Report of the DRAKKAR meeting
Grenoble, 26-28 january 2015

<u>Organizing committee</u>
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The meeting was organized in four sessions (see agenda on the Drakkar web site, www.drakkar-ocean.eu).

Session 1: Global ocean modelling: toward higher resolution.
This session presented results from high resolution global models such as ORCA12, and from global models with improved resolution locally (for example with AGRIF zooms). The presentations were the basis of a discussion on the different strategies to reach higher resolution for a better representation of ocean processes in the global domain.

Session 2: Mixing processes in ocean models: spurious numerical mixing and parameterization of real mixing.
Presentations on mixing effects of internal waves, mixing in boundary layers, mixing downstream of overflows, and numerical /parameterizations issues of their representation in models, including reports from projects such as OSMOSIS (U.K.), SMOC or COMODO (France).

Session 3: ORCA025 as an ocean component for coupled climate models: the search for optimal configuration settings and parameters.
This session summarized our knowledge of the "best settings" for ORCA025, with presentations by different groups of their ORCA025 configuration and the tests and validations they have performed to support their choice.

Session 4: Forcing/coupling strategies
This session was focused on the limitations of forced ocean models, the challenges of coupling with the atmosphere, and other possible strategies to represent the variability of the past decades (e.g., partial coupling, coupling the ocean to an atmospheric boundary layer model, restoring the atmospheric model). This session was an introduction to a dedicated CLIVAR workshop organized by the Ocean Model Development Panel (chairs: G. Danabasoglu, NCAR, and S. Marshland, CSIRO). The workshop took place on January 29th and 30th.

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 are password-protected, as results presented at the DRAKKAR meeting are usually new and preliminary. The aim of the DRAKKAR consortium is to coordinate high resolution global simulations using the ORCA12 model based on NEMO. The annexes provides updated information on the strategy of the different groups, the ORCA12 experiments available or planned, and an updated list of publications based on ORCA12.

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1. Global ocean modelling: toward higher resolution.

Session report: Arne Biastoch, Julie Deshayes

1.1 Session summary and highlights

The session focused on a range of results with high-resolution models, with global or regional focus, in ocean-only or coupled mode. Apart from promising improvements achieved by the resolution of mechanisms, aspects were identified and discussed that require further consideration. These include: model drift in coupled mode, choices for parameterizations, and previously unresolved mechanisms (such as internal waves).

Steve Griffies reported on a series of coupled model experiments with the GFDL CM2-O model suite in which the ocean component was resolved at 1°, 1/4° and 1/10° resolution. Analyses of the ocean heat and model drift under committed warming using 1990 radiative forcing showed that mesoscale eddies act as a gatekeeper for how much heat is pumped into the ocean interior. The comparison between eddy advective processes (through GM in the 1° case) vs. eddy diffusive processes (resolved in the 1/10° case) was unclear at 1/4° resolution, with the latter acting as an outlier in the temperature drift and interpretation of the heat budget. Implications for biogeochemistry due to improved cross-frontal transport in the Southern Ocean in the 1/10° case were presented by Carolina Dufour.

ORCA12 analyses by Adrian New underlined the importance of considering sidewall boundary conditions, topography, advection schemes, even at 1/12° resolution, for a proper representation of the Gulf Stream separation. Julie Deshayes presented energy analyses of the Agulhas Current system in ORCA12 and a quantification of Agulhas leakage among different high-resolution models.

The subpolar North Atlantic was in the focus of talks by Claude Talandier and Arne Biastoch, with nested configurations (FER at 1/32°, VIKING20 at 1/20°) specifically set up to resolve the mesoscale in the subpolar North Atlantic. Both analyses demonstrated the importance of West Greenland Current eddies on the convection in the Labrador Sea. VIKING20, with high resolution up to 82°N, also simulates an improved Denmark Strait overflow, with the benefit of an improved representation of the mid-latitude AMOC.

Configurations with significantly enhanced resolutions were presented by Jean-Marc Molines (1/60° North Atlantic) and Julien Juanno (1/36° tropical Atlantic). Both configurations start to resolve internal waves, demonstrating the importance of further work on subgrid closures and the need to represent tides. The 1/60° configuration acts not only as a high-end technical challenge, but also serves to study upper ocean turbulence (Phillips vs. Charney regimes).

1.2 Discussion items

The discussion started with individual reports from different groups. Apart from the main missions (e.g., MetOffice improving weather and climate forecasting), there is a clear interest towards the role of the sub-mesoscale in large-scale dynamics. This points towards the continuous need to run nested models at significantly higher resolution.

In the open discussion, Steve Griffies pointed toward the necessity to revisit the sidewall boundary conditions. As a direct consequence of the strong sensitivity, even at high resolution, new concepts should be developed. It was mentioned that the real ocean has no sides, thus the no/partial/free slip boundary conditions are rather artificial, and could be replaced using bottom friction also at the sides.

A loose discussion took place at aspects of the ocean heat uptake, in particular in the Southern Ocean and the warming hiatus. Apart from the need to tackle these issue with coupled models, specific emphasis was given to the need to go beyond the current way of forcing the ocean hindcasts by using Bulk formulae. The atmospheric boundary layer model (CheapAML) was seen as a promising compromise between Bulk forcing and a fully coupled model. Despite ongoing efforts, the application of CheapAML was seen as a research question, rather than a standard component.

2 Mixing processes in ocean models

Session report: Julien Jouanno, Adrian New, Steve Griffies

2.1 Session summary and background

This session identified issues with numerical (spurious) mixing, mixing effects from the inclusion of real processes in models, and the development of parameterisations of real processes which are responsible for mixing the ocean. The discussion summarized issues arising from both this session and the previous session on high-resolution global modeling. There were five general issues identified for the discussion, of which there was time to cover the first three only.

Background

Explicit mixing is defined through the harmonic/ biharmonic diffusion terms, which have an explicitly defined viscosity or diffusivity. These viscosities or diffusivities come from eg the TKE/KPP scheme and are attempts to represent sub-grid scale processes which are not resolved by the model. Models can also include explicit processes such as internal tides which can propagate, but their energy is mopped up by the explicit terms. Although these are numerical choices, we define these as explicit mixing terms.

Spurious diapycnal mixing, on the other hand, results from numerical discretization, specifically through the choice of tracer advection schemes, which usually result in dispersion or noise (small scale and unphysical gradients) which are mopped up by the explicit mixing terms. Such mixing can be much larger (up to x10) than the explicit mixing in some cases (Megann), though other models (MOM) report lower levels of spurious mixing (typically 20-30% of the explicit mixing)

2.2 Discussion items

2.2.1 Issue 1: What do we understand by spurious mixing and explicit mixing?

1. Diagnosis of spurious mixing. The methods for diagnosis of spurious mixing are very complex, and the numbers coming from the diagnostics can be non-robust. It is important to use multiple methods to diagnose spurious mixing, such as watermass analysis, sorting methods (Griffies et al 2000, Ilicak et al 2013), and passive tracer methods (Hill et al 2012). However, it seems that there is no clean or optimal way to diagnose mixing, since isopycnal mixing along neutral surfaces has a diapycnal effect, so that the effective diffusivity in a model is different from the explicit (specified) diffusivity (ie even with no explicit diffusivity or numerical mixing, the actual diffusivity in a model will be non-zero). Nonetheless, sigma-2000 may in fact be a useful definition for density surfaces for spurious mixing diagnostics, since much of the spurious mixing is in fact found near 2000dbar (Megann).

2. Energy routes. There is no clean way to diagnose the energy routes and energy consumption in NEMO (from energy inputs at the surface, through processes at various spatial scales in the model, and ultimately into mixing). As identified in the NEMO white paper, more work needs to be done to better understand these concepts, and to better understand and diagnose spurious mixing. This work should be undertaken by the scientists using NEMO, rather than by the systems team. One example of what needs to be done would be to diagnose the mechanical energy budget (including dissipation by the tendency terms in the momentum equations). In addition, the contribution of the time-stepping schemes need to be identified. A formal document is needed to describe what needs to be done.

3. Impact of spurious mixing. The impact of spurious mixing is not clear. If there really is large spurious mixing which swamps the explicit mixing, then we should not see much change in our simulations when changing the explicit diffusivity, but we do. However, in global models, spurious mixing seems largest in the upper, mid- and intermediate-deep waters, at low and intermediate latitudes (Megann), but is lower in near-bottom and high-latitude regions. This could explain why there could be a relatively low impact of spurious mixing (ie mixing matters the most in deepest waters). In any case, spurious mixing would be dependent on the grid-scale Reynolds number, so could be very different between models (eg the apparent differences between NEMO and MOM referred to above). It is furthermore interesting to note that the regions of high spurious diffusivity noted by Megann are similar to the regions of high diffusivity from breaking internal tides identified by de Lavergne, so that in models which include internal tides, the ratio of spurious to non-spurious mixing in these regions might be lower than found by Megann.

4. We should distinguish **spurious lateral versus spurious vertical mixing**, as they have different impact on potential energy (e.g., Ilicak et al 2013). We should also be careful about numerical unmixing (e.g., Hecht et al work).

5. Spurious mixing is expected to be dependent on the **roughness of the bottom topography**. Rough topography injects small scales in the dynamics that can enhance

spurious diffusion. This raises the question of whether or not to filter/smooth the topography (note that this is not done at GFDL).

6. Spurious mixing, ie affecting the w field, can be of **high impact on biology.**

2.2.2 Issue 2: What numerical approaches can we adopt to reduce spurious mixing?

1. Introduction (New): Possible options could include (a) increasing the lateral viscosity (x 3 -10?): biharmonic viscosity in orca025 is currently -1.5×10^{11} m^4 s^{-1} - but this could dampen small-scale realistic variability; use of z-tilde or ALE coordinate schemes (such as in HyCOM and MOM6); use of higher order advection schemes (eg Prather).

2. There are problems with biharmonic Smagorinsky viscosity with the way it is coded in NEMO (Le Sommer). There are generally many problems with piece-meal implementations of various parameterization schemes in NEMO. It is important to have a self-consistent perspective to upgrade the overall framework and better understand the energy routes, grid Re number, etc., all part of Version 4 of NEMO.

3. Vertical coordinate systems. Should we routinely run with z-tilde to reduce spurious mixing? There are currently unresolved issues with how z-tilde interfaces with the partial step option for bottom topography (Le Sommer) so that z-tilde is currently unstable in ORCA02. Is it possible to run ORCA025 with z-tilde and with no partial bottom steps? Perhaps it is more important to run z-tilde than partial bottom steps (Nurser/New). Perhaps we really need z-tilde only when running with tides (Treguier)? But there is much near-inertial wave energy in the models due to wind forcing too, so maybe z-tilde could be of use even without running with tides (New). There was generally little desire to uprate the priority for z tilde or other ALE type systems in NEMO even though HyCOM and MOM6 are ALE (and note that ALE includes wetting and drying). One reason for this is that the remapping schemes in the ALE systems need work (Le Sommer/ Madec).

4. Partial steps. Partial steps interfere with a lot of numerical issues (impacts on numerics, physics, boundary currents, etc.) in NEMO and this is where we should put our effort, rather than into z-tilde (Barnier). Similar problems for partial steps in POP (Danabasoglu). But with enough z-levels, maybe we can do without partial steps (Ferrer). Mike Bell's work is a good start via understanding the fundamental numerics involved. Has there been an attempt to run NEMO at 1/10th degree, 1/12th degree or finer resolution with and without partial steps, to diagnose how important the partial steps are? The earlier work of Penduff et al, which showed model improvements at lower resolutions, may need to be revisited (Nurser).

5. Terrain-following coordinates. If we switch to terrain following coordinates, then we may resolve issues with partial steps, but then will have pressure gradient errors (Deshayes). Also, a terrain following model has lots of spurious mixing due to mis-alignment of sigma and rho/z surfaces. It may also be useful to rotate the diffusive portion of the advection operator a la Lemarie's work with ROMS (Danilov).

2.2.3 Issue 3. Mixing of dense outflows

1. Introduction (New). Outflows (eg Denmark Strait) affect properties of NADW and will affect performance of climate models on long timescales. So we could just do nothing

about the outflows if interested in shorter timescales only. Outflows better in VIKING 20, so do we need to run a high resolution nest in climate models? What about NATL60 – is there continued improvement, and if so, at what resolution is convergence achieved? What about use of s-coordinates in outflow regions (mixed z-s coordinate do better job of dense water cascading from shelves)? Should we use the NCAR stream tube model? (New)

2. VIKING 20. Viking20 looks surprisingly good for N Atlantic overflow regions (Biastoch): good transport, water masses, etc. We also need to have high resolution in a broad region surrounding the overflow region to get good inflows and outflows. Note that the ORCA12 and Viking20 water masses are quite similar. But what is key in Viking20 is the downslope flow, even though it does not fully resolve the entrainment processes. The model has been run 60 years, and it maintains the outflow well throughout the simulation. Gokhan: Legg and Chassignet did regional modeling of NAtl overflow regions - we really need fine vertical resolution to get the entrainment correct, even with $1/20^{th}$ degree simulations.

3. Relation to larger scale flows. AMOC improvements in $1/8^{th}$ degree simulations also arise from improved boundary currents. This is key, and may be simpler to get than overflows (Deshayes). There is also a clear relation between overflows and AMOC (Sinha). If Denmark Strait are wrong then Lab Sea convection adjusts very quickly so upper ocean (and intermediate) water masses in the N Atl respond v quickly – ie so dense outflows matter on shorter timescales than centenntial.

4. Use of terrain-following coordinates? Bernard has a PhD student who will investigate terrain following, sigma-z, and AGRIF nesting.

5. NCAR streamtube model. This is tough to implement (Danabasoglu) and has not been implemented in the NCAR $1/10^{th}$ model - note however that Gibraltar has reasonably good overflows in the $1/10^{th}$ model even without overflow parameterisation. This was also found in OCCAM.

6. Griffies: the Lagrangian blobs (Bates et al) are not a perfect solution. There are many issues.

2.2.4 Issue 4. Internal, Inertial and Lee waves

1. Introduction (New). Waves carry energy away from the surface (inertial, NATL 60, Julien, Xavier ACC) or topography (internal tides, lee waves) into the interior and will mix somewhere, but where is the energy carried to and how is it dissipated? Energy is mopped up by harmonic or biharmonic friction term (for momentum), which is an artificial choice, so this will define how far the internal tides and inertial waves can propagate. Internal tides may propagate too far? Vertical structure function for internal tide dissipation F(z) is a choice we make (max in thermocline or exponential decay from bottom): how realistic is this? (Melet et al 2014, proposes vertical structure function from theory of Polzin.) Transfer of internal tide energy to internal solitary waves through nonlinear processes is not captured. How do we parameterize the dissipation from waves in a more realistic way in terms of resolved model variables? E.g. a Richardson number scheme for internal waves?

2.2.5 Issue 5. Boundary layer processes (and how to parameterise)

1. Introduction (New). We should discuss Langmuir turbulence and shear spiking (OSMOSIS project in the UK); restratification by sub-mesoscale processes (Fox-Kemper etc); geothermal heating (do we know the sources well enough?); mixing in the marginal ice zone.

3 ORCA025 as an ocean component of coupled climate models

Session report: Julien Le Sommer and Matthieu Chevallier.

3.1 Session summary and highlights

Context: Several groups have planned to use ORCA025.L75 for CMIP6 and/or OMIP intercomparison. This includes UK-ESM (MetOffice, NOC), CMCC, IPSL, CNRM-CERFACS, EC-Earth and GEOMAR (only for OMIP). A fraction of these institutions are not member of NEMO consortium. On the french side, the two ESMs have decided to share a number of activities for preparing ORCA1 and ORCA025 for CMIP6. In practice, the two systems will be very close except for the sea ice component, and possibly for vertical physics.

Presentations during this session can be sorted in two categories: presentations reporting on novel components that are meant to be included in global coupled climate models for CMIP6 (especially: sea ice model and freshwater forcing in southern hemisphere high latitudes) and presentations on uses of ORCA025 (sometimes within a hierarchy of configurations).

Sea ice:
Martin Vancoppenolle described current features in LIM3.5. LIM3.5 has now been extensively tested with ORCA2, ORCA1 and ORCA025 configurations. CPU cost increase induced by multi-category could be compensated by using only 2 vertical layers in sea ice (plus one for snow). Additionally, the coming release of LIM3 will feature a virtual ice thickness distribution that emulates the effect of 5 categories while only running with one category. NEMO3.6 will be the last version with LIM2. Plans for LIM3.5 comprise a number of physical features (melt ponds, landfast ice) as well as structural developments (e.g. shared dynamical core for sea ice similar to the TOP interface).
Peteri Uotila presented an evaluation based on simulations of ORCA025.L75 with LIM2 and LIM3 in the stable NEMO3.4, using ERA-Interim as atmospheric forcing. Results show very different mean states in sea ice (thicker ice in LIM3), with differences reflecting in the upper and deep ocean. The presentation raises some questions on changes in methodology while using the new LIM3 (e.g. restarts, spin-up).
Stefanie Rynders presented preliminary results with ORCA2-CICE using a sea ice rheology that combines the widely used EVP in the pack ice and a collisional rheology (dependent on floe size and velocity fluctuations) in the marginal ice zone.

Southern Ocean and freshwater forcing:
Ignacio Merino presented a new climatology of iceberg freshwater flux around Antarctica usable as forcing for ocean model. This climatology is built using an updated

version of NEMO iceberg module, and shows promising results in terms of sensitivity of the sea ice cover in the Southern Ocean.
Pierre Mathiot presented the new parameterization for under-ice shelves melting, based on data from Rignot et al. (2013).
James Orr showed estimates of meridional carbon transport in a hierarchy of global (ORCA2, ORCA05, ORCA025) and regional Antarctic configurations, driven with DFS forcing using NEMO3.2 with LIM2 and PISCES. Sensitivity to the horizontal resolution and the use of GM parameterization is reported.

Studies with ORCA025:
Timothée Bourgeois reported on a first model assessment of air-sea CO2 fluxes in global coastal ocean, using ORCA2, ORCA05 and ORCA025 with PISCES, driven by DFS. The horizontal resolution does not seem to have a significant impact on the estimated coastal carbon budget.
Claus Böning presented some sensitivity tests from the Kiel group using ORCA025 based on NEMO3.4.1. The presentation focused on the GM parameterization and on salinity restoring under sea ice.
Laurent Bessières reported on the NEMO3.5 ensemble protocol for the ANR OCCIPUT project, and on the first results obtained with the NATL025 configuration. ORCA025 50-year 50-member simulations are planned during Spring 2015.

Other related presentation:
Adam Blaker presented a method for statistical tuning of 21 ocean model parameters using ORCA2-LIM2 runs in ensemble mode, based on the 'history matching' techniques described by Williamson et al. (2014). Results show estimations of parameter uncertainty in ORCA2, and improved tuning of ORCA1 using information from ORCA2 tuning.

3.2 Discussion items and tables

The discussion session was mostly targeted at making a status of plans regarding participation in CMIP6 and OMIP and stating interests in a number of sensitivity tests to be discussed further for CMIP6.

A number of short oral presentations have been given in introduction to the discussions

- Matthieu Chevallier : Plans at CNRM-CERFACS
- Clement Bricaud : Brief status on the coarsening
- Laurent Brodeau : Plans in EC-Earth ?
- Arne Biastoch : plans at GEOMAR

List of actions

- most groups intend to use NEMO 3.6 stable for CMIP6
- general agreement on sharing information on ORCA025 and configuration specific file through shaconemo wiki: https://forge.ipsl.jussieu.fr/shaconemo/wiki
- It is necessary to extend the ORCA025 grid southwards to represent the Ross and Weddell sea. To avoid too small grid cells the extended grid has two poles on Antarctica. The new grid eORCA025 and associated bathymetry will be released through the shaconemo wiki channel.

- CMIP6 specific files (e.g. xml specifiers) could also be share through this channel.
- a number of groups of interest for sharing information on sensitivity tests has been established with due contact points in each institution (see table 2)
- When using the new TEOS10 equation of state it is necessary to modify the initial conditions (conservative temperature must be used, not potential temperature).
- New initialization files are required for runoffs (specify the thickness of the runoffs)

Three issues have been raised :
-the CMIP6 "DECK" with ORCA025 is computationally expensive. Gokhan Danabasoglu notes that the DECK simulations require at least 1000 years of coupled runs and 300 years of ocean. To do this with an ocean model, it is necessary to have a throughput of many years of simulation per calendar day on a parallel computer. CPU cost and slow throughput might be problematic to complete the full DECK with ORCA025.
-a reflexion should be carried out on the fact that some modelling groups will need to initialize their ocean component with ocean reanalyses produced with NEMO but necessarily on the extended ORCA grid (ECMWF, Mercator),
-connections with national and international efforts on model outputs/diagnostics should be strengthened (e.g. ANR Convergence).

3.2.1 Plans for CMIP6, code version, specific features. (Table 1)

	DECK with	NE-MO v.	sea ice model	EOS	vertical physics	Initialization strategy	LBC for dynamics	Bathy	Ice cavities phys	Icebergs	free surface formulation	Vertical levels	Contact
CMCC	ORCA1	3.4-3.6?	CICE	?	?	?	?	Extended	Param version	Improved melt flux	NL	46 ORCA1	Dorotea Iovino
UK-ESM	ORCA025	3.6	CICE	?	TKE	WOA+PHC	Old EEN, free slip	"	Param	Explicit	NFL surface, TS?	75	Dave Storkey
IPSL	ORCA1	3.6	LIM3	TEOS10	TKE	PHC	New	"	param	tbd	NL free surface/TS	75	?
CNRM-CERFACS	ORCA1-ORCA025 ?	3.6	GELATO	TEOS10	TKE	Discus-sion with ECMWF for DEC forecasts	New	"	param	tbd	"	75	Matthieu Chevallier+Emilia Sanchez-Gomez
EC-Earth	ORCA1	3.6	LIM3	tbd	TKE	?	?	"	?	Improved melt flux	NL	46	Laurent Brodeau
GEOMAR	ORCA025	3.6	LIM2/3	Old	TKE	WOA+PHC	Old EEN, partial slip or	'	Param	tbd	Linear (?)	75	Markus Scheinert

3.2.2 Coordination of sensitivity experiments (Table2)

	eddy param	grid-scale noise	high latitude FW forcing	run-offs	coarsening	embedded sea ice	vertical physics/TKE	lateral BC for physics	Light penetration	output
CMCC				yes	?					
UK-ESM		yes		yes	?	yes	yes	yes		yes ccf
IPSL/Grenoble		yes	yes		yes			yes		yes. seb denville
CNRM-CERFACS			yes		yes					yes ANR CONVERGENC
EC-Earth			yes				yes			
GEOMAR	yes		yes					yes		
Mercator		yes	yes	yes	yes	yes	yes	yes		yes thickness
ECMWF			yes				yes		yes	
Lead		Alex	JLS	Dorotea	Clément	Andrew	George	Mike		Marie-Pierre

4 Forcing/coupling strategies

Rapporteurs: Laurent Brodeau and Sergey Gulev

4.1 Session summary and highlights

Yevgeny Aksenov presented results from forced ORCA025 simulations with a focus on surface fluxes, lateral transports and conservations issues in the Arctic. The approach is to obtain a better estimate of surface fluxes over the Arctic Ocean from lateral transports of volume, heat and freshwater (liquid+solid) as they are more reliable than other diagnostics. These lateral transports are computed off-line from high-resolution NEMO simulations (both ORCA025 and ORCA12) driven by different atmospheric forcing (CORE, DFS4 and ERAi). Some simulations used the linear free surface and some others the non-linear. Errors and uncertainties when computing these transports off-line were carefully estimated. The results show that, when using this method, the volume budget is often more dependent on the resolution (NEMO) used than on the atmospheric forcing used. The seasonal flux of volume (liquid) into the Arctic is larger in the ORCA12 simulation than in the ORCA025 simulations except when they are maximal in the Arctic summer. Agreement between the different models is better when studying the heat flux. Same for the freshwater water flux except for the summer when ORCA12 seems to overestimate it, probably due to the strong SSS restoring applied in the ORCA12 run.

Claus Böning presented the first results from the work of Rafael Abel who is implementing a “cheap” AML model to force NEMO. The main motivation behind this move is to overcome the main caveat of the bulk approach which mimics an atmosphere with an infinite heat and water capacity and also to void spurious trends of the AMOC without using SSS restoring. In this AML model, the surface air temperature and humidity are let free to respond to the SST while the wind is completely prescribed and advects the resulting anomalies of temperature and humidity. The latent heat flux is ignored in the budget of boundary layer, only the sensible heat flux is considered. They compared 3 different 50-year long ORCA025 simulations starting from a 50-year long spin-up forced with CORE CNY forcing and strong SSS restoring: 2 of which still forced with CORE CNY (1 with strong SSS restoring the other without) and the third one forced by the their AML model. Results are very encouraging as they show that the AML-forced run does not lead to the usual linear decline of the AMOC seen in the two traditionally-forced runs. They show that the AML approach allows the air temperature to adapt to the SST just as in the real world, but that both are drifting away (together) from observations. By allowing a response to the fluctuations of the poleward heat transports of heat, the AML-approach allows for stronger heat loss to the atmosphere in summer and fall, which promotes the onset of Labrador deep convection through good pre-conditioning. The resulting sustained Labrador deep convection is in turn sustaining the AMOC.

Wonsun Park presented sensitivity studies with the Kiel Climate Model to reduce SST biases in the North Atlantic (Drews et al.) and tropical Atlantic (Harlass et al.) that are also common in other CGCMs. North Atlantic cold SST bias can be reduced by adjusting the path of the North Atlantic Current with a flow correction scheme that is a developed version of the semi-prognostic scheme. Although this correction scheme is efficient to reduce subsurface biases, surface biases can be further reduced with correcting surface fluxes, particularly the fresh water forcing. This suggests that proper representation both of the NAC path and freshwater forcing are important in reducing the North Atlantic bias in climate models. Therefore surface freshwater forcing should be considered further in the DRAKKAR development in addition to increasing ocean resolution in the North Atlantic. Tropical Atlantic warm SST bias can be reduced by increasing the atmosphere resolution both in horizontal and vertical, of which improvement is accompanied with improved surface wind stress. Therefore, when increasing horizontal resolution of the atmosphere, enhanced vertical resolution is indispensable in climate modeling.

Pat Hyder and colleagues talked on improving coupled and ocean-only ocean forcing errors, including the HadGEM3 Southern Ocean bias. They argued that forcing sets have significant errors, as the necessary surface variables are poorly observed. These errors, which are often larger than the impact of changing model resolution or configuration, limit our ability to adequately assess models (in combination with incorrect assumptions in the surface boundary condition and limited observational sampling). We employ a new net air-sea flux observational estimate developed by Reading University based on the method of Trenberth and Carron (2001). They then subtract CERES EBAF radiative fluxes to obtain a residual estimate for the turbulent fluxes (making the assumption that CERES estimates are accurate). These estimates suggest there are significant net flux errors in the HadGEM3 atmosphere only model (GA6 AM) and both CORE II and DFS4 ocean forcing sets when run above observed SST. In particularly they also highlighted large errors in Southern Ocean turbulent fluxes and short wave in the HadGEM3 GA6 AM, which prompted a considerable assessment and development effort – in particular they have optimised a new MODE aerosol scheme and developed a new mixed phase cloud scheme to represent know super-cooled liquid water in Southern Ocean clouds. These changed have reduced the Southern Ocean (towards GA7) net heat flux bias by ~30% (although the changes introduced some errors in the low latitudes which they continue to work on). There is a larger ~50% impact on the coupled SST biases, they suspect in part due to error cancellation. A preliminary assessment of IPCC CFMIP5 models suggests there are considerable net heat flux errors, and even for models with low net flux errors, error cancellation between individual heat flux components is common.

Finally, Maria Valdivieso presented Air-Sea Heat Flux Estimates From An Ensemble Of Global Ocean Reanalyses. She looked on surface heat fluxes from ocean reanalyses taking part in the GODAE/CLIVAR-GSOP Intercomparison Project ORA-IP. Global mean heat fluxes generally show small net positive bias compared with observational based products, which is largely compensated by the assimilation increments removing heat globally. Residual heat gain (surface flux + assimilation increments) are typically 1-2 Wm-2, considerably smaller than most atmospheric reanalyses, but still larger than realistic from Earth's energy budget considerations. The reanalysis products are also compared to tropical buoy fluxes (10°S-15°N) over 2007-2009 as well as a long-term (2001-2009) reference dataset of fluxes at the WHOI Stratus buoy in the eastern south Pacific. All the reanalysis products tend to show mean flux biases of similar sign at the tropical buoy sites indicating underestimation of ocean heat gain in this region (1/3 smaller Qnet than observed) primarily due to latent heat flux errors and, to a lesser degree, short and longwave radiation errors. An analysis of the Stratus buoy (20°S, 85°W) however showed that the temporal variability of the net heat flux biases in ORA-IP is completely dominated by latent heat flux errors caused by differences in the surface winds imposed in the reanalysis models and those measured directly at the buoy. This is a strong indication that better surface winds are a likely prerequisite for better surface fluxes. Given the strong relationships between SST gradients and surface winds this suggests coupled reanalyses may provide improved results (see details in Valdivieso et al. (2015, submitted to Climate Dynamics).

4.2 Discussion items

The following discussion focused on the forcing methodologies for ocean models.

4.2.1 Issue 1: Bulk forcing with fixed atmosphere

Bulk formulas:
The Bulk formula that is most used in the Drakkar coordination is that from NCAR (also referred to as the CORE formula as it is used in the CORE experiment). But other bulk formulas are used: The COARE formula, recommended by WCRP, has been used at MISU (Stockholm) and the ECUME formula at CNRM. The discussion suggested to retaining the consistency with the original atmospheric reanalysis data used and therefore to use ECMWF bulk formula when using the DFS forcing sets. The differences induced in the fluxes by those different bulk formulas should be documented, which requires dedicated studies.
The need for improved bulk formulas for ice covered regions recognized, but no suggestions were made from the audience on this issue.

Data sets:
The data sets of atmospheric surface variables and fluxes used in Drakkar are a combination of satellite and reanalysis products (CORE, DFS3, DFS4) or are from reanalysis products only with some corrections estimated from satellite products (DFS5). The need for a single-year climatological forcing was clearly expressed.

The *balancing* of the data sets is recommended, but it was acknowledge that methods to reach it are much too empirical (ad-hoc). A recommendation was the balancing should search for consistency between heat and freshwater, and that the continental runoff should be part of the dataset as it contributes to the *balancing*.

The trends and discontinuities in time-series is an issue on which no consensus was reach regarding how to handle them. A recommendation was to at least document them, especially the trends in winds.

The availability of ensemble reanalyzes (20CR ECMWF, 10 members) was mentionned as a possible forcing for ensemble ocean-only hindcasts.
It should also be considered using new satellite products (mind those already "bulked").

Other forcing issues:
Absolute vs relative winds: It was acknowledged that none of each is fully satisfactory, but the use of absolute wind forcing seemed to be the way most of the participants might go. Prescribing wind stress or the C_D directly from reanalysis could also be considered.

The continuous increase of the difference is resolution between the ocean models (~10 to 1 km) and the atmospheric reanalyses or satellite products (~100 to 50 km) is becoming a problem. The downscaling of at least the wind field should be considered.

The Diurnal cycle is an issue for satellite products.

No alternative was proposed to the current salinity restoring.

4.2.2 – Issue 2: Bulk forcing and "Variable" atmosphere

The discussion addressed the ways the coupling between the ocean and the atmosphere could be better accounted in the forcing of ocean models, such that the main caveat of the bulk approach which mimics an atmosphere with an infinite heat and water capacity could be overcome. Those approaches are just beginning to be implemented and the discussion only mentioned the various directions of research that are being undertaken in the broad Drakkar community.

- The FSU Cheap AML investigated at Geomar.

- The coupling with AGMC (simplified AGCM, or spectral nudging, ...). Experiments are conducted at IPSL with ORCA2.

- The data override based on a coupled system (GFDL, NCAR)

- The downscaling of wind field (and other surface atmospheric variables) with a coupled Atmospheric Marine Boundary layer (as implemented at LJK Grenoble).

4.2.3. Missing processes (in bulk formulas, or others)

There are many physical processes that are not considered in the forcing used in Drakkar. The discussion was brief and limited to few of them.

Surface waves

- There is a NEMO wave working group
- The COARE formula takes already care of waves.
- If explicitly accounting for waves in the forcing, one should be careful of not double counting.

Sub-grid scale in the forcing

The variability of the atmospheric variables at the scale smaller than those resolved by reanalyses (sub-grid scale) are not at all accounted for in the drakkar forcing (many are small). A way to account for that could rely on a statistical approach (MetOffice: using PDFs of SST, etc...)

Albedo

Effect of surface wave breaking is not taken into account in the albedo.

5 Plans for coordinated ORCA12 experiments

DRAKKAR-France, NOCS and GEOMAR groups agree that it is timely to converge on a common ORCA12 configuration, with 75 levels, in order to perform a new set of coordinated ORCA12 experiments at the end of 2015 or in early 2016. The joint analysis of these experiments would be the main result of the DRAKKAR GDRI (International research group) regarding the CNRS funding which covers the 2014-2017 period.

Timeline: prepare a phone/skype conference in summer 2015 to decide on the common settings and the target experiments. One possibility is to explore the sensitivity to different forcing fields (DFS, CORE) and ice models (CICE, LIM3).

Bathymetry:
The MetOffice has found deficiencies with the land mask of the bathymetry ORCA12 v3.5 (bathymetry distribution by Marcator-Océan). Atolls in the Indian Ocean should be present at this resolution but are not. The land-sea mask in the Indonesian throughflow should be corrected. Action: Jean-Marc Molines, with MetOffice and Mercator-Ocean.

Grenoble plans for ORCA12 simulations in 2015:

Finish the ORCA12 run with DFS5.2 (1958 to 2012). This run includes both corrections for the momentum EEN advection scheme and therefore does not isolate de effect of the correction of the Hollingworth instability from that from the masking. We shall perform experiments that will isolate the effect of the Hollingworth Instability and its correction.

We also plan to test and validate the non-linear free surface with time splitting, and to test and evaluate GLS mixing scheme.

Mercator-Ocean plans

Mercator Ocean will produce a new reference simulation with the global 1/12° configuration which will be used to produce high resolution global ocean reanalysis. The current ORCA12 configuration is based on NEMO3.5 using LIM2 sea ice model. The simulated period is 1979 to 2013 forced by ERAinterim atmospheric reanalysis including some large scale bias correction for the long wave and short wave fluxes and for the precipitation. The new parameterisation available in NEMO which will be used in this configuration are the time splitting method to solve the free surface, the EEN advection scheme with a bilaplacian diffusion operator for the momentum and the TVD advevction scheme with a laplacian isopycnal diffusion operator for the tracers. The GLS scheme is used for the vertical mixing.

Met Office ORCA12 simulations with NEMO-CICE

- 15 years of atmosphere N512 and ocean 1/12th coupled, and 2 years of N768-/12th and N1024-1/12th (one of these runs may be slightly shorter due to persistent crash). These are compared to a traceable N216-1/4 run.
- We also plan to run some North Atlantic anomaly experiments to look at NAO paired events at different resolutions
- We have discussed running a NEMO-CICE forced run but planned are not formed up yet (this may be run by NOC).

There are a range of process and bias analyses underway of both these runs and the NOC-MetO NEMO-LIM twin runs (as presented at the DRAKKAR meeting for the latter).

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

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.

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.

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

Sérazin G., Penduff T., Terray L., Grégorio S., Barnier B., and Molines J.-M., 2015. Spatial scales of the low-frequency intrinsic sea-level variability: a global model study. Journal of Climate, in press.

<u>Submitted or in revision:</u>

Drillet, Y., Lellouche, J. M., Levier, B., Drévillon, M., Le Galloudec, O., Reffray, G., Regnier, C., Greiner, E., and Clavier, M.: Forecasting the mixed layer depth in the north east Atlantic: an ensemble approach, with uncertainties based on data from operational oceanic systems, Ocean Sci. Discuss., 11, 1435-1472, doi:10.5194/osd-11-1435-2014, 2014. http://www.ocean-sci-discuss.net/11/1435/2014/osd-11-1435-2014.html

Grégorio S., Penduff T., Sérazin G., Le Sommer J., Molines J.-M., Barnier B., J. Hirshi. Intrinsic variability of the Atlantic Meridional Overturning Circulation at interannual-to-multidecadal timescales. Journal of Physical Oceanography, en révision, 2015.

Akuetevi C.Q.C, B.Barnier, J.Verron, J.-M.Molines and A. Lecointre, 2015:
Interactions between the Somali Current Eddies during the Summer Monsoon: Insights from a numerical study. Ocean Science, submitted.

6.3 Other publications

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