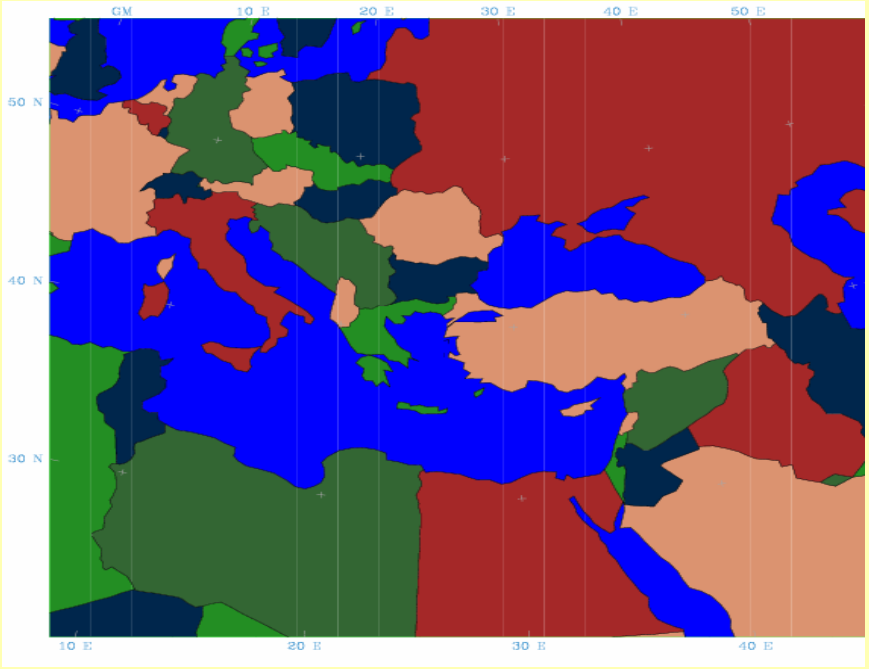


Regional Climate Simulations

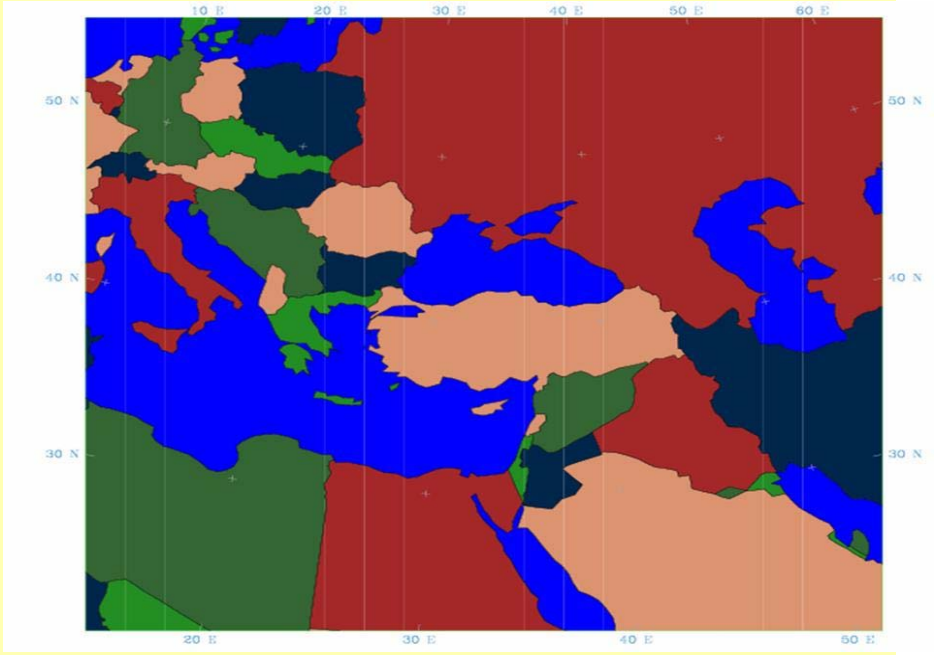
RegCM3 – domains used

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



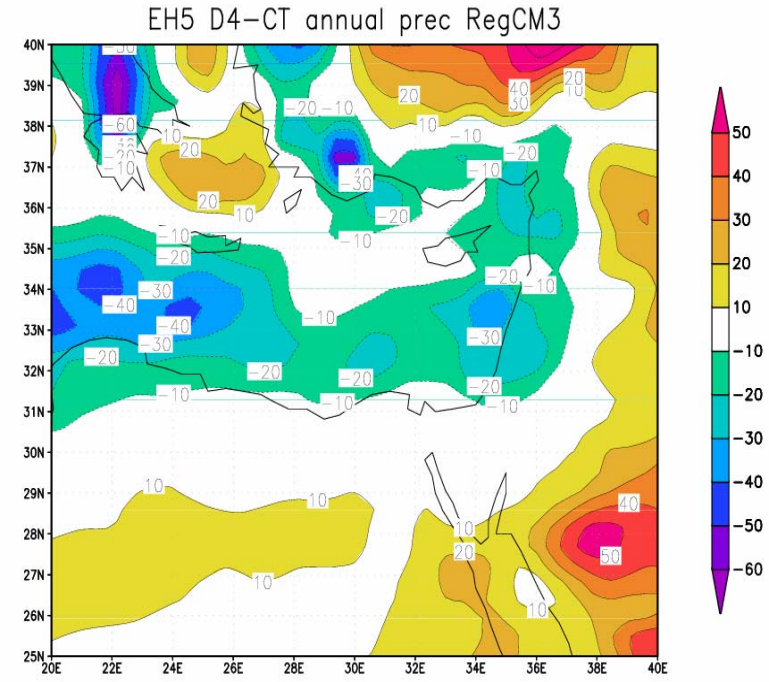
B



Only results of the simulations with domain B are presented below

Regional Climate Simulations

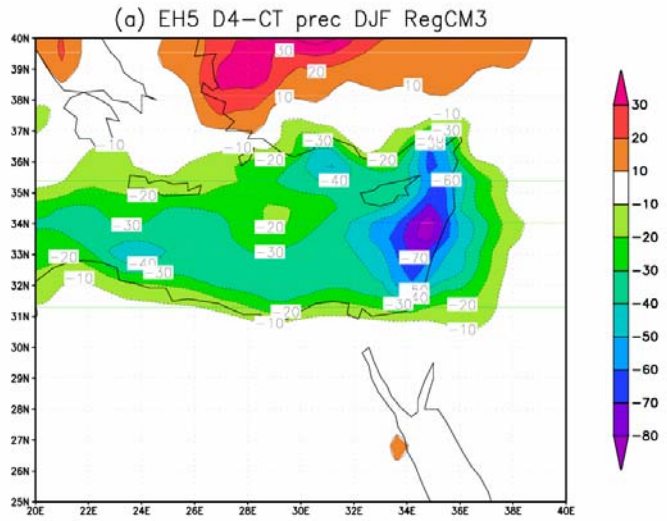
Projected climate change – annual precipitation

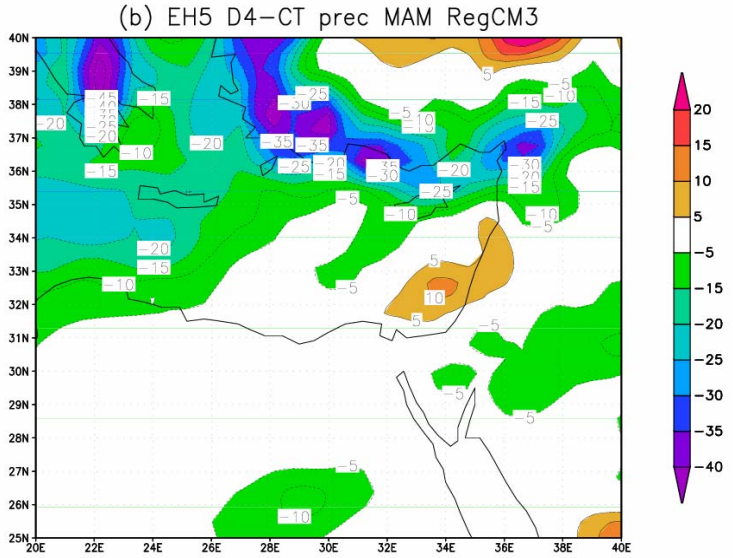


2021-2050 minus 1961-1990

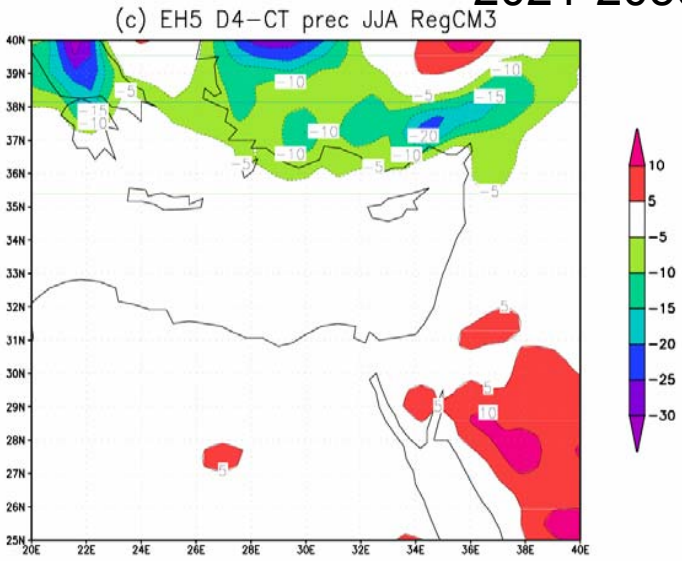
Regional Climate Simulations

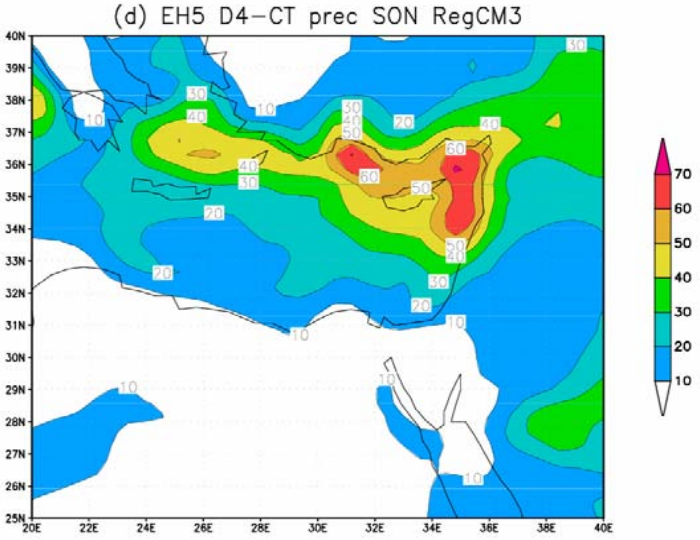
Projected climate change - seasonal precipitation





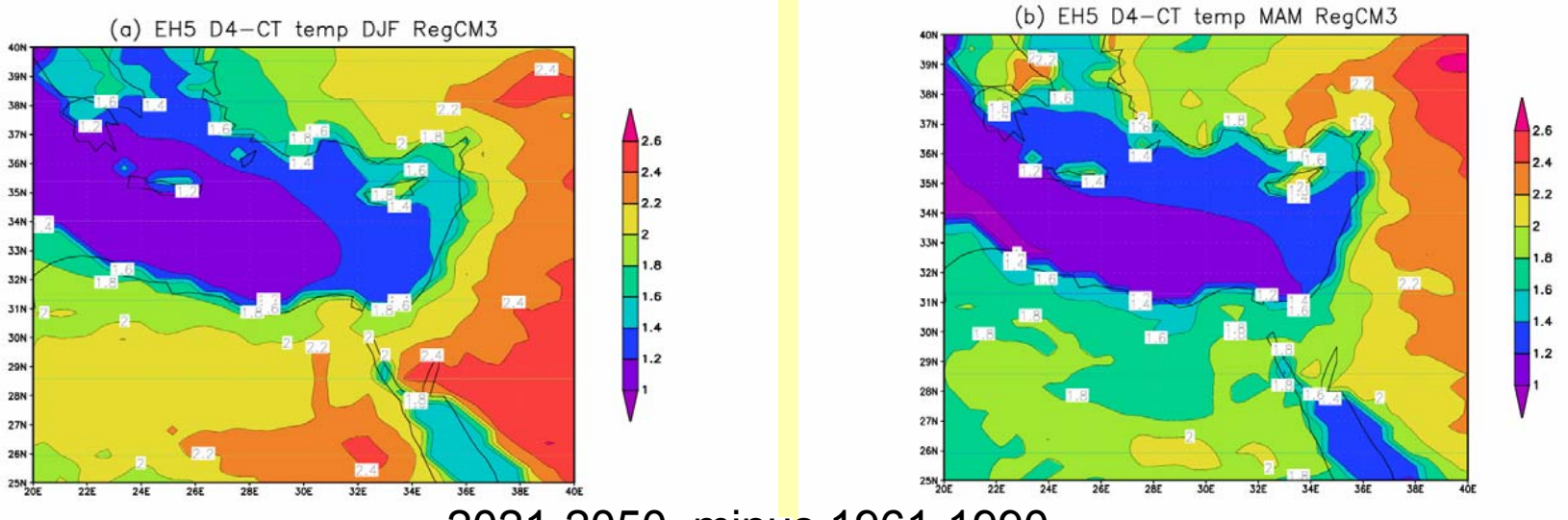
2021-2050 minus 1961-1990





Regional Climate Simulations

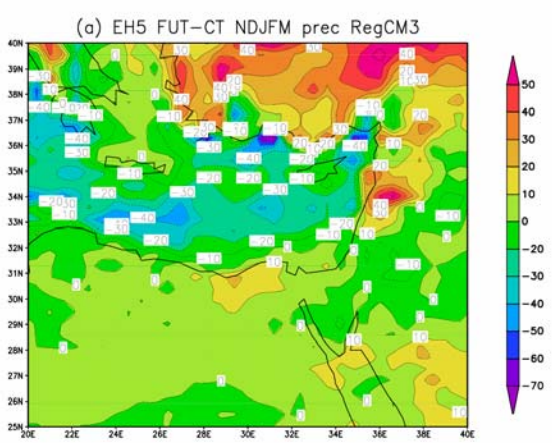
Projected climate change – seasonal air temperature (2m)



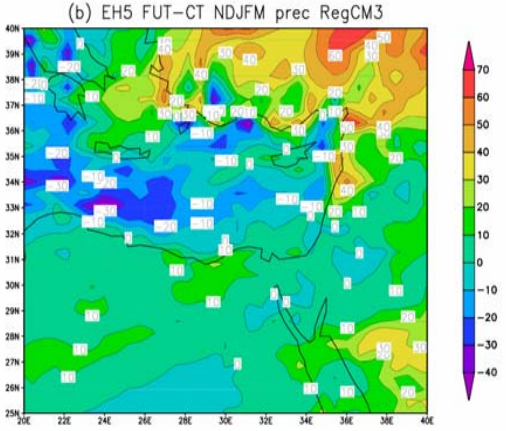
2021-2050 minus 1961-1990

Regional Climate Simulations

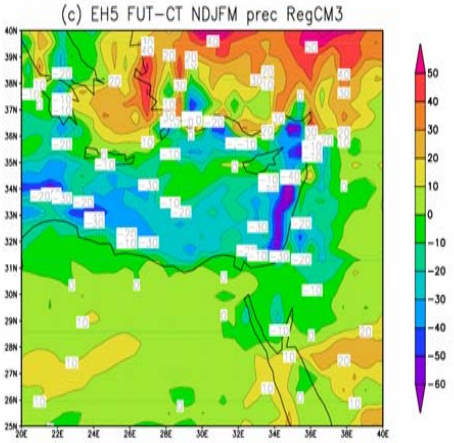
Projection of climate change decadal – wet season precipitation



2001-2030 minus 1961-1990



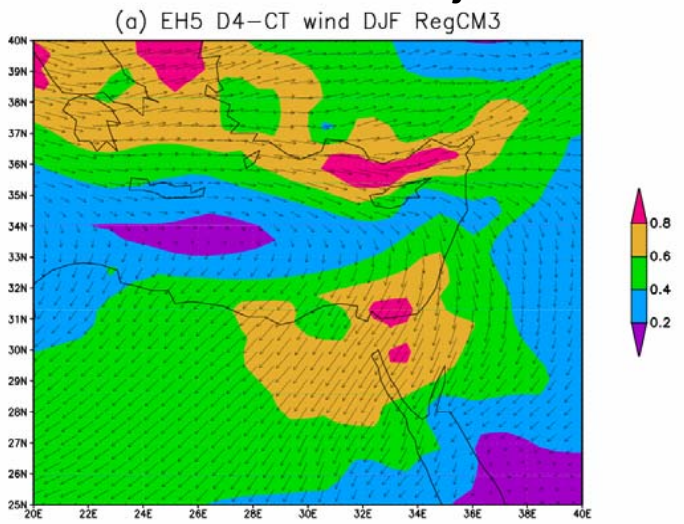
2011-2040 minus 1961-1990

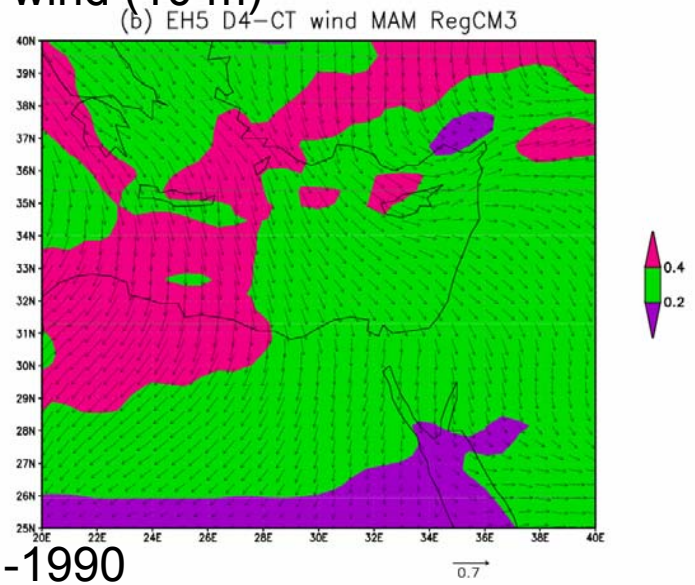


2021-2050 minus 1961-1990

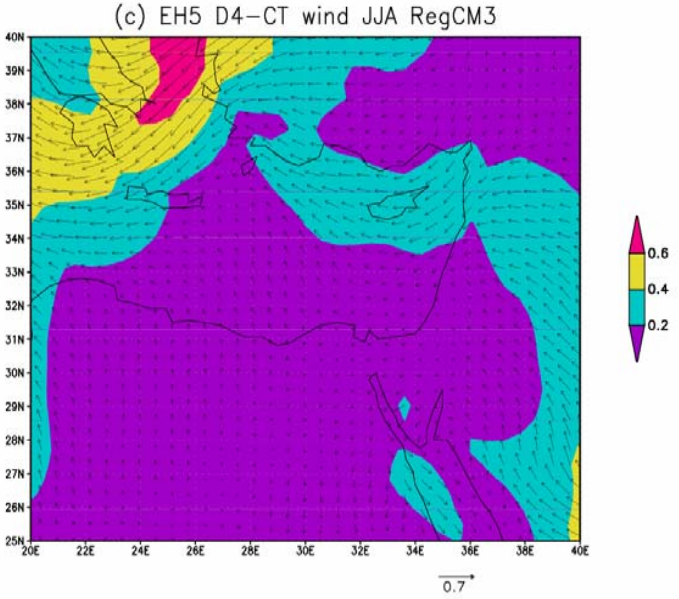
Regional Climate Simulations

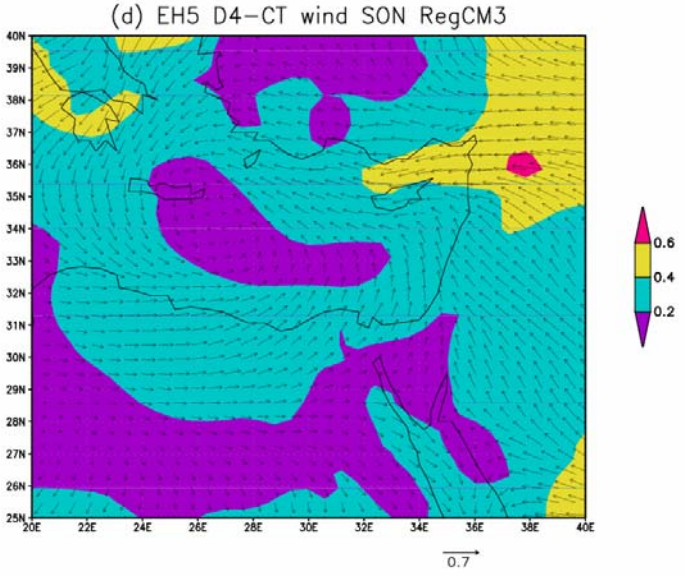
Projected climate change – wind (10 m)





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

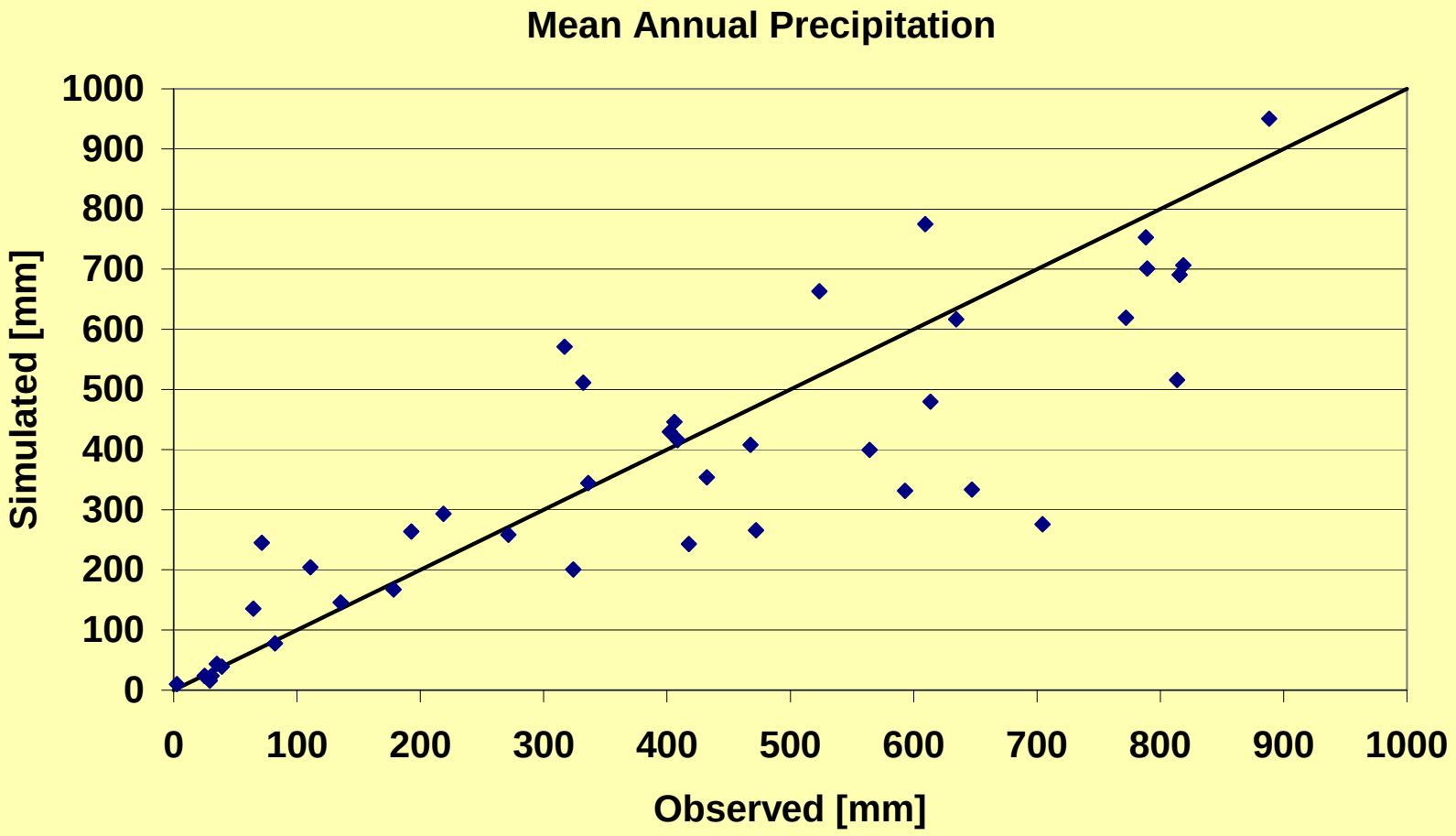
Phase III

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


Thank you for your attention

Control Simulation

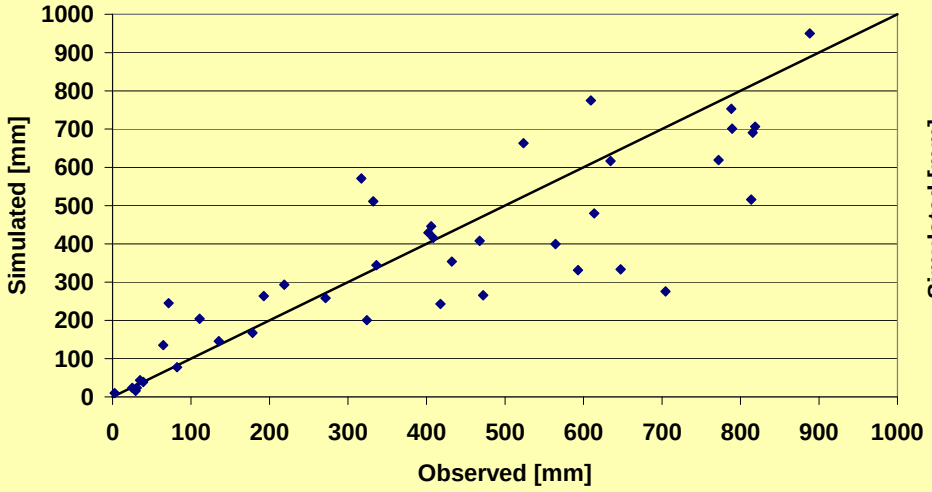
How accurate does the downscaled Control Run reproduce observed precipitation?



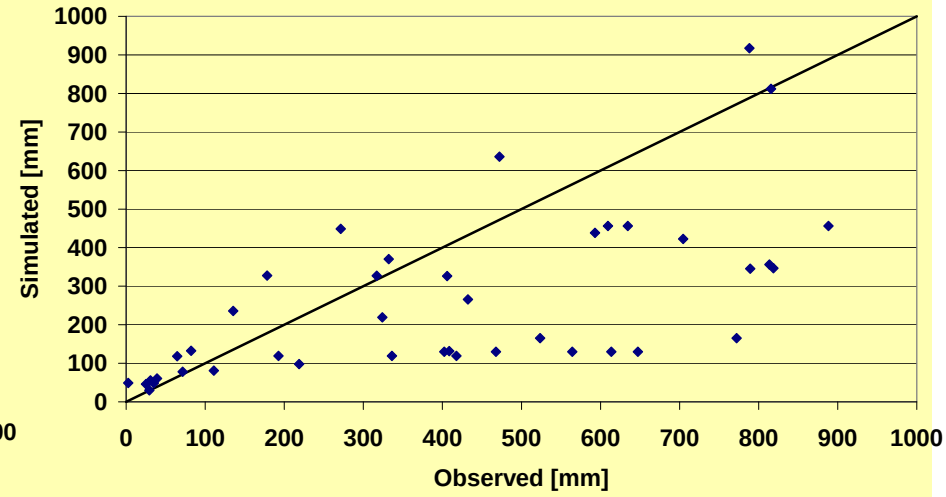
Regional Climate Simulations

ECHAM5 transient vs. ECHAM4 transient

Mean Annual Precipitation



ECHAM4-**MM5**, Δx=18km

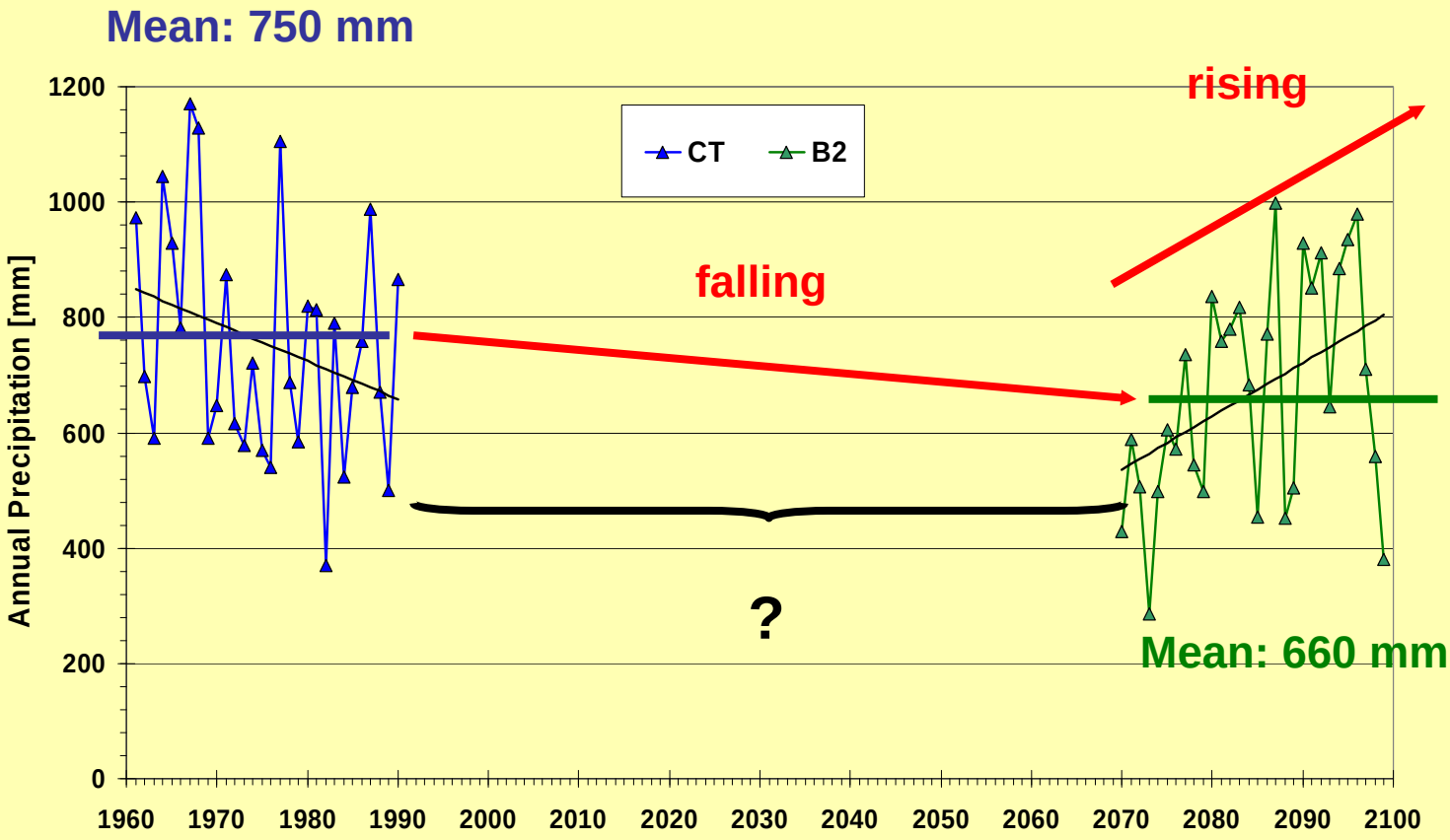


ECHAM5-**RegCM**, Δx=50km

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

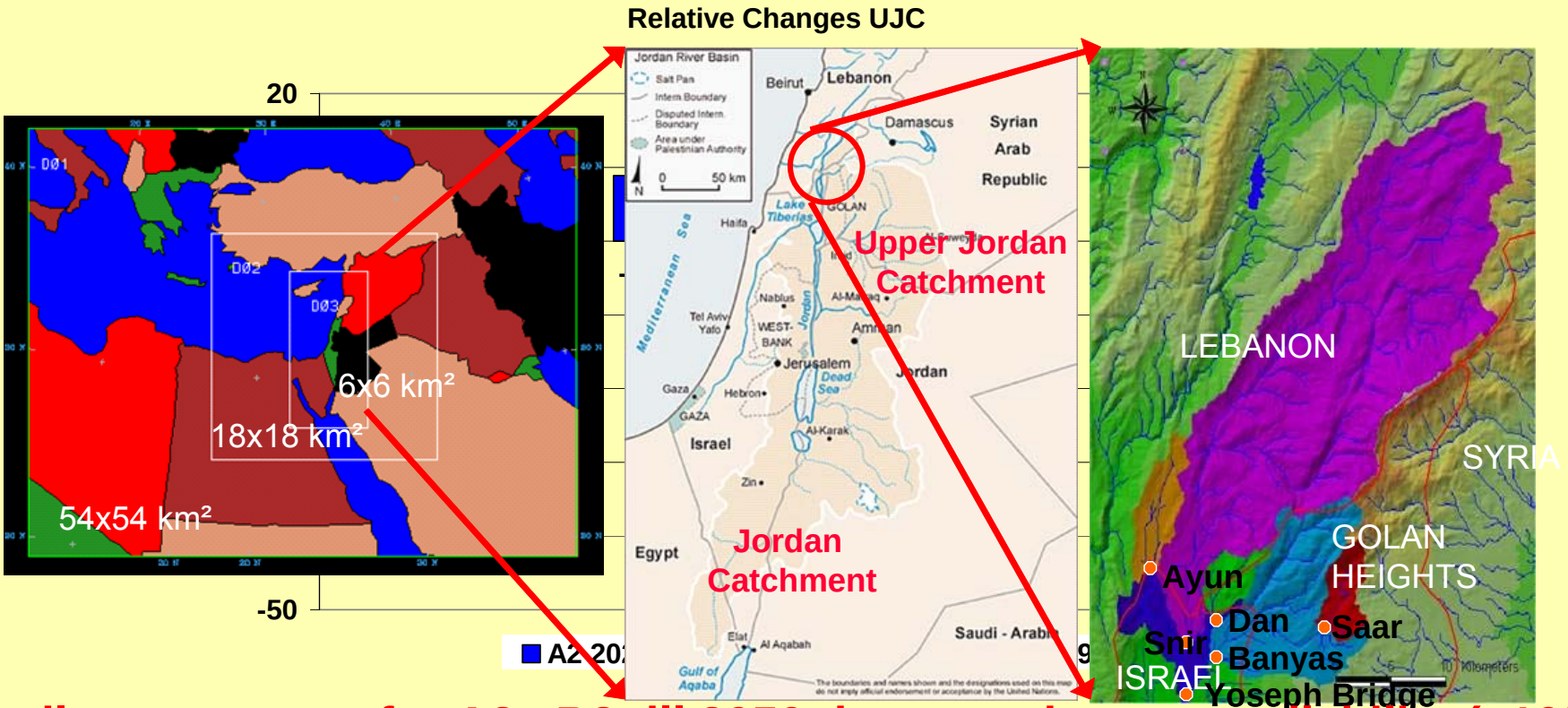
2) Region has sharp climatic gradients:
subhumid mediterranean ↔ arid climate

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

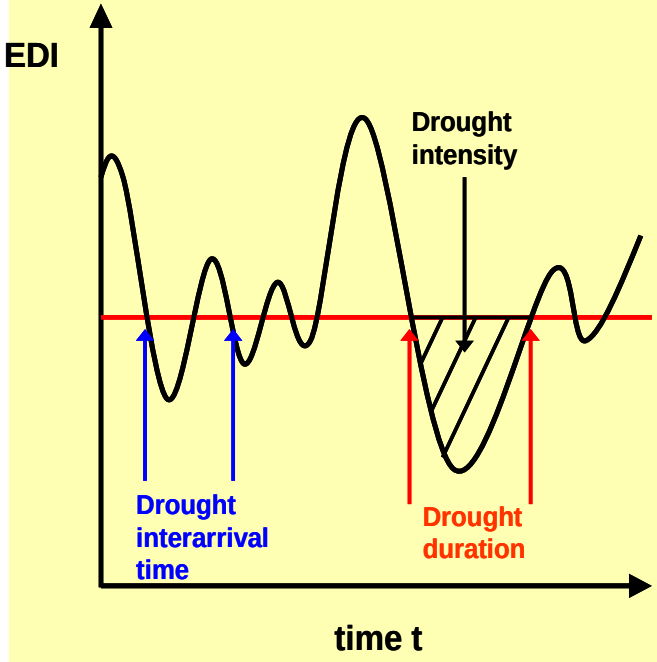


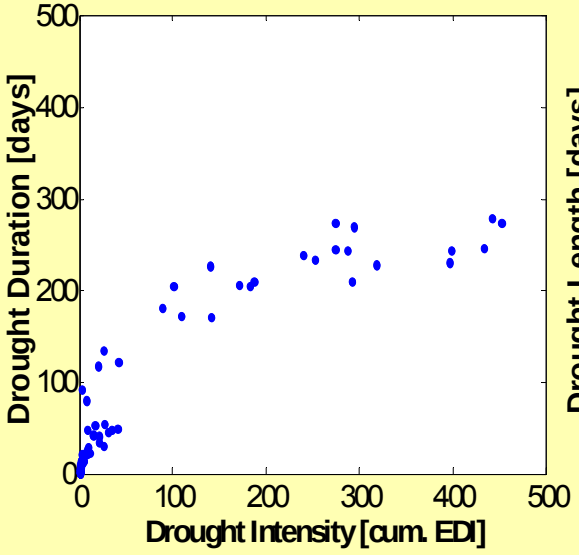
Similar responses for A2 , B2 till 2050: increased water availability (+10%)

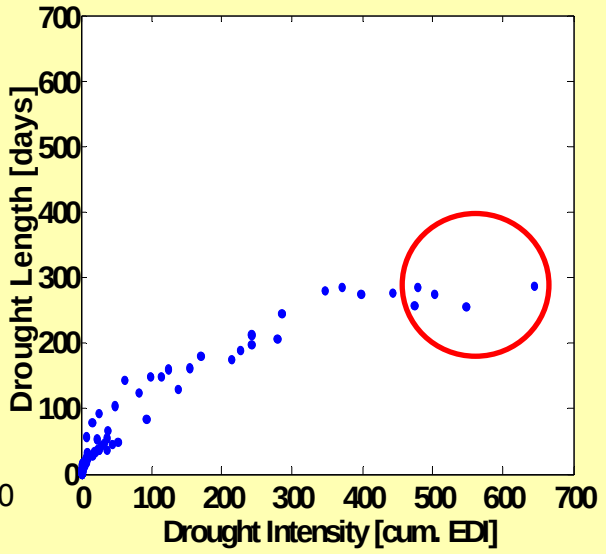
But: till 2100 significantly decreased water availability (-30%) in B2

Regional Climate Simulations

Are drought risks changing? Analysis of effective drought index EDI







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