Report of the DRAKKAR meeting
Grenoble, 16-18 january 2017

<u>**Organizing committee**</u>
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).

<u>**Session reports**</u>
Y. Aksenov, A. Blaker, J Deshayes, J. Hirschi, N. Jourdain, F. Lemarie, C. Lique, T. Martin, A. Megann, G. Maze, P. Mathiot, T. Penduff.

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

Session 1: Benefits of high resolution to the science made with ocean/sea-ice models.
The objective was to highlight the benefits that the continuous resolution increase in ocean GCMs. Studies of the Atlantic, Arctic and Antarctic circulation and processes were presented. Presentations included frontier simulations at high resolution (1/50° Hycom, 1/60° North Atlantic NEMO).

Session 2: Atmospheric driving of eddying OGCMs.
Different ways to account for the atmospheric feedbacks were presented (e.g. the Bulk Formula forcing, coupling with AMBL, Full coupling with AGCM, ...), as well as available atmospheric data sets relevant for high resolution models.

Session 3: The eddy-permitting regime.
This session focussed on scientific applications of ORCA025 simulations. Chaotic or instrinsic variability has been explored using the OCCIPUT ensemble and climatological vs interannually forced experiments. Other presentations discussed the simulation of anthropogenic carbon and the use of ORCA025 for CMIP6.

Session 4: Ocean Global Circulation Models: Evolutions, performances and diagnostics
This session reported progress in the representation of key processes in NEMO : overflows, ice shelves, Langmuir turbulence. Conceptual and numerical issues regarding mixing and spurious instabilities were also discussed.

Session 5: Ocean-wave model coupling
The talks in this session introduced the "NEMO-Wave" workshop that took place the following day.

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.
Each session summary has been written by volunteer "rapporteurs". The results reported here do not convey the whole content of the presentations. Full abstracts are available on the web site, together with the presentations.

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1. Benefits of high resolution to the science made with ocean/sea-ice models.

The first session of the 2017 meeting focused on applications of global and locally refined high-resolution (1/12° and higher) models to mostly high-latitude research questions. Presentations included pathways in the Arctic as well as Sub-arctic and impacts of meltwater from ice shelves and icebergs in the Southern Ocean.

1.1 North Atlantic and polar regions : summary

In the first talk of the meeting Yevgeny Aksenov (NOC) presented results of a Pacific Water mass tracer experiment conducted jointly by several modeling groups. The inflow through Bering Strait increased by 20% over the past decade and the tracer shows that the water mass resides in the Arctic Ocean for up to 5 years before exiting through the Canadian Archipelago (CAA) or Fram Strait. The preferred exit route is tight to the large-scale atmospheric circulation, i.e. the Arctic Oscillation, which is however not captured by all models.

For the Fram Strait region and in particular the section along 79°N, Claudia Wekerle (AWI) showed that a horizontal resolution of 1 km is necessary to correctly model the recirculation of Atlantic Water at this latitude (4.5 km was insufficient). She used the unstructured grid of the FESOM ocean model to highlight the Fram Strait region in a global context and used mooring data to demonstrate the improvements in her simulation.

In two talks Paul Myers and Clark Pennelly (U. Alberta) reported on their various activities on Arctic Gateways to the North Atlantic, sub-polar circulation, Greenland meltwater, and first results with interactive icebergs. The latter simulation shows that iceberg meltwater contributes generally less than precipitation and CAA freshwater outflow but is still significant. While the comparison of using a 1/12° versus a 1/4° grid was generally inconclusive, sea ice dynamics in the CAA are a little better in the 1/12°. Pennelly showed that eddy shedding from the West Greenland Current into the Labrador Sea is greatly improved in a 1/4° resolution when implementing a 1/12° nest in this region but the nested configuration does not reach the level of eddy activity as the "global" 1/12° configuration.

The session then turned its focus towards the Southern Ocean. Nacho Merino and Nicolas Jourdain (IGE) gave talks on the impact of glacial meltwater on Antarctic sea ice and on the circulation in front of and under ice shelves. Merino showed that changes in atmospheric circulation and wind forcing is the dominant driver of the observed trend in sea ice area but for sea ice volume freshwater from glacial sources is equally important. Sea ice decline in the Amundsen-Bellingshausen Seas (ABS) is however enabled by residual heat in the light meltwater outflow from ice shelf cavities in the region. Jourdain demonstrated the plausibility of this mechanism by running ensemble simulations with a 1/12° L75 regional model of the ABS, which also indicate an upstream influence of ice cavity processes on the coastal current.

Claus Böning (GEOMAR) presented work by Lavinia Patara, who was unable to attend, on decadal trends in Southern Ocean eddy activity (measured by modeled EKE in a

1/12° nest of a ORCA025 global run). In most sectors the increase in EKE can be related to increase in wind forcing (deterministic response), only in the Atlantic sector the response is stochastic, which can be explained by generally weaker winds and rougher topography. Future work will make use of a biogeochemistry component in the model to estimate changes in ventilation rate based on the ratio of CFCs and SF6.

Lastly, Joel Hirschi (NOC) took on a global perspective and presented a fresh view in the persistence of mesoscale ocean features. His new approach uses eddy activity to estimate the "memory" of the ocean and shows saturation after 10 to 15 days (only in few regions up to 70 days). This natural perturbation timescale also marks the fastest possible interval over which an ensemble can diverge in a physically meaningful way.

1.2 North Atlantic and polar regions : discussion

Model grid resolution was in the center of attention during the discussion. In particular for the high Arctic it was noted that experiments with a nominal resolution of 1/4° to 1/12° globally (~5 km or more in the Arctic) were not sufficient to fully resolve mesoscale activity and effects. This may also be the reason why results of a model intercomparison were inconclusive in this region. It is known that the Beaufort Gyre is balanced by eddy transport at its boundaries, which only can be shown in models with even higher resolution. Model differences regarding the Pacific Water distribution and Beaufort Gyre strength may also be related to the model dependent circulation and dominance of Atlantic Water inflow from the European side.

Several times during the discussion the topic of atmospheric forcing was touched upon. With increasing resolution and the desire to resolve mesoscale activity correctly in the ocean, atmospheric forcing of sufficient temporal and spatial resolution and quality is critical. Various reanalysis data sets are used by the NEMO community such as DFS, CORE-II, and CGRF (33 km, 3-hourly, superior for the Arcitc and northern North Atlantic), and the new JRA55 is being tested by the group from Kiel.

Regarding the inflow and recirculation of Atlantic Water (AW) through Fram Strait is was concluded that the instability seen in the 4.5km run must be convective (driven by winter surface heat loss) and cannot be baroclinic. Because the Rossby Radius at this latitude (79°N) is about 4-6km only the 1km grid simulation can resolve eddies. While it was unclear yet how this may improve AW circulation in the Arctic, it was stated that the Arctic AW circulation was helped by using the simpler PP scheme for vertical mixing instead of KPP in some models.

The discussion on Southern Ocean dynamics was dominated by the focus on local circulation in and in front of ice-shelf cavities. However, Merino's conclusions raised the question why CMIP5 models fail to simulate the observed positive trend in sea-ice extent, if atmospheric forcing is truly its driver (and not ice-shelf processes, which are missing in these models).

The discussion on the persistence of mesoscale ocean activity focused on the new approach including suggestions for improvement, such as, using reconstructed velocities—which are not provided by AVISO, looking at the spectrum instead of dynamic variability, dependence on spatial resolution, Lagrangian vs. Eularian perspective, and velocity components instead of absolute magnitude.

1.3 Submesoscale-permitting resolution

Clément Rousset & NEMO Team : Parameterization of lateral melting in LIM3 and other infos

A brief overview was given on LIM3 developments in 2016 :
- Missing physics: parameterization of lateral melting within a model grid cell (Josberger, 1979), parameterization of ice-atmosphere drag (Lupkeset al, 2010), parameterization of landfast ice (Lemieux et al, 2015)
- Numerics: New advection scheme UM5 (following Leonard, 1991)
- Tools: Agrif + LIM3 works well in test cases but still problems in realistic cases.
Lateral melting was tested in a regional configuration (CREG025 – ¼°). With lateral melting the unrealistically large ice-thicknesses found around the main sea-ice pack in the Arctic disappear. The large-scale sea-ice distribution is also modified by lateral melting. The consequences of this change are not yet clear and need to be investigated. In addition the UM5 advection scheme was compared with Prather advection. Idealised experiments were set up to investigate how anomalies of different shapes are advected. Which scheme (UM5 or Prather) works best depends on the shape of the anomaly. For a Gaussian peak better results are obtained with Prather advection. However, for a square-shaped anomaly Prather performs worse than UM5 and instabilities rapidly develop at the leading edge of the square.

Rene Schubert : Instability-driven benthic Storms below the separated Gulf stream in a high resolution model.

The configuration used to study benthic storms was Viking 20 with 46 vertical levels (Böning et al. 2016). Benthic storms are defined as events when the bottom velocity exceeds 0.2 m/s. The kinetic energy (KE) at the bottom was split into EKE and MKE and the respective contributions of barotropic instability (BTI) and baroclinic instability (BCI) instability were investigated. The results show that energy transfer from BTI and BCI is largely confined to the Gulf Stream extension, with a maximum west of the New England Seamounts. The highest probability of finding bottom velocities >0.2m/s at the bottom is along the Gulf Stream extension and cyclogenesis is the main mechanism driving benthic storms.

Eric Chassignet: Global 1/12° HYCOM interannual simulation with Drakkar atmospheric forcing — Impact of horizontal resolution (1/12° to 1/50°) on Gulf Stream separation and penetration in a series of North Atlantic numerical simulation

First brief "Update from across the pond": MOM6 is to replace POP as the CESM ocean component (CESM=NCAR coupled earth system model). Most US models now use an ALE (Arbitrary Lagrangian-Eulerian) vertical coordinate (i.e. generalized coord) --> MOM6, HYCOM, MPAS-Ocean, GO2.
A recommendation has been made by NOAA and NCEP to merge HYCOM and MOM6 (following a workshop on ALE in fall 2016).

Presentation of results from the first Multidecadal 1/12° global HYCOM simulation forced with DFS5.2 (about 15 years done). The model has 36 vertical layers and uses the CICE v4.0 sea-ice model. The simulation shows small temperature drifts. There is a slight underestimation of the seasonal cycle of the sea ice extent in the Arctic. A rather pronounced underestimation of winter (austral) sea-ice extent is found around Antarctica. Surprisingly the EKE in the Gulf Stream region is too small. This is an issue that did not occur in earlier 1/12° HYCOM runs. During the simulation the AMOC also decreases from 16 to about 12-13 Sv which coincides with weak overflows. The reason for this is not really understood yet. Possibly, this could be related to the fact that the sea ice initialized with a uniform thickness of 2.5m. This thickness rapidly reduces in the first years of the simulation providing an extra input of freshwater which may contribute to the weak AMOC. It was noted that a similar sea ice initialization was used in the CORE simulations. However, since these simulations were much longer (600 years) the initial melt may have been less of an issue. More investigation is still needed though.

The second part of the talk showed the impact of horizontal resolution on the representation of the Gulf Stream. Identical Atlantic configurations were used at 1/12°, 1/25° and 1/50°. The models use a climatological forcing with daily variability. The viscosity used is a function of grid resolution, but the 1/50° run uses the same viscosity as the 1/25° run. A combination of laplacian and bilaplacian viscosity is used around Cape Hatteras. A relatively weak piston velocity (2 years over 30 meters) is used for SSS relaxation. In the 1/12° model there is excessive recirculation off Cape Hatteras. At 1/25° the recirculation area off Cape Hatteras broadens but there is a better separation and the overshooting is reduced compared to 1/12°. At 1/50° a realistic separation and recirculation is obtained. The Gulf Stream transport slightly increases from 30.8 to 34.9 Sv when the resolution increases from 1/12° to 1/50° (observed transport ~32 Sv). The AMOC is about 17 Sv in all cases. Overall, these sensitivities to resolution are consistent with Hurlburt and Hogan (2000). The 1/50° model has a clearly higher EKE than AVISO. However, this difference is likely due to the smoothing done to grid the altimeter data, since it can largely be accounted for by spatially and temporally averaging the model data. Finally, there is a clear indication that high mean Eddy Kinetic Energy values extend to greater depths with increasing resolution ; at 1/50° results look similar to the EKE section done by Richardson 1985.

Julien Le Sommer: Sensitivity of resolved fine scales to model parameters in the submesoscale range: lessons from NATL60

Presentation of results from the regional North Atlantic model NATL60 (1/60°) resolution. NATL60 is based on NEMO3.5/3.6 and has 300 vertical levels (dz=1m to 30m). Two simulations are carried out: 2004-2008 (een/fct advection scheme) and 2012-2013 (UBS advection). The boundary UVTS forcing is taken from GLORYS2V3 and the surface forcing is DFS5.2. The main questions being addressed with this model are the energy exchange between large and fine scales and the vertical exchange between the interior ocean and the atmosphere. NATL60 is also intended to be used as a testbed to for inversion methods to be used on the upcoming SWOT data which will provide SSH measurements in the range of 10-100km.

An initial comparison of NATL60 with observations shows that overall there is a good agreement with large scale altimetry. However, there is a slight overshoot of the Gulf Stream off Cape Hatteras compared to altimetry. The Gulf Stream position actually looks similar to what is seen in ORCA12, suggesting that the Gulf Stream path did not improve much by increasing the resolution. However, the simulations are very short so the Gulf Stream may not have settled in its final position yet ; another hypothesis is the proximity with the southern open bounday (26°N). Reasonable values are found for the MLD even in the Labrador Sea, but the MLD region is shifted north in the model compared to observations.
Comparison with the OSMOSIS current meter array (Buckingham et al. 2016) suggests (statistically) comparable values of variability for e.g. vorticity. Probability of extreme divergence events is probably too weak in the model, and there is likely to be a slight underestimation of winter peak strain. There are large seasonal changes in relative vorticity. Maps of winter and summer show that the largest differences occur along the Gulf Stream and the Subpolar Gyre. The strength of the seasonal signal depends on the metric; the clear signal seen in relative vorticity is much less pronounced for SSTs. Regarding the slope of the sea surface height wavenumber spectrum, shallower ssh wave number spectra with more variance at fine scales are found in the new run with UBS/UBS. The NATL60 data may be requested to meom-group.github.io .

2 Atmospheric driving of eddying OGCMs.

Alex Megann : Evaluating Forcing Datasets for late 20th-Century NEMO integrations

This study takes place within the ACSIS project (Atlantic Climate System Integrated Study), a UK largescale multi-centre project which aims at detecting, attributing and predicting changes in the North Atlantic Climate System. The objective is to provide acceptable GO6 (the latest Met-Office ORCA025 configuration) and ORCA12 simulations consistent with late C20th observations to the rest of the project. Alex and colleagues have conducted tests at ORCA1/025 using NEMOv3.6 LIM2 with three different forcing datasets : CORE2 (NCAR/Gfdl), DFS5.2 (the latest drakkar dataset from 1958 to 2012) and JRA-55 (v0.8). For depth averaged temperature, JRA-55 forced simulations cool strongly. CORE2 agrees best with ORAS4/EN4 observational estimates, DFS5.2 warms more rapidly than observed. SST in DFS5.2 simulations shows very little surface warming. CORE2 and JRA-55 SST trends are reasonably close to EN4, JRA55 is the only dataset to include transient CO2. Looking at the dependence to horizontal resolution : ORCA1 simulations show cooling in bottom 1 km, not present in ORCA025. JRA-55 forced ORCA025 cools strongly below 100m (consistent with JLS's recent work in SO presented at WGOMD16). Source of cooling comes from SO. Winter ice cover drops off rapidly, consistent with strong cooling over SO. Note that SO wind forcing is very similar among different products. Claus Boning pointed out that the JRA55 used for these studies is probably an earlier version (October 2016), which was found to have significant flux problems around Antarctica (to be confirmed). The trend in Long Wave heat flux (LW) from CMIP5 mean, compares reasonably with JRA. The CORE2 LW shows a decreasing trend in the -40:40 latitude range. Simulations fitting LW in the different forcing datasets to an 'observed' trend suggest that modifying LW does not solve the problem of models not representing observed global warming.

Since the japanese model using JRA-55 performs very well in the SO, a question is to know whether a specific dataset can be tuned for a given model. Bernard Barnier confirmed this is not the case for DFS5.2 and NEMO. A given dataset is, however, usually tuned for a given bulk formulation. All use CORE bulk formulae.

Finally, it was commented that ECMWF is working on ERA5, which will include GHG forcing.

Gilles Garric : Evaluation of 7 atmospheric datasets in the Arctic Ocean over the period 2007-2014

The work presented is dedicated to the arctic sea-ice in preparation of the next release of the Mercator operational system (2017-2018 release). The focus is on the proper representation of the 2007 and 2012 sea-ice extent anomalies. The set-up is based on NEMO v3.6 with LIM3 using the CREG configuration of Greg Smith (environment Canada) at 1/4° without assimilation. Atmospheric forcings for the reference simulation are from IFS (ECMWF). Motivation for forcing comparison was that NCEP R2 shows better ice extent towards Siberian shelf that IFS – can biases be related to atmospheric forcing?

The different atmospheric reanalyses considered are IFS, ERA-Interim, JRA-55, MERRA, NCEP R2, CFSR, CGRF. IFS is 1-2 deg warmer, drier and has higher wind speeds than JRA55, CGRF, NCEP2 and CFSR, but is colder than MERRA and ERA-I. (See Lindsay (2014) paper). None of the datasets reproduce winter extent really well, but all do OK during summer. There is an overestimation of ice concentration for all simulations/forcings in Canadian basin.

MERRA is an outlier from the pack. All forcings apart from MERRA show decreasing trend in ice volume. East/west thickness bias anomaly dipole (too thick ice in west, too thin in east) is found with all forcings except MERRA.

It seems that LIM3 is not able to represent thin ice well. No forcing is able to reproduce the 2012 minimum. There was no real impact of using more realistic (October 2006) thickness initial conditions. The plan is to test the ERA5 forcing once it is available (next spring).

Rafael Abel : Feedback of mesoscale ocean currents on atmospheric winds in high-resolution coupled models and implications for the forcing of ocean-only models

This talk deals with the ocean-atmosphere mechanical coupling. Noting Uwnd = (Ua – alpha.Uo) the wind vector used in the stress calculation, with Ua for atmospheric wind and Uo for ocean current, the question is to know whether we should use absolute (i.e. alpha=0) or relative winds (i.e. alpha=1) in forced simulations? Recent work by Renault et al. showed that oceanic currents could influence significantly both surface stress and near-surface atmospheric winds. In this study the methodology is based on forced (NEMO v3.4, CORE IAF) and coupled (UKMO ORCA12/025) simulations. Using monthly means and a high-pass filter, the objective is to isolate the two coupling coefficients introduced in Renault et al., 2016 : a first one between the ocean currents and the surface stress (noted S_st) and a second (noted Sw) between the curl of oceanic currents and the curl of the atmospheric winds. Using the UKMO coupled experiments a global constant value of Sw around 0.22-0.24 is found. However, this value shows a strong seasonal variability (ranging from 0.2 to 0.5) in the Gulf Stream with low values in winter (associated with an unstable surface-layer) and high values in summer (associated with a stable surface-layer). Less variability is observed in the ACC. There is thus a strong regional imprint on the value of Sw so it is not meaningful to consider a global mean of the coefficient since there is a very strong standard deviation particularly in the tropics. A global climatology of Sw on a 2x2 grid is derived and is used in forced simulations (3 experiments : alpha = 1, alpha=0, alpha = 1-S_w) following the idea of Renault et al., 2016 to parameterize the mechanical coupling by taking alpha = 1-Sw. The key message is that using S_w scaling, a good agreement with results in coupled experiments is found. Applying the parameterization leads to an EKE reduction of order 10% (Abel et al in review, GRL). It is suggested that an idealized set-up could be used to tune a more adequate parameterization of Sw. George Nurser pointed out that the value of Sw should be a function of the stability in the surface layer (i.e. Ta - SST) rather than prescribed, particularly for eddying oceans. Another comment was that the same coefficient alpha should be used for the computation of all turbulent fluxes and not only for the stress.

Lionel Renault : Surface current feedback: which strategy is the best to force a high-resolution ocean model?

This talk deals with the ocean-atmosphere mechanical coupling looking at the mean geostrophic wind work (FmKm) and the mean geostrophic eddy wind work (FeKe). Various model results are showed to illustrate that the use of relative winds leads to a deflection of energy from the ocean to the atmosphere and that the partial re-energization of the ocean by the atmosphere (absent in forced experiments) must be taken into account to obtain a better match with observations (Renault et al 2017). The EKE reduction because of the deflection of energy from Ocean to Atmosphere has been estimated at a regional scale by various recent studies (44% in USWC, 27% in North Atlantic, 25% in Agulhas region) and at global scale by Jullien et al. (35%). At large scale the use of relative winds tends to slow down the gyre circulation and results in a much reduced FmKm. Using the PULSATION coupled simulations (Tropical channel at 1/12° in the ocean and ¼° in the atmosphere) as a reference, the objective is to quantify the error in terms of energy transfer from O to A made when forcing an ocean model (1) using Quikscat winds (which already contains the current feedback but with different eddies) and considering relative winds in the bulk formulation; and (2) with the stress from the coupled simulation computed using absolute winds. In the first case, currents are accounted twice so that there is an overestimation of the eddy-killing effect and too weak FmKm (underestimated by 40%). In the second case there is a lack of eddy-killing effect which results in an overestimation of EKE by 60% and an overestimation of FmKm by 23%. The conclusions are the following : i) the current feedback has to be taken into account to have a realistic representation of the mesoscales and of the large-scale mean ii) less worse solution for forced simulations is to consider reanalysis winds that ignore the current feedback iii) Satellite products may not be suitable to force an ocean model. The author concluded on some somments about the delicacies when using the Sw parameterization discussed in Abel's talk : the value of Sw appears to be model dependent and is expected to be dependent on horizontal resolution and on the type of

PBL scheme used in the atmospheric boundary layer. Nicolas Jourdain wonders about the relevant coupling frequency needed to represent those processes (1 hour coupling frequency is used here). As emphasized by Julie Deshayes, it is not clear so far if adding wave-current interactions will affect the underlying processes.

3 The eddy-permitting regime

Graeme MacGilchrist (U. of Oxford): Characterising chaotic ventilation of the ocean.
Question: what is the role of eddies on ventilation rates and ages?
"Puff pastry" analogy: the folding of pastry layers is similar to the filamentation process, in which nonlinear dynamics create longer and thinner filaments and eventually a chaotic flow regime. The chaotic circulation means that backward fluid trajectories leading to any point may have been ventilated at widely separated times and locations.
An ORCA025/DFS5.2 integration was analysed in terms of a filamentation number F, defined as the time since ventilation, multiplied by the strain rate: this differentiates between "laminar" and "chaotic" ventilation regimes. Evaluations of backward trajectories showed a wide range of ventilation times in the subtropical North Atlantic from 5 to 50 years.
It was remarked that diagnosing the unresolved variance within grid cells in this way, and then relating this to the resolved variance, could inform a parameterisation of mixing.

Stephan Juricke (U. of Oxford): The Random Ocean: Development, implementation, and investigation of stochastic ocean parameterisations.
Uncertainty estimates of a model state can be derived from an initial condition ensemble; an alternative method was presented, in which each member has independent stochastic perturbations applied to represent sub-gridscale variability. This can lead to noise-induced drift, variability and in some cases regime transitions, and these may be used to estimate model uncertainty.
Adding stochastic perturbation to a 1° model increased temperature variability, as well as adding SSH variability more similar to that seen in higher resolution models and in observations. In an idealised gyre model the circulation again became more similar to that in a higher-resolution model. Another application is in seasonal forecasts, where increasing the ensemble spread improves predictive skill on seasonal timescales.
Note: NEMO v3.6 has a stochastic parameter perturbation scheme in module STO.

Guillaume Sérazin (LEGOS – Toulouse): A global probabilistic study of the Ocean Heat Content low-frequency variability: atmospheric forcing versus oceanic chaos.
Under the CHAOCEAN project two 1/12° model runs were carried out, one with interannual forcing and one with normal-year forcing, to estimate the relative importance of intrinsic and forced sea-level variability. It was found that the intrinsic variability was larger than that simulated in CMIP5.
A 50-member 56-year ensemble of ORCA025 runs driven by the same reanalysed DFS5.2 forcing has been analysed in the context of the OCCIPUT project. A "signal-to-noise ratio" was defined as the ratio of forced to intrinsic ("chaotic") Ocean Heat Content (OHC) variability, and this was evaluated in the depth ranges 0-700m; 700-2000m and >2000m in different regions. Above 700m, the interannual-to-decadal OHC variability is

predominantly forced, although chaotic variability was strong in the Southern Ocean. In the intermediate depth range, more chaotic behaviour was found in the South Atlantic, and in the bottom waters more regions of the ocean were characterised as generally chaotic.

The statistical significance of forced (ensemble-mean) OHC trends on multidecadal timescales (1980-2010) was also estimated by comparison with the its chaotic counterpart (ensemble spread); it was found that local warming or cooling was not unambiguously attributable to atmospheric forcing in several regions, although variability is constrained by damping by bulk formulae, by model biases and by spatial resolution.

Thierry Penduff (IGE – Grenoble): Atmospherically modulated oceanic chaos; observational implications.

The Gulf of Mexico Loop Current and eddy shedding were analysed in an initial condition ensemble of 1/4° NEMO integrations, forced with DFS5.2 from 1993 to 2012. The daily, time-dependant SSH ensemble distribution in the Loop Current showed a bimodal PDF, corresponding to co-existing "retracted" and "elongated" paths of the Loop Current every day. ~~It was found that the mean wind forcing tends to oppose shedding of eddies from the Loop Current, while wind variability encouraged eddy shedding~~. [NON CECI EST ISSU DE LA LITTERATURE]

A "normalized entropy" was defined every five days at every location of the Northwestern Subtropical Atlantic from the probabilities of ocean states among the ensemble, with high values of S interpreted as high intrinsic disorder, with little atmospheric influence. High entropy was seen locally, with atmospheric events reducing entropy.

Such ensemble simulations are being used to generate "ensemble synthetic observations", which will be useful in assimilation and in detection/attribution studies, as well as in judging the representativeness of individual observations.

Jan Klaus Rieck (GEOMAR – Kiel): Decadal Variability of Eddy Kinetic Energy in ORCA025 - Sensitivity Studies

The standard deviation of the decadal eddy kinetic (EKE) in a 1/4° NEMO/LIM2 model was evaluated in a region in the south Pacific, as well as its sensitivity to the model bilaplacian viscosity. The sensitivity to interannual forcing variability was examined by running with normal-year buoyancy fluxes and interannual wind stresses, and comparing this with interannual buoyancy fluxes and normal-year wind stresses: the EKE variability is found to be mainly driven by the wind variability. Reducing the viscosity from 1.5×10^{-11} m^4s^{-1} to 0.6×10^{-11} m^4s^{-1} was found to reduce the EKE variability significantly.

Guillaume Maze (LOPS - Brest): Eddy-permitting ORCA025 representation of large-scale stratification features in the North-Atlantic.

The realism of the mode waters in the subtropical North Atlantic was investigated in a 1/4° NEMO integration. Along with a southward shift in the path of the North Atlantic Current (NAC), the 18° mode water was eroded, with a mode water at 21°C forming in its place by the end of the run, and the permanent pycnocline almost disappearing.

Calculating watermass transformation rates, following Walin's method, revealed that the formation rate of 18° water is poorly represented, possibly related to the error in the

NAC path: the NAC shifts southwards, and the surface fluxes change in response to the resulting cool surface bias.
The Profile Classification method was used to group temperature profiles spatially, and showed that the class of profiles matching 18° water disappears in the integration.
It was commented that the NAC path was improved in the higher-resolution 1/12° configuration, which should improve the representation of mode water formation.

Jens Terhaar (LSCE-IPSL – Orsay): Simulated anthropogenic carbon in the Arctic Ocean in three DRAKKAR model configurations.
The Arctic Ocean is particularly vulnerable to acidification as a result of increasing atmospheric CO2, because of the increased solubility of CO2 in cold water. The uptake of an anthropogenic CO2 tracer in DFS-forced simulations of three global configurations of the NEMO-PISCES model (ORCA2, ORCA05, and ORCA025) was compared with available observations. The carbon budget was evaluated, with lateral transport ascribed to the residual after surface fluxes are removed: it was found that lateral advection accounted for about 75% of the uptake, with the total uptake increasing with model resolution.
The model results were compared with observational estimates of anthropogenic CO2 uptake: although it is difficult in practice to separate the anthropogenic component, the models were judged to transport CO2 to deep waters less efficiently than observational estimates. As a proxy for anthropogenic carbon, CFC-12 was used as a tracer, and it was found that higher-resolution runs were in better agreement with observations, although the observed high values in the Canada Basin were not well simulated.
It was noted that there was a wide spread in carbon uptake in the CMIP5 models, with the models that have more realistic lateral transport giving more plausible results.

Julie Deshayes (LOCEAN - Paris): The ORCA025 configuration at IPSL for use in ESM.
Increasing horizontal resolution in ocean and climate models is generally accepted to have some substantial beneficial effects, including: more realistic northern recirculation of the Gulf Stream; more realistic AMOC variability; better representation for Agulhas leakage and its variability; better representation of oxygen minimum zones; and more realistic uptake of anthropogenic tracers in the Arctic. “Eddy-permitting” configurations, however, fit awkwardly in the middle, with poor representation of the mesoscale fields at high latitudes and a tendency to produce grid-scale noise in the vertical velocity field, as well as unsatisfactory overflows in the North Atlantic.
One solution is to add a higher-resolution AGRIF nest in the relevant region, as in the IPSL ERNA model (0.125° nest inside a global 0.5° grid). Other fixes are available, including new mixing schemes (which were found to improve the AMOC) and better advection schemes such as UBS, which can reduce grid-scale noise. The Fox-Kemper sub-mesoscale parameterisation was also found to reduce mixed-layer depths (more realistic).
The speaker believed, however, that parameterisation was philosophically superior to partial resolution. Another priority was to sustain ventilation of the deep ocean, even if this was only possible via open-ocean convection (a “permanent” Weddell polynya).
The namelists and input files from the IPSL model are available on the shaconemo site, and members of the DRAKKAR community are encouraged to share them.

4 OGCM evolution for basin-scale to global eddying simulations: processes and setups

4.1 Processes

Camille Lique (LOPS, Brest) used the GREG12 configuration of NEMO3.6 to show that the Arctic sea ice can be improved by modifying P*, max cc, the lateral slip condition, and including the new lateral melt parameterization in LIM3. She pointed out that the wave breaking accounted for in the TKE scheme should be switched off under sea ice because sea ice damps waves. She found weaker effects of double diffusion or Langmuir cell paramaterization.

Pierre Rampal (NERSC, Bergen) presented the nextSIM Lagrangian sea ice model that is based on an elasto-brittle rheology and thermodynamical equations, and that now includes wave-ice interactions in the marginal zone. This is a parallelized and adaptive-mesh model. This raised questions on how to model marginal ice/small-size floes (< model resolution).

Qiang Wang (AWI, Bremerhaven) used FESOM (up to 24km in the Arctic) forced by various combinations of Normal-Year/Interannual CORE2 forcing inside/outside the Arctic basin. He analysed freshwater export (affected by interannual variability of the atmosphere both inside and outside the Arctic) and the AMOC (little impact of interannual variability of Arctic freshwater). This raised questions about the impact of vertical resolution.

Torge Martin (GEOMAR, Kiel) spoke about Greenland's meltwater routes in the North Atlantic, and gave some thoughts about what to consider for high-res simulations with NEMO. He pointed out the need to pay attention to runoff in AGRIF. He raised the question of the need for iceberg models and showed that SSS restoring can counterbalance or double the freshwater fluxes from sea ice. This led to discussions on the evaluation of icebergs trajectories (not sure it is possible so far) and on the SSS restoring in forced vs coupled runs. Paul Myers mentioned he had some tools for runoff mapping in AGRIF.

Marion Donat-Magnin (IGE, Grenoble) showed some results of a regional NEMO3.6 configuration of the Amundsen Sea sector (with ice-shelf cavities). She found that including interactive ice-shelves changes the coastal subsurface response to the SAM-like poleward wind shift and strengthening. She noticed that future evolution of the ice-shelf cavity shapes might have a stronger effect on melt rates than the SAM trend. There were questions about the resolution of eddies at 1/12° under these ice shelves and on the time scale of cavity evolution.

Pierre Mathiot (Met Office, Exeter) explained us that he played LEGO with the bathymetry during Christmas time. He compared eORCA12 with "LEGO bathymetry" (a mimic of 0.25° bathy on the 1/12° grid), eORCA12 with actual 1/12° bathy, and eORCA025. He analysed the influence of grid resolution vs bathymetry resolution on the Kuroshio and Gulf Stream, mixed layers and dense overflow in the Northern Sub-polar region, and the AMOC. Many people of the audience showed their interest to "play

LEGO" with Pierre: his strategy for evaluating the effect of the resolution of bathymetry in z-coordinate models is novel.

Pedro Colombo (IGE, Grenoble) looked at the Denmark Straight overflow in his DENST12 configuration. Going from 46 to 990 levels or putting an AGRIF at 1/60° in Z-coordinates did not change the overflow to a significant extent (in contrast with computing time…). He then used sigma-coordinates and found quite different spread of the dense overflow compared to Z-coordinates. There were comments to encourage comparisons with observations, and some interest to use AGRIF in sigma-coordinate embedded in a global Z-coordinate models.

4.2 Modelling and simulation practices

Rémi Tailleux (U. of Reading) on Conceptual issues and pitfalls associated with the use of neutral rotated diffusion tensors

There are systematic SST biases in CMIP5 models, presumably due to mixing parameterizations that are used. The key objective is to parameterize heat and salt fluxes in thermodynamic equation. Current parameterizations assume K_T=K_S=Kd (diapycnal diffusion). Why use rotated diffusion ? to avoid Veronis effect, but it is not very convincing. Actually, when temperature and salinity diffusion are not the same, use of horizontal/vertical mixing is a priori possible by using differential diffusion. Current mixing parameterization have in principle enough degrees of freedom to achieve perfect T/S realism. Remaining misfits must be due to inaccurate direction of mixing (d) and non-optimal values of K_{gm}, Ki, Kd. Potential errors due to wrong d can be remedied by allowing for differential diffusion $K_T \neq K_S$, in which case the choice of d becomes arbitrary. GM mixing looks fine but specifying the coefficient K_{gm} is not easy.

Mike Bell (UKMO – Exeter) on Spurious baroclinic instabilities on the Lorenz grid

Motivation : Grid-scale hollingsworth instabilities can destroy the mesoscale field in very high resolution ocean models. This instability is irrealistic and can damage the model. How to make sure that the vertically staggered "modified Lorenz grid" is working OK in NEMO ?

Discussion on the modified Lorentz grid:

On the modified Lorenz grid, spurious short-wave baroclinic instabilities can grow as quickly as the main Eady/Charney waves. For typical configurations, these waves are too short to be represented by our horizontal grids except near the equator. Instabilities only occur where there are horizontal temperature gradients at the boundary. They are trapped and move with the flow near the boundary.

Diagnostics of these instabilities in ORCA025 : they are visible in coupled and uncoupled runs, near the equator, on temperature / SST.

George Nurser (NOC – Southampton) on Upper-ocean mixing by Langmuir circulations: implementing the OSMOSIS Ocean Boundary Layer Model into NEMO

Motivation : the problems with model ML depths, e.g. Southern Ocean summer ML depth being about 30m while it should be 80m. There is a very large variety of processes inducing mixing in the upper ocean, all competing to set the ML depth; there are also stratifying processes like solar radiation and slumping of warm light water over cold (driven by eddies, wind…). The OSMOSIS program focuses on the Langmuir circulation, ie interactions between wind stress and Stokes drift of surface waves. Langmuir turbulence is qualitatively different from shear turbulence : deep coherent structures have relatively stronger vertical velocities than is characteristic of the shear turbulence that informed the development of TKE and GLS. As in convection, fluxes of temperature and momentum may be 'non-local' (ie not down the local gradient). At present, OSMOSIS-OBL model standalone 1D is embedded into the NEMO trunk, and global 3D runs will be attempted in next few months, to appear in a public NEMO branch by autumn 2017.

Klaus Getzlaff (GEOMAR – Kiel) on A series of AGRIF configurations based on NEMO 3.6 using LIM2
The Kiel group develops a strong expertise in running AGRIF. They have developed an extended VIKING20 configuration, a full Atlantic zoom and a south Atlantic + Mozambique channel zoom (INATL). The latter is derived in 3 resolutions (1/10, 1/20 and 1/60). This INALT10, 20, 60 family allows a clean comparison in the South Atlantic in forced and coupled mode. The last configuration presented is PALMOD10. It is a zoom on the subpolar gyre, coupled to the atmospheric model ECHAM6.3 T63.

Helene Hewitt (UKMO – Exeter): Ocean models for seamless prediction
The U.K. MetO's target is to use the same model configuration across time scale (day to centuries). Across horizontal resolutions, MetO tries to keep each configuration as traceable as possible (ie only change resolution dependent parameters). Results of the first coupled simulation with ORCA12 are published (Hewitt et al 2016). Across the possible vertical resolutions, there is scope to look at the issue by analysing the available 300L run. Questions being explored today at the MetO are for example: does the resolution matter for the heat uptake and climate projections? Can we learn from short ensemble runs ?

Laurent Brodeau (BSC-Earth Science – Barcelona): NEMO optimization at BSC

BSC developed a suite of tools (EXTRAE + PARAVER) to trace NEMO and visualize the performance, a trace simulator (DINEMAS) to remove the need to re-run the model every time for performance evaluation, and a tool to find the best decomposition of the domain (ELPiN). Based on these tools BSC found that the model scales well excepted one routine in LIM (limhdf). The lbc_lnk_multi subroutine improves the scalability by decreasing the communication time. To speed-up the model BSC suggests to use single precision but we have to be careful about how the single precision is applied (perform the update at higher precision for example).
One year of eORCA12 coupled to IFS (T255.L91, ERAinterim-like resolution) has been run. The atmospheric model represents 6% of the total cost.

Clément Bricaud (Mercator Océan – Toulouse)) on Coarsening in NEMO: state of the art

The online coarsening of the tracers (run the tracers on a grid coarser than the dynamics) is working. KE spectrum is similar between original and coarsened fields and coarsened tracer fields are closer to the high-res run than to the low-res run. The choice of averaging operator for the vertical mixing coefficient has an impact on the results. By default, the operator is a median filter and it could be changed to a mean(log) filter in the namelist. The current limitations are the cost (use of OASIS to parallelise TOP/OPA could help) and the reduction (coarsening) factor that is set to 3 (need to have the same pivot for the poles of the global ORCA grid, do not deal with half cell …). The other fields, as vertical velocity, are not yet checked.

5 Discussions

5.1 Lessons learned from high resolution simulations.

Introduction

An overview of ORCA12 simulations and the first scientific results was published in 2014 in Clivar Exchanges. An updated list of publications is presented (section 6, 33 publications over 3 years). The results of ORCA12 can be summarized as:

- Use of ORCA12 for boundary conditions (5 papers)
- Studies of mechanisms of ocean variability: many studies are regional (S.O., Arctic, North Atlantic, Somali current…). Focus on Atlantic MOC (Deshayes, Blaker, Gregorio, Rühs)
- A few studies at the global scale: Salt transport (Treguier), seasonal EKE (Rieck), eddy anisotropy (Stewart), uncertainties/instrinsic variability (Serazin, 2015 & 2016), data-model combinations for Operational Oceanography (Rio).
- In 2016, the first 2 papers on the coupled ORCA12 runs at the MetOffice: Hewitt, Roberts.

Discussion about future developments around ORCA12

- ORCA12 is part of a hierarchy of models. It can be used to assess robustnesss/convergence of ORCA025 (the 1/4° configuration that will be used quite extensively as part of CMIP6). For example, the AMOC is very similar in both models. On the other hand, 1/12° is not a high enough resolution in the polar regions. Hence the need for grid refinement strategies and higher resolution regional models.
- The progress towards higher resolution at the global scale allowed us to shed light on the large scale imprint of intrinsic ocean variability.
- ORCA12 could be used more to assess the need for parameterizations in lower resolution configurations. For example, do we need an adapted version of GM in ORCA025?
- How to take advantage of the global scope of our simulations? One suggestion is to use ORCA12 more for OSSE (Observing System Simulation Experiments). There is one such project at NOCS (H2020 AtlantOS)
- ORCA12 is one among other similar models in the world (MIT GCM, Hycom, POP, MOM/GOLD, MPI-STORM). ORCA12 has a large range of uses, from climate to operational oceanography. Can we take advantage of the diversity of the user

community? One idea would be to use assimilation increments to understand better model drifts and biases (as done by N. Jourdain and B. Barnier in the Labrador Sea). However, M. Bell notes that interpretation of assimilation increments is not easy.
- It is difficult to achieving a tight coordination of the simulations. The different groups have many simulations, different set ups, different forcings... but we have learned a lot about model sensitivities, and Drakkar meetings are essential to share that knowledge.

Conclusion: DRAKKAR 2018-2021

The DRAKKAR coordination is supported by CNRS through a GDRI (international research group) between French CNRS research units, Ifremer, GEOMAR and NOC. The GDRI ends in 2017 but the partners have decided to submit a proposal for renewal. The GDRI does not provide funding for research but it helps organise the DRAKKAR meetings and publicize the results obtained with DRAKKAR model configurations. Four axes will be developed:

- The added value of coordination at a European level for high resolution global simulations
- The uncertainties and their propagation (ensemble strategies, stochastic parameterizations)
- Grid refinement strategies for fine scale ocean processes, downscaling and upscaling
- Surface air-sea-ice-ocean interactions

5.2 Discussion of eddy-permitting models (with focus on ORCA025)

Questions : what are the skills and resisting flaws, the priorities for improvements, when and how should we use/not use eddy-permitting models?

- The resolution dependence needs to be explored better. What if eddies are present, but have the wrong properties (too large eddies, for example?). The propagations need to be analyzed.
- ORCA025 will be used for CMIP6, we need to inform the climate community: chat can be fixed at 1/4° with the right parameterization, and what cannot be fixed at that resolution.
- Work has been done in Kiel to assess the GM parameterization in ORCA025. The aim was to improve restratification in the Labrador Sea. However, the GM mask becomes a new variable that must be tuned. The problems in the Lab Sea seem to depend more on the forcings (freshwater fluxes) than on parameterizations.
- the warm bias in the Southern Ocean seems to go away at 1/12° (H. Hewitt's paper).
- Grid point noise is an issue in ORCA025. At high latitude it can lead to excessive mixing. E. Chassignet notes that with hybrid vertical coordinates HYCOM never displays noisy vertical velocities like those found in NEMO or POP. In z-models, numerical schemes can help, but not solve the problem completely (Malte Jansen's presentation at the DRakkar meeting 2016).

5.3 NEMO and DRAKKAR

Status and evolutions of NEMO

The NEMO working groups made their reports during the developers meeting in december 2016. AGRIF and LIM3 are a priori compatible, this need to be tested in realistic mode in 2017. The NEMO simplification has progressed : user interface, ldf interface, suppression of CPP keys. The HPC (M Bell) and config manager (S Ciliberti) are very active working groups. As a result of the COMODO project, new academic test cases are implemented in NEMO.

A development strategy had been defined in 2013 for 2014-2017. The objective was to have a streamlined version with an updated dynamical core (NEMO 4.0) in 2017. An extended developers committee meeting is planned in April 2017, to update the strategy for 2018-2021.

A new method for sharing NEMO configurations, shaconemo, is used by the climate community. It works well for e-ORCA1 and e-ORCA025 for CMIP6. The configurations are shared by a small group of experts who have the same scientific objectifs (coupled climate simulations).

Sharing information within the DRAKKAR community

The cdftools for model output analysis are now on github (meom-group)

A new method to share information about model configurations in the diverse DRAKKAR community is needed. Julien Le Sommer (IGE Grenoble) proposes to start something. The idea is to make available informations such as namelist, parameters, CPP keys, external fields, and some "grey" information about the rationale for choices (such as email exchanges). The information should be searchable. Information should be shared for all simulations we use in scientific papers. The concept of "reference configuration" is no longer useful.

At NOC and the Met Office, there is already a configuration server, most initialization files (bathy, etc) are shared. Other participants point out that not everything should be shared (not every simulation: what is the use of sharing 60 namelists of 60 ORCA2 runs?)

Conclusion: Julien le Sommer sets up a group to implement new tools (members: C. Levy, P. Mathiot, Y. Drillet, L. Brodeau, JM Molines, M Scheinert, A Blaker).

6 List of ORCA12 publications

6.1 Peer-reviewed, published in 2014 (13)

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

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6.5 Other publications (not peer-reviewed)

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