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MED12, OCEANIC COMPONENT FOR THE MODELING OF THE REGIONAL MEDITERRANEAN EARTH SYSTEM

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Introduction

MED12 [Lebeaupin-Brossier et al., 2011, 2012a; Beuvier et al., 2012] is the new regional configuration of the Mediterranean Sea of the ocean general circulation model NEMO [Madec and the NEMO Team; 2008]. The MED12 grid has been extracted from the 1/12° global operational Mercator model [Lellouche et al. 2012]. The development of MED12 is made in the continuity of the evolution of the French modeling of the Mediterranean Sea, following OPAMED16 [Béranger et al., 2005], OPAMED8 [Somot et al., 2006] and NEMOMED8 [Beuvier et al., 2010]. The MED12 domain covers the entire Mediterranean Sea and a part of the Atlantic Ocean, until 11°W. MED12 does not cover the Black Sea. With a horizontal resolution of 1/12°, MED12 is an eddy-resolving model in the major part of the domain. The vertical resolution uses 50 unevenly spaced vertical levels with the partial-cells parameterization for the bottom layer. The time step is 12 minutes.

The bathymetry comes from the 10th version of the Mercator-LEGOS bathymetry at a resolution of 30"x30", composed of the merging between the GEBCO-08 database, the MEDIMAP bathymetry [Medimap Group, 2005] and the Ifremer bathymetry of the Gulf of Lions [Berné et al., 2004]. The initial states come from the MEDATLAS-II climatology [MEDAR/MEDATLAS Group, 2002] in the Mediterranean domain and from the climatology of Levitus et al. [2005] in the Atlantic domain. MED12 includes a new parameterization of the Atlantic inputs modelled through damping of 3D-temperature, 3D-salinity and sea surface height climatologies. The sea surface height climatology is built with GLORYS-1 data [Ferry et al. 2010] to conserve the ocean volume in a regional configuration using the filtered sea surface parameterization of NEMO. The bottom turbulent kinetic energy background in the bottom friction parameterization is a 2D field corresponding to the mean tidal energy computed from a tidal model [Lyard et al., 2006]. The river runoffs of Ludwig et al. [2009] and the Black Sea inputs are included following the method of Beuvier et al. [2010]. More details can also be found in Beuvier et al. [2012].

The MED12 model has been developed in the context of the SiMED and MORCE projects, in collaboration with Mercator Ocean teams and national laboratories. Several ongoing projects aim at coupling MED12 with atmospheric models and biogeochemical models. In the following, we present first results obtained with a free ocean simulation and with an ocean-atmosphere coupled simulation.

Ocean modeling

A 53-year simulation from 1958 to 2011, called hereafter MED12-long [Beuvier, 2011], was carried out. For the initial state, 3D temperature and salinity initial fields are weighted by a low-pass filtering with a time window of ten years of the MEDATLAS data covering the 1955-1965 period. The simulation starts in October 1958 with an ocean at rest. The atmospheric forcing is ARPERA [Herrmann and Somot 2008], a dynamical downscaling of the ERA40 reanalysis [Simons and Gibson, 2000] by the ARPEGE-Climate model [Déqué and Piedelievre, 1995].

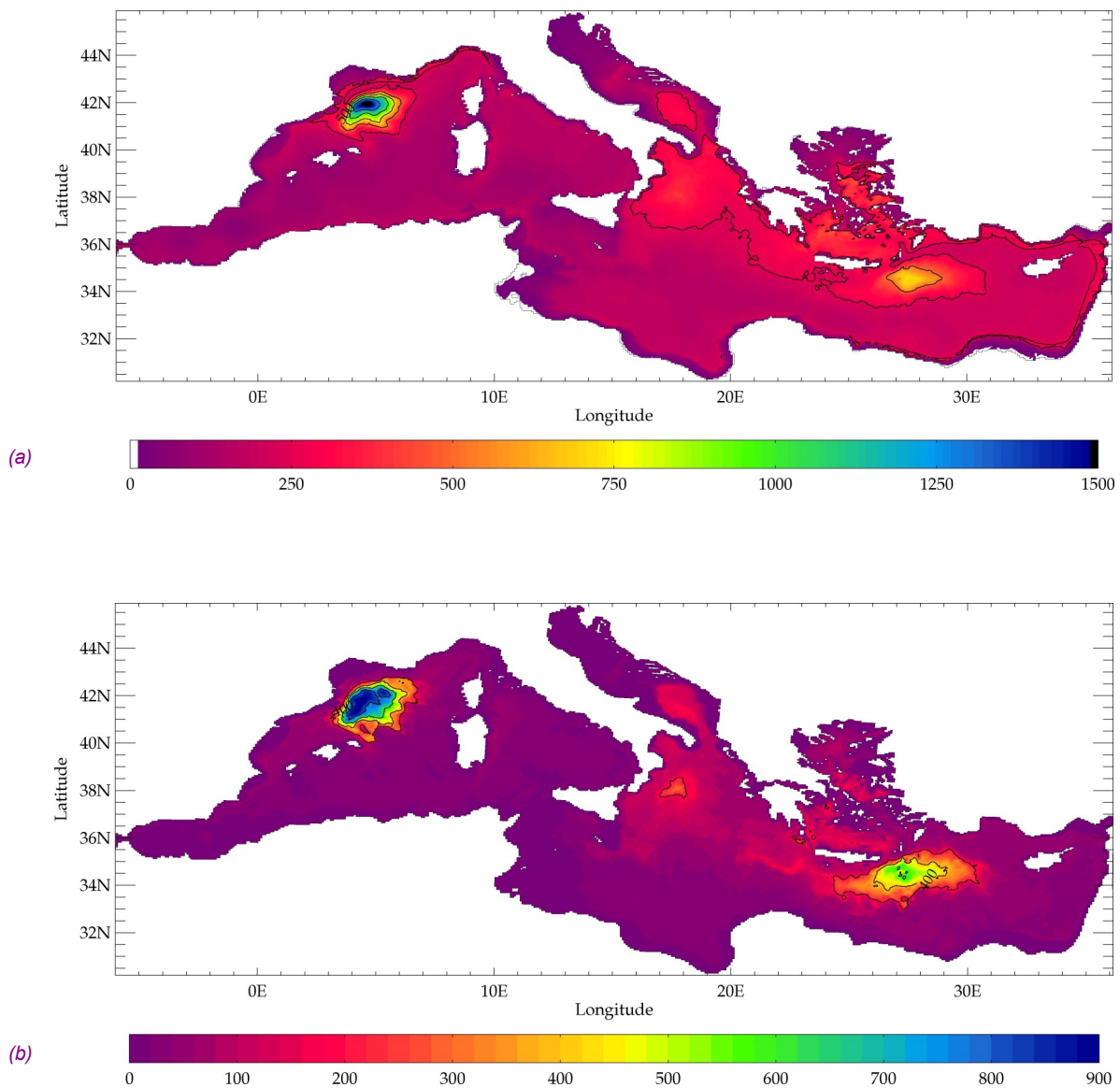
The long-term variability of the Mediterranean Sea is illustrated by interannual variations of heat and salt contents between 1958 and 2011, expressed here by 3D-average temperature and salinity, T3D and S3D respectively (Figure 1). The model is compared with the two gridded climatologies IN3 [Ingleby & Huddleston, 2007] and MEDATLAS [Rixen et al., 2005]. The T3D and S3D of the whole water column (Figures 1a and 1b) are in good agreement with observations. The T3D is a little too high by 0.1°C in MED12-long while the S3D trend is well simulated, but with a lack of interannual S3D variations. In the surface layer (0-150m), the T3D is very well reproduced (Figure 1c), mainly thanks to the retroaction term relaxing the model sea surface temperature towards the "observed" sea surface temperature of Reynolds et al. [2002]. However, values of the surface layer S3D are too low by 0.04 to 0.28 psu (Figure 1d). In the intermediate layer (Figures 1e and 1f), values of both T3D and S3D are too high (+0.2°C for T3D, +0.02 to +0.08 psu for S3D). Nevertheless, the T3D interannual variations of the intermediate layer are well captured. In the bottom layer (Figures 1g and 1h), the T3D and S3D trends are a little higher than in the climatological datasets (+0.08°C, +0.03 psu) and no interannual variations are simulated. However, a large uncertainty exists for this layer, as both gridded datasets may over-estimate deep temperature and salinity interannual variations because of under-sampling (more pronounced for salinity).



Figure 1: Mean potential temperature **T3D** (a, c, e and g) and mean salinity **S3D** (b, d, f and h) for different layers of the Mediterranean Sea: the whole water column (0 m–bottom, a and b), the upper layer (0–150 m, c and d), the intermediate layer (150–600 m, e f), and the deep layer (600 m–bottom, g and h), and, for different datasets: the **MED12-long** simulation (blue solid line), the interannual gridded database of [Rixen et al., 2005] (black dashed lines, with the ± 1 standard deviation interval in grey) and the **EN3** interannual gridded database [Ingleby and Huddleston, 2007] (green solid line). The **S3D** scales are five times smaller than the **T3D** allowing the representation of the same impact on potential density.

Intermediate and deep convection regularly occur in specific areas of the Mediterranean Sea as illustrated in Figure 2. The turbocline depth is used to show the convection depth as it is a better criterion available in NEMO for the low stratified Mediterranean Sea than the criteria on the thermocline or the pycnocline depth. The 53-year mean of the annual turbocline depth maxima (Figure 2a) highlights well known areas of intermediate or deep convection, such as the Gulf of Lions (around $42^{\circ}\text{N} - 5^{\circ}\text{E}$), the Rhodes Gyre in the Levantine sub-basin (around $34^{\circ}\text{N} - 26^{\circ}\text{E}$), the southern Adriatic sub-basin and the Aegean sub-basin. A new area is also captured in the northern Ionian sub-basin. However, the values for the Adriatic sub-basin are not deep enough, barely reaching 300 m depth in average whereas observations show values reaching a maximum of about 1200 m depth during several years. Interannual variations (Figure 2b) are relatively high in the Gulf of Lions (standard deviation of 800 m). Interannual variations are also relatively high in the Levantine sub-basin (standard deviation of 500 m) and in the northern Ionian basin. According to the ratio between the standard deviation and the 53-year mean of turbocline depth (Figure 2c), values over 120% at the north-eastern and the south-western extremities of the convection area in the Gulf of Lions, indicate the maximum spatial extent of the deep water formation that can be reached during strong events. In the same way, high values in the Levantine area are relative to formation of Levantine Deep Water. And values around 80% in the northern Ionian sub-basin show intermediate water formation during very strong winters.

This MED12 configuration is devoted to be used soon in the reanalysis of the Mediterranean circulation driven by ALADIN-Climate atmospheric forcing from CNRM (horizontal resolution of 12 km). At the same time, new versions of Mediterranean configurations are being developed, using more 75 vertical z-levels or using a higher horizontal resolution MED36 ($1/36^{\circ}$, horizontal resolution of 2.5 km).



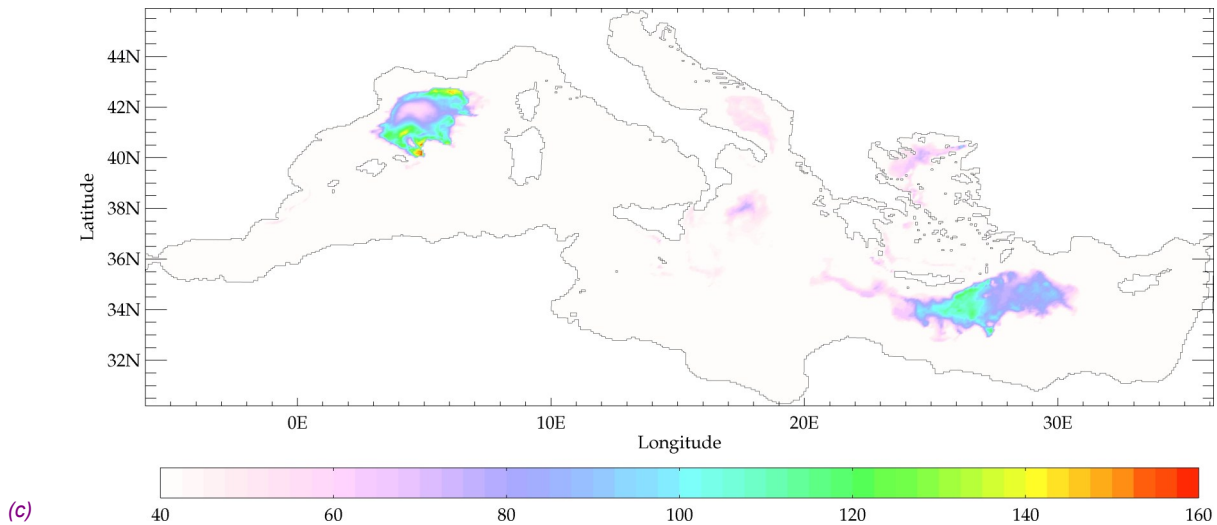


Figure 2: (a) Average of the yearly maximum turbocline depth over the period 1958-2011 (in meters, contours every 250 m), (b) standard deviation of the yearly maximum turbocline depth around the average in (a) (in meters, contours every 200 m), and (c) ratio (in %) between (b) and (a).

Ocean-Atmosphere Coupling

MED12 is the ocean compartment in the MORCE (*Model of the Regional Coupled Earth system*) system [Drobinski et al., 2012]. MED12 is coupled to the *Weather Research and Forecasting* (WRF) atmospheric model [Skamarock et al., 2008]. The WRF domain covers the Mediterranean basin [28°N-50°N, 13°W-42°E] with a 20-km horizontal resolution and has 28 sigma-levels in the vertical. Initial and lateral conditions are taken from the ERA-interim reanalysis [Simons et al., 2007] provided every 6 hours with a 0.75° resolution and a nudging towards the driving fields is applied with a coefficient of $5 \cdot 10^{-5} \text{ s}^{-1}$ for temperature, humidity and velocity components above the planetary boundary layer. The complete set of physical parameterizations chosen for the WRF model is detailed in Lebeaupin Brossier et al. [2012b].

Companion uncoupled and coupled simulations have been done. In the first one, MED12 is driven in surface with a 3-hourly frequency, by WRF fluxes extracted from the dynamical downscaling of the ERA-interim reanalysis obtained with WRF alone. And the coupled simulation runs with two-way interactive exchanges between the two compartment-models managed by the OASIS coupler [Valcke, 2006]. The exchanged variables are the sea surface temperature, the heat flux (solar Q_s and non-solar Q_{ns}), the water flux ($F_w=E-P$) and the momentum flux (τ). The coupling frequency is 3 hours. Both simulations run from January 1989 to December 2008 and start with an ocean at rest.

Focusing on the extreme 2005 deep convection event in the Gulf of Lions, the comparison between the uncoupled and coupled simulations is illustrated by the horizontal and vertical distributions of the convection in Figure 3. Deeper mixed layer is formed in the southern part of the Gulf of Lions (around 4°E-41°N) in the uncoupled simulation (Figure 3a) while the deep convection area is extended farther eastwards in the coupled simulation (Figure 3b). In particular, a larger turbocline depth is found in the Tyrrhenian sub-basin (Bonifacio gyre area) and in the Ligurian sub-basin. In the Ligurian sub-basin, the chronology of the convection events driven by strong winds is the same in the two simulations. But the saltier and colder intermediate layer is rapidly mixed on 15th February 2005 in the coupled simulation and then the mixed layer reaches the sea bottom of the Ligurian sub-basin (2200 m). In the uncoupled simulation, the turbocline depth reached only 450 m depth on 8th March 2005. The difference in the characteristics of intermediate and deep layers is the ocean response to the coupled mode, and is an integrated signature of the air-sea flux modulation by the coupling (for example, larger heat loss over the Ligurian and Bonifacio cyclonic gyres in winter 2005, Figure 3).

The coupling of MED12 with other atmospheric models is currently in development (COSMO-CLM at Frankfurt University, ALADIN-Climate at Météo-France), to be part of multiple-compartment regional climate systems over the Mediterranean region and to further investigate the interannual variability of strong air-sea exchanges that trigger in particular the deep ocean convection.

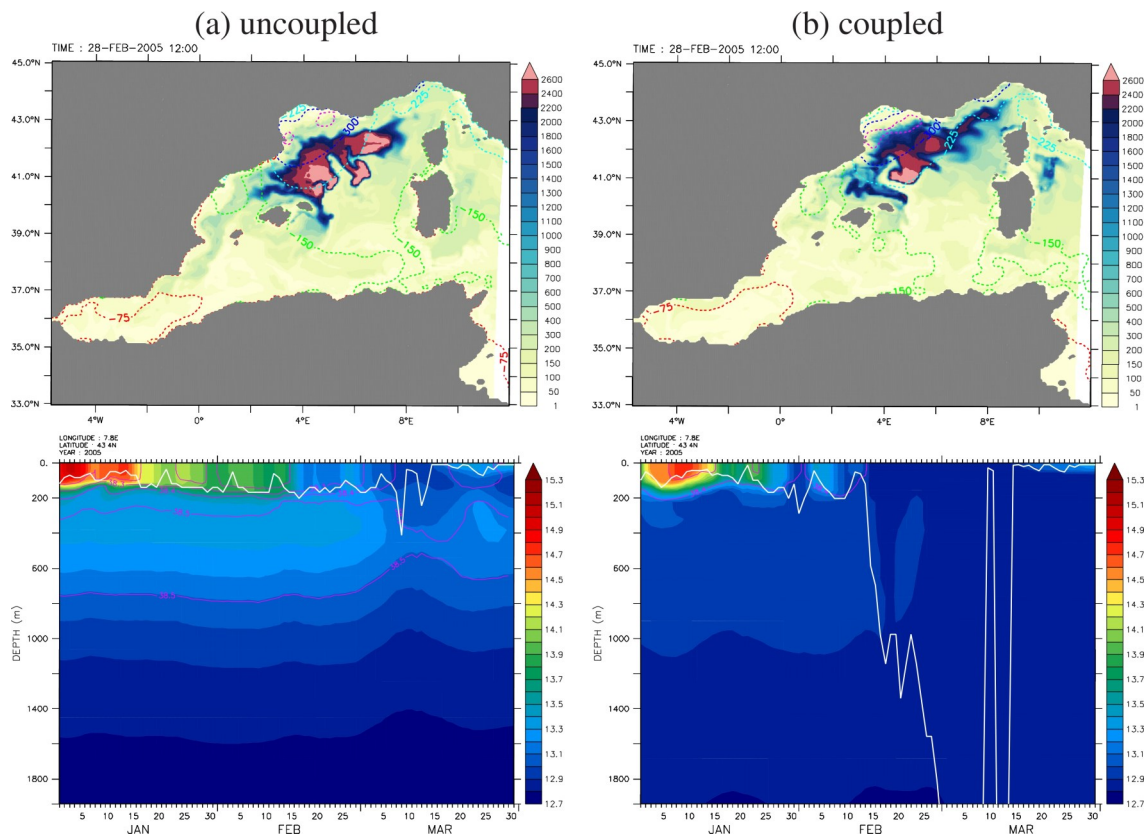


Figure 3: Top panels: Depth of the turbocline for 28th February 2005 (in m, color) and monthly mean heat loss ($W m^{-2}$, dashed lines every $75 W m^{-2}$). Bottom panels: for the period January to March 2005 at $7.8^{\circ}E-43.4^{\circ}N$ between 0 and 2000 m in the Ligurian sub-basin, Howmüller diagrams of temperature profiles ($^{\circ}C$, color), salinity profiles (psu, purple contours every 0.1 psu) and turbocline depth (in m, white contour) - in the (a) uncoupled and (b) coupled experiments.

Conclusion

MED12, oceanic regional model based on the NEMO code, is an efficient numeric tool, dedicated to the study of complex oceanic processes and adapted to the specificities of the Mediterranean Sea. Driven by interannual atmospheric forcings, rivers and Black Sea freshwater inputs, exchanges with the Atlantic Ocean, for long-term runs, MED12 allows assessing the variability of processes such as the open sea convection. MED12 is also coupled to several atmospheric models in order to study the interactions between atmospheric and oceanic fine scale processes on long periods of time. Finally, note that coupling with biogeochemical models (e.g. Eco3M or PISCES) is underway. Added to the coupling of atmospheric models, including hydrological and vegetation models, MED12 is an important modeling component that fully completes several Regional Earth System configurations, and is thus a key model involved in several current projects that investigate the Mediterranean Sea climate system.

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