DRAKKAR

Coordination of high resolution global ocean simulations and developments of the NEMO modelling framework.

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proposal 2010 - 2012

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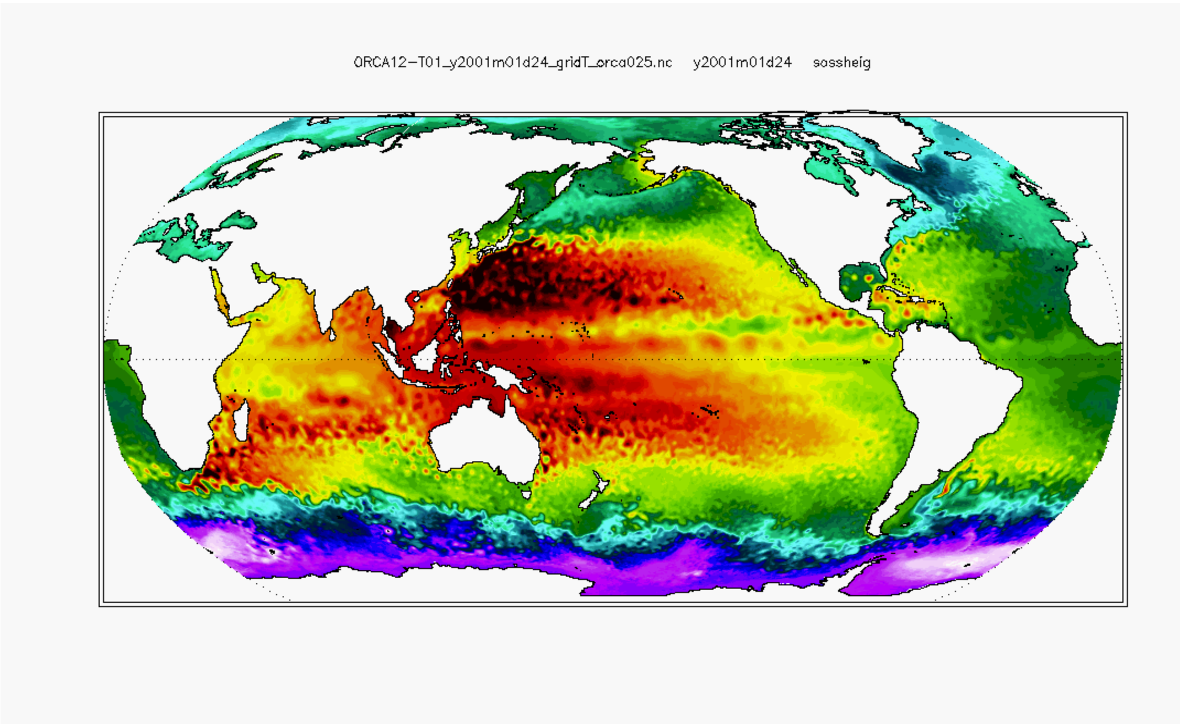

Instantaneous sea surface height in the global 1/12° model. Source: MERCATOR-Ocean

Laboratories: LEGI, LPO, LOCEAN, MERCATOR-Océan

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Summary

DRAKKAR is a scientific and technical coordination project between French research teams and MERCATOR-ocean, with close collaborations in the U.K., Germany and Canada. We propose to design, carry out, assess, and distribute high-resolution global ocean/sea-ice numerical simulations performed over long periods (five decades or more), and to improve and maintain a hierarchy of state-of-the-art ocean/sea-ice model configurations for operational and research applications. This effort is motivated by the need for better numerical simulations of the ocean state and variability over the past decades, in order to address e.g. the following issues: what are the mechanisms that drive the interannual to decadal oceanic variability? what are the relationships between the variabilities of water masses and the circulation? what is the impact of boundary currents, eddies and small scale processes on the large scale circulation and its variability?

Such simulations do complement and bridge gaps between sparse observations, low resolution IPCC-like climate simulations, idealized and theoretical studies, and thus benefit a wide scientific community.

Our general objectives are the following:

- Maintain a coherent hierarchy of global model configurations with up to date parameterisations and numerical algorithms, and in particular, continue the improvement of the global 1/4° model ORCA025;
- Perform coordinated (at the European level) global ocean hindcasts at eddy-resolving resolution (1/12°) and make the results available to a wide community;
- Develop and share among us, and make available to others, the tools and expertise necessary to the development and use of regional model configurations;
- Use realistic ocean simulations as a testbed for new parameterizations, and to evaluate the benefits of higher spatial resolution.

The main challenge of the next three years is to transition from eddy permitting (1/4°) to eddy resolving regime (1/12°) at the global scale, for the model configurations, the simulations, and the parameterizations, in partnership with MERCATOR-ocean.

By achieving these objectives, the DRAKKAR coordination will be profitable to a number of (existing and future) scientific projects within LEFE and beyond (including MyOcean and other FP7 projects). DRAKKAR will contribute to the continuous evolution of the NEMO system, help improve model configurations used for operational oceanography, prepare the ocean components of future coupled climate systems, and contribute to studies of biogeochemical tracers. The DRAKKAR coordination will also foster cooperative scientific activities and model developments within the major ocean modelling groups in France, Germany and the United Kingdom, specifically those using eddy resolving models.

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1 - Background and state of the art

1.1. History of the DRAKKAR project

The present proposal is built on the experience of two previous projects, CLIPPER (1996-2002) and DRAKKAR (2003-2009). Both projects were defined in an international context (WOCE for CLIPPER, CLIVAR/GODAE for DRAKKAR) and used the OPA numerical model (OPA8 for CLIPPER, and OPA9/NEMO for DRAKKAR). The CLIPPER project performed hindcasts of the Atlantic circulation over the past 15 to 20 years, at resolutions ranging from 1° to 1/6°. These simulations have been useful to a wide community: over 35 peer-reviewed publications have used the CLIPPER model configurations and simulations between 2001 and 2008. The North Atlantic CLIPPER configuration NATL3 became the basis for the first MERCATOR operational prototype. This started the transfer of expertise toward operational oceanography and fostered exchanges between this emerging community and the research community.

The DRAKKAR project (2003-2009)[1] extended these regional research themes to the global scale, and pushed significantly further the integration and coordination of the activities and complementary expertise of the participating research groups. The scientific objectives were the variability over the past decades of the North Atlantic subpolar gyre and the Southern ocean in connection with the global ocean. A global 1/4° model was developed by the DRAKKAR team and MERCATOR. It was supplemented by a peri-Antarctic configuration for the Southern Ocean, a high resolution (1/12°) North Atlantic configuration, and several regional configurations. The modelling strategy and sharing of global ocean configurations were organized at a European level (CNRS-PICS project, 2005-2007). The project has been productive (the annual numbers of peer-reviewed papers from 2006 to 2009 are 2, 4, 8 and 14, with 9 more submitted). The first achievement of the project was a significant improvement of numerical schemes and the representation of flow-topography interactions (Barnier et al, 2006; Penduff et al, 2007; Le Sommer et al, 2009). We have performed several long hindcasts (1958-2006) with the global 1/4° model ORCA025 allowing us to better understand several aspects of the ocean variability: e.g. the regional imprint of the global sea-level rise (Lombard et al, 2009); the Southern ocean water mass variability (Dufour et al, 2009; Treguier et al, 2007); the exchanges between the Arctic and the subpolar Atlantic (Lique et al, 2009), the interannual-decadal variability of the meridional overturning circulation (Biastoch et al., 2008a), the impact of the variability in the subtropical-tropical cells on the SST of the equatorial Pacific (Lübbecke et al., 2008). Its relatively high resolution gives ORCA025 a good skill in relatively small regions such as the Mediterranean Sea (study of the sea level variability, Tsimplis et al, 2008), the Bay of Biscay (mechanisms of variability of the heat content, Michel et al, 2009), or the Weddell Sea (Renner et al., 2009). DRAKKAR actually developed a hierarchy of global models at resolutions increasing from 2° to ¼°, allowing a precise assessment of the benefits of using eddy-permitting models for climate-oriented studies (Drakkar group, 2007, Penduff et al, 2009). Many other DRAKKAR publications are based on regional configurations mostly forced at the boundaries by global ORCA025 solutions or using a local grid refinement (see the publication list). Note that the “reference experiments” which are thoroughly assessed and distributed to the community come along with many sensitivity experiments helping the project team improve the solutions and understand the model responses to various changes.

The achievements of DRAKKAR are technical (scientific computing) as well as scientific (in the

1 A complete report of the LEFE project is available at www.ifremer.fr/lpo/drakkar, "publications", "reports"

fields of physical oceanography and ocean modelling). The DRAKKAR team, and especially the engineers working on the project, J.M. Molines, S. Theetten (2003-2007), and R. Dussin (2008-2009), have contributed substantially to the continuous improvement of the NEMO system. This is achieved by participation in the Developers committee (G. Madec, J.M. Molines, A.M. Treguier), by developing new parameterizations, testing and calibrating new model versions on large realistic domains at high resolution. Besides the ORCA025 configuration, DRAKKAR maintains the equivalent of a "development branch" of NEMO, and many tools designed to run, monitor, and analyze large experiments efficiently. These toolboxes are continuously improved, maintained and documented to support our scientific investigations.

The wide audience of annual Drakkar meetings (in Grenoble[2]) and the interest of the international community (Germany, U.K., Canada, USA, Russia, Netherland, Italy...) demonstrate the usefulness of coordinating such ambitious model simulations, sharing tools, experience, and research synergies. One could say that one major achievement of the DRAKKAR project over the past few years lies in its gathering of a community of ocean modelling experts within the same consortium which has favoured the emergence of best practices in the modelling community and has led to a striking shortening of innovation cycles. In addition, it is clear that several young scientists within the consortium have been able to use the scientific expertise and technology of DRAKKAR as a leverage for their own projects. DRAKKAR thus provides a rich and reactive environment which benefits have gone far beyond the initial science objectives of the project.

1.2. Scientific and technical background of the DRAKKAR coordination

The growth of the community interested by the DRAKKAR simulations, as well as the fact that the “project team” has almost doubled in size since the beginning of the project, means that it is no longer feasible to define a single scientific project to support all the modelling activities of the French group (and a fortiori of the European cooperation). However, the challenge of developing realistic ocean models for diverse range of applications is continuously increasing in complexity, and more than ever it can only be met by an effective integration and coordination of the activities and complementary expertises of a critical number of modelling groups. If the DRAKKAR project successfully gathered the expertise and built the cooperation required to meet this challenge, it is now a priority to consolidate and further develop these outcomes. Therefore, DRAKKAR activities are not presented to LEFE as a targeted research project, but as a scientific and technical coordination effort designed to provide various scientific projects with state-of-the-art tools and data. We propose to keep the name “DRAKKAR” for this coordination, because it is now widely known internationally (The Drakkar group, 2007), in reference to our global high resolution configurations based on the NEMO model.

The DRAKKAR coordination will develop the modelling tools and produce the simulations necessary to address a wide range of open questions about the oceanic variability and scale interactions, in particular:

- Which mechanisms drive the variability of the global and regional ocean circulation and water masses over a few decades period, and what are the relative contributions of these mechanisms?
- What is the effect of fine scale processes (mesoscale eddies and mixing, boundary currents and fronts, surface mixed layer processes...) on the ocean dynamics at larger space and time scales?

These questions and others are being and will be addressed within dedicated scientific projects

2 http://www-meom.hmg.inpg.fr/Web/ look for DRAKKAR meetings in the heading Evénements/Events

(Table 1). A common requirement of all these projects is a set of coarse to eddy-resolving ocean-ice global hindcasts of the last five decades, either to serve as a basis to study mechanisms of variability or in order to provide boundary conditions to regional configurations. DRAKKAR will provide such hindcasts based on the NEMO modelling system (Madec 2008) and the rich hierarchy of model configurations it develops (Drakkar Group, 2007). Before we present the detailed objectives of the DRAKKAR coordination (Section 1.3), we briefly expose the motivations for carrying out forced ocean hindcasts and for the new model developments we propose.

Table 1 : Ongoing scientific projects of the DRAKKAR team members, that benefit from the DRAKKAR collaboration. Other projects are presently being defined.

Scientific Project	**P.I.**	**Description**	**Duration**	**Support**
GLORYS	B. Barnier N. Ferry	Global Ocean Reanalyses	2009-2011	PPR GMMC
Southern Cross	J. Le Sommer	Southern Ocean variability and Cross-scale interactions : Understanding and modelling the mechanisms of climate variability in the Southern Ocean	2009-2011	ANR
SSINOC	T. Penduff	enhancing Synergies between Satellite In-Situ and Numerical OCeanography	2009-2011	OST/ST (CNES-NASA)
RICCO	A.M. Treguier	Climate change and variability in the ocean at the regional scale (North Atlantic)	2010-2012	Ifremer
FCVAR	J. Deshayes R. Curry	Relation between changes in freshwater content and circulation in the North Atlantic	2008-2010	NSF
MyOcean	B. Barnier	WP3: Ocean physical modelling WP4: Ocean Reanalysis	2009-2012	FP7
CO2SUD	J. Le Sommer M. Gehlen,	Variability of air-sea CO2 fluxes in the southern Ocean (proposed).	2010-2012	LEFE

Atmospherically-driven (forced) ocean model simulations have substantial skill in representing the past interannual to decadal variability (magnitude, space-time structure). Indeed, a large fraction of the oceanic variability is driven by the atmosphere, the variability of which is well synthesised in meteorological reanalyses such as ERA40 (Uppala et. al., 2005). The skill of the DRAKKAR global model ORCA025 has been assessed regarding complementary aspects in Barnier et al 2006, Penduff et al 2007, Lombard et al 2009, Michel et al 2009, Lique et al 2009, etc. The model solution compares generally very well to remote and in-situ observational references, often better than other models in this class. Eddy-permitting ocean/sea-ice models driven by high quality surface atmospheric variables are also the most appropriate tools to perform deterministic reconstructions of the ocean variability with the explicit resolution of a broad range of space and time scales, while remaining tractable enough for multiple multi-decadal integrations. Such is not the case of ocean-atmosphere coupled models, which simulate the statistics of climatic variability (often at coarser resolutions) but where the phase of the ocean variability is not constrained by actual (atmospheric) observations. Today's oceanic reanalyses are not well suited either for studies of scale interactions over decades because historical observations are too sparse to consistently constrain large and eddy scales, and because most assimilation methods compromise the consistency of momentum and tracer balances. Ocean reanalyses (such as those developed jointly by MERCATOR and DRAKKAR within the GLORYS project) will play an increasing role in helping the description of the recent variability over the satellite and ARGO periods. Nevertheless, forced ocean/sea-ice hindcasts will remain essential for dynamical studies on longer periods.

Such forced ocean hindcasts require a posteriori assessments against observations (DRAKKAR and the SSINOC project have developed original methods on this side), which in turn orient further model developments. Global eddy-permitting and eddy-resolving models have various applications, from operational oceanography to seasonal and decadal climate prediction (two applications undergoing a rapid development at present). Because the model configurations developed by the DRAKKAR project are used by operational groups and climate centres (MERCATOR, IPSL, ECMWF, UK Met Office), improvements made by one group have a big impact at the European level. We wish to continue to assume this leadership in model developments and to improve the global ocean models based on NEMO.

Indeed, despite its success (attested by the number of publications and the number of teams using it), the ORCA025 model in its current version exhibits flaws, two of which limit our ability to investigate decadal variability: wrong water mass formation processes (especially the representation of dense overflows) and a only partial representation of mesoscale variability (especially in the South Indian ocean, the Subpolar Atlantic and Nordic seas). The first problem has been identified early in DRAKKAR. Several methods have been tested for the Nordic and Mediterranean overflows into the Atlantic (Hervieux, 2007), but the results are not yet satisfying. Furthermore, a deficit in formation of Antarctic Bottom Water has been identified, and shown to create a spurious trend of the Antarctic Circumpolar current transport (Treguier et al, 2009, Roquet, PhD thesis, 2009). The inclusion of katabatic winds around Antarctica has led to regional improvements (Mathiot et al, 2009) without solving the problem completely. We propose two complementary approaches to address this problem: one is to use new parametrizations developed for low resolution climate models (especially the parameterization designed at NCAR): this will be implemented by the U.K. Met Office. The other approach is to use simulations at higher resolution to guide further model improvements and eventually new parameterizations: we propose this strategy in the present project, for the simulation of overflows in the North Atlantic subpolar gyre.

The inadequate representation of mesoscale variability calls for a further increase in horizontal resolution. It is now clear that a 1/10° or finer grid is necessary to capture the correct path and eddy field of the Gulf Stream and North Atlantic Drift (Smith et al, 2000). The 1/12° North Atlantic configuration developed by DRAKKAR and Mercator greatly improves the simulated subtropical gyre compared to ORCA025. The representation of the subpolar gyre is not adequate yet, but regional simulations at higher resolution should help correct the remaining problems. We believe that global 50-years hindcasts with the global ORCA12 (1/12°) model will allow more relevant studies of the ocean variability through an improved representation of e.g. the connexion between the Southern Ocean and the other basins (which takes place in a large part through eddies and narrow boundary currents), and of the various water mass transformation processes in the Nordic seas and the Arctic Ocean (some narrow coastal currents on the Arctic shelves are underestimated in ORCA025, Lique et al, 2009b). Improving the consistency and realism of global hindcasts through a threefold increase in resolution is a major objective of DRAKKAR for the next 3 years. However, enhanced resolution raises new database management and distribution issues, which will be addressed within the project.

1.3. Summary of objectives for the DRAKKAR coordination

The **overall objectives** of the DRAKKAR coordination may be summarized as follow:

- Develop and maintain the coordinated DRAKKAR hierarchy of global model *configurations*, share tools and expertise necessary for the development and use of regional model configurations,

- Complement the existing set of coordinated DRAKKAR *simulations and reanalyses* by designing, performing, assessing and distributing new global ocean hindcasts relevant for studies of the ocean variability over the past decades.

- Contribute to the improvement of NEMO, its parameterizations (providing realistic sensitivities for their calibration) and configurations for both research and operational (i.e. MERCATOR-Océan and the GMES Marine Core Services) applications.

The **main challenge** of the next three years is to transition from eddy permitting to eddy resolving regime at the global scale, for the model configurations, the simulations, and the parameterizations. This transition will require additional human resources.

As done in DRAKKAR so far, both 1/4° (ORCA025) and 1/12° (ORCA12) global simulations will be coordinated between the French research and operational teams, the British (NOCS) and German (IFM-Geomar) groups: global *reference simulations* will be assessed thoroughly and regularly made available to the community and associated scientists; in parallel, coordinated *sensitivity simulations* will be continuously performed by the groups to test new physical and numerical choices. This set of DRAKKAR simulations has been and will remain powerful to explore the parameter space, identify the individual/combined dynamical impact of various forcings and parameters, and assess the robustness of our conclusions. The close technical and scientific coordination required by this project between various groups has started several years ago and will continue. Along with constant interaction by email and telephone, participating groups and associated scientists will gather every year to discuss technical/scientific achievements, share their experience, coordinate future developments, experiments and analyses. These annual DRAKKAR meetings have proven very useful for building the high-quality Configuration and Simulation Ensembles that we have, to initiate common publication plans, and to bring to users of our models the informations they need.

Collaboration between DRAKKAR and MERCATOR-Ocean has always been very tight, with a clear focus on the development and the improvement of model configurations and forcing fields suited for research and operational applications (GMMC and joint participation to the FP6 MERSEA project). This cooperation has been reinforced within the projects GLORYS and FP7 MyOcean, DRAKKAR and MERCATOR getting together to carry out a series of global ocean/sea-ice reanalyses at eddy permitting resolution (ORCA025). The present coordination intends to tighten these links even more by setting procedures for a common management of the simulation and reanalysis data base, for a convergence between operational and research configurations, and for the joint development of ORCA12. In the longer term, it is expected that MERCATOR will significantly contribute to the production of eddy-resolving hindcasts simulations relevant for research studies of the ocean variability over the past decades.

2. Project tasks

2.1 - Coordinated global ocean-ice simulations

2.1.1 Laminar and eddy-permitting simulations

The existing 2°, 1°, 1/2° and 1/4° DRAKKAR configurations (ORCA2, ORCA1, ORCA05 and OCA025) will be maintained, especially ORCA025 which has been extremely productive in term of scientific results, and begins to be used by Climate Research Centres in the perspective of the next IPCC. DRAKKAR has shown the usefulness of complementing certain 1/4° global hindcasts with lower resolution hindcasts (1/2°, 1°, 2°) in order to e.g. design and assess forcing functions (Brodeau et al 2009), evaluate the benefits of admitting ocean eddies in climate-oriented simulations compared to present IPCC-like laminar ocean model components (Penduff et al 2009). During the next three years, we will regularly release 50-year 1/4° global hindcasts with up-to-date forcing functions and version of NEMO. Some of these runs will come along with their low-resolution counterparts, and some with their reanalysis counterpart (performed within GLORYS and MyOcean). We estimate that this task requires 9 man.months, 4 for engineers and 5 for scientists.

2.1.2 Eddy-resolving simulations

One main focus of the present proposal is to run hindcasts with the 1/12° model ORCA12. The first simulation will be run in 2011. The aim is to provide a long simulation (1958-2011) during the final year of the project. This simulation will be carried out jointly with MERCATOR-Ocean who already has experience with ORCA12. The targeted supercomputer is JADE at CINES. It will be tightly coordinated with the ORCA1 experiments performed by partners of IFM-Geomar and NOCS. Because of the large increase in the size of the problem from ORCA025 to ORCA12 (more than one order of magnitude), this task will be very demanding regarding human resources. Note that our ambition is not to provide one single hindcast, but also to develop tools and strategies that will make ORCA12 easier to run, and ORCA12 results easy to access and analyse. We estimate that it requires a full time engineer for 16 months, and a contribution of 7 man.month from the project scientists. The joint development of ORCA12 by MERCATOR and DRAKKAR and the related sub-tasks are described in more detail in Annex B.

2.1.3 Assessment and distribution of reference simulations

The DRAKKAR global simulations have been validated quite extensively, and very widely distributed (see DRAKKAR report of activity). These activities require a significant effort from the team, especially for the forthcoming high resolution simulations. We propose to work with MERCATOR to implement common strategies for the new high resolution model. The human resources necessary for this task have yet to be fully evaluated. For the present project we propose a total of 5 man.month for scientists and 7 man.months for engineers. Note that the distribution of the results requires a full documentation of each DRAKKAR simulation (code, parameters, forcing, bathymetry, etc), which will be made available on the DRAKKAR web site.

2.2 Forcing the ocean

2.2.1 Evaluate new forcing functions

The development of improved atmospheric datasets to force global ocean-ice climate models is a key area that needs continual attention. The success of the DRAKKAR simulations relies in part on the development of a new forcing dataset (Brodeau et al, 2009), based on the CORE data of Large and Yeager (2008) as well as the ERA40 reanalysis of ECMWF (Uppala 2005). New datasets describing the atmospheric variability will become available during the coming years (ERA interim, for example, and possibly satellite products). They will be evaluated, and the geophysical representativeness of their trends will be assessed. New atmospheric forcing functions will consequently be produced, using advanced methods, and first tested on the coarse resolution global configurations.

2.2.2 Assess strategies for future scenarios

Climate scenarios for the next 30 to 50 years are now being run using low resolution ocean components. These low resolution ocean models may underestimate or misrepresent future changes in the ocean in terms of circulation and heat content, due to the systematic biases of coupled models and the fact that the nonlinearities of the ocean are not well represented. The shared model configurations provided by DRAKKAR will help compare downscaling and scenario strategies for the ocean that are being developed in various projects. For example, a new atmospheric downscaling technique has been developed with the specific aim to force ocean models for future scenarios (Cassou et al, 2009; Minvielle et al, 2009) and will be further developed within the IFREMER project "RICCO". More generally, we will initiate collaborations with colleagues running coupled models with the ORCA025 DRAKKAR configuration (ORCA025 is being run in coupled mode at IPSL by Sebastien Masson, at ECMWF and soon at the UK Met Office). The growing effort toward decadal prediction of climate variability in Europe will make use of DRAKKAR configurations such as ORCA05 or ORCA025. By ensuring that information and results are shared among the groups, some mechanisms of ocean variability can be studied at eddy permitting resolution in both forced and coupled models, and in both hindcasts and scenarios.

These tasks will be carried out by project scientists (6 man.months) and engineers (3 man.months), and will benefit from collaborations with other projects.

2.3 Algorithms, parameterizations and submesoscale dynamics

The main context elements relevant to this task are the following:

- over 10 to 50 year time scales, basin-scale and even global ocean simulations are transitioning to mesoscale-resolving resolution at least for the mid-latitudes (Δx ~10 km). A 1/12° North and equatorial Atlantic has been developed and run at LPO since 2007. A couple of global solutions at 1/12° over the last fifty years will be run in 2010 by our partners in Kiel and NOCS using NEMO.

- O(10 km) mesh grid sizes are still insufficient despite the tremendous numerical cost of such resolution. The grid refinement techniques implemented in NEMO have allowed us to run solutions at even finer horizontal resolutions over some target regions. The preliminary conclusion is that significant improvements arise once Δx approches the kilometer scale. For example, several of the resisting flaws of the DRAKKAR ensemble that concern the subpolar North Atlantic gyre (e.g., overly deep convection [Chanut et al, 2008]) is alleviated by increased resolution.

- Theoretical arguments and idealized numerical studies [Capet et al, 2008] suggest that, with Δx ~ 1 km (ie, submesoscale permitting) energy fluxes tend to be downscale, because of the growing unbalanced part of the dynamics. This opens up new opportunities for more robust and physically based turbulent closures.

In the context of new scientific projects (J Deshayes and X Capet), submesoscale-permitting OGCM solutions will be available in the coming years. Extensive sensitivity tests will be carried out using OBC/AGRIF strategies with a focus on key regions, i.e., primarily parts of the North Atlantic subpolar gyre where important longstanding biases are well identified, with a target resolution of the order of 2 km. A limited number of simulations for most of the North Atlantic will be carried out at comparable resolutions (submesoscale-permitting North Atlantic or NATL-SP). The coordination within DRAKKAR will allow a more complete evaluation the improvement provided by increased resolution, in a variety of configurations and over extended regions.

Particular attention will be put on making intercomparisons between the baseline eddy-permitting DRAKKAR solutions and their higher resolutions companions. The latter serving as a truth standard, we expect to be able to test/improve existing parameterizations and possibly propose new ones. (An ongoing effort consists in evaluating the parameterization of mixed-layer restratification by submesoscale turbulence developed by Fox-Kemper et al [2008]. The Neptune effect (Holloway, 1986) parameterization is another potential candidate.) Better parameterizations for the impact of fine-scale turbulence will help improve eddy-permitting solutions and this is our main objective. Additional benefits may result from testing the NEMO kernel in higher Reynold number regimes. More generally, this effort will be, well in advance, laying the ground for the future generations of OGCMs.

This task will be coordinated with the TANGGO project (letter of intent submitted to LEFE) which deals with the implications of submesoscales and parameterizations for biogeochemistry. The task will be carried out mainly by the scientists in the project (17 man.month) with the help of one engineer (2 man.month)

2.4 Numerical code, Tools, database management

2.4.1 Numerical code

The numerical code used is NEMO 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. New parameterizations are tested or developed before their introduction in the NEMO reference version.

In DRAKKAR, we developed the DRAKKAR Configurations Manager or DCM (Molines, Theetten, Treguier, 2006), a working/developing environment widely used in the DRAKKAR group. With DCM, the DRAKKAR modified/new modules are clearly isolated from the standard NEMO reference. The DRAKKAR code is thus based on a stable NEMO reference but where all bugs found between two reference releases are fixed, where necessary customization are implemented and where new parameterizations are tested. There is a permanent feedback from DRAKKAR to NEMO system team regarding the issues found in the DRAKKAR configurations.

DCM is updated as soon as a new NEMO reference is released so that early tests can be performed. However, for long hindcast runs and sensitivity studies around these runs, we keep the same stable version for the code. DCM was also designed for sharing common configurations between groups, ensuring a complete code coherency. Independently from the code maintenance, it also provides a robust (machine independent) run-time architecture. DCM is managed under SubVersion and thus we are able to re-construct any DRAKKAR code that has been run in the past.

The workforce needed for this task is the following:

Phasing DCM with NEMO reference released (twice a year) : 1 person.month

Implementing new parameterizations/ bug fixes : 2 person.month
Running test cases on DRAKKAR configurations 3 person.month
Total : 6 person.month

2.4.2 Pre/postprocessing tools

One strength of the DRAKKAR simulations performed so far is that they are systematically monitored for some key points during the run, with synthetic results available to the entire DRAKKAR group, on the monitoring web site. This action is to be continued and enhanced for future simulations. The monitoring of the runs is an early validation step which is also useful when performing the run: any weird anomaly can be investigated and possible errors/problems fixed [e.g: errors in the forcing fields].

Technically, the monitoring is based on CDFTOOLS, which is a set of fortran programs developed within DRAKKAR, for diagnostics and post/pre processing purposes. These tools are continuously evolving and complemented as soon as new functionalities are required. A user manual is made available on a web site. CDFTOOLS are managed under SubVersion for easy update and diffusion.

Another validation step will also be performed in certain caseswhen a run is completed: A space-time collocation procedure, available for NEMO output, will produce model-derived "observations" (altimetry, hydrography) necessary for detailed assessments (ongoing work on metrics), and useful for scientific investigations with associated scientists. This assessment of experiments from all groups against common observational databases provides a powerful way to keep the Simulation Ensemble coherent, quality-controlled, and ready for in-depth scientific investigations. While part of this activity is supported by the OST/ST (definition of metrics), engineering work is required to improve and link both tools with the presently distributed (eventually unified?) simulation database.

All the simulations mentioned in this document are to be run on Massively Parallel Computers (MPC). For the French contribution, MPC resources are now managed by GENCI and runs will likely be performed on different machines in different computing centers (namely, IDRIS, CINES or CCRT). This was actually the case for the last years. A run tool environment was thus developed, completely coherent with the DCM structure, in order to be able to easily perform simulations at any center without changing all the scripts. For that, the generic run script uses DCM defined shell functions, which are coded in separated modules (one for each machine/center). These run tools can be used at any computing center (once functions are customized for this center). For historical reasons, some groups in DRAKKAR (NOCS, Ifm-Geomar) are using their own tools, which is not a problem as far as the results are organized with the same structure. Some additional effort is now necessary to put the run tools under SubVersion management, which will then considerably help the maintenance of these tools.

Workforce : CDFTOOLS update : 3 person.month
Validation tools : 6 person.month
Run Tools : 2 person.month

Total: 11 person.month

2.4.3 Storage, database management

With the increase of model resolution the storage of the results become a very serious issue despite the drastic increase of disk capacities. Ideally, when the spatial resolution is increased, the frequency of output also needs to be increased, in order to capture the small scale physics variability. For instance saving ORCA025 every 5 days during one year takes approximatively 180 Gbytes (46 levels) or 245 Gbytes (75 levels). For ORCA12, with output every 3 days, the required space is about 15 times this amount. Beyond the problem of space, there is also a problem of data access. A working group has been set in DRAKKAR in order to address these problems, in particular for the storage of ORCA12 simulations. Although no choices have been done so far, the following solutions are under investigations:

-using alternate data format (e.g. netcdf 4 with data compression enabled, or GRIB)

-storing data in 16 bits with a scale factor and offset (lost of precision)

-reducing the frequency of output (but saving higher order terms computed on the fly).

-Archiving results on a coarser grid (for instance ORCA025) (loss of informations).

In any case a trade-off is to be found. We also have to keep in mind that model results are likely to be used as input for other simulations, in particular off-line tracer simulations for bio-geochemistry.

One central goal of the DRAKKAR coordination is to distribute the results in the community. A tight connection with MERCATOR-ocean will have to be established for this important operational task. We want to ensure that our model results can be used for offline tracer simulations and offline biogeochemical models: for this purpose discussions will be carried out with the new TANGGO project (which is the continuation of the present "Green Mercator" project).

We also had a meeting with F. Daumas, head of CINES computing center, about the mid to long term data archiving. CINES wishes to develop a long-term archiving center for scientific data bases, and DRAKKAR can be elected for the prototype definition. Collaboration with CINES is foreseen for this task.

Workforce : Strategy and interaction with TANGGO : 1 person.month
Implementation of the technical solutions : 12 person.month
TOTAL: 13 person.month.

2.5 Enhancing capability and tools for regional simulations

Very high-resolution regional configurations forced along their boundaries in a physically-consistent way are necessary for specific parameterization/physical studies. One approach is to use a global (or larger scale model) to prescribe boundary conditions. The other way is to use grid refinement tools (AGRIF). However, setting up such models and calibrating their lateral conditions still requires significant time. We propose developments regarding both methods. Note that the use of the global DRAKKAR models to force regional configurations provides in return a useful validation of the global model and leads to improvements.

2.5.1 Improving open boundary conditions in NEMO

The first open boundary conditions (OBC) algorithms were developed in NEMO (OPA, at the time) as part of the CLIPPER project by Molines et al (see Treguier et al 2001). Although quite empirical, these OBC used so far in DRAKKAR (standard NEMO) gave good enough results, even in complex configurations where both AGRIF and OBC were used together (for example in the SOLWARA configuration for the Salomon sea). Variants of the OBC algorithm (MERCATOR) and a new open boundary condition using flow relaxation scheme (UK Met Office) ware being implemented in NEMO. For the developments of future configurations some work will be necessary to fully evaluate the merits of the different formulations. Regarding sea ice, DRAKKAR has implemented a simple restoring technique for sea ice next to the open boundary conditions, which is now part of the reference version of NEMO. This code may have to evolve in the near future when we begin to use the new version of the ice model (LIM3).

The DRAKKAR coordination will provide advice and expertise to the NEMO system team regarding these issues (3 man.months), but the technical aspects are part of the NEMO development and will be the responsability of the NEMO system team.

2.5.2 AGRIF Grid refinement

The DRAKKAR group has developed a strong expertise with the grid refinement tool AGRIF developed at LJK-Grenoble (Debreu et al, 2008). We proved that AGRIF is a powerful and physically-consistent tool to increase the resolution of ocean models in key regions. Our realistic applications have been very important in driving AGRIF improvements, and yielded substantial scientific results (Jouanno et al, 2008, 2009; Chanut et al, 2008; Biastoch et al, 2008, Cailleau et al, 2008). We propose to continue our coordinated effort to further maintain, improve and use model configurations based on AGRIF.

DRAKKAR scientists participate in various projects that rely on AGRIF. To list only a few, the impact of mesoscale processes in the western subpolar gyre on the large-scale circulation in the North Atlantic are investigated by J. Deshaye (LPO) in cooperation with WHOI. The study will use an AGRIF configuration (1/20° or more) embedded in a regional NATL configuration. This configuration would also be used by LEGI and LPO to investigate the impact of very high resolution on the simulation of the overflows. The source of the variability in the Gulf of Mexico and the Carribean Sea is tackled by the group of J. Sheinbaum (CICESE) in cooperation with LEGI. It uses the NATL4 regional configuration with an AGRIF grid refinement at 1/16° in the above regions. The dynamics of the Salomon Sea is addressed by J. Verron (LEGI) within the SPICE project, and will use 1/12° to 1/20° AGRIF grid refinement in a regional extraction of ORCA025. Vertical shears of currents in the surface layers, with an application to the Gulf of Guinea, will be analysed by A.M. Treguier and a PhD student (Henrick Berger, CIFRE funding). The ability to locally enhance vertical resolution is capital for some of the above studies. This option is not available now, and we propose to work in collaboration with L. Debreu (IMAG Grenoble) to implement this capability in AGRIF.

Most of the work force for the regional configurations will be provided by other scientific projects, but DRAKKAR will coordinate the developments and provide advice and expertise to the different projects (17.8 man.months for scientists, 2 man.month for engineers)

2.6 - Coordination of strategy and DRAKKAR meetings

Organization within the project

The coordination requires frequent interaction among team members. We work in different laboratories, so that regular phone/videoconference meetings are necessary. We will organize one such meeting every 3 months (with a written report).

The Drakkar web sites (general site, monitoring sites) need to evolve and will be maintained.

The DRAKKAR collboration itself (for the development of the global 1/12° model) as well as the other projects that team scientists carry out (see table 1) require considerable computer resources. As we have done in the past, we will coordinate our proposals to GENCI to make the best possible use of the national computing resources.

European collaboration:

One international meeting will be held in Grenoble every winter, for reviewing progresses and coordinating the annual work between the groups. If necessary a topical meeting on burning issues can be organized (like the DRAKKAR meeting dedicated to the subpolar gyre dynamics and the use of AGRIF, meeting organized by J. Deshayes in Brest in july 2009).

3. Expected outcomes

The coordination project we propose aims at maintaining at an international level and further improving two achievements of the DRAKKAR and MERCATOR groups over the last 6 years (i.e. the global ocean model configurations and the set of simulations and reanalyses) which have proven important for both operational and research communities. More precisely this effort is expected to yield by 2012:

- 1/4° and 1/12° ocean/sea-ice model configurations with (i) documentation, (ii) improved subgrid scale parameterizations, (iii) 3D grid refinement capabilities and, (iv) tools[3] needed to build stand-alone regional model configurations driven at open boundaries by long term hindcasts or reanalyses.

- High-quality atmospheric forcing functions over periods covering the past 5 decades, validated by reference ocean simulations.

- The yearly release of a 50-year ¼° global reference hindcast evaluated against observations.

- The release of one 50-year 1/12° global reference hindcast evaluated against observations.

- Sensitivity experiments at 1/4° (e.g. ocean forced by the ERAinterim reanalysis, using modified parameters, etc.)

- A substantial contribution in sustaining scientific interactions among ocean modellers at European scale, and in building a strong and lasting practice of scientific collaborations within the French community.

- Strong and lasting links between the operational and research communities.

4. Budget and resources

The DRAKKAR coordination will require computer resources, typically more than 500000 scalar hours per year on CINES and more than 300000 scalar hours per year at IDRIS.

4.1. Budget

The budget (Table 2) is requested half from MERCATOR GMMC (20 K€/year) and half from LEFE (20 K€/year).

3 These tools will be created initially by the MyOcean project, the NEMO system team and MERCATOR-ocean, but DRAKKAR will use them and contribute to their constant improvement.

<u>Table 2:</u> Budget requested for the DRAKKAR coordination.

	2010	2011	2012
Small equipment (work stations, disk storage)	8	8	8
Fonctionnement (phone, publications, software...)	7	7	7
Travel for DRAKKAR meetings in France	10	10	10
Travel for technical collaborations (one-week of scientists/engineers at another laboratory or at Mercator)	8	8	8
Travel for European collaboration (4 to 5 persons each year)	7	7	7
TOTAL (50% of which is requested to LEFE)	40	40	40

4.2.Human resources requirements

Personnels working on the project are listed in Table 3. Note that a 3 year temporary engineering position is requested to INSU.

Table 3: list of participants for the DRAKKAR coordination

Name	Position	Laboratory	Role	Time
Bernard Barnier	DR CNRS	LEGI Grenoble	Coordination, Forcing, Global and regional configurations, Assessment, Parameterisation, ...	30%
Xavier Capet	CR CNRS	LPO Brest	Parameterisation, Regional configurations & simulations,	20%
Julie Deshayes	CR CNRS	LPO Brest	Assessment, regional simulations	20%
Julien Le Sommer	CR CNRS	LEGI Grenoble	Parameterisation, Regional configurations & simulations,	20%
Gurvan Madec	DR CNRS	LOCEAN & NOCS	NEMO development, global simulations	20%
Jean Marc Molines	IR CNRS	LEGI Grenoble	Models configurations, simulations, diagnostic tools, super computing optimisation, data base management & distribution, ...	30%
Thierry Penduff	CR CNRS	LEGI Grenoble & FSU Tallahassee	Forcing, assessment, global simulations	20%
Claude Talandier	IE CNRS	LPO Brest	Models configurations, simulations, diagnostic tools, numerical improvements and validations	30%
Anne Marie Treguier	DR CNRS	LPO Brest	Coordination, global models, tools	30%
X	CDD (3ans) requested from INSU	LEGI Grenoble	Forcing, ORCA12 development and simulations, data base management & distribution, ...	100%
Y. Drillet	Mercator		Coordination	10%
R. Bourdalle Badie, O. Le Galloudec, C. Bricaut, G. Garric, C. Derval	Mercator		ORCA12 development and simulations	90%
PhD Students	Several PhD students of LPO and LEGI will partly contribute to the work done in the context of the coordination.			90%

Total		510.00 %

Table 4 below summarizes the human resources required for the project. Two tasks are very demanding technically, because of the size of the ORCA12 model we propose to implement and develop further: the realization and validation of the simulations (Task 1) and the development of new methods for the database management (Task 4).

Table 4: *Human resources needed for the different tasks, at CNRS (scientists and engineers) and MERCATOR.*

Task	Title	Coordinators	Scientist (man. month)	Engineer (man. month)	TOTAL CNRS	MER CATOR
1	coordinated global ocean-ice simulations	A.M. Treguier, T. Penduff	17	27	44	25
2	forcing the ocean	B. Barnier, A.M. Treguier	6	3	9	9
3	algorithms, parameterization, submesoscale dynamics	X Capet, J. Le Sommer	17	2	19	
4	numerical code, tools, database management	J.M. Molines, C. Talandier	6	24	30	10
5	capabilities for regional configurations	J. Deshayes	17.8	2	19.8	
6	coordination of strategy and drakkar meetings	A.M. Treguier, B. Barnier	4.6	0	4.6	3
		TOTAL	68.4	58	126.4	47

Developing and running the DRAKKAR ocean models require scientific expertise and technical skills. The transition from a single eddy permitting basin model (CLIPPER) to a global eddy permitting model and a North Atlantic higher resolution model (first DRAKKAR project) has been made possible by the contribution of a new engineer at LPO, to share the work with Jean Marc Molines at LEGI (S. Theetten joined the team at the end of 2001). Additional help has been provided by engineers supported by short-term contracts, for example C. Guiavarc'h for the development of the 1/12 North Atlantic model, or L. Brodeau who worked on the improvement of the DRAKKAR forcing data.

At present, the two engineers contributing to the project are Jean Marc Molines (LEGI) and Claude Talandier (LPO). They contribute to DRAKKAR for 30% of their time, due to their involvement in other projects (for example, ANR "Southern Cross", FP7 "My Ocean", GMMC Glorys...), and to their other technical duties at LPO and LEGI.

The transition from the eddy permitting ORCA025 configuration to the higher resolution ORCA12 can be achieved **only with the help of one additional engineer working full time on the project during the next 3 years**. We ask INSU to support this effort by a 3 years contract for an engineer who will work at LEGI.

5. Publications and references

Note: bibliographic references quoted in the text (other than the DRAKKAR publications) are listed at the end of this section.

5.1. Peer-reviewed scientific papers (by year)

We list here, by year, ONLY the publications of the scientists involved in the previous DRAKKAR project, that used CLIPPER or DRAKKAR outputs, expertise, and/or model configurations. This is not an exhaustive list of the publications of the team members (note that the publications of J. Deshayes and X. Capet are not listed). Although CLIPPER ended in 2002, publications using the CLIPPER outputs still appear 6 years afterwards : the publication list demonstrates the long lifetime and scientific relevance of good ocean hindcasts.

CLIPPER models 2006 (4)

Arhan M., A. M. Treguier, B. Bourlès, S. Michel, 2006: Diagnosing the annual cycle of the Equatorial Undercurrent in the Atlantic Ocean from a General Circulation model. J. Phys. Oceanogr., 26, 1502–1522

Penduff, T., Barnier, B., Molines, J.-M., Madec, G.: On the use of current meter data to assess the realism of ocean model simulations (2006) Ocean Modelling, 11 (3-4), pp. 399-416.

Thierry, V., H. Mercier and A.M. Treguier, 2006: Seasonal fluctuations in the deep central equatorial Atlantic Ocean: a data-model comparison. Ocean Dynamics, doi: 10.1007/s10236-005-0045-y

Treguier, A.M., Gourcuff, C., Lherminier, P., Mercier, H., Barnier, B., Madec, G., Molines, J.-M., Penduff, T., Czeschel, L., Böning, C.Internal and forced variability along a section between Greenland and Portugal in the CLIPPER Atlantic model (2006) Ocean Dynamics, 56 (5-6), pp. 568-580.

DRAKKAR models 2006 (2).

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. *(Note that this reference paper for the DRAKKAR ORCA025 model has 34 citations)*

Béranger K., B. Barnier, S. Gulev and M. Crépon, 2006 : Comparing twenty years of precipitation estimates from different sources over the world ocean. Ocean Dynamics, Vol. 56-2, 104-138, DOI: 10.1007/s10236-006-0065-2 2006.

CLIPPER models 2007 (1)

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.

DRAKKAR models 2007 (5)

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.

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,

Koch-Larrouy A., G. Madec, P. Bourruet-Aubertot, T. Gerkema, L. Bessières, R. Molcard, 2007: On the transformation of Pacific Water into Indonesian throughflow Water by internal tidal mixing. Geophys. Res. Lets, Volume: 34, 4 L04604.

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

CLIPPER models 2008 (3)

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.

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.

DRAKKAR models 2008 (8)

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.

Biastoch, A., C.W. Böning, J. Getzlaff, J.M. Molines, and G. Madec, 2008: Causes of Interannual–Decadal Variability in the Meridional Overturning Circulation of the Midlatitude North Atlantic Ocean. *J. Climate*, 21, 6599–6615, doi :10.1175/2008JCLI2404.1.

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.

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.

DRAKKAR models 2009 (14)

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.

Griffies, S.M., Biastoch, A., C. Böning, C., Bryan, F., Danabasoglu, G., Chassignet, E.P., England, M.H., Gerdes, R., Haak, H., Hallberg, R.W., Hazeleger, W., Jungclaus, J., Large, W.G., Madec, G., Pirani, A., Samuels, B.L., Scheinert, M., Gupta, A.S., Severijns, C.A., Simmons, H.L., Treguier, A.M., Winton, M., Yeager, S., Yin, J.: Coordinated Ocean-ice Reference Experiments (COREs) (2009) Ocean Modelling, 26 (1-2), pp. 1-46. 1.

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.

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Lombard, A., G. Garric, and T. Penduff, 2009 : «Regional patterns of observed sea level change: Insights from a 1/4° global ocean/sea-ice hindcast ». Ocean Dynamics, 59, 3, 433-449.

Michel, S., A.M. Treguier and F. Vandermeirsch, 2009: Temperature variability in the Bay of Biscay during the past 40 years, from an in situ analysis and a 3D global simulation. Continental Shelf Research, 29 (8) 1070-1087, doi:10.1016/j.csr.2008.11.019.

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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.

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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.

Bonhommeau, S., B. Blanke, A.M. Treguier, E. Rivot, Y. Vermard, O. Le Pape, 2008: Can the European eel larvae cross the Atlantic Ocean in 6 months? Fisheries Oceanography, in press.

Skandrani C., Brankart J.-M., Ferry N., Verron J., Brasseur P. and Barnier B., 2009: Controlling atmospheric forcing parameters of global ocean models: sequential assimilation of sea surface Mercator-Ocean reanalysis data. *Ocean Science*, in press.

Drakkar models, submitted publications (2009) (9):

Arsouze T., Treguier, A.M., Peronne, S., Dutay, J.-C., Lacan, F., Jeandel, C.: Modeling the Nd isotopic composition in the North Atlantic basin using an eddy-permitting model. Submitted to Geophys. Res. Lets.

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.

Juza M., T. Penduff, B. Barnier, and J.-M. Brankart, 2009: Analysis of monthly ARGO sampling errors in the global ocean mixed layer: a DRAKKAR model study. Journal of Geophysical Research, submitted.

Lique, C., A. M. Treguier, B. Blanke, and N. Grima, 2009: 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.

Penduff, T., M. Juza, L. Brodeau, G.C. Smith, B. Barnier, J.M. Molines, A.M. Treguier, 2009: Impact of model resolution on sea-level variability characteristics at various space and time scales:insights from four DRAKKAR global simulations and the AVISO altimeter data. *Ocean Science*, in revision.

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.

5.2.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.

Biastoch, A, J. R. E. Lutjeharms, C. W. Böning, and M. Scheinert, 2008: Mesoscale perturbations control inter-ocean exchange south of Africa, *Geophys. Res. Lett.*, 35, L20602, doi:10.1029/2008GL035132

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.

Lachkar Z., J. C. Orr, J.-C. Dutay, and P. Delecluse, 2006: Effects of mesoscale eddies on global ocean distributions of CFC-11, CO2 and 14C. *Ocean Sciences*, 3, 461-482.

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.
Roquet F., 2009 (LOCEAN): La circulation océanique autour du plateau de Kerguelen: de l'observation à la modélisation.

Newletters and proceedings (2006-2009)

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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6. Annex A : Collaborations

List of laboratories/teams part of the international DRAKKAR group:

Laboratory	contact	Town, country
LEGI	B. Barnier	Grenoble, France
LPO	A.M. Treguier	Brest, France
LOCEAN	G. Madec	Paris, France
MERCATOR-ocean	Y. Drillet	Toulouse, France
National Oceanographic Centre, NOCS	A. New	Southampton, U.K.
IFM-Geomar	C. Böning	Kiel, Germany
University of Alberta	P. Myers	Edmonton, Canada
ESSC Univ. of Reading	K. Haines	Reading, UK
SIO-RAS	S. Gulev	Moscow

National collaborations: a (non-exhaustive) list of colleagues and/or scientific projects that will benefit from the DRAKKAR coordination, based on the responses to a call sent by email in july 2009

Name	Laboratory	Collaboration
P. Bourruet-Aubertot, F. Vivier	LOCEAN	use of tools and boundary conditions for a regional model of the Arctic (ANR OPTIMISM)
P. Brasseur (and collaborators)	LEGI	use of configurations and tools to support studies of data assimilation.
B. Chapron	IFREMER, LOS	use of hindcasts to complement studies based on satellite data
C. Frankignoul	LOCEAN	Use of hindcasts (Gulf Stream and AMOC variability)
M. Gehlen, J. Orr	LSCE	Use of ORCA025 configuration for biogeochemistry
T. Huck	LPO	Use of hindcasts and tools (Atlantic and global variability)
A. Lazar	LOCEAN	use of tools and boundary conditions for a regional model of the tropical Atlantic
P. Lazure, F. Dumas, S. Theetten	IFREMER, DYNECO	use of hindcasts as boundary

		conditions for coastal models.
M. Levy (and TANGGO: L. Bopp, O. Aumont, etc)	LOCEAN (and LSCE, LPO...)	Collaboration DRAKKAR-TANGGO, to be defined.
F. Marin	LEGOS	use of hindcasts to study the tropical Atlantic
H. Gallée	LGGE	Use of ORCA025 simulations to initialise and to drive open boundaries of a regional coupled Ocean-Atmosphere model of the Ross Sea.
S. Pous, C. Deltel	LOCEAN	use of global hindcasts as boundary conditions for an Indian ocean configuration.
C. Ritz	LGGE	use of hindcasts to study the dynamics of ice shelves around Antarctica.
V. Thierry and the OVIDE group	LPO	use of hindcasts to study the variability of the subpolar Atlantic
J. Weiss	LGGE	use of DRAKKAR configurations to test new sea-ice models
Y. H. Park, F. Roquet	LOCEAN	Use of ORCA025 simulations to study the circulation in the viscinity of the Kerguelen Shelf.

7. Annex B : Coordinated workplan for the development of ORCA12

Summary of the first steps for the development of ORCA12 realised at Mercator Ocean.

- 2008 : Production of the first global 1/12° (ORCA12) simulation over the period 2000-2008, forced by daily mean operational ECMWF atmospheric forcing. The NEMO1.09, LIM2 sea ice model and CLIO bulk formulation have been used to realise this simulation.
- 2009 : upgrade of the ORCA12 configuration including new version of NEMO (NEMO3.1), evp rheology in LIM2 sea ice model, parameterisation of the tidal mixing, atmospheric forcing from ERAinterim atmospheric reanalysis will be introduced.
- End 2009 : A new ORCA12 simulation over the same period (2000-2008) including the new parameterizations and forced with ERAinterim atmospheric fields will be performed.

Plan for the joint development of ORCA12 by DRAKKAR and MERCATOR.

R. Bourdalle-Badie will participate in the coordination of Task 1.2 (eddy resolving simulations) and Y. Drillet will oversee the coordination between DRAKKAR and Mercator (Task 6).

task 1.2: Eddy resolving simulations

MERCATOR contribution: 22 man/month.
DRAKKAR contribution: 22 man/month
During the first 2 years of the project (2010-2011), we will work to improve the ORCA12 configuration. These improvements will be especially in term of physics over the upper layer of the ocean (surface velocities, heat and salt content in the mixed layer, meso scale representation, sea ice at high resolution …). We will coordinate this work ORCA12 in order to converge, as much as possible, toward a common configuration between DRAKKAR and MERCATOR.
Some improvements have already been tested in the latest DRAKKAR ORCA025 configuration and MERCATOR NATL12 configuration, and will be added in ORCA12:

- Water turbidity and impact on solar flux penetration.
- Vertical physic and new mixed layer model.
- Tidal mixing
- diurnal cycle.

We will additionally consider:

- improvements of forcing fields (see task 2.1)
- Improvement of sea ice model for high resolution model
- introduction of large river runoffs as a lateral flux rather than a surface flux.

Other improvement concerning input files of the model will be also realised as:

- New bathymetry fields
- Atmospheric fields from ERAinterim reanalysis
- Initialisation fields for ocean and sea ice
- Runoff data (interannual whenever possible)

For the end of 2011, an interannual simulation over the ERAinterim period (1988-2010) will be produced by MERCATOR. A companion simulation (over the same period or shorter, according to computing resources) will be produced by the DRAKKAR group. The two simulations will be designed so as to provide the best possible sensitivity experiment, within the international context of DRAKKAR (taking into account other ORCA12 simulations performed in 2010 par NOCS and GEOMAR).
For the end of 2012, an interannual simulation over the longest possible period (ERA40+ERA

interim, or ERA interim if long enough) will be produced by the French DRAKKAR group.

task 1.3: Assessment and distribution of reference simulations

DRAKKAR: 5 man.month (for ORCA12 only)
MERCATOR: 3 man.month
The validation of simulations will be carried out by both DRAKKAR and MERCATOR. We will make use of tools beveloped by DRAKKAR (monitoring based on cdftools) and at MERCATOR to adapt those tools to the assessment of ORCA12. We will perform intercomparisons with other simulation produced in the Drakkar project at lower resolution. We will define a strategy to make easier the distribution of high resolution simulations (see task 4.3).

task 2.1: Evaluate new forcing functions

DRAKKAR: 6 man.month (ORCA12 only)
MERCATOR: 9 man.month
MERCATOR will contribute to this task by testing a high frequency atmospheric forcing (3h) including diurnal cycle. MERCATOR and DRAKKAR will try to agree on a common forcing, as well as common bulk formulae for ORCA12. This will require dedicated sensitivity experiments.

task 4.3 Storage, database management

DRAKKAR: 13 man.month
MERCATOR: 10 man.month
During the first 18 months of the project we will define a common strategy for storage and distribution of simulations, suitable for the needs of research. The new possibilities offered by the NEMO I/O system (version 3.2) need to be explored. The possibility of creating a database at lower resolution (while preserving heat and salt content and transports) will be examined. The strategy will take into account the possibilities offered by the national computing centres (especially CINES). It will also have to take into account the requirements for offline simulations of tracers (coordination with "Green Mercator" and the TANGGO project).

8. Annex C: Job definition for an engineer at LEGI

Demande de recrutement, Ingénieur de Recherches expert en calcul scientifique

LEGI Grenoble, projet DRAKKAR, CDD de trois ans

L'ingénieur de recherches en calcul scientifique apportera un soutien au projet DRAKKAR pour la modélisation globale à haute résolution de l'océan (1/12°), utilisant la plateforme de modélisation NEMO (www.nemo-ocean.eu). L'ingénieur fera évoluer la configuration de modèle (développement numériques, algorithmes, forçages), en évaluera les performances sur des calculateurs massivement parallèles, effectuera des simulations numériques et participera à leur validation. L'ingénieur devra également participer à la définition et à l'implémentation d'une nouvelle stratégie de stockage des résultats et de post-traitement adaptée aux simulations haute résolution. Il/elle devra documenter les développements effectués et participer à l'animation technique du projet DRAKKAR (site web, circulation des informations).

Le travail s'effectuera dans le cadre d'une collaboration étroite avec MERCATOR-Océan et avec les partenaires Européens du projet DRAKKAR (en particulier NOCS Southampton et IFM-Geomar Kiel).

Compétences requises:
Formation d'ingénieur en mécanique des fluides et modélisation numérique. Des connaissances de base en océanographie physique ou météorologie dynamique, ainsi qu'une expérience dans la simulation numérique de ces milieux seront appréciées. Langages de programmation (Fortran si possible), parallélisme (MPI), outils de visualisation et de calcul (matlab, IDL, Python, ...). Bonne capacité de communication en anglais à l'oral et à l'écrit, goût pour le travail en équipe, rigueur et organisation.