Technical Report

1-D VERTICAL CONFIGURATION IN NEMO SYSTEM

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Objectives

The objective of this work is the creation of a stand alone vertical water column of ocean or sea-ice based on the OPA 3-D model.

This 1-D model must be a very simple tool useful to :

- Learn about the physics and numerical treatment of vertical mixing processes
- investigate suitable parameterizations of unresolved turbulence (wind steering, langmuir circulation, skin layers)
- Compares the performances of different mixing vertical scheme
- Perform some tests of sensibility to the vertical diffusion on a particular point of the ocean global domain
- Introduce specific diagnostics, aside from the standard model variables, because of having small in core memory requirement

Methodology

The methodology is the use of the zoom functionality offered in the 3-D NEMO code in its global configuration, coupled with specific routines, without defining a new set of mesh, bathymetry, initial state and forcings.

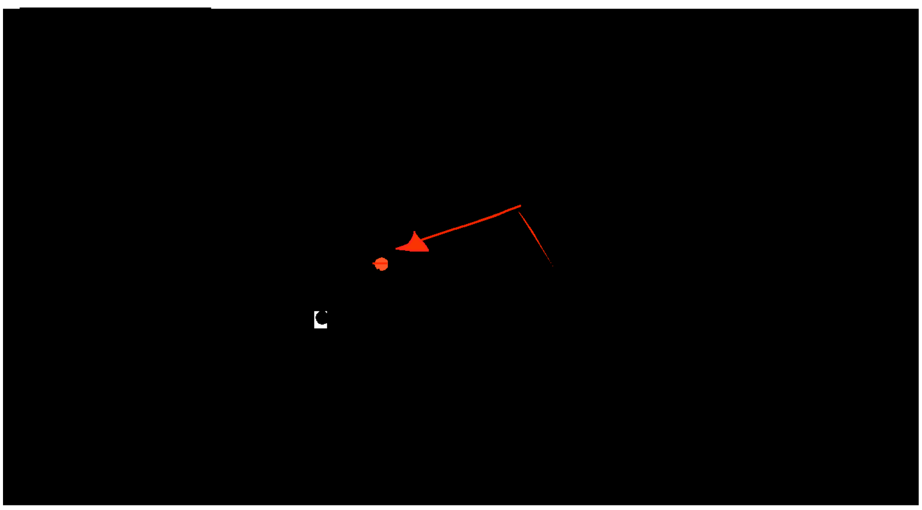

Figure 1 : position of the computational point compared to the data input domain in the 1-D NEMO system configuration

When running the model over a sub-domain with the zoom functionality, the data inputs are set over the whole global domain defining by the *jpidta, jpjdta* dimensions (and *jpkdta* for the vertical dimension). The user have to provide, in the parameter file, the size of the sub-domain (*jpiglo, jpjglo, jpk)* and the indices of the south western as *jpizoom* and *jpjzoom*.

In the 1-D configuration, the size of the sub-domain is *(jpiglo=3,jpjglo=3,jpk)* and the computation will be performed at the point whose horizontal indices are *jpizoom+1* and *jpjzoom+1*.

In the Figure 1, we can see the position of the computational point compared to the data input domain in the 1-D NEMO system configuration when using the zoom functionality.

Note that there is no specific treatment of boundaries conditions : the four bands are considered as artificial walls ; they are set to zero.

Model formulation

The one-dimensional vertical model only considers the vertical – z, sigma or partial steps – coordinate and time as independent variables in the primitive equations, with no horizontal variations. All the horizontal derivatives are set to zero.

Thus, the horizontal velocities are purely Ekman and inertial, depending only on the time step and forcings. There is no vertical velocity associated to Ekman pumping.

The temperature and salinity are controlled only by vertical diffusion equations and the density, need for the turbulent mixing closure scheme, is computed using an equation of state of sea water. For a sea-ice point, only the thermodynamics processes are take into account.

Equations

The principal balance in the equations of motion comes from a balance of momentum acceleration, vertical momentum diffusion and the Coriolis force due to the earth's rotation

$$\frac{\partial u}{\partial t} = f\,v + \frac{\partial}{\partial z}\left(K_M \frac{\partial u}{\partial z}\right)$$

$$\frac{\partial v}{\partial t} = -f\,u + \frac{\partial}{\partial z}\left(K_M \frac{\partial v}{\partial z}\right)$$

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(K_T \frac{\partial T}{\partial z} - \gamma\right)$$

$$\frac{\partial S}{\partial t} = \frac{\partial}{\partial z}\left(K_S \frac{\partial S}{\partial z} - \gamma\right)$$

$$w = 0$$

$$\rho = F(T, S, z)$$

with the vertical boundary conditions prescribed as follows :

at the top : $K_M \left(\frac{\partial u}{\partial z}, \frac{\partial v}{\partial z} \right) = \frac{(\tau_u, \tau_v)}{\rho_0}$

$$K_T \frac{\partial T}{\partial z} = \frac{Q_T}{\rho_0 C_p}$$

$$K_S \frac{\partial S}{\partial z} = \frac{EMP\ S|_{z=0}}{\rho_0}$$

at the bottom : $K_M \left(\frac{\partial u}{\partial z}, \frac{\partial v}{\partial z} \right) = 0$

$$K_T \frac{\partial T}{\partial z} = 0$$

$$K_S \frac{\partial S}{\partial z} = 0$$

In these equations, t is the time variable and z the vertical coordinate. u, v and w are components of the velocity vector, f the coriolis acceleration and g the gravitational acceleration.
T and S are respectively the potential temperature and the salinity of the ocean, while ρ is the *in-situ* density.

K_M, K_T , K_S are the vertical turbulent mixing coefficients, defined by the vertical closure scheme. Note that K_T , K_S are equal in case of no double diffusion mixing parameterization which includes the effect of salt fingering and diffusive convection.
γ is a non-local transport term using only in case of KPP vertical mixing scheme.

For the boundary conditions, τ_u and τ_v are the surface wind stress components , Q_T the non penetrative part of the net surface heat flux, EMP the evaporation minus the precipitation minus river runoff plus – in case of sea-ice point - the rate of change of the sea-ice thickness budget and $S|_{z=0}$ is the sea surface salinity.

Thus in this one-dimensional vertical configuration, there is no advection, no lateral mixing on tracers nor dynamics. The parameterization of the vertical mixing for momentum and tracers is done via a 1.5 second order turbulence closure model based on a prognostic equation of turbulent kinetic energy and a closure assumption for turbulent length scales - TKE - and a non local K-Profile Parameterization of boundary layer scheme – KPP –

Code structure

The integration of the 1-D turbulence code into a the NEMO 3-D circulation model is done via a CPP key **key_cfg_1d**, and is as easy as calling a subroutine.

After the initializations phase in the opa main routine (initializations of physical and numerical parameters, space and time domain, etc…), the time stepping routine step1d is call in the case of one-dimensional configuration ; otherwise the classic time stepping routine for global configuration is call

The time stepping starts at the end of the initialization phase. It ensures ice time stepping in the case of an sea-ice point ; otherwise, it starts by updating forcings and data. Afterwards the vertical mixing coefficients are calculated; then tracer and dynamics vertical diffusion trend are computed. In the next step, time stepping of prognostic variables (temperature, salinity, u and v velocities components). Finally variable are saved on output, diagnostics and restart files

In global configuration, the dynamics time stepping is perform in the **dynspg.F90** module that compute the pressure gradient trend which is not need in 1-D configuration ; that's why we created a specific dynamics time stepping module called **dynnxt1d.F90**

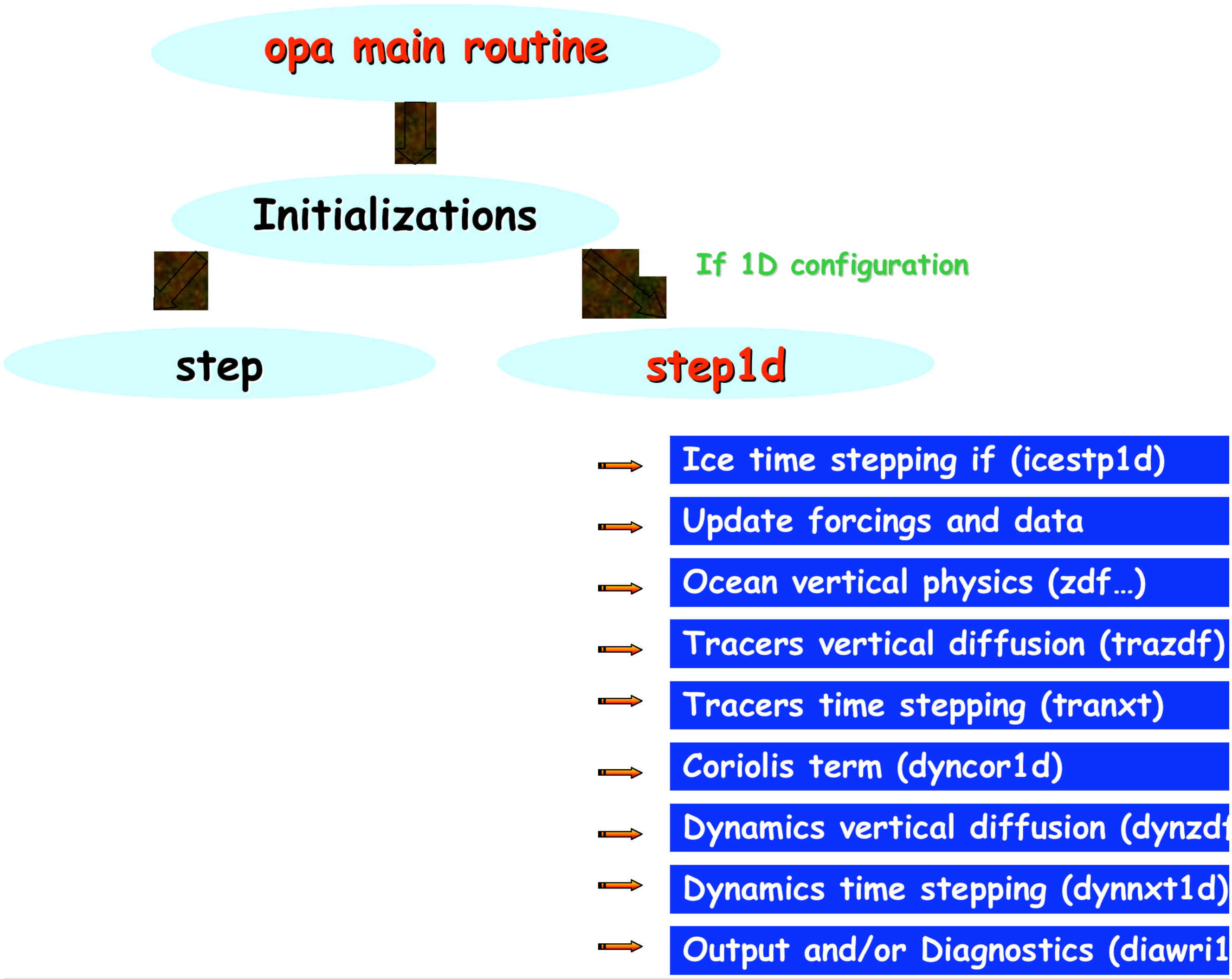

Figure 2 : Schematic view of 1D vertical code structure

Specific modules

The modules for 1-D configuration are in the new subdirectory **C1D** of the **OCE_SRC** directory (see the reference manual of the NEMO).

Description

ini1d.F90
Initialization of 1D configuration - masks umask and vmask are set to tmask -

dyncor1d.F90
computation of coriolis factor at T-point in subroutine **fcorid_1d** and the total vorticity trend in subroutine **dyncor_1d**

dynnxt1d.F90
ocean dynamics time-stepping (In global configuration, the dynamics time stepping is perform in the dynspg routine that compute the pressure gradient trend which is not need in 1-D configuration)

step1d.F90
time stepping loop in 1-D configuration

icestp1d.F90
ice model time stepping loop in 1-D configuration

diawri1d.F90
ocean diagnostics (one file for the outputs)

Modified modules (routines) in NEMO_ORCA2_LIM configuration

par_ORCA_R2.h90
set the dimensions parameter under the key **key_cfg_1d**

opa.F90
call the routine ***ice_stp_1d*** if 1-D vertical configuration is needed

zdftke.F90
store specific diagnostics variables under the key **key_cfg_1d**

domzgr.F90
routine ***zgr_bat_ctl*** : No check of ocean isolated point is needed in 1-D vertical configuration

iceini.F90
routine ***ice_run*** : force the ice dynamics flag **ln_limdyn** to FALSE if 1-D vertical configuration is needed

Model setup

To setup the one-dimensional model, the user just have to defined the CPP key **key_cfg_1d** and set in the parameter file, the jpizoom and jpjzoom indices of the computational point.
For examples, one present here three tests case to improve the capabilities of the 1D model. The three points ARC, PAC and ANT are represented in figure 3.
The model variables are calculated here in the ORCA2 grid and for 31 vertical levels configuration. Note that one can only perform one simulation per point – one test case for one point - .

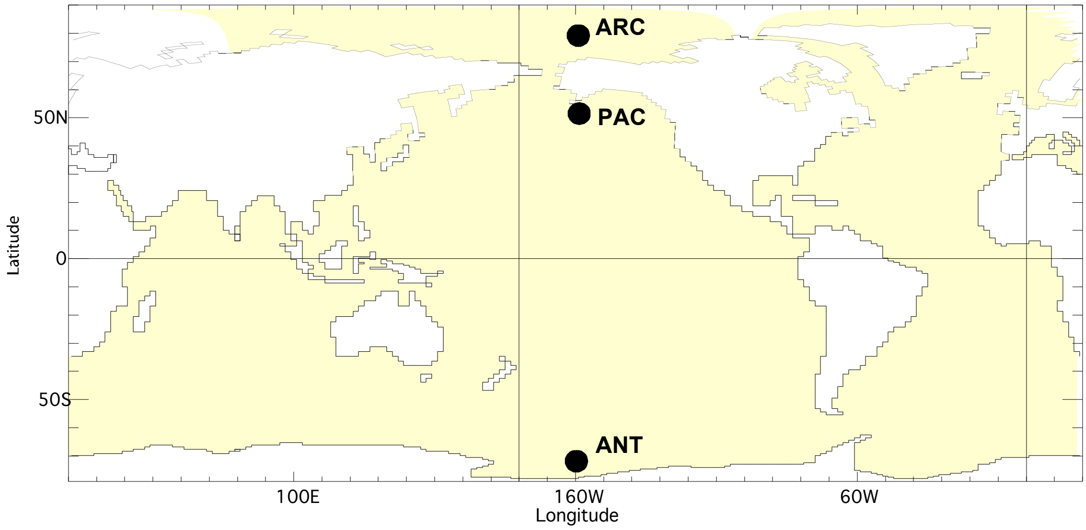

Figure 3 : Position of 3 points in the ORCA2 grid

CPP key : **key_cfg_1d**

Lateral boundary conditions :
jperio = 0 ; closed boundary, solid walls are imposed at model boundaries : first and last rows and columns are set to zero

Grid dimensions :
jpidta = 182
jpjdta = 149
jpkdta = 31
jpiglo = 3
jpjglo = 3
jpk = 31

indices of the point

- for the point located in the Pacific North at 160°W and 50°N : **PAC**
  jpizoom = 61
  jpjzoom = 110

- for the point located in the Artic at 160°W and 75°N : **ARC**
  jpizoom = 61
  jpjzoom = 133

- for the point located in the Antarctic at 160°W and 75°S : **ANT**
  jpizoom = 61
  jpjzoom = 7

1st example

The figures 4 and 5 represent the hovmoller diagrams of temperature and salinity respectively, obtained by a one year simulation using the NEMO ORCA2-LIM codes, at the PAC ocean point.

The figures of the left are obtained with a global 3D simulation using the TKE mixing scheme – we have extracted in the outputs the point of interest - , the figures of the middle are obtained with the 1D vertical model using the TKE mixing scheme and the figures of the right are obtained with the 1D vertical model using the KPP mixing scheme.

We observe very few differences between the three figures.

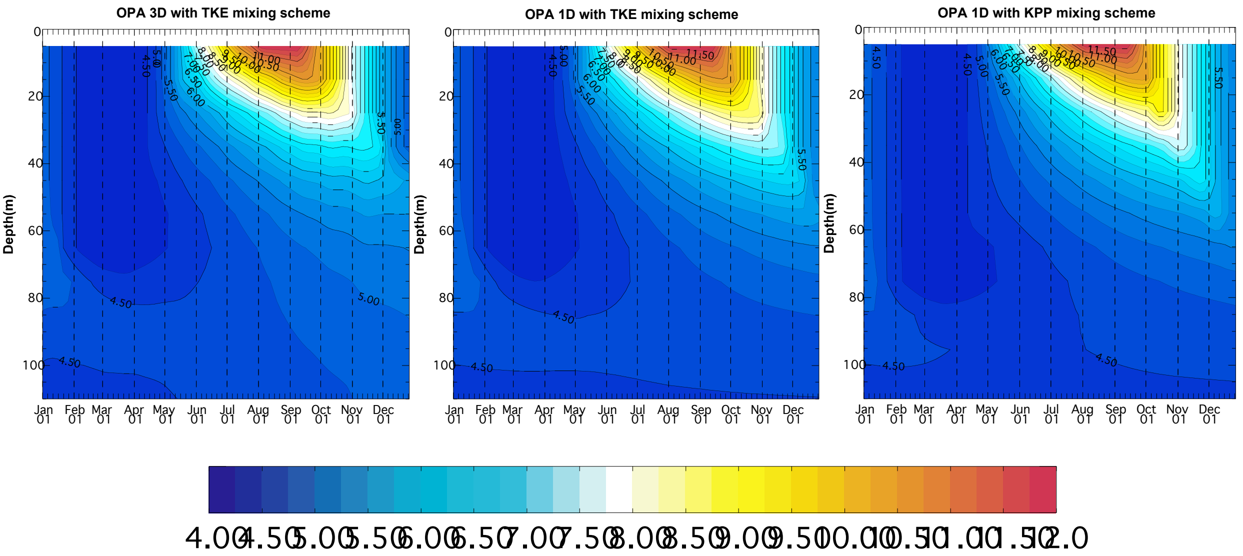

Figure 4 : Hovmoller time series of temperature obtained in NEMO one-year simulation.
Left : Global 3-D simulation with TKE vertical mixing scheme
Middle : NEMO 1-D simulation with TKE vertical mixing scheme
Right : NEMO 1-D simulation with KPP vertical mixing scheme

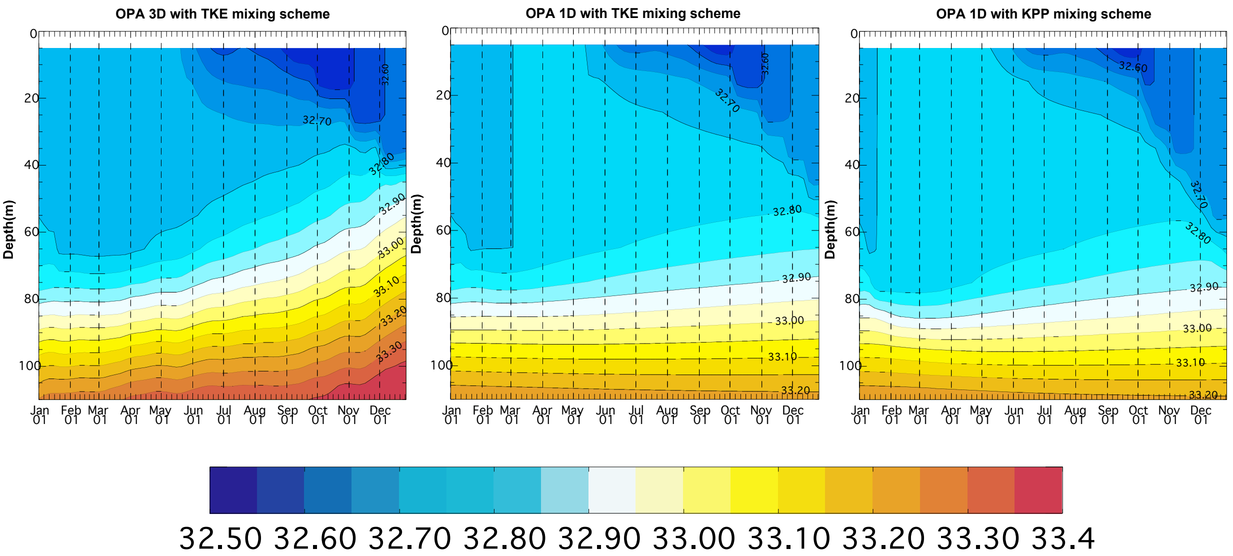

Figure 5 : Hovmoller time series of salinity obtained in NEMO one-year simulation.
Left : Global 3-D simulation with TKE vertical mixing scheme
Middle : NEMO 1-D simulation with TKE vertical mixing scheme
Right : NEMO 1-D simulation with KPP vertical mixing scheme

2nd example

The figure 6, 7 and 8 are obtained by the 1-D vertical at the PAC ocean point using the TKE vertical mixing scheme. They show some diagnostics we can have with the model.

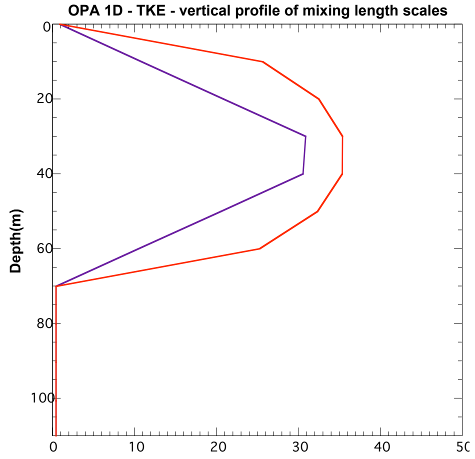

Figure 6 : vertical profile of mixing length scale (blue) and dissipation length scale (red)

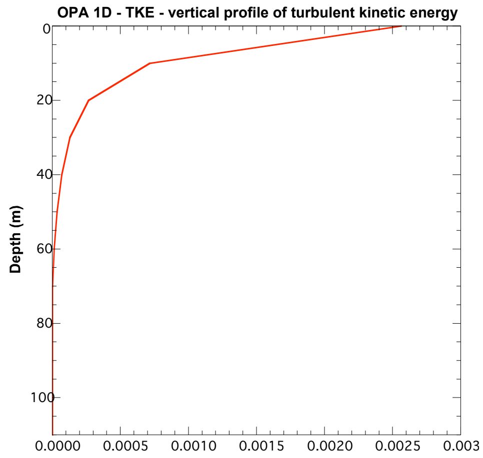

Figure 7 : vertical profile of turbulent kinetic energy

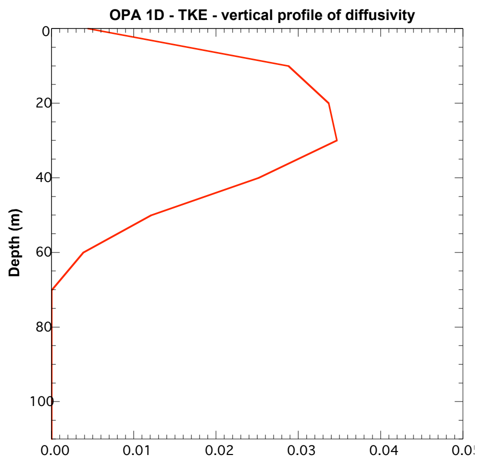

Figure 8 : vertical profile of diffusivity on temperature

3rd example

The figure 9, 10 and 11 are obtained by the 1-D vertical at the PAC ocean point using the KPP vertical mixing scheme.

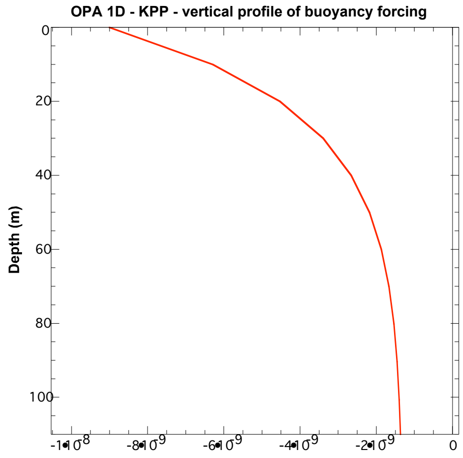

Figure 9 : vertical profile of buoyancy force

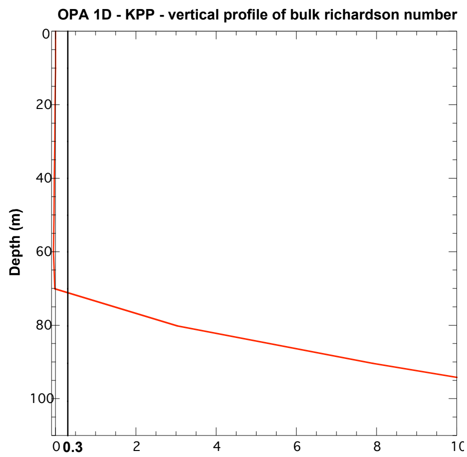

Figure 10 : vertical profile of bulk richardson number.
The bulk Richardson number gives the depth of the boundary layer, when it reaches its critical value (here = 0.3)

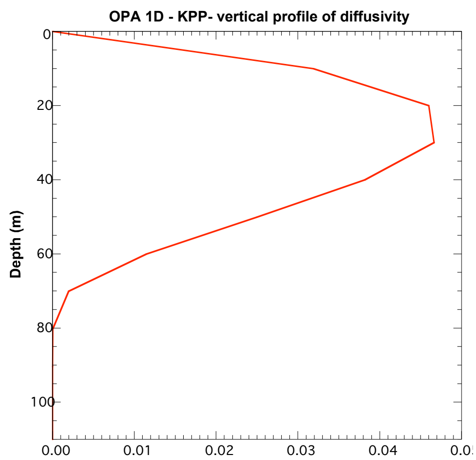

Figure 10 : vertical profile of diffusivity on temperature

4''' example

The figures 12 and 13 represent time series of sea ice fraction (left), sea ice thickness (middle) and snow thickness (right) in ORCA2-LIM one year simulation, respectively at the ANT ocean point – figure 12 – and the ARC ocean point – figure 13.
Note that the ice model in its global configuration allows via a parameter, to take into account ice dynamics or not.
The black curve is obtained with a global 3-D simulation with ice transport take into account, the blue one is obtained with a global 3-D simulation with no ice transport and the red one is obtained with the 1-D vertical configuration.
We observe a good agreement between the 1-D model and the global 3-D model with no ice transport.

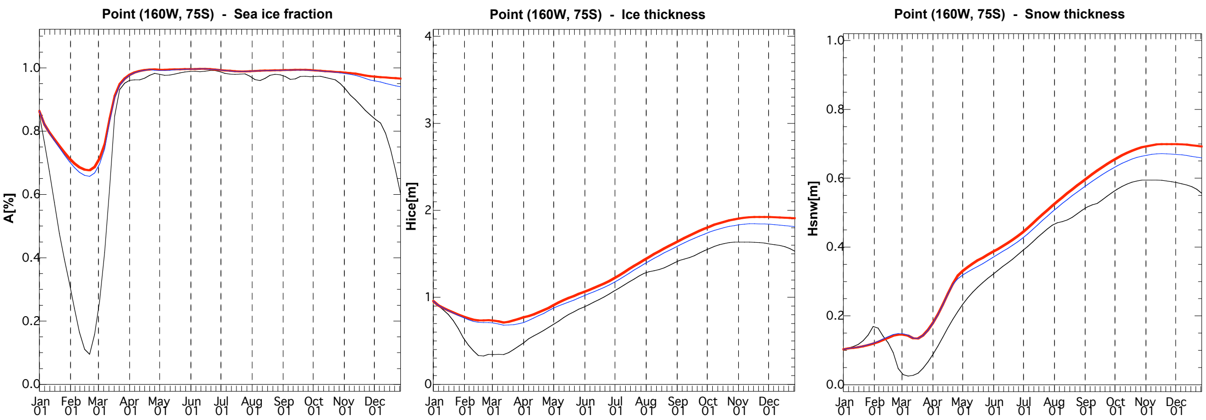

Figure 12 : Time series of sea ice fraction (left), sea ice thickness (middle) and snow thickness (right) in ORCA2-LIM one year simulation at the ANT ocean point, located at 160°W and 75°S
Black : global 3-D simulation with ice transport take into account
Blue : global 3-D simulation with no ice transport
Red : 1-D vertical model

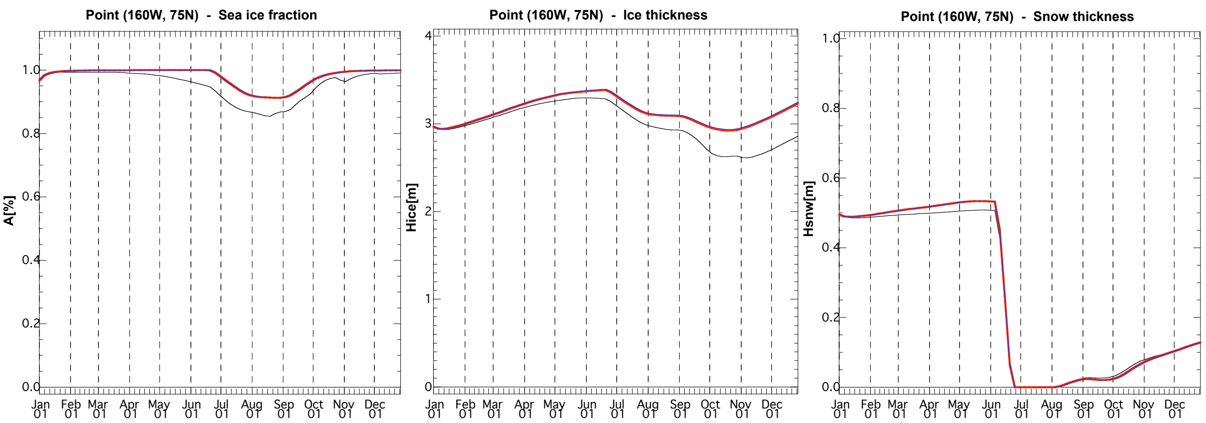

Figure 13 : Time series of sea ice fraction (left), sea ice thickness (middle) and snow thickness (right) in ORCA2-LIM one year simulation at the ARC ocean point,, located at 160°W and 75°N
Black : global 3-D simulation with ice transport take into account
Blue : global 3-D simulation with no ice transport
Red : 1-D vertical model

Conclusions and perspectives

The 1D vertical model has been tested on 31 or 301 vertical levels configuration ; it can be restarted from a file. It will be introduce in the NEMO system by the ESOPA team.

The future developments will be :

- the introduction of vertical velocity which takes into account the effects of possible upwelling that could bring tracers towards the surface
- the integration of observations that come from ocean weather stations like PAPA
- the possibility to use analytical initial variables and forcings
- the extension of the 1-D vertical configuration to a biogeochemical models (PISCES & LOBSTER)