Recent developments in **RegESM** modeling system and plans to support higher resolution and multi-component applications

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Earth System

• It is represented by complex and non-linear interaction between different elements (atmosphere, hydrosphere, geosphere and biosphere).

• All the processes have different spatial and temporal scales
Earth System …

• All the processes have different spatial and temporal scales
• Response time under forcing also differs

IPCC Report
Earth System Models

- Defines interaction between components to simulate the state of the climate system in regional and global scale.
- ESMs include processes, impacts, and complete feedback cycles; for example, they can simulate droughts as well as the resulting change in plant cover due to the drought, which may lead to more or less drought (Heavens et al, 2013).
- Climate Model vs. Earth System Model
Regional Earth System Modeling (RESM)

- Higher resolution representation of physical processes
- Includes more sophisticated physical parameterizations and additional processes along with their non-linear interactions
- It might also include human behavior (pollution, irrigation etc.)
- Apart from the global ESMs, they require boundary condition (global ESMs, reanalysis datasets etc.), which adds extra complexity to the system

Prein et al., 2015 @ Reviews of Geophysics
## RESM@ITU and @ICTP - History

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
<th>Domains</th>
</tr>
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</table>
| 2012 | • No driver  
      RegCM is hosting also ocean component  
      • Single ocean model is supported (ROMS)  
      • Poor mass and energy conservation for exchange fields  
      • No automatized extrapolation (unaligned land-sea masks !!!)  
      • Hard to include additional components such as river, wave etc. | Caspian Sea  
      (Turuncoglu et al., 2013; GMD) |
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(Turuncoglu et al., 2013; GMD) |
| 2013 | • Centralized driver using ESMF’s NUOPC layer (via connectors)  
• All components are plugged into the driver  
• Added support for two different ocean model component  
(ROMS and MITgcm)  
• Mass and energy conservation is improved via customized bilinear interpolation along with global conservation support  
• Support for extrapolation (unaligned land-sea masks)  
• River Routing (Max Planck’s HD) component is included | Med. Sea |
| 2014-2015 | • The wave component (ECMWF’s WAM) is included (Surenkok & Turuncoglu, 2015; EGU)  
• Extensive benchmarking (PRACE – 2010PA2442) | Med. Sea  
Black Sea |
| 2016 | • ESMF library is updated to 7.0.0  
• Validation for Mediterranean domain  
(Turuncoglu & Sannino, 2016; CD – under revision)  
• Extensive validation with different configuration (2/3/4 component, different coupling intervals etc.) – paper is on-the-way | Med. Sea  
Caribbean  
Indian Ocean  
South Atlantic |
RegESM Design

- Model components merged with ESMF/NUOPC

Two different land surface model

Two different ocean model

ATM:
ICTP’s RegCM 4.4 / 4.5

OCN:
Rutgers Univ.
ROMS (r737)
MITgcm (63s / 64s)

WAV:
ECMWF’s WAM
4.5.3 MPI

RTM:
Max Planck’s HD
(1.0.2 modified)
Special thanks to Prof. Stefan Hagemann

# Following combination of model components can be used: 2 component: ATM-OCN, ATM-WAV,
3 component: ATM-OCN-RTM, 4 component: ATM-OCN-WAV-RTM
Performance Benchmark @ PRACE

- Test with Mediterranean domain (Standard + Extended)

- Tests:
  - Different coupling interval (30 min., 1 hour, 3 hours)
  - Different execution type (sequential vs. concurrent)
  - Different number of component (ATM-OCN, ATM-OCN-RTM)

- Test Environment:
  - CURIE @ France (PRACE – 2010PA2442)

ATM: 12 km - 24 layer

OCN: 1/12 deg. - 32 layer (ROMS)

# extended domain is configured to feed the computational resources
Performance Benchmark…

- Individual model components

Better scaling results for extended domain

To find best 2d decomposition parameters for ROMS
Performance Benchmark ...

• Coupling interval (only two component)

• The effect of coupling interval is very limited 😊

• 30 min case has more fluctuations (it might be related with the overload of the cluster)

• It is better to repeat tests couple of time to take more reliable measurements 😞
Performance Benchmark ...

- Number of model components (const. coupling time step)

- Last processor is shared between OCN and RTM

- RTM component reduces the performance ~ 30% in higher processor counts 😞

- Solutions:
  - Integrated RTM component (with RegCM4, i.e. Chym)
  - Using higher resolution and parallelized (MPI) RTM component such as RAPID etc. It could also help to improve river rep.
Model for Mediterranean Basin

The Scientific and Technological Research Council of Turkey (TUBITAK) founded 2 year project (under grant 113Y108), ended in Dec. 2015

- Atmosphere: RegCM4 revision 4283 (~50 km)
- Ocean: ROMS revision 783 (1/12 deg. ~ 9 km)
  - Closed boundary in Atlantic – used as a buffer zone
  - The coupling time step is 3 hour
  - ATM-OCN: wind stress, net heat and freshwater flux (E-P), shortwave rad., surface pressure and OCN-ATM: sea surface temperature
  - Prescribed river discharge (generated by Max Planck HD model)

# It is the first attempt for the validation of ROMS (Regional Ocean Modeling System) ocean model for Med.
Validation

• Sea Surface Temperature

SST anomaly over Med. Sea

Seasonal SST Climatology

ERSST used in standalone simulation
Validation ...

- Surface Wind and Circulation

Wind speed underestimated over Gulf of Lion

# coupled model tends to decrease wind speed over the sea when it is compared with standalone simulation.

Surface and 300 m circulation is well represented.
Validation …

- Heat flux components over Med.
- Coupled and Standalone model simulations are very similar except LHF
- The net heat flux is in the range for both CPL and STD runs

<table>
<thead>
<tr>
<th></th>
<th>SWF</th>
<th>LWF</th>
<th>SWF+LWF</th>
<th>SH</th>
<th>LH</th>
<th>NET</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CORE.2</strong></td>
<td>180.41</td>
<td>-81.24</td>
<td>99.17</td>
<td>-20.18</td>
<td>-99.80</td>
<td>-20.81</td>
</tr>
<tr>
<td><strong>NOCS</strong></td>
<td>200.02</td>
<td>-62.21</td>
<td>137.81</td>
<td>-8.79</td>
<td>-91.93</td>
<td>37.10</td>
</tr>
<tr>
<td><strong>EINT</strong></td>
<td>218.26</td>
<td>-100.14</td>
<td>114.12</td>
<td>-17.03</td>
<td>-112.12</td>
<td>-15.03</td>
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<tr>
<td><strong>R50E</strong></td>
<td>200.75</td>
<td>-82.34</td>
<td>118.41</td>
<td>-11.38</td>
<td>-121.72</td>
<td>-14.70</td>
</tr>
<tr>
<td><strong>C50E</strong></td>
<td>200.70</td>
<td>-81.31</td>
<td>119.39</td>
<td>-9.85</td>
<td>-110.52</td>
<td>-0.99</td>
</tr>
</tbody>
</table>

The coupled model reduces LH over Mediterranean Sea

Turuncoglu and Sannino, 2016 @ CD
Validation ...

- E, P and E-P over Med.
- Coupled model tends to reduce evaporation
- The monthly distribution of E, P and E-P are very similar for STD and CPL
- The accepted E-P is 1000 mm/yr

Turuncoglu and Sannino, 2016 @ CD
Validation …

- Spatial distribution of E, P and E-P
- The effect of coupled model is more apparent in EMED
- The CPL model has more P in south of EMED
- The E-P estimates are consistent with available obs. for CPL model

Turuncoglu and Sannino, 2016 @ CD
Data Access

• Currently, ITU is a data provider for MedCORDEX project
• Both coupled (RegCM4+ROMS) and standalone model simulations (RegCM4) are uploaded
  • Spatial resolution is MED44
  • Daily and monthly averages of surface variables
  • Monthly average of atmospheric variables \((u_a, v_a, t_a, z)\) at 850 and 500 mb
• Documentation of simulations
  • ITU-RegCM4 - [http://mistrals.sedoo.fr/?editDatsId=1434](http://mistrals.sedoo.fr/?editDatsId=1434)
  • ITU-RegESM1 - [http://mistrals.sedoo.fr/?editDatsId=1433](http://mistrals.sedoo.fr/?editDatsId=1433)
  • Turuncoglu and Sannino, 2016 @ Climate Dynamics
• Data Access
  • It is distributed via MedCORDEX database
• Atmosphere: RegCM4.4 (20 km)
• Ocean: MITgcm (1/12 deg. ~ 9 km)
  • Closed boundary in Atlantic – used as a buffer zone
  • The coupling time step is 3 hour
  • ATM-OCN: wind stress, net heat and freshwater flux (E-P), shortwave rad., surface pressure and OCN-ATM: sea surface temperature
• River Routing: Max Planck’s HD model (17 major rivers)
Validation

• Precipitation (1979-2013 climatology)

# This reduction is mainly associated with a decrease of evaporation over the sea

# precipitation pattern is well represented: a slight overestimation is observed in Alps and Eastern Europe where the orography is more accentuated

• Evaporation

# This reduction is mainly associated with a decrease of evaporation over the sea
Validation …

- Circulation at 20 m and Sea Surface Height (SSH)

  a. MITgcm
  b. MITgcm_RegESM
  c. MyOcean
  d. MITgcm SSH
  e. MITgcm_RegESM SSH
  f. Aviso ADT SSH

# Surface circulation (m/s) is well represented in both standalone and coupled model with respect to MyOcean Med. Reanalysis (1987-2012) and Aviso (1993-2012) datasets.
# Reduced evaporation (Eastern-Med.) affects the strength of Rhodes Gyre.
Validation …

- Sea Surface Temperature (SST) and Salinity (SSS)

  a. MITgcm SST  
  b. MITgcm-RegESM  
  c. MyOcean SST  
  d. ERA-Interim SST  
  e. MITgcm SSS  
  f. MITgcm-RegESM  
  g. MyOcean SSS

Both coupled and standalone exhibit both positive/negative significant biases (up to 1°C) in the SST with respect MyOcean and Era-Interim SST in areas where air-sea interactions are dominant (Adriatic Sea, Gulf of Lions, Rhodes Gyre, Aegean Sea).

Spatial distribution of SSS is well represented except Adriatic Sea where both models overestimate the SSS.

In the Ionian the northward shift of MAW in the coupled and MyOcean lead to lower values of SSS with respect the standalone.
Extensive Testing of Modeling System

<table>
<thead>
<tr>
<th>Run Short Name</th>
<th>Run Id</th>
<th>Coupling Type</th>
<th>Coupling Time Step</th>
<th>Active Models</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AO1</td>
<td>A1</td>
<td>Explicit</td>
<td>30 mins</td>
<td>ATM+OCN</td>
<td></td>
</tr>
<tr>
<td>AO2</td>
<td>A2</td>
<td>Explicit</td>
<td>1 hour</td>
<td>ATM+OCN</td>
<td></td>
</tr>
<tr>
<td>AO3</td>
<td>A3</td>
<td>Explicit</td>
<td>3 hours</td>
<td>ATM+OCN</td>
<td>base run</td>
</tr>
<tr>
<td>AO4</td>
<td>A5</td>
<td>Semi-implicit</td>
<td>3 hours</td>
<td>ATM+OCN</td>
<td></td>
</tr>
<tr>
<td>AW1</td>
<td>B1</td>
<td>Explicit</td>
<td>3 hours</td>
<td>ATM+WAV</td>
<td>u and v &lt;-&gt; rough.</td>
</tr>
<tr>
<td>AW2</td>
<td>B2</td>
<td>Explicit</td>
<td>3 hours</td>
<td>ATM+WAV</td>
<td>wdir, friction vel. &lt;-&gt; rough.</td>
</tr>
<tr>
<td>AOR</td>
<td>C1</td>
<td>Explicit</td>
<td>3 hours</td>
<td>ATM+OCN+RTM</td>
<td>river discharge as SBC</td>
</tr>
<tr>
<td>AORW</td>
<td>D1</td>
<td>Explicit</td>
<td>3 hours</td>
<td>ATM+OCN+RTM+WAV</td>
<td></td>
</tr>
<tr>
<td>Standalone</td>
<td>E, F, G, H</td>
<td>-</td>
<td>-</td>
<td>ATM/OCN/RTM/WAV</td>
<td></td>
</tr>
</tbody>
</table>

- Fast time step (i.e. 1 hour, 3-hours)
- Slow time step (i.e. 1 day)
Comparison based on # used models

- Inter-annual variability and monthly climatology of E, P and E-P
- The effect of WAV component is minimal in E, P and E-P
- The OCN mainly affects the E-P balance by reducing E and P
- The monthly climatology is also modified

Comparison based on # used models:

A – ATM-OCN
B – ATM-WAV
C – ATM-OCN-RTM
D – ATM-OCN-RTM-WAV
### Applications

#### Mediterranean

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<tr>
<th>Models</th>
<th>ATM</th>
<th>OCN</th>
<th>RTM</th>
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<td>RegCM 4.4.5.9</td>
<td>MITgcm c64s</td>
<td>HD</td>
<td></td>
</tr>
<tr>
<td>Res.</td>
<td>20 km, 23L, 353x253</td>
<td>1/12°, 75L, 276x408</td>
<td>0.5° global</td>
</tr>
<tr>
<td>ICBC</td>
<td>ERA-Int ERSST</td>
<td>online ATM</td>
<td></td>
</tr>
<tr>
<td>Details</td>
<td>BATS, Grell+MIT</td>
<td>GGL90</td>
<td>17 major rivers</td>
</tr>
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- Coupled with RegESM driver
- 3 hours coupling interval between ATM and OCN and 1 day in interaction with RTM
- 1979-2013 (35 years)

#### South Atlantic

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<tr>
<td>Res.</td>
<td>50 km, 23L, 330x206</td>
<td>1/8°, 40L, 800x510</td>
<td>0.5° global</td>
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<td>ICBC</td>
<td>ERA-Int ERSST</td>
<td>online ATM</td>
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<tr>
<td>Details</td>
<td>CLM, UW-PBL, MIT</td>
<td>KPP</td>
<td>7 major rivers</td>
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- Coupled with RegESM driver
- 3 hours coupling interval between ATM and OCN and 1 day in interaction with RTM
- 1979-2007 (25 years)

#### Central America

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<tr>
<td>Res.</td>
<td>50 km, 23L, 308x170</td>
<td>1/8°, 40L, 1050x540</td>
<td>0.5° global</td>
</tr>
<tr>
<td>ICBC</td>
<td>ERA-Int ERSST</td>
<td>online ATM</td>
<td></td>
</tr>
<tr>
<td>Details</td>
<td>CLM, Grell, KF</td>
<td>KPP</td>
<td>10 major rivers</td>
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- Coupled with RegESM driver
- 3 hours coupling interval between ATM and OCN and 1 day in interaction with RTM
- ?

#### Central Asia

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- Coupled with RegESM driver
- 3 hours coupling interval between ATM and OCN and 1 day in interaction with RTM
- 1979-2007 (25 years)
RegESM Modeling System

THE GOOD

1/ easy to use and extend flexible modeling system
2/ model components can be upgraded easily
3/ state-of-art driver design that follows common conventions / standards
4/ ready to use with new non-hydrostatic core
5/ supports both CLM and BATS

THE BAD

1/ only global conservation is supported and might have a problem for large domains
2/ the bottleneck due to sequential RTM component
3/ WAM uses 1d decomposition and limits higher number of processor for seq. type coupling

AND THE UGLY

1/ sharp gradient between interactive and prescribed SST (issue #12)
2/ no wind rotation algorithm for Polar Stereographic (POLSTR) projection (issue #14)
# Plans: Short - Mid - Long

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<td>1</td>
<td>• Using modeling system for different applications and domains</td>
<td>Med. Sea.</td>
</tr>
<tr>
<td></td>
<td>• Future climate scenarios using CMIP5 models</td>
<td>Black Sea</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Caspian Sea</td>
</tr>
<tr>
<td>2</td>
<td>• New applications using hydrostatic core at higher spatial (3-12 km)</td>
<td>Med. Sea.</td>
</tr>
<tr>
<td></td>
<td>and temporal resolution for Med-CORDEX-2, extreme events and fast-moving</td>
<td></td>
</tr>
<tr>
<td></td>
<td>processes</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>• Wave effect on current (WEC): 1) gradient of radiation stress tensor or</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2) vortex force (VF)</td>
<td></td>
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<tr>
<td></td>
<td>• Additional wave component such as WW3 to support curvilinear grids in the</td>
<td></td>
</tr>
<tr>
<td></td>
<td>wave component. It will allow to cover whole atmospheric model domain</td>
<td></td>
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<tr>
<td></td>
<td>• Higher resolution river routing component for better representation of</td>
<td></td>
</tr>
<tr>
<td></td>
<td>rivers (i.e. Chym, CaMa-Flood etc.)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>• Continuous Integration (CI)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Standardization of model installation (integrate with Travis-ci to test the build)</td>
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</tr>
<tr>
<td></td>
<td>• Usage of virtualization technologies such as Docker containers to run and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>test modeling system in the cloud (Google, Azure, Amazon etc.)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>• New approaches to analyze fast-moving processes in high res.</td>
<td></td>
</tr>
</tbody>
</table>
Questions !!!

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http://faculty.itu.edu.tr/turuncogl11/