Ocean modelling tutorial 1

1 NEMOMED12 regional ocean model

Regional ocean models have several specificities with respect to global ones. First, because the domain is reduced, a higher resolution can be afforded. This concerns the physics which can be made eddy-resolving (resolving mesoscale eddies, that is $\sim 1/10°$), the bathymetry which can better resolve channels, straits and interactions with topography, and the atmospheric forcing whose regional features can be made more accurate. In addition, regional domains usually have open boundaries which will have to be specified.

During this tutorial, we will be analyzing the so-called NEMOMED12 model, a regional NEMO configuration on the Mediterranean Sea (Fig.1). It is a semi-enclosed mid-latitude basin where high-resolution regional modelling is required by its key exchanges at narrow straits, key high-resolution atmospheric jets and the need to resolve mesoscale dynamics. Its horizontal resolution is $1/12°$, that is $\sim 6-8km$, it is hence named an eddy-permiting model because it starts resolving mesoscale eddies. Vertical resolution ranges from 1m at surface to $\sim 100m$ at the bottom. The atmospheric flux forcing is a $12km$ resolution regional atmospheric reanalysis covering the period 1979–2013, meaning that observations are assimilated. Hence it is expected that the ocean represents the chronology of past events, and the simulation is qualified as a hindcast run. At its only open boundary with the global ocean, in the near-Gibraltar Atlantic Ocean, θ, S and η are restored towards an oceanic reanalysis and the domain is assumed to be closed. Initial conditions are from an oceanic climatology. Finally, most of the physical options are identical to those presented in Chapter 2.

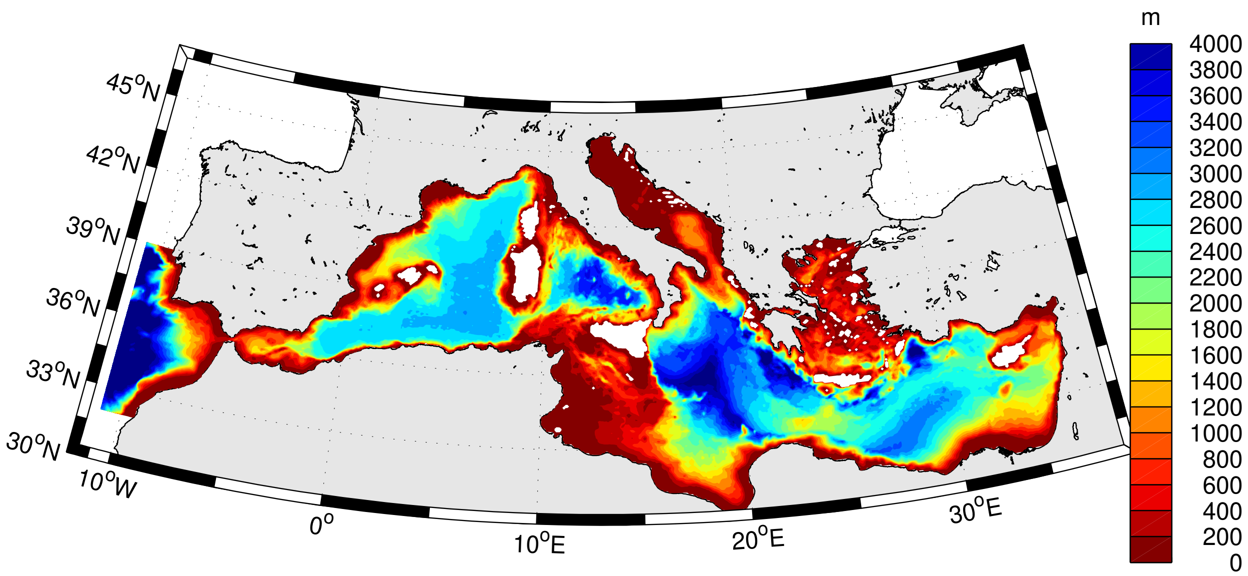

Figure 1: *NEMOMED12 domain and bathymetry (source: Waldman et al 2017a).*

2 Mean state

- Provide a climatology of surface fluxes (heat, momentum and water) over the Mediterranean Sea. What are the main spatial patterns? What do you conclude regarding the water and heat balance of the Mediterranean Sea? What is the expected transport structure at Gibraltar Straits? What is the role of the sea surface temperature restoration in this run?

- What are the average patterns of sea surface temperature and mixed layer depths? How do they relate to air-sea fluxes? What are their seasonal amplitudes and how do you interpret them? Do they show any significant long-term trend?
- What are the main sea surface velocity patterns, and how do they compare to Sverdrup theory presented in Chapter 1? Any idea of their main forcing? Compute the geostrophic and Ekman surface velocities, comment on their patterns and compare them to total velocities.

3 Heat budget

3.1 Mixed layer heat budget

- We define oceanic heat waves when sea surface temperature exceeds the 99th quantile of annual distributions. Focus on two oceanic heat waves, one in the northern and the other in the southern basin. What are the main physical drivers for their initiation and end? How do you interpret them?
- We define spring warming when the sea surface temperature reaches its maximum increase in the spring period (April to June). Focus on two locations, one in the northern and the other in the southern basin. What are the main physical drivers for the spring warming? How do you interpret them?
- We define fall cooling when the sea surface temperature reaches its maximum decrease in the fall period (October to December). Focus on two locations, one in the northern and the other in the southern basin. What are the main physical drivers for the fall cooling? How do you interpret them?
- Focus separately on the winter and summer seasons. What are the main differences in the leading terms of the mixed layer heat budget? How do you interpret them?

3.2 Subsurface heat budget

- From a quick look at trend terms, what is the main difference between the mixed layer heat budget and that over the top 150m? How do you interpret it? What are the respective advantages of both methods?
- Compute the annual mean top 150m layer temperature trend over one grid point, a sub-basin and the whole Mediterranean Sea. What is the main difference between the three domains? What are the dominant terms that drive the top 150m annual cycle of temperature?
- Compute the long-term interannual trend of the top 150m temperature. Is there a significant trend? What terms are responsible for it?

3.3 Vertically-integrated heat budget

- From a quick look at trend terms, what is the main difference between the mixed layer and top 150m trend and the vertically-integrated trend? How do you interpret it? Comment on differences in the contributions of lateral exchanges (advection and mixing).
- What is the dominant mode of heat exchange between basins?
- Do individual basins or the Mediterranean Sea display long-term trends in their heat content? How do they compare to the top 150m trends? Comment on the difference.

4 Momentum budget

- Analyze the momentum budget over one water column in the open ocean. How does the trend compare to individual terms? How do you interpret it?
- Determine at that location the approximate Ekman layer depth. How does it compare to the mixed layer depth? How do you interpret it?
- Compare at that location the momentum budget between February and August. How do you interpret differences?
- Consider a meridional section in the western Mediterranean. What are the different momentum balance regimes? How do you interpret them?
- We now turn to the vertically-integrated momentum balance. What is the leading-order balance? Do some regions stand out with distinct balances?

5 Glossary of NEMOMED12 variables

5.1 ncdump and ncview

The commands "ncdump -h file.nc" and "ncview file.nc" should be used prior to any analysis to get an idea on the content of the model files. The former command lists the header of file.nc, which contents the description of all variables and dimensions. The latter gives a quick view of all variables contained in file.nc.

5.2 Mesh and mask variables

Mesh and mask variables are the first parameters that should be loaded. They include space coordinates, horizontal and vertical scale factors for all grid points, bathymetry and the land-sea mask for all grids. They are all included in the file mesh_mask_MED12_75lev.nc. Space coordinates are necessary because there is no simple relation between the horizontal indices (i,j) and the longitude-latitude of each grid point. Scale factors and land-sea masks are necessary whenever a space averaging or integration is performed because all grid cells have distinct volumes.

- Coordinates: glamt (resp. glamu, glamv) is the longitude (lam for λ) in the T-grid and W-grid (resp the U-grid, V-grid), and similarly gphit (resp. gphiu, gphiv) is the latitude (phi for ϕ) in the T-grid and W-grid (resp the U-grid, V-grid). Similarly, gdept (resp. gdepu, gdepv, gdepw) is the depth in the T-grid (resp the U-grid, V-grid and W-grid). It is not simply a one-dimensional parameter because as we saw in Chapter 2, the last level depth can vary because of partial cells.

- Scale factors: the i grid size (close to δx) is given by e1t (resp. e1u, e1v, e1w) in the T-grid (resp. in the U-grid, V-grid and W-grid). Similarly, the j grid size (close to δy) is given by e2t, e2u, e2v and e2w, and the k grid size (which is exactly δz) is given by e3t, e3u, e3v.

- Land-sea masks: tmask (resp. umask, vmask and wmask) is the land-sea mask in the T-grid (resp the U-grid, V-grid and W-grid). It contains values of 0 over land points and 1 over sea points.

- Bathymetry: it is deduced from either the vertical sum of e3t (masked with tmask), or at each grid point from $gdepw(mbathy(j,i)+1,j,i)$, $mbathy(j,i)$ being the vertical index of the last defined T-point.

In addition, the file NM12_masks.nc includes the mask for the main Mediterranean basins, for regional focuses.

5.3 Physical variables

All of NEMOMED12 physical outputs have the standard name for NEMO model outputs, with a description in each file's header. We distinguish daily and monthly files, the former with a suffix _1d concerning two-dimensional variables and the latter with a suffix _1m concerning three-dimensional variables. Three-dimensional variables include:

- Dynamics: vozocrtx, vomecrty and vovecrtz are the i (quasi-zonal), j (quasi-meridional) and k (vertical) velocities;

- Hydrography: votemper, vosaline and vodensity are the potential temperature, salinity and potential density;

- Vertical physics: vovaisala and avt are the squared Brunt-Vaisala frequency (the buoyancy stratification) and the vertical turbulent diffusivity for tracers;

- Momentum trend: utrd and vtrd terms are all the contributions to the momentum trend equation. The most important ones are: pressure force (suffixes spg and hpg), Coriolis (pvo), lateral advection (rvo and keg), vertical advection (zad), lateral and vertical diffusion (ldf and zdf), bottom friction (bfr) and total trend (tot).

Two-dimensional variables include:

- Air-sea fluxes: heat fluxes (solar soshfldo, SST restoration sohefldp and total sohefldo), wind stress (wind speed sowindsp, zonal stress sozotaux and meridional stress sometauy) and water fluxes (precipitation soprecip, runoff sorunoff and total sowaflup)

- Surface ocean properties: surface hydrography (sosstsst and sosaline), velocities (zonal ssu and meridional ssv), sea level (sossheig), mixed layer depth (somxl010)

- Layered temperature trend: tml terms are all the contributions to the layered (either mixed layer, top 150m or whole column) temperature trend. The most important ones are: lateral advection (xad and yad), vertical advection (zad), lateral and vertical diffusion (ldf and zdf), atmospheric forcing (for) and total trend (tot). The layer depth and average temperature are also given by mxl_depth and tml.