Modelling of the Mediterranean circulation using atmospheric fields at different space-time resolutions

Cindy LEBEAUPIN BROSSIER[1,2,3], Karine BERANGER[2,3] and Philippe DROBINSKI[1]

[1]*Laboratoire de Météorologie Dynamique (CNRS, ENS, Ecole Polytechnique, Univ. P. et M. Curie), Palaiseau, France*
[2]*Ecole Nationale des Sciences et Techniques Avancées (ParisTech), Palaiseau, France*
[3]*Laboratoire d'Océanographie et du Climat: Expérimentation et Approches Numériques (CNRS, Museum National d'Histoire Naturelle, IRD, Univ. P. et M. Curie), Paris, France*

Introduction

The Mediterranean Sea circulation with its complex patterns (overturning - dense water formation and deep convection - upwellings - weddies and circulation over shelfs) is sensitive to the regional climate and to local extreme meteorological events, that could not be fully represented in ocean-atmosphere global climate models. Identifying the Mediterranean region's climate coupled mechanisms calls for the development of integrated approaches by regionalization.

In the framework of the ***MORCE-MED*** project (http://www.gisclimat.fr/Doc/GB/D_projects/MORCE_MED_GB.html), a two-way ocean-atmosphere coupling is developed between the Weather Research and Forecasting (WRF) atmospheric model and the NEMO ocean model over the Mediterranean basin. Before applying the full two-way interactive coupling between the ocean and atmospheric regional models for long-term simulations over the Mediterranean, ***the forcing mode is considered through a sensitivity study*** in order to evaluate the impact of a higher resolution over a sub-basin and of a higher temporal resolution in the forcing on the whole Mediterranean circulation as on local ocean processes.

Evaluation of the atmospheric forcing

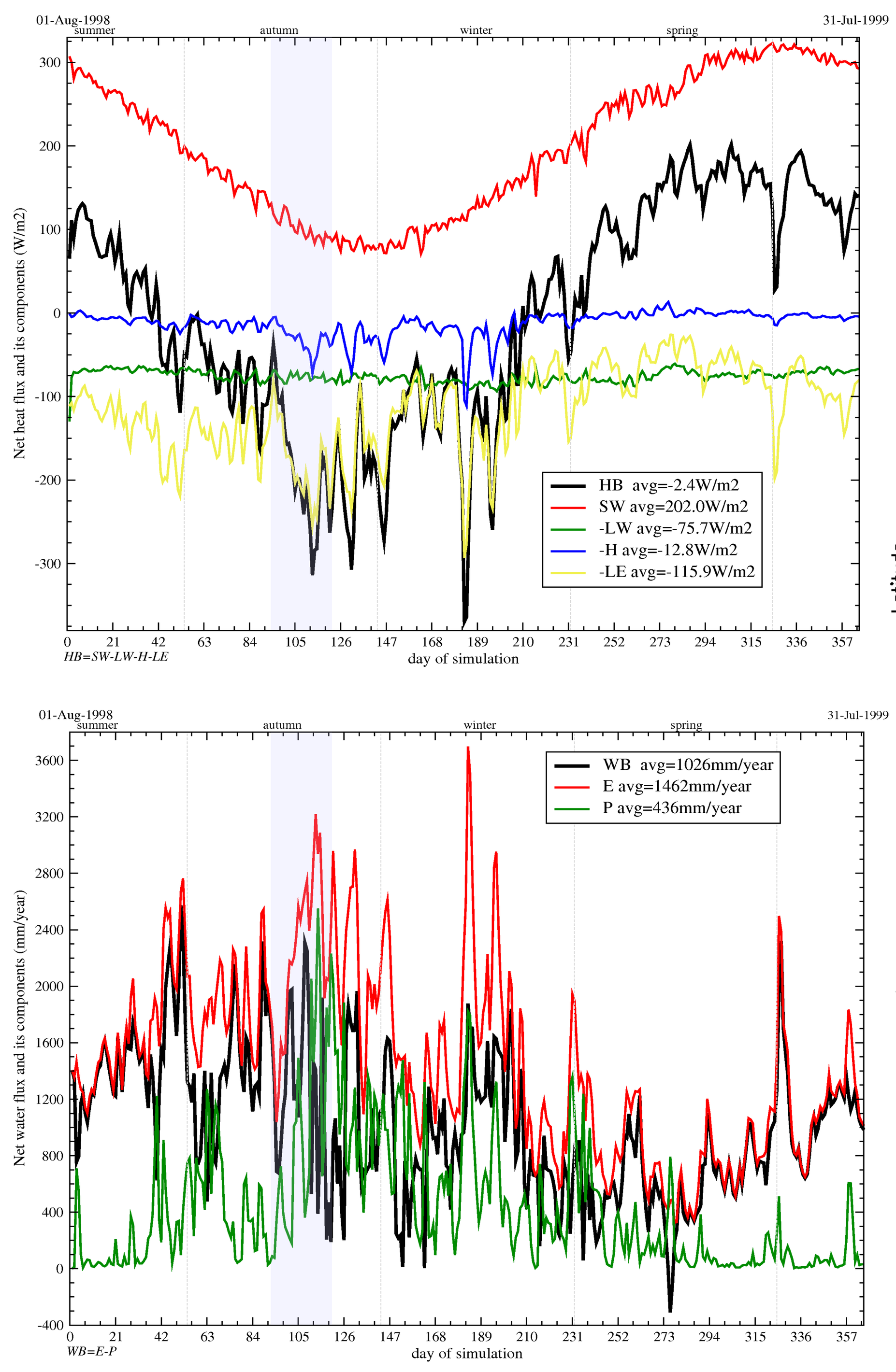


Fig.3 (on left) : Mean heat budget (HB) and water budget (WB) over the Mediterranean Sea between 1-Aug-98 and 31-Jul-99.

We investigated the annual budgets in order to anticipate the MED12 model response to the forcing imposed, and to eventually identify the defaults of the physical schemes chosen for the WRF simulation. A comparison of our annual budgets to those of G. Casagrande [2001] and to those obtained by a group of regional models over 40 years [Sanchez-Gomez et al., 2009] shows a good agreement.

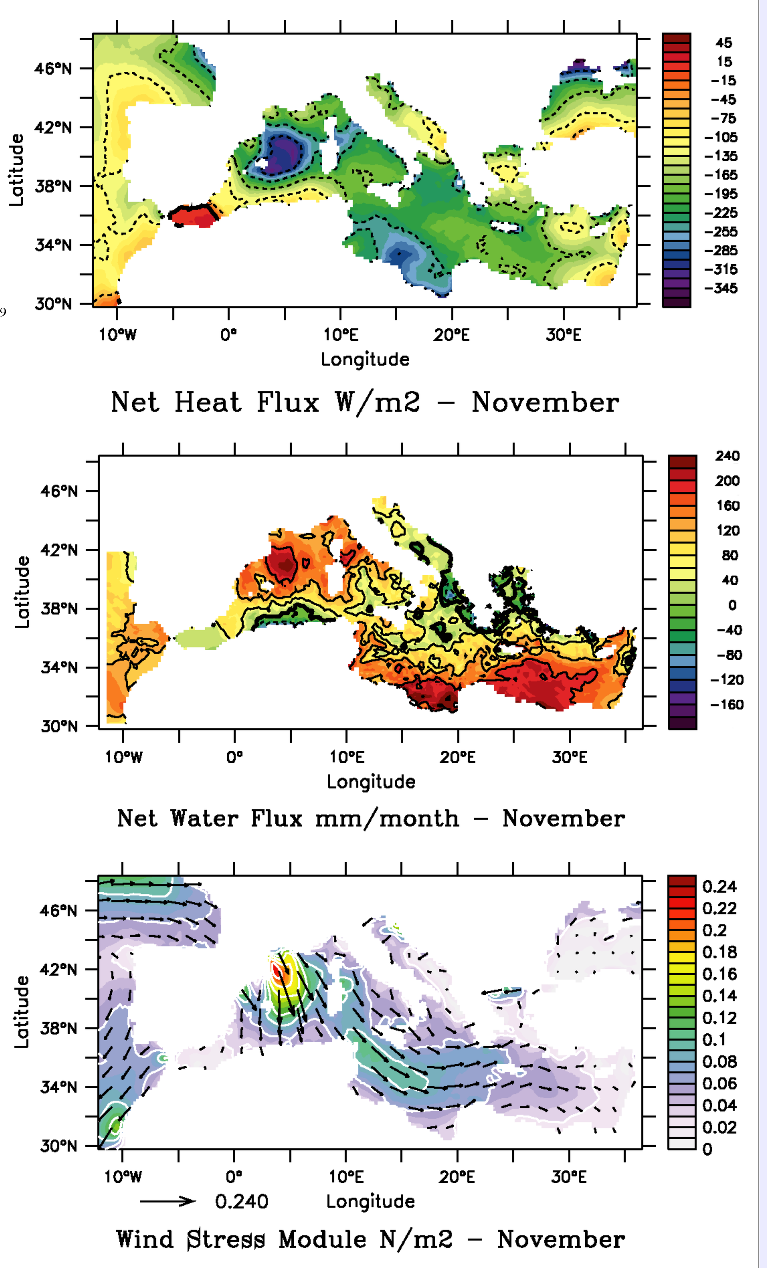


Fig. 4: Monthly mean forcing for November extracted from the WRF simulation.

Forcing components:

SW=(1-α) x $F_{sol}\downarrow$: solar net heat flux
LW=$F_{IR}\uparrow$-$F_{IR}\downarrow$: infra-red net heat flux
H : sensible heat flux
LE : latent heat flux

τ_x, τ_y : wind stress components

P : precipitation
E : evaporation

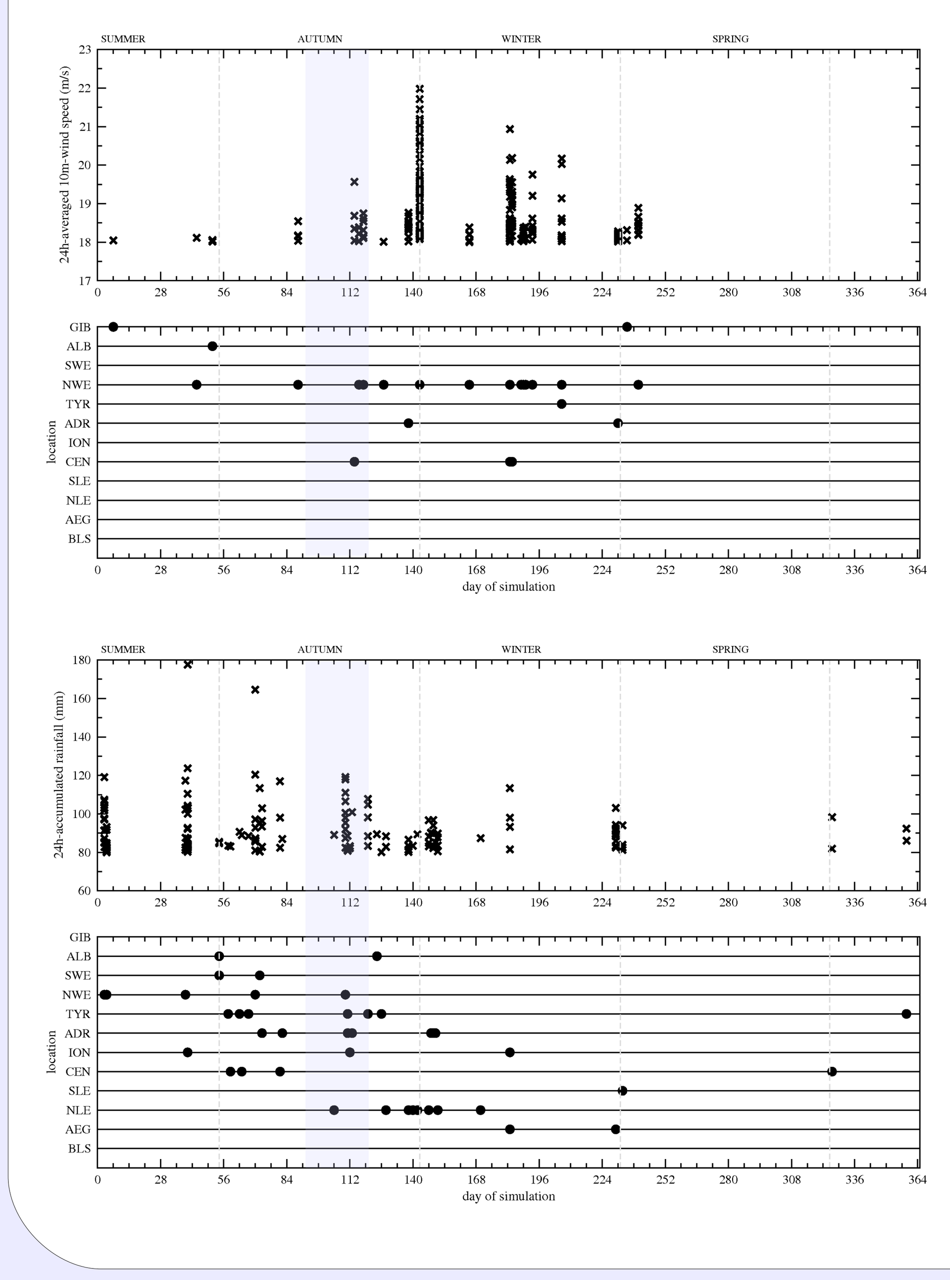


Fig. 5 (on left): Heavy wind (mean >18 m/s during 24 hrs) and precipitation (>80 mm accumulated in 24 hrs) events detected (intensity on top – location on bottom) between 1-Aug-98 and 31-Jul-99

Fig. 6: Illustrations of high wind events with surge and strong precipitation events leading to flooding often occurring over the Mediterranean basin

The extreme meteorological events detection has also been tested (Fig. 5) with thresholds. Heavy windy episodes (10m-wind superior to 18 m/s in daily average) have been detected and are mainly located in the North-Western part of the Mediterranean during the winter (NWE - Fig. 1) [see also Lebeaupin Brossier and Drobinski, 2009]. Heavy precipitation events (accumulated surface rainfall superior to 80 millimeters in 24hrs) are more scattered over the basin and more frequent in summer and autumn.

The numerical models

The ***Weather Research and Forecasting*** (WRF) atmospheric model from NCAR [Skamarock et al. 2008]:

Regional domain (Fig. 1): 240x130 grid-points – Δx=20km – Δt=60s
28 vertical levels
Initial and boundary conditions from NCEP reanalysis (2.5°x2.5°)

Zoom domain: 105x105 grid-points – Δx=6.7km – Δt=20s
28 vertical levels
Initial and boundary conditions from the regional domain simulation

microphysics: WSM3
convection: Kain-Fritsch
turbulence: YSU-PBL
IR radiation: RRTM [Mlawer et al., 1997]
solar radiation: Dudhia [1989]
turbulent fluxes: «MM5 similarity» [Monin and Obhukov, 1954]
SST field updated every 6 hrs from reanalysis

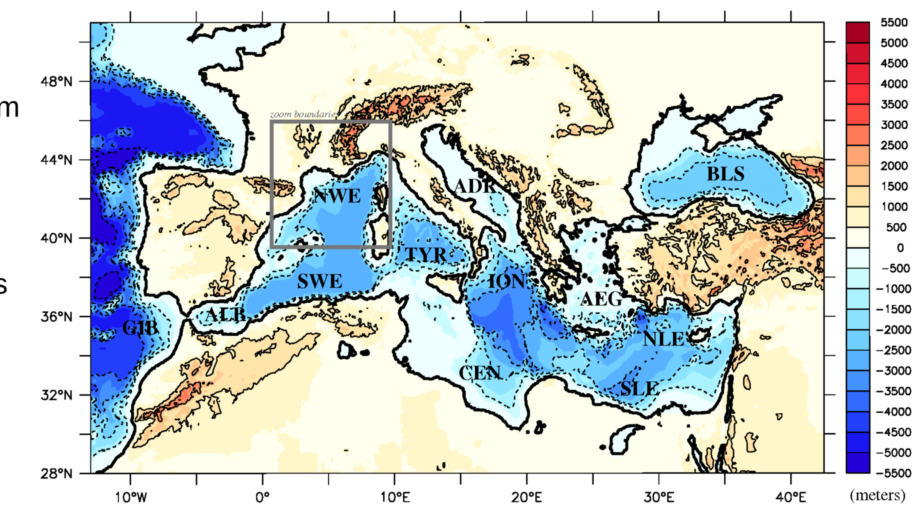


Fig. 1: The WRF domain over the Mediterranean region illustrated by the topography in meters (contours every 1000 meters) and its 12 subdomains over sea considered. The atmospheric zoomed model boundaries are indicated with a grey square.

The ocean model ***NEMO-MED12*** (Fig. 2) for the Mediterranean Sea is based on the ATL12 configuration from Mercator-Ocean:

NEMO v3.1 code [Madec 2008]
ORCA12 grid, *i. e.* Δx≈6 to 8km-resolution from North to South
50 vertical levels
Δt=12mn
Initial conditions (T,S) from the Levitus [2005] climatology

Exchanges with the Atlantic Ocean via a climatological bufferzone
A climatology for the main rivers catchments is taken for runoffs
Free surface parameterization (first z-level has a variable height/volume): The evaporated volume in the Mediterranean zone is reported in the Atlantic bufferzone in the form of rain.

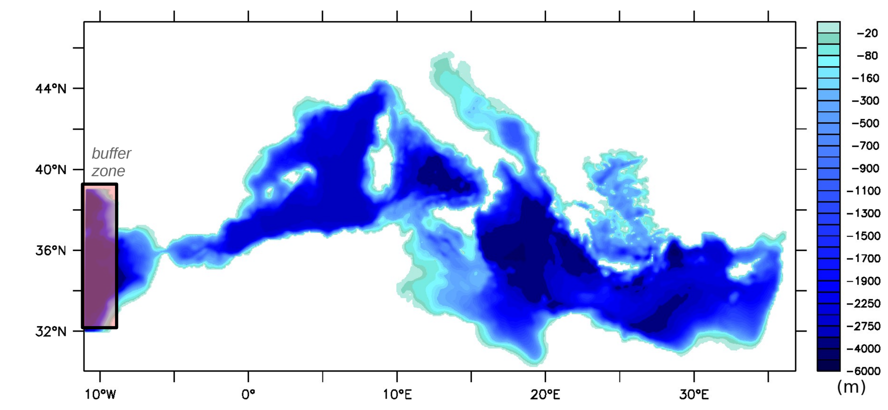


Fig. 2: The MED12 domain illustrated by its bathymetry in meters.

The Mediterranean circulation response

Experimental design:

The downscaling of the NCEP reanalyses done with the WRF model over the regional domain between August 1998 and July 1999 is used as atmospheric forcing to drive the NEMO-MED12 model (Fig. 7). First the daily-averaged fields over the regional domain are used in a perpetual mode during a spin-up of 8 years.

Then, three experiments are done for a period of 4 years:

- The control experiment (CTL) is the continuity of the spin-up.
- In ZOOMGOL, we used *a higher spatial resolution (6.7km) over the Gulf of Lions* (NWE area - Fig. 1)
- In 3HFREQ, we used a *higher temporal resolution* (3 hours)

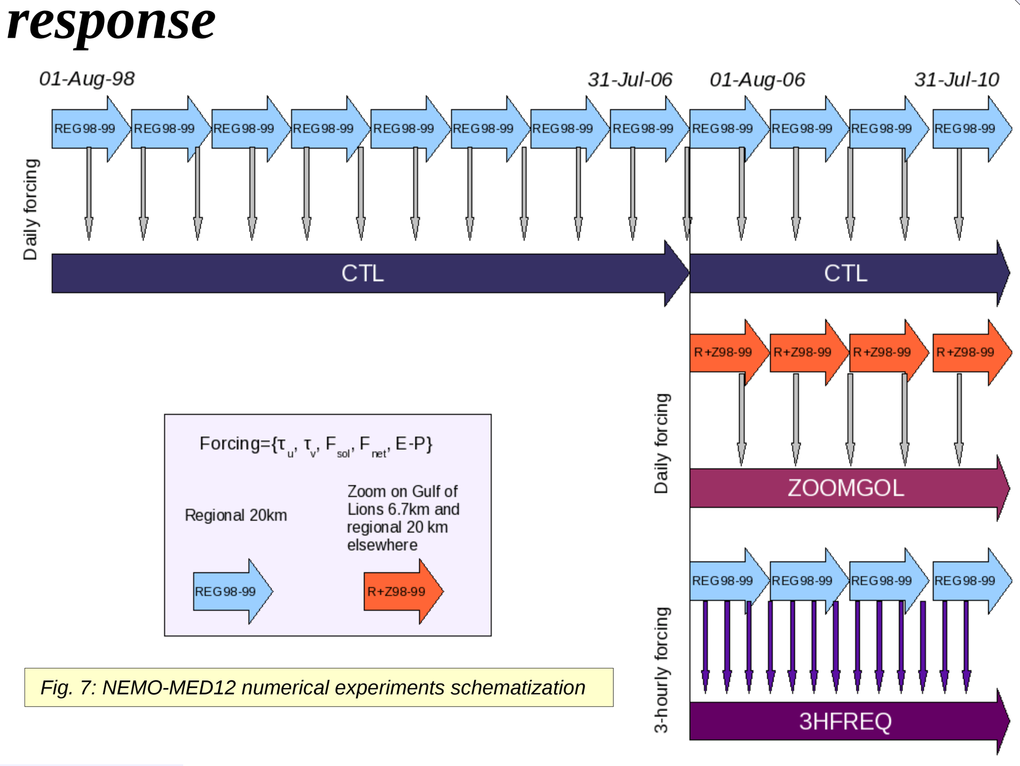


Fig. 7: NEMO-MED12 numerical experiments schematization

Ongoing work:

➢Evaluate the control (CTL) experiment performances with climatologies and available observations.

➢Compare CTL to ZOOMGOL to estimate how the finer resolution and a better representation of extreme events as high wind (Mistral and Tramontane) or heavy precipitation, modify *the deep water formation, the convection, the coastal upwellings...*

➢Compare CTL to 3HFREQ to estimate how a better representation of the diurnal cycle change *the Mediterranean circulation* simulation, how the extreme peak in the forcing influence the ocean simulation [see also Lebeaupin Brossier et al., 2009]...

➢*Anticipate the future coupled mode:*
What is the optimal time frequency of coupling ? What is the required horizontal resolution in the atmospheric model to well represent the Mediterranean circulation at mesoscale in the coupled mode ?

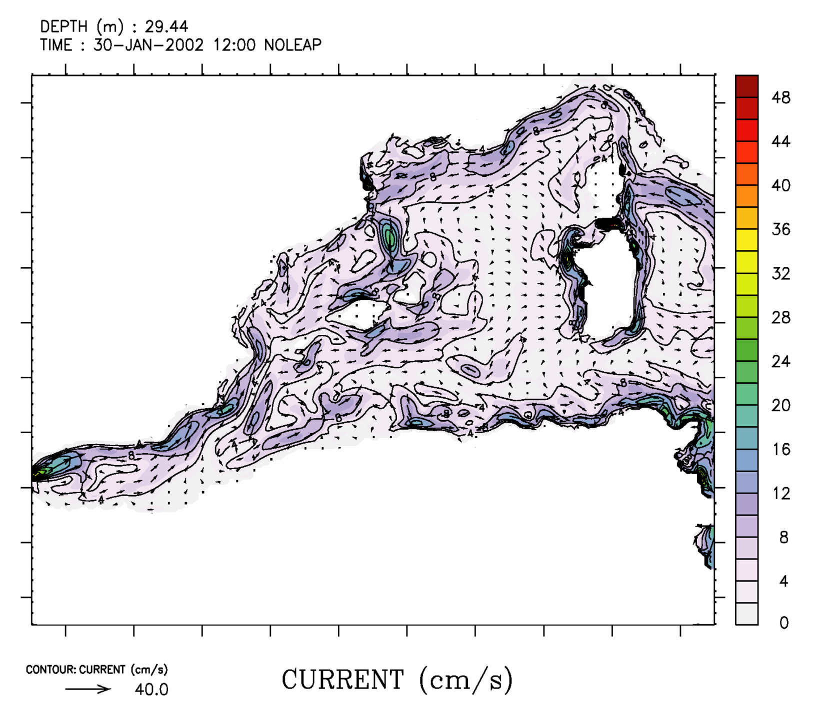


Fig. 8: Horizontal current (cm/s) at nearly 30m-depth in the Western Med simulated by MED12 on 10 January for the fourth year of the spin-up.

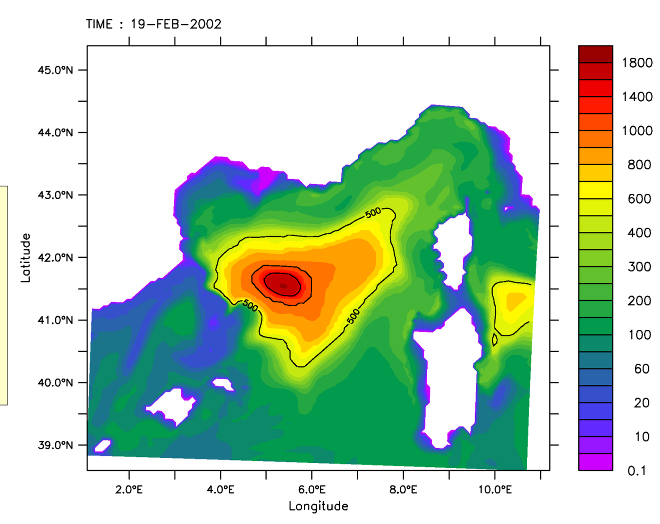


Fig. 9: Mixed layer depth (meters) simulated by MED12 over the NWE area on 19 February for the fourth year of the spin-up

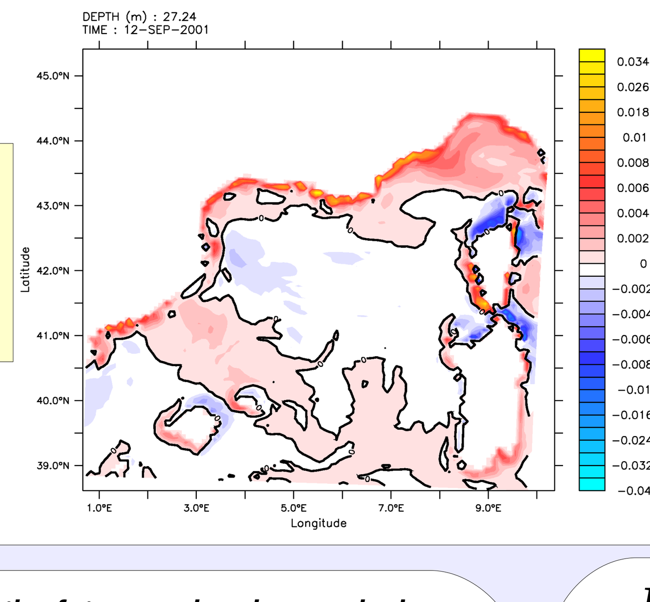


Fig. 10: Vertical velocities (cm/s) simulated by MED12 at nearly 27m-depth over the NWE area on 12 September for the fourth year of the spin-up.

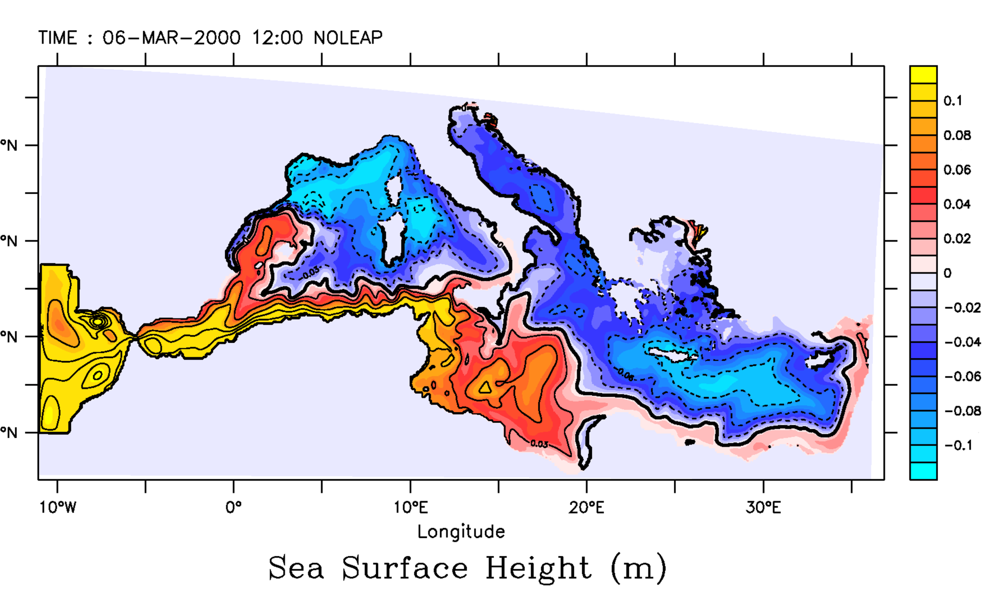


Fig. 11: Sea Surface Height (meters) simulated by MED12 on 6 March for the second year of the spin-up.

These experiments are also part of the *SiMed* project that achieves the development effort of the MED12 model and its evaluation in collaboration with Mercator-Ocean and the GAME/CNRM.

Conclusion and perspectives

Experiments in the forcing mode are currently done at LMD/LOCEAN/ENSTA between the WRF atmospheric model and the NEMO-MED12 ocean model.
The atmospheric forcing obtained by the downscaling of one-year reanalyses with the WRF model at a 20km-resolution has been examined. We found:

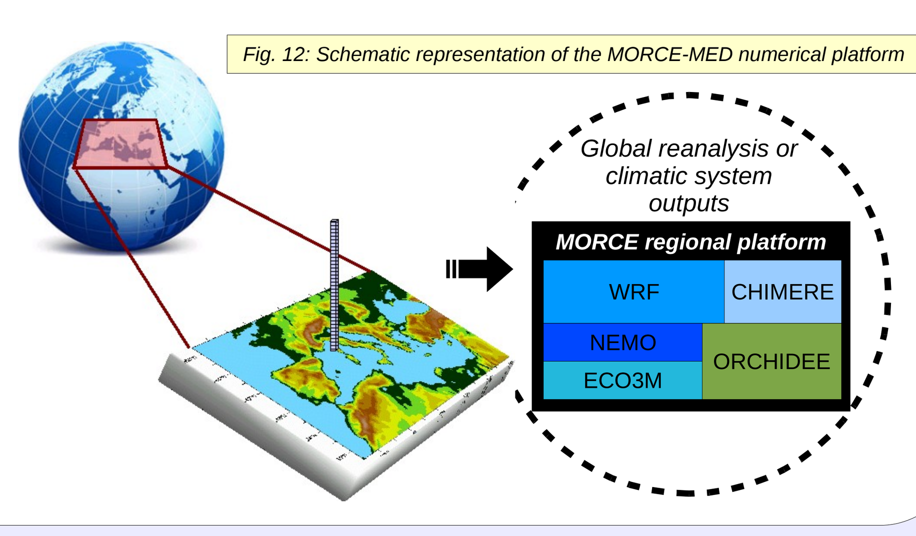
- ✔ A good estimation of the heat and water annual budgets
- ✔ A correct representation of extreme meteorological events
- ✗ A under-estimation of the precipitation amounts (the convection parameterization used should be evaluate)
- ✗ Few mesoscale patterns are produced in the turbulent heat fluxes fields (because using the SST field from reanalyses)

Our sensitivity experiments would also determine the optimal configuration for the coupled mode.

Air-sea high-resolution coupled simulations over the Mediterranean region are expected in the next few months.

The future ocean-atmosphere coupled system is part of ***the future regional numerical platform*** including also the modelling of the continental superficial layers, atmospheric chemistry and marine biogeochemistry. Forced by global reanalyses or by global climatic numerical system outputs, the whole regional coupled model could contribute to the *HyMex* project, in particular to study the different terms of the water cycle budget in the present climate and in climate projections. In addition, the observational phases of the *HyMeX* project will constitute a unique opportunity to validate our regional coupled system.

Fig. 12: Schematic representation of the MORCE-MED numerical platform



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Contact: Cindy LEBEAUPIN BROSSIER, LMD/IPSL, Ecole Polytechnique, F-91128 Palaiseau cedex, cindy.lebeaupin@lmd.polytechnique.fr