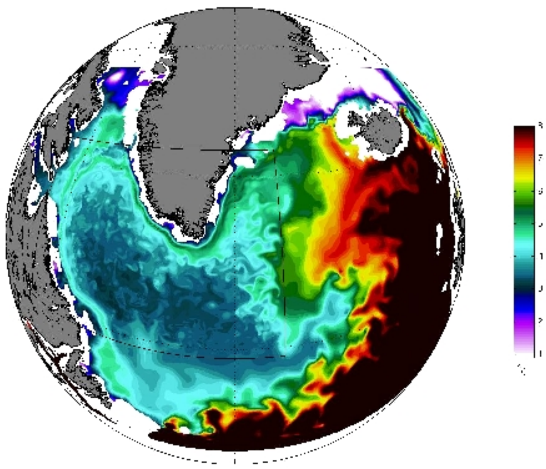
DRAKKAR Project

The ocean circulation in the North Atlantic and the Nordic seas: Variability, processes and interactions with the global ocean.



Report of Activity 2003-2004
For the MERCATOR scientific committee
March 2005

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1. The Drakkar science program (2003-2004)

The Drakkar science project has been written in march 2003. There were three major scientific objectives:

- The North Atlantic and Nordic Seas variability in relation with the world ocean.
- Circulation and variability processes within the North Atlantic and the Nordic Seas, and interactions between processes of different scales.
- Improvement of representation and parameterisation of key processes in ocean models, including atmospheric forcing, representation of bottom topography and eddy effects.

To address these objectives, the project was organized in two phases: Phase 1 (2003-2004) was dedicated to global and North Atlantic experiments at eddy permitting resolution, and phase 2 to high resolution modelling and the study of scale interactions. Phase 2 is scheduled for 2006-2007, with 2005 being a transition year.

The main results of years 2003-2004 concern the third objective (improvement of models) which is the most important for MERCATOR.

2. Development of NEMO

2.1. Development of the standard version

NEMO (Nucleus for European Models of the Ocean) is an *ocean modelling framework* which is composed of 'engines' nested in an 'environment'. The 'engines' provide numerical solutions of ocean, sea-ice, tracers and biochemistry equations and their related physics. The 'environment' consists of the pre- and post-processing tools, the interface to the other components of the Earth System, the user interface, the computer dependent functions and the documentation of the system.

The initial version of NEMO is based on version 9.0 of OPA. It will be released in march 2005 and will consist of:

- source codes: an ocean general circulation model (OCE_SRC), on/off-line ocean tracer and biochemistry models (TRC_SRC, TRC_OFF_SRC) and a sea-ice model (ICE_SRC).
- a built-in interface to the PRISM couplers and IOIPSL library
- scripts to compile, create executables and run the experiment on target platforms.
- pre- and post-processing tools built on IDL (INTERP, REVTERP, SAXO) to configure input file and analyse output files.
- standard configurations, including a 3 polar global ocean (ORCA2). They are provided for illustrative purposes enabling one to verify that the code flow is correct.
- a configuration control system based on CVS
- on-line and off-line documentation of the model formulation and codes

The contribution of the DRAKKAR team to this new code has been very important. In 2003, Jean Marc Molines has written an original exchange procedure between processors located near the geometric poles where the grid is folded, allowing the domain to be cut along longitude as well as latitude lines. He has also written new outputs in dimg format and modules to combine them as netcdf files (Molines, 2004b). This was essential for good performance on the IBM computer and also to give us freedom in the management of the database: for large configurations it is desirable to have one time-averaged output by file, and this is not possible with the ioipsl software. A new vorticity diagnostic has been coded and implemented in the reference version (L. Brunier, 2004). The input routines for open boundaries to handle netcdf format input have been rewritten (A.M. Treguier, with help from F. Durand at LEGOS). The Drakkar team has also helped identify and correct a number of bugs in the early versions of OPA9. It has also played an active role in developping and debugging a procedure to test the reproductibility of experiments on massively parallel machines (mpp) independently of the number of processors used (this involved the development by G. Madec of a new elliptic solver). Finally, a new code management tool

(Drakkar configuration manager) has been developed by J.M. Molines and S. Theetten (Molines et al, 2004a) to help the maintenance of multiple configurations shared between users.

All these developments are now used by MERCATOR as the project prepares its transition to OPA9.

2.2. Configuration-specific developments

New features have been developed for OPA9 that are specific to the DRAKKAR configurations. The Drakkar team tries to ensure they are made in compliance with OPA9 coding rules so that, when fully tested, they can become part of the reference version.

A "buffer zone" for the sea ice has been implemented (S. Theetten, option "limdmp"). This is necessary to ensure a correct transport of ice near the northern boundary of the NATL4 configuration (Theetten et al, 2004). Relaxation of ice cover and ice thickness is performed near the boundary.

The possibility for reading surface salinity data (independently of the 3D climatology) has been implemented by J. Molines (key_sssdta). This was necessary for the global ORCA025 model because a monthly 3D climatology file is too large for this configuration.

The superposition of both a laplacian and bilaplacian viscosity at the equator has been added (this was found necessary in the CLIPPER models).

A new forcing function including new bulk formulae following Large and Yeager (2004) has been developed in Kiel. This forcing function is called CORE (common ocean reference experiments) and is intended to be distributed widely to foster model intercomparisons exercises in the framework of CLIVAR (http://data1.gfdl.noaa.gov/nomads/forms/mom4/CORE.html) This package is now being rewritten and adapted at LEGI (L. Brodeau, J. Molines).

2.3. The new vorticity advection scheme

During 2003, eddy permitting experiments were run for the first time with OPA9 and the partial step representation of topography by the Drakkar group. Those were experiments with the 1/3° North Atlantic configuration, inherited from CLIPPER (run at LEGI) and the first experiment with NATL4 (1/4° North Atlantic and Nordic seas), run in Brest by Sebastien Theetten. Those experiments revealed spurious barotropic circulations especially at high latitudes, with a dramatic impact on the overturning (this has been documented in the first DRAKKAR/MERCATOR report, april 2004).
These features did not appear at low resolution (indeed, the partial step scheme had been validated in the global 2° ORCA2 model). This led Gurvan Madec to suspect a problem with the advection of relative vorticity. He implemented a new scheme with better conservation properties (option dynvor_een) which was tested by the Drakkar group using the NATL3 configuration, with good results (see section 3.3).

3. Global configuration ORCA-R025

3.1. Implementation on the IDRIS MPP Computer

The ¼ ° global configuration ORCA-R025 has been developed in 2003. Sensitivity experiments to confirm the choices made about parameterizations and numerical schemes have been carried out in 2004. This large configuration counts 1442x1021x46 grid points on an ORCA-type 3 polar grid (Fig. 1). Grid, masking and initial conditions are inherited from the POG global configuration of Mercator-Ocean. The topography has been recalculated for the partial step representation of the bathymetry, with smoothing using a shapiro filter and hand editing of speical key regions (Treguier, 2004). We chose a strategy of calculation on massively parallel machines (MPP), and the targeted machine is the 194 proc. IBM at the IDRIS computer Center. Taking into account the scientific constraints of the project (in particular the use "partial steps"), and of the technical constraints (computing time), it was essential to work with the new version of the code NEMO (i.e. its ocean component OPA 9.0 and its sea-ice component LIM2). The efforts related to the numerical model in 2004, mainly carried out by Jean Marc Molines, are summarized afterwards, and can be found in notes (Molines et al., 2004a and 2004b).

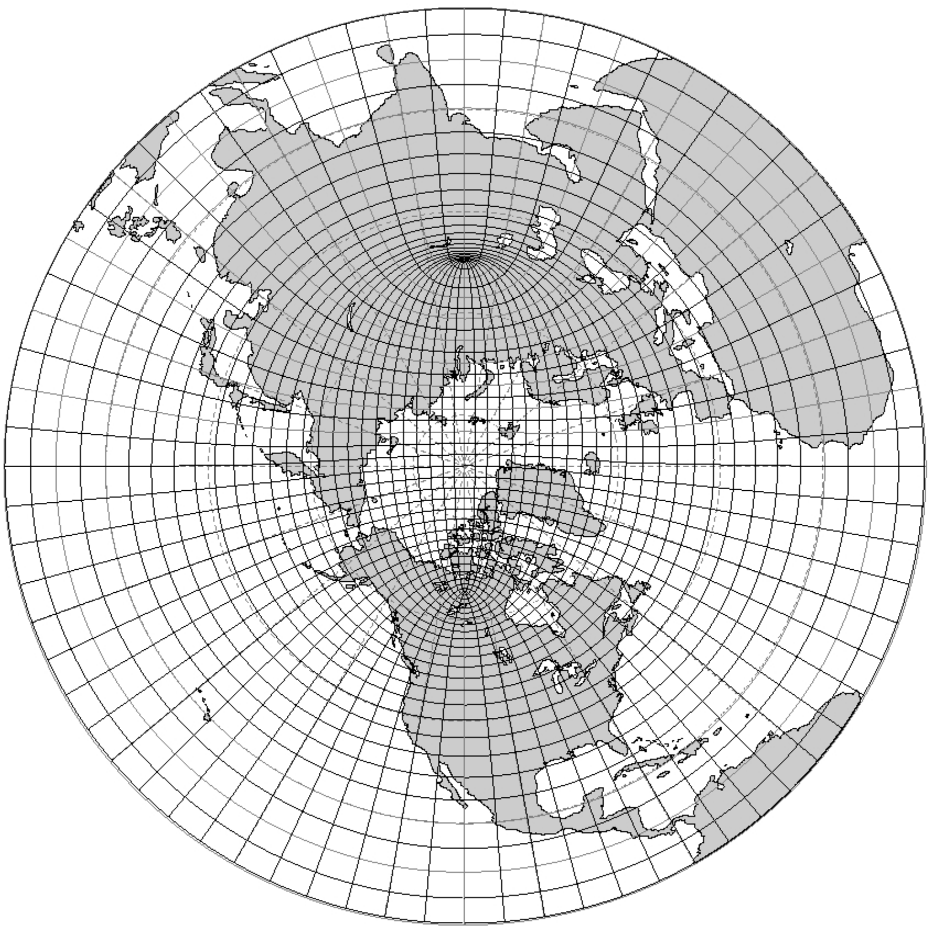


Figure 1: Polar sight of the northern hemisphere of the computational grid of ORCA-R025 (resolution 1/4°, 1 point out of 20 is represented). The parallelization of the code implies specific procedures of exchange between the processors located in the folding zone of imposed by the two geometrical poles of the grid.

The ORCA-R025 configuration started running in july 2004 on 186 processors (Fig.2). These tests contributed to the identification of hardware problems on the IBM machine which were solved in August 2004. From september to december 2004, seven sensitivity experiments, each 10 year long, have been carried out with ORCA-R025, stating from rest, with climatic CLIO forcing. These experiments are being analyzed to determine the adjustments of parameterizations and the setting of the experiments planned with the interannual forcing.

Improvements in communications (lib_mpp) between processors, provided by the Mercator group, improved the efficiency of the model on the IBM by 30%. The time step is 1440 s (60 time steps per day).One year of model simulation requires 2200h CPU on 186 processors, and takes about 12 h of elapsed time). Those performances were dramatically altered at the end of december due to a hardware failure. J.M. Molines worked with the engineers at IDRIS to help diagnose the problem. Performances are now almost (but not completely) back to their 2004 level.

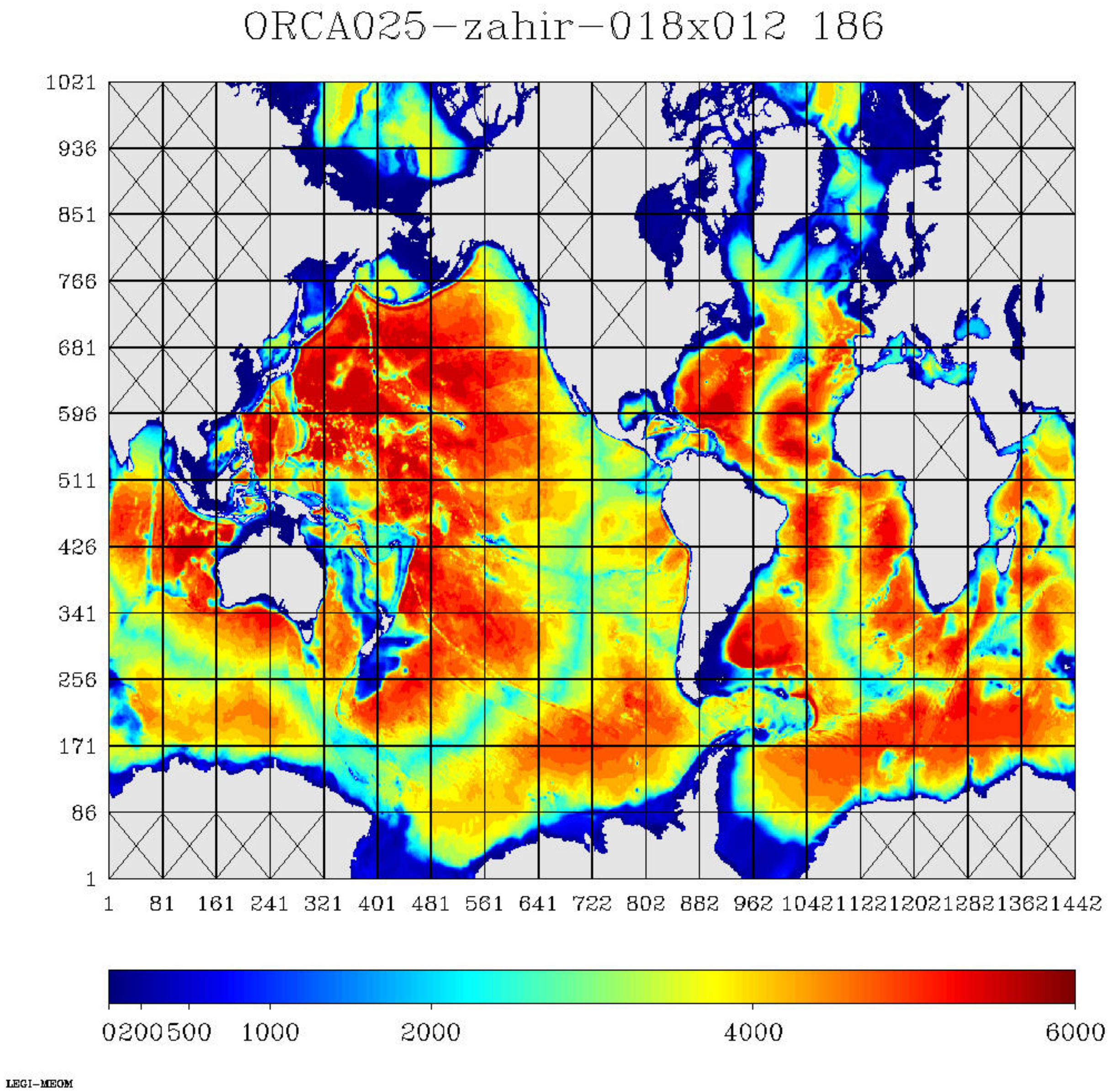


Figure 2: Decomposition on 186 IBM processors of the DRAKKAR global ¼° ocean circulation model. Colours indicate the ocean depth. Boxes represent the domain account for by a processors. Crossed boxes are 'land processors' not retained in the calculation. Numbers in abcissa and ordinate indicate model grid points

3.2. Sensitivity to parameterizations and numerics

A series of seven 10-years experiments have been run by Jean Marc Molines. All experiments use the same climatological forcing (the Drakkar forcing set 1, Talandier et al., 2003), with no relaxation to salinity in the freshwater forcing. Common features and specific details of the configurations listed in Table 1 are described in detail in a note by Molines et al. (2004b). The main objectives were to test different advection schemes, the impact of the new vorticity scheme, side-wall boundary condition, and the representation of topography. After an initial series of sensitivity experiments (G0x with full step topography, and G2x with partial steps), additional runs (starting with G30) have been made to fix a bug in the freshwater flux correction and to switch back to the standard Drakkar vertical grid (the grid was slightly modified by mistake during the first experiments). The G30 experiment is considered our reference case.

Table 1: List of the 10 year long sensitivity experiments carried out with ORCA-R025

Run	Scheme U∇U	T,S Advection	Side-Wall Boundary Condition	Bottom Topography*	Maximum depth**	Relaxation to SSS	Fresh water budget correction***
G03	New	TVD	Free-slip	Full Step	5750 m	no	Yes
G04	Old	TVD	Free-slip	Full Step	5750 m	no	Yes
G22	New	TVD	Free-slip	Partial Step	5720 m	no	Yes
G23	New	MUSCL1	Free-slip	Partial Step	5720 m	no	Yes
G24	New	TVD	No-slip	Partial Step	5720 m	no	Yes
G30	New	TVD	Free-slip	Partial Step	5750 m	no	No
G32	New	TVD	Free-slip	Partial Step	5750 m	yes	No

*partial steps. This option is used with criterion that the thickness of the bottom level is the minimum between 25 m or 20% of the level above)

**Maximum depth. The vertical grid has been defined with maximum depth of 5720m instead of 5750m as required. The difference between the level depths of the two grids is 5m at 1000m, 10m at 2000m and 30m at the bottom. As a result, the model grid (5720m) is not exactly the one that has been used to generate the initial conditions (5750m), but this is not a problem since the Levitus dataset has a resolution of 500m below 2000m. The full step bathymetry for run ORCA025-G03 has also been calculated assuming a maximum depth of 5750m. This causes a small horizontal shift of the places where the bottom depth jump from one vertical layer to the next, noticeable in the deep basins but not on the continental slopes where the topography varies rapidly. The differences between the various sensitivity experiments, including the full-step and partial-step experiments should not be influenced much by this small inconsistency. This has been corrected for run G30 and beyond.

***Fresh water budget (*fwb*) correction. The fwb correction has been wrongly operating for the series G0x and G2x. The main effect is to introduce shifts linked to the model restarts (i.e. at the scale of 256 days) in the freshwater budget, noticeable on the annual mean of the zonally averaged sea surface salinity. It however likely limited the drift of the surface elevation. This should not have an impact when comparing experiments from the series G0x and G2x. However, it introduces a significant year to year variability in the freshwater transport as derived from the surface freshwater budget. This series of run experiments are thus not appropriate to study the freshwater forcing of the model. For this reason, the new series of experiments G3x has been started, after a proper application of the *maximum depth offset* and the *fwb correction* totally removed. This way to apply this *fwb correction* needs to be discussed at the January 2005 meeting, and will require more testing.

All experiments have in common a laplacian lateral isopycnal diffusion on tracers (300 m^2s^{-1}), an horizontal biharmonic viscosity for momentum (-1.5×10^{11} m^4s^{-1}). In the equatorial wave guide, an extra laplacian viscosity (500 m^2s^{-1}) is applied on the first three levels. All experiments share the same climatological forcing (Drakkar forcing set 1), inherited from LODYC, which is briefly described in section 5.

3.3. Results of the reference experiment ORCA025-G30

Unless specified otherwise, we consider the average of years 8 to 10 of the 10-years experiment.

3.3.1. Heat transport and water mass properties

The drift in temperature is comparable in magnitude to a simulation at lower resolution using the same forcing (ORCA2), but the drift in salinity is especially large. This is to be expected in a simulation with no relaxation to surface salinity. This shows the need to improve the forcing fields and runoffs. The main problems are a warming and salinization of the southern ocean near the surface and at intermediate depths, with a cooling near 2000m and below. The large cooling in the Weddell sea is linked with excessive convection there. The model drifts towards higher temperatures and salinities in the subpolar

gyre, and there is a drift associated with the wrong position of the Medditerranean outflow (too high in the water column).
There are majors flaws in the representation of deep winter convection. The convection is too intense in the Labrador Sea and probably also the Norwegian sea. The situation is even worse in the Weddell Sea, with convection reaching the bottom aver a large area. It is not yet clear wether these problem can be corrected with a better forcing or wether a parametrization of unresolved eddies is needed in the high latitudes.

The meridional heat transport is shown in Fig 3 for individual basins and the global domain. Transports estimated from data by Ganachaud and Wunsch (2004) are shown for comparison (red lines). The heat transport is less comparable to observations after 10 years than after 2 years. For the Atlantic, this is quite dramatic since the heat transport has the wrong sign (southwards) at the end of the experiment. This is linked with a decrease of the overturning in the South Atlantic. Preliminary analysis of the experiment with relaxation to sea surface salinity do not show this time-evolution, suggesting that it is mainly related to the forcings (Anne Marie:: VERIFY!!!!)

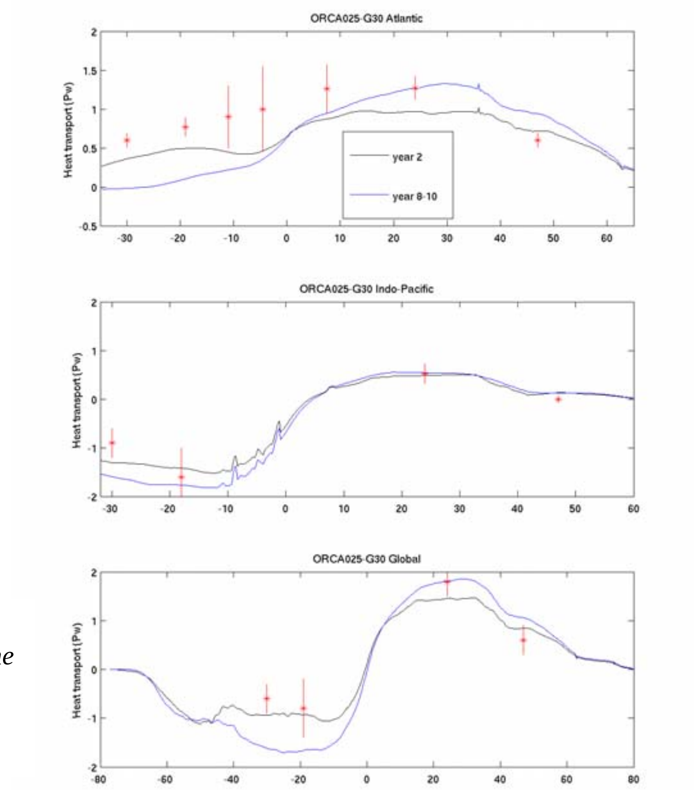


Figure 3 Meridional heat transport (global and by basins) for year 2 and the average of years 8-10 of the ORCA025-G30 experiment.The red lines are the values estimated by Ganachaud and Wunsch (2004)

3.3.2. Circulation

The transport through some key passages is indicated in table 2, as well as a comparison with other models. Time series have been calculated for these transports and the variability is also comparable to other models. The transport through Florida Straits has a clear upward trend (from about 27 Sv to 32 at the end of the 10 years). This trend is probably related to the drift of the thermohaline circulation and heat transport due to the forcing fields (with no surface salinity relaxation).

	POP	MOM	POG04	**G30**	Obs
Drake	140	152.5	162	**144.5**	130
ITF	12	9.2	17	**20.5**	10 +-10
Bering	1		0.92	**1.4**	0.83
FRAM	2			**1.4**	1 to 4
Florida	19.8		21	**31.2**	32
Mozambique	20	14		**32.1**	15 +-15

Table 2: Transports (in Sverdrups) in different models. POP is the global 1/10° model of Maltrud and Mc Clean (2005); MOM refers to the 1/10° global model of Masumoto et al (2004); POG04 is the MERCATOR prototype (a run with climatological forcing and no ice model). The numbers from observations are estimates from various sources meant to be indicative, not exhaustive.

Generally, the circulation and the position of the major fronts is remarkable in the ORCA025-G30 simulation, for a model of this resolution (1/4°). An exemple is provided by figure 4 with compares the temperature front across the Gulf Stream and North Atlantic current in the CLIPPER 1/6° model (left) and ORCA025-G30 (right). Although the Gulf Stream separation at Cape Hatteras is still not well represented, the standing eddy that appeared there in the CLIPPER simulations is weaker in ORCA025. Farther downstream, the front position in ORCA025 allows the presence of cold water on the shelf, as observed, and the North West corner is quite realistic. This remarkable progress is due to a combination of the new advection scheme and the partial cell topography (see next section). Similarly, the Brazil-Malvinas confluence zone, which was too far south in CLIPPER, is much better represented.

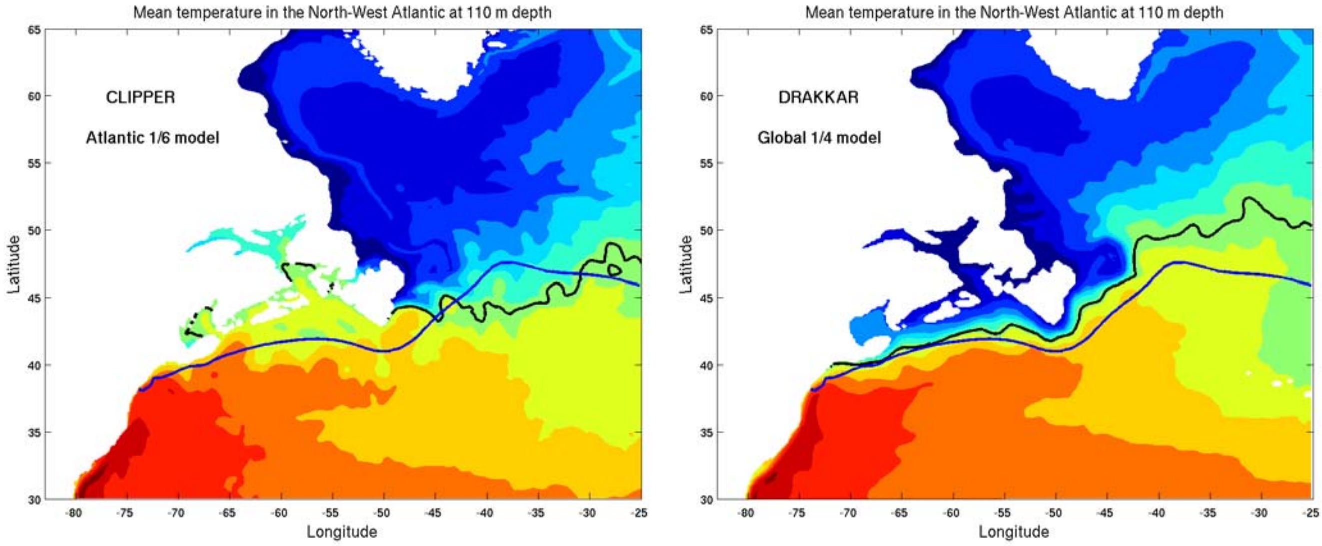


Figure 4: temperature at 110m depth in two models. Left, the CLIPPER 1/6° model; right, the ORCA025-G30 experiment. The black contour is the 13° isotherm in the model, that can be compared to its position in the climatology (indicated in blue).

In the ocean, the fronts are often marked by maxima of eddy kinetic energy. In this sense, the comparison of the model eddy kinetic energy (EKE) with satellite observations validates both the mean flow field and the eddy distribution (figure 5). The pattern of eddy kinetic energy in the Agulhas region is especially remarkable. It is better than the higher resolution model of Maltrud and Mc Clean (2005) which shows Agulhas eddies drifting along an irrealistic path (too regular and northwards). The EKE in the Argentine bassin shows the observed "C" shape, with a minimum corresponding to the Zapiola Anticyclone. The EKE maxima along the path of the Antarctic Circupolar current are well located, although sometimes not with the right magnitude. A quantitative comparison is provided by the curves in Fig. 7. In the western Atlantic (blue curves) starting from the south, the EKE maxima in the Brazil-Malvinas confluence zone are faithfully reproduced by the model. The EKE is good in the tropical Atlantic but underestimated north of 20°N and in the Gulf Stream. Considering now the Eastern Atlantic (red curves), the agreement is even better. The model picks up the righ amplitude of the EKE maximum linked with the Azores front (near 30°N) and the North Atlantic current (near 45°N) despite a deficit in between. Note that an agreement can be expected between the model and the satllite measurements because the time scales (larger than a week) and the space space scales resolved in both datasets are the same.

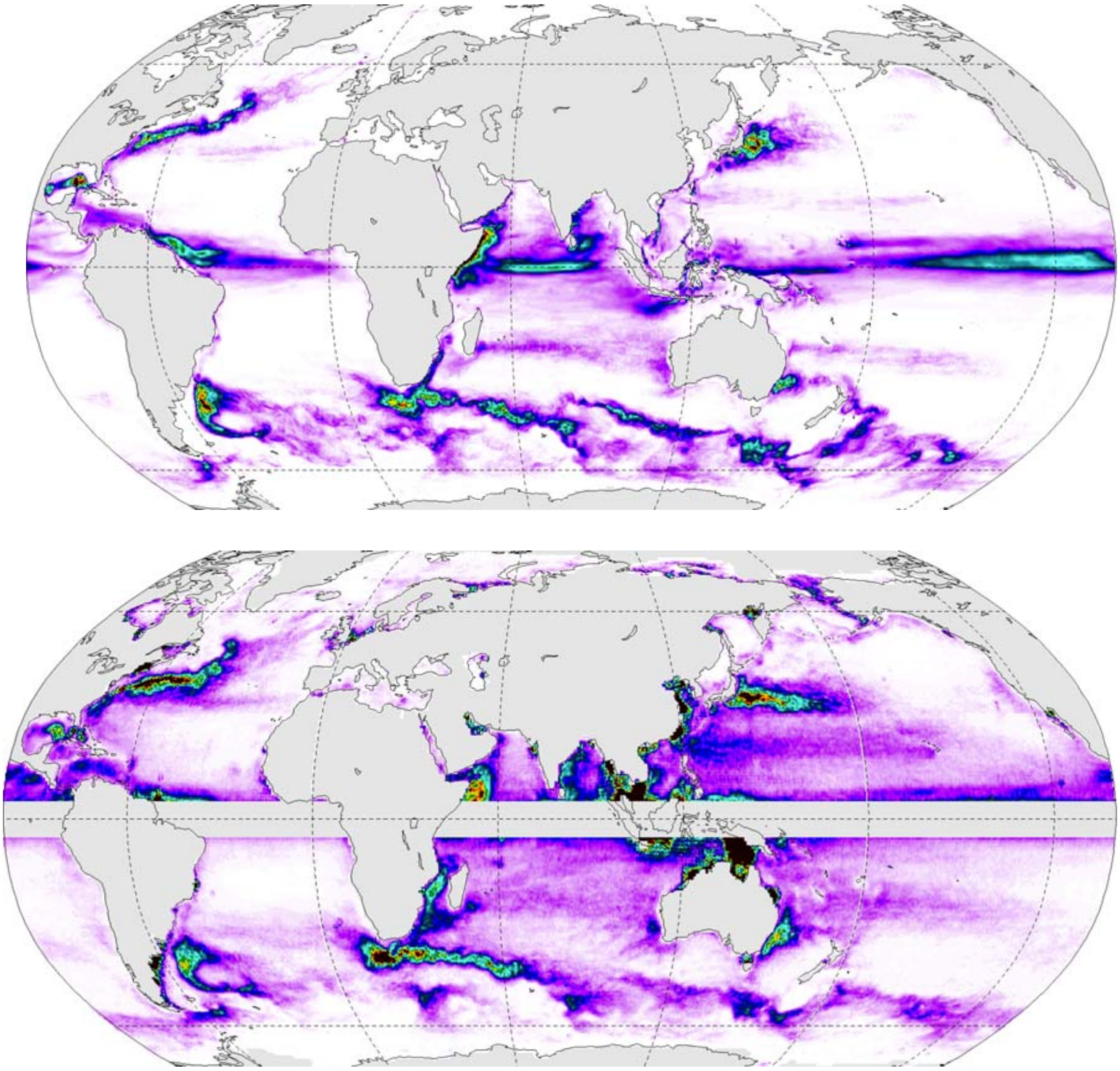


Figure 5: Eddy kinetic energy in ORCA025-G30 (top) and observed by satellites (bottom).The color scale is the same for both fields.

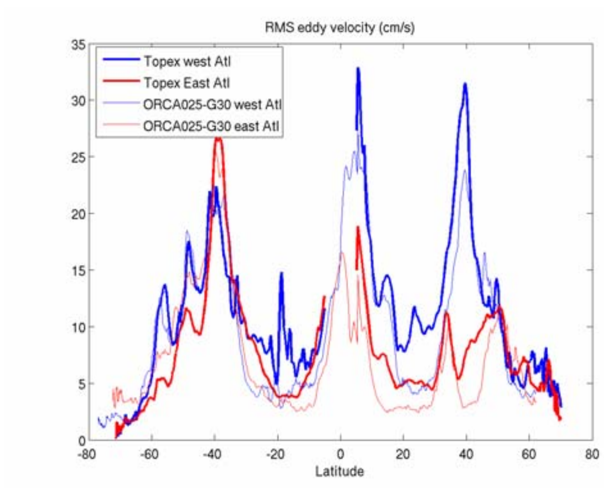


Figure 6: Eddy kinetic energy averaged over the western Atlantic (blue) and the Eastern Atlantic (red). The limit between the two regions is 15W for the southern part of the section and 35W for the northern part of the section. In each case, the thick line is calculated from data (altimetry) and the thin line is calculated from the model.

3.4. Preliminary results of the sensitivity experiments

The sensitivity studies examined here are listed in table 1. Experiment G22 with the new vorticity scheme and partial cell topography is our "pivot" experiment around which parameters are varied. The analysis has just started and results are very preliminary.

3.4.1. Vorticity advection scheme and partial cells

The different sensitivity experiments that have been run (table 1) allow us to understand the significant improvements compared to the CLIPPER era. Unexpectedly, we have found that the new *vorticity scheme* in the momentum equation represents the most drastic improvement, with partial cell topography also contributing. The sequence of improvements is represented in Fig 7, for the western part of the North and South Atlantic. The left panels represent a solution with full step topography and the old vorticity advection scheme. Noticeable problems in the North Atlantic are the large eddy north of Cape Hatteras and the absence of strong recirculation north and south of the Gulf Stream. In the South Atlantic, the Malvinas Current does not reach northwards enough along the coast of South America (wrong position of the Brazil-Malvinas confluence zone at 39°S) and the Zapiola anticyclone in the Argentine basin is missing. The middle panels show how the solution changes when only the vorticity advection scheme is modified. The eddy at Cape Hatteras is reduced and the amplitude of the recirculation North of the Gulf Stream doubles (from 10 to 20 Sv). The Confluence zone shifts to its observed position (34°S). The addition of partial cell topography (right panel) causes further changes in the same direction, with the recirculation north of the Gulf Stream reaching 30 Sv, and a realistically elongated recirculation developing also south of it. The transport of the subpolary gyre increases similarly in this sequence of experiments (40 to 50 and then 60 Sv), but this may not be an improvement compared with observations. The most spectacular change brought about by the partial cell topography is the appearance of the Zapiola anticyclone, with an intensity of 160 Sv (observations suggest circulations of 100 to 150 Sv).

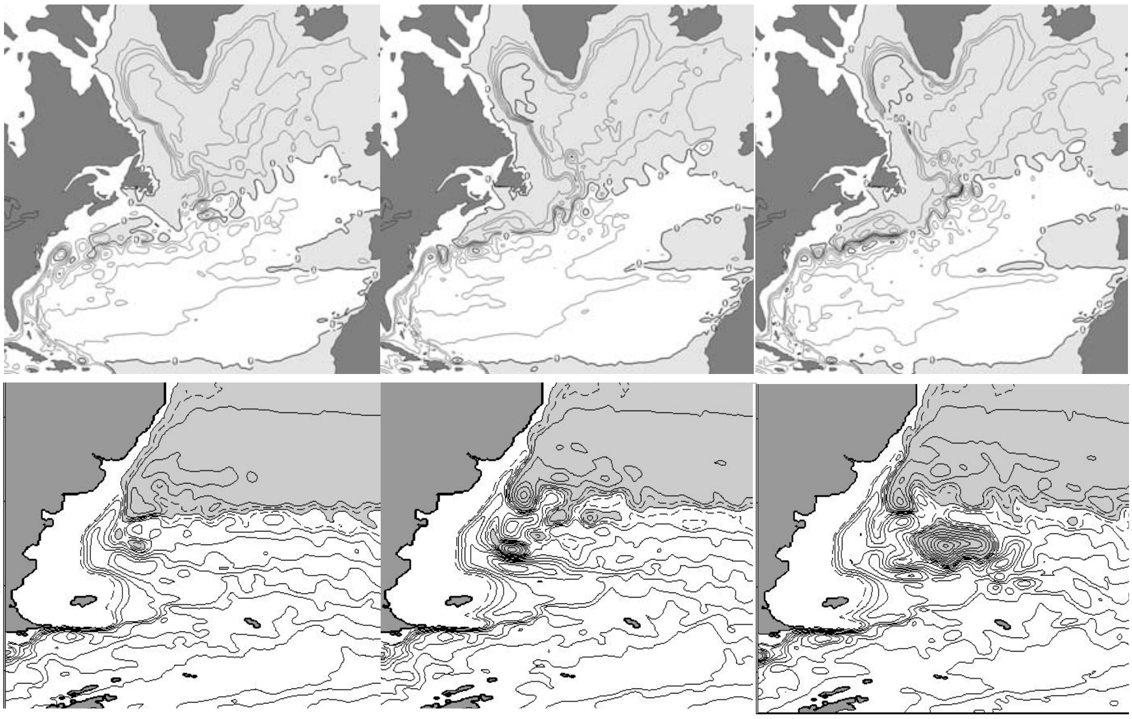
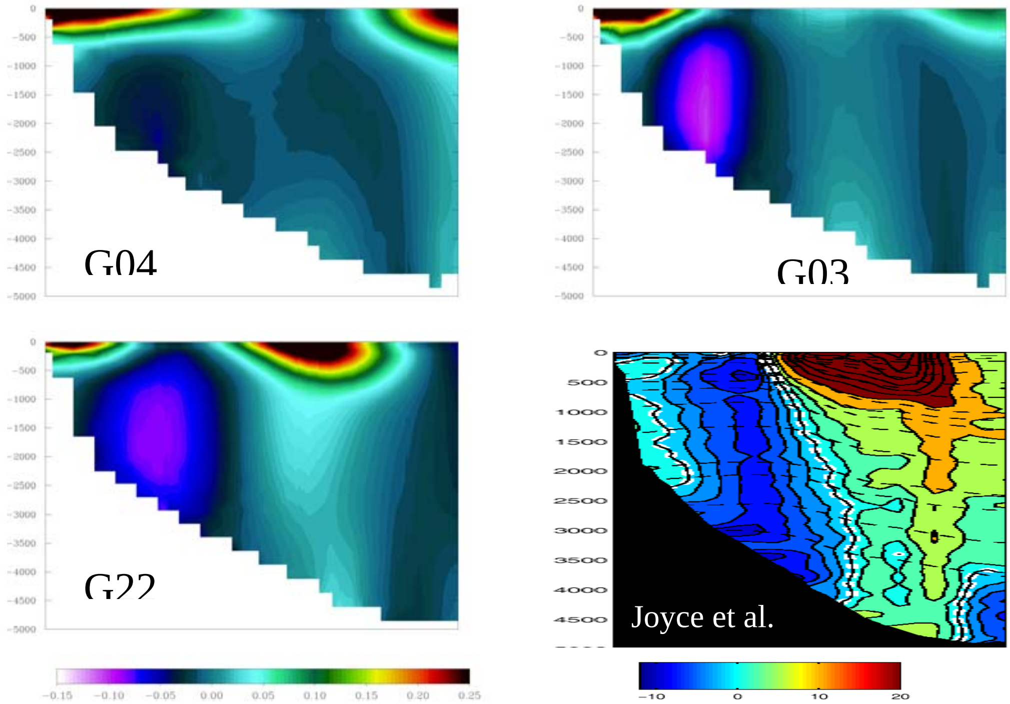


Figure 7: Barotropic streamfunction in the North Atlantic (top) and the South Atlantic (bottom). Contour interval in 10 Sv (top) and 20 Sv (bottom), negative regions are shaded. A series of three sensitivity experiments is presented from left to right: ORCA025-G04 with full step topography and the old vorticity advection scheme; ORCA025-G03 where the vorticity advection scheme has been switched to the new one, and ORCA025-G22 with new vorticity advection scheme and partial cell topography.



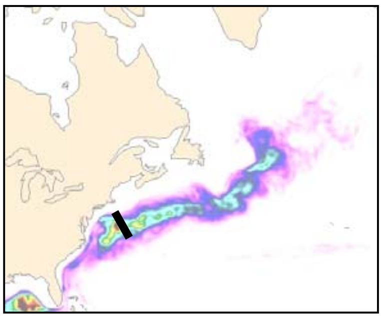


Figure 8: Section of velocity across the Gulf Stream at 69°W (the position of the section is indicated). Three model solutions are presented: G04 (full steps, old vorticity scheme), G03 (full steps, new vorticity scheme) and G22 (partial steps, new vorticity scheme). Observations from Joyce et al, 2005 (paper submitted to Deep Sea Research) are indicated, with a separate color scale. The G22 solution shows the best agreement with data regarding the position of the currents and vertical structure. The maximum velocity in the Gulf Stream is underestimated (80 cm/s in the data, about 40cm/s in the G22 model).

Fig 8 provides another example of the improvements brought about by the new advection scheme and the partial step representation of topography, this time in comparison with observed velocities. The improvements seem to occur mainly in western boundary currents, and also in the Agulhas region and the Southern Ocean.

We do not understand yet why the numerical details of the advection of vorticity matter so much at this eddy-permitting resolution. We note that it improves the solutions in regions of flow-topography interaction, in a manner similar to the partial step representation of the topography. We thus supect that this new scheme better represents the conservation of vorticity in the presence of steep topography, perhaps because the topographic effets are averaged differently over neighbouring grid points. This is now being investigated using specific diagnostics of the vorticity balance (Le Sommer et al).

The influence of partial cells topography is less unexpected, but it needs to be examined more fully since it is the first time such a comparison run is done in a global domain at eddy permitting resolution.

3.4.2. Other sensitivity experiments

Three advection schemes for tracers (temperature and salinity) are available in OPA9, as documented by Levy et al (2001). We have not used the centered scheme, which led to erroneous extrema in water mass properties in the CLIPPER models. The other schemes (called MUSCL and TVD) ensure a better conservation of tracer extrema, at the cost of some numerical diffusion. Levy et al (2001) concluded that MUSCL was more diffusive than TVD. MUSCL was chosen for low resolution global simulations where a large dissipation of variance near the grid scale is desirable. At eddy permitting resolution, we try to resolve the main frontal regions of the ocean, so we chose TVD. However we needed to perform a sensitivity experiment to confirm this choice (experiment G23, see table 1). Comparison of with experiment G22 using TVD shows that the MUSCL scheme weakens considerably the deep circulations. The global overturning deep cell is reduced from 23 Sv in G22 to 18 Sv in G23. Transports through straits tend to decrease. The EKE is much lower and less comparable to observations. Figure 9 illustrates one spectacular results of this comparison, in the deep western boundary current (DWBC) carrying North Atlantic Deep Water along the coast of South America. Dengler et al (2004) have recently observed that the DWBC is destabilized at 8°S and breaks down as a series of eddies. They found that this behavior was captured by the FLAME 1/12° model (Fig. 9), and it was also found in the CLIPPER ATL6 model. The Drakkar experiment ORCA025-G22 reproduces the destabilization of the current even at 1/4°, but this feature is lost when the MUSCL scheme is used. MUSCL being more diffusive is likely to have a stabilizing effect on the current.

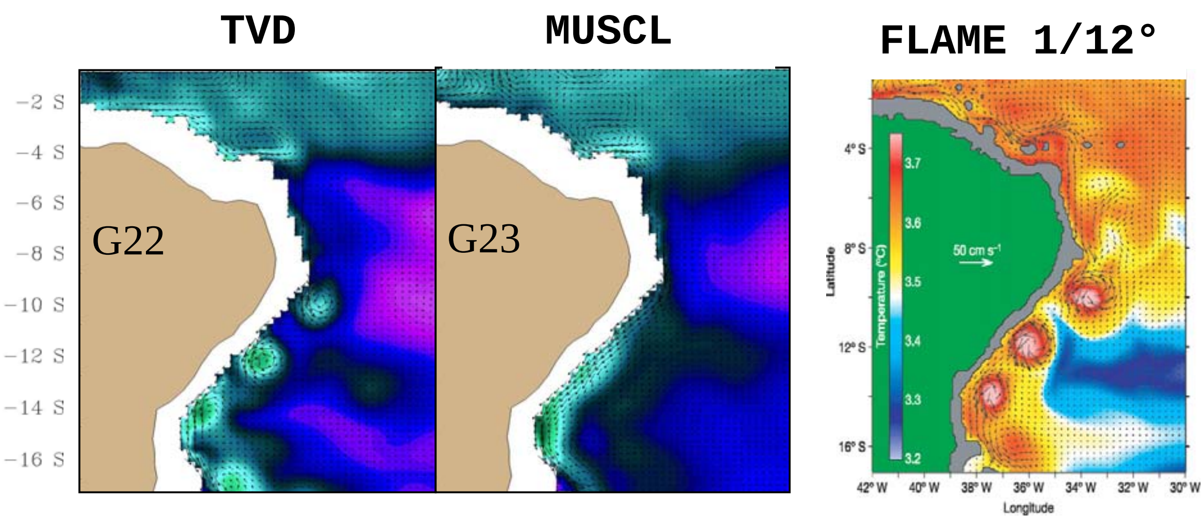


Figure 9: Snapshots of velocities (arrows) and temperature (color) during the austral winter at 2500m depth for two DRAKKAR experiments (G22 and G23) as well as the FLAME high resolution model at 1900m depth (see Dengler at al, 2005).

The role of the lateral boundary condition (free slip or no slip) was investigated next. In the CLIPPER project we chose to use free slip boundary conditions which produce stronger transports through narrow straits and a larger eddy kinetic energy at depth. However, free slip boundary conditions have also been shown to have adverse effects, for example by making the Gulf Stream separation worse. Those effects have been studied mainly in idealized model or models of the North Atlantic, it was thus useful to revisit the issue in a global domain (experiment G24). The results have not been analyzed completely yet, but our conclusion is that the free slip solution seems generally better. It was anticipated that the use of the lateral no-slip boundary condition would prevent generation of mean flows following f/h contours, like the Zapiola anticyclone. It is indeed weaker in G24 (about 50 Sv) compared to G22 but it does not disappear completely. We find that the lateral boundary condition has a strong and unexpected effect on the path of the Agulhas eddies which then drift along a more regular (and unrealistic path) in the South Atlantic. More generally, the global solution with no-slip boundary condition tends toward that found with full step topography and the old vorticity advection scheme, strongly supporting the hypothesis that this latter choice (same as in CLIPPER) overestimates near-bottom energy dissipation (see Penduff et al 2005).

Finally, the comparison of experiment G22 (where the freshwater forcing was affected by a small bug) and experiment G30 (where this bug has been corrected) has made us aware of the large sensitivity of this global ice-ocean model to freshwater forcing. Although the extra freshwater input in experiment G22 was small and uniform over the domain, regional differences have developed during the course of the 10 years simulation. The southern ocean display the largest sensitivity, because a small difference in freshwater forcing modifies the ice cover which has a dramatic effect on the air-sea fluxes and deep water convection. The deep global overturning differs between G22 (23 Sv) and G30 (25 Sv). It is possible that part of the model sensitivity is artificial and linked to the wrong behavior in the Weddell sea (inadequate ice extent and unrealistic convection down to the bottom). Anyway, this points out the necessity to find better forcing fields before running long experiments with interannual variability.

4. Development of the 1/4° North Atlantic/Nordic Seas configuration NATL4

The main part of the scientific objectives of the DRAKKAR project relate to the North Atlantic and the Nordic Seas. It is thus necessary to lay out a coupled ocean-ice regional configuration for these areas, which is not too expensive, in order to carry out experiments on interannual variability and also to prepare the future DRAKKAR configuration with very high resolution. We developed to this end the NATL4 configuration, which comprises the North Atlantic and the Nordic Seas with a 1/4° resolution. It is in fact a sub-domain of the global configuration ORCA -R025 (Fig. 10), using the same grid, bathymetry and forcing. The development using OPA9 coupled with the LIM sea-ice model started in 2003. We run a first experiment using partial cell topography, which revealed the problems with the existing vorticity advection scheme and led to the development of the new one. Note that in the context of DRAKKAR vorticity diagnostics have been implemented (L. Brunier, 2004) that will help understand the effect of the partial step topography and new vorticity advection scheme.

A new experiment has been performed in may 2004 and analyzed in a report (Theetten et al, 2004). This extensive report provides a first validation of the configuration; this information is not repeated here.

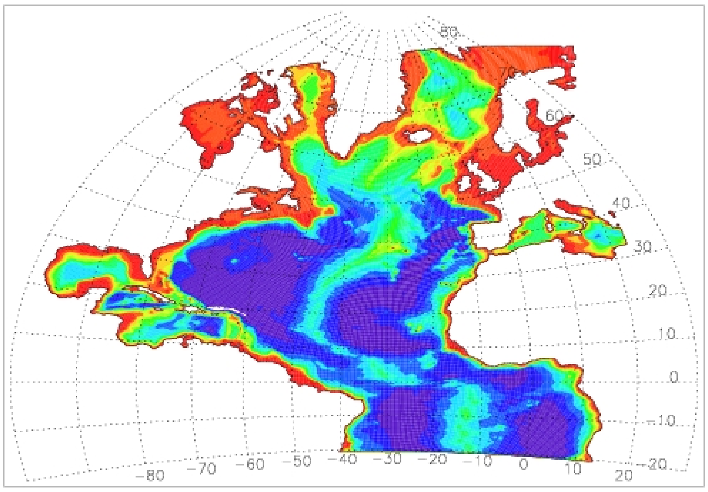


Figure 10 *: Model domain and bathymetry of NATL4 configuration.*

The first results are encouraging. In particular, the sea-ice model was used for the first time at such a high resolution and buffer zones were implemented with the strait of FRAM (towards 80°N), which allow a realistic flow of ice in the NATL4 domain (Theetten et al, 2004). Figure 5 shows the extension of the sea-ice cover in winter, and underlines the character of the surface currents, intensified along Greenland and turbulent in the North Atlantic Current (south of Iceland).

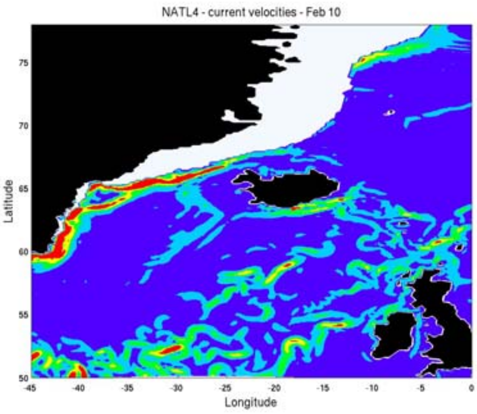


Figure 11: *Extension of the cover of sea-ice during February of the 5th year (in white), superimposed on the speed of surface currents (in color).*

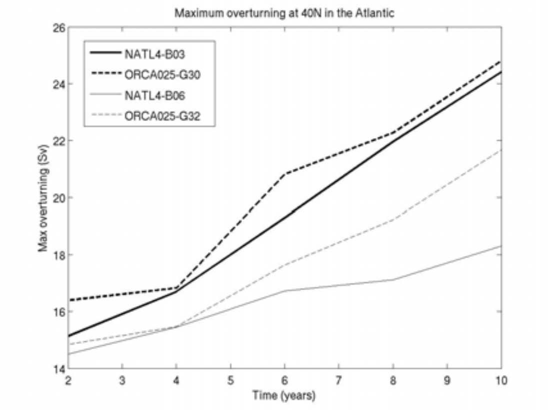


Figure 12: evolution of the meridional overturning at 40°N in the Atlantic (averages from year 2 to year 10 of four different experiments. Thick lines: experiments with no SSS relaxation; thin lines: experiments with SSS relaxation.

The main defects of NATL4 are also present in ORCA025: salinization of the subpolar gyre, wrong depth of the Med outflow, inaccurate representation of the overflows, and excessive convection in the Labrador, Irminger and Nordic seas. Two 10 years experiments have been run, one (NATL4-B03) exactly comparable to G30 and the other (NATL4-B06) with relaxation to sea surface salinity (SSS), comparable to G32. Note that the relaxation to surface salinity used in DRAKKAR is weaker than the one chosen for CLIPPER, or usually for ORCA2: the coefficient we use would be the equivalent of 11.3 W/m²/K for heat flux (instead of the usual 40 W/m²/K, a very strong one). The results show that without SSS relaxation, the meridional overturning drifts to larger values over the course of the 10 years, with no hint of a stabilization (figure 12). This behavior follows closely the global model ORCA025-G30 (fig 12) and is under investigation. Our current hypothesis is that the excessive salinity along the Norwegian coast and north of Iceland, linked with an inadequate freshwater input along the coasts, leads to the presence of very saline waters in those regions. The water masses going through Denmark straits become saltier, warmer, but also much denser, and this in turn can spin up the overturning (FLAME model results demonstrate a clear relationship between the MOC and the maximum density at 64°N, C. Böning, personal communication). We are now trying to improve the freshwater fluxes (runoff, precipitations, evaporation) to correct this problem. Introducing relaxation to SSS helps for NATL4 but apparently not for ORCA025 (Fig 12): this very preliminary result needs to be confirmed.

Regarding NATL4, it is desirable to have an open boundary at FRAM Straits rather than a solid wall. Based on the present results, it is likely that an open boundary for ocean currents and the existing buffer zone for the ice mdoel will give good results. A preliminary study with ORCA05 has shown that this lower resolution model could not provide suitable open boundary conditions at FRAM Strait, so that suitable boundary conditions must be taken from the 1./4° global model.

5. Forcing function.

5.1. Drakkar forcing fields for model development

Drakkar project uses *bulk formulae* for heat and freshwater forcing. The basic atmospheric variables needed are *air temperature*, *relative humidity*, *total cloud cover*, *scalar wind spe*ed and *precipitation*. The momentum equation uses direct estimate of the *wind stress vec*tor as boundary condition. Claude Talandier (2003) built the BULK-TEST tool using OPA forcing routines for the purpose of evaluating the forcing parameters entering the calculation of the model surface fluxes. BULK-TEST computes the forcing fields applied to the model, on the model grid, for a given SST and a given set of atmospheric variables. Performing diagnostics like MHT calculation, comparison with climatic flux estimates, one can get a quick evaluation of the impact of a particular forcing parameter on the forcing fields. A small correction relative to the calculation of relative humidity has been implemented by Laurent Brodeau (Brodeau, 2004a). The interpolation scheme and the process of extrapolating on land have been completely revised in 2004 by Laurent Brodeau and Sergei Gulev (Brodeau, 2004b), to provide a tool suitable for large configurations like ORCA025.

Based on the results of a study carried out in 2003 (Talandier et al., 2003), it was decided at the 2004 January meeting that the forcing parameters used for model development would be referred to as the Forcing Set N°1; defined below:

Bulk formula : The default bulk formula for OPA9 and LIM, referred to as the CLIO formulas

Forcing parameters:
- Air temperature: Daily mean value from NCEP
- Precipitation: monthly from CMAP
- Humidity: monthly from CLIO
- Cloud cover: monthly mean from CLIO
- Wind Speed: daily from a merging of ERS and NCEP winds.
- Wind stress in I direction: daily from a merging of ERS and NCEP winds.
- Wind stress in J direction: daily from a merging of ERS and NCEP winds.

The winds are from the ERS scatterometer between 50°N and 50°S. A linear combination with NCEP is performed between 50° and 60°, and NCEP winds are used poleward of 60°. The forcing fields have been interpolated onto the ORCA-R05 grid by Christian Ethe (LODyC). Then, a linear interpolation has been performed from the ORCA-R05 to the ORCA-R025 grid by Sébastien Theetten (LPO). No particular effort has been made to balance the net heat flux provided by this data set at global scale. An estimate of heat fluxes based on Reynolds SST by Talandier et al. (2003) showed a global imbalance of -14 Wm^{-2}.

5.2. Drakkar forcing fields for interannual experiments

It was decided at the Drakkar Kiel meeting of September 2004 that the CORE forcing set (Large and Yeager, 2004) would be the default choice for Drakkar for the interannual experiments. This forcing set has its own bulk formulas and largely uses the NCEP re-analysis. It covers the period 1958-2000 (43 years). The CORE forcing has been implemented in the ½° Drakkar configuration ORCA-R05 2004 by the Kiel group in 2004, and this forcing set is presently being evaluated from several simulations. Later on, experiments with ERA 40 may be run, according to the results of the 1/2° model.

The project will need to perform short (10 years) experiments for the recent years, to allow validation of the model against recent observations and for specific scientific projects. For these experiments other forcings may be considered.

6. Conclusion

The Drakkar project has started in 2003. The development of the first eddy permitting configurations (ORCA025 and NATL4) took longer than anticipated. The numerical developments needed in OPA9 had been underestimated, and the IBM computer at IDRIS has been operational for large model runs only since september 2004.

Despite these initial delays, a large number of results has been obtained, most of them quite unexpected. The large effect of the vorticity advection scheme came as a surprise, and needs to be understood better (this study is ongoing). Our working hypothesis is that the changes brought about by the new scheme happen because the dynamics of flow-topography interactions are modified. This is based on the similaritiy of the effects with other changes that concern topographic effects, like going from a full-step topography representation to partial cells, or switching the lateral boundary condition from no-slip to free-slip. These results are very significant and publications are in preparation on these various aspects.

The global 1/4° configuration ORCA025 is up and running with high performances on the IBM machine at IDRIS. Although only eddy permitting, this model displays mean (and even certain eddy) features usually only seen in higher resolution experiments (good representation of the North west corner, of the Zapiola eddy and the pattern of currents in the Confluence region, a strong and continuous deep western boundary current, a significant reduction of the inertial eddy at the separation of surface western boundary currents, etc...). However improvements still need to be made before performing inter-annual runs in 2005. A parameterization of the type of GM90 will have to be adapted with a space (and possibly time) varying coefficient to improve deep winter convection at high latitudes. Although improved by the new vorticity scheme, the overshoot of western boundary currents is still a problem, and no solution is foreseen right now at this model resolution. Deep overflows are still not reproduced correctly, a thorough investigation of the joint use of partial steps with the advective/diffusive BBL is required. A key issue to be addressed early in 2005 concerns the freshwater forcing. The ORCA025 results will be used to specify boundary conditions for many local studies (Indonesian throughflow, NATL4 ...)

The limited-area configuration NATL4 is now the main working tool in Drakkar to test parameterizations, pursue investigations relative to the vorticity advection scheme, and improve the freshwater forcing in this key region of the world ocean. This configuration is now used at Mercator to help with the transition to OPA9, and to prepare the new North Atlantic high resolution model. It is also used in Kiel, at LEGI by scientists associated to the Drakkar Group (Nadia Ayoub and Pierre Brasseur) and will be soon used in Canada by Paul Myers. The early results (fig 12) suggests that because of the inclusion of the Nordic Seas and sea ice, this configuration has more degrees of freedom than the previous ones (CLIPPER, the German FLAME program, the Community model experiments, Dynamo, all had a buffer zone at 70°N). We believe that by using adequate boundary conditions from the global configuration, NATL4 will be a good tool for the investigation of the mechanisms of interannual variability.

The Drakkar project was planned in two phases. The first one, of global and regional modelling at eddy permitting resolution, is not yet finished. Year 2005/2006 will be a transition period between the first phase and the second (high resolution modelling and the study of scale interactions). On the one hand, interannual experiments with ORCA025 will be performed. On the other hand, local mesh refinements in the NATL4 configuration will be used to prepare the second phase of the project.

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Thesis in progress at LEGI in the DRAKKAR project (2004-2007)

Gaëlle Hervieux: Etude numérique des interactions courant/topographie : application au gyre subpolaire, aux seuils de Gibraltar et des mers Nordiques.

Laurent Brodeau: Amélioration et développement des conditions de forçage atmosphérique des modèles de circulation océanique globale.