Definition of the interannual experiment ORCA025.L75-GRD100, 1958-2010

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Introduction

This report describes in details the ORCA025.L75-GRD100 simulation performed in the frame of the DRAKKAR project. This run is the second ORCA025.L75 50 years-long simulation computed at MEOM (LEGI, CNRS) (after ORCA025.L75-G85). The mesh is an ORCA grid $1/4^{\circ}$ at equator, with partial-steps, 75 levels Drakkar type. The simulation is initialized from Levitus/PHC 2.1. Regarding the forcing fields, the run is divided into two parts : from 01/01/1958 to 31/12/1988 the ocean is forced by the standard DFS4.3 forcing set. From 01/01/1989 to 31/12/2010, the ocean is then forced by an ERA-interim forcing set (let's say DFS5.0). This DFS5.0 forcing set is based on the reduced period 1989-2009 of ERAinterim (an extended period is now available and is the base for further developments). This will be described in surface boundary conditions section. The purposes of this run is to provide a 50-years long hindcast with all the improvements obtained from the various 20-years long ORCA025.L75 experiments performed so far. The code is based on version NEMO 3.2.2. [12] and is very close to ORCA025.L75-MJM95, the companion free run of the GLORY2 reanalysis, which is described in a MyOcean report (Molines et al. 2011, [13])

This report is organized in different sections. The first one deals with the details of the numerical code, the parametrizations used and the forcing issues. The second section describes the model configuration, e.g. the model grid and the input data of the model. A third section is dedicated to the technical details of the production of the run and give some informations about the computing performance. Finally, the last section gives some elements of validation of the run.

1 Numerical code

1.1 Overview

This experiment was performed with version 3.2.2 of NEMO, issued from Drakkar Config Manager (DCM) revision 455. CPP keys used for compilation are:

CPP key name	**Action:**
key_orca_r025_l75	ORCA025 horizontal grid with 75 vertical levels
key_dynspg_flt	Filtered free surface
key_zdftke	Tke turbulent closure for vertical diffusion
key_zdftmx	Tidal mixing parametrization
key_dtatem	Initialize model from temperature climatology
key_dtasal	Initialize model from salinity climatology
key_traldf_c2d	2D horizontal dependency on lateral diffusivity
key_dynldf_c2d	2D horizontal dependency on lateral viscosity
key_ldfslp	Lateral diffusion along isopycnal slopes
key_dimgout	Use temporary binary files for mpp output
key_mpp_mpi	Parallel processing using MPI library
key_lim2	Use LIM2 ice model
key_lim2_evp	Use Elasto-Visco-Plastic ice reology
key_trabbl_dif	Use BBL enhanced diffusion on tracers
key_trabbl_dif	Use BBL enhanced diffusion on tracers
key_trabbl_adv	Use BBL advective on tracers
key_dynbbl_adv	Use BBL advective on dynamics
key_tradmp	Use BBL tracers damping

1.2 Ocean details

1.2.1 Vertical physics

TKE scheme and deep convection parameterization

TKE is used to determine the vertical diffusion coefficient. The relevant namelist data are indicated below. Similarly to ORCA025.L75-MJM95, a non-standard treatment is performed on ice-covered area: (a) The background avt coefficient is divided by 10 under ice. (b) The coefficient for surface input of tke (ebb) is reduced from 60 (open ocean) to 3.75 (ice covered regions). (c) Lang-Muir cells parametrization is turned off below ice.

The deep convection is parameterized with enhanced vertical diffusion at the interface between unstable layers (aka EVD algorithm), with values set in the namelist as shown below. A bug was recently advertised in this version of TKE (and present since NEMO 3.2) (Storkey et al. 2012 [1], Bourdallé-Badie 2011, [4]); the effect of this bug is to produce a positive feed-back between TKE algorithn and EVD algorithm, leading to and extra deepening of the winter mixed layer (in general already too deep). However, in this run, contrary to previous simulation, we set nn_evdm=0, so that only tracers (T and S) are mixed during a convection episode and not the momentum (shear is then preserved). Fortunatly, with this setting the impact of the bug is drastically reduced, and we observe an overall major improvement in the simulation of the deep mixed layers (in the Labrador Sea, for example).

```
&namzdf        !   vertical physics
!----------------------------------------------------------------------
   rn_avm0     =   1.e-4   !  vertical eddy viscosity   [m2/s]          (background Kz if not "key_zdfcst")
   rn_avt0     =   1.e-5   !  vertical eddy diffusivity [m2/s]          (background Kz if not "key_zdfcst")
   nn_avb      =    0      !  profile for background avt & avm (=1) or not (=0)
   nn_havtb    =    1      !  horizontal shape for avtb (=1) or not (=0)
   ln_zdfevd   = .true.    !  convection: enhanced vertical diffusion (T) or not (F)
   nn_evdm     =   0       !  enhanced mixing apply on tracer (=0) or on tracer and momentum (=1)
   rn_avevd    = 10.       !  vertical coefficient for enhanced diffusion scheme [m2/s]
   ln_zdfnpc   = .false.   !  convection: Non-Penetrative algorithm (T) or not (F)
   nn_npc      =    1            !  frequency of application of npc
   nn_npcp     =  365            !  npc control print frequency
   ln_zdfexp   =  .false.  !  split explicit (T) or implicit (F) time stepping
   nn_zdfexp   =   3       !  number of sub-timestep for ln_zdfexp=T
/
```

```
&namzdf_tke    !   turbulent eddy kinetic dependent vertical diffusion  ("key_zdftke")
!----------------------------------------------------------------------
   rn_ediff    =   0.1     !  coef. for vertical eddy coef. (avt=rn_ediff*mxl*sqrt(e) )
   rn_ediss    =   0.7     !  coef. of the Kolmogoroff dissipation
   rn_ebb      =   60      !  coef. of the surface input of tke
   rn_ebbice   =   3.75    !  coef. of the surface input of tke under ice

   nn_havti    =    1      !  horizontal shape for avtb (=1) or not (=0) under ice
   rn_emin     =   1.e-6   !  minimum value of tke [m2/s2]
   rn_emin0    =   1.e-4   !  surface minimum value of tke [m2/s2]
   rn_bshear   =   1.e-20  !  background shear (>0)
   nn_mxl      =   3       !  mixing length: = 0 bounded by the distance to surface and bottom
                           !                 = 1 bounded by the local vertical scale factor
                           !                 = 2 first vertical derivative of mixing length bounded by 1
                           !                 = 3 same criteria as case 2 but applied in a different way
   nn_pdl      =   1       !  Prandtl number function of richarson number (=1, avt=pdl(Ri)*avm) or not (=0, avt=avm)
   ln_mxl0     = .true.    !  mixing length scale surface value as function of wind stress (T) or not (F)
   rn_lmin     =   0.001   !  interior buoyancy lenght scale minimum value
   rn_lmin0    =   0.01    !  surface  buoyancy lenght scale minimum value
   nn_etau     =   1       !  exponentially deceasing penetration of tke due to internal & intertial waves
                           !        = 0 no penetration ( O(2 km) resolution)
                           !        = 1 additional tke source (rn_efr * en)
                           !        = 2 additional tke source (rn_efr * en) applied only at the base of the mixed layer
                           !        = 3 additional tke source (HF contribution: mean of stress module - module of mean stress)
   nn_htau     =   1       !  type of exponential decrease of tke penetration
                           !        = 0  constant 10 m length scale
                           !        = 1  0.5m at the equator to 30m at high latitudes
                           !        = 2  30 meters constant depth penetration
               ! option used only id nn_etau /= 0
   rn_efr      =   0.05    !  fraction of surface tke value which penetrates inside the ocean
               ! option used only if nn_etau = 3
   rn_addhft   =  -1.e-3   !     add offset   applied to the "mean of stress module - module of mean stress" (always kept > 0)
   rn_sclhft   =   1.      !     scale factor applied to the "mean of stress module - module of mean stress"
   ln_lc       = .true.    !  Langmuir cell effect
   rn_lc       =   0.15    !  coef. associated to Langmuir cells
/
```

1.2.2 Horizontal physics

Tracers

We use a laplacian isopycnal diffusivity for tracers. The diffusivity is proportionnal to the local grid size (it decreases poleward).

```
&namtra_ldf    !   lateral diffusion scheme for tracer
!----------------------------------------------------------------------
!                          !  Type of the operator :
   ln_traldf_lap    =  .true.   !     laplacian operator
   ln_traldf_bilap  =  .false.  !     bilaplacian operator
                          !  Direction of action  :
   ln_traldf_level  =  .false.  !     iso-level
   ln_traldf_hor    =  .false.  !     horizontal (geopotential)         (require "key_ldfslp" when ln_sco=T)
   ln_traldf_iso    =  .true.   !     iso-neutral                       (require "key_ldfslp")
!                          !  Coefficient
   rn_aht_0         =  300.     !     horizontal eddy diffusivity for tracers [m2/s]
   rn_ahtb_0        =    0.     !     background eddy diffusivity for ldf_iso [m2/s]
   rn_aeiv_0        =    0.     !     eddy induced velocity coefficient [m2/s]    (require "key_traldf_eiv")
/
```

Momentum

We use a bi-harmonic viscosity for the lateral dissipation. The viscosity is proportional to the grid size power 3.

```
&namdyn_ldf    !   lateral diffusion on momentum
!----------------------------------------------------------------------
!                          !  Type of the operator :
   ln_dynldf_lap    =  .false.  !     laplacian operator
   ln_dynldf_bilap  =  .true.   !     bilaplacian operator
!                          !  Direction of action  :
   ln_dynldf_level  =  .false.  !     iso-level
   ln_dynldf_hor    =  .true.   !     horizontal (geopotential)        (require "key_ldfslp" in s-coord.)
   ln_dynldf_iso    =  .false.  !     iso-neutral                      (require "key_ldfslp")
                          !  Coefficient
  rn_ahm_0    = -1.5e11        !     horizontal eddy viscosity if lap : >0  [m2/s]
                               !                               if bilap : <0  [m4/s2]
   rn_ahmb_0   =     0.        !     background eddy viscosity for ldf_iso [m2/s]
/
```

1.2.3 Bottom Boundary Layer

Bottom boundary layer parametrization (Beckmann et al. 1997, [2]) were used in this simulation, with all the enhancements developed by Hervieux (2007, [10]) at LEGI. Both diffusive and advective BBL parameterization are used for tracers. The parametrization of BBL advection for momentum was also used. Previous runs have shown that despite the fact that the effect of this parameterization is still unsatisfactory with regard to overflow modeling, it does have some positive effects.

```
&nambbl        !   bottom boundary layer scheme
!----------------------------------------------------------------------
!                          !  diffusive bbl                             ("key_trabbl")
!                          !  advective bbl                             ("key_trabbl_adv")
   rn_ahtbbl     =  1000.  !  lateral mixing coefficient in the bbl  [m2/s]
   ln_kriteria   = .true.  !  activate BBL on k-criteria instead of depth criteria
   ln_counter    = .false. !  save BBL counts [T] or not [F]
/
```

1.2.4 Surface boundary conditions

The surface boundary conditions are prescribed to the model using the CORE bulk formulation. Input fields required for this forcing function are: 4 'turbulent' variables (2m air temperature [t2], 2m specific humidity [q2], 10m wind velocity components [u10, v10]), 2 radiative fluxes (short wave radiation –solar radiation– [radsw], long wave radiation –infra-red– [radlw]), 2 fresh water fluxes (total precipitation [precip] and solid precipitation [snow]). The sources or origin as well as the particular processing of these different fields define a Drakkar Forcing Set (DFS).

In this run we choose to use absolute 10m wind in oposition to relative 10m wind, generally used in NEMO (difference between 10m winds and surface currents). This choice has a direct impact on the wind stress applied to the ocean, but also to the exchange coefficients computed by the bulk formulae, (Cd, Ce, Ch respectively the drag coefficient, the exchange coefficients for evaporation and sensible heat flux).

During the first part of the experiment (01/01/1958 to 31/12/1988) the forcing set used is DFS4.3, which is fully described in Brodeau et al. 2010, [5]. This forcing set is based on ERA-40 and has 6-hourly turbulent variables (t2,q2,u10,v10) on a 1.125°regular grid. Daily radiative and monthly freshwater fluxes are based on satellite data and are on a coarser 2.5°regular grid. In the second part of the experiment (01/01/1989 to 31/12/2010), the forcing set is based on ERA-interim (first release, from 1989 to 2009). The turbulent variables are then 3-hourly and radiative and freshwater fluxes are daily. All the variables share the same 0.7°grid. Some corrections were applied to forcing files to build a custom forcing set (DFS5.0) :

- Air temperature and humidity at 2m are corrected in the arctic using the POLES climatology, as described in Brodeau et al. 2010, [5].
- Shortwave radiative fluxes and precipitation were corrected (more details below)
- Total Cloud Cover (tcc) is not used

```
&namsbc        !   Surface Boundary Condition (surface module)
!-----------------------------------------------------------------------
   nn_fsbc     = 5         !  frequency of surface boundary condition computation
                           !             (= the frequency of sea-ice model call)
   ln_ana      = .false.   !  analytical formulation (T => fill namsbc_ana )
   ln_flx      = .false.   !  flux formulation       (T => fill namsbc_flx )
   ln_blk_clio = .false.   !  CLIO bulk formulation  (T => fill namsbc_clio)
   ln_blk_core = .true.    !  CORE bulk formulation  (T => fill namsbc_core)
   ln_cpl      = .false.   !  Coupled formulation    (T => fill namsbc_cpl )
   nn_ice      = 2         !  =0 no ice boundary condition   ,
                           !  =1 use observed ice-cover      ,
                           !  =2 ice-model used                         ("key_lim3" or "key_lim2)
   nn_ico_cpl  = 1         !  ice-ocean coupling : =0 each nn_fsbc
                           !                       =1 stresses recomputed each ocean time step ("key_lim3" only)
                           !                       =2 combination of 0 and 1 cases            ("key_lim3" only)
   ln_dm2dc    = .true.    !  daily mean to diurnal cycle short wave (qsr)
   ln_rnf      = .true.    !  runoffs (T => fill namsbc_rnf)
   ln_ssr      = .true.    !  Sea Surface Restoring on T and/or S (T => fill namsbc_ssr)
   nn_fwb      = 0         !  FreshWater Budget: =0 unchecked                              ,
                           !                     =1 global mean of e-p-r set to zero at each time step
                           !                     =2 annual global mean of e-p-r set to zero
                           !                     =3 global emp set to zero and spread out over erp area
!   ln_tair_celsius = .false.  ! The Tair file is in celsius (NEMO needs Kelvins)
!   ln_stress_gridT = .true.   ! Wind stress read in T grid (.true.) or in U,V grid (.false)
!   ln_precip_kgms = .false.   ! Precip read in kg/m/s (.true.) or in mm/day (.false.)
/
```

From 1958 to 1988 (DFS4.3), the namelist is :

```
!-----------------------------------------------------------------------
&namsbc_core   !   namsbc_core  CORE bulk formulea
!-----------------------------------------------------------------------
!              !      file name      ! frequency (hours) !  variable  ! time interpol. !  clim   ! 'yearly' or ! weights            !
!              !                     !  (if <0  months)  !    name    !    (logical)   !  (T/F)  !  'monthly'  ! filename           !
   sn_wndi = 'drowned_u10'  ,     6      ,  'u10'     ,    .true.      , .false. ,  'yearly'  ,  'weight_bicubic_TURB' , 'U1'
   sn_wndj = 'drowned_v10'  ,     6      ,  'v10'     ,    .true.      , .false. ,  'yearly'  ,  'weight_bicubic_TURB' , 'V1'
   sn_qsr  = 'drowned_radsw',     24     ,  'radsw'   ,    .false.     , .false. ,  'yearly'  ,  'weight_bilin_FLX' ,   ''
   sn_qlw  = 'drowned_radlw',     24     ,  'radlw'   ,    .false.     , .false. ,  'yearly'  ,  'weight_bilin_FLX' ,   ''
   sn_tair = 'drowned_t2'   ,     6      ,  't2'      ,    .true.      , .false. ,  'yearly'  ,  'weight_bilin_TURB' ,   ''
   sn_humi = 'drowned_q2'   ,     6      ,  'q2'      ,    .true.      , .false. ,  'yearly'  ,  'weight_bilin_TURB' ,   ''
   sn_prec = 'drowned_precip' ,  -1      ,  'precip'  ,    .true.      , .false. ,  'yearly'  ,  'weight_bilin_FLX' ,   ''
   sn_snow = 'drowned_snow' ,    -1      ,  'snow'    ,    .true.      , .false. ,  'yearly'  ,  'weight_bilin_FLX' ,   ''
   sn_tdif =     'taudif'   ,    24      ,  'taudif'  ,    .true.      , .false. ,  'yearly'  ,  ''                  ,   ''


!
   cn_dir      = './'      !  root directory for the location of the bulk files
   ln_2m       = .true.    !  air temperature and humidity referenced at 2m (T) instead 10m (F)
   ln_taudif   = .false.   !  HF tau contribution: use "mean of stress module - module of the mean stress" data ?
   rn_pfac     = 1.00      !  multiplicative factor for precipitation (total & snow)
!
   ln_kata     = .false.    !  enhanced katabatic winds (T) or no (F).
   sn_kati     =     'katamask'     ,      -1           , 'katamaskx',    .false.     , .true.  ,  'yearly'  , ''       , ''
   sn_katj     =     'katamask'     ,      -1           , 'katamasky',    .false.     , .true.  ,  'yearly'  , ''       , ''
   ln_abswind  = .true.
   ln_abswind_ice  = .false.
!
/
```

From 1989 to 2010, the namelist is :

```
&namsbc_core   !   namsbc_core  CORE bulk formulea
!-----------------------------------------------------------------------
!              !      file name      ! frequency (hours) !  variable  ! time interpol. !  clim   ! 'yearly' or ! weights            !
!              !                     !  (if <0  months)  !    name    !    (logical)   !  (T/F)  !  'monthly'  ! filename           !
   sn_wndi = 'drowned_u10'  ,     3      ,  'u10'     ,    .true.      , .false. ,  'yearly'  ,  'weight_bicubic' , 'U1'
   sn_wndj = 'drowned_v10'  ,     3      ,  'v10'     ,    .true.      , .false. ,  'yearly'  ,  'weight_bicubic' , 'V1'
   sn_qsr  = 'drowned_radsw',     24     ,  'radsw'   ,    .false.     , .false. ,  'yearly'  ,  '' ,   ''
   sn_qlw  = 'drowned_radlw',     24     ,  'radlw'   ,    .false.     , .false. ,  'yearly'  ,  'weight_bilin' ,   ''
   sn_tair = 'drowned_t2'   ,     3      ,  't2'      ,    .true.      , .false. ,  'yearly'  ,  'weight_bilin' ,   ''
   sn_humi = 'drowned_q2'   ,     3      ,  'q2'      ,    .true.      , .false. ,  'yearly'  ,  'weight_bilin' ,   ''
   sn_prec = 'drowned_precip' ,  24      ,  'precip'  ,    .true.      , .false. ,  'yearly'  ,  '' ,   ''
   sn_snow = 'drowned_snow' ,    24      ,  'snow'    ,    .true.      , .false. ,  'yearly'  ,  'weight_bilin' ,   ''
   sn_tdif =     'taudif'   ,    24      ,  'taudif'  ,    .true.      , .false. ,  'yearly'  ,  ''                  ,   ''


!
   cn_dir      = './'      !  root directory for the location of the bulk files
   ln_2m       = .true.    !  air temperature and humidity referenced at 2m (T) instead 10m (F)
   ln_taudif   = .false.   !  HF tau contribution: use "mean of stress module - module of the mean stress" data ?
   rn_pfac     = 1.00      !  multiplicative factor for precipitation (total & snow)
!
   ln_kata     = .false.    !  enhanced katabatic winds (T) or no (F).
   sn_kati     =     'katamask'     ,      -1           , 'katamaskx',    .false.     , .true.  ,  'yearly'  , ''       , ''
   sn_katj     =     'katamask'     ,      -1           , 'katamasky',    .false.     , .true.  ,  'yearly'  , ''       , ''
   ln_abswind  = .true.
   ln_abswind_ice  = .false.
!
/
```

Note that no time interpolation on radiative fluxes is performed, because we use a pseudo diurnal cycle, that split the daily solar flux during the day, according to insolation and position on the earth. DFS4.3 has two set of weights due to the ERA40 and NCAR grids. From 1989 to 2010, corrected radsw and precip were on ORCA025 grid.

Radiative flux and precipitation corrections

Large-scale shortwave radiation is corrected according to Gilles Garric (Mercator-Océan) correction towards GEWEX (first version of the corrective weights). In contrast from previous simulations, the correction is not computed online but is done offline using the same methodology used for ORCA025.L75-MJM95 (100 shapiro filter passes to separate spatial scales). In addition, in an intent to to improve the insufficient melting of sea-ice in summer (especially in the antarctic), we chose not to reduce solar flux of 30% in the Arctic and 20% in the Southern Ocean as was suggested in the original Garric correction. This has improved considerably the solution in the southern ocean. These corrected files are available on the ORCA025 grid and are labeled radsw_ERAinterim_corrected_GIG_nopolar-ORCA025_yXXXX.nc. Re-projected files on the native ERA-interim grid are also available. Longwave radiation has not been corrected. Precipitation were corrected everywhere using G.Garric correction towards GPCP (first version of the corrective weights).

Light penetration algorithm according to ocean color

In this simulation we use RGB penetration of the solar flux in the ocean. In this solar radiation penetration formulation, visible light is split into three wavebands: blue (400-500nm), green (500-600nm), red (600-700nm). By mistake, we use a constant chlorophyll concentration (nn_chldta = 0): Though the ocean color monthly climatology developed by Lengaigne et al. 2007 [11] deduced from satellite (SeaWIFS ocean color products) is read, it is not used. We also discovered that this defect was already present in the ORCA025.L75-MJM95 experiment. The impact of this mistake is not evaluated yet.

```
&namtra_qsr        !   penetrative solar radiation
!----------------------------------------------------------------------
!             !   file name  ! frequency (hours) ! variable   ! time interpol. !  clim   ! 'yearly'/ ! weights  ! rotation !
!             !              !  (if <0  months)  !   name     !    (logical)   !  (T/F)  ! 'monthly' ! filename ! pairing  !
   sn_chl      = 'chlorophil' ,        -1         , 'CHLA'     ,    .true.      , .true.  , 'yearly'  , ''       , ''

   cn_dir      = './'      !  root directory for the location of the runoff files
   ln_traqsr   = .true.    !  Light penetration (T) or not (F)
   ln_qsr_rgb  = .true.    !  RGB (Red-Green-Blue) light penetration
   ln_qsr_2bd  = .false.   !  2 bands              light penetration
   ln_qsr_bio  = .false.   !  bio-model light penetration
   nn_chldta   =      0    !  RGB : Chl data (=1) or cst value (=0)
   rn_abs      =   0.58    !  RGB & 2 bands: fraction of light (rn_si1)
   rn_si0      =   0.35    !  RGB & 2 bands: shortess depth of extinction
   rn_si1      =   23.0    !  2 bands: longest depth of extinction
   rn_si2      =   62.0    !  3 bands: longest depth of extinction (for blue waveband & 0.01 mg/m2 Chl)
/
```

Diurnal Cycle on solar fluxes

Due to the high vertical resolution near the surface, we used the parameterization of the diurnal cycle on the solar flux (Bernie et al., 2007 [3]). Input is the daily mean flux, which is spread over the day according to the time, and geographical position on the earth. This parameterization aims at better representing the night-time convection which takes place in the upper most layer (0-5m) of the ocean.

In ORCA025.L75-MJM95, there was a small bug in the diurnal cycle parameterization, reported afterward by S.Masson (pers. comm.). This bug was linked to the fact that forcing function is not called at every step but only every nn_fsbc time steps. The consequence shows up when comparing the daily mean solar flux used as input and the *a posteriori* daily mean computed from the parameterization: a suspicious spatial pattern shows up on the difference, however with a very small amplitude (order of few miliwatt/m2). This bug was corrected in this simulation.

River Run-off

```
&namsbc_rnf    !   runoffs namelist surface boundary condition
!-----------------------------------------------------------------------
!              !     file name      ! frequency (hours) ! variable   ! time interpol. !  clim   ! 'yearly' / ! weights  ! rotation
!              !                    !  (if <0  months)  !   name     !    (logical)   !  (T/F)  ! 'monthly'  ! filename ! pairing
   sn_rnf    =   'runoff_1m_nomask' ,        -1         , 'sorunoff' ,    .true.      , .true.  , 'yearly'   , ''       , ''
   sn_cnf    =   'runoff_1m_nomask' ,         0         , 'socoefr'  ,    .false.     , .true.  , 'yearly'   , ''       , ''
!
   cn_dir       = './'      !  root directory for the location of the runoff files
   ln_rnf_emp   =   .false. !  runoffs included into precipitation field (T) or into a file (F)
   ln_rnf_mouth =   .true.  !  specific treatment at rivers mouths
   rn_hrnf      =   10.e0   !  depth over which enhanced vertical mixing is used
   rn_avt_rnf   =   2.e-3   !  value of the additional vertical mixing coef. [m2/s]
   rn_rfact     =   1.e0    !  multiplicative factor for runoff
/
```

For the river run-off, the novelty of this run concerns the Antarctic coastal run-off: we push up the idea of taking into account the melting of the drifting icebergs. A crude representation (uniform runoff south of 60°S) was already tested in ORCA025.L75-MJM95. Following the work of Silva et Al. 2006 [14], Gilles Garric (Mercator-océan) provided a new runoff file with an "iceberg-mask" which gives a better representation of icebergs melting in the antarctic. This file is the basis of the runoff used in GRD100. We only have made a minor correction to coastal runoff along the antarctic in order to keep the total mean runoff at the value of 1.31 Sv given by Dai et Trenberth (2002) [7],

Figure 1 shows the difference of annual means between the new runoff file and the runoff used for ORCA025.L75-MJM95 : the coastal runoff along the antarctic is the same and the uniform runoff south of 60°S is replaced by a more complex representation. (The icebergs melting occurs northward of 60°S in the Atlantic and in a few places in the Pacific.) Figure 2 shows the integrated runoff and its seasonal cycle in those two files : the seasonal cycle is conserved but the mean integrated runoff is slightly less than in ORCA025.L75-MJM95.

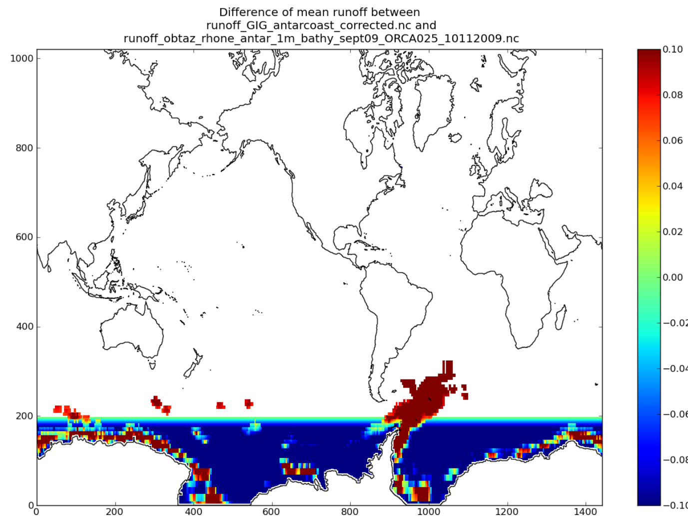


Figure 1: Annual mean runoff difference between new runoff and runoff_obtaz_rhone_antar_1m_bathy_sept09_ORCA025_10112009.nc (used in ORCA025.L75-MJM95)

In order to validate the modification, it is useful to compare with older version of the runoff file. Figure 3 shows the same difference but with the runoff used in ORCA025-B83 and ORCA025-MJM01. The coastal runoff along the antarctic was replaced by the "iceberg-mask" representation. Figure 4 shows that the seasonal cycle has a greater amplitude in the new representation of the runoff but keeps its mean unchanged.

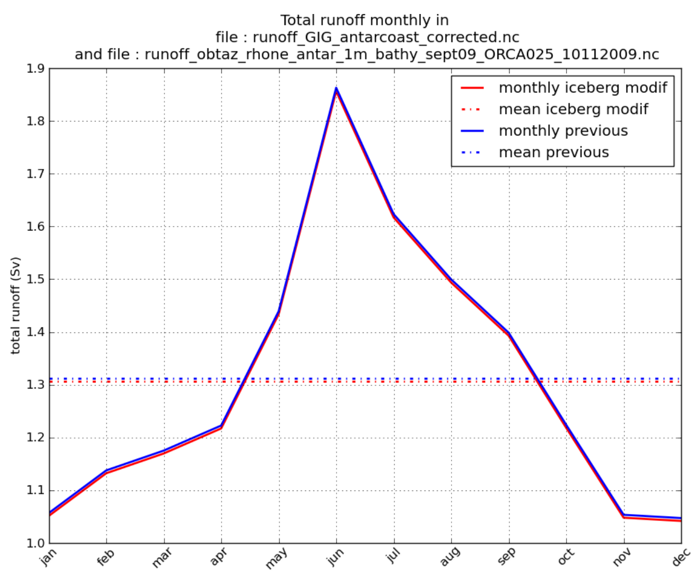


Figure 2: Integrated runoff : seasonal cycle and annual mean in the new runoff and runoff_obtaz_rhone_antar_1m_bathy_sept09_ORCA025_10112009.nc (used in ORCA025.L75-MJM95)

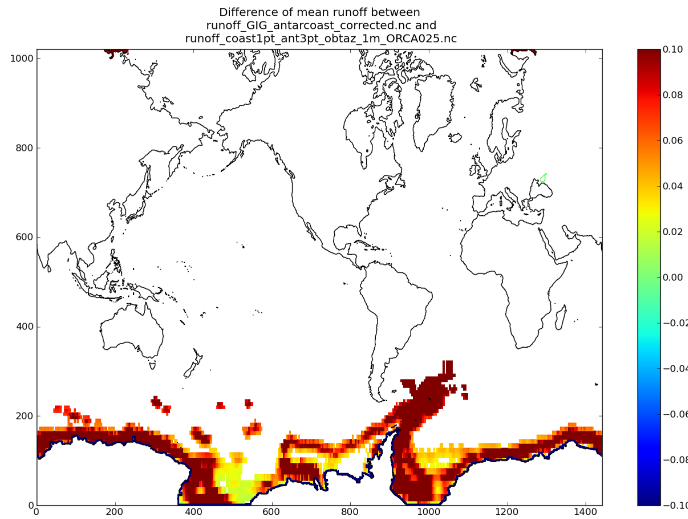


Figure 3: Annual mean runoff difference between new runoff and runoff_coast1pt_ant3pt_obtaz_1m_ORCA025.nc (used in ORCA025-B83 and ORCA025-MJM01)

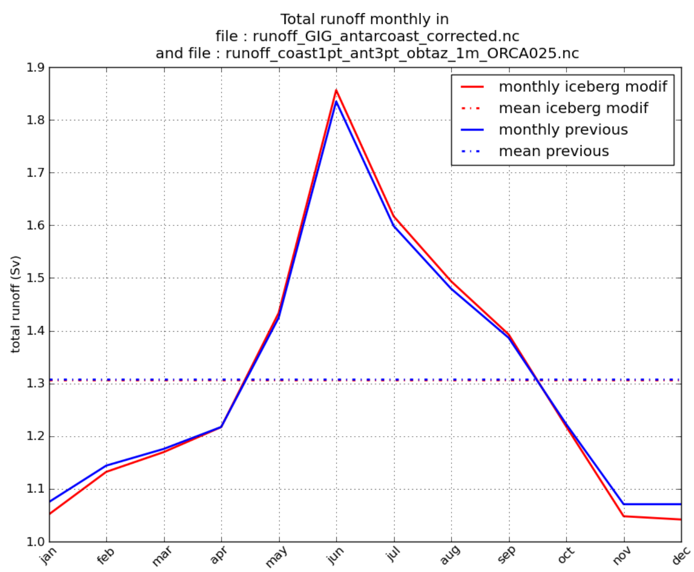


Figure 4: Integrated runoff : seasonal cycle and annual mean in the new runoff and runoff_coast1pt_ant3pt_obtaz_1m_ORCA025.nc (used in ORCA025-B83 and ORCA025-MJM01)

SSS restoring strategy

This run uses Sea Surface Salinity restoring, with a time scale of 60 days/10 meters (considered as rather strong). The restoring is identical for the open sea and ice covered areas. It is enhanced by a factor of 5 in the Mediterranean Sea. The restoring term is bounded to a maximum absolute value of 4 mm/day (after the Med Sea enhancement). In this run, we implemented 2 changes to the standard SSS restoring: (a) The coastal area remain free of restoring. A fading coefficient (function of the distance to coast) is used, with a characteristic length scale of 150 km. (b) In the restoring term, the SSS difference between model and observation climatology (Levitus) is computed using a spatially filtered model field. The filtering is achieved with a shapiro filter applied 100 times.

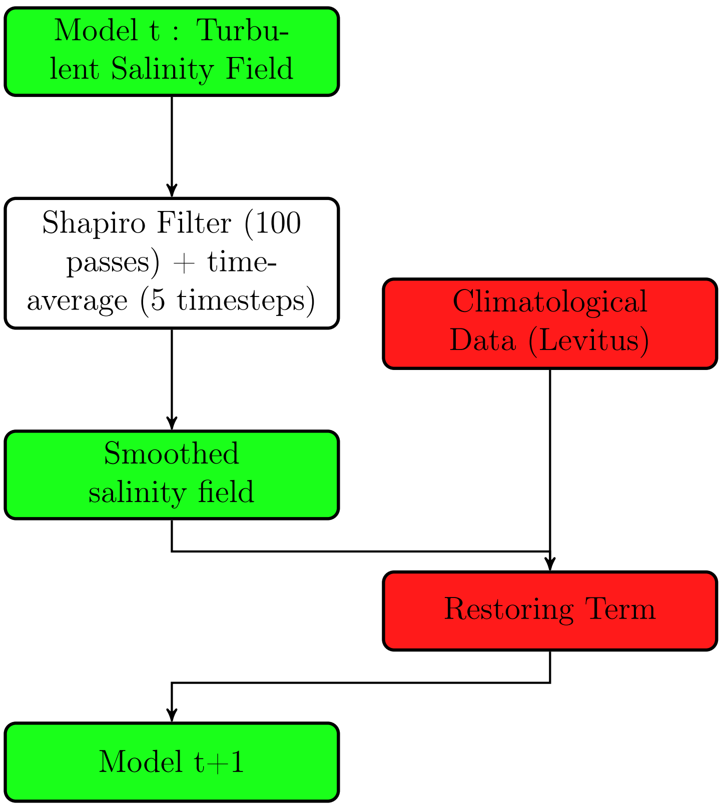


Figure 5: Method of filtered SSS restoring

In this simulation, we have modified this "distance to coast" file in order to keep a strong restoring near the various archipelagos worldwide and especially in the vicinity of Indonesia. The method is simply to apply cdfcofdis on a fake tmask where all the island and Indonesia where flooded. Thus we expect to improve the sea surface salinity in the western equatorial pacific, which was one of the flaws of ORCA025.L75-MJM95. The entire Med Sea as well as Red sea, Black sea and persian Gulf have a strong restoring, distance to coast in these basins being set artificially to 5000 km to ensure that restoring is applied everywhere.

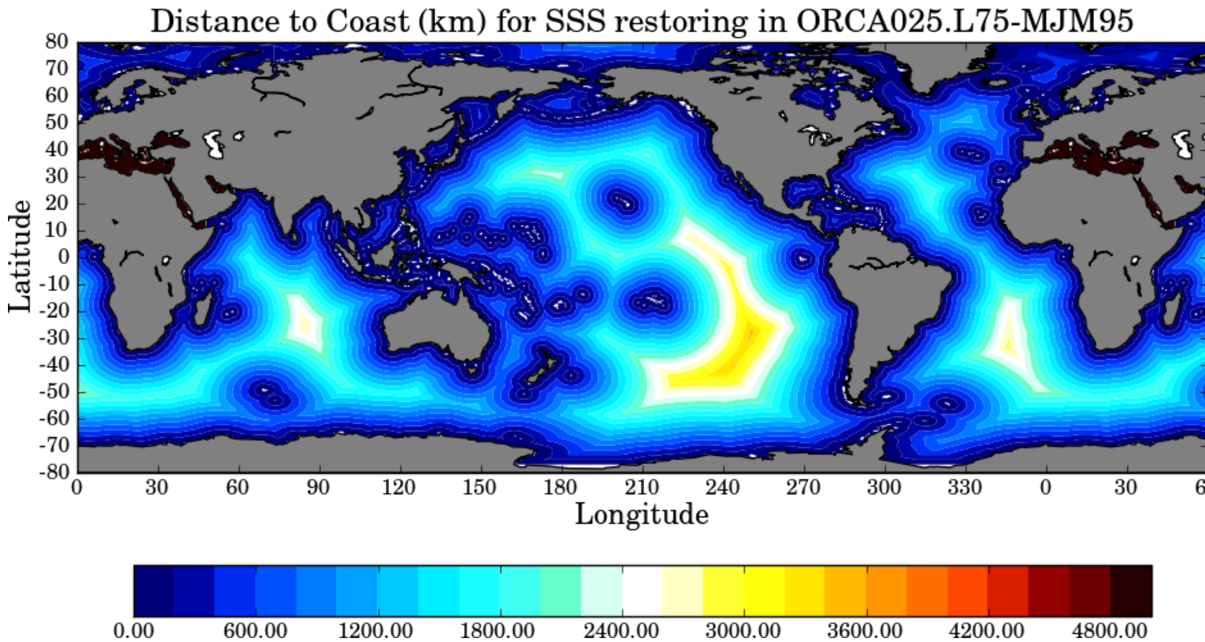


Figure 6: distance to coast file used in ORCA025.L75-MJM95

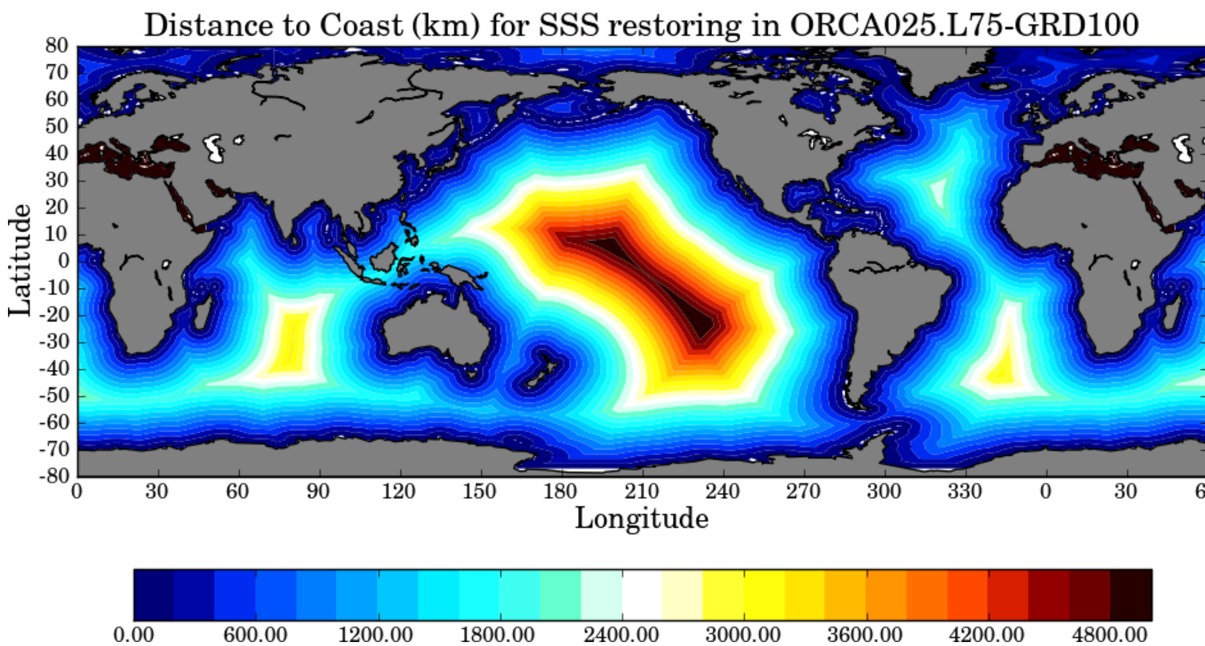


Figure 7: distance to coast file used in ORCA025.L75-GRD100

```
&namsbc_ssr    !   surface boundary condition : sea surface restoring
!-----------------------------------------------------------------------
!              !     file name      ! frequency (hours) ! variable   ! time interpol. !  clim   ! 'yearly' / ! weights  ! rotation
!              !                    !  (if <0  months)  !   name     !    (logical)   !  (T/F)  ! 'monthly'  ! filename ! pairing
   sn_sst      =    'sst_data'     ,        24          , 'sst'      ,     .false.    , .false. ,  'yearly'  , ''       , ''
   sn_sss      =    'sss_1m'       ,        -1          , 'vosaline' ,     .true.     , .true.  , 'yearly'   , ''       , ''
!
   cn_dir      = './'      !  root directory for the location of the runoff files
   nn_sstr     =     0     !  add a retroaction term in the surface heat       flux (=1) or not (=0)
   nn_sssr     =     2     !  add a damping     term in the surface freshwater flux (=1) or not (=0)
                           !  or to SSS only (=1) or no damping term (=0)
                           !  when nn_sssr = 2 damping term contributes to SSH
   rn_dqdt     =   -40.    !  magnitude of the retroaction on temperature   [W/m2/K]
   rn_deds     =   -166.667 !  magnitude of the damping on salinity   [mm/day]
   ln_sssr_bnd =   .true.  !  flag to bound erp term (associated with nn_sssr=2)
   rn_sssr_bnd =   4.e0    !  ABS(Max/Min) value of the damping erp term [mm/day]
   ln_sssr_flt =   .true.  !  flag to filter sss for sss restoring

   ln_sssr_msk =   .true.  !  flag to use distance to coast to weight SSS restoring
   sn_coast    = 'distcoast'    ,        0            , 'Tcoast'  , .false.       , .true.   , 'yearly' ,  ''        , ''
   rn_dist     =  150.     !  Decaying length scale (km) for SSS retoring fading near the coast

/
```

1.2.5 Lateral and bottom boundary condition

The lateral momentum boundary condition was set to 0 (free slip condition) except is a small region near Bering strait (ln_shlat2d = .true.). In order to reduce the transport at Bering strait, we have made a few adjustments in the bathymetry and the local lateral and bottom friction. A land point was added in the strait to account for the Diomede islands (see figure 8). The lateral boundary condition was set to no-slip (nn_shlat = 2) over a wide area upstream the strait (see figure 9). Due to the lack of efficiency of this modification (very small impact), an enhanced bottom friction (see figure 10) was added over the same area from January, 1st 1963. The enhanced bottom friction corresponds to the coefficient bfr_coef multiplied by rn_bfien = 10.

```
&namlbc        !   lateral momentum boundary condition
!-----------------------------------------------------------------------
   rn_shlat    =    0.     !      shlat = 0 : free slip
                           !  0 < shlat < 2 : partial slip
                           !      shlat = 2 : no slip
                           !  2 < shlat     : strong slip
   ln_shlat2d = .true.
/
```

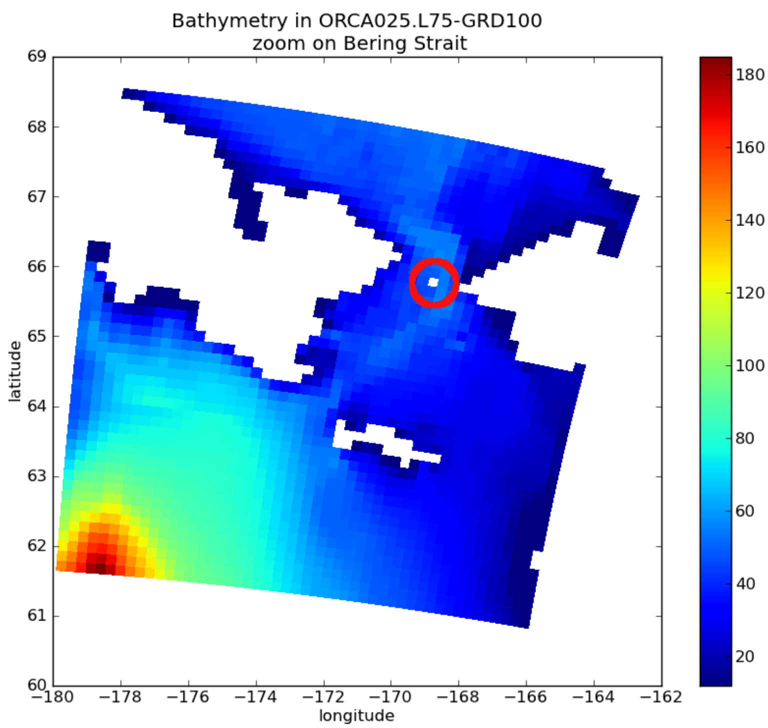


Figure 8: Bathymetry in the vicinity of Bering Strait. The Diomede islands (in red circle) have been added.

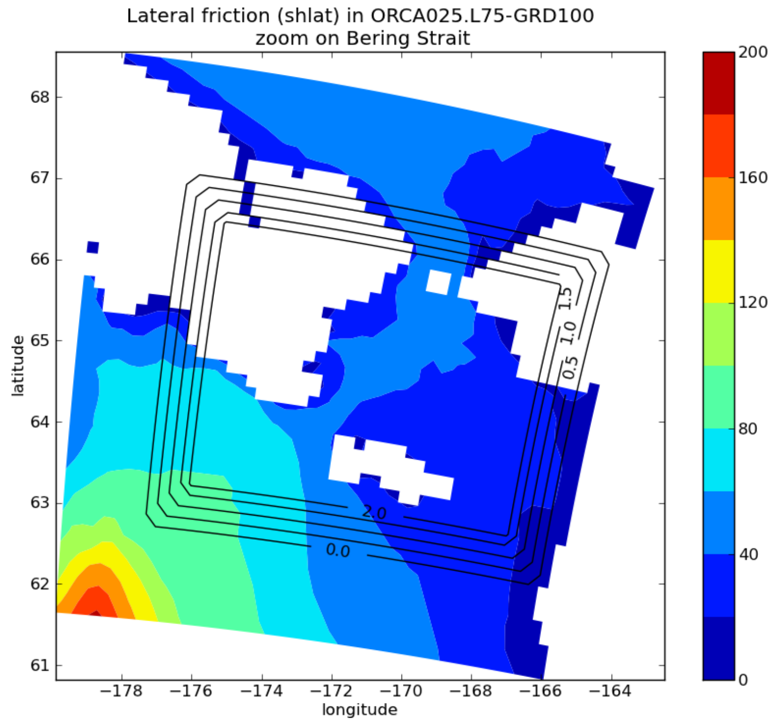


Figure 9: Lateral boundary condition in the vicinity of Bering Strait. Color countours are bathymetry.

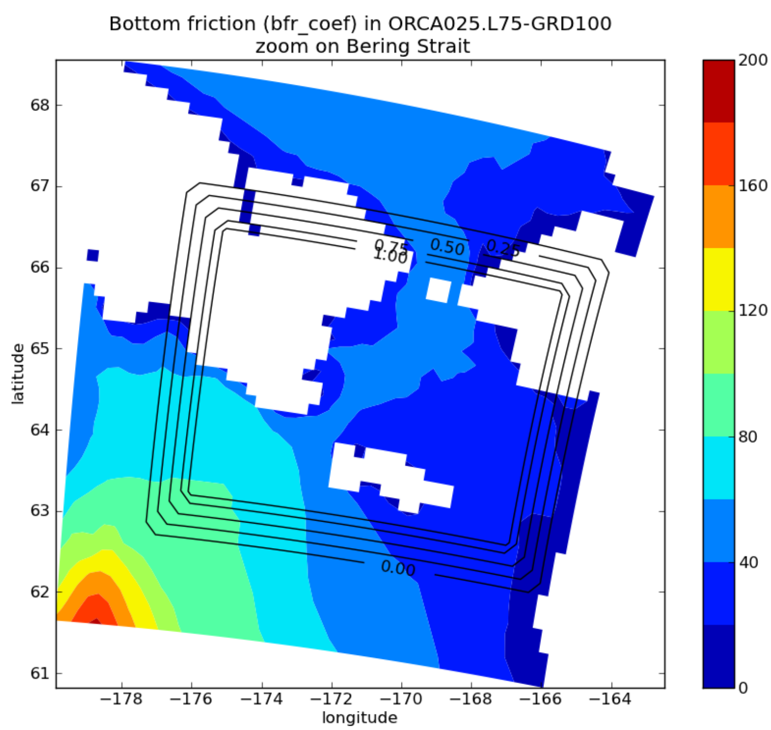


Figure 10: Bottom friction coefficient in the vicinity of Bering Strait. Color countours are bathymetry.

1.2.6 Tracer damping strategy

There are some very well identified and unfortunately robust flaws in the simulations, basically linked with the poor representation of the overflows. The main concerns are for the Mediterranean Sea outflow, and the Antarctic Bottom Water. The semi-enclosed seas such as the Red Sea, Black Sea of Persian Gulf have very specific water mass properties and act as reservoir for the open ocean. In order to fix those major flaws, or to keep water mass properties in the reservoir, we decided to use restoring of temperature and salinity toward climatology in very specific areas. The climatology used in this run is the same for all regions, and is the annual climatology of Gouretski and Koltermann (2004) [9]. This choice is driven by the AABW restoring zone where this climatology is recognized as the more suitable.

Regional 3D damping (semi-enclosed seas)

For the semi-enclosed seas already mentioned (Red and Black Seas, Persian Gulf) we apply a 3D T and S restoring with a time scale of 180 days.

Downstream the overflows

In the Gulf of Cadix, downstream Gibraltar strait, we have a very localized (and strong restoring), in the depth range 600-1300m, with a time scale of 6 days. In the Gulf of Aden, downstream Bab-el-Mandeb, we have the same kind of restoring (same time scale) but over the whole water column. The last spot where we have such a restoring is in the Arabian Gulf, downstream of the Ormuz Strait.

Antarctic Bottom Water Restoring

In order to refrain the erosion of the AABW in the Southern Ocean (lack of production, or miss representation of the down-slope motion), and according to a series of dedicated experiments (see for example Dufour et Al, 2010 [8]), we decided to implement a 3D, T and S weak restoring (time scale of 2 years) in an area limited by the sigma-2=34.7 isopycnal, a depth greater than 1000 m and south of 30 S.

1.3 Ice details

1.3.1 EVP rheology

This simulation used the LIM2 model, but with the Elasto-Visco-Plastic rheology, similar to the LIM3 rheology. The ice-ocean coupling is done every 5 model steps, but the wind stress is computed at every time step. This proved to be efficient to fix model instability that was observed previously.

1.3.2 Thermodynamics

The standard LIM2 thermodynamics is used. The only change with respect to ORCA025.L75-MJM95 is that we do not use cloud cover files. We use the standard constant value for nebulosity.

```
!-----------------------------------------------------------------------
&namicedyn     !   ice dynamic
!-----------------------------------------------------------------------
   epsd        =   1.0e-20 !  tolerance parameter
   alpha       =   0.5     !  coefficient for semi-implicit coriolis
   dm          =   0.0e+03 !  diffusion constant for dynamics
   nbiter      =   1       !  number of sub-time steps for relaxation
   nbitdr      = 250       !  maximum number of iterations for relaxation
   om          =   0.5     !  relaxation constant
   resl        =   5.0e-05 !  maximum value for the residual of relaxation
   cw          =   1.0e-02 !  drag coefficient for oceanic stress
   angvg       =   0.0     !  turning angle for oceanic stress
   pstar       =   2.0e+04 !  1st bulk-rheology parameter
   c_rhg       =  20.0     !  2nd bulk-rhelogy parameter
   etamn       =   0.0e+07 !  minimun value for viscosity
   creepl      =   1.0e-09 !  creep limit
   ecc         =   2.0     !  eccentricity of the elliptical yield curve
   ahi0        = 100.e0    !  horizontal eddy diffusivity coefficient for sea-ice [m2/s]
   nevp        = 360       !  number of iterations for subcycling
   telast      = 3600      !  timescale for elastic waves
   alphaevp    = 1.0       !  coefficient for the solution of int. stresses
/
```

```
!-----------------------------------------------------------------------
&namicethd     !   ice thermodynamic
!-----------------------------------------------------------------------
   hmelt       = -0.15     !  maximum melting at the bottom
   hiccrit     = 0.6 , 0.5 !  ice thickness for lateral accretion in the Northern (Southern) Hemisphere
   hicmin      = 0.2       !  ice thickness corr. to max. energy stored in brine pocket
   hiclim      = 0.05      !  minimum ice thickness
   amax        = 0.999     !  maximum lead fraction
   swiqst      = 1.        !  energy stored in brine pocket (=1) or not (=0)
   sbeta       = 1.        !  numerical caracteritic of the scheme for diffusion in ice
                           !        Cranck-Nicholson (=0.5), implicit (=1), explicit (=0)
   parlat      = 0.0       !  percentage of energy used for lateral ablation
   hakspl      = 0.5       !  slope of distr. for Hakkinen-Mellor's lateral melting
   hibspl      = 0.5       !  slope of distribution for Hibler's lateral melting
   exld        = 2.0       !  exponent for leads-closure rate
   hakdif      = 1.0       !  coefficient for diffusions of ice and snow
   thth        = 0.2       !  threshold thickness for comp. of eq. thermal conductivity
   hnzst       = 0.1       !  thickness of the surf. layer in temp. computation
   parsub      = 1.0       !  switch for snow sublimation or not
   alphs       = 1.0       !  coefficient for snow density when snow ice formation
/
```

---

2 Model configuration

2.1 Bathymetry

The bathymetry for this run was built from etopo1 for the deep ocean and gebco1 for the coastal areas and shelves. The minimum depth in the model was set to 12 meters, except in the Bahamas region (3 meters), the Torres Strait (5 meters). The Palk Strait has been closed. For reference, the name of the bathymetric file is

`ORCA025_bathy_etopo1_gebco1_smoothed_coast_corrected_bering_may11.nc`

2.2 Horizontal grid

The horizontal grid is the standard ORCA025 tri-polar grid (1440 x 1021 grid points). The nominal resolution (0.25) corresponds to the equator. Resolution increases poleward (the grid size is scaled by the cosine of the latitude, except in the Arctic, of course).

2.3 Vertical grid

The vertical grid have 75 levels, with a resolution of 1m near the surface and 200 meters in the deep ocean.

Reference z-coordinate depth and scale factors:

level	gdept	gdepw	e3t	e3w
1	0.51	0.00	1.02	1.00
2	1.56	1.02	1.08	1.05
3	2.67	2.10	1.15	1.11
4	3.86	3.25	1.23	1.19
5	5.14	4.49	1.34	1.28
6	6.54	5.83	1.47	1.40
7	8.09	7.30	1.63	1.55
8	9.82	8.93	1.83	1.73
9	11.77	10.77	2.08	1.95
10	13.99	12.85	2.37	2.22
11	16.53	15.22	2.71	2.53
12	19.43	17.93	3.11	2.90
13	22.76	21.04	3.56	3.33
14	26.56	24.60	4.05	3.80
15	30.87	28.65	4.59	4.31
16	35.74	33.24	5.15	4.86
17	41.18	38.39	5.73	5.44
18	47.21	44.12	6.33	6.03
19	53.85	50.45	6.95	6.64
20	61.11	57.40	7.58	7.26
21	69.02	64.98	8.24	7.91
22	77.61	73.23	8.94	8.59
23	86.93	82.18	9.70	9.32
24	97.04	91.88	10.53	10.11
25	108.03	102.42	11.46	10.98
26	120.00	113.89	12.50	11.96
27	133.08	126.39	13.68	13.07
28	147.41	140.07	15.01	14.32
29	163.16	155.10	16.54	15.75
30	180.55	171.64	18.27	17.38
31	199.79	189.92	20.25	19.23
32	221.14	210.18	22.50	21.34
33	244.89	232.70	25.05	23.74
34	271.36	257.76	27.94	26.45
35	300.89	285.72	31.19	29.52
36	333.86	316.92	34.83	32.96
37	370.69	351.77	38.89	36.81
38	411.79	390.68	43.39	41.09
39	457.63	434.09	48.35	45.81
40	508.64	482.46	53.76	51.00
41	565.29	536.23	59.62	56.63
42	628.03	595.87	65.92	62.72
43	697.26	661.81	72.61	69.22
44	773.37	734.43	79.66	76.10
45	856.68	814.11	87.00	83.30
46	947.45	901.12	94.56	90.76
47	1045.85	995.69	102.26	98.40
48	1151.99	1097.95	110.01	106.14
49	1265.86	1207.96	117.71	113.87
50	1387.38	1325.67	125.29	121.52
51	1516.36	1450.95	132.64	129.00
52	1652.57	1583.58	139.71	136.22
53	1795.67	1723.28	146.43	143.12

54	1945.30	1869.69	152.75	149.64
55	2101.03	2022.42	158.64	155.75
56	2262.42	2181.04	164.08	161.41
57	2429.03	2345.10	169.06	166.62
58	2600.38	2514.14	173.58	171.37
59	2776.04	2687.70	177.67	175.68
60	2955.57	2865.35	181.33	179.55
61	3138.56	3046.66	184.60	183.01
62	3324.64	3231.24	187.50	186.09
63	3513.45	3418.72	190.06	188.82
64	3704.66	3608.77	192.31	191.22
65	3897.98	3801.07	194.29	193.34
66	4093.16	3995.35	196.02	195.19
67	4289.95	4191.37	197.53	196.80
68	4488.15	4388.89	198.84	198.21
69	4687.58	4587.73	199.98	199.43
70	4888.07	4787.70	200.97	200.49
71	5089.48	4988.67	201.83	201.41
72	5291.68	5190.49	202.57	202.21
73	5494.58	5393.05	203.20	202.90
74	5698.06	5596.25	203.75	203.49
75	5902.06	5800.00	204.23	204.00

2.4 Initial conditions

2.4.1 Ocean

The simulation started at rest, on January 1rst 1958, with initial climatological temperatures and salinities. The used climatology is a merge of the Levitus 98 climatology, patched with PHC2.1 for the Arctic regions, and Medatlas for the Mediterranean Sea.

2.4.2 Ice

Initial conditions for ice (ice concentration, ice thickness) was inferred from the NSDIC Bootstrap products for January 1989. (Cosimo, 1990 [6])

```
!-----------------------------------------------------------------------
&namiceini     !   ice initialisation
!-----------------------------------------------------------------------
   ln_limini   = .true.    !  read the ice initial state in the file 'Ice_initialization.nc' (T) or not (F)
   ttest       =  2.0      !  threshold water temperature for initial sea ice
   hninn       =  0.5      !  initial snow thickness in the north
   hginn       =  3.0      !  initial ice  thickness in the north
   alinn       =  0.05     !  initial leads area     in the north
   hnins       =  0.1      !  same  three parameter  in the south
   hgins       =  1.0      !       "                  "     south
   alins       =  0.1      !       "                  "     south
```

2.5 Restoring zones

As already mentioned, the 3D restoring implemented in this simulation, uses the Gouretski [9] annual climatology. This climatology was built using interpolation on isopycnal surfaces and is by far more suitable for the AABW restoring that the monthly Levitus Climatology.

2.6 Miscellaneous

Time step : at the beginning of the run we used a time step of 1080 seconds. We had to reduced it to 960 seconds at the end due to repeated model instability. We even decreased it to 800 sec to be able to pass very strong atmospheric events.

Bering : enhanced bottom friction was added only in 1963 (after 5 years of run) because local lateral no-slip conditions and bathymetry adjustments were not able to control the flow through the Bering Strait by themselves (see figure 25)

Shortwave radiation : Six years of integration were performed with the 30% arctic and 20% antarctic decrease of solar flux (radsw). It led to an abnormally too high ice extent, so we produce a new radsw set without these high latitude corrections, and re-run the experiment.

Year 2010 was performed a few months later when we obtained the extended (1979-2010) period of ERAinterim. The DFS5.0 corrections were applied on the 2010 files.

3 Run production

3.1 Integration and computing performance

The run started January, 1^{st}, 1958 (from Levitus) and ended December, 31^{st}, 2010, corresponding to the period covered by DFS4.3 and available ERA-interim forcing field. The run was performed at IDRIS HPC center in Orsay, using 255 cores of the IBM Power6 (Vargas). The domain decomposition used is 18 x 17 cores along x- and y- directions respectively. One model timestep takes 1.7 seconds.

3.2 Model output

Model output is done as 5-days averages. Then monthly and annual means are computed in the post processing.

3.3 Journal of the run

A detailed journal of the run production is available on demand. We emphasize that the only changes allowed during the run, in order to avoid numerical instabilities, were to adjust the time-step, leaving all other parameters unchanged.

4 Validation

The ORCA025.L75-GRD100 validation that is presented here is extracted from the monitoring of the experiment, available on demand on the Drakkar web site (contact bernard.barnier@legi.grenoble-inp.fr). In order to get familiar with validation metrics used for ocean modeling in the frame of MyOcean or Godae, we give the Class of the metrics.

4.1 Mean state of the ocean (2000-2009)

In order to assess the mean state of the ocean, we present maps of the long term mean (2000-2009) of the major ocean variables (temperature, salinity, sea surface height, barotropic transport streamfunction and meridional overturning circulation).

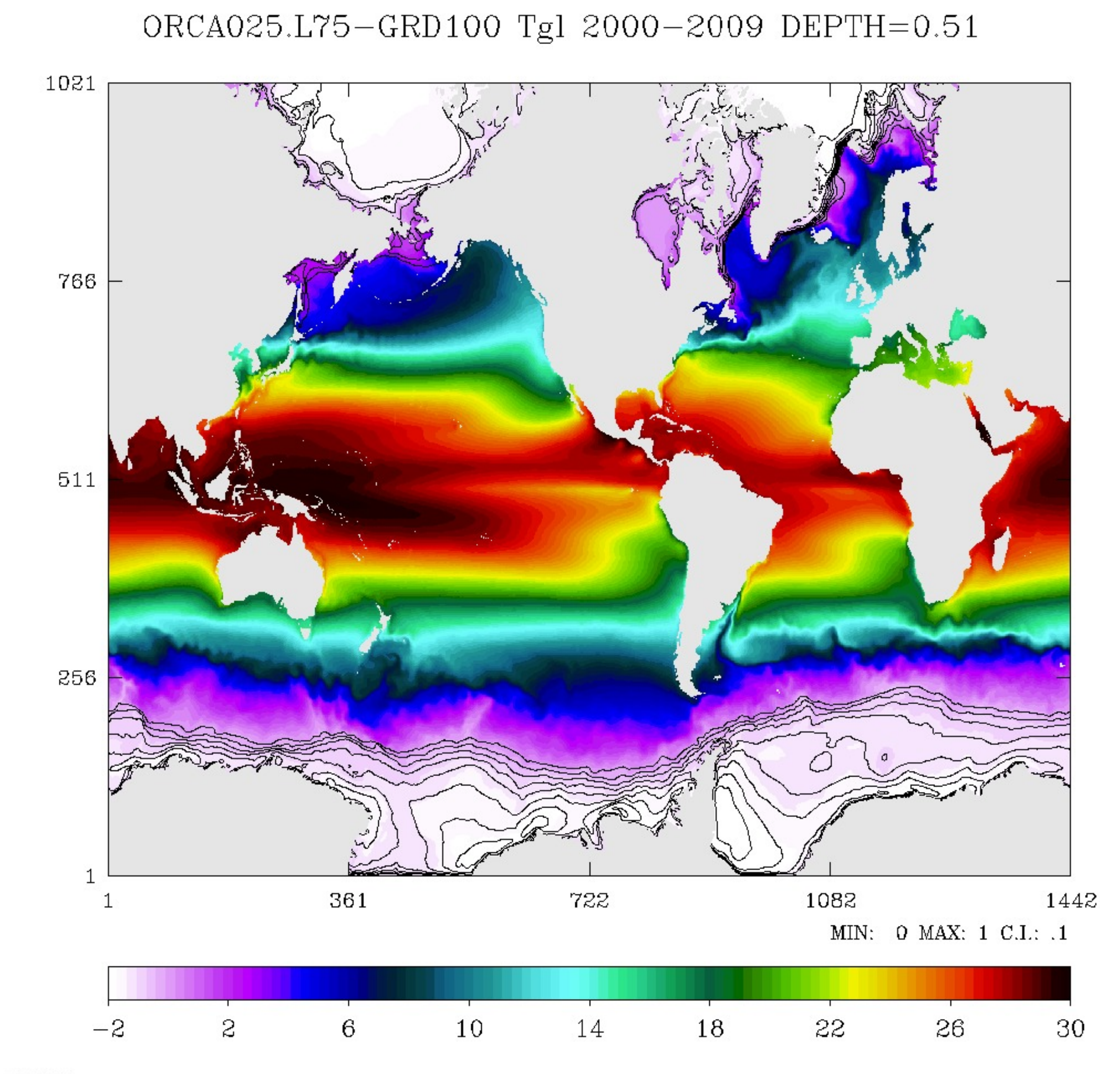


Figure 11: Mean Sea Surface Temperature over the period 2000-2009. Colours indicate the SST in ˚C, and contour lines indicate the sea ice thickness.

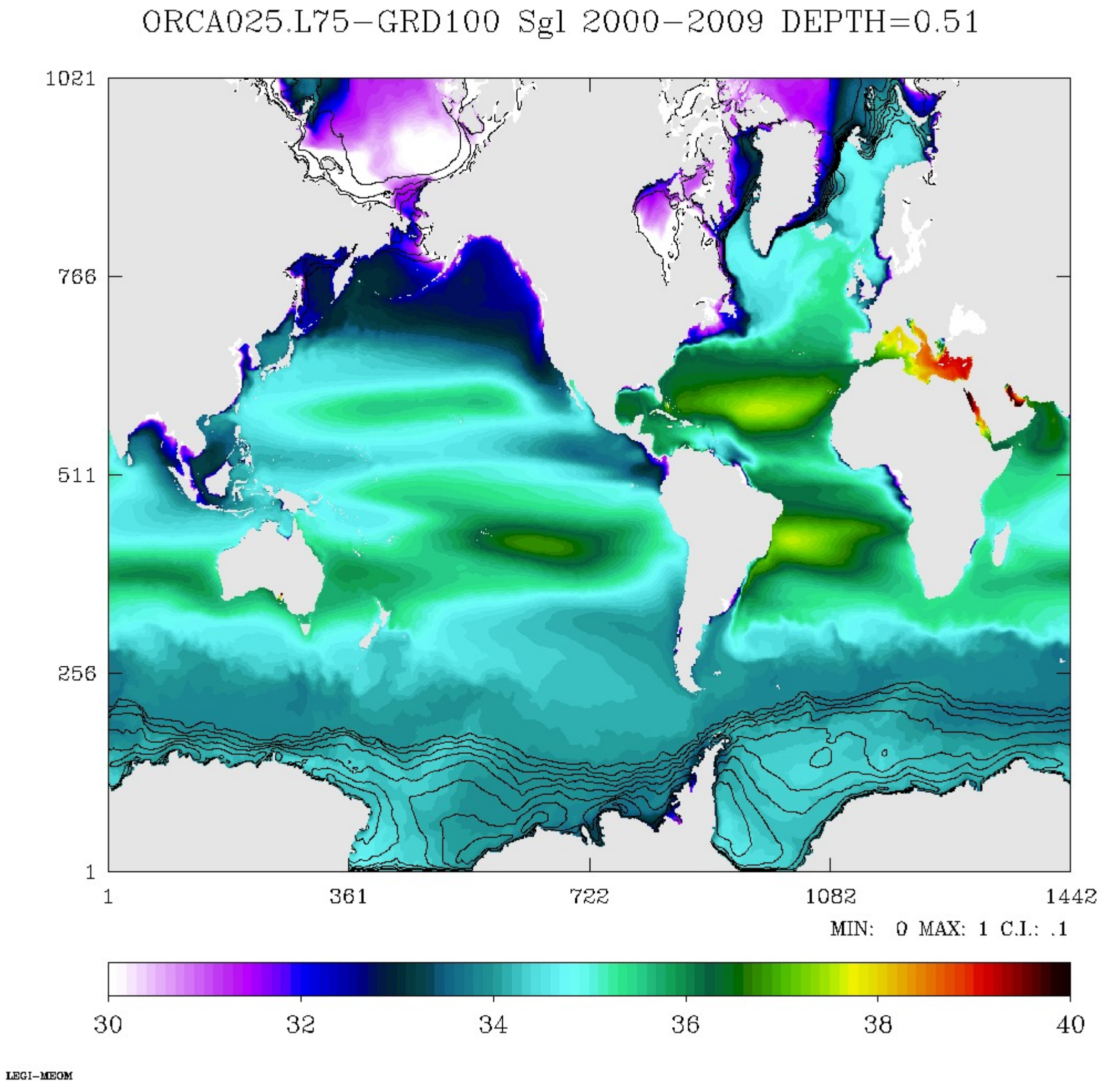


Figure 12: Mean Sea Surface Salinity over the period 2000-2009. Colours indicate the SSS, and contour lines indicate the sea ice thickness.

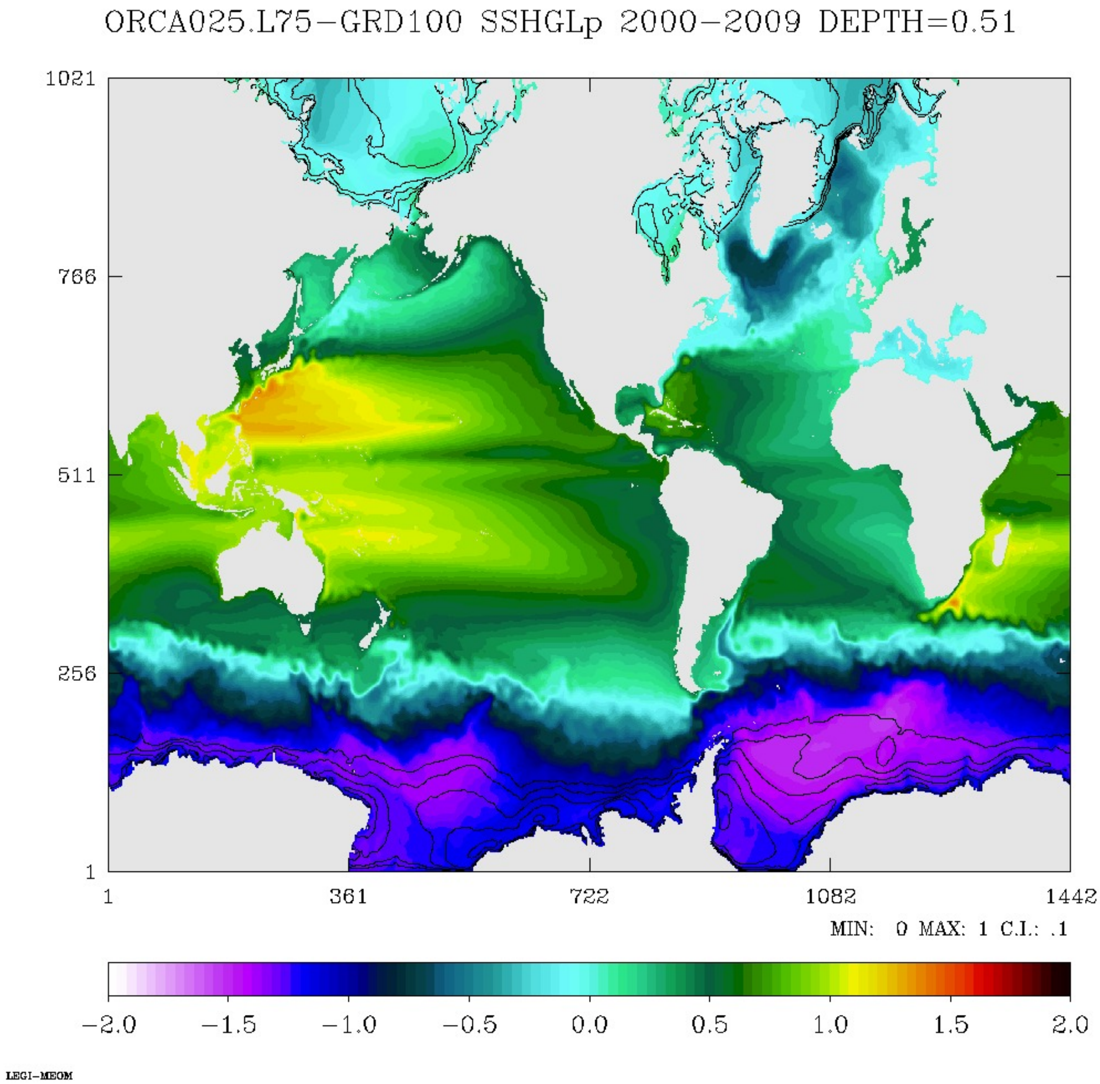


Figure 13: Mean Sea Surface Height over the period 2000-2009. Colours indicate the SSH in meters, and contour lines indicate the sea ice thickness.

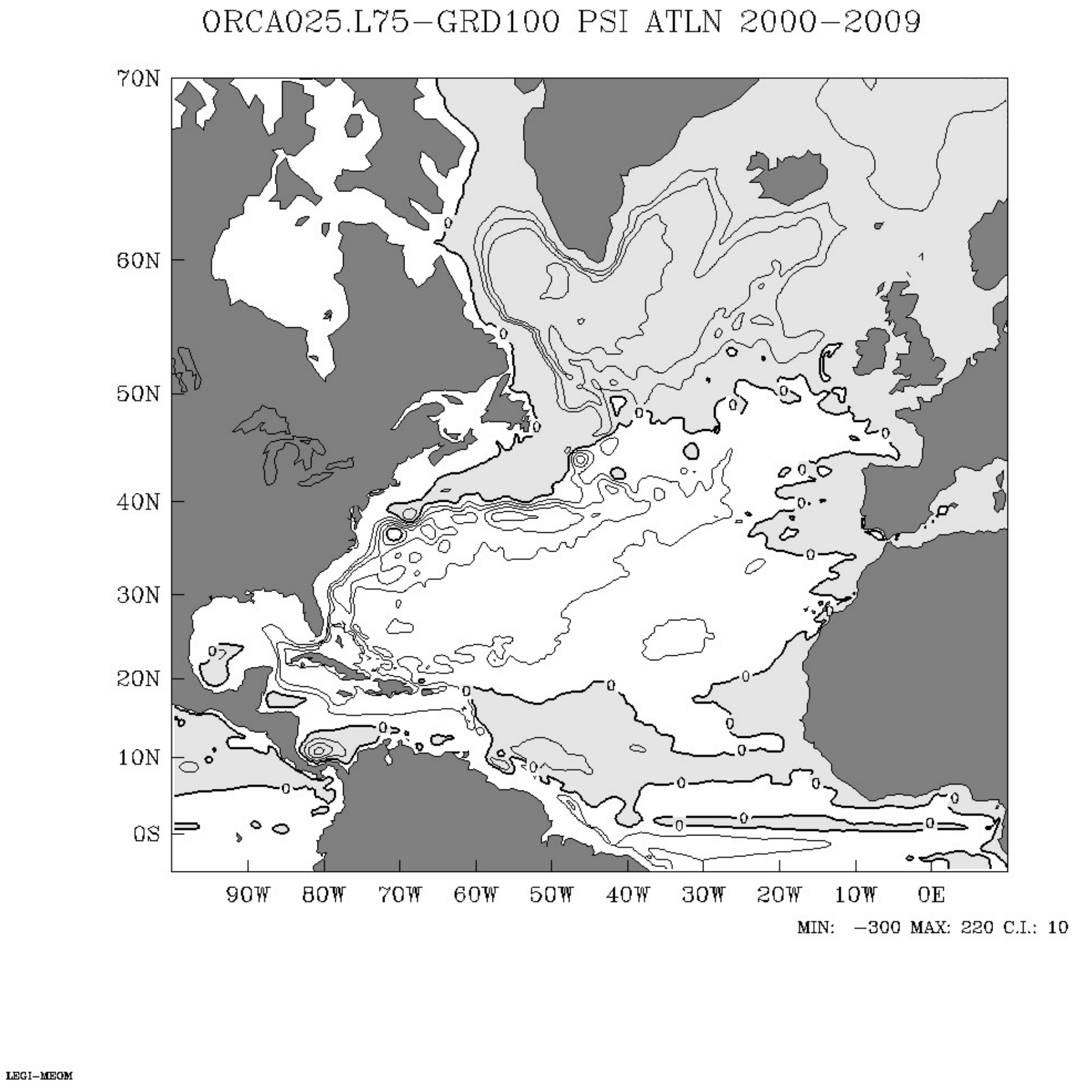


Figure 14: Mean Barotropic Streamfunction over the period 2000-2009. Contours by 10 Sv, negative values are shaded.

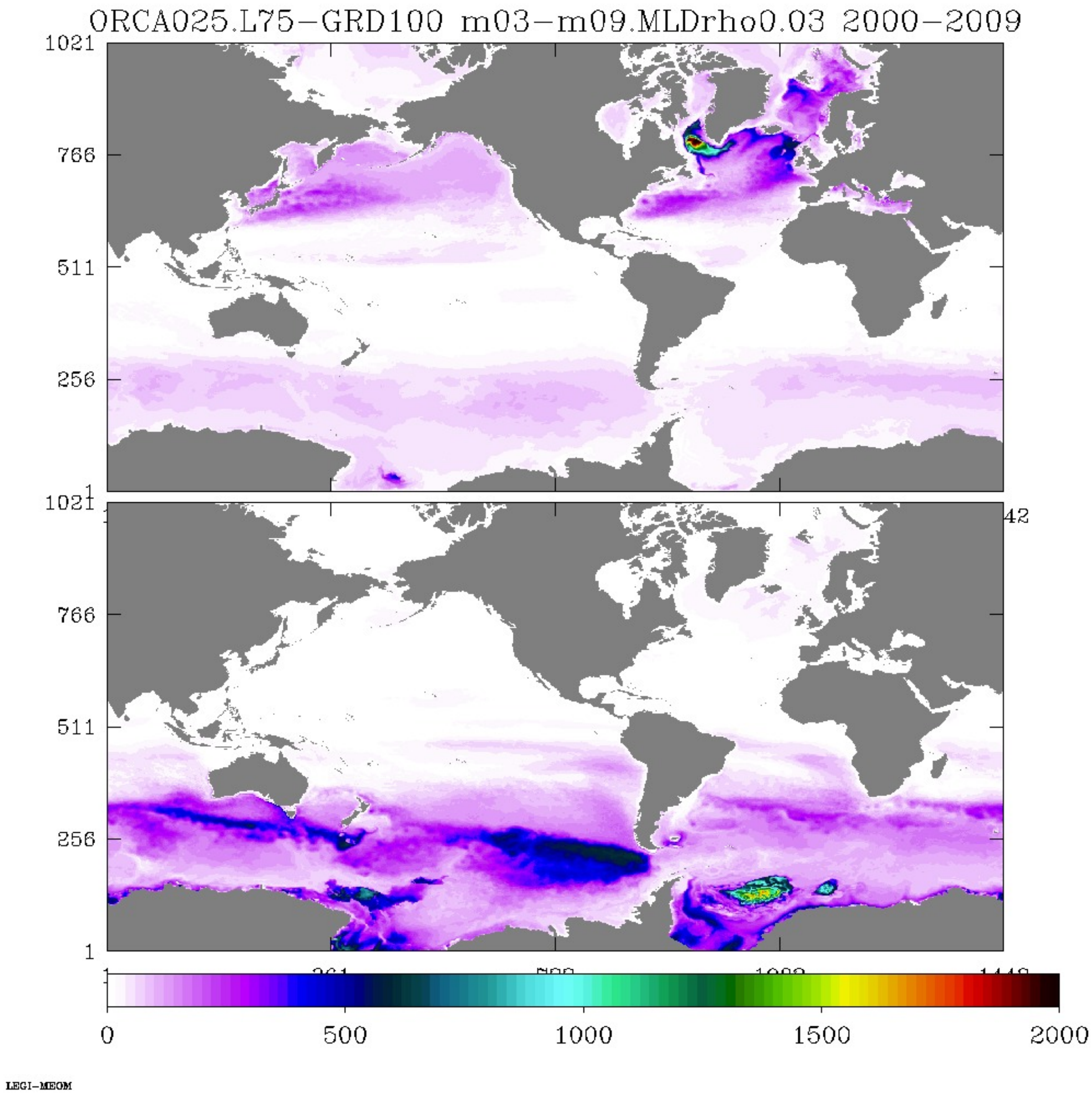


Figure 15: Mean Mixed Layer Depth in March (top) and September (bottom) over the period 2000-2009. The deep convection in the Weddell and Ross seas is due to an extreme event (polynia) that happens in 2005-2007

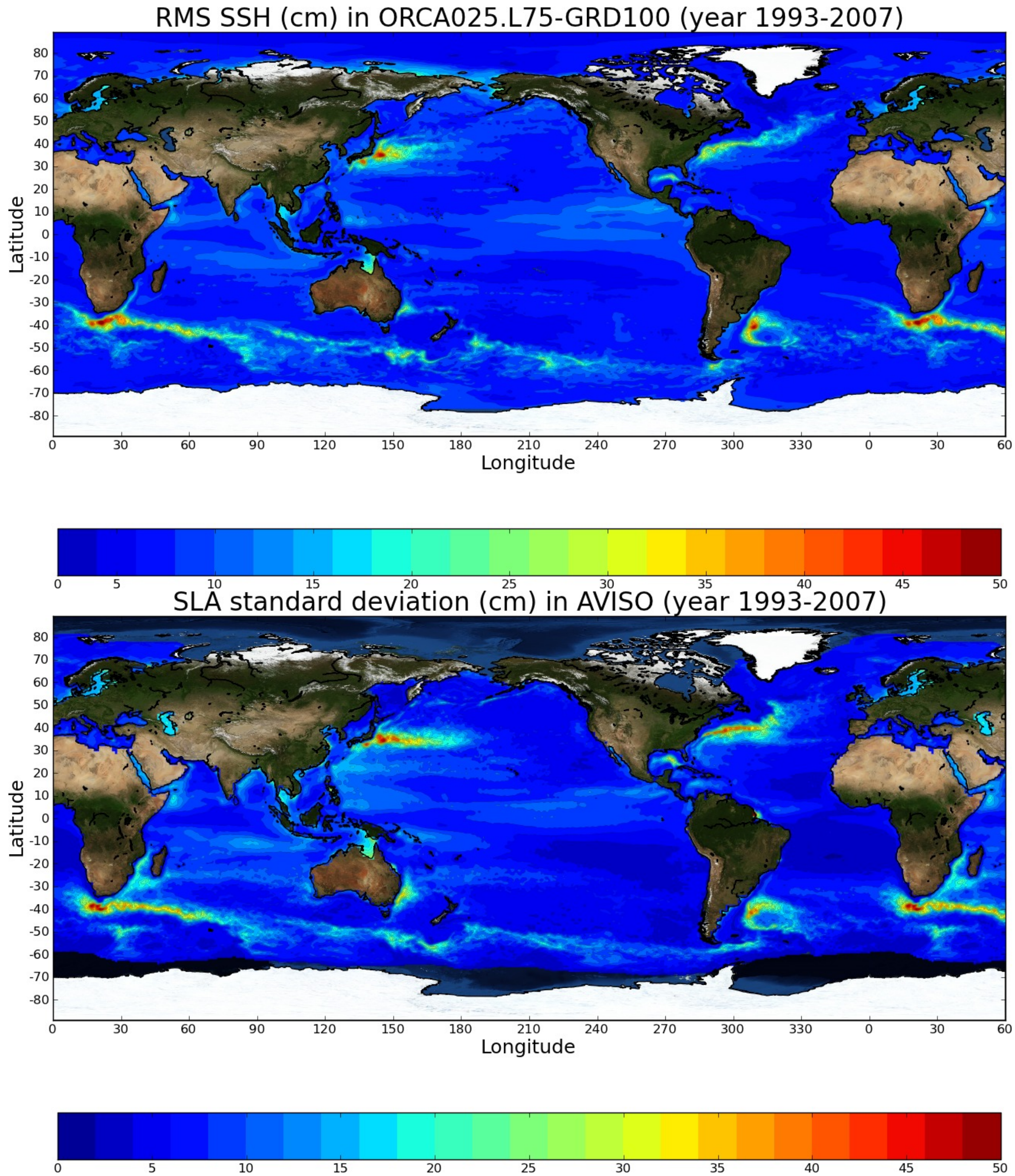
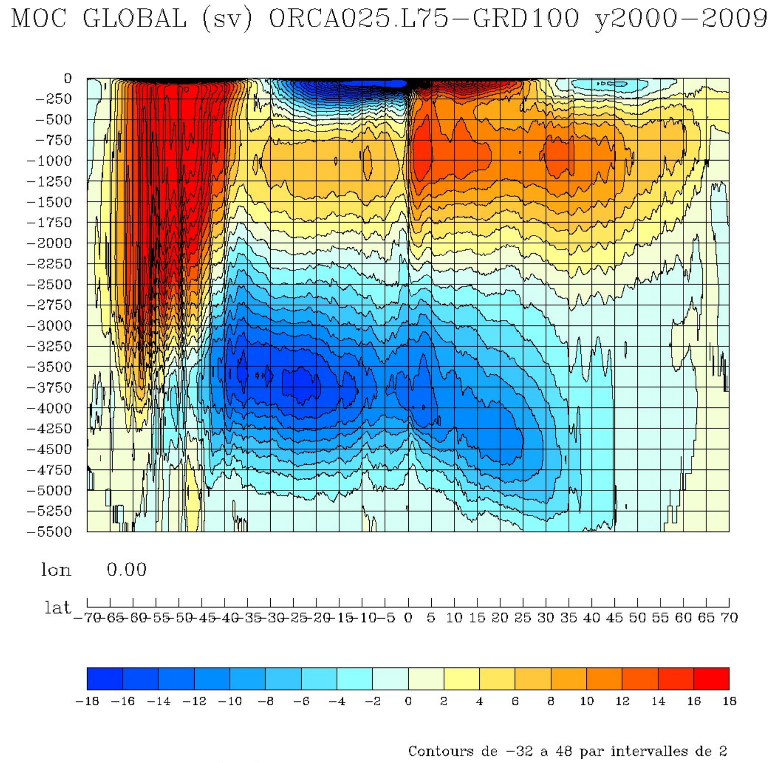


Figure 16: RMS SSH in ORCA025.L75-GRD100 (top) and AVISO data (bottom) over the period 1993-2007



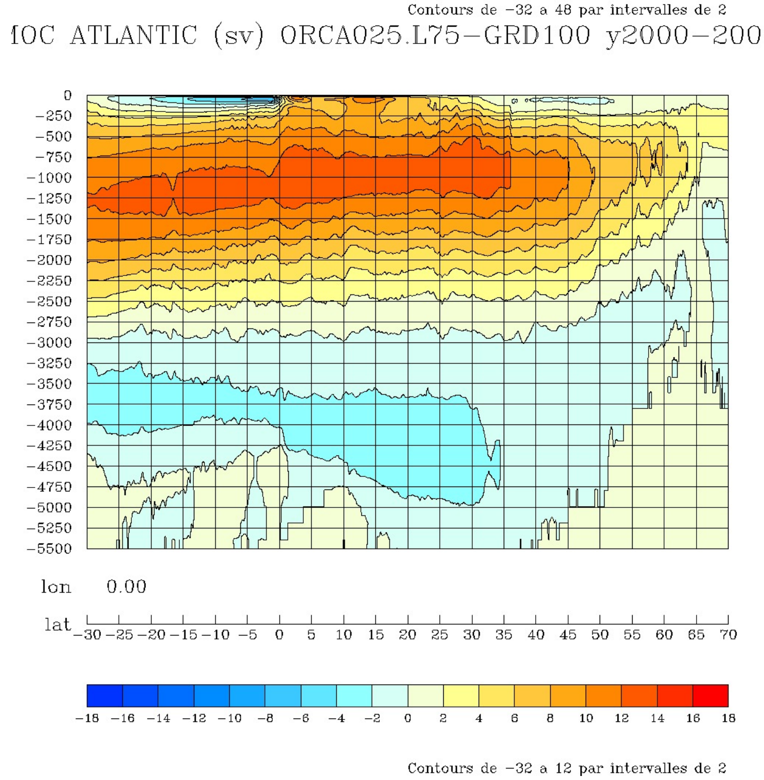


Figure 17: Mean Overturning over the period 2000-2009. Top: Global Ocean, bottom: Atlantic Ocean. Contours by 2 Sv.

4.2 Temperature and salinity CLASS1-1

The 10-year mean temperature difference with Levitus 1998 climatology at various depths (0m, 150m, 450m) is shown below.

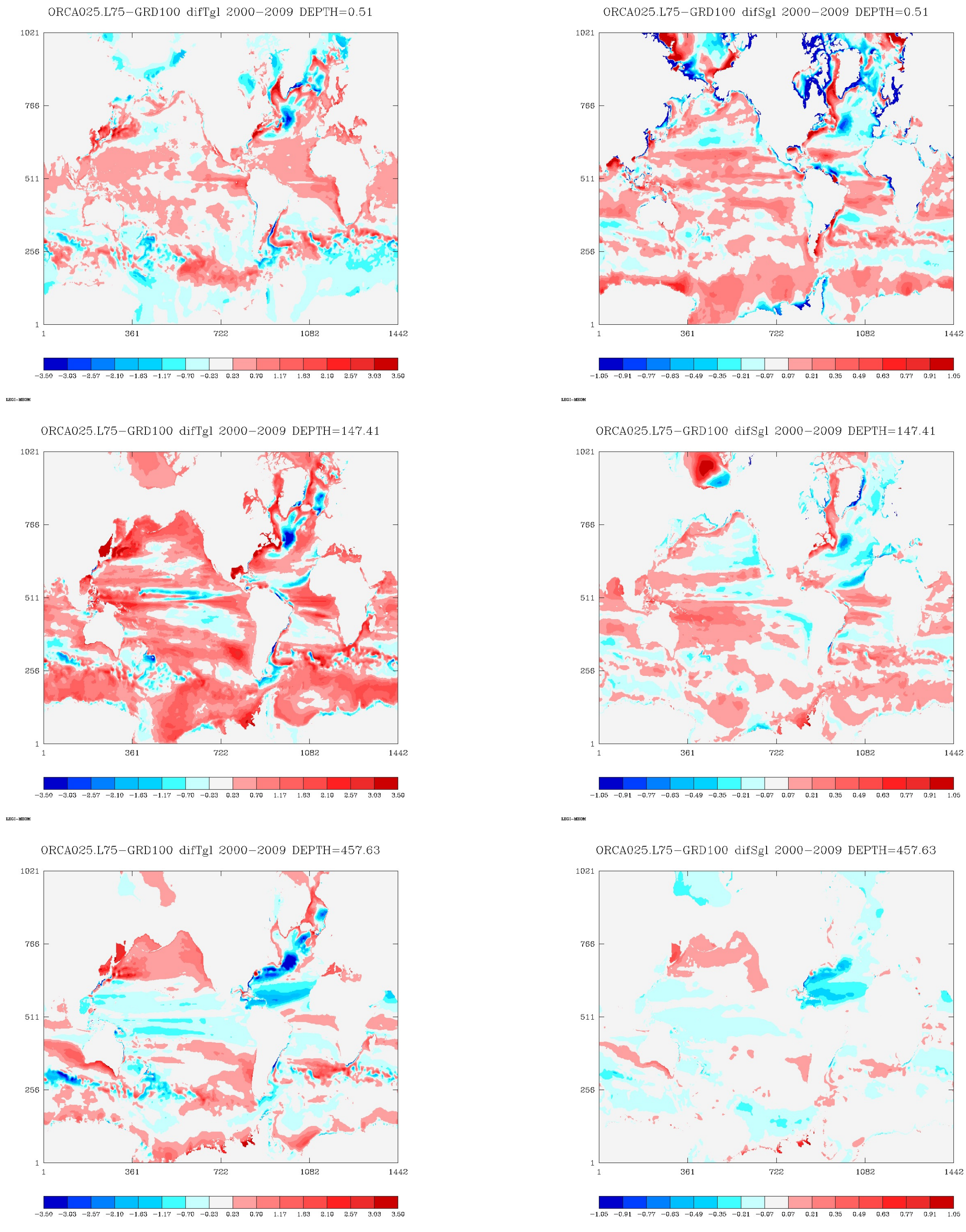


Figure 18: Difference between the 10-year mean temperature (left) and salinity (right) of the ORCA025.L75-GRD100 simulation with Levitus 1998 climatology at various depths (0m, 150m, 450m). Positive (negative) values indicate that the model solution is warmer or saltier (cooler or fresher) than the climatology.

4.3 Heat and Freshwater surface fluxes CLASS1-4

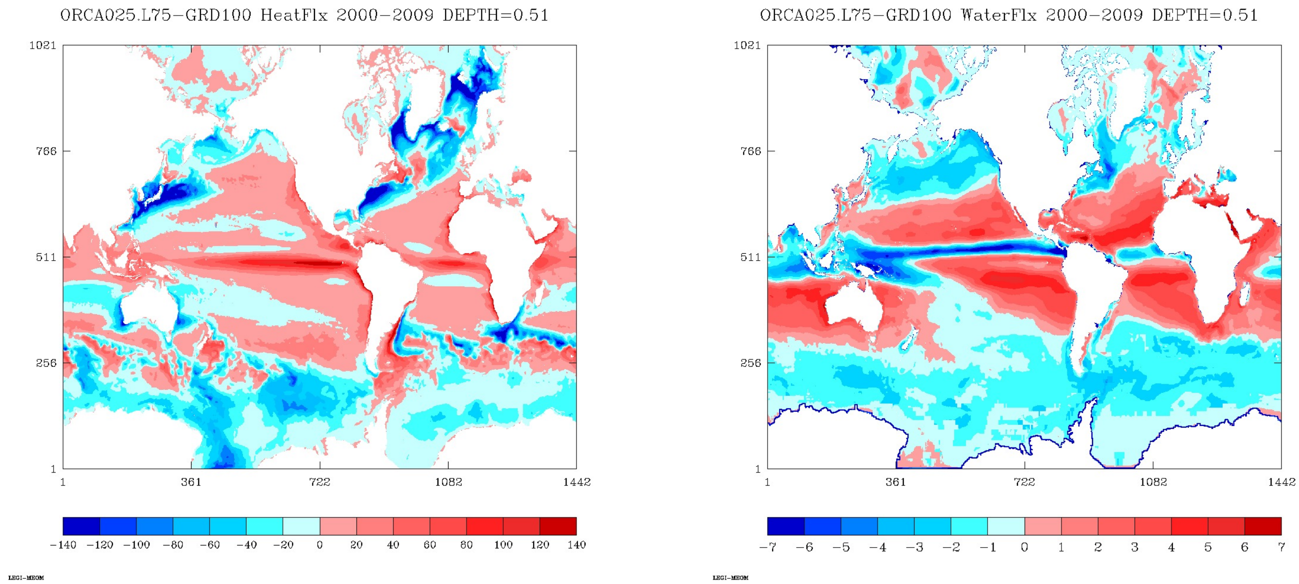


Figure 19: ORCA025.L75-GRD100 10-year mean net heat flux in W/m2 (left), and freshwater flux in mm/day (right).

4.4 Eddy Kinetic Energy

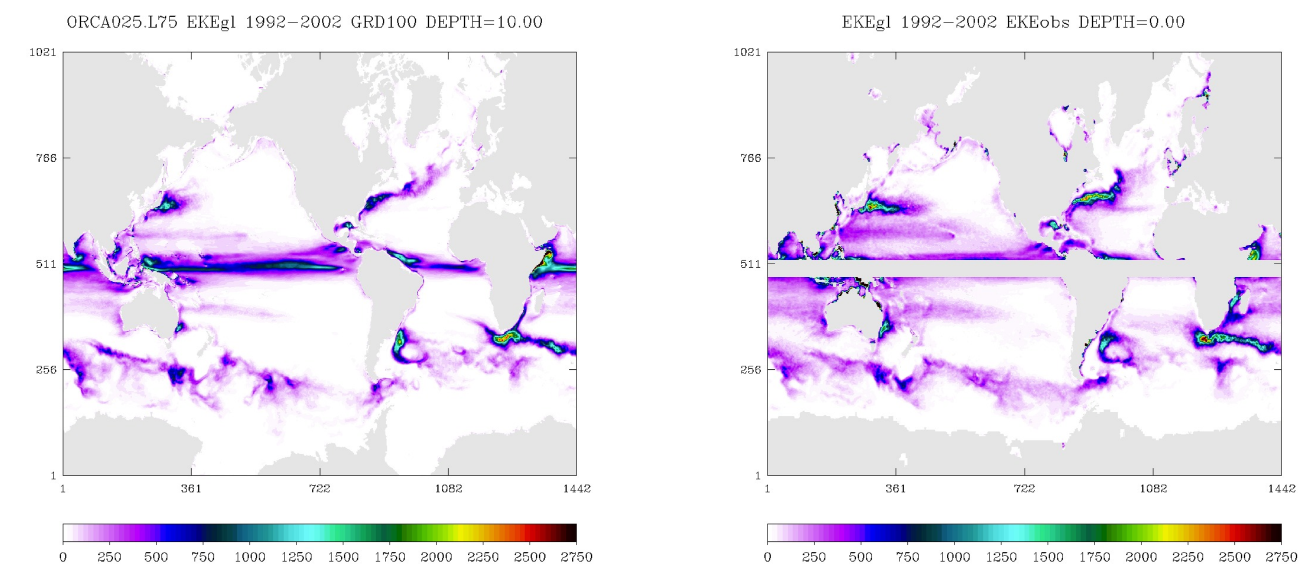


Figure 20: ORCA025.L75-GRD100 10-year mean Eddy Kinetic Energy (left), compared to Observations (right).

4.5 Sea-Ice CLASS1-3

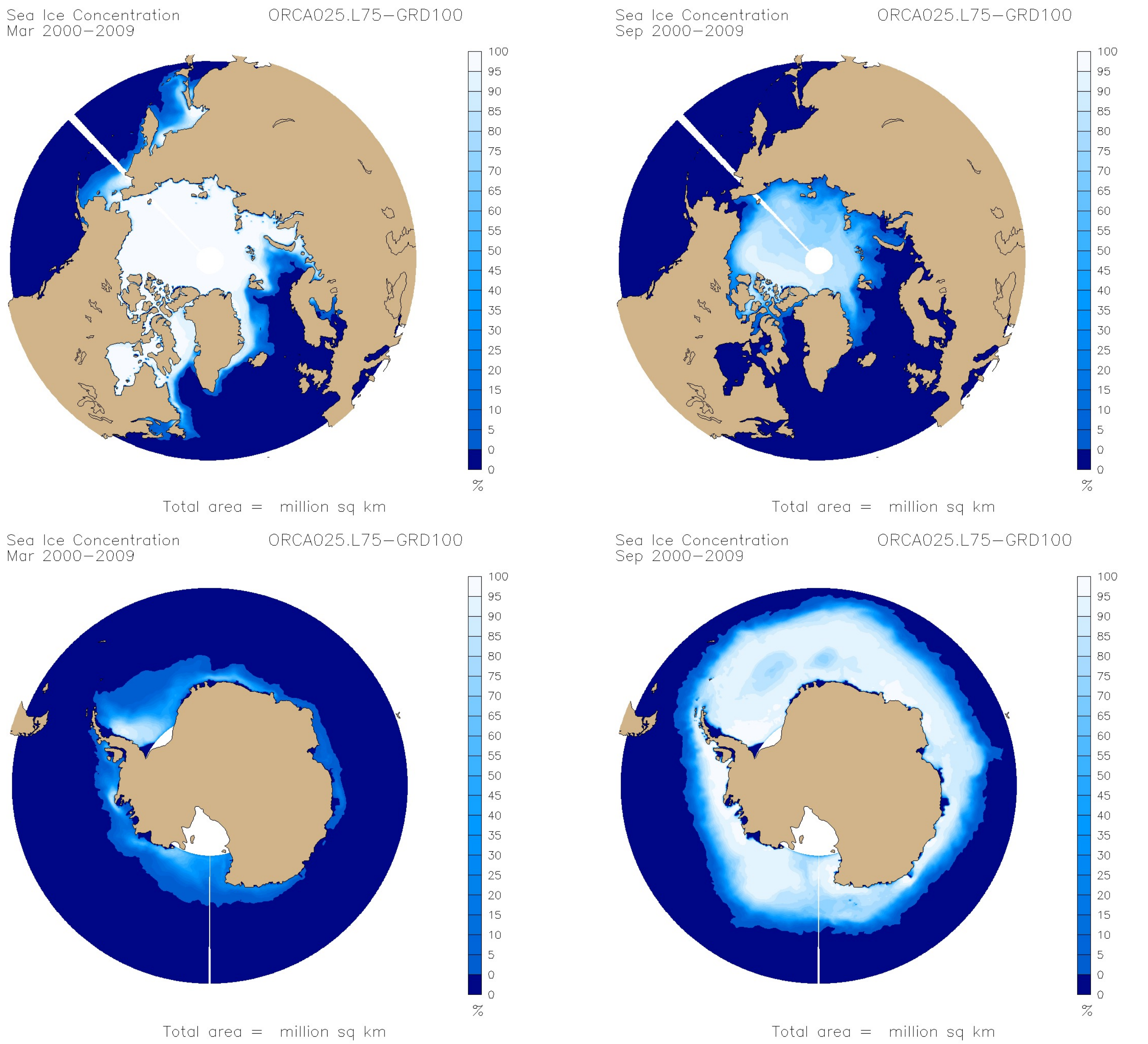


Figure 21: ORCA025.L75-GRD100 10-year mean sea-ice concentration in March (left) and September (right) in the Arctic (top) and in the Antarctic (bottom).

4.6 Variability

4.6.1 Temperature and salinity drifts

The basin averaged drifts for temperature and salinity during the model integration are shown below.

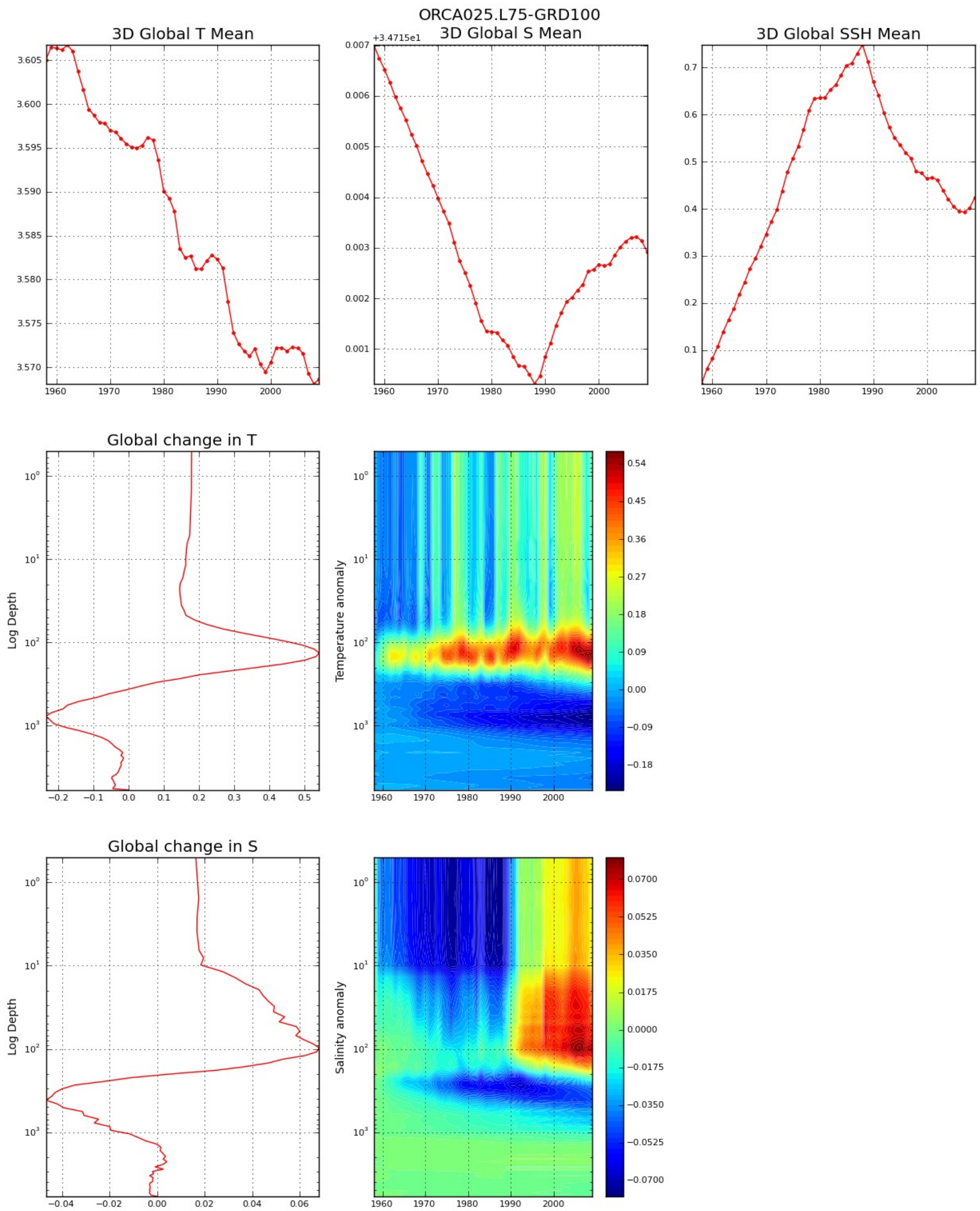


Figure 22: Top plots: Year-to-year variations of the world ocean average temperature and salinity over the integration period (1958-2009). Middle and bottom plots: Changes compared to initial condition in horizontally averaged temperature and salinity (vertical logarithmic depth range), left is the final minus initial profile, and right is the time evolution of the difference with initial condition.

4.6.2 Overturning and Transport

In order to assess the interannual variability represented by the model, we present the variations of two important climatic indexes during the model integration: the strenght (i.e. the maximum) of the overturning streamfunction in the North Atlantic, and the barotropic transport at Drake Passage.

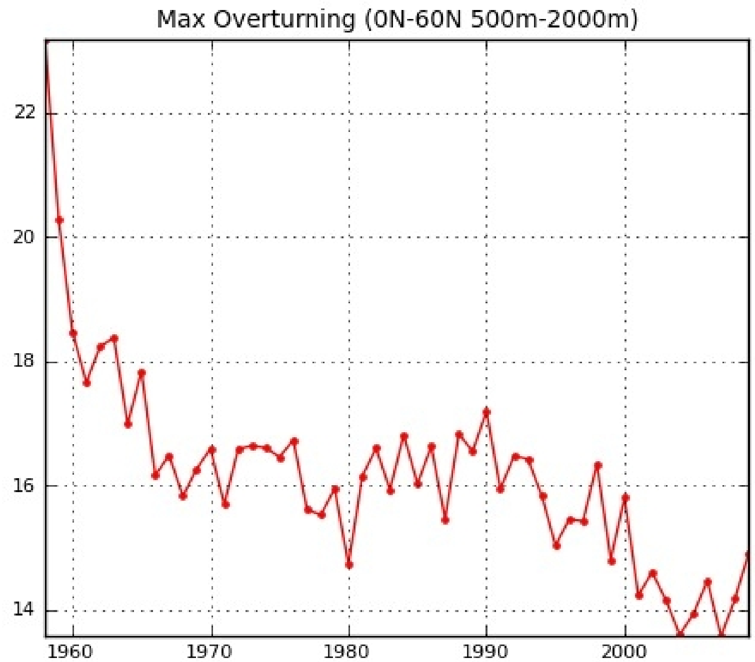


Figure 23: Variations of the annual mean maximum overturning (Sv) in the Atlantic Ocean over the integration period (1958-2009).The change from DFS4.3 winds to ERAi winds in 1989 results in a noticeable reduction of the overturning.

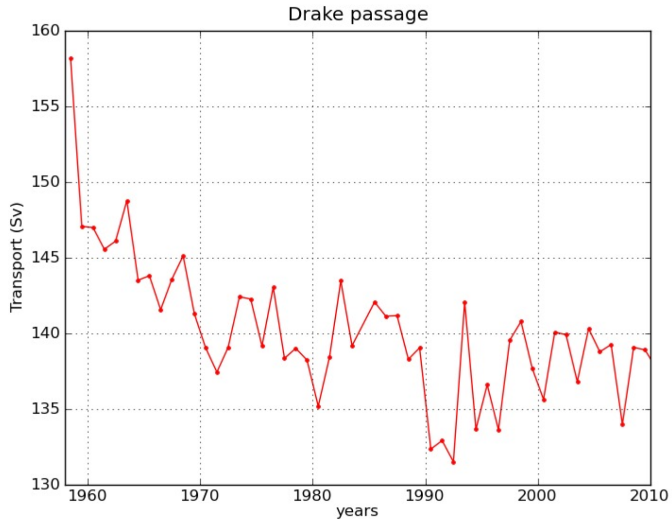


Figure 24: Variations of the annual mean transport (Sv) at the Drake Passage.

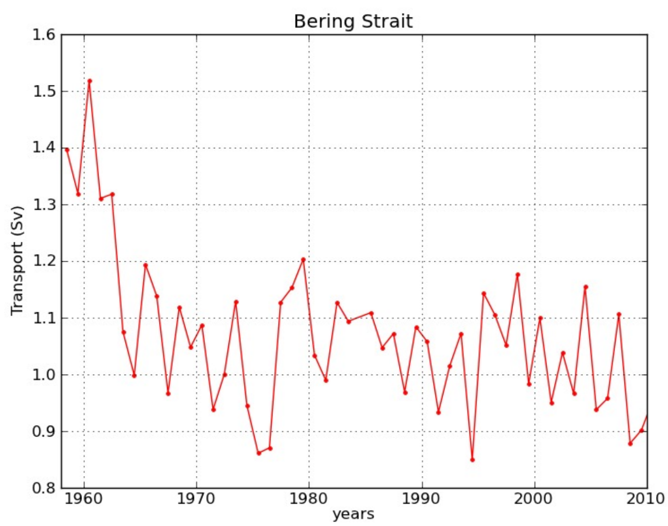


Figure 25: Variations of the annual mean transport (Sv) at the Bering Strait. The effect of the increased bottom friction in January 1963 produces a clear reduction of the transport which amplitude is much closer to observations (order of magnitude of 1 Sv).

4.6.3 Sea-Ice variation CLASS1-3

The variation of sea-ice characteristics and especially (CLASS1-3) the sea-ice concentration in summer 1996 (period of maximum sea-ice coverage) and in summer 2007 (period of minimum coverage) can be appreciated on the following plots. To be compared with satellite observations.

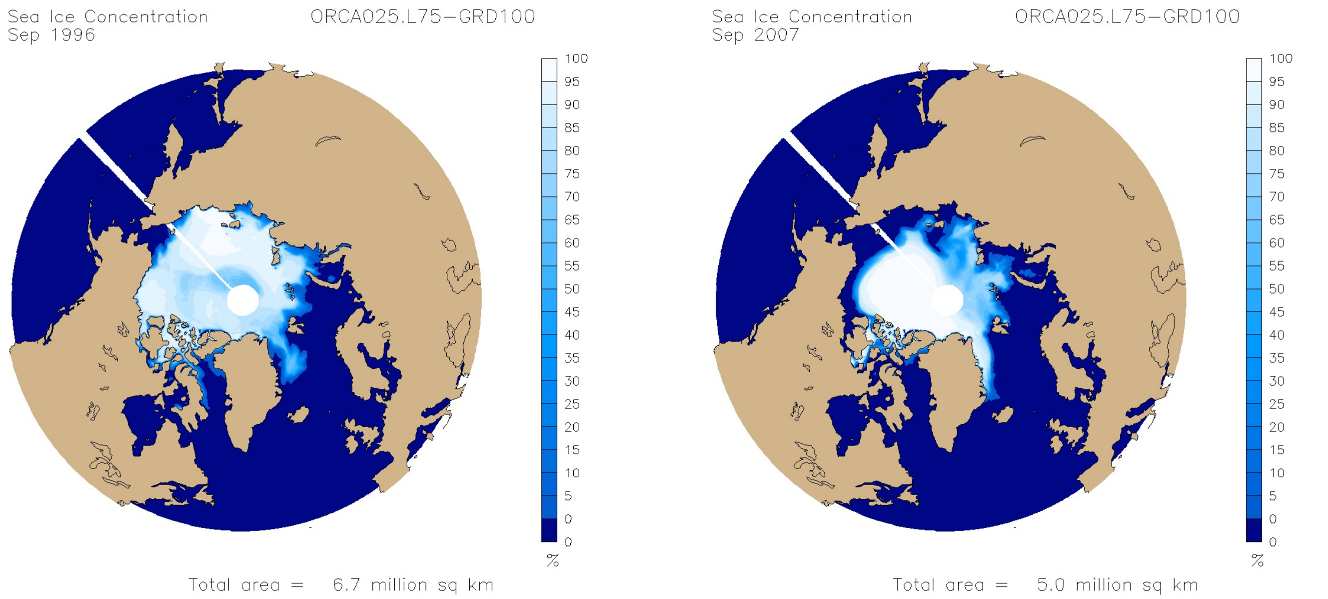


Figure 26: Sea-Ice Concentration (%) in the Arctic in September in 1996 (left) and in 2007 (right).

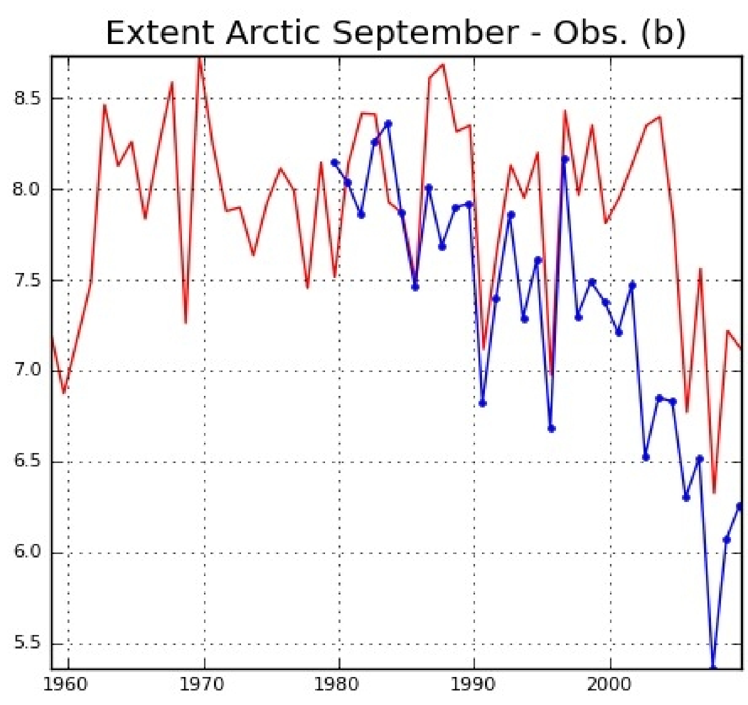


Figure 27: Sea-Ice Extent in September in the Arctic during the integration period (1958-2009). Blue curve is the model results and red curve is obtained from satellite observation. Annual means are centered on the middle of the year.

4.7 El Nino

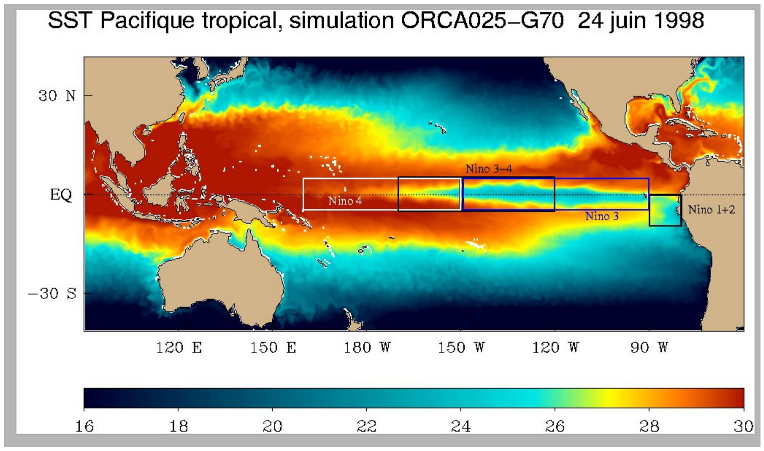


Figure 28: Definition of the Nino boxes.

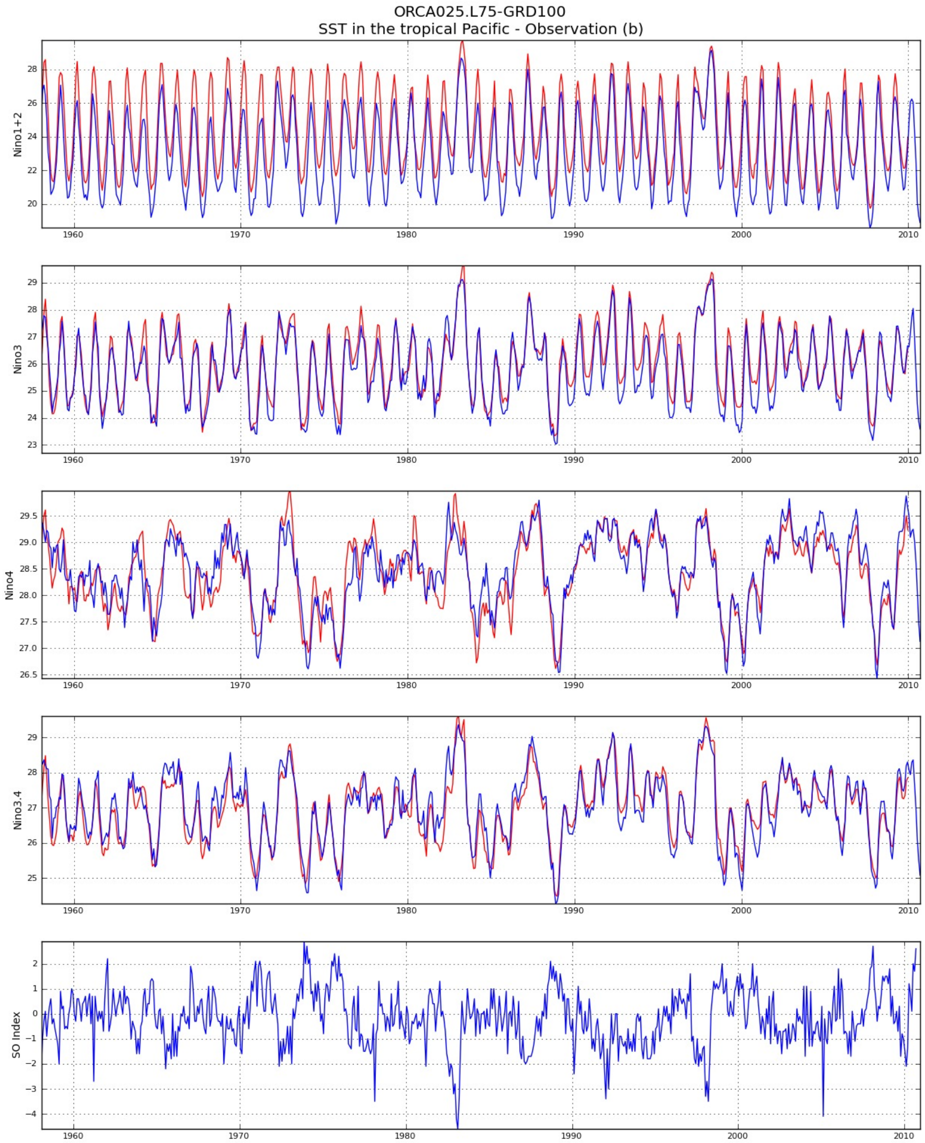


Figure 29: Monthly mean variations of the averaged temperature in el Nino boxes. Model is in black and observations (TOA array) are in green. Bottom plot is the Southern Oscillation index (monthly fluctuations in the air pressure difference between Tahiti and Darwin: sustained negative values of the SOI often indicate El Nino episodes).

Acknowledgement

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