Overview of climate modeling and new high-resolution projections for the Mashreq Region

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Weather and Climate modelling: time scales

<table>
<thead>
<tr>
<th>Time Scale</th>
<th>Forecast Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours to 2 weeks</td>
<td><strong>Weather forecast</strong> - atmospheric initial conditions important</td>
</tr>
<tr>
<td>2 weeks to 1 year</td>
<td><strong>Seasonal forecast</strong> - initial conditions (slow varying natural variability: soil moisture, SST, sea ice etc.) + boundary conditions in less degree</td>
</tr>
<tr>
<td>1 to 10 years</td>
<td><strong>Decadal predictions</strong> – initial conditions (slow varying natural variability) + boundary conditions (radiative forcing scenarios etc.) probable development</td>
</tr>
<tr>
<td>10 years to centuries</td>
<td><strong>Climate projections</strong> – only boundary conditions (scenarios etc.), initialization is not important – possible development</td>
</tr>
</tbody>
</table>

**Climate predictions vs climate projections:** we can verify predictions (historical data) but not projections
Different generations of climate scenarios

- 1992 IS92 – ”the first global scenarios to provide estimates for the full suite of greenhouse gases” (e.g. IS92a)
- 2000 SRES – four different possible future trajectories of population, economic growth and greenhouse gas emissions (e.g. A1, B1)
- 2010 RCP – Representative Concentration Pathways (e.g. RCP8.5)
- 2016 SSP – Shared Socioeconomic Pathways (e.g. SSP1, SSP2)
Methodology for producing scenarios

**RCPs**
- General characteristics
  - Broad range of forcing in 2100
  - Shape of radiative forcing over time
- Radiative forcing
  - Representative concentration pathways (RCPs)
    (four pathways from existing literature)
  - Greenhouse gases
  - Short-lived gases and aerosols
  - Land cover/use

**SSPs**
- New socio-economic and emissions scenarios; vulnerability storylines
  - Adaptation
  - Mitigation
  - Stabilization
  - Overshoots
  - ...
  - Consistent with RCPs
  - Independent of the RCPs
- Integration of climate and socio-economic scenarios
  - Integrated scenarios
  - Pattern scaling (climate)
- Downscaling of climate and socio-economic scenarios
  - ...

New research and assessments
- Impact, adaptation, and vulnerability studies
- Climate change feedbacks
- Model development
- ...

Timeline:
- 2008
- 2009
- 2010
- 2011
- 2012
- 2013
What does an "RCP-world" look like?

RCP8.5 – continued increases in em.
• World population 12 billion
• High energy intensity
• Slow development towards energy efficiency
• Large dependence on fossil fuels
• No further policies

RCP6.0 – emissions increase to 2060
• World population 10 billion
• Lower energy intensity than RCP8.5

RCP4.5 – emissions increase to 2040
• World population 9 billions
• Lower energy intensity
• Forest replanting programs

RCP2.6 – emissions peak 2020
• World population 9 billion
• Low energy intensity
• Reduced use of oil
• Increased demand for agricultural land
• Negative emissions in 2100
SSP narratives

- a world of sustainability-focused growth and equality (**SSP1**)
- a “middle of the road” world where trends broadly follow their historical patterns (**SSP2**)
- a fragmented world of “resurgent nationalism” (**SSP3**)
- a world of ever-increasing inequality (**SSP4**)
- a world of rapid and unconstrained growth in economic output and energy use (**SSP5**).
Integrating SSPs-RCPs

SSPs can be coupled to different degree of radiative forcing

- SSP2-4.5
- SSP1-2.6
Need of regional climate information

- Climate change information at regional and local scale is highly demanded by a wide range of stakeholders worldwide: **high spatial resolution is important**
- Global climate models (GCMs) are the main tool to provide climate data
- Resolution of GCMs is increasing (e.g. 25-50km), although complex Earth System Models (ESMs) still have resolution of about 100 km (long multi-decadal simulations)
- Regional climate downscaling complements GCMs/ESMs by Regional Climate Models (RCMs) or Empirical-Statistical methods (ESD) including Machine Learning (ML)
Climate Model Intercomparison Project (CMIP)

CMIP is a WCRP’s project and international effort divided into phases

The objective of CMIP is to better understand past, present and future climate changes arising from natural, unforced variability or in response to changes in radiative forcing in a multi-model context.

Eyring et al., 2016

<table>
<thead>
<tr>
<th>Phase</th>
<th>IPCC AR</th>
<th>Start Year (preparation)</th>
<th>Scenarios</th>
<th>Number of models</th>
<th>Resolution range</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMIP3</td>
<td>AR4</td>
<td>2000</td>
<td>SRES</td>
<td>about 25</td>
<td>150-500km</td>
</tr>
<tr>
<td>CMIP5</td>
<td>AR5</td>
<td>2008</td>
<td>RCP</td>
<td>about 35</td>
<td>100-300 km</td>
</tr>
<tr>
<td>CMIP6</td>
<td>AR6</td>
<td>2014</td>
<td>SSP-RCP</td>
<td>131</td>
<td>80-250 km (25km)</td>
</tr>
<tr>
<td>CMIP7</td>
<td>AR7</td>
<td>2022</td>
<td>SSP-RCP ???</td>
<td>???</td>
<td>???</td>
</tr>
</tbody>
</table>
Climate downscaling using HCLIM

- **Global Climate Model - GCM** (≈ 100 km)
- **Regional Climate Model - RCM** (≈ 10 km for HCLIM-ALADIN)
- **Convection-Permitting model (CPM)** (km-scale, e.g., HCLIM-AROME at 3 km)

Even higher resolution (e.g., 300 m) using SURFEX (land model of HCLIM)

- **ALADIN**: mostly transient simulations, e.g. 1951-2100 in CORDEX-CMIP6
- **AROME**: mostly time slices, e.g. 10- or 20-yr periods
- **AROME**: event-based downscaling – to downscale many short-term (few days/weeks) extreme events (e.g. heatwaves, extreme precipitation)
Coordinated Regional climate Downscaling EXperiment

- **CORDEX** - WCRP project running since 2009: 14 continental-scale domains
  Middle East North Africa (MENA) is one of the CORDEX domains

- Current resolution in CORDEX is about 10-25km depending on domain size
- CORDEX continental-scale framework cannot fit all needs
- Running MENA or Africa at 10km is possible but a heavy task
- -> Smaller project-based domains for high-resolution climate simulations
Convection Permitting scales (2-3km)

• Continental-scale CORDEX domains are too large to generate large multi-decadal CP ensembles

• Focus on smaller “regional” domains leads to fragmentation: most modelling groups are interested in their “home” region

Directions:

• Event-based downscaling
• Applying Machine Learning methods to extend small CP ensembles
CORDEX Training Workshops

a strong CORDEX component:
• analysis of RCM and GCM simulations over a region
• training young scientists in climate data analysis
• engaging users of climate data (VIA)

a high demand on such regional training workshops but funding

Africa (10)

South East Asia (8+)

Latin America and the Caribbean (3+)
CORDEX-Africa Analysis Campaign

- coordinated by Climate Section Analysis Group (University of Cape Town)
- more than 40 African scientists (4 teams: west, central, east and southern Africa)

**Phase 1**: 4 training workshops (2011-2012) (funded by START), 11 publications

**Phase 2**: 2 workshops (2015/2016) (funded by Sweden)

**Phase 3**: 4 workshops in 2017-2018 (funded by Sweden); contribution to the 1.5deg IPCC report (6 papers in “Focus Collection” of Environ. Research Letters)

more than 100 papers and 6 participants are lead authors in IPCC AR6
A project-based domain was established in 2020 (ESCWA/RICCAR and SMHI) regional model - HCLIM-ALADIN38 is used to generate new regional climate projections at 10km resolution by downscaling the latest generation of global climate models from CMIP6

1961-2014 is the historical CMIP6 experiment and then 2015-2070 under SSP2-4.5 and SSP5-8.5

about 50 variables (many at 1-hr frequency)

Daily rainfall and mean/max/min temperature are bias adjusted
GCMs for downscaling were selected to provide a range of climate sensitivity

- **ECS** - equilibrium climate sensitivity
- **TCR** - transient climate response

### Mashreq ensemble

<table>
<thead>
<tr>
<th>Driving CMIP6 GCM</th>
<th>ECS (°C)</th>
<th>TCR (°C)</th>
<th>SSP2-4.5</th>
<th>SSP5-8.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>NorESM2-MM</td>
<td>2.5</td>
<td>1.33</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>MPI-ESM1-2-HR</td>
<td>3.0</td>
<td>1.84</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>CMCC-CM2-SR5</td>
<td>3.5</td>
<td>2.09</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>EC-Earth3-Veg</td>
<td>4.4</td>
<td>2.60</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>CNRM-ESM2-1</td>
<td>4.8</td>
<td>1.83</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>IPSL-CM6A-LR</td>
<td>4.7</td>
<td>2.35</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>MRI-ESM2-0</td>
<td>3.1</td>
<td>1.64</td>
<td>no forcing</td>
<td>✓</td>
</tr>
</tbody>
</table>

Mashreq ensemble: 6 members
Mashreq ensemble data and its use

A subset of variables are available from the RICCAR Regional Knowledge Data Portal (riccar.org) for climate change vulnerability and impact assessments with focus on the water sector and water resources.
Climate projections for Sand and Dust Storms?

Global climate models with interactive aerosol;
- provide AOD for dust aerosol
- only monthly means in CMIP6
- coarse resolution (about 100km or coarser)
- no visibility

Regional climate models:
- static aerosol climatology (old approach)
- transient aerosol forcing from GCMs (monthly means, interpolated from coarser GCM grids)
- running an RCM fully coupled with an aerosol model is very expensive for long multi-decadal simulations
Mashreq ensemble for Sand and Dust Storms?

HCLIM-ALADIN38 has a static aerosol climatology (only annual cycle)

**Dust Uplift Potential (DUP)** as a dynamical proxy of SDS

\[
DUP = U^3 \left(1 + \frac{U_t}{U}\right) \left(1 - \frac{U_t^2}{U^2}\right)
\]

- **DUP** — the wind speed
- **Uₜ** — a threshold wind speed

- **DUP** = 0 if \( U \leq Uₜ \)

- Input: 1-hr wind speed at 10m
- Threshold: 7 m/s is a commonly used for bare soil
- DUP is calculated for all grid boxes and different filters can be applied later
Evaluation of Dust Uplift Potential

Dust Uplift Potential (dup7)
MSH-10 | CTL: 1981-2010 | AMJJAS

April-September
1981-2010

ERA5 - reference
0.25° resolution

HCLIM underestimates DUP over central and eastern part of the Arabian Peninsula
Projected changes in Temperature (2041-2060)

April-September

Ensemble mean

Consistent warming for the entire domain, stronger under SSP5-8.5

all 6 ensemble members agree on an increase
Projected changes in Precipitation (2041-2060)

- April-September
- Ensemble mean
- A tendency to drier conditions in eastern Mediterranean, stronger under SSP5-8.5
- Some wet signal along the Red Sea coast in south
- Projected changes in precipitation have larger uncertainties than temperature
Projected changes in Dust Uplift Potential (2041-2060)

April-September

- Ensemble mean

- a tendency to a decrease in DUP in norther part of the domain (regional spots)

- some increase in DUP in southern part of the domain (regional spots)

DUP is based on wind that has large uncertainties for future climate projections
Summary

✔ Dust Uplift Potential can be used as a simple dynamical proxy for climate projections of Sand and Dust Storms

✔ Sub-daily wind from climate models is necessary (1hr)

✔ Seasonal means presented here are basic diagnostic that can smooth many temporal details

✔ More sophisticated analysis:
  - focus on statistics of individual events (extreme events)
  - indices describing duration and intensity of events (e.g. the number of consecutive hours when DUP > 0)
Thank you for your attention !!!