Report of the DRAKKAR meeting
Grenoble, 25-27 january 2016

Organizing committee

Bernard Barnier (CNRS, LGGE), Arne Biastoch (GEOMAR), Claus Böning (GEOMAR), Joël Hirschi (NOCS), Camille Lique (IFREMER, LPO), Adrian New (NOCS), Anne Marie Treguier (CNRS, LPO).

The meeting was organized in four sessions (see agenda on the Drakkar web site, www.drakkar-ocean.eu).

Session 1: Dynamics and biogeochemistry of high latitudes and sea-ice covered ocean regions and experience with LIM3.

This session focussed on simulations of the Arctic and Antarctic oceans and sea ice, with NEMO coupled to different sea ice models (CICE, LIM2 and LIM3). Results from two groups using numerical models other than NEMO (LANL, Los Alamos and AWI-Bremerhaven) have also been presented.

Session 2: Numerical, physical parameterisation and resolution issues in global and regional model configurations.

The session combined theoretical presentations about parameterisations with talks on the representation of processes vs parameterisation in simulations using NEMO (issues regarding overflows, lateral mixing, or the energy cycle).

Session 3: Variability of the turbulent physical and biogeochemical ocean: generating mechanisms, simulation strategies to deal with model uncertainties, comparison to observations, forcing/coupling with the atmosphere.

The first part of this session was devoted to coupled ocean-atmosphere simulations, ocean turbulence and biogeochemistry. The second part focussed on stochastic variability and intrinsic variability.

Session 4: Ocean Global Circulation Models: Evolutions, performances and diagnostics

This session focussed on the evolution of NEMO, on spurious mixing, and new diagnostic methods for ocean simulations.

Note in introduction to this report:

The present report presents highlights for each session as well as a synthesis of the relevant discussion items. Individual presentations are available on the Drakkar web site but they are password-protected, as results presented at the DRAKKAR meetings are usually new and preliminary.

Table of contents

1. Dynamics and biogeochemistry of high latitudes and sea-ice covered ocean regions and experience with LIM3.

Session report: Camille Lique and Pierre Mathiot

1.1 Session summary

The session started with a presentation by P. Mathiot on the development of the new parameterisation to include the effect of the Greenland melt. The melt rate parameterisation is currently developed in an idealized 2D NEMO configuration of a fjord. Different parameterisations are tested and the best results are obtained from a plume model parameterisation.

The presentation of R. Marsh also focused on the development of parameterisations to account for additional sources of freshwater in NEMO. Here, the aim is to include the additional contribution of icebergs. The module NEMO-ICB is based on lagrangian trajectories of different categories of iceberg, which depends of the atmosphere, ocean and sea ice conditions. Tests in an ORCA025 configuration show promising results when compared with in-situ data, although the activation of the module in NEMO remains very computationally expensive.

Several talks have addressed specific scientific polar-oriented questions, based on regional high resolution NEMO/LIM2 (Myers & Behrens) or NEMO/CICE (Kjellsson & Zhai) configurations. Additionally to their scientific focus, these talks emphasize the importance of the choice of the viscosity (Zhai), the high frequency in forcing fields and freshwater input from Greenland (Myers), or the representation of air/sea ice drag (Kjellsson).

P. Uotila presented a comparison of twin simulations performed with LIM2 and LIM3 (using ORCA1). In general, using LIM3 improves the realism of the Arctic sea ice conditions (less so in the Southern Ocean), although some large biases in the representation of the stratification remain when using LIM3. C. Rousset presented results from a very high resolution regional configuration of the Spitzberg using LIM3. The simulations reproduce well some key features in this region, such as polynyas.

J. Raulier presented results from simulation in which a Maxwell-elasto-brittle rheology has been implemented in LIM3. This allows a better representation of sea ice leads and more generally of the sea ice dynamics.

Finally, two talks (Q. Wang and M. Hecht) have presented results from projects based on two different models than the traditional DRAKKAR/NEMO, namely FESOM and CESM. Q. Wang presented results from simulations based on the unstructured mesh FESOM model at low (24km) and high resolution (4.5 km). The high resolution version is able to represent realistic sea ice lead and sea ice divergence/convergence. Sensitivity tests on the convergence of EVP suggest that more iterations than usually set (including in Drakkar configurations) are required to allow a full convergence of the scheme (cf Danilov's talk). M. Hecht presented an overview of the modeling project HiLat, which is based on CESM/CICE and include and biogeochemistry component. The project aims at putting together an improved model of the Arctic/Southern Ocean, in order to examine how the changing cryosphere drives physical and biogeochemical response, and how the changing cryosphere might impact polar/extra-polar interactions.

1.2 Discussion summary

The discussion, lead by Petteri Uotila, focused on 3 different topics: the fresh water input on polar regions (river runoff, iceberg melting …), LIM3 and the Weddell Sea polynya.

1) Fresh water flux:

The presentations in this session highlighted a clear interest onto freshwater forcing (river runoff, iceberg melt ...) for polar region. A variety of data set used, a variety of application pattern and a variety of method to implement the freshwater was presented and used (see talk from Marsh, Uotila, Myers ...). The discussion focused on 2 topics: What are the remaining issues and how can we organize better the community to avoid the duplication of work amongst groups.

- **Remaining issues**

  Recent study (Whitefield et al. 2015, Ocean Mod.) suggests that temperature of the river runoff could also be important. In DRAKKAR the river runoff is assumed to be at the model sea surface temperature at the input cells.
  The other issue on river runoff is where to specify the river runoff input in case of long fjords. If the freshwater input is prescribed into the fjord, it can leads to negative salinity because the runoff input is stuck into the fjord. To avoid this Paul Myers and Mercator specify it at the mouth of the fjord.
  For coupled model, a strategy is required to redistribute the precipitation onto the continent toward the runoff. Dave S. highlighted that a NEMO branch is available to do the job for precipitation over Antarctica and Greenland. It spreads the solid precipitation between iceberg/ice shelf melting with a constant ratio and it spreads, for each component (icb or isf), at each time step, the corresponding fresh water input onto a specified pattern.

- **Action**

  Based on the experience of sharing information on ORCA025 and configuration specific file through shaconemo for CMIP6 last year, shaconemo could be used to share data/method used to build the fwf forcing files in the DRAKKAR community. This could avoid duplication of work and leads to better collaboration. The suggested way to work is based on 2 step process: ticket (to describe the file/data/method ...) and a link toward the file. As the data set will be 2d, it should be easy to share.
  People who agreed to share their data and methods about the polar fresh water flux through shaconemo web site are:
  - P. Mathiot: ice shelf parametrisation file and ice shelf melting beneath ice shelf
  - N. Merino: Iceberg melting climatology
  - P. Myers: Greenland runoff

2) Sea ice model: LIM3

- **Achievement**
  LIM3 has improved since last year. On the science side, LIM3 has been successfully used in a regional ORCA12 with MAR atmospheric forcing (C. Rousset), ORCA025 and ORCA1 with NCEP/NCAR atmospheric forcing. LIM3 shows a much better sea ice state than LIM2 in ORCA025 and ORCA1. It is a step forward. On the technical side, LIM3 is now able to run on another cpu distribution than the one used by NEMO. All these improvements during the last year arised from the hard work of G. Madec, M. Vancoppenolle and C. Rousset.

- **Remaining issue**

  Despite these large improvements in LIM3, several bottlenecks have been highlighted for wider used of LIM3 within the DRAKKAR consortium:

  - LIM3 is still slower than LIM2 (P. Uotila). LIM3 performance has been improved for the ice temperature. However, a lot of work has to be undertaken to improve the performance of the advection scheme and this is not an easy task (C.Rousset).
  - AGRIF with LIM3 is not yet available. It has been put into the NEMO work plan 2016 (Clement R. leads this task).
  - How to set up LIM3 for a given resolution. The current method to set up LIM3 is through a "try and error" approach (number of categories, namelist parameters ...). If a list of coefficient for namelist is available at different resolution, it should be shared more efficiently.

3) Weddell sea polynya

The last point highlighted during the discussion was the occurrence of the Weddell Sea polynya. LIM3 is very sensitive to fwf, especially when we look at the Weddell Sea polynya. A strong sea surface restoring has to be used to get rid of the polynya. When no damping is used, the polynya pops up. This is true in the runs performed by different groups using different sea ice models (MISU, BAS, Mercator). The problem of using a restoring is that we rely on the (poor) quality of the SSS data under sea ice. Putting together a new dataset including all the data from seals could help although challenging.

2 Numerical, physical parameterisation and resolution issues in global and regional model configurations.

Session report: Julie Deshayes ; **discussion lead and report :** Mike Bell.

2.1 Summaries of presentations

Dave Storkey : "Noise, mixing and Smagorinsky in the Denmark Strait overflow"

Using Smagorinsky parameterisation in global ORCA025 (and comparing with constant bilaplacian diffusivity) increases viscosity within boundary currents and reduces it in the middle of gyres. This substantially reduces mixing in the Irminger Sea, which in turn increases density of Denmark Strait Overflow Water (DSOW) at Labrador Sea inflow (within West Greenland Current) and finally reduces the time drift of thermohaline properties in the Labrador Sea.

However the convective patch in the Labrador and Irminger Seas enlarges with Smagorinksy, probably because processes ensuring post-convective restratification are still missing. As a consequence, the very dense water formation in Irminger Sea actually feeds the Labrador Sea at depth, compensating for under-represented entrainment of DSOW. As a conclusion : using Smagorinsky in ORCA025 (warning : Smagorinsky in ORCA025 with C=4 is too high) may be useful to control grid scale Reynolds number and hence numerical mixing, but this requires more analysis.

Mike Bell : "Partial cells and instabilities"

NEMO's "een" momentum scheme suffers from grid-scale instabilities in high resolution models, near grid-scale in the vertical and the horizontal, and this weakens the ocean mesoscale activity

(Hollingsworth instabilities = destabilised inertia-gravity waves). With the correction of Ducousso/Madec, the "blue spot" (a cold-pool due to the absence of the North-West corner) re-emerges to the south of Flemish Cap, as observed in ORCA1 runs, which is not acceptable. Partial cells new formulation of vorticity above steps yields to the same biases as Ducousso/Madec correction. Finite volume approach to pressure forces (which calculates pressure forces acting on faces of velocity cells) works best for a modified Lorenz grid (where pressure and density are on different levels). This could allow sloping lower boundaries and achieve a 2nd order accuracy, presumably. However for s-coordinates, there is a need to use higher order accurate formulae. Note that all z and s-coordinate ocean models use a Lorenz grid on the vertical, although this grid is very poor for non-hydrostatic motions. With Lorenz grid there is a form of potential vorticity conservation, but there are spurious short-wave baroclinic instabilities near boundaries with vertically sheared flows. These instabilities are not usually resolved by our grids.

Nicolas Ducousso : "impact of the 'Symmetric Instability of the Computational Kind' (SICK) on Drakkar simulations at mesoscale and submesoscale permitting resolutions"

The instability (described by Holllingsworth) is due to the different imprint of stencils in two terms of the momentum conservation equation, which makes all internal inertio-gravity waves unstable. The use of an extended stencil for the KE gradient scheme suppresses the instability. This is illustrated on a theoretical barotropic vortex. In ORCA025, in the Eastern equatorial Pacific, suppressing instability brings the solution closer to observations. A snapshot of TKE vertical diffusivity along same section reveals large values below the equatorial jet in the reference solution, that disappear in a sensitivity experiment (with correction of instability). In NATL60, EKE when correction is activated is much higher than in the reference (which EKE is actually lower than in ORCA12), hence the Gulf Stream is much better reproduced with correction. As a conclusion, Hollingsworth instability initiates a very direct route to dissipation; this is strongly resolution dependent, and probably ORCA025 is the coarsest configuration with a noticeable impact of this instability.

Malte Jansen : "Parameterising subgrid-scale eddy effects using energetically consistent backscatter"

The idea is to add energy backscatter via "negative viscosity". Application in an idealized test case (zonal channel) improves the mean flow interacting with topography. In a global 1/4 configuration (MOM6): while the reference simulation has too weak EKE compared to AVISO, the sensitivity experiment with backscatter viscosity shows significant improvements in the Antarctic Circumpolar Current, in subtropical regions, Kuroshio and Gulf Stream (which transport also increases) although there is still room for further improvements. Sub-grid EKE budget with negative viscosity backscatter can be used in idealized primitive equation model to greatly improve flow characteristics at eddy permitting resolution. Closure behaves well in global model configuration and gives promising first results. Issues that remain to be addressed are the following : [i] higher EKE near grid scale increases spurious diapycnal mixing (hopefully hybrid coordinates will solve this), [ii] vertical structure and transport of sub-grid EKE, [iii] transition to non-eddying regime.

Remi Tailleux : "on the directions of mixing in mixing parameterisations : a criticism of current approaches"

Ideal density variable is both materially conserved and neutral, but thermobaricity and density-compensated T/S anomalies forbid both properties to hold simultaneously. Neutral vectors don't define the envelope of a mathematically well-defined surface. Diapycnal flux of rotated diffusive heat and salt fluxes are necessarily contaminated by isoneutral mixing for any well defined density surfaces, hence z-models with isoneutral / dianeutral mixing are not traceable to isopycnal models. Frozen p-dependence cannot be maintained when taking divergence (Heat or Salt flux) which will be impacted by thermobaricity, in contrast to what would be the case with using a truly materially conserved density variable. As a result, it would be better to base directions of mixing on a well-defined density variable, but if so, which one? Using potential density referenced to any constant reference pressure is not really acceptable. Using neutral density is not either because neutral density is a priori ill-posed and lacking a mathematical expression, but can this be remedied? A new neutral density is introduced : the thermodynamic neutral density, which approximates the mathematically ill-defined neutral density. This is a way to reconcile neutral density theory with Winters et al. (1995) suggestion to use Lorenz reference state to define diapycnal mixing and GM parameterisation of mesoscale ocean eddies as sinks of Available Potential Energy. Finally, thermodynamic neutral density is computationally efficient to compute for arbitrary temperature/salinity climatologies, not just present-day.

Siren Ruhs : "Lateral diffusivity estimates deduced from Lagrangian trajectory simulations"

The motivation of this study is to evaluate how well Lagrangian trajectories represent the spreading of water masses (for example modelled velocities do not resolve submesoscale processes that influence the fate of water masses). Previous studies suggest that adding additional diffusion parameterisation to trajectory calculation is useful as it changes the trajectories, but this is not available in the ARIANE software. However, how should lateral diffusivity be derived ? Single-particle diffusivity can be estimated from drifters. This is tested in the eddy resolving ocean model INALT01 (global-nested OGCM 1/10, 46 zlev), hindcast simulation for 1995-2007 coupled to ARIANE (in 2005) for the introduction of virtual drifters. Estimates of lateral diffusivity in the model corresponds well to that based on observations (only slightly lower). This methodology could be applied to global configurations to quantify how sensitive the results are to model resolution.

Arne Biastoch : "ORCA025 with Gent McWilliams parameterisation at higher latitudes"

This study focusses on the specific issue of convection in the Labrador Sea, which extent and depth are effectively controlled by lateral eddy fluxes of buoyancy. Switching GM parameterisation poleward of 30° in latitude in ORCA025 strongly reduces EKE but also reduces MLD in Labrador Sea hence lowers the production of LSW. A sensitivity experiment is presented where GM is applied only where there are 1 or less grid points per Rossby Radius (although Rossby Radius is calculated on observed climatology rather than model outputs). Another sensitivity experiment introduces a mask to apply GM only to subpolar latitudes. All implementations of GM have different impacts on LSW production rate hence different behaviours of AMOC.

Marta Martin del Rey : "On the impact of the resolution on the Eastern Tropical Atlantic Ocean bias"

This study is motivated by the presence of biases in the eastern subtropical Atlantic in most climate models, which are reduced by the use of higher resolution atmospheric products. What is the impact of increasing horizontal oceanic resolution ? It is expected that increasing oceanic resolution induces more resolved mesoscale processes, which may reduce the warm bias in the cold tongue region and coastal upwelling, but this remains to be verified. Three ORCA ocean simulations are diagnosed : 1/4° L46, 1/12° L46, 1/4° L75. The seasonal cycle in the equatorial Atlantic shows that 1/12° and 1/4° L46 have the same timing as observations, while 1/4° L75 has 1 month advance. Also 1/12° has a reduced warm bias in spring/summer. Actually, at 1/12°

the upper ocean stratification increases, leading to cooler conditions which could favor a faster cooling of the surface. Stratification at 1/12° is also more realistic at depth, which could be due to more realistic SST gradients in the subtropical regions. Hence the higher 1/12° resolution generally improves subtropical upwelling regions, compared with ORCA025.

Sergey Danilov : "Eddy dynamics on meshes with variable resolution"

Those are first illustrated in a reentrant channel with a mesh stretching factor to refine resolution locally and enable representation of eddies. Nesting should take into account the "retarded" turbulence equilibration (about 10 degrees into the nest, in the periodic channel experiments). Then circulation in a double-gyre rectangular basin is compared at 10km *vs* 30km. As there is variability only at the boundary between the two gyres, the resolution is first refined only at this location. This induces an increase in EKE but not enough improvement of the mean SSH. The latter only improves when the area of refinement is enlarged. Application to the global configuration of FESOM (with mesh size ranging from 50km in center of gyres to <10 km along boundaries, hence mimicking ratio of resolution to the Rossby radius from Hallberg) shows that EKE compares well with AVISO, except that it is too weak in GS and NAC. Besides, regions where resolution is increased have reduced anomalies in temperature over upper 100m. As a conclusion, variance-based mesh refinement is a good way to follow, but [i] some a priori information has to be taken into account in order to minimize the errors, [ii] refined areas should be sufficiently large.

Sybren Drijfhout : "The Lorenz energy cycle in ORCA025 and ORCA0083"

Comparing Lorenz energy cycles, maps of EKE and EPE in ORCA025 vs MPIOM 1/10° vs ORCA12, shows that mean to kinetic energy transfers, which is the largest term in Agulhas region, ACC, GS (except for offshore extent), are systematically better represented in ORCA12 than in ORCA025. In the Subpolar Atlantic, ORCA12 is doing a much better job in the fine boundary currents. Eddy energies are 30% higher in ORCAO12 compared to its ORCA025 counterpart probably because of Hollingsworth instability. As a conclusion, the Lorenz cycle is qualitatively similar in ORCA025 and ORCA12 and the MPI-model, although eddy energies are 50% to 80% higher in ORCA12. The MPI model seems to have even larger values and discrepancies are surprising. EKE is more driven by baroclinic than by barotropic instability, but locally barotropic conversion has larger amplitudes than baroclinic conversion. It is more often multi-signed. The spatial scale of baroclinic conversion is smaller than for barotropic conversion, but the global average of baroclinic conversion increases more with resolution. Energy conversion in large (western) boundary currents is well resolved in ORCA025 but especially baroclinic conversion in weaker and narrower (eastern / northern / southern) coastal currents improves in ORCA12.

Clement Bricaud : "Superparameterisation of ocean dynamics for tracer transport models"

Coarsening ocean high resolution simulation is motivated because ocean mesoscale and submesoscale turbulence contribute to shaping the distribution of biogeochemical tracers distribution, but increasing resolution of the biogeochemical model is costly. The first step for coarsening is the construction of masks : umask and vmask used to closed passages between coarse grid cells have to be open. Several sensitivity experiments are run with an age tracer, using different solutions for coarsening the vertical diffusivity Kz: using a mean Kz yields too strong values. Validation is performed when vertical diffusion alone is activated. There seems to be a problem with advection when there are gradients at small scales. Limitations of the coarsening are the following: [1] grid spacing of the low-resolution grid should remain smaller than half the effective resolution of the high-resolution grid [2] in the case of high-resolution dynamical models with high spatial variance at grid scale (presumably numerical noise), the outputs of the biogeochemical model at low resolution may significantly differ from those of the biogeochemical model at high resolution, [3] temporal coarsening : factor 2 for the moment, [4] spatial coarsening : factor 3 for the moment. Here is the list of future plans of development: [1] compatibility with VVL (OK), [2] put in a branch in phase with NEMO 3.6.stable, [3] switching to eORCA025_LIM3, [4] development test to compare different solutions of NEMO OPA+PISCES : 1/4-1/4 and 1/4-3/4 to 3/4-3/4, [5] parameterisation of vertical velocity variance (additive vertical diffusion term), [6] long simulations to compare 1/4-1/4 vs 1/4-3/4 vs 1/4 offline 1day (as used in mercator forecasting systems and reanalysis) vs offline 1/4 1 month (CMIP5-IPSL), [7] Agrif.

2.2 Discussion : numerical and parameterisation issues

Mike Bell gave an introduction putting the discussion into the context of societal needs leading to modelling effort to answer various scientific questions. The numerical and parametrisation development that we should prioritise are those that help us answer the key science questions. The discussion was structured in three parts: 1) List issues with current simulations that are probably due to deficiencies in the numerics or parametrisations ; 2) Discuss ORCA025 specifically: ongoing issues? are parameter settings fixed? 3) Discuss what what information and coordination already exists and what sorts of outcomes Drakkar might aim for.

1) Issues with current simulations

The following issues were mentioned:

1. Southern Ocean warm bias in coupled models (partly an atmosphere problem).
2. Formation of AABW through open ocean convection rather than from shelf outflow.
3. Gridscale noise (especially for ORCA025) which degrades results from BGC models.
4. Poor representation of overflows.
5. Poor representation of connection between shelf and deep ocean in Antarctica – warm water doesn't get onto the shelves.
6. Problems in the Labrador Sea: salinity drift and distribution of deep mixed layers.

There was some discussion of how to diagnose problems:

1. For forced models might be better to look at 100m temperature rather than SST which is highly constrained by the fluxes.
2. Drifts in runs initialised with data assimilation are useful indicators of biases.
3. Coupled integrations could be useful to try to disentangle which parts of the SST biases are due to flux biases and which are due to ocean model biases.

2) Ongoing issues and parameter settings in ORCA025

The discussion centred around numerical noise in the vertical velocity field and the possible link to excessive numerical mixing.

1. ORCA025 is probably an awkward transition resolution. There may be a trade off between having more EKE and accepting a higher level of noise or having less noise but less EKE. The problem appears to reduce as you go to higher resolution.
2. Diagnosing numerical mixing is hard. There may be large mixing associated with the vertically coherent vertical velocities in eddies, as well as large mixing associated with the noisy velocities.
3. An available solution now would be to move to higher vertical resolution – we know that this improves things, e.g. the experiment done at Grenoble with ORCA025 with 300 vertical levels.
4. There was some discussion of alternative vertical coordinates as a way of reducing numerical mixing. It is thought unlikely that the z tilde coordinate will help with the

noisy velocity fields.

Regarding the optimal choice of parameters, Adam Blaker mentioned experiments that he is planning to do systematically exploring the parameter space for ORCA025.

3) Shared information, coordination and goals

Julien Le Sommer proposed the following four areas of coordination for 2016:

1. Diagnosis of the impact of numerical noise in ORCA025 and possible ideas for reducing it.
2. Work on the protocol for OMIP forcing.
3. Determination of optimal parameters for LIM3 at high resolution.
4. Sharing information on freshwater forcing at high latitudes.

There was some discussion of the best way to coordinate activities and what can realistically be achieved given that people have limited time to commit to coordination activities.

1. Julien suggested an informal online wiki page or forum where people could post information that might be of general interest.
2. It was agreed that it would be useful if there was some documentation of the different groups' configurations. Some are documented already with GMD papers or reports. The use of "shaconemo" should be generalized.

3 Variability of the turbulent physical/biogeochemical ocean

Session report: Arne Biastoch (GEOMAR), Thierry Penduff (LGGE) and Pat Hyder (UKMO).

3.1 Session summary part 1: variability, coupling, biogeochemistry

The session focused on a series of talks on the importance of increased ocean resolution on coupling to the atmosphere and biogeochemistry.

Pat Hyder reported on the UK MO/NOC consistent coupled HadGEM3 (and ocean-only) runs at various atmosphere and parameterised, permitted and resolved eddy ocean resolutions. An N512-1/12th coupled simulation demonstrated some improvements compared to an equivalent N216-1/4 run, e.g. reduced Southern Ocean and mid latitude SST biases, reduced ACC drift, better-represented boundary currents and associated air-sea flux, etc.

By using idealized experiments with biogeochemistry with a horizontal resolution of up to 1/54°, Marina Levy (LOCEAN) demonstrated the importance of the mesoscale turbulence in driving large biogeochemical interannual variability at mid and high latitudes. The intrinsic variability also reflects in the spring bloom. Marion Gehlen, Roland Séférian, and Virginie Racapé (both LSCE Orsay) contributed to the analysis of the chaotic contribution to the variability of biogeochemical tracers at interannual timescales, e.g. by determining that about 10% of the global scale variability in geochemical fluxes can be attributed to intrinsic variability, up 30% locally (i.e. Southern Ocean).

As an example of an interdisciplinary study with societal relevance, Arne Biastoch (GEOMAR) reported on a joint DRAKKAR initiative to back-trace the flight MH370 flaperon found at La Reunion in 2015.

Jan Klaus Rieck (GEOMAR) presented an analysis of the seasonal cycle of EKE in ORCA025 and ORCA12. He concluded that wind stress does not seem to the main driver of EKE seasonality.

3.2 Discussion items part 1

The discussion started with points raised by Marina Levy on the quality of current biogeochemical models, their requirements in terms of physics, numerics and resolution, and the question what can be learnt from biogeochemistry (BG) to constrain the physical model. It was agreed that the mean distribution, maybe also the seasonal variance, is reasonably represented. However, below the seasonal timescale little variability exists in the models. Hereby, it is important to note that biases in the (physical) mixed layer depth are as bad as the BG fields itself. It was emphasized that the atmospheric forcing, in particular in upwelling zones, is crucial for a successful presentation, not only for the physical but also the BG distribution. Thierry Penduff (LGGE) motivated sensitivity experiments, e.g. with constrained surface fields (SST or fluxes). Finally, it remained unclear how much the uncertainty comes from the BG model, how much from the physical model, how much from the uncertainty in the atmospheric forcing. It was concluded that the intrinsic variability in BG (that is currenty not represented by the equations) should be taken into account.

In respect to air-sea exchange, huge fluxes in western boundary current regions were mentioned, connected to the questions on their impact on model biases. It was also reported that coupled seasonal forecast models employing 1/4° ocean resolution simulate a low signal to noise ratio when predicting the NAO. The cause is not yet known but ocean resolution is one of several candidates.

3.3 Session summary part 2 : intrinsic variability

In a second part of the session, the internal variability of the ocean circulation was reported and discussed.

Thierry Huck (LPO Brest) reported on the horizontal structure of unstable basin modes due to large scale baroclinic instability and demonstrated that growth rates strongly dependent on viscosity in idealized ocean models. In contrast, larger viscosity shifts instability to longer wavelength.

In a series of contributions from the OCCIPUT project, Laurent Bessières (CERFACS), Stéphanie Leroux (LGGE) and Thierry Penduff (LGGE) described the stochastic nature of the ocean variability at 5-daily-to-decadal timescales, using ensembles of 1/4° ocean/sea-ice hindcasts perturbed initially then forced by the same DFS forcing. Three ensemble hindcasts were compared: two North Atlantic 20-year ensembles (10- and 50-member) differeing by their forcing, and a global 50-member ensemble performed over 1958-2014. The probabilistic version of NEMO allows the online computation and use of ensemble statistics at each timestep. The intrinsic variability estimated by the ensemble spread emerges and saturates within a few months/years. This interannual-to-decadal chaotic variability substantially impacts SSH, SST, MOC, and water mass features (depth, spiciness, potential vorticity, etc), and can locally exceed the atmospherically-forced standard deviation in eddy-active regions and at depth.

3.4 Discussion items part 2

The discussion was centered around the question of whether stochastic parametrization and probabilistic modelling approaches could be a way forward in the DRAKKAR context. It was agreed that ensemble simulations are interesting to estimate both dynamical uncertainties (e.g.

intrinsic variability that spontaneously emerges from initial perturbations) and model uncertainties (regarding forcing, subgrid-scale parameterizations, numerics). Comparing these may help identify the main sources of uncertainty in ocean models, hence target the most critical parameters for model improvements.

NEMO's stochastic noise generator may be applied to various terms of model equations (examples are provided in Brankart et al, GMD 2015, as an extension to Juricke et al J. Clim 2013). Probabilistic metrics (CPRS, Brier scores, rank histograms) and tools have been developed in MEOM during the SANGOMA project to robustly assess ensemble simulations against observations; they are available for assessing OCCIPUT runs. It was mentioned that combining ensemble simulations with Bayesean statistics may be useful to e.g. explore and reduce a model's parameter space ("history matching" methods, see Williamson et al., Clim Dyn 2013), or to build statistical emulators that help understand the behavior of complex/nonlinear OGCMs simulations (see Tokmakian et al., JAOT 2012).

4 Ocean Global Circulation Models: Evolutions, performances and diagnostics

4.1 Diagnostics and algorithms

Mehmet Ilicak presented a new method to quantify the spatial distribution of spurious mixing in ocean models. The method has been applied to idealized experiments such as the "lock exchange" test case. A manuscript is in preparation for Ocean Modelling.

Two presentations focussed on potential problems with ORCA025:

1) Alex Megann estimated watermass transformations rates from cabelling, but the preliminary results are not robust yet.
2) Julien le Sommer and Claude Talandier mapped the grid scale noise in vertical velocities. The noise is large in ORCA025 simulations with 46 or 75 levels. It is reduced considerably by moving to 300 levels, and also reduced at higher horizontal resolution. What is the impact of this vertical noise on the quality of the solution? We need to know in order to decide how much we need to reduce it by, e.g, increasing the horizontal mixing.

Sergey Danilov presented an analysis of the convergence of the solutions for sea ice rheology, using the VP. vs. EVP rheologies. A new approach, "adaptative EVP", is proposed in a paper published in Ocean Modelling (Kimmritz, Danilov and Losch, 2016, doi:10.1016/j.ocemod.2016.03.004).

4.2 NEMO : performances and evolution

Fritz Kruger presented an analysis and Improvement of Computational Performance of NEMO, using ORCA05. The small number of grid points for ORCA05 limits the scalability relative to larger configurations such as ORCA12.

Julien le Sommer presented the way forward, from NEMO 3.6 to NEMO 4.0. NEMO3.6 has been released and validated in 2015. Preliminary steps (simplification) will be undertaken in 2016 to start preparing the next major release (NEMO 4.0). The new version will be a significant step, with new numerical schemes that will produce less spurious diapycnal mixing. The NEMO documents describing the annual work plans and the characteristics of NEMO 4.0 are available on the NEMO web site to registered NEMO users. A European project "COPPER", coordinated by Mike Bell (U.K. Met Office) has been submitted to support the development of NEMO 4.0.

5 Final discussion: Drakkar and the way forward

5.1 Benefits of DRAKKAR

A survey has been done regarding the benefits of DRAKKAR to the community.

Scientific benefits
Scientific exchanges at DRAKKAR meetings (in an informal and honest atmosphere), share new concepts and analyses, access up to date information on science made with NEMO configurations, get information on problems encountered by numerical modellers, that can lead to new theoretical and mathematical research topics. Good opportunity to present new science and get valuable feedback (for senior scientists as well as students). Opportunities for new collaborative projects.

Technical benefits
"State of the art" information on NEMO strengths, weaknesses, namelists, etc.
"State of the art" information on supercomputing for ocean models.
Stimulate new development based on NEMO and feedback to other users
Avoid reproducing common errors, thus saving time
Learn about model biases, how they depend on resolution and forcing.
"labelled" model configurations, useful when writing a paper, applying for computer resources...
Centralized distribution of configurations (NEMODRAK) and tools, distribution of forcing datasets,
Information on NEMO-based reanalyses and operational products.

Visibility
Help for growing communities working with NEMO (e.g., in Canada), enhanced recognition of each group's work, knowledge of what other groups are doing,

A few weaknesses of DRAKKAR have also been noted:
- few collaborations as a group within FP7/H2020 projects (except for MyOcean/MyOcean2)
- difficulty to make progress on "resisting flaws" (overflows, spurious mixing)
- simulations performed by the groups sample parameter space rather randomly, not systematically.

5.2 Drakkar coordination, meetings and GDRI

The coordination and the Grenoble meeting are supported in part by a GDRI (international Research Group), a French funding scheme that allows the French participants to benefit from CNRS and Ifremer funding. Geomar and NOCS are presently partners of the GDRI, which is supported for four years, 2014-2017. Contact will be made with CNRS to know the time frame to submit a proposal for renewal of the GDRI over years 2018-2021. The proposal may have to be submitted either in the autumn 2016 or 2017. The focus of the GDRI 2014-2017 is the coordination of forced ORCA12 simulations and the development of ORCA025 for CMIP: these goals will be revisited for the new proposal. This will be discussed at the next Drakkar meeting in January 2017 in Grenoble.

5.3 Forcing sets

LGGE does develop DFS any longer, because the plan for the international community of to use the new forcing set based on the Japanese reanalysis JRA. This has been decided during the CLIVAR OMDP meeting in Grenoble in 2015. Results of different simulations using JRA have been presented at the OMDP meeting in Japan in January 2016.

The forcing DFS5 has been designed to be easily updated for the most recent years, as far as ERA-Interim is continued. Only the precipitation field requires a special treatment that takes time. Raphael Dussin (Rutgers) is still willing to help update DFS5.2. The update of DFS5.2 to 2015 will be available in February 2016.

A discussion about the wind stress calculation for forced ocean-ice models (absolute vs relative winds?) is ongoing within OMDP, coordinated by Peter Gaube (APL, Univesity of Washington).

5.4 ORCA025 development

ORCA025 sensitivity experiments initiated in 2015 are still ongoing. Reports have been presented this year on grid scale noise and coarsening. We need one person to report on additional items for the next meeting:
Eddy parameterisations: Arne Biastoch
Lateral boundary conditions for physics: Mike Bell
High latitude freshwater forcing: Julien le Sommer

George Nurser is coding results from the UK OSMOSIS project into NEMO v 4.0, which will provide a parameterisation of Langmuir turbulence. He is interested in participating in (but not leading) a working group on vertical mixing and the formation of spurious polynyas (the issue is that there is evidence from C. Heuze at al that the addition of extra vertical mixing could help reduce the spurious formation of polynyas in the Weddell gyre).

Simulations have been run at LEGI with ORCA025.L300 (3 10-years runs with 300 vertical levels, sensitivity experiments with different advection schemes and representations of the bathymetry). The analysis is starting.

A dedicated workshop for the NEMO-based ocean components of Earth System Models, ORCA1 and ORCA025, has been organized by the NEMO system team (just following the DRAKKAR meeting).

5.5 ORCA12 development

New simulations have been run in 2015:
- At NOCS a run from 1958-2015 has been run with the ORCA12.L75, using NEMO 3.6 and LIM2, forced by DFS5.2. This run includes the MEDUSA biogeochemical model from 1990 - 2015.
- At LEGI, the run ORCA12.L46-MJM189 has been completed using NEMO 3.5, forced by DFS5.2. The run has been continued to 2015 when the latest years have been added to DFS5.2, in February 2016.

The plan at LGGE is to run a new simulation with e-ORCA12.L75 in 2016, with NEMO3.6 and LIM3 sea ice model. The grid e-ORCA12 is extended South into the Weddell and Ross Seas. The new bathymetry, grid and runoffs are ready (collaboration with Mercator and the U.K.).

At CMCC ORCA12 is not used but their global NEMO-based model has a similar resolution (1/16°). CMCC asks to be included in discussions about ORCA12.

The following suggestions are made:

- the ORCA12 configurations should be shared using shaconemo.
- the first step is a French-U.K meeting to first share with each other and then make everything available to a larger group. This meeting should be prepared during the Exeter Workshop in April.
- phone/videoconference meetings should be held more regularly during the year.

5.6 Toward higher resolution

At GEOMAR, the strategy is to use AGRIF nests in ORCA025, like Viking (1/20° North Atlantic). The benefit of going from 1/12° to 1/20° is very significant, regarding the subpolar gyre dynamics and the overflows. New nest are planned, one full Atlantic nest and one Agulhas nest.

LGEE has a proposal to run more experiments with NATL60 (1/60° North Atlantic with 300 vertical levels), in the context of the preparation of the SWOT satellite mission. A short report describing the 2015 NATL60 experiment is available on the DRAKKAR monitoring web site.

6 List of ORCA12 publications

6.1 Peer-reviewed, published in 2014

Deshayes, J., A.M. Treguier, B. Barnier, A. Lecointre, J. Le Sommer, J.M. Molines, T. Penduff, R. Bourdalle-Badie, Y. Drillet, G. Garric, R. Benshila, G. Madec, A. Biastoch, C. Böning, M. Scheinert, A.C. Coward, J.J.M. Hirschi: Oceanic hindcast simulations at high resolution suggest that the Atlantic MOC is bistable. Geophysical Research Letters. vol 40, issue 12 3069–3073, DOI: 10.1002/grl.50534

Drillet, Y., Lellouche, J. M., Levier, B., Drévillon, M., Le Galloudec, O., Reffray, G., Regnier, C., Greiner, E., and Clavier, M., 2014: Forecasting the mixed layer depth in the north east Atlantic: an ensemble approach, with uncertainties based on data from operational oceanic systems, Ocean Sci. 10, 1013-1029, doi:10.5194/os-10-1013-2014,

Duchez, A., E. Frajka-Williams, N. Castro, J. Hirschi, and A. Coward, 2014: Seasonal to interannual variability in density around the Canary Islands and their influence on the Atlantic meridional overturning circulation at 26N, J. Geophys. Res. Oceans, 119, 1843–1860, doi:10.1002/2013JC009416.

Ferrari, R., Provost, C., Park, Y.-H., Sennéchael, N., Koenig, Z., Sekma, H., Garric, G., Bourdallé-Badie, R., 2014: Heat fluxes across the Antarctic Circumpolar Current in Drake Passage: Mean flow and eddy contributions. J. Geophys. Res., 119, 6381-6402.

Hughes, C.W., J. Williams, A.C. Coward, and B.A. de Cuevas, 2014: Antarctic circumpolar transport and the southern mode: a model investigation of interannual to decadal timescales. Ocean Science, 10, 215–225.

Treguier, A.M., J. Deshayes, J. Le Sommer, C. Lique, G. Madec, T. Penduff, J.-M. Molines, B. Barnier, R. Bourdalle-Badie, and C. Talandier, 2014: Meridional transport of salt in the global ocean from an eddy-resolving model. Ocean Sci., 10, 243-255, 2014

6.2 Peer-reviewed, published in 2015

Barrier, N., J. Deshayes, A.M. Treguier and C. Cassou, 2015: Heat budget in the North Atlantic subpolar gyre: impacts of atmospheric weather regimes on the 1995 warming event. Progress in Oceanography, 130, 75-90.

Blaker, A., J. Hirschi ,_ G. McCarthy, B. Sinha, S. Taws , R. Marsh, A. Coward, B. de Cuevas, 2015: Historical analogues of the recent extreme minima observed in the Atlantic meridional overturning circulation at 26N. Climate Dynamics, 44, 457-473.

Grégorio, S., T. Penduff, G. Sérazin, J.-M. Molines, B. Barnier, and J. Hirschi : Intrinsic variability of the Atlantic Meridional Overturning Circulation at interannual-to-multidecadal timescales. J. Phys. Oceanogr., 45, 7, pp. 1929-1946.

Marzocchi, A., J.M. Hirschi, P. Holliday, S. Cunningham, A.T. Blaker, A. Coward, 2015: The North Atlantic subpolar circulation in an eddy-resolving global ocean model, Journal of Marine Systems. Vol 142, 126-143. doi:10.1016/j.jmarsys.2014.10.007

Rieck, Jan Klaus, Böning, Claus W., Greatbatch, Richard John and Scheinert, Markus (2015) Seasonal variability of eddy kinetic energy in a global high-resolution ocean model Geophysical Research Letters, 42 (21). pp. 9379-9386. DOI 10.1002/2015GL066152.

Rühs, S., Getzlaff, K., Durgadoo, J. V., Biastoch, A. and Böning, C. W. (2015) On the suitability of North Brazil Current transport estimates for monitoring basin-scale AMOC changes Geophysical Research Letters, 42 (19). pp. 8072-8080. DOI 10.1002/2015GL065695.

Sérazin, G., T. Penduff, S. Grégorio, B. Barnier, J.-M. Molines, and L. Terray, 2015 : Intrinsic variability of sea-level from global 1/12° ocean simulations: spatio-temporal scales. J. Climate, 28, 4279–4292.

Steinle, L., C. Graves, T. Treude, B. Ferré, A. Biastoch, I. Bussmann, C. Berndt, S. Krastel, R. H. James, E. Behrens, C. W. Böning, J. Greinert, M. Scheinert, C.-J. Sapart, S. Sommer, M. F. Lehmann, and H. Niemann, 2015: Water column methanotrophy controlled by a rapid oceanographic switch, Nature Geoscience, 8, 378-382, doi: 10.1038/NGEO2420.

Vivier F., Park Y.-H., Sekma H. and Le Sommer J., 2015: Variability of the Antarctic Circumpolar Current transport through the Fawn Trough, Kerguelen Plateau. [doi] Deep Sea Research II, 114, 12-26.

6.3 Peer-reviewed, published in 2016 and in press

Akuetevi C.Q.C, B.Barnier, J.Verron, J.-M.Molines and A. Lecointre, 2016:
Interactions between the Somali Current Eddies during the Summer Monsoon: Insights from a numerical study. Ocean Science, 12, 185-205, doi:10.5194/os-12-185-2016, 2016.

Heuzé, C., F. Vivier, J. Le Sommer, J.-M. Molines, and T. Penduff, 2015: Can we map the interannual variability of the whole upper Southern Ocean with the current database of hydrographic observations? J. Geophys. Res., in press.

6.4 Other publications

Drakkar Group, 2014: DRAKKAR: developing high resolution ocean components for European Earth system models. Clivar Exchanges, 65, 18-21.

Penduff, T., B. Barnier, L. Terray, L. Bessières, G. Sérazin, S. Grégorio, J.-M. Brankart, M.-P. Moine, J.-M. Molines, and P. Brasseur, 2014 : Ensembles of eddying ocean simulations for climate. CLIVAR Exchanges, Special Issue on High Resolution Ocean Climate Modelling, 65, Vol 19 No.2, July 2014.