Design and first simulation with a tri-coupled AORCM dedicated to the Mediterranean study

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The Mediterranean Sea can be considered as a thermodynamic machine that exchanges water and heat with the Atlantic Ocean trough the Strait of Gibraltar and with the atmosphere through its surface. Considering the Mediterranean Sea Water Budget (MSWB) multi-year mean, the Mediterranean basin loses water by its surface with an excess of the evaporation over the freshwater input (precipitation, river runoff, Black Sea input). Moreover the MSWB largely drives the Mediterranean Sea water mass formation and therefore a large part of its thermohaline circulation. This could even have an impact on the characteristics of the Atlantic thermohaline circulation through the Mediterranean Outflow Waters (MOW) that flow into the Atlantic at a depth of about 1000 m. From a climate point of view, the MSWB acts as a water source for the Mediterranean countries and then plays an important role on the water resources of the region. Consequently the Mediterranean basin can impact the global climate through two branches, the fast atmospheric branch through the regional air-sea interactions and the water vapour transport and the slow oceanic branch through the Mediterranean deep water masses, the MOW and the Atlantic Ocean thermohaline circulation.

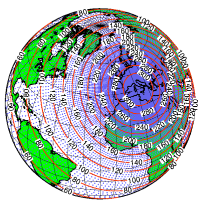
To represent the impact of the Mediterranean basin on the global climate, we must at least accurately simulate the MSWB that drives the fast branch as well as the formation of the Mediterranean deep water masses that lead to the MOW. This requires to work with both high resolution atmosphere models and high resolution ocean models. This is mainly due to the complexity of the topography surrounding the Mediterranean basin, as well as the complexity of the Mediterranean sub-basins and straits, its air-sea fluxes and its water mass system. Moreover we must also simulate the feedbacks of the MSWB and of the MOW on the global coupled climate system that is to say the branches themselves.

Pursuing that goal we decided to develop a Mediterranean high-resolution Atmosphere-Ocean Regional Climate Model (AORCM) embedded in a global coupled model. This new numerical tool should allow to address the following scientific issues:

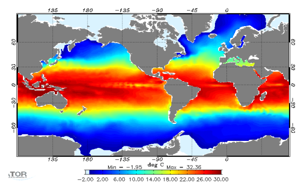
- What is the full climate variability of the Gibraltar Strait exchanges ?
- How does it affect the Mediterranean air-sea fluxes variability ?
- What is the full climate variability of the MOW ?
- What is the impact of the MOW on the Atlantic thermohaline circulation and then on the global climate ?
- What is the impact of the water vapor transport from the Mediterranean area on the global climate ?

Technically speaking, we created a tri-coupled model coupling the stretched-grid ARPEGE-Climate model (Déqué and Piedelievre 1995) with two ocean models, the global NEMO-ORCA2 (Madec, 2008) and the Mediterranean NEMO-MED8 (Somot et al. 2006, Sevault et al. 2009).
The ARPEGE-Climate atmosphere model is used here in its version 4.6 for the physics www.cnrm.meteo.fr/gmgec/site_engl/arpege/arpege_en.html and with the *mediash* configuration (TL159c2.5, 31 vertical levels). This particular configuration covers the whole planet with a stretched grid allowing a refinement over the Mediterranean area (see Figure 1a) with a spatial resolution of about 50 km over the area of interest. The stretched version of ARPEGE-Climate has already been coupled to a Mediterranean Sea ocean model (Somot et al. 2008).

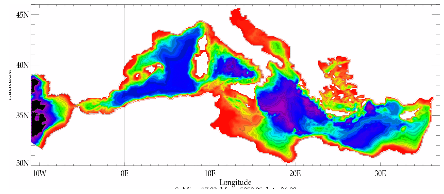
(a)



(b)



(c)



<u>Figure 1:</u> Domain and grid definition of (a) the stretched ARPEGE-Climate, (b) the global NEMO-ORCA2 ocean model and (c) the NEMO-MED8 regional ocean model.

The global ocean is a global version of the NEMOv2 ocean platform in which the ocean model is based on OPA9 (Madec 2008). The horizontal mesh is based on a 2° by 2° Mercator grid (i.e., same zonal and meridional grid spacing). The ORCA2 grid (see Figure 1b) is used in this study in which the resolution evolves from 0.5° in the tropics to 2° close to the poles. The resolution is about 1° at the latitude of the Mediterranean Sea. There are 31 levels in the vertical, with the highest resolution (10 m) in the upper 150 m. This version of the model is developed at LOCEAN with modification mainly concerning the ocean-atmosphere coupling done at CERFACS.
The NEMO-MED8 model is a Mediterranean version of the same NEMOv2 platform developed at CNRM. The NEMO-MED8 model (Sevault et al. 2009) has an implicit free surface option, a buffer zone in the near Atlantic ocean, explicit river runoff fluxes, 43 Z-levels with partial steps and a spatial resolution of 1/8°

(actually from 9 to 12 km from the north to the south of the basin). NEMO-MED8 does not cover the Black Sea (see Figure 1c). Its grid is tilted and stretched within the Gibraltar Strait to increase locally its resolution up to 6 km and to follow better the SW-NE orientation of the strait. The grid definition, the surface forcing method as well as many physical options are the same as in the previous CNRM Mediterranean Sea model (OPAMED8, Somot et al. 2006).

Both ocean models are daily two-way coupled at the Gibraltar Strait and the atmospheric model is daily two-way coupled with both ocean models. The SST of NEMO-MED8 is used over the Mediterranean Sea whereas the SST of NEMO-ORCA2 is used everywhere else. The version 3 of the OASIS coupler developed at CERFACS (Valcke 2006) is used for the air-sea coupling.

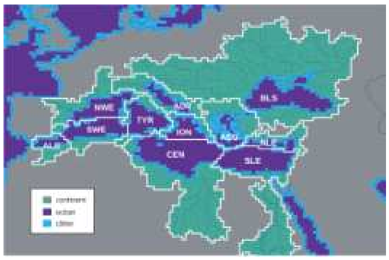
The communication between global ocean and Mediterranean Sea is performed as follows: the exchanged fields are temperature and salinity from the global ocean to the Mediterranean Sea and water, heat and salt transports from the Mediterranean Sea to the global ocean.

The near Atlantic of the high resolution Mediterranean Sea model NEMO-MED8 is simulated as an Atlantic box, also called buffer zone in which the 3D temperature and salinity profiles are relaxed towards observed monthly-mean climatology in the stand-alone mode. At the contrary, along the tri-coupled simulation, these profiles are updated every day by the corresponding Atlantic zone of the global ocean model. This allows the NEMO-MED8 model to take into account the daily variability of the near Atlantic surface waters and its likely evolution along the 21^{st} century for example.

From the Mediterranean model to the global ocean, we use the so-called Cross-Land Advection (CLA) parameterization available in NEMO-ORCA2 (Madec 2008, A. Bozec, pers. comm.). The Gibraltar Strait is closed in this low resolution version and the heat, salt and water exchanges through the wall are parameterized. This parameterization allows to assess the MOW characteristics (heat and salt transport) in the Atlantic part of the global model with respect to the characteristics of the Mediterranean deep waters (on the other side of the wall in the stand-alone mode) and of the Atlantic sub-surface waters (entrainment process during the MOW cascading). In the tri-coupled model we replace the low-resolution Mediterranean values by the heat, salt and water transports computed by the high-resolution NEMO-MED8. In the stand-alone mode, the water transports (Gibraltar Inflow, entrainment rate, Atlantic recirculation) are imposed by the CLA. In the tri-coupled model, the Gibraltar inflow is computed by NEMO-MED8, the Gibraltar outflow is computed thanks to the high-resolution MSWB. The only remaining imposed variables are the volume and the depth of the sub-surface entrainment, the Atlantic recirculation at different layers and the depth of the MOW in the Atlantic (1000m). Note that this last and strongest hypothesis is however sustained by a previous Mediterranean Sea climate change scenario (Somot et al. 2006).

The CLA parameterization allows the MOW volume and hydrological characteristics of the global model to evolve at the daily time-scale depending on NEMO-MED8 evolution.

In the future, a river runoff routing scheme TRIP will be added in this tri-coupled model to simulate the river component of the regional coupled system. The Mediterranean and Black Sea catchment basin is detailed in Figure 2.



<u>Figure 2:</u> River catchment basin of the Mediterranean Sea (extracted from Ludwig et al. 2009) also used for the TRIP routing scheme model

After spin-up, a first 50-year long simulation using observed GHG and aerosols concentrations has been performed with this Mediterranean tri-coupled AORCM (1950-2000) in the framework of the European CIRCE project. The integrated Mediterranean heat and water (E-P-R) losses are equal to –3.1 W/m^2 and –0.59 m/year in average over 30 years in agreement with current estimates. At the Gibraltar Strait, the surface inflow is equal to 0.78 Sv and the net transport to 0.045 Sv in very good agreement with the latest estimates.

The first scientific goals of such simulation are to study the variability of the Gibraltar Strait exchanges (heat, salt, water transports) and its impact on the variability of the Mediterranean Sea Water Budget and on the variability of the Mediterranean Outflow Waters.

References

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