How can high-resolution representation of the regional seas and aerosols modify regional climate change?

A fully-coupled regional climate system approach to question current CORDEX experimental protocol

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Potential sources of added-value in RCM projection runs

Med-CORDEX domain

- Better representation of the time-varying Forcings (sea surface temperature, aerosol load, land composition)
- Better representation of the constant Surface Boundary Conditions (topography, land-sea contrast)
- Better representation of the turbulence due to higher resolution
Potential sources of added-value in RCM projection runs

But … today the standard protocol in RCM projection simulations (e.g. PRUDENCE, ENSEMBLES, CORDEX)

High-resolution Atmosphere-RCM (with high-resolution constant SBCs) is driven by

1. low-resolution LBCs from GCM runs (1°-3°)
2. low-resolution SST from GCM runs (1°-2°)
3. low-resolution Aerosol forcing data from GCM runs (or even no aerosol varying forcing)
4. no land composition change

Better representation of the time-varying Forcings (sea surface temperature, aerosol load, land composition)

Better representation of the constant Surface Boundary Conditions (topography, land-sea contrast)

Better representation of the turbulence due to higher resolution

Med-CORDEX domain
Objectives and methods

- Explore protocols for RCM projection simulations that includes new potential sources of added-value
  - Twin simulations using the same RCM and the same driving GCM
  - Given a large-scale climate change signal, how is modified the regional/local signal?
  - RCP8.5, 2071-2100 vs reference period, Summer season
  - Comparison with the standard CORDEX Atmosphere-only RCM run
  - Comparison with the CMIP5 driving GCM

- Evaluate the impact of high-resolution representation of the regional SST forcing (Mediterranean Sea)
  - Using a fully-coupled atmosphere-ocean-river RCM

- Evaluate the impact of high-resolution representation of the regional aerosol forcing (African dust, European sulfate)
  - Using a fully-coupled atmosphere-aerosol RCM
Simulation protocols

**GCM:** CNRM-CM5
- Low-Resolution Atmosphere
- Low-Resolution Aerosols
- Low-Resolution Ocean

**RCM:** CNRM-ALADIN52
- High-resolution Atmosphere
  - Low-Resolution ocean SST
  - Low-Resolution aerosol forcing
Simulation protocols

**GCM: CNRM-CM5**
- Low-Resolution Atmosphere
- Low-Resolution Aerosols
- Low-Resolution Ocean

**RCM: CNRM-ALADIN52**
- High-resolution Atmosphere
- Low-Resolution ocean SST
- Low-Resolution aerosol forcing

**HR-SST**
- High-Resolution Ocean
- High-Resolution ocean SST
- Low-Resolution aerosol forcing

**CORDEX**
- Atm, SST, Aero
- Atm, Aero

ICRC-CORDEX 2016, Stockholm
Simulation protocols

**GCM:** CNRM-CM5
- Low-Resolution Atmosphere
- Low-Resolution Aerosols
- Low-Resolution Ocean

**HR-AER**
- Atm, SST
- Atm, Aero

**RCM:** CNRM-RCSM5
- High-resolution Atmosphere
- High-Resolution Aerosols
- Low-Resolution ocean SST
- High-Resolution aerosol forcing

**HR-SST**
- High-resolution Atmosphere
- High-Resolution Ocean
- Low-Resolution ocean SST
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**CORDEX**
- CNRM-ALADIN52
  - High-resolution Atmosphere
  - Low-Resolution ocean SST
  - Low-Resolution aerosol forcing
Simulation protocols

- Historical runs (HIST): 1950-2005 (CORDEX, HR-SST) or 1971-2000 (HR-AER)
- Scenario runs (RCP8.5): 2006-2100 (CORDEX, HR-SST) or 2071-2100 (HR-AER)
- Spin-up (SPIN): 2 years (CORDEX, HR-AER), 130 random years from 1949-1979 (HR-SST)
Summer climate change signal in the CORDEX run

- Large-scale climate change signal is consistent in the GCM and RCMs runs
- Summer precipitation increase in Central Mediterranean (CORDEX, CNRM-CM5)

Climate change signal in the CORDEX run in Summer (RCP8.5, 2071-2100 vs 1976-2005, JJA)
Impact of the high-resolution SST representation

- SST warms less in HR-SST run than in CORDEX run
- Spatial pattern of the warming is different (Balearic Sea, Adriatic Sea)

Climate change signal in Summer (RCP8.5, JJA, 2071-2100 vs 1976-2005)

* Here CORDEX means the GCM ocean model and HR-SST means the high-resolution Mediterranean Sea model
Impact of the high-resolution SST representation

- SST warms less in HR-SST run than in CORDEX run
- Spatial pattern of the warming is different (Balearic Sea, Adriatic Sea)

Climate change signal in Summer (RCP8.5, JJA, 2071-2100 vs 1976-2005)

Difference of climate change signal between HR-SST and CORDEX in Summer (2071-2100 vs 1976-2005, RCP8.5, JJA)

\[ \Delta \Delta = \Delta \text{HR-SST} - \Delta \text{CORDEX} \]

* Here CORDEX means the GCM ocean model and HR-SST means the high-resolution Mediterranean Sea model
Impact of the high-resolution SST representation

- T2m climate change signal is modified over sea and surrounding lands
- Enhanced drying over sea and surrounding lands in HR-SST

Climate change signal in Summer (RCP8.5, 2071-2100 vs 1976-2005, JJA)

Difference of Summer climate change signal between HR-SST and CORDEX

ΔT2m (°C)

ΔPrec (mm/d)

ΔΔT2m (°C)

ΔΔPrec (mm/d)
Impact of the high-resolution SST representation

- T2m climate change signal is modified over sea and surrounding lands
- Enhanced drying over sea and surrounding lands in HR-SST
- Land-sea contrast and dynamical modifications explain the West Europe signal

**Difference of climate change signal between HR-SST and CORDEX in Summer**
(2071-2100 vs 1976-2005, RCP8.5, JJA)
Impact of the high-resolution SST representation

- Contrary to the surface, deep layer heat content increases more in HR-SST.
- SST signal difference is the surface signature of a difference in the vertical distribution of the heat storage by the Mediterranean Sea.

**SST anomaly (°C)**

**Total heat content anomaly (°C)**

**Temperature profile anomaly (°C, 2071-2100 vs 1976-2005)**

- West Med
- East Med

- CORDEX
- HR-SST
Impact of the high-resolution SST representation

- The high-resolution sea model has a deeper, stronger and more realistic Mediterranean ThermoHaline Circulation (MTHC) in present-climate than the low-resolution ocean GCM.
- The MTHC in HR-SST is more efficient to redistribute heat over the vertical.

**Mixed layer depth** (m, DJF, 1976-2005)

**Yearly maximum MLD** (m)

**Zonal overturning streamfunction** (Sv, 1976-2005)

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- Low-Resolution Aerosols
- Low-Resolution Ocean

**RCM: CNRM-ALADIN52**
- High-resolution Atmosphere
- Low-Resolution ocean SST
- Low-Resolution aerosol forcing

**RCM: CNRM-RCSM4**
- High-Resolution Ocean
- High-Resolution Aerosols
  - High-Resolution ocean SST
  - Low-Resolution aerosol forcing

**HR-SST**
- High-resolution Atmosphere
- High-Resolution Ocean
- High-Resolution aerosol forcing
Impact of the high-resolution aerosols representation

- AOD (Aerosol Optical Depth) decreases in both runs, but less in HR-AER
- Over North Africa, AOD can even increase in HR-AER
- HR-AER shows small-scale pattern in the AOD signal (Po valley, mountain, cities)

△AOD (-)

CORDEX

HR-AER

France: -0.28
Tunisia: -0.14

France: -0.23
Tunisia: -0.06

△△AOD (-)

France: +18%
Tunisia: +57%

Climate change signal
(RCP8.5, 2071-2100 vs 1971-2000, JJA)

Difference of climate change signal between HR-AER and CORDEX
(2071-2100 vs 1971-2000, RCP8.5, JJA)
Impact of the high-resolution aerosols representation

- The aerosol forcing modifications lead to climate change signal modifications for the surface shortwave and surface temperature (North Africa, Po valley, Eastern Europe).

\[ \Delta \Delta AOD (\cdot) \]

\[ \Delta \Delta SW_{surf-down} (W/m^2) \]

\[ \Delta \Delta T2m (^\circ C) \]

France: +18%
Tunisia: +57%

France: +32%
Tunisia: -240%

France: +9%
Tunisia: -11%

Difference of climate change signal between HR-AER and CORDEX
(2071-2100 vs 1971-2000, RCP8.5, JJA)

Climate change signal modifications mostly due to aerosol forcing modifications
Impact of the high-resolution aerosols representation

- Dynamical effects (cloud, advection) also contribute for Western and South-East Europe

\[ \Delta \Delta \text{AOD (-)} \quad \Delta \Delta \text{SWsurf-down (W/m2)} \quad \Delta \Delta \text{T2m (°C)} \]

**Difference of climate change signal between HR-AER and CORDEX**
(2071-2100 vs 1971-2000, RCP8.5, JJA)
Impact of the high-resolution aerosols representation

- Over North Africa, AOD forcing modification in HR-AER is due to:
  - an increase in dust AOD
  - a reduced decrease in anthropogenic AOD

\[ \Delta \text{AOD-total} \]

\[ \Delta \text{AOD-Dust} \]

\[ \Delta \text{AOD-Anthropo} \]

\[ \Delta \text{AOD-Anthropo} \]

Climate change signal
(RCP8.5, 2071-2100 vs 1971-2000, JJA)

* Here CORDEX means the aerosol data coming from the GCM run
Impact of the high-resolution aerosols representation

- The increase in HR-AER dust AOD due to emission increase
- Dust emission increase due to an increased frequency of windy days in Africa

### Emission change (kg.m-2.s-1)

- **All aerosols**
- **Sea salt**
- **Desert Dust**
- **Sulfate**

#### Climate change signal in HR-AER
(RCP8.5, 2071-2100 vs 1971-2000, JJA)

#### Wind speed change (km/h)

- **Change in the number of windy days (wind speed ≥ 1 m/s)**

#### Emission decrease for Europe (-97%)

#### Emission increase for Africa (+60%)
Conclusions

- Sensitivity studies using one RCM forced by a given GCM allow to investigate the impact of regional forcing representation on regional to local climate change signal.

- Better representation of the Mediterranean Sea (MTHC, heat storage vertical distribution) can lead to different SST evolution (reduced warming) with impacts on the regional climate change (reduced or enhanced warming, enhanced drying).

- Better representation of the Mediterranean aerosols (emission process) can lead to different AOD evolution (increased dust) with impacts on the regional climate change (sign change in surface shortwave, reduced or enhanced warming).

- Physical understanding of the results increases our confidence. Direct and indirect (dynamical, cloud) effects of the forcing modifications contribute to explain the results.

- Results must be verified in multi-model exercises

(see proposed CORDEX FPS in Med-CORDEX)
Open issues for CORDEX

- The potential forcing roles of the regional SST evolution and of the regional aerosol evolution are underestimated in the current standard CORDEX protocol.
- RCM added-value can come from other elements than turbulence and topography.
- Regional/Local climate change may be driven by specific regional climate drivers (SST, aerosols), not only by the interactions between the large-scale drivers and the surface boundary conditions.
- To be investigated through dedicated regionally-designed FPS.

Discussion about the use of coupled RCM in CORDEX
Thursday, 5-7pm,
room U36 in the Geoscience building

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Summer climate change signal in the CORDEX run

- Large-scale climate change signal is consistent in the GCM and RCMs runs

ΔT2m (°C)

**Climate change signal in the CORDEX and CMIP5 runs in Summer**
(RCP8.5, 2071-2100 vs 1976-2005, JJA)