COMODO: *On the Lock Exchange experiment*

Flav Gouillon, V. Garnier

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1 Objectives - Relevancy

Representing accurate abyssal turbulent mixing rates in numerical models of the global ocean has became key in order to have realistic water mass properties. The use of sub-grid scale parameterization has been developed and a plethora of those exist. However, one needs to be sure that the spurious diapycnal mixing generated by truncation errors in numerical advection scheme are smaller than the parameterized turbulent rates.

The main goal of the present study is to evaluate different numerical advection schemes using different models on representing the adiabatic process in a dam breaking experiment.

Lock exchange definition: A vertical density front separates two density classes. Adjustment occurs in which lighter water moves above heavier water.

There are several points that motivate the use of this experiment:

- a quantification of the spurious diapycnal mixing is possible when configuration is run adiabatically
- we can easily investigate the accuracy of advection schemes (over and under-shooting of the tracer, wave propagation, etc.)
- impact of numerical choices on numerical solution easy to study such as the effect of model resolution (vertical and horizontal)

2 Physical description

2.1 Equations, Domain, Boundary conditions

The model experiments are designed to reproduce the lock exchange problem described in *Haidvogel and Beckmann*, as well as *Burchard and Rennau* (2008).

2.1.1 Problem equations and analytical solutions

Primitive equations. The Coriolis force, the bottom friction, and the physical mixing are neglected (i.e., set or force to zero or infinitesimally small), such that the only effective density mixing is due to the advection of the density (i.e., numerically induced mixing) because the configuration is run adiabatically.

Analytical solutions to this problem exist and have been presented in *Haidvogel and Beckmann*, (1999).

Benjamin (1968) derived a theory a steady gravity current propagating in a rectangular channel and from Bernouilli's equation for an ideal fluid, the flow speed u_f can be written as:

$$u_f = \frac{1}{2}\sqrt{gH(\partial\rho/\rho_0)} \tag{1}$$

2.1.2 Domains

The scenario is a closed, two-dimensional (x, z) domain with a constant depth of H = 20 m and a length of L = 64 km ($x \in [-32\text{km}, 32\text{km}]$).

2.1.3 Boundary conditions

Closed domain

2.2 Initialization

Initially the right half of the domain (L > 0 km) has a density of $\rho_r = 1020$ kg/m^3 while the left side of the domain (L < 0 km) has a density of $\rho_l = 1025$ kg/m^3 . The salinity is held constant (i.e., it is a passive tracer) in the domain at 35 psu. At $t = 0$ the two initial densities that represent the two water masses are separated by a vertical barrier. Initializing the model in this manner simulates the removal of the barrier at time $t = 0$. A steep gradient depicted by a tanh variation can also separate the two masses of fluids (see experiment 2).

The experiments use a linear equation of state to avoid cabbeling, thermobaricity processes, and the initial surface elevation and velocity are equal to zero.

$$
\begin{aligned}
T(z) &= 5/0.28 \approx 17.857 \ (x < 0), \\
T(z) &= 10/0.28 \approx 35.714 \ (x > 0), \\
S(z) &= 35, \\
\sigma(t, s) &= 30 - 0.28T, \\
\rho_0 &= 1000.
\end{aligned} \tag{2}
$$

3 Computational parameters

Vertical resolution	evenly spaced vertical levels
Period of integration	17 hours
Instantaneous outputs	every 15 minutes
Time step	1 seconde for both barotropic and baroclinic time steps to satisfy the CFL criterion of the finest resolution and solve the equations at the same time whatever the configuration (Ilicak et al. 2011)

4 Numerical experiments

4.1 Experiment 1

4.1.1 Objectives : sensitivity to horizontal resolution

To investigate the impact of the model resolution and the choice of advection scheme on the spurious mixing, the experiments employ three different horizontal and vertical model grid spacings. The experiments are summarized in Table 1 and can be repeated for any advection scheme.

Experiment Name	Nx	Nz
Coarse	32	10
Medium	128	40
Fine	512	160

Table 1: Experiment description. Repeat for any advection scheme you want to use

4.2 Experiment 2

4.2.1 Objectives : sensitivity to viscosity

Some explicit viscosity might be required for most of the model to achieve a realistic dynamics. To assess the tracer advection schemes and the tracer mixing, the previous experiments are run with a constant viscosity of 10 $m^2.s{-}1$ and 100 $m^2.s{-}1$.

4.3 Experiment 3

4.3.1 Objectives : sensitivity to the initial conditions

A vertical barrier is not such a realistic condition. The previous invertigations are reproduced in presence of a sharp density front that separates the two water masses.

$$T(z) = 7.5/0.28 + 2.5/0.28 * \tanh(\frac{x - x_0}{1000}) \quad (x_0 = 0, x \; distance \; from \; x_0 \; [m]), \tag{3}$$

5 Available Diagnostics

- It is easy to have diagnostic about the front location and determine the error on its propagation speed.
- If the advection scheme is perfect and the experiment run adiabatically (no dissipation/diffusion sources or sinks) then the two initial water masses volume should remain constant through time. If it is not the case, it easy to determine at which rate the volume of these water is decreasing and thus the rate of numerical mixing that is associated to this decrease.
- RPE or Reference potential energy (based on the work of *Winters and D'Asaro*, 1995) The RPE is well described in the appendix A of the Ilicak et al. (2011) paper.
- Density classes volume distribution (*Gouillon*, 2010,*Ilicak et al.*, 2011)

6 Preliminary numerical results

In this section, preminiminary results are shown based on the work from *Gouillon* (2010). The results are from the medium model resolution using FCT2 for scalar advection scheme and give an example of what type of diagnostics we can use.

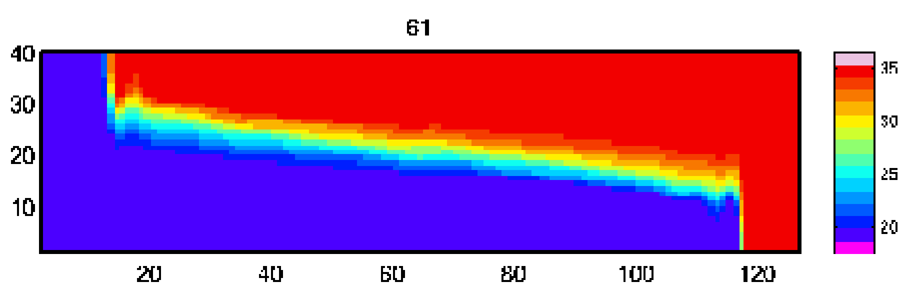

Figure 1: Temperature field for the HYCOM experiment. Axis are indexes of the model grid in x and z directions.

7 References

- Haidvogel, D. B., and Beckmann, A., 1999: Numerical Ocean Circulation Modeling. Imperial College Press, 312pp.
- Griffies, S., 2000: Developments in ocean climate modeling. Ocean Modelling, 2, issue 3-4, pp. 123-192.
- Gouillon, F., 2010: Internal Wave Propagation and numerically induced diapycnal mixing in Oceanic general Circulation Models. PhD Thesis at Florida State University, 93pp.)

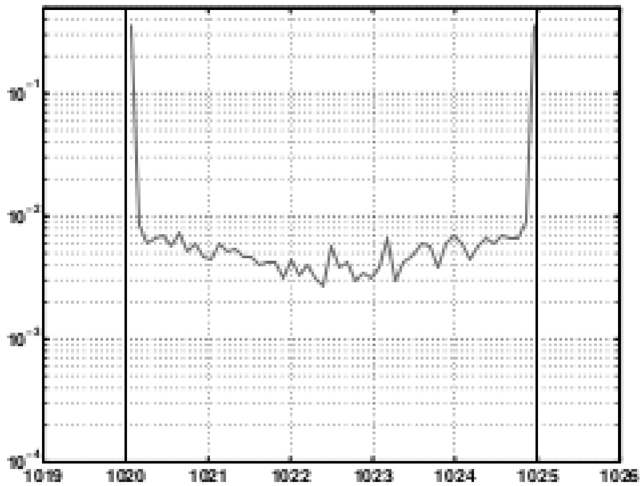

Figure 2: Example of normalized density classes volume distribution at the end of the HYCOM experiment

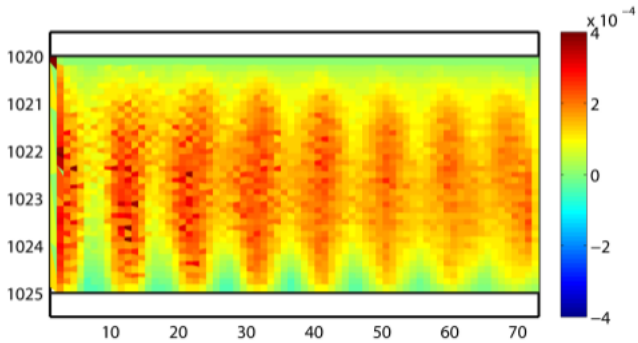

Figure 3: Hovmoller (density-time) type diagram of the diapycnal diffusivity for the ROMS experiment

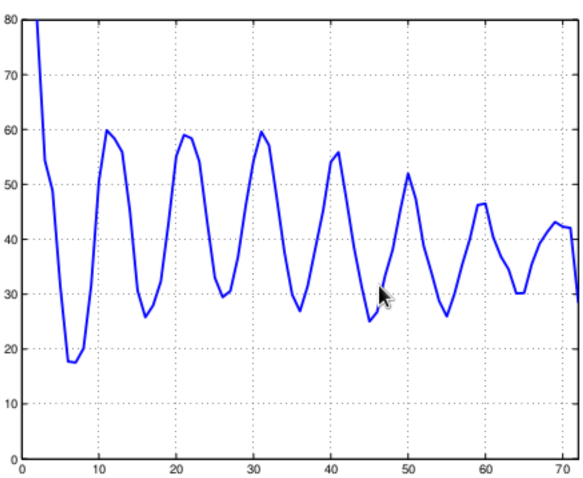

Figure 4: Numerical tracer variance decay for the HYCOM experiment. Abscissa is time in hours and ordinate is in $kg^2/(m^3 s)$

- Ilicak, M, Adcroft, A., Griffies, S., Hallberg, R., 2011: Spurious dianeutral mixing and the role of momentum closure. Accepted to Ocean Modelling.
- Winters, K. B., D'Asaro, E. A., 1996: Diascalar flux and the rate of fluid mixing. J. Fluid. Mech., 317, 179-193.
- Shin, Dalziel, S., Linden, P, 2004: gravity currents produced by lock exchange. Journ Fluid Mech.