Ocean modelling tutorial 2

1 CNRM-CM6 global coupled model

1.1 General description

CNRM-CM6 model is a global coupled climate model participating in the next Climate Model Intercomparison Programme (CMIP6) in the framework of the International Panel on Climate Change (IPCC) sixth Assessment Report (AR6). It includes the main components of the climate system: ocean, sea ice, atmosphere, continental surfaces and atmospheric aerosols (Fig.1). Horizontal resolutions are typically 1° for all components, the vertical oceanic resolution being identical to NEMOMED12 regional Mediterranean model (1m at surface to 200m at deepest levels). We focus here on the historical simulation covering the 1850–2014 period. Its only time-varying external forcings are solar radiations, anthropogenetic greenhouse gases and aerosols (both natural and anthropogenetic) and they follow historical records. An ensemble of 10 members have been run to document the internal climate variability. They only differ in their initial states which come from different years of the control pre-industrial run. This control run has been priorly performed over several hundred years and it ensures a climate equilibration of CNRM-CM6 model under constant pre-industrial external forcings.

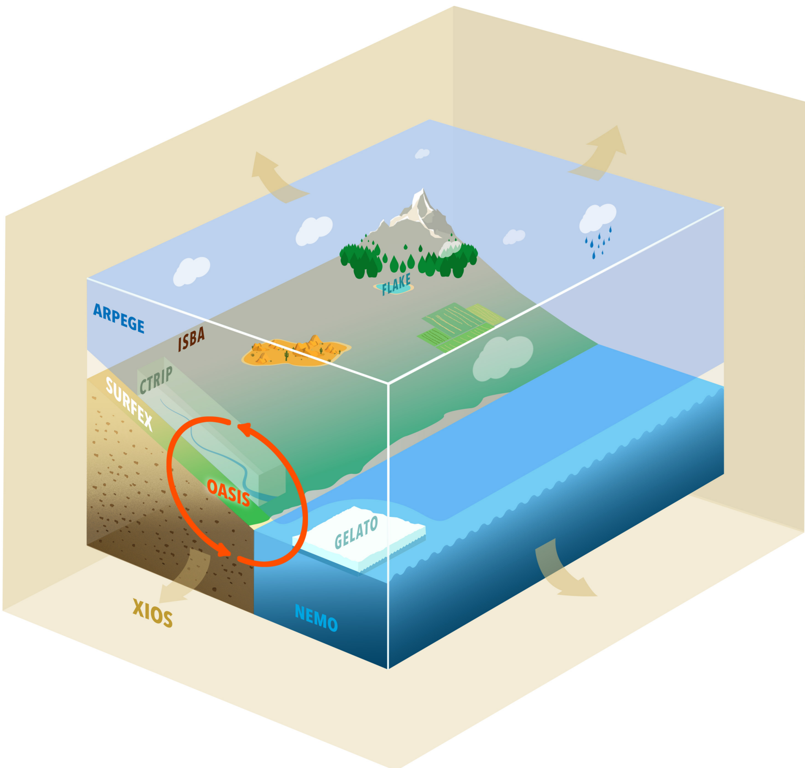

Figure 1: *Schematic of CNRM-CM6 coupled model. Its atmospheric component ARPEGE includes an atmospheric aerosol module; its continental surface component SURFEX includes the river drainage module CTRIP, the soil module ISBA and the lake module FLAKE; its oceanic component NEMO includes the embedded sea ice model GELATO; and all components are coupled via OASIS coupler.*

1.2 Ocean - Sea Ice component

The ocean component included into CNRM-CM6 is the 1° resolution configuration of NEMO model. Its physical parametrizations are essentially identical to those presented in Chapter 2 and to those of NEMOMED12. The only notable difference is the inclusion of the mesoscale eddy-induced velocity parametrization for tracers (temperature and salinity). Indeed, at this resolution, the ocean does not resolve mesoscale eddies at all. Therefore, eddy-induced velocities aim at mimicking the restratification induced by them (see section on the Antarctic Circumpolar Current in Chapter 3). The ocean surface is fully coupled with the atmosphere at a 6-hourly frequency using so-called "Bulk aerodynamic formulas", hence no sea surface temperature restoration is required (see Chapter 2 for a discussion on this point).

In addition, and contrary to the regional model NEMOMED12, the coupled climate model includes a sea ice component, GELATO model, fully embededed into the ocean model. It resolves both the sea ice and snow (above sea ice) dynamics and thermodynamics, including their exchanges with both the atmosphere and ocean. Prognostic variables are the sea ice and snow volume and enthalpy, the snow density and the sea ice surface, salinity and age. Hence over each oceanic grid cell, a fraction between 0 and 1 of sea ice area covered with snow is present. Their properties evolve in time as a function of the sea ice interaction with atmosphere and ocean, its transport and vertical heat exchanges.

2 Air-sea fluxes

1 Diagnose the main surface air-sea fluxes: solar and non-solar heat fluxes, water fluxes. What patterns stand out? How do they compare the climatologies presented in Chapter 1?

2 Surface heat and water budget: what are the main regions of oceanic heat and water loss and gain? What do you deduce in terms of oceanic heat and water transport?

3 Mixed layer properties

1 What are the main sea surface temperature and salinity patterns, and how do they compare to the climatologies presented in Chapter 1?

2 What are the main regions of deep convection, and what are the hydrographic properties of those water masses?

3 Compute the seasonal amplitude of sea surface temperature and mixed layer depth. Comment on the main regions that stand out.

4 Is there any significant long-term trend of either sea surface temperature or mixed layer depth? Which regions stand out?

5 Is there any significant internal climate variability of either sea surface temperature or mixed layer depth? Which regions stand out?

4 Surface dynamics

1 What are the main sea surface velocity patterns, and how do they compare to the climatology presented in Chapter 1?

2. Compute surface Ekman velocities from the surface wind stress, excluding the Deep Tropics (within $\pm 5°$ of latitude). What patterns stand out?
3. Compute surface geostrophic velocities from the dynamic sea level, excluding the Deep Tropics. What dynamical structures stand out?
4. To what extent are mean currents the result of Ekman plus geostrophic dynamics. Which component dominates?

5 Gyre and overturning circulations

5.1 Gyre circulation

1. What are the main barotropic circulation patterns, and how do they compare to the climatology presented in Chapter 1?
2. Use the barotropic streamfunction to compute the North Atlantic subpolar and subtropical gyre maximum transports.
3. Deduce from the barotropic streamfunction transports at the Drake Passage.
4. To what extent does the change of sign in the wind stress curl explain the separation between the subtropical and subpolar gyres?
5. Compute Sverdrup transports at the latitudes of the North Atlantic subpolar and subtropical gyres. How do they compare to the actual gyre transports?
6. Is there any long-term trend of either gyre circulation?
7. Is there any internal climate variability of either gyre circulation?

5.2 Overturning circulation

1. Identify the main Atlantic meridional overturning cells from the meridional overturning streamfunction. What are the associated water mass properties? Which ones are wind-driven?
2. How does the depth and latitude of the deep North Atlantic overturning compare to those of deep convective regions?
3. Diagnose the North Pacific meridional overturning circulation. Why is there no deep overturning cell?
4. Is there any long-term trend of either Atlantic meridional overturning circulation?
5. Is there any internal climate variability of either Atlantic meridional overturning circulation?

6 Heat budget

1. What vertical layers are most concerned by anthropogenetic warming?
2. What basins experience most warming? How does it relate to vertical oceanic exchanges?

3 Comment on the meridional heat transport per basin and as a function of latitude. How does it evolves with time?

4 Which regions are dominated by gyre versus overturning heat transport? Does this distribution display a long-term trend?

4 What is the global surface heat imbalance and how does it evolve in the historical period?

7 Sea Ice

1 What is the average late winter and late summer (March and September) sea ice extent and volume? How do they relate to sea surface temperature patterns? Deduce privileged pathways for the poleward oceanic heat transport.

2 Is there any long-term trend in late summer and late winter sea ice extent?

3 Is there any internal climate variability of the sea ice extent?

8 Glossary of CNRM-CM6 ocean and sea ice variables

8.1 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.

8.2 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_NEMO1_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 NEMO1_masks.nc includes the mask for the main oceanic basins, for regional focuses.

8.3 Physical variables

Because the ocean model interacts with other components of the climate system and because CNRM-CM6 participates in a coordinated climate modelling exercise, oceanic outputs do not have the standard NEMO names. Also, because of the wider domain and longer integration time, all outputs are produced at the monthly frequency. Three-dimensional variables include:

- uo, vo and wo which are the i (quasi-zonal), j (quasi-meridional) and k (vertical) velocities;
- bigthetao, so and rhop which are the potential temperature, salinity and potential density;
- obvfsq which is the squared Brunt-Vaisala frequency (the buoyancy stratification).

Two-dimensional variables include:

- Air-sea fluxes: heat fluxes (solar rsntds and total hfds), wind speed and stress (speed uas, vas and stress tauuo, meridional stress tauvo) and water fluxes (total wfo and runoff friver);
- Surface ocean properties: surface hydrography (tos and sos), sea level (zos), mixed layer depth (mlotst);
- Sea ice properties: thickness (sithick), volume (sivol), velocities (siu, siv), sea ice fraction (siconc), surface sea ice temperature (sits);
- Vertically-integrated heat content (heatc), above 700m (hc700) and 2000m depth (hc2000);
- Vertically-integrated zonal (hfx) and meridional (hfy) heat fluxes;
- Meridional overturning (mstfyz) and barotropic (sobarstf) streamfunctions.

Low-dimensional global diagnostics include:

- Global averages: thermosteric sea level (zostoga), sea surface temperature (tosga) and salinity (sosga), temperature (bigthetaoga), salinity (soga);
- Basin averages: meridional heat flux due to the gyre (htovgyre) and overturning (htovovrt) circulation, and meridional heat transport per basin (hfbasin).