Joint High Resolution Climate-Hydrology Simulations for the Middle East and the Upper River Jordan Catchment

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Regional Climate Change Middle East and Upper Jordan River

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

• hydrological focus: Upper Jordan catchment

⇒ provides 1/3rd of drinking water resources in Israel
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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 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
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The Mesoscale Meteorological Model MM5

- Dynamic Downscaling of ECHAM4 with MM5
- 3 nests: 54x54 km², 18x18 km², 6x6 km²
- 26 Vertical Layers, Model Top: 100 mbar
- Coupled OSU-Land-Surface Model
- Time slices: 1961-1990 & 2070-2099
Global 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 & Hydrological Impact Analysis

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)
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High resolution Control Run

Intermediate results of 6 km runs: mean 1961-1975

Yearly Mean Precipitation 1961-1975

54km 18 km 6 km

… more detailed spatial information: land-sea & orography dependent features
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What are the expected changes in temperature?

Absolute Change of Yearly Mean Temperature Future - Past

- Temperature [°C]
- Longitude (°E)
- Latitude (°N)
- Absolute Change of Yearly Mean Temperature Future - Past

Yearly Mean Temperature

- 1960-89
- 2070-2100

2.5 2.6 2.7 2.8 2.9 3.0 3.1 3.2 3.3 3.4 3.5 3.6 3.7 3.8 3.9 4.0
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What are the expected changes in precipitation?

ECHAM4 & MM5, 18 km, B2, 2070-2099 vs 1961-1990
How does the temporal distribution of precipitation change?

ECHAM4 & MM5, 18 km, B2, Jordan Area North of Dead Sea

Strongly decreased winter, slightly increased absolute late spring precipitation
How do precipitation intensities change?

![Graph showing precipitation intensities]

Tendency towards decrease of precipitation intensity
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How does seasonal precipitation change depend on the region?

For all subregions: Decreased winter, increased spring precipitation
Are drought risks changing? Analysis of effective drought index EDI

Subregion A: shift towards drier conditions & increased drought risks
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Are drought risks changing? Analysis of effective drought index EDI

Subregion A: Increasing drought intensities, but “unchanging” drought durations
How does the expected atmospheric change translate into change of terrestrial hydrology of Upper Jordan Catchment?
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Example of joint climate-hydrology simulation for hydrological impact analysis

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

- High resolution dynamical downscaling of global climate scenarios
- Distributed hydrological modeling of surface and subsurface water balance in 90 m resolution

- MM5
- WaSiM

Distributed hydrological modeling

MM5

WaSiM

High resolution dynamical downscaling of global climate scenarios

Distributed hydrological modeling of surface and subsurface water balance in 90 m resolution
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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 Modeling & Hydrological Impact Analysis

Joint climate-hydrology simulation for hydrological impact analysis

Annual mean temperature

Temperature change [°C]

Upper Jordan River catchment

1961 - 1990

2070 - 2099

11 - 12
12 - 13
13 - 14
14 - 16
16 - 17
17 - 18
18 - 20
20 - 22
22 - 24

3,2 – 3,4
3,4 – 3,5
3,5 – 3,7
3,7 – 3,9
3,9 – 4,1
4,1 – 4,2
4,2 – 4,4
4,4 – 4,5
4,5 – 4,7
Joint climate-hydrology simulation for hydrological impact analysis

Upper Jordan River catchment

Mean annual precipitation

Precipitation change [%]

1961 - 1990

2070 - 2099

-25,0 - -22,7
-22,7 - -20,6
-20,6 - -18,6
-18,6 - -16,5
-16,5 - -14,5
-14,5 - -12,4
-12,4 - -10,4
-10,4 - -8,3
-8,3 - -6,3
Joint climate-hydrology simulation for hydrological impact analysis

Runoff

Groundwater Recharge

Upper Jordan River catchment
Summary & Conclusions

Climate change Jordan River area north of Dead Sea (2070-99 vs. 1961-90):
• Temperature increase of annual mean up to 3.5°C
• Summer temperatures up to 5°C

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

Upper Jordan River
• In spite increased spring precipitation, decreased spring runoff recharge
• Significant reduction of snow

⇒ Significantly reduced water availability & increased drought risks!
Thank you for your attention
Eastern Mediterranean/Near East: is in between increasing and decreasing dominant large scale patterns of DJF precipitation change
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
Joint climate-hydrology simulation for hydrological impact analysis
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
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Boundary Conditions for Groundwater Model

Maximum depth of unsaturated zone assumed:
= 100 m
Hydrological Simulations

<table>
<thead>
<tr>
<th>Episode</th>
<th>Gauge</th>
<th>Banyas</th>
<th>Saar</th>
<th>Snir</th>
<th>Ayun</th>
<th>Yoseph Bridge</th>
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Gauge Ayun

Gauge Saar
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Joint climate-hydrology simulation for hydrological impact analysis

1961-90

\[ Q_{tot} + ET: \quad 737 \text{mm} \quad \Rightarrow \quad 639 \text{ mm (-13\%)} \]
\[ Q_{tot}: \quad 375 \text{ mm} \quad \Rightarrow \quad 289 \text{ mm (-23\%)} \]

2070-99

\[ Q_{tot} + ET: \quad 737 \text{mm} \quad \Rightarrow \quad 639 \text{ mm (-13\%)} \]
\[ Q_{tot}: \quad 375 \text{ mm} \quad \Rightarrow \quad 289 \text{ mm (-23\%)} \]