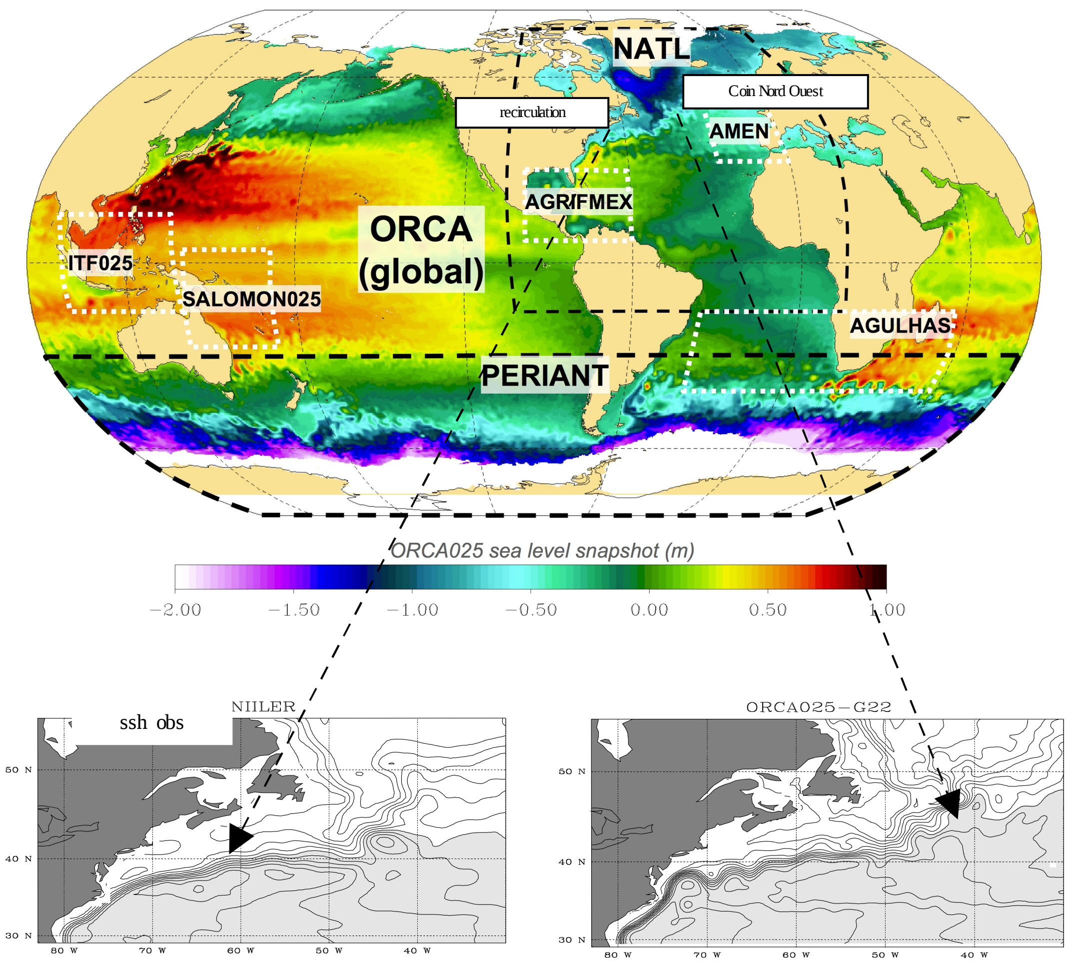
Drakkar

Variability of the subpolar Atlantic and Southern ocean: local processes and interactions with the global ocean

Report of the LEFE project, 2007-2009
LPO report 09-09



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Cover figure

The sea surface height (ssh, color) from the DRAKKAR global 1/4° model ORCA025. Because of improved numerical schemes, ORCA025 has a better representation of boundary currents such a as the Gulf Stream (see comparison with observed ssh, bottom panels). The global model has been used to prescribe boundary conditions for a number of regional models, as indicated on the figure.

Foreword

The DRAKKAR project, submitted in 2007, was organized in four parts:
1 - Implementation of model configurations and simulations
2 - Improvement of model configurations and development of validation tools
3 - Scientific studies: variability of the subpolar Atlantic
4 - Scientific studies: variability of the Southern Ocean.

In the present report of activity, we describe only briefly the first two points (in section 1) because these activities were mainly supported by the GMMC and TOSCA, and are reported in detail elsewhere. Section 2 of this report presents the results of the scientific studies in the Subpolar Atlantic (which have been extended to the exchanges with the Arctic Ocean) and part 3 presents the results of the Southern Ocean studies.

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Table of Contents

1. Model configurations, atmospheric forcing and simulations

1.1. Model configurations and simulations

Although DRAKKAR developed a full hierarchy of global and regional model configurations at various resolutions (from 2° to 1/12°), the focus of the project has been the global model at 1/4°, ORCA025, developed jointly with MERCATOR-OCEAN. This model configuration benefits from a particularly efficient implementation on vector and massively parallel supercomputers (Fig. 1, Molines et al., 2009). The success of this model is attested by the impact of the reference paper which demonstrates the significant improvement of numerical schemes (Barnier et al, 2006, 34 citations). Another index is the wide range of publications using this model (see 4.1). ORCA025-based studies range from global to local (e.g., the regional analysis of Tsimplis et al, 2008, Michel et al, 2009 or Lique et at, 2009) and from physics (e.g, the paper by Froyland et al, 2008, in Physical Review Letters) to biology (e.g, the paper by Bonhommeau et al, 2009, in the Journal of Fish Biology).

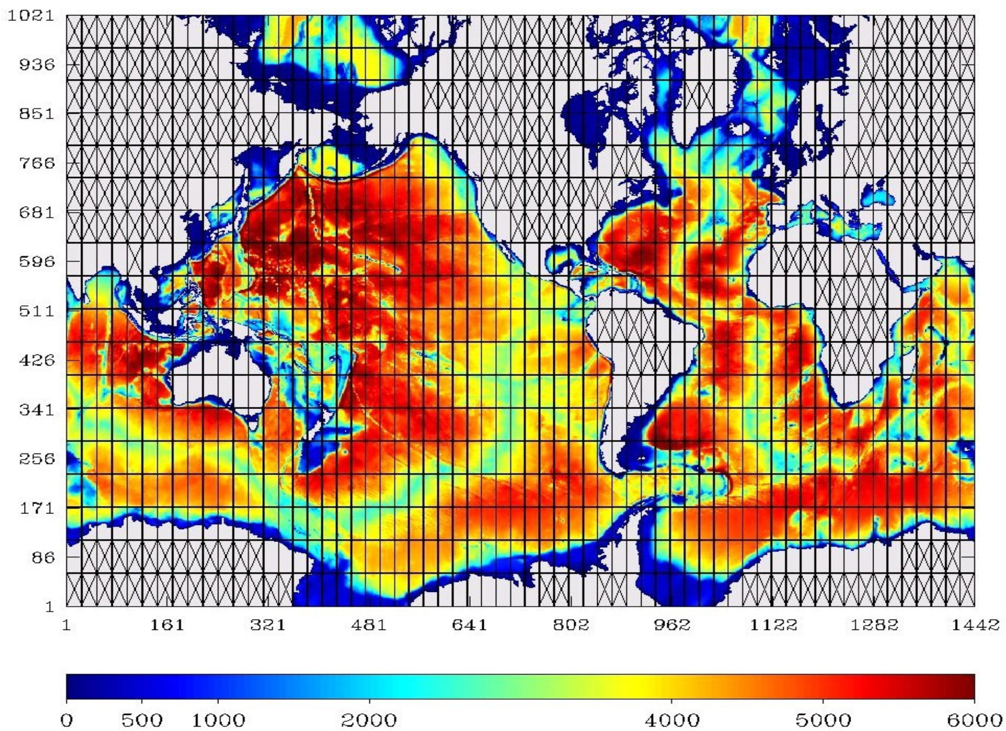

Figure 1: Global bathymetry of ORCA025 and its repartition on 864 cores of the JADE computer at CINES. Out of the 1116 subdomains, 252 are located on land (crossed out on the figure) and eliminated from the computation, which allows a gain of 20% in CPU time.

The first long global hindcast ORCA025-G70, covering the period 1958 to 2004, was completed in 2007. ORCA025-G70 allows a remarkable representation of the eddy kinetic energy field for a 1/4° model (Fig. 2). The results have been distributed to a number of colleagues in France and abroad (a list is given in the annex). Out of the 29 published papers of the DRAKKAR team listed for 2007-2009 in section 4.1, 12 papers use ORCA025 as a basis for the analysis or as boundary conditions . Three papers from other teams make use of ORCA025 (see section 4.2: Huck et al, 2008;

Rennel et al, 2009, Sokolov and Rintoul, 2008).

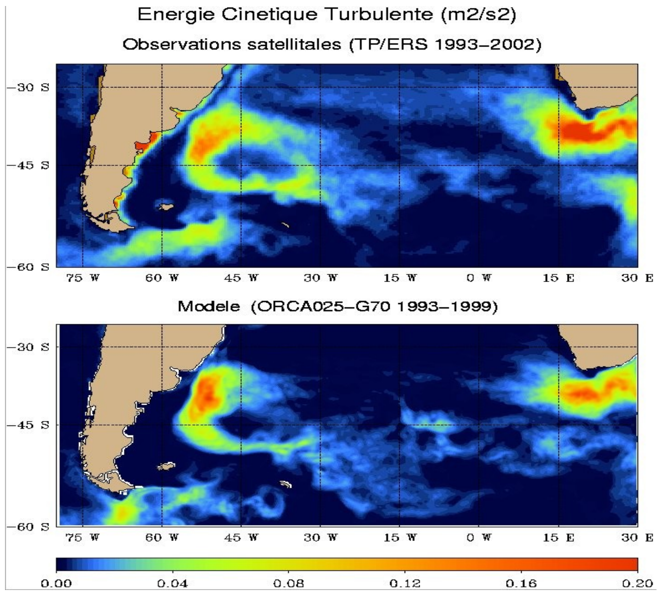

Figure 2 : Eddy kinetic energy (m^2s^{-2}) in the Southern Atlantic from satellite observations and from the ORCA025-G70 model simulation.

In 2008, we have taken the opportunity of the new computer at CINES to run the longest simulation ever with an eddy admitting model (300 years with a repeated seasonal cycle, Molines et al., 2009). This experiment now serves as a baseline to understand the different time scales of adjusment in the global ocean. The analysis of the Southern ocean trends has helped design targeted experiments in the framework of an ANR project (J. Le Sommer). In 2009, the model configuration has been updated in partnership with MERCATOR and European colleagues. we have agreed on a common vertical grid (75 levels, with enhanced resolution near the surface, i.e., 1 m) that will be used for both forced hindcasts and reanalyses. New processes have been added (shortwave radiation penetration depending on a climatology of sea color, resolution of the diurnal cycle of solar radiation, for example). The new numerical experiment, covering the period 1958 to 2006, has just been completed.

Atmospheric forcing fields: The development of improved atmospheric datasets to force global ocean-ice climate models is a key area that needs continual attention. The DRAKKAR group has tackled this task, and has prepared forcing data sets for global ocean-ice model multi-decadal simulations (Brodeau et al., 2009). We developed, calibrated and tested a dataset intended to drive global ocean hindcasts simulations of the last five decades. This dataset (referred to as the Drakkar Forcing Set #3, DFS3) provides surface meteorological variables needed to estimate air-sea fluxes and is built from 6-hourly surface atmospheric state variables of ERA40. We first compared the raw fields of ERA40 to the LYDS (Large and Yeager, 2004) dataset, and discussed our choice to use daily radiative fluxes and monthly precipitation products extracted from satellite data rather than their ERA40 counterparts. Both CORE and DFS3 datasets lead to excessively high global imbalances of heat and freshwater fluxes when tested with a prescribed climatological surface sea surface temperature. After identifying unrealistic time discontinuities (induced by changes in the nature of assimilated observations, Fig. 3) and obvious global and regional biases in ERA40 fields (by comparison to high quality observations), we propose a set of corrections that yield the DFS4. Tropical surface air humidity is decreased from 1979 onward, representation of Arctic surface air temperature is improved using recent observations and the wind is globally increased. These corrections lead to a significant decrease of the excessive positive global imbalance of heat. Radiation and precipitation fields are then submitted to a small adjustment (in zonal mean) that yields a near-zero global imbalance of heat and freshwater. A set of 47-year-long simulations is carried out with the coarse-resolution (2°x2°) version of the NEMO OGCM to assess the sensitivity of the model to the proposed corrections. Results show that each of the proposed correction contribute to improve the representation by the model of central features of the global ocean circulation.

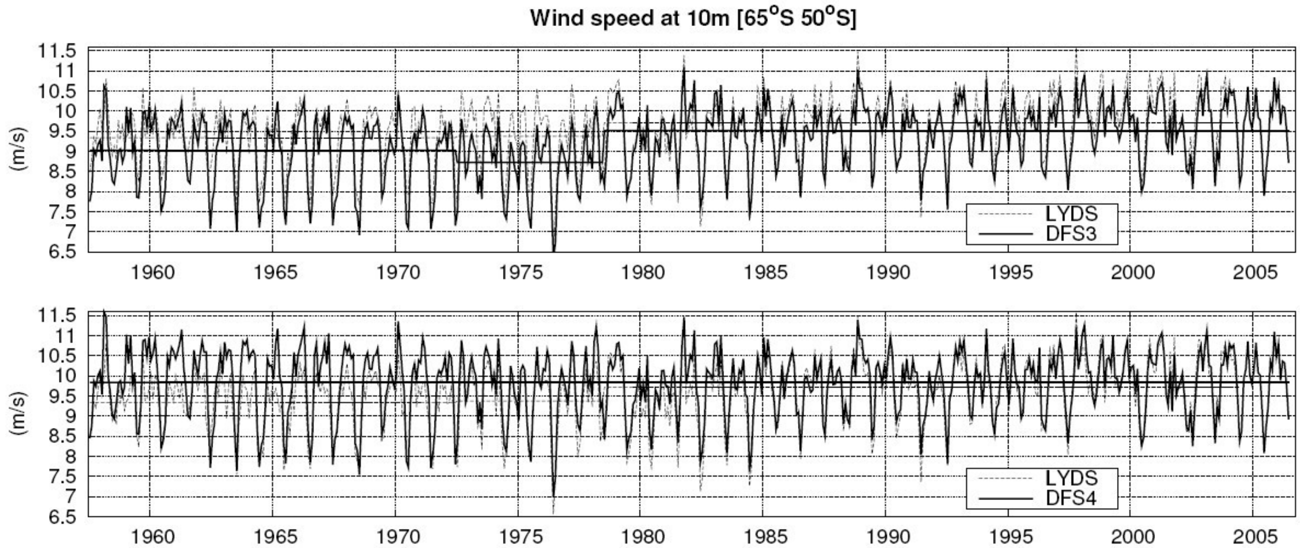

Fig. 3: Mean monthly wind speed in mid-high southern latitudes (spatially-averaged between 50S and 65S) and its mean value for each of the 4 periods 1958-1972, 1973-1978, 1979-2001 and 2002-2006; (a) LYDS and ERA40-ECMWF not corrected,(a) LYDS and ERA40-ECMWF corrected.

In addition to these adjustments, a correction of DFS3 and DFS4 winds were developed to compensate for the drastic underestimation of these katabatic winds in the ERA40 reanalysis (Mathiot et al., 2009a). This correction derives from a comparison over 1980 to 1989 between wind stresses in ERA40 and those downscaled from ERA40 by the MAR regional atmospheric model. The representation in MAR of the continental orography surrounding the ocean, like the Trans Antarctic Mountains, and a specific parameterisation of roughness length in the planetary boundary layer yield a major improvement in the representation of katabatic winds along the coast of Antarctica. Wind stress directions at the first ocean point are remarkably similar in ERA40 and MAR, but MAR wind stress amplitudes are much larger. The wind stress correction thus consists in a local amplification of the 6-hourly ERA40 wind stress components at ocean points near the coast (Fig.4). This scale factor is constant in time (i.e. no seasonal variation) but is spatially variable (decreasing off shore over a distance of about 150 km).

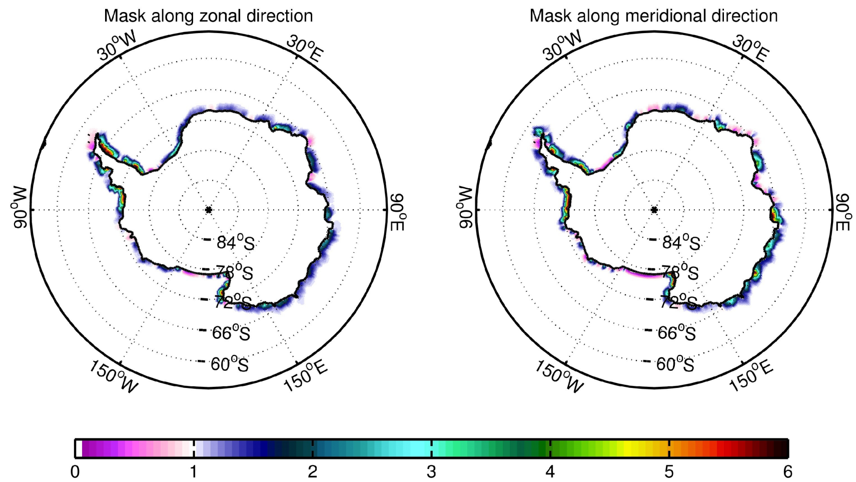

Fig. 4: *Multiplicating factor applied to the wind stress for correction of katabatic winds along the zonal (left) and meridional directions (right).*

Regional configurations: DRAKKAR has also developed regional configurations. A North Atlantic model has been developed for sensitivity studies and to provide boundary conditions for regional studies. The DRAKKAR team continuously seeks to improve open boundary strategies (e.g, the work by Cailleau et al, 2008). This expertise has helped us implement a number of configurations forced at the boundaries by ORCA025: the PERIANT model of the Southern Ocean, used for the PhD study of P. Mathiot (LEGI), a regional model of the Indonesian Throughflow used for the PhD of A. Koc'h Larrouy, or a regional model of the Kerguelen archipelago used for the PhD of F. Roquet (LOCEAN). The 1/4° regional model NATL4 is being used in a large number of teams, including those involved in the "MERCATOR vert" activities. It has been used for a dedicated study of tropical instability waves by Athie et al (2009). It was also used in a stochastic study of the temperature response of the upper ocean to uncertainties in the atmospheric forcing in the North Atlantic (Lucas et al., 2008). NATL4 has provided high frequency boundary conditions for a 1/12° model of the Gulf of Guinea: the GUINEA model, which produced the first maps of biweekly energy along the slope and demonstrated that equatorial yanai waves are the source of energy for coastal-trapped waves in the Gulf of Guinea (Guiavarc'h et al, 2008 and 2009). Starting in 2007, we have begun to use the higher resolution NATL12 configuration developed at MERCATOR. We have improved the bathymetry and adapted open boundary conditions from the global model. One long simulations (27 years) has been run in 2008 and a second one is being run.

1.2. Improvement of numerical schemes and grid refinements

The good representation of the eddy kinetic energy in the ORCA025 model (Fig 1) is due to improvements of the numerical schemes (Barnier et al, 2006), and these effects needed to be better understood. We have investigated thoroughly this issue, as well as the impact of the representation of bottom topography and of the lateral boundary conditions on the eddy energy and on the mean global circulation. These results are described in two papers (Penduff et al, 2007; Le Sommer et al, 2009).
Several different momentum advection schemes have been tested during the project. The mean kinetic energy vertical profile has been found to change up to 10% depending on the chosen scheme. This

sensitivity is maximum in bottom layers. The analysis of the vorticity tendency due to horizontal momentum advection has revealed that the schemes differ mostly in bottom layers as well. Our investigations have shown that the differences between the schemes are related to the grid-scale irregularity of the velocity field. Both the grid scale irregularity and the differences between the schemes have been found to be enhanced in bottom layers. We concluded that the model solution depends crucially on the ability of the momentum advection scheme to handle under-resolved flows close to the bottom topography. This work emphasized the critical influence of topography in eddy-active regions on mean circulation features such as the position of the North-Atlantic current or the Gulf Stream separation. Note that DRAKKAR configurations were used as testbed for the development of new parameterizations, and important results were obtained on the representation of the effect of tidal mixing on the water mass properties (Bessière et al., 2008, Koch-Larrouy et al., 2008).

Grid refinement: The AGRIF software (Debreu et al, 2005[1]) which allows one way and two way local grid refinement in NEMO was adapted by the MOISE team at LJK-Grenoble for massively parallel calculations. The first application of AGRIF in such context was performed in a cooperation between DRAKKAR and CICESE-Mexico (Jouanno et al., 2008, 2009). The variability in the Caribbean Sea has been investigated using a high resolution (1/15°) 2-way AGRIF refinement over this region in the North Atlantic NATL3 (1/3°) configuration, a DRAKKAR configuration inherited from the CLIPPER project, and which reproduces the main features of the North Atlantic and Equatorial circulation capable of influencing ocean dynamics in the Caribbean Sea. This numerical study highlights strong dynamical differences among basins and modifies the view that dynamics are homogeneous over the whole Caribbean Basin. The Caribbean mean flowis shown to organize in two intense jets flowing westward along the northern and southern boundaries of the Venezuela Basin, which merge in the center of the Colombia Basin. Diagnostics of model outputs show that width, depth and strength of baroclinic eddies increase westward from the Lesser Antilles to the Colombia Basin. The widening and strengthening to the west is consistent with altimetry data and drifter observations. Although influenced by the circulation in the Colombia Basin, the variability in the Cayman Basin (which also presents a westward growth from the Chibcha Channel) is deeper and less energetic than the variability in the Colombia/Venezuela Basins. Main frequency peaks for the mesoscale variability present a westward shift, from roughly 50 days near the Lesser Antilles to 100 days in the Cayman Basin, which is associated with growth and merging of eddies.

A zoom of the intergyre area in the North-East Atlantic at 1/12° has been implemented in the regional configuration NATL4 using the grid refinement tool AGRIF. This configuration, named AMEN, is used to investigate the life cycle and the variability of the mode water observed in that area (Szekely 2008, report)

1.3. Development of new tools

The numerical code used is NEMO (Nucleus for European Modelling of the Ocean, www.nemo-ocean.eu) and there is a very close interaction between the DRAKKAR group and the NEMO system team, DRAKKAR configurations being used for performing numerical and physical sensitivity tests, at high resolution and for realistic ocean simulations. Besides helping with the NEMO development, DRAKKAR has developed a number of tools. The first one is the DRAKKAR Configurations Manager or DCM (Molines, Theetten, Treguier, 2006), a working/developing

1Debreu L., E. Blayo and B. Barnier, 2005: "A general multi-resolution approach to ocean modelling: experiments in a primitive equation model of the north Atlantic", in *Adaptive Mesh Refinement - Theory and Applications*, Lecture Notes in Computer Science, Vol. 41, Plewa, Tomasz; Linde, Timur; Weirs, V. Gregory (Eds.).

environment widely used in the DRAKKAR group. During the last two years the DCM has been updated to enhance its portability, and it is now maintained with SubVersion (svn). A package of diagnostic tools in fortran (cdftools) is also maintained and distributed. It is used for monitoring and validating the experiments.

A real-time *monitoring* of all DRAKKAR runs in progress automatically updates a large series of common diagnostics (regional and global evolutions of e.g. MOCs, MHTs, SSHs, sea-ice cover, air-sea fluxes, key current transports, integrated T and S contents, subsurface T/S/current maps, overflow characteristics, etc) that proved very useful for model-observation and model-to-model comparisons (e.g. Barnier et al 2006). These quasi-automatic scripts are complemented by more in-depth post-processing tools (developed and maintained with the support of the OST/ST program): [1] simulations are collocated in 4 dimensions onto AVISO altimeter and ENACT-ENSEMBLES hydrographic (XBTs, sections, TAO, Pirata, ARGO, buoy) datasets; [2] these modelled-observed collocated fields are jointly analyzed using the same statistical tools to precisely quantify the 4D structure of model biases, the impact of key model parameters (resolution, forcing, parameterizations, etc) on the realism of simulations (e.g. Penduff et al 2009), thus providing material for dedicated science studies about e.g. intermediate water masses (Koch-Larrouy et al, 2009) or the accuracy of the ARGO observing array (Juza et al, 2009).

2. Variability of the Subpolar North Atlantic and exchanges with the Arctic Ocean

This part of the DRAKKAR project proposed to address three main questions: the variability of Mode Waters in the subpolar gyre, the variability of boundary currents, and the link between large scale variability modes and local processes. The strategy has evolved to take into account the influence of the Arctic ocean on the subpolar variability, a study made possible by the good performance of the global ORCA025 model in the Arctic ocean.

2.1. Mode water variability

(V. Thierry, A.M. Treguier E. de Boisséson, collaboration with the OVIDE project)

The life cycle and the variability of the subpolar mode water observed in the North-Iceland Basin and in the intergyre area of the eastern North-Atlantic have been investigated by Eric de Boisséon during his Phd and by Tanguy Szekely during an internship in 2008. In comparing the ORCA025-G70 outputs to Hydrobase2 climatological Atlas and to CTD data collected during the period 1990-2006, Eric de Boisséson shows that the position, the properties and the variability of the SPMW in the Iceland Basin are correctly represented in the ORCA025-G70 simulation (Figure 5). Using the lagrangian tool ARIANE, Eric de Boisséson additionally shows that the SPMW in the Eastern North Atlantic are fed by the two main branches of the North-Atlantic Current that cross the Mid-Atlantic Ridge between 48 and 53°N (Figure 6). During positive NAO index years, the relative contributions of the subpolar and subtropical waters to the SPMW observed above the Reykjanes Ridge are similar (about 50% each) while during NAO negative or neutral years, the contribution of the subtropical waters increased and the ratio is about 2/3 for the subtropical waters and 1/3 for the subpolar waters.

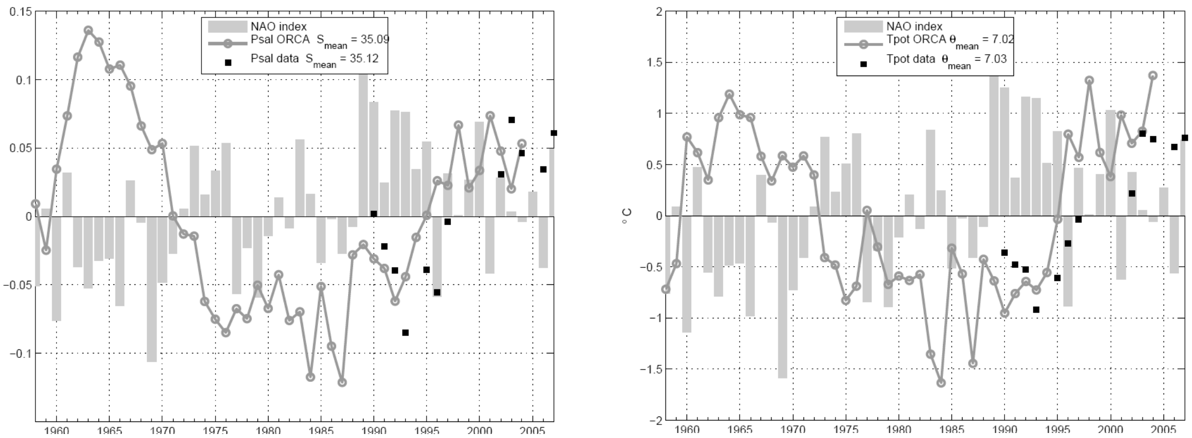

Figure 5: Salinity and temperature of the Subpolar Mode Water observed above the Reykjanes Ridge. (Gray line) SPMW properties in ORCA025-G70. (Black square) SPMW properties deduced from ship-based and Argo hydrographic data (Thierry et al 2008). (Gray bars) Winter NAO index.

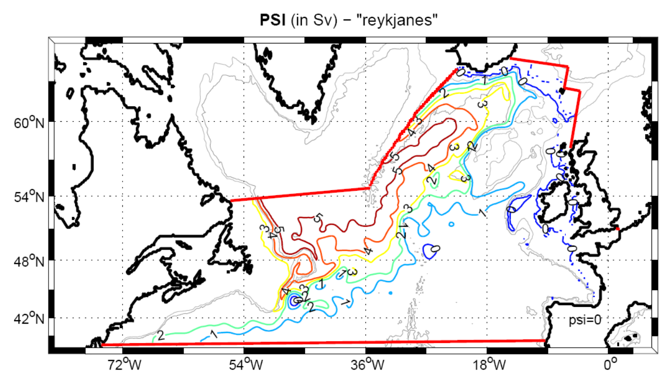

Figure 6: Streamfunction of the particles that fed the SPMW observed above the Reykjanes ridge in summer 1990 in ORCA025-G70.

The Iceland basin being an area of formation of mode water, the ORCA025-G70 configuration has been used to investigate the mixed layer heat budget in the North Atlantic Ocean. A lagrangian budget is first estimated from Argo data. We show that the annual mean heat storage rate (-89W/M2) is balanced within 10W/m2 by the surface heat fluxes from NCEP and ECMWF. In subsampling the model outputs at the Argo sampling, a similar calculation is done with the ORCA025-G70 dataset. Despite model errors, the annual mean heat storage rate is 85W/m2 and the closure is about 25 W/m2. An eulerian budget is then estimated over the whole North Iceland Basin to quantify all contributions to the budget and the Argo sampling errors. The model indicates that the advective term is the second highest contribution to the budget after the surface hat fluxes. According to the model, the advection and the surface heat fluxes are the terms that are the most sensitive to the resolution. At the resolution of the Argo floats; the sampling error for the advection and surface fluxes are 20 and 10 W/m2, respectively. Those results are detailed in de Boisséson et al (2010).

Subpolar mode waters are also observed in the intergyre area of the Eastern North-Atlantic, in between the North Atlantic Current and the Azores current. The mode waters have been studied in the ORCA025-G70 simulation and in the AMEN configuration (1/4° with AGRIF zoom in the Eastern Atlantic) by Tanguy Szekely. We focussed on the mode water observed near 43°N. With the Lagrangian tool Ariane, we investigated the role of the Azores Current and of eddies on the subduction of the mode water and on the ventilation of the ocean interior. The mode waters located near 43°N follow an overall southward movement. In the Amen configuration, among the mode waters that reach the Azores Current, 43% of the particles are transported toward the Gulf of Cadiz while the other particles succeed in crossing the current. More than half of the particles that were mode waters initially re-circulate northward either to the west with the North-Atlantic Current or to the east along the Iberian peninsula.

The southward and westward extension of the potential vorticity minimum tongue in the North-East Atlantic is greater in AMEN compared to ORCA25-G70 (figure 7), suggests a greater ventilation of the ocean interior in AMEN. In the high-resolution model the mode waters cross the Azores Current without being modified and succeed in ventilating the ocean interior south of the current. On the contrary, in ORCA025-G70, the mode waters are mixed with surrounding water masses when they reach the Azores Current. They become lighter and shallower and are trapped in the current that carry them toward the Gulf of Cadiz.

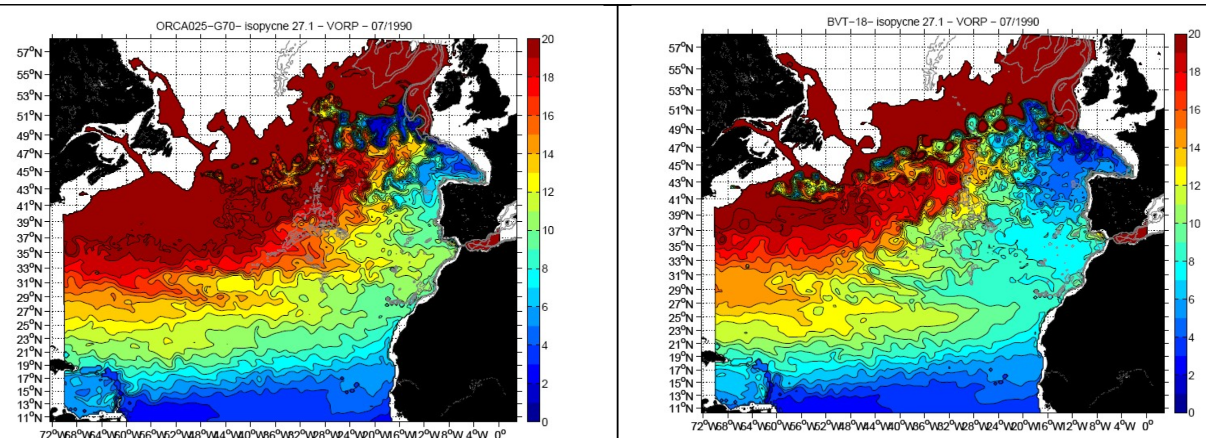

Figure 7: Potential vorticity along the 27.1 isopycnal in July 1990 in the ORCAO25-G70 simulation (left) and in AMEN-BVT18 (right). The southward extension of the potential vorticity minimum tongue in the North-East Atlantic allows us to follow the southward extension of the mode water and the ventilation of the thermocline.

Note that the good performance of ORCA025 has also made possible a study of the interannual variability of heat content in the Bay of Biscay (Michel et al, 2009). The ORCA025-G70 simulation reproduces the observed interannual variability of the sea surface temperature (compared with satellite data) as well as upper layer heat content (compared with in-situ data). The multidecadal trends are also present in the model, although the warming since the seventies is underestimated. The model suggests that the intereannual variability is driven by the surface fluxes, with oceanic transport possibly playing a more important part at decadal scales.

2.2. Freswater exchanges with the Arctic

(Camille Lique, A.M. Treguier, T. Penduff)
The PhD work of Camille Lique was initially targeted at the variability of the subpolar Atlantic, but due to the importance of the freshwater exchanges with the Arctic and considering the relatively good Arctic circulation in ORCA025 (the model resolution is 12 km there), the study has been focussed on exchanges between the Arctic and the subpolar Atlantic. In the first part of this work, published in Climate Dynamics (Lique et al, 2009a) we have investigated the variability of the Arctic freshwater content and exprots during the 1965-2002 period. A comparison with recent mooring sections shows that the model realistically represents the major advective exchanges with the Arctic basin, through Bering, Fram and Davis Straits, and the Barents Sea. This allows the separate contributions of the inflows and outflows across each section to be quantified (Figure 8). In the model, the Arctic freshwater content variability is explained by the sea-ice flux at Fram and the combined variations of ocean freshwater inflow (at Bering) and outflow (at Fram and Davis). At all routes, except trough Fram Strait, the freshwater transport variability is mainly driven by the ocean, with small contributions from the sea-ice flux. The ocean freshwater transport variability through both Davis and Fram is controlled by the variability of the export branch (Baffin Island Current and East Greenland Current, respectively), the variability of the inflow branches playing a minor role.

We have examined the respective role of velocity and salinity fluctuations in the variability of the ocean freshwater transport. Fram and Davis Straits offer a striking contrast in this regard. Freshwater transport variations across Davis Strait are completely determined by the variations of the total volume flux (0.91 correlation). On the other hand, the freshwater transport through Fram Strait depends both on variations of volume transport and salinity. As a result, there is no significant correlation between the variability of freshwater flux at Fram and Davis, although the volume transports on each side of Greenland are strongly anti-correlated (-0.84). Contrary to Davis Strait, the salinity of water carried by the East Greenland Current through Fram Strait varies strongly due to the ice-ocean flux north of Greenland.

In the second part of the study, we have investigated the origin of the water masses exported from the Arctic to the North Atlantic along both sides of Greenland through Davis Strait and Fram Strait, using the ARIANE software developed by B. Blanke and N. Grima. We have quantified the relative contributions of the different branches of circulation for the export to the North Atlantic, as well as the related timescales and water mass transformations (Lique et al, 2009b, in revision for J. Geophys. Research).

In the model, the outflow through Davis Strait consists in equal part of Pacific and Atlantic Water, whilst the export through Fram Strait consists almost fully of Atlantic Water. Pacific Water is transferred quickly (O(10 years)) to the North Atlantic, through the Beaufort Gyre, where gradual warming and salinification occur.
Atlantic Water exiting in the surface layer along both sides of Greenland remains about 10 years in the Arctic Basin, and undergoes cooling and significant freshening. Atlantic Water exiting through the intermediate and deep layers in Fram Strait follows different possible pathways in the Arctic, with trajectories being subject to topography constraints. The travel time depends strongly on the followed pathway (from 1 year to 1000 years) and the transformations (mainly an intense cooling) are less

important than in the surface layer. The role of the Barents Sea in the modification of the Atlantic inflow is specially emphasized. We find that the Barents Sea Branch is almost fully transformed there in less than a year, due to exchanges with the very cold atmosphere. This circulation scheme shows little sensitivity to a change of the Arctic Oscillation state.

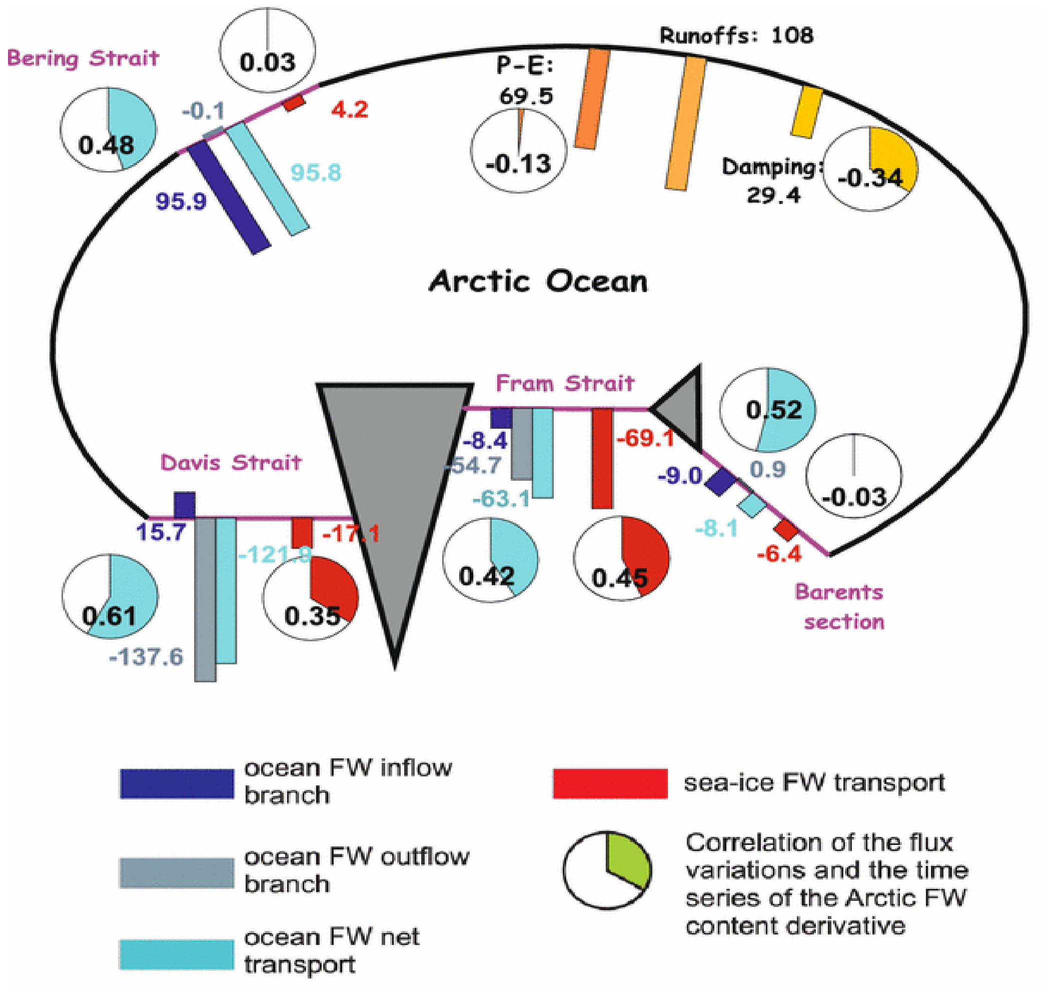

Figure 8 (Lique et al, 2009b): Schematic view of the freshwater budget of the Arctic Ocean in ORCA025. The transports (bars) are indicated for inflowig, outflowing branches, and the net (in 1000m3/s), Circles show the correlations between each transport and the variations of the Arctic freshwater content, over the 1965-2002 period.

2.3. Variability of boundary currents, and exchanges with the interior

Exchanges between the boundary and the interior (B Barnier, J. Chanut):

The possibility of increasing locally the resolution was exploited to investigate the role of mesoscale eddies in the exchanges of heat between the boundary current and the interior Labrador Sea (Chanut et al., 2008). The cycle of open ocean deep convection in the Labrador Sea was studied in a realistic, high-resolution (4km) regional model, embedded (with AGRIF) in a coarser (1⁄3°) North Atlantic setup. This configuration allows the simultaneous generation and evolution of three different eddy types that are distinguished by their source region, generation mechanism, and dynamics. Very energetic Irminger Rings (Irs) are generated by barotropic instability of the West Greenland and Irminger Currents (WGC/IC) off Cape Desolation and are characterized by a warm, salty subsurface core. They densely populate the basin north of 58°N, where their eddy kinetic energy (EKE) matches the signal observed by satellite altimetry. Significant levels of EKE are also found offshore of the West Greenland and Labrador coasts, where boundary current eddies (BCEs) are spawned by weakly energetic instabilities all along the boundary current system (BCS). Baroclinic instability of the steep isopycnal slopes that result from a deep convective overturning event produces convective eddies (Ces) of 20–30km in diameter, as observed and produced in more idealized models, with a distinct seasonal cycle of EKE peaking in April.

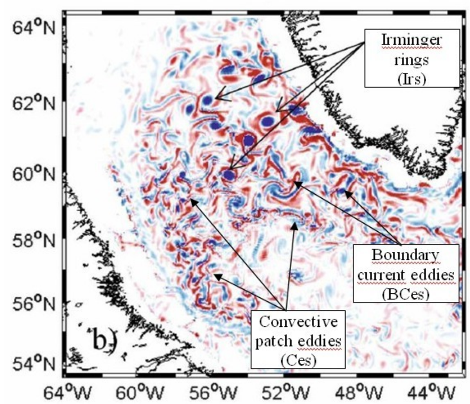

Figure 9: snapshot of the model relative vorticity in the refined region of the Labrador Sea. The three different types of eddies (identified by their source region, generation mechanism, and dynamics) are indicated.

Sensitivity experiments show that each of these eddy types plays a distinct role in the heat budget of the central Labrador Sea, hence in the convection cycle. As observed in nature, deep convective mixing is limited to areas where adequate preconditioning can occur, that is, to a small region in the south western quadrant of the central basin. To the east, west, and south, BCEs flux heat from the BCS at a rate sufficient to counteract air–sea buoyancy loss. To the north, this eddy flux alone is not enough, but when combined with the effects of Irminger Rings, preconditioning is effectively inhibited here too. Following a deep convective mixing event, the homogeneous convection patch reaches as deep as 2000m and a horizontal scale on the order of 200km, as has been observed. Both Ces and BCEs are found to play critical roles in the lateral mixing phase, when the patch restratifies and transforms into Labrador Sea Water (LSW). BCEs extract the necessary heat from the BCS and transport it to the deep convection site, where it is fluxed into convective patches by Ces during the initial phase. Later in the phase, BCE heat flux maintains and strengthens the restratification through out the column, while solar heating establishes a near-surface seasonal stratification. Incontrast, Irs appear to rarely enter the deep convection region. However, by virtue of their control on the surface area preconditioned for deep convection and the interannual variability of the associated barotropic instability, they could have an important role in the variability of LSW.

High frequency variability of the boundary currents in the North Atlantic

(A.M. Treguier, C. Guiavarc'h, collaboration with G. Roullet)

One of the purposes of the development of regional North Atlantic model at 1/12°, NATL12, was to study the variability of boundary currents. As a first step, we implemented "virtual" currentmeters on the continental slope all around the basin, and performed sensitivity experiments to demonstrate the respective role of high frequency (daily to seasonal) winds and ocean eddies in the generation of variability of the currents on the slope. Preliminary results have been presented at intrernational meetings (Guiavarc'h et al, 2008; Roullet et al 2008). We have found that the currents on the slope tend to be oriented along the bathymetry at the surface as well than at the bottom, even in the very stratified regions near the equator, and even though the vertical structure of the eddy energy is surface intensified. The analysis is pursued at LPO, Brest as part of the PhD of Arnaud Le Boyer, in collaboration with G. Roullet.

Note that a preliminary comparison between ORCA025-G70 and the OVIDE current-meters on the continental slope of Greenland at 60°N has shown extremely good agreement for the amplitude and phase of subtidal current variability (N. Daniault, personal communication). The DRAKKAR models will allow us to investigate the origin of the variability; this work will be carried out within the OVIDE project.

2.4. Adjustment processes, sea level rise, MOC variability

(T. Penduff, A. Lecointre)

The surface signature of westward-propagating features (1st-mode Rossby waves, eddies) in the subtropical Atlantic has been assessed using collocated altimetry, and further investigated below the surface from distinct eddy-permitting simulations, i.e. CLIPPER and DRAKKAR (whose numerics, resolution, forcing, periods of integrations differ). Lecointre et al (2008) and Meinvielle (2008) demonstrated that the surface signature of these simulated adjustment processes match altimeter data, and revealed that both numerical models simulate a 10-15% downward decrease of their phase speeds. Associated analysis tools are now being used to complement the assessment of the multi-resolution hierarchy of DRAKKAR models. These studies stimulated a collaboration between modellers (DRAKKAR), Rossby-wave observationalists (P. Cipollini) and theoreticians (R. Tailleux), which is now supported by an OST-ST project (co-PIs T. Penduff and R. Tailleux).

The mean structure, decadal trend and interannual variability of the Meridional Overturning Circulation (MOC) is being compared by A. Lecointre (PhD student in Grenoble) from a 8-member ensemble of non-assimilated (DRAKKAR) and assimilated (from MERCATOR and University of Reading) runs. This study aims at assessing against in-situ observations the representation of these essential climatic indexes, to quantify their robustness and investigate their sensitivity to model resolution and assimilation techniques. Present results quantify MOC sensitivities to model resolution (see Lecointre et al 2007), link some of them (intensity, phase) with the representation of westward-propagating structures, document in detail unreported differences in reanalyses, and should eventually help improve both model numerics and methods used to constrain large-scale features from the assimilation of local observations.

Although the globally-averaged sea-level rise is not accurately represented in forced Boussinesq configurations like DRAKKAR, the regional patterns of long-term SSH trends are explicitly simulated. From a joint analysis of altimeter data and of the ORCA025-G70 simulation, Lombard et al (2009) demonstrated that most observed regional sea level changes arise from temperature changes in the upper 750 m of the ocean, with locally significant contributions of salinity changes and deep steric changes. The realistic SSH trends found in the DRAKKAR simulation also led to a diagnostic of non-steric regional trends (i.e. related to bottom pressure), impossible to measure directly.

3. Variability of the Southern Ocean

3.1. Role of eddies in the Southern Ocean

(A.M. Treguier, J. Le Sommer)

The investigation of the role of eddies in the meridional overturning circulation (MOC) of the Southern Ocean has been initiated in 2005-2006, in collaboration with M. England (University of new South Wales, Sydney; this collaboration has been funded by a FAST project and the Australian Research Council). In Treguier et al, 2007 the eddy contribution to the MOC has been calculated in two ORCA025 experiments. We demonstrated that it is necessary to calculate the MOC following mean streamlines in order to recover a picture of the MOC compatible with theory. Indeed, in high resolution models such as ORCA025 or the most recent OCCAM model, the *zonally averaged* MOC displays a poleward flow of the less dense layers, contrary to the equatorwards Ekman transport: we have demonstrated that it is an artefact of the zonal average, and that the *streamline-averaged* MOC is opposite. By calculating the MOC following streamlines we have been able to quantify the eddy contribution, and compare it with the theoretical value deduced from the surface buoyancy fluxes. We show that although the simplest zonally-symmetric theory explains qualitatively the model balances, it cannot be used make quantitative estimates of the MOC.

The same method has been used to study the response of the Southern Ocean meridional overturning to the increase in the Southern Annular mode (SAM) observed between 1972 and 2001 (Treguier et al, 2009). The eddy contribution to the response is of interest because a growth of the poleward eddy transport could, in theory, oppose the increase of the mean overturning circulation forced by the SAM. Time series of the model response are presented in Fig. 10. the In our model, the total meridional circulation at 50° is well correlated with the SAM index (and the Ekman transport) at interannual time scales, and both increase over three decades between 1972 and 2001 (Fig 10a). However, contrary to the mean, the eddy contribution to the meridional overturning has no trend (dashed line in Fig 10b). The increase of the meridional overturning is due to the time-mean component, and is compensated by an increased buoyancy gain at the surface. In the model, we have found that the zonal circulation does not vary in a simple relationship with the meridional circulation. The transport of the Antarctic Circumpolar Current (ACC) is correlated with the SAM at interannual time scales but exhibits a drift due to the thermodynamic adjustment of the model (the ACC transport decreases due to a low renewal rate of dense waters around Antarctica). The interannual variability of the eddy kinetic energy (EKE) and the ACC transport are uncorrelated, but the EKE decreases like the ACC transport over the three decades, even though meridional eddy fluxes of heat and buoyancy remain stable. Our model solution points out that the zonal circulation and the eddy kinetic energy are governed by different mechanisms according to the time scale considered (interannual or decadal).

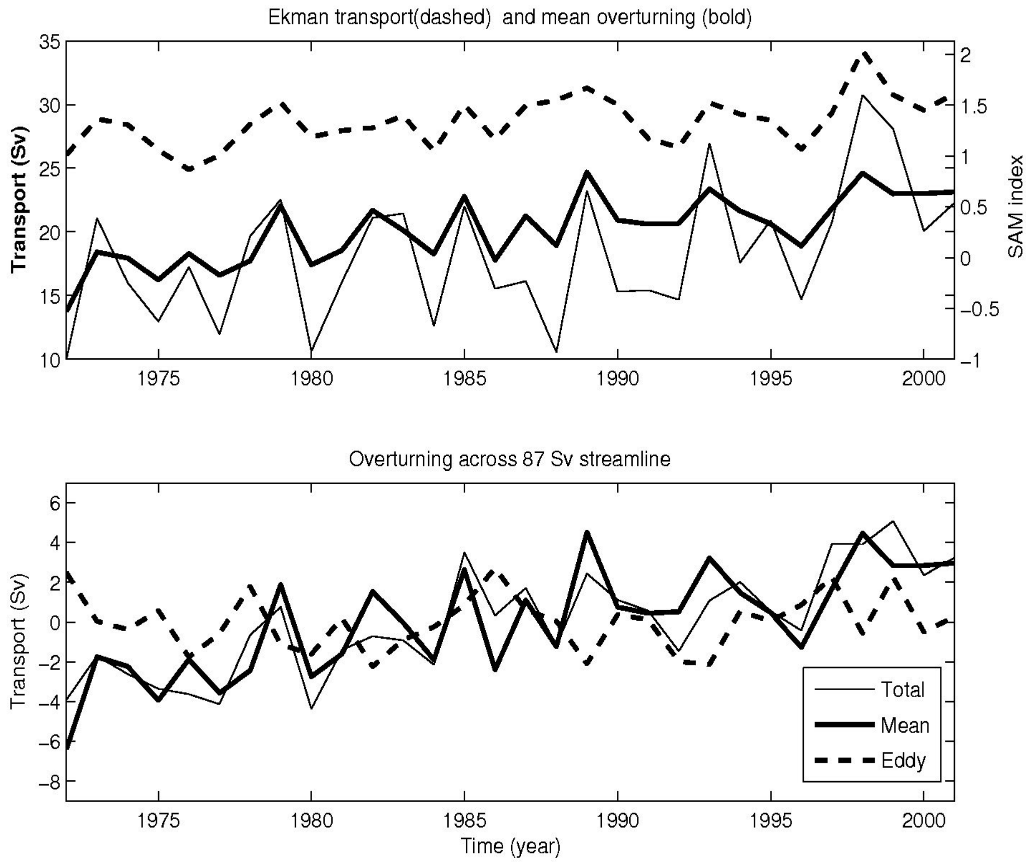

Fig. 10: *Time series of annual averages of ORCA025 results, 1972 to 2001. Top (a): time series of meridional Ekman transport at 50°S (bold dashed line), and meridional overturning of the time-mean flow in density coordinates across the 87~Sv streamline (bold line). The SAM index is superimposed. Bottom (b): anomalies of the meridional overturning across the 87~Sv streamline (in Sv), for the total MOC (thin black line), time mean MOC (thick black line) and transient eddy MOC (dashed line).*

3.2. Life cycle of Antarctic Bottom Waters

(P. Mathiot, B. Barnier, J. Le Sommer)

The impact of katabatic winds on the near coast dynamics of the ocean and sea-ice around antarctica has been investigated in twin 40-year long simulations of the global ORCA05 ocean/sea-ice model (Mathiot et al., 2009a). Katabatic winds yield an increase of the extent of coastal polynyas and of the total sea ice produced (Fig. 11), a marked decrease of the sea-ice thickness and of the ice-fraction near the coast of Antarctica. This effect extends far beyond the coastal area into the open sea. Katabatic winds induce an increase of the local overturning in polynya with a more intense transformation of Antarctic Surface Waters into colder and denser shelf waters (a 2 Sv increase). The modification of shelf water properties and of the zonal surface wind stress yields an increase of the seasonal cycle of the Antarctic Coastal Current.

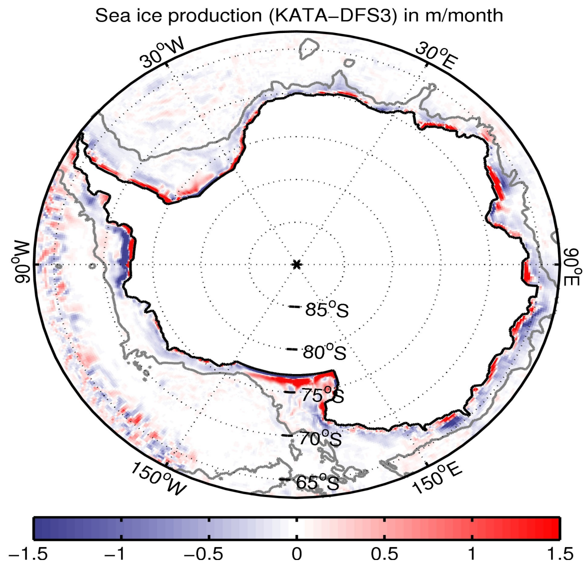

Figure 11: *Changes in sea-ice production induced by the correction of the Katabatic winds in a simulation driven by DFS3. Units are m/month. Areas adjacent to the coast where the absolute value of the difference is greater than 1 correspond to polynyas. Red/blue colours indicate a greater/smaller ice production when the katabatic wind correction is used.*

Considering the consistent response of the model to the Katabatic wind forcing, one investigated the sensitivity of coastal polynyas and high salinity shelf water production in the Ross Sea, Antarctica, to the Atmospheric Forcing (Mathiot et al., 2009b). Numerical simulations were conducted with a high resolution (20 km), regional ocean/sea-ice model of the Ross Sea. The objective was to evaluate the sensitivity of the model representation of the polynyas of Terra Nova Bay (TNB) and Ross Ice Shelf (RIS) and of the production of High Salinity Shelf Water (HSSW) to different atmospheric forcings. One forcing, the DFS3 forcing, uses ERA40 surface atmospheric state variables for turbulent fluxes, and satellite products for radiation fluxes and precipitation. The other, the MAR forcing, is produced by a dynamical downscaling of ERA40 performed at 40 km resolution with a mesoscale atmospheric model applied to the Ross Sea area. The comparison of MAR and DFS3 shows that a major gain of the dowscaling concerns the representation of the katabatic winds at the coast, due to a better representation of the continental orography surrounding the Ross Sea. The response of the Ross Sea ocean/sea-ice model to the different forcing fields suggests that the downscaling brings a noticeable improvement of the geographical distribution of polynyas. The MAR forcing generates polynyas which are significantly more active, in the sense that the polynya season lasts longer, and that polynyas show greater ice production rates and a greater export of dense water. HSSW formed in polynyas is saltier and denser when the MAR forcing is used (Fig. 12). The DFS3 forcing, which uses the raw ERA40 variables does not produces dense enough waters to form realistic HSSW (Fig. 12), the activity of the polynya being too weak and the HSSW too fresh. On the contrary, Terra Nova Bay polynya and the Ross Ice Shelf Polynya simulated by the MAR forcing are more realistic, as they export a total 0.4 Sv in annual mean of that type of water.

Annual bottom density (σ_2)

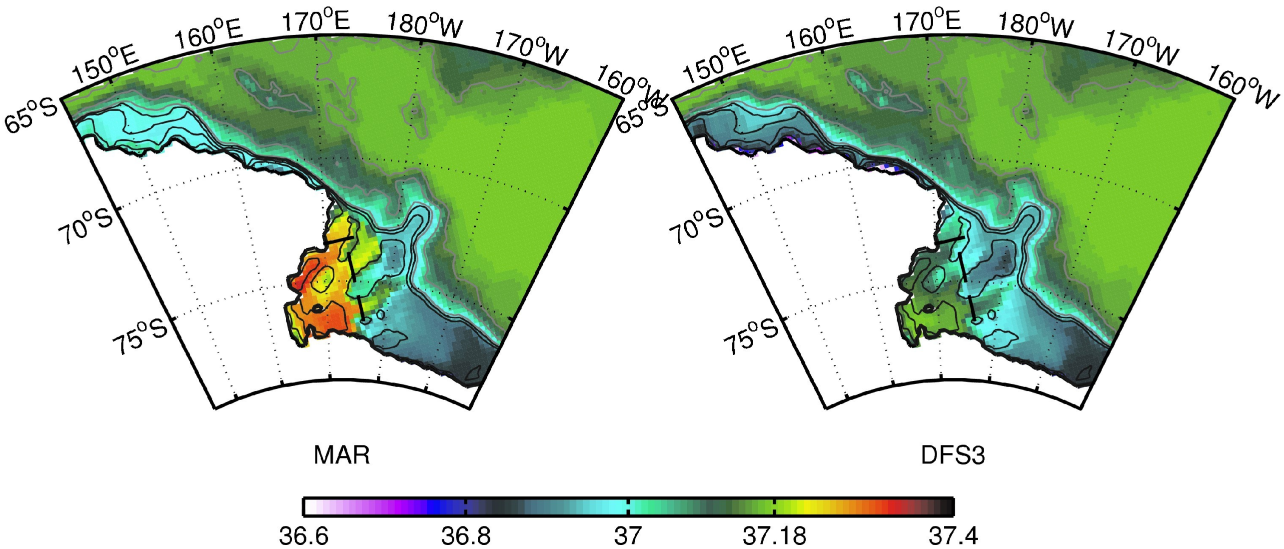

Figure 12: *Bottom density in 1993 at the end of the polyna season in: (left) the MAR simulation driven with the atmospheric forcing produced by the dynamical downscaling with MAR; and (right) in the DFS3 simulations driven by the DFS3 forcing (including the Katabatic correction). Yellow to black area shows presence of RSBW in simulation. Thin black line show bathymetry between 800 and 0m by step of 200m, thin grey line show bathymetry by step of 1000m*

3.3. Variability of ACC fronts south of Australia

(C. Dufour, J. Le Sommer, B.Barnier)

This activity was initiated in 2008 by C.Dufour and J. Le Sommer in collaboration with M. England at UNSW (Sydney, Australia). The aim was to investiage the dominant mode of thermohaline variability within the ACC soutth of Asutralia and its impact on mode water properties. Our investigation have shown that the dominant mode known as the pulsation mode and initialy detected from repeated in situ hydrographic sections was actually related to the intermittent formation of cold core eddies above the South Indian ridge. These results, which have been submitted to the Journal of Physical Oceanography in a paper currently in revision, are briefly summarized in the following paragraph.

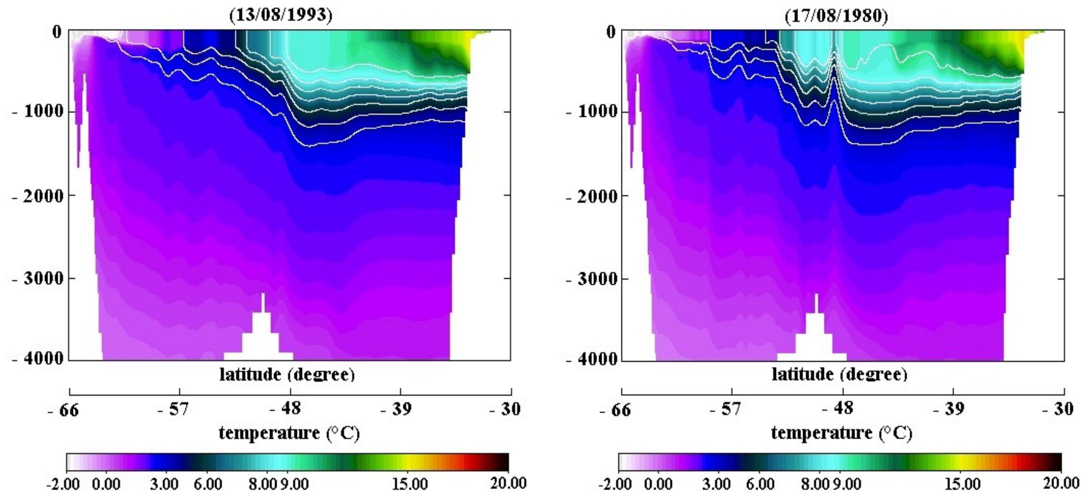

Figure 13: *Temperature field snapshots for a positive phase of the Pulsation Mode (left panel) and a negative phase of the Pulsation Mode (right panel). White lines indicate isopycnals ranging from* $\sigma_0 = 26.8\, kg.m^{-3}$ *to* $\sigma_{.} = ٢٧.٤\, kg.m^{-٣}$ *with a* $0.1\, kg.m^{-3}$ *contour interval.*

A streamfunction EOF method is applied to study the variability of potential temperature and salinity fields from ORCA025-G70 simulation. The data analysis is done over a 25 year period (1980-2004) on a section along 130\degrees E, South of Australia. A streamfunction-EOF method proposed by Sun and Watts (2002) is applied in order to study the characteristics of the so-called ``Pulsation Mode'', a semi-annual frequency mode, first observed by Sun and Watts from in situ hydrographic lines along the WOCE SR3 section. It is found that a mode, similar to Sun and Watts' Pulsation Mode, actually dominates thermohaline variations in the model below 300 dbar with a maximum of variability located at the Subantarctic Mode Water (SAMW) and Antarctic Intermediate Water (AAIW) interface. Still, the associated principal component shows a mode that does not exhibit an intrinsic semi-annual frequency, but rather an intermittent interseasonal frequency (3 to 6 months) notable during three periods (1983-1984, 1990 and 1994-1996); and a 4 year period is also noticed. Our analyses also show a like-looking mode seems to exist along the other southern australian sections (from 120\degrees E to 150\degrees E). It is suggested that the Pulsation Mode is a consistent atmospherically forced pattern of variability of the ACC south of Australia. The physical origin of the Pulsation Mode is then investigated. The observed maximum variability is shown to be associated with a pure warming process above 700 dbar which could possibly be due to horizontal advection. In the deep layers, the mode is essentially associated with pure heave which shows the freshening process is not dominant in driving the variations of the deepest waters as Sun and Watts suggested. Further analyses demonstrate that the Pulsation Mode can also be observed in physical space and is related to a regional circulation pattern constrained by the bathymetry which leads to an intermittent splitting of the Subantarctic Front (SAF). Intrinsic limitations of the streamfunction EOF method are highlighted which may lead to misinterpretations of the nature of the variability.

4. Publications of the project (2007-2009)

4.1. Peer reviewed publications of the DRAKKAR team (2007-2009)

We list only publications directly related to DRAKKAR (using DRAKKAR configurations or analysis tools), not all the publications of the project scientists. **Note that the reference paper on the ORCA025 DRAKKAR model, published in 2006, has already been cited 34 times:**

Barnier B., G. Madec, T. Penduff, J.-M. Molines, A.-M. Treguier, J. Le Sommer, A. Beckmann, A. Biastoch, C. Böning, J. Dengg, C. Derval, E. Durand, S. Gulev, E. Remy, C. Talandier, S. Theetten, M. Maltrud, J. McClean, and B. De Cuevas, 2006: Impact of partial steps and momentum advection schemes in a global ocean circulation model at eddy permitting resolution. Ocean Dynamics, Vol 4, DOI 10.1007/s10236-006-0082-1.

<u>Publications 2007 (5)</u>

Froyland, G., K. Padberg, M. England and A.M. Treguier, 2007: Detection of Coherent Oceanic Structures via Transfer Operators, Physical Review Letters, 98, 22,DOI: 10.1103/PhysRevLett.98.224503.

Gulev S.K., Barnier B., Molines J.-M., Penduff T. and Chanut J., 2007: Impact of spatial resolution on simulated surface water mass transformation in the Atlantic. *Ocean Modelling*, Vol. 19, 138-160.

Hughes, C.W., Stepanov, V.N., Fu, L.-L., Barnier, B., Hargreaves, G.W. Three forms of variability in Argentine Basin ocean bottom pressure (2007) Journal of Geophysical Research C: Oceans, 112 (1), art. no. C01011,

Penduff, T., J. Le Sommer, B. Barnier, A.-M. Treguier, J.-M. Molines, and G. Madec, 2007: Influence of numerical schemes on current-topography interactions in 1/4° global ocean simulations. Ocean Science,3, 509-524, 2007

Treguier, A.M., M. England, S. R. Rintoul, G. Madec, J. Le Sommer, and J.-M. Molines, 2007: Southern Ocean overturning across streamlines in an eddying simulation of the Antarctic Circumpolar Current. Ocean Sci., 3, 653-698, 2007

<u>Publications 2008 (11)</u>

Bessières L., G. Madec, F. Lyard, 2008 : Global Tidal Residual Mean Circulation: Does it affect a Climate OGCM? Geophys. Res. Let. 35, L03609, doi:10.1029/2007GL032644.

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Cailleau S., V. Fedorenko, B. Barnier, E. Blayo, and L. Debreu, 2008: Comparison of different numerical methods used to handle the open boundary of a regional ocean circulation model of the Bay of Biscay. Ocean Modelling, 25, 1-16.

Chanut J., B. Barnier, W. Large, L. Debreu, T. Penduff, J.-M. Molines, and P. Mathiot, 2008 : Mesoscale eddies in the Labrador Sea and their contribution to convection and re-stratification. Journal of Physical Oceanography, 38, 1617-1643.

Guiavarc'h C., A. M. Treguier, A. Vangriesheim (2008), Remotely forced biweekly deep oscillations on the continental slope of the Gulf of Guinea, J. Geophys. Res., 113, C06002, doi:10.1029/2007JC004471.

Jouanno J., J Sheinbaum, B. Barnier, J. M. Molines, L. Debreu, and F. Lemarié, 2008: The mesoscale variability in the Caribbean Sea. Part I: simulations with an embedded model and characteristics, Ocean Modelling, 23, 82-101.

Koch-Larrouy, A., Madec, G., Iudicone, D., Atmadipoera, A., Molcard, R.: Physical processes contributing to the water mass transformation of the Indonesian throughflow (2008) Ocean Dynamics, 58 (3-4), pp. 275-288.

Koch-Larrouy, A., Madec, G., Blanke, B., Molcard, R.: Water mass transformation along the Indonesian throughflow in an OGCM (2008) Ocean Dynamics, 58 (3-4), pp. 289-309.

Lecointre A., T. Penduff ,P. Cipollini, R. Tailleux, and B. Barnier, 2008: Depth dependence of westward propagating North Atlantic features diagnosed from altimetry and a numerical 1/6° model. Ocean Science, 4, 99-113.

Lucas M., N. Ayoub, B. Barnier, T. Penduff, and P. de Mey, 2008: Stochastic study of the temperature response of the upper ocean to uncertainties in the atmospheric forcing in an Atlantic OGCM. *Ocean Modelling*, 20. 90-113.

Tsimplis M., M. Marcos, S. Somot, and B. Barnier, 2008: Sea level forcing in the Mediterranean Sea between 1960-2000. Global and Planetary Change, 63 (4), pp. 325-332.

<u>Publications 2009 (13)</u>

Girard, L., J. Weiss, J. M. Molines, B. Barnier, and S. Bouillon; 2009: Evaluation of high-resolution sea ice models on the basis of statistical and scaling properties of Arctic sea ice drift and deformation, J. Geophys. Res., 114, C08015, doi:10.1029/2008JC005182.

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Jouanno J., J Sheinbaum, B. Barnier, J. M. Molines, 2009: The mesoscale variability in the Caribbean Sea. Part II: energy sources. Ocean Modelling, 26 (3-4), pp. 226-239.

Langlais C., B. Barnier, J.M. Molines, P. Fraunié, D. Jacob, and S. Kotlarski, 2009: Evaluation of a dynamically downscaled atmospheric reanalysis in the prospect of forcing long term simulations of the ocean circulation in the Gulf of Lions. *Ocean Modelling*, in press.

Le Sommer J, Penduff T., Theetten S., Madec G., and Barnier B., 2009: How momentum advection schemes influence current-topography interactions at eddy permitting resolution, Ocean Modelling, 29(1), pp. 1-14.

Lique, C., Treguier, A.M., Scheinert, M., Penduff, T., 2009: A model-based study of ice and freshwater transport variabilities along both sides of Greenland. Climate Dynamics, 33 (5), 685-705, DOI: 10.1007/s00382-008-0510-7.

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Park, W., N. Keenlyside, M. Latif, A. Ströh, R. Redler, E. Roeckner, G. Madec, 2009 : Tropical Pacific Climate and its Response to Global Warming in the Kiel Climate Model. J. Climate, 22, 1, pp. 71–92 DOI: 10.1175/2008JCLI2261.1

Bonhommeau, S., D. Gascuel, B. Blanke, A.M. Treguier, E rivot, Y Vermard, M. Castonguay and O. Le Pape, 2009: Estimates of the mortality and the duration of the trans-Atlantic migration of European eel Anguilla anguilla leptocephali using a particle tracking model. Journal of Fish Biology (2009) 74, 1891-1914. doi:10.1111/j.1095-8649.2009.02298.x.

Guiavarc'h, C., A.M. Treguier and A. Vangriesheim, 2009: Deep currents in the Gulf of Guinea: along slope propagation of intraseasonal waves. Ocean Science, 5, 141-153.

Athie, G., F. Marin, A.M. Treguier, B. Bourles and C. Guiavarc'h, 2008: Sensitivity of near-surface tropical instability waves to submonthly wind forcing in the tropical Atlantic. Ocean Modelling, in press.

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Brodeau, L., B. Barnier, A.M. Treguier, T. Penduff, S. Gulev, 2009: An ERA40-based atmospheric forcing for global ocean circulation models. *Ocean Modelling*, in revision.

Dufour, C., J. Le Sommer, T. Penduff, B. Barnier, M. England, 2009: Is there a pulsation mode in the Antarctic Circumpolar Current South of Australia? *J. Phys. Oceanogr.*, in revision.

Jourdain, N., P. Mathiot, Gallée, H., Barnier, H., 2009 : Influence of coupling on atmosphere, sea ice and ocean regional models in the Ross Sea sector, Antarctica. Climate Dynamics, submitted.

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Lique, C., A. M. Treguier, B. Blanke, and N. Grima, 2009b: On the origins of water masses exported along both sides of Greenland: A Lagrangian Model Analysis. submitted to J. Geophys. Res.

Mathiot, P., B. Barnier, H. Gallée, J.-M. Molines, J. Le Sommer, M. Juza, and T. Penduff, 2009: Introducing katabatic winds in global ERA40 fields to simulate their impact on the Southern Ocean and sea-ice. *Ocean Modelling*, Submitted.

Mathiot P., N. Jourdain, B. Barnier, H. Gallée, J. M. Molines, J. Le Sommer, 2009b: Sensitivity of Coastal Polynyas and High Salinity Shelf Water Production in the Ross Sea, Antarctica, to the Atmospheric Forcing. Submitted to *Ocean Dynamics.*

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Treguier, A.M., J. Le Sommer, J.M. Molines, and B. de Cuevas, 2009: Response of the Southern Ocean to the Southern Annular Mode: interannual variability and multidecadal trend. submitted to J. Phys. Oceanogr.

4.2. DRAKKAR-related publications, Thesis and newletters

Other publications using the results of global DRAKKAR experiments (publications without direct participation of the French DRAKKAR team members)

Biastoch, A, C. W. Böning, and J. R. E. Lutjeharms, 2008: Agulhas leakage dynamics affects decadal variability in Atlantic overturning circulation, *Nature*, 456, doi:10.1038/nature07426, 489-492.

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Brown, J.N., and A.V. Fedorov, 2008: Mean energy balance in the tropical Pacific Ocean. J. Mar Res., 66, 1-23**.**

Huck T, A. Colin de Verdiere, P. Estrade, R. Schopp, 2008: Low-frequency variations of the large-scale ocean circulation and heat transport in the North Atlantic from 1955-1998 in situ temperature and salinity data. Geophys. Res. Lets. 35, 23, L23613.

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Lübbecke J. F., C. W. Böning, and A. Biastoch, 2008: Variability in the subtropical-tropical cells and its effect on near-surface temperature of the equatorial Pacific: a model study. Ocean Science, 4, 73-88.
Renner, A.H.H., K.J. Heywood, S.E. Thorpe, 2009: Validation of three global ocean models in the Weddell Sea. Ocean Modelling, 30, 1-15.
Sokolov S, Rintoul SR, 2007: On the relationship between fronts of the Antarctic Circumpolar Current and surface chlorophyll concentrations in the Southern Ocean. J. Geophys. Res, 112, C7, C07030 .

PhD thesis using DRAKKAR results or configurations (2007-2009)

Langlais C., 2007: Variabilité interannuelle de la circulation dans le Golfe du Lion, Université de Toulon et du Var, Toulon. (Co-direction avec P. Fraunié du LSEET-Toulon).
Guiavarc'h C., 2007: Modélisation haute-résolution des courants dans le Golfe de Guinée : Etude des oscillations bimensuelles. Thèse de l'Université de Bretagne Occidentale.
Hervieux G., 2007: Etude de l'impact des schémas numériques, de la représentation de la bathymétrie, et de la résolution verticale sur la stabilité d'un courant de bord et sur les courants de gravités. Thèse de l'Université Joseph Fourier, Grenoble.
Brodeau L., 2007: Forçages des modèles océan/glace-de-mer permettant la méso-échelle et flux air-mer. Thèse de l'Université Joseph Fourier, Grenoble.
Mathiot P., 2009: Etude de l'impact des vents catabatiques sur les glaces de mer et la formation d'eau profonde en Antarctique. Thèse de l'Université Joseph Fourier, Grenoble.
Nicolas Jourdain, 2008 (LGGE): Thèse de l'Université Joseph Fourier, Grenoble.

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Ayoub, N., M. Lucas, B. Barnier, T. Penduff, G. Valladeau, and P. de Mey, 2006 : « A study of model errors in surface layers due to uncertainties in the atmospheric forcing fields. ». Mercator Ocean Quaterly Newsletter, 22, July 2006.
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5. Annex: distribution of DRAKKAR 1/4° simulations

This is the list of the know users of the DRAKKAR 1/4° experiments for years 2007-2009. "Drakkar contacts" in the table are B. Barnier, G. Madec, T. Penduff, J.M. Molines, A.M. Treguier. There are 59 entries, from French laboratories (mainly LEGI, LPO, LOCEAN, but also LEGOS, LGGE, IFREMER, AgroCampus, LSCE), from other labs participating in Drakkar (NOCS Southampton, IFM-Geomar Kiel) and other laboratories in the world (Spain, Canada, other labs in the U.K., Mexico, U.S.A., Australia, Norway).

User Name	Lab	Drakkar contact	Region	Experiment	Theme	Collaborations
Arnaud S, Tanguy Y	LOCEAN	AMT	Tropical Atlantic	ORCA025-G70	Barrier layers	
Arsouze Thomas	LEGOS/LSCE	AMT	North Atlantic	NATL4	Use NATL4 to simulate offline tracers (Neodymium isotopes)	A.M. Treguier, J.C. Dutay, C. Jeandel
Athie Gabriela	IRD/LEGOS/BREST	AMT	Tropical Atlantic	ORCA025-G70	Tropical instability waves (TIW), comparison with data	F. Marin, A.M. Treguier
Biastoch Arne	IFM-GEOMAR	GM	Agulhas	ORCA025-G70 , KAB001, AGRIF	Agulhas dynamics and interoceanic exchanges	M. Scheinert
Bonhommeau Sylvain	AgroCampus Rennes	AMT	North Atlantic	ORCA025-G70	Migration of eels (use of Ariane software)	A.M. Treguier, B. Blanke, et al
Brodeau Laurent	LEGI	BB	Global	ORCA2	PHD Evaluation and improvement of forcing function	B. Barnier, S. Gulev
Caplan Alexei	LDEO	TP	Paleoceano-graphy	ORCA025-G70	help interpret the records from Cariaco Basin	G. Reverdin, T.Penduff
De Cuevas Beverly	NOCS	BB , TP	North Atlantic	ORCA025-G70	Ocean variability in response to surface fluxes; MOC at 25N	Adrian New, Thierry Penduff
Deltel Charles,	LOCEAN	GM	Indian ocean	ORCA025-G70	Indian ocean configuration (boundary forcing), surface forcing improvements	Gurvan Madec
Deshayes julie	LOCEAN, WHOI	TP AMT	North Atlantic	ORCA025-G70	Interannual variability, statistical analysis	C. Frankignoul, T. Penduff
Duchez Aurélie	LEGI/ISITV	JMM BB	Zapiola anticyclone	ORCA025-G70 -KAB001, 002	Dynamics of Ziapola anticyclone	B. Barnier
Ferrer Macu	Puertos del Estado, Spain	BB	Around Spain	ORCA025-G70	High resolution model (Nemo based) around Spain, forced with ORCA025-G70 data	B. Barnier
Fossum Ingerid	LPO/Met NO, Norway	AMT	Barents Sea	ORCA025-G70	Aspects of recent variability in the Barents sea – comparison with Met NO models	A.M. Treguier,
Frankignoul Claude	LOCEAN	TP	North Atlantic	ORCA025-G70	Gulf Stream variability, MOC and NAO	Thierry Penduff, N. Chouaib
Froyland Gary	UNSW Sydney	AMT	Southern ocean	ORCA025-G42	Simulate trajectories and test methods to reveal mixing barriers 2D approach	A.M. Treguier, M. england, K. Padberg
Gourrion Jérome	IFREMER/SPAIN	AMT	Global	ORCA025-G70,2000-2001	Vaidation of future salinity from SMOS- coherence between atmospheric forcings and SSS variability	Nicolas Reul (IFREMER)
Guilyardi Eric	LOCEAN	GM	Global	ORCA05-G50	Variability in the tropical pacific	A Fedorov, GFDL
Herbaut Christophe	LOCEAN	JMM	Arctic ocean, Nordic Seas	ORCA025-G70, ORCA05-G70	Compare with their regional ARCTIC/Atlantic ½ model.	M.N. Houssais
Hervieux Gaelle	LEGI	TP	Atlantic	ORCA025-Gxx NATL025-Gxx	PHD Improvement of boundary layer parametrization: BBL and lateral (no slip accurate).	T. Penduff, B. Ferron
Holloway Greg	Canada	TP JMM	Global	ORCA025-G70 and olders	model skill estimate. Topostrophy	T. Penduff
Huck Thierry	LPO	AMT	North Atlantic	ORCA025-G70 + ORCA05	Variability of the heat transport: comparison with diagnostic methods	A.M. Treguier, C. Cabanes
Jourdain Nicolas	LGGE/LEGI	BB	Ross Sea	ORCA025-G70	PHD: Coupled model of the	H. Gallée, B.

Mathiot Pierre					Ross sea (based on DRAKKAR code for the ocean and MAR for the atmosphere). Use ORCA025-G70 at boundaries	Barnier, W. Park (Kiel)
Jorda Sanchez Gabriel	UIB Spain	BB	Global	ORCA025-G70 ORCA025-G22	SMOS project	
Juza Melanie	LEGI	TP	Global	ORCA025-G70 ORCA05-G50 ORCA05-G70 ORCA1-G70	Model validation using 4D collocalisation of model data and in situ observations (Altimetry, ARGO, ENSEMBLE ....)	T. Penduff, Greg Smith
Koch Larrouy Ariane	LOCEAN	GM	Indonesian Throughflow	ORCA025-G42 + zoom	Water mass transformation in the Indonesian Throughflow	B. blanke, D. Iudicone
Le Cointre Albane	LEGI	TP	Atlantic	NATL025-Gxx	PHD Low frequency variability modes in the Atlantic + MOC at 25N	T. Penduff
Lengaigne Mathieu	LOCEAN	GM	Equatorial Pacific	ORCA2-G70, ORCA05,ORCA 025-G70	ENSO in global models at different resolution	
Lique Camille	LPO	AMT	Arctic/Nordic seas, Labrador Sea	ORCA025-G70, KAB01, KAB02	Interannual variability	A.M. Treguier, M. Scheinert, others?
Lombard Alix	LEGOS/LSCE	TP JMM	Global	ORCA025-G70	Regional variability of sea level change	Gilles Garric (MERCATOR)
Lu Y	DFO, Canada	BB	Arctique	ORCA025-G70	volume, heat and freswater transports through Canadian Archipelagoe and Arctic Basin	Gilles Garric (MERCATOR)
Maes Christophe	IRD, Noumea	TP	Equatorial Pacific	ORCA025-G70	Comparison with observed data. Upper ocean. Salinity.	T. Penduff
Markus Scheinert	IFM-GEOMAR	AB, AMT	North Atlantic	ORCA05, ORCA025-G70 , KAB001	Mechanisms of interannual and decadal variability of Atlantic MOC	A. Biastoch, C. Böning
Mathiot Pierre	LEGI/LGGE	BB	Periantarctic	ORCA025-G70 PERIANT05 PERIANT025	PHD Effect of a downscaling of the forcing field on the periantarctic circulation (polynias, current etc)	B. Barnier, H. Gallee
Melet Angélique	LEGI /IRD Nouméa	JMM	Solomon Sea	ORCA025-G70	PHD Data assimialtion in the tropical atlantic. Local model extracted from ORCA025 and forced at open boundaries by ORCA025-G70	J. Verron, L. Gourdeau
S. Speich, Bruno Blanke, G. Dencausse	LPO	AMT	Southern Ocean	ORCA025-G70	Lagrangian trajectories, Indo-Atlantic exchange	S. Speich, M. Arhan, J. Le Sommer
Michel Sylvain	POL Liverpool	AMT BB	Global	ORCA025-G70	Force the boundaries of regional shelf models	Jason Holt, Roger Proctor
Michel Sylvain	IFREMER DYNECO	AMT	Bay of Biscay	ORCA025-G70 /AMEN-B12	Climate change and halieutic resources	F. Vandermeirsch, V. Thierry
Myers Paul	U. Alberta, Canada	AMT	North Atlantic	NATL4, ORCA025	Representation of boundary currents and mode water	V. Thierry, A.M. Treguier
Orr James	MEL /IAEA	BB	Global	ORCA025-G70	Transient tracers and biogeochemistry	Z. Lachkar, J.C dutay, P. Delecluse
Padín Toni	IIM, Vigo, Spain	JMM BB	Bay of Biscay	ORCA025-G70	Carbon cycle	Aida Ríos
Pares Alejandro	CICESE, Ensenada, MExico	BB	Mar de Cortès (Gulf of California)	ORCA025-G50	Circulation in the Gulf of California	
Pascual Ananda	UIB Spain	JMM BB	Global T/S, monthly	ORCA025-G70	Steric effect	B. Barnier
Perez Fiz	VIGO, Spain	AMT	North Atlantic	ORCA025-G70	Variability of transports of Anthropogenic carbon – compare with OVIDE data	P. Lherminier, H. Mercier
Pinsart Françoise	LOCEAN	GM	Global	ORCA025-G42	Interpretation of earth gravimetry	F. Vivier
Pous Stephane	LOCEAN	GM		ORCA025-G70	Boundary conditions for Indian Ocean	
Rampal Pierre	LGGE	TP BB	Arctic	ORCA025-G70	Arctic Ice Dynamics	L. girard T. Penduff, B. Barnier, J. Weiss
Renner Angelika	British Antarctic Survey	JMM BB	Weddell Sea	ORCA025-G70	Circulation in the Weddell sea, observations	

Resplandy Laure	LOCEAN	JMM	Indian	ORCA025-G70	PHD: Biogeochemical offline model of the Indian Ocean	M. Levy, O. Aumont
Roquet Fabien	LOCEAN/MNH	TP	Kerguelen	ORCA025-G70	PHD student, uses the model to help with interpretation of in-situ data	Y. Park
Saraseno	LOCEAN/OSU	BB	Zapiola anticyclone	ORCA025-G70		Christine Provost
Rouault Mathieu, Golhen Mathieu	UCT Cape Town, South Africa	AMT	South Altantic	ORCA025-G70	Variability of the "Benguela nino" events	A.M. Treguier
Schwarzhopf Franziska	IFM-GEOMAR	AB	Southern Ocean	ORCA025-KAB001	Variability and trends of western boundary currents in the southern Hemisphere	
Sokolov Alexei	CSIRO, Hobart	AMT	Southern ocean	ORCA025-G42	Interpretation of phys/bio data	S. Rintoul
Swart Sebastian	UCT/ S. Africa	AMT	Southern Ocean	ORCA025-G70	A.C.C. South of Africa – Goodhope project	Sabrina Speich (LPO Brest)
Thierry Virginie	LPO	AMT	N.East Atlantic	ORCA025-G70	Variability of mixed layer and transports in the region of the POMME experiment	Carole Grit
Trasviñas Armando	CICESE, La Paz, Mexico	JMM BB	Eastern Tropical Pacific	ORCA025-G50 ORCA05-G50	Isthm of Tehuantepec dynamics	
Michael Tsimplis Marta Marcos	NOC Southampton	BB	Med Sea	ORCA025-G70	Forcing of sea level in the Mediterranean Sea between 1960-2000	Somot (CNRM)
Treguier Anne Marie	LPO	AMT	Southern ocean	ORCA025-G42, ORCA025-G70	Eddies and the upper meridional circulation	J. Le Sommer, M. England, S. Rintoul, G. Madec
Ubelmann clement	LEGI	JMM	Tropical Atlantic	ORCA025-G70	PHD Data assimialtion in the tropical atlantic. Local model extracted from ORCA025 and forced at open boundaries by ORCA025-G70	J. Verron